Response of Adirondack Ecosystems to Atmospheric Pollutants and Climate Change at the Huntington Forest and Arbutus Watershed: Research Findings and Implications for Public Policy

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Executive Summary

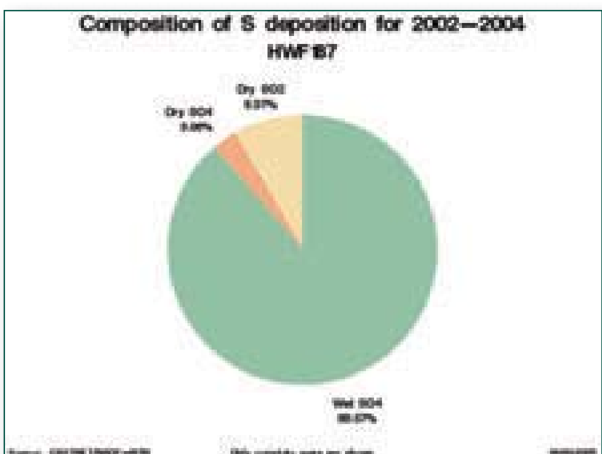
For the past 30 years, scientists associated with the Huntington Forest (HF) scientists have investigated the effects of "acid rain" on forest ecosystems and their associated surface waters. The Adirondack Region of New York state has received considerable attention by scientists, policy makers and the general public due to its spatial extent of natural habitats, elevated inputs of atmospheric deposition and sensitivity to disturbances. The region has a large number of water bodies, many of which are highly sensitive to acidic inputs. Research in the Adirondacks has also documented concerns related to forest health in northern forests and linkages to acidic deposition.

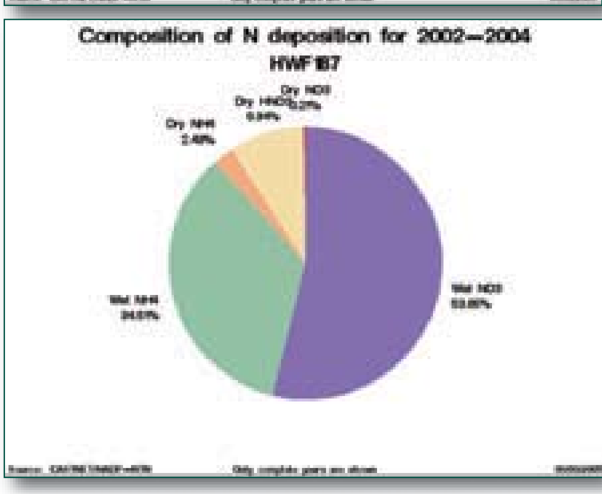
In addition to initiating the "acid rain" research at the HF, NYSERDA funding has been used to support the base operation of deposition monitoring, water chemistry responses and hydrological measurements at the HF, including the Arbutus Watershed system. Substantial support of these research activities has also been provided by the National Science Foundation, U.S. Environmental Project Agency and the United States Department of Agriculture Forest Service. The HF has the only infrastructure within the Adirondacks that supports a complete array of measurements that facilitate quantitative evaluations of the effects of air pollutants on forest ecosystems and their interconnected surface waters. The analysis of acid rain was initiated with establishment at the HF of a National Atmospheric Deposition /National Trends Network (NADP/NTN) Site in 1978. After the initiation of the NADP/NTN station at the HF various studies have been conducted to evaluate the effects of atmospheric deposition.

There has recently been an increase in the interest on the role of climate change on global processes, as well as regional effects within the Northeast United States and the Adirondack Mountains of New York State. Meteorological data have been collected since 1940 at the HF, but annual mean temperatures, precipitation and snowfall have not shown any significant change through 2007. Although we have not been able to detect changes in the climate at the HF, there is a clear indication that the climate is being altered throughout the Northeast. These alterations include changes in temperature, precipitation quantity, the relative distribution of precipitation as rain and snow, and hydrology. Research efforts at the Huntington Forest and the Arbutus Watershed have included an integration of analyses of the effects of air pollutants and climatic effects including the role of changes in winter and summer conditions.

To decrease atmospheric deposition, Congress passed amendments to the Clean Air Act in 1990 that required electric utility power plants to further control the emissions of sulfur dioxide. There have been significant changes in atmospheric deposition at the HF. The most notable change has been a decrease in sulfate deposition, but other inputs have also decreased including nitrate and calcium. The effects of changes in atmospheric deposition in the Adirondacks with respect to the recovery of surface waters from acidification have been evaluated. Time-series analyses have shown that concentrations of sulfate, nitrate, ammonium and basic cations have decreased in precipitation, resulting in increases in pH. Only recently have these declines in sulfate concentrations of Adirondack lakes, including Arbutus Lake, resulted in substantial increases in pH and Acid Neutralizing Capacity (ANC) in these surface waters. Our studies have shown that there is a substantial internal source of sulfur from the watershed that may play an important role in delaying the recovery of acid impacted surface waters from acidification.

Most recent measurements at the HF indicate that dry deposition is a relatively small part of nitrogen and sulfur total deposition. These and other data from the HF on deposition chemistry have been used in developing a predictive model of atmospheric deposition of major air pollutants for the entire Adirondack Park. This regional model of atmospheric deposition has been used in other studies that have evaluated the contribution of acidic deposition to ecosystem response in the Adirondacks, with particular focus on nitrogen dynamics.





The Arbutus Lake Watershed is part of the original Adirondack Long Term Monitoring (ALTM) project and is the only ALTM site with hydrological monitoring. Within the Arbutus Watershed, we have quantified changes of both the concentrations and the fluxes of major solutes. Decreases in concentrations and fluxes of sulfate and calcium are responses to changes in atmospheric deposition. We have also been able to evaluate the role of within lake processes in affecting biogeochemical responses showing that responses to atmospheric and climatic changes differ substantially across the landscape (i.e., uplands, wetlands, lakes). The Arbutus Watershed was upgraded in 2007 with a "state of the art" wireless communication system that includes near real-time data and digital images from the site. Both archived data and realtime data are available on our Web site.

Realtime data are available at:

http://www.esf.edu/hss/em/huntington/data_map_click.html

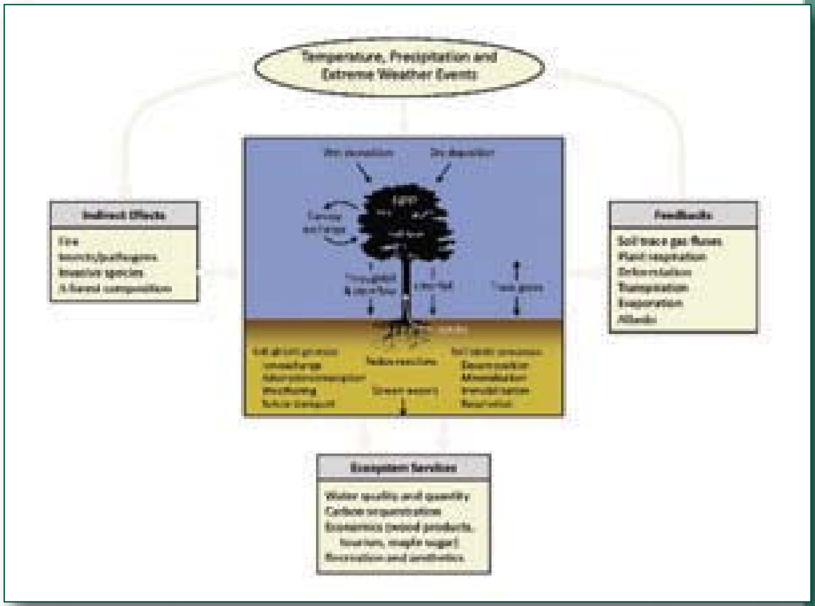
Archived data are accessible at:

http://www.esf.edu/hss/em/huntington/archive.html

Although a linkage has been found between nitrogen atmospheric deposition and nitrate concentrations in the surface waters, the importance of other factors in affecting both the temporal and spatial patterns of nitrate concentrations has been emphasized in our investigations at the Arbutus Watershed and other sites in the northeast U.S. including other ALTM (Adirondack Long Term Monitoring) lakes. Second-growth western Adirondack sites have higher soil solution nitrate concentrations and fluxes than the HF. Differences in soil solution nitrate concentrations between old-growth sites are due to the relative dominance of sugar maple that produces higher concentrations of nitrate within the soil. Within the Adirondacks the presence of sugar maple is a function of calcium availability in the soil, but other factors including gap formation can affect nitrate concentrations in forest stands. Within the Arbutus Watershed, nitrate concentrations are also higher at those locations with nitrogen fixing alders.

As part of the Adirondack Manipulation and Modeling Project (AMMP), we did experimental additions of nitrogen and found that the patterns of nitrogen loss varied with site and form of nitrogen addition and most of the nitrogen input was retained. The complexities associated with evaluating the effects of nitrogen deposition on forest ecosystems and simulation modeling have suggested that marked nitrate losses will only be manifested over extended periods. Specific findings at the Arbutus watershed as well as Grass Pond and Constable Pond in the western Adirondacks have clearly demonstrated the importance of within lake processes in affecting the retention of nitrate and the generation of dissolved organic nitrogen. The heterogeneous topography in the Adirondacks results in diverse landscape features and patterns of hydrological connectivity that are especially important in regulating the temporal and spatial patterns of nitrate concentrations in surface waters. Analyses of nitrate generation patterns between subcatchments S14 and S15 in the Arbutus Watershed have amplified our findings on the importance of vegetation type (i.e., presence of sugar maple and basswood) and geology (i.e., elevated calcium concentrations) result in high nitrate concentrations in surface waters. Understanding the relative importance of both edaphic (e.g., soils and vegetation) and atmospheric (e.g., deposition) factors in affecting nitrate transport to surface waters is critical for evaluating the relative importance of nitrogen pollutant additions in affecting nitrate concentrations.

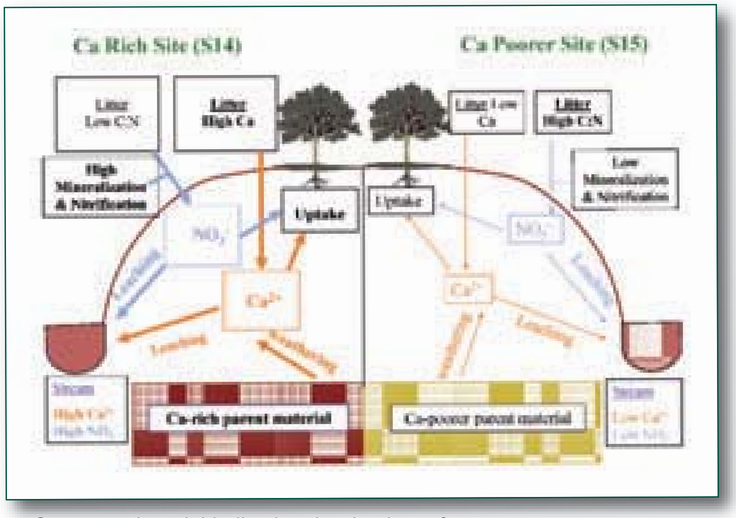
Hydrological and chemical observations from the outlet of Arbutus Lake and its major inlet (Archer Creek Watershed) have been used to analyze climatic impacts on ecosystem processing. Both climatic conditions and changes in atmospheric deposition have a major influence on dissolved organic carbon and the dynamics of nitrate and sulfate. These results suggest that climatic change in conjunction with atmospheric deposition of nitrogen may alter nitrate export, especially during snowmelt when episodes may result in deleterious surface water conditions.



Conceptual diagram showing the direct and indirect effects of changes in temperature andprecipitation on biogeochemical processes in forests and on the services forests provide. Also, shownare feedbacks that further influence climatological effects. Adapted from Campbell et al. (2009).

We have studied the influence of climate change on watershed response by evaluating how storms affect hydrology and biogeochemistry. It is expected that both the intensity and frequency of storms will increase in the northeastern U.S., including the Adirondacks. Work within the Archer Creek watershed has demonstrated linkages between hydrological and biogeochemical responses including evaluations of how hydrological connectivity affects chemical responses to these storms. Following droughts, a substantial decrease in pH in stream water was noted due to the mobilization of sulfur previously stored in wetlands, suggesting the importance of wetlands in affecting watershed responses to droughts.

Forest vegetation in the Adirondacks plays a critical role in the response of watersheds to atmospheric pollutants and climate change. Sugar maple presence and abundance have been clearly linked to nitrate concentrations in soils and surface waters of the Adirondacks as well as other regions in the northern forest. There has been considerable concern associated with the loss of calcium from forested ecosystems due to acidic deposition and the concomitant decline in sugar maple. A calcium rich subcatchment in Archer Creek has a greater proportion of sugar maple and basswood while a subcatchment with lower calcium concentrations has a higher proportion of American beech. A combination of these chemical and biological attributes result in the more calcium rich catchment having substantially higher nitrate concentrations in soils and surface waters. Analyses on the effects of calcium concentrations to determine vegetation relationships and soil nitrate levels have been done for a wide range of sites across the entire Adirondacks. Within the Adirondacks soil calcium availability has a major influence on vegetation type and the type of vegetation has a major effect on stream nitrate concentrations and fluxes. We have documented marked changes in vegetation at the HF due to beech bark disease. The influences of geology and vegetation need to be considered when evaluating the response of Adirondack ecosystems to changes in atmospheric deposition associated the emissions of nitrogen oxides associated with the combustion of fossil fuels.



Conceptual model indicating the dominant factors controlling the variation in stream waterchemistry across sites with similar hydrology, atmospheric deposition and land use but varying parentmaterial, vegetation and soil processes. Thicker arrows indicate relatively greater fluxes and larger boxesindicate relatively larger pools (Adapted from Christopher et al., 2006).

We have employed a variety of approaches for integrating the results of the HF/Arbutus Watershed for larger regions including the Adirondacks, northeastern U.S. and southeastern Canada. The results of studies on the Arbutus Watershed have been considered in assessments of the effects of acidic deposition for the Adirondacks and New York State. More specifically as part of the ALTM project, the Arbutus Watershed has been part of the analyses on lake/watershed

Photo: G. Lampman

responses including analyses of nitrogen budgets and acid neutralizing capacity. The evaluation of Adirondack nitrogen budgets emphasized the importance of specific watershed features including the presence of lakes have an influence on the level of nitrogen retention. Using the detailed hydrological and biogeochemical information available for the Arbutus Watershed, we have also employed the forest watershed biogeochemical simulation model PnET-BGC to predict long-term changes in watershed chemistry including an analysis of how various scenarios associated with changes in atmospheric emission and resultant deposition will be reflected in future surface water chemistry conditions. Such simulation modeling has also been used to compare and contrast watershed responses of the Arbutus Watershed with other watersheds in the region.

The HF/Arbutus Watershed has also been associated with various regional projects that have synthesized results from the northeastern U.S. and southeast Canada. Many of these studies have been supported by the Northeast Ecosystem Research Cooperative (NERC). These regional syntheses have included the use of stable nitrogen isotopes to evaluate nitrogen saturation and a variety of studies that have evaluated watershed elemental budgets. The HF has also been part of a network of sites Global Change and Terrestrial Ecosystem (GCTE) that have evaluated the effects of soil warming on ecosystem response.

We have also shown that there has not been a concomitant substantial change in nitrogen deposition; hence the relative importance of nitrogen in contributing to acidic deposition is increasing. Long-term measurements have also shown a decrease in sulfate concentrations.

Public Policy Implications

Our research has provided information relevant to policymakers and resource managers on the effects of air pollution on forest and aquatic ecosystems. Our ongoing measurements of atmospheric deposition at the Huntington have revealed that sulfate deposition to the Adirondacks has decreased over the last 30 years. This decrease is consistent with decreases in emissions of sulfur dioxide. These observations are important because they indicate that the 1970 and 1990 Amendments of the Clean Air Act have helped reduce acidic deposition and inputs of sulfate, which is the major source of acidity to acid-sensitive lakes in the Adirondacks. Using mass balance calculations we have confirmed the contribution of internal sulfur sources that may delay the recovery of forested ecosystems from decreases in sulfur deposition.

We have documented the importance of within lake processes in affecting chemistry. These within lake processes result in different chemical responses to changes in atmospheric deposition and climate than upland systems and their associated surface waters. Our studies have shown that these upland systems in the Adirondacks are much more responsive than lakes to climatic events including snowmelt and droughts. These upland systems need to be monitored for a full evaluation of atmospheric and climatic effects. Climatic events associated with snowmelt and drought effects have a major influence on watershed responses including the generation of acidic episodes. Climatic predictions for the region indicate that the period of snow cover will decrease, and drought frequency and duration will increase. Both in-lake biological processing of nitrogen as well as nitrogen inputs and transformations associated with nitrogen fixation and the cycling, storage and export of nitrogen in wetlands add to the complexity of differential patterns of nitrate concentration across the Adirondack region. The reason for the long-term decline in lake nitrate is unclear. It is possible that this trend is due to changes in climate and/or hydrology. Our analysis showing the importance of geology (e.g., calcium concentrations) and vegetation type (e.g., sugar maple and basswood) indicate that these factors have an important influence in affecting the response of Adirondack ecosystems to changes in atmospheric pollutants.

Biogeochemical model PnET-BGC calculations for the Arbutus watershed have clearly demonstrated that acidification of soil and water has resulted from inputs of acidic deposition over the last 150 years, and that chemical recovery has occurred over the last 30 years in response to the 1970 and 1990 Amendments to the Clean Air Act. Projections of potential future changes suggest that under current deposition patterns Adirondack lakes will either continue to acidify or recover at a very slow rate. Model predictions suggest that additional reductions in sulfur and nitrogen will help accelerate the rate of ANC increase but the period of chemical recovery will be decades.

Future research efforts at the HF and the Arbutus Watershed will include an integrated effort to analyze the effects of air pollutants and climatic change on ecosystem responses including changes in surface water chemistry. We anticipate evaluating various policy scenarios that affect the emissions of pollutants and their effects on ecosystem processes. We will continue ongoing, long-term measurements of atmospheric deposition and evaluate the response of the HF/Arbutus Lake Watershed system to these changes. Our approaches will use a combination of chemical mass balances, isotopic evaluations, statistical determinations and modeling to evaluate acid deposition on Adirondack ecosystems. Our studies are being done in the context of other intensive and extensive analyses of vegetation and soil components and processes in the region. These results are being made available as part of the historical data base of HF/Arbutus Watershed that has been used for evaluating the influences of atmospheric deposition and climate on key biogeochemical processes. The integration of watershed measurements within the Arbutus Watershed is also being facilitated by the availability of near real time measurement system that provides results to the general community on the World Wide Web.

Photo: J. Harvey

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