FULL THROTTLE MODEL:
Using Scientific Models to Quickly Assess Water Quality

Meet the Scientists!

Photo courtesy of Titus Seilheimer.

◀ Titus Seilheimer,
Fisheries Specialist

My favorite science experience was working on all five Great Lakes. I got my feet wet in all of them in graduate school when I studied fish habitat in coastal wetlands. When I worked for the Forest Service, I explored the watersheds of Lake Michigan and Lake Superior entirely by computer. Now I spend my time as a fisheries specialist with Wisconsin Sea Grant working on fisheries problems in Wisconsin's Great Lakes.

▶ Charles "Hobie" Perry,
Soil Scientist

My favorite science experience is interacting with international scholars. We have hosted scholars at our laboratory in Minnesota, and I have visited scientists on every continent across the globe, except Antarctica. Science is a great way to meet interesting people and make new friends.

Photo courtesy of Charles "Hobie" Perry.

What Kinds of Scientists Did This Research?

- **fisheries specialist:** This scientist studies fish ecology and populations to control disease, maintain habitat quality, and develop conservation methods and safe industry practices.
- **soil scientist:** This scientist studies soils as one of Earth's natural resources.

Thinking About Science

Many scientists make discoveries by comparing or summarizing information, or data. A collection of data is called a dataset. A dataset is organized in rows and columns of data (table 1). Datasets represent information using numbers, and numbers may be used to represent words.

Often, scientists collect data themselves and create their own datasets. Scientists may also use datasets created by other scientists. An example of a dataset created by other scientists is the collection of daily weather measurements, such as daily air temperatures, for communities across the Nation.

The National Oceanic and Atmospheric Administration (NOAA), for example, collects and electronically stores daily weather measurements for U.S. communities. Scientists interested in studying the relationship of weather to other **variables** might use this dataset. Anyone with Internet access can view and use these weather measurements, which are stored on computers in databases.

Computers have enabled scientists to create and use large datasets. As computers become more powerful, scientists are able to analyze larger and larger datasets and to combine large datasets. Sometimes, scientists combine existing datasets with their own datasets. As more datasets are created and are available to many scientists, scientists can learn even more about our world.

Identification number	Boy = 1 Girl = 2	Average number of minutes to type a text	Average number of texts per day	Use phone to talk with friends at least once every day Yes = 1 No = 2	Phone operating system iOS = 1 Android = 2
1	2	0.2	110	1	1
2	1	0.2	74	2	2
3	2	0.3	88	1	2
4	1	0.5	43	1	2
5	2	0.4	96	2	1
6	2	0.7	104	1	1

Table 1. A dataset showing the average number of minutes taken by teenagers to type a text, the average number of texts typed per day, whether a phone is used to talk with friends at least once every day, and the phone operating system for six teenagers in Lakeview Middle School. (Note: These numbers are not real data!)

Thinking About the Environment

Over time, natural environments may become degraded through human activities or natural disturbances. Land managers often work to restore these environments to a healthier condition. In 2010, the White House Council on Environmental Quality addressed watershed restoration (figure 1). The Council recommended that degraded watersheds be identified. The Council was interested in watersheds where restoration actions could be taken easily and quickly.

The Great Lakes Restoration Initiative (GLRI) was started in 2010. The goal of the GRLI is to protect and restore the largest system of freshwater lakes in the world. The Great Lakes contain about 20 percent of the world's freshwater (figure 2).

The watersheds surrounding the Great Lakes contribute either to each lake's good health or to a degraded condition. In particular, water near the shorelines, also called nearshore water, is likely to be degraded if nearby watersheds are unhealthy. Nonpoint sources of pollution in these watersheds may affect nearshore water quality. Nonpoint sources of pollution cannot be easily identified because they do not come from a single known source, or point. Examples of nonpoint pollution sources include cities and agriculture.

The scientists in this study were interested in helping land managers identify watersheds that might be sending pollutants into Great Lakes nearshore waters.

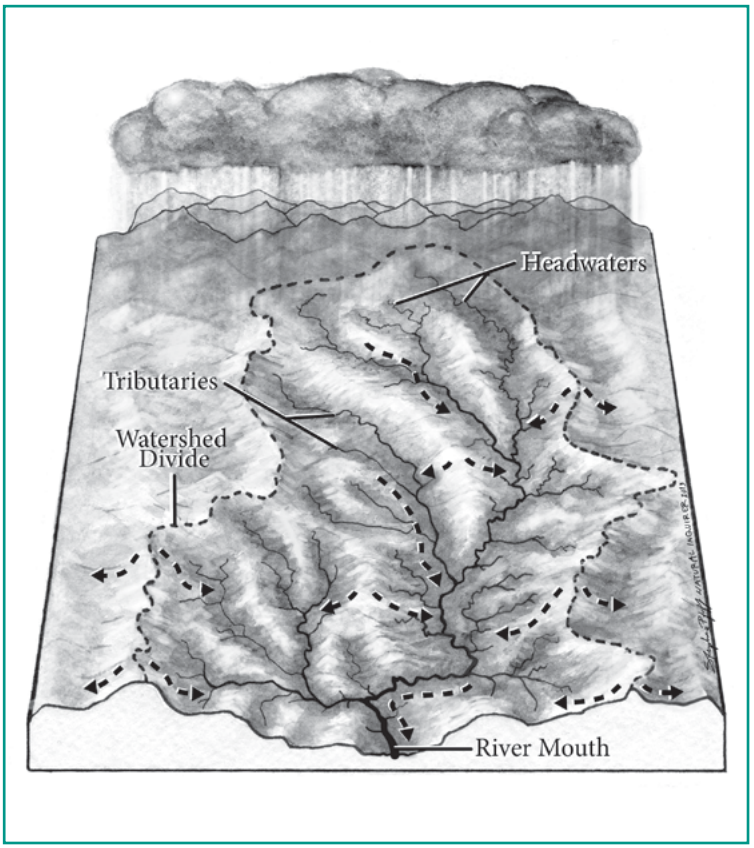


Figure 1. A watershed is the area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean. Any place on land, like your house or school, is in a watershed. Identify the closest waterway into which rainwater drains from your home or school.

Illustration by Stephanie Pfeiffer.

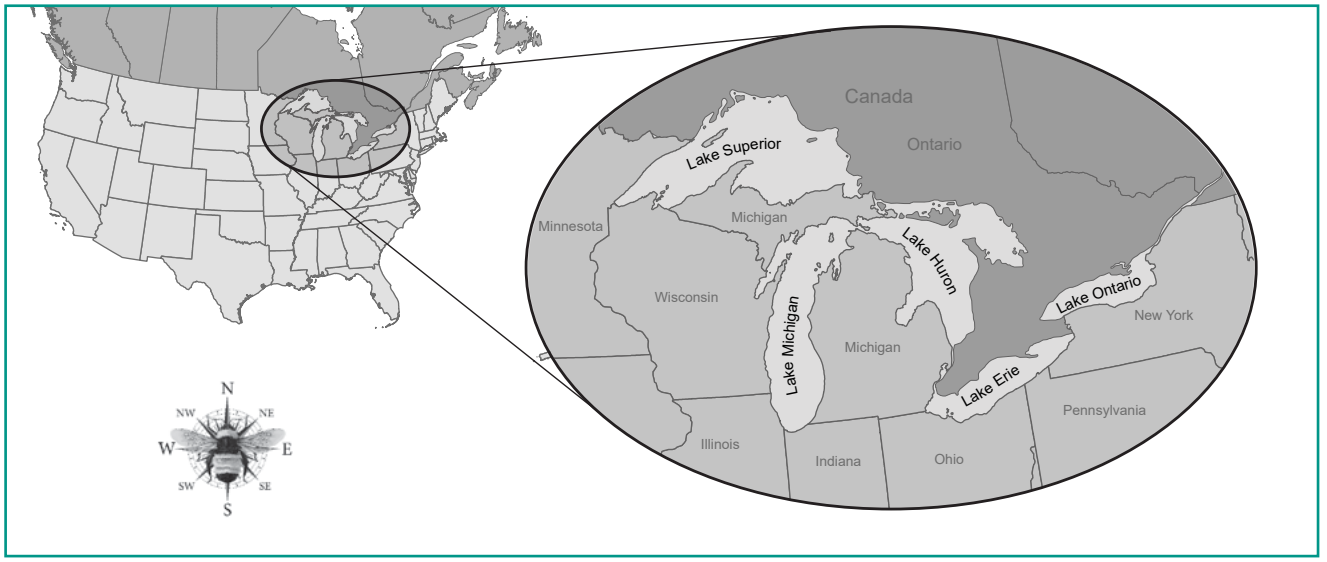


Figure 2. The Great Lakes contain a large amount of water. Spread evenly across the United States, the Great Lakes would submerge the States under about 9.5 feet of water, excluding Alaska and Hawai'i. (Source: Great Lakes Information Network.)

Map by Carey Burda.

Introduction

Water quality in lakes is influenced by the characteristics of the watersheds that surround them. Lakeside watersheds affect water quality because water that runs off and through them enters the lake water. Water quality affects the health of **economies** that depend on water and water bodies.

The Great Lakes contribute much to the economies of eight U.S. States, tribal communities, and one Canadian province that border the lakes. Ontario is the Canadian province that borders the Great Lakes. Identify Ontario in figure 2. What do you notice about Ontario, compared with the States south of the Great Lakes?

The nearshore region is important to Great Lakes communities. The nearshore region is defined as the water area extending from the shoreline to 20–30 meters of water depth (figure 3). The nearshore region is important because it is used as a drinking water source, is used for recreation, and is an important **aquatic** ecosystem.

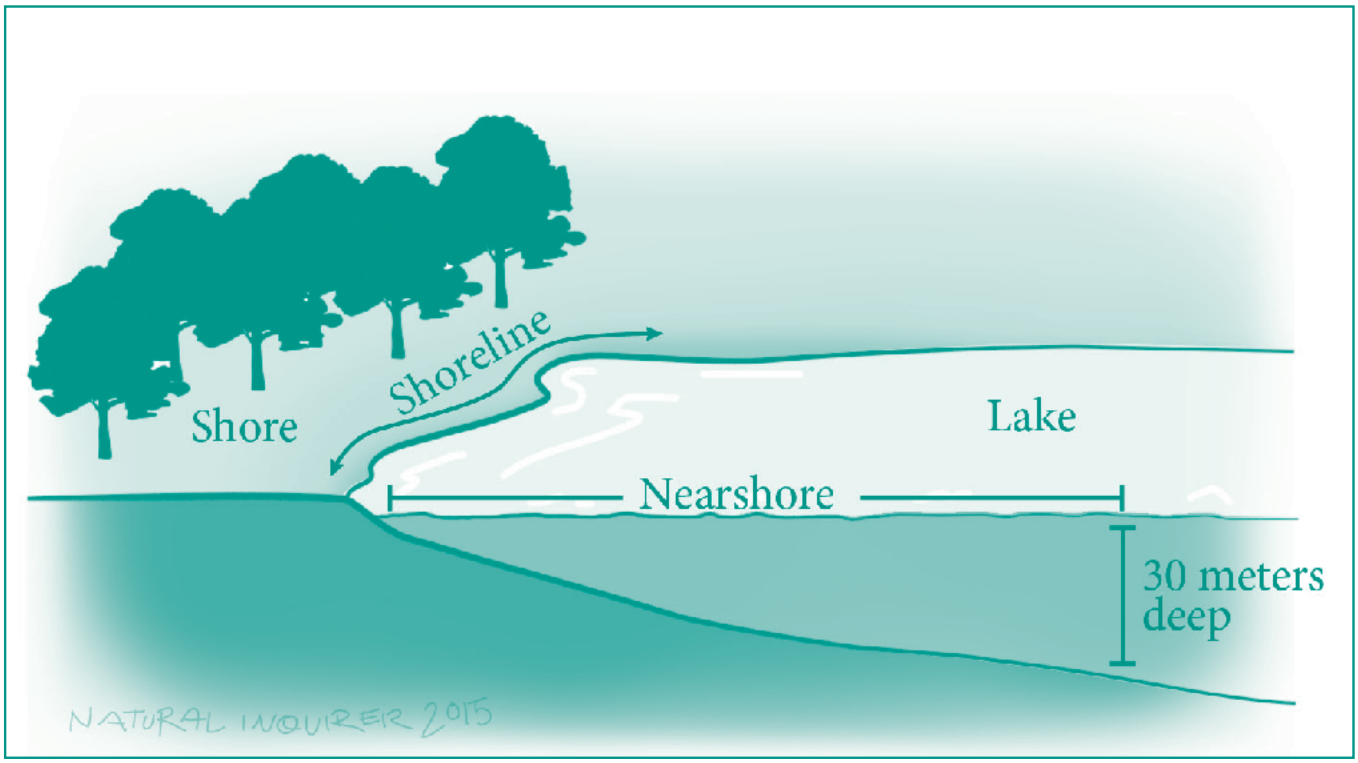


Figure 3. The nearshore region includes water from the shoreline to 30 meters in depth.

Illustration by Stephanie Pfeiffer.

Number Crunch

How many feet is 30 meters?

Multiply 30 times 3.281 to find out.

The Great Lakes nearshore waters' health is dependent upon having healthy watersheds (figure 4). These watersheds sometimes suffer from nonpoint source pollution. Nonpoint source pollution is pollution coming from a wide area, such as from agriculture or cities (figure 5). In contrast, point source pollution can be traced to one particular source, such as a factory (figure 6).

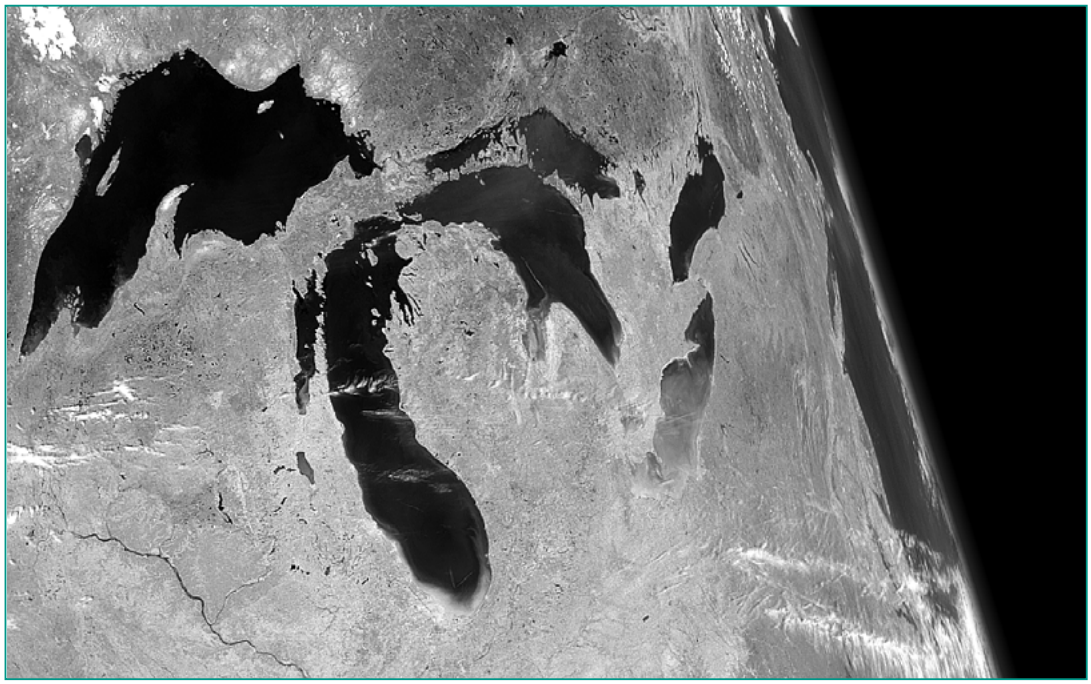


Figure 4. The land areas along the Great Lakes are the watersheds that drain into each lake.

National Aeronautics and Space Administration, NASA Visible Earth photo.

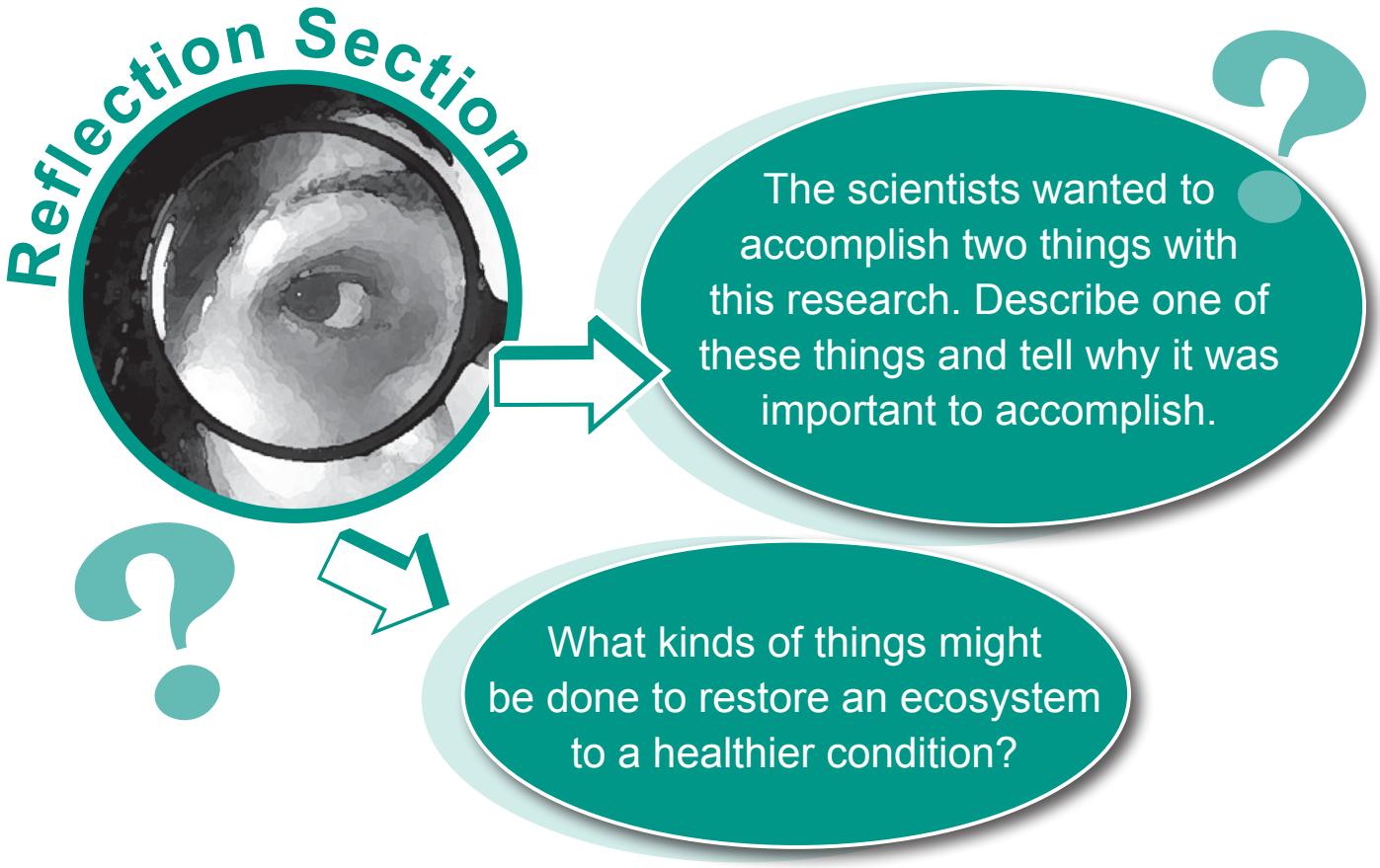
The scientists in this study were interested in figuring out a way to identify Great Lakes watersheds that need ecosystem restoration. Ecosystem restoration involves land management to restore the ecosystem to an earlier, healthier condition.

The scientists wanted to provide watershed managers with mathematical models that would predict nearshore water quality based on land use changes occurring in the watersheds. Models are a representation of something. Models can be made from materials, mathematics, or images. The scientists also wanted to be able to identify watersheds for which restoration could be done quickly and at a reasonable cost.

Figure 5. Agriculture is a nonpoint source of pollution for Great Lakes nearshore waters. Agricultural pollutants include sediment, nutrients like phosphorus, and chemicals used to kill unwanted insects and plants. Cattle can reduce water quality by increasing bacteria and sending too much nitrogen and other nutrients into water from their waste products.

Photo by Babs McDonald, used with permission.

Figure 6. Factories and power plants are point sources of pollution for Great Lakes nearshore waters.
Photo by Babs McDonald, used with permission.



Methods

The scientists studied watersheds around Lake Superior and Lake Michigan (figure 7). The scientists identified ecoregions within these watersheds (figure 8).

Ecoregions are areas that contain similar ecosystems. Ecoregions are identified by a different mix of natural vegetation as compared with the other ecoregions.

Figure 7. Great Lakes watershed boundaries are shown in light gray. The U.S. Geological Survey identifies the United States' watershed boundaries. Why do you think the U.S. Geological survey did not identify watershed boundaries to the north of the Great Lakes?

Map by Carey Burda, adapted from the U.S. Geological Survey.

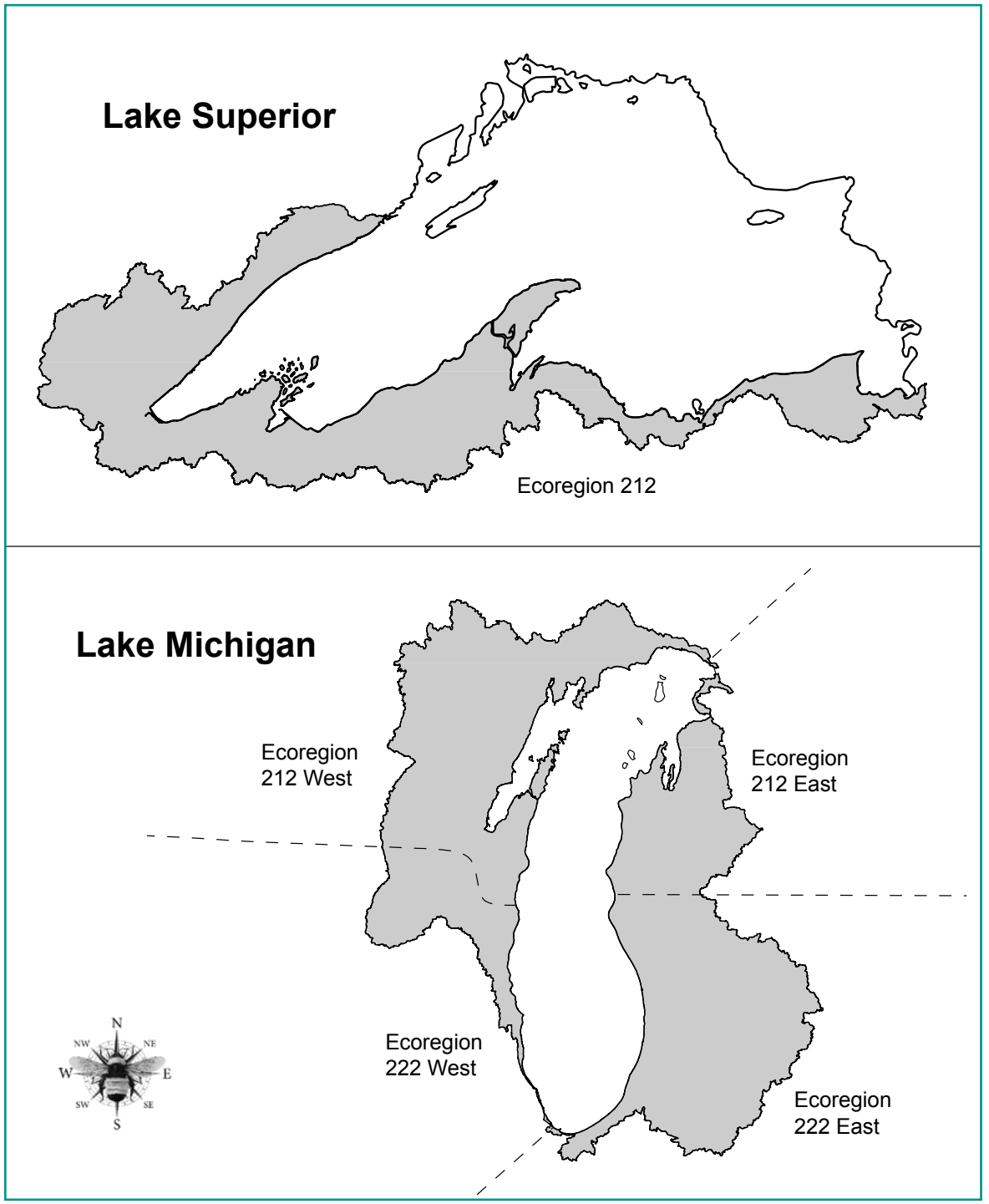


Figure 8. The Great Lakes watersheds were divided into ecoregions. This map shows only the part of each ecoregion that is included in the Great Lakes watersheds.

Map by Carey Burda.

The scientists used several existing databases to describe the conditions in each watershed (table 2). To learn more about existing databases, read "Thinking About Science" on page 12.

Database name	What was measured	Condition described
Vegetation Change Tracker (VCT)	Landsat images taken over a period of time **(figures 9 and 10)**	Forest disturbance and forest **persistence**
National Hydrologic Dataset Plus	How waterways drained into the lake	Stream network
National Land Cover Dataset (NLCD)	How much of the land is covered in agriculture and urban development; the amount of surface water in watersheds	**Land cover**
Forest Inventory and Analysis Plot Data (FIA)	Proportion of **softwood** trees in the forest and the proportion of **hardwood** trees in the forest	**Forest composition**

Table 2. Existing databases were used to describe each watershed. Forest disturbance was defined as the amount of forest land that was changed to a non-forest use during the study period. Examples of non-forest uses are agriculture, roads, or buildings. Forest persistence was defined as the amount of forest that remained forest during the study period. Land cover describes what covers the land, such as crops, fields, and buildings. Forest composition describes the percentage of softwood and hardwood trees in a forest.

Figure 9. Landsat images of Earth's surface are taken by Landsat satellites.

National Aeronautics and Space Administration photo.

Figure 10. Landscape conditions were identified by observing Landsat images. You can see the landscape in this Landsat image of the island of Hawai'i.

National Aeronautics and Space Administration photo, courtesy of http://www.geology.com.

The scientists used water quality information collected at various places near and within the watersheds (figure 11). Notice that much of the water quality information was collected in the nearshore region, near the coastline. Some of the water-quality information was collected in streams within the watershed. This information had already been collected by State, tribal, and Federal agencies. The scientists used measures of phosphorus and **turbidity** as indicators of water quality. Water quality is lowered when phosphorus and turbidity increase.

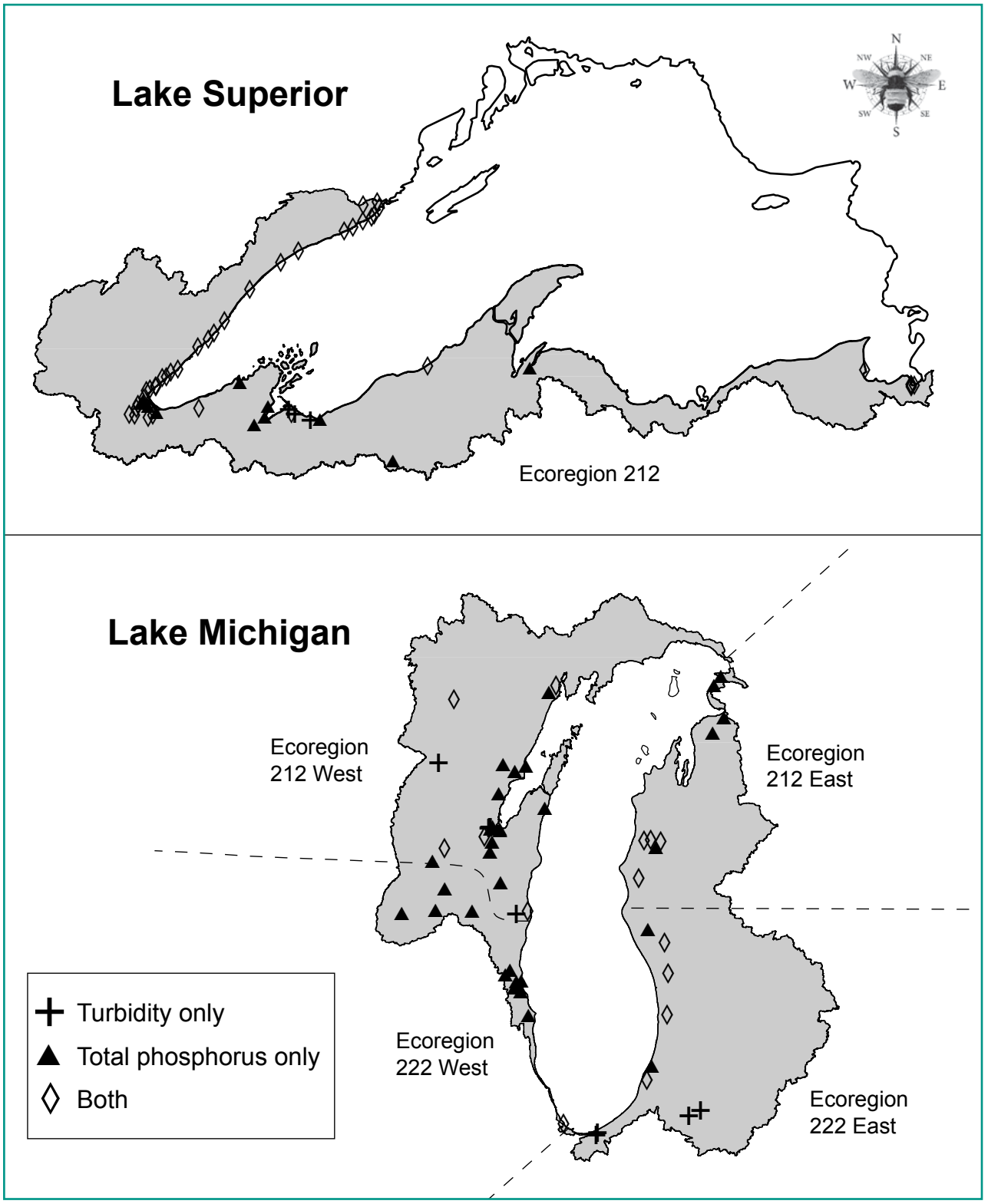


Figure 11. Water samples were collected near and within the watersheds by people in other agencies. These samples described the levels of phosphorus and turbidity in the water at each sample location.

Map by Carey Burda.

What Is Phosphorus?

Phosphorus is an element with the symbol P. Plants take up phosphorus from the soil as they grow. Low levels of phosphorus are found naturally in soil. Phosphorus, therefore, is often used as a soil fertilizer.

Phosphorus is also used in **pesticides** and detergents, and it is found in animal and industrial wastes. Pesticides, fertilizers, detergents, and animal and industrial wastes can be washed into water bodies by rain, melting snow, and irrigation. When too much phosphorus gets into a water body, the amount of oxygen in the water is reduced and water quality decreases.

The scientists used existing phosphorus and turbidity data collected within and near Great Lakes watersheds. The scientists retrieved information about the watersheds from other databases. They used all of this information to develop mathematical models on a computer. The models explored relationships between the amount of phosphorus and turbidity in the water and the watershed conditions shown in table 2 on page 21.

The models enabled the scientists to discover which of the landscape conditions in table 2 were most closely related to increased phosphorus and increased turbidity. Once the scientists understood which landscape conditions were most closely related to water quality, they were able to identify watersheds that had the greatest likelihood of contributing to water quality problems. This finding included watersheds from which the scientists had no water quality data, but for which the landscape conditions were known.

What Is Turbidity?

Turbidity is a measure of the amount of sediment, such as soil, silt, or sand, suspended in water. Sediment reduces or prevents sunlight from reaching aquatic plants. When sunlight cannot reach aquatic plants, photosynthesis is reduced. Plants produce oxygen during photosynthesis, so less sunlight reduces the amount of oxygen in the water. Like humans and other animals, fish and other aquatic life need oxygen to live.

Some fish need clear water to see their prey. Turbidity reduces water clarity. Sediment also absorbs heat from the sun, raising the water's temperature. When the water temperature gets too warm, some species, like brook trout, cannot live in the nearshore region of the Great Lakes. Although some turbidity is natural in some waterways, too much turbidity is harmful.

When you see a lake or river that looks muddy, it probably has a high level of turbidity.

Turbidity is commonly measured in nephelometric (**ne** fə lō **me** trik) turbidity units, or NTUs (figure 12). A nephelometer (**ne** fə **lȯ** mə tər) is used to measure the amount of light either penetrating a liquid or reflected off of sediment in a liquid. "Nephele" (**nef** ə lē) is the Greek word for "cloud," and "metric" means "measure." Nephelometric, therefore, means "to measure cloudiness." In Greek mythology, Nephele was a goddess who was created from a cloud.

For more information on turbidity, visit http://extension.usu.edu/waterquality and http://www.wsdot.wa.gov/research/reports/fullreports/526.1.pdf.

Figure 12. Turbidity can be measured using a hand held machine with a probe (like the one pictured) that goes into the water.
U.S. Geological Survey photo.

Reflection Section

How did the use of existing databases help the scientists understand which watershed conditions affected water quality?

Look at the number of water quality sampling sites in figure 11. For each of those sites, the scientists also retrieved a lot of information about nearby landscape conditions in the watersheds. Why do you think a computer was necessary to discover the relationships between landscape conditions and water quality?

How could the scientists identify water quality problems near watersheds for which they had no water quality data?

Findings

The scientists used several different variables to help them understand water quality. The Vegetation Change Tracker (VCT) database enabled the scientists to explore the relationship between changing landscapes and water quality. This exploration was possible because the VCT database includes information about how forests change over time. The relationship between forest change and water quality varied across the watersheds studied.

The scientists found that when urban development and other landscape conditions such as agriculture increased, water quality decreased (table 3).

Lake	Landscape conditions related to increased phosphorus	Landscape conditions related to increased turbidity
Lake Superior	• Percent agriculture • Amount of forest disturbance	• Amount of forest disturbance • Percent agriculture
Lake Michigan	• Percent urban land	• Amount of forest disturbance • Abundance of softwood (pine) trees

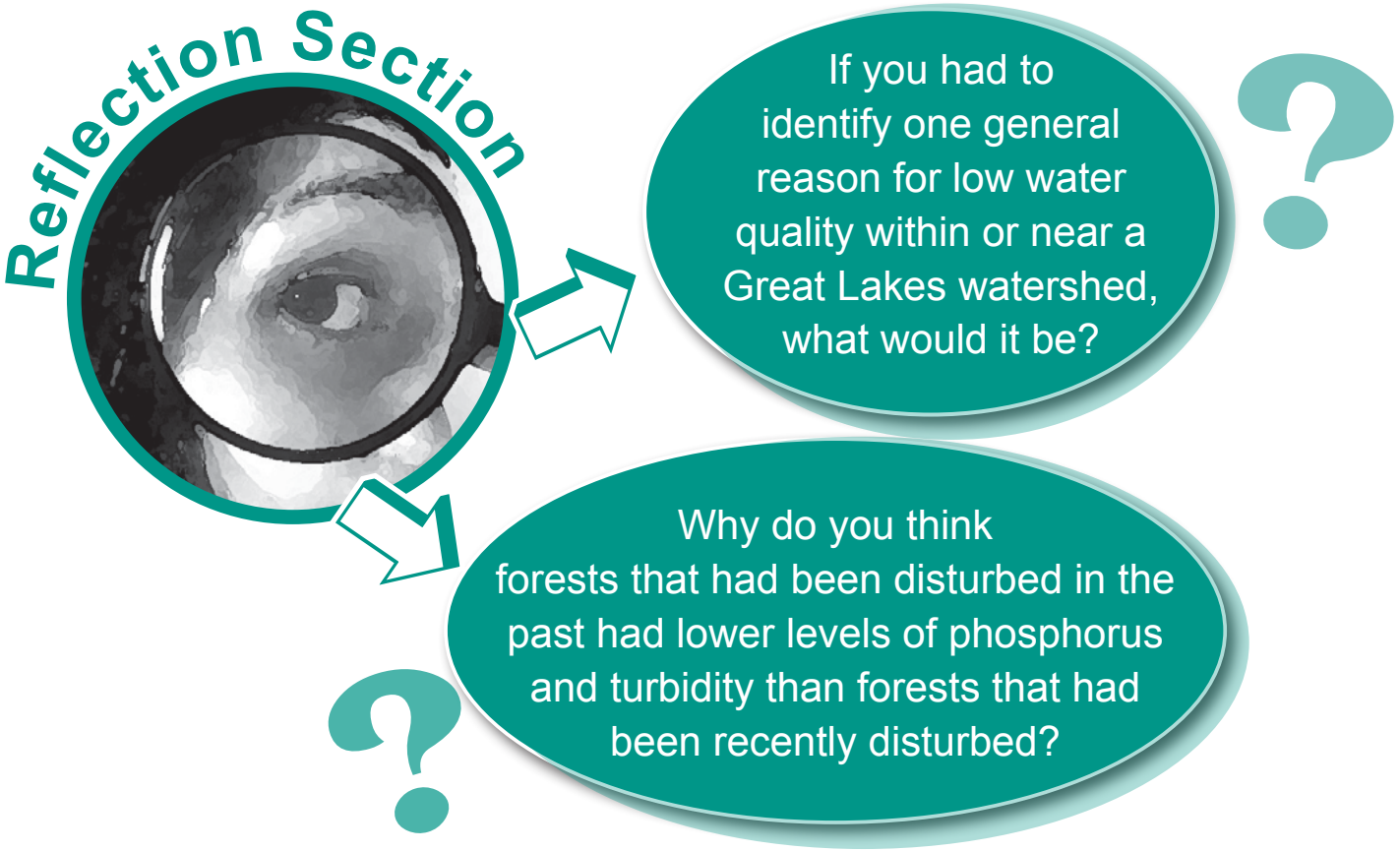
Table 3. Landscape conditions most closely related to increased phosphorus and increased turbidity in Lake Superior and Lake Michigan.

If a forest had been disturbed in the past but was not recently disturbed, turbidity and phosphorus levels were lower than in areas with recent forest disturbance. In watersheds with more open water or wetlands, water quality was higher (figure 13).

The scientists' models identified differences between water quality within and near Lake Michigan and Lake Superior watersheds, between ecoregions, and between watersheds within ecoregions. The scientists, therefore, had confidence in their ability to identify which watersheds needed immediate restoration.

Figure 13. Watersheds containing wetlands and open water had less phosphorus and less turbidity.

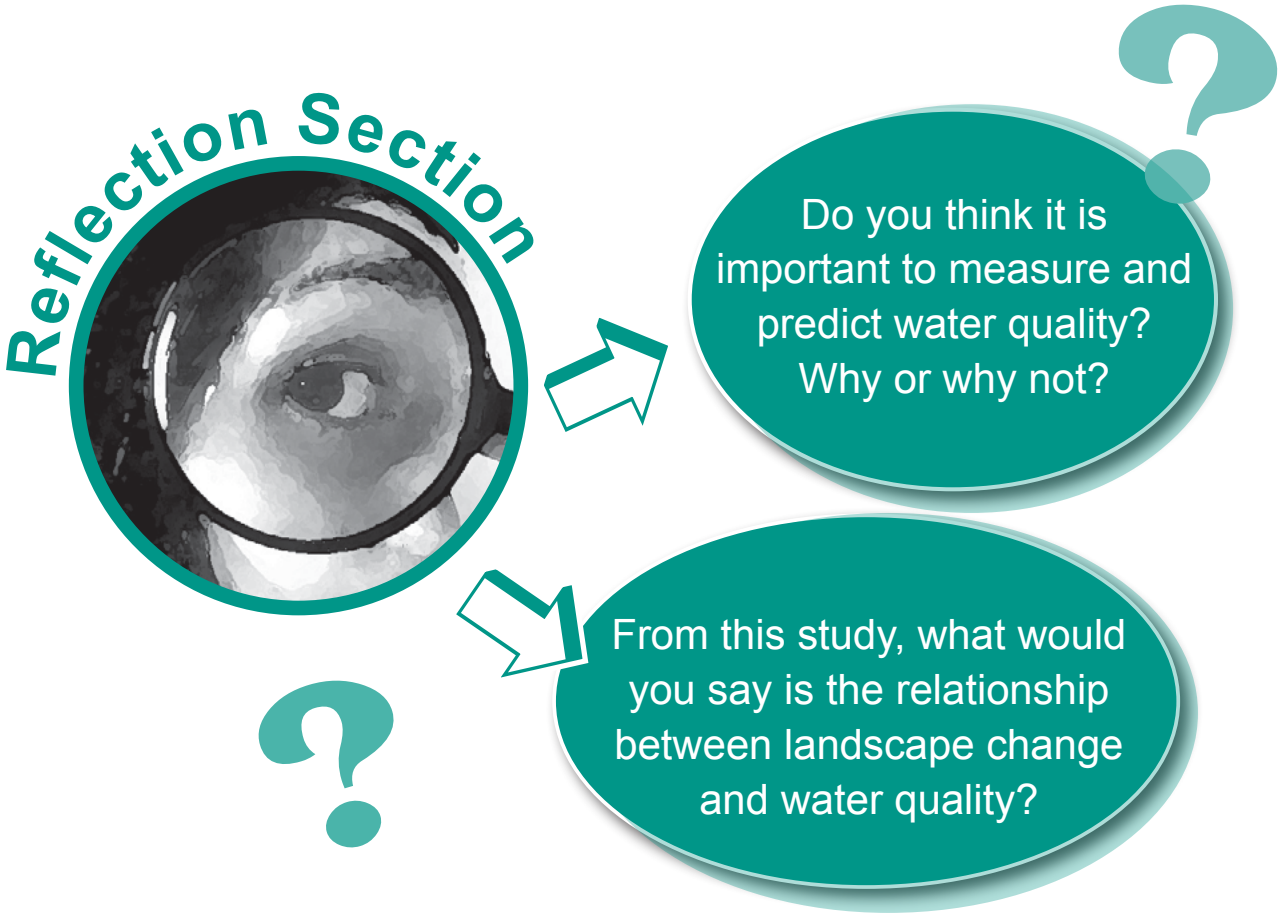
Photo by Sarah Gross, U.S. Army Corps of Engineers.



Discussion

The computer models enabled the scientists to identify which watersheds needed immediate restoration. The models also enabled the scientists to estimate water quality within and near watersheds where they did not have water quality data. The scientists were also able to predict water quality within and near watersheds where the landscape was expected to change.

With this information, watershed managers could respond to watersheds needing the most attention. Managers could also identify which watersheds would be most easily restored, and they could plan for the future as they expected the landscape to change.



Article adapted from Seilheimer, T.S.; Zimmerman, P.L.; Stueve, K.M.; Perry, C.H. 2013. Landscape-scale modeling of water quality in Lake Superior and Lake Michigan watersheds: How useful are forest-based indicators? Journal of Great Lakes Research. 39: 211-133. http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_seilheimer_001.pdf

FACTivity

Common Core Connection

Time Needed

- One class period

Materials (for each group of three students)

- Clear plastic container, such as a clear plastic soda bottle
- Electrical, masking, or other tape (if you are using a plastic bottle)
- Scissors (if you are using a plastic bottle)
- Paper clip
- Teaspoon or other device for stirring
- 2 tablespoons
- 1 cup of soil
- Water

The question you will answer in this FACTivity is, “How might fish (figure 14) and other aquatic life be affected by turbidity?”

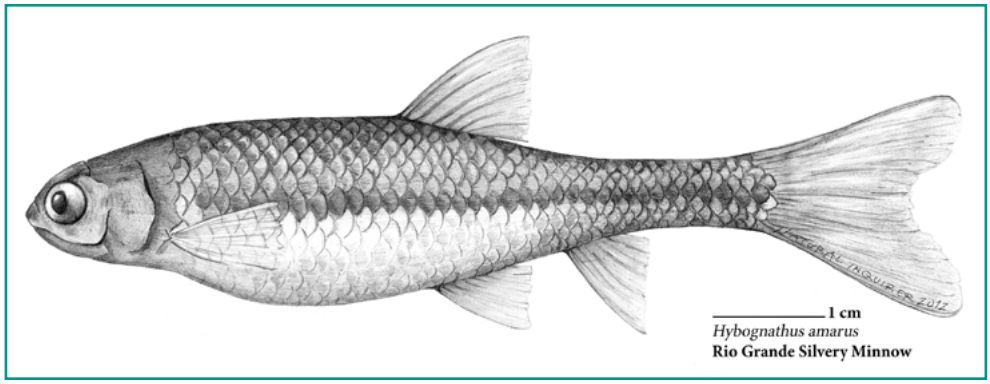


Figure 14. How do you think a minnow might be affected by turbidity?

Illustration by Stephanie Pfeiffer.

Methods

1. Your teacher will cut off the top of the plastic bottles, about 5 inches from the top and tape the edge of the bottles. (Taping will reduce the sharpness of the plastic edge.)
2. Fill the bottom of your plastic bottle with tap water to about 1 inch from the top.
3. Place the paperclip in the water.
4. One student will stir gently along the edge using the teaspoon, keeping the water and the paperclip moving.
5. Another student will use one of the tablespoons to scoop up the paperclip.
6. Using the second tablespoon, the third student will then add a heaping tablespoon of soil to the water. Continue to gently stir the water.
7. Observe what is happening to the water.
8. Replace the paperclip in the water.
9. Repeat steps 4-8 until all of the soil has been added to the water.

In this FACTivity, the water represents nearshore lake water. The soil represents soil running off of the watersheds (erosion), creating turbidity. The teaspoon represents water currents. The paperclip represents a small fish. The second tablespoon represents a larger fish, searching for and capturing smaller fish for food.

What happened to the larger fish's search for food as the water became more turbid? What is one disadvantage of turbidity for the small fish? How does this FACTivity relate to the study you just read? Now answer the question posed at the beginning of this FACTivity. Write your answer on a piece of paper, using complete sentences and proper punctuation and grammar.

Glossary

accumulation (ə **kyü** m(y)ə **lā** shən): The act of collecting or gathering.

analyze (**a** nə līz): To study or examine carefully.

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

control (kən **trōl**): Something used for comparison when checking the results of an experiment.

degrade (di **grād**): To impair in respect to some physical property. To lower or wear by erosion.

economy (ē **kä** nə mē): A system relating to the production, distribution, and consumption of goods and services.

forest composition (**fȯr** əst **käm** pə **si** shən): All plant species found in an area or landscape, including trees, shrubs, forbs, and grasses.

hardwood (**härd** wůd): The wood of a tree without cones; a tree without cones.

hypothetical (hī pə **the** ti kəl): Imagined as an example for further thought.

land cover (**land kə** vər): Whatever is covering the land, such as trees, grasses, buildings, or roads.

longitudinal (län jə **tüd** nəl): Involving the repeated observation over time with respect to one or more study variables.

persistence (pər **sis** tents): The state of occurring or existing beyond the usual, expected, or normal time.

pesticide (**pes** tə sīd): A chemical that is used to kill animals or insects that damage plants or crops.

prescribed fire (pri **skrīb(d) fīr**): Human application of fire to wildland vegetation under certain weather conditions as a forest management tool.

restoration (res tə **rā** shən): The act of bringing back to an earlier condition.

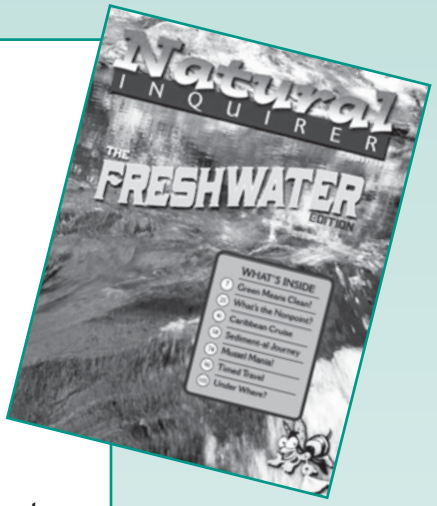
softwood (**sȯft** wůd): The wood of a tree (such as a pine tree) that is soft and easy to cut. A tree that produces softwood.

turbidity (tər **bi** də tē): The state of being cloudy or muddy.

variable (**ver** ē ə bəl): Something that is able or apt to vary.

Accented syllables are in bold. Marks and definitions are from http://www.merriam-webster.com. Definitions are limited to the word's meaning in the article.

Natural Inquirer Connections



You may want to reference these *Natural Inquirer* resources for additional information and FACTivities:

- "Green Means Clean" in the *Natural Inquirer* Freshwater edition to learn more about the importance of watersheds to water quality.
- "What's the Nonpoint?" in the *Natural Inquirer* Freshwater edition to learn more about nonpoint source pollution.
- "Sediment-al Journey" in the *Natural Inquirer* Freshwater edition to learn more about sediment in waterways.

These resources, along with others, can be found at http://www.naturalinquirer.org/all-issues.html.

If you are a trained Project Learning Tree educator, you may use "Pollution Search," "400-Acre Wood," "We Can Work It Out," and "Watch On Wetlands" as additional resources.

Web Resources

Great Lakes Restoration Initiative
http://greatlakesrestoration.us/

About Our Great Lakes: National Oceanic and Atmospheric Administration
http://www.glerl.noaa.gov/pr/ourlakes/ecology.html

Crash Course: Conservation Biology and Restoration Ecology
https://www.youtube.com/watch?v=Kaeyr5-O2eU

The National Zoo: Measuring Turbidity
http://nationalzoo.si.edu/Education/ClassroomScience/Turbidity/Teacher/

Environmental Protection Agency: Old MacDonald's Farmland Fertilizer Dilemma
http://water.epa.gov/polwaste/nps/kids/middleschool/farmx1.cfm

USDA Blog: Getting a New Perspective on the Great Lakes' Water Quality
http://blogs.usda.gov/2016/10/07/getting-a-new-perspective-on-the-great-lakes-water-quality/#more-66863