Maine High Elevation Lakes
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Indicator Watersheds for Detecting Environmental Trends

Long-term environmental monitoring has historically been a challenge to sustain, despite generating long-term data records that form the basis for most questions underlying environmental science. It is increasingly clear that monitoring is an essential component of research (Lovett et al. 2007). Well-designed monitoring programs address clear questions that are relevant to policy, use consistent and accepted methods to produce and document quality data, and typically directly involve the researchers that will utilize the results. We recommend that government agencies commit to the highly cost-effective support needed to maintain existing long-term data records, rather than abandoning these successful, but perhaps seemingly mundane, programs in favor of new observing networks du jour that have no data record.

One example of a research/monitoring program that is successfully addressing the effectiveness of the Clean Air Act Amendments of 1990 (CAAA) (Stoddard et al. 2003) is the USEPA program TIME (Temporally Integrated Monitoring of Ecosystems). This program uses a random sample of lakes that represents a statistical population of lakes in the northeastern U.S. The data record for some of these lakes extends back to 1984. Our part of the program since 1993 spans the region from the Adirondacks to Maine. USEPA has made a commitment to this program because the agency needs the data to report to Congress on the effectiveness of the Clean Air Act Amendments, yet the continuity of funding for the program is in question virtually every year.

High Elevation Lakes as “Canary” Lakes?
TIME represents a random sample of lakes that have low alkalinity and are therefore expected to respond to changes in the acidity of atmospheric deposition. To complement TIME lakes, which are typically low-elevation lakes with at least some development in their watersheds, we have been sampling remote lakes at high elevation in Maine (Figure 1). This paper describes the characteristics and trends in chemistry of Maine high-elevation lakes that make these lakes good candidates as indicator systems capable of providing an advance signal of the response to stressors such as acidic deposition and climate change. Data for these lakes extend back at least 20 years (Kahl and Scott 1988) in the program established by Matt Scott, Past President of NALMS.

Federal Acidic Deposition Policy
The 1990 Clean Air Act Amendments set target reductions, beginning in 1995, for acid precursor emissions from industrial sources as a means to reduce the acidity in atmospheric deposition. The intended result was to decrease the acidity in surface waters and thereby improve their biological condition. In setting policy for acidic deposition, policymakers face the difficult challenge of dealing with an environmental issue that has rather subtle effects, takes decades to unfold, and...
may require years to reach a consensus about what “recovery” entails (Kahl et al. 2004).

Although acidic deposition is the ultimate non-point source pollutant because it falls on the entire landscape, only a small percentage of surface waters are “acidified” (e.g., Landers et al. 1988). Therefore, the choices for future Clean Air Act policy depend on awareness of the scientific consensus about the magnitude of the resource at risk for a given region or resource. Differences in environmental sensitivity and capacity also require decision support tools capable of capturing regional variation.

Scientific Context for Acidic Deposition

Title IV of the 1990 Clean Air Act Amendments set target reductions for sulfur and nitrogen emissions from industrial sources as a means to reduce the acidity in deposition. One of the intended effects of the reductions was to decrease the acidity of low alkalinity waters, largely in the Northeast (Figure 2), thereby improving their biological condition. The measures of expected “recovery” in biological condition include decreased acidity, sulfate, and toxic dissolved aluminum concentrations.

Nitrate and sulfate from the combustion of fossil fuels react with water in the atmosphere to produce “acid rain”, a dilute solution of nitric and sulfuric acids. This acidity (and the acid anions sulfate and nitrate) may travel hundreds of miles before being deposited on the landscape. The northern and eastern U.S. receives precipitation with mean pH that ranges from 4.3 in Pennsylvania and New York to 4.8 in Maine and the Upper Midwest. The acidity (hydrogen ion concentration) in precipitation in the eastern U.S. is at least twice as high as in pre-industrial times. In the Northeast, sulfate in precipitation has declined significantly for at least 30 years (Lynch et al. 2000). Nitrate concentrations have declined slightly in the Northeast since 2000.

Acidic Lakes at High Elevation

In 1984 the EPA began monitoring the status of lakes in the Northeast through the Eastern Lake Survey (ELS) (Landers et al. 1988). The HELM (high elevation lakes of Maine) project was designed to enhance the relevance of the data coming from Maine by monitoring lakes at the high elevations. Beginning in 1986, 90 Maine lakes, greater than 600m elevation, at least 0.4 ha surface area and 1m deep, have been sampled periodically (Figure 3). On average, the HELM lakes are more acidic than the rest of Maine’s lakes because they:

- receive higher amounts of precipitation
- have a larger input of organic acids
- have low or no development disturbance
- have low acid neutralizing capacities (ANC) due to the characteristics of geology and soils (steep slopes, shallow soils, chemical-weathering resistant bedrock) (Figure 4)

All of these factors make the population of HELM lakes preferentially suited as an indicator of recovery from acidic deposition.

The Low-Cl Advantage in HELM Lakes

A recent study by Rosfjord et al. (2007) used the EPA ELS statistical framework of lakes representing the population of lakes with low acid neutralizing capacity (ANC) in the northeastern U.S. to provide a regional figure adapted from Stoddard et al. 2003) with the red circle indicating the region of Maine High Elevation Lakes.

Figure 3. Aerial view of Cranberry Pond with Cranberry Peak rising out of its western shoreline. The majority of the HELM lakes are set in similar topographic backdrops.
assessment of 20-year changes in Cl and major cation chemistry. The study region included urban/suburban areas in southern New England and more remote settings in the Adirondack Mountains and Maine. The conclusions were that assessments of acid-base chemistry are compromised by major changes in chlorine (Cl\(^-\)) (largely from road salt) in much of the population of lakes (Figure 5). The more remote regions of the Adirondack Mountains and Maine were relatively less impacted by increases in Cl\(^-\). Within Maine, the HELM lakes have a mean Cl\(^-\) concentration of only 11 µeq/L (0.4 mg/L) compared to an average of 148 µeq/L in Maine, with no increase in Cl\(^-\) through time. This lack of impact from development enhances the suitability of HELM lakes for long-term assessment of recovery from acidic deposition.

Acid-base Status of Surface Waters

EPA ELS estimated the number of acidic lakes at 4.2 percent of the population in northeastern U.S. (Landers et al. 1988). Surface waters in most other regions are not sensitive to the impacts of acidification due to the nature of the local geology. “Acidic” waters are defined as having acid neutralizing capacity (ANC) less than zero (i.e., no acid buffering capacity in the water), corresponding to a pH of about 5.2. In Maine, the percentage of acidic waters was estimated by EPA to be less than 1 percent, but we were aware in the mid-1980s of more than 100 acidic lakes not considered in the EPA estimate. The high-elevation lake population, with 13 percent acidic lakes, was established as a sensitive subset of Maine lakes to track the response of surface waters to reduced acidic deposition.

Declining Conductance

One of the regional trends in the chemistry of low ANC surface waters is declining conductance. The reason is a combination of chemical trends occurring due to decreases in acidic deposition. Concentrations of sulfate, nitrate, and hydrogen (acidity) are decreasing due to lower levels of acidic anions in deposition. As the acidity is reduced, the concentration of acid neutralizing base cations (Ca\(^{2+}\) and Mg\(^{2+}\)) in the surface waters is also reduced due to changes...
in soil chemistry. Typically, the only concentrations that are increasing are ANC (alkalinity) and natural organic anions represented by increased Dissolved Organic Carbon (DOC). Therefore, the concentration of declining constituents outweighs the increasing ones leading to an overall decline in conductance. This decline likely represents a return to a more pre-industrial condition for surface waters.

In the Northeast, Maine high-elevation lakes and lakes in the Adirondacks have declining sulfate as expected from declining deposition of sulfate in precipitation (Figure 6). However, the decline in sulfate is being offset by the decline in base cations, resulting in only small increases in pH and ANC. The response in the past 10 to 15 years suggests that the indicator systems such as the HELM lakes show greater “recovery” than the general population of lakes in the region.

**Indicators of Recovery.** A main goal of the Clean Air Act Amendments (CAAM) is to decrease the acidity of surface waters. Although a major decrease in acidity has not occurred, some factors appear to point toward recovery, forecasting an improvement in biologically relevant surface water chemistry. It is not yet clear if further reductions in emissions and deposition will be necessary for widespread recovery to occur. These factors suggest that continued data collection is essential to document the effectiveness of the Clean Air Act Amendments:

- Sulfate constitutes an increasingly smaller percentage of total ions in sensitive surface waters.
- Base cations have declined in concentrations similar to the decline in sulfate, offsetting the sulfate decline and resulting in typically small increases in ANC in the region.
- Dissolved organic carbon has increased in many surface waters. This change probably represents a return to a more natural pre-industrial acid-base condition.
- Toxic aluminum concentrations, which is the major biological impact resulting from acidic deposition, have decreased in indicator systems such as the HELM lakes.

The scientific and regulatory communities need data from ongoing monitoring programs to determine the extent to which these indicators are indeed predicting recovery, and whether recovery will continue with at current levels of deposition without further deposition reductions.

**Expectations for recovery.** An important consideration for measuring the success of the CAAA is to have appropriate expectations for the magnitude of recovery. Lakes inferred to have been measurably acidified by atmospheric deposition were already marginally acidic before anthropogenic atmospheric pollution began more than 100 years ago. Lakes acidified by acidic deposition were naturally at least marginally acidic before anthropogenic acidic deposition began. Therefore, full recovery of acidic lakes may yield more sustainable fisheries, but there is no reason to expect neutral pH in presently acidic lakes.

**Conclusions**

Surprising or unexpected results sometimes are discovered as part of long-term monitoring, typically results that cannot be uncovered by short-term research. Moreover, baseline data can often immediately rule out or suggest hypotheses. In the case of the Maine high elevation lakes, current results confirm that the lack of impact from Cl makes these lakes well suited to determining long-term trends in response to declining acidic deposition. Widespread application of road salt in many non-HELM watersheds interferes with our ability to detect trends in lake chemistry related to other regional stressors such as climate change and acidic deposition. We suggest that regional monitoring programs used to assess the status and trends in the chemistry of aquatic systems should consider the effect of widespread salt contamination on water chemistry when interpreting policy-relevant data.

**References**


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**Next Issue – Spring 2008**

LakeLine

The theme of the winter issue of LakeLine is “Fisheries Management.”

The spring issue will feature articles on balancing water quality and fisheries in lake management projects; managing macrophytes and fisheries; economic values of fishing; and several case studies of fisheries renovation and management.