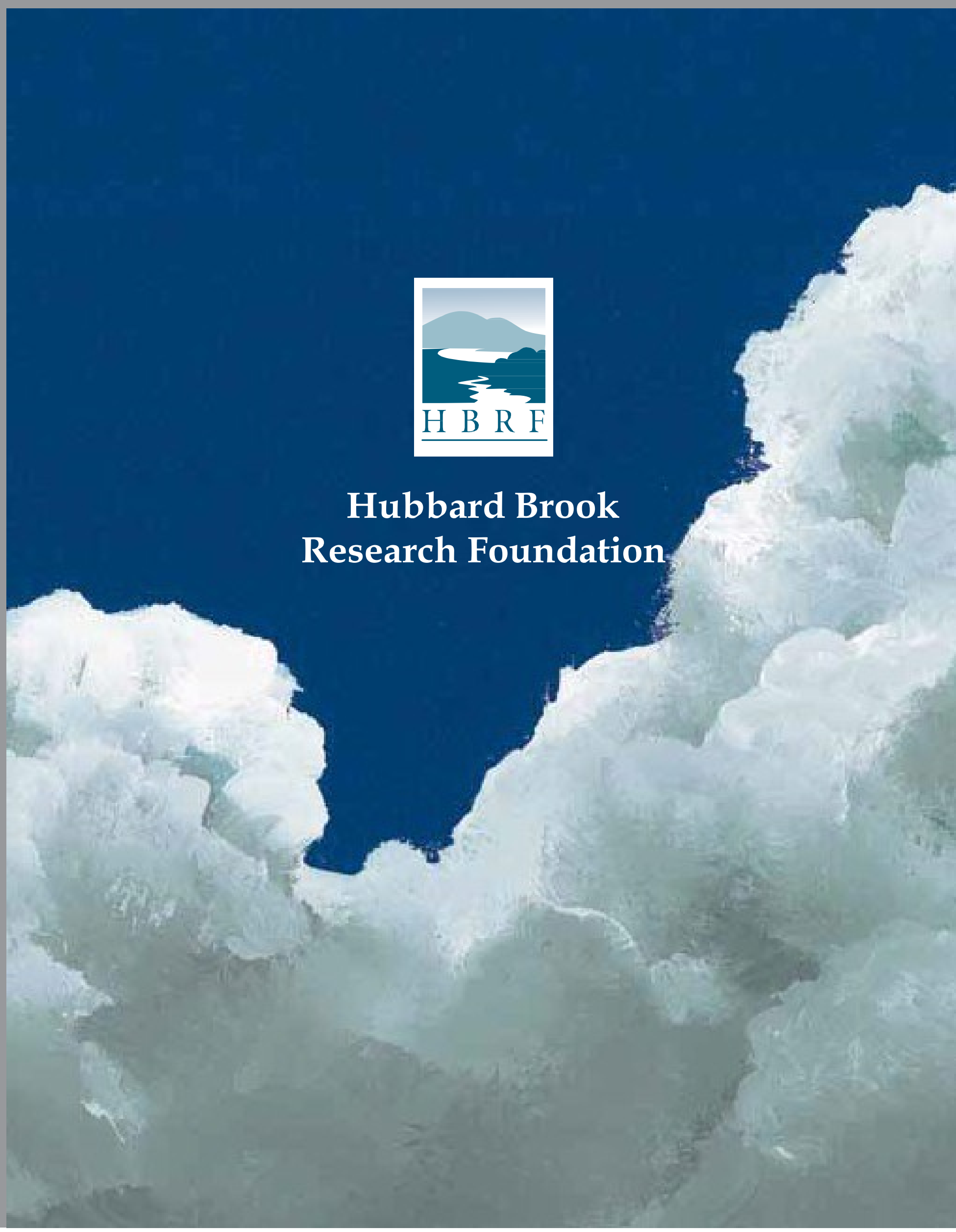
Environmental Literacy Program

Exploring Acid Rain

A Curriculum Guide



Data from the Hubbard Brook Ecosystem Study used in this guide were provided by Gene E. Likens through funding from the National Science Foundation and the Andrew W. Mellon Foundation.

Hubbard Brook Experimental Forest is one of 26 national Long-Term Ecological Research (LTER) sites established by the National Science Foundation to support research on long-term ecological phenomena in the United States. The Network is a collaborative effort involving more than 1800 scientists and students investigating ecological processes over long temporal and broad spatial scales. The Network promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs.

The Hubbard Brook Experimental Forest is one of 22 experimental forests administered by the USDA Forest Service, Northern Research Station which partners with the Hubbard Brook Research Foundation to develop and implement the Environmental Literacy Program (ELP), of which this guide is a component. Experimental forests are dedicated to long-term research on ecosystem processes, silviculture and forest management options, wildlife habitat characteristics, and forest growth and development. The ELP program works to bring the lessons of this research to teachers, students and the public.

Table of Contents

Introduction

This teaching guide was designed by the Hubbard Brook Research Foundation to be a resource for teachers of grades 7 through 12. It offers content information, classroom lessons, experimental activities, outdoor fieldwork, and data analysis suggestions that will introduce acid rain and build knowledge about the complex interactions between acid rain and **ecosystems**. Students who participate in fieldwork and data analysis will generate information and data that can be used to raise local awareness about acid rain.

About Hubbard Brook

The Hubbard Brook Experimental Forest (HBEF) is a 7,800-acre forested valley in central New Hampshire that was set aside by the United States Forest Service in 1955 and dedicated exclusively to the long-term study of forest and aquatic ecosystems. The first stream at the forest was fitted with measuring devices (**weirs**) in 1956 and, since then, water samples, stream flows, soil profiles, and other scientific measurements have been taken by research technicians on a weekly basis, in all kinds of weather conditions. Neatly stacked rows of thousands of water samples are testament to the on-the-ground efforts of countless researchers and technicians over nearly half a century. These samples and other data represent a treasure trove for scientists seeking to understand the long-term changes that occur in forests.

In the early 1960s, scientists from Dartmouth College and the U.S. Forest Service began conducting long-term ecological research at the forest, which led to the establishment of the Hubbard Brook Ecosystem Study. Over the years, the study has involved researchers from dozens of universities, government agencies, and other institutions representing a wide range of disciplines, from botany to **geochemistry**, limnology to avian biology. The Hubbard Brook Ecosystem Study employs the "small watershed approach" to understanding ecosystems, which was once considered a novel, even revolutionary, idea. Today more than 2,000 scientific papers using Hubbard Brook data have been published in peer-reviewed journals and books. Perhaps no paper was more important than the 1968 study documenting the link between the increasing acidity of precipitation and fossil fuel combustion in North America, a study in which Hubbard Brook researchers coined the phrase "acid rain."

Hubbard Brook is one of the nation's 26 Long-Term Ecological Research (LTER) sites, which are supported by the National Science Foundation. The Hubbard Brook Experimental Forest is operated and maintained by the U.S. Forest Service, Northern Research Station.

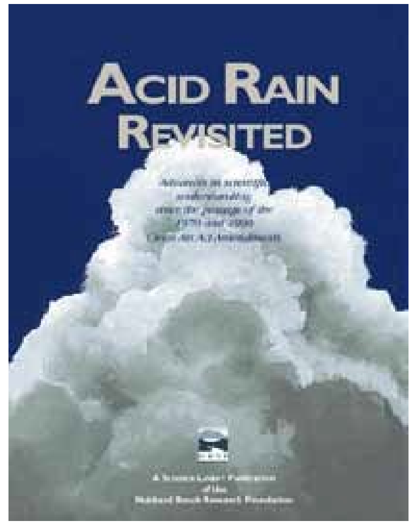
The Hubbard Brook Research Foundation (HBRF) is a nonprofit organization that supports the Hubbard Brook Ecosystem Study. Our mission is to promote the understanding and stewardship of ecosystems through scientific research, long-term monitoring and education.

Photo: Buck Sleeper

View at Hubbard Brook Experimental Forest

Monitoring equipment at Hubbard Brook

Our Environmental Literacy Program (ELP) has been developed and conducted in partnership with the U.S. Forest Service, Northern Research Station, and is aimed at middle and high school level education. The goal of the ELP is to foster a society where individual and collective decisions are informed by a working knowledge of ecosystem functioning. We strive to meet this goal by facilitating the transfer of scientific knowledge from researcher to teacher by developing curriculum, offering teacher professional development, and working directly with interested local schools. Education for college-level students is conducted through our Research Experience for Undergraduates Program (REU) which provides in-depth, hands-on research experiences at the Hubbard Brook Experimental Forest. The program emphasizes both the process of scientific research and the skills and importance of communicating that research to broader audiences. After an eight-week session students are partnered with research mentors and with regional non profit organizations and management agencies involved with communicating ecological information to broad audiences.



HBRF's Science Links program was established to bridge the gap between science and public policy, working with Hubbard Brook scientists to communicate the results of their research to government, the media, environmental and public-interest groups, and the general public. Our first Science Links project, *Acid Rain Revisited*, published in 2001, synthesized long-term monitoring data and ecosystem experiments that shed light on acid rain in the Northeast. A valuable resource, the report is used by policy makers, land managers, and the general public, including high school and college classes. You may wish to use the entire *Acid Rain Revisited* report or the summary as a resource for your students during your study of acid rain. For more information on the pH scale and the causes and chemistry of acid rain, please view the PowerPoint slideshow titled *Acid Rain 101*, or use one of the resources listed in Appendix B.

Why Was This Teaching Guide Created?

Photo: U.S. Forest Service archives

Sampling stream water at Hubbard Brook

Acid rain continues to degrade ecosystems. Acid rain was first documented in North America in the early 1960s at the HBEF. The results of early sampling of upland streams in the Hubbard Brook valley perplexed scientists when the water indicated unusually high acidity. They subsequently traced the source of the pollution to coal-burning electric utilities located in the Midwestern U.S. and transportation sources. Further investigations showed that acid rain was altering and degrading the ecosystem. This research played an important role in shaping the Clean Air Act of 1970, subsequent Clean Air Act Amendments (CAAA) of 1990, and the Clean Air Interstate Rule of 2005, which collectively mandated reductions in emissions that contribute to acid rain. Hubbard Brook scientists have since been able to document that ecosystems have benefited from this federal legislation, but that acid rain is still a problem and has had a greater environmental impact than previously projected. See Chapter 2 for more information.

All citizens should become environmentally literate. When students graduate from high school, they should understand how to use ecological knowledge to make informed decisions for themselves and society. An environmentally literate citizenry has the skills, knowledge, and motivation needed to promote a sustainable future. Students need to be aware of the issues, why they matter, and how they can be addressed.

Environmental literacy is fostered through place-based education. Some students may know about the issue of acid rain, but do they know how acid rain affects their region? When lessons directly link students to their community, they become meaningful learning opportunities that help students to make decisions long into the future.

Acknowledgments

This teacher's guide was written by Jacquelyn Wilson, Education Associate of the Hubbard Brook Research Foundation, with the input and advice of many. We would like to warmly thank all those who contributed time and expertise to this project. We are grateful for their vision and motivation to bring quality science education materials to secondary school educators in the Northeast and beyond.

We would like to thank all the Hubbard Brook scientists who reviewed the content of the guide and/or provided assistance in the development of lessons and activities: Drs. Gene E. Likens (Cary Institute of Ecosystem Studies), Scott W. Bailey (U.S. Forest Service), Charles T. Driscoll (Syracuse University), J. Steve Kahl (University of New Hampshire), and Kristie Judd (Eastern Michigan University); and Don Buso (Cary Institute), Phyllis Likens (Cary Institute), Ellen Denny (U.S. Forest Service), Amey Bailey (U.S. Forest Service), and Geoff Wilson (HBRF). Other reviewers include: David Sleeper (HBRF), Kim Driscoll (Syracuse University), and Cronin Sleeper (HBRF). Joseph Homer (USDA New Hampshire Natural Resources Conservation Service) and Jamie Shanley (USGS Sleepers River Research Watershed) provided assistance and resources in the development of soil-based activities.

Thanks also to our Education Advisory Council for helping us plan and develop this teaching guide. While many people played a part, our core group included Judy Filkins, Carol Foley, Dean Goodwin, Debbie Groveman, Lisa Hjelm, Jeannie Kornfeld, Jim Nourse, and Michael Quinn.

We also thank Jenna Guarino, formerly of HBRF, who initiated the development of this guide; and Judy Brown who edited the manuscript and guided the project through the design process.

We would like to acknowledge resources instrumental to this guide. Exploring Acid Rain utilizes complementary Web-based resources, primarily that of the GLOBE Program (Global Learning and Observations to Benefit the Environment) on the web at www.globe.gov. Globe is a worldwide, hands-on, primary and secondary school-based education and science program and is a cooperative effort of schools in partnership with colleges and universities, state and local school systems, and non-governmental organizations. Other resources that were important to this guide include the Hubbard Brook Ecosystem Study and Environmental Inquiry from Cornell University.

This project was funded by the U.S. Forest Service/Northern Research Station, Mascoma Savings Bank Foundation, and the Wellborn Ecology Fund of the New Hampshire Charitable Foundation, Upper Valley Region. Additional funding was provided by the U.S. Forest Service, Northern Research Station and Mascoma Savings Bank Foundation.

What Do You Think?

We strive to produce quality teaching guides that are scientifically current and educationally useful. Your feedback is fundamental to this process. Please let us know what you think about this teaching guide and how we can improve it. Please send comments to:

Anthea Lavallee, Executive Director, Hubbard Brook Research Foundation:
alavallee@hubbardbrookfoundation.org

Chapter 1

About This Teaching Guide

Exploring Acid Rain is designed to help students develop the following enduring understanding:

Human activities can degrade ecosystems and the services they provide. Scientific research and long-term monitoring are necessary to understand how to promote the recovery of degraded ecosystems.

This teaching guide was developed to help teachers, students, and schools meet the following goals:

- Learn about acid rain science and how ecosystems can recover from acid rain
- Learn skills in scientific inquiry and environmental monitoring
- See themselves as contributors of knowledge and data on local environmental conditions to their community
- Apply this set of understandings to local and global environmental issues
- Achieve academic standards
- Promote environmental and scientific literacy
- Integrate chemistry, biology, and earth science within the context of environmental science

Environmental Literacy Program

Arrangement of this Guide

The heart of the teaching guide is found in Chapters 3 through 5, which provide content, lessons and investigations, fieldwork, and assistance with data representation and interpretation. Each chapter has an accompanying chart that lists the New Hampshire Science Literacy Standards addressed by the activities contained in that chapter. These chapters are described briefly below.

Chapter 3: Concept-Building Activities

This chapter provides information and offers experiences that range from discussion-based to lab-based activities. Depending on your students and their academic experiences, you may decide to skip one or more of them. We recommend that you administer a pre-test to assess what your students already know to identify gaps that can be addressed by these lessons. All of the lessons in this chapter include assessments and rubrics; for more on assessment, please see additional information in Chapter 6: Curriculum Options.

Chapter 4: Fieldwork

Giving students the opportunity to do fieldwork allows them to participate in the process of "doing science" and directly connects them with environmental conditions within their community. The first lessons in this chapter will aid you and your students in preparing to do fieldwork. Lessons 4.5 through 4.9 provide **protocols** for collecting data on precipitation,

Photo: Amey Bailey

Photo: Hubbard Brook archives

Hubbard Brook

precipitation pH, alkalinity (of a water body), soil characterization, and soil pH. In addition, this chapter offers ways for students to synthesize, interpret, and communicate results once students have completed data collection.

Chapter 5: Slideshows

Four Power Point slideshows have been developed for this teaching guide. The first, *Acid Rain 101*, can serve as a primer for teachers wishing to learn content information about acid rain. Three additional slideshows tell the story of acid rain research within the Hubbard Brook Ecosystem Study: *Part I: The Discovery, Part II: The Calcium Experiment,* and *Part III: Ecosystem Recovery*.

Chapter 6: Curriculum Options

This chapter offers ideas that you may wish to incorporate in your acid rain unit including the "Understanding by Design" curriculum planning method and a framework for using inquiry in middle school. It also includes several tools and resources that allow for student-directed learning, culminating in student independent research projects.

Curriculum Planning

Before getting started, we suggest that you ask yourself the following questions to help determine your approach to this study and where your students might go with it.

- How many class periods or blocks of time can I devote to this unit?
- Would I like to incorporate fieldwork into this unit? If so, where will we conduct the fieldwork and how will I get my students to the location? (Please see Chapter 4: Fieldwork for a more thorough discussion of fieldwork considerations.)
- What supplies and equipment do I already have that might be useful? What additional supplies and equipment might I need to obtain?
- How much direction or guidance do I need to provide to help my students conduct scientific investigations?

Answers to these questions will become more apparent after you review the chapters of this teaching guide and consult other resources. If you need even more basic background about the concepts discussed below, the Environmental Protection Agency's (EPA) guide, *Learning about Acid Rain*, is a good resource for grades 6 through 8.

Photo: kevin mcGuire

At work in the forest

Most lessons in *Exploring Acid Rain* cover the first two of the following spectrum of inquiry-based approaches:

Teacher-directed student learning, with strong teacher direction and oversight throughout the study;

Teacher-guided student learning, where the teacher actively teaches important concepts, helps get students started on an investigation, and provides ongoing guidance;

Student-directed learning, where students initiate investigations based on their own questions and carry them out while the teacher serves as a facilitator.

If you are interested in having your students pursue a student-directed learning approach, please see Chapter 6: Curriculum Options.

Science Standards

Chapters 3, 4, and 5 contain links to a *New Hampshire Science Standards* table that shows which standards are met by each lesson or activity within that chapter.

We have chosen a subset of the New Hampshire Department of Education Science Literacy Standards that we feel are addressed well by the lessons and activities. This is by no means a comprehensive list and other standards can be addressed by this guide as well. We have chosen to highlight 9-11 Grade Span Expectations (GSE), although GSE's for grades above and below this range are also well-served by these lessons and activities. We use these 9-11 GSE's because they hit the middle of the grade range (7 through 12) addressed by this teaching guide. The standards in the boxes are the "assessment targets" for the science portion of the New England Common Assessment Program (NECAP) exam given to students in grade 11 each year. While inclusion in the NECAP exam makes these boxed standards important to teach, all standards, taken together, represent the body of knowledge and skills students should gain in secondary school. Lessons and activities in this guide address one or more of the following standards.

New Hampshire Department of Education Science Literacy Standards

Earth Space Science

Earth Space Science 1
The Earth and Earth materials, as we know them today, have developed over long periods of time, through constant change processes.

S:ESS1:11:2.1 Recognize that elements exist in fixed amounts and describe how they move through the solid Earth, oceans, atmosphere and living things as part of geochemical cycles, such as the water, carbon, and nitrogen cycles.

S:ESS1:11:7.1 Explain that water quality can be affected positively or negatively by outside sources.

Earth Space Science 4
The growth of scientific knowledge in Earth Science has been advanced through the development of technology, and is used (alone or in combination with other sciences) to identify, understand, and solve local and global issues.

S:ESS4:11:3.3 Explain how the use of technologies at a local level, such as burning of fossil fuels for transportation or power generation, may contribute to global environmental problems.

Life Science

Life Science 2
Energy flows and matter recycles through an ecosystem.

S:LS2:11:1.4 Analyze and describe how environmental disturbances, such as climate changes, natural events, human activity and the introduction of invasive species, can affect the flow of energy or cycling of matter in an ecosystem.

S:LS2:11:1.5 Using data from a specific ecosystem, explain relationships or make predictions about how environmental disturbance (human impact or natural events) affects the flow of energy or cycling of matter in an ecosystem.

S:LS2:11:2.2 Explain that as matter and energy flow through different levels of organization in living systems and between living systems and the environment, elements, such as carbon and nitrogen, are recombined in different ways.

Life Science 3
Groups of organisms show evidence of change over time (e.g., evolution, natural selection, structures, behaviors, and biochemistry).

S:LS3:11:1.1 Identify ways humans can impact and alter the stability of ecosystems, such as habitat destruction, pollution, and consumption of resources; and describe the potentially irreversible effects these changes can cause.

S:LS3:11:1.2 Identify ways of detecting, and limiting or reversing, environmental damage.

S:LS3:11:1.3 Analyze the aspects of environmental protection, such as ecosystem protection, habitat managements, species conservation and environmental agencies and regulations, and evaluate and justify the need for public policy in guiding the use and management of the environment.

Life Science 4
Humans are similar to other species in many ways, and yet are unique among Earth's life forms.

S:LS4:11:2.6 Use evidence to make and support conclusions about the ways that humans or other organisms are affected by environmental factors or heredity (e.g., pathogens, diseases, medical advances, pollution, mutations).

Physical Science

Physical Science 2
Energy is necessary for change to occur in matter. Energy can be stored, transferred, and transformed, but cannot be destroyed.

S:PS2:11:2.3 Recognize that a large number of important reactions involve the transfer of either electrons or hydrogen ions between reacting ions, molecules, or atoms.

Science Process Skills

Science Process Skills 1: Scientific Inquiry and Critical Thinking Skills

1. Making Observations and Asking Questions
S:SPS1:11:1.1 Ask questions about relationships among variables that can observed directly as well as those that cannot.

2. Designing Scientific Investigations
S:SPS1:11:2.2 State a hypothesis and prediction based on available evidence and background information.

3. Conducting Scientific Investigations
S:SPS1:11:3.1 Select and use apparatus and materials safely.
S:SPS1:11:3.2 Use instruments effectively and accurately for collecting data.
S:SPS1:11:3.3 Compile and organize data, using appropriate tools.

4. Representing and Understanding Results of Investigations

S:SPS1:11:4.1 Compile and display data, evidence, and information by hand and computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots.

5. Evaluating Scientific Explanations

S:SPS1:11:5.1 Explain how data support or refute the hypothesis or prediction.

S:SPS1:11:5.2 Provide a statement that addresses the question investigated in light of the evidence generated in the investigation.

Science Process Skills 2: Unifying Concepts of Science

1. Nature of Science

S:SPS2:11:1.3 Sometimes scientists can control conditions in order to focus on the effect of a single variable. When that is not possible for practical or ethical reasons, they try to observe as wide a range of natural occurrences as possible to be able to discern patterns.

2. Systems and Energy

S:SPS2:11:2.1 Systems may be so closely related that there is no way to draw boundaries that separate all parts of one from all parts of the others.

S:SPS2:11:2.3 Even in some very simple systems, it may not always be possible to predict accurately the result of changing some part or connection.

4. Patterns of Change (constancy, change, evolution, and equilibrium)

S:SPS2:11:4.2 Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change.

Science Process Skills 3: Personal, Social, and Technological Perspectives

2. Common Environmental Issues, Natural Resources Management, and Conservation

S:SPS3:11:2.2 Design investigations to answer particular questions about the environment.

3. Science and Technology; Technological Design and Application

S:SPS3:11:3.1 Analyze environmental issues such as water quality, air quality, hazardous waste, and depletion of natural resources.

Chapter 2

The Hubbard Brook Ecosystem Study and Acid Rain

Chapter Overview

Environmental Literacy Program

The Hubbard Brook Ecosystem Study (HBES) and Acid Rain

A Brief History of Acid Rain Research at the Hubbard Brook Experimental Forest

The existence of **acid rain** (more accurately called acidic deposition to include snow, fog, and dust), has been known for more than 100 years.[1] Documentation of the **acidification** of surface waters began in Scandinavia,[2] but the first research project to document and study acid rain in North America was led by Gene E. Likens, F. Herbert Bormann, and Noye M. Johnson, who began to measure the acidity of rain and snow samples in 1963 at the Hubbard Brook Experimental Forest in Woodstock, New Hampshire.[3] However, researchers were not looking for acid rain when they discovered it. As part of their study on the **biogeochemical** cycles of the northern hardwood forest, they collected precipitation samples and noticed something curious: the pH of rain and snow was very low. Instead of measuring pH values close to 5.2, the average pH of natural precipitation, the researchers frequently recorded values between 4.0 and 4.2, which reflect very acidic conditions. In fact, they once measured a rain sample with a pH of 2.85, which is much more acidic than orange juice! The heavily forested White Mountains are located in a very rural and upland region of New England. Why was the pH of the precipitation over this region so low? Where was the acidity coming from?

The discovery of acid rain at Hubbard Brook represents a scientific anomaly — something that cannot be explained by currently accepted scientific theories. This acid rain mystery ceased to be an anomaly once it was understood that emissions from Midwestern power plants were being carried to the White Mountains by prevailing westerly winds and dropped on the forest below as precipitation and dry deposition. But it was the Hubbard Brook Ecosystem Study's ongoing monitoring efforts coupled with experimentation that solved the mystery of the unexpected pH data. Chapter 5 includes three slide shows that trace the acid rain research of the Hubbard Brook Ecosystem Study.

---

[1] R. A. Smith, Air and rain: *The Beginnings of a Chemical Climatology.* Longmans, Green, London, 1872.

[2] S. Oden, *The Acidification of Air and Precipitation and Its Consequences in the Natural Environment.* Swedish National Research Council, Stockholm, 1968.

[3] G. E. Likens, F.H. Bormann, and N.M. Johnson. "Acid Rain." *Environment* 14: 33-40, 1972.

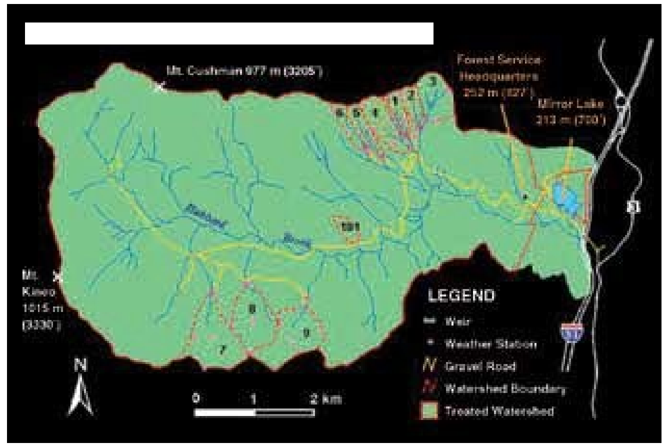


Figure 2.1 Hubbard Brook Experimental Forest map, Woodstock, New Hampshire

Photo: U.S. Forest Service

Aerial view of experimental watersheds at Hubbard Brook (1984)

The Interplay between Monitoring and Experimentation

In order to understand how an entire **ecosystem** (like a forest or a lake) is affected by pollutants and how human actions can worsen or improve environmental conditions within that ecosystem, we need to study it as an intact unit and monitor it for many years. We also need to understand the distinct characteristics of each unique ecosystem we study and how its components interact with **disturbances** such as air pollution caused by human activities. (See Figure 2.2.) For example, the northern hardwood forest in the White Mountains of New Hampshire has soils that tend to be naturally acidic. These soils react differently to acid rain than the same type of forests in western Vermont, where the soils have greater **alkalinity** and so are better able to neutralize anthropogenic acids.

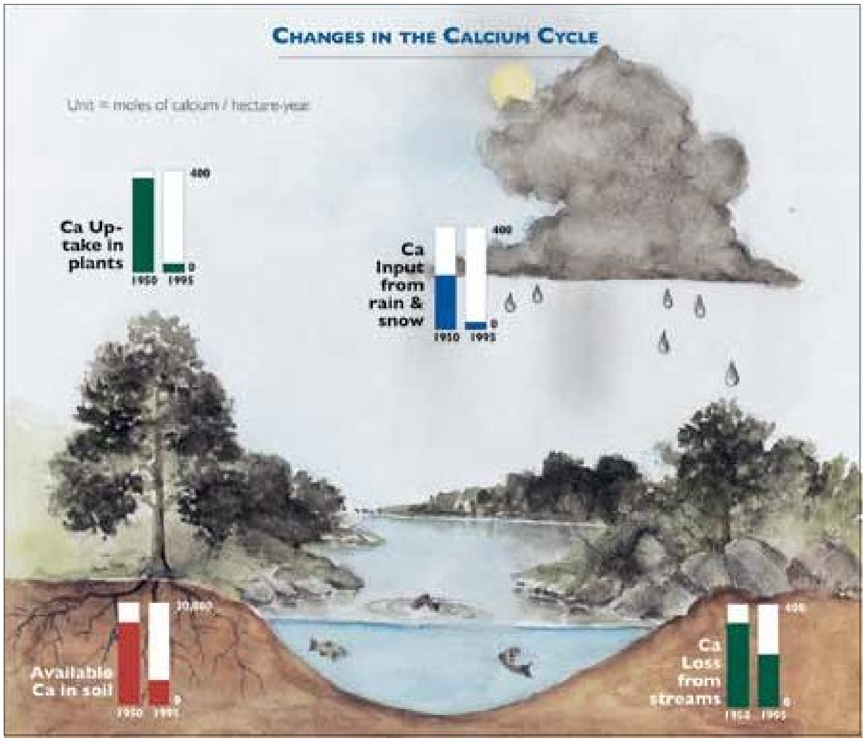


Figure 2.2 Calcium Cycle

The Hubbard Brook Ecosystem Study (HBES) combines two powerful research methodologies to shed light on acid rain: 1) the weekly collection of biogeochemical data that goes back to 1963; and 2) the small **watershed** ecosystem approach that allows scientists to design and implement ecosystem-level experiments that manipulate specific watersheds and leave others as "reference" watersheds for comparison. Several small watersheds in the Hubbard Brook Experimental Forest (see previous page) have been designated for experimental study. Here are two links for more information about **reference** watersheds and a description of Hubbard Brook watersheds.

What Does Long-term Data from the HBES Tell Us about Acid Rain?

Long-term monitoring efforts documented that, as a result of the Clean Air Act and its amendments, emissions of sulfur dioxide and concentrations of sulfate in surface waters have decreased since 1970; the acidity of stream water has decreased slightly in the Hubbard Brook valley as well. The buffering, or neutralizing, capacities of the soil and surface water in the Hubbard Brook valley, however, did not improve with these changes[4] and have resulted in a delay of chemical and biological recovery in its aquatic and terrestrial ecosystems.

1.

[4] G. E. Likens, C.T. Driscoll, and D.C. Buso. "Long-Term Effects of Acid Rain: Response and recovery of a forest ecosystem." *Science,* 272:244-246, 1996.

Recent studies at Hubbard Brook and other places have shown that acid rain has changed the chemical composition of soils in the following ways:

Base cations in the soil (such as calcium and magnesium) have become depleted. Figure 2.2, Changes in the Calcium Cycle, illustrates changes to the calcium cycle in the Northeast between the years 1950-1995 and shows that there is significantly less calcium available in the soil at Hubbard Brook. The reduction of base cations fundamentally alters soil processes and hinders the ability of acid sensitive soils to buffer (neutralize) ecosystems. In addition, the reduction of base cations has compromised the nutrition of trees such as red spruce and sugar maple.

2. Acid rain causes aluminum to be released in an inorganic, dissolved form, from soil into soil water, vegetation, lakes, and streams. Figure 2.3, Acid Deposition Effects on Trees, illustrates how high concentrations of aluminum in this form can be toxic to organisms.

3. Sulfur and nitrogen have accumulated in forest soils across the region. Even if less sulfur and nitrogen are deposited in precipitation, sulfate and nitrate continue to be released from soil, which continues the acidification process in lakes and streams.

Ecosystem Recovery from

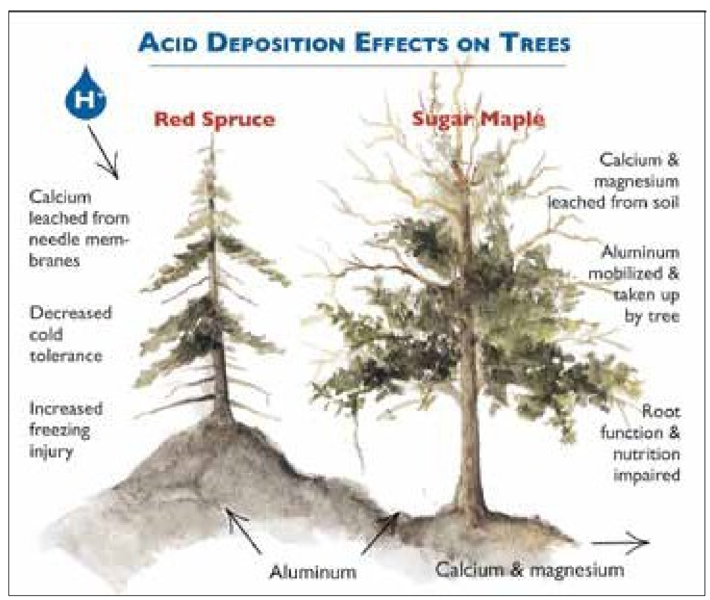


Figure 2.3 Acid Deposition

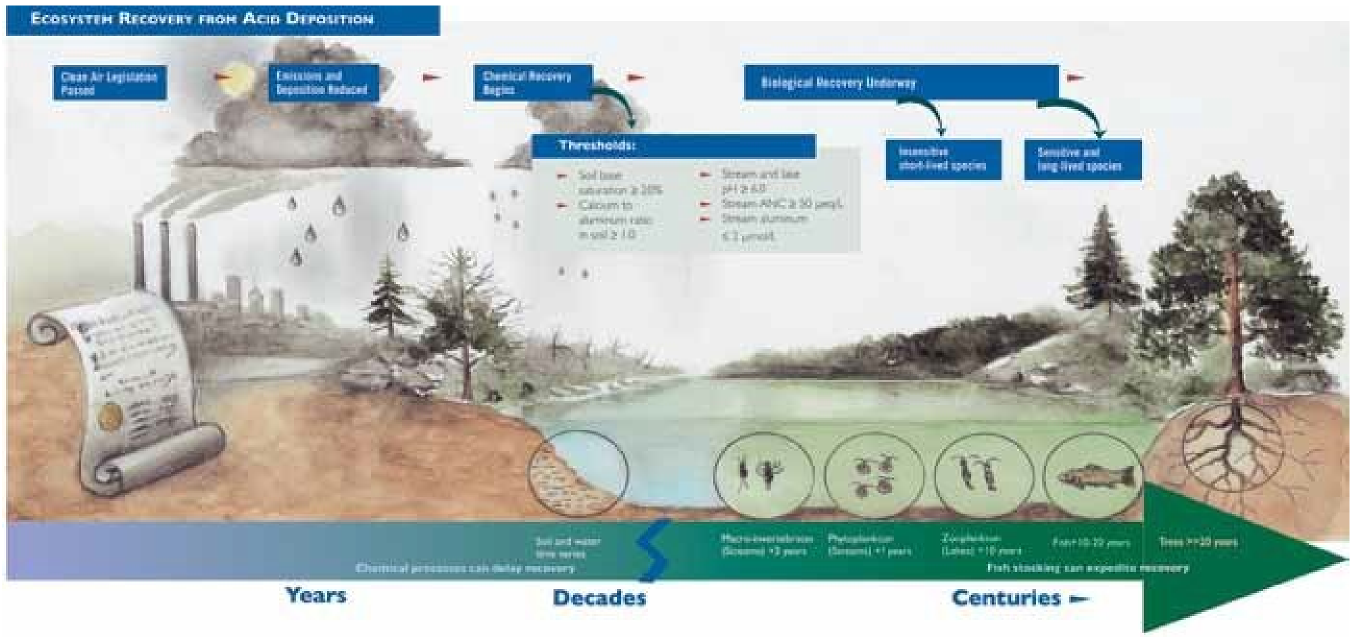


Figure 2.4 Ecosystem Recovery Over Time

Acid Deposition

How do ecosystems recover from acid rain and how do scientists know that recovery is occurring? To assess the recovery of an ecosystem from **acid deposition**, long-term monitoring is essential, as background conditions (data prior to acid deposition) must be compared to current conditions.

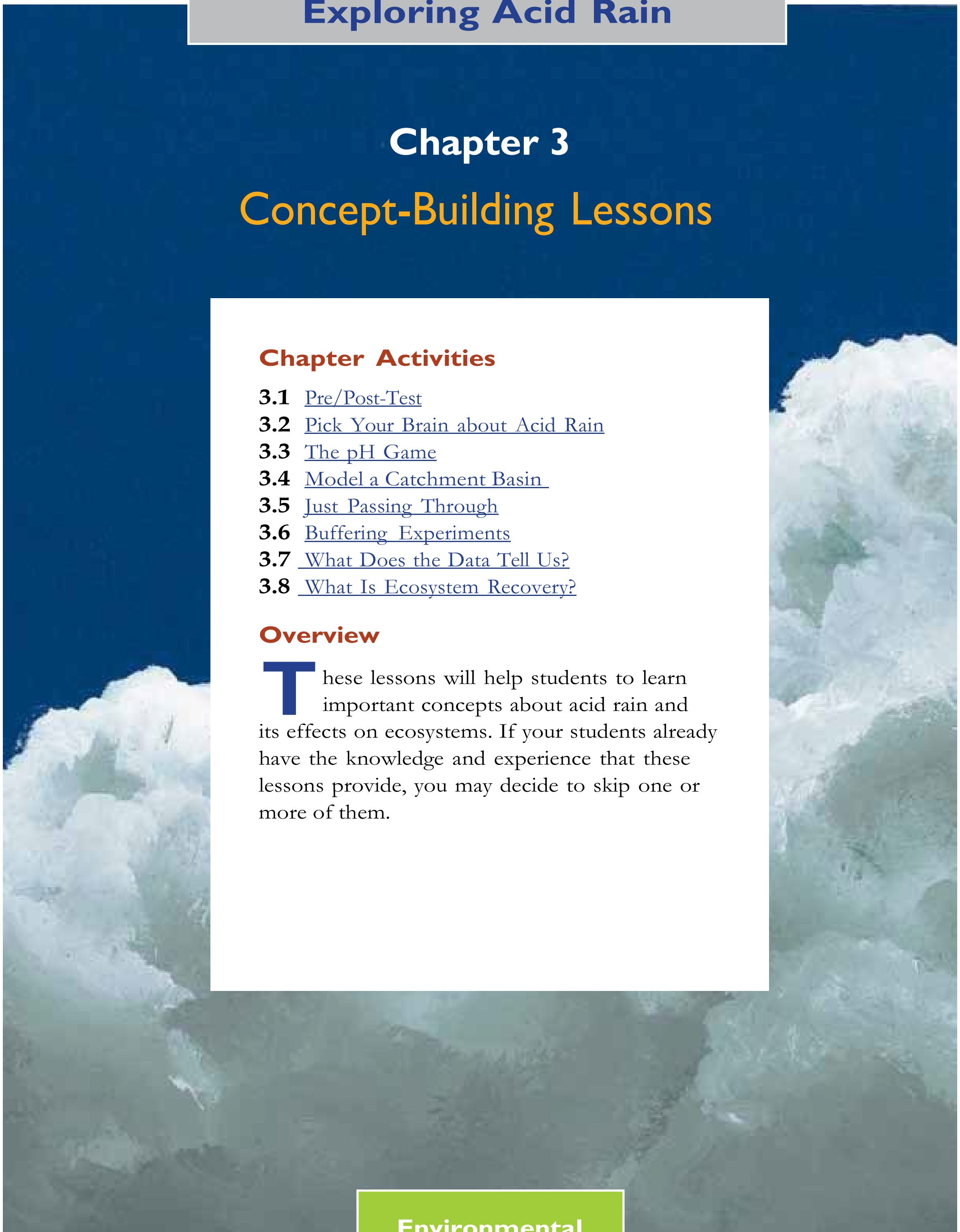
In order for an ecosystem to recover, there must first be chemical recovery (decreased concentrations of sulfate, nitrate and aluminum in soils, lakes and streams). As chemical conditions improve, biological recovery can start to happen. Biological recovery will most likely occur in stages, as not all organisms can recover at the same rate and some may be more sensitive to acidic conditions than others. Figure 2.4, Ecosystem Recovery from Acid Deposition, above, details the process of ecosystem recovery by listing specific thresholds required for chemical recovery and by describing biological recovery rates for various aquatic organisms and trees.

The Calcium Experiment

A major HBES research project that involves both long-term monitoring and experimentation is the calcium experiment initiated in 1999. (See Figure 2.3.) HBES scientists hypothesized that if calcium — an important plant nutrient and a base cation that buffers incoming acids — was replaced across a whole forested watershed, recovery from acidification would accelerate. They calculated the amount of calcium that had been lost, and then commissioned a helicopter to broadcast **wollastonite** (a mineral that contains calcium) pellets evenly over Watershed 1. Since then, data has been gathered in both Watershed 1 and the reference watershed, Watershed 6, which received no **treatment**. Data include measurements on stream chemistry, soil chemistry, and the health of trees such as sugar maple and red spruce. The results obtained thus far show that there is a difference between the two forested watersheds (data from Watershed 1 indicates better growth of sugar maples, more seedlings, more soil base cations and higher pH of stream water), but new questions surface even as understanding continues to grow. The HBES provides a model for scientific inquiry, which can be imagined as a spiral that leads the inquirer through a repeating series of steps that involve questioning and experimentation, which generate results which spawn more questions, etc.

The table that follows shows how long-term monitoring and experimentation interact and enhance each other at the HBEF to produce valuable insights into ecosystem functions. The table uses acid rain to illustrate how this inquiry process works.

MONITORING AND EXPERIMENTATION		
Long-Term Monitoring	Experimentation	
↓	Question	Why is the pH of precipitation falling on the Hubbard Brook Experimental Forest so acidic? (Low pH of rain first documented in 1963.)
↓ ↓	Hypothesis	Sulfur emissions from Midwestern electric utility plants are causing acid rain in NH forests. *Data produced from the HBES informed Congress' decision to legislate the 1970 Clean Air Act.*
↓	Test	The 1970 Clean Air Act is passed with limits on six major pollutants to reduce pollution, including sulfur dioxide and particulate emissions from Midwestern electric utilities.
↓	Response/ Results	HBES scientists measure less acidic precipitation (pH is increasing), but acid-sensitive surface waters throughout the region do not show a recovery in acidity or buffering capacity.
Analysis → ↓	Conclusion	NH forests are still impacted by acid rain because 1) the acid neutralizing capacity (ANC) of forest soils has been depleted due to past acid rain inputs; and 2) sulfur and nitrogen emissions, mainly from electric utilities and transportation sources, continue to produce acid rain.
↓	New Question	Would a forest ecosystem show signs of recovery if calcium (lost in soil due to acid rain) was replaced? Calcium is an important plant nutrient and a base cation that buffers incoming acids.
↓	Hypothesis	Forest ecosystem functions would recover if the amount of calcium lost due to acid rain was replaced.
↓	Test	Calcium was added to an entire watershed (W1) at HBEF and compared over time with a reference (untreated) watershed (W6).
↓	Response/ Results	The watershed with added calcium (W1) shows better growth of sugar maples, more seedlings, more soil base cations, higher pH of stream water, etc., compared with the reference (W6).
Analysis →	Conclusion	Replacing calcium promotes ecosystem recovery in a forest that has been damaged by acid rain.
↓	New questions arise that lead to further experimentation and the inquiry spiral continues.	



Chapter 3

Concept-Building Lessons

Chapter Activities

Overview

These lessons will help students to learn important concepts about acid rain and its effects on ecosystems. If your students already have the knowledge and experience that these lessons provide, you may decide to skip one or more of them.

Environmental Literacy Program

Activity

3.1 Pre/Post-test

top of chapter 3

Overview

We recommend administering a pre-test to students before beginning any unit of study. This serves two purposes: As an advance organizer, it lets students know what they are expected to learn by the end of the unit, and it allows the teacher to gauge the range of knowledge already held by students. We also recommend administering the same set of questions as a post-test at the end of the unit. This allows teachers to check for understanding and to help build a sense of accomplishment in the students through their demonstration of what they have learned. The following pre/post-test primarily covers acid rain pollutants. You may wish to add or omit questions, depending on the content areas you choose to cover in your unit.

Source

Hubbard Brook Research Foundation

Materials and Tools

Copies of pre/post test for students (see following page)

Answer Key for Pre/Post-test

1. C

2. A and B

3. C

4. A

5. C

6. A

7. B

Estimated Time to Complete Lesson

10 minutes

Background Needed

None

Name:____Date: _____________________

1. What are the two major pollutants that create acid rain? *Choose one answer.*

   A. ozone and sulfur dioxide

   B. chlorofluorocarbons and ozone

   C. nitrogen oxides and sulfur dioxide

   D. mercury and methane

2. What are the two major sources of acid rain pollutants? *Choose two answers.*

   A. coal burning power plants and factories

   B. automobile emissions

   C. solid waste incineration plants

   D. nuclear power plants

3. How is "acid rain" commonly defined? *Choose one answer.*

   A. rain (or any deposition) that has a pH value less than neutral (7.0)

   B. rain (or any deposition) that has a pH value greater than neutral (7.0)

   C. rain (or any deposition) that has a pH value of 5.2 or less

   D. rain (or any deposition) that contains sulfuric, nitric or organic acids

4. How does acid rain affect acid-sensitive ecosystems such as the Hubbard Brook Experimental Forest? *Choose one answer.*

   A. It mobilizes toxic substances and leads to loss of important plant nutrients in the soil.

   B. It increases growth of trees, resulting in injury due to weaker wood density.

   C. It creates changes in physical soil structure, resulting in more compacted soil.

   D. It decreases concentrations of sulfate in soils and stream water.

Questions 5-7

To reduce emissions of pollutants that create acid rain, the 1990 Clean Air Act Amendments instituted a "cap and trade" policy on one of the major contributors. *Choose one answer*.

5. For which acid rain pollutant was this "cap and trade" policy created?

   A. nitrogen oxides

   B. ammonia

   C. sulfur dioxide

   D. chlorofluorocarbons

6. Which acid rain pollutant was addressed but not "capped"? *Choose one answer*.

   A. nitrogen oxides

   B. ammonia

   C. sulfur dioxide

   D. chlorofluorocarbons

7. Which acid rain pollutant was not addressed at all by the CAAA? *Choose one answer*.

   A. nitrogen oxides

   B. ammonia

   C. sulfur dioxide

   D. chlorofluorocarbons

Activity

3.2 Pick Your Brain about Acid Rain

top of chapter 3

Overview

Students are encouraged to recall anything they have heard about acid rain and generate questions about it. This process reflects the usual starting point for scientific investigations, and it helps teachers find out what students already know and what misconceptions they may have. Students also discover what their classmates have heard and begin to explore and synthesize some initial information about acid rain.

At the end of the activity, the class will have a list of statements and a list of questions about acid rain. These lists will help students sort out the scientific validity of hearsay information and, as the unit progresses, to correct misconceptions and separate factual information from statements more related to social values.

Sources

Modified and adapted from *Acid Rain,* one of more than 70 teachers' guides in the Great Explorations in Math and Science (GEMS) series. The guide is copyrighted by The Regents of the University of California, but the copyright holder is not responsible for any modifications or adaptations. GEMS guides are available from GEMS, Lawrence Hall of Science, University of California, Berkeley, CA 94720, on the Web at http://www.lhsgems.org.

Standards Addressed

(refer to NH Science Standards)

- S:ESS4:11:3.3
- S:LS2:11:1.4
- S:LS3:11:1.1, 11:1.2, 11:1.3
- S:SPS3:11:3.1

Student Outcomes

- Articulate initial understandings and questions about acid rain.
- Sort through complex, science-related social issues surrounding acid rain and distinguish between incorrect, factual, and value statements.
- Discuss and use various learning modes in investigating the range of scientific issues surrounding acid rain.

Materials and Tools

- 30 to 40 sheets of blank paper
- approximately 30 "question strips" (24-inch by 3-inch strips of paper or card stock) — 5 or more for each group of 4 students
- newsprint sheets
- markers
- masking tape
- Acids in Your Life homework page, one per student

Assessment

- Acids in Your Life homework
- Homework Rubric

Estimated Time to Complete Lesson

One 40-minute period

Background Needed

None

Lesson Planning: Pick Your Brain about Acid Rain

Part 1: Introduce the "Challenge of the Day"

1. Introduce the topic by telling the class that you want to find out what they've heard about acid rain. Emphasize that this is the same way that scientists start an investigation: they find out what is already known in order to figure out what to investigate next and how to do it.
2. Ask students to write down what they've heard about acid rain. They don't need to be sure the information is correct; rather, anything that they've heard about the topic from books, TV, newspapers, or word of mouth is acceptable. Ask them to write down short, concise statements, rather than long explanations. They will have about three minutes to make a list of everything that comes to mind. No one else will read their list; it's simply to help them collect their thoughts for the next part of the activity.
3. Tell students that if they run out of things to write down (or if they don't have anything to write in the first place), to turn over the paper and write down any questions they have about acid rain.
4. Ask the students if they understand what they're supposed to do. Then pass out pieces of blank paper and ask them to begin.

Part 2: Organize the "Mind Swap"

1. After three minutes (or a little longer if needed), have the students end the exercise.
2. Explain that they will work in teams to combine what they have heard about acid rain by doing a "mind swap" in their groups.
3. Explain the following rules
   a) In each group, one student begins by sharing all she/he has heard about acid rain. No one is to interrupt the speaker or discuss anything yet.
   b) The other group members listen and, if they wish, they can add things the speaker has said to their own individual lists. Again, no discussion at this point.
   c) Each person, in turn, tells the group what's on his/her list. Make sure everyone in the group has a chance to speak.
   d) After everyone has had a turn, they can ask each other questions and discuss what was shared.
4. Organize the class into groups of 3 or 4 students. Ask if there are any questions, then have the groups begin.

Part 3: Share What Everyone Has Heard

1. After about five minutes, conclude the group discussions. Ask the groups to take turns sharing one thing that their group has heard about acid rain. List these items on a sheet of newsprint to keep for reference as the unit develops. Continue until all groups have shared all of their ideas. Tell them that it is okay to "pass" if all of their statements have already been said by someone else. *(Note: You may want to have a student help write the ideas on the sheet of newsprint so you can facilitate and keep the process flowing.)*
2. Ask students if they see any two statements on the sheet of newsprint that can't both be true. Encourage discussion. You can make several important points:
   - There is often controversy and disagreement in science.
   - Sometimes we *think* we know something, and it *might* have been true at one time, but as knowledge in the scientific community grows, this "fact" can be shown to be inaccurate.
   - It is sometimes easy to confuse what we know about acid rain with information about other environmental topics.
3. Remind the class that what the groups have been sharing is what they have *heard* to be true. Explain that as the class continues its study of acid rain, they will be better able to determine whether any of the statements are correct.

Part 4: Generate Questions: What We *Don't* Know about Acid Rain

1. Tell the class that they will work together to generate questions about acid rain. While some of them may have already begun this individually, now you'd like them to focus on it as a group.
2. Explain that the "rule" here is that they will only list questions for which no one in the group has an acceptable answer. So each group needs to discuss the question to see if anyone might know the answer. Ask each group to come up with at least one question per person.
3. Tell groups that they will have about five minutes to write each question in large, clear print on a question strip. Then they will post their question strips on a large sheet of paper on the wall.
4. Check to make sure all students understand, then hand out markers and question strips and have them begin.

Part 5: Post the Questions

1. After about five minutes, stop the groups and ask them to post their questions. If you have time, you may want to sort these questions into groups or categories, such as technical questions about acid rain, questions about its effects, questions about the future, questions about possible solutions to the acid rain problem, etc.
2. After all groups have posted their questions, ask students to read through them and then ask if anyone can offer a response to any of the questions.
3. Point out that scientists and others working on the acid rain problem also have many questions for which they don't know the answers. That's one of the reasons why acid rain is a difficult problem to address. But science is the process of asking good questions about the world and building knowledge through investigation.
4. Tell students that you will keep their statements and questions to refer to in later sessions. *(If possible, find a place to post them on the classroom wall until the unit is completed. If you can't keep them on the wall the whole time, be sure to record them on sheets of newsprint so you can post them at appropriate times.)*

Here is a sample list of statements and questions about acid rain, generated by a 7th grade class.

ACID RAIN	
Student Statements	**Student Questions**
Acid rain is harmful to people.	What is acid rain?
Acid rain comes from factories.	How does acid rain fall?
Acid rain ruins farmers' crops.	Why does acid rain fall?
Acid rain is made of poisonous smoke.	What does acid rain come from?
Acid rain is a deadly chemical.	Can acid rain be useful?
Acid rain kills fish.	How does acid rain affect the ecosystem?
Acid rain can kill trees.	How does acid rain affect the ozone layer?
Acid rain poisons plants.	What is the "acid" in acid rain?
Acid rain kills animals.	Does acid rain destroy metals and rocks?
Acid rain comes from air pollution.	What does acid rain smell like?
	Does it harm people?
	Is it straight acid when it falls?
	Is there a way to filter or clean acid rain?
	Is all rain acid rain?

Homework Assignment

Tell students that in order to gain a better understanding of acid rain, it's first necessary to learn more about acids and how they affect the world. To prepare for this, you will be asking them to do a homework assignment. Show them the Acids in Your Life homework sheet. Ask them to look around their homes or at a grocery store for labeled items that they think are acids, and to record them on the sheet. Emphasize the safety information on the sheet.

3.2 Student — Assignment: Acids in Your Life

Name:____Date:______________________________

We sometimes think of acids as nasty chemicals that can cause skin burns and holes in our clothes. But not all acids are like that. Acids are everywhere in our lives and some are very useful to us.

Look around your home or at the grocery store to find as many different acids as you can, as determined by the product's label. If the label says the word "acid" anywhere, then the enclosed substance probably contains something acidic. Food items will probably not say whether ingredients are acidic, but don't forget to look through your refrigerator and pantry! **Find at least five items.**

> ***CAUTION:*** *Do not touch any containers or substances that you would NOT normally use at home! If you're not sure about the safety of a substance, such as a strong cleaning liquid or something in a medicine cabinet, ask an adult to help you.*

For each acid you find, fill in the details in the table below.

Name of substance listed on the label	Brand name on the container	Purpose of the substance (e.g., food, cleaning supply, etc.)

[Adapted and modified from *Acid Rain*, one of more than 70 teachers' guides in the Great Explorations in Math and Science (GEMS) series, available from the Lawrence Hall of Science, University of California at Berkeley.]

Assessment Rubric: Acids in Your Life

The Acids in Your Life homework assignment has a value of 15 points. To earn 15 points, students must accurately identify the name of substance, brand name, and purpose of five labeled substances.

	HIGHEST				LOWEST
Score	5	4	3	2	1
Name of substance on label	Student has accurately listed 5 separate items.	Student has accurately listed 4 separate items.	Student has accurately listed 3 separate items.	Student has accurately listed 2 separate items.	Student has accurately listed 1 item.
Brand name on container	Student has accurately listed 5 separate brand names.	Student has accurately listed 4 separate brand names.	Student has accurately listed 3 separate brand names.	Student has accurately listed 2 separate brand names.	Student has accurately listed 1 brand name.
Purpose of substance	Student has accurately listed 5 separate purposes.	Student has accurately listed 4 separate purposes.	Student has accurately listed 3 separate purposes.	Student has accurately listed 2 separate purposes.	Student has accurately listed 1 purpose.

Activity

3.3 The pH Game

top of chapter 3

Overview

Students become familiar with the pH scale and everyday acids and bases by measuring the pH of water samples, soil samples, plants and other natural materials from different places. Students create mixtures of materials in order to collect different pH measurements.

Source

Globe, The pH Game

Standards Addressed

(refer to NH Science Standards)

- S:ESS4:11:3.3
- S:SPS1:11:1.1, 11:2.2, 11:3.1, 11:3.2, 11:3.3
- S:SPS3:11:3.1

Student Outcomes

- Identify the pH of common substances.
- Explain how high or low pH levels may result in dangerous conditions in the environment.
- Give examples of factors that can change the pH of a solution.
- Describe the concept of acid neutralizing capacity and predict the ability of a solution to buffer pH.

Materials and Tools

For each team:

- 20 pH strips
- 3 to 5 small cups
- paper and pencil
- labels to attach results to results board

For the class:

- results board (one line of pH levels from 2 to 9 for each team)
- flip chart with rules
- additional pH strips
- cups of solutions prepared for analysis

Estimated Time to Complete Lesson

Two 40-minute periods

Assessment

- Student Assessment Questions
- Performance Assessment Task and Rubric

Background Needed

- Discussion of lab safety procedures
- Basic knowledge of the pH scale

Using a pH meter

Lesson Planning: The pH Game

The following student handout includes procedural steps for the activity. For assessment purposes, items marked with an arrow indicate places where responses are expected as students perform the activity. Four analytical questions follow the activity description. A performance assessment task with a rubric follows the analytical questions.

Depending on the type of assessment the teacher wishes to assign, students might simply record answers on the student handout to submit to the teacher, or students might write a lab report instead. In this case, the teacher can eliminate photocopying by displaying assessment questions on an overhead or board and students can record responses in lab books.

Click here for a Lab Report Assessment Rubric. Also see Chapter 6.6 for information on assessing lab reports.

3.3 Student Assignment: The pH Game

Name:____Date: ________________________

Please provide responses for questions and tasks marked with an arrow (⟶).

The objective of the game is for each team to identify as many solutions with a different pH value as possible.

⟶ 1. In your lab books or in the space below, draw a horizontal line and label it with the pH scale from 0 to 14, marking pH 7 as the neutral point. Each pH unit should be spaced at least 1 cm apart so that you will have room to write notes below each unit number.

2. Your teacher will divide the class into teams and draw the following matrix on the board:

pH value														
Teams	1	2	3	4	5	6	7	8	9	10	11	12	13	14	TOTAL
Team 1															
Team 2															
etc.															

⟶ 3. Now each team will measure the pH of various solutions, and the goal is to try to find as many different pH values as possible. Each time you measure the pH of a solution, mark and label that solution on the pH scale you drew above. Record all the information about the solution from the labels and any other information that might be important. For pH values with a decimal point like 2.5, you can choose whether to have this count for a pH of 3 or 4. For example, let's say you took the pH of solutions A and B and got the following results:

Solution A (black coffee): pH value = 3.0

Solution B (orange juice): pH value = 2.5

You can choose whether to mark Solution B as pH= 2.0 or pH=3.0, but since you've already found that Solution A has a value of 3.0, you'd probably decide to mark Solution B's value as 2.0 to get more points for your team.

To gain a point for each solution, show your teacher your team's notes and sample. Together with your teacher, measure the pH with a new pH strip. If the pH agrees with your team's measurement, your sample will be approved and the points will be added to your team's score. One point is awarded for each box filled, even if your team finds two samples with the same pH.

Here is an example of results for different teams:

pH value									
Teams	2	3	4	5	6	7	8	9	TOTAL
Team 1	1		1			1	1		4
Team 2		1		1				1	3
Team 3	1				1		1		3

The following are analysis questions:

⟶ 1. Which solution had the lowest pH value and which had the highest? Did either of these surprise you? Explain.

⟶ 2. Compare the pH of the lake or river water with the pH of the tap water. Explain why you think the pH values are different.

⟶ 3. Compare the pH of the lake or river water with the pH of the soil solution. Explain why you think the pH values are different.

⟶ 4. Why do you think were there no solutions with a pH value of 1 or a pH value of 14?

Performance Assessment Task

Students create/draw a horizontal pH scale line from 0 to 14 from memory, marking pH 7 as the neutral point, and writing in numbers from 1 to 14 in the appropriate order. Then list at least five substances with different pH values, writing the name of each substance under the appropriate pH on the scale. The substances should be items that were tested by teams or discussed in class — items with which everyone is familiar.

Rubric

Use rubric below to score students' completion of task.

Note: A score of 4 is exemplary and a score of 1 is inadequate, indicating either high or low mastery of the content and skills.

	HIGHEST			LOWEST
Score	**4**	**3**	**2**	**1**
Criteria	Student creates a pH chart as directed and lists five substances in the appropriate pH range with no mistakes.	Student creates a pH chart as directed and lists five substances in the appropriate pH range with less than one mistake.	Student creates a pH chart as directed and lists at least two or three substances in the appropriate pH range, with at least two being accurate.	Student fails to follow directions to complete a pH chart as requested.

Activity

3.4 Model a Catchment Basin

top of chapter 3

Overview

Students construct a three-dimensional model of a catchment basin and use it to investigate watersheds and water pathways in a landscape, a scientific study known as **hydrology.** They experiment with the model to explore how catchment basins can change due to the earth's destructive and constructive forces as well as a result of human activities.

Source

Globe, Model a Catchment Basin

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:2.1, 11:7.1
- S:LS2:11:1.5, 11:2.2
- LS3:11:1.1
- S:SPS1:11:1.1, 11:2.2, 11:3.1, 11:5.1, 11:5.2
- S:SPS3:11:3.1

Student Outcomes

- Define the concept of a catchment basin and a watershed.
- Provide examples of how their model relates to the real world.
- Provide examples of basic concepts of catchment basins and watersheds; for example, water runs downhill, hills make divides, low-lying areas create pooling, water quality is affected by what is upstream, etc.

Materials and Tools

- miscellaneous objects that may be used to create the model infrastructure
- outdoor models may use sand, wood, rocks, etc.
- indoor models may use classroom items such as buckets, bowls, rolls of paper towels, etc.
- plastic sheet (2 x 2 meters)
- spray bottle with water
- sponges
- blue food coloring (or other color you choose)
- permanent marker that will write on plastic or black electrical tape
- ruler
- topographic map

Estimated Time to Complete Lesson

Two 40-minute periods

Assessment

- Assessment Questions
- Performance Assessment Task and Rubric

Background Needed

None

The following student handout includes procedural steps for the activity. For assessment purposes, the items marked with arrows indicate places where responses are expected as students perform the activity. A performance assessment task with rubric follows the analytical questions.

Depending on the type of assessment the teacher wishes to assign, students might simply record answers on the student handout to submit to the teacher, or students might write a lab report instead. In this case, the teacher can eliminate photocopying by displaying assessment questions on an overhead or board and students can record responses in their lab books. Click here for a Lab Report Assessment Rubric. Also see Chapter 6.6 for information on assessing lab reports.

See additional description and photos on page 37.

3.4 Student Assignment: Model a Catchment Basin

Name:____Date: _______________________________

Provide responses for questions marked with an arrow (⟶).

How to Make the Model

1. Find an area about 1 meter square to build a catchment basin model. This could be a tabletop or plywood sheet if you are working inside or a grassy or sandy area outside.

2. Gather the various objects to make the model, such as a plastic sheet, rocks, buckets, sponges, spray bottles with water, and food coloring.

3. Arrange objects of various sizes inside the area. The tallest objects will represent mountains. Shorter objects or buckets or bowls may represent hills, lakes, or plains.

4. Cover the entire area and all of the objects with a sheet of plastic. Use your hands to mold the plastic loosely around the covered objects. This is now a model of a landscape with hills, valleys, and connections between them.

5. Add food coloring to water in spray bottle.

Adding Rain to Model

⟶ 5. Predict what will happen if it 'rains' on your model. Where will the water go? Will it move faster in some places? Will some places form pools? How do you know?

6. Use the spray bottle to make it rain on the top of your highest mountain. Continue spraying water until you can see where streams, rivers, and lakes form.

7. Choose a small pool on your model to be your ***hydrology site***. Mark the site with a marker, stone, or other object.

⟶ 8. Make it rain by using the spray bottle and then answer the following questions:

(a) Where does the water come from that flows to your hydrology site?

(b) Where does water flow away from your site?

(c) What features on the landscape determine what will be part of your basin?

(d) What determines the watershed?

The places where water (precipitation) lands and flows in your hydrology site is considered the **catchment basin** for your site, and the **watershed is the basin boundary** — the high elevation areas surrounding and defining your site.

⟶ 9. (a) Where would be a good place to locate our school on your model?

(b) Where would you like your house to be located?

Mark these places on the model.

⟶ 10. Explore the consequences of changes in the catchment basin:

(a) What happens if you dam the stream that flows to your water site? (Use a sponge to create a dam.)

(b) What happens if you plant a forest above your site? (Use a large flat sponge for the forest – it will soak up water for a time just like soil and vegetation.) What happens if you remove the forest?

(c) What happens if someone builds an industry that causes pollution? (Place a small piece of sponge soaked in food coloring where your industry will be located and watch the 'pollution plume' as it rains.)

(d) What happens if someone decides to draw water from your stream for irrigation or urban use? (Make 'canals' that take the water away from your stream to other places.)

After you have completed your model, think about your hydrology site if you made the following changes on the landscape:

⟶ 11. What would happen if you poured a pile of salt on the mountain above your site?

⟶ 12. What would happen if you poured the pile on the other side of the mountain?

⟶ 13. Use a marker to outline the watershed boundary for your hydrology site.

⟶ 14. List three things that might affect the water quality (flow, temperature, sedimentation, etc.) at your site and describe the effect that each might have on water quality.

Model a Catchment Basin

This hydrology experiment allows students to investigate watersheds and water pathways in a landscape.

all Photos: mary ann mcGarry

These are the materials that the students used to "create topography" in making their catchment basin (watershed). Students placed items such as rocks, funnels and bottles inside the lid of a cardboard box and then covered everything with plastic. This plastic represents the soil surface in a catchment basin (watershed).

Here you can see the students' watershed in the cardboard box lid. Notice the spray bottle that is filled with water. The water has been colored with food coloring to make it easier to see the flow paths that the water creates as it moves downhill. To represent rain falling in the watershed, students sprayed the colored water on the plastic and observed where it went.

Students were asked to observe where "streams" and "rivers' formed/started, and to notice where ponds/lakes formed.

This plastic dish contains 3 types of colored sponges: The green sponges represent trees, the orange represent industry that is leaking pollution, and the blue sponges either represent the students' school, house, a dam. Notice that the orange sponges have been dipped in food coloring or ink…you will see what happens in the following pictures.

See how the water leaving the industry is carrying the pollution into the watershed. This example could be used for other things that aren't are obviously "bad," such as wastewater treatment plants — they discharge their clean water into the rivers, but often the water coming from the wastewater treatment plant isn't exactly the same in quality or temperature compared to river water.

Notice the green "trees" sponge has soaked up some of the water. This truly represents what trees do: they soak up water. This shows students the value of trees in retaining water in an ecosystem; without trees, steep slopes would erode away. Making students aware that trees draw water up from the soil is important also because it helps students realize that trees need clean water, too!

Some students put their blue sponge (school or house, or dam) in the middle of a river! The teacher asked them to place the sponges BEFORE they started spraying their "rain." If the blue sponge is a dam, then they put it in a good site. But if the blue sponges was a building… bad choice!

The black "X" drawn on the plastic represents the students' "hydrology site." The teacher asked questions, like "Where did the water at your hydrology site come from?" The teacher also asked students to notice "ridgelines," as these create mini-watersheds. This activity shows that although it is easy to understand how pollution affects things downstream, it is not easy to picture what a watershed is, and how something that seems far away really might be in the same watershed. For example: if a large area of trees are cut right beside a river, high up in a watershed, a lot of erosion will happen. What if there is a reservoir farther down, even on the other side of a small ridge, in that same watershed? The reservoir would feel the effects — be filled with silt, etc., from the erosion of the steep hillside.

Performance Assessment Task

Provide a topographic map that depicts a catchment basin. Ask students to indicate the following using different colored pencils

(a) The boundary of the catchment basin (RED pencil)

(b) Drainage from the watershed divide into the catchment basin using arrows (BLUE pencil)

(c) The steepest slope using a thick arrow (YELLOW pencil)

Students then create a legend on the map explaining/defining the colors and their meanings. (The legend can be created on a separate white sheet and taped or pasted to the map.)

Lastly, instruct students to write a short paragraph explaining a catchment basin and how and why the term is used by scientists. Students may elect to do additional research to write a clear paragraph.

Rubric

Complete the task described above using the rubric below for guidance.

Note: A score of 4 is exemplary and a score of 1 is inadequate, indicating either high or low mastery of the content and skills.

	HIGHEST			LOWEST
Score	**4**	**3**	**2**	**1**
Criteria	The student completes all of the required tasks as indicated for a score of "3" and also includes additional useful features or information on the map and legend, and/or writes a stellar description of a catchment basin with no grammatical mistakes and which shows extra insight into understanding the usefulness of this concept to scientists.	The student completes all of the requested tasks following the guidelines provided: adding appropriate color-coded symbols with a matching legend explaining the symbols, and writing a concise and accurate description of a catchment basin mentioning the most important features and purposes.	The student completes some, but not all, of the assigned tasks: a) adding color-coded symbols to the map as described, b) adding a matching legend, and c) writing a description of a catchment basin. Students must attempt at least two of the three tasks above indicating he/she understands the directions.	Student does not follow directions, and does not complete all the information requested using appropriate color-coded pencils. Student does not create a legible, complete legend. Student does not write a paragraph describing a catchment basin.

Activity

3.5 Just Passing Through

top of chapter 3

Overview

Students time the flow of water through soils with different properties and measure the amount of water held in these soils. They also experiment with filtering and buffering abilities of soils by observing changes to clarity of water and characteristics of soil and testing the pH of water before and after it passes through soil.

Source

Globe, *Just Passing Through*

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:PS2:11:2.3
- S:SPS1:11:1.1, 11:2.2, 11:3.1, 11:3.2, 11:3.3, 11:4.1, 11:5.1, 11:5.2
- S:SPS3:11:3.1

Student Outcomes

- Identify the physical and chemical changes that occur as water passes through soil.
- Design experiments that test soil and water properties.

Materials and Tools

Note: Review the Materials and Tools section of the Globe *Just Passing Through* activity for important details.

For each team of three to four students:

- two or three clear 2L bottles (prepared as described in set-up instructions below.*)
- four to six (maybe more) 500ml beakers or similar size clear containers
- soil samples
- fine window screen or other fine mesh that does not absorb or react with water (mesh size 1mm or less)
- strong tape
- scissors
- water
- laboratory ring stands with rings, if available
- pH paper, pen, or meter

*** How to construct funnels using clear 2L plastic bottle:**

- Remove the labels and lids and cut off the bottoms of the clear plastic 2L bottles. The pour spout or top will fit into a 500 mL beaker or other clear container and serve as a funnel.
- Discard the bottoms; or, bottoms can be used in place of beakers, though students will have to mark gradations by pouring in known volumes of water and marking water levels at various gradations.
- Cut a circle of a fine mesh window screen, nylon net or panty hose about 3 cm larger than the opening made in the top of the bottle. Using strong tape or rubber bands, secure the mesh circle around the end of the bottle top.
- Pour 3-4 cm of sand onto the screen. The sand will keep the screen from becoming clogged.
- Place the bottle, mesh side down, on a beaker (or plastic bottle bottom), or set it in a ring stand and place a catchment beaker underneath.

Estimated Time to Complete Lesson

One 40-minute period.
Two-three 40-minute periods for *Further Investigations*

Assessment

- Student Assessment Questions
- Performance Assessment Task and Rubric

Background Needed

None

Photo: Jenna Guarino

Comparing the flow of water through different soil types

3.5 Teacher Lesson Planning: Just Passing Through

There are two distinct parts to this activity: the first is completed as a whole class with teacher demonstration, and the second part is completed by students working in groups. The following student handout includes procedural steps for the activity. For assessment purposes, the items marked with an arrow indicate places where students are expected to note responses as they perform the activity. A performance assessment task with rubric follows the analytical questions.

Depending on the type of assessment the teacher wishes to assign, students might simply record answers on the student handout to submit to the teacher, or students might write a lab report instead. In this case, the teacher can eliminate photocopying by displaying assessment questions on an overhead or board and students can record responses in their lab books. Click here for a Lab Report Assessment Rubric. Also see Chapter 6.6 for information on assessing lab reports.

3.5 Student Assignment: Just Passing Through

Name:____Date: ______________________________

Provide responses for questions marked with an arrow (⟶).

Part I: Class Investigation with Teacher Demonstration

⟶ 1. Observe the properties of the soil samples that will be used. Record your observations. Record where each sample was found and the depth at which it was found. If you have done the Globe *Soil Characterization Protocol*, you can also record the moisture status, structure, color, consistence, texture, and presence of rocks, roots and carbonates.

2. As a class, choose one soil (a sandy loam works best) to use as a demonstration and place 1.2L of the soil in one of the 2L bottle set-ups you have constructed.

⟶ 3. Pour 300ml of water into a 500ml beaker or other clear container. A small plastic bottle labeled with ml or cm measurements works well and does not spill easily. Measure the pH of the water and note it here. Also describe the clarity of the water.

⟶ 4. What will happen when water is poured onto this soil? On your own, explain why you think the soil will react this way when water is poured onto it. Consider:

- How much water will flow out the bottom of the container?
- How fast will the water pass through the soil?
- Will the pH of the water change? If so, how?
- What will the water look like when it comes out the bottom (i.e. color, clarity)?

⟶ 5. As a class, share your hypotheses. Record them here:

- How much water will flow out the bottom of the container?
- How fast will the water pass through the soil?
- Will the pH of the water change? If so, how?
- What will the water look like when it comes out the bottom (i.e. color, clarity)?

→ 6. One person is to pour the water onto the soil and begin timing. Describe what is happening as the water is poured.

- Is all the water staying on top?
- Where is the water going?
- Do you see air bubbles at the top of the water?
- Does the water coming out of the soil look the same as it did going in?
- What is happening to the soil structure, especially at the soil surface?

→ 7. Record how long it takes for the water to pass through the soil.

→ 8. Describe how the water and soil interacted in one sentence.

- Record any other observations you may have.

→ 9. Once the water has stopped dripping from the bottom of the bottle, measure the amount of water that moved out of the soil into the beaker.

- How much water came out of the soil compared with what went in?
- What happened to the water that is missing?

→ 10. Notice the clarity of the water. Is it more or less clear than before it passed through the soil?

→ 11. Test the pH of the water that has flowed through the soil, record the results, and compare the results with the pH of the water that was poured into the soil. Compare with the student hypotheses.

- Did the pH change?
- If so, what might have caused this change?

⟶ 12. What do you think will happen if you pour another 300ml of water into the bottle of saturated soil?

- How much water will stay in the soil?

- How fast will it move through?

- Will the pH change?

- How clear will the water be after it flows through the soil?

13. Perform a saturation test by pouring the water back through the soil. Observe the results and compare with the hypotheses you listed above.

Part II: Group Investigation

1. Look at the display of the various soil samples that all of the students brought in. Each bag of soil should be labeled with a letter to aid in clarity of student responses.

⟶ 2. Which soils might be different and how?

⟶ 3. Do you think water would pass through all of the types of soils in the same amount of time?

⟶ 4. Do you think all the soils would hold the same amount of water?

⟶ 5. Each group of students is to select one of the various soil samples.

⟶ 6. Each group is to repeat steps 1-13 from Part I on their selected soil sample and record the experiment here or in their lab notebooks.

7. Each group is to report the results of their experiment to the class. Reports should include questions, hypotheses, and observations regarding the following variables, as well as their conclusions about the variables and how they affected the results of their experiment:

- soil characteristics
- original water pH and clarity
- amount of time for the water to pass through the soil
- the amount of water which passed through the soil
- changes in water pH and clarity
- results of the saturation test.

8. Review all results as a class. As a class, determine the soil characteristics, such as different particle size, space between the particles, organic material which may hold water, etc., that are associated with:

- the fastest infiltration;
- the slowest infiltration;
- retention of water in the soil;
- changes in pH; and
- changes in clarity.

⟶ 9. Based on a comparison of your hypotheses with the experimental results, record conclusions about how the water and soil interact and how different soils behave differently.

⟶ 10. Think about how what you have learned from this experiment may be used in real life circumstances. How does it help us to understand what might occur in our local watershed?
Explore the following questions:

- What might happen if the soil in an area is tightly compacted and there is an extended heavy rain?

- How does soil with vegetation on it vary from bare soil?

- Does the atmosphere influence soil characteristics?

- How does soil influence infiltration rates and groundwater?

Performance Assessment Task

Provide individual soil samples along with a description of where the samples were collected. Ask students to make observations and describe an experiment/process to assess physical and chemical properties of the soil sample as water interacts with it. Responses should be based on group experiments conducted in the *Just Passing Through* exercise.

Rubric

The rubric below is intended to help teachers assess student's work.

	HIGHEST			LOWEST
Score	**4**	**3**	**2**	**1**
Criteria	Student describes a hypothetical scientific experiment aligned with the scientific method as described for a score of 3. For a score of 4, student provides additional scientific content relating to soil moisture, demonstrating higher order thinking skills such as drawing conclusions from experimental observations and justifying conclusions with evidence. Exemplary answers might incorporate information about the location of the soil sample site.	Student describes a hypothetical scientific experiment aligned with the scientific method to describe physical and chemical properties of the physical soil sample in front of them. The written report includes the following sections/headings: Introduction, Research question/s, Methods, Results, and Conclusions. Some of the information provided must be based on observations of the soil sample.	Student describes a hypothetical scientific experiment analyzing the physical and chemical properties of the soil sample in front of them, aligned with the scientific method as described in the Score of 3 column to the left. Responses for *all* of the sections/headings are not complete, but are adequate for at least three of the headings.	Student does not follow the directions to describe a scientific experiment to analyze the soil sample in front of the student. Student does not provide enough information for a reader to have clarity about the procedural steps involved, or the reason for following certain procedural steps in analyzing a soil sample.

Note: A score of 4 is exemplary and a score of 1 is inadequate, indicating either high or low mastery of the content and skills.

Activity

3.6 Buffering Experiments

top of chapter 3

Overview

Students explore the ways in which the **buffering capacity** (sometimes called **alkalinity** or **acid neutralizing capacity**) in an ecosystem can protect soils and freshwater systems from changes in pH that can stress organisms. Students design and carry out experiments.

Sources

Adapted from materials developed by Cornell University's Environmental Inquiry Program, funded by the National Science Foundation. The original exercise was written by Nancy Trautmann (Cornell University) under NSF Award #9454428.

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:ESS4:11:3.3
- S:LS2:11:1.5, 11:2.2
- S:LS3:11:1.1, 11:1.2
- S:LS4:11:2.6
- S:PS2:11:2.3
- S:SPS1:11:1.1, 11:2.2, 11:3.1, 11:3.2, 11:3.3, 11:4.1, 11:5.1, 11:5.2
- S:SPS3:11:3.1

Student Outcomes

- Define and discuss the terms alkalinity, acid neutralizing capacity, and buffering capacity.
- Explain how and why different soils have different buffering capacities and give geographic examples of where such soils are found.
- Explain the connection between the buffering (neutralization) process and loss of **base cations** from soil.
- List the benefits that well-buffered soil provides to associated freshwater systems.

Materials and Tools

- one-way valve
- drinking straw
- Nalgene or other heat proof, sealable bottle
- distilled water
- buffered solution (2.5g baking soda to 1L distilled water)
- acid rain solution (2ml 1M H_2SO_4 to 1L distilled water)
- pH meter, test kits, or pH paper
- Bromothymol Blue or Universal Indicator Solution
- beakers or clear plastic cups
- 250ml graduated cylinders
- 10ml pipette
- assorted soil samples
- coffee filters
- rubber bands
- safety goggles
- gloves
- *Optional:* alkalinity test kit.

Estimated Time to Complete Lesson

Two to three 40-minute periods, depending on level of involvement of students

Assessment

- Buffering Demo Student Handout
- Buffering Experiment
- Short Answer Questions (and answers)
- Authentic Assessment Questions (and answers)
- Lab Report Rubric

Background Needed

- Discussion of lab safety procedures.
- Understanding of the pH scale and how acids and bases work.
- It is recommended that the teacher becomes familiar with background information on the following pages. A diagram is included that explains the connection between the buffering (neutralization) process and loss of base cations from soil.

Notes: More background and resources can be found on Cornell University's Environmental Inquiry (EI) Web site, including teachers' experiences using EI as well as assessment tools. Many thanks to Scott Bailey (U.S. Forest Service), Elissa Levine (NASA/Goddard Space Flight Center), Kim Postek Driscoll (Syracuse University), Nancy Trautmann (Cornell University), Kristi Judd (Eastern Michigan University), and Ina Ahern (Plymouth Regional High School) for their assistance developing this activity.

The goal of the following two experiments is for students to learn about **buffering capacity** as well as the ability of some soils to alter the pH of water as it passes through them.

The first experiment can be performed as a demonstration. In it, a weak sulfuric acid solution is added to two beakers—one contains distilled water and a **pH indicator** and the other contains baking soda (sodium bicarbonate) dissolved in distilled water and the same pH indicator. Students count the number of drops of acidic solution needed to cause a color change in each beaker and learn that it takes more acidic solution to cause a color change in the buffered solution than in the distilled water.

Photo: Mary Ann McGarry

The second experiment is inquiry-based. Students are given a list of questions and choose one (or one of their own) around which to design an experiment. The questions serve as a context for students to think about the buffering capacities of different types of soils. The following will provide some background.

Precipitation Is Naturally Slightly Acidic

Even rain that falls in a remote area, far from pollution sources, does not have a pH of 7.0. Because rain is in constant contact with carbon dioxide, it becomes slightly acidic as carbon dioxide combines with water to form carbonic acid (H_2CO_3). Normally, the pH of rainwater, regulated only by carbon dioxide gas in the air, would be 5.6, or only slightly acidic. Acid precipitation is defined as having a pH value of 5.2 or lower. In the Northeast, the average pH of rainfall is 4.0-4.5 and rainfall during individual storms as low as 3.0 is not unusual.

Optimal pH Range for Aquatic Organisms

The pH of a lake or a stream is important to the flora and fauna living in that water body, as an organism's enzymatic reactions can only happen within certain pH ranges. The optimal pH range for most organisms is 6.5 to 8.2. A pH below 5.0 is lethal to many fish species because heavy metals, such as aluminum, come into solution. Free (monomeric) aluminum clogs the gill tissues of fish, which inhibits their ability to acquire oxygen from water.

Optimal pH Range for Soil Organisms

The pH of soil, or more precisely the pH of the soil solution, is very important because soil solution carries in it nutrients such as nitrogen (N), potassium (K), and phosphorus (P) that plants need in specific amounts to grow, thrive, and fight off diseases. If the pH of the soil solution is increased above 5.5, nitrogen (in the form of nitrate) is made available to plants. Phosphorus, on the other hand, is available to plants when soil pH is between 6.0 and 7.0. If the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. In acidic soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity (poisoning).

Measuring Buffering Capacity

There are two measures of buffering capacity, or the ability to neutralize strong acids: **alkalinity** and **acid neutralizing capacity** (ANC).

Alkalinity is determined by the sum of bases in a solution. In natural waters, alkalinity largely depends on the presence of bases like bicarbonate, carbonate, and hydroxide **ions**:

$$1.\ [Alk] = [HCO_3^-] + 2\,[CO_3^{2-}] + [OH^-] - [H^+]$$

Alkalinity = (bicarbonate ions + carbonate ions + hydroxide ions) - hydrogen ions

As you can see, the buffering capacity will increase when there are more bicarbonate, carbonate, and hydroxide ions in solution, and the buffering capacity will decrease as hydrogen ions are added.

Alkalinity is often measured by **titration** with a strong acid and is expressed in milli-equivalents per liter.

> **Note 1:** Alkalinity can be a confusing term: although water that is alkaline is basic (has a pH greater than 7.0), alkalinity is a measure of buffering capacity, not pH.
>
> **Note 2:** Technically, alkalinity should also take into account borate and silicate, but this is only important in oceans and some salt lakes.

Like alkalinity, acid neutralizing capacity (ANC) is also the sum of bases and acids in solution, but ANC includes organic acids as well as the bicarbonate buffering system. While the definitions of ANC and alkalinity are slightly different, in practice they are often measured in the same way: as the sum of carbonate ions (see equation above).

There are many slightly different definitions of alkalinity and ANC; this makes it difficult to keep it simple. The main difference is that ANC is the balance of ALL **cations** and **anions** (including organic acids), while alkalinity is the balance of carbonates, H+, and borate and silicate (the last two are unimportant in most freshwater systems). In practice, both are often measured as the sum of the carbonate buffering system (equation #1 above).

The Buffering System in a Natural Body of Water

Because much of the water that enters streams and lakes travels through soils, the chemical reactions that occur in soils can have a large influence on aquatic ecosystems. The carbonate equilibrium reactions play a large role in determining soil buffering capacity:

$$2.\ [CO_2] + [H_2O] \leftrightarrow [H_2CO_3] \leftrightarrow [HCO_3^-] + [H^+] \leftrightarrow [CO_3^{2-}] + 2[H^+]$$

Carbon dioxide + water ↔ carbonic acid ↔ bicarbonate ion+ hydrogen ion ↔ carbonate ion + hydrogen ions

Where do these carbonate ions come from? Microbial respiration and decomposition of organic matter release carbon dioxide into the soil. In soil solution, carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) are in **flux** and are important in the neutralization of acids. Another source is the weathering of carbonate minerals in mineral soils and bedrock (see next page).

When a strong acid such as sulfuric acid is added to water, it dissociates into hydrogen and sulfate ions.

$$3.\ [H_2SO_4] \rightarrow [2H^+] + [SO_4^{2-}]$$

sulfuric acid → hydrogen ions + sulfate ion

Bicarbonate and carbonate ions bind with the hydrogen ions, taking them out of solution, thereby reducing acidity.

$$4.\ [HCO_3^-] + [H^+] \rightarrow [CO_2] + [H_2O]$$

bicarbonate ion + hydrogen ion → carbon dioxide + water

Note that each bicarbonate ion neutralizes one H+, or that 2 moles of bicarbonate ions are needed for each mole of H_2SO_4.

$$5.\ [CO_3^{2-}] + 2[H^+] \rightarrow [CO_2] + [H_2O]$$
carbonate ion + hydrogen ions → carbon dioxide + water

Note that each carbonate ion neutralizes 2 H^+ ions, or that 1 mole of carbonate anions is needed to neutralize each mol of H_2SO_4.

How Can Soil Change the pH of Water Passing Through It?

As water seeps through the ground it comes into contact with many different minerals. The minerals dissolve into the water and produce a buffered system in our ground waters. For example, limestone rock contains calcium carbonate ($CaCO_3$). The weathering of calcium carbonate from limestone supplies the bicarbonate ion (HCO_3^-) according to the reaction:

$$6.\ [CaCO_3] + [CO_2] + [H_2O] \rightarrow [Ca^{2+}] + 2\ [HCO_3^-]$$
calcium carbonate + carbon dioxide + water → calcium ion + bicarbonate ions

The bicarbonate ion then acts as a base to neutralize acids:

$$7.\ [HCO_3^-] + [H^+] \rightarrow [CO_2] + [H_2O]$$
bicarbonate ion + hydrogen ion → carbon dioxide + water

A buffered system will resist quick and dramatic changes to the pH of a solution, and a healthy buffered water system will absorb changes to its acidity or alkalinity. In areas such as New England, however, lakes are surrounded by granite rather than limestone. These lakes do not have the same acid neutralizing capacity and are more susceptible to changes in pH.

Factors That Affect the pH of Soil and the pH of Water Seeping Through Soil

Mineral weathering. As in the example above, the weathering of minerals can increase the amount of bicarbonate in the soil, which serves to take hydrogen ions out of solution. However, mineral weathering also supplies the soil with base cations, which are integral to the **cation exchange capacity (CEC**) of the soil (see below). Depending on the minerals present and weathering rates, mineral weathering can provide soil with long-term resistance to the effects of acidification.

Cation exchange capacity **and leaching of base cations from soil.** Because the minerals that compose clay usually give clay particles a negative charge, positively charged ions (cations) in the soil are attracted to clay particles. Picture a particle of clay that has base cations such as **calcium** (Ca^{2+}), magnesium (M^{2+}), sodium (Na^+) and potassium (K^+) attracted to it (see diagram on following page). Each place on the particle that contains one of these base cations is called an exchange site; one particle of clay has many exchange sites. Normally base cations have a stronger attraction to clay particles than do hydrogen ions. However, when sulfuric acid dissociates into hydrogen ions and sulfate anions, soils are overwhelmed with hydrogen ions, and these "knock" the base cations off of clay particles. Because the hydrogen ions are taken out of solution, the acidity of the water passing through the soil is neutralized. However, the base cations necessary for plant growth become bound to the sulfate anions and are leached from the soil.

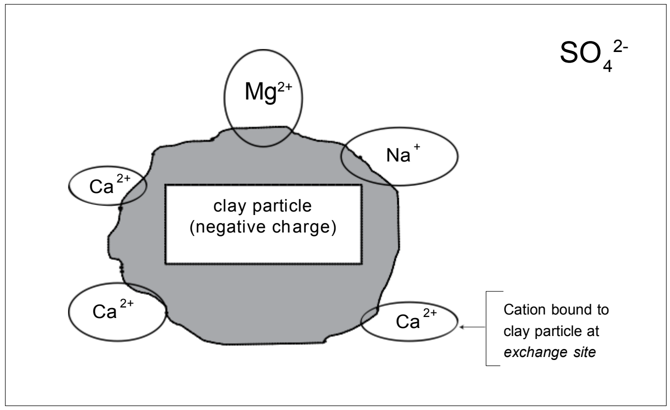
The buffering capacity, also known as cation exchange capacity (CEC), of soil is the capacity for cation exchange between the soil and soil solution. The higher the amount of exchangeable base cations, the more the acidity of the water passing through the soils can be neutralized. Sites with a high CEC take longer to acidify (and longer to recover from acidification) than sites with low CEC.

The Leaching of Base Cations from Soil

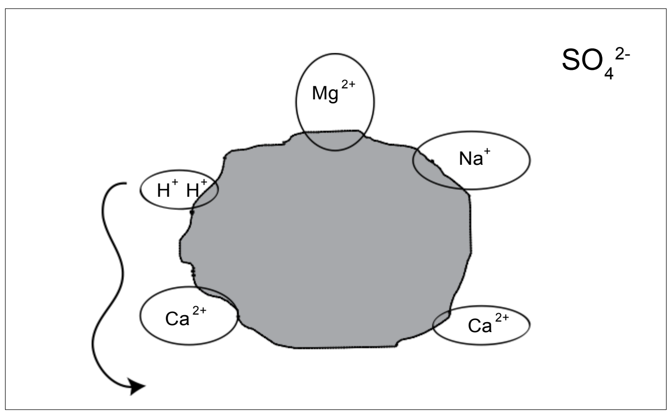
Sulfuric acid dissociates into two hydrogen ions and a sulfate anion in the soil solution:

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

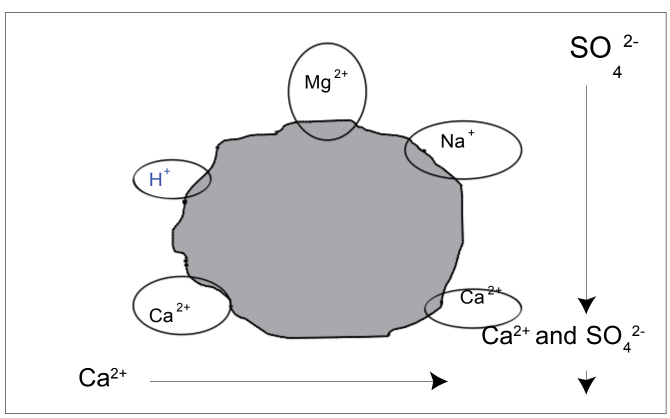
Note: Ovals enclosing cations on exchange sites do not represent ionic radii of ions.



When hydrogen ions are taken out of the soil solution during the neutralization process, base cations are knocked off of soil exchange sites.



Because sulfate is a strong anion it may attract the calcium cation. If so, the two ions exit the soil together and pass into streamwater, depleting the soil of calcium.



3.6 Teacher and Student Buffering Demonstrations

What is a buffer? What happens to the pH of a buffered solution when acid rain or base is added and how does this compare to an unbuffered solution?

Prepare in Advance

Boil 1L distilled water for 15 minutes to remove carbon dioxide from water. You will only use 500ml of this water but some will boil away. (Carbon dioxide in the atmosphere naturally enters into solution in water to form carbonic acid, which is why the pH of even distilled water is not a neutral 7. (See section Precipitation Is Naturally Slightly Acidic.)

1. Pour 250ml of this boiled water into a Nalgene (or other heat proof, sealable) bottle labeled "boiled water," cap immediately, and allow to cool to room temperature.

2. Pour remaining 250ml of the boiled water into another Nalgene (or other heat proof, sealable) bottle labeled "buffered solution," add .75g baking soda, cap immediately, and allow to cool to room temperature.

Introduction

Introduce experiment by discussing the following with students. (The teacher might wish to have students write their answers down on the student handout or in their lab books.)

- What is acid rain?
- Why do you think acid rain is more harmful to some areas than others?
- Define the terms **buffer** and **buffering capacity**.
- Define the term pH indicator. What is the name of the pH indicator solution that will be used for the demonstrations? (See the first step in Procedure section below.)

Procedure

Discuss pH indicators with your students to make sure they understand why indicator solutions are used, and what it means when a solution containing an indicator turns color. You can quickly demonstrate this by blowing through a straw that's been fitted with a one-way valve into a beaker of water to which Bromothymol Blue has been added; be sure to wear goggles and cover the opening of the beaker with your hands while doing so. As you blow into the straw and add carbon dioxide to the water, the concentration of carbonic acid in the water will increase. This will be reflected in the color change from bluish to yellow.

Bromothymol Blue indicator in acidic (yellow = pH 6.0), neutral (green = pH 7.0), and basic (blue = pH 7.6) conditions. Photo credit: http://en.wikipedia.org/wiki/Bromothymol_blue

Pour 25ml boiled, distilled water into one beaker labeled "distilled" and 25ml buffered solution into another beaker labeled "buffered."

1. Add 5 drops of either Bromothymol Blue or Universal Indicator Solution to each beaker. Note the color differences between the two solutions. The distilled water is slightly acidic because of dissolved carbon dioxide; the baking soda is slightly basic.

- If using Bromothymol Blue, students will look for the color to change to green (indicating a neutral pH of 7.0).
- If using Universal Indicator Solution, students will look for the color to change to pink.

2. Using a pipette, carefully add the acid rain solution drop by drop to the beaker containing distilled water, swirling after each addition until the color stabilizes. How much do you need to add to make the solution turns a stable green/pink and stay that way, indicating that it is acidic?
3. Now carefully add the acid rain solution to the beaker containing the buffered solution. Add a few ml at a time, swirling and observing the color changes. How much do you need to add to make the solution turn a stable green/pink?
4. *Optional:* Measure the alkalinities of the distilled water and the buffered solution, then relate these measurements to the amounts of acid needed to cause a pH change in the two solutions.

3.6 Student Assignment: Buffering Demonstrations

Name:____Date: __________________________

We'll explore the following in this lesson: What is a buffer? What happens to the pH of a buffered solution when acid or base is added, and how does this compare to an unbuffered solution?

Please answer the questions marked with an arrow (⟶).

Introduction

⟶ What is acid rain?

⟶ Why is acid rain more harmful to some areas than others?

⟶ Define the terms buffer and **buffering capacity**.

⟶ Define the term **pH indicator**. What is the name of the pH indicator solution your teacher will use for the demonstrations? What color will you be looking for?

Procedure

Your teacher will:

1. Demonstrate the color change that happens in a container of water containing Bromothymol Blue when she/he increases the carbonic acid within it by blowing carbon dioxide into the water.

2. Pour 25ml of boiled, distilled water into one beaker labeled "distilled" and 25ml of a buffered solution into another beaker labeled "buffered".

3. Add five drops of Bromothymol Blue or Universal Indicator Solution to each beaker. (Note the color differences between the two solutions. The distilled water is slightly acidic because of dissolved carbon dioxide; the baking soda is slightly basic.)

⟶ 4. Add the Acid Rain Solution, drop by drop, to the beaker containing distilled water, swirling after each addition until the color stabilizes. How much is needed to make the solution turn and remain green/pink, indicating that it is acidic?

⟶ 5. Add the Acid Rain Solution to the beaker containing the buffered solution. Add a few milliliters at a time, swirling and observing the color changes. How much is needed to make the solution turn a stable green/pink?

⟶ 6. *Optional*: Using an alkalinity kit, measure the alkalinities of the distilled water and the buffered solution. Relate these measurements to the amounts of acid needed to cause a pH change in the two solutions.

Discussion

What happens to the pH of a buffered solution when acid or base is added, and how does this compare to an unbuffered solution?

The pH of rainwater falling across New England is about the same across the region, but the soils, lakes, and streams in some parts of New England are more adversely affected than others. Why is this? Please address the following in your answer: define buffering capacity, discuss which areas are more "acid sensitive" (adversely affected) than others, and explain the benefits that a well-buffered soil can provide to surrounding lakes and streams.

3.6 Teacher and Student Buffering Experiment

Purpose

To select a research question to serve as a context in which to investigate concepts such as buffers, buffering capacity, alkalinity, and acid neutralizing capacity. Students will work in groups to design an experiment or set of experiments that address one or more of these questions:

- Does soil change the pH of water that drains through it?
- Can soil reduce the acidity of water draining into a lake?
- Do some soil types buffer drainage water better than other soil types?
- Can the buffering capacity of soils be depleted?
- Does the buffering capacity of a soil relate to the alkalinity of the water that has drained through it?
- What components of soil provide its buffering capacity?

Materials

Use the same materials as for "Buffering Demonstration" (page 49) plus assorted soil samples, coffee filters, and rubber bands.

Procedure

1. With your lab group, choose a research question from the list above or think of one of your own. Be sure that it is something around which you can design an experiment to test.

2. Prepare for your experiment by writing up the *research question, prediction (hypothesis) statement, materials,* and *procedures* section for your lab report. Have your teacher approve this before beginning your experiment.

3. Perform the experiment.

4. Record your results by summarizing the data in a table, identifying trends, and discussing possible sources of error.

5. Provide the conclusions to your experiment, and address the following in your narrative:

- Compare actual results to the predicted results.
- Discuss the meaning of the results in terms of the original research question.
- Make conclusions that are well supported by your data.
- Identify improvements that could be made in your experiment's design.
- Suggest new directions for future research.

3.6 Student Assignment: Acid Rain Buffering Experiments

Name:____Date: __________________________

Short Answer Questions (Circle one)

1. Which of these two lakes is more likely to experience large drops in pH due to acid precipitation? Why?

	Mirror Lake	Loon Lake
pH	7.5	6.0
temperature	6°C	4°C
alkalinity	50 ppm	200 ppm
dissolved oxygen	13 ppm	7 ppm

2. If you steadily add acid to a well-buffered solution, you would expect the pH to do the following:

(a) Increase immediately

(b) Initially remain constant, then begin dropping

(c) Decrease gradually but steadily

(d) Stay constant for a while, then begin rising

3. Universal Indicator Solution is used to indicate the pH of liquids: it turns red in acidic solutions, green in neutral solutions, and purple in basic solutions. When Universal Indicator Solution is added to a sample of water from Mystery Lake, the water turns green. Adding some weak acid turns the solution red, but after mixing it returns to green. The most likely reason:

(a) Mixing increases dissolved oxygen and therefore affects the pH.

(b) Buffers in the water neutralize the acid.

(c) The acid dissolves organic matter in the water, releasing compounds which cause the color change.

(d) pH changes over time in all solutions.

4. Acid precipitation causes greater changes in lake acidity in some parts of the Northeast, such as the Adirondacks of New York and the White Mountains of New Hampshire, than in other parts of the Northeast because of differences in:

(a) The type of bedrock and soil.

(b) The acidity of the precipitation.

(c) The size and shape of the lakes.

(d) The lower fish populations

Authentic Assessment Questions

1. Suppose you are the lake manager for an exclusive fishing club. You have read about acid precipitation in the news and you are worried about its possible effects on your fish populations. Design a study to determine whether acid precipitation is likely to cause problems in your club's lakes. What will you study, and why?

2. Lime is commonly applied to gardens and agricultural fields to neutralize acidity. Experimental programs have been carried out to add lime to Adirondack lakes and streams. What questions and challenges do you think might have been encountered as a result of these programs?

Answers to Short Answer Questions

1. Answer: Mirror Lake

Students should focus on alkalinity data to answer this question. Temperature has just a small effect on pH because microbes in the water are more active at higher temperatures and produce CO_2, which then forms the weak acids bicarbonate and carbonate. Although it does have an effect on dissolved oxygen (less gas can stay in water as it warms and fauna in water use oxygen), temperature has only a slight effect on alkalinity.

2. B

3. B

4. A

Answers to Authentic Assessment Questions

1. The manager of the fishing club would need to know

- the species of fish living in the lake and the pH requirements of each species;
- the pH requirements of other organisms in the lake upon which the fish rely for food;
- the pH of the precipitation in the area; and
- the mineral composition of the bedrock beneath the lakes and surrounding soils, learned via soil maps. (This would provide information about the buffering capacity of the lake, as well as data regarding the alkalinity or acid neutralizing capacity of the soils and water, which can be learned via alkalinity test kits.)

Student answers should discuss the connection between the surrounding soils and the lake water.

2. Questions and challenges which might have been encountered in the application of lime to Adirondack lakes and streams include

- how much lime to apply;
- how often to apply it;
- the best method of application (think about side effects of helicopter applications that might disturb people and other organisms);
- how the addition of calcium carbonate increases available calcium [recall $(CaCO_3) + (CO_2) + (H_2O) \rightarrow (Ca^{2+}) + 2\ (HCO_3^{-})$] and how this affects organisms in the lakes and streams;
- public attitudes regarding the application of lime over a large area;
- the expense of the research needed to answer the above questions; and
- the expense of the lime application.

3.6 Teacher Assessment: Buffering Experiment

There are two distinct parts to this lesson: a *buffering demonstration* and an inquiry-based *buffering experiment*. The buffering demonstration is teacher-directed, and depending on the type of assessment the teacher wishes to assign, students might simply record answers on the student handout to submit to the teacher. Alternatively, students can write a lab report. In this case, the teacher can eliminate photocopying by displaying the student handout questions on an overhead or board and students can record responses in lab books.

The Buffering Experiment is student-directed. It asks students to select a research question, develop a hypothesis, materials and procedure, and is best written up as a lab report. Follow link below to a rubric for assessing lab reports. See also Chapter 6.6 for information on assessing lab reports.

In addition to the student handout and lab report, short answer and authentic assessment questions are included and may be used whether the students have completed just one or both parts of the lesson.

Click here to view and download a lab report assessment rubric.

Activity

3.7 What Does the Data Tell Us?

top of chapter 3

Overview

This activity uses graphing data from the Hubbard Brook Ecosystem Study and explores the following:

1. Have Clean Air Act (CAA) regulations helped to reduce the amount of acid deposition falling on our landscape?

2. Which component of acid rain—sulfur dioxide or nitrogen oxides—has been most effectively addressed?

3. What happens to water between when it enters a forest as rain or snow, and when it exits as stream water? Why might this be?

4. What value does a long-term data set like this have when compared with one taken over a shorter time period, such as four years?

The goal is to create two graphs (with an optional third graph), each containing data collected between 1965-2005 from a small watershed within the Hubbard Brook Experimental Forest:

5. Graph one will contain the average annual pH in both precipitation and stream water over time.

6. Graph two will contain the average annual concentration of nitrate and sulfate in both precipitation and stream water over time.

7. The third, optional, graph will show concentrations of calcium in both precipitation and streams over time. This is meant to illustrate the buffering action of the soil as water passes through it, since clearly more calcium is leaving the system than entering.

Source

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS:11:1.2, 7.1
- S:LS2:11:1.5, 2.2
- S:LS3:11:1.1, 1.2, 1.3
- S:PS2:11:2.3
- S:SPS1:11-4.1, 5.1, 5.2
- S:SPS2:11:1.3, 2.1, 2.3, 4.2
- S:SPS3:11:3.1

Rain gauges and other monitoring equipment at Hubbard Brook

Student Outcomes

- Display and interpret data in graphs.
- Explain how water passing through the soil of an ecosystem interacts chemically.
- Explain how legislation to reduce sulfur emissions affected the acidity of precipitation.
- Explain how lack of legislation on nitrogen has affected the acidity of precipitation.
- Describe the value of long-term ecosystem monitoring in demonstrating the link between environmental policies and ecosystem dynamics.

Materials and Tools

- Excel data file: Graphing Data from the Hubbard Brook Ecosystem Study (either printed copies or accessed via link on computer)
- Computers connected to printers, or graph paper and rulers

Estimated Time to Complete Lesson

One to two 40-minute periods, depending upon which concepts the teacher chooses to highlight

Assessment

- Student Assessment Questions
- Graphs and Assessment Questions Rubrics

Background Needed

- The students may need background information about the transformation of sulfur dioxide (SO_2) to sulfuric acid (H_2SO_4) and nitrogen oxide (NO_x) to nitric acid (HNO_3) so they can understand the difference between what is emitted and what is deposited.

- Students will need an understanding of pH, basic acid rain chemistry, calcium, Clean Air Act(s), and long term monitoring. See Slideshow Acid Rain 101 for information.

Acknowledgment

The data used in this activity was provided by Dr. Gene E. Likens through funding from the National Science Foundation and the A.W. Mellon Foundation.

One of Hubbard Brook's gauged weirs

Introduction

Every week since 1963, Hubbard Brook scientists have been collecting and analyzing weekly samples of inputs (precipitation) to and outputs (stream water) from forested watersheds at Hubbard Brook. Water samples are analyzed for pH as well as concentrations of several solutes, including the major ions associated with acid rain: sulfate and nitrate.

Procedure

Note: The procedure below can be simplified for smaller classes or shorter time frames by having all students work with the entire dataset, rather than splitting them up into groups using five-year blocks.

1. Provide students with the spreadsheet in the Excel file titled Graphing Data from the Hubbard Brook Ecosystem Study. The data are grouped for ease in constructing the graphs. Notice also the headings at the top of the columns.

2. Divide students into pairs or groups, and each pair/group will graph and analyze three to five years of data, or use whatever combination of numbers of students and years of data that suits your class size. Time periods of three to five years will probably best illustrate the differences between short-term and long-term monitoring. Each group will graph different five-year periods of time.

3. Instruct the groups to copy the row of headings from the main dataset and paste them into blank cells either below or adjacent to the main dataset.

4. Instruct the groups to copy and paste the data from the years assigned to their group underneath the headings they just pasted. In this way, they will have a smaller dataset that contains the appropriate headings and only the years they have been assigned to work with.

5. Each team will create two to three graphs. The directions for making the graphs using Excel are as follows:

Instructions for Mac and PC Computers Using Excel

Using Excel (Version 2008) on a Mac:

(a) Highlight the data you wish to graph. Include the column headings.

(b) Under Insert in the toolbar, select Chart.

(c) A horizontal ribbon appears under the main toolbar. At the top of this ribbon are 12 small ovals with the main graph types (bar, bubble, column, scatter, etc). Select “XY Scatter,” all the way to the right.

(d) Subtype choices appear: choose “Straight Lined Scatter,” which is also the right-most choice.

(e) The graph is produced as you soon as graph subtype has been selected.

(f) To edit things like the title, use the right-hand sidebar, called the “Formatting Palette.” Inside this palette are the “Chart Options.” The chart title, X-axis, and Y-axis labels all appear in one drop down menu near the top of the Chart Options section, under the label “Titles.”

(g) You can choose to either imbed your graph in the current sheet or to place it in a separate sheet. You have to click on the chart and then press control and click at the same time. Now select "Move Chart." A dialog box appears asking if you want it inside an existing sheet or if you want the chart to occupy a new sheet all by itself.

(h) For the pH graph, the Y-axis may go from 0-6, which makes the data look compressed. To change this, double-click on the Y-axis once the graph is complete, select the "Scale" tab, and insert your own values. A range from 3 to 5.5 works well, but try different presentations.

(i) By default, the graph background should be set to white, but to save printer ink, be certain of this before printing.

Using Excel (version 2007) on a PC:

(a) Highlight the data you wish to graph. Include the column headings as you highlight.

(b) Under "Insert" in the toolbar go to "Charts."

(c) Choose "Scatter," then select the icon subtype "Scatter with only Markers."

(d) Data range should be fine, but check to see if things are making sense.

(e) To label chart title, X-axis and Y-axis, go to Chart Layouts and click "Layout 1." Now you can insert the titles by clicking in the area that you want to insert and typing the title.

(f) For the pH graph, the Y-axis may go from 0-6, which makes the data look compressed. To change this, click on the Y-axis values once the graph is complete, then right click and select the "format axis" tab. To insert your own values choose "fixed" next to "minimum" and enter a value in the tab next to it such as "3.5" and choose "fixed" for "maximum" and enter a value in the tab next to it such as "5.5". A range from 3.5 to 5.5 works well, but feel free to try different presentations.

(g) By default, the graph background should be set to white, but to save printer ink, be certain of this before printing. If the background is not white, click in chart area, right click, and choose "Format Chart Area." You will see a toolbar — click on the "paint bucket" icon and choose white. (You can also click on the right-hand tab "Fill" and select "No FIll.")

(h) Be sure to click on the chart before you print, or you will end up printing the chart with the spreadsheet of data in the background.

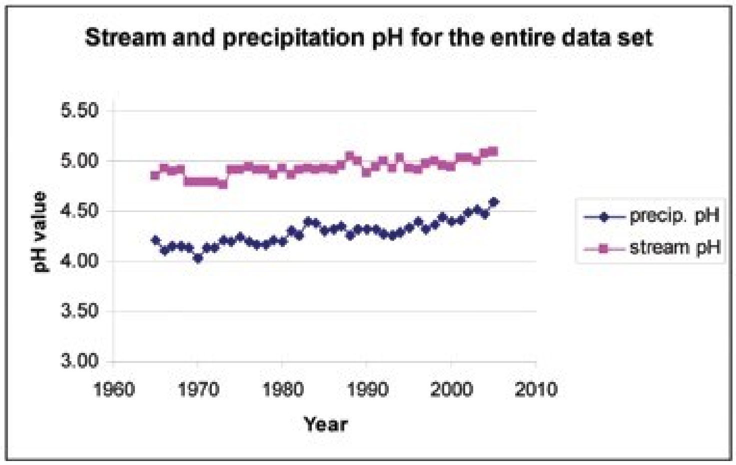
Option: Look at how scale changes one's impression of data. For instance, if you graph the pH with a scale from 3 to 8, it looks much different than if you use a scale from 4 to 6.

6. Answer Questions on page 70.

Graphs

Note:

An important point to note (which leads up to the third, optional graph), is the relatively higher pH of the stream water as compared to the precipitation. This is because of buffering reactions in the soil — mainly the exchange of base cations (Ca^+, Mg^+, K^+, Na^+) from the soil with H^+ ions from the water.

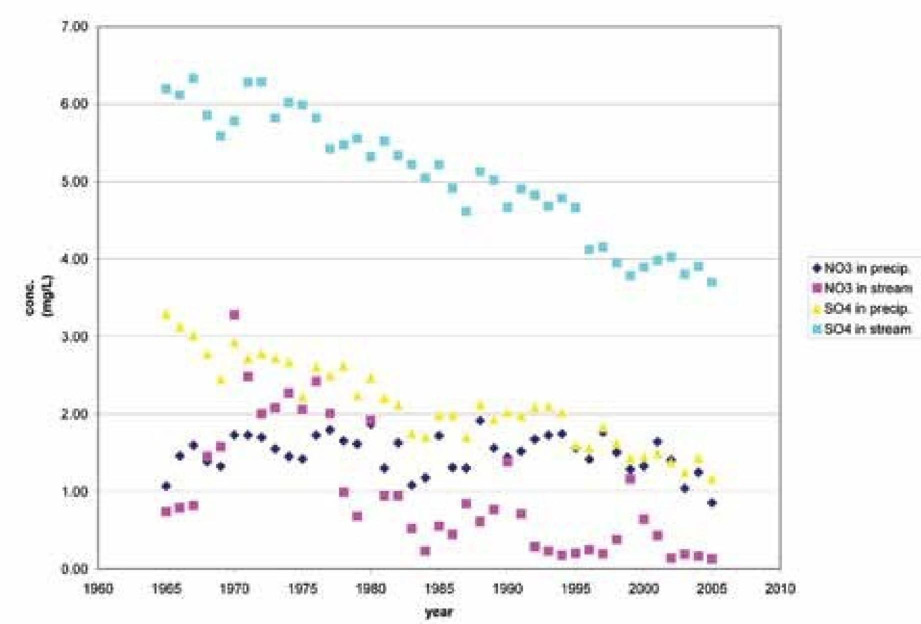


I. Average Annual pH in Precipitation and Stream Water vs. Time

Notes:

There are at least three important points that can be made using the entire dataset here:

1. First, sulfate deposition has been declining since soon after the CAA of 1970, and this can be seen in both the precipitation and stream chemistry. The ecosystem has little biological demand for sulfur, so the system becomes saturated, and it basically passes right through the system (although it does leach base cations like calcium as it does so). The concentrations are higher in the stream water mainly due to evapotranspiration, which concentrates SO_4 in water since it does not leave the system with the water that leaves as water vapor.



II. Average Annual Concentrations of Nitrate and Sulfate in Precipitation and Stream Water vs. Time

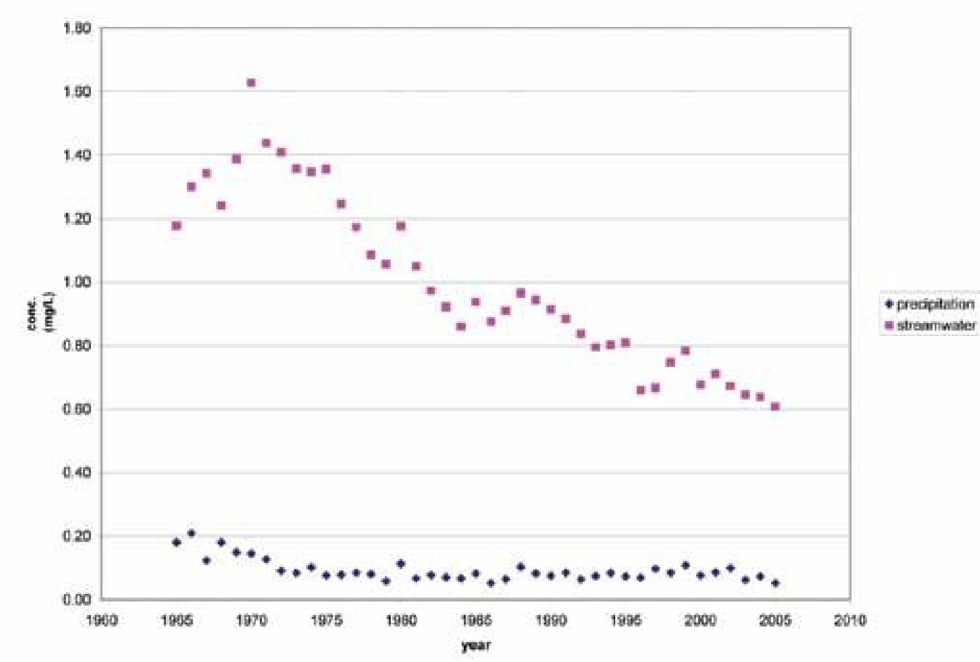
2. Second, there is no such decline in nitrate deposition. Many nitrogen emission sources have not been effectively regulated by the CAA(s), so NOx emissions continue to contribute to the problem of acid rain.

3. Third, there is no obvious relationship between nitrate inputs in precipitation and outputs in stream water.

- The system is currently holding on to most of the nitrogen that enters it.
- Nitrogen acts as a fertilizer, so plants and microbes generally take up available nitrogen and little passes through to the streams.
- The amount of nitrogen in forested ecosystems is increasing over time. This is an extremely interesting phenomenon (that is beyond the scope of this guide) due to the importance of the nitrogen cycle in all life.*

- **Many scientists wonder what will happen if the system becomes saturated with nitrogen.** At that point, any further inputs would essentially pass straight through to the streams, as sulfur does now.

A third, optional, graph can be made to illustrate some of what happens in the soils. Graphing the calcium concentrations of both precipitation and stream water on the same graph will illustrate that more calcium is leaving the system than entering it.



III. Average Annual Calcium Concentrations in Precipitation and Stream Water vs. Time

Notes:

This graph should stand alone pretty well, but in case you get into the discussion of higher SO_4 in streams relative to precipitation, working with this graph may require some background information.

1. The main reason the SO_4 is more concentrated in the stream is because of evaporative water loss between entering as precipitation and leaving as stream water. This concentrates the solute, which otherwise passes through *without a lot of biological interaction.* This is fundamentally different from calcium, which is very important biologically and would not be expected to simply pass through the system.

2. In addition, unlike sulfate, the main sources of calcium in the system are from soil parent material (glacial till), not precipitation. There are more sources and more internal cycling of calcium than sulfate. The calcium exiting the system is dominated by existing pools of calcium in the forest, not by the small amount entering in the precipitation.

3. Some calcium would always be expected to exit the system due to leaching by organic acids from plant material, but these acids are weak compared with the SO_4 ions which dominate the leaching of calcium which we see in the graph.

**For a thorough discussion of the problem of nitrogen pollution, please see Nitrogen Pollution: From the Sources to the Sea (2003), a report from the Hubbard Brook Research Foundation.*

3.7 Student Assignment: What Does the Data Tell Us?

Name:____Date: ____________________________

Answer the following questions after your graphs are complete.

Procedure Questions

1. In your five-year block of time, do you see a trend in pH in either precipitation, stream water, or both? If so, is it increasing or decreasing?

2. Pair up with one other group and compare your graphs. Does the other group's graph show any trends? If so, are these trends similar to yours?

Interpretation Questions for pH Graph

3. Combine all the pH graphs from the entire class — either tape them together to form a continuous graph, or make a graph from the complete data set using Excel. Then answer these questions.

(a) Which has a higher pH, precipitation or stream water? Why might this be?

(b) Is there much variability from year to year, or only a little?

(c) What might be the cause of any variability you observe?

(d) Do you see any trends?

(e) Is the "picture" you get about the change in chemistry in the shorter term data set different from what you see in the longer term data set?

(f) What does this tell you about the importance of short-term versus long-term data?

Interpretation Questions for Calcium Graphs

Combine all of the graphs showing sulfate and nitrate concentrations — either tape them together to form a continuous graph, or make a graph from the complete data set with Excel. Then answer the following questions.

4. Do you see a trend in either sulfate or nitrate in precipitation? If so, for which solute and in what direction do you see the trend?

5. If you have noted any trends, what do you think might be causing them?

6. Does the stream water data behave the same way?

7. What differences do you see between the precipitation and stream water concentrations for each solute?

Combine all of the graphs showing calcium concentrations — either tape them together to form a continuous graph, or make a graph from the complete data set using Excel. Then answer the following questions.

8. Where is this calcium coming from?

9. While some calcium naturally passes from the soil into water as plants decompose, the loss of calcium from the soils of Hubbard Brook cannot be explained entirely by this natural leaching. Provide a hypothesis for the loss of calcium from soils at Hubbard Brook.

Analysis Questions

10. Have CAA regulations helped to reduce the amount of acid deposition falling on our landscape? Explain your answer.

11. Which component of acid rain — sulfur dioxide or nitrogen oxides — has been most effectively addressed?

12. What happens to water between the time it enters a forest as rain or snow and exits as stream water? Why might this be?

13. What value does a long-term data set like this have when compared with one taken over a shorter time (e.g., four years)?

Rubric for Graphs

Students can earn up to 18 points per graph.

Category	3	2	1
Title	Title clearly relates to the problem being graphed and is printed at the top of the graph.	A title is present at the top of the graph.	A title is not present.
Labeling of X-axis	The X-axis has a clear label that describes the units used for the independent variable.	The X-axis has a label.	The X-axis is not labeled.
Labeling of Y-axis	The Y-axis has a clear label that describes the units and the dependent variable (concentration in mg/L).	The Y-axis has a label.	The Y-axis is not labeled.
Accuracy of Plot	All points are plotted correctly and are easy to see.	All points are plotted correctly.	Points are not plotted correctly OR extra points are included.
Legend Included	A legend is provided that accurately explains the meaning of plot symbols.	A legend is provided, but it is inaccurate.	No legend is provided.
Neatness and Attractiveness	Neat and relatively attractive. A ruler and graph paper (or graphing computer program) are used to make the graph more readable.	Lines are neatly drawn but the graph appears quite plain.	Appears messy and "thrown together" in a hurry. Lines are visibly crooked.

Rubric for Student Assessment Questions

There are a total of 18 questions, and each question has a value of 2 points.

1 point: An answer is provided to the question, but the thought is not complete, and/or no explanation is given, when asked for.

2 points: An answer expressing a complete thought is given. If asked for, a thoughtful explanation is given.

Activity

3.8 What Is Ecosystem Recovery?

top of chapter 3

Overview

Students explore the concept of ecosystem recovery by working in groups to consider ecosystem health, stressors to an ecosystem, and ways to monitor recovery. They also examine the role scientists play in ecosystem recovery. Students will be introduced to the following terms: **abiotic**, **biotic**, **dynamic ecosystems**, **ecosystem**, **ecosystem services**, **residence times**, **resistance** and **resilience**, and **turnover**.

Source

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11-2.1
- S:ESS4:11-3.3
- S:LS2:11:1.4, 1.5, 2.2
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS1:11:1.1, 5.1, 5.2
- S:PS2:11:1.3,2.1, 2.3
- S:SPS3:11:3.1

Student Outcomes

- List characteristics that indicate a healthy ecosystem, ways to measure these characteristics, and events that can stress an ecosystem.
- Describe conditions that can lead to recovery and list ways humans can promote it.
- Explain the role of science in: defining and diagnosing ecosystem health; making recommendations to promote recovery; and monitoring recovery.

Materials and Tools

- markers
- newsprint sheets

Estimated Time to Complete Lesson

One 40-minute period, perhaps longer for upper-level students

Assessment

- Group Work Rubric
- Student Assessment Questions
- Assessment Questions Rubric

Background Needed

Knowledge of the terms **biotic** and **abiotic** and a complex understanding of the term **ecosystem**.

3.8 Teacher Lesson Planning: What is Ecosystem Recovery?

The purpose of this group exercise is to explore the concept of ecosystem recovery and gain an appreciation of the challenges faced when determining the health and recovery of an ecosystem. Teachers will need to emphasize the following points in the lesson:

(a) **Ecosystems provide services.** Why worry about ecosystem recovery from acid rain? Healthy ecosystems provide us with essential ecosystem "services" that ensure our survival and foster our well-being. Clean water, the pollination of our crops, the decomposition of wastes, and the regulation of disease-carrying organisms are a few examples of the services provided by healthy ecosystems. Since we rely on functioning ecosystems, we benefit when degraded ecosystems recover from such stresses as acid rain. For more information, please see Ecosystem Services: A Primer, from the Ecological Society of America.

(b) **Ecosystems are dynamic.** A healthy ecosystem is stable, referring to its ability to withstand change or to recover from change. Ecosystems are rarely in equilibrium, so assessing health, response to a stressor, and recovery must be done in the context of a **dynamic ecosystem**. Examples: a forest that experiences fire once every 100 years; a flood in a stream caused by a spring rainstorm during snowmelt; road salt that enters a lake during snowmelt.

(c) **Ecosystems differ in their ability to withstand stressors**, the degree to which they respond to stressors, and the rate at which they can recover. For example, most ecosystems in the Northeast are sensitive to acid rain, while Midwestern forests have a greater buffering capacity.

(d) **Long-term monitoring is valuable** because it allows us to assess background conditions, measure responses to stressors, and assess recovery.

(e) **It is difficult and challenging to assess ecosystem health and recovery!** As ecosystems experience multiple stressors (both natural and **anthropogenic**) simultaneously, the above points illustrate the challenge of measuring the "health" of an ecosystem.

Group Work

1. Begin by asking: Why do we care if ecosystems recover from acid rain? Explain the phrase *ecosystem services* and, as a class, brainstorm some of the ecosystem services that a forest, lake, and stream each provides.
2. Explain to students that they will work in small groups to brainstorm ideas to address a list of questions related to ecosystem health. Each group will focus on a particular ecosystem: a forest, a stream, or a lake. Students will answer the following questions for their ecosystem.

   Question 1: What are the characteristics of a healthy [forest, stream, lake]? Next to each characteristic, state how it can be measured.

   Question 2: What types of stressors can cause a [forest, stream, lake] ecosystem to change?

   Question 3: What allows a [forest, stream, lake] to recover from a stressor?

   Question 4: How do you know if a [forest, stream, lake] has recovered?

3. Make sure students understand the definition of an ecosystem and have them list some specific ecosystems in their community (e.g., the town forest, the local pond, etc.). This step should get at the idea that an ecosystem is an integrated concept and should consider the **biotic** and **abiotic** processes that contribute to ecosystem health.
4. Lead a discussion about health.
   - **How do you know if a person is healthy? An animal? An ecosystem?** Health implies that an organism can perform all functions required to keep it in **homeostasis**, such as acquiring and using energy, reproducing cells/other parts, eliminating wastes, etc. Just like humans and animals, ecosystems are never in a steady state.
   - **There are two aspects to health: resistance and resilience**. The teacher may wish to relate these two aspects to the students' own health to illustrate this point.
   - **How can you measure the health of an organism or ecosystem?** **Baseline** data is needed to compare something that is healthy to something that has been affected by a stressor. Again, it may be beneficial to use students' health as an example. This is an important lead into Question 1.

> **Your ecosystem: Forest**
>
> **Q1: What are the characteristics of a healthy ecosystem?**
>
> **Brainstormed ideas to address question:**

5. Divide students into three groups and assign each group an ecosystem — forest, stream, or lake — for their work. Give each group one newsprint sheet for each question and a marker. Ask the groups to write their ecosystem name on all of the sheets, and then write one of the four questions on each sheet.
6. Ask them to consider Question 1 and record their brainstormed ideas on the appropriate sheet. Remind them that ideas must be quantifiable — things that can be measured!
7. Reconvene the class and ask groups to post their newsprint sheets and present their ideas. Students probably have limited knowledge of ecosystem processes and might provide such responses as "big trees" or "large numbers of fish." The teacher might need to prompt them to think of ways to measure these things. (Teacher may also need to add concepts such as nutrient cycling, etc.)

8. Introduce the term stressors and have students return to their groups to brainstorm answers to Question 2.

9. Reconvene. Ask students to group their answers into two categories: natural or human-caused (anthropogenic). To teach or reinforce the effect of these stressors on ecological processes, the teacher may wish to ask what the effect(s) of these stressors is on the ecosystem. See ideas list below.

10. Students return to groups to brainstorm answers to Questions 3 and 4.

11. Reconvene and have each group briefly present their ideas. Have the class look for common themes and ideas among all the groups' sheets and circle them with a red marker.

12. Discuss differences between the three ecosystems, such as forests grow more slowly and take longer to recover from a disturbance than a stream. The concept of turnover might be introduced here; e.g., trees are much longer-lived than algae. You could introduce the concept of residence times: lakes and soils have longer residence times than streams; toxins can be flushed through a stream quickly, but lakes can retain toxins in sediments and forests can retain toxins in soils. In addition, some ecosystems are more dynamic than others. For example, a flood in a stream may not last long but it can still act as a disturbance.

13. Students should complete Ecosystem Recovery Student Handout.

Here is a list of ideas and themes for each question.

Question 1: What are the characteristics of a healthy ecosystem [forest, stream, lake]?

Next to each characteristic, state how it can be measured. Measurement ideas are in bold type.

- Species diversity and healthy population sizes. (Caution needed: Tropical rainforests have high species diversity while harsh environments such as the Arctic do not.) **Species inventory, population counts**
- Food web that is self-supporting, sometimes with a high diversity of species depending on the ecosystem. **Species inventory, population counts**
- Cycles nutrients to support plant and animal growth. **There are many ways to measure growth: tree diameter, tree rings, biomass, rate of photosynthesis, fecundity, population size, etc.**
- Resilient: The ability to recover from stressors. After a disturbance, **monitor to see if the same species return.** This can take a long time: think primary and secondary succession.
- Dynamic (can respond to change). Again, after a disturbance, **monitor species, growth, etc.**

Question 2: What types of stressors can cause an ecosystem [forest, stream, lake] to change?

Stressors in a forest might include the following:

- Fire
- Windstorm (a small-scale disturbance)
- Hurricane (a large-scale disturbance)
- Logging
- Development (building, roads)
- Pollution

Teacher should then ask the following:

- Which of these stressors are natural and which are anthropogenic (human-caused)?
- How do these stressors impact the ecosystem? Examples include
  - Soil erosion (which removes nutrient material and destabilizes tree roots)
  - Overharvesting of trees (which removes organic matter and resources such as shelter and food)
  - Disappearance of a predator species (which can lead to overpopulation of prey species and such issues as overgrazing by herbivores)
  - Introduction of invasive species (which can outcompete some native species and reduce diversity)
  - Acid rain (which changes the chemistry of the soil and water, leaches out essential nutrients, and mobilizes aluminum, which is toxic)

Question 3: What — in addition to time — allows a [forest, stream, lake] to recover from a stressor?

- Removal of the stressor(s), such as the removal of an invasive species or a reduction in acid rain and other pollutants.
- Restoration of the ecosystem to previous conditions by replacing key organisms that have disappeared (e.g., a predator or native vegetation); replacing important habitat features that have disappeared (e.g., riparian vegetation along an eroded river bank); the continued removal of invasive species; continuous monitoring of the ecosystem.

Note: These actions do not ensure the recovery of an ecosystem and continued stressors or a very large stressor may impair its ability to recover.

Question 4: How do you know if a [forest, stream, lake] has recovered?

Answers to Question 1 and Question 4 should be similar. Use the same measurements listed in Question 1 to monitor the ecosystem. Either compare baseline ("before") measurements to current ("after") measurements or compare data from a similar, unaffected ecosystem. **(Stress the importance of baseline data.)**

Group Work Rubric

Category	4	3	2	1
Focus on the task	Consistently stays focused on the task and what needs to be done. Very self-directed.	Focuses on the task and what needs to be done most of the time. Other group members can count on this person.	Focuses on the task and what needs to be done some of the time. Other group members must sometimes nag, prod, and remind to keep this person on-task.	Rarely focuses on the task and what needs to be done. Lets others do the work.
Contributions	Routinely provides useful ideas when participating in the group and in classroom discussion. A definite leader who contributes a lot of effort.	Usually provides useful ideas when participating in the group and in classroom discussion. A strong group member who tries hard.	Sometimes provides useful ideas when participating in the group and in classroom discussion. A satisfactory group member who does what is required.	Rarely provides useful ideas when participating in the group and in classroom discussion. Perhaps refuses to participate.
Time-management	Routinely uses time well throughout the project to ensure things get done on time. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Usually uses time well throughout the project, but may have procrastinated on one thing. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Tends to procrastinate, but always gets things done by the deadlines. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Rarely gets things done by the deadlines AND group has to adjust deadlines or work responsibilities because of this person's inadequate time management.
Working with others	Almost always listens to, shares with, and supports the efforts of others. Tries to keep people working well together.	Usually listens to, shares with, and supports the efforts of others. Does not cause "waves" in the group.	Often listens to, shares with, and supports the efforts of others, but sometimes is not a good team member.	Rarely listens to, shares with, and supports the efforts of others. Often is not a good team player.

3.8 Student Handout Assignment: What Is Ecosystem Recovery?

Assessment Questions

Name:____Date: __________________________

1. Which ecosystem did your group discuss?

Think back to the Ecosystem Recovery activity you did in class. Based on the ideas that your group came up with and the information you learned as your class discussed each question, answer each question below. Give details whenever possible.

2. What are the characteristics of a healthy [forest, stream, lake]? Next to each characteristic, state how it can be measured.

3. List three types of *natural stressors* that can cause a [forest, stream, lake] ecosystem to change.

4. List three types of *anthropogenic stressors* that can cause a [forest, stream, lake] ecosystem to change.

5. What allows a [forest, stream, lake] to recover from a stressor?

6. How do you know if a [forest, stream, lake] has recovered?

7. List some of the ecosystem services that a [forest, stream, lake] provides.

8. What is meant by *ecosystem recovery*?

9. What role can scientists play in ecosystem recovery?

Assessment Questions Rubric

Score	3	2	1
For the answer to each question, 2 through 6	Answer contains substantial, accurate information gained from classroom group work as well critical thought by the individual student, and answer contains no grammatical and/or spelling errors.	Answer contains substantial, accurate information gained from classroom group work, and answer contains not more than one grammatical and/or spelling error.	Answer contains little or no accurate information gained from classroom group work, information given is inaccurate, and answer contains more than one grammatical and/or spelling error.
For the answer to each question, 7 through 9	Answer provides critical thought that reflects synthesis of information learned in group work and answer contains no grammatical and/or spelling errors.	Answer reflects synthesis of information learned in group work, and answer contains not more than one grammatical and/or spelling error.	Answer does not reflect synthesis of information from group work, and answer contains more than one grammatical and/or spelling error.

Chapter 4

Fieldwork

Chapter Activities

Preparation

Protocols

Results

Environmental Literacy Program

Overview

There are many things to consider when doing fieldwork with students and this chapter provides some tools that should help. It is divided into three parts:

Preparation: This section includes two Globe videos, an activity that gives students practice using scientific protocols, and an activity that helps you to plan your fieldwork sessions.

Protocols: This section provides methods for measuring parameters related to acid rain.

Results: What do we do with our data? An investigation does not end with the collection of data. By itself, data doesn't mean much unless it is organized and analyzed. Ways for students to synthesize, analyze, interpret, and communicate results are offered in this section.

Much of the material in this chapter was developed by the Globe program. A worldwide, hands-on, primary and secondary school-based education and science program, Globe (Global Learning and Observations to Benefit the Environment) is a cooperative effort of schools in partnership with colleges and universities, state and local school systems, and non-governmental organizations. Internationally, Globe is a partnership between the United States and more than 100 countries that manage and support their unique national and regional program infrastructure and activities.

Globe offers a comprehensive framework for ecological study and fieldwork. In addition to a teacher implementation guide, learning activities, training videos, and a wealth of other resources, Globe offers student protocols to help gather scientific information that is useful to both local communities and professional scientists. Much material is available at www.globe.gov.

We have selected five Globe protocols that will allow students to collect data related to acid rain. For your convenience, key points follow the summary box for each protocol. Whether done as a one-time activity, several times over a school year, or with consecutive classes over a period of many years, students will benefit from being directly involved in pH and alkalinity data collection of precipitation, soil, and stream or lake water. Please see Chapter 6 for suggested activities and projects that allow students to analyze, represent, and communicate their data.

All of the protocols included in Activities 4.5 through 4.9 have a section called "Looking at the Data." Real data collected by students from around the world are provided in graphic form and encourage students to question if the data are reasonable and to consider what scientists look for in the data.

Examples of a student research project are also given for each protocol, including: forming a hypothesis; collecting data; analyzing data; and future thoughts and research.

Why engage students in fieldwork? A good field experience requires a high level of advance planning, preparation and coordination on the part of teachers. So why take students outdoors into a natural laboratory? Here are some good points to consider:

- The natural environment is full of rich possibilities for authentic investigations.
- Students gain experience using tools and following procedures.
- It represents "whole body" learning, which engages students fully.
- Kids need to get outside and connect with nature (witness the outpouring of support for Richard Louv's book, *Last Child in the Woods*).
- The natural environment is an integrator of studies and learning experiences.
- It promotes teamwork to accomplish a common goal.
- It fosters the notion that learning can take place in nature, that the world is a teacher, that learners are part of the whole environment.
- Secondary students can gather information at the local level that helps to educate community members and local officials.
- It is important to learn how to protect our world.
- It's adventurous and fun!

Preparation

Activity

4.1 Globe Video, *Student Inquiry*

Overview

Students explore an inquiry-based approach to conducting outdoor fieldwork. Two tools are presented here: a video that shows students generating questions and designing an experiment to test them, and a section on inquiry starting on page 8 of the Globe Implementation Guide Appendix, including a flow chart called "The Process of Scientific Inquiry in Earth Science."

These tools show that authentic inquiry starts with a question and follows a carefully designed path to greater understanding, often producing more questions as it progresses. Unexpected results also often occur, and sometimes results that are confusing or even contradictory lead to further questions that become the starting points for new investigations.

Sources

- Globe: *Student Inquiry* video (length: 19 minutes, 19 seconds). Scroll down to "*Student Inquiry*". **VLC Media Player must be installed,** click here to install now (free)**.** We advise you download the video to your hard drive in advance so it's readily available for class.
- Globe: Appendix, page 8

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:1.1, 2.2, 3.1, 3.2, 3.3
- S:SPS3:11:3.1

Student Outcomes

- Generate testable experimental questions.
- Explain the steps of the scientific method and appreciate the role that unexpected results can play in this process.

Materials and Tools

- Globe Video, *Student Inquiry*
- Globe Implementation Guide for Teachers: Appendix

Assessment

Class discussion recommended as formative assessment.

Estimated Time to Complete Lesson

One 40-minute class period

Background Needed

None

Activity

4.2 Practicing Your Protocols

top of chapter 4

Overview

Students practice the Globe protocols for pH and Alkalinity, using the appropriate field guides, lab guides, and supplies, and explore sources of variation and error.

Source

- Globe: *Practicing Your Protocols:* "pH Station" (p. 7) & "Alkalinity Station" (p. 10)
- Globe: *pH Protocol (includes pH Field Guide)*
- Globe: *Alkalinity Protocol (includes Lab Guides and Field Guide)*

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:LS3:11:1.1, 1.2, 1.3
- S:SPS1:11:3.1, 3.2, 3.3, 4.1
- S:SPS3:11:2.2, 3.1

Student Outcomes

- Perform chemistry measurements correctly and understand how to interpret results.
- State reasons for quality control.
- Identify anomalous data.

Materials and Tools

See each protocol (pH and Alkalinity) for materials/tools lists.

Assessment

See student assessment on of Globe *Practicing Your Protocols*, page 3.

Estimated Time to Complete Lesson

One to four class periods, depending on how many protocols are done.

Note: In addition to pH and Alkalinity protocols, protocols for measuring transparency, temperature, dissolved oxygen, electrical conductivity, salinity, and nitrate are included in this document.

Background Needed

- Discussion of lab safety procedures.
- It's helpful to have students see the measurements demonstrated.

Activity

4.3 Globe Video, *Data, Process, and Flow*

Overview

This video covers important steps in a scientific investigation related to data collection, data recording, data entry, and data use within the context of a Globe project. This video is most useful for teachers who choose to participate in the Globe program.

Source

Globe Video, *Data, Process, and Flow* under "Using Globe Data" (video, 16 minutes, 39 seconds). Scroll down to "*Data Process and Flow*." **VLC Media Player must be installed,** click here to install now (free)**.**We advise you to download this video to your hard drive in advance so that it is readily available for class.

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:1.1, 2.2, 3.1, 3.2, 3.3, 4.1
- S:SPS3:11:3.1

Student Outcomes

- Relate the steps shown in the video to steps taken with the scientific method.
- Describe uses for application of data collected in video.

Materials and Tools

Globe Video, *Data, Process and Flow*

Assessment

Class discussion recommended as formative assessment.

Estimated Time to Complete Lesson

Approximately 25 minutes

Background Needed

None

Activity

4.4 Planning Fieldwork Sessions

Overview

Teacher and students need to prepare carefully for outdoor fieldwork sessions and develop a thorough plan that considers useful introductory activities, scheduling, transportation, supplies and equipment, available budget, permission, chaperones, weather conditions, safety, and clothing — as well as the actual fieldwork!

Sources

Hubbard Brook Research Foundation and the National Wildlife Federation

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:2.2, 3.1, 3.2, 3.3

Student Outcomes

Participate in planning for outdoor fieldwork.

Materials and Tools

Blackboard or whiteboard, chalk, markers, paper

Assessment

No formal assessment, though teacher may wish to grade student participation

Estimated Time to Complete Lesson

One to two class periods, based on how involved teacher would like students to be in making decisions

Background Needed

Lessons 4.1, 4.2 and/or 4.3 would be helpful

Photo: mary ann mcGarry

There are many things to consider when you take students outside to do fieldwork, so careful planning is critical. We encourage you to enlist your students to help develop a fieldwork plan. Student involvement will increase their investment in this program while teaching them important planning skills. You might consider having students — individually, in pairs, or in groups — develop their own fieldwork plans based on the suggestions below. Or, ask them to brainstorm the kinds of details they need to include in a fieldwork plan and then have them check their ideas against the suggestions below. As a final step, work with students to develop a final fieldwork plan that addresses all class needs and accomplishes your goals.

The following helpful tips come from "Field Trips: The Good, Bad and Ugly," an article in *Green Teacher* magazine, a subscription-based resource for environmental education teachers.

- Apply the same good teaching techniques you use in the classroom to your work in the field.
- Give students choice and ownership over their learning.
- Provide students with the opportunity to learn through direct experience with the environment before learning about the place from an expert.
- Establish behavioral expectations for the new learning environment.
- Break tasks into manageable chunks.
- Set students up for success by modeling and providing ongoing feedback before, during, and after learning experiences.

Below are some important questions to discuss with your students to develop your fieldwork plan:

1. What kinds of introductory learning experiences do students need to prepare them for productive fieldwork? Make sure they build a solid foundation of understandings and skills through appropriate classroom activities and lessons before taking them outside. Good indoor prep work results in more focused fieldwork that leads to greater learning.

2. How many outdoor fieldwork sessions do you need? One outdoor session may be enough, but several sessions may be required for meaningful fieldwork to occur.

3. How much leeway do you have in your schedule and curriculum? Inquiry-based education sometimes takes you to unexpected places. Your students may encounter mysteries or questions that they would like to pursue, or that you feel they should pursue to round out the study. It's useful to think about this possibility ahead of time and how you might respond if the unexpected happens.

4. What are some possible fieldwork sites? It's good to identify several sites in case one or more become unavailable due to landowner concerns, lack of safe access, or other issues.

5. How will students get to their fieldwork site, and how much time will be required for transportation there and back? If students cannot walk to the site, you will need to arrange for transportation and cover any travel costs.

6. How much time will be available for fieldwork at your site, once you get there and before you need to leave to return to school? Factor in extra time to organize supplies and people once you arrive, settle into your work, and then pack things up at the end.

7. Can you visit your fieldwork site well before the actual fieldwork session(s)? A visit ahead of time allows you to locate an unfamiliar site before taking students out and gives you the chance to think through the logistics of having a whole class out there at once. It would be ideal to bring a small "scouting group" of students with you on the visit to involve them in this planning exercise. During the visit, consider

- The best pathway for reaching your site
- Places where the whole class can gather
- Places where individual groups can work
- Places that illustrate concepts you plan to teach
- "Problem" places like a patch of poison ivy or prickles
- Benefits and challenges of the site

8. What do you plan to accomplish, and how will you get the work done? What is your research question(s) and what are your intended outcomes? What should students plan to accomplish during fieldwork, and what will they need to do as follow-up in the classroom? Will they work individually, in pairs, in groups? If in groups, what roles will be required to ensure that the time is well spent and the results are valid?

9. What equipment and supplies will you need? How will you get everything out to your site? Make sure that you have gathered all necessary equipment and supplies well before your first scheduled fieldwork day to allow time to acquire items you may have overlooked. Backpacks (see below), plastic milk crates, or plastic storage boxes can be used to haul equipment and supplies to your site. These containers are important supplies as well — don't forget to add them to your list!

10. How many chaperones will come with you? Whom can you recruit? It is advisable to have at least three adults per class of students and one for every four or five students is even better. We suggest that the teacher plans to "float" around to visit all groups and that another adult is assigned to work with each group. In the event of an emergency, several adults will be needed to manage the situation and keep students calm. Chaperones can help with "crowd control," facilitate group work, help out in case of an emergency, and help with transportation, if needed.

Be sure to talk with the adult chaperones ahead of time to explain their role and discuss your expectations for student behavior and how to handle inappropriate behavior.

11. What planning is required in case of bad weather? Schedule rain/snow dates and consider how to protect equipment and supplies from the weather.

12. From whom do you need permission? You may need to check in with several groups to make sure that everyone is supportive of your fieldwork, such as the school administration, students' parents, the landowners of your fieldwork site, and teachers whose classes your students may miss as a result of the fieldwork.

13. Do any students need additional assistance getting to the fieldwork site and working safely? Handicapped students may require special arrangements. Students with allergies or medical conditions may need to bring along medication.

14. How will you keep everyone safe and comfortable? Some suggestions:

- Bring any needed medications and be aware of pertinent allergies (e.g., bee sting allergy).
- Coach students in safe bee behavior: encourage calmness and little movement since quick movements and swatting behaviors may result in stings!
- Encourage students to wear long pants in areas with ticks, poison ivy, prickles, etc.
- Encourage students to wear sunscreen and hats in sunny areas.
- Make sure students have plenty of liquids to drink.
- Know the signs of hypothermia and heatstroke.

15. What will you do in case of an emergency? You will need an emergency response plan that includes:

- A protocol that is acceptable to your school and to the students' parents.
- Knowledge of the nearest emergency care facility in the area of your site.
- A way to call for help, such as a cell phone or a mental map of the phone nearest your site. Please be aware that cell phones do not work in certain areas.
- A way to transport injured or sick people to safety.
- High-energy, nutritious snacks and warm drinks in case of hypothermia (in cold or wet conditions)
- Plenty of drinking water (to prevent dehydration).
- A good first aid kit that has been recently inventoried for appropriate supplies.
- A procedure for using your adult chaperones effectively to deal with an emergency. For instance, someone can be tasked with contacting an ambulance, someone can administer first aid, someone can stay with the students or get them back to the school, etc.

What to Wear and What to Bring for Fieldwork Sessions

Have students brainstorm what they need to wear and bring. Then go over their lists and add anything important that's missing. Here are our suggestions.

Warm, weather-proof clothes and footgear
Be attentive to the weather forecast and make sure to dress appropriately. Everyone is more cheerful and more productive when they are comfortable. Some things to bring under certain conditions:

- **Cool or cold conditions:** several layers that can be added or peeled off
- **Hot or sunny conditions:** sun hats, sunglasses, sunscreen
- **Rainy conditions:** a rain coat, rain pants, and waterproof boots
- **Places with biting insects or ticks:** long sleeves, long pants, and bug spray
- **Functional footgear:** sneakers or boots (or sandals if toe protection is not a factor) that allow you to move around comfortably and that you don't mind getting dirty or banged up.

Well-Supplied Backpacks:

Student Backpacks	*Teacher Backpacks*
• Water bottle • Layers of clothes • Raingear (if needed) • Bug spray (if needed) • Writing supplies and paper (or journal) • Clipboard (if needed) • Lunch and/or snacks (if needed) • Fieldwork supplies	All student supplies, plus: • Map(s) of the site • First aid kit • Directions to the nearest hospital • Extra writing and paper supplies • Watch or other timepiece • Any needed medications for the class • Plenty of snacks, especially if it's cold or wet! • Extra liquids • Cell phone (if available; note that it won't work in some places)

While Outside Doing Fieldwork

Here are some suggestions for you, the teacher, while you have students outside doing fieldwork.

1. **Be a positive role model, a guide, an explorer, an active learner**
   - Exude excitement, enthusiasm, and a positive attitude.
   - Create a sense of adventure and/or mystery to entice them to get involved.
   - Enjoy what your students find and share these discoveries with the class.
   - Embrace the unknown and use it as an opportunity for inquiry.
   - Bring along reference materials (field guides, etc.) and encourage students to look up answers to their questions.
   - Ask students guiding questions to help them answer their own questions.
2. **Emphasize observation**
   - Encourage students to use their senses of sight, sound, touch, and smell.
   - Draw their attention to both "natural" and "human" stimuli.
   - Encourage them to record their observations (in writing and drawing).
3. **Use "teachable moments"**
   - Let students experience nature in the moment and then link that moment back to your study.
   - If possible, allow time for quiet, unstructured reflection — journaling is a great excuse for reflection.
4. **Design lessons that flow**
   - Help your students to transition from one thing to another (e.g., indoors to outdoors, idea to idea).
   - Do an introductory activity that excites and intrigues your students, or that creates a mystery to ponder.
   - Use a closing activity to summarize student findings and prepare them to return indoors.
5. **Engage all students during all activities**
   - Students who are actively engaged have fewer behavior problems!
   - Give each group a specific task to accomplish.
   - Give each person a role to play (e.g., recorder, identifier, etc.).
   - Explain that field sheets are assignments that count!
6. **Use backpacks to manage supplies (see previous page for contents lists)**

Protocols

Activity

4.5 Precipitation Collection

top of chapter 4

Overview

Students use a rain gauge and a snowboard to collect and measure the daily amount of precipitation that has occurred. Special pH measuring techniques for precipitation are used to determine the pH of rain and melted snow. A brief, quality discussion of acid rain with useful graphics is included in the introduction of Precipitation Protocols.

Note: This protocol should be used in conjunction with the Globe *pH Protocol*.

Source

Globe *Precipitation Protocols*

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:LS3:11:1.1, 1.2, 1.3
- S:SPS1:11:3.1, 3.2, 3.3, 4.1
- S:SPS2:11:4.2

Student Outcomes

- Explain and demonstrate how precipitation is measured.
- Explain that snow is an input of water to the surface just like rain and that each snowfall is equivalent to some amount of rainfall.
- Demonstrate that precipitation has a pH that can vary.

Materials and Tools

- installed rain gauge
- snowboard (40 cm X 40 cm wooden board, painted white)
- clean containers for pH samples — 100ml or larger
- two or three containers for snow samples
- carpenter's level
- meter stick
- pH paper or pH meter
- pH 4.0 and 7.0 buffer solutions
- salt and salt card or tweezers
- sampling jar with lid
- 500ml beakers or cups
- tweezers
- stirring rods/spoon
- latex gloves
- distilled water for cleaning rain gauge
- Precipitation Data Sheet
- Globe *pH Protocol*

Assessment

It is recommended that students follow the teacher's standard procedure for recording collected data in their lab notebooks. [Usually, students will be asked to write the Title, Purpose, Hypothesis (if appropriate), Materials, and Procedures prior to beginning the experiment/protocol. Observations and data should be recorded throughout the protocol, and Results and Discussion should be written after completion of the protocol.] Students have opportunities to demonstrate acquired knowledge and skills via completion of a Globe data sheet and by answering the focus questions and data questions (following) in the Results and Discussion sections of their lab reports.

Estimated Time

- In the field: five minutes for rain, 10-15 minutes for snow
- In the lab: five minutes for snow-rain equivalent, five minutes for pH
- Rain gauge maintenance: 10 minutes weekly for cleaning

Background Needed

None

Photo: hubbard Brook archives

Hubbard Brook archives contain thousands of precipitation and stream water samples taken since 1963.

A rain gauge, used to collect precipitation samples.

Protocol Summary

Focus Questions

- Is this year particularly wet or dry for our location?
- What is the seasonal variation in precipitation?
- When and how fast does snow melt and make water available to the environment?
- What is the pH of precipitation and how does it vary from storm to storm?
- Where do snowstorms and rainstorms come from before reaching our area?
- What special considerations must be made before installing a rain gauge or a snowboard in order to collect accurate, representative data?
- Why can't you just measure the depth of a snowfall to know how much water actually fell?

Data Questions

- What was the volume of the rainwater (or snow water equivalent) of this past precipitation event? Your answer should be given to the nearest one-tenth of a millimeter.
- What was the pH of the precipitation of this past event?
- How did you determine the correct reading when measuring the volume of water?
- Did you check your rain gauge even if there was no precipitation? Why is this important?

Points to Emphasize from Precipitation Protocol

1. Knowing the volume and chemistry of precipitation are important to understanding the impact of precipitation on ecosystems. Rain gauge measurements sample the amount, or volume, of precipitation that falls. These measurements assume that the same depth of water fell over the larger area surrounding the rain gauge (the larger the area, the poorer the assumption). It is also important to know the chemistry of precipitation. The atmosphere contains small amounts of many different chemicals, some in the form of gases and others in the form of aerosols, which are small particles suspended in air. Gases and aerosols are picked up in rain and snow and many can change precipitation pH, which in turn affects soil, vegetation, lakes, and surface water.

2. Daily measurement of the rain gauge is desired, which also allows students to check for bird droppings, debris, etc. If left unchecked for a few days, water can evaporate, samples can become contaminated, pH readings for events might be combined, etc. If students report data to Globe, it's important to report "zero" when there is no rain in the gauge, to report "missing" if it was spilled, and to report "trace" if less than half a millimeter has been collected.

3. A snowboard is used to sample the snow that falls, but just measuring the depth of snowfall isn't enough to calculate the volume of water since some snow is light and fluffy, while other snow is heavy and wet. To determine the rain equivalent of a snow event, a known quantity of snow must be collected. To do so, collect snow in a container of known size and melt it. The outer cylinder of a rain gauge may be used as a snow collection device: push the large cylinder straight down through snow, melt the snow, and measure the volume of the water. See finding rain equivalent depth equations below to determine depth of precipitation.

4. Daily measurement of snowfall on the snowboard is also desirable. (Again, if students report data to Globe, they must report the number of days since last reading.) Also, an area should be marked off near the snowboard for students to measure the total snow depth on the ground. This gives an idea of how quickly snow is melting or sublimating – going from solid to gas with no liquid phase.

Placement of Rain Gauge

- Where is the best place to locate the rain gauge that will be representative of the surrounding area?
  - Trees, buildings, and other structures should be at least 4 times as far away from the rain gauge as they are tall. Example: If a site is surrounded by pines that are 10 meters tall, place the rain gauge at least 40 meters away from the trees.
  - Place it on a grassy area is optimal.
  - Put it on a post as low to ground as practical.
- Make sure the rain gauge is level by using a carpenter's level across the top of the funnel in two directions.
- Check for debris, even if it has not rained.
- Clean once a month with water and a bottle brush (no soap).
- Bring the gauge inside when the temperature falls below freezing to prevent measurement tube from cracking. (During transition seasons when both rain and snow are possible, leave a large overflow tube outside. Any precipitation that falls into the overflow tube can be brought inside and poured into a small tube for accurate measurement.)

Placement of Snowboard

- Find an area away from buildings, trees, rain gauge — any objects that might affect snow depth. Think about the surface (concrete vs. grassy). Would a large flat area differ from a hilly area? Will people walk through and disturb the area will salt or sand contaminate the snow, etc.?
- Use a flag to mark the snowboard's location.
- Make sure the snowboard is cleared off after each measurement.
- Check the snowboard occasionally to make sure it's not warped.

To Find the Rain Equivalent Depth of Melt Water

1. Determine the area of the opening of the container:

If round

A. Radius = diameter/2

B. Area (cm^2) = ∏ x $(radius)^2$

If rectangular

Area (cm^2) = width (cm) x length (cm)

2. Depth (mm) = volume of melt water (mL or cm^3)

Area (cm^3) X 10 mm/cm

Activity

4.6 pH

top of chapter 4

Overview

Students will use either a pH meter or pH paper to measure the pH of rainwater, melted snow, or surface water (lakes and streams). If using a pH meter, the meter needs to be calibrated with buffer solutions that have pH values of 4.0 and 7.0.

Source

Globe *pH Protocol*

Photo: m. mcGarry

pH meter.

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS1:11:3.1, 3.2, 3..3, 4.1
- S:SPS2:11:4.2
- S:SPS3:11:3.1

Student Outcomes

- Learn how to use either a pH meter or pH paper.
- Explain the differences among acid, basic, and neutral values.
- Examine reasons for changes in the pH of a water body.
- Communicate project results with other Globe schools.
- Share observations by submitting data to the Globe archive.

Materials and Tools

- Globe data sheets: Precipitation Data Sheet and/or Water Chemistry Data Sheet
- Two 50ml or 100ml beakers
- latex gloves
- either "Using pH Paper" (pages 7 and 8 in Globe *pH Protocol*) OR "Using a pH Meter" (pages 10 and 12 in Globe *pH Protocol*)
- pH paper or pH meter
- distilled water
- clean paper towel/tissue
- pH 4.0 and 7.0 buffer solutions
- three 100ml jars with lids

Assessment

It is recommended that students follow the teacher's standard procedure for recording collected data in their lab notebooks. [Usually, the students will be asked to write the Title, Purpose, Hypothesis (if appropriate), Materials, and Procedures prior to beginning the experiment/protocol. Observations and data should be recorded throughout the protocol, and Results and Discussion should be written after completion of the protocol.] Students have opportunities to demonstrate acquired knowledge and skills via completion of Precipitation Data Sheets and Water Chemistry Data Sheets and by answering the focus and data questions in the Results and Discussion sections of their lab reports.

Estimated Time

10 minutes

Background Needed

None

Protocol Summary

Focus Questions

- If measuring precipitation pH: Does the pH of the rain and snow that you collect vary over time?
- How does the pH of precipitation relate to the pH of the soil, lakes, and streams in your area?
- What animals and plants would live in your water at the current pH reading? Are there animals and plants that would not live here?
- What changes in your watershed could have an effect on the pH reading at your water site?
- How do the pH values at your site compare with values from other sites within your watershed?

Data Questions

- If you took several pH measurements for each rain or snow event, or for each water body sampled, state the average pH reading for each event. Tell how many samples were measured to calculate the average.
- If you took only one measurement per event or per water body, list the pH reading.

Points to Emphasize from Protocol

1. A good discussion on pH scale and as it relates to acid rain is included in Globe's *pH Protocol*.
2. Details are given on the use of pH paper vs. pH meters. (Note that meters should have two calibration points as well as automatic temperature compensation, and should be calibrated before each use.)
3. Most precipitation has low **conductivity** and neither pH paper nor pH meters perform accurately for samples with less than 200 microSiemans/meter. Students can add salt crystals to rain or melted snow to increase conductivity to the appropriate level. Large salt crystals (.5 to 2 mm diameter) or table salt (less than 0.5 mm diameter) can be used. If using table salt, use a 'salt card' to measure the proper amount.
4. Protocols included for the following using pH paper:
   - Using pH paper with water that has EC > 200 microSiemens/meter (microS/m)
   - Using pH paper with water that has EC < 200 microS/m
   - Using pH paper with water that has EC > 200 microS/m
   - Using pH paper with water that has EC < 200 microS/m

Activity

4.7 Alkalinity

top of chapter 4

Overview

Students will use an alkalinity kit to measure the alkalinity in the water at their hydrology site. The exact procedure depends on the instructions in the alkalinity kit used.

Source

Globe: *Alkalinity Protocol*

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS1:11:3.1, 3.2, 3.3, 4.1
- S:SPS2:11:4.2
- S:SPS3:11:3.1

Student Outcomes

- Learn how to use an alkalinity kit.
- Examine reasons for changes in the alkalinity of a water body.
- Explain the difference between pH and alkalinity.
- Communicate project results with other Globe schools (Globe membership required).
- Share observations by submitting data to the Globe archive (Globe membership required).

Materials and Tools

- Alkalinity test kit
- Globe Water Chemistry Data Sheet
- Globe Making the Baking Soda Alkalinity Standard (page 5 of *Alkalinity Protocol*)
- Alkalinity Protocol Field Guide (page 7 of *Alkalinity Protocol*)
- distilled water in wash bottle
- latex gloves
- safety goggles

Assessment

It is recommended that students follow the teacher's standard procedure for recording collected data in their lab notebooks. [Usually, the students will be asked to write the Title, Purpose, Hypothesis (if appropriate), Materials, and Procedures prior to beginning the experiment/protocol. Observations and data should be recorded throughout the protocol, and Results and Discussion should be written after completion of the protocol.] Students have opportunities to demonstrate acquired knowledge and skills via completion of data sheets and by answering the focus and data questions (following) in the Results and Discussion sections of their lab reports.

Estimated Time

15 to 35 minutes, depending on whether students perform Quality Control Procedure (page 3 of *Alkalinity Protocol*)

Background Needed

Discussion about safety procedures when using chemical test kits

Protocol Summary

Focus Questions

- What is the relationship between changes in pH and alkalinity of the surface water at your site?
- How might the type of rocks and soil in your watershed affect the alkalinity of your water samples?
- What factors in your environment might cause a change in the alkalinity at your site?
- How might your alkalinity measurement help you to understand your pH measurement from the same water sample?

Data Questions

- What were the results when you measured the alkalinity of your alkalinity standard?
- How do these compare with the actual value of your alkalinity standard?
- What was the average alkalinity reading for the three water samples measured?

Points to Emphasize from Protocol

- Alkalinity is a measure of the pH buffering capacity of water, and is expressed as the amount of calcium carbonate ($CaCO_3$) in water, either in ppm or mg/L.
- Water with high alkalinity is well buffered; it resists a decrease in pH when acidic water enters into solution.
- When alkalinity is below about 100 mg/L $CaCO_3$, it is poorly buffered and pH sensitive.
- A quality control procedure should be performed every six months by making a baking soda standard solution, which has a known alkalinity of about 84 mg/L.
- Follow the directions on the alkalinity kit to test the baking soda standard before testing water samples to be sure test kit is accurate.

Activity

Back

4.8 Soil Characterization

top of chapter 4

Overview

Students identify the horizons of a soil profile at a soil characterization site, then measure and record the top and bottom depth for each horizon. For each horizon, students describe the structure, color, consistence, texture, and abundance of roots, rocks, and carbonates. Samples are collected and prepared for additional laboratory analysis.

Source

Globe *Soil Characterization Protocol*

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:3.1, 3.2, 3.3, 4.1

Student Outcomes

- Practice field methods for soil analysis and record field data.
- Prepare soil samples for laboratory testing.
- Relate physical and chemical properties of soil at a site to the climate, landscape, parent material, and land cover of an area.

Materials and Tools

- spray bottle full of water
- golf tees, nails, or other horizon markers
- soil color book
- pencil/pen and marking pen
- trowel/shovel
- paper towels
- meter stick/tape measure
- sealable bags/containers
- camera
- latex gloves
- rubber gloves
- acid bottle filled with vinegar
- hammer/crushing tool
- #10 sieve (2mm mesh openings)
- sheets of paper or paper plates
- Soil Study Data Sheet

Photo: Scott Bailey

A typical soil profile at Hubbard Brook

Assessment

It is recommended that students follow the teacher's standard procedure for recording collected data in their lab notebooks. [Usually, the students will be asked to write the Title, Purpose, Hypothesis (if appropriate), Materials, and Procedures prior to beginning the experiment/protocol. Observations and data should be recorded throughout the protocol, and Results and Discussion should be written after completion of the protocol.] Students have opportunities to demonstrate acquired knowledge and skills via completion of data sheets and by answering the focus and data questions (following) in the Results and Discussion sections of their lab reports.

Estimated Time to Complete Protocol

Two or three 40-minute class periods, or one 90-minute session in the field

Background Needed

None, although the Globe *Selecting, Exposing, and Defining a Soil Characterization Site* protocol might be helpful.

Protocol Summary

Focus Questions

- What creates the different horizons in a soil profile?
- What natural changes could alter the **soil horizons**?
- How long might it take to alter the depths of the different horizons?
- In your opinion, what is the best use of the land at this site? Is this a good place to establish a garden? Is this soil prone to flood or drought? What types of vegetation will grow in this soil?

Data Questions

- What was the structure type for each horizon in your soil sample?
- What was the main color for each horizon in your soil sample?
- What was the consistency for each horizon in your soil sample?
- Were free carbonates present in your sample?
- Using the soil textural triangle and the work you did to determine the texture of your soil, what is the texture of the type of soil you sampled?

Points to Emphasize from Protocol

- First follow the protocol for the Globe *Selecting, Exposing and Defining a Soil Characterization Site.*
- See the Globe *Soil Study Data Sheet* for data collected during this study.

Selecting the Site

- Ascertain that it is safe for digging (check with school maintenance staff, utilities, etc.).
- Choose an area that is representative of the general site.
- Site should be covered with natural vegetation if possible.
- Site should be at least three meters from buildings, roads, playing fields, etc.
- A site that receives sunlight is helpful as students need to take samples into sunlight to determine soil color, etc.

Exposing the Site

There are three methods that can be used to expose the soil site.

1. Pit method
   – Use a shovel to dig a pit 1.5 meter x 1.5 meter wide and 1 meter deep.

2. Auger method
   – Use a Dutch auger to access a sample one meter in depth.
   – Spread a tarp over a flat surface to lay out soil profile.
   – A rain gutter or other container can be placed on the tarp to lay out soil profile (allows for transport and storage).
   – Remove successive samples and lay samples end-to-end on tarp/gutter to assemble a profile 1 meter deep.

3. Near Surface method
   – Use a trowel to dig to a depth of at least 10cm.
   – Use only if digging deeper is not possible.

Defining the Site

The following are examples of metadata and are important to include if students report data to Globe. Even if data is not shared with Globe, this information may be included in students' research journals/lab books.

- Latitude, longitude, and elevation
- Site exposure method
- Site location
- Slope
- Aspect
- Landscape position
- Cover type
- Parent material
- Land use
- Distance from major features and other distinguishing characteristics of the site

Activity

4.9 Soil pH

top of chapter 4

Overview

Students mix dried and sieved soil samples with distilled water. The mixture is allowed to settle until a relatively clear layer, called the supernatant, is formed. Students use a pH pen, pH meter, or pH paper to determine the pH of the sample. The procedure is done three times for each horizon.

Source

Globe *Soil pH Protocol*

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- SPS1:11:3.1, 3.2, 3.3, 4.1
- SPS3:11:3.1

Student Outcomes

- Apply laboratory tests for pH to soil samples.
- Relate pH to physical and chemical properties of a soil sample.

Materials and Tools

- oven-dried, sieved soil
- distilled water
- pencil/pen
- 100ml graduated cylinder
- glass stirring rod
- 100ml beaker
- pH meter, pH pen, or pH paper
- balance
- Globe *Soil Study Data Sheet*

Assessment

It is recommended that students follow the teacher's standard procedure for recording collected data in their lab notebooks. [Usually the students will be asked to write the Title, Purpose, Hypothesis (if appropriate), Materials, and Procedures prior to beginning the experiment/protocol. Observations and data should be recorded throughout the protocol, and Results and Discussion should be written after completion of the protocol.] Students have opportunities to demonstrate acquired knowledge and skills via completion of data sheet and by answering the focus and data questions (following) in the Results and Discussion sections of their lab reports.

Estimated Time

One 40-minute class period

Background Needed

Soil Characterization Protocols

Protocol Summary

Focus Questions

- How does the pH of your soil relate to the pH of the precipitation falling on your soil?
- How does the pH of soil affect the pH of local water bodies?
- How do slope and aspect affect the pH of a horizon?
- How does the type of vegetation growing on your site affect the pH of soil?
- What natural changes can alter the pH of a horizon?

Data Question

What was the average pH for each horizon of your soil sample?

Points to Emphasize from Protocol

1. The introduction contains a good, brief discussion of pH and how it affects the chemistry of soil, which, in turn, affects nearby water bodies. It also discusses crops that grow in soils of different pH levels.

2. Students can bring samples from home to practice with before measuring pH with samples collected in the field.

3. For each horizon sampled, mix dry soil samples 1:1 with distilled water and allow this mixture to settle until a supernatant is formed. Then take the pH of the supernatant.

4. Some sort of change is expected to be seen between horizons, depending upon the amount of organic matter, free carbonates present, and weathering of soil.

Additional Information

While the Globe protocols are recommended for student use, truly accurate measurement of pH is not a simple task, and we wish to share the following with you to add to your knowledge of the methods used to study acid rain. According to Dr. Steve Kahl, an acid rain researcher at the University of New Hampshire, "the methods for measuring soil pH are entirely arbitrary, varying from a solution of 1:1 (soil to water) ranging up to 10 to 1. The pH will vary depending on the method. In addition, there is the question of adding an ionic strength adjuster. Some methods add KCl (potassium chloride), but the added salt displaces hydrogen from soil exchange sites and lowers the pH. A soil with a pH of 4 in water may have a pH of 2.5 after you add KCl." In short, measuring pH, whether of soil or water, is not simple!

A Note on Soil Alkalinity

If students aim to measure the pH of soil horizons, it would seem a natural extension to measure the alkalinity as well and relate the two parameters. However, as Dr. Kahl shared with us, "the concept of alkalinity applies theoretically to soils, but there is a catch in the Northeast (and many other parts of the world with similar soils): the alkalinity is so negative that it doesn't make sense to measure it. For example, a typical protocol for measuring alkalinity in water is to titrate the sample with acid to a pH of 3.5. But soils in our area may have a pH of 3.2!"

If you would like your students to relate and explore the concepts of pH and alkalinity (also known as **acid neutralizing capacity or ANC**), it is recommended that students perform activity 3.6 Buffering Experiments.

Results

Activity

4.10 Interpreting and Synthesizing Results

top of chapter 4

Overview

When using Globe protocols, refer to the "Looking at the Data" section at the end of each protocol. This section is designed to be used by teachers of younger students and by the older students on their own. It provides guidance for interpreting your results and checking to make sure that these results are reasonable, given your experimental design and the landscape you're studying. As an example, refer to page 19 of the Globe *Precipitation Protocols*.

Source

Globe *Precipitation Protocols*

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:3.1, 3.2, 3.3, 4.1, 5.1, 5.2
- S:SPS2:11:4.2
- S:SPS3:11:3.1

Student Outcomes

Unique to each protocol

Materials and Tools

Unique to each protocol

Assessment

Unique to each protocol

Estimated Time

One to two 40-minute class periods

Background Needed

Unique to each protocol

Activity

4.11 Representing and Communicating Results

top of chapter 4

Overview

The following resources provide teachers and students with methods for representing results (tables, charts, diagrams, and graphs) as well as ideas for communicating these results. Written reports, posters, and/or presentations containing graphic representations of data may be shared via the Web, at science symposia/fairs, or at town meetings.

Sources

Globe and Tom Mitchell, Science Teacher at Milford High School, Milford, NH

Standards Addressed

(refer to NH Science Standards)

- S:SPS1:11:4.1, 5.1, 5.2
- S:SPS2:11:4.2
- S:SPS3:11:3.1

Student Outcomes

- Compile and display data, evidence, and information by hand and computer in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots.
- Explain how data support or refute the hypothesis or prediction.
- Provide a statement that addresses the question investigated in light of the evidence generated in the investigation.
- Analyze environmental issues, such as the effects of acid rain on precipitation, soils, etc.

Materials and Tools

Depending on project chosen, materials may include Computer graphing program or graph paper, rulers, pencil/pen, poster board

Assessment

Varies depending on what project is chosen (display data in tables and/or in graphs; present findings on a poster via oral presentation, etc.)

Estimated Time to Complete Lesson

Varies according to project chosen

Background Needed

Understanding of the research question and data collection leading up to the results; sufficient background knowledge to interpret results

4.11 Teacher Lesson Planning: Representing & Communicating Results

Representing Results

Teachers wishing to participate and/or utilize Globe resources, such as tutorials and datasets, should sign up for Globe. Attending a Globe workshop is required, see schedule on site.

Communicating Results

Student can also develop scientific posters (Chapter 6: Curriculum Options) using a curriculum model developed by teacher Tom Mitchell at Milford High School in Milford, NH. This is a great way to communicate results at science symposia/fairs or any place where people can walk around and view posters.

Chapter 5

Slideshows

Chapter Activities

Overview

Four slideshows have been developed for this teaching guide. The first, *Acid Rain 101*, can serve as a primer for teachers wishing to learn content information about acid rain. Three additional slideshows tell the story of acid rain research within the Hubbard Brook Ecosystem Study and are presented in three parts: *The Discovery, The Calcium Experiment*, and *Ecosystem Recovery*.

Each slideshow is provided in Power Point and PDF format. The Power Point version allows teachers to customize the presentations to meet the appropriate grade level and subject matter being covered.

Environmental Literacy Program

Activity

5.1 Acid Rain 101

top of Chapter 5

Overview

Designed for teachers as well as students, this slideshow presents an introduction to the basics of acid rain: sources, formation, chemistry, effects on terrestrial and aquatic ecosystems, and legislation to remediate. It has been designed as a tutorial for teachers as well as for students.

Note: As it is lengthy and covers many topics, it is not recommended that it be shown in its entirety to students without first customizing it to emphasize specific content areas.

Sources

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:2.1, 7.1
- S:ESS4:11:3.3
- S:LS2:11:1.4, 1.5, 2.2
- S:LS3:11:1.1, 1.2
- S:LS4:11:2.6
- S:PS2:11:2.3

Student Outcomes

- Define terms pH, pH scale, and acid rain.
- List pollutants and origin of pollutants emitted and deposited that create acid rain.
- Describe effects of acid rain on water, soil, and organisms (including humans).
- Explain measures required by the Clean Air Act and Amendments to remedy the problem of acid rain.

Materials and Tools

- **Slideshow:** *Acid Rain 101*.
- Computer with projector, or computers with Internet access for all students.

Estimated Time to Complete Lesson

One 40-minute period

Background Needed

None

Activity

5.2 Part I: The Discovery

top of Chapter 5

Overview

This slideshow gives a brief history of the Hubbard Brook Experimental Forest (HBEF), describes parameters measured at HBEF that contribute to long-term monitoring, and explains how acid deposition was first documented at HBEF.

Source

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:2.1, 7.1
- S:ESS4:11:3.3
- S:LS2:11:2.2
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS2:11:1.3, 2.1, 2.3

Student Outcomes

- Define "inputs" and "outputs" in terms of an ecosystem.
- List the parameters measured at HBEF that contribute to long-term monitoring.
- Describe what led to the discovery of acid rain in North America.

Materials and Tools

- **Slideshow:** *Part I: The Discovery.*
- Computer with projector, or computers with Internet access for all students

Estimated Time to Complete Lesson

One 40-minute period

Background Needed

None

Activity

5.3 Part II: The Calcium Experiment

top of Chapter 5

Overview

This slideshow describes the story of a watershed-scale experiment designed to evaluate how the addition of calcium might affect forest and aquatic ecosystems stressed by calcium depletion due to acid rain.

Source

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:2.1, 7.1
- S:LS2:11:2.2
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS2:11:1.3, 2.1, 2.3
- S:SPS3:11:3.1

Student Outcomes

- Describe the reasoning behind the addition of calcium to a watershed.
- Explain hypotheses generated for this experiment.

Materials and Tools

- **Slideshow:** *Part II: The Calcium Experiment..*
- Computer with projector, or computers with Internet access for all students

Estimated Time to Complete Lesson

One 40-minute period

Background Needed

Helpful slideshow: *Part I: The Discovery*

Activity

5.4 Part III: Ecosystem Recovery

top of Chapter 5

Overview

This slideshow introduces the concept of ecosystem recovery and explains thresholds that must be met for the Northern Forest ecosystem to be considered "recovered" from acid rain.

Source

Hubbard Brook Research Foundation

Standards Addressed

(refer to NH Science Standards)

- S:ESS1:11:7.1
- S:ESS4:11:3.3
- S:LS2:11:1.4, 1.5, 2.2
- S:LS3:11:1.1, 1.2, 1.3
- S:LS4:11:2.6
- S:SPS1:11:5.1, 5.2
- S:SPS2:11:1.3, 2.1, 2.3
- S:SPS3:11:3.1

Student Outcomes

- Describe the value of long-term monitoring in determining ecosystem "health."
- Explain that chemical recovery of an ecosystem must happen before biological recovery can occur.
- List some benchmarks that must be reached for an ecosystem to be considered "recovered."

Materials and Tools

- **Slideshow:** *Part III: Ecosystem Recovery.*
- Computer with projector, or computers with Internet access for all students

Estimated Time to Complete Lesson

One 40-minute period

Background Needed

Helpful slideshows: *Part I: The Discovery* and *Part II: The Calcium Experiment*

Chapter 6

Curriculum Options

Chapter Activities

Overview

This chapter provides a sampling of tools for developing curricula that can be used to guide student learning and assess achievement of the standards chosen for this study.

Note: Additional assessments are included for each specific activity in Chapters 3 and 4.

Environmental Literacy Program

Activity

6.1 A Suggested Framework for Middle School Inquiry

This lesson to help guide middle school students through a study of acid rain was provided by Lisa Hjelm, science teacher at the Crossroads Academy in Lyme, NH. The teacher gives the class an overview of acid rain, then each student researches one question about this issue or its ecological effects. Student questions can be offered by the teacher or generated by the students themselves. Activity 3.2 Pick Your Brain about Acid Rain, helps students practice posing questions about acid rain, some of which may be appropriate for investigations.

Suggested process

Step 1: The teacher facilitates common experiences for the whole class to orient them to the issue of acid rain and teach important concepts.

Step 2: Each student chooses one research question, either given by the teacher or self-generated.

Step 3: Students conduct research to address their question.

Step 4: Students present their findings to the class.

Step 5: The teacher and students summarize and synthesize the information to generate an overarching understanding — an "enduring understanding;" see next page.

Step 6: The class "publishes" its study using one of several possible methods, such as written report, scientific poster(s), video, public presentation, etc.

Step 7: The class organizes a symposium for students, either within the school or at the regional level with other schools that are studying acid rain.

6.2 Understanding by Design

top of Chapter 6

"Understanding by Design" (UbD) uses a "backward design" approach that asks a teacher to begin the curriculum planning process by considering the desired outcome of the unit they are creating: what *enduring understanding(s)* do they want their students to gain from this effort? UbD describes an enduring understanding as a big idea that is at the heart of the unit. It helps students make sense of what they know, know *why* it is so, and apply this knowledge to various situations and contexts. An enduring understanding is a mental organizer of information, a concept that helps students make connections to create a deeper understanding of the world. A teacher may choose one or more enduring understandings as the aim of their unit. We have chosen one enduring understanding around which to focus this teaching guide; you may decide to feature different enduring understandings or add others to this one. UbD was developed by Grant Wiggins and Jay McTighe of the Association of Supervision and Curriculum Development.

Enduring Understanding for *Exploring Acid Rain*

- Human activities can degrade ecosystems and the services they provide.
- Scientific research and long-term monitoring can help people understand how to promote the recovery of degraded ecosystems.

Once one or more *enduring understandings* of a unit have been developed, UbD asks teachers to assemble a list of *essential questions* that will help students achieve the desired outcome. Essential questions cannot be answered in one sentence. They are key inquiries that provide doorways into the exploration of big ideas. They can be revisited again and again for deeper meaning to allow students to reach more subtle levels of understanding. Rather than helping teachers cover certain concepts, essential questions help students uncover information and knowledge. Here are some essential questions that we developed for this teaching guide.

Essential Questions for *Exploring Acid Rain*

- What causes acid rain?
- How does acid rain affect the chemistry of soil and water?
- How does this, in turn, affect an ecosystem?
- What is ecosystem health and how do we know when ecosystems become degraded?
- How do ecosystems recover from degradation, and how do we monitor recovery?

Teachers may want to pose some essential questions to get a student investigation started. Through practice with investigations, students can learn to pose their own essential questions, which come from their own curiosity and are therefore more compelling than those suggested by others. Chapter 3.2 Pick Your Brain about Acid Rain and 3.8 What Is Ecosystem Recovery? give students practice asking questions and exploring possible answers to them.

After the enduring understanding(s) are stated and the essential questions are posed, teachers consider the knowledge and skills that their students will gain from the unit. Teachers may choose to refer to state and national standards for guidance. Please refer to a subset of the New Hampshire Science Literacy Standards included in Chapter 1 of this guide.

Using UbD, assessment occurs throughout the unit and all participants are involved in it. The teacher uses results from student assessments as feedback to adjust their teaching approach. Students are assessed by the teacher, but also perform self- and peer-assessments. A variety of tools and methods are used, such as quizzes and tests, rubrics, and performance tasks.

A variety of assessments is needed throughout the unit to help students achieve specific objectives and to guide them toward the desired outcome. UbD suggests that teachers anchor student assessment around a performance task that asks students to apply their knowledge and skills to a new situation and practice making connections. Examples of such tasks in this teaching guide include designing a scientific poster that summarizes an investigation (6.4 Scientific Posters); and performance-based assessments (6.6 Designing Student Assessments).

After building the curriculum foundation with enduring understandings, essential questions, knowledge and skills, and assessments, the teacher is ready to plan learning experiences for his/her students. The teacher reviews the student activities section of this teaching guide, Chapters 3 through 5, as well as other resources, and creates a body of student experiences.

An example of a unit planning template based on the UbD approach is provided next as a curriculum planning tool.

For more information on Understanding by Design, visit the Association of Supervision and Curriculum Development. ASCD offers a variety of resources, including books, audios, videos, on-line professional development courses, the Understanding by Design Exchange, on-site training, and conferences and workshops.

***Unit Planning Template* ***

Name of Unit: ____

Stage 1: Desired Results

Established Goals:
What relevant goals (for example, content standards, course, or program objectives, learning outcomes) will this design address?

Enduring Understanding(s):

Students will understand the following:

- What are the big ideas?
- What specific understandings about them are desired?
- What misunderstandings are predictable?

Essential Questions:

- What provocative questions will foster inquiry, understanding, and transfer of learning?
- What key knowledge and skills will students acquire as a result of this unit?
- What should students eventually be able to do as a result of such knowledge and skill?

Stage 2:Assessment Evidence

Performance Tasks:

- Through what authentic performance tasks will students demonstrate the desired understandings?
- By what criteria will performances of understanding be judged?

Other Evidence:

- Through what other evidence (for example, quizzes, tests, academic prompts, observations, homework, journals) will students demonstrate achievement of the desired results?
- How will students reflect upon and self-assess their learning?

* Source: Adapted from Understanding by Design, by Jay McTighe and Grant Wiggins, at Association for Supervision and Curriculum Development

Stage 3: Learning Plan

What learning experiences and instruction will enable students to achieve the desired results?
How will the design do the following:

W = Help the students know Where the unit is going and What is expected? Help the teacher know where the students are coming from (prior knowledge, interests)?

H = Hook all students and Hold their interest?

E = Equip students, help them Experience the key ideas and Explore the issues?

R = Provide opportunities to Rethink and Revise their understandings and work?

E = Allow students to Evaluate their work and its implications?

T = Be Tailored (personalized) to the different needs, interests and abilities of learners?

O = Be Organized to maximize initial and sustained engagement as well as effective learning?

Activity

6.3 Student Investigations

top of Chapter 6

Student investigations provide a holistic, engaging way for students to gain science content as well as practice science process skills. The Globe Program was designed to engage students in authentic scientific investigations and help them share their results with other students and scientists around the world. Globe has developed some tools to help students initiate, carry out, and synthesize their investigations. One such tool is The Student Investigation Report Format.

Jeannie Kornfeld, AP Environmental Science teacher at Hanover High School in Hanover, NH, designed a three-week study, assigning students to do an environmental impact assessment of the now-defunct Elizabeth Copper Mine on the Ompompanoosuc River in Strafford, Vermont. This project gives students the opportunity to chemically measure and evaluate the effects that mine tailings have on water that drains from the mine. Teachers interested in this type of local, authentic study may find these paper requirements, method of evaluation, and student field checklists useful.

- Copper Mine Impact Assessment — Paper Requirements
- Copper Mine Impact Assessment — Evaluation
- Fieldwork Checklist
- Materials Checklist

An oral presentation at the end of the students' investigations provides another way to share their learning with others as well as a method for assessment by the teacher. Dean Goodwin, Executive Director of the Center for Inquiry-Based Education offers an Oral Report Evaluation for this purpose.

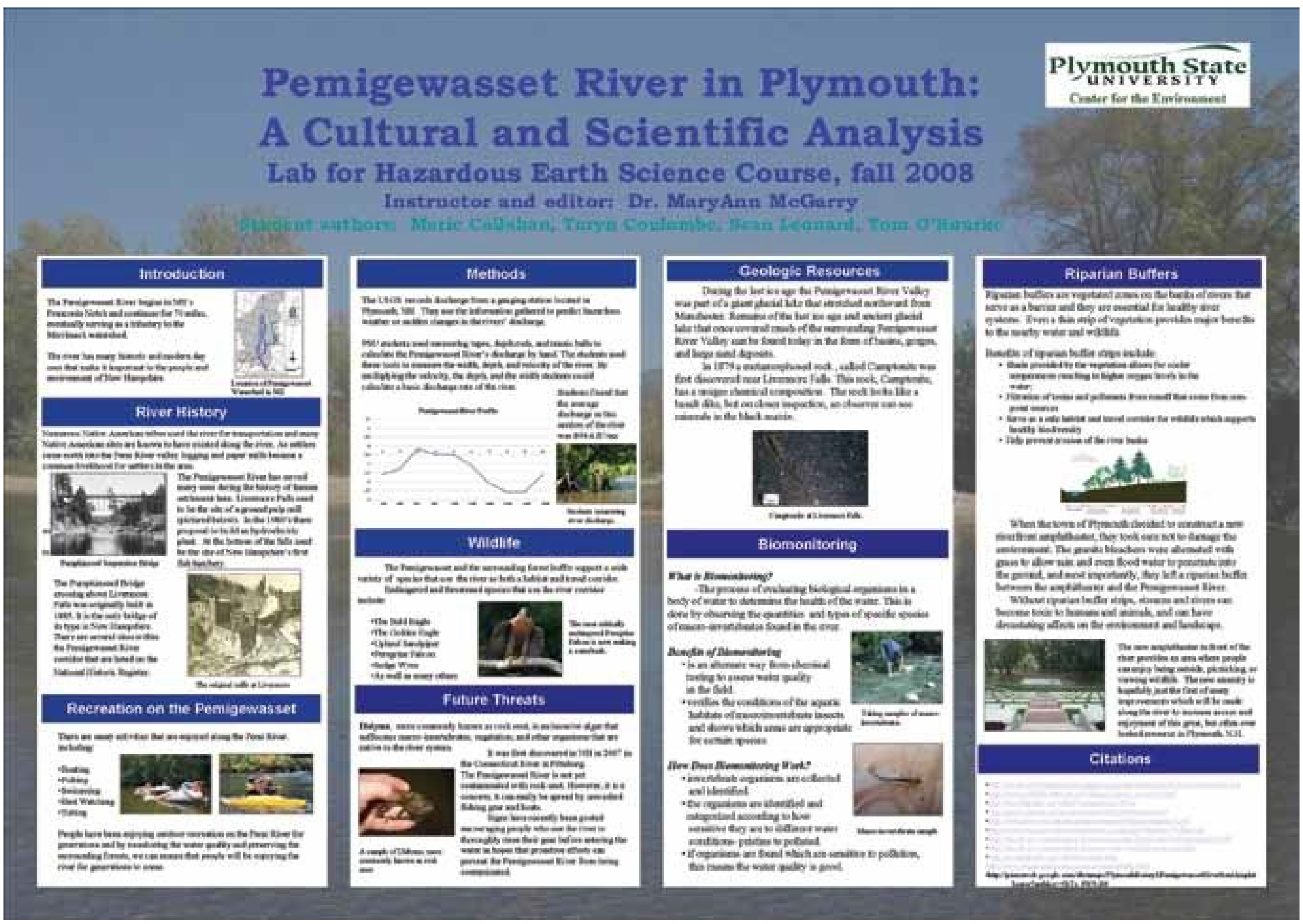
Activity

6.4 Scientific Posters

[top of Chapter 6]

Posters are an effective way for students to synthesize their investigations and communicate their results to others. This set of guidelines was developed by Tom Mitchell, a biology teacher at Milford High School (NH), to help his students create scientific posters.

This poster was an assignment from a course entitled, "The Hazardous Earth" (ESDI 2610-Earth Systems Science), an undergraduate course taught at Plymouth State University by Dr. Mary Ann McGarry. The assignment required students to conduct research on the Pemigewasset River (NH) by studying water quality, quantity and flooding. Students were asked to synthesize what they'd learned about the river firsthand as well as from other research, such as web resources and reports.



Activity

6.5 Student Independent Research Projects

top of Chapter 6

The Globe Web site describes how students can conduct a research project using Globe materials and also provides a research paper format and guidelines for writing a successful paper.

Tom Mitchell, biology teacher at Milford High School (NH), engages his students in semester-long independent projects of their choosing. He has developed a set of documents that introduce his students to scientific study through independent projects, provide guidelines to follow as they design and carry out their projects, and assessments that gauge student learning. Links to these documents are provided here.

- How to Start Your Semester Project
- Semester Project Description
- Project Proposal Outline
- Project References
- Abstract Requirements (evaluation)
- Progress Update (evaluation)
- Semester Project Evaluation — Rubric #1

Students interested in learning about the research and experiences of actual scientists can visit Hubbard Brook Scientists. Teachers might ask students to choose a researcher of particular interest and profile her/his career and major research projects.

Activity

6.6 Designing Student Assessments

top of Chapter 6

Lab Reports

Several of the lessons in this guide are experiment-based, a method that best reflects the process of doing science. Lab reports are the best way to assess these lessons; however, methods for evaluating such activities are varied, and depend on the time and outcomes designated. Depending on the amount of time a teacher wishes to devote to a lesson, students might simply answer procedural and discussion questions, or they might participate in a more holistic assessment, as described in the Globe *Just Passing Through* activity excerpted here:

> "In general, students should know the scientific method and how to use it to set up an experiment. They should also be able to demonstrate higher order thinking skills such as drawing conclusions from experimental observations and they should be able to justify their conclusions with evidence. These can be assessed by using a portfolio assessment of their lab notebooks, class participation in discussions and the contribution of questions, hypotheses, observations and conclusions. The quality of their presentations is another mechanism for assessing students' progress. It is also a good idea to have the students prepare a written report or a paper on their experiment. The experimental work should be done in groups as should the presentations and the reports so that their ability to work cooperatively in groups can also be assessed."

Certainly, it requires significant time for a teacher to develop class participation assessment instruments, an oral presentation rubric, a written report rubric, and a group work rubric. Alternatively, the teacher can ask different groups of students to design evaluation criteria for the different rubrics/evaluation instruments mentioned above. Each rubric/instrument can then be shared and discussed with classmates for a final revision. If students have ownership in creating the rubrics they may pay more attention to the criteria, resulting in higher quality work.

The following pages contain a rubric that we've designed with the help of RubiStar, a free on-line tool that helps teachers create rubric.

Other Assessments

The Globe Teachers Implementation Guide Appendix provides a variety of assessment tools that are valuable for assessing student-directed investigations and projects.

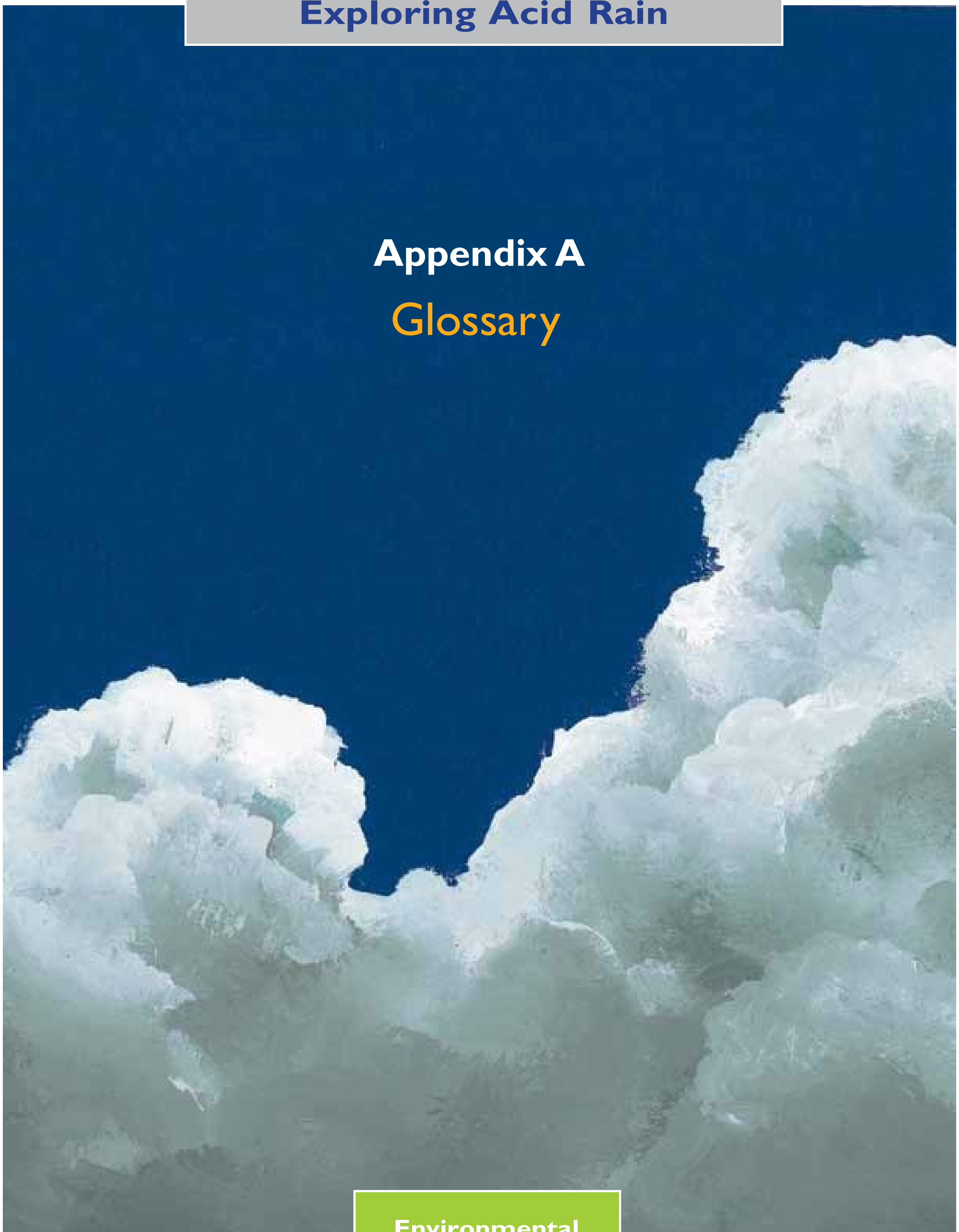
- Globe Assessment Portfolios (page 11)
- Rubrics: Sample Generic Rubric (page 14); Research and Analysis (page 17); Communication (page 18)
- Science Journals — Student Journal Grading Criteria (page 15)
- Open-Ended Questions (page 19)
- Performance-Based Assessments (page 20)

Rubric: Lab Report

CATEGORY	4	3	2	1	0
Title	Title concisely and accurately describes experiment.	Title describes experiment well.	Title describes experiment, but not particularly well.	Title does not describe experiment.	Title absent.
Purpose	The purpose of the experiment is clearly and accurately stated in a complete sentence.	The purpose of the experiment is stated well in a complete sentence.	The purpose of the experiment is stated well but not in a complete sentence.	A purpose is given, but not stated clearly or accurately, and/or not in a complete sentence.	Purpose absent.
Hypothesis (Hypotheses)	A complete sentence that describes and explains a predicted outcome between the variables ("what you think and why") is clearly stated and reasonable based on what has been studied.	A complete sentence that describes and explains a predicted outcome between the variables ("what you think and why") is stated and related to what has been studied.	A complete sentence that describes and explains a predicted outcome between the variables ("what you think and why") is stated, but appears to be based on flawed logic.	A prediction is given, but it does not relate variables, and/or is not in a complete sentence.	Hypothesis absent.
Materials	All materials and setup used in the experiment are clearly and accurately described.	Almost all materials and the setup used in the experiment are clearly and accurately described.	Most of the materials and the setup used in the experiment are accurately described.	Many materials are described inaccurately.	Materials absent.
Procedures	Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences.	Procedures are listed but are not in a logical order or are difficult to follow.	Procedures do not accurately list the steps of the experiment.	Procedure absent.
Results* *See Lesson 3.9 for a separate rubric for graphs	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in written form, but no graphs or tables are presented.	Data inaccurate.	No data presented.
Conclusion	Conclusion includes whether the findings supported the hypothesis, possible sources of error, and what was learned from the experiment.	Conclusion includes whether the findings supported the hypothesis and what was learned from the experiment.	Conclusion includes what was learned from the experiment.	Conclusion shows little effort and reflection.	Conclusion absent.
Appearance/ Organization	Lab report is typed and uses headings and subheadings to visually organize the material.	Lab report is neatly handwritten and uses headings and subheadings to visually organize the material.	Lab report is neatly written or typed, but formatting does not help visually organize the material.	Lab report is handwritten and looks sloppy with cross-outs, multiple erasures and/or tears and creases.	No lab report submitted.

Appendix A

Glossary



Environmental Literacy Program

Glossary

abiotic – Non-living chemical and physical factors in the environment.

acid rain – Rain containing acids that form when compounds released into the atmosphere from the burning of fossil fuels, agricultural practices, and other human activities combine with water. "Normal" rain is slightly acidic with a pH of about 5.6; acid rain has a lower pH.

acid deposition – Deposition that is acidic, including rain, fog, and clouds (wet deposition), as well as particle and gas deposition (dry deposition). The term "acid deposition" includes acid rain and refers to all forms of wet and dry deposition that have a lower than normal pH.

acid precipitation – Precipitation that is acidic. Acid rain is a type of acid precipitation.

acid neutralizing capacity (ANC) – A measure of the ability of water or soil to neutralize added acids, such as those from acid deposition. Streams with higher ANC levels are affected less by acid rain than streams with lower ANC values.

acidification – The process whereby an ecosystem become acidic.

alkalinity – A measure of the buffering capacity of a system. Traditionally defined as a function of carbonate and bicarbonate ions.

anion – A negatively charged ion such as nitrate (NO_3^-) or chloride (Cl^-).

anthropogenic – Caused by humans. For example, acid rain sources are anthropogenic.

base cation – A positively charged ion such as magnesium, sodium, potassium, or calcium that increases the pH of water (makes it less acidic) when released into solution through mineral weathering and exchange reactions.

baseline – A measurement, calculation, or location used as a basis for comparison. In terms of ecology, "baseline" refers to how a system functions in its natural state, or before an experiment.

biogeochemistry – The study of the relationship between the **geochemistry** of a region and the animal and plant life in that region.

biotic – Living organisms in the environment; can also be used to describe things that are related to, produced by, or caused by living organisms.

budget (of an ecosystem) – A measurement of the **fluxes** as affecting pools of water, nutrients, and materials in an ecosystem.

buffering capacity – The ability, or capacity, of a discrete system (i.e., volume of soil) to buffer, or neutralize, acids; similar to and sometimes used interchangeably with the terms **acid neutralizing capacity** and **alkalinity**.

calcium – A **base cation** that is an important plant nutrient. Acid rain **leaches** calcium out of the soil.

cation – A positively charged ion such as sodium (Na^+) or ammonium (NH_4^+).

cation exchange capacity (CEC) – A measure of the number of sites on soil surfaces that can retain positively charged ions (cations) by electrostatic forces.

conductivity – A measure of the transmission of heat, electricity, or sound through something. For example, the electrical conductivity of water samples is often measured to determine ion concentration.

control – A treatment that reproduces all aspects of an experiment except the variable of interest. Most well-designed experiments have control and **treatment** groups. An experimental manipulation is applied to the treatment group, and nothing is done to the control group. There should be no other differences between control and treatment groups.

disturbance – A natural or human-induced disruption or alteration of an ecosystem. Forest fires, tornadoes, or rock slides are examples of natural disturbances; logging, **acid rain**, and road-building are examples of human disturbances.

dynamic ecosystem – Dynamic refers to the idea that living organisms interact with every other element in their local environment. Ecosystems are not static (i.e., unchanging). Rather, to paraphrase Eugene Odum (a founder of ecology), all of the organisms in a community interact with the physical environment of that community so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e., exchange of materials between living and nonliving parts).

ecology – The study of the interactions of living organisms with one another and with their nonliving environment of matter and energy.

ecosystem – A community of different species interacting with one another and with the chemical and physical factors making up the nonliving environment.

ecosystem services – Refers to the resources and processes that are supplied by natural ecosystems, and include products such as clean drinking water, as well as processes, such as decomposition of wastes.

evapotranspiration – The loss of water from a given area during a specified time by evaporation from the soil surface and by transpiration from plants.

flux – The rate of flow of energy or chemical compounds from a source (a place that holds the energy or compounds) to a sink (a place that accepts more energy or compounds).

geochemistry – The chemistry of the composition of, and changes to, the solid matter of the earth.

homeostasis – In biology, this usually refers to the ability of an organism or to regulate its internal environment and to maintain a stable, constant condition. It can also be used to describe an ecosystem, though it should be noted that ecosystems are never in a steady state.

hydrology – The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

ion – An atom or a compound with a net positive or negative electrical charge.

leaching – The process in which nutrients and other compounds (such as calcium) in the upper layers of soil are dissolved and carried to lower layers and, in some cases, to groundwater.

lysimeter – A device that is placed in the ground to collect soil water. There are two types of lysimeters at HBEF: zero-tension and tension.

> **zero-tension lysimeters** collect soil water that is naturally percolating downward through soils because of gravity. They are designed to capture soil water that might otherwise make its way into groundwater or lower soil horizons.
>
> **tension lysimeters** have a vacuum applied to them (similar to the pull that roots might exert on soils) and gently "suck" soil water through porous materials. They are designed to capture soil water that roots might take up.

pH indicator – A chemical compound that is added in small amounts to a solution so that the pH of the solution can be determined easily by observing the color of the solution. Commonly used pH indicators are Bromothymol Blue and Universal Indicator solution.

protocol – The plan of a scientific experiment.

rain gauge – A device used to quantitatively measure rainfall. Weekly rainfall is measured at the ~30 rain gauges throughout the HBEF.

reference – Similar to "control," referring to a treatment that reproduces many of the aspects of an experimental design, while excluding the variable of interest. Whereas in an experiment using a true control, the treatment and control differ *only* in terms of the variable of interest, a reference and a treatment are designed to be as *similar as possible*, but may have several differences. For example, at the HBEF, Watershed 3 and Watershed 6 serve as "references" to the "experimental" watersheds. That is, when Watershed 2 was logged, scientists compared what happened after the logging in Watershed 2 to what happened in Watershed 3. Presumably, any difference between the two could be attributed to the logging effects. However, Watershed 3 cannot be referred to as a "control" because it was not *exactly the same* as Watershed 2 before the experiment. It is often impossible to have true controls in field experiments (i.e. it is impossible to find two absolutely identical watersheds), so references are often the best option.

residence time – The ratio of the size of a compartment to the flux through it, expressed in units of time; thus, the average time spent by energy of a substance in the compartment. For example, scientists are often interested in the residence time of certain nutrients in a lake. The lake is the compartment, and the nutrient is the substance. Residence time is a measure of how long this nutrient (e.g. after it arrives via a stream, or deposition, etc.) stays in the lake before being removed (e.g., by the outflow stream).

resilience – In ecology, an ecosystem that is resilient is one that is able to withstand stressors (i.e., fire, acid rain, etc.). This is determined by the degree to which the ecosystem can respond and the rate at which it can recover from stressors.

resistance – In ecology, a resistant ecosystem is one that is able to maintain the organisms and processes that define it as that particular ecosystem even in the presence of stress.

soil horizons – Soils are generally composed of many different layers, or horizons lying on top of one another. A variety of biological (e.g., decomposition), chemical (e.g. rain/soil interactions), and physical (e.g., weathering) processes form these horizons. In the HBEF, soils often consist of an organic horizon containing dead plant material in various stages of decay at the surface, with mineral (non-organic) soil horizons underneath it. The O (organic) horizon is closest to the surface, with mineral horizons such as A, E, B, and C lying underneath the O horizon and above bedrock. View Hubbard Brook Acid Rain Story, Part III to see a typical HBEF soil profile.

stream gauge – Also known as a "weir", a device used to measure streamflow volume over time. At the HBEF there are nine watersheds that have stream gauges. Weirs are permanent concrete structures that consist of a large stilling basin with a v-notch at one end. By constantly measuring how high the stream is at it passes over this v-notch, and entering this height into a known formula, researchers can determine streamflow volume.

throughfall – Rain that falls through and can be collected under the tree canopy of a forest. Throughfall interacts with leaves and materials present on leaves (for example, dust, plant secretions, insect droppings, etc.) and therefore can be chemically very different from rain that falls directly to the surface.

titration – A common laboratory method of determining the concentration of a solution (titrand) by adding a standard reagent of known concentration (titrant) to it in carefully measured amounts until a reaction of definite and known proportion is completed, as shown by a color change or by electrical measurement. After determining the volume of titrant added, the unknown concentration of the titrand may be calculated.

treatment – In an experiment, the group to which an experimental manipulation has been applied; paired with a control group. See **control** for an example.

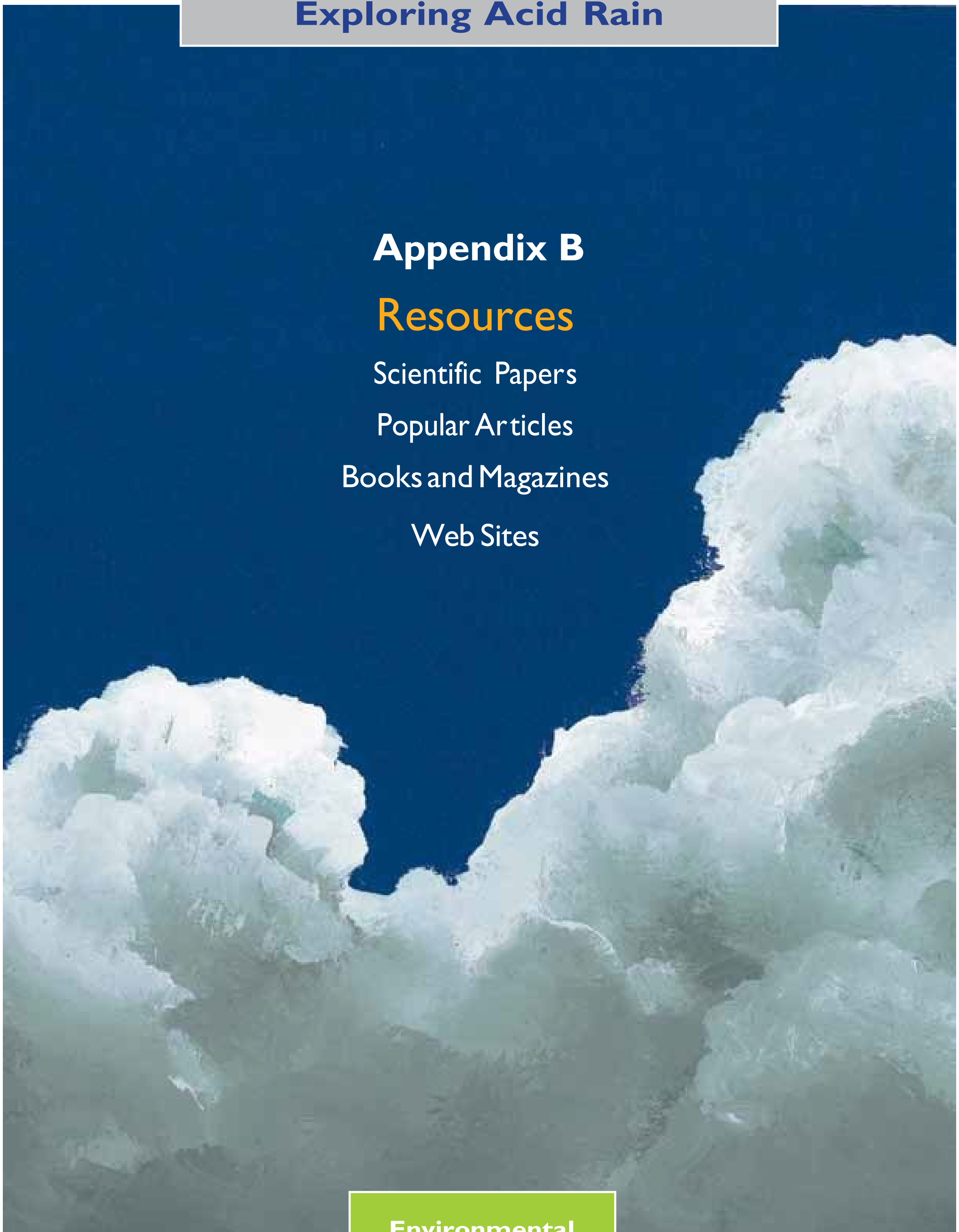
turnover or turnover time – The time it takes for a something to be completely replaced in a given area. An example is the northern forest: turnover time for all of the trees in a given area of forest is equal to the number of years that it would take to replace the whole forest. To calculate this, the total area of trees is divided by the area of trees that blow down per year. Another example is nitrogen turnover, which is when a molecule of nitrogen leaves a given population of soil microbes and is replaced by a new molecule of nitrogen. To calculate the number of days that it would take for all of the nitrogen in a given population of microbes to be replaced, or "turned over," the total microbial nitrogen pool (mg of N) would be divided by the rate of nitrogen uptake by the microbes.

watershed – The drainage area of a stream, river, or other body of water. There are nine gauged watersheds in the HBEF, ranging in size from 11 to 76 hectares, and researchers have conducted experiments on many of them. Because these watersheds are similar to each other, researchers can experiment with one entire watershed (for example, by cutting all the trees down in the "treatment" watershed), leave another one alone (the "reference" watershed), and then compare them. If, in following years, the treatment watershed is very different from the reference watershed, scientists will learn how cutting down trees affects entire forests. This type of experiment is referred to as a "paired watershed" experiment.

weir – Also known as a "**stream gauge"**, a device used to measure streamflow volume over time. At the HBEF there are nine watersheds that have stream gauges. Weirs are permanent concrete structures that consist of a large stilling basin with a v-notch at one end. By constantly measuring how high the stream is at it passes over this v-notch, and entering this height into a known formula, researchers can determine streamflow volume.

wollastonite (CaSiO3) – A mineral containing calcium silicate. In 1999 a new experiment was started at the HBEF in which scientists began looking at how an addition of calcium affects a watershed that has had its calcium soil pools depleted by acid rain over several decades. Calcium was applied to the watershed in the form of pelletized wollastonite.

zooplankton – Microscopic animal organisms that drift in bodies of water.



Appendix B

Resources

Scientific Papers

Popular Articles

Books and Magazines

Web Sites

Environmental Literacy Program

Resources

This teaching guide is principally based on the Hubbard Brook Research Foundation's *Science Links* report, *Acid Rain Revisited: Advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments*. View and download *Acid Rain Revisited* here.

The following list represents some of the many other resources available on the topic of acid deposition. Items within each subheading are listed alphabetically.

Scientific Papers

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eager, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acidic Deposition in the Northeastern U.S.: sources and inputs, ecosystem effects, and management strategies. 2001. BioScience 51(3): 180-198.

Galloway, J.N., G.E. Likens, W.C. Keene, and J.M. Miller. 1982. The composition of precipitation in remote areas of the world. Journal of Geophysical Research 87: 8771-8786.

Hall, R.J., C.T. Driscoll, G.E. Likens, and J.M. Pratt. 1985. Physical, chemical and biological consequences of episodic aluminum additions to a stream. Limnology and Oceanography 30(1): 212-220.

Juice, S.M., T.J. Fahey, T.G. Siccama, C.T. Driscoll, E.G. Denny, C. Eager, N.L. Cleavitt, R. Minocha, and A.D. Richardson. 2006. Response of Sugar Maple to Calcium Addition to Northern Hardwood Forest. Ecology 87(5):1267-1280.

Kahl, J.W., J.L. Stoddard, R. Haeuber, S.G. Paulsen, R. Birnbaum, F.A. Deviney, J.R. Webb, D.R. DeWalle, W. Sharpe, C.T. Driscoll, A.T. Herlihy, J.H. Kellogg, P.S. Murdoch, K. Roy, K.E.Webster, and N.S. Urquhart. 2004. Have U.S. Surface Waters Responded to the Clean Air Act Amendments? Environmental Science and Technology 38: 484-490.

Likens, G.E., F.H. Bormann, and N.M. Johnson. 1972. Acid Rain. Environment 14: 33-40.

Likens, G.E. and F.H. Bormann. 1974. Acid Rain: a serious regional environmental problem. Science 184(4142):1176-1179.

Likens, G.E., C.T. Driscoll, and D.C. Buso. 1996. Long-Term Effects of Acid Rain: response and recovery of a forest ecosystem. Science 272:244-246.

Likens, G.E., D.C. Buso, and T. Butler. 2005. Long-term relationships between SO2 and NOx emissions and SO4 and NO3 concentrations in bulk deposition at the Hubbard Brook Experimental Forest, NH. Journal of Environmental Monitoring 7: 964-968.

Oden, S. 1968. The acidification of air and precipitation and its consequences in the natural environment. Swedish National Research Council, Stockholm.

Smith, R.A. 1872. Air and Rain: The Beginnings of a Chemical Climatology. Longmans, Green, London.

Stoddard, J.L., J.S. Kahl, F.A. Deviney, D.R. DeWalle, C.T. Driscoll, A.T. Herlihy, J.H. Kellogg, P.S.

Murdoch, J.R. Webb, and K.E. Webster. 2003. Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990. U.S. Environmental Protection Agency Office of Research and Development National Health and Environmental Effects Research Laboratory Research Triangle Park, NC 27711

Weathers, K.C., G.E. Likens, and T.J. Butler. 2006. Acid Rain. In: Rom W.N., ed. Environmental and Occupational Medicine (4th edition). Philadelphia: Lippincott, Williams and Wilkins: 1507-1520.

Popular Articles

Acid Deposition Fact Sheet
Ecological Society of America, Summer 2000.

Acidic Deposition in the Northeastern United States
Driscoll et al., BioScience, March 2001, Volume 51, Number 3.

Basic Ecological Literacy: A First Cut (The Ecological Society of America)
Explains the importance of ecology education, some of the inherent challenges involved in implementing it, and describes Eleven Basic Ecological Concepts that provide a very useful framework for the study of ecology.

Books and Magazines

Acid Rain, by Louise Petheram, published by Capstone Press Inc., 2002.
Explains the effects of acid rain on our planet, such as the health risks to humans, plants, and animals, and suggests ways to help alleviate the problem.

Acid Rain, Acid Snow, by John Slade, Woodgate International, PO Box 190, Woodgate, NY 13494, 2001.
A non-fiction description of acid precipitation in clear, lively language. The book examines all aspects of the problem in layman's terms, and provides a complete understanding on the regional, national, and international levels. The book also offers positive alternatives in energy production, and recommends specific options for people who want to do something about global pollution. Used as a textbook in high school and college courses.

Assessing Student Understanding in Science: A Standards-Based K-12 Handbook, by Sarah K. Engler and Robert E. Yager, Corwin Press, Inc., A Sage Publications Company, Thousand Oaks, California, 2001. www.corwinpress.com

Effects of Acid Rain on Forest Processes, by Douglas L. Godbold, published by John Wiley & Sons, Inc., 1994.
A detailed analysis of acidification effects on forest soil, rhizosphere, and plant life and on the processes connecting them such as nutrient uptake and mineral cycling. Presents findings from the Solling project, an important long-term study on acid rain effects in Germany's Black Forest, as well as other European forests which have experienced severe acid rain damage as a means of evaluating and predicting similar harm to U.S. forests.

Experimental Reversal of Acid Rain Effects: The Gardsjon Roof Project, edited by Hans Hultberg and Richard A. Skeffington, published by John Wiley & Sons, Inc., 1997.
Acid rain researchers in Sweden and the United Kingdom embarked on a significant experiment to eliminate acid deposition in an acidified catchment near Lake Gardsjon in southwestern Sweden and monitor the effects. This book records the results from the first five years of the project which lasted

from 1991 – 2001. The implications for pollution control policies and what still needs to be researched are emphasized. The book should be of interest to a wide variety of environmental scientists, especially those interested in pollution effects, forestry, freshwater fisheries, and ecosystem function, and to environmental managers and policymakers.

Green Teacher Magazine: Education for Planet Earth, edited by Tim Grant and Gail Littlejohn. Canada: Green Teacher, 95 Robert Street, Toronto, ON M5S 2K5; United States: Green Teacher, PO Box 452, Niagara Falls, NY, 14304-0452. (416) 960-1244 or (888) 804-1486. www.greenteacher.com. Electronic subscriptions available (back issues may be purchased).

Books

Teaching Green: The Middle School Years: Hands-on Learning in Grades 6-8

Teaching Green: The High School Years: Hands-on Learning in Grades 9-12

Rubrics for Assessing Student Achievement in Science Grades K-12, by Hays B. Lantz, Jr., Corwin Press, A Sage Publications Company, Thousand Oaks, California, 2004. www.corwinpress.com.

Web Sites

Chemistry Department at the University of Maine
Helpful site for understanding soil chemistry.

Cornell Science Inquiry Partnerships
Cornell University graduate students have collaborated with middle and high school science teachers to design and implement inquiry-based lesson plans and student research projects.
http://csip.cornell.edu/ and http://ei.cornell.edu

Ecology Education Network (EcoEdNet)
A library that provides educators with a forum to contribute and locate peer-reviewed, scientifically and pedagogically sound ecology education content. Strives to foster a community of users and contributors to ecology education.

Ecological Society of America: Teaching and Learning
https://www.esa.org/esa/education-and-diversity/educator-resources/

Environmental Inquiry (see above, Cornell University) http://ei.cornell.edu/

Environmental Literacy Council
The Council gives teachers the tools to help students develop environmental literacy: a fundamental understanding of the systems of the world, both living and non-living, along with the analytical skills needed to weigh scientific evidence and policy choices. Excellent background information, data, maps, classroom links. www.enviroliteracy.org

Environmental Protection Agency: www.epa.gov

EPA Acid Rain: http://www.epa.gov/acidrain/

EPA Acid Rain Program: http://www.epa.gov/airmarkets/progsregs/arp/index.html

EPA: Clean Air Act: www.epa.gov/air/caa/peg

EPA Educational Resources, Science Experiments: http://www.epa.gov/acidrain/education/index.html

EPA Acid Rain Students Site: http://www.epa.gov/acidrain/education/site_students/index.html

Learning About Acid Rain: A Teachers' Guide for Grades 6-8: http://www.epa.gov/acidrain/education/teachersguide.pdf

Field-tested Learning Assessment Guide (FLAG)

The FLAG offers broadly applicable, self-contained modular classroom assessment techniques (CATs) and discipline-specific tools for STEM instructors interested in new approaches to evaluating student learning, attitudes and performance. Each has been developed, tested and refined in real colleges and universities classrooms. The FLAG also contains an assessment primer, a section to help you select the most appropriate assessment technique(s) for your course goals, and other resources.

Globe Program (Global Learning and Observations to Benefit the Environment) Teachers must attend a workshop to join (www.globe.gov). See information at this site.

Great Explorations in Math and Science (GEMS): Acid Rain Teacher's Guide (Revised in 1999)

GEMS develops and publishes science and math curriculum, offers professional development, and maintains an international support network. Read about the educational effectiveness of GEMS materials. http://www.lhsgems.org

Hands on the Land

Provides a national network of field classrooms to enhance kindergarten through high school student-learning. www.handsontheland.org

Hubbard Brook Ecosystem Study and Hubbard Brook Research Foundation: Teacher and Student Resources https://hubbardbrook.org/k-12-classroom-resources-environmental-literacy-program

North American Association for Environmental Education (NAAEE)

NAAEE is the professional association for environmental education. Members promote professional excellence in nonformal organizations, K-12 classrooms, universities (both instructors and students), government agencies, and corporate settings throughout the U.S. and in over 55 other countries. www.naaee.org

Physical Geography.net: Fundamentals of Physical Geography

An excellent site for those wishing to learn more about biogeochemistry. Check out the diagram and description of the nitrogen cycle – it's clear, concise, and informative. http://www.physicalgeography.net/fundamentals/9s.html

Promise of Place

Fosters student achievement and sustainable communities through place-based education. www.promiseofplace.org

Soil Science Education Home Page

NASA Web site helpful for understanding soil formation and processes related to soil. http://soil.gsfc.nasa.gov/