

Did They Make the Gradient?



***Climate and Stream Temperatures
Now and Into the Future***

Photo courtesy of Ge Sun.

Meet the Scientists

► **Mr. Johnny Boggs, Biological Scientist:** My favorite science experience is having the opportunity to continuously explore how and why our environmental system works the way it does. Growing up as a kid, I used to hunt, fish, and farm, so I have always felt a connection to nature and natural resources. In my current position, I offer scientific stories in the form of published papers. I hope these papers add further understanding to how our environment will respond to future changes and offer a benefit for future generations.



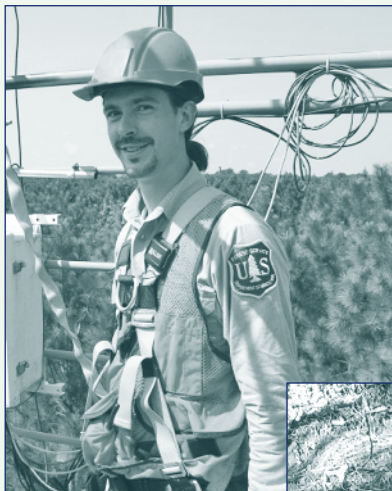
◄ **Dr. Ge Sun, Research Hydrologist (hī drä lə jist):** My favorite science experience is getting my ideas and study results published in scientific journals. That way, they will be recorded and hopefully used by future generations to understand their environment and improve their lives. I come to work every day with excitement because I meet bright people with good ideas and I learn and see new things around the world. Most importantly, I am excited about my work because I can contribute to solving problems and can answer questions to make people happy.

► **Dr. Steve McNulty, Ecologist:** My favorite science experience is when I am analyzing data and learn something that no one else has ever known before. It's sort of like being the first person to ski down a mountain of fresh snow, or being the first person to canoe down a remote river. This photo was taken on a recent trip to China. To the left and in the middle are Dr. Ge Sun, Hydrologist, and Dr. Jim Vose, Ecologist. Dr. Sun and Dr. Vose are also Forest Service scientists. You can read more about Dr. Vose's research in the *Natural Inquirer* "Woolly Bully" monograph (<http://www.naturalinquirer.org>).





► **Mr. Emrys Treasure**, Forestry Technician: My favorite science experience happens almost every day. I learn something new by testing my beliefs about how the natural world works. These are often quite simple observations about the water cycle, how trees grow, or how soils form. Sometimes these thoughts lead to a breakthrough in understanding more complex aspects of the natural world, including the impacts of climate change. It is through this step-by-step process that science and scientists solve problems.

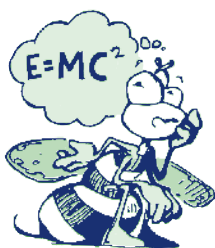


▼ **Mr. Will Summer**, Forest Hydrologist: My favorite science experience is being outside during a rainstorm. As a forest hydrologist, I study what happens to water from the time it falls from the sky until it gets to a stream. During a rainstorm is the best chance I have to really understand what is happening. Did you know that only a tiny fraction of rainfall falls directly on a stream? Most of it falls on land and must travel along the ground's surface or through the soil to get to the stream. Everything the water encounters as it flows towards the stream will affect how clean the water is when it gets to the stream. That is why understanding hydrology is so important to keeping our streams and rivers clean.



Thinking About Science

Scientific knowledge usually advances in small steps. When similar results are reported by different scientists, scientists have more confidence that the results are accurate. When scientists generally agree that existing results are accurate, they do new studies to push their knowledge even further. For example, scientists agree that a change in air temperature will cause a change in stream temperature. Scientists also generally agree that if the air temperature in an area rises, then stream temperatures in the area will likely rise as well.



In this study, the scientists wondered if the shape of a stream would also affect the stream's temperature. In other words, they wondered if the temperature of some streams would change more than other streams, if the temperature rose by the same amount and the only difference was the stream's shape. The scientists designed a study to answer this question.

You can see that scientists develop specific questions to answer. Research advances our knowledge one question at a time. Scientists are like detectives who must answer one question before they can move to the next.

Thinking About the Environment



Streams are found all over the world. Streams are waterways that carry water to rivers, and rivers carry water to oceans. Streams provide habitat for many animals, including **invertebrates**, fish, reptiles, amphibians, birds, and mammals. To provide **habitat** for animals, the water temperature of streams must not exceed an upper limit. The State of North Carolina has determined that mountain and upper **Piedmont** streams must not be higher than 29 degrees Centigrade (**figure 1**). The State has also determined that the temperature should not be higher than 32 degrees Centigrade for lower Piedmont and coastal streams and rivers.

Many things affect a stream's temperature. The amount of shade over a stream may affect its temperature. The air temperature also affects a stream's temperature. What else might affect a stream's temperature? The scientists in this study were interested in discovering as much as they could about what causes a stream's temperature to rise during the day. You may be surprised at what they discovered!

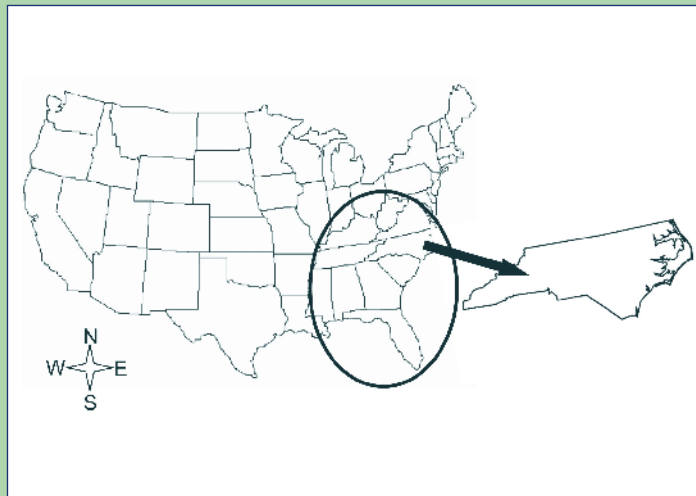


Figure 1. North Carolina is in the Southeastern United States.

Number Crunches



What is the upper temperature limit of North Carolina streams in Fahrenheit? To calculate, multiply the degrees in Centigrade by $9/5$ and then add 32.

Introduction

If the temperature of a stream rises too high, the animals that live in the stream may find it difficult to survive. Big changes in a stream's daytime temperature as compared with its nighttime temperature may also cause a problem for **aquatic** animals. It is important, therefore, for daytime stream temperatures to stay as low as possible.

In a natural forest **ecosystem**, streams are protected from high daytime temperatures by natural processes. First, trees and other plants growing beside the stream provide shade from the Sun. Second, the depth of the stream may affect its water temperature, with deeper streams generally cooler than shallow ones. Another process that affects stream

temperatures is the way water comes into the stream. If a stream is fed by an underground spring or by **groundwater**, the cooler water from underground may keep the stream's temperature cooler, at least in that area.

People can affect some of these natural processes. For example, people might remove trees from a streambank, allowing more sunlight to reach the stream. This would raise the stream's temperature. Another way people might affect stream temperatures is through

activities that result in global climate change. If the **average** air temperature continues to rise in an area, a stream's temperature will likely rise too.

The scientists in this study were interested in answering three questions: (1) How does the shape of a stream affect its daytime water temperature? (2) How does the shape of a stream affect the difference between its daytime and nighttime water temperatures? (3) How might a rise in average air temperature over time affect a stream's water temperature?

Reflection Section

- What do you think determines the shape of a stream?
- Do you think that a rise in the average air temperature would cause a rise in a stream's water temperature? Why or why not?



Methods

The scientists studied four watersheds in the Piedmont area of North Carolina. A watershed is an area of land where all of the water that is under it or drains off of it goes into the same place (**figure 2**). Two of the watersheds

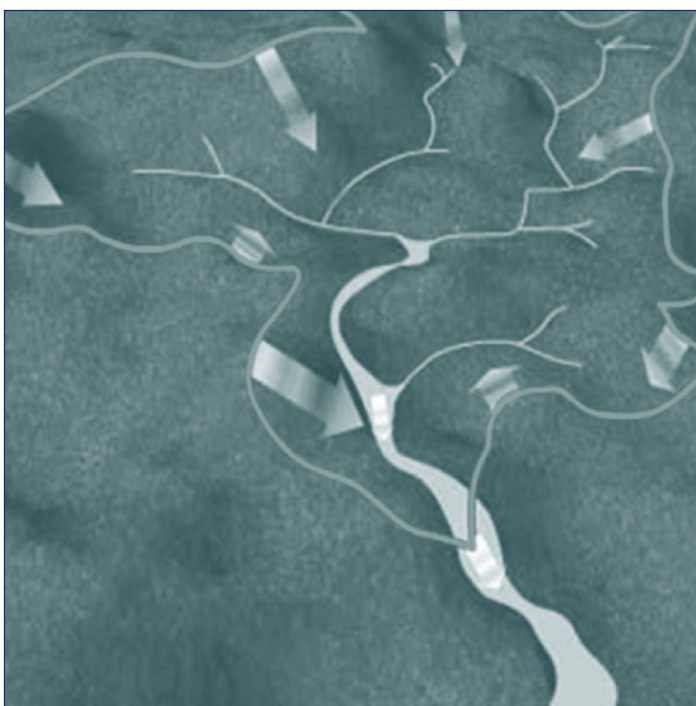


Figure 2. A watershed. Image from <http://www.kidsgeo.com>.

contained rocks that formed from the deposits of ancient volcanoes and minerals. The other two watersheds contained rocks formed from the deposits of mud, sand, silt, and gravel that were carried away by mountain streams millions of years earlier (**figure 3**). Although the **geology** of these areas was different, the areas were only 8 kilometers apart.

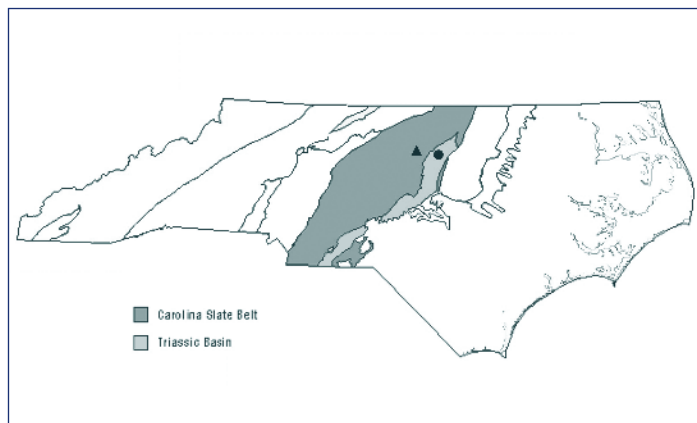


Figure 3. The four watersheds studied by the scientists were located in two areas indicated by the circle and the triangle. One watershed was in the Carolina Slate Belt, and the other was in the Triassic Basin.

Number Crunches

🍁 How far apart were the watersheds in miles? To calculate, multiply 8 times .621.

The scientists first located the stream in each watershed. Then, they located the area closest to the stream's beginning. This is called the stream's headwaters. The scientists placed equipment in the stream's headwaters to measure the amount of streamflow (**figure 4**). Streamflow is the rate at which water passes a given point in a stream. The scientists also measured the height of each streambank and the stream's depth. They measured how much of the stream was covered by the leaves of trees. A thermometer was placed in each stream to measure water temperature. Every 10 minutes, this equipment automatically measured and recorded the amount of streamflow and the water temperature. Each stream's **gradient** was also measured (**figure 5**).

On the bank nearby, weather equipment measured and recorded things like air temperature, solar radiation, rainfall, and humidity. The weather equipment recorded the data every 10 minutes. The scientists then used a computer program to compare each of the weather measurements with daytime and nighttime stream temperatures. They also compared daytime and

nighttime stream temperatures with streamflow and the amount of leaves covering and shading the stream (**figure 6**).

The scientists then used a computer program to investigate what effect an increase in air temperature would have on the streams' temperatures. They assumed everything else was the same, except that they added 2 degrees Centigrade to each air temperature value.

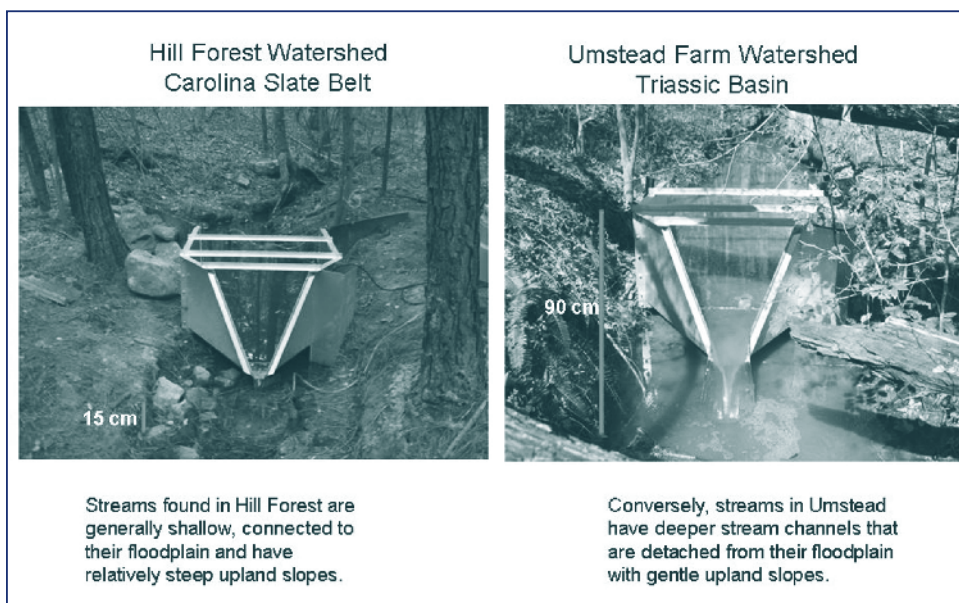


Figure 4. A flume was placed in each stream to measure the amount of streamflow. You can see the differences in the two streams. Forest Service photo.



Figure 5. Different stream gradients. Photos courtesy of Babs McDonald.

Stream Temperatures ►	Daytime water temperatures (measured and recorded every 10 minutes)	Nighttime water temperatures (measured and recorded every 10 minutes)
Weather and Stream Properties ▼		
Weather data (measured every 10 minutes, recorded every hour): <ul style="list-style-type: none"> • Air temperature • Amount of solar radiation • Amount of rainfall • Humidity 		
Height of streambank		
Depth of stream		
Gradient of stream		
Amount of streamflow (measured and recorded every 10 minutes)		
Amount of shade over the stream (measured once using a fisheye lens) (figure 7)		

Figure 6. The scientists compared daytime and nighttime stream temperatures with weather information and stream properties.

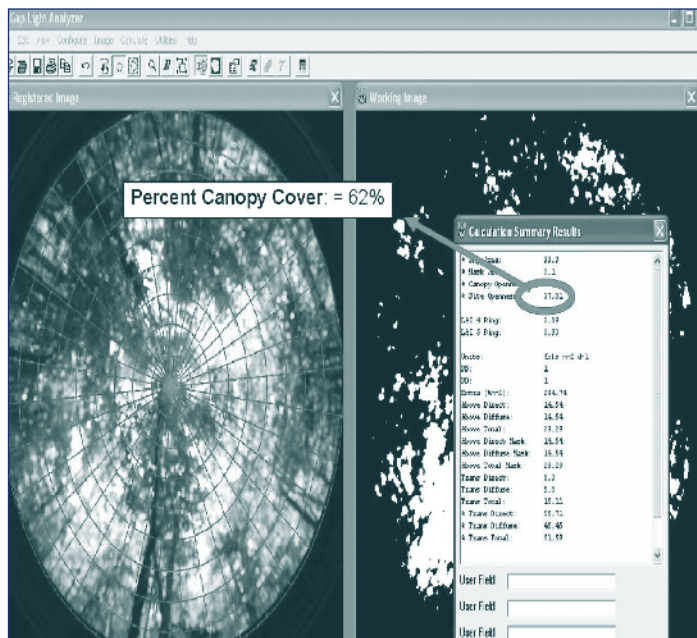


Figure 7. A fisheye lens and a computer program were used to calculate the amount of shade over the stream. Forest Service image.

Reflection Section

- Why do you think the scientists studied streams that were near each other but had a different geology?
- Why was it important to study streams with similar day-to-day weather?
- Look at figure 6. Why did the scientists not compare the two **variables** represented by the lower right rectangle? Which other variable in this figure would not be compared with nighttime water temperatures?

Findings

The scientists found that the most shaded streams had the lowest daytime temperatures during the summer. They also found that for all streams, the difference between daytime and nighttime temperatures was greatest during the summer. When the scientists compared the stream's temperature with the stream's gradient, they found that the steeper the gradient, the lower the water temperature.

The scientists also found that if the air temperature were to rise 2 degrees Centigrade over time, stream temperatures would likely rise between 0.6 and 1.0 degrees Centigrade.

Reflection Section

- ❦ Why do you think the most shaded streams had the lowest daytime summer temperatures?
- ❦ Why do you think that stream temperatures in a future warmer climate might rise more in the winter than the summer? (Hint: think about what is different about many of the trees along streambanks in the summer and winter.)



Discussion

The scientists believe a stream's gradient affects its temperature in this way: When the gradient is steeper, molecules of water stay in any area of the stream for a shorter period of time because of gravity pulling them quickly downstream. The heat energy in each of the water molecules is carried away before it can affect the stream's temperature.

A stream's gradient is a result of the geology of the area. Gradient is also one way to describe the stream's shape. The shape of a stream affects both its daytime temperature and the difference between daytime and nighttime temperatures. The steeper the gradient, the lower the daytime temperature, which means there is less difference between nighttime and daytime temperatures.

Although people cannot change the gradient of a stream, they can plant and protect trees along a stream's banks. This will help keep the daytime stream temperature lower. Although stream temperatures in the North Carolina Piedmont may rise in the future as the climate changes, they are not predicted to go higher than the upper limit for healthy streams set by the State of North Carolina.

Reflection Section

- ❦ Think back to the first question in the first Reflection Section. Did you or your class consider the gradient of the stream as one way to describe its shape? Do you agree that the gradient of a stream is part of its shape? Why or why not?
- ❦ Most States have laws that protect streams and rivers. These laws prohibit the removal of trees and other plants within a certain number of feet from the water's edge. Do you think this is a good thing? Why or why not?



Glossary

aquatic (ə kwä tik): Growing or living in or upon water.

average (ə v(ə rij): The usual kind or amount. The number gotten by dividing the sum of two or more quantities by the number of quantities added.

ecosystem (ē kō sis tēm): Community of plant and animal species interacting with one another and with the nonliving environment.

flume (flüm): A sloping channel for directing the flow of water.

geology (jē ä lə jē): Earth's matter, including its materials, structure, physical properties, dynamics, and history, and the processes by which Earth's matter is formed, moved, and changed.

gradient (grā dē ənt): The rate of sloping upward or downward.

groundwater (graund wä tər): Water that sinks into the soil.

habitat (hə bə tat): Environment where a plant or animal naturally grows and lives.

invertebrate (in vər tə brət): An animal with no spinal column. About 95 percent of all animals are invertebrates. These include all animals except mammals, birds, reptiles, amphibians, and fish.

Piedmont (pēd mänt): An area of land lying at or near the base of a mountain range. In the Eastern United States, the Piedmont area lies between the Appalachian Mountains and the Atlantic coastal plain.

solar radiation (sō lər rā dē ā shən): Electromagnetic energy from the Sun; sunlight.

variable (vər ē ə bəl): Thing that can vary in number or amount.

Accented syllables are in **bold**. Marks are from the Merriam-Webster Pronunciation Guide.

FACTivity



Time Needed

1 class period

Materials needed:

- Three clear 1-quart plastic containers (or four for extension). A plastic soft drink bottle will work, but the tops should be cut so that the opening is at least 3 inches across.
- Two aquarium thermometers (or four for extension).

In this FACTivity, you will answer the following question: Does the movement of water affect its temperature?

You may do this FACTivity in pairs or in groups, depending on how many thermometers and containers are available.

First, develop and write a hypothesis for this FACTivity. You should develop your hypothesis based on your reading of this article and a review of the FACTivity. A hypothesis is an educated guess about something. Your hypothesis should take the form of a specific statement, and it should be written as if no change is expected as a result of the experiment. It should also be something you can test in an experiment. The following is an example of a hypothesis: "A glass of water left in the Sun for 3 hours will not have a higher water temperature than a glass of water left in the shade."

After you have read the article and reviewed the FACTivity, write your hypothesis on a piece of paper.

Test your hypothesis using the following process:

Perform this experiment outside on a sunny and warm day.

Fill two of the plastic containers with water up to 3 inches from the top. Use water from a refrigerated water fountain or refrigerated water. The water must be cooler than the outdoor air temperature, and the water must come from the same source at about the same time. The temperature of the water should be exactly the same in each container. If the two samples vary at all, mix them together and then divide the water between the two containers. Put one water-filled container in the Sun and place a thermometer in the water. Record the beginning water temperature after 3 minutes, then every 3 minutes until the temperature has raised 2 degrees.

At the same time a student, holding one filled container and one empty one, should stand in the Sun close to the area where the first water container has been set. The student will pour the water continually from container to container. If more students want to be involved, a relay may be set up. The important thing is to keep the water moving from container to container while in the Sun.

Continue pouring the water back and forth until the water in the “still” container has raised 2 degrees.

Using the second thermometer, measure the water temperature of the “moving” water. Is it 2 degrees warmer than its starting temperature? Why do you think it is the temperature that it is? Has your hypothesis been proven true or false? What is the answer to the question posed at the beginning of this FACTivity? Do the results of your experiment agree with the results in the research you just read? Develop and write an explanation of your results. How is this FACTivity similar to and different from the scientists’ research?

Assessment

Collect students’ written hypotheses and explanations of results. Use the rubric below to assess their work.

HYPOTHESIS	Included in report?	Clearly written?	Grammar/punctuation correct/no mistakes?
In form of statement?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
In form of null hypothesis (no change expected)?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
Is hypothesis testable?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
RESULTS			
Written statement of results?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
Stated whether hypothesis is proven true or false?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
Provided answer to FACTivity question?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
Stated whether results agree with article research?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)
Provided written explanation of results?	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)	Yes (1 pt) No (0 pt)

Scoring categories: 0-6, 7-12, 13-19, 19-24 (0-6=Lowest achievement, 19-24=Highest achievement)

Extension



Repeat the experiment in the shade.
Compare all four temperatures.

What You Can Do:

Be a stream detective! Around your home, school, and community, notice whether streams and rivers have trees and other plants growing near their banks. If not, begin a campaign to grow and care for trees and other plants along waterways. Always have an adult you know and trust with you when you begin your detective work. Also, always get permission from the landowner to walk on his or her private land. In addition, you can create posters to educate adults about the importance of having trees and other plants near waterways.



If you are a PLT-trained educator, you may use Activity # 38: "Every Drop Counts."

National Science Education Standards

Standards addressed in this article include:

Science As Inquiry:

Abilities Necessary To Do Scientific Inquiry,
Understandings About Scientific Inquiry

Earth Science:

Structure of Earth System

Science and Technology:

Understandings about Science and Technology

History and Nature of Science:

Science as a Human Endeavor,
Nature of Science

Additional Web Resources

More possible impacts of climate change on streams:

<http://www.sciencedaily.com/releases/2009/07/090723142116.htm>

<http://www.sciencedaily.com/releases/2007/05/070504101355.htm>

Adapted from Boggs, J.L.; Sun, G.; McNulty, S.G.; Swartley, W.; Treasure, E.; and Summer, W. 2009. Temporal and spatial variability in North Carolina Piedmont stream temperature. *AWRA 2009 Spring Specialty Conference*, May 4-6, Anchorage, AK. http://www.srs.fs.usda.gov/pubs/ja/ja_boggs005.pdf.