LONG TERM ECOLOGICAL RESEARCH

Teacher's Manual

Activity 3

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Activity 3

Long-term Research on Soil and Water Systems

Background

Research at the Hubbard Brook Experimental Forest started about 50 years ago. At 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, scientists wondered whether it might be a good idea to cut down the trees around drinking water reservoirs. They came up with a hypothesis that could be tested through long-term research: if trees were cut down and therefore not sucking up water, more water would flow into the reservoirs.

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 laboratory experiments, scientists use controls to determine whether the treatments they impose cause any changes. For example, a scientist studying the effect of salt on plants would expose treatment plants to salt and compare their growth to control plants growing without salt. Similarly, scientists at Hubbard Brook devised experimental treatments for three watersheds to see whether different ways of cutting trees would affect the amount of water reaching the stream. When scientists manipulate the world outside of the laboratory, they are conducting a field experiment.

In one 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. In another watershed, all the trees were cut and entirely removed. In a third watershed, researchers divided the forest into 25-meter-wide strips. In the first year, they cut and removed all the "merchantable" materials (leaving branches and tree tops) in every third strip. In subsequent years, they returned and cut the adjacent strips. This treatment was designed to look at less damaging ways of cutting an entire watershed. And finally, the last watershed was left intact, similar to a control. However, unlike laboratory or greenhouse studies, the ecosystem experiments did not have true controls. Although the different 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 variations 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 different watersheds, scientists installed special gauges on forest streams, called "weirs." 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 less turbulent, and then flows out over the v-notch. By constantly measuring how high the stream is at is passes over this v-notch, and entering this height into a known formula, researchers can determine streamflow volume. A picture of a weir at Hubbard Brook is on the next page.

In addition to measuring water quantity, the scientists at Hubbard Brook measured nutrients in the water, including nitrogen and sulfate, and pH. These data have helped us to understand how nitrogen and other nutrients cycle through the plants, soil, water, and atmosphere. The pH and related measurements have helped us to understand the impact of acid rain on northeastern forests. The scientists also erected weather stations with precipitation collectors to measure water and nutrients coming into the watersheds from rain and snow.

While scientists at Hubbard Brook have conducted a great deal of research on disturbances caused by humans, they have also conducted research on natural disturbances. For example, they have studied how outbreaks of leaf-eating caterpillars affect water and nutrient cycling, and how powerful ice storms can affect forests. Hubbard Brook is truly an “experimental” forest.

In this activity, you will be looking at some of the original streamflow data collected at Hubbard Brook to determine the short-term and long-term results of a forest tree-cutting experiment. You will be examining data from Watersheds 2 and 3. Watershed 2 is the clearcut 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 an herbicide was applied to the entire watershed to prevent the regrowth of any vegetation. Watershed 3 was not disturbed. This field experiment was the first study to examine how forest cutting might influence streamflow and subsequent reservoir levels.

Note to Teachers

In this activity, students will compare a treatment watershed (clear-cutting followed by herbicide application in Watershed 2) with the reference watershed (uncut forest in Watershed 3). Students will manipulate the data to determine whether the treatment produced the desired result: less water taken up by vegetation and more water running off into streams. (Another way to present this would be that students are testing the hypothesis that clearcutting reduces streamflow.) Students will compare the results suggested by a few years of data to the conclusions that can be drawn from a long-term study. To improve the quality of interpretation, students will look at a supplemental data set containing annual rainfall amounts. In the "Suggestions for Further Study" there is also an opportunity to examine vegetation surveys.

In each Hubbard Brook watershed, scientists collected streamflow data on a daily basis as instantaneous flow rates: liters of water per second. They then integrated these values over time and standardized them for the area of the watershed. The results are reported as millimeters per day per standard area. This conversion makes it possible to conveniently compare streamflow to precipitation, and to compare streamflow in watersheds of different sizes. For example, in 1958 in Watershed 2, a value of 645.15 is listed in the data files. This means that during 1958, 645.15 mm of water (for any given area – for example, 1 square meter or 100 square meters) flowed out of Watershed 2.

In this activity, students will be working with streamflow and precipitation data collected from Watersheds 2 and 3 at the Hubbard Brook Experimental Forest. The student procedure indicates that they will receive either printed spreadsheets or computer files containing these data. We have provided the data in formats suitable for either option. Students may work in small groups or as individuals.

The file containing easily printable spreadsheets is an MS Word file named, "Activity 3 Data (Word)." It contains annual streamflow and precipitation data for both Watersheds 2 and 3 in a handout for students. There is also a teacher's section that includes another data column containing the difference between Watershed 2 and Watershed 3 (i.e., WS2 – WS3). The teacher's file also contains several graphs of precipitation and streamflow, for your reference.

There are two MS Excel computer files: one for teachers, and for students. They are named, respectively, "Activity 3 Data Teachers (Excel)," and "Activity 3 Data Students (Excel)." The teacher's file contains annual precipitation, streamflow, and streamflow difference in Watersheds 2 and 3, and also includes graphs for your reference. The student version does not contain graphs or streamflow difference values.

Your students will use either graph paper or spreadsheet software to generate a figure that shows 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.

Students should create two separate graphs: annual streamflow in WS2 and annual streamflow in WS3, or one graph containing both. One interesting way to compare the treatment and reference watersheds is to transfer the graph for WS3 (reference) to a transparency, so that it can be superimposed on the graph for WS2 (treatment). It is also instructive to graph the annual average precipitation for each watershed on transparencies and superimpose it on the two streamflow graphs.

Students will first graph results from the five years immediately following the clearcut, and will then look at 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 (using the questions in the Procedure). Repeat this for the second data section (the five years after the clearcut) and again for the third section (the final 18 years).

In addition to graphing changes in the two watersheds over time, students can use the annual streamflow values to calculate the difference in streamflow (WS2 - WS3) between the watersheds. They will observe a pre-treatment difference between WS2 and WS3. Then they will see that in the years immediately after the treatment, the difference between WS2 and WS3 increases dramatically. Streamflow in WS2 increased an average 32 % in the three years after clearcutting.

With time, however, the difference between the two watersheds returns to baseline values. And then, something very interesting happens. Streamflow in WS2 becomes even smaller than it was before the treatment. Thirteen to 23 years after treatment, the average streamflow in WS2 is 7% less than it had been BEFORE treatment.

What's going on? For three years after the trees were cut, herbicides were applied to prevent any vegetation from re-growing. 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 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 WS2 can be found on the Hubbard Brook website (see "Suggestions for Further Study").

The story is not over, however, because pin cherry trees do not live very long — usually only about 30 years. The data set provided only goes 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.

Table 1. Hubbard Brook Watershed Treatments.

Watershed	**Size (hectares)**	**Treatment**
2	15.6	Clearcut in winter 1965-66. Trees left on the ground. Herbicides applied in 1966, 1967, 1968.
3	42.4	Reference (no treatment).
4	36.1	Strip-cut in 3 phases, in 1970, 1972, 1974. Trees removed from watershed.
5	21.9	Whole-tree harvested during the dormant season of 1983-1984.

For students who would like to carry out an additional activity, data from a second treatment (strip cutting in Watershed 4) can be located on the Hubbard Brook LTER website. This activity is in "Suggestions for Further Study," below. Watershed 4 was divided into 49 strips, each strip 25 meters wide. In autumn of 1970, every third strip of forest was cut. A second set of strips was cut in 1972. In 1974, the third and final set of strips was cut. In contrast to WS2, where all the felled trees were left in place, on WS4 the trees were removed. However, no herbicide was applied to prevent vegetation regrowth.

Objectives

Students will:

Develop an understanding of the importance of long-term data
Learn to graph by hand or using Excel software, making decisions about what data to graph
Interpret graphs showing ecosystem response to an experimental treatment
Learn about methods scientists use to examine ecosystem functions
Examine the importance of "controls" in experiments
Examine how hypotheses are not always completely correct
Learn about human attempts to modify ecosystems

National Science Education Standards covered:

Science as Inquiry – Development of:
Abilities necessary to do scientific inquiry (5-8 & 9-12)
Understandings about scientific inquiry (5-8 & 9-12)

Life Science – Development of an understanding of:
Populations and ecosystems (5-8)
Matter, energy, and organization in living systems (9-12)

Science and Technology – Development of:
Understandings about science and technology (5-8 & 9-12)

Science in Personal and Social Perspectives – Development of an understanding of:
Populations, resources, and environments (5-8)
Science and technology in society (5-8)
Science and technology in local, national, and global challenges (9-12)
Natural resources (9-12)
Environmental quality (9-12)

History and Nature of Science – Development of an understanding of:
Nature of science (5-8)
Nature of scientific knowledge (9-12)

Materials

- Pencils, graphing paper or access to computer workstations with spreadsheet/graphing software such as EXCEL
- Transparencies

Procedure

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.
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. Initially, you will be graphing the streamflow data in Watersheds 2 and 3 for the years before the clearcutting 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.
4. 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 clearcutting treatment. Your teacher may lead a classroom discussion about the best way to graph these data.
5. Graph streamflow in Watershed 2 (the treatment watershed) from 1958 – 1965. These are the baseline data.
6. Do the same with Watershed 3. Decide if you want to graph the two watersheds together or on separate pages.
7. 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 (clearcut) to the streamflow *before* the experiment, for both watersheds. (What mistakes might you make if you did not have data from before the clearcutting?) Think about why it is important to monitor the reference watershed (Watershed 3) as well as the treatment watershed (Watershed 2) both before and after the treatment.
8. 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 we clearcut and applied herbicide to a watershed, more water would flow out of it. Did this happen? Can you make any conclusions?

9. 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?
10. 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?
11. 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?
12. You have probably noticed that there are differences between the short-term and long-term WS2 streamflow data. Why might this have happened? Your teacher may lead the class in a discussion of possible reasons.
13. 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 response. What does this experiment say about the need for long-term research? If the research had stopped five years after the clearcut, do you think your (and other people's) perceptions of clearcutting effects on streamflow would be different than they are now? If communities are trying to increase reservoir levels, is clearcutting nearby forests a good way to do it?

Suggestions for Further Study

Vegetation Data

Find vegetation data on the Hubbard Brook website that might help explain short- vs. long-term Watershed 2 streamflow results following clearcutting. The Hubbard Brook website can be found by first going to the National Long Term Ecological Research program's website at http://lternet.edu/ and then following appropriate links.

Other Watersheds

You could do the same graphing steps using the data for Watershed 4, where trees were strip cut over the course of a four-year period. Visit the Hubbard Brook website (see immediately above), where you should be able to find the Watershed 4 streamflow information by clicking on the "data" button and following links to "stream." Getting data off of the HBEF website can be difficult: the data need to be downloaded and reformatted for database software. You may need to ask your teacher for help, or click on the "email" link of the HBEF website to ask the HBEF data manager for assistance.

1. Given the results you saw when an entire watershed was clearcut, how much of an increase in streamflow would you expect to see in Watershed 4 after one-third of the trees had been cut? After 2/3 of the trees had been cut? After ALL of the trees had been cut?
2. Compare your predictions to the actual results. How are they different from your prediction? What could explain this difference?

Societal Influences on Research

Consider the following question: Why did clearcutting and herbiciding a forest to get more water for human use seem like a great idea in 1955? How would society react to clearcutting and herbiciding a forest to increase water supply today? How have changing societal values influenced the research being conducted at Hubbard Brook and elsewhere? How does current research at Hubbard Brook differ from the research that was conducted in the 1950's and 1960's?

Acid Rain

Hubbard Brook is very famous because it was here that scientists first discovered acid rain. The knowledge gained from Hubbard Brook acid rain research was instrumental in the development of the federal Clean Air Act and subsequent amendments. The Clean Air Act and its amendments called for a reduction in acid rain-causing emissions from coal-fired power plants and other pollution sources. Because Hubbard Brook is a long-term ecological research site, scientists have had the opportunity to continue studying the effects of acid rain on northeastern forests after the passage of the Clean Air Act. And, unfortunately, while research shows that precipitation is generally becoming slightly less acidic, current studies indicates that acid rain and its effects are still a big problem.

In March 2001, Hubbard Brook scientists issued a news release urging the public to continue to work to reduce acid rain. "The science on this issue is clear," says Dr. Gene Likens, director of the Institute of Ecosystem Studies in Millbrook, New York, and one of the scientists who discovered acid rain at Hubbard Brook. "Current emission control policies are not sufficient to recover sensitive watersheds in New England. The deeper the emissions cuts, and the sooner they are achieved, the greater the extent and rate of ecological recovery from acid deposition." Dr. Likens' work is a powerful example of how scientists can influence policy at the national level. You may want to visit recent HBEF acid rain publications, located at: http://www.hbrook.sr.unh.edu/hbfound/hbfound.htm.

You may want to do more research on the Clean Air Act and acid rain using internet sources, including the Hubbard Brook website. Check out the Environmental Protection Agency's (EPA) acid rain website at http://www.epa.gov/airmarkets/arp/, or the National Atmospheric Deposition Program (NADP) at http://nadp.sws.uiuc.edu/. The National Science Teachers Association is another good source for acid rain materials, at http://www.nsta.org/.