

# Acid Rain: An Overview

## What Is Acid Rain?

Acid rain, or acid precipitation, refers to any precipitation that is more acidic (i.e., has a lower pH value) than that of normal rainwater. Carbon dioxide (CO<sub>2</sub>) in the atmosphere makes all rain slightly acidic because carbon dioxide and water combine to form carbonic acid, commonly known as carbonated water. The pH of normal rainwater ranges from 5.5 to 5.6, while most acid rain has a pH value of 4.0 to 4.6. In isolated cases, rainwater has been measured to have a pH as low as 3.0. In extreme cases, where high concentrations of acid-forming pollutants dissolve in freshly condensed water vapor, pH values have approached that of battery acid.

Because acid rain includes snow, sleet, hail, dew, frost, and fog, it may also be referred to as acid precipitation or wet deposition. Some types of acid-forming solids and gases, called dry acid deposition, also fall to the earth from the atmosphere.

## What Is pH?

The pH scale ranges from 0 to 14 and is used to measure whether a substance is acidic or basic. Pure water has a neutral pH value of 7, and is neither acidic nor basic. Values on the pH scale below 7 are acidic, and those above 7 are basic. Substances having a pH of 1 (battery acid, for example) are very acidic; substances having a pH of 13 (such as lye) are very basic.

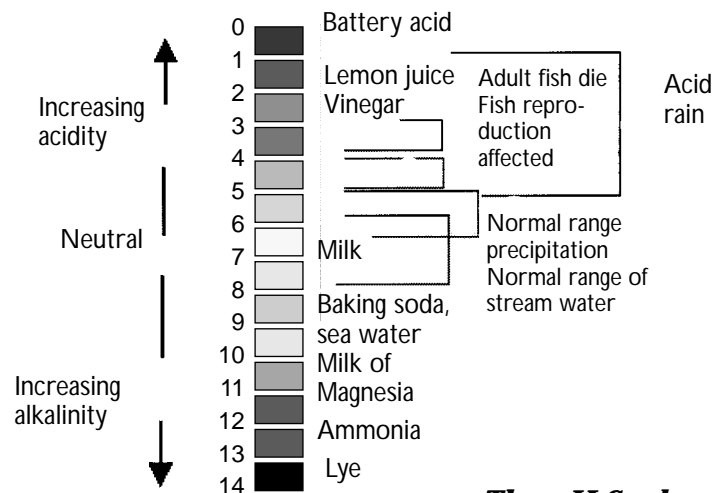
The pH scale is logarithmic, with a tenfold difference between each whole number value. For example, when pH decreases from 7 to 6, acidity is increased 10 times; when it goes from 7 to 5, acidity is one hundred times greater; from 7 to 4, one thousand times greater; and so on. Vinegar at pH 3 is ten thousand times more acidic than distilled (neutral) water, with its pH of 7. The pH scale and value of a number of substances, including normal precipitation and acid rain, are represented in the following figure.

## What Causes Acid Rain?

The burning of fossil fuels for energy, particularly fuels such as coal or oil that contain sulfur, contributes to the acidity

of rain. During burning, the sulfur in these fuels combines with oxygen from the atmosphere, forming sulfur dioxide (SO<sub>2</sub>). The burning also produces nitrogen oxides. The sulfur dioxide and nitrogen oxides are carried up the smokestack by hot exhaust gases and may remain mixed in the air for several days. The longer they remain airborne, the greater the likelihood that they will form solutions of sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) and nitric acid (HNO<sub>3</sub>). These acids may be dissolved in droplets of water and carried by winds for many miles.

The largest sources of sulfur dioxide and nitrogen oxides are coal-fired, electric power-generating facilities. Industrial processes such as the smelting



**The pH Scale**

Courtesy of Environment Canada (<http://www.ns.ec.gc.ca/>)

of sulfide minerals also contribute to the formation of these gases. The exhausts from internal combustion engines release large amounts of nitrogen oxides to the atmosphere; so areas with high automobile traffic generally have significant levels of air pollution and acid rain.

## How Is Acid Rain Harmful?

There are three major ways that acid rain harms our environment: 1) by contact with plants, 2) by contact with soil and water, and 3) by mobilizing trace metals (from terrestrial settings), which are often toxic to plants and animals at high concentrations. Acid rain effects on plants, soil, and water ultimately affect many living organisms that depend on these resources for their survival. Entire ecosystems can be damaged or destroyed by acid rain.

### Plant Damage From Acid Rain.

Acid rain can harm terrestrial plants by damaging outer leaf surfaces and by changing the root environment. Acid rain can strip away the waxy protective coating from plant leaves. Important nutrients such as calcium, magnesium, and potassium can then more readily leach out of leaf tissue by acid rain.

Acid rain can kill tree saplings as well as cause *crown droop*, or the death of limbs at the tops of mature trees. Acid rain can keep seeds from germinating. Plants growing in high altitudes (especially cloud forests) are the first to show the effects of acid rain, because they are often literally bathed in acid mist.

Plants also suffer from the loss of available nutrients when soil is degraded by acid rain. Aluminum dissolves rapidly once the soil water's pH is below 4.5. High aluminum levels in soil solution will completely stop the growth of many plants.

### Soil Damage From Acid Rain.

Acid rain can cause minerals in the soil to dissolve much quicker than normal, thus allowing nutrients to be released and leached away. While we depend on normal rain to slowly dissolve some of these minerals, acid rain can deplete this natural reserve. It takes millions of years for rocks to weather into fresh parent material that forms soil, one of our most valuable non-renewable natural resources. Long-term weathering of soil minerals supplies many of the essential nutrients for both plant and animal productivity.

Most soils can tolerate some extra acidity in rainfall with little impact on soil pH. This is because they have a residual buffering capacity due to the presence of limestone and bicarbonate in solution that can neutralize additional acidity. However, thin soils in some parts of the United States and eastern Canada, which are shallow to bedrock that contains no carbonate, are particularly sensitive to acidity. These soils are very susceptible to the effects of acid rain. Lakes and streams adjoining soils in these areas lack a naturally occurring source of alkalinity and have little or no capacity to neutralize acid rain. Parts of the Rocky Mountains and the North-Central, Southeastern, and Northwestern United States are among regions most susceptible to acid-rain effects.

Soil microorganisms form the first link of a food chain that has evolved for that particular soil-water environment. As the acidity of their environment increases, the number of hydrogen and aluminum ions in solution increases, but the available nutrients decrease. If the nutrients available to these basic links in the food chain are reduced, their population, along with the ecosystem that depends on them, suffers.

### Damage to Water Resources and Aquatic Ecosystems.

Water in lakes can come from direct precipitation into the lake, from runoff water that collects from nearby soil, or by water from the water table. Acid rain can significantly change the pH of a lake and the surrounding soil. We frequently hear about the death of fish and amphibians in acidic lakes or ponds. Because acidic water permeates their entire environment, aquatic animals are among the first to show ill effects. They act as the *canaries in the mine* to warn us of changes in the acid environment of a lake. Different aquatic organisms have different sensitivities to acid. Even though many adult organisms are able to survive in acidic environments, reproductive cycles might be interrupted or impaired. The formation, development, or hatching of eggs or the development of the young at various stages of growth can all be adversely affected. As water becomes more acidic, fewer eggs hatch, and many of the organisms that do will not mature.

Some aquatic organisms are more tolerant of acid conditions than others. Species living in naturally acid waters such as bogs are less likely to be sensitive to acidity. However, many species of fish, including rainbow trout, brown trout, small mouth bass, and minnows of several species, are unable to survive below a pH of 5.

Many species of amphibians (frogs, toads, and salamanders) breed in temporary pools formed by spring rains and melted snow. These pools can be very acidic, and acidity in these temporary pools may cause deformities and death in the eggs and developing embryos.

### **Affects of Acid Rain on**

**People.** Although acid rain will not eat through our clothing or dissolve our skin, it affects us at a very basic level. It can affect the quality of the water we use for drinking and cleaning. When acid rain degrades the soil, it affects our ability to grow the food, fuel, and fiber products we need to support human life. Acid water can dissolve trace metals like mercury, aluminum, cadmium, copper, zinc, and lead from soil, water pipes, and other sources. Some of these elements can cause acute toxicity or chronic health problems if they get in our food or water supplies. Acid rain can corrode and erode buildings, marble statues, and other artwork, thus ruining centuries of human construction and expression.

## **Global Impacts of Acid Rain**

Acid rain often falls far from its source. Once deposited into the atmosphere, airborne gaseous pollutants are often blown hundreds of miles. Depending on wind speed, direction, and duration, pollutants can stay aloft for 5 days or longer. Another factor affecting the distance that pollutants travel is how high they are deposited in the atmosphere. The tallest smokestacks can deposit pollutants high into the atmosphere, where they get carried by the jet stream and other powerful winds.

Canada has a problem with acid rain that is generated in the coal-burning power plants of the Ohio Valley. The acid rain problem in the Black Forest in Germany has been traced to industrial emissions from the British Isles. These facts help us realize that some environmental problems do not follow state or government boundaries. Establishing policy to eliminate acid rain problems becomes especially difficult when the source of the problem resides in a different country than where the problem occurs.

## **Alleviating Acid Rain Problems**

A wide variety of solutions to the problem of acid rain have been attempted with varying levels of success. Some of the solutions address only the symptoms of the problem; others attempt to address the source.

**Taller Smokestacks.** An early solution sought by industry was to build taller smokestacks so the pollutants could be carried away by winds high in the atmosphere. Sending the pollution elsewhere was a solution from the perspective of industries being confronted by local groups, but as was addressed earlier, taller smokestacks do not solve the problem.

### **Increasing Lake Buffer**

**Capacity.** The natural buffer capacity of adversely affected lakes can be modified by adding lime. While liming lakes can raise the pH and increase alkalinity of lake water, it does not correct some of the other adverse effects caused by acid rain such as high levels of aluminum ions leached from adjoining soils. In addition, liming has to be continued as long as acid rain is being deposited, and the lime itself can have major effects on lake ecosystems.

### **Developing Acid-Resistant**

**Fish.** In response to the outcry about depleted fish resources, some scientists have worked on developing strains of fish that are resistant to higher levels of acidity. This is another short-sighted solution that does not address the real issue of preventing the pollution that causes acid rain.

### **Increasing Use of Low Sulfur**

**Coal.** Coal deposits vary in their sulfur content. Burning low sulfur coal reduces the SO<sub>x</sub> emissions, but it does not reduce NO<sub>x</sub> emissions. Also, in the long run, there is often great pressure to use high-sulfur coal sources

after available supplies of low-sulfur coal have run out.

**Removing Sulfur and Nitrogen Compounds From Fuels and Emissions.** Scientists have investigated methods of removing compounds that lead to the creation of  $\text{SO}_x$  and  $\text{NO}_x$  from fuels (coal, oil, and gasoline) and emissions from factories, power plants, and vehicles. Washing coal to remove sulfur, spraying wet limestone into hot factory exhaust gases, burning fuel at a lower and constant temperature, and reacting coal with steam and air at high temperatures to produce a gas consisting mainly of hydrogen and carbon monoxide have had some success. In this last solution, hydrogen gas is burned, causing a turbine to generate electricity; waste heat generates steam, turning yet another turbine.

Each of these solutions has its price. Burning fuel at a lower and more even temperature reduces factory efficiency, costing more money and requiring more fuel to be burned in the long run. The spraying of limestone only reduces  $\text{SO}_x$  emissions, not  $\text{NO}_x$  emissions. It also produces solid sulfur waste, which creates a difficult type of disposal problem. Burning hydrogen gas is an efficient system once established, but it costs a great deal of money to install such a system.

### **Substituting Energy Alternatives for Fossil Fuels.**

Hydroelectric, nuclear, solar, and wind power are all energy alternatives that create little or no acid-producing pollutants. Each of these forms of power generation, however, has its own cost of installation, maintenance, and impacts on the environment.

**Conserving Energy.** Expanding the use of mass transit, producing more fuel-efficient cars, driving less, insulating buildings against heat loss, and using less electricity are just some of the ways we can conserve energy, thereby reducing the emission of pollutants that cause acid rain.

### **Everyone Can Help Reduce Acid Rain**

As an individual, you can help reduce acid rain by saving energy, conserving water and reducing the generation of waste products. All of these will reduce the use of fossil fuels and thereby reduce air pollution that causes acid rain. Specific practices that can be readily adopted to save energy and reduce acid rain include the following: 1) Frequent use of carpooling and mass transit when available, 2) Proper maintenance of vehicles

and their pollution control devices, 3) Better insulation of homes to make them more efficient for heating and cooling, 4) Installation of fluorescent lighting and other energy efficient appliances and turning them off when they are not in use, and 5) Recycling and using recycled materials.

### **For More Information**

The Internet is a valuable resource for information on acid rain. Some of the more useful Web sites include the following:

EPA's Acid Rain Program  
(<http://www.epa.gov/airmarkets/arp/index.html>)

National Park Service's Acid Rain Lesson Plan (<http://www.aqd.nps.gov/ard/edu/Acidrain/lessons.html>)

U.S. Geological Survey's online data and reports on acid rain  
(<http://bqs.usgs.gov/acidrain/>)

The National Atmospheric Deposition Program  
(<http://nadp.sws.uiuc.edu/>)



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