Tools of Environmental Science

CHAPTER 2

PRE-READING ACTIVITY

FOLDNOTES

Key-Term Fold

Before you read this chapter, create the **FoldNote** entitled "Key-Term Fold" described in the Reading and Study Skills section of the Appendix. Write a key term from the chapter on each tab of the key-term fold. Under each tab, write the definition of the key term.

This photograph shows a researcher filming a Weddell seal in Antarctica. Although scientists often use sophisticated tools in their work, their most important tools are those they carry with them—their senses and their habits of mind.

SECTION 1

Scientific Methods

The word *science* comes from the Latin verb *scire*, meaning "to know." Indeed, science is full of amazing facts and ideas about how nature works. But science is not just something you know; it is also something you do. This chapter explores how science is done and examines the tools scientists use.

Objectives

- List and describe the steps of the experimental method.
- Describe why a good hypothesis is not simply a guess.
- Describe the two essential parts of a good experiment.
- Describe how scientists study subjects in which experiments are not possible.
- Explain the importance of curiosity and imagination in science.

Key Terms

observation
hypothesis
prediction
experiment
variable
experimental group
control group
data
correlation

The Experimental Method

You have probably heard the phrase, "Today scientists discovered..." How do scientists make these discoveries? Scientists make most of their discoveries using the *experimental method*. This method consists of a series of steps that scientists worldwide use to identify and answer questions. The first step is observing.

Observing Science usually begins with observation. Someone notices, or observes, something and begins to ask questions. An **observation** is a piece of information we gather using our senses—our sight, hearing, smell, and touch. To extend their senses, scientists often use tools such as rulers, microscopes, and even satellites. For example, a ruler provides our eyes with a standard way to compare the lengths of different objects. The scientists in **Figure 1** are observing the tail length of a tranquilized wolf with the help of a tape measure. Observations can take many forms, including descriptions, drawings, photographs, and measurements.

Students at Keene High School in New Hampshire have observed that dwarf wedge mussels are disappearing from the Ashuelot River, which is located near their school. The students have also observed that the river is polluted. These observations prompted the students to take the next step in the experimental method—forming hypotheses.

Figure 1 ▶ These scientists are measuring the tail of a tranquilized wolf. What questions could these observations help the scientists answer?

QuickLAB

Hypothesizing and Predicting

Procedure

1. Place a **baking tray** on a table, and place a **thin book** under one end of the tray.
2. Place **potting soil, sand,** and **schoolyard dirt** in three piles at the high end of the baking tray.
3. Use a **toothpick** to poke several holes in a **paper cup.**
4. Write down a hypothesis to explain why soil gets washed away when it rains.
5. Based on your hypothesis, predict which of the three soils will wash away most easily.
6. Pour **water** into the cup, and slowly sprinkle water on the piles.

Analysis

1. What happened to the different soils?
2. Revise your hypothesis, if necessary, based on your experiment.

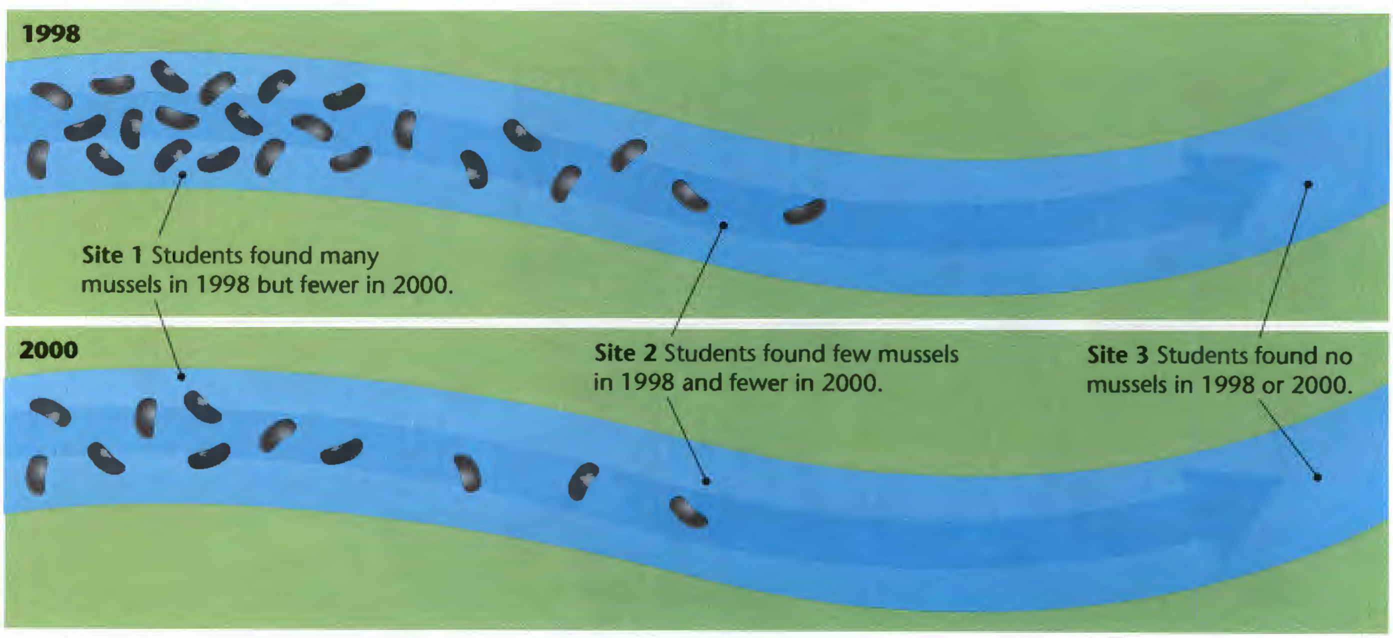
Hypothesizing and Predicting Observations give us answers to questions, but observations almost always lead to more questions. To answer a specific question, a scientist may form a hypothesis. A **hypothesis** (hie PAHTH uh sis) is a testable explanation for an observation. A hypothesis is more than a guess. A good hypothesis should make logical sense and follow from what you already know about the situation.

The Keene High School students observed two trends: that the number of dwarf wedge mussels on the Ashuelot River is declining over time and that the number of dwarf wedge mussels decreases at sites downstream from the first study site. These trends are illustrated in **Figure 2.** Students tested the water in three places and found that the farther downstream they went, the more phosphate the water contained. Phosphates are chemicals used in many fertilizers.

Armed with their observations, the students might make the following hypothesis: *phosphate fertilizer from a golf course is washing into the river and killing dwarf wedge mussels.* To test their hypothesis, the students make a **prediction,** a logical statement about what will happen if the hypothesis is correct. The students might make the following prediction: *mussels will die when exposed to high levels of phosphate in their water.*

It is important that the students' hypothesis—high levels of phosphate are killing the mussels—can be disproved. If students successfully raised mussels in water that has high phosphate levels, their hypothesis would be incorrect. Every time a hypothesis is disproved, the number of possible explanations for an observation is reduced. By eliminating possible explanations a scientist can zero in on the best explanation with more confidence.

Figure 2 ▶ The diagram below illustrates the trends observed by the students at Keene High School.



Experimenting The questions that arise from observations often cannot be answered by making more observations. In this situation scientists usually perform one or more experiments. An **experiment** is a procedure designed to test a hypothesis under controlled conditions.

Experiments should be designed to pinpoint cause-and-effect relationships. For this reason, good experiments have two essential characteristics: a single variable is tested, and a control is used. The **variable** (VER ee uh buhl) is the factor of interest, which, in our example, would be the level of phosphate in the water. To test for one variable, scientists usually study two groups or situations at a time. The variable being studied is the only difference between the groups. The group that receives the experimental treatment is called the **experimental group.** In our example, the experimental group would be those mussels that receive phosphate in their water. The group that does not receive the experimental treatment is called the **control group.** In our example, the control group would be those mussels that do not have phosphate added to their water. If the mussels in the control group thrive while most of those in the experimental group die, the experiment's results support the hypothesis that phosphates from fertilizer are killing the mussels.

internet connect

www.scilinks.org
Topic: Experimenting in Science
SciLinks code: HE4040
SCILINKS. Maintained by the National Science Teachers Association

CASE STUDY

The Experimental Method In Action at Keene High School

▶ **Keene High School** students are conducting an experiment to study the effect of phosphate levels on the growth rates of freshwater mussels.

Keene High School students collected mussels (nonendangered relatives of the dwarf wedge mussel) and placed equal numbers of them in two aquariums. They ensured that the conditions in the aquariums were identical—same water temperature, food, hours of light, and so on. The students added a measured amount of phosphate to the aquarium of the experimental group. They added nothing to the aquarium of the control group.

A key to the success of an experiment is changing only one variable and having a control group. What would happen if the aquarium in which most of the mussels died had phosphate in the water and was also warmer? The students would not know if the phosphate or the higher temperature killed the mussels.

Another key to experimenting in science is *replication*, or recreating the experimental conditions to make sure the results are consistent. In this case, using six aquariums—three control and three experimental—would help ensure that the results are not simply due to chance.

CRITICAL THINKING

1. Applying Ideas Why did the students ensure that the conditions in both aquariums were identical?

2. Evaluating Hypothesis How would you change the hypothesis if mussels died in both aquariums?

Figure 3 ▶ This scientist is analyzing his data with the help of a computer.

Organizing and Analyzing Data Keeping careful and accurate records is extremely important in science. A scientist cannot rely on experimental results that are based on sloppy observations or incomplete records. The information that a scientist gathers during an experiment, which is often in numeric form, is called **data.**

Organizing data into tables and graphic illustrations helps scientists analyze the data and explain the data clearly to others. The scientist in **Figure 3** is analyzing data on pesticides in food. Graphs are often used by scientists to display relationships or trends in the data. For this reason, graphs are especially useful for illustrating conclusions drawn from an experiment.

One common type of graph is called a *bar graph*. Bar graphs are useful for comparing the data for several things in one graph. The bar graph in **Figure 4** displays the information contained in the table above it. Graphing the information makes the trends easy to see. The graph shows that phosphates decrease downstream and that nitrates increase downstream.

Table 1 ▼

Pollutant Concentrations		
Site	Nitrates	Phosphates
1	0.3	0.02
2	0.3	0.06
3	0.1	0.07

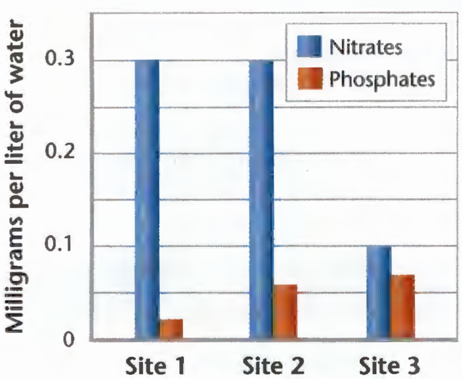


Figure 4 ▶ The table (top) presents data on the amount of phosphates and nitrates found at Sites 1, 2, and 3 on the Ashuelot River in 2000. The bar graph (bottom) displays this information in graphical form.

Drawing Conclusions Scientists determine the results of their experiment by analyzing their data and comparing the outcome of their experiment with their prediction. Ideally, this comparison provides the scientist with an obvious conclusion. But often the conclusion is not obvious. For example, in the mussel experiment, what if three mussels died in the control tank and five died in the experimental tank? The students could not be certain that phosphate is killing the mussels. Scientists often use mathematical tools to help them determine whether such differences are meaningful or are just a coincidence. Scientists also repeat their experiments.

Repeating Experiments Although the results from a single experiment may seem conclusive, scientists look for a large amount of supporting evidence before they accept a hypothesis. The more often an experiment can be repeated with the same results, in different places and by different people, the more sure scientists become about the reliability of their conclusions.

Communicating Results Scientists publish their results to share what they have learned with other scientists. When scientists think their results are important, they usually publish their findings as a scientific article. A scientific article includes the question the scientist explored, reasons why the question is important, background information, a precise description of how the work was done, the data that were collected, and the scientist's interpretation of the data.

The Correlation Method

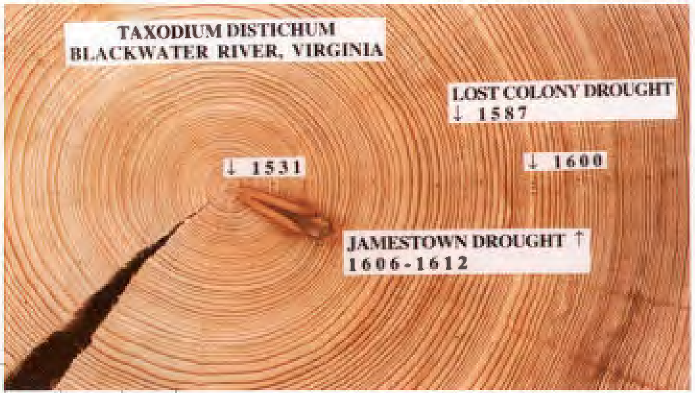
Whenever possible, scientists study questions by using experiments. But many questions cannot be studied experimentally. The question "What was Earth's climate like 60 million years ago?" cannot be studied by performing an experiment because the scientists are 60 million years too late. "Does smoking cause lung cancer in humans?" cannot be studied experimentally because doing experiments that injure people would be unethical.

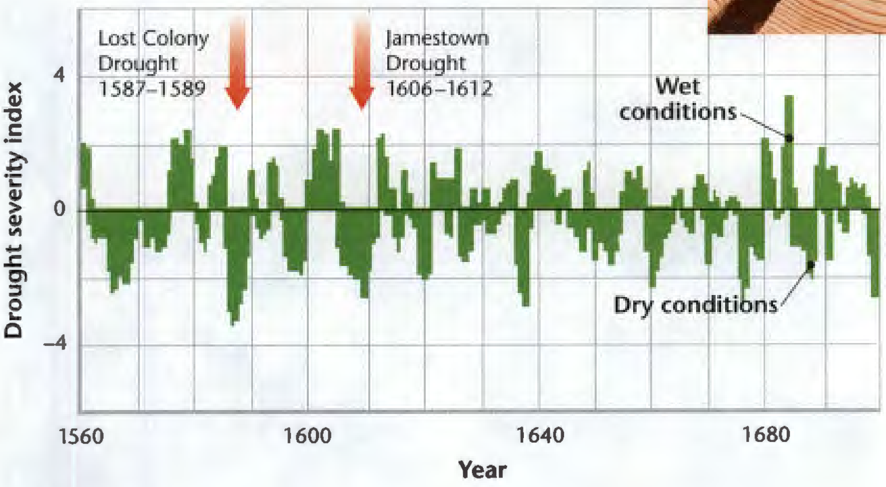
When using experiments to answer questions is impossible or unethical, scientists test predictions by examining **correlations,** or reliable associations between two or more events. For example, scientists know that the relative width of a ring on a tree trunk is a good indicator of the amount of rainfall the tree received in a given year. Trees produce wide rings in rainy years and narrow rings in dry years. Scientists have used this knowledge to investigate why the first European settlers at Roanake Island, Virginia (often called the Lost Colony) disappeared and why most of the first settlers at Jamestown, Virginia, died. As shown in **Figure 5**, the rings of older trees on the Virginia coast indicate that the Lost Colony and the Jamestown Colony were founded during two of the worst droughts the coast had experienced in centuries. The scientists concluded that the settlers may have been the victims of unfortunate timing.

Although correlation studies are useful, correlations do not necessarily prove cause-and-effect relationships between two variables. For example, the correlation between increasing phosphate levels and a declining mussel population on the Ashuelot River does not prove that phosphates harm mussels. Scientists become more sure about their conclusions if they find the same correlation in different places and as they eliminate possible explanations.

Connection to Geology

Coral Correlation Some geologists use an interesting correlation to study records of past climates. Certain species of coral put down layers of skeleton every year and can live for 300 years. Coral skeletons contain the elements strontium, Sr, and calcium, Ca. In some corals, the ratio of these elements in a layer of skeleton correlates with local sea surface temperatures at the time that layer forms. The correlation between the Sr to Ca ratio and the sea temperature provides scientists with one record of how Earth's climate has changed over the centuries.





Source: *Science.*

Figure 5 ▶ This cross section of a baldcypress from southeastern Virginia (above) shows a record of rainfall beginning in 1531. The graph translates the relative tree ring width into what is called a *drought index,* which allowed scientists to compare rainfall between different years.

Connection to Biology

Discovering Penicillin Alexander Fleming discovered penicillin by accident. Someone left a window open near his dishes of bacteria, and the dishes were infected with spores of fungi. Instead of throwing the dishes away, Fleming looked at them closely and saw that the bacteria had died on the side of a dish where a colony of green *Penicillium* mold had started to grow. If he had not been a careful observer, penicillin might not have been discovered. You may find *Penicillium* yourself on moldy bread.

Scientific Habits of Mind

Scientists actually approach questions in many different ways. But good scientists tend to share several key habits of mind, or ways of approaching and thinking about things.

Curiosity Good scientists are endlessly curious. Jane Goodall, pictured in **Figure 6**, is an inspiring example. She studied a chimpanzee troop in Africa for years. She observed the troop so closely that she came to know the personalities and behavior of each member of the troop and greatly contributed to our knowledge of that species.

The Habit of Skepticism Good scientists also tend to be skeptical, which means that they don't believe everything they are told. For example, 19th century doctors were taught that men and women breathe differently—men use the diaphragm (the sheet of muscle below the rib cage) to expand their chests, whereas women raise their ribs near the top of their chest. Finally, a female doctor found that women seemed to breathe differently because their clothes were so tight that their ribs could not move far enough to pull air into their lungs.

Openness to New Ideas As the example above shows, skepticism can go hand in hand with being open to new ideas. Good scientists keep an open mind about how the world works.

Figure 6 ▶ Jane Goodall is famous for her close observations of chimpanzees—observations fueled in part by her endless curiosity.

Intellectual Honesty A scientist may become convinced that a hypothesis is correct even before it has been fully tested. But when an experiment is repeated, the results may be different from those obtained the first time. A good scientist is willing to recognize that the new results may be accurate, even though that means admitting that his or her hypothesis might be wrong.

Imagination and Creativity Good scientists are not only open to new ideas but able to conceive of new ideas themselves. The ability to see patterns where others do not or imagine things that others cannot allows a good scientist to expand the boundaries of what we know.

An example of an imaginative and creative scientist is John Snow, shown in **Figure 7**. Snow was a physician in London during a cholera epidemic in 1854. Cholera, a potentially fatal disease, is caused by a bacterium found in water that is polluted with human waste. Few people had indoor plumbing in 1854. Most people got their water from public pumps; each pump had its own well. In an attempt to locate the polluted water source, Snow made a map showing where the homes of everyone who died of cholera were located. The map also showed the public water pumps. In an early example of a correlation study, he found that more deaths occurred around a pump in Broad Street than around other pumps in the area. London authorities ended the cholera epidemic by taking the handle off the Broad Street pump so that it could no longer be used. Using observation, imagination, and creativity, Snow solved an environmental problem and saved lives.

Figure 7 ▶ John Snow (bottom) created his famous spot map (top), which enabled him to see a pattern no one had noticed before.

SECTION 1 Review

1. **Describe** the steps of the experimental method.
2. **Name** and explain the importance of three scientific habits of mind.
3. **Explain** why a hypothesis is not just a guess.
4. **Explain** how scientists try to answer questions that cannot be tested with experiments.

CRITICAL THINKING

5. **Analyzing Methods** Read the description of experiments. Describe the two essential parts of a good experiment, and explain their importance. READING SKILLS
6. **Analyzing Relationships** How can a scientist be both skeptical and open to new ideas at the same time? Write a one-page story that describes such a situation. WRITING SKILLS

SECTION 2

Statistics and Models

Objectives

- Explain how scientists use statistics.
- Explain why the size of a statistical sample is important.
- Describe three types of models commonly used by scientists.
- Explain the relationship between probability and risk.
- Explain the importance of conceptual and mathematical models.

Key Terms

statistics
mean
distribution
probability
sample
risk
model
conceptual model
mathematical model

Environmental science provides a lot of data that need to be organized and interpreted before they are useful. **Statistics** is the collection and classification of data that are in the form of numbers. People commonly use the term statistics to describe numbers, such as the batting record of a baseball player. Sportswriters also use the methods of statistics to translate a player's batting record over many games into a batting average, which allows people to easily compare the batting records of different players.

How Scientists Use Statistics

Scientists are also interested in comparing things, but scientists use statistics for a wide range of purposes. Scientists rely on and use statistics to summarize, characterize, analyze, and compare data. Statistics is actually a branch of mathematics that provides scientists with important tools for analyzing and understanding their data.

Consider the experiment in which students studied mussels to see if the mussels were harmed by fertilizer in their water. Students collected data on mussel length and phosphate levels during this experiment. Some mussels in the control group grew more than some mussels in the experimental group, yet some grew less. How could the students turn this data into meaningful numbers?

Statistics Works with Populations Scientists use statistics to describe statistical populations. A *statistical population* is a group of similar things that a scientist is interested in learning about. For example, the dwarf wedge mussels shown in **Figure 8** are part of the population of all dwarf wedge mussels on the Ashuelot River.

Figure 8 ▶ Students found these dwarf wedge mussel shells in a muskrat den. These mussels are part of the statistical population of all dwarf wedge mussels on the Ashuelot River.

What Is the Average? Although statistical populations are composed of similar individuals, these individuals often have different characteristics. For example, in the population of students in your classroom, each student has a different height, weight, and so on.

As part of their experiments, the Keene High School students measured the lengths of dwarf wedge mussels in a population, as shown in **Figure 8.** By adding the lengths of the mussels and then dividing by the number of mussels, students calculated the average length of the mussels, which in statistical terms is called the *mean*. A mean is the number obtained by adding up the data for a given characteristic and dividing this sum by the number of individuals. For scientists, the mean provides a single numerical measure for a given aspect of a population. Scientists can easily compare different populations by comparing their means. The mean length of the mussels represented in **Figure 9** is about 30 mm.

The Distribution The bar graph in **Figure 9** shows the lengths of dwarf wedge mussels in a population. The pattern that the bars create when viewed as a whole is called the *distribution*. A distribution is the relative arrangement of the members of a statistical population. In **Figure 9,** the lengths of the individuals are arranged between 15 and 50 mm.

The overall shape of the bars, which rise to form a hump in the middle of the graph, is also part of the distribution. The line connecting the tops of the bars in **Figure 9** forms the shape of a bell. The graphs of many characteristics of populations, such as the heights of people, form bell-shaped curves. A bell-shaped curve indicates a *normal distribution*. In a normal distribution, the data are grouped symmetrically around the mean.

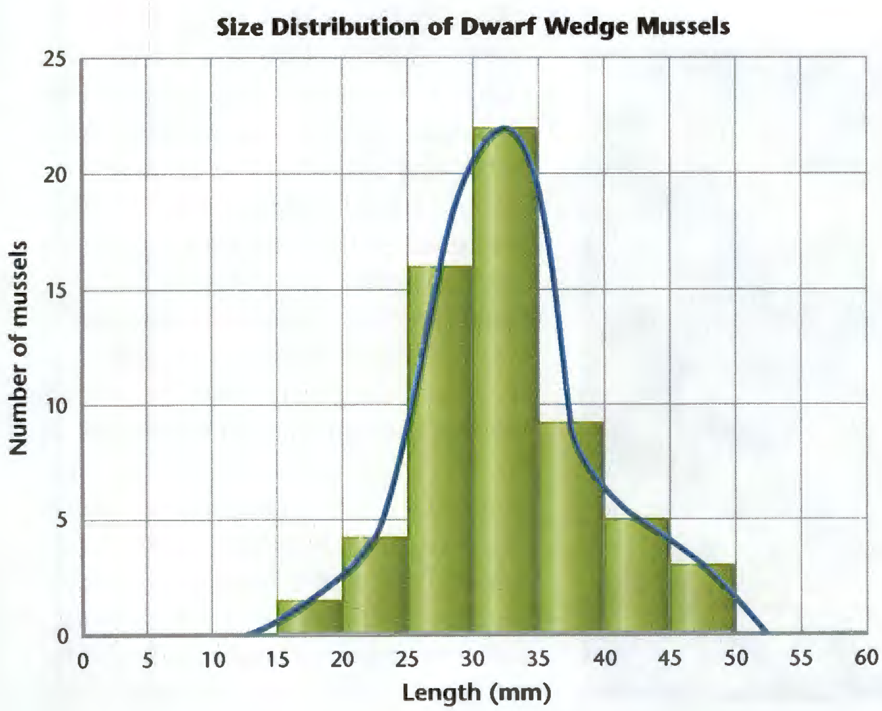
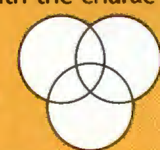


Figure 9 ▶ This bar graph shows the distribution of lengths in a population of dwarf wedge mussels. The location of each bar on the x-axis indicates length. The height of each bar represents the number of mussels as shown on the y-axis. For example, the second bar indicates that there are four mussels between 20 and 25 mm long.

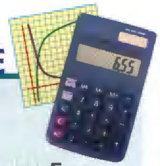
internet connect

www.scilinks.org
Topic: Statistics in Science
SciLinks code: HE4105
SciLINKS. Maintained by the National Science Teachers Association

Graphic Organizer **Venn Diagram**
Create the **Graphic Organizer** entitled "Venn Diagram" described in the Appendix. Label the circles with "Statistics" and "Models." Then, fill in the diagram with the characteristics that each way of interpreting the data shares with the other.



MATHPRACTICE



Probability Probability is often determined by observing ratios or patterns. For example, imagine that you count 20 pine trees in a forest and notice that four of those trees have pine cones. What is the probability that the next pine tree you come across will have pine cones?

What Is the Probability? The chance that something will happen is called **probability.** For example, if you toss a penny, what is the probability that it will come up heads? Most people would say "half and half," and they would be right. The chance of a tossed penny coming up heads is ½, which can also be expressed as 0.5 or 50%. In fact, probability is usually expressed as a number between 0 and 1 and written as a decimal rather than as a fraction. Suppose the penny comes up heads 7 out of 10 times. Does this result prove that the probability of a penny coming up heads is 0.7? No, it does not. So what is the problem?

The problem is that the *sample size*—the number of objects or events sampled—is too small to yield an accurate result. In statistics, a **sample** is the group of individuals or events selected to represent the population. If you toss a penny 10 times, your sample size is 10. If you continue tossing 1,000 times, you are almost certain to get about 50% heads and 50% tails. In this example, the sample is the number of coin tosses you make, while the population is the total number of coin tosses possible. Scientists try to make sure that the samples they take are large enough to give an accurate estimate for the whole population.

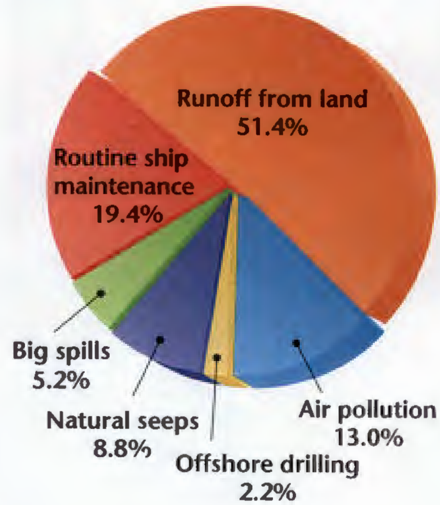
Statistics in Everyday Life

You have probably heard, "There is a 50 percent chance of rain today." **Figure 10** shows an example of a natural event that we often associate with probability—a thunderstorm. You encounter statistics often and use them more than you may think. People are constantly trying to determine the chance of something happening. A guess or gut instinct is probably just an unconscious sense of probability.

Figure 10 ▶ Most people are familiar with statistics regarding the weather, such as the chance, or probability, of a thunderstorm.

Understanding the News The news contains statistics every day, even if they are not obvious. For example, a reporter may say, "A study shows that forest fires increased air pollution in the city last year." We could ask many statistical questions about this news item. We might first ask what the average amount of air pollution in the city is. We could gather data on air pollution levels over the past 20 years and graph them. Then we could calculate the mean, and ask ourselves how different last year's data were from the average. We might graph the data and look at the distribution. Do this year's pollution levels seem unusually high compared to levels in other years? Recognizing and paying attention to statistics will make you a better consumer of information, including information about the environment.

Figure 11 ▶ People may worry about the risk of a big oil spill, but as the graph below shows, most of the oil polluting the oceans comes from ordinary sources.



Thinking About Risk In scientific terms, risk is the probability of an unwanted outcome. For example, if you have a 1 in 4 chance of failing a class, the risk is ¼, or 0.25. **Figure 11** shows a well-publicized environmental problem—oil spills. But as you can see in the pie graph, the risk of pollution from large oil spills is much smaller than the risk of oil pollution from everyday sources.

The most important risk we consider is the risk of death. Most people overestimate the risk of dying from sensational causes, such as plane crashes, and underestimate the risk from common causes, such as smoking. Likewise, most citizens overestimate the risk of sensational environmental problems and underestimate the risk of ordinary ones, as shown in **Table 2.**

Table 2 ▼

Perceptions of Risk by Experts and Ordinary Citizens

	High risk	Low risk
Experts	ozone depletion; global climate change	oil spills; radioactive materials; water pollution
Citizens	ozone depletion; radioactive waste; oil spills	global climate change; water pollution

Source: U.S. Environmental Protection Agency.

Connection to Law

Oil Tankers The Oil Pollution Act of 1990 was a direct response to the *Exxon Valdez* oil spill. The controversial bill had been debated for 14 years; it passed swiftly in the aftermath of the disaster. Under the law, all oil tankers operating in United States waters must be protected with double hulls by 2015.

Figure 12 ▶ This plastic model of a DNA molecule is an example of a physical model.

Models

You are probably already familiar with models. Museums have models of ships, dinosaurs, and atoms. Architects build models of buildings. Even crash-test dummies are models. Models are representations of objects or systems. Although people usually think of models as things they can touch, scientists use several different types of models to help them learn about our environment.

Physical Models All of the models mentioned above are physical models. *Physical models* are three-dimensional models you can touch. Their most important feature is that they closely resemble the object or system they represent, although they may be larger or smaller.

One of the most famous physical models was used to discover the structure of DNA. The two scientists that built the structural model of DNA knew information about the size, shape, and bonding qualities of the subunits of DNA. With this knowledge, the scientists created model pieces that resembled the subunits and the bonds between them. These pieces helped them figure out the potential structures of DNA. Discovering the structure of DNA furthered other research that helped scientists understand how DNA replicates in a living cell. **Figure 12** shows a modern model of a DNA molecule. The most useful models teach scientists something new and help to further other discoveries.

Graphical Models Maps and charts are the most common examples of *graphical models*. Showing someone a road map is easier than telling him or her how to get somewhere. An example of a graphical model is the map of the Denver, Colorado, area in **Figure 13**. Scientists use graphical models to show things such as the positions of the stars, the amount of forest cover in a given area, and the depth of water in a river or along a coast.

Geofact

Fossil-Fuel Deposits Fossil fuels, such as coal and oil, are often buried deep underground in particular rock formations. We find kinds of fossil fuels by drilling for rocks that indicate the presence of fossil fuels and then we make models of where the coal or oil is likely to be found.

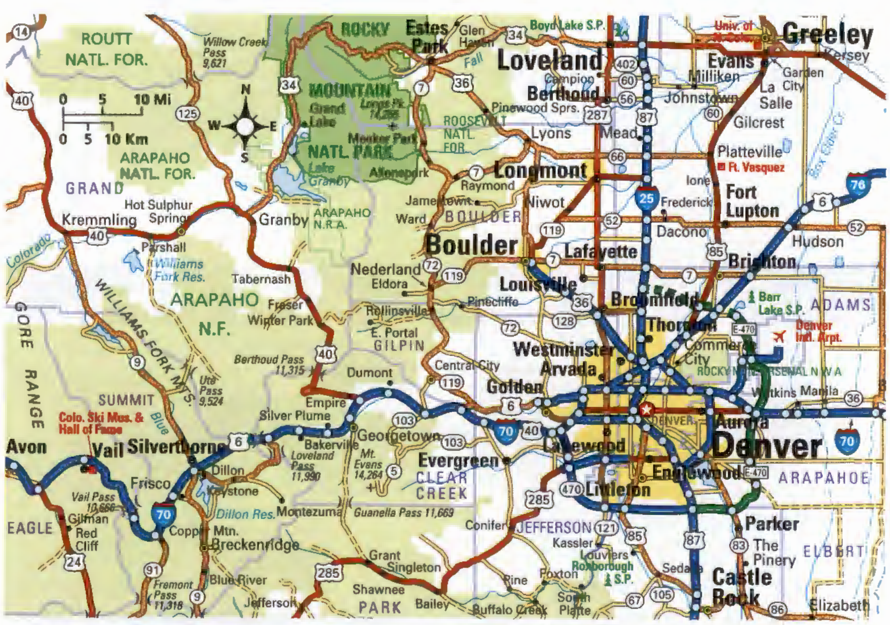


Figure 13 ▶ This map of the Denver, Colorado, area is an example of a graphical model.

Conceptual Models A **conceptual model** is a verbal or graphical explanation for how a system works or is organized. A flow-chart diagram is an example of a type of conceptual model. A flow-chart uses boxes linked by arrows to illustrate what a system contains and how those contents are organized.

Consider the following example. Suppose that a scientist is trying to understand how mercury, a poisonous metal, moves through the environment to reach people after the mercury is released from burning coal. The scientist would use his or her understanding of mercury in the environment to build a conceptual model, as shown in **Figure 14.** Scientists often create such diagrams to help them understand how a system fits together—what components the system contains, how the components are arranged, and how they affect one another.

Conceptual models are not always diagrams. They can also be verbal descriptions or even drawings of how something works or is put together. For example, the famous model of an atom as a large ball being circled by several smaller balls is a conceptual model of the structure of an atom. As this example shows, an actual model can be more than one type. An atomic model made of plastic balls is both a conceptual model as well as a physical model.

FIELD ACTIVITY

Conceptual Model Accompany your class outdoors. Observe your surroundings, and write down observations about what you see. In your ***Ecolog,*** draw a conceptual model of something you observe. Your model should be of a system with components that interact, such as a small community of organisms.

internet connect

www.scilinks.org
Topic: Using Models
SciLinks code: HE4119

SCILINKS. Maintained by the National Science Teachers Association

Conceptual Model of Mercury Contamination

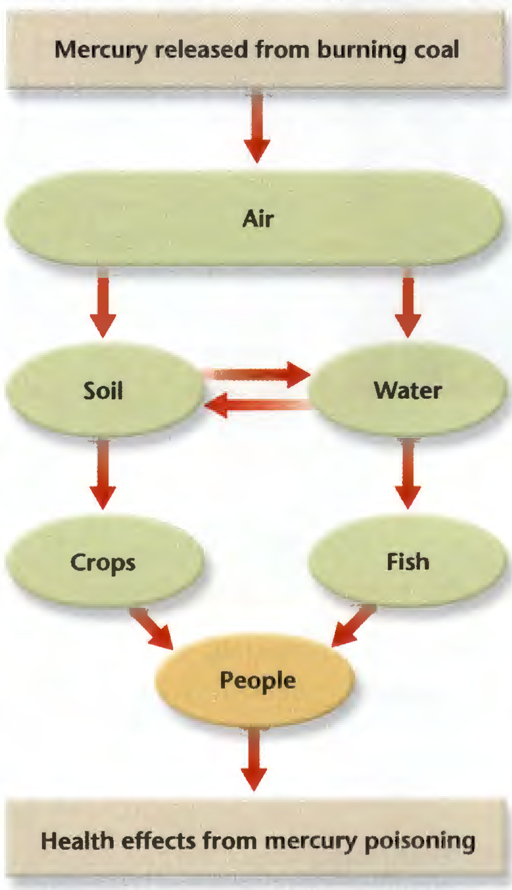


Figure 14 ▶ This conceptual model shows how mercury released from burning coal could end up reaching people, where it could cause poisoning.

Mathematical Models A mathematical model is one or more equations that represents the way a system or process works. You can represent many common situations using math models.

For example, suppose that the grapes in a fruit basket at home are getting moldy. You notice that every day the mold covers two more grapes. Here is a mathematical model for the number of moldy grapes on Tuesday:

$$M_{Tue} = M_{Mon} + 2, \text{ where } M = \text{number of moldy grapes}$$

Mathematical models are especially useful in cases with many variables, such as the many things that affect the weather.

Because mathematical models use numbers and equations, people may think the models are always right. But weather models, for example, sometimes predict rain on dry days. In fact, people are the ones who interpret data and write the equations. If the data or the equations are wrong, the model will not be realistic and so will provide incorrect information. Like all models, mathematical models are only as good as the data that went into building them.

People may think of mathematical models as being confined to blackboards and paper, but scientists can use the models to create amazing, useful images. Look at the image of the San Francisco Bay Area in **Figure 15**. This is a "false color" digital satellite image. The satellite measures energy reflected from the Earth's surface. Scientists use mathematical models to relate the amount of energy reflected from objects to the objects' physical condition.

Figure 15 ▶ This is a satellite image of the San Francisco Bay Area. Scientists use mathematical models to understand the terrain from the way objects on the surface reflect light. In this image, healthy vegetation is red.

SECTION 2 Review

1. **Explain** why sample size is important in determining probability.
2. **Explain** what "the mean number of weeds in three plots of land" means.
3. **Describe** three types of models used by scientists.

CRITICAL THINKING

4. **Analyzing Relationships** Explain the relationship between probability and risk.
5. **Applying Ideas** Write a paragraph that uses examples to show how scientists use statistics. WRITING SKILLS
6. **Evaluating Ideas** Why are conceptual and mathematical models especially powerful?

SECTION 3

Making Informed Decisions

Scientific research is an essential first step in solving environmental problems. However, many other factors must also be considered. How will the proposed solution affect people's lives? How much will it cost? Is the solution ethical? Questions like these require an examination of **values,** which are principles or standards we consider important. What values should be considered when making decisions that affect the environment? **Table 3** lists some values that often affect environmental decisions. You might think of others as well.

Objectives

- Describe three values that people consider when making decisions about the environment.
- Describe the four steps in a simple environmental decision-making model.
- Compare the short-term and long-term consequences of two decisions regarding a hypothetical environmental issue.

Key Terms

value
decision-making model

An Environmental Decision-Making Model

Forming an opinion about an environmental issue is often difficult and may even seem overwhelming. It helps to have a systematic way of analyzing the issues and deciding what is important. One way to guide yourself through this process is by using a decision-making model. A **decision-making model** is a conceptual model that provides a systematic process for making decisions.

Figure 16 shows one possible decision-making model. The first step of the model is to gather information. In addition to watching news reports and reading newspapers, magazines, and books about environmental issues, you should listen to well-informed people on all sides of an issue. Then consider which values apply to the issue. Explore the consequences of each option. Finally, evaluate all of the information and make a decision.

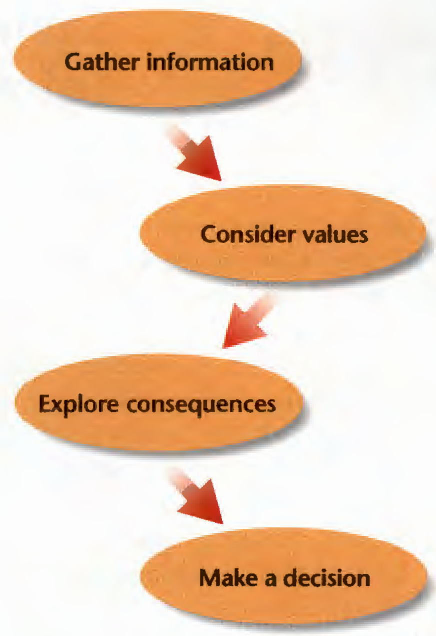


Figure 16 ▶ The diagram above shows a simple decision-making model.

Table 3 ▼

Values That Affect Environmental Decision Making	
Value	**Definition**
Aesthetic	what is beautiful or pleasing
Economic	the gain or loss of money or jobs
Environmental	the protection of natural resources
Educational	the accumulation and sharing of knowledge
Ethical/moral	what is right or wrong
Health	the maintenance of human health
Recreational	human leisure activities
Scientific	understanding of the natural world
Social/cultural	the maintenance of human communities and their values and traditions

A Hypothetical Situation

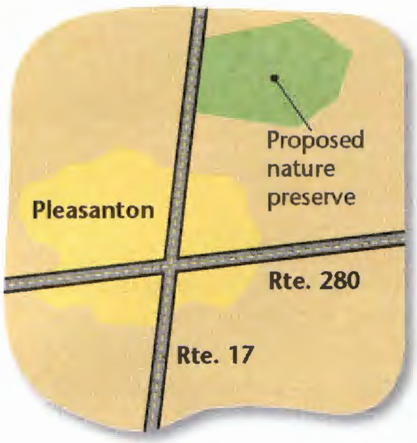


Figure 17 ▶ The map (above) shows the proposed nature preserve, which would be home to warblers like the one pictured (right).

Consider the following hypothetical example. In the town of Pleasanton, in Valley County, biologists from the local college have been studying the golden-cheeked warbler, shown in **Figure 17.** The warblers have already disappeared from most areas around the state, and the warbler population is declining in Valley County. The biologists warn county officials that if the officials do not take action, the state fish and wildlife service may list the bird as an endangered species.

Pleasanton is growing rapidly, and much of the new development is occurring outside the city limits. This development is destroying warbler habitat. Valley County already has strict environmental controls on building, but these controls do not prevent the clearing of land.

Several groups join together to propose that the county buy several hundred acres of land where the birds are known to

CASE STUDY

Saving the Everglades: Making Informed Decisions

The Florida Everglades is an enormous, shallow freshwater marsh. The water in the Everglades slowly flows from Lake Okeechobee to Florida Bay. Much of the marsh is filled with sawgrass, mangroves, and other water-loving plants. It is also home to wildlife, from 40 species of fish to panthers, alligators, and wading birds such as herons and roseate spoonbills.

In the 1880s, marshlands were considered wastelands. Developers began to drain the Everglades. They replaced marsh with houses and sugarcane fields. Between 1940 and 1971, the Army Corps of Engineers built dikes, canals, and pumping stations that drained even more water. The Corps also straightened the Kissimmee River, which runs into Lake Okeechobee.

Scientists have shown that what remains of the Everglades is dying. Its islands and mangrove swamps are vanishing, its water is polluted with fertilizer from farms, and its wading-bird colonies are much smaller than before. These effects have economic consequences. Because much of the Everglades' water has been diverted from Florida Bay into the Atlantic Ocean, the towns of southeast Florida are running out of fresh water and much of the marine life in Florida Bay has died.

In the 1990s, a commission reported that the destruction of the Everglades had jeopardized the state's tourism industry, farming, and the economic future of south Florida. The solution was obvious—undo the water diversion dikes and dams and restore water to the Everglades.

▶ **The roseate spoonbill** is a colorful resident of the Everglades.

breed and save that land as a nature preserve. The groups also propose limiting development on land surrounding the preserve. The group obtains enough signatures on a petition to put the issue to a vote, and the public begins to discuss the proposal.

Some people who own property within the proposed preserve oppose the plan. These property owners have an economic interest in this discussion. They believe that they will lose money if they are forced to sell their land to the county instead of developing it.

Other landowners support the plan. They fear that without the preserve the warbler may be placed on the state's endangered species list. If the bird is listed as endangered, the state will impose a plan to protect the bird that will require even stricter limits on land development. People who have land near the proposed preserve think their land will become more valuable. Many residents of Pleasanton look forward to hiking and camping in the proposed preserve. Other residents do not like the idea of more government regulations on how private property can be used.

Ecofact

The Everglades Scientists have identified more than 400 endangered species of plants and animals that live in the Florida Everglades.

internet connect

www.scilinks.org
Topic: Environmental Decision Making
SciLinks code: HE4035

SCILINKS. Maintained by the National Science Teachers Association

▶ **The Everglades** can be thought of as a shallow, slow-moving river that empties into Florida Bay.

In 2000, the $7.8 billion Everglades Restoration Plan was signed into law. The plan was put together by groups that had been fighting over the Everglades for decades: environmentalists, politicians, farmers, tourism advocates, and developers. Over the course of 5 years, members from the groups met and crafted a plan. At first people were afraid to break up into committees for fear that other people would make deals behind their backs. The director instituted social gatherings, and the members got to know and trust each other.

In the end, no one was completely satisfied, but all agreed that they would be better off with the plan than without it. Already Florida has restored 7 mi of the Kissimmee River to its original path. Native plants are absorbing some of the pollution that has killed an estimated $200 million worth of fish and wildfowl. The Everglades Restoration Plan is not perfect, but the process of creating and approving it shows how science and thoughtful negotiation can help solve complex environmental problems.

CRITICAL THINKING

1. Analyzing Processes Explain why it was so difficult for people to agree on how to restore the Everglades.

2. Analyzing Relationships If your county decided to build a landfill, do you think the decision-making process would resemble the Everglades example?

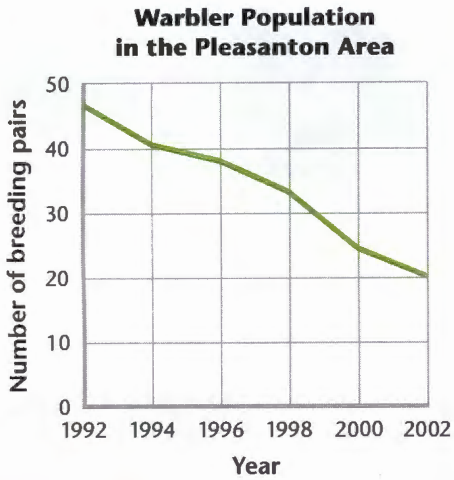


Figure 18 ▶ The population of golden-cheeked warblers in the Pleasanton area has declined in recent years.

How to Use the Decision-Making Model

The hypothetical situation in Pleasanton can be used to illustrate how to use the decision-making model. Michael Price is a voter in Valley County who will vote on whether the county should create a nature preserve to protect the golden-cheeked warbler. The steps Michael took to make his decision about the proposal are outlined below.

Gather Information Michael studied the warbler issue thoroughly by watching local news reports, reading the newspaper, learning more about golden-cheeked warblers from various Web sites, and attending forums where the issues were discussed. An example of scientific information that Michael considered includes the graph of warbler population decline in **Figure 18.** Several of the arguments on both sides made sense to him.

Consider Values Michael made a table similar to **Table 4** to clarify his thoughts. The values listed are environmental, economic, and recreational. Someone else might have thought other values were more important to consider.

Table 4 ▼

Should Valley County Set Aside a Nature Preserve?

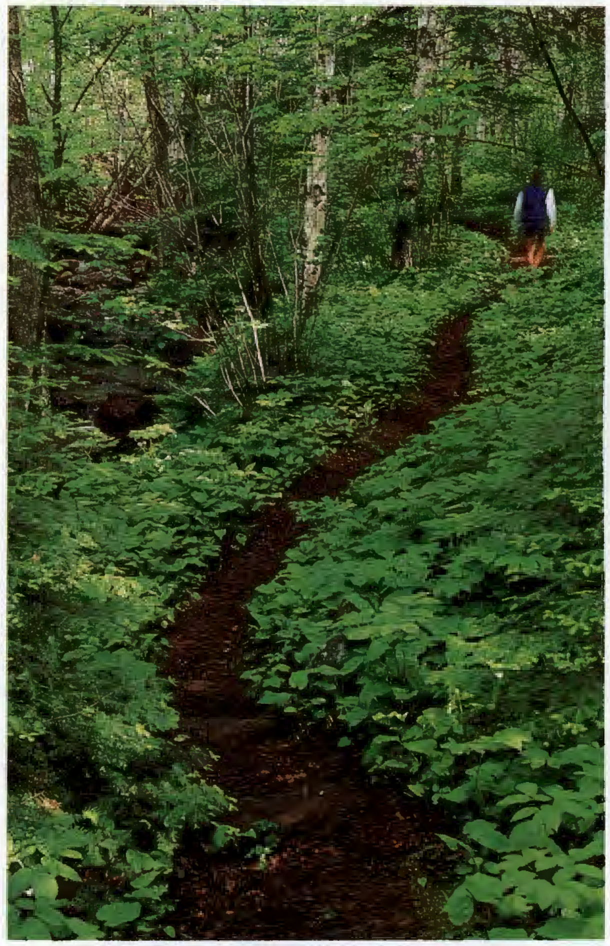
	Environmental	Economic	Recreational
Positive short-term consequences	Habitat destruction in the nature preserve area is slowed or stopped.	Landowners whose property was bought by the county receive a payment for their land. Property outside the preserve area can be developed with fewer restrictions.	Parts of the preserve are made available immediately for hiking and picnicking.
Negative short-term consequences	Environmental controls are made less strict in parts of the county outside the preserve area.	Property owners inside the preserve area do not make as much money as if they had developed their land. Taxpayers must pay higher taxes to buy preserve land.	Michael could not think of any negative short-term consequences.
Positive long-term consequences	The population of warblers increases, and the bird does not become endangered. Other species of organisms are also protected. An entire habitat is preserved.	Property near the preserve increases in value because it is near a natural area. Businesses move to Valley County because of its beauty and recreational opportunities, which results in job growth. The warbler is not listed as endangered, which avoids stricter controls on land use.	Large areas of the preserve are available for hiking and picnicking. Landowners near the preserve may develop campgrounds with bike trails, swimming, and fishing available on land adjacent to the preserve.
Negative long-term consequences	Other habitat outside the preserve may be damaged by overdevelopment.	Taxpayers must continue to pay for maintaining the preserve. Taxpayers lose the tax revenue that this land would have provided if it was developed.	State officials might restrict some recreational activities on private land within the preserve.

Explore Consequences Michael decided that in the short term the positive and negative consequences listed in his table were almost equally balanced. He saw that some people would suffer financially from the plan, but others would benefit. Taxpayers would have to pay for the preserve, but all the residents would have access to land that was previously off-limits because it was privately owned. Some parts of the county would have more protection from development, and some would have less.

It was the long-term consequences of the plan that allowed Michael to make his decision. Michael realized that environmental values were an important factor in his decision. The idea of a bird becoming extinct distressed him. Also, protecting warbler habitat now would be less costly than protecting it later under a state-imposed plan.

Michael considered that there were long-term benefits to add to the analysis as well. He had read that property values were rising more rapidly in counties where land was preserved for recreation. He found that people would pay more to live in counties that have open spaces. Michael had found that Valley County contained very little preserved land. He thought that creating the preserve would bring the county long-term economic benefits. He also highly valued the aesthetic and recreational benefits a preserve would offer, such as the walking trail in Figure 19.

Figure 19 ▶ Land set aside for a nature preserve can benefit people as well as wildlife.



Make A Decision Michael chose to vote in favor of the nature preserve. Other people who looked at the same table of pros and cons might have voted differently. If you were a voter in Valley County, how would you have voted?

As you learn about issues affecting the environment, both in this course and in the future, use this decision-making model as a starting point to making your decisions. Make sure to consider your values, weigh pros and cons, and keep in mind both the short-term and long-term consequences of your decision.

SECTION 3 Review

1. **Explain** the importance of each of the four steps in a simple decision-making model.
2. **List** and define three possible values to consider when making environmental decisions.
3. **Describe** in a short paragraph examples of two situations in which environmental values come into conflict with other values. WRITING SKILLS

CRITICAL THINKING

4. **Making Decisions** Pick one of the situations you described in question 3. Make a decision-making table that shows the positive and negative consequences of either of two possible decisions.
5. **Analyzing Ideas** Suggest how to make the decision-making model presented here more powerful.

CHAPTER 2 Highlights

1 Scientific Methods

Key Terms

observation, 31
hypothesis, 32
prediction, 32
experiment, 33
variable, 33
experimental group, 33
control group, 33
data, 34
correlation, 35

Main Ideas

- Science is a process by which we learn about the world around us. Science progresses mainly by the experimental method.
- The experimental method involves making observations, forming a hypothesis, performing an experiment, interpreting data, and communicating results.
- In cases in which experiments are impossible, scientists look for correlations between different phenomena.
- Good scientists are curious, creative, honest, skeptical, and open to new ideas.

2 Statistics and Models

Key Terms

statistics, 38
mean, 39
distribution, 39
probability, 40
sample, 40
risk, 41
model, 42
conceptual model, 43
mathematical model, 44

Main Ideas

- Scientists use statistics to classify, organize, and interpret data.
- Measures such as means and probabilities are different ways of describing populations and events.
- Statistics provides a powerful tool for evaluating information about the environment.
- Scientists use models, including conceptual and mathematical models, to understand the systems they study.

3 Making Informed Decisions

Key Terms

value, 45
decision-making model, 45

Main Ideas

- Making environmental decisions involves gathering information, considering values, and exploring consequences.
- Decisions about the environment should be made thoughtfully. Using a decision-making model will provide you with a systematic process for making knowledgeable decisions.
- Making a table that lists positive and negative short- and long-term consequences will help you recognize and weigh your values about an environmental decision.

CHAPTER 2 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *experiment*
2. *correlation*
3. *model*
4. *distribution*
5. *values*

For each pair of terms, explain how the meanings of the terms differ.

6. *hypothesis* and *prediction*
7. *risk* and *probability*
8. *distribution* and *population*
9. *sample* and *population*

STUDY TIP

Imagining Examples To understand how key terms apply to actual examples, work with a partner and take turns describing an environmental problem and explaining how the key terms relate to the problem.

Understanding Key Ideas

10. Scientists form _______ hypotheses to answer questions.
    a. accurate
    b. short
    c. mathematical
    d. testable
11. Risk is the _______ of a negative outcome.
    a. sample
    b. statistic
    c. probability
    d. event
12. If the results of your experiment do not support your hypothesis, you should
    a. publish your results anyway.
    b. consider the results abnormal and continue working.
    c. find a way to rationalize your results.
    d. try another method.
13. In a population, characteristics such as size will often be clustered around the
    a. sample.
    b. mean.
    c. distribution.
    d. collection.
14. Models used by scientists include
    a. conceptual models.
    b. variable models.
    c. physical models.
    d. Both (a) and (c)
15. Reading scientific reports is an example of
    a. assessing risk.
    b. considering values.
    c. gathering information.
    d. exploring consequences.
16. A conceptual model represents a way of thinking about
    a. relationships.
    b. variables.
    c. data.
    d. positions.
17. In an experiment, the experimental treatment differs from the control treatment only in the _______ being studied.
    a. experiment
    b. variable
    c. hypothesis
    d. data
18. To fully understand a complex environmental issue, you may need to consider
    a. economics.
    b. values.
    c. scientific information.
    d. All of the above
19. Scientists _______ experiments to make sure the results are meaningful.
    a. perform
    b. repeat
    c. conclude
    d. communicate

CHAPTER 2 Review

Short Answer

20. Explain the statement, "A good scientist is one who asks the right questions."

21. Explain the role of a control group in a scientific experiment.

22. How are statistics helpful for evaluating information about the environment?

23. Explain why environmental scientists use mathematical models.

24. How does making a table help you evaluate the values and concerns you have when making a decision?

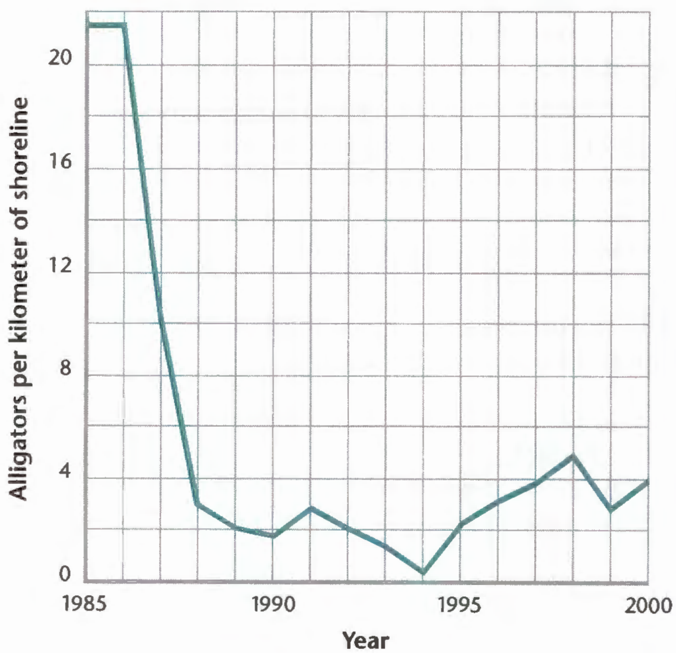
Interpreting Graphics

The graph below shows the change in size of a shoreline alligator population over time. Use the graph to answer questions 25–27.

25. What happened to the density of alligators between 1986 and 1988?

26. What happened to the trend in the alligator concentration between 1994 and 1998?

27. How many times greater was the alligator population in 1986 than it was in 2000?



Concept Mapping

28. Use the following terms to create a concept map: *control group, experiment, experimental group, prediction, data, observations, conclusions,* and *hypothesis.*

Critical Thinking

29. Drawing Conclusions What does a scientist mean by the statement, "There is an 80 percent probability that a tornado will hit this area within the next 10 years"?

30. Making Inferences How does a map of Denver allow you to navigate around the city?

31. Evaluating Assumptions Are complicated models always more accurate? Write a paragraph that uses examples to explain your answer. WRITING SKILLS

32. Interpreting Statistics Explain what the following statement proves: "We sampled pet owners and found that three out of five surveyed own dogs and two out of five surveyed own cats."

Cross-Disciplinary Connection

33. Language Arts The word *serendipity,* which means "luck in finding something accidentally," came from a Persian fairy tale called *The Three Princes of Serendip.* In the story, each of the princes discovers something by accident. Research and write a short report on a serendipitous discovery about the environment. WRITING SKILLS

Portfolio Project

34. Make a Poster Choose an environmental issue in your area. You can choose a real-life problem that you have heard about on the news, such as improving the sewage system or building a new landfill, or you can choose a project that you think should be considered. Research the issue at your school or local library. Prepare a poster listing the groups of people likely to be involved in the decision and the factors that may be taken into consideration, including economic, social, and environmental factors.

MATH SKILLS

This table shows the results of an experiment that tested the hypothesis that butterflies are attracted to some substances but not to others. Twenty-four trays containing four substances were placed in random order on a sandbank to see if butterflies landed on the trays. The number of butterflies that landed on each type of tray and stayed for more than 5 min during a 2 h period was recorded in the table. Use the data in the table below to answer questions 35–36.

Butterfly Feeding Preferences

	Sugar solution	Nitrogen solution	Water	Salt solution
Number of butterflies attracted	5	87	7	403

35. **Evaluating Data** Do the results in the table show that butterflies are attracted to salt solution but not any other substance? Why or why not? What other data would you like to see to help you evaluate the results of this experiment?

36. **Analyzing Data** Are there any controls shown in this table?

WRITING SKILLS

37. **Communicating Main Ideas** How is the experimental method an important scientific tool?

38. **Writing Persuasively** Write a letter to the editor of your local paper outlining your opinion on a local environmental issue.

STANDARDIZED TEST PREP

For extra practice with questions formatted to represent the standardized test you may be asked to take at the end of your school year, turn to the sample test for this chapter in the Appendix.

READING SKILLS

Read the passage below, and then answer the questions that follow.

Jane and Jim observed a group of male butterflies by the roadside. Jane said that this behavior was called puddling and that the butterflies were counting each other to see if there was room to set up a territory in the area. Jim said he did not think butterflies could count each other and suggested the butterflies were feeding on nitrogen in the sand. Jane agreed that the butterflies appeared to be feeding, but she said that they may not be feeding on nitrogen, because female butterflies need more nitrogen than males.

Jim and Jane decided to perform some experiments on the butterflies. They put out trays full of sand in an area where butterflies had been seen. Two trays contained only sand. Two contained sand and water, two contained sand and a salt solution, and two contained sand and a solution containing nitrogen. Butterflies came to all the trays, but they stayed for more than 1 min only at the trays that contained the salt solution.

1. Which of the following statements is a useful hypothesis that can be tested?
   - **a.** Male butterflies mate with female butterflies.
   - **b.** Salt is a compound and nitrogen is an element.
   - **c.** Butterflies are never seen in groups except on sandy surfaces.
   - **d.** Butterflies are attracted to salt.

2. Which of the following conclusions is supported by the observations Jane and Jim made?
   - **a.** Male butterflies can count each other.
   - **b.** The butterflies were probably feeding on nitrogen in the sand.
   - **c.** The butterflies were probably feeding on salts in the sand.
   - **d.** Female butterflies need less nitrogen than male butterflies.

CHAPTER 2 Skills Practice Lab: OBSERVATION

Objectives

- **USING SCIENTIFIC METHODS** **Formulate** a hypothesis about the relationship between temperature and fermentation by yeast.
- **USING SCIENTIFIC METHODS** **Test** your hypothesis.
- **Analyze** your data.
- **Explain** whether your data support or refute your hypothesis.

Materials

beakers, 100 mL (3)
beakers, 400 mL (3)
clock
delivery tubes, rubber or plastic (3)
graph paper
ice cubes
solution of yeast, corn syrup, and water
stoppers, no. 2, one-hole (3)
test tubes, 20 mm × 200 mm (3)
thermometer

▶ **Step 3** Carbon dioxide bubbles will be released from the delivery tube.

Scientific Investigations

A scientist considers all the factors that might be responsible for what he or she observes. Factors that can vary and that can be measured are called *variables*. The variable that you experimentally manipulate is the *independent variable*. The variable that you think will respond to this manipulation is the *dependent variable*.

You can practice the scientific method as it relates to everyday observations, such as the observation that bread dough rises when it is baked. According to a bread recipe, you dissolve a package of yeast in warm water and add flour, corn syrup, salt, and oil. Yeast is a microorganism that plays an important role in making bread. Yeast obtains energy by converting sugar to alcohol and carbon dioxide gas in a process called *fermentation*. The carbon dioxide forms bubbles, which make the bread dough rise. But what role, if any, does temperature play in this process? In this investigation, you will work as part of a team to try to answer these questions. Together, you will form a hypothesis and conduct an experiment that tests your hypothesis.

Procedure

1. Restate the question relating temperature to fermentation in yeast as a hypothesis.
2. Set up three test tubes containing yeast, water, and corn syrup stoppered with a gas-delivery tube. Label the test tubes "A", "B", and "C". Place each test tube in a water bath of different temperature. Place tube A in a water bath cooled by a few ice cubes, place tube B in room-temperature water, and place tube C in a warm water bath.
3. Allow the apparatus to sit for 5 min. Then place the open end of the delivery tube under water and begin to collect data on gas production. For the next 10 min, count the number of gas bubbles released from each tube, and record your data in the table on the next page.
4. Prepare a graph of data by placing time on the x-axis and the total number of gas bubbles released on the y-axis. Plot three curves on the same graph, and label each with the temperature you recorded for each test tube. Compare your graph with that of three other teams before handing in your report.

Carbon Dioxide Bubbles Released by Yeast										
Time (min)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Tube A:_____										
Tube B:_____										
Tube C:_____										

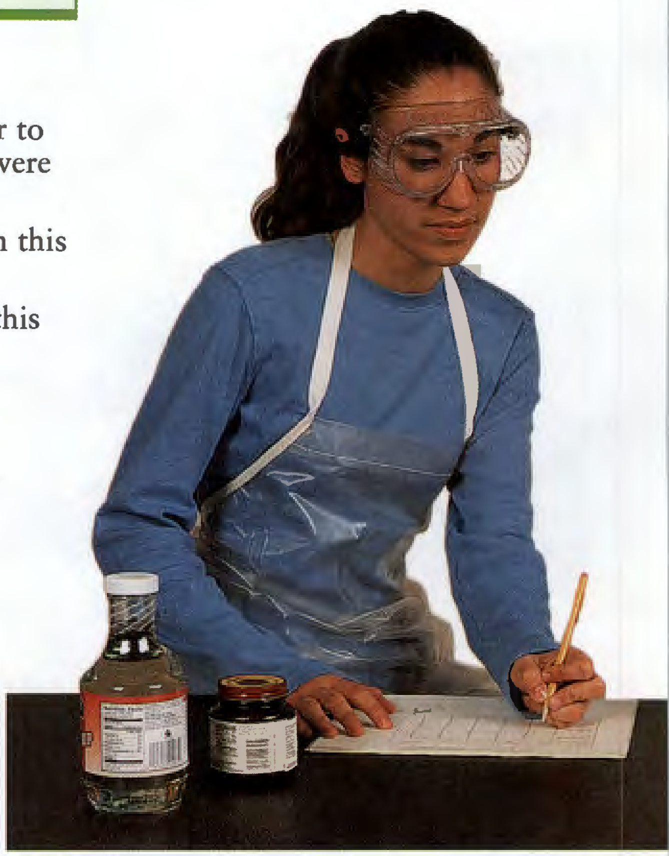
DO NOT WRITE IN THIS BOOK

Analysis

1. **Classifying Data** Which set of conditions is most similar to the conditions for the bread dough in the recipe? Why were two other conditions used in this experiment?
2. **Classifying Data** What was the independent variable in this experiment? Explain your answer.
3. **Classifying Data** What was the dependent variable in this experiment? Explain your answer.

Conclusions

4. **Drawing Conclusions** Write a conclusion for this experiment. Describe how the independent and dependent variables are related. Tell how the data supports your conclusion.
5. **Evaluating Results** What does temperature have to do with making bread dough rise?
6. **Evaluating Methods** Why did you compare your results with those of other teams before writing your conclusions?
7. **Applying Conclusions** Science is not just something you know but also something you do. Explain this statement in light of what you have learned in this investigation.



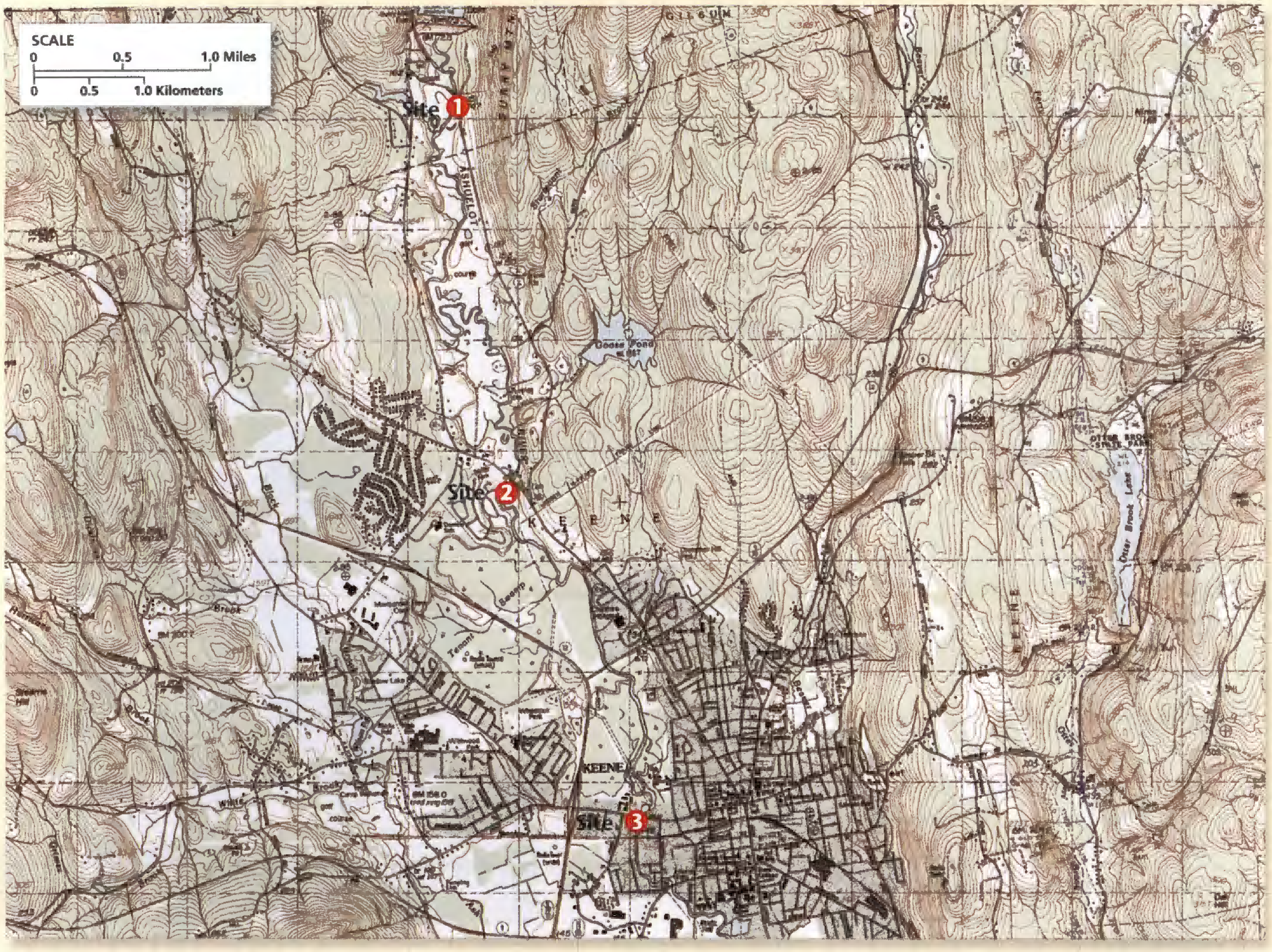
▶ **Recording Data** Count the number of bubbles produced under each experimental condition and record the data in a table.

Extension

1. **Designing Experiments** Formulate a new hypothesis about the effect of different types of sugar on carbon dioxide production by yeast. Test your new hypothesis under controlled conditions. Did your results support your hypothesis? Research the types of sugar you used, and write a short explanation for your findings.

MAPS *in action*

A TOPOGRAPHIC MAP OF KEENE, NEW HAMPSHIRE



MAP SKILLS

Topographic maps use contour lines to indicate areas that share a common elevation. Where the lines are close together, the terrain is steep. Where the lines are far apart, the landscape is flat. In this map, the Ashuelot River flows downhill from Site 1 to Site 3. Use the map to answer the questions below.

1. **Using a Key** Use the scale at the top of the map to calculate the distance between Sites 1 and 2 and between Sites 2 and 3.
2. **Understanding Topography** Are the hills to the east and west of the town of Keene more likely to drain into the river around Site 3 or Site 2? Explain your answer.
3. **Identifying Trends** Which site is more likely to be polluted? Explain your answer.
4. **Analyzing Data** Trace the sections of the Ashuelot River between each site to determine the length of stream between each site.
5. **Interpreting Landforms** A flood plain is an area that is periodically flooded when a river overflows its banks. Interpret the contour lines to locate the flood plain of the Ashuelot River.

SOCIETY & the Environment

BATS AND BRIDGES

A large colony of Mexican free-tailed bats lives under the Congress Avenue Bridge in Austin, Texas. These bats eat millions of insects a night, so they are welcome neighbors. Communities around the country and around the world have learned of the bats and have asked Austin for help in building bat-friendly bridges. But all that the people of Austin knew was that the bats appeared after the Congress Avenue Bridge was rebuilt in the 1980s. What attracted the bats? The people of Austin had to do a little research.

A Crevice Will Do

In the wild, bats spend the day sleeping in groups in caves or in crevices under the flaking bark of old trees. They come back to the same place every day to roost. Deep crevices in tree bark are rare now that many of our old forests have been cut down, and many bats are in danger of extinction.

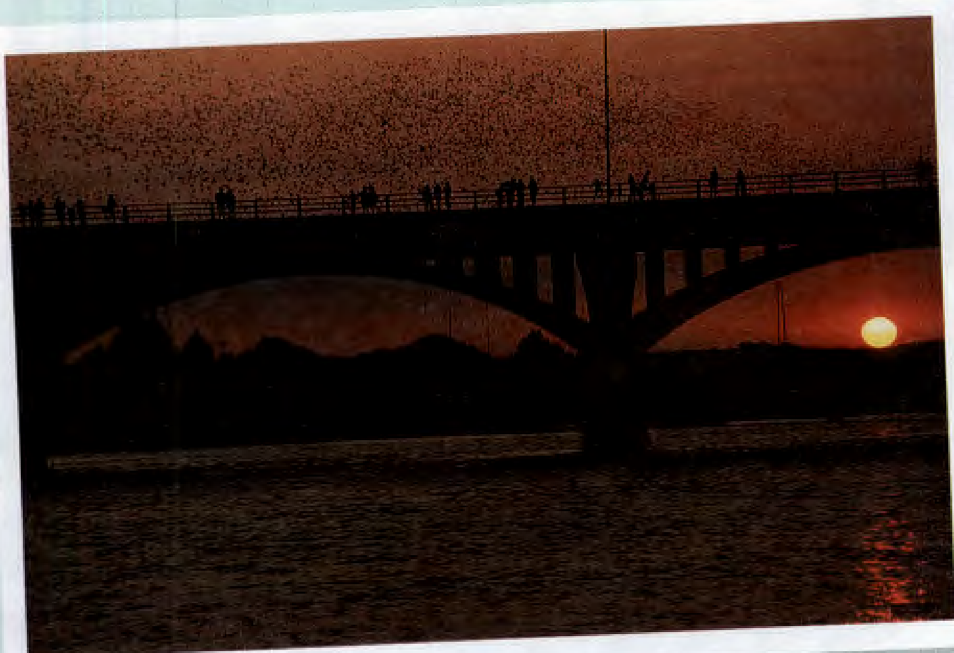
In the 1990s, the Texas Department of Transportation and Bat Conservation International, a nonprofit organization located in Austin, set out to discover what made a bridge attractive to bats. They collected data on 600 bridges, including some that had bat colonies and some that did not. They answered the following questions: Where was the bridge located? What was it made of? How was it constructed? Was it over water or land? What was the temperature under the bridge? How was the land around the bridge used?

Some Bridges are Better

Statistical analysis of the data revealed a number of differences between bridges occupied by bats and bridges unoccupied by bats. Which differences were important to the bats and which were not? The researchers returned to the Congress Avenue Bridge in Austin to find out. Crevices under the bridge appeared to be crucial, and the crevices had to be the right size. Free-tailed bats appeared to prefer crevices 1 to 3 cm wide and about 30 cm deep in hidden corners of the bridge, and they prefer bridges made of concrete, not steel.

The scientists looked again at their data on bridges. They discovered that 62 percent of bridges in central and southern Texas that had appropriate crevices were occupied by bats. Now, the Texas Department of Transportation is adding bat houses to existing bridges that do not have crevices. These houses are known as Texas Bat-Abodes, and they can make any bridge bat friendly.

Bat Conservation International is collecting data on bats and bridges everywhere. Different bat species may have different preferences. A Texas Bat-Abode might not attract bats to a bridge in Minnesota or Maine. If we can figure out what features attract bats to bridges, we can incorporate these features into new bridges and make more bridges into bat-friendly abodes.



▶ **Mexican free-tailed bats** leave their roost under the Congress Avenue Bridge in Austin, Texas, to hunt for insects.

What Do You Think?

Many bridges in the United States could provide roosting places for bats. Do you think communities should try to establish colonies of bats under local bridges? How should communities make this decision, and what information would they need to make it wisely?