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Environmental Protection
Agency

Office of Acid Deposition, Environmental
Monitoring and Quality Assurance
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Research and Development

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EPA

# Project Summary

# Characteristics of Lakes in the Eastern United States

**The United States Environmental Protection Agency (EPA) initiated the National Surface Water Survey (NSWS) to assess the present chemistry of surface waters, to quantify the temporal variability and key biological resources associated with these surface waters and to initiate long-term monitoring in characteristic systems.**

**The NSWS is a three-phase study focusing on regions of the U.S. that are potentially susceptible to change as a result of acidic deposition, and is one of several major projects in the Acid Deposition Aquatic Effects Research Program in the EPA Office of Research and Development.**

***This Project Summary was developed by EPA's Office of Research and Development, Washington, DC, to announce key findings of the research project that is fully documented in three separate volumes (see Project Report ordering information at back).***

## Introduction

The Aquatic Effects Research Program addresses four primary policy-related issues:

- the extent of damage to aquatic resources as a result of current levels of acidic deposition;
- the anticipated extent and rate of change to these resources in the future;
- levels of damage to sensitive surface waters associated with various rates of acidic deposition; and
- the rate of change or recovery of affected systems, given decreases in acidic deposition rates.

Four major research projects within the Aquatic Effects Research Program specifically address these issues within a regionalized framework. These projects and their goals are:

- *National Surface Water Survey (NSWS)*: to determine the present chemistry, characterize the temporal variability in chemistry, and determine the key biological resources of lakes and streams in potentially sensitive regions of the U.S.;
- *Direct/Delayed Response Project*: to predict future changes in these resources at present levels of acidic deposition, giving consideration to both the terrestrial and aquatic variables that influence these changes;
- *Watershed Manipulation Project*: to verify that predictions of future change are reasonably sound by manipulating watershed catchments or system components; and
- *Long-Term Monitoring Project*: to test the validity of predicted future changes through long-term monitoring of regionally characteristic lake and stream systems.

The NSWS, including surveys of both lakes and streams, addresses the first goal of the Aquatic Effects Research Program. The Eastern Lake Survey-Phase I (ELS-I) was designed to statistically describe present surface water chemistry on a regional scale. To further the current understanding of the effects of acidic deposition on aquatic resources requires that the present chemical status of surface waters be understood on large geographical scales.

## Summary

The ELS-I was conducted in the fall of 1984 and had three primary objectives:

- determine the percentage (by number and area) and location of lakes that are acidic in potentially sensitive regions of the eastern U.S.
- determine the percentage (by number and area) and location of lakes that

- have low acid neutralizing capacity (ANC) in potentially sensitive regions of the eastern U.S.; and
- determine the chemical characteristics of lake populations in potentially sensitive regions of the eastern U.S. and provide the data base for selecting lakes for further study.

To accomplish these objectives, a water sample was collected from each of 1612 lakes. This subset of lakes was selected from within three regions of the eastern U.S. (the Northeast, Upper Midwest and Southeast) expected to contain lakes having a low capacity to neutralize acidic inputs. Each region was divided into subregions, shown below:

Each subregion was further stratified by alkalinity map class, which differentiated among areas within each subregion based on the surface water alkalinity range expected to dominate in different areas within these subregions.

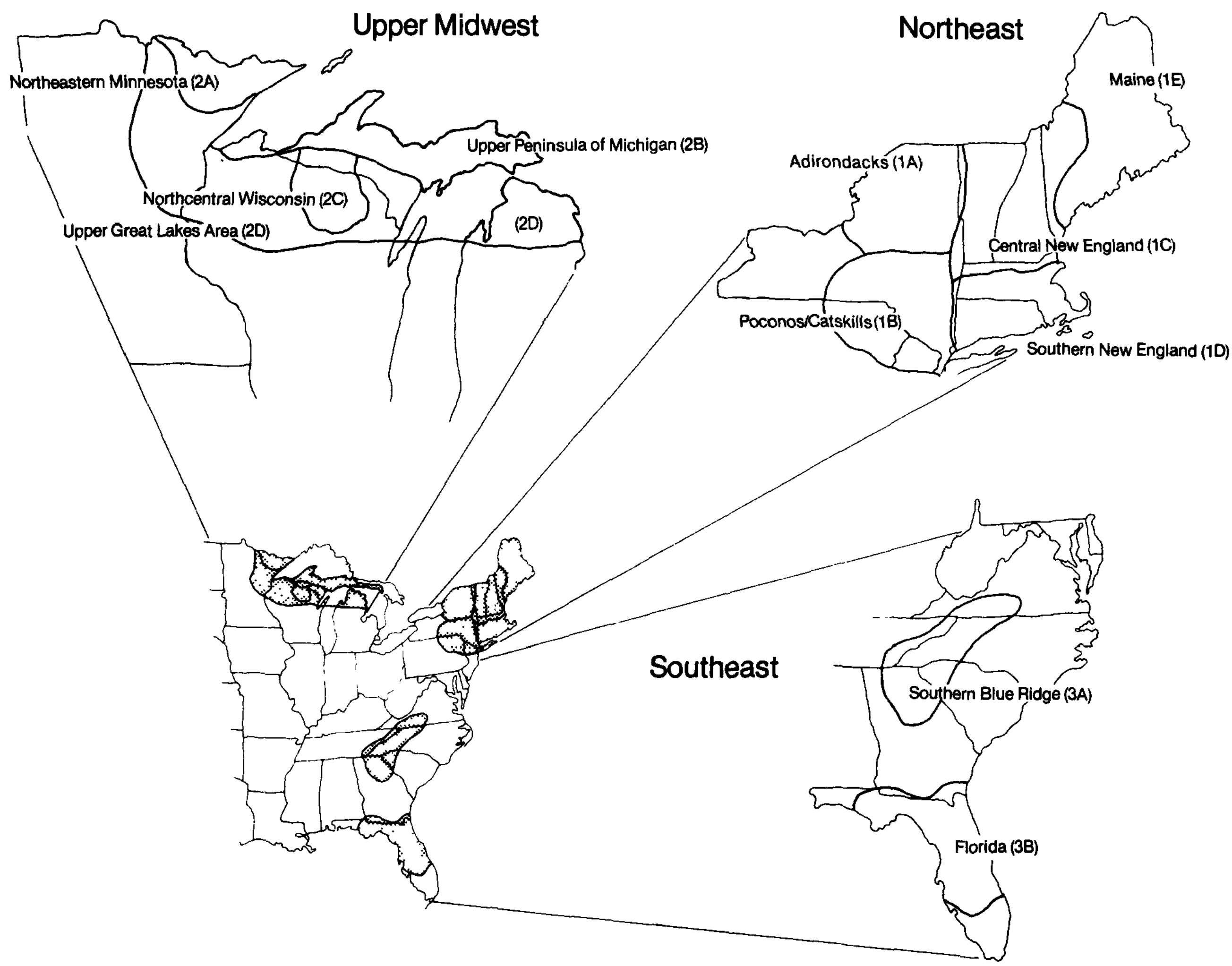
A suite of chemical variables and physical attributes thought to influence, or be influenced by, surface water acidification was measured for each lake. The results of these measurements form the ELS-I data base.

The ELS-I design, in which lakes were selected by a systematic random process from the population of lakes in the regions investigated, permits the use of the ELS-I data base to estimate the chemical status of lakes within a specific region or subregion. Additionally, the data base can be used to investigate correlative relationships among chemical variables on a regional basis.

The full report, *Characteristics of Lakes in the Eastern United States*, consists of three volumes. Volume I, *Population Descriptions and Physico-Chemical Relationships*, provides details about the ELS-I design and its implementation, presents data collected in the ELS-I, discusses results obtained and draws conclusions about these results. Volumes II and III contain descriptive statistics for each lake sampled and a data compendium of site characteristics and chemical variables.

The purpose of the full report is to describe the results and to make the ELS-I data available to researchers and policy makers as more in-depth analyses and interpretive efforts are undertaken. Additional analyses of these data will be performed in subsequent activities of the EPA Aquatic Effects Research Program and by independent researchers.

The use and interpretation of any data set are restricted by the design, the quality of the data obtained and the sampling protocols. These aspects of the Survey should be well understood before drawing conclusions both within and beyond the scope of the original objectives. For



example, these data alone may not be sufficient to determine causality. However, Survey data, coupled with data from ongoing and future projects, are expected to significantly advance our understanding of the relationship between acidic deposition and lake water chemistry.

## Selected Results

The first two observations presented below address the first two ELS-I objectives. The remaining observations address the third objective of the Survey. These observations lead to hypotheses that can be tested in subsequent phases of the NSWS and/or the Aquatic Effects Research Program.

It should be noted that the numbers and percentages of lakes cited are population estimates.

### *Extent and Location of Acidic and Low pH Lakes*

The subregions in the eastern U.S. that contain the largest proportion of acidic (ANC ≤0 μeq $L^{-1}$) and low pH (≤5.0) lakes are the Adirondacks (1A), the Upper Peninsula of Michigan (2B), and Florida (3B).

#### Acidic Lakes

- Within the Northeast (Region 1), the Adirondacks (1A) had the largest estimated number (138) and percentage (11%) of lakes with ANC ≤0 μeq $L^{-1}$, followed by Southern New England (1D; 5%), and the Poconos/Catskills (1B; 5%). Maine (1E) had the lowest percentage of acidic lakes (<1%). Most acidic lakes in the Adirondacks occurred in the western portion of the subregion.
- In the Upper Midwest (Region 2), 10 percent of the lakes in the Upper Peninsula of Michigan (2B) had ANC ≤0 μeq $L^{-1}$, and three percent in Northcentral Wisconsin (2C) were acidic. In Northeastern Minnesota (2A) and the Upper Great Lakes Area (2D) no acidic lakes were sampled.
- In the Southeast (Region 3), no acidic lakes were sampled in the Southern Blue Ridge (3A). In contrast, an estimated 22 percent of the lakes in Florida (3B) had ANC ≤0 μeq $L^{-1}$.
- Acidic lakes in the Northeast had higher concentrations of sulfate, calcium, and extractable aluminum than did acidic lakes in the Upper Midwest and Southeast.

#### Low pH Lakes

The estimated number of lakes and lake area with low pH (pH ≤5.0) also varied substantially among and within regions.

- Within the Northeast, the Adirondacks (1A) had the largest estimated number (128) and percentage (10%) of lakes with pH ≤5.0. Subregion 1D (Southern New England) contained the second highest estimated number (66) and percentage (5%) and the largest area (2295 ha, 6%) of low pH lakes. Maine (1E) had the fewest lakes (8, <1%) and least area (95 ha) with pH ≤5.0.
- In the Upper Midwest, no lakes with pH ≤5.0 were observed in Northeastern Minnesota (2A) or the Upper Great Lakes Area (2D). The Upper Peninsula of Michigan (2B) was estimated to contain 99 lakes with pH ≤5.0, representing nearly the same proportion as in the Adirondacks (9% and 10%, respectively).
- In the Southeast, no lakes with pH ≤5.0 were sampled in the Southern Blue Ridge (3A). Florida (3B) had the highest estimated number and percentage of lakes (259, 12%) and the largest estimated lake area with pH ≤5.0.

#### Extent and Location of Low ANC Lakes

The estimated number of lakes with low ANC varied among and within regions:

- Within the Northeast, the Adirondacks (1A) contain the highest percentages of lakes with ANC ≤50 μeq $L^{-1}$ and ≤200 μeq $L^{-1}$ (35% and 70%, respectively). Central New England (1C) and Maine (1E) contain the next highest percentages of lakes among all ELS-I subregions with ANC ≤200 μeq $L^{-1}$ (68% and 67%, respectively).
- Northcentral Wisconsin (2C) contained the highest percentage (41%) of lakes with ANC ≤50 μeq $L^{-1}$ among all subregions. Northeastern Minnesota (2A) and Northcentral Wisconsin contained the highest percentage of lakes in the Upper Midwest with ANC ≤200 μeq $L^{-1}$ (57%). Although the Upper Great Lakes Area (2D) contained the lowest percentages of lakes with ANC ≤200 μeq $L^{-1}$ in the Upper Midwest, it contained the largest number of lakes among all ELS-I subregions in this category (1411).
- The Southern Blue Ridge (3A) contained the lowest percentage (1%) and number (4) of lakes in the ELS-I with ANC ≤50 μeq $L^{-1}$ and the lowest number of lakes with ANC ≤200 μeq $L^{-1}$ among all subregions. Florida (3B) contained the highest number of lakes among all ELS-I subregions with ANC ≤50 μeq $L^{-1}$, and the second highest number of lakes with ANC ≤200 μeq $L^{-1}$.

### *Chemical Characterization*

In addition to addressing the primary objectives of the ELS-I, the Survey permits an evaluation of other chemical variables. The primary findings regarding the chemical status of regional and subregional lake populations are described below:

#### Sulfate

Sulfate concentrations in lakes were greatest in Florida and the southern portions of the Northeast. No linear relationship between lakewater sulfate and pH or ANC was evident in any region. High concentrations of sulfate were found at low and high pH values.

- Sulfate concentrations were relatively high in the Northeast Region (median concentration [M] = 115.4 μeq $L^{-1}$). Within the Northeast, sulfate concentrations were highest in the Poconos/Catskills (1B; M = 159.3 μeq $L^{-1}$) and Southern New England (1D; M = 141.1 μeq $L^{-1}$). The lowest sulfate values were observed in Maine (1E; M = 74.6 μeq $L^{-1}$).
- The median sulfate concentration in the Upper Midwest Region was half that of the Northeast. Median sulfate concentrations also varied among subregions within the Upper Midwest, ranging from 50.1 μeq $L^{-1}$ in the Upper Great Lakes Area (2D) to 77.7 μeq $L^{-1}$ in the Upper Peninsula of Michigan (2B).
- In the Southeast, the Southern Blue Ridge Subregion (3A) contained few lakes with high sulfate (22 or 8% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$). This subregion also had the lowest median sulfate concentration, 31.8 μeq $L^{-1}$. Florida (3B) contained the largest number of lakes with high sulfate concentrations (846 or 40% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$). Subregion 3B also had the most variable sulfate concentrations of any subregion.

## Calcium

Calcium concentrations were lowest in the Upper Midwest and Florida lakes.

- Within the Northeast Region, Southern New England (1D) had the highest percentage and number of lakes with calcium concentrations ≤50 μeq $L^{-1}$ (10%; 133). The Adirondacks (1A) contained the second highest percentage and number (8%; 108) of low calcium lakes (≤50 μeq $L^{-1}$).
- Northcentral Wisconsin (1C) contained the highest percentage (22%) and second highest number (34) of low calcium lakes among all ELS-I subregions. The Upper Peninsula of Michigan (2B) contained the second highest percentage (16%) of low calcium lakes and the Upper Great Lakes Subregion (2D) contained the second highest number (256) of low calcium lakes in the Upper Midwest.
- In the Southeast, 12 percent of the lakes in the Southern Blue Ridge (3A) had low concentrations of calcium, whereas in Florida (3B), 19 percent of the lakes were in this group. Florida contained the highest number (402) of low calcium lakes among all subregions.

## Extractable Aluminum

Extractable aluminum concentrations were higher in lakes with lower pH values, and higher in the Northeast than in other regions.

- The largest estimated number of clearwater lakes (true color ≤30 PCU) having extractable aluminum concentrations ≥150 μg $L^{-1}$ occurred in the Adirondacks (1A; 82 lakes or 10%). Few lakes in the Poconos/Catskills (1B; 3 lakes or <1%) and Southern New England (1D; 7 lakes or 1%) had extractable aluminum ≥150 μg $L^{-1}$. No clearwater lakes sampled in Maine (1E) had extractable aluminum concentrations ≥50 μg $L^{-1}$.
- Extractable aluminum concentrations *in clearwater lakes were lower in the* Upper Midwest (80th percentile = 8.5 μg $L^{-1}$) than in the Northeast (80th percentile = 11.6 μg $L^{-1}$). Extractable aluminum was lowest in clearwater lakes in Northeastern Minnesota (2A; 80th percentile = 3.0 μg $L^{-1}$), and highest in clearwater lakes in the Upper Peninsula of Michigan (2B; 80th percentile = 11.9 μg $L^{-1}$).
- Extractable aluminum concentrations in clearwater lakes were low in the Southern Blue Ridge (3A; 80th percentile = 2.5 μg $L^{-1}$). In Florida (3B), clearwater acidic lakes had lower extractable aluminum concentrations *(80th percentile = 18.6 μg $L^{-1}$) than did* clearwater lakes in the Adirondack Subregion (1A; 80th percentile = 29.4 μg $L^{-1}$).
- In each region extractable aluminum concentrations were higher at lower pH values. The Northeast had the greatest increase in extractable aluminum with decreasing pH and Florida the least increase at low pH values.

## Dissolved Organic Carbon

Dissolved organic carbon (DOC) con*centrations did not correlate with the* distribution of acidic or low ANC lakes.

- In the Northeast, as in other regions, 80 percent of acidic lakes contained concentrations of DOC <5 mg $L^{-1}$. A positive relationship existed between pH and DOC. Those lakes with highest DOC concentrations were drainage lakes with short hydraulic residence times and high ANC.
- In the Upper Midwest, most acidic lakes, especially those in the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), were clearwater, low DOC, seepage lakes. Lakes in Northeastern Minnesota (2A) had the highest concentrations of DOC in the Upper Midwest and no acidic lakes were sampled in this subregion.
- In the Southeast, only the lakes within the Okefenokee Swamp exhibited a strong association between low pH and high DOC. No apparent relationship between pH and DOC was evident in Florida (3B) lakes.

## Major Cations and Anions

The anions were most useful in characterizing differences in the relative importance of major ions among regions and subregions.

- In the Northeast, sulfate was the predominant anion at the 20th percentile in three of the subregions (Adirondacks, 1A; Poconos/Catskills, 1B; and Central New England, 1C). Sulfate was also the dominant anion at the median value in the Adirondacks.
- In Maine (1E), bicarbonate ion concentrations exceeded sulfate at both the 20th percentile and the median.
- Chloride was the dominant anion in Southern New England (1D) at both the 20th percentile and median values estimated for the population.
- Bicarbonate was the dominant anion *at the 20th percentile and median* values in the Upper Midwest, with the exception of the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), where sulfate was dominant at the 20th percentile.
- The *ionic composition* of lakes in Florida (3B) was similar to that of lakes in Southern New England (1D) in that sodium was the dominant cation and chloride the dominant anion at the 20th percentile. Total ionic concentration of many Florida lakes was high.
- Organic anions, as indicated by anion deficit, were not the dominant anions in any subregion at either the 20th or 50th percentile. Concentrations of organic anions were lowest in the Northeast.

## Conclusions and Future Studies

The results of the ELS-I presented in the full report are largely descriptive but lead one to formulate hypotheses that can be tested with this data base, singularly or combined with other data. The statistical design of the Survey makes it possible to test hypotheses related to acidification using regional data and relate the results to defined, regional lake populations.

Five major observations from the ELS-I are given below. Each is followed by a related question that should be addressed in the future:

- Sulfate concentrations in lakes across the Northeast and the Upper Midwest show an apparently strong relationship with the general patterns of sulfate deposition as measured by the National Trends Network.
  *What is the nature of the relationship between lake chemistry and atmospheric deposition of sulfate?*
- The majority of acidic lakes in all three regions contained relatively low concentrations of organic acids.
  *How important are the contributions of organic acids in explaining the occurrence of acidic lakes?*
- Some portions of the coastal areas of the Northeast contained moderate numbers of acidic lakes.
  *To what degree can the acidity of these coastal lakes be attributed to a neutral salt effect from sea spray deposition?*

- The estimated hydraulic residence times for clearwater lakes were approximately 3 times greater than for darkwater lakes. Residence time was inversely related to DOC.
  *Does an apparent difference in hydrology between clearwater, acidic lakes and darkwater, higher ANC lakes indicate that acidic lakes generally are not derived from darkwater lakes?*

- Florida (3B) contained the largest proportion of acidic lakes and the chemistry of many Florida lakes differed considerably in many respects from lakes in the Northeast, Upper Midwest and Southern Blue Ridge (3A).
  *To what degree are the acidic lakes in Florida affected by acidic deposition, and are other factors important in explaining the occurrence of acidic lakes in Florida?*

*The complete report was prepared by numerous contributors with various affiliations.*
***Dixon H. Landers** is the EPA Project Officer (see below).*
*The complete report consists of three volumes, entitled "Characteristics of Lakes in the Eastern United States:" (Set Order No. PB 87-110 375/AS; Cost: $79.00)*
*"Volume I. Population Descriptions and Physico-Chemical Relationships," (Order No. PB 87-110 383/AS; Cost: $18.95)*
*"Volume II. Lakes Sampled and Descriptive Statistics for Physical and Chemical Variables," (Order No. PB 87-110 391/AS; Cost $36.95)*
*"Volume III. Data Compendium of Site Characteristics and Chemical Variables," (Order No. PB 87-110 409/AS; Cost $36.95)*
*The above reports will be available only from: (costs subject to change)*
*National Technical Information Service*
*5285 Port Royal Road*
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