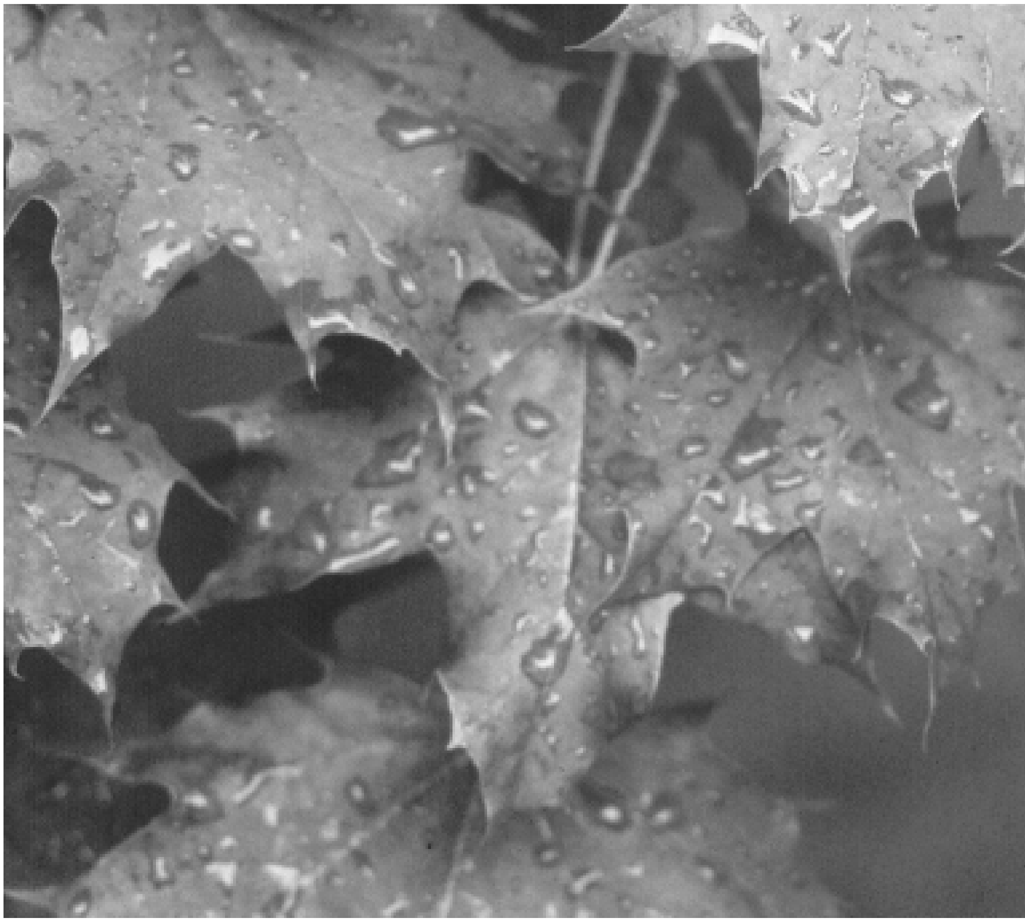
ACID RAIN

The Pennsylvania Connection



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Welcome to Acid Rain Central

Pennsylvania receives some of the most acidic rain of any place for which records are kept. The state is also a top producer of one of the chief components of acid rain: sulfur dioxide. Acid rain is very much a concern for Pennsylvanians, but its consequences can be difficult to spot.

Your favorite trout stream may still be an angler's paradise. The forest where you spend your weekends hiking, camping, or hunting may still look much as you remember it the first time you visited. The water coming from your tap may look crystal clear, just as it always has.

But subtle changes are taking place. A year's worth of trout may be missing from the stream. Hay-scented ferns may cover larger areas of the forest than they once did. Metals such as copper and lead may be present in your drinking water in greater concentrations.

The subtlety of the changes and the lack of any long-term historical data clouds the issue, making the exact effects of acid rain difficult to document. However, the evidence is mounting.

The Acid Rain Chain

"Acid rain," a term coined in the 1850s, is responsible for a set of environmental consequences that extend far beyond rainfall. "Acidic deposition" more fully identifies atmospheric acids deposited on the earth as wet deposition (snow, rain, fog, or mist) or dry deposition (gas and dry particles). However, we'll stick with the common term, "acid rain."

Acid rain is caused by burning fossil fuels to produce electricity and propel automobiles. As the fuels burn, sulfur dioxide and nitrous oxide are emitted into the atmosphere. Drops of rain, snow, and fog mix with these pollutants, which are consequently

changed into sulfate and nitrate. These chemicals then fall to the earth in dissolved form with the precipitation. Sulfate and nitrate are the components of acid rain that are most harmful to ecosystems.

In the 1990s the amount of sulfate and nitrate deposited on Pennsylvania as rain and snow averaged about 27 and 16 pounds per acre per year, respectively. An additional 30 percent or more of pollutants may fall as dry deposition (dust or gas). Many scientists believe sulfate deposition greater than 9 pounds per acre per year will damage sensitive ecosystems. The heaviest deposition occurs in western Pennsylvania; the least falls in the southeast region. Areas 50 to 75 miles downwind of major coal-fired power plants in western Pennsylvania generally receive the highest deposition of sulfate and nitrate. As the distance from a plant increases beyond the 50 to 75 mile zone, the amount of deposition decreases.

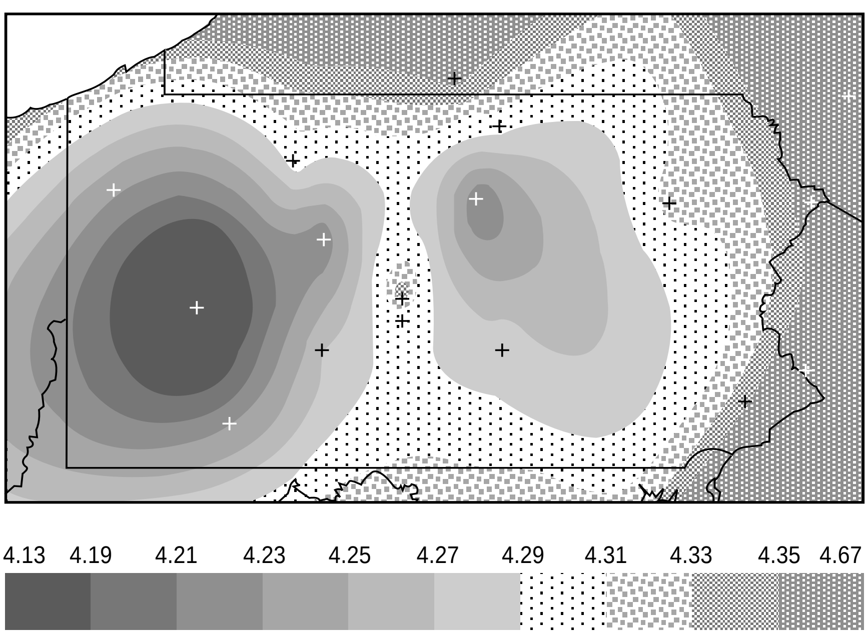
Measuring Acidity

A measure commonly associated with acid rain is the pH scale, which ranges from 0 (most acidic) to 14 (most alkaline, or basic). A pH of 7 is neutral. Lemon juice is acidic, with a pH of 2.3; baking soda is alkaline, with a pH of 8.2.

The pH scale is logarithmic; every one-unit drop in pH represents a tenfold increase in acidity. For example, a liquid with a pH of 5 is 10 times as acidic as a liquid with a pH of 6 and 100 times more acidic than a liquid of pH 7, and so on.

Uncontaminated rainwater has a pH of 5.6 (slightly acidic). Precipitation with a pH less than 5.6 is abnormally acidic. The presence of sulfate and nitrate and other pollutants from the atmosphere makes precipitation in Pennsylvania quite acidic.

Mean annual pH of precipitation in Pennsylvania, 1995–98.



Range in precipitation pH

Crosses represent monitoring locations.
SOURCE: J. GRIMM AND J. LYNCH

Acidity in the State

In 1996 the average pH of precipitation in Pennsylvania was 4.3, with rain across the state ranging from a pH of 4.2 to 4.4. These readings are approximately 20 times more acidic than the pH of uncontaminated rainwater (5.6) and nearly 1,000 times more acidic than the neutral pH of 7. The pH of rain falling in individual storms in Pennsylvania has been as low as 3.5.

Effects on Forests and Forest Soils

Until a few years ago, little was known about the effects of acid rain on forests and forest soils. However, the availability of new research results has changed this. We now have a picture, although somewhat fuzzy, of how acid rain affects forests.

Acid rain damages trees by causing short- and long-term changes in the availability of soil nutrients that trees require for growth and nourishment. Short-term changes occur in soil water chemistry because acid rain goes directly into the soil. Soil water is the water between grains of soil. The acidity in the rain may cause the aluminum (Al) concentration in the soil water to increase sharply and cause damage to tree root tips. This damage results in reduced uptake of essential plant nutrients like calcium (Ca) and magnesium (Mg) into the root tip.

Long-term changes in soil chemistry result from changes in the amounts of nutrients essential for plant growth that are stored in soil in a form that plants can take up (plant-available). The nutrients that exist in soil water all have a positive or negative charge. These charged particles are known as ions. A positive charge must be present for every negative charge in soil water. Because acid rain adds positively charged ions to the soil, positively charged calcium and magnesium are often released from the soil into the soil water. If the calcium and magnesium ions are not captured from soil water by plant roots, they move downward in the soil and sometimes into streams. These nutrients are

then no longer available to satisfy plant needs. Over time, the loss of these nutrients may reduce the ability of forest soils to properly nourish trees and plants.

Recent studies have calculated significant long-term losses in calcium over the normal lifetime of common forest trees. Other studies have shown that these losses can result in an excess of aluminum, which is toxic to plant roots.

Soils with low amounts of calcium relative to aluminum (low calcium-to-aluminum ratio) are unfavorable to tree growth because the calcium and magnesium that trees need from the soil may not be readily taken up in adequate amounts through aluminum-damaged root tips. The stress of poor nutrition weakens trees over a period of years and makes it more difficult for them to withstand other stresses such as drought and insect attacks. A combination of these stresses may eventually kill trees.

Recent research has found strong evidence that dying sugar maples and northern red oak in Pennsylvania tend to occur on soils with unfavorable calcium-to-aluminum ratios. Trees on these soils often have inadequate amounts of calcium and magnesium in their leaves because aluminum blocks the uptake of these nutrients by the root tips.

Applications of lime containing magnesium (dolomitic lime) have greatly improved the health and vigor of both sugar maple and northern red oak trees growing on sites with unfavorable calcium-to-aluminum ratios. This confirms the notion that the observed tree growth reductions and mortality are a consequence of the acidic soils. By supplying the trees with the nutrients they need through lime application, the trees become healthier.

Tree regrowth after a timber harvest can be a very big problem on soils with low ratios of calcium to aluminum. Tree seedlings have small root systems that must struggle to become established in this hostile environment. Competition for nutrients and growing space is keen. To help with this competition, roots form mutually beneficial associations with certain types of fungi called mycorrhizae (mi-ka-RYE-zee). Mycorrhizae improve the plant's ability to acquire nutrients. In return, plants supply mycorrhizae with carbon for energy. This relationship is especially beneficial for seedlings with small root systems.

Unfortunately, for reasons that are not yet known, the mycorrhizae that are found on sugar maple roots appear to be harmed by extremely acidic soils. Seedlings on acid soils with low calcium-to-aluminum ratios have fewer beneficial mycorrhizae than those with higher calcium-to-aluminum ratios. This, coupled with the low amounts of calcium and magnesium in these soils, makes a sugar maple seedling's existence very difficult. In fact, recent research has shown that when soil has a calcium-to-aluminum ratio below 2 or 3, sugar maple seedlings do not exist naturally and die when planted. Roots of the seedlings of common trees such as northern red oak, quaking aspen, and certain hickories do not grow well in soil with a calcium-to-aluminum ratio less than 0.25.

Fortunately, some species of forest trees and other plants are not very sensitive to high concentrations of plant-available aluminum. White pine, chestnut oak, red maple, black birch, and mountain laurel fare well in these conditions.

It is also fortunate that many Pennsylvania soils have reserves of calcium and magnesium that can replace nutrient losses inflicted by acid rain for many decades to come. Soils that have become too acidic for sensitive tree species are found on ridge tops throughout unglaciated portions of the Allegheny Plateau and the Ridge and Valley regions of the state.

Effects on Groundwater

In most forested areas of the state, groundwater supplies all stream water during the summer (base flow) and provides buffering against inputs of more acidic storm water.

Research on the Laurel Hill in southwestern Pennsylvania found that groundwater quality was largely controlled by the type of bedrock present and, to a lesser extent, by the quality of water moving through the soil. Streams receiving groundwater from alkaline limestone were protected against the rush of low pH water that occurs during storms or snowmelts. Trout mortality was not observed in these streams. Conversely, streams receiving groundwater from acidic sandstones and shales were quite acidic and fishless. Recent studies have shown that even acidic groundwater becomes more acidic during acid runoff events, and sulfate and aluminum concentrations increase dramatically.

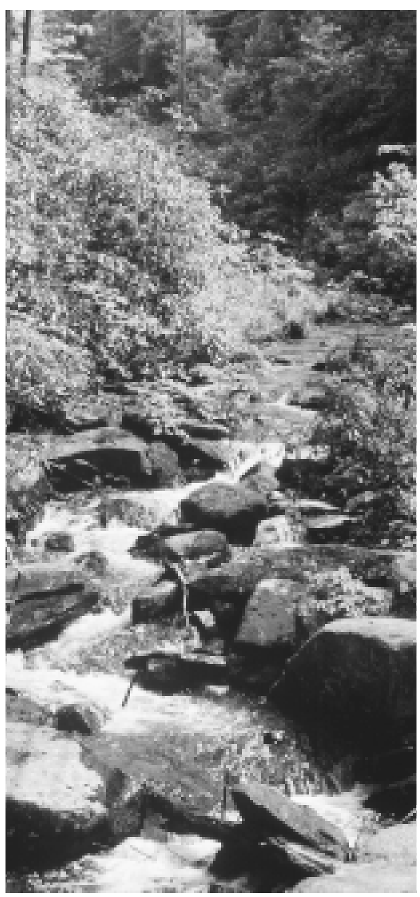
Acid runoff episodes happen when precipitation or snowmelt overwhelms the ability of the stream or watershed (the land that drains into the stream) to neutralize the acids in the runoff.

Both temporary and long-term effects of acid rain on groundwater have been found in Pennsylvania. In southwestern Pennsylvania, the pH and alkalinity of a near-surface spring temporarily declined during and immediately after acidic runoff from a storm or snowmelt entered the spring. Alkalinity pertains to the ability of a stream to maintain a stable pH as acidic material is added. A stream with low alkalinity is highly sensitive to acidic inputs.

A study of 10 Pennsylvania groundwater databases found that pH declined in 80 percent of the samples over a 20-year period. Four of the five databases with sulfate data showed an increase in groundwater sulfate concentrations. Sulfate is a component of acid rain and higher concentrations indicate increased acidity.

Effects on Surface Waters

Many of the state's sandstone ridge watersheds are vulnerable to acid runoff episodes. Pennsylvania Fish Commission officials estimate that nearly 5,000 miles of stocked trout streams and more than 3,600 miles of unstocked trout streams in the state are vulnerable to acid rain.



The increase in the aluminum concentration of stream water can be significant during episodes. Aluminum is generally considered to be more important than pH in explaining fish deaths. During acid runoff episodes, concentrations of aluminum increase greatly to levels that are deadly to fish such as brook trout.

The increased aluminum in streams comes from water moving through the soil. The amount of aluminum in the stream is determined by the chemistry of soils on the watershed and the amount of soil water that enters the stream. Acid rain influences soil chemistry and increases the amount of aluminum carried into streams to toxic levels.

The largest recorded rapid drop in stream pH in the state (from 7.32 to 4.95) occurred in central Pennsylvania. It resulted from a storm that dropped 4.38 inches of rain on a very small headwater stream. Depressions in stream water pH to as low as 4.2 have been observed in other Pennsylvania streams. The depressions develop rapidly (in 1 to 36 hours), and the low pH level can persist for more than a week.

The largest drops in stream pH often occur in late summer and early fall following extended dry periods, although significant acidic runoff episodes can occur at any time. Summertime episodes are usually of shorter duration and are not always deadly to aquatic life. Rapid snowmelt can also send large rushes of acidic water into streams.

Although the lack of reliable historical records makes the detection of long-term declines in stream pH and alkalinity very difficult, short-term pH and alkalinity declines have triggered changes in biological communities. The disappearance of fish species, declines in fish populations, and changes in insect and microscopic plankton communities have been reported.

Effects on Aquatic Life

Persistent reports of fish loss continue in the Laurel Hill area of the Allegheny Mountains between Johnstown and the Youghiogheny River. Many of the streams can no longer support trout fisheries.

Studies of the area found that fish populations were wiped out in 13 of 61 streams, although 34 streams continued to support significant trout populations. Five streams had reduced populations and showed signs of acid rain impacts, and nine streams had no trout populations but showed evidence of water quality problems unrelated to acid rain. Trout mortality in the Laurel Hill area has been linked to stress in the fish prompted by high concentrations of aluminum and low pH in acidified streams.

In 1994 and 1995, Penn State researchers resampled 70 headwater streams that were originally sampled between 1961 and 1971. On the Appalachian Plateau, 76 percent of streams lost fish species during the time between samplings, and in the Ridge and Valley region, 65 percent of streams lost fish species. Many species that disappeared are known to be sensitive to acidification. During acid runoff episodes, 42 percent of the streams sampled had large increases in aluminum concentration and 58 percent had sizeable drops in pH (>0.5 units). Streams that lost fish species had a lower pH and alkalinity compared to the 1961–71 sampling. Streams that gained or had no change in fish species did not have significant changes in acidity during the same period. The authors of the study concluded that during the past 24–34 years a reduction in the diversity of fish species occurred in many Pennsylvania streams. Changes in stream pH and alkalinity during this period and the persistence of toxic or near-toxic concentrations of aluminum during acid runoff events suggest that this loss of diversity is linked to acidification of these streams.

A separate study found decreased pH and increased levels of aluminum in three lakes in the Pocono Mountains of eastern Pennsylvania. In all three lakes, the number of fish species declined. One lake supported only a stunted population of pumpkinseed sunfish, and the growth rate of these fish was declining each year.

Some fish species are more sensitive than others to low pH and high aluminum. These sensitive species are the first to disappear in acidic waters. Many minnow species and some darters have disappeared from stream reaches where they once occurred. Water sampling has linked these fish losses to acid runoff episodes. Studies show that the addition of alkaline groundwater can improve trout survival by reversing severe acidification.

Insects that live on the bottom of streams provide an important food source for fish. These insects also

appear to be affected by the acidification of streams. A study of 11 Laurel Hill streams found a trend toward fewer types of these insects with increasing acidity. Mayflies were nonexistent in the most severely acidified streams.

The temporary forest ponds that provide breeding sites for amphibians such as salamanders and frogs also are vulnerable to acid rain. These small ponds dry up each fall and refill each spring from snowmelt and rainwater. A study in central Pennsylvania found varying reactions of amphibians to acidic water. For example, Jefferson salamanders were very sensitive, but wood frogs hatched and developed in extremely acidic water. Spotted salamanders were intermediate in sensitivity.

Effects on Drinking Water

Little research has been done on the effects of acid rain on drinking water supplies, but it is safe to assume that lower pH and higher trace metal concentrations, such as lead and copper, are occurring in many areas due to acid rain.

Approximately 60 percent of the state's private water supplies and many of the state's public water supplies deliver corrosive water that deteriorates metal pipes over time. Acid rain makes water more corrosive by lowering its pH. This increases the concentrations of dissolved metals in the water. The metal of chief concern from corrosion is lead, which is known to affect the central nervous system of the fetus and young child. Even small amounts of lead in drinking water may impair the intellectual development of preschool children and increase the risk of high blood pressure in adults. Corrosion also can raise levels of copper, iron, and zinc, which give water a metallic taste.

One study in Pennsylvania found lower pH, higher corrosivity, and increased aluminum content in the source water of two public supplies following acid runoff episodes. A follow-up study of one supply revealed increased metal concentrations in tap water during acid runoff episodes on the source stream.

The Future: Where Are We Heading?

The 1990 Clean Air Act Amendments were a very important first step in controlling the acid rain problem. Research has shown that controlling the outflow of pollution from power plants was much less costly than predicted. The precipitation in Pennsylvania is becoming less acidic as a result of this legislation.

However, it is obvious from new studies that the damage to Pennsylvania's aquatic and forest resources has been much greater than was earlier thought. This damage is continuing because there is still too much acid deposition in Pennsylvania to permit complete rehabilitation of fish populations and to prevent future widespread forest damage. Further reductions in acidic deposition are required to allow for a slower rate of degradation and to allow recovery to begin in the forests.

At Penn State, research on the acid rain problem continues. Currently, the focus is on what acid rain is doing to our forests and how we can sustain and regenerate these forests. The news thus far is not good, but continued research will provide forest managers with the tools necessary to handle this problem in the best manner possible.

For More Information

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