Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2003 Volume V: Water in the 21st Century

Do We Need to Wear a Rainhat? Acid Rain: Causes, Effects, and Possible Solutions

Curriculum Unit 03.05.01
by Joanna Maria Ali

Unit Goals

This unit will attempt to allow students to explore the causes and effects of acid precipitation, relate this phenomena to their own lives and come up with possible solutions to the problem. It is my hope that this unit will empower students to make environmentally sound choices based on information that is relevant to their lives and experiences. The unit is designed for high- level juniors and seniors in an environmental science course, but the lessons can be easily adapted for other grades and ability levels. The progression of the unit is based upon building on layers of knowledge according to Bloom's Taxonomy. The first stage is comprehension and basic understanding of the concept of pH, leading to the final stage, which is the synthesis and evaluation of a complex environmental issue.

Unit Objectives:

- Students will be able to explain the pH scale and distinguish between acids and bases.

- Students will be able to explain the causes of acid precipitation

- Students will be able to determine and explain how acid precipitation affects ecosystems.

- Students will be able to describe the 'history' of acid rain

- Students will be able to describe how the problem of acid rain is a "global problem"

- Students will be able describe ways that the Environmental Protection Agency and other groups and companies are attempting to reduce the emissions that cause acid rain

- Students will be able to describe ways that acid precipitation affects the environment they live in

- Students will be able to describe ways in which they can help to solve the problem of acid rain in their own communities.

- Students will be able to evaluate the existing measures to reduce acid rain and devise schemes of their own.

This unit will closely follow the standards set forth by the New Haven Public Schools science curriculum. Under content standard 1.0 scientific inquiry this unit addresses four points.

- Students will be able to identify questions and concepts that guide scientific investigation.

- Students will be able to design and conduct a controlled scientific investigation that will demonstrate the connection between a hypothesis and the design of an experiment

- Students will be able to use scientific criteria with alternative explanations and scientific models

- Students will be able to communicate effectively and defend scientific arguments in response to critical comments

This unit will also address the following standards set forth under section 3.0 life science:

- Students will be able to recognize the interdependence of living organisms and the environment

- Students will be able to discuss the impact of humans on the world's ecosystems

The Problem

The Earth's ecosystem is fragile and interconnected. Whatever happens to one aspect of the environment may affect some of the other parts. The abiotic and biotic components work together to make up the environment we live in. When we place air pollutants into the atmosphere, such as sulfur dioxide and nitric oxide, they do not just "go away". They are carried by air currents over great distances and can chemically react with other chemicals in the air. They can form compounds like nitrogen dioxide, sulfuric acid and nitric acid. These chemicals are able to dissolve in rainwater, snow, sleet, fog and dew. When this polluted water falls to Earth, it is called "acid precipitation."

Regular rainwater is slightly acidic (pH 5.1) naturally. This is due to the presence of carbon dioxide in the atmosphere, which dissolves in the rainwater to form a weak carbonic acid. Natural rainwater's slight acidity is advantageous because this allows other minerals that plants need to dissolve. However, sometimes the pH is lowered enough to cause grave damage to trees, crops, buildings and even human health among others.

According to the Environmental Protection Agency, "Acid Rain is a broad term used to describe several ways that acids fall out of the atmosphere. A more precise term is acid deposition, which has two parts: wet and dry." (www.epa.gov/airmarkets/acidrain) This unit will deal mainly with wet deposition and its effect on the environment.

"Wet deposition refers to acidic rain, fog, and snow. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of the effects depends on many factors, including how acidic the water is, the chemistry and buffering capacity of the soils involved, and the types of fish, trees, and other living things that rely on the water." (epa.gov/airmarkets/acidrain)

Even though some acidity in precipitation is normal, acid rain is a human-related phenomenon. It is created when power-production companies and industries burn fossil fuels, such as coal and oil. This releases sulfur into the air which combines with oxygen to form sulfur dioxide (SO_2). These power plants also give off nitrogen oxides (NO_X). When these gases are allowed to dissolve in rainwater they form sulfuric acid and nitric acid. Most of the sulfur dioxide and nitrogen oxides released into the atmosphere are from anthropogenic sources with about "2/3 of all SO_2 and ¼ of NO_X coming from electrical power generation that relies on burning fossil fuels like coal" (epa.gov/airmarkets)

Acid rain is measured on a pH scale. On this scale, pure water is a neutral 7. Any substance measuring lower than seven on the scale is an acid. The lower the substance is on the acid side of the pH scale, the stronger it is. Any substance over seven on the pH scale is called an alkali. The alkalis range from over 7 to14, with the strongest alkalis in the highest part of the range. (See figure 1) Acids and alkalis can 'cancel' each other out if they are combined and become closer to neutral. When soils and water resist changes in their pH this is called their buffering capacity.

The abbreviation pH stands for the "power of hydrogen" and it is a measure of the number of hydrogen ions in a given volume of solution. Acids release hydrogen ions in a solution and bases remove hydrogen from solution therefore; the low pH numbers have the highest power of hydrogen, and the higher numbers have the lowest power of hydrogen.

The pH scale is a logarithmic scale. This means that a pH of 6.0 is ten times more acidic than a substance with a pH of 7.0, a substance of pH 5.0 is one hundred times more acidic than a substance with a pH of 7.0, a substance of pH 4.0 is one thousand times more acidic than a substance of pH 7.0, and so on.

Because of the chemically opposite nature of acids and bases, they can neutralize each other. Neutrals have a balance of proton donors and proton acceptors. Thus if you mix equal amounts of proton donors (acids) with equal amounts of proton acceptors (bases) you will produce a neutral solution.

"Buffers are special chemicals that can change a pH of a solution toward a different, specific, predetermined pH" (Acid Rain, Lawrence Hall of Science). For instance you can have a buffer of pH 9, that when mixed with an acid solution of pH 4, would raise the pH, making it more basic. If enough buffer were added then the solution would remain at a pH of 9.

When the sulfur dioxide and nitrogen oxides get into the atmosphere and dissolve in rainwater they enter the hydrological cycle. When the water vapor condenses to form clouds these become acidic as well. Eventually when the clouds become saturated and release water as rain, the acid comes pouring down. But clouds know no boundaries and are moved by wind currents across many miles before they disperse into rainfall. So therefore it seldom happens that the point where the harmful gases are emitted and the point at which the precipitation falls are ever the same spot. Therefore the problem of acid rain is a regional and global issue, not solely a local one.

"The air pollutants that contribute to the formation of acid rain have long been released by natural processes such as volcanoes, and the activity of soil bacteria and other organisms. However, it has only been with the Industrial Revolution, including the invention of the combustion engine and the extensive use of fossil fuels, that these gaseous pollutants have been produced in great enough amounts to significantly affect the acidity of rain." (Acid Rain, Lawrence Hall of Science)

Oxides of sulfur and nitrogen are the principal air pollutants contributing to acid rain. These are mostly produced from fossil fuel combustion in power plants, industry, and vehicles. Sulfur oxides come from mainly coal burning industry and power plants. Nitrogen oxides (NO and NO_2) are found mainly in vehicular emissions. The combustion of fossil fuels increase the levels of carbon dioxide in the atmosphere, thereby increasing the amount of carbonic acid formed. However, carbonic acid accounts for less than 5% of the acid in acid rain.

General Equations

SOx - (combines with oxygen to produce) --> SO_2 (reacts with H_2O) -->H_2SO_4 (sulfuric acid)

NOx - (combines with oxygen to produce) --> NO_2 (reacts with H_2O) --> HNO_3 (Nitric Acid)

CO_2 + H_2O --> H_2CO_3 (carbonic acid)

Tables one through four shows the relative amounts of sulfur and nitrogen dioxide emissions in the United States and Canada. These table are used in the lesson plans to make graphs. By being able to visualize the data the students will be able to make fair comparisons between the two nations and see just where the main sources of acid rain pollutants originate.

Although the problem of acid rain was not considered to be a serious environmental issue until the 1970's,effects of acid deposition were observed well before that time. "In 1306 King Edward I of England issued a proclamation banning the use of sea coal in London due to the smoke it cause." (Clean Air Act Right Frame) According to the Environmental Protection Agency acid rain was first observed in the 19th century when "some people noticed that forests located downwind of large industrial areas showed signs of deterioration." (Acid Rain in New England) In 1872 an English Scientist named Robert Angus Smith observed that certain precipitation could cause damage to plants and materials and he called this "Acid Rain".

It was during the 1970's that scientists began to observe an increase in acidity in many lakes and streams. Simultaneously, there was also research into problems associated with the transport of air pollutants such as sulfur dioxide. Scientists eventually saw the link between the two. They realized that many power plants used coal that contained high amounts of sulfur as fuel. It was this sulfur that was being transported via winds and dissolving in rainwater to produce acid rain.

Effects

The effects of acid precipitation are as varied as they are dramatic. The harmful effects of acid rain are felt some great distances away from where the source of the problem lies. For instance, sulfur dioxides released from Midwestern power plants rise high into the air and are carried by winds toward the East Coast of the United States and Canada. "Acid lakes and streams have been found all over the country, such as in Acadia National Park on Maine's Mount Desert Island. The lakes here are very acidic due to pollution from the Midwest." (EPA, Air Quality and Planning Standards)

Acid rain affects the following components of the global ecosystem; soils and soil microhabitats, vegetation, aquatic ecosystems, terrestrial ecosystems, materials and buildings, visibility and human health.

Results from the National Surface Water Survey (NSWS) showed that many lakes and streams suffer from 'chronic acidity' a condition in which the water has constantly low pH level. "Of the lakes and streams surveyed acid rain caused acidity caused in 75 of the lakes and about 50% of the acidic streams…Several regions in the U.S. were identified as containing many of the surface waters sensitive to acidification. These include the Adirondacks and Catskill mountains in New York State, the mid-Appalachian highlands along the east coast, the upper Midwest, and the mountainous areas of the Western United States." (EPA clean Air Markets) In addition to receiving regular doses of acidic rainfall, these areas are at risk for even more risk because they are prone to 'episodic acidification'. This occurs when acid snow builds up over the winter months and melts in the spring. The sudden influx of acid into lakes and streams all at one, raises the levels of acid and lowers the pH rapidly causing harm to the aquatic life. This is also called 'acid shock'.

"Acid rain causes a cascade of effects that harm or kill individual fish, reduce fish population numbers, completely eliminate fish species from a water body and decrease biodiversity." (EPA Clean Air Market Programs) This occurs when the acid rain falls directly into the water body, reducing the pH. In addition to this however, acid rain that flows through soil in a watershed area releases aluminums. It is the combination of low pH and elevated aluminum levels that are especially toxic to the fish.

There are some species that are able to tolerate some levels of acidity, but most organisms have a specific pH range and if the pH level is too low the organisms will be unable to carry out its mist basic functions. This is partially because enzymes (biological catalysts) found in the bodies of organisms have a pH range that is optimum (See Figure 4.) Any major deviations from this will result in the denaturing of these enzymes (breaking down the protein structure) therefore the organism cannot carry out metabolic and other functions (See Figure 5.) "For instance at pH 5 most fish eggs are unable to hatch" (EPA Clean Air Market Programs.)

In an ecosystem, the organisms are highly inter-dependent. A food chain shows the feeding relationships between organisms. The base of all food chains is a producer, which is an autotrophic organism. This organism is capable of making its own food from the sun's energy. When a first-order consumer feeds on the producer most of the energy is lost as heat, but some of it remains in the body of the consumer. Other consumers fed on the primary consumer and a biological hierarchy is formed. A combination of these food chains result in a highly complex and delicate food web. Each organism plays a vital role in this web. It has its own niche so as to reduce competition with other species.

Unfortunately, when one part of the web is destroyed this could possibly mean a collapse of the entire ecosystem. When there are high levels of acid in an aquatic environment, the producers may not be able to tolerate it, the insects that feed on the producers will loose their food source and so their numbers decline. Therefore, organisms such as frogs, that are able to tolerate relatively high levels of acidity, will have no energy passed on to them because their food supply has been eliminated.

The pollution that causes acid rain can make the air hazy or foggy, reducing visibility. This has happened in the Eastern United States for example the Great Smokies. Yet acid rain causes far more that just damage to the environment. It can create problems with human health as well. "Acid air pollution has been linked to breathing and lung problems in children and in people who have asthma. Even healthy people can have their lungs damaged by acid air pollutants." (EPA's Plain English Guide to the Clean Air Act.)

Acid rain can also cause economic problems if crop yields are lessened or fish harvests depleted. Humans are also affected by acid rain because it can cause damage to stone monuments or buildings (especially those made from limestone).

Solutions

So what is being done to counteract the effects of acid rain? Well, when it became apparent that acid rain was a global problem the federal government got involved and started to implement legislation to reduce the emissions of harmful gases into the atmosphere including those that were linked to acid rain. This started in 1967 with the Air Quality Act of 1967 and evolved into the Clean Air Act that exists today. The following timeline charts this progression. This is for acid rain emissions only and does not include the many other important events that led to the evolution of the Clean Air Act. (From a timeline of the Clean Air Act) This will be used in the lesson plans so that students can research the evolution of the Clean Air Act evaluate its progress.

A Timeline of The Clean Air Act

1967: Air Quality Act of 1967

The first ever legislation aimed at reducing pollution in the United States. It fails because no there were no deadlines or enforcement. But it is a good first step.

1970: Clean Air Act- the federal law designed to make sure that all Americans have safe air to breathe. “The law seeks to protect or environment from damage caused by air pollution.” (Clean Air Trust) The law targets six “criteria” pollutants including nitrogen dioxide and sulfur dioxide.

1977: Clean Air Act Amendments **-** many states failed to make the mandated targets so amendments had to be made. The New Source Review was one of these. This targeted older factories that did not have to comply with the Clean Air Act because lawmakers thought that they factories would have been retired before long. But many of these factories were still going strong and some were even expanding. The New Source Review required that all factories that wanted to expand needed to undergo EPA assessment and adopt pollution control technology.

1988: New Source Review Challenged in Court- Wisconsin Electric Power Company sues the EPA. In this case the Wisconsin Electric Power Company challenged the EPA, charging that they did not have to abide by the new laws because they were ‘grandfathered’ in. The power company was upgrading its factories and since it was adding new facilities the EPA felt that these should comply with the new laws. The power company did not agree.

1990: Clean Air Act Amendments-acid rain control added in the form of offering companies “choices to meet emission standards” (Environmental Defense) These were broken down into phases I and II. “Phase I went into effect in 1995 requiring big coal burning boilers in 110 power plants in 211 Midwest, Appalachian, Southeastern and Northeastern states will have to reduce releases of sulfur dioxide. In 2000 Phase II went into effect to further reduce sulfur dioxide emissions. Total sulfur dioxide releases for the country’s power plants will be permanently limited to the level set by the Clean Air Act for the year 2000.” (EPA’s Plain English Guide to the Clean Air Act)

2000 **-** sulfur dioxide emissions are reduced 27% from 1970

It is clear that the Clean Air Act has worked, but more still needs to be done.

EPA Trading Rights

The EPA's Acid Rain Program, created in 1990 during the second round of amendments to the Clean Air Act of 1970, has been credited with successfully reducing air pollutants that contribute to acid rain formation. The cornerstone of the acid rain program is the innovative allowance - trading component. This encourages affected utilities to reduce SO2 emissions through a market-based trading system designed to cap the total amount of emissions each year while giving companies the flexibility to determine the most cost-effective means by which to meet EPA limits.

The program requires affected companies to install emission detection equipment to monitor all regulated pollutants. This allows the EPA to track overall emissions and compliance with regulations. Each company is given a certain number of allowances, which for SO2 is equivalent to one ton of SO2 emitted per year per allowance. The amount of a particular pollutant a company is permitted to emit is therefore dictated by the number of allowances it has in its possession. If the company goes over its limit, the EPA can levy fines or take allowances away from future years, reducing the company's limit in the future and helping maintain the overall emissions limit over time. If, on the other hand, the company uses less than what it is permitted, it may bank the remaining allowances for future years or may sell them to other entities which may need to increase their own limits in the current or future years.

This creative program gives incentive to companies to develop new cost-effective technologies by which to reduce emission of pollutants, while allowing those companies who cannot do so due to various restraints in the short term to continue on without facing undo hardships from new regulations.

While the location of emissions can be varied due to trading, the overall level of emissions is maintained. Unfortunately for those in the Northeast, some Midwestern companies fell under a separate "grandfather" clause of the program. It was recognized early on that it was much more expensive to retrofit older facilities with modern cleaning and monitoring equipment than it was to build new ones with the same features. Due to this, and the fact that the economy as a whole could have been devastated should all companies be forced to comply immediately, many older utilities were granted asylum from the new regulations, allowing them to produce more pollutants than their newer and future counterparts. Although lengthening the time which it may take to reduce pollution overall, the program nevertheless provides several incentives to replace these older plants with newer cleaner facilities.

The allowance program has received praise by many groups around the country, credited with reducing acid rain-inducing pollutants over the past decade since its inception. As figure 6 shows, SO2 emissions have been reduced by 24% since 1992, as opposed to 1% during the previous decade, prior to the acid rain program. Air quality has improved at twice the rate in regards to SO2 since the start of the program, improving 17% from 1982-1992 while jumping 35% in the past decade alone. (See Tables 7 and 8)

In addition to the market scheme developed by the government there are other things being done to help alleviate the problem of acid rain, with varying levels of success. Some solutions target the symptoms of the problem while others still target the source. With each possible solution the potential benefits and costs must be weighed before a choice can be made.

Building taller smokestacks

An early possible solution to acid rain was for industrial polluters to build taller smokestacks that would remove emissions from an immediate area and send it away with the wind. This was very self-serving and did not address the real issues. For instance Electric Utilities in the Midwestern United States built taller smokestacks to reduce pressure from local environmental activists to reduce smog, but what resulted was a movement of the emissions via wind to the Northeastern United States where it fell to the earth as acid precipitation. The end result being that over 90% of the lakes in the Adirondack mountains are acidic.

Developing Acid Resistant Fish

This is an example of a short - sighted solution. There is actually scientific research being conducted to develop fish that can withstand low pH environments. (See Table 5 for a list of aquatic organisms and their relative pH tolerances) Again this does not address the real issue at hand.

Using coal naturally low in sulfur

Coal deposits vary in the amount of sulfur they contain. It is possible to find deposits low in sulfur and use these, but these are non-renewable resources and once these supplies have been exhausted, then it may be inevitable to go back to the regular, high sulfur coal.

Removing sulfur and nitrogen compounds from fuel and emissions

Scientists have investigated methods of removing compounds that lead to the creation of SOx and NOx from fossil fuels as well as from emissions. For example, washing coal to remove sulfur, spraying wet limestone into hot factory exhaust and burning fuel at a lower more even temperature. Each of these solutions has a drawback. Burning fuels at a lower temperature reduces factory efficiency and spraying limestone seduces sulfur emissions but not nitrogenous ones.

Using alternate forms of energy

There are other ways to generate power than burning fossil fuels. Hydroelectric, nuclear, solar and wind power are all energy alternatives that create little or no acid-producing pollutants. But each of these has its own impact on the environment that must be considered before they are implemented.

Adding buffer to lakes

Buffer has been added to some acidic lakes in the Adirondacks in upstate New York and to lakes in the Black Forest in Germany. This is also called “liming” the lakes, because it is limestone that is used to neutralize the acid. This does not solve the problem because more lime needs to be added if acid rain continues. Also too much lime can have negative effects on the ecosystem.

Even though it may seem like acid precipitation is such a large problem that the individual is helpless to control, it is important to realize that “acid rain is caused by the cumulative actions of millions of individual people” (EPA’s Clean Air Market Programs). Therefore we have the individual responsibility of reducing our consumption of fossil fuels thereby reducing the harmful emissions into the atmosphere.

The government can do its part with big businesses, but what can the everyday person do to help reduce the effects of acid rain? Firstly, we need to find alternate sources of energy. There are many other ways to generate electricity other than burning fossil fuels. These include solar power, nuclear power, hydropower and wind energy. While using these sources may pose some unique problems (such as what to do with nuclear waste?) they are avenues that deserve further exploration if we are to reduce our dependency on fossil fuels. There are new vehicles on the market that are hybrids which use a combination of fossil fuel and electricity and electric cars that help to reduce the consumption of gasoline.

Additionally we can:

- Turn off all appliances, lights and computers when not in use

- Use more energy efficient appliances, which are becoming more and more available nowadays

- Properly insulate your home

- Carpool, use mass transportation, ride a bicycle or walk to your destination

- Maintain your vehicle well

- Keep the thermostat at 68 F in the winter and 72 F in the summer

- Stay well informed

Lesson One

Main objectives:

What is pH? What is acid rain? How can acid rain do?

Journal writing

This will help to assess the students' prior knowledge. The questions will be general so that the students can write whatever comes to mind. Questions can include what is acid rain? How is it formed? What is pH? What are the effects of Acid Rain? Collect journals, read and generate questions for the next class based on responses.

Group Brainstorming

Break students up into groups of three. Give each group a sheet of butcher paper and have them write with a marker all the things that they have heard about acid rain (what it is, what it is not, students can even draw pictures!) Student groups will include a timekeeper, a scribe and a presenter. Each group presenter will stick their butcher paper of ideas on the wall and go through their group's list. The class will note the similarities and differences in the lists.

Sentence Strip

Each group will be given one sentence strip. The group will generate one question about acid rain that they want answered and write it on the sentence strip. The rule here is that if even one person in the group knows the answer then they cannot use that question.

Closure:

Read off sentence strips and ask students one thing that they learned.

Lesson Two

Main Objectives:

Students will be able to define pH and explain/use the pH scale

Students will be able to describe the formation of acid rain

Initiation :

Begin by asking students if they or anyone they know has ever had the unfortunate experience of acid indigestion or 'heartburn'. Why does this happen? Explain to them that our stomach contains acid (HCl) that is used in digestion, but sometimes our body produces too much of it. How do we combat this? We usually take *Tums, Rolaids* or *Pepto Bismol* . Have these packages available to the students and read out the ingredients. What do they all contain and how does it help reduce stomach acid symptoms?

Materials:

Assorted antacid packages, transparency of Figure 1, various food, drink and water samples (vinegar, soda, ammonia, milk, rainwater etc.), pH paper

Instructional input:

Make a transparency of (or draw on the board) a line that will represent the pH scale. Explain to the students that this is like a ladder that has 14 rungs. The acids are found with a pH lower than 7 and the bases have a pH higher than 7. The pH is a logarithmic scale with 7 being neutral. Have the students draw the line and pH 7. Explain to the students that pure water has a pH of 7 and explain the concept of neutrality and the process of neutralization.

Modeling:

Demonstrate to the students how to use pH indicator paper by dipping a strip in some pure water. Show the students on the pH indicator chart that the pH is 7 or neutral.

Guided Practice:

Divide the students into groups of two and supply them with about seven various samples, pH paper and an indicator chart. Have the students test their samples and write in the pH they find for each on their pH scale. Have the students share their findings with the class.

Instructional input :

Ask students why the rainwater had a pH of less than 7. Explain to them that rainwater is naturally only slightly acidic because of the dissolved carbon dioxide forming carbonic acid. But, there are other gases that can dissolve in the rainwater that could lower the pH. Introduce the students to SOx and NOx and draw the equations of sulfuric and nitric acid formation on the board or on an overhead.

Closure:

Ask the following questions:

What is an acid? Give an example.

What is a base? Give an example?

What is the pH of pure water?

Why does rainwater have a low pH?

How is acid rain formed?

Lesson Three

Main objective:

Students will be able to measure the pH of soil and natural bodies of water

Materials:

Apron, Gloves, goggles, collected soil samples, collected water samples, small plastic measuring cups, 1 pipet, pH paper strips, wax pencil

Instructional input:

Adapted from Neo Science: simulating the effects of acid rain

This activity works well with groups of 2 or 3

Prior to the investigation students are to collects three water samples from various locations such as a pond, river, creek, lake or even rainwater. Students may collect the water samples in small jars. In addition students will collect a small soil sample form the same area and place this in a zipper bag. The students must label the sample locations accurately. Have students collect from different locations so that there is a wide range of pH and buffering capacities. Granite rocks have little or no buffering capacity, whereas limestone or soils with a high calcium carbonate content have a high buffering capacity.

Procedure:

pH of water

1.Using a wax pencil, have students label the measuring cups with the locations from which the water samples were collected.

2.Using a pipet, students should carefully transfer 4 - 5 ml of each water sample into the corresponding cup. (Be sure to have the students rinse the pipet in distilled water after each transfer to avoid contamination.)

3.Provide students with the pH test strips and have them dip the end into the water for about 2 seconds, carefully shake off any excess water and compare the color that appears to the color on the pH indicator chart. Have students record the pH and other observations in a data table A.

4.Students will repeat step three with the remaining water samples they have collected.

Data table A

Water sample number	Water sample location	pH of sample	Comments or observations
1			
2			
3			

Procedure:

pH of soil

1.Students should place about 2 tablespoons of the first soil in a plastic cup containing distilled water.

2.Have the students allow the particles to settle for 15 - 20 minutes

3.Have students pipet about 5 ml of the top layer of water into a measuring cup.

4.The students should use the pH test strips to determine the pH of the soil sample. Record the data in table B

5.Repeat steps 1 - 4 with remaining soil samples

Data table B

Soil sample	Soil sample location	Soil description or makeup (limestone, granite etc.)	pH of sample	Comments or observations
1				
2				
3				

Students should write up a lab report according to the scientific method. They should include a statement of the problem, hypothesis, procedure (including dependent and independent variables and a control), data, conclusions and validity.

Lesson Four

Main Objective:

Students will be able to describe the effects of acid rain on plant growth.

Materials:

Apron, gloves, goggles, 2 flower pots, pipet, potting soil, radish seeds, water solutions with a pH of 3 and 7

Instructional input:

Divide class into groups of two for this activity.

Adapted form Neo Science: Simulating the effects of acid rain.

Procedure:

1.Provide students with two identical flowerpots. Let them label them 1 (pH 3) and 2 (pH 7) Fill with potting soil to about 1 cm below the rim

2.Using the pipet, students should thoroughly moisten the soil of both pots with pure water (pH 7). You can use distilled water.

3.Students should plant 5 radish seeds spaced apart, in each pot. The seeds should be about 2 mm below the soil surface.

4.Place pots under a light source or window and water with distilled water until the plants germinate (about 5 days)

5.Once the plants have germinated, students should start to apply 2- 3 ml of each type of water pH 3 and pH 7 to corresponding pot everyday. Make sure the water touches the leaves like rain.

6.Students should make careful observations of the overall plant and leaf appearance and color, plant height and any physical abnormalities. Results should be recorded in Data table C

Data table C

Day	Observation of Plants Pot treated with pH3	Observation of Plants Pot treated with pH 7
5 (Before treatment)		
8		
12		
16		

Students should write up a lab report according to the scientific method. They should include a statement of the problem, hypothesis, procedure (including dependent and independent variables and a control), data, conclusions and validity.

Students should also answer the following questions:

1.Based on your observations, what effect does acid rain have on plant growth and development?

2.What is the purpose of pot 2?

Lesson Five

Main objective:

Students will be able to describe the effect of acid rain on plants.

Materials:

Sodium nitrite, 1 molar sulfuric acid, 2 potted houseplants of the same type, 2 large clear plastic bags, 50 ml beaker, twist tie or tape.

Procedure:

1.Place 2 g of sodium nitrite in a beaker. Place a plant and the beaker inside the plastic bag. Do not seal the bag yet.

2.Steps 2 - 4 should be carried out only under a fume hood. Carefully add 2 ml of I M solution of sulfuric acid to the beaker. Immediately seal the bag tightly, and secure the seal with a twist tie or tape. (This reaction produces sulfur dioxide)

3.Seal an identical plant in an identical bag that does not contain sodium nitrite or sulfuric acid.

4.After 10 minutes, cut both bags open. Stay at least 15 ft. away from the bags as the sulfur dioxide dissipates. Keep the bags in the fume hood.

5.Predict the effects of the experiment upon each plant over the next few days. Record these predictions.

6.Observe both plants over the next three days and record those observations in data table D

Data table D

Day	Control Plant	Experimental Plant
1		
2		
3		

Students should write up a lab report according to the scientific method. They should include a statement of the problem, hypothesis, procedure (including dependent and independent variables and a control), data, conclusions and validity.

Students should also answer the following questions:

1.What can you conclude about the effects of acid rain on plants?

2.In what ways is this experiment a realistic representation of acid rain?

3.In what ways is this experiment not a realistic simulation of acid rain?

Lesson Six

Main objectives:

Students will be able to describe the effects of acid rain on building materials.

Instructional input:

Acid rain degrades many types of materials that we use to build buildings and monuments, if they are exposed to it for long periods of time. Even though these materials would disintegrate with exposure to regular rainwater, acid rain speeds up this process. The damage that acid rain can cause to buildings costs billions of dollars to repair.

Materials:

Apron, gloves, goggles, acidic water solution (pH 3), 2 medicine cups, limestone chips, magnifying lens, pipet, pure distilled water (pH 7)

Procedure :

Be sure to follow all safety precautions

1. Students should label the medicine cups #1 (pH 3) and #2 (pH 7) and place three limestone chips in each. They should examine their limestone chips and record their observations in data table E. If students wish, they may weight eh limestone chips on a triple beam balance or other scale.

2. Using a pipet students should and 2 ml of acid water solution to the cup labeled #1 and 2 ml of water to the cup labeled #2. After 15 minutes students should remove the rocks from the cups with tweezers and record their observations in the data table.

3. Students should replace the rocks into their respective cups and leave them overnight and take observations the next day.

Data Table E

Time	Observations Cup #1 (pH 3)	Observations Cup #2 (pH 7)
Start (prior to treatment)		
15 minutes		
24 hours		

Students should write up a lab report according to the scientific method. They should include a statement of the problem, hypothesis, procedure (including dependent and independent variables and a control), data, conclusions and validity.

Students should also answer the following questions:

1. What changes did you observe in the limestone chips in both cups?

2. How can acid rain affect building materials?

Alternate activity Worksheet

The Effect of Acid Rain on Building Materials

When a chemical is applied to a sample of another chemical and bubbles are given off a chemical reaction is taking place. Acids can react chemically with some kinds of rocks. In this activity, you will find out whether acid (vinegar) reacts with various kinds of rocks.

Materials:

Strong vinegar, different types of rocks (marble, sandstone, granite and cement)

Procedure:

Adhere to all safety guidelines

Demonstrate the method for testing for reactions with acids. Apply 1 ml of strong vinegar to the rock sample and observe closely for bubbles or fizzing (look and listen)

Record the data in table F

Data Table F

Rock Type	Observations Visual Observations	Observations Sounds	Observations Other
1. Sandstone			
2. Marble			
3. Granite			
4. Concrete			

5.

6.

Post lab activity

Answer the following questions:

1.How are the rocks that you tested used by people?

2.What implications do your observations have for builders?

3.Which building material that you tested seemed to be the most resistant to the vinegar?

4. In what ways is this activity a realistic simulation of the effects of acid rain and in what ways is it not realistic?

Lesson Seven

Major objectives:

Students will be able to examine and evaluate the possible solutions to the problem of acid rain.

Students will be able to examine and evaluate the evolution of the Clean Air Act

Instructional input:

It was during the 1970's that scientists began to observe an increase in acidity in many lakes and streams. Simultaneously, there was also research into problems associated with the transport of air pollutants such as sulfur dioxide. Scientists eventually saw the link between the two. They realized that many power plants used coal that contained high amounts of sulfur as fuel. It was this sulfur that was being transported via winds and dissolving in rainwater to produce acid rain. When it became apparent that acid rain was a global problem and not solely a local one, the federal government stepped in and started to implement legislation to reduce the emissions of the harmful gases that were the cause of acid rain. Thus leading to the evolution of The Clean Air Act.

Materials:

Access to computers with the Internet, butcher paper, construction paper, pens and pencils.

Procedure:

1. Place students into groups of about three or four

2. Assign to each group a period of time and have them conduct research on the status of The Clean Air Act. Use the years given in the unit narrative as a guide.

1967: Air quality act

1970: Clean Air Act

1977: Clean Air Act Amendments

1988: New Source Review challenged in court

1990: Clean Air Act Amendments

2002: SO_2 reductions (including the SO_2 trading rights scheme and allowances)

3.Have the students use the internet and scientific article to generate their research. When completed students will give oral presentations of their findings as well as a written report.

4.Place the reports on a timeline made with butcher paper and hang it p in the classroom.

5. Have students evaluate the evolution of the Clean Air Act by asking them which events in their opinion had the most significant effect on the environment. This should lead to a class discussion about the SO_2 trading rights scheme and its success in reducing emissions.

Lesson Eight

Main objectives :

1. Students will be able to make evaluations of the sulfur dioxide trading rights scheme by using visual representations of data and playing a game.

2. Students will be able to prioritize the possible solutions to the problem of acid rain and discuss the moral and ethical concerns of each possibility.

Instructional Input:

This lesson will be well suited to high- level juniors and seniors in a high school environmental science course.

Materials:

Handout of EPA Trading Rights section of the narrative, handouts of the Table 1 through 4 and 7&8, graph paper, materials to make a board game.

Procedure:

1. Have students read the handout aloud in class and facilitate a class discussion on the issue. Discuss the ethical implications of being allowed to trade pollution credits, especially focusing on the geographical distribution of territories.

2. Divide the class into groups of about four and have them adopt a position on the issue. The groups will

represent various perspectives on the issue. One group can represent older companies that have the "grandfather" clause, another group can represent a new company that has new, environmentally friendly equipment, one group representing the EPA, one group representing pollution allowance brokers, other groups representing various states in Northeast and the Midwest.

3. Give the class a scenario involving these groups and haven them debate the issue.

4.Place tables 1 through 4 on an overhead and have students draw graphs that represent the sources of sulfur and nitrogen emissions in the Unites States and Canada and have the students compare the two countries.

5. Place tables 7 and 8 on an overhead and have students draw graphs of the changes in air quality and emissions since 1982. Have the students use this data and compare it to the change in acid rain prevalence where they live (or nearby) and have students note any trends in the dada that might show a relationship.

Alternate assignments:

1. Have students develop a game that will model the activity of pollution credit trading. This game can be modeled after monopoly where the properties are companies that give off emissions containing SO2. Each player can purchase companies but must also find ways to reduce the SO2 emissions, if they don't they will face steep fines from the EPA. The players will be allowed to or trade their pollution credits with other players, they will also be able to buy scrubbers and other pieces of equipment for their companies. The player with the highest profit will win. If designed properly, the student with the least number of pollution credits will loose because they will be fined heavily for each allowance at the end of the game. (An example of this game can be found on teachersinstitute.yale.edu)

2. Give students a blank map of the United States and have them draw in the areas that are being affected the most by acid rain. Then have them put in the areas that are producing the most acid rain causing emissions. Have them compare the two and facilitate a class discussion about the implications of their findings. (A great map can be found in *Environmental Science* , Karen Arms, Holt 1997)

Table 1: Sources of Sulfur Dioxide Emissions in United States

Source	Percentage of Total Emissions
Transportation	7%
Fuel combustion	3%
Industrial sources	15%
Other	8%
Electric Utilities	67%

Source: www.ec.gc.ca/acidrain

Table 2: Sources of Sulfur Dioxide Emissions in Canada

Source	Percentage of Total Emissions
Transportation	5%
Fuel Combustion	1%
Industrial Sources	74%
Electric Utilities	20%

Source: www.ec.gc.ca/acidrain

Table 3: Sources of Nitrogen Dioxide Emissions in United States

Source	Percentage of Total Emissions
Transportation	53%
Fuel Combustion	5%
Electric Utilities	25%
Industrial Sources	12%
Other	5%

Source: www.ec.gc.ca/acidrain

Table 4: Sources of Nitrogen Dioxide Emissions in Canada

Source	Percentage of Total Emissions
Transportation	53%
Fuel Combustion	3%
Electric Utilities	1%
Industrial Sources	26%
Other	7%

Source: www.ec.gc.ca/acidrain

Table 5: Showing the Acid Tolerances of Various Aquatic Organisms

Organism	Range of pH tolerance
Trout	6.5 - 5.0
Bass	6.5 - 5.5
Perch	6.5 - 4.5
Frogs	6.5 - 4.0
Salamanders	6.5 - 5.0
Clams	6.5 - 6.0
Crayfish	6.5 - 5.5
Snails	6.5 - 6.0
Mayfly	6.5 - 5.5

Source: www.epa.gov

Table 6: Table Summarizing the Effects of pH on Aquatic Life

pH	Effect
3.5 - 3.0	Toxic to most fish
4.0 - 3.5	Lethal to salmonids
4.0 - 4.5	Harmful to salmonids, bream, roach, goldfish and the common carp. All stock of fish disappears because embryos fail to mature at this level.

5.0 - 4.5	Harmful to salmonid eggs. The lake is usually considered dead as it is unable to support a wide variety of life
6.0 - 5.0	Critical pH level, when the ecology of the ecology of the lake changes greatly the number and variety of species begin to change rainbow trout do not occur and mollusks become rare - Most of the green algae disappear - This reduction in green plants allows light to penetrate further so acid lakes seem crystal clear and blue snails and phytoplankton disappear
9.0 - 6.5	Harmful to most fish
9.5 - 9.0	Harmful to salmonids, harmful to perch if persistent
10.0 - 9.5	Slowly lethal to salmonids
11.0 -10.5	Lethal to salmonids, carp, goldfish and pike
11.5 -11.0	Lethal to all fish

Source: www.epa.gov

Table 7: Improvements in Air Quality and Decreased Emissions Since 1982

Percent Change in Air Quality

Pollutant	1982-2001	1999-2001
NO2	-24	-11
O3	-38	-3
SO2	-52	-35
PM10	---	-14
PM25	Trend Data	Not Available
CO	-62	-38
Pb	-94	-25

Table 8: Improvements in Air Quality and Decreased Emissions Since 1982

Percent Change in Emissions

Pollutant	1982-2001	1999-2001
NO2	+9	-3
VOC	-16	-8
SO2	-25	-24
PM10	-51	-73
PM25	---	-16
CO	0	+6
Pb	-93	-3

Source: www.epa.gov

Bibliography

Arms, Karen, *Environmental Science.* 1999; Holt, Reinhart and Winston

The standard textbook used throughout New Haven Public Schools. This text is clearly written with colorful illustrations. The charts and graphics are easy to read and comprehend. There is a new edition to this text that was recently published.

Miller, G. Tyler, *Living in the Environment* . 1988,1990; Wadsworth Publishing Company

Another standard textbook used in New Haven Public Schools. The language can pose a problem for even high level juniors and seniors, but is an excellent resource for charts and data.

Nebel, Bernard J *., Environmental Science-The Way the World Works.* 1990; Prentice Hall Publishing

A difficult textbook for most students to decode and comprehend. The data tables and graphs are valuable. This books focuses on the inter-dependence of various aspects of the environment.

Roa, Michael, Environmental Science Activities Kit. 1993; The Center for Applied Research in Education

An invaluable teaching resource that is simple enough for the low level student, and challenging enough for the highest of achievers. This book has ready - made worksheets, labs and activities that make teaching preparation much less time consuming.

Acid rain . 1980; United States Environmental Protection Agency, Office of Research and Development.

This EPA publication is a great introduction to acid rain, as it requires no prior scientific knowledge. It discusses the problem, effects and solutions. It is available free form the EPA and well worth the shipping charge.

"The Challenge of Acid Rain ," V.A. Mohnen, Scientific American, Volume 259, Number 2, August 1988

This article is for the teacher to read to gain a better understanding of the problem of acid rain. It looks and the problem as well as effects and solutions. High level students may also enjoy this.

"Liming Fails the Acid Test," Sarah Woodin and Ute Skiba, New Scientist, Volume 125, Number 1707, March 10, 1990.

A case study, showing how the possible solution of liming has many limitations.

Pringle, Lawrence, *Rain of Troubles: The Science and Politics of Acid Rain* .1988;Macmillan, New York.

For grades 5 to adult this book is a *one - stop shop* of acid rain information. It has a nice introductory section that discusses the history of acid rain.

Websites

The Clean Air Trust

http://www.cleanairtrust.org

A simple to understand question and answer page that explains the Clean Air Act. It discusses what it is, how it works, when it was passed and how ell it has worked.

The Plain English Guide to The Clean Air Act

http://www.epa.gov

As the name implies this is an easy to understand site devoted to explaining the evolution of the Clean Air Act

Clean Air Act Timeline

http://www.environmentaldefense.org

This site describes the evolution of the Clean Air Act form its inception through present day. It is continuously updated. The site is somewhat difficult to navigate.

Acid Rain, Water Science for Schools

http://www.ga.water.usgs.gov/edu/acidrain

This site is designed for students and teachers. It includes a section on the water cycle and discusses water pollution. It is especially helpful in explaining pH.

Canadian Government Environmental Agency Homepage

http://www.ec.gc.ca/acidrain.html

A great site for current data on acid rain and emission trends.

Clean Air Markets

http://www.epa.gov/cleanairmarkets

An invaluable resource for understanding the market - based approach to reducing SO2 emissions. There is an *Acid Rain SO2 Allowances Fact Sheet* that is clearly written. The site is surprisingly easy to navigate given its size.

Student Website

Acid Rain, Water Science for Schools

http://www.ga.water.usgs.gov/edu/acidrain

This site is designed for students and teachers. It includes a section on the water cycle and discusses water pollution. It is especially helpful in explaining pH.

Materials

Materials required are listed at the beginning of all lessons and can be easily obtained from a science supply company.

Appendix

Figure 1 The pH scale ()

0= maximum acidity

7= neutral point in the middle of the scale

14= maximum alkalinity