ACID RAIN - LEARNING FROM THE PAST AND LOOKING TO THE FUTURE: A PRIMER

September 2005

INTRODUCTION

Freshwater in the northeastern United States supports agriculture, fish and wildlife, recreation, drinking needs, and industry. While the region enjoys a relative abundance of water, the quality of our water has degraded over the past century as a consequence of human activities, although some improvements have been observed lately as a result of pollution reduction measures. With improved understanding of the impacts of these activities, we will be better prepared to address this problem effectively, so that current and future generations can rely on the use of this vital resource.

An important impact of human activities on water quality that warrants continued attention is acid deposition, commonly called acid rain. Through the emission and deposition of sulfur dioxide and nitrogen oxides associated with the burning of fossil fuels, many lakes and streams across the region have become too acidic to continue to support aquatic life as in the past. Over the past 40 years, scientists, government officials, industry representatives, and environmentalists have investigated the causes and consequences of this problem and proposed many solutions. This primer provides a short summary of the history, causes, and consequences of acid rain, as well as certain policy approaches for mitigating its impacts in New York and the Northeast.

This document was produced by the Environmental Monitoring, Evaluation and Protection (EMEP) program of the New York State Energy Research and Development Authority (NYSERDA), and represents one of several primers on topics related to the program.

NYSERDA is a public benefit corporation created in 1975 by the New York State legislature. NYSERDA administers the New York Energy $mart^SM program, which is designed to support certain public benefit programs during the transition to a more competitive electricity market. The New York Energy $mart^SM program provides energy efficiency services, including those directed at the low-income sector, research and development, and environmental protection activities.

NYSERDA has been developing innovative solutions to environmental problems associated with energy production through its support for research and development of energy-efficiency projects. Early efforts included projects that focused on acidic deposition, including the Adirondack Manipulation and Modeling Study and the Long-Term Monitoring Program of The Adirondack Lakes Survey Corporation. Through its EMEP program, NYSERDA continues to provide scientifically credible and objective information on the environmental impacts of energy systems and to assist the State in developing science-based and cost-effective policies to mitigate these impacts. The EMEP program currently sponsors 20 projects related to the response of ecosystems to the deposition of sulfur, nitrogen and mercury.

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WHAT IS ACIDIC DEPOSITION?

Acidic deposition results from the combustion of fossil fuels, which provides heat and/or energy. When coal, oil, or other fossil fuels are burned, acid-rain Aprecursors@ are emitted into the atmosphere. These include nitrogen oxides (NO_x) and sulfur dioxide (SO_2). Once in the atmosphere, NO_x and SO_2 are transformed, depending upon atmospheric conditions, into acid nitrate and acid sulfate, otherwise known as nitric acid and sulfuric acid, and fall back to earth in rain, snow, fog, cloud water, particles, and gases. The term Aacidic deposition@ encompasses all forms of inputs of acids. AWet deposition@ is the portion that is contributed in rain, snow, cloud water, and fog, while Adry deposition@ includes acids attached to particles, gases, and aerosols. Rain and snow are naturally somewhat acidic, owing to the presence of carbon dioxide in the air, which dissolves to form carbonic acid, the weak acid that is responsible for the fizz in soda. However, natural acidity has been substantially augmented by inputs of the strong acids that are byproducts of fossil-fuel combustion.

The level of acidity of a substance is measured by its pH, a numerical value determined by a solution=s concentration of hydrogen ions (Figure 1). The pH scale ranges from 1 to 14, where 7 represents neutral. As the scale is logarithmic, each unit change represents a ten-fold increase or decrease in acidity (Figure 2). For example, pH 4.0 is 10 times more acidic than pH 5.0.

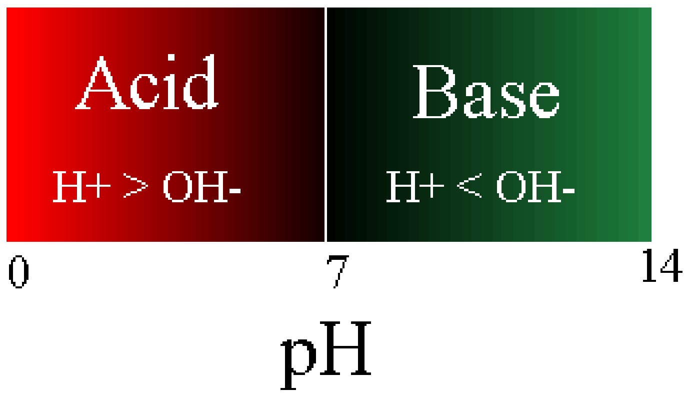


Figure 1. Understanding the pH scale.

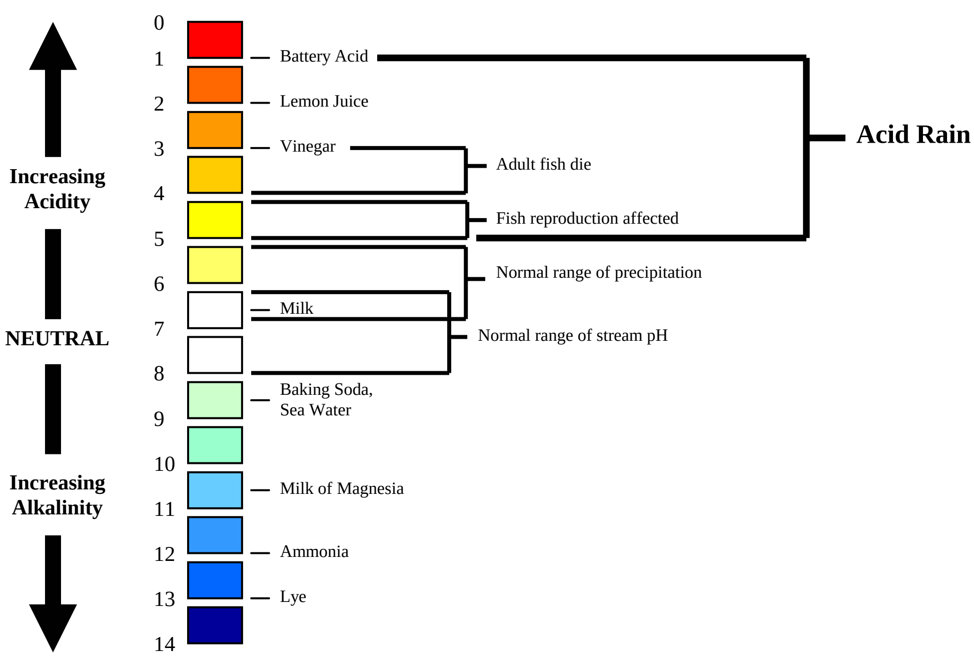


Figure 2. The pH Scale.

Principal sources of acid rain precursors (SO_2 and NOx) include power generation utilities, transportation, and industry, as shown in Figure 3. In the United States, electric utilities are the leading source of SO_2 emissions, while transportation sources generate the highest amount of NO_x. These sources are distributed throughout North America, although a higher concentration of utility and manufacturing sources are located in the Midwest and Mid-Atlantic regions, and large clusters of transportation sources are found along the Eastern seaboard.

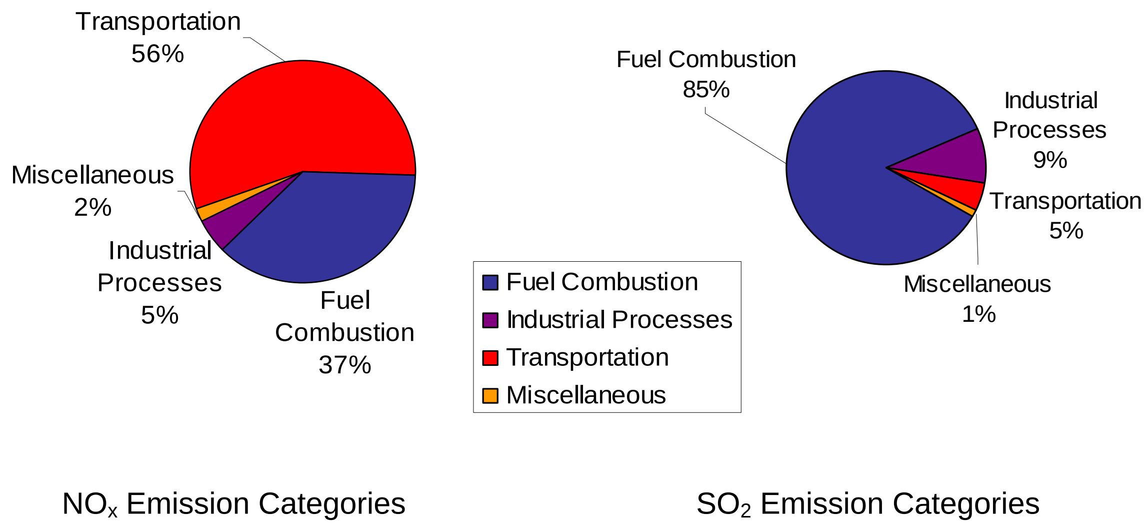


Figure 3. Sources of Acid Rain Precursors in the U.S. (EPA 2002)

The basic processes for the formation of acidic deposition have been known since the mid-1800s (Cowling 1982). However, nearly 200 years later, effectively addressing its causes and impacts is still a major public policy issue.

A RECENT HISTORY OF ACIDIC DEPOSITION

Measurement of the acidity of rain and snow associated with industrial pollution was first done for the entire U.S. in the late 1950s by the U.S. Public Health Service and National Center for Atmospheric Research (EPA, 1980). At that time, there was growing concern that increased fossil fuel combustion was causing air pollution problems. Industry responded to this concern by raising smokestack heights to disperse their emissions. The effect was to transform a local urban problem into a national and international one. (Gould 1985)

During the 1970s, New York=s Adirondacks Mountains emerged as a Aposter child@ for acid rain. High deposition rates, shallow soils, mountainous terrain, and mountain lakes made the region particularly susceptible to acidic deposition. The Adirondacks= status as an international wilderness and popular fishing destination led to heightened public interest in the region=s conditions that continues to date.
In the public policy arena, the 1970 Clean Air Act (CAA) empowered the U.S. Environmental Protection Agency (EPA) to regulate SO_2 and NO_x emissions to ensure that national air quality standards were met. The U.S. EPA issued regulations giving states the responsibility of controlling emissions and making certain that one state did not Asignificantly interfere@ with the attainment of standards in other states. Despite these policies, acid deposition was not seen as an important national environmental issue until the 1980s, when the U.S. government established an international acid-rain working group that resulted in the U.S./Canada Memorandum of Intent on Transboundary Air Pollution (1983). At the same time New York State filed a petition with the U.S. EPA to require Midwestern states to reduce emissions because of their impact on Adirondack lakes and watersheds. The petition was denied on the grounds that it had not made a persuasive technical case that interstate transport of pollution caused violations of CAA standards.

To address this growing concern, New York State responded with its own State Acid Deposition Control Act (SADCA) in 1984, recognizing that about 80% of the sulfur deposited in the Adirondacks originates outside of New York State, requiring regional and national solutions to mitigate the problem.

Despite advances in the understanding of acid rain causes and effects, the 1980s were marked by political debate and policy stalemate, and the U. S. Congress launched the National Acid Precipitation and Assessment Program (NAPAP), and to report to the Congress. The 1990 Clean Air Act Amendments brought about federal action aimed specifically at reducing acid rain. This created a market-based pollution reduction program to address SO_2 emissions. Since its implementation in 1995, Title IV has led to a 40% reduction of SO_2 emissions nationwide from electric utilities. The cost of achieving these reductions has turned out to be significantly less than anticipated, owing to the effectiveness of the market-based system.

However, the continued damage to sensitive aquatic and terrestrial ecosystems, fisheries losses, red spruce dieback, as well as impact of increased mercury in biota, to name a few, has led New York State to regulate additional emissions reductions in acid rain precursors through the Acid Deposition Reduction Program (ADRP) in 2004. With these changes and the not yet implemented federal Clean Air Interstate Rule aimed at control of acid rain precursors, further reduction in acidic deposition should be forthcoming.

WHAT ARE RECENT TRENDS IN EMISSIONS AND ACID DEPOSITION?

While SO_2 emissions from all sources in the U.S. have decreased from 17.3 million tons in 1980 to 10.2 million tons in 2002 (U.S. EPA 2003), a 41% reduction resulting from Title IV of the 1990 CAAAs, the picture for NO_x emissions is less encouraging. Since 1990, NO_x emissions have declined by 12% (U.S. EPA 2003). However, while NO_x emissions from transportation sources have decreased by 14%, emissions from heavy-duty vehicles have increased by 10%. In New York State, SO_2 emissions have decreased by ~18 % since 1985, while NO_x emissions have risen slightly over the same period (U.S. EPA; see Figure 4).

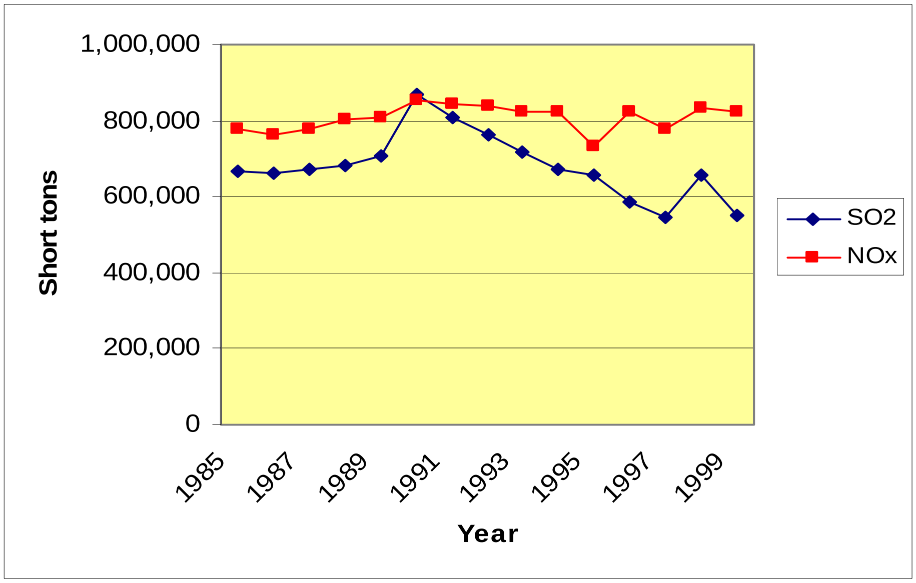


Figure 4. Annual SO_2 and NO_x Emissions in New York State. Source: EPA Office of Air and Radiation, NEI database, 2002.

ANatural@ rainwater has a pH of approximately 5.6. In 2002, wet deposition pH in the country had a range of 4.4 to 6.0. The areas of highest acidity were concentrated in the Northeast, while in New York State, the average annual pH of wet deposition was 4.28 to 4.84 in 2002 (Figure 5). The Adirondacks and Catskills, which receive high levels of acidic deposition, are especially sensitive to its effects. Precipitation pH has increased an average of about 0.02 units in the Adirondacks and Catskills from 1984 to 2001; three-fourths of this increase has resulted from decreases in SO_4^{2-} concentrations and about one-fourth from decreases in NO_3^- concentrations. These changes are paralleled by, and are assumed to result from, similar decreases in sulfur (S) and nitrogen oxide (NO_x) emissions largely from power plants in the predominant source region of acidic precipitation to the State (Burns 2003).

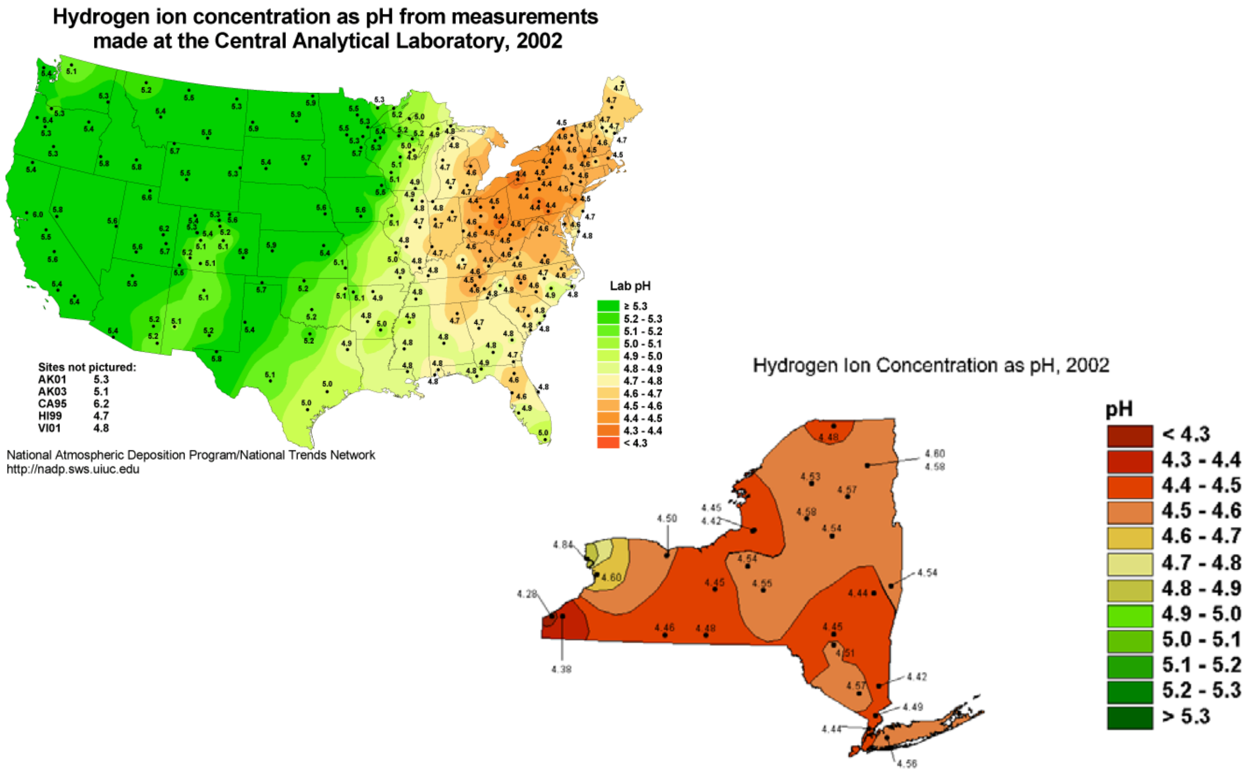


Figure 5. Hydrogen Ion Concentrations as pH in the U.S. and in New York State. Source: NADP 2003; NYSDEC 2002.

Acid deposition also results in elevated inputs of nitrogen in the form of nitric acid and nitrate. Across the Northeastern states there is a gradient in nitrogen deposition from west to east. The higher nitrate deposition in the western region tends to result in increased nitrate in streams (Aber et al. 2003). Specifically, at deposition above 8 kg per hectare per year (kg/ha/yr) of nitrogen or nitrate, streams show a more pronounced response (Figure 6). Interpretation of these data suggests that forested watersheds may approach nitrogen saturation when deposition exceeds this level. The increase in nitrate that occurs in stream water at these levels is an indicator of saturation. As the map in Figure 6 illustrates, nitrate inputs ranged from 13 to 27 kg/ha/yr in New York State in 2002.

New model-based research clarifies the link between nitrate in precipitation and NO_x emissions: a 50% decline in total NO_x emissions from appropriate source regions would result in a ~38% decline in nitrate concentrations in precipitation. By comparison, a 50% reduction in non-vehicular emissions, which is a 23% decline in total emissions impacting the area, would lead to a 19%B22% decrease. Reducing NO_x emissions is therefore predicted to have an efficiency of 75%B95% in reducing precipitation nitrate concentrations, depending on the source of the reductions (Butler et al. 2003).

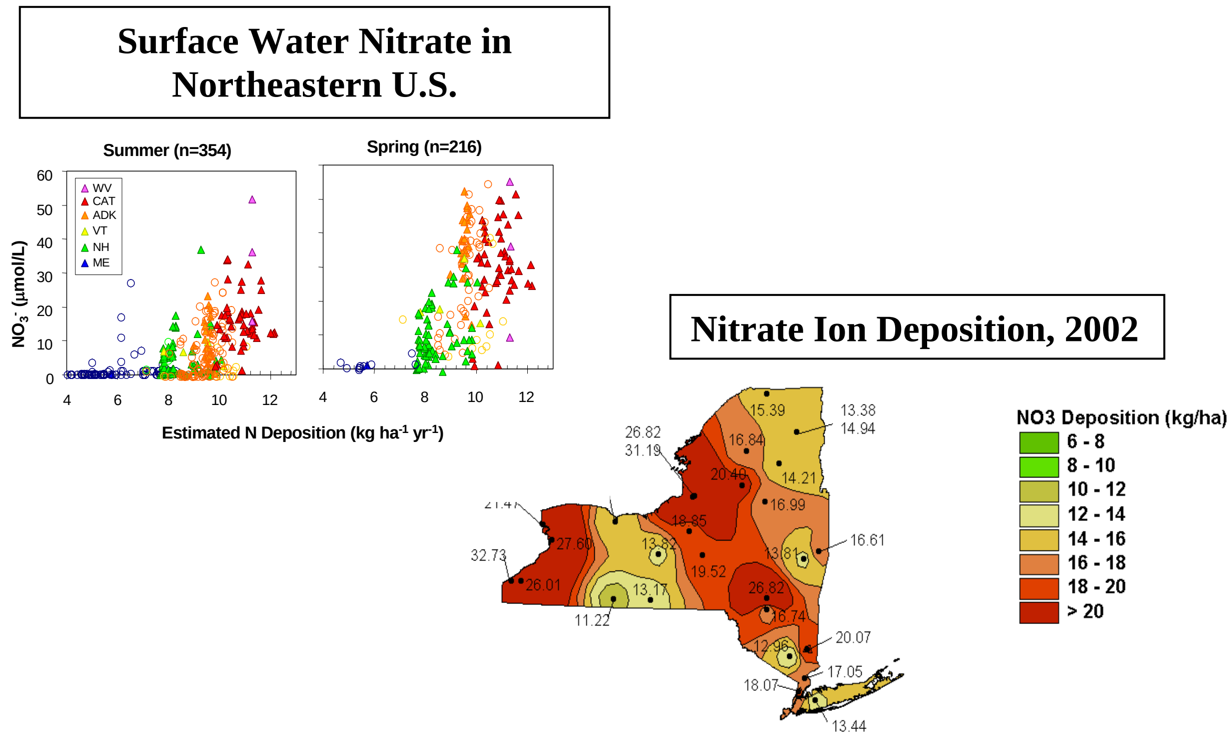


Figure 6. Nitrate Patterns in the Northeast U.S and NY State. Sources: Aber et al (2003); NYSDEC 2002.

Monitoring in New York State (source: NYSDEC)

The New York State Atmospheric Deposition Monitoring Network was designed in 1985 in response to the mandate of the "State Acid Deposition Control Act" (SADCA). The objectives of the network are to:

- Provide a consistent, quality-assured, long-term acid deposition database.
- Measure acid deposition in sensitive receptor areas.
- Measure acid deposition in urban and upwind areas.
- Use these data to perform spatial and temporal analyses of acid deposition, its precursors, and its effects.
- Track the effectiveness of precursor emissions reductions.

The state's monitoring network measures acid deposition and related quantities to assess the effectiveness of sulfur control policy and other strategies aimed at reducing the effects of acid rain. The monitoring network consists of 20 sites located throughout the state in both rural and urban areas (see Figure 7). New York State also operates an ambient air quality monitoring network. This continuous monitoring network collects O_3 (ozone), SO_2, NO_x, CO, and meteorological data.

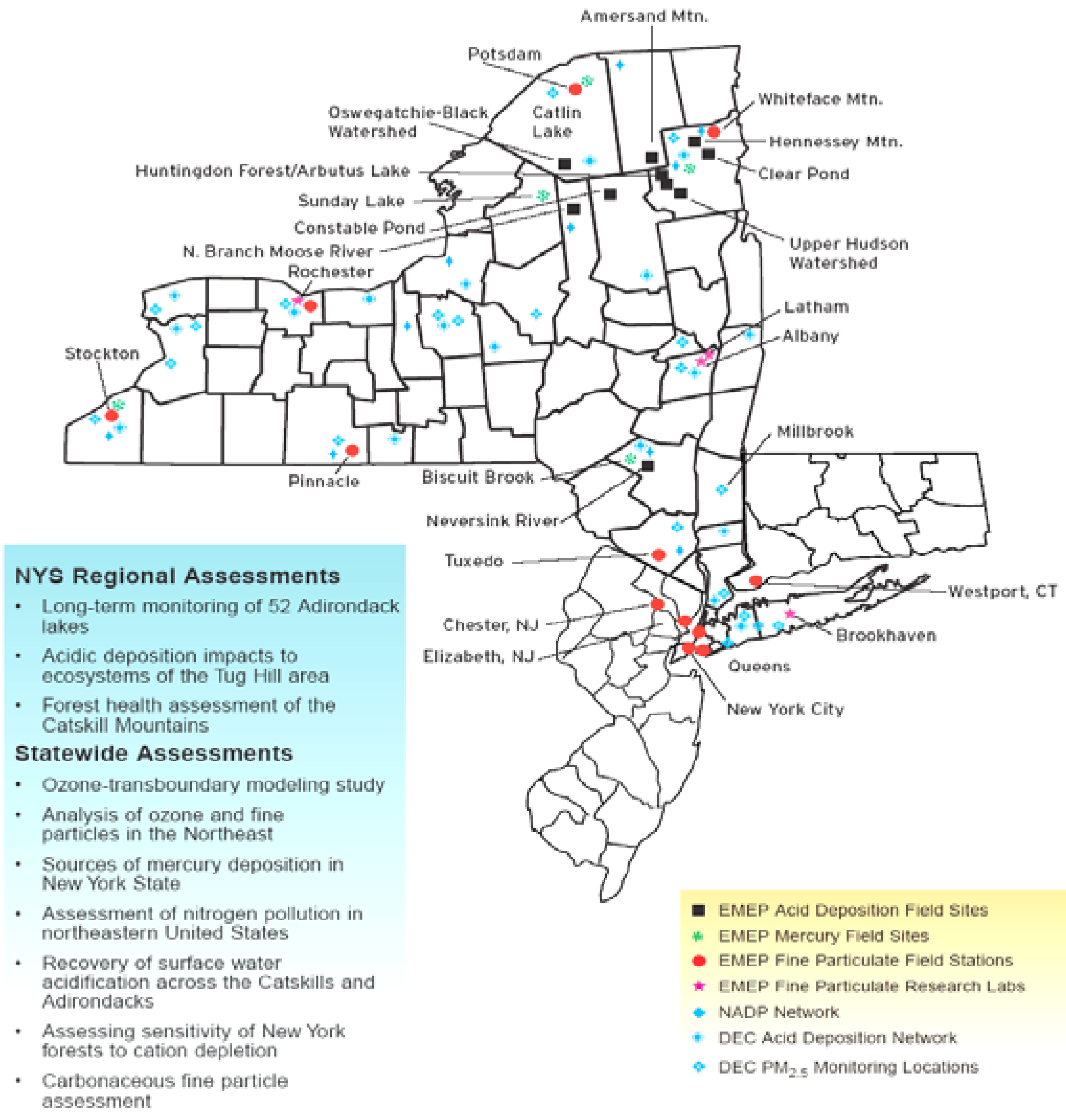


Figure 7. NYSERDA's EMEP Program: Field Stations and Research Sites.

NEW YORK AND BEYOND: WHAT ARE THE IMPACTS OF ACID DEPOSITION?

Acid deposition induces changes in soils, lakes, and streams. Over several decades of this deposition, surface waters in New York and the Northeast have become more acidic, less productive, and higher in toxic metals such as aluminum and mercury. Soils have generally become more acidic and less fertile. In some areas, forests show signs of acid-associated nutrient stress, and effects on animal and plant life, including mortality, are becoming apparent.

Lakes and Streams

Lakes and streams across sensitive areas of the state exhibit chronic and episodic acidity with related negative impacts on water quality and aquatic life. Surface waters, particularly in the Adirondacks and Catskills, have been deteriorating, showing lowered pH, decreased acid-neutralizing capacity (ANC), and elevated toxic aluminum concentrations.

What is ANC?

Acid neutralizing capacity, or ANC, is a measure of how much acidity can be neutralized in a liter of solution. ANC provides one way of determining the acid-base status of a lake or stream. An ANC < 0 microequivalents per liter (µeq/L) indicates that the body of water is likely to be chronically acidic. An ANC between 0 and 50 µeq/L indicates that acidic events are probably limited to specific times of year when runoff and streamflow are high (e.g., snowmelt).

Many organisms are sensitive to pH levels and to metals such as aluminum and mercury, which are often related to low pH. Under low pH and high aluminum conditions that occur during spring melt, adult fish may be able to move downstream in search of better conditions, but fish embryos and fry and other juvenile fish are more vulnerable. Consequently, acidification can lead to fish decline through attrition (Baker and Christensen 1991). Surveys of 1,469 Adirondack lakes conducted from 1984 through 1987 found that 48% of the waters had little to no buffering capacity or were extremely sensitive to further acidification (Kretser et al. 1989). These findings are consistent with research in the Adirondacks that found a significant relationship between lake pH and the number of fish species present (Kretser et al. 1989; Driscoll et al. 2001; see Figure 8).

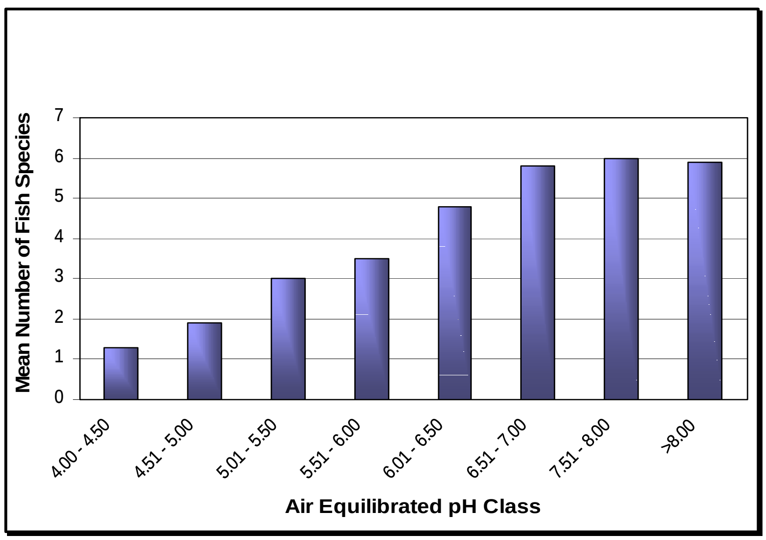


Figure 8. Changes in Fish Species Richness with Surface Water Acidity.
Source: Kretser et al. 1989; Driscoll et al. 2001.

In addition to chronic acidity, bodies of water may undergo abrupt changes associated with acid episodes that flush inorganic aluminum from soils to surface waters. Experiments have shown that this form of aluminum is directly toxic to fish (Baker and Schofield 1982; Figure 9). These conditions allow few areas of refuge and can directly cause mortality in fish and other aquatic life (Driscoll et al. 2001).

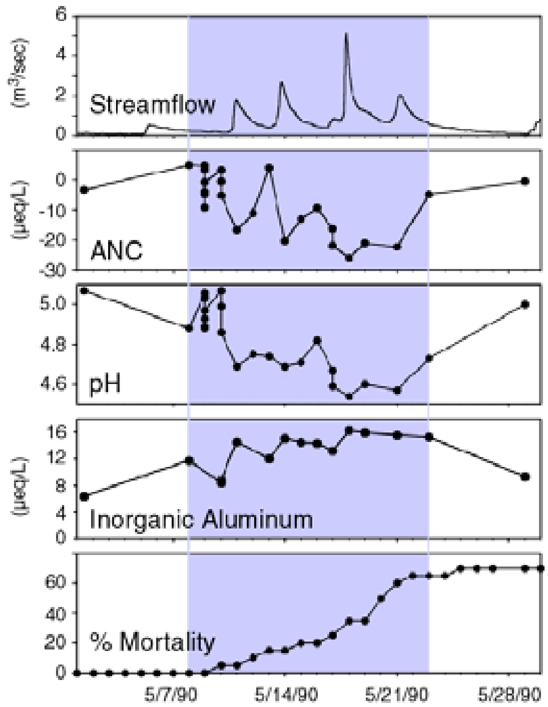


Figure 9. Short-term Changes in Stream Water Chemistry and Resulting Brook Trout Mortality, Buck Creek, NY. Source: U.S. EPA Episodic Response Program.

Aquatic plants and organisms other than fish are also affected by acid rain. Various insects, such as mayflies, that constitute an important food source for fish are sensitive to pH levels less than 6.0 (Baker and Christensen 1991; Figure 10). Studies in New York State have also shown that lake pH is directly related to total invertebrate richness, diversity, composition, and abundance (Smith et al. 1990) as well as

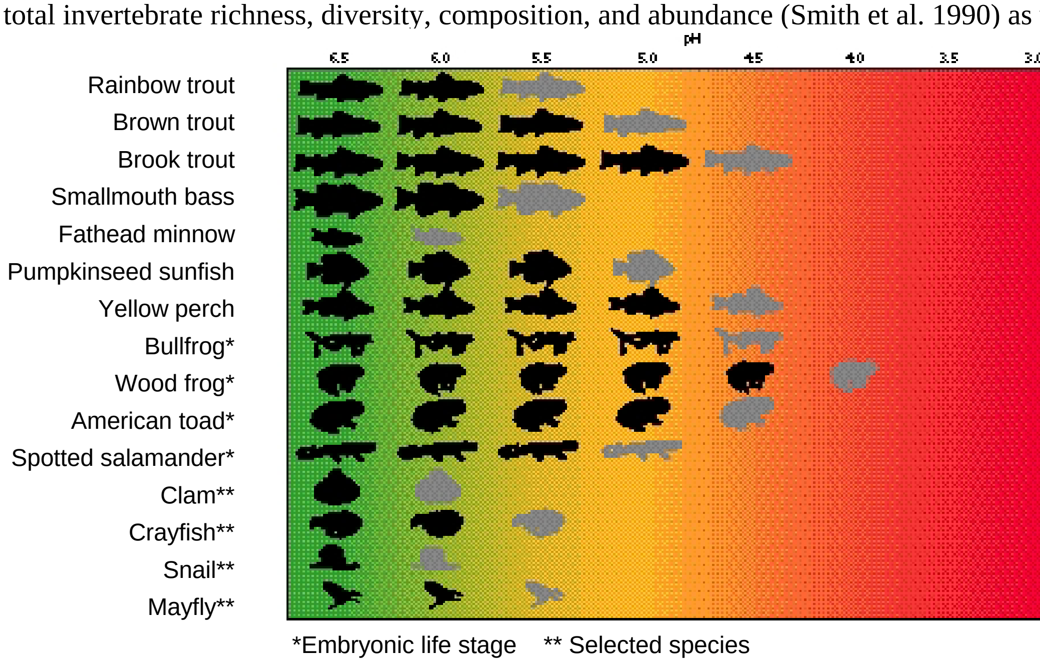
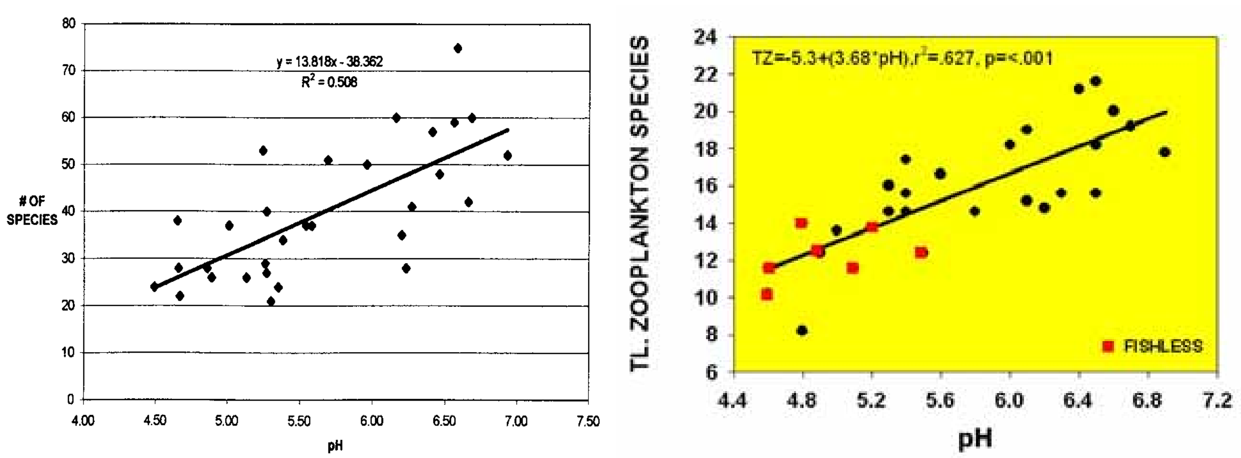


Figure 10. Aquatic Organisms - Tolerance to Acidity. As pH decreases in lakes and streams, some species are lost (grey). Source: USGS.

to the number of phytoplankton and zooplankton species present in surface waters (Figure 11). Thus, as a result of both chronic and episodic acidity, the entire aquatic food chain can be Asimplified,@ leaving a lake or stream less healthy, less resilient, and less productive (Figure 12).



Phytoplankton **Zooplankton (5-year average)**

Figure 11. Number of Phytoplankton and Zooplankton Species vs. pH. Source: Nierzwicki-Bauer 2003

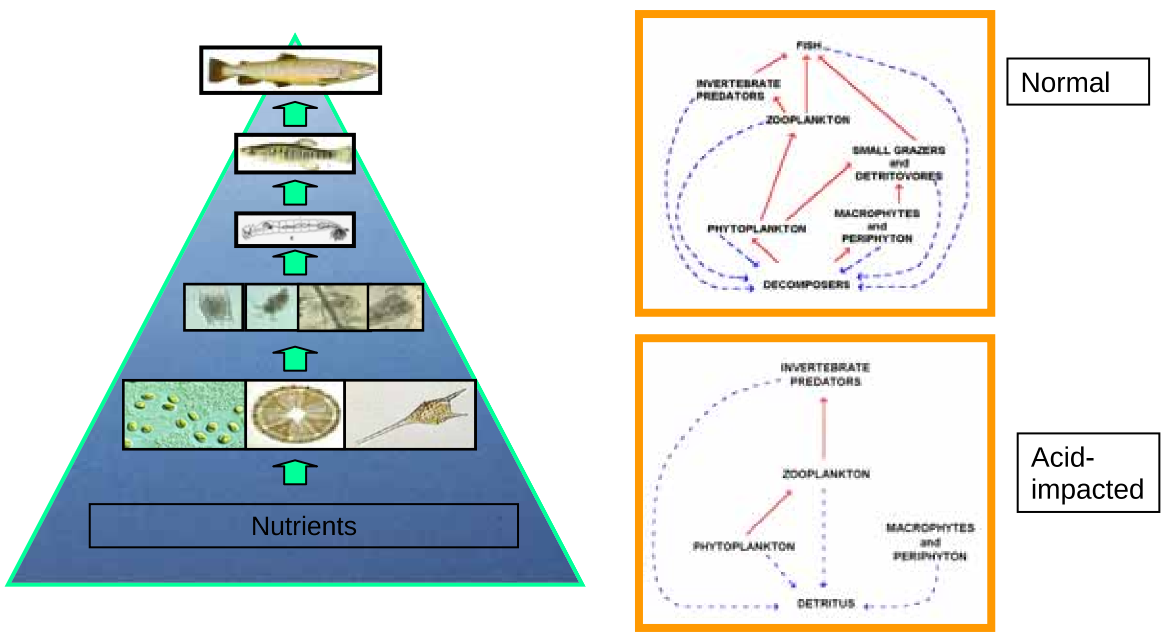


Figure 12. Food chain alterations due to acidification. Source: Nierzwicki-Bauer 2003.

Water-dependent amphibians such as frogs and salamanders are also affected. While research on this subject has been limited, a study of vernal pools (temporary spring waters) in the eastern U.S. shows that 10% to 15% of these pools had pH levels that could be lethal to some amphibians; an additional 10% to

14% had pH levels that could delay the growth of tadpoles (Freda 1991). A further study in New York has shown a positive correlation between soil pH and the distribution of 11 of 16 local amphibian species (Baker et al. 1990).

The Link Between Acidic Deposition and Mercury in Fish

Many studies across eastern North America have reported increases in fish mercury concentrations occurring with decreases in surface water pH (Grieb et al. 1990; Suns and Hitchin 1990; Driscoll et al. 1994; Kamman et al. 2004). Recent research suggests that this relationship is likely related to the fact that the atmospheric deposition of sulfate that is associated with sulfur dioxide emissions provides the material for the growth of bacteria that convert mercury into the methylmercury form, which then is bioavailable to fish (Gilmour et al. 1992).

To examine this relationship, a team of researchers used Areference@ data as well as data from a lake that was experimentally acidified with sulfuric acid to determine the relative contribution of mercury and acidic depositions to mercury concentrations in fish. They observed that decreases in fish mercury in an experimentally de-acidified basin exceeded those in the reference basin (where no acid was added). Specifically, they found that one-half of the change in fish mercury over a six-year period could be attributed to decreased acidity in the lake (Hrabik and Watras 2002). This study suggests that the acidification of lakes resulting from acidic deposition has enhanced fish mercury concentrations and that concentrations of mercury in fish are likely to decrease with decreasing acidic deposition.

Soils: Getting to the Root of the Problem

Many surface-water impacts are related to changes in soils that have been caused by decades of acid deposition. Acid deposition has altered soils across large areas of New York and the Northeast by

- Depleting calcium and other nutrients (Likens et al. 1996);
- Mobilizing inorganic aluminum so it enters into soil water, and ultimately into surface waters; and
- Increasing the accumulation of sulfur and nitrogen (Driscoll et al. 2001).

Despite evidence dating back to the 1950s, the capacity of acid deposition to alter soil continued to be widely debated through the 1980s. Increased attention and expanded research in the past decade has confirmed that acid deposition can induce these changes.

While acid-driven changes in soils enter soil waters and subsequently Atrickle down@ to lakes and streams, the loss of important nutrients and increased levels of toxic metals in the soil also can have adverse effects on forests. Although research into the mechanisms whereby acid deposition impacts forest ecosystems is ongoing, the emerging consensus is that the leaching of base cations from foliage and soils, the mobilization of harmful aluminum, and reduced soil fertility have contributed to Amultiple stress syndrome@ in Northeast forests.

For example, red spruce canopy and trees at high elevations also have suffered the effects of acid deposition. Clouds are the largest source for deposition of pollutants to high elevation ecosystems, including small lakes and streams, which receive 4 times more sulfur and 5 times more nitrogen pollution than lower elevation vegetation in the Adirondacks (Miller et al. 1993). Through observational studies and experiments, scientists have determined that the strong acids delivered to the spruce needles in acid fog and mist can leach membrane-associated calcium from the needles, leaving them more susceptible to winter injury (DeHayes et al. 1999). As a result, a 25% to 50% mortality of red spruce canopy trees has occurred, as documented across the Northeast in the 1980s (Craig and Friedland 1991).

ARE NEW YORK WATERSHEDS RECOVERING?

What is Recovery?

Recovery entails improvements in water and soil chemistry that are necessary to support a more diverse and abundant aquatic community and productive forests. Recovery from acid deposition is a process that is closely linked to reductions in emissions of SO_2 and NO_X , and there appears to be no longer a debate about the direct connection between reduction in acid rain precursors and reduction in the level of acidic deposition. The record of evidence suggests that in the Adirondacks and elsewhere, changes are beginning to be observed in lake water chemistry.

Following a review of the literature, Driscoll et al. (2001) have proposed several chemical thresholds above or below which it is unlikely that damage from acid deposition would continue to occur. These thresholds incorporate emissions, deposition, soil, and surface-water effects (Figure 13). The timeline for achieving them will vary significantly across the landscape, as it depends on historic inputs of acids, the remaining buffering capacity, and future deposition levels. Once chemical improvements can be sustained at levels hospitable to a healthy biota, it could take decades for biological communities to fully re-establish themselves. It may be possible to accelerate recovery through management activities such as liming and fish stocking. However, liming at a landscape level was found not to be feasible in the Adirondacks due to the remoteness, quick flushing characteristics and the large number of water bodies.

Liming

After nearly two decades of using lake liming experimentally and for fisheries management, the NYS DEC developed an environmental impact statement (EIS) in 1990 to update its findings and recommendation on its use based on the Adirondack Lake Survey results and new research findings from Scandinavia and elsewhere. The EIS and public hearings found that lake liming was not a feasible alternate to reductions in emissions of acid rain precursors. Liming was however found effective (cost beneficial) in a limited number of candidate lakes where an important fishery would be lost or need to be reestablished while awaiting a long-term solution to the acid rain problem.

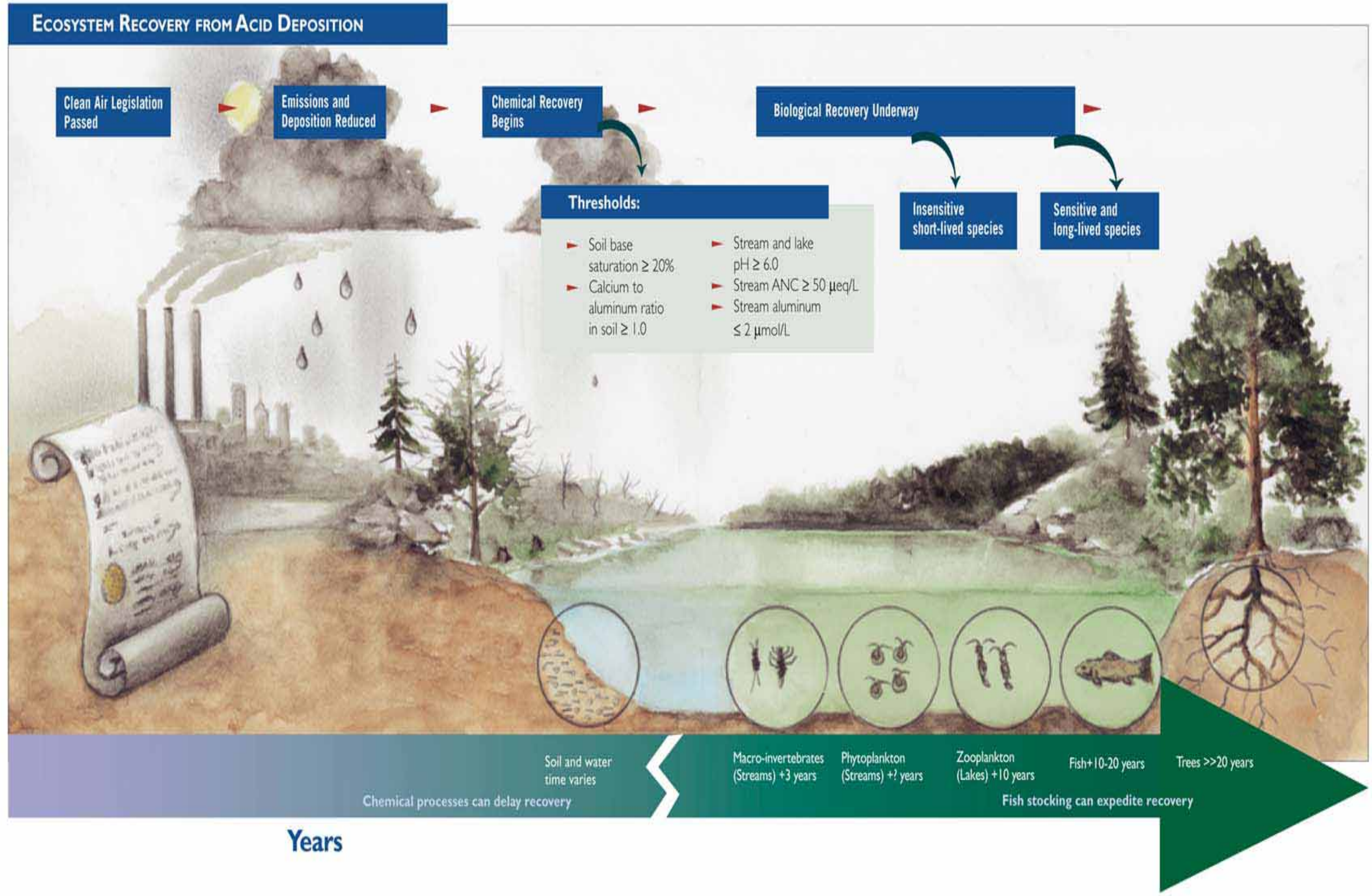


Figure 13. Ecosystem Recovery from Acid Deposition. Source: Hubbard Brook Research Foundation, 2001

Progress Toward Recovery in New York State

The implementation of Title IV of the 1990 CAAAs has resulted in substantial declines in SO_2 emissions from electric utilities. The decrease in sulfur emissions and deposition is reflected in lower sulfate levels of surface waters in New York and the Northeast. These signs of improvement affirm the link between SO_2 emissions and sulfate concentrations in surface waters.

A trend analysis using data from 48 Adirondack lakes for the period 1992B2000 and from 16 lakes for a longer period (1982B2000) indicates the following:

- Widespread improvement in surface-water sulfate;
- Varied improvement in surface-water nitrate;
- Improved acid-neutralizing capacity (ANC) in 29 lakes;
- Reduced inorganic aluminum (Al) in 28 lakes; and
- Increased pH in 18 lakes, and decreased pH in 2 lakes.

According to these results, the process of chemical recovery is beginning in the Adirondacks, but the rate of improvement is slow. Moreover, chemical conditions are still critical in many lakes. In the 48 lakes examined, the mean ANC is less than 50 µeq/L in 34 lakes; pH is less than 5.5 in 23 lakes, and inorganic Al is greater than 2 µmol/L in 16 lakes (Driscoll et al. 2003). Researchers used models to estimate how long it would take for lakes in the study to achieve an ANC of 50 µeq/L under current deposition conditions. The results show that, depending on the starting value, many lakes will require decades before they reach the target ANC value (Figure 14).

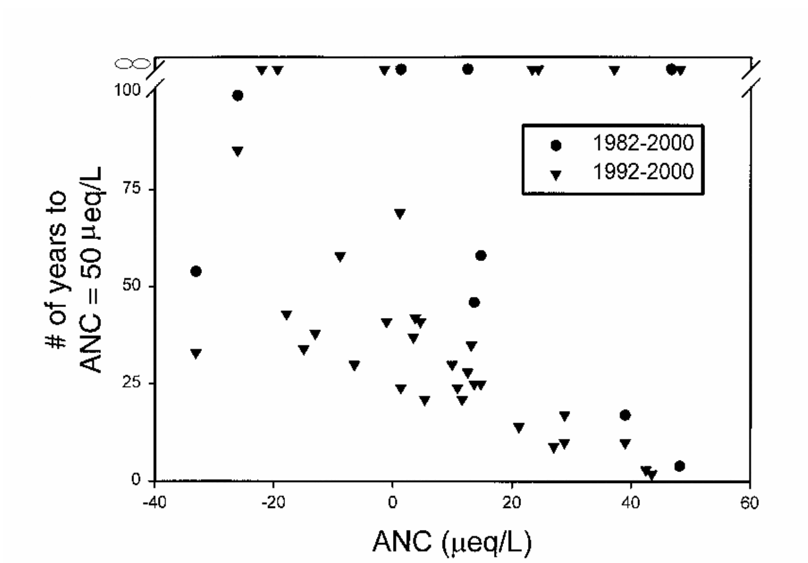


Figure 14. Adirondack Surface Waters Under Current Acid Deposition. Source: Chen and Driscoll.

Future Recovery from Acid Deposition

The chemical thresholds used by researchers can also help assess the potential for recovery. Computer models are available to estimate the timeline for the improvement of water chemistry in New York State under different policy scenarios. For example, models may be used to predict the extent and rate of recovery under current emission levels in comparison with additional reductions. In an analysis of 37 lake catchments in New York=s Adirondack region using the model PnET-BGC, Chen and Driscoll have estimated changes in soil and surface water chemistry under three future policy scenarios: with a base case, with moderate control, and with aggressive controls (Chen and Driscoll, in review).

Model Scenarios*

Scenario	SO2 Emissions	NOx Emissions
Base Case	40% reduction	~%5 reduction
Moderate	55% reduction	20% reduction
Aggressive	75% reduction	30% reduction

*Emissions reductions are relative to 1990 figures and are assumed to be achievable by 2010 in all cases.

Percentage of Adirondack Streams That Will Not Achieve Chemical Thresholds by 2050

Results	Base Case	Moderate Scenario	Aggressive Scenario
Stream ANC	60%	50%	45%
Stream pH	50%	40%	30%
Stream Al	15%	10%	5%
Soil Ca/Al			40%
Soil Base Saturation	65%	50%	45%

Source: Chen and Driscoll, in review.

The results from Chen and Driscoll demonstrate that the rate of recovery in regions subjected to years of acid deposition will require decades to recover. The slow recovery in these ecosystems, like the Adirondacks and Catskills is related to several factors:

- Loss of available base cations from the soil that would otherwise help buffer acid inputs (Likens et al.1996);
- Elevated nitrate levels (Stoddard 1994); and
- Accumulation of sulfur in soil that is now being released to surface waters (Gbondo-Tugbawa et al. 2002; Likens et al. 2002).

More aggressive emissions reductions will bring faster and more extensive improvements.

WHAT POLICY AND RESEARCH INITIATIVES ARE ON THE HORIZON?

A variety of policies to address acid deposition have been proposed and implemented at the state, regional, and national levels. The table below describes a few of the major policies aimed at reducing emissions from two of the largest sources: electric utilities and transportation. Experience with the Acid Rain Program at the federal level suggests that the costs of regulatory programs may be lower than anticipated. In fact, the U.S. EPA estimates that SO emissions reductions, when fully implemented by 2010, will ultimately cost only 25% of the amount originally projected (EPA 2003).

Research initiatives in the coming decade will likely focus on biological and chemical recovery, methods for applying research findings from intensively studied sites to the larger region, and expanded monitoring to determine the environmental response to changes in emissions. Trends in acid deposition and projections of recovery demonstrate the need for persistence in confronting this widespread environmental and human health issue. Early and continued policy action aimed at significantly reducing emissions of SO_2 and NO_x from the full range of sources is critical to the restoration of the rain, rivers, and lakes that sustain us.

NYSERDA Programs and Activities

NYSERDA sponsors a wide range of research initiatives which monitor changes in acid deposition and surface water acidity over time, increase the current understanding of basic ecological processes related to acidification, apply site-specific results regionally, assess the impacts of public policy, and provide the scientific basis for decision-making. Within these broader areas, NYSERDA's Environmental Monitoring, Evaluation and Protection (EMEP) program has supported several projects to assess the processes and extent of chemical and ecological recovery from acid deposition. NYSERDA-supported research projects will continue to enhance scientific understanding of the impacts and changes in acid deposition with the goal of supporting effective public policy decisions.

For more information, visit the EMEP website at: www.nyserda.org/programs/environment/emep/ .

Level	Name	Affected sources	SO_2	NO_x	Other
NY State	Acid Deposition Reduction Program	Stationary sources	50 percent reduction below requirements of 1990 Clean Air Act, phased in over3 years beginning 2005.	Reduced by 20,000 tons per year beginning 2004.	
	Zero Emission Vehicle Sales Mandate	Model-year 2007 passenger cars and light-duty trucks	N/A	N/A	Fleet produced and delivered for sale in New York must meet requirements set by California.
Regional	Clean Air Interstate Rule*	Sources within 28 eastern states and the District of Columbia	50% below current levels by 2015, 70% when fully implemented.	65% below current levels by 2015.	Meet fine particle and ozone standards.
National	Title IV of the 1990 Clean Air Act	Over 4,000 fossil fuel burning electricity generating units.	50% reduction in utility emissions below 1980 levels by 2010. (From 17.5 million tons to 8.95)	Estimated 5% reduction in utility emissions below 1997 levels.	Deadline for targets is 2010.
	Proposed – Clear Skies	Electric utilities meeting certain definitions.	2010 Phase I -4.5 million ton cap with national trading. 2018 Phase II – 3.0 million ton cap with national trading.	2008 Phase I -2.1 million ton cap with trading programs. 2018 Phase II- 1.7 million ton cap assigned to two zones with trading programs.	
	Proposed – other legislation	Title IV units.	Up to 80 percent reduction from 1990 levels.	Up to 50 percent reduction from 1997 levels.	2005-2010 deadline.
	Tier 2 vehicle emission standards	Model-year 2004 passenger vehicles		Average of 0.07 grams/mile for passenger vehicles.	
	Nonroad Diesel Rule	Diesel engines in construction vehicles and other "nonroad" equipment	Reduce sulfur content in diesel fuel by 99 percent.	90 percent reduction from current levels.	"Exhaust emissions" will decrease by 90 percent.
	Clean Diesel Trucks and Buses		Reduces sulfur content in diesel fuel by 97 percent		"Harmful emissions" will be reduced by 95 percent between 2007 and 2010.
	Proposed - Locomotives, Boats and Ships			90 percent reduction from current levels.	

* See NYSERDA report 05-02, "Reducing emissions from the electricity sector: the costs and benefits nationwide and in the Empire State" for a full description of CAIR

Developments in the Study of Acid Rain

1954-61 Gorham demonstrates that acidity in precipitation markedly influences geological weathering processes and the chemistry of soils.

1963 Gordon and Gorham describe serious damage to vegetation downwind of an iron sintering plant. They categorize the damage as ranging from "very serious" (barren) to "moderate" (reddened needles and crown thinning of hardwoods).

1968 Oden describes biological uptake and ion-exchange processes whereby the natural acidification of soils would be accelerated by the atmospheric deposition of ammonia and other cations.

Acidity in precipitation is postulated as the probable cause of impoverished forest soils, decreased forest growth, increased disease in plants, and other effects

1972 Jonsson and Sundberg establish an experimental basis for the suspicion that acidic precipitation had decreased the growth of forests in Sweden.

Overrein demonstrates accelerated loss of calcium and other cations from soils receiving acid precipitation.

Likens documents the problem of acid deposition and its effects in North America.

1973 Wiklander proposes a general theory to account for the effects of acid precipitation on soil chemical properties.

1974 Shriner demonstrates that simulated rain that is acidified with sulfuric acid can accelerate erosion of the protective waxes on leaves, inhibit nodulation of leguminous plants, and alter plants' host-pathogen interactions.

1976 Schofield's work shows a decline in fish populations in the lakes of New York's Adirondack Mountains.

1979 Cronan and Schofield discover that aluminum ions in soils are leached by acid precipitation into streams and lakes in concentrations that are toxic to fish.

1980 Abrahamson determines that the negative effects of acid deposition on growth are most likely to occur when it increases nutrient imbalances or deficiencies.

Ulrich demonstrates a significant correlation between the amount of soluble aluminum in forest soils, the death of feeder roots in spruce, fir, and birch forests, and widespread decline in the growth of these forests.

1981 The National Academy of Sciences notes that while the effects on soils, forests, and plants have not been proven, "long-term permanent damage to the ecosystem may result" from the leaching out of necessary nutrients.

1982 Siccama et al. describe the decline of red spruce on Camel's Hump in Vermont, noting foliar injury similar to drought under conditions of ample water availability. Nearly half of the large canopy red spruce died over an 18-year period.

Vogelmann points out that the aluminum present in soil water at Camel's Hump could be responsible for the lack of water uptake through roots. He also reports a 15% - 30% decline in the basal area of sugar maple and beech since 1965 on Camel's Hump.

1983 The President's Office of Science and Technology Policy (OSTP) panel asserts that it is "especially concerned" about the deleterious effects of acidity on soils.

Johnson and Siccama report high mortality among red spruce in New York, Vermont, and New Hampshire, which they attribute to synergistic effects of acid deposition and drought.

1984 Johnson et al. document a correspondence between incidents of highly acidic cloud water and red spruce winter injury in the Adirondacks and Green Mountains.

1988 Shortle and Smith identify aluminum-induced calcium deficiency in soils and its association with fine-root dysfunction.

1989 Nilsson and Grennfelt define critical loads of sulfur and nitrogen as levels below which harmful effects on sensitive elements of the environment are not expected to occur.

Based on critical analysis of available information, the NAP AP forecasts that up to 30% of southern forest soils would show major changes in soil chemistry within the next 50 years.

Aber et al. introduce the possibility that atmospheric inputs of nitrogen could exceed vegetation demand in the Northeast, with possible negative effects on forest productivity.

1991 Craig and Friedland quantify forest decline in the White Mountains to be ~25%.

1993 DeVries determines critical loads of sulfur and nitrogen for acidification of watersheds in the Netherlands.

1995 Cronan and Grigal determine that Ca:Al ratios < 1 in the soil correspond to a greater than 50% probability of impaired growth in red spruce.

1996 Likens et al. quantify the loss of available calcium from the ecosystem at Hubbard Brook, NY, finding that ~50% has been leached out by acid rain over the preceding 50 years.

1997 Long et al. find that liming significantly increases sugar maple growth and flower and seed crops, increases exchangeable base cations, and decreases exchangeable aluminum in soil.

1999 DeHayes et al. describe the mechanism for tree decline associated with acid deposition, including the loss of membrane-associated calcium in foliage.

Horsley et al. find that dieback of sugar maple at 19 sites in PA and NY is correlated with a combination of defoliation and deficiencies of magnesium and calcium.

2001 Driscoll et al. predict that even reductions greater than 50% of SO_2 and NO_x emissions from electric utilities would not restore soil chemistry to critical thresholds at sensitive sites for decades. They cite the slow rate of base generation from mineral soil and the accumulation of sulfur and nitrogen in soils as causes for the protracted recovery.

2002 Watmough and Dillon use a "critical loads" approach to estimate that sulfate deposition would have to be reduced by 37% - 92% in watersheds that are harvested in order to maintain ANC above critical levels in Ontario.

Sources: Information compiled from Cowling 1982; Driscoll et al. 2001.

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