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# Lake-Watershed Acidification in the North Branch of the Moose River: Introduction

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**Abstract.** An integrated analysis of a terrestrial-aquatic ecosystem, the North Branch of the Moose River in the Adirondack region of New York, was conducted. This basin contains a large number of interconnected surface waters that exhibit marked gradients in pH and acid neutralizing capacity (ANC). As a result, the basin has been the focus of research activity, including the Regional Integrated Lake-Watershed Acidification Study (RILWAS). The objective of the current analysis was to use the North Branch of the Moose River as a case study to:

1. Evaluate processes regulating the acid-base chemistry of surface waters.
2. To assess the effects of surface water acidification on fish populations.

The observations of this study were consistent with the model of surface water acidification developed during the Integrated Lake-Watershed Acidification Study (ILWAS). The processes depicted in the original ILWAS simulation model were adequate to describe the acid-base chemistry of surface waters in the North Branch of the Moose River. However, the reduction of $SO_4^{2-}$ in lake sediments, a process not represented in the original model, proved to be a significant source of acid neutralizing capacity (ANC) for some of these waters. As a result, reduction processes were added to the model.

Analysis of in-situ bioassay and survey data indicate that acid-sensitive fish species have disappeared from the more acidic areas of the basin over the last half century. Paleoecological analyses indicate that pH has decreased from the high 5's to about 5 in Big Moose Lake during this period. ILWAS model simulations indicate that the pH of Big Moose Lake would increase by at least 0.1 to 0.5 pH units (depending on the season) in response to a 50% reduction in total atmospheric S deposition.

Considerable variability in processes regulating acid/base chemistry was evident in the North Branch of the Moose River. Therefore, regional assessments of past or possible future effects of acidic deposition require widespread application of ILWAS theory within the Adirondack region and other potentially acid-sensitive areas.

## Introduction

The Integrated Lake-Watershed Acidification Study (ILWAS) (Goldstein *et al.*, 1984; Goldstein *et al.*, 1985) developed a mechanistic theory of surface water acidification. This theory, which takes the form of a mathematical simulation model (Gherini *et al.*, 1985), quantitatively relates the acid-base status of lakes and streams to the acidity of atmospheric deposition taking into account the production and consumption of acidity that occurs by lake-watershed processes.

Goldstein *et al.*, (1985) summarized the major conclusions of ILWAS as follows:

1. The acid-base status of lakes is determined by the interaction of many factors including: vegetation, soil, water movement, geologic characteristics, climate, in-lake processes and atmospheric deposition
2. The absolute and relative contribution of any single factor can vary considerably among lake-watershed systems and temporally.
3. The response of lakes to changes in the chemical composition of atmospheric deposition can be highly variable among lake-watershed systems and temporally.
4. The analysis of the role of an individual factor in determining the acid-base status of a lake or the response of a lake to changes in deposition quality can only be understood, in general, within an integrated ecosystem framework.
5. The relative routing of water through a lake-watershed (e.g., direct precipitation to lake, terrestrial interflow, groundwater flow) is a major determinant of lake water alkalinity (acid neutralizing capacity) and the susceptibility to acidification by atmospheric deposition.
6. Alkalinity is a key variable for characterizing the acid-base status of a surface water.

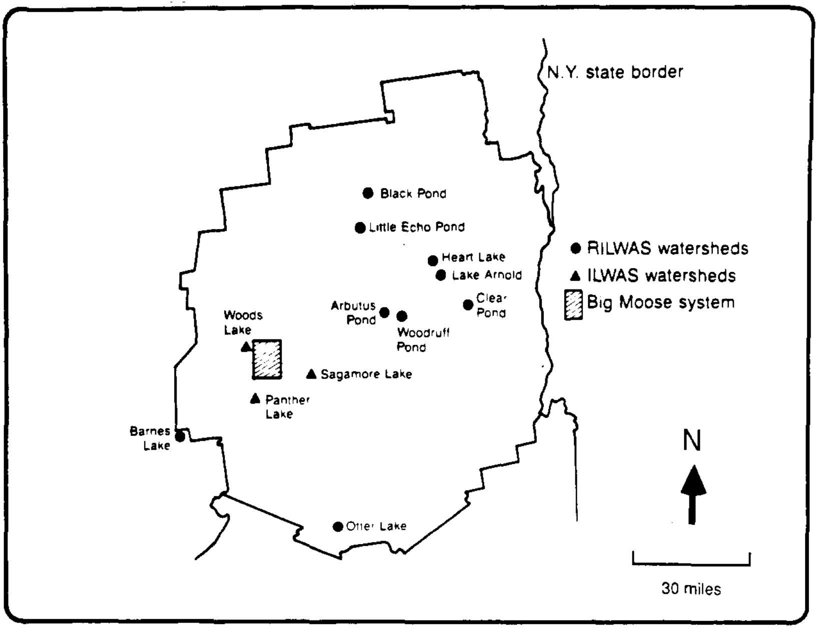

Figure 1. Sites for the Integrated Lake-Watershed Acidification Study (ILWAS) and the Regional Integrated Lake-Watershed Acidification Study (RILWAS) in the Adirondack Park Region of New York State.

7. To understand the acid-base status and dynamics of surface waters, it is necessary to understand the processes regulating the aqueous concentrations of all major cations and anions (inorganic and organic).

The ILWAS model was developed as a result of an intensive study of three forested lake-watershed systems in the Adirondack region of New York State. Because it was formulated using fundamental biogeochemical concepts, it has been assumed to be generally applicable to lake-watersheds within the Adirondacks and other regions (Goldstein *et al.*, 1984). In 1982, a new program, the Regional Integrated Lake-Watershed Acidification Study (RILWAS) was initiated (Goldstein *et al.*, 1984) to evaluate the general applicability of the ILWAS model and to test the major conclusions of ILWAS (Goldstein *et al.*, 1985). This program was to be

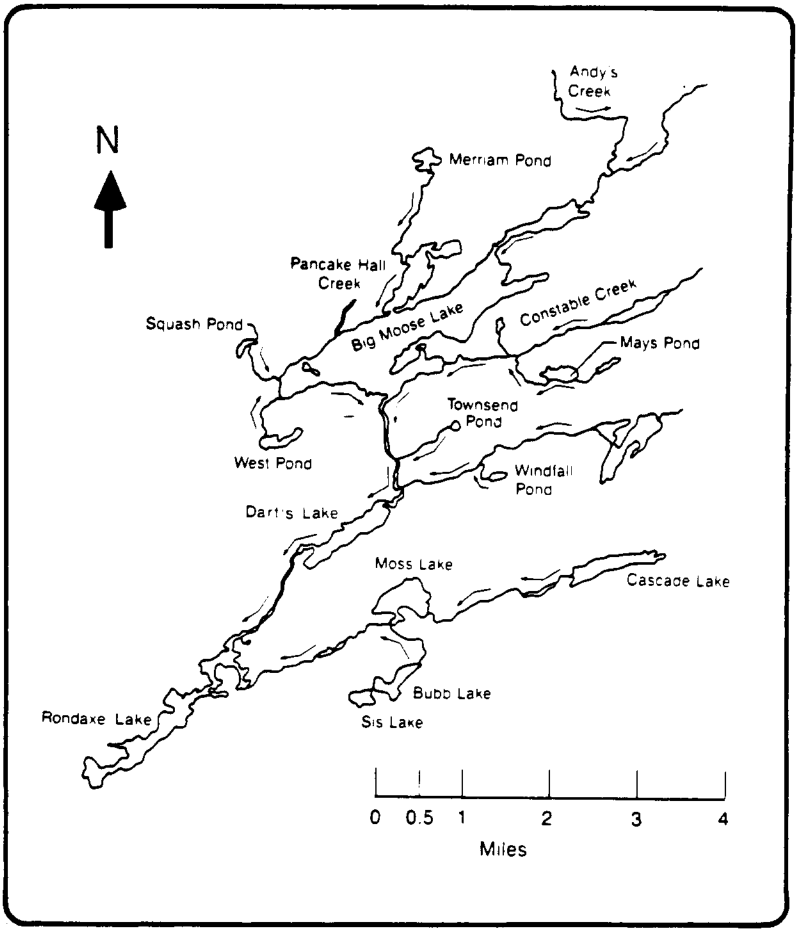

Figure 2. Map of North Branch of the Moose River showing RILWAS sites.

*Table 1.* Characteristics of Big Moose system watersheds

| | Study Category | Basin Area*, km$^2$ | Lake Surface Elev. m | Relief m | Forest Cover, % | Lake Surface Area, km$^2$ | Lake Max. Depth, m | AEPH$^{\dagger\dagger}$ | | | ANC, $\mu$eq/l | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Min. | Mean | Max. | Min. | Mean | Max. |
| Andy's Creek | Longitudinal gradient | 50.7 | 552$^\dagger$ | 328 | 95 | — | — | 4.46 | 4.86 | 6.37 | −28.8 | 5.2 | 51.9 |
| Big Moose Lake | Longitudinal gradient | 95.55 | 557 | 206 | 85 | 5.2 | 20 | 4.60 | 5.03 | 5.25 | −26.7 | 3.1 | 16.7 |
| Bubb Lake | Longitudinal gradient | 1.78 | 554 | 146 | 95 | 0.18 | 2.5 | 5.14 | 6.07 | 6.94 | −1.5 | 40.2 | 145.4 |
| Cascade Lake | Longitudinal gradient | 4.84 | 554 | 197 | 95 | 0.44 | 5 | 5.81 | 6.55 | 7.40 | 15.0 | 96.4 | 238.9 |
| Constable Crk | Longitudinal gradient | 13.83 | 558$^\dagger$ | 201 | 95 | — | — | 4.45 | 4.89 | 6.61 | −32.4 | 6.9 | 63.9 |
| Darts Lake | Longitudinal gradient | 105.19 | 536 | 184 | 90 | 0.53 | 16 | 4.65 | 5.09 | 5.90 | −28.4 | 7.4 | 28.5 |
| Mays Pond | Longitudinal gradient | 1.42 | 578 | 155 | 95 | 0.08 | — | See Constable Crk | | | | — | |
| Merriam Pond | Longitudinal gradient | 2.47 | 651 | 94 | 90 | 0.08 | 5 | 4.30 | 4.47 | 5.29 | −59.4 | −23.8 | 10.1 |
| Moss Lake | Longitudinal gradient | 13.80 | 536 | 183 | 90 | 0.39 | 10 | 4.45 | 5.48 | 7.29 | −26.0 | 64.0 | 185.9 |
| Pancake Hall Crk | Longitudinal gradient | 0.73 | 625$^\dagger$ | 143 | 95 | — | — | 4.32 | 4.85 | 6.59 | −70.9 | 17.6 | 109.4 |
| Rondaxe Lake | Longitudinal gradient | 136.14 | 525 | 195 | 90 | 0.91 | 10 | 4.95 | 5.72 | 6.90 | −30.1 | 30.7 | 85.5 |
| Sis Lake | Longitudinal gradient | ** | 555 | 146 | 95 | 0.11 | — | see Bubb Lake | | | | — | |
| Squash Pond | Longitudinal gradient | 0.82 | 650 | 203 | 95 | 0.02 | 7 | 4.21 | 4.41 | 6.61 | −61.6 | −24.2 | 93.5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Townsend Pond | Longitudinal gradient | 0.89 | 561 | 119 | 90 | 0.02 | < 1 | 4.68 | 5.20 | 6.77 | − 18.2 | 19.4 | 72.2 |
| West Pond | Bog influence, longitudinal gradient | 1.16 | 579 | 80 | 75 | 0.12 | 4 | 4.67 | 5.11 | 7.08 | − 22.8 | 26.6 | 199.8 |
| Winfall Pond | Longitudinal gradient | 7.38 | 595 | 140 | 95 | 0.02 | 5.5 | 4.81 | 5.73 | 7.00 | − 8.5 | 41.7 | 114.4 |

* Basin area measured upstream of sampling station. Any tributary drainages are included.

** Included in drainage area for Bubb Lake

† Elevation of sampling station.

†† Air equilibrated pH.

done by using the ILWAS model as a framework to analyze the acid-base dynamics of 25 additional sites (Figure 1) in the Adirondacks, as well as sites in other regions of the U.S.

Sixteen of the Adirondack RILWAS sites (Figure 2; Table 1) comprise a system of chain lakes within the basin of the North Branch of the Moose River. The North Branch of the Moose River is located in the west-central Adirondacks, a district containing a large number of acidic lakes (Colquhoun *et al.*, 1984). This basin has been the focus of considerable research activity in recent years. R. April, C. Driscoll and C. Schofield organized a meeting which was held April 1985 at Colgate University to summarize the RILWAS analyses for these sites. In addition to RILWAS Principal Investigators (E. Altwicker, R. April, D. Charles, C. Chen, C.Cronan, C. Driscoll, S. Gherini, A. Johannes, R. Newton, N. Peters and C. Schofield), other researchers (M. Heit, D. Johnson, C. Kelly, J. Rudd, and J. White) working in the North Branch of the Moose River, participated (Table 2).

A number of factors contribute to make the North Branch of the Moose River an important study site. There is considerable variability in watershed characteristics (Cronan *et al.*, 1987; Newton *et al.*, 1987; Peters and Driscoll, 1987) and surface water chemistry (Driscoll *et al.*, 1987; Table 1) which facilitates an evaluation of the processes regulating surface water acidification. The basin exhibits a general pattern of increasing ANC and pH with the movement of water from north to south, with a dramatic contrast in acid-base chemistry between the subcatchment north of Big Moose Lake and the subcatchment east of Lake Rondaxe (Figure 2). Furthermore, there is the anomaly of Windfall Pond, which is an ANC-enriched lake in the center of an acidic subregion, and the low sulfate concentration in West Pond and Pancake-Hall Creek relative to the rest of the basin (Driscoll *et al.*, 1987; Driscoll *et al.*, 1987).

In addition, there is considerable historical information on changes in land use, water chemistry and fish populations within the North Branch of the Moose River. This information has facilitated paleoecological evaluations of Big Moose Lake (e.g., Charles *et al.*, 1987) as well as an assessment of historical changes in fisheries (Schofield and Driscoll, 1987).

Finally, because the North Branch of the Moose River is a chain-lake system with no physical barriers that would limit fish movement, and large spatial variations in water quality are observed within the system, it is a good setting to assess the effects of surface water acidity on fish. This assessment was accomplished by an evaluation of fish distribution relative to water quality (Schofield and Driscoll, 1987) as well as by in-situ bioassays (Schofield and Driscoll, 1987; Johnson *et al.*, 1987).

Because of the amount and diversity of research within the North Branch of the Moose River, this watershed makes an ideal case study to:

1. Evaluate the processes regulating the acid-base chemistry of Adirondack surface waters.
2. Assess effects of surface water acidity on fish populations.
3. Test the ILWAS theory of surface water acidification.

To accomplish these objectives, many researchers (Table 2) have summarized the results of their studies within the basin. These studies include atmospheric deposition, terrestrial and hydrologic processes, water chemistry and in-lake processes, paleoecological analyses, effects of water quality on fish, and model simulations of the basin surface water quality.

### *Processes regulating the acid-base chemistry of surface waters in the North Branch of the Moose River*

Waters draining the North Branch of the Moose River have varying sensitivity to acidic deposition. The differences in sensitivity are attributable to varying degrees of basic cation supply from soils (Newton *et al.*, 1987), and acidic anion removal by soil and sediment (Rudd *et al.*, 1986a,b; Schafran and Driscoll, 1987; G.F. Davis *et al.*, 1987; Driscoll *et al.*, 1987). When surface water concentrations of strong acid anions ($SO_4^{2-}$, $NO_3^-$, $Cl^-$ expressed in $eq.l^{-1}$) exceeded the concentration of basic cations ($Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$ in $eq.l^{-1}$), elevated concentrations of $H^+$ and inorganic Al were observed (Table 1; Driscoll *et al.*, 1987).

Nitrate concentrations were low during the biologically active summer season and peaked during spring snowmelt. These $NO_3^-$ concentrations were largely attributed to the flushing of mineralization and nitrification by-products from the organic soil horizons during snowmelt (Rascher *et al.*, 1987). These pulsed inputs of $NO_3^-$ are significant because they represent an additional source of acidity superimposed on $SO_4^{2-}$ acidity. Moreover, in chronically acidic waters, short-term increases in $NO_3^-$ were strongly correlated with increases in the concentrations of $H^+$ and Al (Schofield *et al.*, 1985, Driscoll *et al.*, 1987; Schafran and Driscoll, 1987; Driscoll *et al.*, 1987).

The observations and results for the North Branch of the Moose River, that are reported in the following papers (Table 2), are generally consistent with the major conclusions of ILWAS and the conceptual structure of the ILWAS model. With one exception, all of the acidity production and consumption processes that appear to be important in the North Branch of the Moose River were included in the original version of the ILWAS simulation model (Chen *et al.*, 1983; Gherini *et al.*, 1985). The exception is lake sediment reduction of $SO_4^{2-}$ (Kelly *et al.*, 1986; Rudd *et al.*, 1986a,b; Driscoll *et al.*, 1987), which can be a significant source of ANC; for example, in West Pond (Driscoll *et al.*, 1987; Newton *et al.*, 1987) and Pancake-Hall Creek during summer (Driscoll *et al.*, 1987).

There was no appreciable loss of $SO_4^{2-}$ to sediments in most of the study

*Table 2.* A summary of participants in lake-watershed acidification in the North Branch of the Moose River

| Topic | Title | Authors |
|---|---|---|
| Atmospheric deposition | | |
| 1. | Temporal and spatial gradients of atmospheric deposition in and around the North Branch of the Moose River (RILWAS) | A.H. Johannes, E.R. Altwicker and D.F. Rogoswki |
| Terrestrial and hydrologic processes | | |
| 1. | Forest vegetation in relation to surface water chemistry in the North Branch of the Moose River (RILWAS) | C.S. Cronan, J.C. Conlan and S. Skibinski |
| 2. | The relationship between surface water chemistry and geology of the North Branch of the Moose River (RILWAS) | R.M. Newton, J. Weintraub and R. April |
| 3. | Hydrogeologic controls of surface water chemistry in the Adirondack region of New York State (RILWAS) | N.E. Peters and C.T. Driscoll |
| 4. | Concentration and flux of solutes from snow and forest floor during snowmelt in the west-central Adirondack region of New York (RILWAS) | C.M. Rascher, C.T. Driscoll and N.E. Peters |
| Water Chemistry and Aquatic Processes | | |
| 1. | Trends in the water chemistry of the North Branch of the Moose River (RILWAS) | C.T. Driscoll, C.P. Yatsko and F.J. Unangst |
| 2. | Processes regulating temporal and longitudinal variations in the chemistry of a low-order woodland stream in the Adirondack region of New York | C.T. Driscoll, B.J. Wyskowski, C.C. Cosentini and M.E. Smith |
| 3. | Spatial and temporal variations in the aluminum chemistry of a dilute acidic lake | G.C. Schafran and C.T. Driscoll |
| 4. | Manganese cycling in an acidic Adirondack Lake | J.R. White and C.T. Driscoll |
| Paleolimnology | | |
| 1. | Paleolimnological evidence for recent acidiciation of Big Moose Lake, Adirondack Mountains, NY (RILWAS) | D.F. Charles, D.R. Whitehead, D.R. Engstrom, B.D. Fry, R.A. Hites, S.A. Norton, J. Owen, L.A. Roll, S. Schindler, J.P. Smol, A.J. Uutala, J.R. White, and R.J. Wise |

| | | |
|---|---|---|
| 2. | Cesium-137 sediment depth profiles and inventories in Adirondack lake sediments: implication for reconstructing pollutant deposition chronologies | M. Heit and K.M. Miller |
| Fisheries | | |
| 1. | *In-situ* toxicity tests of fishes in acid waters | D.W. Johnson, J.J. Colquhoun, F.M. Flack and H.A. Simonin |
| 2. | Fish species distribution in relation to water quality gradients in the North Branch of the Moose River Basin (RILWAS) | C.L. Schofield and C.T. Driscoll |
| Modeling | | |
| 1. | Big Moose Basin: Simulation of response to acidic deposition (RILWAS) | G.F. Davis, J.J. Whipple, S.A. Gherini, C.W. Chen, Goldstein, P. Chan and R.K. Munson |

sites within the North Branch of the Moose River (Rudd *et al.*, 1986a) because of the short mean residence times (all less than a year) of water in these lakes (Kelly *et al.*, 1987). The reductive loss of $SO_4^{2-}$ can be a key factor controlling water column concentrations. However, the hydraulic residence time must be long enough for the process to appreciably reduce $SO_4^{2-}$ concentrations. The current version of the ILWAS model has been modified to include simulation of $SO_4^{2-}$ reduction processes.

Reduction processes may be significant, particularly during the low flow, biologically active, summer season. In-lake consumption of $NO_3^-$ increases ANC and pH and leads to hydrolysis and deposition of Al in chronically acidic lakes during summer stratification periods (Schafran and Driscoll, 1987). Moreover, $SO_4^{2-}$ reduction within a beaver impoundment along Pancake-Hall Creek was most pronounced during the low flow summer season, presumably due to the longer hydrologic retention time and increased reaction rates due to the elevated temperature (Driscoll *et al.*, 1987).

Goldstein *et al.*, (1985) have indicated the futility of trying to identify a single factor that regulates the acid-base status of lakes. This problem (Rapp *et al.*, 1985) is supported by the analyses of Peters and Driscoll (1987), Cronan *et al.*, (1987) and Newton *et al.*, (1987) each of which demonstrates the inability to correlate lake acid-base status to a different single factor; frequency distribution of instantaneous water discharge, distribution of tree communities, and soil-till depth, respectively.

Although soil-till depth was an excellent index for differentiating the acid-base status of the three ILWAS lakes (April and Newton, 1985), Goldstein *et al.*, (1985) cautioned that this index may not be broadly applicable. Indeed, it failed to hold true over the relatively small drainage area (136 $Km^2$) of the North Branch of the Moose River, which is in the same general region of the Adirondacks as the ILWAS lakes (Figure 1). Reasons for this discrepancy include significant $SO_4^{2-}$ reduction in some surface waters (West Pond, Driscoll *et al.*, 1987; Pancake-Hall Creek, Driscoll *et al.*, 1987) and the presence of calcium-rich minerals (e.g. calcsilicates and carbonate) in some watersheds (Windfall Pond, Cascade Lake, Newton *et al.*, 1987). These observations demonstrate the potential difficulty of making a regional assessment from analysis of just a few watersheds.

The results of Newton *et al.*, (1987) and Peters and Driscoll (1987) strongly support the importance of flow path analysis. To assess flow path considerations, it is essential to know how watershed properties (e.g. soil-till depth; slope; hydraulic conductivity; soil minerals) are spatially distributed throughout a basin. If a potential source of ANC is inaccessible to the water flowing to a lake, then its ability to contribute ANC to that lake will be limited. The importance of knowing the spatial distribution of watershed characteristics tends to increase with the size of the watershed. Although 13% of the Big Moose Basin is covered by thick till and stratified drift, the distribution is highly heterogeneous with the northern catchments having little or none (Newton *et al.*, 1987). Were these deposits uniformly distributed, one would assume that the northern lakes and streams would have a higher pH. Furthermore, small amounts of carbonate-bearing rock may have an overriding effect on the ANC of individual lakes.

In addition to patterns in the concentration of the major solutes, interesting trends in trace metal levels were evident within the basin. Concentrations of Al (Driscoll *et al.*, 1987; Schafran and Driscoll, 1987; Driscoll *et al.*, 1987) and Mn (White and Driscoll, 1987) were elevated in acidic waters. Elevated concentrations of trace metals have implications with regard to metal toxicity to fish (Johnson *et al.*, 1987; Schofield and Driscoll, 1987).

Considerable variation exists in dissolved organic carbon (DOC) concentrations within the basin, with the waters draining into Big Moose Lake having considerably higher DOC than the water leaving the lake (Driscoll *et al.*, 1987). Organic acids can play several roles with respect to surface water acidification. Inputs of organic acids represent potential sources of acidity. Moreover, they serve to buffer changes in solution pH (Driscoll and Bisogni, 1984). Organic acid anions can form complexes with trace metals, such as Al (Schafran and Driscoll, 1987) and reduce the potential toxicity of the metal to fish (Johnson *et al.*, 1987). Furthermore, organic acids can lead to analytical errors in Gran plot analysis (Barnard and Bisogni, 1985; Driscoll and Bisogni, 1984; Keene and Galloway, 1985; Lindberg *et al.*, 1984) that produce underestimation of true ANC (Davis *et al.*, 1987).

From lake and stream water samples from the RILWAS sites (25 locations), a difference (ΔpH) between measured air equilibrated pH and theoretical air equilibrated pH (based on measured ANC and equilibrium with atmospheric $CO_2$) was evident (Figure 3). These deviations, which are greatest between pH 5 and 6.5, reflect the contribution of non-$CO_2$ weak acids (e.g. organic acids and Al) to pH depression, as well as measurement errors. The ILWAS model (Gherini *et al.*, 1985) provides a means of quantifying the effects of organic acids and Al on the acid-base status of surface waters.

### *Historical changes in water quality and fish species distribution*

Water quality in the North Branch of the Moose River indicates that elevated concentrations of $SO_4^{2-}$ and $NO_3^-$ coupled with relatively low concentrations of basic cations are largely responsible for acidic conditions (Driscoll *et al.*, 1987). Atmospheric inputs largely regulate surface

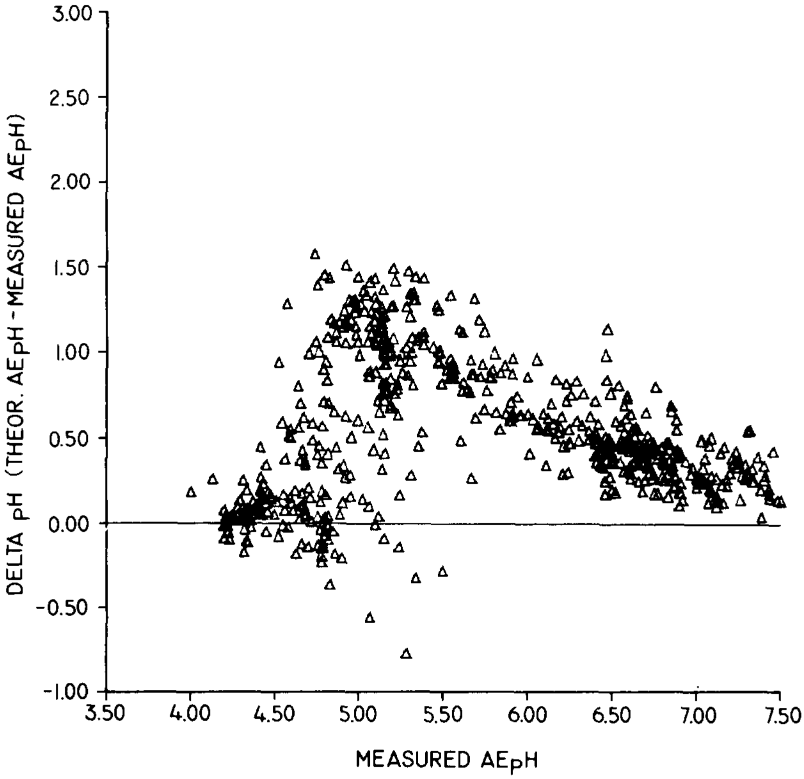

Figure 3. Deviation (ΔpH) of measured air equilibrated pH below the theoretical air equilibrated pH (AEpH) as a function of measured air equilibrated pH, for water samples for Regional Integrated Lake-Watershed Acidification Study sites. Theoretical air equilibrated pH was calculated from measured alkalinity and $P_{CO_2} = 10^{-3.5}$ atm. ΔpH is a measure of the depression in pH due to non-$CO_2$ weak acids (e.g. organics and aqueous aluminum).

water concentrations of $SO_4^{2-}$ in the basin (A.H. Johannes *et al.*, 1986; G.F. Davis *et al.*, 1986).

Analysis of diatom and chrysophyte stratigraphies by Charles *et al.* (1987) indicate that acidification of Big Moose Lake has occurred from pH values in the high 5's in the 1930's to about 5 today. The standard deviation in this analysis is about 0.3 pH units. Estimation of errors with respect to dating the stratigraphies is less certain and is an active area of research. The possibility of Pb-210 movement in the sediment similar to that reported for Cs-137 by Heit and Miller (1987) should certainly be evaluated. Moreover, given this uncertainty, dating of sediments should probably be independently confirmed by using both Pb-210 and Cs-137. Charles *et al.*, (1987) report increased S concentrations in the upper part of sediment cores from Big Moose Lake which implies increased S deposition to the sediments over the last several decades. Unfortunately, because of the mobility of S in the sediments, S deposition to the sediments cannot be quantified and dated as accurately or precisely as diatom deposition.

Schofield and Driscoll (1987) show that the acidity of surface water is correlated with the number of fish species found in the various water bodies in the North Branch of the Moose River. This finding is consistent with the results of in-situ bioassay studies by Johnson *et al.*, (1987).

Schofield and Driscoll (1987) report that the range of less acid tolerant fish species in the North Branch of the Moose River has decreased since 1931 with the species disappearing from the more acidic regions of the basin. This is the same general time period for which the pH reconstructions of Charles *et al.*, (1987) indicate that acidification has occurred in Big Moose Lake.

Using the ILWAS model, G.F. Davis *et al.* (1987) simulated the response of Big Moose Lake water quality to a 50% reduction in S deposition (both wet and dry). Simulations indicate that four years following this reduction, the lake pH would increase by 0.1 to 0.5 units depending on the season. Since steady-state was not attained within the four years of simulation, it is expected that the magnitude of pH increase would ultimately be larger.

In summary, there is evidence to correlate increased S concentrations in recent sediments of Big Moose Lake, the acidification of the lake based on paleolimnological reconstructions, and disappearance of acid-sensitive fish species. Furthermore, simulations of the Big Moose Lake watershed with the ILWAS model indicated that changes in atmospheric S deposition will result in changes in lake acidity.

### *Assessment*

As with ILWAS, lake-watershed behavior of the North Branch of the Moose River should not be considered representative of the entire Adirondacks or other "acid-sensitive" lake districts. There are large variations in observed geologic, biogeochemical and hydrologic characteristics within the Adirondacks (Figure 1; Driscoll and Newton, 1985; Peters and Driscoll, 1987), and between the west-central Adirondacks and other lake districts in North America. As indicated previously, hydrologic flow paths are a critical factor influencing susceptibility of waters to acidification. For example, many low ANC and acidic lakes in the upper Midwest (Eilers *et al.*, 1983), Florida, New England and the Adirondacks (Driscoll and Newton, 1985) are seepage lakes, with no surface inflow and outflow (e.g., Barnes Lake and Little Echo Pond in Figure 1). The hydrogeologic characteristics of seepage lakes are distinctly different from drainage lakes (Driscoll and Newton, 1985). It is therefore not realistic to extrapolate water chemistry trends from drainage lake systems like the North Branch of the Moose River to districts of seepage lakes.

Kelly *et al.*, (1987) have demonstrated that the importance of inlake reduction processes increases with increasing hydraulic detention time. Because of the extremely short detention times of waters within the North Branch of the Moose River (less than 0.5 years; Driscoll *et al.*, 1987), terrestrial processes are more important than in-lake processes in controlling the acid-base chemistry of the surface waters. Moreover, the role of in-lake processes in ANC generation is less significant in the Adirondacks than in other lake districts, with longer hydraulic residence times (Rudd *et al.*, 1987).

In addition to hydrologic considerations, there are distinct differences in the water chemistry of the west-central Adirondacks with other lake districts. For example, $NO_3^-$ concentrations are elevated relative to other lake districts in eastern North America (Driscoll and Schafran, 1984). Episodic acidification during snowmelt in the west-central Adirondacks is largely accomplished by $NO_3^-$ inputs coupled with dilution of basic cations (Schofield *et al.*, 1985; Driscoll *et al.*, 1987; Driscoll *et al.*, 1987; Peters and Driscoll, 1987, Rascher *et al.*, 1987). In other regions episodic acidification has been attributed to dilution of basic cations and/or inputs of $SO_4^{2-}$ or organic acids (Johannessen *et al.*, 1980; Cadle *et al.*, 1984). The large contributions of $NO_3^-$ inputs to the acidification of surface waters appears to be a unique characteristic of the west-central Adirondacks.

Because of regional differences in the predominant processes regulating acid-base status, the application of empirical acidification models (Henriksen, 1979; Wright, 1984) to different lake districts as an assessement tool should be made with great caution. One of the chief strengths of the ILWAS model in comparison to other acidification models (e.g. the Trickle Down Model, Schnoor *et al.*, 1984; the Birkenes Model, Christophersen *et al.*, 1982; the MAGIC Model, Cosby *et al.*, 1985) is its completeness with respect to mechanistically simulating all potentially significant acid consumption and production processes. Furthermore, since the model tracks all major cations and anions, it provides a robust means for quantifying the relative importance of various acid-base processes (Munson and Gherini, 1986). In any given system, not all processes or ions may be significant. However, the contribution of a given process in regulating surface water chemistry is highly variable from lake to lake (Driscoll and Newton, 1985; Driscoll *et al.*, 1987) and between lake districts (Kelly *et al.*, 1987; Rudd *et al.*, 1986a). Therefore, if a model is to be applied in regional assessments, it is essential that all relevant processes and ions are depicted.

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