Eastern Lake Survey – Phase I
Documentation for the Data and the Derived Data Sets

Alan Douglas & M. Delampady

Technical Report 160

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UNIVERSITY OF BRITISH COLUMBIA
Eastern Lake Survey - Phase I
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by Alan Douglas and Mohan Delampady
University of British Columbia

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Documentation for the Data Base and the Derived Data Sets

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Summary

This report provides documentation for the Eastern Lake Survey – Phase I (ELS-I) database maintained in the Department of Statistics at the University of British Columbia. ELS-I is a component of a much larger database on acidic deposition maintained in the Department of Statistics. To make these components readily available for statistical analyses, documentation is extremely important. The purpose of this report is to provide researchers in the Department of Statistics (and also elsewhere) enough information about ELS-I. We briefly explain the purpose of ELS first, then explain the sampling scheme and the survey procedures adopted in ELS-I. It can be seen from this report that, even though the survey set out to adopt a systematic random sampling scheme of a prescribed sample size for each stratum, the final sampling scheme used was substantially different due to various limitations. Finally we explain the data sets we have derived from ELS-I, describing all the important variables measured.

This documentation has already been found useful in many of the research projects in the Department of Statistics at UBC. Two of these projects include the application of thin plate splines and interaction splines to derive contours of acidic deposition. The application of Bayesian smoothing techniques is another area of research where ELS-I will be used. Other uses of ELS-I and this report include projects to train graduate students in the analysis of large data sets that have interesting statistical features.
We hope to combine the ELS-I database with ELS-II and other future surveys on surface waters. This will, among other things, allow us to study the rate of change of acidification of lakes, and the biological effects of long term acidification of lakes. Without adequate documentation of the databases, these studies are not feasible, or will not lead to interpretable results.
1 Introduction

This report provides documentation for the database on the Eastern Lake Survey - Phase I (ELS-I) maintained at the University of British Columbia. It outlines the purpose of the ELS, as well as some of its procedures and guidelines. It also provides some description of the ELS-I data files as well as explaining how to use the ELS-I Data Base guide. Finally, it details the data sets that we have derived from ELS-I, describing all the variables contained, and how they were measured.

ELS-I is only one of the components of a very large database on acid deposition maintained in the Department of Statistics at the University of British Columbia. Gentleman, Zidek, and Olsen (1985) describe the component, the MAP3S/PCN data set, and S. Wu (1988) provides details on another component, the NADP data set.

2 Eastern Lake Survey - Phase I

2.1 Overview

The Eastern Lake Survey, in combination with the Western Lake Survey (WLS), constitutes the National Lake Survey (NLS), which is a component of the National Surface Water Survey (NSWS). The NSWS is a project implemented by the EPA as part of the Aquatic Effects Research Program which is a part of the National Acid Precipitation Assessment Program.

The NLS consists of two phases: Phase I is designed to provide a large scale examination of the present chemical status of those lakes judged to be potentially sensitive to acidification; Phase II will then provide information on the seasonal variation in the lake water chemistry. Those lakes sampled in Phases I and II will then be used to establish a long-term regional monitoring program to study trends in surface water chemistry.
2.2 Lake Selection

The sampling plan for the selection of lakes in ELS-I can be described as a stratified design with three levels of stratification. At the top level of stratification, three regions were chosen for this study, on the basis that they were judged to contain 95% of the lakes in the Eastern United States that had an alkalinity level <400 µeq/L, and are thus at the greatest potential risk from acidic deposition. These regions, the Northeast, Upper Midwest, and the Southeast, were further subdivided using a second stratification factor, geographic homogeneity, into eleven subregions as follows:

<table>
<thead>
<tr>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>Upper Midwest</td>
<td>Southeast</td>
</tr>
<tr>
<td>1A: Adirondacks</td>
<td>2A: Northeastern Minnesota</td>
<td>3A: Southern Blue Ridge</td>
</tr>
<tr>
<td>1B: Poconos and Catskills</td>
<td>2B: Upper Peninsula of Michigan</td>
<td>3B: Florida</td>
</tr>
<tr>
<td>1C: Central New England</td>
<td>2C: Northcentral Wisconsin</td>
<td></td>
</tr>
<tr>
<td>1D: Southern New England</td>
<td>2D: Upper Great Lakes Area</td>
<td></td>
</tr>
<tr>
<td>1E: Maine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A geographical map of these regions and subregions, extracted from Linthurst, et al. (1986), is provided at the end of this report. It should be noted that while the subregions in each of regions 1 and 2 are geographically connected, subregions 3A and 3B are disjoint. These subregions were then stratified by alkalinity class, a factor which differentiated among areas within each subregion based on the range of surface water alkalinity values expected to dominate in different areas. Three classes were used:

<table>
<thead>
<tr>
<th>Class</th>
<th>Alkalinity (µeq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>2</td>
<td>100 - 200</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 200</td>
</tr>
</tbody>
</table>
Spatial representations of the three alkalinity classes within each region were derived from preliminary versions of regional surface water alkalinity maps (Omernik and Kinney, 1985; Omernik and Griffith, 1985; Omernik, 1985). These maps, extracted again from Linthurst et. al. (1986), are provided at the end of this report. According to Linthurst et. al. (1986), the justification for using the above mentioned classes is as follows: 200 \( \mu \text{eq/L} \) is considered a boundary distinguishing between those surface waters considered to be potentially “sensitive” and those considered “insensitive” to long-term acidification as a result of current levels of acidic deposition. The choice of 100 \( \mu \text{eq/L} \) was based on evidence that biological effects of acidification might become apparent in the alkalinity range 10–90 \( \mu \text{eq/L} \).

At the end of these three levels of stratification, a stratum emerged as an alkalinity map class within a subregion within a region. 33 such strata were defined (15 in the Northeast, 12 in the upper Midwest, and 6 in the Southeast). Region, subregion, and alkalinity map class boundaries were delineated and labeled on 1:250,000 scale U.S. Geological Survey topographic maps. A frame for sampling of lakes is then generated (for exact details see Omernik et al., 1986). Each lake represented on the maps was the assigned a unique number. Lakes were numbered consecutively starting in its northeast corner. The final number in each stratum was the total number of lakes in the frame population for that stratum.

Within each stratum a systematic random sample was used to select lakes. Lake numbers were entered into a computer file in numerical order as labeled on the maps. For each stratum the frame population was divided by the prescribed sample size to obtain a number \( k \). The first sample lake was then selected at random between lakes 1 and \( k \). Thereafter, every \( k \)th lake was selected. The prescribed sample size was 50 for all strata except 1A1 (60 lakes), 1C1 (70 lakes), and 1E1 (90 lakes). Only 19 lakes occurred in 3A1, so all were included.
The frame population was then refined through the elimination of “non-target” lakes, first by examining the lakes in the frame on a finer scale, and then by using the information obtained during field sampling. A lake was considered “non-target” if it was discovered to be:

- Something other than a lake.
- In marsh or swamp.
- Adjacent to intense urban, industrial, or agricultural activity.
- Smaller than 4 hectares (ha) in area. This was required for consistency as lakes < 4 ha were not always visible on the 1:250,000 scale map, and were thus excluded from the original population.

Those lakes which were found to be unsuitable, as explained above, were removed from the sample, and replaced using another random draw. The same systematic random sampling scheme was used here, and more than the prescribed number of lakes were selected, since it was anticipated that additional lakes would be eliminated as “non-target” during field operations. The initial frame consisted of 2681 lakes, of which 805 lakes were found to be unsuitable, and designated as non-target lakes as a result of map evaluation. 151 lakes were found to be unsuitable when visited by the sampling crew, and were removed from the sample distribution. A further 113 target lakes were not visited because of weather, time constraints, lack of access permission, or on account of the lake being frozen. These lakes were designated as “not visited”. Thus water samples from 1612 lakes (probability sample lakes) were collected and analyzed. The following tables list the frame population \( N^* \), the number of lakes in the probability sample \( n^* \), and the number of lakes eventually sampled \( n^{**} \) for each of the 33 strata.
<table>
<thead>
<tr>
<th>Stratum</th>
<th>1A1</th>
<th>1A2</th>
<th>1A3</th>
<th>1B1</th>
<th>1B2</th>
<th>1B3</th>
<th>1C1</th>
<th>1C2</th>
<th>1C3</th>
<th>1D1</th>
<th>1D2</th>
<th>1D3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N^*$</td>
<td>711</td>
<td>542</td>
<td>431</td>
<td>208</td>
<td>96</td>
<td>1682</td>
<td>631</td>
<td>752</td>
<td>650</td>
<td>443</td>
<td>656</td>
<td>1568</td>
</tr>
<tr>
<td>$n^*$</td>
<td>75</td>
<td>65</td>
<td>68</td>
<td>70</td>
<td>70</td>
<td>68</td>
<td>88</td>
<td>70</td>
<td>74</td>
<td>70</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>$n^{**}$</td>
<td>57</td>
<td>51</td>
<td>47</td>
<td>49</td>
<td>48</td>
<td>47</td>
<td>63</td>
<td>54</td>
<td>47</td>
<td>47</td>
<td>43</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stratum</th>
<th>1E1</th>
<th>1E2</th>
<th>1E3</th>
<th>2A1</th>
<th>2A2</th>
<th>2A3</th>
<th>2B1</th>
<th>2B2</th>
<th>2B3</th>
<th>2C1</th>
<th>2C2</th>
<th>2C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N^*$</td>
<td>1038</td>
<td>606</td>
<td>744</td>
<td>176</td>
<td>778</td>
<td>1178</td>
<td>118</td>
<td>250</td>
<td>1330</td>
<td>464</td>
<td>348</td>
<td>895</td>
</tr>
<tr>
<td>$n^*$</td>
<td>130</td>
<td>74</td>
<td>72</td>
<td>60</td>
<td>62</td>
<td>85</td>
<td>74</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>$n^{**}$</td>
<td>89</td>
<td>48</td>
<td>41</td>
<td>56</td>
<td>46</td>
<td>48</td>
<td>41</td>
<td>57</td>
<td>48</td>
<td>50</td>
<td>56</td>
<td>49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stratum</th>
<th>2D1</th>
<th>2D2</th>
<th>2D3</th>
<th>3A1</th>
<th>3A2</th>
<th>3A3</th>
<th>3B1</th>
<th>3B2</th>
<th>3B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N^*$</td>
<td>97</td>
<td>699</td>
<td>5351</td>
<td>19</td>
<td>76</td>
<td>443</td>
<td>1608</td>
<td>113</td>
<td>6332</td>
</tr>
<tr>
<td>$n^*$</td>
<td>90</td>
<td>85</td>
<td>70</td>
<td>19</td>
<td>60</td>
<td>100</td>
<td>140</td>
<td>113</td>
<td>181</td>
</tr>
<tr>
<td>$n^{**}$</td>
<td>40</td>
<td>53</td>
<td>48</td>
<td>11</td>
<td>47</td>
<td>44</td>
<td>52</td>
<td>62</td>
<td>36</td>
</tr>
</tbody>
</table>

In addition to the probability sample lakes, there were also 199 special interest lakes that were included in the survey. These lakes consisted of all lakes in the EPA Long-Term Monitoring Program, as well as others suggested by various state and federal agencies. Of these 199 lakes, only 186 could be sampled.

### 2.3 Survey Procedures

Field sampling was done by helicopter from October 7, 1984 to December 14, 1984, as it was expected that lake water chemistry would be most homogeneous during the fall turnover season. Field crews would record the lake’s watershed description, make simple
measurements, and collect various samples of lake water. All samples were taken from one location on each lake, generally from a depth of 1.5 meters below the surface.

Those samples that required immediate analysis were sent to one of the eight field station laboratories, while the others were sent to one of the four analytical laboratories. Extensive quality assurance criteria were established to ensure standardized analysis.

3 ELS-I Data Sets

3.1 Data3 and Data4

The Eastern Lake Survey - Phase I has provided us with two large data sets "data3" and "data4" which are located in the directory "/home/acid/lakes/". In the ELS-I Data Base Dictionary, "data3" is referred to as data set 3, and "data4" is called data set 4.

"data3" is the raw data set, containing all the original measurements as well as comments and qualifiers on the data in the form of flags and tags. Tags are one letter codes used to qualify the data as it was recorded in the field or the laboratory. Flags are two-character codes entered during the data verification and validation process. Most of the over 100 numeric variables recorded for each lake have an associated tag and flag.

"data3" also contains the duplicate sets of measurements (collected at the same time and place as the first set) that were made for some of the lakes as a quality control procedure. "data4" represents the final data set. It contains most of the information found in "data3", but the duplicate measurements have been averaged out, and the tags, as well as some of the more useless pieces of information, have been omitted. Both data sets contain information on 1798 (1612 from the probability sample and 186 special interest) lakes, though "data3" has 1922 entries owing to its duplicate measurements. Each lake entry occupies 39 lines in "data3" and 24 lines in "data4".

Much of the data in these files is not original observed data, but rather has been
derived from other data entries. For example a measurement that is given in feet will also be repeated but with the units converted to meters. Indeed almost all chemical concentrations are given both in mg/L and in μeq/L. Clearly these data sets could be considerably reduced in size by weeding out these redundancies. Below is a list of the key variables associated with each lake, taken from the Data Base Dictionary.

**Geographic Information**

- County
- Elevation
- Lake ID
- Lake area
- Lake name
- Latitude
- Longitude
- State
- USGS map names
- Watershed area

**Collected on the Lake**

- Air temperature
- Conductance
- Depth
- Number of inlets/outlets
- pH
- Secchi disk transparency
- Watershed disturbance
- Water temperature

**Measured in the Field Laboratory**
Color
Dissolved inorganic carbon
pH
Turbidity

Measured in the Analytical Laboratory

Acid neutralizing capacity
Air-equilibrated pH
Ammonium
Calcium
Chloride
CO2 acidity
CO3 alkalinity
Conductance
Dissolved inorganic carbon
Dissolve organic carbon
Extractable aluminum
Fluoride
Initial titration pH
Iron
Magnesium
Manganese
Mineral acidity
Nitrate
Phosphorus
Potassium
Silica
Sodium
Sulfate
Total aluminum

**Calculated or Interpolated**

Anion deficit
Bicarbonate ion
Calculated conductance
Carbonate ion
Conductance
Deposition (H+, NO3-, SO4-2)
Distance from ocean
Estimated hydraulic residence time
Lake volume
Organic anions
Precipitation
Runoff
Sum of anions
Sum of base cations
Sum of cations
Sum of cations/sum of anions
Watershed to lake area ratio

### 3.2 Data Base Guide

The ELS-I Data Base guide provides a good description of the ELS-I survey, including an outline of the lake selection process, a complete account of the statistical weighting that must be done when extrapolating data from more than one strata, as well as a brief
summary of some of the survey's results.

Of more importance to the understanding of the data sets, is the Data Base Dictionary which appears as Appendix A. It contains a summary of the variables collected during the survey (Table 1); the definitions of the flag and tag codes (Tables 3 and 4); a list of variables for data set 3 ("data3"), and data set 4 ("data4") (Tables 5 and 6); the definitions for all variables (Table 8); the format specifications of the data sets (Tables 9 and 10); the characteristics of the numerical variables for the two data sets (Tables 12 and 13), to be used for checking successful transport of the data; and a printout of the first five lake entries in data set 3.

Detailed description of the exploratory analysis of these data are found in the three volumes of Characteristics of Lakes in the Eastern United States, Linthurst, R.A. et. al. (1986), Overton, W.S. et. al. (1986), and Kanciruk, P. et. al. (1986).

4 Derived Data Sets

4.1 Introduction

For our purposes, it was decided that "data4" would be the better source of data for the analysis. Of the initial 150 variables, 22 were selected for study. These variables were read from the "data4" file and written into four new files (using programs written in Fortran). These files are located in the directory "/stat/data/lakes".

The new derived data files are:

- "geog" contains the lake ID and geographical information
- "acidity" pH and alkalinity measurements
- "cation" concentrations of main cations
- "anion" concentrations of main anions

Below is a detailed description of these files. Each file consists of one line of data for each
of the 1798 lakes, with each line containing several fields. Missing data is denoted by "-999". The category "name" refers to the variable name as found in the Data Base Dictionary. Unless otherwise stated, measurements were performed in the analytical laboratory.

4.2 "Geog"

The "geog" file contains six fields, each separated by two spaces:

newid type: CHAR width: 10

name: LAKE ID + "-" + ST . A unique identification code for each lake. The first three characters represent the region, subregion, and alkalinity class. These together designate the strata to which the lake belongs. They are followed by a dash. The next three digits are the assigned lake number for a lake within that strata, followed by another dash. The last two characters give the state in which the lake lies.

latitude type: REAL width: 7.4 units: degrees

name: LAT-DD . The latitude of the lake, taken from USGS topographic maps, expressed in degrees to four decimal places.

longitude type: REAL width: 7.4 units: degrees

name: LONG-DD . The longitude of the lake, also taken from USGS topographic maps, in degrees to four decimal places.

elevation type: REAL width: 6.1 units: meters

name: ELEV . The elevation of the lake, from USGS topographic maps.

volume type: REAL width: 8.3 units: millions of cubic meters
name: LAKE-VOL. The estimated lake volume \( V \), based on lake surface area \( A \), measured using an electronic planimeter on USGS topographic maps, and the lake depth \( d \) at the measuring site. \( V = A \times d \times 0.464 \)

precip type: REAL width: 5.3 units: meters

name: PRECIP. Annual precipitation. This was calculated using precipitation data from over 600 stations, and then interpolating values in each region for 3.75 minute latitude/longitude cells.

4.3 "Acidity"

The "acidity" file contains eight fields, each separated by two spaces:

newid type: CHAR width: 10 - As before.

alkalinity type: REAL width: 8.3 units: \( \mu \text{eq/L} \)

name: ALKA11. Acid neutralizing capacity, the measure of the amount of acid necessary to neutralize the bases (carbonate, bicarbonate etc) in a sample. Determined in an unfiltered, unacidified aliquot using acidimetric titration and Gran analysis.

phtop type: REAL width: 7.2 units: pH

name: PH-TOP. pH measured from the helicopter using the Hydrolab probe at roughly 1.5 meters below the surface.

phbottom type: REAL width: 7.2 units: pH

name: PH-B. pH measured from the helicopter using the Hydrolab probe at roughly 1.5 m above the lake depth at the measuring site. Nearly 38% of the lakes did not have this measurement performed on them.
name: PHAC11. Initial pH from the acidity titration. A sample from an unfiltered, unacidified aliquot was placed into a CO2 free titration vessel and stirred. The pH was measured with an electrode (without exposure to the atmosphere) before addition of base titrant.

name: PHAL11. Initial pH from the alkalinity titration. A sample from an unfiltered, unacidified aliquot was placed into a titration vessel (not CO2 free) and stirred. The pH was measured with an electrode before addition of acid titrant.


name: PHSTVL. Closed system pH, measured in the field laboratory using an Orion Model 611 meter and an Orion Ross combination pH electrode on a syringe sample unexposed to the atmosphere.

4.4 “Cation”

The “cation” file contains six fields, each separated by two spaces. Except for “ammonium”, all measurements were made using filtered, acidified (HNO3) aliquots.

As before.

As before.
name: CA11. Dissolved calcium.
magnesium type: REAL width: 9.4 units: mg/L

name: MG11. Dissolved magnesium,
sodium type: REAL width: 9.4 units: mg/L

name: NA11. Dissolved sodium.
potassium type: REAL width: 9.4 units: mg/L

name: K11. Dissolved potassium.
ammonium type: REAL width: 9.4 units: mg/L

name: NH411. Ammonium ion, measured using a filtered, acidified (H2SO4) aliquot.

4.5 "anion"
The "anion" file contains five fields, each separated by two spaces. All measurements were performed using filtered, acidified aliquots.

newid type: CHAR width: 10. As before.
chloride type: REAL width: 9.4 units: mg/L

name: CL11. Chloride ion.
fluoride type: REAL width: 9.4 units: mg/L

name: FTL11. Total dissolved fluoride, analyzed using an ion-selective electrode.
nitrate type: REAL width: 9.4 units: mg/L

name: NO311. Nitrate ion.
sulfate type: REAL width: 9.4 units: mg/L

name: SO411. Sulfate ion.

Acknowledgements

We thank Mr. Dixon Landers, Research Director of the National Lake Survey, Environmental Research Laboratory, Corvallis for making available to us the Database dictionary and related documents. The work involved in organizing the different data files mentioned in this report as well as in preparing this report was done with support from a grant of Natural Science and Engineering Research Council of Canada, a British Columbia Challenge 89 Student Summer Scholarship, and SIMS (through a Co-operative Research Agreement with the Environmental Protection Agency of the United States). We are grateful to Dr. A.J. Petkau for his encouragement and support during the preparation of this document.

References


Figure 2-2. Northeastern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.

Alkalinity Map Classes (μeq L⁻¹)

1. < 100
2. 100-200
3. > 200

Subregion Boundary

Adirondacks (1A)
Poconos/Catskills (1B)
Central New England (1C)
Southern New England (1D)
Maine (1E)

Figure 2-3. Upper midwestern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.

Alkalinity Map Classes (μeq L⁻¹)

1. < 100
2. 100-200
3. > 200

Subregion Boundary

Northeastern Minnesota (2A)
Upper Peninsular of Michigan (2B)
Upper Great Lakes Area (2D)
Northcentral Wisconsin (2C)

(2D)
Figure 2-4. Southeastern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.