Using Environmental Models to Determine the Effect of Acid Rain on an Ecosystem

SPN LESSON #20

TEACHER INFORMATION

LEARNING OUTCOME

After completing a reading on acid precipitation and pH, and conducting small-scale investigations of the effect of acid on aquatic and terrestrial ecosystems, students are able to predict the environmental effects of acid precipitation.

LESSON OVERVIEW

In this lesson, students select one of two questions associated with acid precipitation and design an experiment that addresses a question. Students complete a short reading that provides background information on acid precipitation and pH. They also conduct a literature search to find out more about acid precipitation.

In addition to designing a controlled experiment, students become involved in the process of modeling. They use small containers to represent ecosystems, and manipulate a single variable in order to determine its impact. By using multiple, small setups, students predict what is likely to happen on a larger scale in the environment.

GRADE-LEVEL APPROPRIATENESS

This Level II environmental considerations lesson is intended for use with students in grades 7–8.

MATERIALS

Materials required per team of two students will vary, depending on how many replications and trials the team elects to do. What students decide to bring in from home will also result in variation in materials used. The two questions, and the necessary items to be used in investigating them, are:

A. How does acid precipitation affect aquatic ecosystems?
- 200 mL of dilute sulfuric acid or white vinegar
- 200 mL of distilled water
- 1 L of pond water containing aquatic organisms. Algae and plants such as duckweed should be obvious and plentiful in the pond water.
- 2 graduated cylinders (1 100-mL and 1 10-mL)
- 2 or more pipettes for applying the acid and distilled water
- 4 or 5 plastic cups (6-, 8-, or 10-oz. are acceptable)
- marking pen

- pH paper or pH meter
- slides and cover slips
- compound microscope or stereoscope

B. How does acid precipitation affect terrestrial ecosystems?

- 200 mL of dilute sulfuric acid or white vinegar
- 200 mL of distilled water
- 1 100-mL graduated cylinder
- 1 10-mL graduated cylinder
- 2 or more pipettes for applying the acid and distilled water
- 4 or 5 plastic cups (6-, 8-, or 10-oz. are acceptable)
- 1 metric ruler
- marking pen
- pH paper or pH meter
- slides and cover slips
- compound microscope
- soil*
- seeds or small plants

*Have students bring in "real" soil for use in their experiments. The results will be more authentic because the soil will contain organisms, natural buffers, etc. In a pinch (as a backup for those who do not comply), potting soil will work—but soil from a local habitat is preferable.

SAFETY

- Caution students to use "reasonable" quantities of sulfuric acid or vinegar since this is a small-scale experiment.
- Insist that students wear goggles and gloves when handling the acid, pond water, and soil. They may protest, but wearing goggles and gloves is good laboratory practice.
- Have students obtain permission from you prior to bringing ancillary items from home, and again, prior to their use in school.
- Caution students to wash the tabletops and their hands after handling laboratory materials.

TEACHING THE LESSON

- You might choose to set up these chalk activities as a demonstration. Use containers of clear liquid (white vinegar or dilute sulfuric acid) labeled "Liquid X" and "Liquid Y." Add these liquids to the containers of chalk. Have students make observations and record them in their notebooks. At this point there is no need to share observations. Indicate to students that their observations should be exact; should changes occur by the next day's class period, they are more likely to be noticeable.

  Drain the liquids off into separate beakers having the appropriate labels. Elicit observations for both the chalk and the liquids. Have students refer to the notes made the day before and describe any differences. Call on students willing to share one of the differences they have observed.

Students should come to the conclusion that the two liquids are different. Use pH paper to establish that one is more acidic than the other. This is a good way to introduce or review pH. Then ask students what they know about acid precipitation and its impact on the environment as a natural way to lead into the reading and design components of the lesson.

- Point out to students that scientists can control variables in artificial ecosystems, and this allows them to study food webs, and energy flow through an ecosystem, more easily than in a natural ecosystem. Acid precipitation impacts an ecosystem by disrupting food webs and therefore energy flow. But this is not the typical perception. Students are likely to think that acid precipitation is a problem because it kills organisms. This is true marginally but is just a small part of the "big picture." Biosphere II is a large artificial environment that you might want students to investigate. Although some scientists view the project as a failure scientifically, others feel that the research community has learned much from the endeavor. Students will establish many smaller scale artificial ecosystems. By controlling variables, students can obtain information about interactions within these ecosystems. Students should be aware that their results will serve only to predict what *may* happen in a natural ecosystem.
- To prepare dilute sulfuric acid, measure 5.5 mL of concentrated H_2SO_4 and pour it slowly, while stirring, into 1 L of distilled water. Another option is to have students use white vinegar, which has a pH of 4. Either liquid should provide observable differences in the student setups.
- The ability of the soil to resist some pH change is called "buffering capacity." Without any buffering capacity, soil pH changes rapidly. Typically, the buffers maintain the pH of the soil through numerous assaults of acid. This presence or absence of buffers may be a factor in the investigations some students design and carry out for this lesson. Since the pH of the 0.1 molar sulfuric acid and white vinegar is not extremely low, the buffering capacity of the soil may maintain the pH students measured at the beginning of the experiment. Garden soil is a better choice than potting soil. If you must use potting soil, check the potting soil label to make sure that lime or other buffers have been added, or purchase one that is suitable for acid-loving plants such as rhododendrons.
- Students may need help in determining how to measure soil pH. Have them place about 5 or 10 grams of soil in a glass jar/beaker and mix it with 10 or 20 mL of distilled water. They can then use pH paper to determine the pH of the soil. If using a pH probe, mix 30 grams of soil with 60 mL of distilled water and let the mixture sit overnight. Pour the water from the top of the mixture into a clean, dry beaker. Follow the instructions for the pH probe system you use.
- Plants students might use include coleus, begonia, or grass. (They can plant the seed directly in their cups, or to shorten the time needed, you could plant several large, flat containers with grass seed about two days before you plan to do the activity. That way you can "cut" sections from your planting and place these in the student containers on top of an appropriate amount of soil.) There are many other suitable plants that are easy to obtain and/or grow. Rapid radishes and brassica are two plants with short life cycles that are easy to grow. The systems described in many science supply catalogs are not necessary for the successful use of these plants in the classroom. The light and fertilizer requirements should be heeded.

- At some point in the lesson, refer students to the "Avoided Emissions" screen of the photovoltaic system display. Ask students how the information provided relates to what they are doing. Help them see that alternative energy forms can lessen the amount of sulfur dioxide and nitrogen oxides released into the atmosphere and thus lessen the amount of acid deposition.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Activity Analysis

- Any number of hypotheses are possible. Be sure that students write hypotheses in an acceptable format, and do not simply write a question or problem statement. An acceptable hypothesis does not have to be true but it does need to be testable. Sample hypotheses are listed below:

  Acid rain impacts plant survival.
  The level of acid precipitation affects the growth of plants.
  Acid precipitation affects the diversity of organisms that can live in an area.

- Any number of procedures are possible. Be sure that students include replications (repeated trials). One cup having a different pH than another, or one plant in each setup, will not provide statistically valid results.
- Sample controls are a cup or cups of pond water or soil with tap water added. The tap water should be added to the terrestrial control cup(s) in the same amounts and on the same schedule as the acid is added to the experimental cups. Rainwater or melted snow would be a better control than tap water. However, tap water is readily available and should be somewhat reflective of the precipitation received in the area. This is truer in rural areas than in urban. Additional water should also be added to the aquatic control on the same schedule as acid is added to the experimental containers. *Caution:* Be sure to allow the water to sit overnight before using if it has been treated with chlorine. The experimental cups would have acid added on the same schedule. Students may want to apply more drops to indicate a lower pH (more acid rain), or they may wish to dilute the acid by adding distilled water. For example, they may wish to mix x mL of acid with y mL of distilled water for one setup, x mL of acid with z mL of distilled water for a second, and so forth. Of course, they can add "straight" acid to some of the setups.
- The independent variable is the amount of acid added to the setups.
- The dependent variable might be *the amount of plant growth,* or *the diversity of the population of organisms present*.
- The final report should include the approved Experimental Design Matrix; student observations to be evident through drawings, measurements, photos, and so forth, to be presented through such devices as dated charts and graphs; and a conclusion based on the results of the experiment. Students should be sure to indicate whether the hypothesis they were testing was supported or not supported.

Extended Activities

- Have students observe the effect of acid rain on marble and limestone. These are two commonly used building materials.
  (1) Label two beakers or plastic cups as follows: “chalk in vinegar” and “chalk in water.”
  (2) Have students place a piece of chalk in each beaker or plastic cup.
  (3) Next, students should be directed to pour enough white vinegar into the container labeled “chalk in vinegar” to cover the chalk.
  (4) Students should then add enough water to the “chalk in water” container to cover the chalk.
  (5) Let the dishes stand overnight.
  (6) After a day or two, have students remove the chalk from the two containers and observe any differences. They should see that the chalk in the vinegar is more worn away. These observations are intended to reveal through analogy the effect of acid rain on structural marble and limestone. Chalk is composed of calcium carbonate. In addition to being an ingredient of chalk, calcium carbonate occurs in rocks such as marble and limestone. It is also found in some animal bones, and in shells and teeth. For more information go to http://mineral.galleries.com/minerals/carbonat/calcite/calcite.htm
- Students might construct ecocolumns using two-liter clear plastic soda bottles. Directions for constructing the ecocolumns can be found in “Bottle Biology,” published by Kendall/Hunt Publishing Company, 2460 Kerper Boulevard, P.O. Box 539, Dubuque, Iowa 52004-0539. Students could construct larger model ecosystems and manipulate selected variables over a longer period of time.
- Invite an expert speaker from a government agency such as the New York State Department of Environmental Conservation, or from a local college, to talk with the students about acid precipitation in New York State.
- Relate this science activity to art and literature. Students could read a book such as *The Giving Tree* by Shel Silverstein or *A Tree Grows in Brooklyn* by Betty Smith. They could then discuss the significance of trees in the book. They would need to bring together real-world science problems and literary symbolism. Another book for use with this lesson is *The Sky Tree*, written by Candace Christiansen. It brings science and art together, using the theme of changing seasons. Oil paintings show a single tree and its surroundings as the seasons change from winter to autumn. Scenes of clouds, birds, and stars challenge the reader to imagine the tree interacting with the sky and its inhabitants. The text points out incremental changes in atmosphere and their effects. Each image is paired with a question or two such as “Why does this painting make you feel sad? Is the tree dying?” and “How does this painting capture the stillness of a snowy day?”

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

“The Formation of Fossil Fuels” from *Fossil Fuels: Student Activities*. Revised edition. New York Energy Education Project. Published by the Research Foundation of the State of New York. 1988.

“Question: What is pH and why is it important?” from *Energy and Safety: Science Activities for Elementary Students*. New York Energy Education Project. Published by the Research Foundation of the State of New York. 1984.

The *Experimental Design Template* is modified from a matrix developed by Sue Holt (retired), Williamsville High School, Williamsville, NY.

BACKGROUND INFORMATION

As the water from rain or snowmelt moves down through the soil, some or all of its acidity may be neutralized by naturally occurring buffers. Soils in regions of the Northeast, such as New York’s Adirondack Mountains, have little buffering capacity. In the Adirondack Mountains, the natural buffers are not there in large quantities due to the composition of the soil. In other areas, over time, soils lose their ability to buffer acid precipitation. The application of lime to both terrestrial and aquatic systems in New York State represents one attempt to help boost an ecosystem’s buffering capacity. In terms of both time and money, this is a costly way to remediate the impact of acid precipitation, especially since such applications must be repeated periodically.

Acid rain does not usually kill trees directly but weakens them by damaging their leaves, thus limiting available nutrients, or by poisoning them with toxic substances that are slowly released from the soil. Acidic water reacts with and dissolves nutrients in the soil and then washes them away before plants can use them. Acid rain also causes the release of toxic substances such as aluminum into the soil. These substances are very harmful to plants, even if contact is limited.

It is not only below the ground where acid precipitation causes problems, but also above. Forests in mountain areas receive acid from the clouds and fog that often surround them. The clouds and fog are often more acidic than rainfall. When leaves are bathed in acid fog, their protective waxy coating is gradually eaten away. Leaves that have lost this coating are damaged upon further exposure. Brown spots are one sign that this is happening. The damaged leaves cannot carry out sufficient photosynthesis to produce an adequate food supply for the plant. The weakened plants are more likely to be attacked by insects and a variety of plant diseases. They are also more likely to be injured by cold weather.

The effects of acid rain are clearly seen in aquatic environments such as streams and lakes. Such bodies of water have a natural pH somewhere between 6 and 8. Some lakes, however, are naturally acidic. They typically become acidic when the water in the lake and surrounding soil cannot buffer the acid precipitation enough to neutralize it. In different parts of the northeastern United States where the soil buffering ability is poor, some lakes now have a pH of less than 5. Little Echo Pond in Franklin, New York, is one of the most acidic lakes known: it has a pH of 4.2.

Generally, the young of most species are more sensitive than the adults. Adult frogs may tolerate relatively high levels of acidity, but may die out if insects such as the mayfly are a large part of their diet. The mayfly cannot tolerate a pH less than 5.5. When the mayfly population is reduced, then the frog population is reduced, and in fact may disappear if mayflies represent a large enough part of the frogs’ food supply. As lakes and streams become more acidic, the numbers and types of fish and other aquatic organisms decrease. For some types of plants and animals, a lower pH is not a problem; these types are able to tolerate acidic waters. Other organisms, however, are acid-sensitive and will have to move or die out as the pH declines. Some lakes are so acidic, they lack fish altogether. At pH 5, most fish eggs fail to hatch. At lower pH levels, even some adult fish die. Toxic substances such as aluminum that wash into the water from the soil also kill fish and other aquatic organisms, typically by affecting the intake of oxygen in the gill area.

The air pollution that causes acid rain is damaging to human health. Sulfur dioxide and nitrogen oxides, the major sources of acid rain, irritate or even damage our lungs. The primary pollutant associated with acid rain is sulfur dioxide. Emissions of sulfur dioxide form small sulfate particles, or aerosols, in the atmosphere. Nitrogen oxide emissions are also associated with the formation of acid precipitation.

In 1980, Congress established the National Acid Precipitation Assessment Program (NAPAP) to conduct a comprehensive ten-year research, monitoring, and assessment program on the causes, effects, and controls of acid rain. In 1996, NAPAP conducted an integrated assessment of cost benefits and effectiveness of acid rain controls specified in the 1990 Clean Air Act Amendments as implemented by the U.S. Environmental Protection Agency. Some of the findings are:

- There have been reductions in SO_2 emissions since 1980.
- The acidity of, and sulfate concentrations in, precipitation have decreased in the midwestern, middle Atlantic, and northeastern regions of the United States.
- Since 1980, lakes and streams throughout many areas of the United States have experienced decreases in sulfate concentrations. Additional reductions in sulfur and nitrogen deposition would be required for full recovery of sensitive Adirondack lakes.
- Sulfur and nitrogen deposition has caused adverse impacts on certain highly sensitive forest ecosystems in the United States, especially high-elevation spruce-fir forests in the eastern United States. If deposition levels are not reduced in areas where they are currently high, adverse effects may develop in more forests due to chronic, multiple-decade exposure.
- Decreased emissions are expected to reduce fine-particulate sulfate and nitrate concentrations in air, possibly leading to reductions in adverse health effects.
- Quantifiable economic benefits could be relatively large in the areas of human health and visibility and exceed the costs of reducing emissions.

In 1990, Congress passed the landmark Acidic Deposition Control Program as Title IV of the 1990 Clean Air Act Amendments (Public Law 101-549). The Acid Deposition Control Program mandates by 2010 a 40% annual reduction in the emissions of sulfur dioxide (SO_2) from a 1980 base, and imposes a national cap of about 15 million tons. In addition, annual emissions of nitrogen oxides (NO_x) from stationary sources were to be cut by about 10% by the year 2000. However, there is no national cap on the emissions of nitrogen oxides.

REFERENCES FOR BACKGROUND INFORMATION

Acid Rain: The Invisible Threat (VHS videotape). Scott Resources. 1992.

Miller, Kenneth and Joseph Levine. *Biology.* Pearson Education, Inc., Upper Saddle River, NJ, 2003.

Smith, Leo. *Ecology and Field Biology.* 4th edition. HarperCollins Publisher. New York, 1990.

Wright, Richard T. and Bernard J. Nebel. *Environmental Science: Toward a Sustainable Future.* Pearson Education, Inc., Upper Saddle River, NJ, 2002.

National Acid Precipitation Assessment Program
NOAA, MailCode R/SAB
1315 East-West Highway
Silver Spring, MD 20910
E-mail: **napap@noaa.gov**
The National Acid Precipitation Assessment Program (NAPAP) is an interagency scientific research, monitoring, and assessment program that examines the effects of sulfur and nitrogen oxides on the environment and human health.

Web resources
http://www.geog.ouc.bc.ca/physgeog/contents/8h.html This is an excellent site developed by Michael J. Pidwirny, Ph.D., Department of Geography, Okanagan University College. It includes extensive background information on the sources of sulfur and nitrogen oxides and the formation of atmospheric acids. There are several colorful diagrams that illustrate pH, processes involved in the formation of acid precipitation, and the deposition of the by-products of acid precipitation.

http://www.epa.gov/airmarkets/cmap/index.html This is an Environmental Protection Agency site with access to GIS data downloads and maps showing sensitive areas and other information.

http://heg-school.aw.com/bc/companion/cmr2e/activity/AP/APWelco.htm This site is designed to support the text *Biology: Concepts and Connections* by Campbell, Mitchell, and Reece. It provides background information and relates how science research is done to investigate acid precipitation. There is a virtual lab that is too advanced for middle school students but provides excellent background for the teacher.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematics Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

M1.1: Extend mathematical notation and symbolism to include variables and algebraic expressions in order to describe and compare quantities and express mathematical relationships.

M1.1a: Identify independent and dependent variables.

M1.1b: Identify relationships among variables including: direct, indirect, cyclic, constant; identify non-related material.

Science Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

S1.1: Formulate questions independently with the aid of references appropriate for guiding the search for explanations of everyday observations.

S1.1a: Formulate questions about natural phenomena.

S1.1b: Identify appropriate references to investigate a question.

S1.1c: Refine and clarify questions so that they are subject to scientific investigation.

Science Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

S2.1: Use conventional techniques and those of their own design to make further observations and refine their explanations, guided by a need for more information.

S2.1a: Demonstrate appropriate safety techniques.

S2.1c: Design and conduct an experiment to test a hypothesis.

S2.1d: Use appropriate tools and conventional techniques to solve problems about the natural world, including: measuring, observing, describing, classifying, sequencing.

S2.2: Develop, present, and defend formal research proposals for testing their own explanations of common phenomena, including ways of obtaining needed observations and ways of conducting simple controlled experiments.

S2.2a: Include appropriate safety procedures.

S2.2b: Design scientific investigations (e.g., observing, describing, and comparing; collecting samples; seeking more information; conducting a controlled experiment; discovering new objects or phenomena; making models).

S2.2c: Design a simple controlled experiment.

S2.2d: Identify independent variables (manipulated), dependent variables (responding), and constants in a simple controlled experiment.

S2.2e: Choose appropriate sample size and number of trials.

S2.3: Carry out their research proposals, recording observations and measurements (e.g., lab notes, audiotape, computer disk, videotape) to help assess the explanation.

S2.3a: Use appropriate safety procedures.

S2.3b: Conduct a scientific investigation.

S2.3c: Collect quantitative and qualitative data.

Science Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

S3.1: Design charts, tables, graphs, and other representations of observations in conventional and creative ways to help them address their research question or hypothesis.

S3.1a: Organize results, using appropriate graphs, diagrams, data tables, and other models to show relationships.

S3.1b: Generate and use scales, create legends, and appropriately label axes.

S3.2: Interpret the organized data to answer the research question or hypothesis and to gain insight into the problem.

S3.2a: Accurately describe the procedures used and the data gathered.

S3.2b: Identify sources of error and the limitations of data collected.

Standard 2—Information Systems: Students will access, generate, process, and transfer information, using appropriate technologies.

Key Idea 1: Information technology is used to retrieve, process, and communicate information as a tool to enhance learning.

1.1: Use a range of equipment and software to integrate several forms of information in order to create good-quality audio, video, graphic, and text-based presentations.

1.2: Use spreadsheets and database software to collect, process, display, and analyze information. Students access needed information from electronic databases and on-line telecommunication services.

1.3: Systematically obtain accurate and relevant information pertaining to a particular topic from a range of sources, including local and national media, libraries, museums, governmental agencies, industries, and individuals.

1.4: Collect data from probes to measure events and phenomena.

1.4a: Collect the data, using the appropriate, available tool.

1.4b: Organize the data.

1.4c: Use the collected data to communicate a scientific concept.

Standard 4—Science: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Living Environment

Key Idea 6: Plants and animals depend on each other and their physical environment.

6.1: Describe the flow of energy and matter through food chains and food webs.

6.1c: Matter is transferred from one organism to another and between organisms and their physical environment. Water, nitrogen, carbon dioxide, and oxygen are examples of substances cycled between the living and nonliving environment.

Key Idea 7: Human decisions and activities have had a profound impact on the physical and living environment.

7.1: Describe how living things, including humans, depend upon the living and nonliving environment for their survival.

7.2: Describe the effects of environmental changes on humans and other populations.

7.2a: In ecosystems, balance is the result of interactions between community members and their environment.

7.2d: Since the Industrial Revolution, human activities have resulted in major pollution of air, water, and soil. Pollution has cumulative ecological effects such as acid rain, global warming, or ozone depletion. The survival of living things on our planet depends on the conservation and protection of Earth's resources.

Physical Setting

Key Idea 2: Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.

2.1: Explain how the atmosphere (air), hydrosphere (water), and lithosphere (land) interact, evolve, and change.

2.2: Describe volcano and earthquake patterns, the rock cycle, and weather and climate changes.

2.2r: Substances enter the atmosphere naturally and from human activity. Some of these substances include dust from volcanic eruptions and greenhouse gases such as carbon dioxide, methane, and water vapor. These substances can affect weather, climate, and living things.

Process Skills Based on Standard 4

General Skills

1. Follow safety procedures in the classroom and laboratory.
2. Safely and accurately use the following measurement tools: metric ruler, stopwatch, graduated cylinder, thermometer.
3. Use appropriate units for measured or calculated values.

4. Recognize and analyze patterns and trends.
8. Identify cause-and-effect relationships.

Living Environment Skills

1. Manipulate a compound microscope to view microscopic objects.
3. Prepare a wet mount slide.

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www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

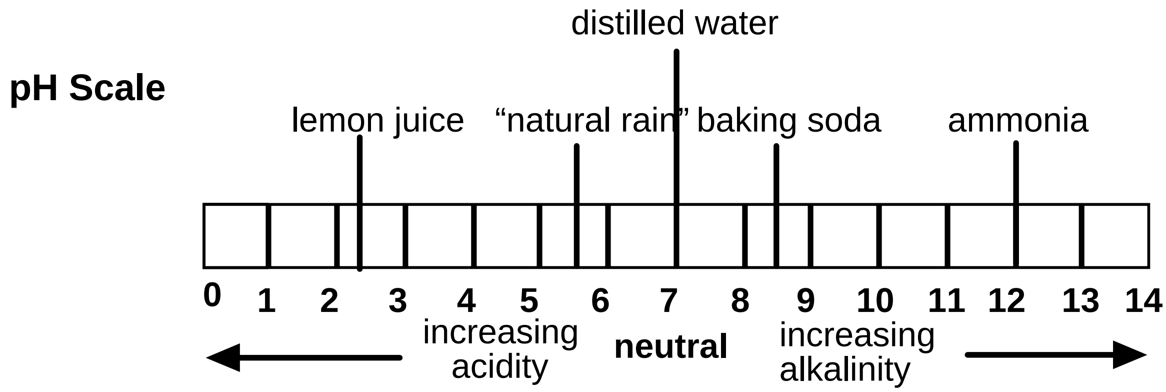
Date ____________________________________

Using Environmental Models to Determine the Effect of Acid Rain on an Ecosystem

Background Information

Acid precipitation, usually called acid rain, consists of sulfuric and nitric acids in the atmosphere. These acids reach Earth's surface in rain, snow, sleet, fog, hail, or dew. Acid precipitation is a large problem in New York State and in other eastern regions of North America.

The pH scale (which measures acidity) is used to determine if precipitation is acidic. In this scale, the smallest numbers are the most acidic and the largest numbers are the least acidic (most "basic" or alkaline). A pH of 7 is neutral. It is neither acidic nor basic.



The pH scale is a "power of 10" scale. This means that a liquid with a pH of 5 is ten times as acidic as a liquid having a pH of 6. It is 100 times as acidic as a liquid having a pH of 7. pH is typically measured with litmus paper, pH paper, or pH meter. There are other indicators (chemicals that change color at a specific pH).

The main ingredients in acid precipitation are sulfur dioxide (SO_2) and nitrogen oxides (NO_x). These gases are produced naturally by volcanic activity and electrical storms. Another source of these gases is the burning of fossil fuels. Industries such as smelters and electric generating plants emit sulfur dioxide. Cars, trucks, buses, and power plants emit nitrogen oxides. Sulfur dioxide and nitrogen oxides enter the atmosphere as gases and then, through a series of chemical reactions, they are changed to acids.

Precipitation has a *natural* pH of 5.6. It is slightly acidic due to carbon dioxide in the air combining with water vapor to form a weak acid, carbonic acid. For thousands of years, ecosystems in northeastern North America have received precipitation with a pH of 5.6. Within the last 100 years, the pH of precipitation in the United States has become increasingly acidic. Annual rainfall in much of the northeastern U.S. now has an average pH of 4.2 – 4.6. This is more than ten times as acidic as "natural" rain.

Acid precipitation has harmful effects on the environment. Scientists continue to investigate the effects of the increasing acidity of the soil and water. Acid precipitation is responsible for making lakes in the Adirondack Mountains and other areas of the world too acidic for fish and other living organisms. Acidic precipitation washes nutrients from the soil, making them unavailable for plants. Toxic metals such as aluminum become soluble in lake water, causing adult fish to die. These toxic metals may also be absorbed by tree roots, eventually killing the trees. Acids in the air are responsible for slow, long-term damage to statues, stone buildings, paint on automobiles, and metals.

Scientists question just how much acidity various ecosystems can handle. Through computer simulation, environmental models allow scientists to study what could happen to organisms in an ecosystem if there are changes in the abiotic components. Models help scientists check predictions without disrupting large ecosystems.

You are to design an experiment to model what the effect of acid precipitation might be on an aquatic ecosystem or a terrestrial ecosystem.

Question

Select one of the two questions below to investigate. Record the question in the appropriate place on your Experimental Design Matrix.

A. How does acid precipitation affect an aquatic ecosystem?

Materials and equipment you have available for use include:

- dilute sulfuric acid and/or white vinegar
- distilled water
- pond water containing aquatic organisms
- pipettes
- graduated cylinders
- plastic cups
- marking pen
- pH paper or pH meter
- slides
- cover slips
- compound microscope and stereoscope
- You may request additional materials or obtain permission to bring in other items from home.

B. How does acid precipitation affect terrestrial ecosystems?

Materials you have available for use include:

- dilute sulfuric acid and/or white vinegar
- distilled water
- pond water containing aquatic organisms
- pipettes
- graduated cylinders
- plastic cups
- metric ruler
- soil
- seeds
- small plants
- marking pen
- pH paper or pH meter
- slides
- cover slips
- compound microscope

Hypothesis

- Begin by doing research on one of the questions.
- Prepare a one-page report on the problem as a preliminary step to developing your investigation. Include a bibliography of the books and/or Internet sites you used in collecting information.
- Create a hypothesis for the question you are investigating. The hypothesis is formulated on the basis of observations and other knowledge gained by experiences and/or research. The hypothesis is a proposed explanation about the relationship between the variables that can be tested. An example of a hypothesis for a different investigation is “Fertilizer will influence the growth of tomato plants.”
- Record your hypothesis in the appropriate place on the Experimental Design Matrix.

Title

- You may want to decide on your title last. The title should tell the reader what you are trying to find out. Use the following as a guide: “The Effect of (independent variable) on (dependent variable) in (organism/ecosystem studied).”
- A statement of what is being investigated should include the independent variable, the dependent variable, and the organism (or ecosystem) being studied. An example is “The Effect of Fertilizer on Tomato Plant Height.”
- Once you have written your title, record it in the appropriate place on the Experimental Design Matrix.

Experimental Design

- Discuss with your partner the design of an experiment that will answer the question you have chosen to investigate. Identify your dependent and independent variables.
- Record the dependent and independent variables and include a description of how this is a controlled experiment in the appropriate places on the Experimental Design Matrix.
- Be sure to include safety precautions in the appropriate place. Record these in the Experimental Design Matrix.
- Before writing out the procedure for your experiment, show your completed Experimental Design Matrix to your teacher. Once it has been reviewed and approved, finish designing your experiment.

Procedure

- Write out step-by-step procedures. Be sure to include the amounts of materials, number of trials, and measurements and observations you will make. Decide how you will keep track of data you collect during the experiment. Will you make drawings, take pictures, use a data table or graph?
- Collect your materials, review your procedure, and conduct your experiment!

Analysis

Analyze the results of your experiment by doing the following:

(1) Organize your data in table(s), graph(s), and/or a series of illustrations/photos.

(2) Draw a conclusion—decide and describe whether your hypothesis is supported or not supported by the data collected.

(3) Prepare and submit a final report of your research. It should include: your approved Experimental Design Matrix; listing of the procedures followed; observations, drawings, photos, and data collected; graphs and charts; and conclusion.

Experimental Design Matrix

Question asked
Hypothesis
Title of the experiment
Independent (manipulated) variable
Dependent (responding) variable
Description of variables held constant
Description of how this is a controlled experiment
Materials and equipment needed to conduct the experiment
Safety precautions

Experimental Design Matrix

Question Asked
The question is what you are curious about. It is what you would like to know. Examples of possible questions are “Does fertilizer affect the growth of tomato plants?” and “Does adding fertilizer make tomato plants grow better?”

Hypothesis
The hypothesis is formulated on the basis of observations and other knowledge gained by experiences and/or research.

The hypothesis is a proposed explanation about the relationship between the variables that can be tested.
An example is “Fertilizer will influence the growth of tomato plants.”

Title of the Experiment
What are you trying to find out? An example is “The Effect of (independent variable) on (dependent variable) in (organism or ecosystem studied).”

A statement of what is being investigated should include the independent variable, the dependent variable, and the organism being studied. An example is “The Effect of Fertilizer on Tomato Plant Height.”

Independent Variable
What are you testing in your experiment? What are your units of measurement?

The variable that is changed on purpose and the units that are used for measurement of this variable are established by the experimenter. An example is “Fertilizer concentration could be expressed in %.”

If it is appropriate, you should also record the levels of the independent variable. Examine the chart below.

Levels of Independent Variable	For amounts of independent variable, you could list, for example, “0, 5, 10, 15, and 20 drops of fertilizer.”	--------->	in increasing order	--------->	
Number of Repeated Trials	This would be the number of times tested or the number of objects/organisms tested at each level of the independent variable. For example, you might test four tomato plants at each concentration of fertilizer.				

Dependent Variable
What results will you measure? What are your units of measurement? An example is “tomato plant height (cm).”

Description of Variables Held Constant
This must be the same in every setup so that you will know that any differences you observe are due to the variable you are testing.

In the fertilizer experiment, you will use the same species of plants. They should be the same size, grown in identical containers of soil that receive the same amount of water and light. They should all be kept at the same temperature.

Control
What is the control in your experiment? How would you convince someone that your experiment is a controlled experiment?

The control in an experiment is usually the group that is used as a standard for comparison. It is typically the group that receives no treatment. You could describe the control group as “the group of tomato plants that were treated with 0% fertilizer.” Or you could state that your experiment was controlled because “only the fertilizer concentration was changed in each setup—all other factors were kept the same.”

Safety Precautions
It is important that safety precautions be described. Since someone else may want to repeat your experiment, you should describe how to do it safely.