Hubbard Brook Research Foundation

Data-based Inquiry Lessons

Go with the Flow!

Does more water flow out of a watershed when trees are removed? By graphing and analyzing data to answer this question, students will think about the role that trees and transpiration play in the water cycle. **Go with the Flow** is a multi-part lesson, and all or parts of it may be used. The graphing exercise is the heart of the lesson, but an introductory slideshow and reading (with questions) are also provided, which provide important background information on the Hubbard Brook Experimental Forest, ecosystem-level experimental design and the water cycle.

Many thanks to teacher Rebecca Steeves, who developed this lesson for her Lin-Wood Middle School students in Lincoln, NH.

Summary	Students learn about the Hubbard Brook Experimental Forest and ecosystem-level experimental design while graphing and analyzing data from a well-known experiment at the HBEF. Teachers may show optional slideshow and/or assign student reading with questions before graphing exercise, as well extend learning with further investigation into the role of trees and transpiration in the water cycle.
Grade level/subject areas	Middle school or high school; Earth science, ecology, environmental science
Objectives	• Describe a well-known, first-of-its-kind experiment designed to assess ecosystem level response to deforestation at the Hubbard Brook Experimental Forest in Woodstock, NH. • Explain the difference between monitoring and experimentation. • Hypothesize how streamflow is affected when vegetation is removed. • Represent data in graphical form. • Analyze and evaluate data. • Apply knowledge of water cycle to investigate the impact of transpiration on streamflow.
NH Science Framework Standards	• SPS1:8:1.7 Ask questions about relationships between and among observable variables. • SPS1:8:2.1 Identify the manipulated, responding and controlled variables in an experiment. • SPS1:8:4.3 Draw appropriate conclusions regarding the scientific question under investigation, based on the data collected. • SPS4:8:4.2 Use evidence collected from observations or other sources and use them to create models and explanations. • LS2:8:1.3 Using data and observations, predict outcomes when abiotic/biotic factors are changed in an ecosystem. • LS3:8:1.1 Describe the type of impact certain environmental changes, including deforestation…. could have on local environments.
Time	Two-three hours (including slideshow, reading and questions, and graphing exercise.
Materials	• Student Reading: *Studying a Watershed* and questions • Student Handout: *Go with the Flow* and graphing instructions • Excel data file Go_with_the_Flow.xlsx (link on website) • Slideshow Overview of Hubbard Brook.pdf (link on website)
Assessment	• Reading Questions • Student handout plus graphs. (**Answer key** included)

Notes to teacher

- All or parts of the lesson may be used to:
  - Practice science process skills, such as:
    - Developing hypotheses, identifying variables, and representing and analyzing data. The data-based component of the lesson can be performed as a self-contained lesson that allows students to practice these skills. Graphing instructions included.
    - Ecosystem-level experimental design. When the Student Reading and Questions are combined with the graphing exercise, students will increase awareness about whole-watershed monitoring and experimentation.
  - Increase content knowledge about the water cycle and hydrology. As the data represent stream flow from different watersheds, this lesson can be used as part of a water cycle unit to investigate transpiration and the effect of vegetation (or removal of vegetation) on streamflow.
- An optional **slideshow** is included that introduces students to the Hubbard Brook Experimental Forest (HBEF). The show describes the establishment of HBEF, methods used to monitor ecosystem inputs and outputs, and watershed experiments. Though optional, it provides valuable context for students planning to do the graphing lesson.
- Additionally, the Student Reading: ***Studying a Watershed*** is designed to provide an introduction to the Hubbard Brook Experimental Forest and ecosystem-level experimental design, as well as to put the lesson in context of the water cycle. The reading is accompanied by short-answer **questions**, and is an ideal introduction to the graphing lesson. If the teacher does not wish to use these resources, the teacher should provide students with an introduction that covers this material.

Acknowledgements: We are grateful to the U.S.D.A. Forest Service for contribution of data and for the valuable assistance contributed by the following people: Tammy Wooster (Cary Institute of Ecosystem Studies); Amey Bailey (US Forest Service-HB); Adam Welman (Mountlake Terrace High School, WA); Marianne Krasny (Cornell University); and Cynthia Berger (WPSU).

Some material in this lesson was adapted from Krasny M., Berger C., and Welman T. A. 2001. *Long Term Ecological Research: teacher's manual of classroom activities.* (http://www.dnr.cornell.edu/ext/LTER/lter.asp). Portions of original text appear verbatim in this lesson.

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Student Reading: Studying a Watershed

We are all familiar with the water cycle: water falls to the Earth as precipitation, collects in soil and water bodies, enters back into the atmosphere as water vapor, and then condenses back into clouds to precipitate down upon the Earth once again. But have you ever *really* thought about what might happen to a single water droplet, once it hits the Earth?

Fate of a water droplet

During a raging snowstorm in late March, a frozen water droplet falls on a New Hampshire forest in the form of a snowflake. It stays in the meter-deep *snowpack* until the arrival of warm weather and snowmelt a month later. When the droplet warms and melts, its water ***molecules*** slowly seep into the forest soil, where the roots of a yellow birch tree quickly take them up. The tree transports the water molecules up to its newly emerged leaves, where they evaporate back into the atmosphere in a process known as ***transpiration***.

What else might happen to the water droplet as it warms and leaves the snowpack? Perhaps a trout lily – a small plant that flowers in the spring in northeastern forests – could take up the water molecule. When the leaves of the trout lily make food through the process of photosynthesis, the water molecule may exit its leaves through small openings called stomata. Or if the molecule stays in the trout lily, when summer arrives and its leaves die back, the water molecule might then be returned to the atmosphere as water vapor. If the molecule is not taken up by a plant, it might move through the soil and seep directly into a small stream. The stream would flow into larger and larger streams and rivers, and the molecules would eventually make it to the ocean. In fact, there are dozens of possibilities for the fate of a water droplet!

Now, consider what might be ***in*** the water droplet when it falls on the forest as ***precipitation***. Rain drops can contain different types of compounds (for example, nitrate or sulfate) that come from the airborne particulates from around which they formed and also from gasses in the atmosphere. What happens to these compounds when they enter a forest ecosystem: do they quickly leave by flowing out in streams or are they used by plants and animals that live in the forest? How do they cycle, or move through, the ecosystem? Could some compounds even have negative effects on the forest?

Scientists at Hubbard Brook Experimental Forest (HBEF) in New Hampshire have been asking these and other questions for over 50 years. Their research is part of the Hubbard Brook Ecosystem Study (HBES), and is the focus of this activity.

The HBEF is located in Woodstock, New Hampshire, and is within the boundaries of the White Mountain National Forest. It is about a 15 minute drive north of Plymouth and an hour's drive north of Concord, the state capital. The HBEF has hilly terrain, ranging from 222 to 1,015 meters in altitude, and it is generally covered by an unbroken forest of ***northern hardwood trees***. The Hubbard Brook flows through the experimental forest and drains a range of small mountains. The ***tributaries*** of Hubbard Brook form a set of ***watersheds***, separated by mountain ridges. Because these *watersheds share many characteristics in common (for example, similar slope, soil and vegetation), they provide an ideal setting for conducting ecosystem experiments over entire watersheds.*

Scientists have identified and marked out nine small watersheds in the HBEF, each of which contains a stream that drains a small, forested area. Four of these watersheds have been treated experimentally. *Go with the Flow* focuses on the experiment done in Watershed 2, and the information included here provides important background for the lesson.

While the scientists who conduct research in the HBEF are interested in many different topics, many study how the biological components of an ecosystem interact with each other and with the physical features of the ***ecosystem***. The branch of science that studies the relations that living organisms have with respect to each other and their natural environment is called ***ecology***, and scientists who study this are called ***ecologists***.

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Answering questions about ecosystems is neither quick nor easy for several reasons.

First, much of what happens in a terrestrial (on land) ecosystem happens below the ground, and it is this very nature that makes observation and measurement difficult: it is not possible to study below-ground biotic and abiotic factors without disturbing the environment in which they are found. There are many, many organisms living in the soil (bacteria, fungi, nematodes and insects, to name a few) and they are affected by the moisture, geology and chemistry of the soil. All of these factors affect the roots of plants as well, and influence the types and amounts of nutrients and water available to plants.

Second, the interactions between physical and biological factors can be very complicated. In the HBEF, the physical factors include a large number of environmental variables (for example: wind, temperature, and precipitation) and the biological factors include many different types of organisms (for example: trees, smaller plants, birds, invertebrates, and microorganisms). The potential interactions between these factors are numerous and complex.

Third, many ecosystem processes happen slowly or occur only once in a great while. For example, it can take tens or even hundreds of years for a fallen tree to decay and for the nutrients in that tree to cycle back into the soil. It may take hundreds or thousands of years for small amounts of bedrock to erode. A forest may experience only gradual changes for several decades, but in a span of a few hours or days can be drastically altered by a large storm. For example, in 1998 a tremendous two-day ice storm ripped through HBEF, coating everything with ice and causing massive damage to limbs, branches, and entire trees. For these reasons, ecosystems need to be monitored over long periods of time: gradual changes might go unnoticed, and infrequent events might be missed were scientists to conduct only short-term studies.

When studying complex interactions over long time periods and large areas, it is difficult to find all the answers in laboratory studies. Thus, ecologists often conduct long-term research outside in the ecosystems they are studying. Scientists use a variety of methods, including ***monitoring*** changes in plants and animal populations or in atmospheric conditions. For example, avian ecologists may ***monitor*** the date of first arrival of spring migrant birds while meteorologists may monitor high and low temperatures, both over many years. Field experiments are another kind of long-term research. As opposed to monitoring, where scientists observe changes occurring naturally, in field ***experiments*** scientists actually change something in nature and then compare the area they have altered to an area that is left intact.

Before field experiments can happen over an entire watershed, scientists must first monitor the ***inputs*** and ***outputs*** to the watershed. Examples of inputs are water, nutrients, and other chemicals (compounds) that enter watersheds in precipitation or dry deposition. (Dry deposition consists of small particles that fall on the forest, similar to the dust in your house.) Examples of outputs are the water and compounds leaving each watershed in streamwater, through evapotranspiration (transpiration from plants and evaporation from the soil), or as different gases. By comparing inputs to outputs, scientists can get an idea of water and compounds that remain in the watershed. This is important information for anyone studying the trees, birds, soil or any other part of the ecosystem within that watershed. Studying inputs, outputs, and how the living and non-living components within an entire watershed interact is known as the "***Small Watershed Concept***."

When research at the HBEF began about 50 years ago, 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 taking up water, then more water could flow into streams and thus, reservoirs.**

As you probably know, laboratory experiments use controls to determine whether the treatments being tested cause any changes. For example, a person studying the effect of salt on plants would expose treatment plants to salt and compare their growth to control plants growing without salt. Unlike laboratory studies, ecosystem experiments do not have true controls; due to variation found in nature, it is impossible to find two watersheds that are exactly the same. However, it would be meaningless to do an experiment without anything with which to compare the treated watershed. To get around this hurdle, some of the watersheds at HBEF are kept as 'reference' watersheds, and no experimental treatments are performed on them. The experimental watersheds are then compared to the reference watersheds. In this way, scientists are able to perform field experiments.

You will learn about one of these field experiments in this lesson. Remember that scientists hypothesized that if trees were cut down

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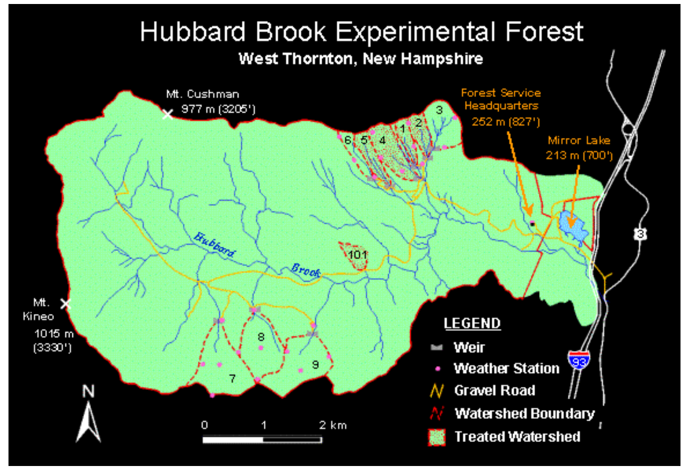
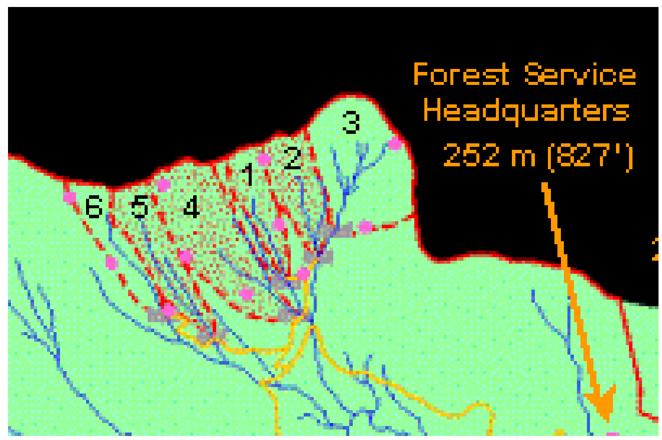
and therefore not taking up water, then more water could flow into the reservoirs. To test this idea, they removed trees in Watershed 2 and then applied herbicides for three years after to prevent regrowth of trees. Watershed 3 was left intact, and similar to a control, served as the reference watershed. Streamflow was measured in both watersheds to see if there were any changes in water flow out of Watershed 2 in comparison to water flow out of Watershed 3.



Watershed	Size (hectares)	Treatment
2	15.6	Entire watershed cut in winter 1965-66. Trees left on the ground. Herbicides applied in 1966, 1967, 1968 to prevent trees and other plants from regrowth.
3	42.4	Reference (no treatment)



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Student Handout: Studying a Watershed

Name ____

Read *Studying a Watershed* and answer the questions that follow.

1. What might happen to a water droplet that falls as rain to Earth before it returns to the atmosphere as water vapor? Give one example.

2. Why are the small watersheds within the Hubbard Brook Experimental Forest considered to be an ideal place in which to conduct experiments?

3. Why is it difficult to answer questions about whole ecosystems? Give one example.

4. People can ***monitor*** an ecosystem as well as ***experiment*** with an ecosystem. Explain the difference between these two terms.

5. It is not possible to provide controls for ecosystem-wide experiments. What do scientists use in place of a control so that they have something with which to compare their experimental data?

6. What was the hypothesis that the Watershed 2 experiment was designed to test?

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Glossary

Ecology: The study of the interactions of living organisms with one another and with their nonliving environment of matter and energy. An example of an ecological research question is, "How do weather, soil type, and topography affect the presence and growth of tree species?"

Ecologist: A person who studies ecology.

Ecosystem: A community of different species interacting with one another and with the chemical and physical factors making up the nonliving environment. An ecosystem can be small (for example, a pond), or very large (for example, a major river valley).

Experiment: To alter or change something in order to learn new information.

Input (to an ecosystem): Something that enters into an ecosystem, most likely from mineral weathering or the atmosphere, in the form of precipitation, dust or gas.

Molecule: The smallest physical unit of an element or compound, consisting of one or more like atoms in an element and two or more different atoms in a compound.

Monitor: To systematically keep track in order to collect information.

Northern hardwood forest biome: A type of biome in the northeastern US, consisting primarily of sugar maple, beech, and yellow birch. The Hubbard Brook Experimental Forest is located in the northern hardwood forest biome.

Nutrient cycle: Pathway of a nutrient through an ecosystem from assimilation (transformation into living tissue) by organisms to release by decomposition. In other words, the path of a nutrient through an ecosystem from living to non-living things and back.

Output (to an ecosystem): Something that exits out of an ecosystem, most likely through the atmosphere (as a gas) or through streamwater.

Precipitation: Any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface.

Small watershed concept: The idea of studying inputs, outputs, and how the living and non-living components within a single unit- an entire watershed- interact.

Snowpack: A quantity of fallen snow that has become massed together on the ground.

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Transpiration: The process by which water is absorbed by the root systems of a plant, moves up through the plant, passes through pores (stomata) in leaves, and then evaporates into the atmosphere as water vapor.

Tributary: A stream that flows to a larger stream or other body of water.

Watershed: The drainage area of a stream, river, or other body of water.

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Student Handout: Go with the Flow

- **How much of a role do trees play in the water cycle?**
- **If all the vegetation in a watershed is removed, will the volume of streamflow in that watershed increase?**

1. Scenario: all the trees in a watershed were cut down one winter and then **not allowed** to grow back the following spring. Write a hypothesis that describes what you think would happen to the streamflow in this watershed. Include whether you think the changes would be large or small, and be sure to explain your reasoning.

2. What are the independent (manipulated), dependent (responding) and controlled variables in this scenario?

    Independent:

    Dependent:

    Controlled:

As you learned prior to this lesson, scientists at Hubbard Brook had a similar question, and wanted to assess an ecosystem's response to deforestation. You will examine original streamflow data collected at Hubbard Brook to determine the short-term and long-term results of this experiment, which was the first of its kind to examine how forest cutting might influence streamflow within a watershed. You will examine data from Watershed 2, the cut watershed, and Watershed 3, the reference watershed, in three parts:

- ***First, you will graph "Baseline data"- the streamflow data for Watersheds 2 and 3 for the years before the cutting treatment (1958-1965).***
- ***You will then graph streamflow data in both watersheds for the five years following the treatment (1966-1970) in order to assess the streamflow response of Watershed 2.***
- ***Lastly you will graph the remaining data (1971-2010) from both watersheds.***

3. Why is it important to graph the baseline data?

It is important to note that the units for streamflow and precipitation data are in millimeters per standard area per year. This means that these values have been adjusted to account for the difference in size between the two watersheds.

4. Open the file GoWiththeFlow.xlsx. Discuss with your partner:
   a. What type of graph is most appropriate to make with this data?
   b. Which data will you put on your X-axis?
   c. Which data will you put on your Y-axis?

Your teacher may lead a classroom discussion about the best way to graph these data before your start making your graphs.

5. Graph the baseline data for streamflow in Watershed 2 and in Watershed 3 from 1958-1965. (See instructions if needed.) ***Do not print out graph****- you are going to add to it.*

6. What do the baseline data tell you about the watersheds' streamflow?

7. What might explain the year-to-year variability?

8. Delete the first graph and now graph the streamflow data AND precipitation data from 1958-1965 on the same graph. ***Do not print.***
   a. In question 7, did you mention precipitation as a factor that might affect the variability of streamflow?
   b. Based on the graph you just made, does it seem like precipitation affects streamflow? Explain by describing what you see on the graph.

9. Delete the last graph and make one with streamflow data only, that includes the next 5 years (1958-1970), after the trees in Watershed 2 were cut down. ***Do not print.***

10. Does it appear that the cutting of trees and prevention of new growth affected the volume of streamflow in Watershed 2 between 1965- 1970? How do you know? Describe what you observe for both watersheds.

11. One of the original hypotheses for this experiment was that if people cut all the trees and stopped the regrowth of new trees in a watershed, more water would flow out of it. Did this happen? Can you make any conclusions?

12. Now delete the last graph and plot all of the streamflow data on a graph (1971-2010). Include a descriptive title, X- and Y-axes labels, and a legend. Expand the graph, vertically and horizontally, so that you can better compare the two watersheds. **Print this graph.**

13. What do you see now? What has happened to the streamflow of both watersheds, and how do they compare to each other? How can you explain what is happening?

14. What if the scientists had stopped collecting streamflow data after 1970? Is there important information they would have missed?

15. Given all of the streamflow data you have seen, what can you say about the original hypothesis: **if trees are cut down and therefore not taking up water, then more water will flow into streams**? Does cutting all the trees in a watershed increase streamflow? (Think about short- and long-term effects.)

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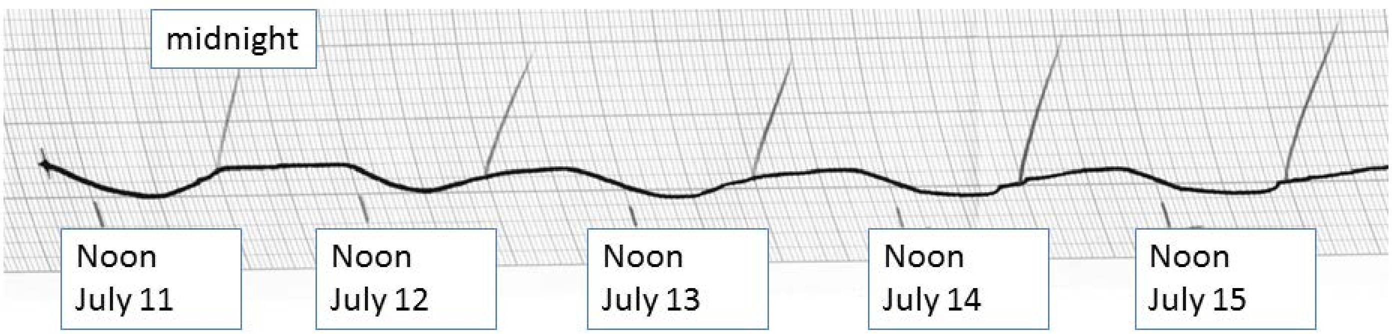
Further Investigation

Name ____

We have seen data that shows that trees affect the flow of water to streams. But what do trees do with water? (Click if you need to review the water cycle.)

Through the process of transpiration, plants move water from the soil up to and out of their leaves while they are performing photosynthesis. (Photosynthesis is a process that takes water, energy from the sun, and carbon dioxide from the air to make sugars.)

It may surprise you to know that transpiration has enough impact to actually affect stream levels in a forest! We can see this in a hydrograph, which is a chart that shows the level of a stream over time:



This hydrograph shows changes in the water level of a stream in a northeastern forest over time in the month of JULY. The line began around 9 am on July 11, 2011 and ended around 9 am on July 16, 2011. The tick marks above the line indicate midnight, and the tick marks below the line indicate noon-time.

16. What is happening to the water level throughout this time period?

17. Around what time of the 24-hour day does the water reach its highest level?

18. Around what time of the 24-hour day does the water fall to its lowest level?

19. Since there was no rain during this time, explain why the water level is fluctuating. Think about all steps of the water cycle.

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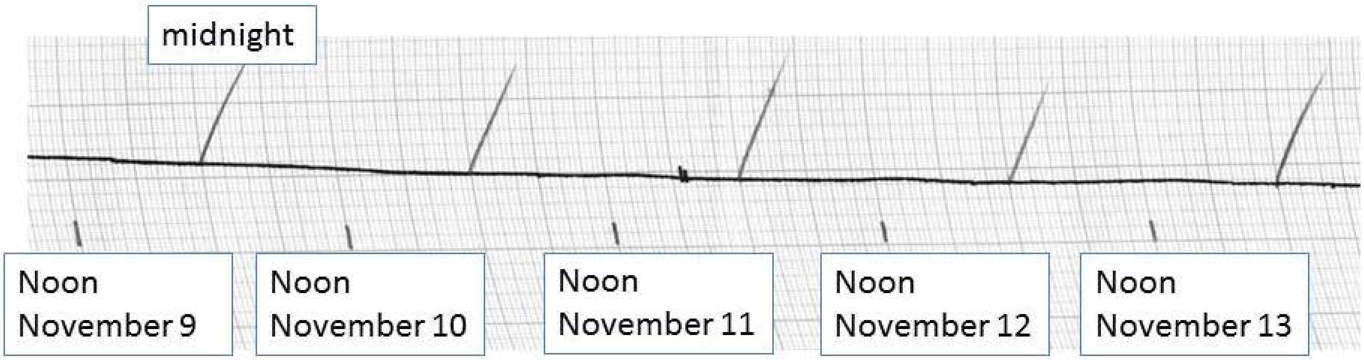
Contrast the July hydrograph with one from November:



This line began around 9 am on November 9, 2010 and ended around 8 am on November 13, 2010. The tick marks above the line indicate midnight, and the tick marks below the line indicate noon-time.

20. What is happening to the water level throughout this time period?

21. As with the July hydrograph, there was no rain during this entire time. Hypothesize why this line is different from the July 2011 line.

Clearly, transpiration plays a significant role in the water cycle! How big? Think back to the Watershed 2 experiment: in the first three years after the trees were cut, streamflow out of the watershed was much greater. Once trees were allowed to regrow, streamflow returned to baseline levels. But then, something interesting happened that is difficult to see in the graph that you made: streamflow in Watershed 2 became **even smaller** ***than it was before the treatment. Thirteen to 23 years after treatment, the average streamflow in Watershed 2 was 7% less than it had been BEFORE treatment.***

22. Hypothesize why, in the 13-23 years after treatment, the streamflow in Watershed 2 was less than it was before the experiment. (Hint: think transpiration!)

Instructions for making graphs in Excel 2010 on a PC

How have streamflow (and precipitation) changed over time in Watersheds 2 and 3 at the Hubbard Brook Experimental Forest? *Technically, you should make a line graph with the data because a line graph is used to look at data over a period of time. Unfortunately, this is more complicated than it should be in Excel and is actually easier to graph using the scatter graph option. However, by definition, a scatter is not the correct graph to choose, as scatter graphs are used to examine cause and effect relationships between two variables (or to examine the relationship of two variables with an unknown third factor), and that is not what you are doing. Directions for making both kinds of graphs follow.*

To make a scatter plot:

1. Highlight the columns of data you wish to graph and click on the **Insert** tab. Click on **Scatter** and choose "Scatter with Straight Lines" (bottom left).
2. The graph will appear before you. Check to see if things are making sense.
3. You will need to change the Chart Title and add x- and y- axis labels:
    a. Click on **Chart Tools** and on the **Layout** tab.
    b. To add title, click on **Chart Title** and choose whether you want a **Centered Overlay Title** or a title **Above Chart**. Enter a descriptive, correctly capitalized title and hit 'enter.'
    c. To add x-axis label, click on **Axis Titles**, then **Primary Horizontal Axis Title**, then **Title Below Axis**. Enter a descriptive, correctly capitalized label and hit 'enter.'
    d. To add y-axis label, click on **Axis Titles**, then **Primary Vertical Axis Title**, then **Rotated Title**. Enter a descriptive, correctly capitalized label and hit 'enter.'
    e. You can edit these titles at any time by clicking once to highlight the appropriate textbox and then clicking again to make changes to the text.

To make a line graph in Excel:

The process isn't as simple when making a line graph. If you simply highlight your data as described above, your graph doesn't come out right! Follow these directions instead:

1. Click on **Insert** and then on **Line**, choose the first 2-D Line.
2. Right click in the blank graph 'canvas.'
3. Choose **Select Data**: click in **chart data range box** and then highlight the 'W2 Streamflow' and 'W3Streamflow' columns of data, including the titles of the columns, for the time period you want to graph.
   (For question 8, which asks you to graph the streamflow data AND precipitation data from 1958-1965, highlight the 'W2 Streamflow,' 'W3Streamflow,' W2Precip,' and 'W3Precip' columns of data for that time period.)

4. Click **Edit** in the Horizontal (Category) Axis Labels window; the axis labels dialog box appears. Now highlight the Years column of data *without* including the title ('Year') and click **OK**.
5. Now click **OK** to close the Select Data Source box.
6. You will need to change the Chart Title and add x- and y- axis labels:
    a. Click on **Chart Tools** and on the **Layout** tab.
    b. To add title, click on **Chart Title** and choose whether you want a **Centered Overlay Title** or a title **Above Chart**. Enter a descriptive, correctly capitalized title and hit 'enter.'
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Student Handout: Go with the Flow

- **How much of a role do trees play in the water cycle?**
- **If all the vegetation in a watershed is removed, will the volume of streamflow in that watershed increase?**

1. Scenario: all the trees in a watershed were cut down one winter and then **not allowed** to grow back the following spring. Write a hypothesis that describes what you think would happen to the streamflow in this watershed. Include whether you think the changes would be large or small, and be sure to explain your reasoning.
   Answers will vary, but at the middle school level hypotheses might sound something like this: "I think/predict that streamflow decreased/increased/remained the same after the cutting treatment because …..(reason based in logical thinking)."

2. What are the independent (manipulated), dependent (responding) and controlled variables in this scenario?

   Independent: *Trees (cutting of trees, lack of trees)*

   Dependent: *Streamflow*

   Controlled: *Answers will vary. Hopefully students will apply what was learned from Student Reading (please see for further discussion).*

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- *First, you will graph "Baseline data"- the streamflow data for Watersheds 2 and 3 for the years before the clear-cutting treatment (1958-1965).*
- *You will then graph streamflow data in both watersheds for the five years following the treatment (1966-1970) in order to assess the streamflow response of Watershed 2.*
- *Lastly you will graph the remaining data (1971-2010) from both watersheds.*

3. Why is it important to graph the baseline data?

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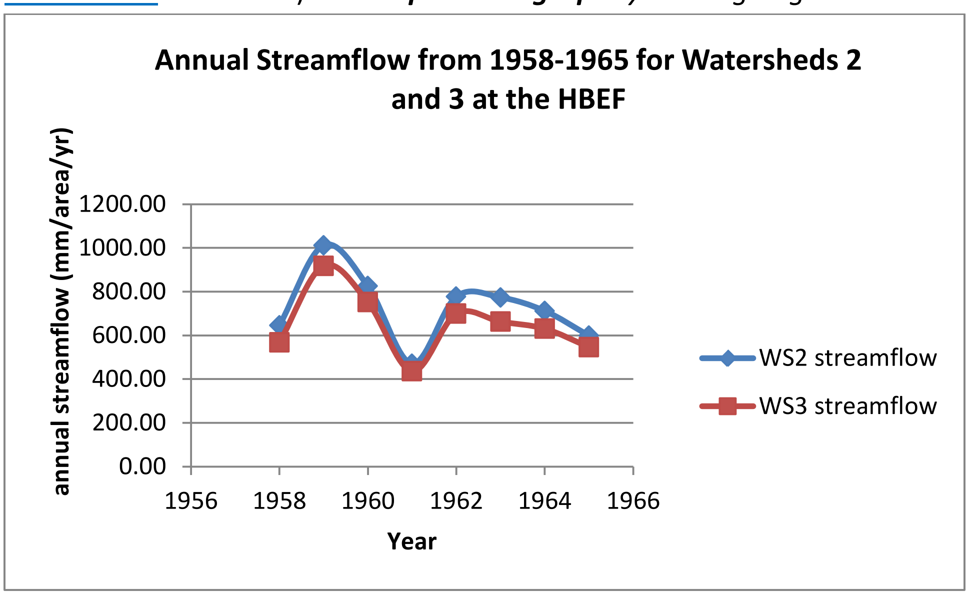
When doing field experiments, scientists try to have an understanding of how the ecosystem is working before the treatment. In interpreting the results of a field experiment, it is important to compare the watershed streamflow after the treatment (clear-cut) to the streamflow before the experiment, for both watersheds. Think about the mistakes you might make if you did not have data from before the cutting. 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.

It is important to note that the units for streamflow and precipitation data are in millimeters per standard area per year. This means that these values have been adjusted to account for the difference in size between the two watersheds.

4. Open the file GoWiththeFlow.xlsx. Discuss with your partner:
    a. What type of graph is most appropriate to make with this data? *Line graph.*
    Technically, a line graph should be made with the data because a line graph is used to look at data over a period of time. Unfortunately, this is more complicated than it should be in Excel and is actually easier to create as a scatter graph. However, by definition, a scatter is not really the correct graph to choose, as scatter graphs are used to examine cause and effect relationships between two variables (or to examine the relationship of two variables with an unknown third factor), and that is not what students are doing. They are trying to see how/if streamflow changes over time. Directions to make both types of graphs are included in the link to instructions below.
    b. Which data will you put on your X-axis? *Year*
    c. Which data will you put on your Y-axis? *Streamflow (mm/area/year)*

Your teacher may lead a classroom discussion about the best way to graph these data before your start making your graphs.

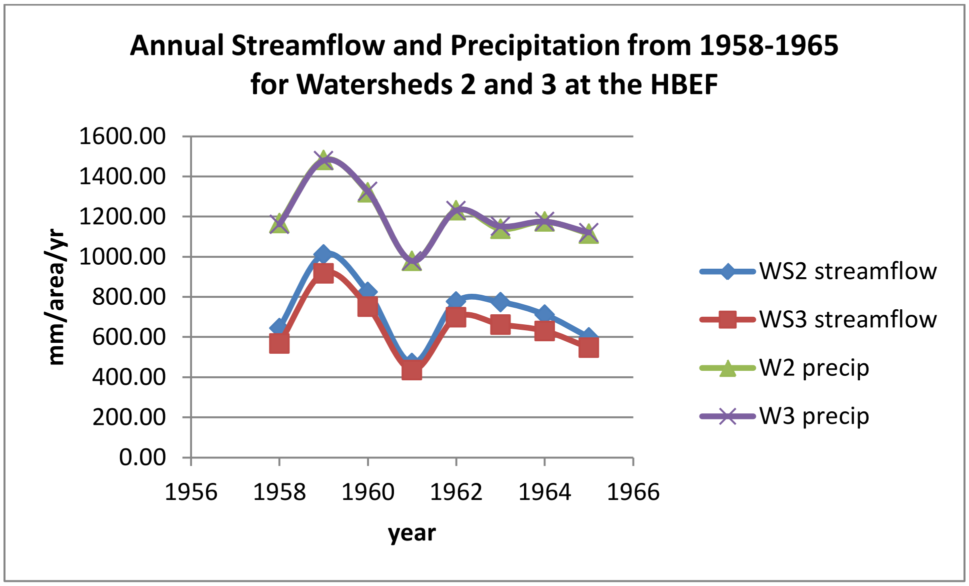
5. Graph the baseline data for streamflow in Watershed 2 and in Watershed 3 from 1958-1965. (See instructions if needed.) ***Do not print out graph**- you are going to add to it.*



6. *What do the baseline data tell you about the watersheds' streamflow?*
   There is variability from year to year and watershed 2 always has a greater volume of streamflow. Changes in streamflow in one watershed mirror changes in streamflow in the other.

7. What might explain the year-to-year variability?
   Answers will vary, but precipitation would be the most logical answer.

8. Delete the first graph and now graph the streamflow data AND precipitation data from 1958-1965 on the same graph. ***Do not print.***



   a. In question 7, did you mention precipitation as a factor that might affect the variability of streamflow?
      Answers will vary, but hopefully, yes!

   b. Based on the graph you just made, does it seem like precipitation affects streamflow? Explain by describing what you see on the graph.
      Yes, it does. First observe that the volume of precipitation received in Watershed 2 is so similar to that of Watershed 3 that the lines are on top of each other. Then observe that when precipitation increases, streamflow increases and when precipitation decreases, streamflow decreases. The volume of precipitation directly affects the volume of streamflow.

9. Delete the last graph and make one with streamflow data only, that includes the next 5 years (1958-1970), after the trees in Watershed 2 were cut down. ***Do not print.***

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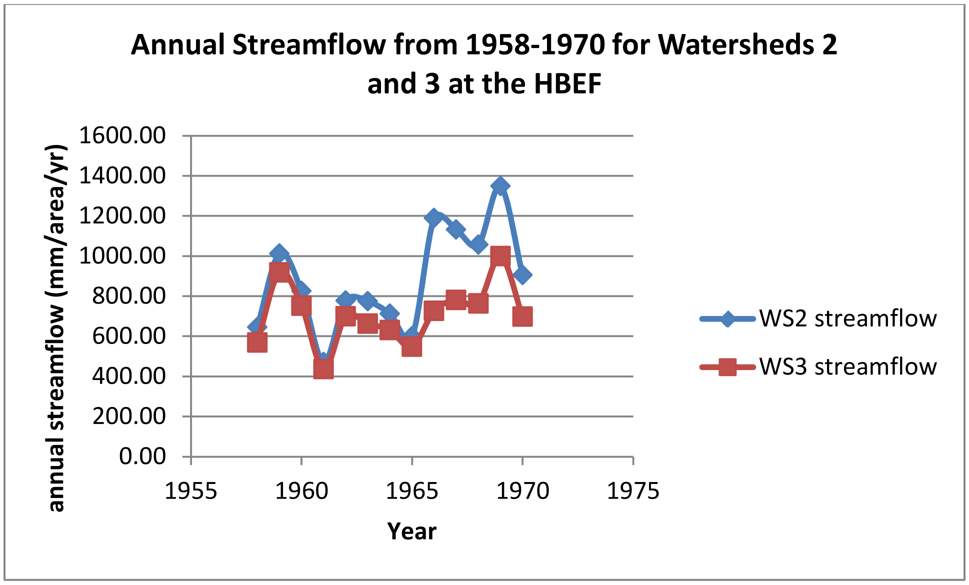

10. Does it appear that the cutting of trees and prevention of new growth affected the volume of streamflow in Watershed 2 between 1965- 1970? How do you know? Describe what you observe for both watersheds.
Yes, it does appear that the treatment affected streamflow. Even though Watershed 2 had a greater volume of streamflow before the treatment, the difference between the two watersheds is much greater between 1965 -1970. More water was coming out of watershed 2 relative to watershed 3 during this time.

11. One of the original hypotheses for this experiment was that if people cut all the trees and stopped the regrowth of new trees in a watershed, more water would flow out of it. Did this happen? Can you make any conclusions?
Yes, it did happen, and the hypothesis was correct. We can't yet make conclusions, because we have only looked at 6 years of data after treatment.

12. Now delete the last graph and plot all of the streamflow data on a graph (1971-2010). Include a descriptive title, X- and Y-axes labels, and a legend. Expand the graph, vertically and horizontally, so that you can better compare the two watersheds. **Print this graph.**

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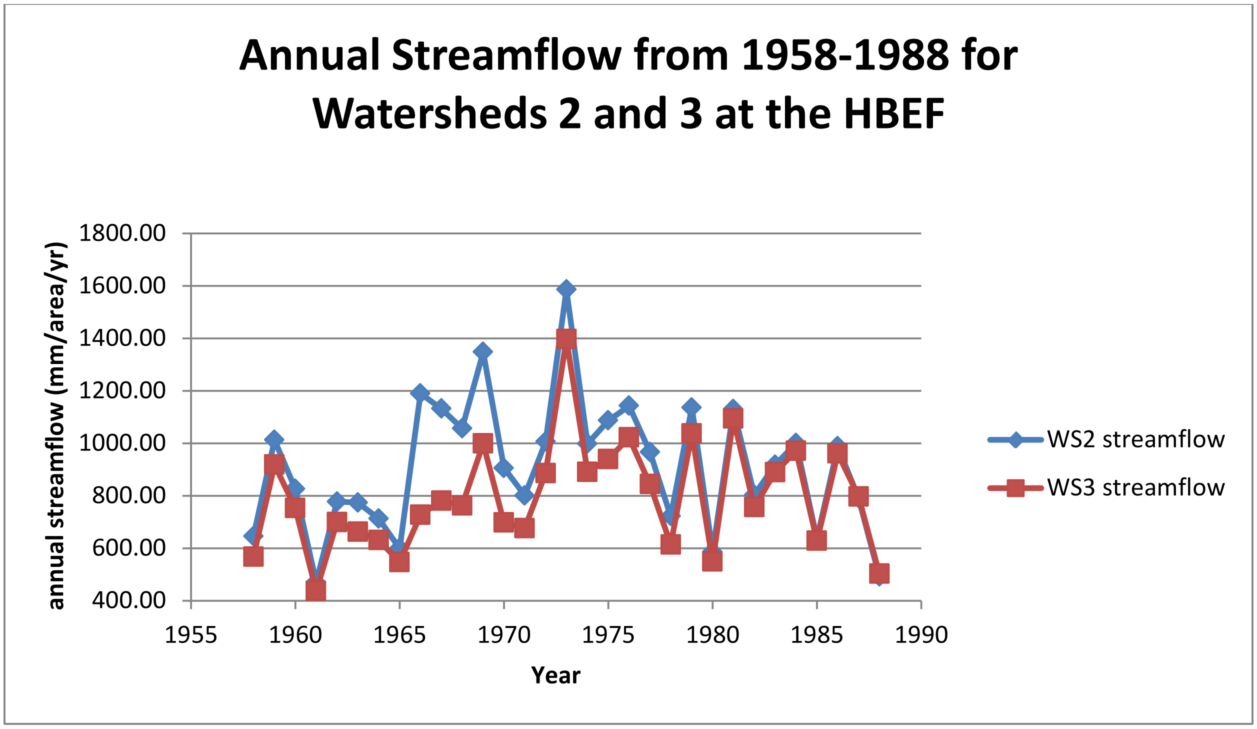

13. What do you see now? What has happened to the streamflow of both watersheds, and how do they compare to each other? How can you explain what is happening?
Now it looks like the difference between streamflow for the two watersheds is not as great; it looks like the differences between the two watersheds is returning to what it was prior to the treatment. Vegetation is starting to regrow in watershed 2. Because these plants are taking water up out of the soil, there is less to enter the stream.

14. What if the scientists had stopped collecting streamflow data after 1970? Is there important information they would have missed?
If scientists stopped collecting streamflow data after 1970, they would not have noticed that streamflow levels in watershed 2 returned to similar levels as prior to the treatment.

15. Given all of the streamflow data you have seen, what can you say about the original hypothesis: **if trees are cut down and therefore not taking up water, then more water will flow into streams**? Does cutting all the trees in a watershed increase streamflow? (Think about short- and long-term effects.)
The hypothesis was correct. The cutting experiment in Watershed 2 showed that removal of vegetation increases streamflow, and also that once the vegetation begins to grow back, streamflow decreases as trees take up water.

So we know that trees affect the flow of water to streams. But what do trees do with water? (Click if you need to review the water cycle.)

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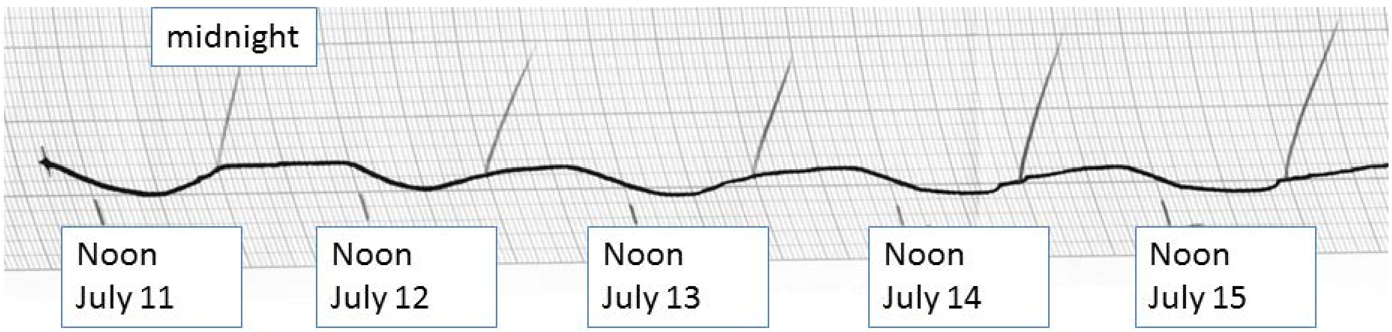
Through the process of transpiration, plants move water from the soil up to and out of their leaves while they are performing photosynthesis. (Photosynthesis is a process that takes water, energy from the sun, and carbon dioxide from the air to make sugars.)

It may surprise you to know that transpiration has enough impact to actually affect stream levels in a forest! We can see this in a hydrograph, which is a chart that shows the level of a stream over time:



This hydrograph shows changes in the water level of a stream in a northeastern forest over time in the month of JULY. The line began around 9 am on July 11, 2011 and ended around 9 am on July 16, 2011. The tick marks above the line indicate midnight, and the tick marks below the line indicate noon-time.

16. What is happening to the water level throughout this time period?
    It is fluctuating up and down throughout each day.

17. Around what time of the 24-hour day does the water reach its highest level?
    Water levels are highest around 6 am.

18. Around what time of the 24-hour day does the water fall to its lowest level?
    Water levels are lowest in late afternoon and early evening.

19. Since there was no rain during this time, explain why the water level is fluctuating. Think about all steps of the water cycle.
    The water levels fluctuate due to use of water by trees. Between noon time and 6 pm, water levels decrease because tree roots are removing water from soil (for use in photosynthesis) and transpiring water out of leaves. So water that could be entering the stream is being taken up by tree roots. When night falls and trees stop photosynthesis, transpiration stops too, and water flows though soil into the stream.

Contrast the July hydrograph with one from November:

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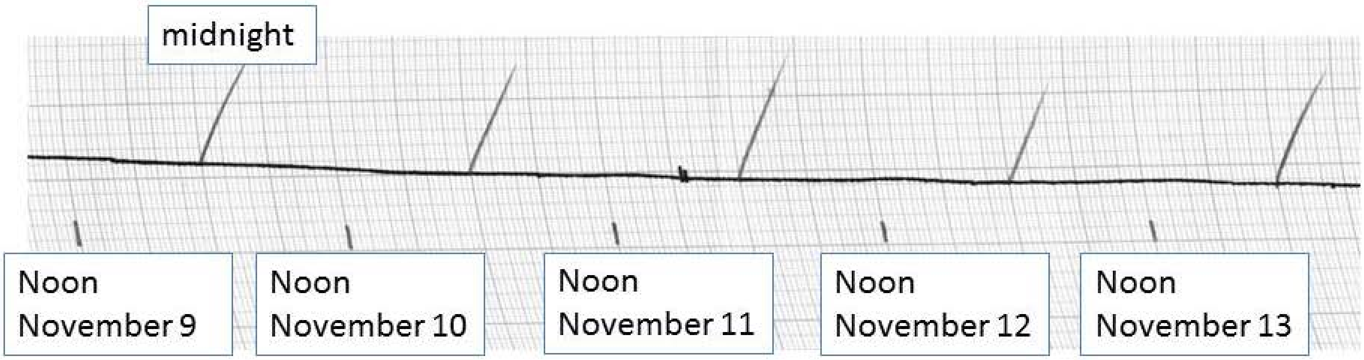

This line began around 9 am on November 9, 2010 and ended around 8 am on November 13, 2010. The tick marks above the line indicate midnight, and the tick marks below the line indicate noon-time.

20. What is happening to the water level throughout this time period?
The water level is not fluctuating as in the July hydrograph.

21. As with the July hydrograph, there was no rain during this entire time. Hypothesize why this line is different from the July 2011 line.
Since it is November, there are no leaves on deciduous trees. Thus photosynthesis and transpiration are not occurring for many of the trees surrounding the stream, and there is not much water demand by trees to disrupt the flow of water as it moves through the soil and into the stream.

Clearly, transpiration plays a significant role in the water cycle! How big? Think back to the Watershed 2 experiment: in the first three years after the trees were cut, streamflow out of the watershed was much greater. Once trees were allowed to regrow, streamflow returned to baseline levels. But then, something interesting happened that is difficult to see in the graph that you made: streamflow in Watershed 2 became even smaller than it was before the treatment. Thirteen to 23 years after treatment, the average streamflow in Watershed 2 was 7% less than it had been BEFORE treatment.

22. Hypothesize why, in the 13-23 years after treatment, the streamflow in Watershed 2 was less than it was before the experiment. (Hint: think transpiration!)

The original forest had been composed of mature hardwood species such as sugar maple, American beech, and yellow birch. But after the treatment, when plants were allowed to regrow, the 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.

**Note to teachers- this is hard to see in the graph because the differences in values between baseline data and data from 13-23 post treatment are small.*