Actions and Response:

Impacts of Emissions Policy on the Recovery of Ecosystems in New York From Damages Caused by Nitrogen and Sulfur Air Pollution

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*"When one tugs at a single thing in nature,
he finds it attached to the rest of the world"*

John Muir

ON THE COVER
View of Adirondack lake and forest
Photograph by Bill Ingersoll

BACKGROUND
Objective

Many of the lakes, streams, and forests in mountainous areas of New York State have been damaged by **acid deposition** caused by sulfur and nitrogen air pollutants. In fact, some of these mountainous regions are among the most damaged in the United States. These pollutants can enter soil and water as acid deposition, which lowers the **pH** and causes chemical changes that affect the suitability of that soil or water to support sensitive species of plants and animals. Estuaries and marine coastal waters have been affected by over-enrichment with nitrogen deposited from the atmosphere, which acts to stimulate algal growth. As a consequence, fish, plants, and other life forms in New York have suffered varying degrees of damage from **acidification** and nutrient enrichment effects of air pollution. The public has shown great concern over the issue of air pollution and subsequent damage to brook trout, sugar maple, and red spruce in mountainous areas. In recent years, however, air pollution levels have been decreasing, leading to hope for natural resource recovery from both acidification and nutrient enrichment.

Some lakes and forest soils in New York have been acidified by atmospheric deposition of sulfur and nitrogen. (Photo: Barry Baldigo)

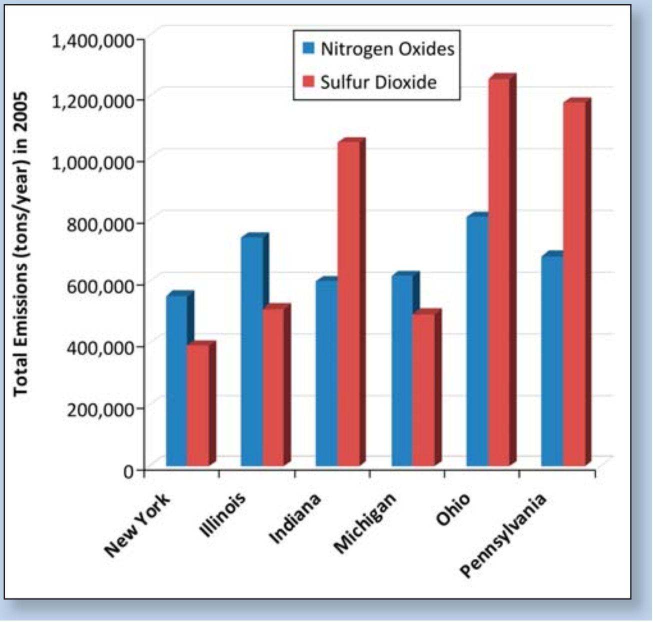
This report describes the general patterns of damage to natural resources in New York caused by acid deposition of sulfur and nitrogen (commonly known as "**acid** rain"), and highlights subsequent, on-going, **ecosystem** recovery. It also offers an indication of what scientists expect will happen to the damaged resources in the future as pollutant emissions continue to decrease. Particular topics are explored in greater detail within inset boxes. Key terms are printed in blue, boldface type the first time they appear and are defined on the inside back cover of this paper.

The goal of this report is to educate interested citizens regarding the extent to which sensitive natural resources in New York are recovering from past damage caused by atmospheric deposition of sulfur and nitrogen. The material presented is intended to help the reader to better understand this complicated environmental issue. There are other effects of air pollution in New York that are not addressed here. These include effects on human health, visibility, formation of ozone that damages plants, and global climate change.

tourists to the mountainous and coastal regions each year. Air pollution has already caused significant damage to these valuable resources, and further damage could occur in the future under continued high levels of air pollution. However, federal and State efforts over the past several decades to curb air pollution emissions from power plants, industry, and motor vehicles have resulted in a pronounced decrease in air pollution levels. As a result, expectations have risen for resource recovery from past damage.

Scientific data show that air pollution in New York has damaged many of the plants, soils, waters, fish, and other species that make up the ecological framework of New York's ecosystems, but great progress has been made over the past few decades in improving air quality. For this trend to continue, additional emissions controls may be required. This paper focuses on aspects of the resources that are sensitive to air pollution and how these resources interact with each other. As awareness builds about the effects of pollution on natural resources, there is greater support for natural resource recovery and hope for a better future for the natural world. The scientific principles that govern these interactions are technical and complex, but the general explanations are easily understandable.

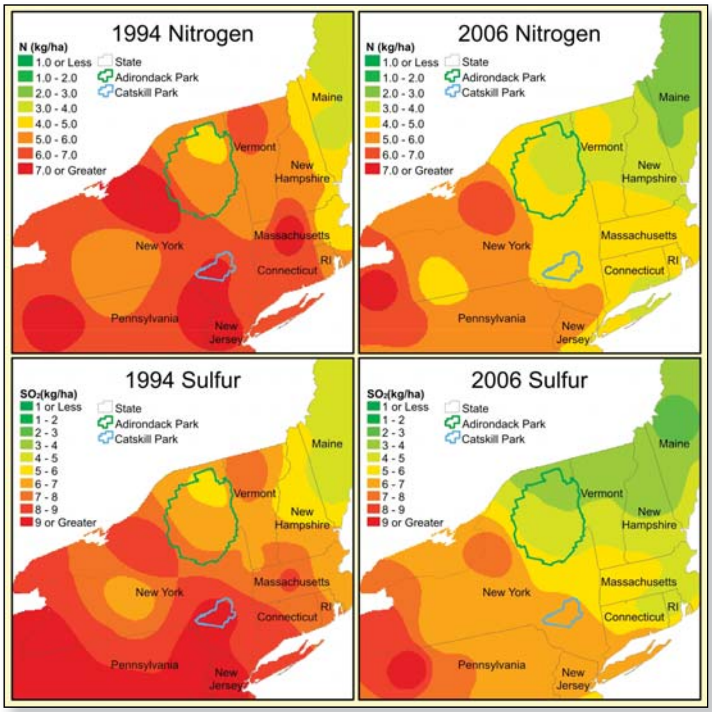
Emissions



Estimated total annual emissions of sulfur dioxide and nitrogen oxides within New York and the five principal up-wind states. These estimates were generated by EPA for the year 2005.

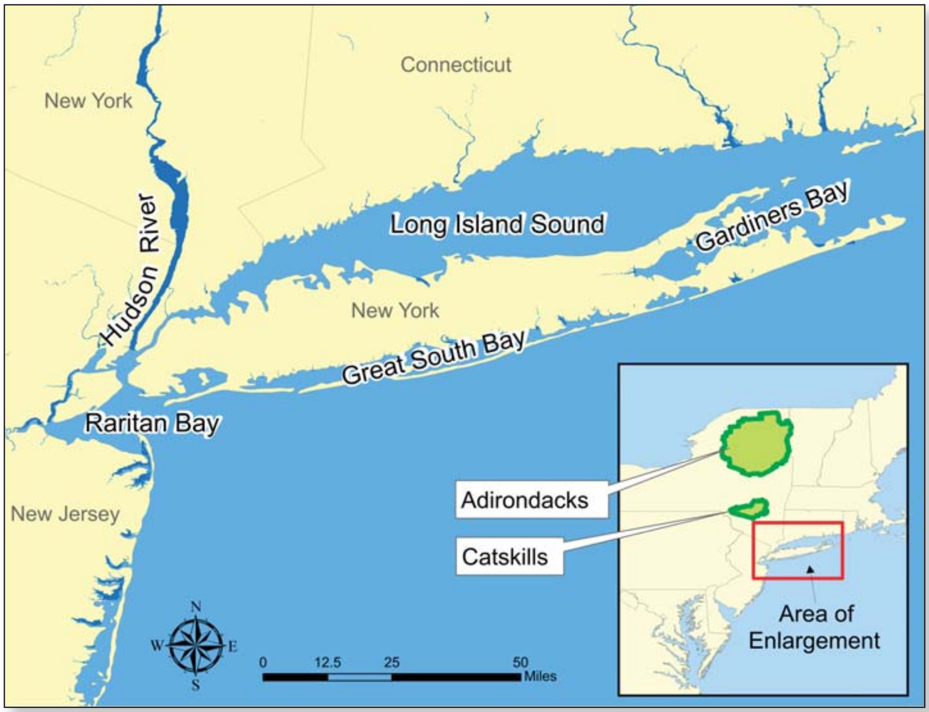
Air Pollution in New York

Sulfur and nitrogen air pollution effects are governed by three fundamentally different sets of processes. The first has to do with emissions of air pollutants into the atmosphere, largely from electricity generating facilities, agriculture, and transportation. Emissions of sulfur and nitrogen in, and upwind of, New York are described in the text box on Emissions. The second key set of processes occurs in the atmosphere. Emitted pollutants are transported with the prevailing winds,



Average levels of wet nitrogen and sulfur deposition measured by the National Atmospheric Deposition Program throughout the northeastern United States in 1994 and 2006. Areas receiving relatively high deposition levels are colored in warm colors, grading to cooler colors to represent lower deposition levels. Deposition decreased between 1994 and 2006 due to emissions controls. Although sulfur and nitrogen deposition levels are not especially high in New York compared with other eastern states, there has been considerable damage to some New York ecosystems due to their high degree of sensitivity.

modified by physical and chemical processes, and eventually deposited to the Earth's surface by the process of atmospheric deposition (described in the Acid Deposition box). The third set of processes involves the various transformations that occur within the soil and water and the resulting effects on diverse ecosystems.



Map of New York showing the locations of the Adirondack and Catskill parks, and estuaries that are sensitive to damage from air pollutants

Emissions of sulfur and nitrogen into the atmosphere are generally higher in neighboring up-wind states as compared with New York (see graphic in Emissions box on page 2). Nevertheless, deposition of sulfur and nitrogen from the atmosphere to the ground in New York has increased since pre-industrial times and is high enough to cause damage to sensitive ecosystems. Many of the ecosystems in New York are unusually sensitive to air pollution damage, as described more fully below. Scientists have identified the various major environmental threats, quantified many of the resource sensitivities and damages, and measured environmental conditions and changes over time. In response to the federal Clean Air Act and its Amendments, and through other federal and state legislation and policies, air pollution levels in New York have been steadily declining since **monitoring** began around 1980.

As noted in the Acid Deposition box, two of the air pollutants that cause the greatest environmental damage when they are deposited from the atmosphere to the Earth's surface are sulfur and nitrogen. Atmospheric sulfur and nitrogen deposition contribute to two major effects on the environment: acidification and over-fertilization, or nutrient enrichment. Acidification entails a decrease in the pH of water in soils, lakes, and streams. It can be caused by deposition of sulfur and/or nitrogen. Nutrient enrichment (also called eutrophication) from excess nitrogen often results in an increase in the growth of algae and plants. This is especially important in estuaries and coastal marine waters. In New York, deposition of atmospheric sulfur and nitrogen is most damaging to mountainous (Catskill and Adirondack) and coastal areas. Lands between are less affected.

Studying the Effects of Air Pollution

The effects of air pollution on streams, lakes, estuaries, oceans, soils, and vegetation often accumulate over time, are only partially reversible, and may persist into the future for centuries. Such effects began more than one hundred years ago, following the Industrial Revolution. Air pollution continues to affect New York's ecosystems, even though the levels of pollutant emissions have been falling since the 1970s.

Acid Deposition

Emissions and Deposition

Air pollution monitoring station on Whiteface Mountain in the Adirondacks. (Photo: Greg Lampman)

It would not be possible to understand the effects of air pollution in New York without having access to measurements (data) from the various national and State surveys and monitoring programs. Since about the 1970s, scientists have been measuring how the environment in New York responds to air pollution. Some of these key research studies include lake and stream surveys conducted by the Adirondack Lakes Survey Corporation (ALSC), the U.S. Geological Survey (USGS), and the U.S. Environmental Protection Agency (EPA); the New York State Department of Environmental Conservation's (NYSDEC) Long Term Monitoring program for lake chemistry; federal and New York monitoring programs for wet, dry, and cloud atmospheric deposition; and Rensselaer Polytechnic Institute's Adirondack Effects Assessment Program (AEAP) that monitored lake biology. Data from these survey and monitoring programs provide the foundation for determining current conditions; changes (trends) over time; seasonal and year-to-year variability; and the influence of other stresses on resource conditions, including climatic change and human activities.

These studies have found that environmental effects are highly variable, even within a relatively small region. Similar amounts of acid deposition have acidified some lakes, streams, and forest soils, but not others, and have damaged some fisheries and left others unharmed. Some effects are seasonal and only appear during the snowmelt period or during rainstorms. Furthermore, the acidity in some lakes and streams is natural, having originated from the breakdown of organic materials occurring naturally in the soil and water; in other lakes and streams, the culprit is mineral acidity caused by air pollution.

Scientists now know a great deal about the effects of acid deposition on sensitive natural resources in New York. Additional important scientific questions that must be addressed in order to effectively manage these resources include the following:

- Are the chemical and biological resources recovering from acidification and nutrient enrichment as air pollution levels decline?
- Will the resources continue to recover in the future under expected future air pollution levels as new emissions regulations take effect, or will larger emissions cuts be required?
- What levels of acid and nutrient deposition can the sensitive New York resources tolerate, and what levels allow recovery from past damage?

These are some of the questions addressed here. As described in the discussion that follows, scientists currently only have partial answers, at best. The New York State Energy Research and Development Authority (NYSERDA) funds much of the research in New York designed to address such questions.

The lake recovery process can be complex since wetlands also provide a natural source of organic acidity to lakewater. Natural organic acidity is less damaging to sensitive life forms than human-caused inorganic acidity from acid rain. (Photo: Bill Ingersoll)

AIR POLLUTION EMISSIONS AND ACID DEPOSITION (ACID RAIN)

Forests, soils, and waters in the Adirondack and Catskill mountains are all sensitive to the acidifying effects of air pollution. (Photo: Barry Baldigo)

Most of the air pollution in New York originates outside the State's boundaries. Emissions of sulfur into the atmosphere in New York and states that lie up-wind from the Adirondack and Catskill mountain regions were very high in past decades but have been gradually decreasing since the 1970s (see breakdown of recent emissions, by state, in the box on page 2). By contrast, emissions of nitrogen were at a relatively constant high level over that period of time, but have begun to decline since about 2000. In 2005, the total emissions from New York State and the top five additional states contributing air pollution to New York were about 4.9 million tons of sulfur dioxide and 4.0 million tons of nitrogen oxide. There are at least 10 major coal-burning power plants situated up-wind (to the southwest) of the Adirondack and Catskill mountains.

Sulfur and nitrogen air pollutants are deposited to the ground through the process of acid deposition. This deposition is measured in kilograms per hectare (or pounds per acre), which reflect the mass (of sulfur or nitrogen) that is deposited over a given area of the Earth's surface over the course of one year. Several networks operate monitoring sites throughout the United States to measure the atmospheric concentrations and deposition of pollutants. Some of these monitoring stations are located in the Adirondack and Catskill mountains.

In the 1970s and 1980s, watersheds in the Adirondack and Catskill mountains received roughly twice as much sulfur deposition as nitrogen deposition on a mass basis. With the more stringent emissions controls that have been placed on sulfur by the Clean Air Act and its Amendments, this ratio has changed. The inputs of sulfur and nitrogen are now nearly equal. These regulations will further control both sulfur and nitrogen emissions. As a result, deposition levels are expected to continue to decrease for at least the next several years.

EXTENT AND MAGNITUDE OF PAST DAMAGE AND RECENT RECOVERY IN NEW YORK

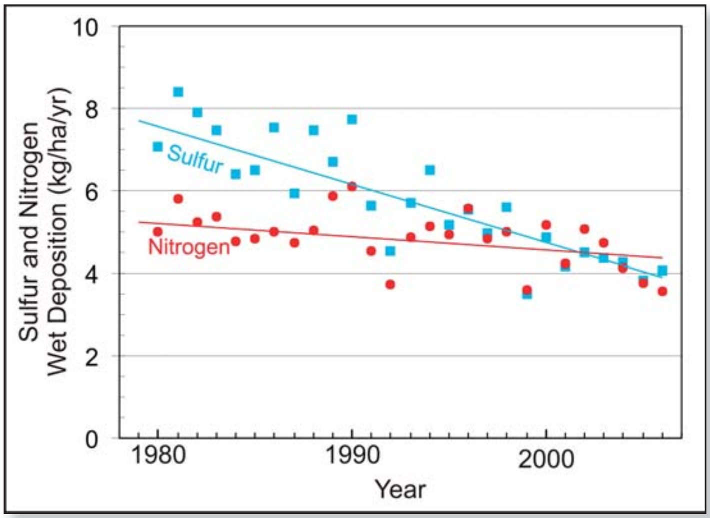
Overview of Effects

Sulfur and nitrogen air pollution can cause two very different kinds of environmental effects: acidification and nutrient enrichment. These effects have substantial economic, as well as ecological, consequences. Each is discussed below.

Acidification Effects

Acidification entails a reduction in pH and in the ability of an ecosystem to neutralize, or buffer, added acidity. Acidification can be caused by excessive deposition of sulfur, nitrogen, or a combination of the two. The soil can become acidified, and this can affect the ability of that soil to support plant growth. Fresh water (lakes or streams) can become acidified and this can affect the water body's ability to support fish and other aquatic life forms. Some species are more sensitive than others to the effects of acidification.

Mountainous areas are often especially sensitive to the acidifying effects of atmospheric sulfur and nitrogen deposition. Rocks and thin soils that occur in such areas often have low availability of **base cations**, such as calcium, that can neutralize acidity. Water moves quickly down steep hillsides, thereby providing limited opportunity for acid neutralization to occur



Measured values of wet sulfur and nitrogen deposition (in kilograms per hectare per year) over the period of measurement recorded by the National Atmospheric Deposition Program at Huntington Forest in the Adirondacks. Wet sulfur deposition has decreased steadily since about 1980; wet nitrogen deposition has decreased since about 2000. Total deposition is roughly 1.5 to 3 times these values as a consequence of dry and cloud deposition.

Determination of the Extent of Past Acidification

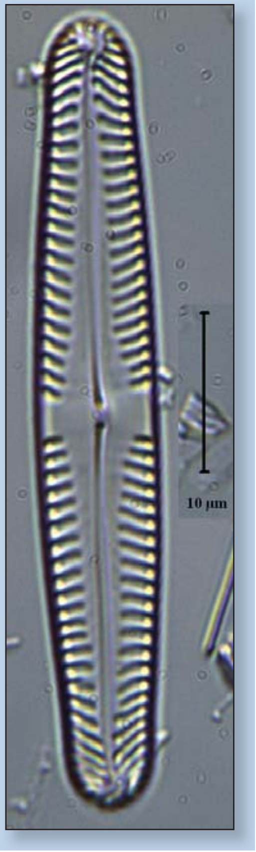


Photo of a microscopic diatom called *Pinnularia abaujensis* var. *lacustris*, Camburn and Charles, which is relatively acid tolerant and is widely found in acidified Adirondack lakes. (Photo: Ling Ren)

within the soil. Rain and snow amounts are often high, causing natural leaching of base cations out of the soil. The Adirondack and Catskill mountains contain some of the most acid-sensitive lakes, streams, and forests in the United States, and also receive relatively high levels of sulfur and nitrogen air pollution. Thirty years of scientific research and monitoring have shown that, despite some recent improvements, sensitive vegetation and water resources in these mountainous regions remain degraded by air pollution.

Lakes and streams vary greatly in their sensitivity to acidification from acid deposition. Different types of lakes or streams respond differently to changing levels of acid deposition. This is largely dependent on the types of rocks and soil in the watershed, the size of the watershed, and the pathway followed by water as it moves through the soil, and whether the water started as rainfall or snowmelt. Effects of acid deposition start with the soil, and are mainly governed by the quantity of base cations available in the soil. Base cations are derived from the slow breakdown (weathering) of rocks and are then stored in the soil and vegetation. They play two very important roles in New York forests:

1. Base cations partially decrease the acidity contributed by acid deposition, thereby lessening the degree to which lakes, streams, and soil water become acidified.

2. Base cations serve as essential plant nutrients that are continuously cycled between soil and vegetation.

These roles sometimes conflict. When base cations neutralize acidity from the atmosphere, they are lost from the soil and are no longer available to serve as plant nutrients. Furthermore, they are no longer available to neutralize the acidity of future acid deposition. Once the pool of stored base cations in the soil becomes depleted, it takes a very long time (many decades to centuries) for rock and soil weathering processes to replenish the supply. Under normal unpolluted conditions, the cycle of calcium and other base cations runs like an efficient machine. Plants take up base cations from the soil to sustain growth; when leaves and wood decay, the base cations are returned to the soil and the cycle starts again. Normally, only small amounts of new base cations are provided from outside the watershed to the unpolluted soil/plant system, and only small amounts of these base cations leak out into drainage water. Acidification speeds up the cycle and causes more base cation loss from the soil to the drainage water. If the initial amount of base cation storage in the soil is relatively small, problems soon develop if high levels of acid deposition further deplete that storage reservoir.

Effects Related to Nutrient Enrichment

Effects of air pollution on estuaries and other coastal marine waters are quite different than the effects on fresh waters, soils, and forests. Nutrient enrichment is a term used to describe a host of environmental changes that can occur when the availability of a key nutrient is increased as a consequence of air or water pollution. Estuaries and coastal marine waters are especially susceptible because nitrogen tends to be the main growth-limiting nutrient in estuarine and marine waters. This means that addition of more nitrogen would be expected to increase the growth of algae and plants whereas addition of a nutrient other than nitrogen would not be expected to increase growth. Growth of plants and algae in fresh waters, by contrast, is more commonly limited by the availability of phosphorus, which is not an important component of atmospheric deposition. For that reason, nitrogen addition generally does not have such a pronounced impact on plant or algal growth in most fresh waters. There are some fresh water bodies, however, that are limited in their algal growth by both nitrogen and phosphorus.


Estuaries, such as Barnegat Bay, pictured here, are sensitive to over-enrichment with nitrogen from air pollution and other human sources of pollution. This nutrient enrichment, called eutrophication, can damage fisheries, shellfish beds, and seagrass habitat, and can create odor and aesthetic problems.

In addition to the deposition of atmospheric nitrogen to water bodies, other sources of nitrogen pollution include discharges from waste water treatment plants (treated sewage), industrial discharges, and runoff from agricultural or developed land. Nutrient enrichment can cause some species of plants or algae to thrive at the expense of others. Thus, the mix of species present in an ecosystem can change as a consequence of nutrient addition.

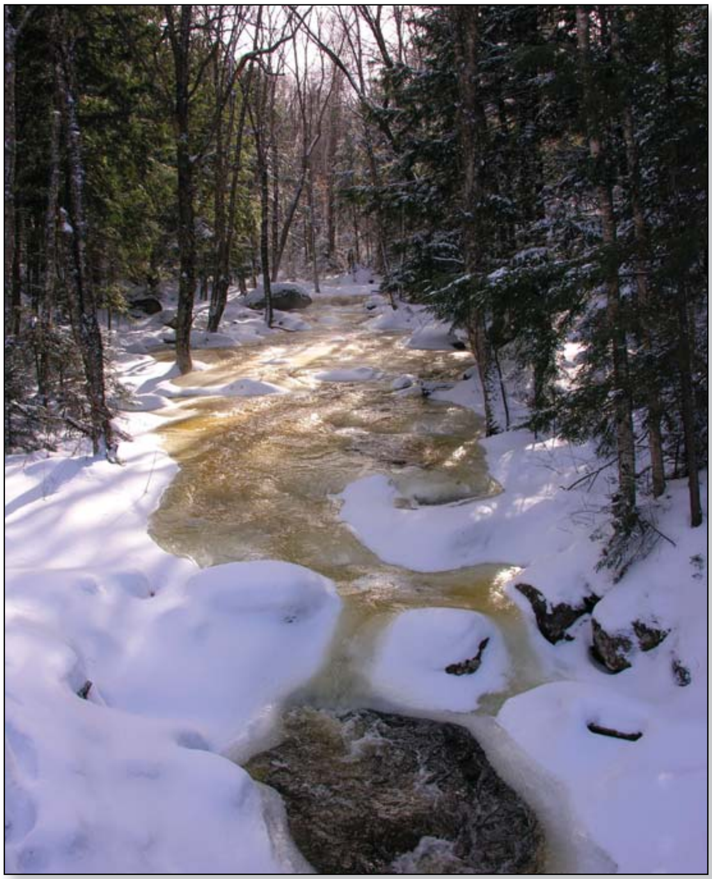
Nutrient enrichment can be caused by nitrogen deposition, but generally not by sulfur deposition. Too much nitrogen can cause excessive growth of algae in water bodies which can in turn cause a multitude of environmental effects, including reduced levels of dissolved oxygen in the water, fish kills, bad odors, and damage to shellfish resources. Dense algae shade out the seagrasses that normally grow on some portions of the estuary bottom, thereby destroying important habitat for fish and other estuarine life. When algae reproduce and then die in large quantities, the microorganisms that decompose them consume such large quantities of oxygen from the water that under extreme conditions fish and shellfish can suffocate from lack of oxygen. The shift in nutrient availability that can be caused by atmospheric nitrogen deposition can also promote the growth of types of algae that release toxins into the water or that are aesthetically unpleasant.

The amount of nutrient enrichment that an estuary can tolerate without substantial biological damage depends on a complex set of factors such as estuary size and shape, amount of tidal flushing that occurs, and the size of the watershed that drains into the estuary. Eutrophication is one of the most critical environmental problems in coastal waters of the United States. All coastal waters in New York are affected to some degree.

How To Define Recovery from Air Pollution

How can the varied goals of ecosystem recovery from acidification or nutrient enrichment damage be evaluated? Different people have different views of what recovery means. One goal might be to restore ecological conditions to what they were before the Industrial Revolution triggered air pollution in North America and Europe. It must be recognized first, however, that this goal might be impossible to achieve, given the extent of existing damage, and second, that other human actions besides air pollution emissions have caused changes to these natural resources. For example, human activities such as logging, agriculture, urban development, and fish stocking have caused degradation of water bodies. Other complications include effects of climate change and the introduction of plant diseases or non-native species.

Another goal might be to restore species that are highly valued by people, such as brook trout to particular waters, or sugar maple trees to particular forest locations. But again, there are difficulties with this view of recovery because not all water bodies supported brook trout and not all forests supported sugar maple prior to human-caused air pollution. For example, a lake might have lacked suitable spawning habitat for brook trout; the soil might have been too shallow or too wet to support sugar maple. Therefore, it may be unreasonable to consider restoring a species that didn't live in a particular ecosystem in the first place. Furthermore, although the chemical conditions suitable for supporting a particular species might be restored, it may be impossible for that species or its



Many small streams in the Adirondack and Catskill mountains are very sensitive to damage from air pollution. (Photo: Barry Baldigo)

principal food source to recolonize a given location without human intervention.

There is no clearcut solution to the problem of defining what is meant by ecosystem recovery. In general, ecologists seem to be moving toward a goal of restoring water and soil chemistry to conditions capable of supporting an array of species that likely characterized that habitat in the absence of air pollution.

Degradation and Recovery of Soils and Forests

Soils have been damaged by air pollution throughout the western Adirondack and the Catskill mountains. Base cation stores in soils, which were naturally low to begin with, have been further depleted. In soils that are low in base cations, aluminum can be mobilized by acidity from soils to drainage water. Aluminum is present naturally in soils, where it occurs mostly in solid form. Under high levels of acid deposition, at locations where the soil base cation supplies are limited, some soil aluminum becomes dissolved in soil water. Dissolved aluminum is toxic to plant roots, fish, and other life forms. Base cation depletion has resulted in higher soil acidity and increased aluminum toxicity to plants. It is difficult to quantify these effects, in part because plants are simultaneously being affected by multiple stressors. Besides air pollution, plants are particularly affected by changing climatic conditions, insect pests, and disease. Nevertheless, it is clear that red spruce, sugar maple, and likely other plant species throughout the western Adirondack and Catskill regions of New York have been damaged by air pollution. These impacts have resulted from the effects of acidity on plant foliage, aluminum toxicity to plant roots, and insufficient calcium nutrition.

Effects of acid deposition on the soils are key to acidification and recovery throughout a watershed. Soils play several important roles. They store, and in some cases release, some of the deposited sulfur and nitrogen. They contribute base cations to water, neutralizing some of the acidity.

In the past, most of the sulfur deposited in watersheds in the Adirondack and Catskill mountains moved directly through soils and into water as sulfate, with the capacity to acidify soil and water along the way. Nevertheless, a fraction of the sulfur deposited each year was stored in the soil. Now that sulfur deposition inputs to the watersheds have decreased due to air pollution regulations, some of that stored sulfur is being released to drainage water. This process is contributing to a delayed acidification recovery response. Recovery is slower than it would be otherwise as a consequence of the cumulative damage to the soil from past air pollution.

Perspectives on Ecosystem Recovery

Ecosystem recovery from air pollution damage can encompass different variables. One aspect includes chemical recovery, such as restoration of the nutrient conditions in an estuary, the acidity status of a mountain stream, or the calcium availability in the soil of a sugar maple forest stand. Biological recovery can entail restoration of the various species of plants and animals that were lost or depleted due to air pollution damage. Measurement of chemical recovery from damage is often more straightforward and less complicated than is measurement of biological recovery. Consideration of biological recovery adds an additional layer of complexity and tends to be more difficult to measure and to predict. In addition, biological recovery might require that a previously eliminated species has the capacity to return to the ecosystem after air pollution levels are decreased. For example, once water chemistry returns to favorable conditions, a fish species may require re-introduction to a lake if there is not an available stream migration route to enable recolonization.

There is no scientific consensus regarding how ecosystem recovery from air pollution damage should be defined or evaluated. Strictly speaking, this is not a scientific question; rather, it is a societal question of importance to natural resource managers and various stakeholder groups, including environmentalists, industry representatives, politicians, and the general public.

Sugar maple trees (seen above with red maple and pine trees) are sensitive to calcium depletion, which can be exacerbated by acid deposition.

Sugar maple is a key species of the northern hardwood forest that predominates in many portions of upstate New York. The health of sugar maple trees is strongly influenced by the availability of calcium in soil. Calcium is depleted by acid deposition. Trees that grow on soils having low base cation supply are stressed and consequently often become more susceptible to damage from defoliating insects, drought, and extreme weather. The overall response includes death of mature trees and poor regeneration of seedlings. A current NYSERDA-sponsored research project is focused on quantifying the extent of damage to sugar maple trees in the Adirondack Mountains.

Red spruce trees at sensitive locations were dying at a rapid pace throughout the Adirondacks and northern New England in recent decades. This effect was linked with two aspects of air pollution: exposure of foliage to acidic cloud water and an increase in the amount of dissolved aluminum compared with dissolved calcium in soil water. Some of the red spruce decline was documented at high-elevation sites which frequently experience cloud cover. Research suggests that more than a third of the total atmospheric nitrogen deposition at such locations likely comes in the form of cloud deposition, which is often more acidic than acid rain.

Acidification of Water

Acidification of water is usually measured in units of ANC or pH. If either of these decreases, the water is said to be acidifying. When ANC is low, so is pH. Low pH water is toxic to aquatic life at all levels of the food web, from microscopic algae to predatory trout. But it is usually not low pH that kills fish in acidifying lakes or streams. More commonly, the principal toxic agent is dissolved aluminum.

Aluminum is one of the most abundant elements in the Earth's crust. Most soils contain a great deal of aluminum. It occurs naturally, and under normal circumstances is not toxic to plants or to aquatic species found in lakes and streams. However, if sulfur or nitrogen air pollution is high and soils contain limited amounts of base cations (especially calcium) with which to neutralize that acidity, then the water in the soil can become more acidic and some of the soil aluminum can dissolve into soil water, and eventually move into stream and lake water. Dissolved aluminum can be highly toxic to plant roots, fish, and to other aquatic life forms. Especially important is the ratio of calcium to aluminum in the water: conditions of lower dissolved calcium and higher dissolved aluminum (yielding a lower ratio) are most toxic.

Research conducted for NYSERDA in the Neversink River watershed in the Catskill Mountains and throughout the western Adirondack Mountains demonstrated base cation depletion from forest soil in response to air pollution. Base cation depletion from soil is, in turn, associated with the increased likelihood of aluminum toxicity to plants and the death and decline of red spruce and sugar maple trees in some areas. The extent of this kind of forest damage in New York is not yet well understood.

In many terrestrial (land-based as opposed to water-based) ecosystems, nitrogen is the most important nutrient that limits the growth of plants. If nitrogen is added to such ecosystems from atmospheric deposition, plant growth rates can increase. Because some species are better able to take advantage of added nitrogen than others, the end result can be an increase in the growth of some plant species at the expense of others. The species that benefit are often non-native, opportunistic species; those that are suppressed are sometimes rare and native species.

An undisturbed, unpolluted forest typically uses and stores almost all of the small amount of nitrogen that it receives from atmospheric deposition. This nitrogen is stored mostly in the soil, and is cycled between soil and vegetation. However, forests have a maximum capacity to store nitrogen that they receive from outside the watershed. This capacity is determined by the plant species present on the site and the history of logging and other disturbances that previously removed some of the nitrogen that was stored in the soil and trees. When nitrogen inputs exceed this storage capacity, the site becomes **nitrogen saturated**, and more of the incoming nitrogen leaches (or leaks) as nitrate to soil water and eventually to streams and lakes. It is the leaching of nitrate (just like

Atmospheric nitrogen deposition alters plant species composition by favoring some species at the expense of others. (Photo: Paul Bukaveckas) sulfate from sulfur deposition) that can contribute to acidification of soil and water, with harmful consequences to plants, fish, and other life. In the early stages of nitrogen saturation, however, the trees may actually grow faster because they are being fertilized by nitrogen, which is the most-important growth-limiting nutrient in these forests. During the latter stages of nitrogen saturation, however, tree health deteriorates and the forest may release more nitrogen to drainage water than is coming into the watershed from atmospheric deposition. This can result in stream and lake acidification. Under conditions of advanced nitrogen saturation, tree growth declines and sensitive tree species die.

Degradation and Recovery of Water Bodies

There are two distinctively different kinds of air pollution damage to the natural waters of New York. Freshwater lakes and streams in some locations have acidified. Estuaries and coastal marine waters have been enriched by nitrogen that has been deposited from the atmosphere, causing eutrophication. As atmospheric deposition of sulfur and nitrogen declines, both fresh water and marine water environments are expected to recover to some degree.

The Complications of Nitrogen

When it comes to nitrogen in the environment, things can get complicated. Nitrogen can take many forms in the atmosphere, soil, water, and living tissue, depending upon the identity and amount of the other things (mainly oxygen, hydrogen, and/or carbon) to which the nitrogen is attached. Atmospheric nitrogen from motor vehicles is emitted mostly as oxidized nitrogen (one nitrogen atom attached to one or more oxygen atoms). Nitrogen from agricultural croplands or livestock is emitted mostly as reduced nitrogen (ammonia, containing one nitrogen atom and three hydrogen atoms). Within the soil, there are multitudes of conversions and transformations that take place, many facilitated by microorganisms, such as bacteria and small fungi. The form of nitrogen can change rather rapidly. Different plants and different kinds of algae vary in their needs for nitrogen nutrition. Some prefer oxidized forms; some prefer reduced forms; some can use small organic nitrogen molecules that also contain carbon atoms. When nitrogen leaches from the soil into drainage water, and eventually to a stream or lake, it is mostly in the form of nitrate (one nitrogen atom attached to three oxygen atoms). This is the form of nitrogen that acidifies the environment.

When nitrogen deposition and its effects are discussed, all these different forms of nitrogen, and others, are included. Because so many of the nitrogen forms can change in the environment, it is better to ignore the complexities and focus on nitrogen as one substance.

Fresh Water Acidification

The Adirondack region contains large numbers of protected lakes, streams, and forests. It also has perhaps suffered as much ecological damage from air pollution as any region in the United States. The Adirondack Park has been the focus of extensive scientific research and monitoring efforts since the 1970s. These have included surveys of hundreds to more than a thousand lakes and streams, investigations of short-term changes in water chemistry during periods of rain and snowmelt, studies of acidification processes in soil, development and application of mathematical models to predict the rate of future recovery as air pollution levels decline, and regular sampling of some lakes for more than 25 years to document changes over time. As a result, a great deal is known about the recent recovery of fresh waters in this region from past acidification.

Although hundreds of Adirondack lakes have been acidified by acidic deposition, most have been slowly recovering over the past two decades. Whether recovery will continue in the future is unclear. (Photo: Bill Ingersoll)

<u>Chemical Indicators of Damage and Recovery</u> **-** Scientists commonly estimate the sensitivity of a lake or stream to potential acidification, and also the degree of acidification or recovery that occurs over time, using a measurement that is called the acid neutralizing capacity, or ANC. ANC reflects the ability of water to neutralize strong acid. Strong acid can be added in the form of sulfate (which is comprised of sulfur and oxygen) or nitrate (which is comprised of nitrogen and oxygen), each of which can be contributed to a watershed by air pollution in the form of sulfur or nitrogen deposition, respectively. ANC values can be positive or negative. Waters that have an ANC value below zero microequivalents per liter (a common unit of chemical concentration) during the summer or fall season when it has not been raining are defined as chronically "acidic." Waters having an ANC value of less than 50 or 100 microequivalents per liter are generally considered potentially "sensitive" to acidification. Those having higher ANC values are generally considered less sensitive or insensitive. When the ANC value is low, and especially when it is negative, stream water pH is also low (less than about 5 to 6) - meaning the level of acidity is high - which has adverse effects on fish and other life forms that live in the water. The process of a decreasing ANC over time is called "acidification." The capacity of a watershed to resist decreases in ANC, and associated decreases in pH, is determined mainly by the relative amounts of base cations, such as calcium, compared with acidic **anions**, such as

sulfate and nitrate, in the water. The base cations are mostly derived from the soils and ultimately from the rocks that break down to form those soils. The acidic anions are mostly derived from atmospheric deposition of sulfur and nitrogen.

The sensitivity of waters to acidification from acid deposition is determined mainly by the types of rocks found beneath the streams and lakes and the characteristics of the watershed soils. Effects can be complicated. As an example, in very general terms, the geology controls soil characteristics that interact with precipitation, topography, and air pollution to determine water chemistry, which affects trees and fish. If the underlying geology is poor in base cations and water drains through the soil very quickly, the soil and water in the watershed will have poor ability to neutralize acids deposited from the atmosphere.

Mathematical models of watershed acidification estimate that lakes and streams in such watersheds have typically lost much of their natural ANC, largely in response to more than a century of industrial emissions of air pollutants and acid deposition. As a consequence, pH values in many lakes and streams are low, especially during the spring. Prior to human-caused air pollution, most lakes and streams in the Adirondack and Catskill mountains probably had pH above about 5.5 to 6. Many lakes and streams currently have pH as low as about 4.5 to 5. Water with a pH of 5 contains 10 times more acidity than water with a pH of 6.

The high rates of atmospheric deposition of sulfur and nitrogen on the watersheds of Adirondack and Catskill lakes and streams, combined with naturally low contributions from some rock types of base cations that serve to neutralize acidity, are the most important causes of acidity in many lakes and streams within these regions. Some waters can also become temporarily acidic for short periods (hours to weeks) during rainstorms or snowmelt. This is termed “episodic acidification” and, like chronic acidification, can harm aquatic life. This episodic acidity is partly due to natural processes and partly due to a flush into streams of meltwater acidity from nitrogen that had been deposited and then stored in the soil and snowpack in the watershed during winter.

Spring season melting of a snowpack that contains acids from atmospheric deposition contributes to a flush of acidity in streams and lakes. This acidity can harm fish and other aquatic life.
(Photo: Bill Ingersoll)

Mathematical Models

The environmental systems that are sensitive to air pollution damage are highly complex. A change in one part of an ecosystem often triggers changes to other parts. Because of this complexity, environmental scientists frequently employ mathematical models to predict ecosystem response to changing conditions. These models approximate key processes and ecosystem components as mathematical equations. As such, the models over-simplify highly complex natural systems. Nevertheless, a well-designed model represents state-of-the-art scientific knowledge about the ecosystem and how it would be expected to respond to changes in future conditions.

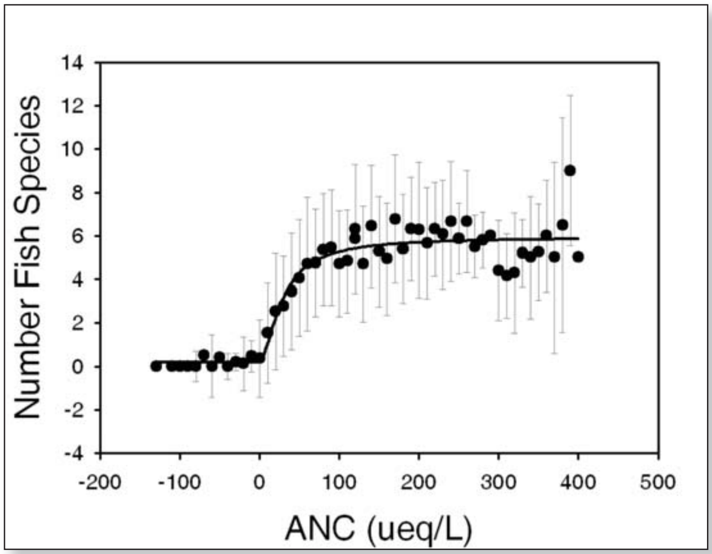
Predictions using these models cannot be accepted with absolute certainty. But the models represent cumulative scientific knowledge gained through several decades of environmental research, and the model predictions therefore can be interpreted as realistic estimates, given current scientific uncertainties.

With support from NYSERDA, scientists are now using such models to estimate the **critical load** of sulfur deposition for sensitive lakes and forest soils in the Adirondack Mountains. Knowledge of the level of deposition load at which ecological effects begin to occur will allow resource managers to set interim emissions and deposition targets to allow for recovery from past acidification damage and prevent further future damage.

For most of the year, the predominant cause of acidification of most Adirondack and Catskill mountain lakes and streams is sulfur. However, at the peak of snowmelt, the influence of nitrogen deposition becomes proportionately much more important, and in some waters is just as important as sulfur acidity. The reasons for the seasonal shift in the relative importance of sulfur- and nitrogen-caused acidity is related to the dynamics of plant and microbial (bacteria and small fungi) growth cycles and snowpack accumulation and melting. Because the amount of stored base cations in the soil is gradually declining in response to acid deposition, lakes and streams are expected to acidify more in the future than they have so far, relative to the amount of acid deposition received. This means that the effects of acid deposition are not totally reversible, and that some damage may persist for a long time even if society severely curtailed air pollution inputs today.

Although one might argue that recovery of biological systems is most important to humans, scientists generally are better able to predict future chemical recovery. Nevertheless, it is clear that biological recovery cannot occur unless chemical conditions are improved in damaged ecosystems.

Biological Response **-** Low values of ANC and pH can harm biological resources in the water, including fish and aquatic invertebrates. In general, aquatic life is considered to be at risk if the pH falls below about 5.5 to 6.0, ANC is less than 50 microequivalents per liter, or the concentration of inorganic aluminum (the toxic form) is greater than 2 micromoles per liter (another common unit of chemical concentration). Often, it is the dissolved aluminum mobilized from the soil that kills fish and perhaps other species when water acidifies. Young fish tend to be more sensitive than adults. Adirondack lakes that have an ANC value above 50 microequivalents per liter (pH above about 6) on average contain around 5 species of fish, and some have 10 or more. Lakes with an ANC value below zero microequivalents per liter (pH below about 5) often have high aluminum concentrations and generally contain no fish. On the basis of modeling tools and a variety of diagnostic features of lake chemistry, scientists have been able to determine relative sensitivities of Adirondack lakes to acidification and to quantify the extent of past damage that has actually occurred due to acid deposition.



A graph from a NYSERDA-sponsored study showing the number of fish species in Adirondack lakes as a function of ANC. The values shown represent the mean (filled circles) and standard deviation (bars) of the number of fish species identified in lakes shown within ANC classes. Typically, fish are absent at ANC below zero, and the number of fish species increases steadily until ANC exceeds about 50 to 100 microequivalents per liter. Data from Adirondack Lakes Survey.

There are more than 1,800 lakes in the Adirondacks (excluding small ponds). About 40% of those (approximately 700 lakes) currently have an ANC value below 50 microequivalents per liter. Most become temporarily acidic or nearly so during rainstorms and spring snowmelt and have likely experienced some degree of biological harm from acidification. About 11% (200 lakes) are chronically acidic and support few or no fish or other acid-sensitive life forms.

During 2003-2005, USGS, supported by NYSERDA, sampled 200 western Adirondack streams during spring, summer, and fall seasons (http://www.nyserda.org/programs/Environment/EMEP/finalreports.asp). The ANC value was below zero microequivalents per liter in 15% of the streams during summer, 25% during fall, and 29% during spring. In addition, 25% (summer) to 41% (spring) and 44% (fall) of the streams had ANC and pH low enough to cause inorganic aluminum concentrations to

Threats to Aquatic Ecosystems

Brook trout are widely distributed in lakes and streams in upstate New York and are moderately sensitive to acidification.

Fish differ in their sensitivity to acidification. Some are harmed at pH values below about 6, whereas others are tolerant of pH values near 5. In addition to such differences among species, there are differences in tolerance among life stages of an individual species. In general, eggs and young fish are more sensitive than adults. Thus, rather low-level acidification impacts can interfere with fish reproduction and cause a gradual decline in fish abundance over time, as opposed to a rapid die-off of adult fish.

Acidification poses a threat to the four trout species found in Adirondack and Catskill mountain lakes and streams: brook, brown, lake, and rainbow trout. Particular concern has been expressed about the effects on brook trout, the least sensitive of the four, because this species is native to, and widely distributed throughout, the acid-sensitive portions of the region. Other fish species, although perhaps not as well known to visitors, are also sensitive in varying degrees to acidification. These include various species of dace, chub, sculpin, darter, perch, and bass. Many species of small aquatic animals known as **benthic macroinvertebrates** and **zooplankton** occur in streams and lakes. They exhibit wide ranges of sensitivity to acid conditions. Of particular importance to the ecology of the streams are the macroinvertebrates, especially the aquatic insects. They play critical roles in the breakdown of leaves and other organic materials in the stream and provide food for fish and other members of the food web. Mayflies, caddisflies, and stoneflies are groups of insects that are important food sources for trout, are of great interest to fly fishers, and tend to be very sensitive to acidification. Among the zooplankton in lakes, crustaceans are particularly sensitive to acidity. They constitute important parts of the lake food web.

increase above 2 micromoles per liter, which is the threshold for killing young brook trout in the western Adirondacks. Many other aquatic species are more sensitive than brook trout. For example, during the spring survey, algae communities were severely affected in more than half of the study streams, and moderately to severely affected in 80% of the streams.

During the 1980s, there were nearly 600 Adirondack lakes with pH below 5.5, most of which had probably been acidified by acid deposition. Most Adirondack fish species occur in lakes and streams having pH between about 5.5 and 6.5. Some are largely restricted to pH above 6.0. Only a few fish species (including central mudminnow, brown bullhead, and yellow perch) are commonly found at pH levels below 5. More than three-fourths of the Adirondack lakes with a pH of less than 5.0 are fishless. Most of the fishless lakes are located in the southwestern Adirondacks, where acid deposition and watershed acid sensitivity are both highest.

As pH and ANC decline, the number of fish species declines, and there is a greater likelihood of fish being absent altogether. In some cases of fish absence, the cause is acidification from acid deposition; in other cases, the habitat would not support fish, irrespective of acidity status. Adirondack lakes that have a pH level below about 4.5 to 5.0 and ANC below zero typically support only one or no fish species. At pH above 6.0 and ANC above about 50 to 100 microequivalents per liter, lakes more commonly support four to six species of fish (see graph on page 12).

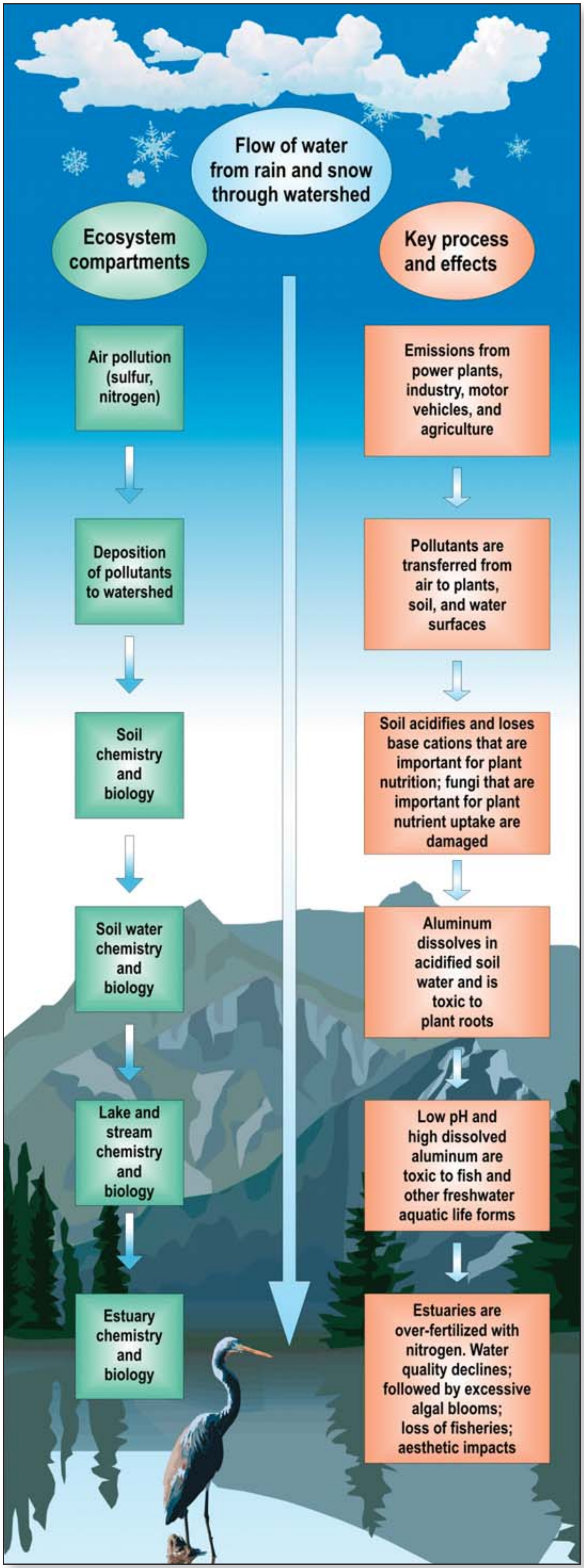
Analysis of Adirondack Lakes Survey data found 346 Adirondack lakes that were fishless during the 1980s, one-third of which appeared to be fishless primarily as a consequence of acid deposition. In addition, for every lake that is fishless due to acid deposition, there are likely several others that still have some fish but that have lost the more sensitive fish species, lost life forms other than fish, or now contain reduced numbers of fish as a consequence of acidification. In response to acidification, some Adirondack lakes have probably lost up to four fish species and four species of zooplankton, which are small invertebrates that constitute part of the food web in the lakes. Acidified streams have lost several species of fish (often including brook trout) and invertebrates (especially mayflies, an important food source of brook trout and other fish species).

The Neversink River is the most acid-sensitive watershed in the Catskill Mountains, owing to its geologic and soil characteristics and its topography. Numerous tributary streams, especially in the upper reaches of the watershed, are chronically acidic, with low pH and high aluminum concentrations that have impacted fish populations. There has been some improvement in conditions over the past 15 years, as documented in a study sponsored by NYSERDA (http://www.nyserda.org/publications/Final%20Report%2006-16-web.pdf). The acidity of the most impacted sites that are furthest upstream has decreased slightly over the past few years. As a consequence, some streams now show somewhat higher diversity of aquatic invertebrates and perhaps an expanded range for brook trout.

Air pollutants that affect water quality and fish populations also can affect the food chain and influence the populations of fish-eating species, such as this common loon.

Another NYSERDA-sponsored research project developed past and future model projections for Adirondack lakes (http://www.nyserda.org/publications/Final%20Report%2006-17complete-web.pdf). The results suggest that the typical acid-sensitive Adirondack lake has lost about 50 microequivalents per liter of ANC due to acid deposition over the past century. Modest chemical recovery of up to 20 microequivalents per liter in some lakes has occurred since the 1980s in response to reductions in air pollution. The model projections also show that continued recovery of these lakes beyond approximately 2015 is unlikely unless emissions are further reduced below levels that occurred in 2001.

Assessments from long-term monitoring sites indicate that the on-going chemical recovery of Adirondack lakes has slowed since 2000. This observation agrees with model projections, which suggest that continued recovery of water chemistry will require additional emissions reductions beyond those required by regulations in effect as of about 2003. Model projections conducted for NYSERDA suggest that the on-going chemical recovery of the more acid-sensitive Adirondack lakes will come to an end over approximately the next decade. Unless air pollution emissions are further reduced, this recovery will likely be followed by a lengthy period of renewed acidification of lakes that were recently recovering from past acidification. This is because recent levels of acid deposition, even though they are lower than during past decades, have nevertheless been high enough that base cations continue to be removed from soils by the sulfates and nitrates from atmospheric deposition. Two different ecosystem models estimated that the number of Adirondack lakes having an ANC value below 50 microequivalents per liter will increase in the future, even with assumed modest continued reductions in emissions of sulfur (a further 11% decrease) and nitrogen (about 20% decrease) below levels that occurred during 2001. However, model estimates suggest that substantial additional future reductions in sulfur and nitrogen deposition would result in biological improvements in many of the most severely degraded lakes. Such projected improvements would include the return of one to two species of fish to the lakes, improved conditions for brook trout, and an



increase by one or two in the number of species of zooplankton. Nevertheless, even if sulfur and nitrogen emissions are reduced to half or less of their recent values, the most acid-impacted Adirondack lakes are unlikely to increase to an ANC value high enough whereby episodic acidification to an ANC value below zero during snowmelt is no longer a threat.

Estuarine and Marine Eutrophication

Just like forests, estuaries and coastal marine waters can become saturated with too much nitrogen. The two largest sources of nitrogen to New York's estuaries and other coastal waters are human activities related to food and atmospheric nitrogen deposition. The production of food and its consumption, which results in human waste elimination, contribute nutrient pollution to estuaries through fertilizer runoff and waste water treatment plant discharge.

Low dissolved oxygen has occurred across large areas of Long Island Sound each year for at least the past decade. Oxygen concentrations below 3 milligrams per liter, a level that contributes to adverse impacts on many aquatic life forms, typically cover at least 50% of the estuary area. Lack of oxygen most seriously affects the western half of the sound. The primary sources of nitrogen that contribute to the algal production that causes oxygen depletion include waste water treatment plant effluent; urban runoff from New York City, Long Island, and Connecticut; and atmospheric deposition. A national assessment of estuary conditions by the National Oceanic and Atmospheric Administration (NOAA) in 2007 rated Long Island Sound as High for eutrophic conditions. Other New York estuaries were rated somewhat better, with Great South Bay as Moderately High, Hudson River/Raritan Bay as Moderate, and Gardiners Bay as Low (see map on page 3).

So Now What?

Since passage of the Clean Air Act (1970) and its Amendments (1990), it is tempting to believe that the acid rain and associated air pollution problems have been solved in the United States. Unfortunately, this is not true. The damage has been only partially reversed. Hundreds of lakes and streams in New York are still acidic. Many more are not quite acidic but sustain biological damage. The health of some tree species has been compromised, and many species of fish and other aquatic animals can no longer exist in many affected waters.

Over the past 25 years, sulfur deposition to acid-sensitive watersheds in New York has decreased by about half, the pH of rainfall has increased by about a fourth of a pH unit, and nitrogen deposition has decreased slightly. Such accomplishments are impressive. It was hoped that emissions reductions required by the Clean Air Act Amendments would result in recovery of lake and stream chemistry, including increases in pH and ANC values and decreases in inorganic aluminum concentrations in water. Such improvements in water chemistry would, in turn, benefit acid-sensitive fish, invertebrates, and other life forms. It also was hoped that damaged soils and plant

Nutrient enrichment of estuaries can affect species at all levels of the food web, including this great blue heron.

species would show signs of recovery. Hopes for recovery have varied among scientists. The prevailing expectation has shifted from the rapid recovery expected during the 1980s to the prevailing current expectation of a long-term (decades or longer) gradual process of chemical recovery. Such recovery will entail depleting the acids that have accumulated in sensitive watersheds through a century of acid deposition and restoring some of the base cations that have been lost from the soil.

Lake and stream monitoring data collected so far have supported the view that recovery will be slow and limited. Mathematical modeling further suggests that the on-going slow process of chemical recovery is not necessarily sustainable without further emissions reductions. One unfortunate aspect of the response of watersheds to acid deposition is that the watershed's ability to neutralize acids from acid deposition changes over time. As more atmospheric acidity is neutralized and more sulfur and nitrogen are stored in the soil, the watershed's ability to neutralize and store newly deposited acids is progressively reduced. This has a significant effect on the capacity of watersheds to recover from acidification. In short, the longer emissions controls have been, or will be, delayed, the less effective those emissions controls will be with respect to recovery of soil and water from acidification.

In the typical acidified Adirondack or Catskill mountain watershed, every square meter of the Earth's surface has received more than 0.15 kilograms (0.33 pounds) of pure sulfur deposition from the atmosphere as a consequence of air pollution since 1900. The amount of nitrogen deposition has been less, but it is sizeable. This long history of sulfur and nitrogen deposition has profoundly affected the recovery potential of damaged watersheds.

Scientists know much less about the effects of acid deposition on plants than they do about effects on water. They know that some tree species, including red spruce and sugar maple, have been damaged in some areas. The degree of damage and the extent of more recent recovery, if any, in response to recent reductions in pollutant emissions and acid deposition are not known. It is unlikely that plant recovery from soil damage has occurred to a significant extent in the Adirondack or Catskill mountains in response to decreased levels of air pollution. More likely, soil conditions and plant health are continuing to decline. This is because the base cation supply of the soil in the most acid-sensitive watersheds continues to be depleted by current air pollution levels. In order to achieve soil and plant recovery from soil acidification damage at some locations, it appears that more stringent reductions in air pollution might be necessary. Some degree of vegetation recovery from cloud acidity and from the effects of nutrient enrichment from nitrogen may be beginning to occur in New York as air pollution levels decline, but scientists have not yet been able to confirm that response.

Sulfur and nitrogen emissions controls put into place in the United States (and neighboring Canada) since passage of the Clean Air Act and its Amendments have slowed the pace of damage to sensitive ecosystems in New York. Limited chemical, and likely biological, recovery has occurred. Current scientific understanding suggests that additional cuts in emissions, beyond those required as of 2003 might be required to enable the most sensitive ecosystems to continue to recover and to prevent renewed acidification in response to base cation loss from soils under continued (albeit lower) levels of atmospheric sulfur and nitrogen deposition. Federal and state governments continue to make important decisions regarding what levels of atmospheric deposition are acceptable and what costs are associated with implementation of further emissions controls.

CONCLUSIONS AND PROGNOSIS FOR THE FUTURE

Conclusions

As described in this paper, there are a variety of ways in which air pollutants and associated acid (sulfur and nitrogen) and nutrient (nitrogen) deposition affect the sensitive natural resources in New York. Human activities are responsible for most of the emissions of these pollutants into the atmosphere. Each type of pollutant is associated with one or more effects on natural resources (see graphic on page 14). Model estimates, measurements, and scientific judgments of the effects of air pollution on sensitive resources reveal a mixed picture.

The good news for New York is that:

- Atmospheric deposition of sulfur to acid-sensitive watersheds has been declining for three decades and continues to decline. Nitrogen deposition was stable for many years but started to decline after the turn of the 21st Century. Existing and anticipated federal and State rules and regulations are expected to result in further reductions in sulfur and nitrogen deposition in the near future.
- Natural ecosystems typically are able to buffer some level of air pollution. Sensitivity varies across the landscape. Only some of the soil, plant, and water resources in New York are sensitive to existing air pollution levels, and many remain largely unaffected.

The bad news is that:

- The sensitive regions of New York still experience air pollution levels higher than many other parts of the United States.
- Despite some recent improvements, the Adirondack and Catskill mountain regions still have levels of acidity in many lakes and streams that are harmful to many species of fish and other aquatic life forms.
- Continued exposure of vegetation to high atmospheric deposition and associated soil acidification will likely cause further damage to plants and a gradual decline in the abundance of the more sensitive plant species.
- Estuaries and coastal marine waters in New York have experienced varying degrees of eutrophication from nitrogen addition, and air pollution is partly responsible.
- Some of the damages that have occurred to soils and aquatic ecosystems are only partially reversible over the next century, even with additional large cuts in pollutant emissions.

In order to achieve substantial progress toward resource recovery, further reductions in regional emissions of air pollutants will likely be required. To markedly improve estuary conditions, non-atmospheric sources of nitrogen also must be further reduced.

Prognosis

NYSERDA-sponsored research has shown that resource conditions in some of the most sensitive watersheds likely will deteriorate in the future if sulfur and nitrogen emissions remain high (http://www.nyserda.org/publications/Final%20Report%20 06-17 complete-web.pdf). If emissions are further reduced, the future improvements in resource conditions that are projected to occur generally are expected to be proportional to the level of emissions reductions achieved.

Overall, environmental conditions that reflect air pollution impacts do seem to be improving in New York, or at least getting worse more slowly than previously. It appears that emissions controls are on the right track in New York and the nation. More time is needed to allow various air pollution emissions control policies to have their full beneficial effect.

Aerial view of the Adirondacks. (Photo: Jeremy Farrell)

In addition, society faces on-going questions and decisions concerning the desirability of further cuts in emissions of sulfur and nitrogen. Research results suggest that some lakes that have been recovering may re-acidify in the near future unless emissions levels are further reduced. Costs and benefits must be carefully weighed to determine the levels of air pollution that balance competing environmental, economic, and societal goals. New Yorkers and Americans must continue to make important decisions concerning what levels of air and water pollution are acceptable. However, the future of New York's outstanding natural resources, especially those in the coastal areas and the Adirondack and Catskill mountains, will be affected by the decisions that are made. To learn more about air pollution and its effects in New York, consult one or more of the many books, scientific reports, and journal articles available on this topic. For some general sources of information, see the short list of titles in the box below.

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Some Useful Terms and Their Definitions

ACID - a compound that has extra hydrogen ions (protons); lemon juice is a well-known example.

ACIDIC - for this publication, stream or lake water is defined as being acidic if it has acid neutralizing capacity less than zero.

ACID DEPOSITION - the transfer of acids and acidifying compounds from the atmosphere to the ground and eventually to a stream or lake via rain, snow, sleet, hail, cloud droplets, particles, and gas. Commonly called "acid rain."

ACID NEUTRALIZING CAPACITY (ANC) - the capacity of a stream or lake to neutralize added strong acids, such as from acid deposition.

ACIDIFICATION - decrease of acid neutralizing capacity, and usually pH, of water.

AQUATIC - living in, or pertaining to, water.

ANION - an atom or group of atoms with a negative charge. Examples of anions include the sulfate (SO_4^{2-}) and nitrate (NO_3^-) ions.

BASE CATION - an alkaline earth metal with a positive charge (cation), such as calcium, magnesium, potassium, or sodium. These are carried in soil water from soil to stream water, and act to neutralize the acidity in acid deposition.

BENTHIC MACROINVERTEBRATE - animal without a backbone that can be seen with the unaided eye and that is found on the bottom of a stream, for example attached to a stone in the streambed. This term includes the immature (larval) forms of many insects.

CRITICAL LOAD - atmospheric deposition load (or amount) that will cause ecological damage to a sensitive receptor, such as a stream, according to current scientific understanding.

ECOSYSTEM- A community of organisms together with their physical environment, viewed as a system of interacting and interdependent relationships and processes.

EUTROPHICATION - over-enrichment of a water body with nutrients, which can result in excessive growth of organisms and depletion of oxygen concentration.

MODEL - mathematical representation of something, such as an ecosystem or set of ecosystem processes.

MONITORING - repeated collection of data over a long period of time to document changes (trends).

NITROGEN SATURATED - condition whereby the amount of available nitrogen exceeds the amount needed to support the growth of plants and other organisms in the ecosystem.

NONPOINT SOURCE - a relatively small and diffuse source of pollution, such as motor vehicle, farm, or residential area.

pH - a measure of the acidity or basicity of a solution. It is defined as the cologarithm of the activity of dissolved hydrogen ions (H^+). The pH scale is generally presented from 0 (most acidic) to 14 (most alkaline); pH of 7.0 is neutral.

POINT SOURCE - relatively large individual source of pollution, such as a power plant or industrial facility.

WATERSHED - all of the land area that drains water to a common stream, river, lake, reservoir, or other body of water.

ZOOPLANKTON - microscopic animals found in the water column of a lake or estuary.

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New York Energy Smart SM

EMEP

Environmental Monitoring, Evaluation, & Protection

NYSERDA's Environmental Monitoring, Evaluation, and Protection (EMEP) program provides objective policy-relevant research in New York focused on electricity-generation issues. Primary goals are to enhance understanding of energy-related pollution and its impacts, and to characterize pollution sources and define opportunities for emissions reductions.