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**Northeastern
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# Database for Chemical Contents of Streams on the White Mountain National Forest

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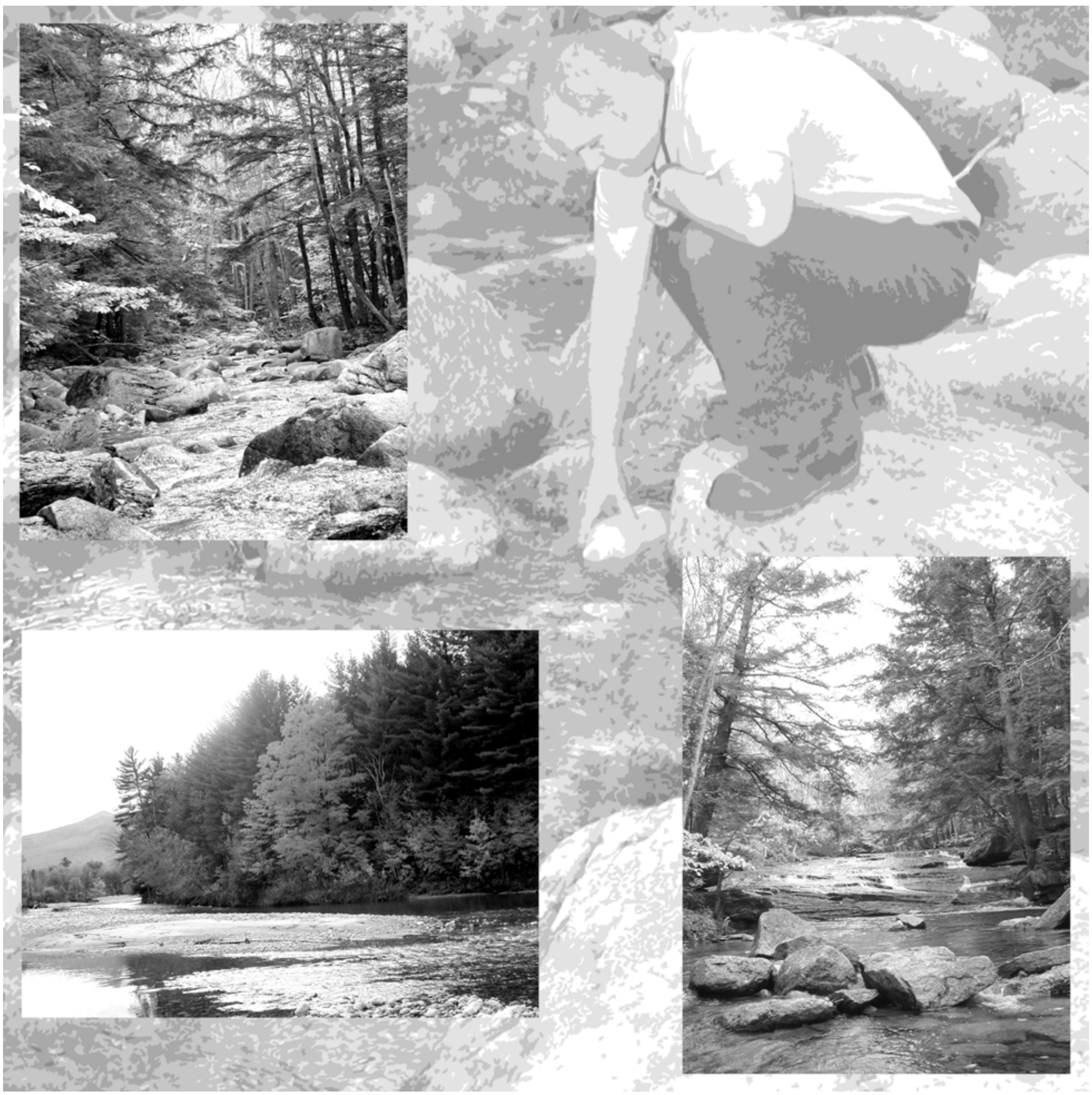

## Abstract

Producing and protecting high-quality streamwater requires background or baseline data from which one can evaluate the impacts of natural and human disturbances. A database was created for chemical analyses of streamwater samples collected during the past several decades from 446 locations on the White Mountain National Forest (304,000 ha in New Hampshire and Maine). The database is described and examples illustrating how the data can be used to examine ranges, trends, and relationships are included.

## The Authors

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# Introduction

Producing and protecting high-quality water has always been a management goal on the White Mountain National Forest (WMNF). Stimulus for this goal began with the Organic Act of 1897 and the Weeks Law of 1911, which led to purchase of land for National Forests to "secure favorable conditions of water flows," and "protect the watersheds of navigable streams." This mandate was strengthened by requirements of the Resources Planning Act, the National Forest Management Act, the National Environmental Protection Act, and the Clean Water Act.

Producing high-quality water requires background or baseline data from which one can evaluate the impacts of natural and human disturbances. We created a database for chemical analyses of stream samples collected over the past several decades from managed watersheds on the WMNF that were not subjected to recent disturbance such as harvesting or land development. In this report we describe the database and present some examples that illustrate how the data can be used to examine ranges, trends, and relationships. The database is available free of charge from the WMNF.

# White Mountain National Forest

The WMNF (304,000 ha) is located in central New England in the heart of the Appalachian-New England Mixed Forest-Coniferous Forest-Alpine Meadow Ecological Province (McNab and Avers 1994). The WMNF is well watered with an average annual precipitation of 1,100 mm (about one-third is snowfall) that is distributed uniformly throughout the year. About 60 percent of annual precipitation becomes streamflow, giving rise to several thousand kilometers of perennial streams that are highly valued for recreation, municipal, and commercial purposes. The chemical quality of these streams is affected by factors such as vegetation, geologic and soil characteristics, biological processes, and natural and human disturbances.

## Vegetation

About two-thirds of the WMNF supports forests capable of timber production. Northern hardwoods, dominated by some combination of sugar maple, yellow birch, and American beech, is the dominant forest type. Northern conifers, including mixtures of balsam fir, red spruce and hemlock, are dominant in rocky and sandy habitats and at elevations above 775 m. At elevations above1400 m (approximately tree line), vegetation grades from montane spruce-fir to alpine krummholz and alpine meadow.

Below tree line, most watersheds on the WMNF are forested with mixed types, making it difficult to determine whether one forest type influences stream chemistry more than another. However, all forest types on the WMNF, if not recently disturbed, have tight nutrient cycles, and leaching of nutrient ions to streams is minimal (Hornbeck et al. 1997). Recent findings suggest that stand aging may reduce nutrient concentrations of streamwater (Martin et al 2000a).

## Geologic and Soil Characteristics

Bedrock underlying the WMNF includes Cambrian to Devonian sedimentary rocks that have been metamorphosed to quartzites, phyllites, schists, and gneiss, as well as a variety of intrusive and extrusive igneous rocks of Ordovician, Devonian, and Mesozoic age. Bedrock is mostly mantled by Wisconsin-age till deposited about 13,000 years ago during the last retreat of continental glaciation. Glaciofluvial and glaciolacustrine sediments are present in valleys. Otherwise, the till is unconsolidated and varies widely in composition and depth.

Soils developed in these glacial parent materials are primarily Haplorthods, Haplaquepts, and Dystrochrepts with sandy loam textures and high infiltration capacities. Mineralogical content of soils is highly variable due to the variety of lithologies present in bedrock and transported parent materials (Bailey and Hornbeck 1992). The variability in mineralogical content and accompanying weathering rates is partly responsible for the range in alkalinity, acidity, and concentrations of base cations and aluminum found in streamwater within the WMNF.

Soil depths range from zero on exposed ledge to less than 0.1 m on ridge tops, to more than 1.0 m on benches, lower slopes, and valley bottoms. On upper slopes and at higher elevations, hydrologic flow paths and residence times for soil solution generally are short, lessening opportunities for chemical change before precipitation becomes streamflow. Deeper soils on lower slopes, benches, and valley bottoms provide for longer residence times for soil solution and greater opportunities for chemical and biological processes to both add to and subtract from the chemical content of the soil solution that eventually reaches streams (Johnson et al. 2000).

### Biological Processes

Because streams on the WMNF tend to be cool, chemically dilute, shallow, and fast moving, biological processes and activities within streams are at low levels and have relatively minor impact on stream chemistry. Biologically mediated processes within terrestrial ecosystems (e.g. mineralization and nitrification) can affect chemical content of soil solution. However, as mentioned earlier, plant uptake and tight nutrient cycles on the WMNF limit leaching losses of nutrient ions generated by these processes, absent recent disturbances.

### Natural and Human Disturbances

Natural disturbances on the WMNF include those from wind, ice, fire, insects and diseases, and beaver dams. Human disturbances include forest harvesting, recreational use and development, road and trail construction, and atmospheric deposition. If the disturbance is severe enough to adversely effect forest soils and/or disrupt plant nutrient uptake and cycling, there may be an increase in leaching losses of chemicals to streams. For example, intensive harvesting can elevate concentrations of base cations and nitrate in streams for 3 to 4 years after harvest (Hornbeck et al. 1987; Martin et al. 2000b). Atmospheric deposition can acidify streamwater and elevate concentrations of base cations, nitrate, sulfate, and aluminum. Such impacts range from severe at higher elevations with shallow soils to minimal on watersheds with abundant, base-rich minerals and buffered soils (Lawrence and Huntington 1999; Hornbeck et al. 1997). The database described in this report does not include samples collected from streams draining recent harvests (within the past 10 years) or those influenced by urban development.

## The Database

Figure 1 shows locations of 446 sample stations from which stream chemistry data were obtained and entered into the database. Some of the stream sample stations are located outside the boundary of the WMNF. In such cases, a substantial portion of the upstream watershed is within the WMNF. The following shows the sources of stream data and the number of sample stations for each source.

| Source | Number of stations |
|---|---|
| USDA Forest Service, Region 9 | 201 |
| U.S. Geological Survey | 25 |
| U.S. Environmental Protection Agency, Region 1 | 48 |
| U.S. Environmental Protection Agency, Headquarters | 20 |
| Maine Department of Environmental Protection | 4 |
| Institute of Ecosystem Studies | 2 |
| Northeastern Research Station | 54 |
| Christy Goodale (University of New Hampshire) and Peter Vitousek (Stanford University) | 92 |
| Total | 446 |

Samples included in the database were collected between 1953 and the end of 1999. The number of samples collected at any given site ranged from fewer than 5 to more than 1,000; sampling intervals ranged from weekly to sporadic. The number of chemical determinations for a sample ranged from one to many depending on the objectives and analytical and financial resources available. Analyses were conducted by numerous laboratories and methods. The laboratories were of high quality and used current methods and equipment. In keeping with continuing improvements in analytical equipment and methods, more recent data may be more accurate and precise than earlier data.

The final database included more than 86,000 chemical determinations divided among 25 chemical parameters (Table 1). To facilitate comparisons, hydrogen ion was stored in the database as both pH and mg/L. Concentrations of all other elements and compounds were stored as *u*g/L or mg/L; conductivity was stored as microsiemens.

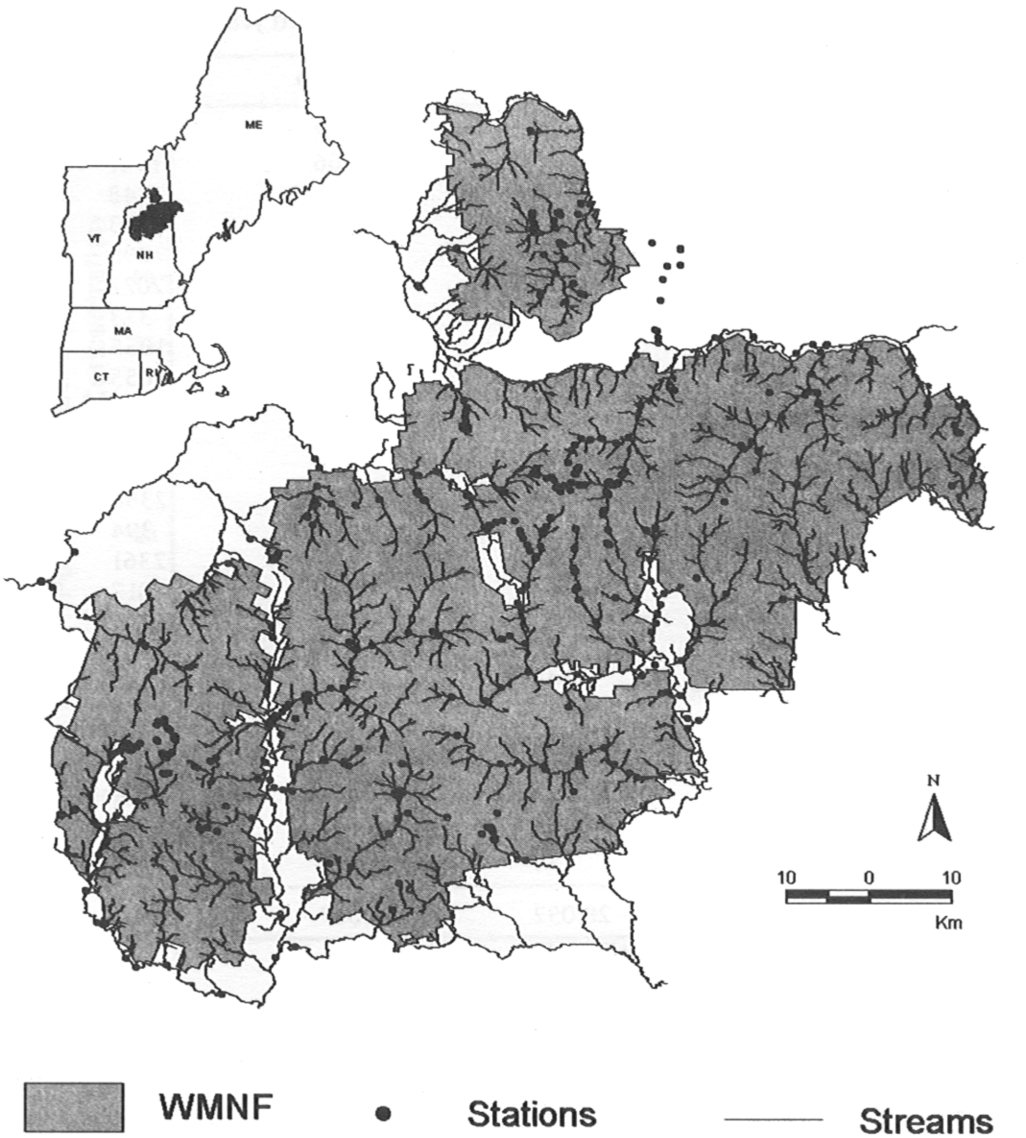


Figure 1.—Locations of sampling stations on the White Mountain National Forest.

Microsoft® Access 97[1], a relational database, was used for storing and analyzing the stream chemistry data. A substantial amount of the data for WMNF, especially that collected by federal agencies, was downloaded into Microsoft® Excel and then Access 97 from the STORET (short for STOrage and RETrieval) database for water chemistry maintained by the U.S. Environmental Protection Agency (www.epa.gov/OWOW/STORET/index.html). Additional information for the database were obtained from literature searches, reports, and theses.

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or Forest Service of any other product or service to the exclusion of others that may be suitable.

Data are stored as an Access file titled "WMNF Stream Chemistry." Associated files contain descriptions of fields and formats used to store data and individual station variables (latitude, longitude, elevation, etc.), and information on the laboratory methods used to obtain chemical data. The "WMNF Stream Chemistry" file is available upon request from:

Watershed Specialist, Forest Supervisor's Office
White Mountain National Forest
719 Main Street
Laconia, NH 03246-0772

Use of the WMNF Stream Chemistry file requires a working knowledge of Microsoft® Access 97. The requested file will not contain data from the Hubbard Brook Experimental Forest located on the WMNF. Data for Hubbard Brook streams can be obtained from a web

**Table 1.—Number of samples in database by chemical parameter and year**

| Parameter | Before 1970 | 1970-79 | 1980-89 | 1990-99 | Total |
|---|---|---|---|---|---|
| Aluminum | 212 | 374 | 1243 | 1526 | 3355 |
| Ammonimum | 268 | 1138 | 966 | 1941 | 4313 |
| Antimony | 0 | 0 | 3 | 348 | 351 |
| Arsenic | 1 | 16 | 80 | 373 | 470 |
| Calcium | 368 | 3424 | 1449 | 2299 | 7540 |
| Chloride | 288 | 2704 | 1496 | 2077 | 6565 |
| Chromium | 0 | 82 | 99 | 373 | 554 |
| Conductivity | 74 | 2112 | 1695 | 1955 | 5836 |
| Copper | 7 | 149 | 342 | 655 | 1153 |
| Iron | 16 | 386 | 654 | 1265 | 2321 |
| Lead | 2 | 141 | 98 | 372 | 613 |
| Manganese | 24 | 64 | 339 | 720 | 1147 |
| Mangesium | 345 | 2576 | 1433 | 2358 | 6712 |
| Nickel | 2 | 23 | 67 | 394 | 486 |
| Nitrate | 272 | 3108 | 1454 | 2361 | 7195 |
| pH | 279 | 2795 | 1941 | 2817 | 7832 |
| Potassium | 388 | 2462 | 1045 | 2254 | 6149 |
| Selenium | 0 | 14 | 74 | 391 | 479 |
| Silica | 251 | 648 | 809 | 1280 | 2988 |
| Silver | 0 | 2 | 50 | 375 | 427 |
| Sodium | 388 | 2652 | 1437 | 2345 | 6822 |
| Sulfate | 262 | 1056 | 1380 | 2237 | 4935 |
| Alkalinity | 59 | 280 | 1232 | 1093 | 2664 |
| Phosphate | 74 | 1692 | 1345 | 1251 | 4362 |
| Zinc | 6 | 154 | 276 | 644 | 1080 |
| Total | 3586 | 28,052 | 21,007 | 33,704 | 86,349 |

site (www.hbrook.sr.unh.edu), which contains special instructions for using and citing data.

## Using the Database

The stream-chemistry data can be used to examine a variety of subjects, including ranges, trends, and relationships, and to determine how chemical data from individual locations compare with WMNF-wide data. Rather than address the many possible applications for the database, we choose calcium ($Ca^{2+}$) concentrations of streamwater to illustrate potential applications because $Ca^{2+}$ is the dominant cation in most streams, has been measured frequently, and is a concern with respect to nutrient depletion and forest health (Hornbeck et al. 1997; Lawrence and Huntington 1999).

### Cumulative Frequency Plots

The use of cumulative frequency plots with mean concentration for each location (Figs. 2-3) is an effective way to display the range in values for the WMNF and to determine where individual locations fall within that range. The range in mean $Ca^{2+}$ concentrations of 348 stations that were sampled for $Ca^{2+}$ is ~0 to 240 ueq/L; and the median concentration is slightly more than 75 µeq/L (Fig. 2). About 95 percent of the 348 stations have mean $Ca^{2+}$ concentrations less than 150 µeq/L. Closer examination of the database shows that the low end of the range (less than 50 µeq/L) usually include streams that drain small or high-elevation watersheds, while mean values at the higher end of the range include larger river basins. Cumulative frequency plots for pH and other ions including potassium, sodium, magnesium, aluminum, chloride, sulfate, and nitrate are shown in the Appendix.

Figure 3 shows the same cumulative frequency plot for $Ca^{2+}$ but with one standard deviation about each mean. The plot shows that variation in $Ca^{2+}$ concentrations at individual sampling locations is relatively small, particularly at the lower end of the range. The relatively small range and variability for $Ca^{2+}$ in streamwater is indicative of low weathering rates and tight nutrient cycles across the WMNF.

### Relationships to Elevation

A plot of mean $Ca^{2+}$ concentrations versus elevation (Fig. 4) suggests that concentrations decrease with increasing elevation, though the relationship is not especially

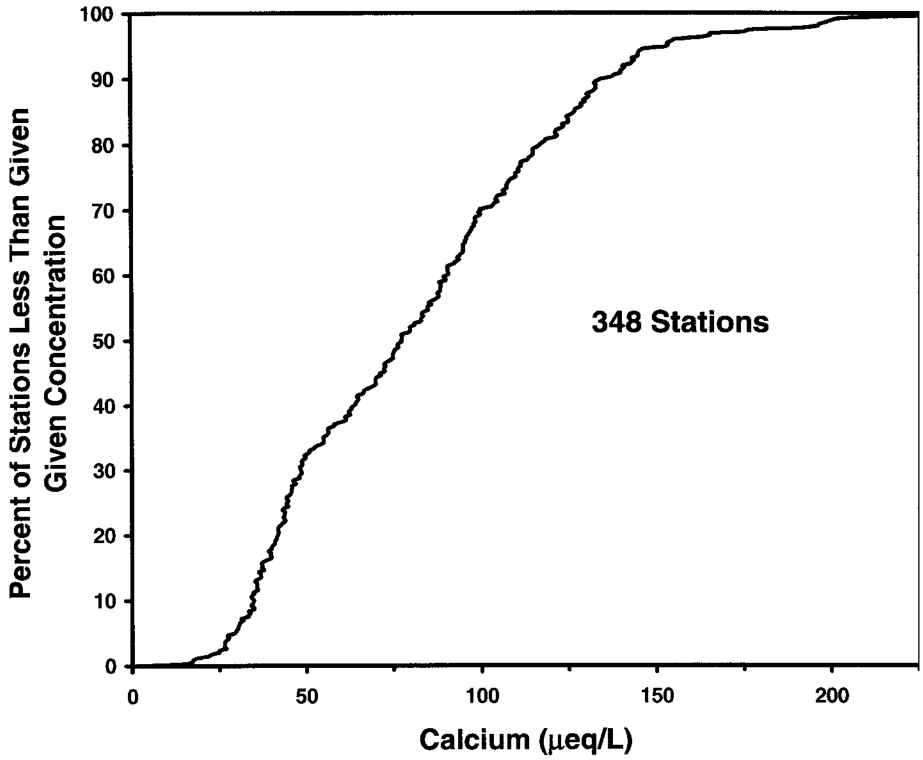


Figure 2.—Cumulative frequency plot for mean $Ca^{2+}$.

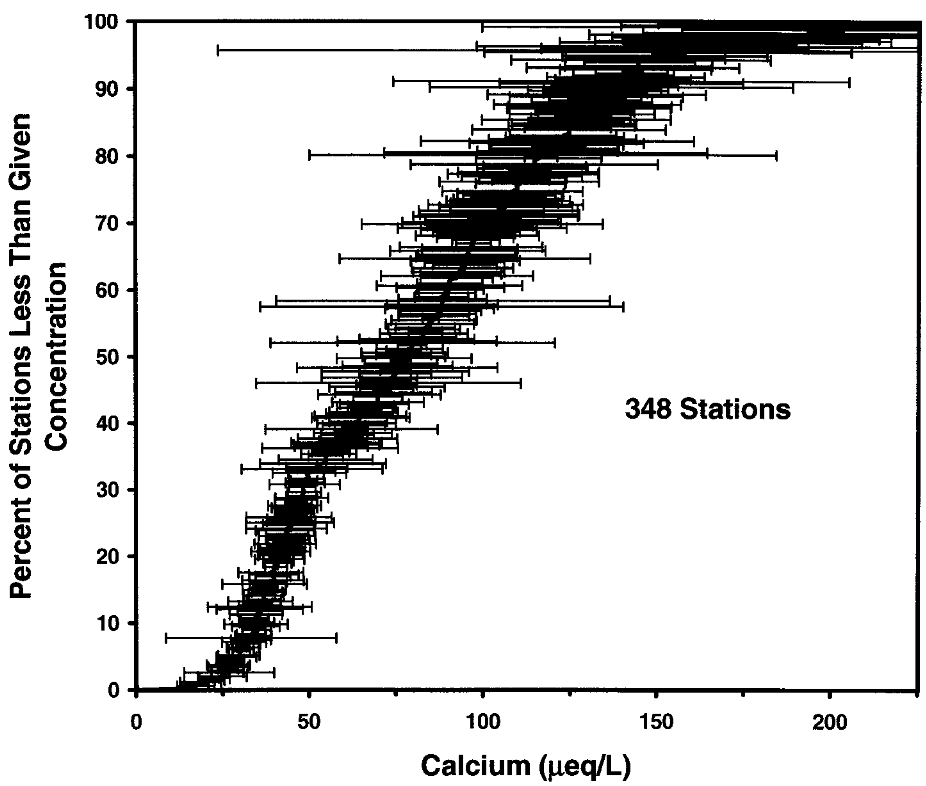


Figure 3.—Cumulative frequency plot for $Ca^{2+}$ with one standard deviation about mean.

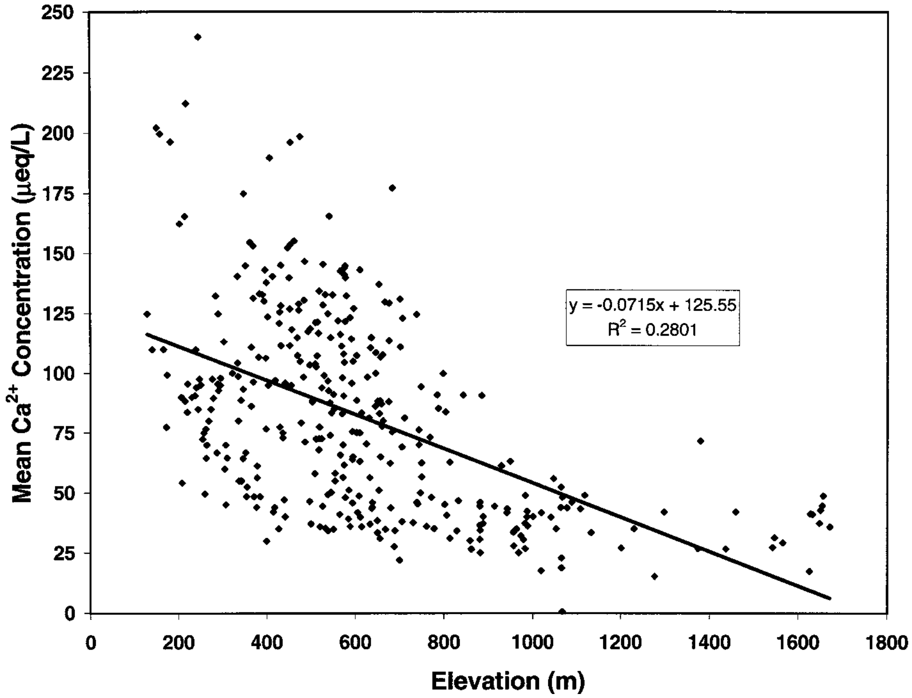


Figure 4.—Mean $Ca^{2+}$ versus elevation.

strong ($R^2$ = 0.28). This is in keeping with the earlier discussion suggesting that the lowest concentrations are associated with small, high-elevation watersheds.

## Relationships to Acidic Deposition

Acidic deposition provides hydrogen ions ($H^+$), which displace cations such as $Ca^{2+}$ on soil surfaces, and sulfate ions ($SO_4^{2-}$) and nitrate ions ($NO^{3-}$), which keep cations dissolved in soil solution that eventually becomes streamwater. The mobility of $Ca^{2+}$ and its occurrence in streamwater is related to sulfate concentrations (Hornbeck et al. 1997). This relationship holds for the WMNF stations, as shown by a plotting of mean $Ca^{2+}$ versus mean $SO_4^{2-}$ (Fig. 5).

As a result of controls on sulfur emissions imposed in the 1970's, concentrations of $SO_4^{2-}$ in both precipitation and streamwater have been declining over the past several decades. These reductions in $SO_4^{2-}$ have resulted in a gradual decline in base cations such as $Ca^{2+}$ in streamwater (Driscoll et al. 1989; Likens et al. 1996; Lawrence and Huntington 1999). A plotting of monthly means of streamwater $Ca^{2+}$ over time suggests a gradual reduction in streamwater $Ca^{2+}$ across the WMNF (Fig. 6). Linear regressions fitted to individual stations having at least 2 years of continuous sampling also indicated a downward trend in $Ca^{2+}$ over time for most stations, though several also indicated an opposite trend (Fig. 7).

## Other Possibilities

The WMNF geographic information system consists of a variety of layers (e.g., watersheds by stream levels, forest types, and bedrock geology) that could be used to develop relationships and better understand streamwater chemistry. Regional maps and models of atmospheric deposition could be used to determine whether variations in deposition by latitude, longitude, and elevation might affect streamwater chemistry. Also, there are a variety of research results on the impacts of natural and human disturbances on streamwater chemistry on the WMNF (see www.hbrook.sr.unh.edu for a bibliography on Hubbard Brook Ecosystem Studies). These results could be contrasted with the database to predict how background levels for streamwater chemistry would change following disturbances.

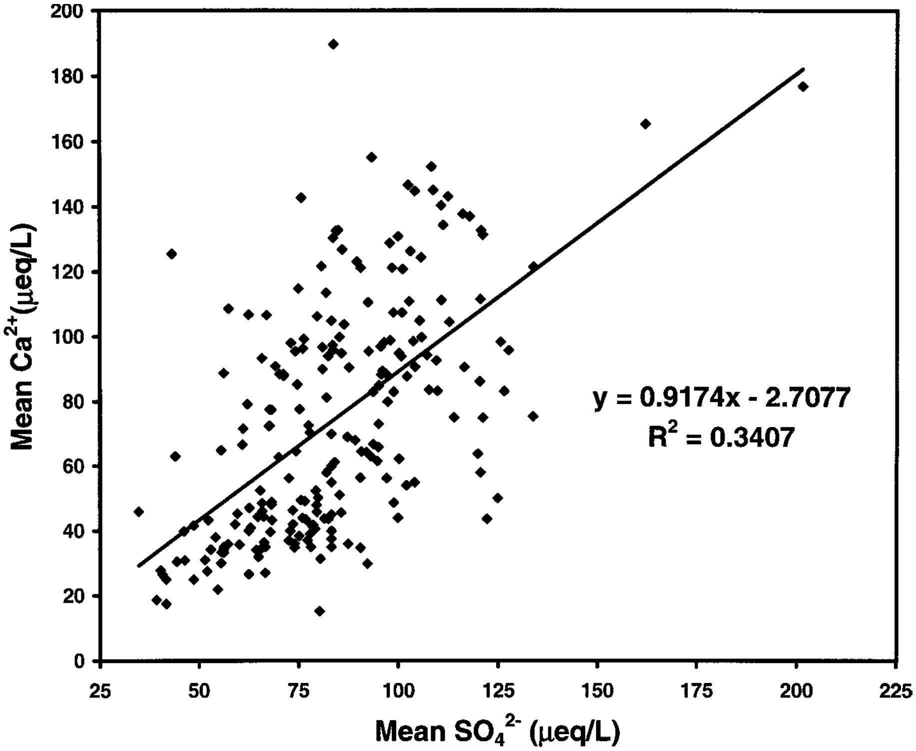


Figure 5.—Relationship of streamwater $Ca^{2+}$ to $SO_4^{2-}$.

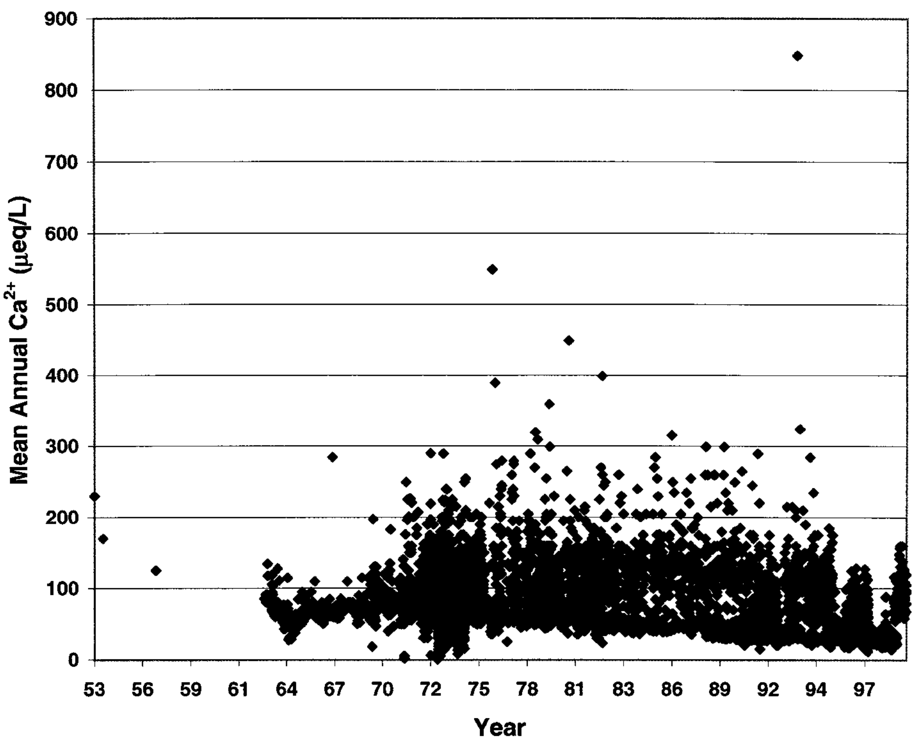


Figure 6.—Mean annual $Ca^{2+}$ for all stations over time.

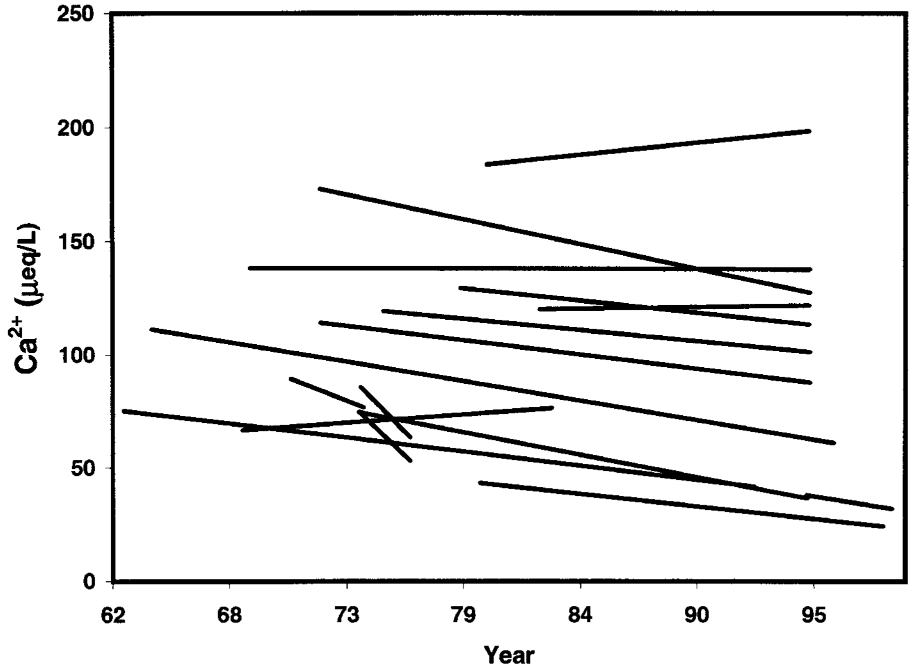


Figure 7.—Regression relationships of $Ca^{2+}$ versus time for selected stations.

## Acknowledgement

In addition to the many individuals from various organizations who provided data for this report, Steve Jones, Forest Technician on the Ammonoosuc Ranger District, White Mountain National Forest, collected many of the samples included in the database, and assisted in retrieving data from STORET. Ken Dudzik, USDA Forest Service, provided the cover design.

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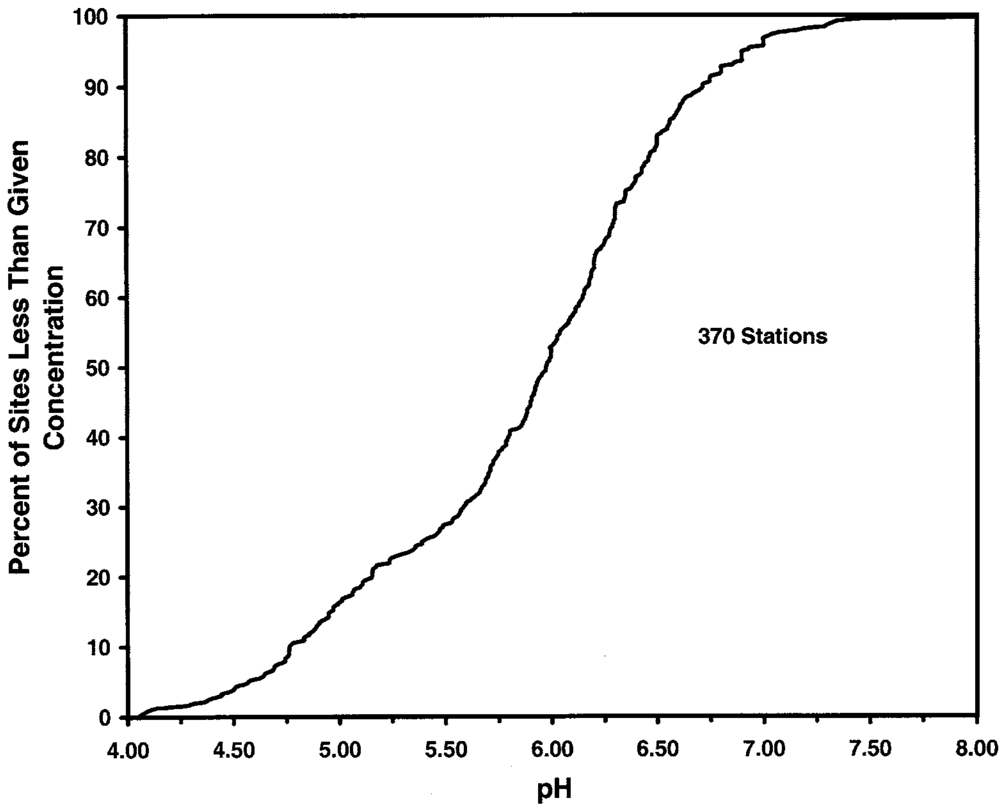
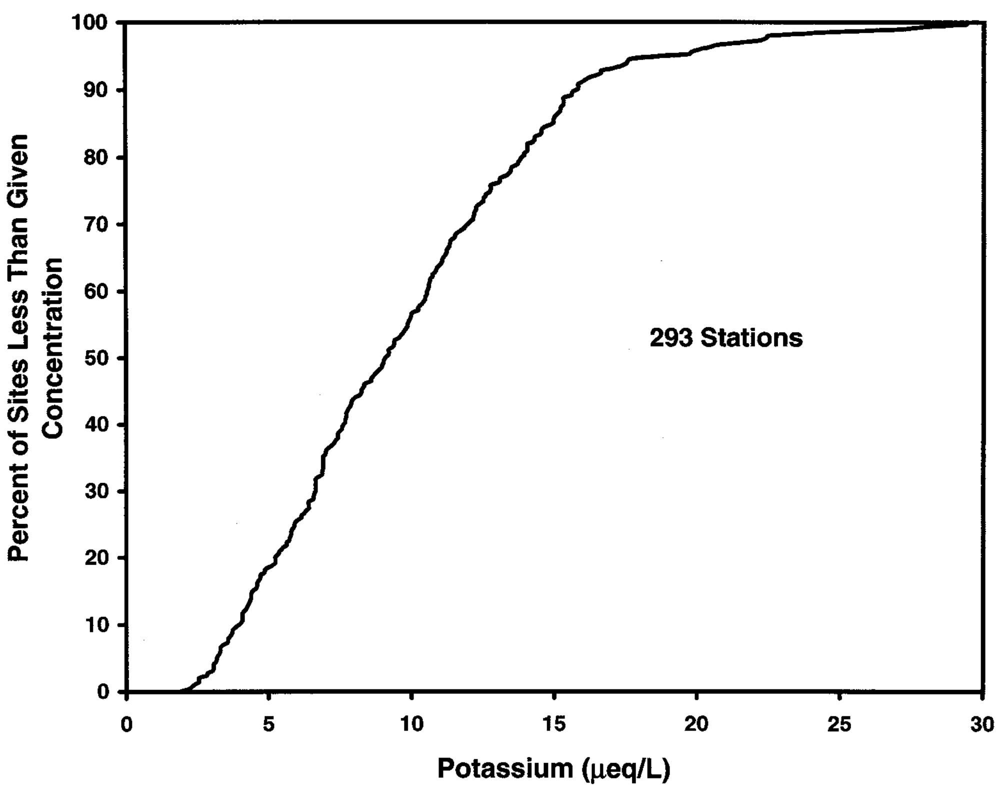
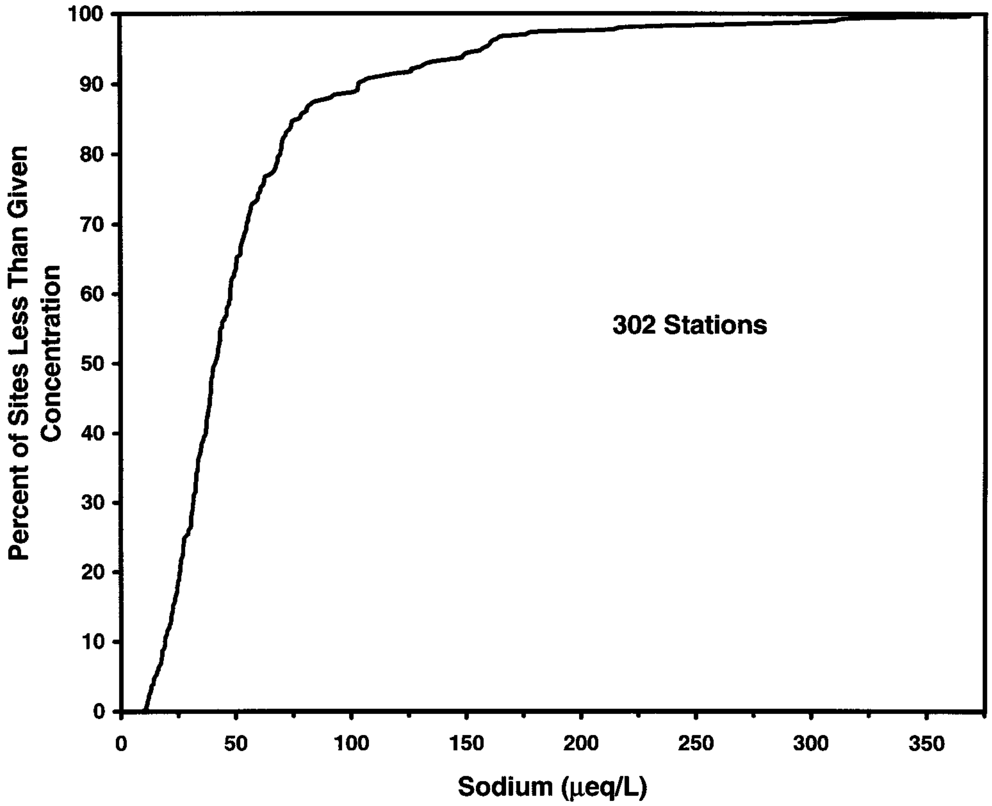
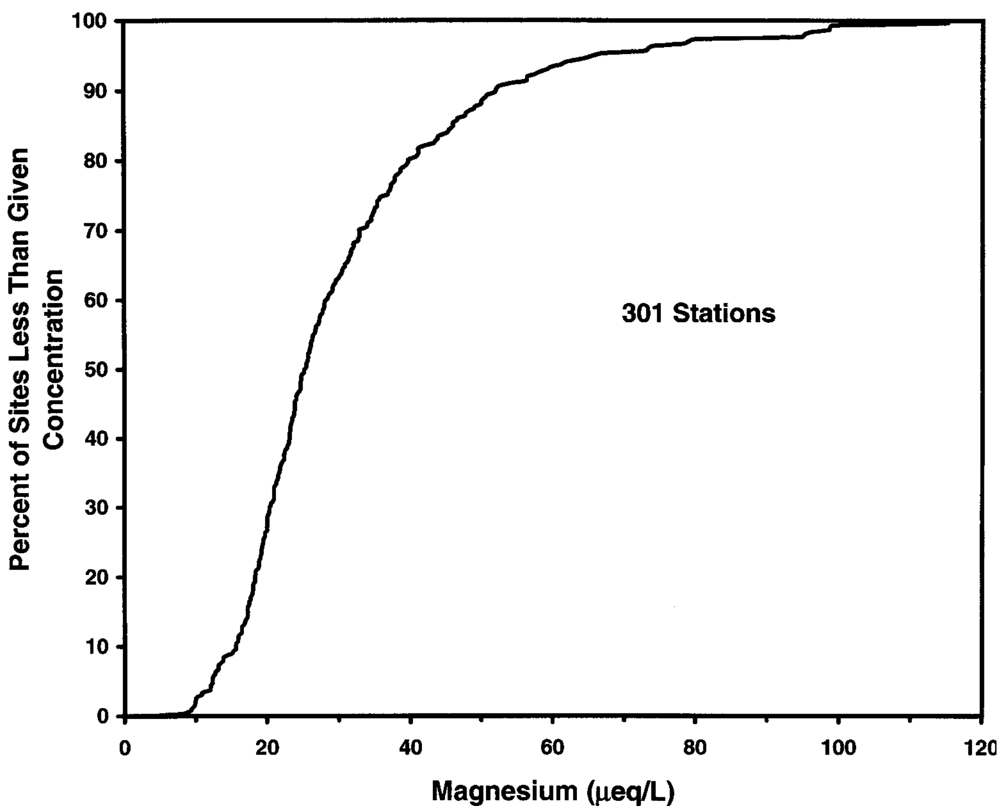
# Appendix

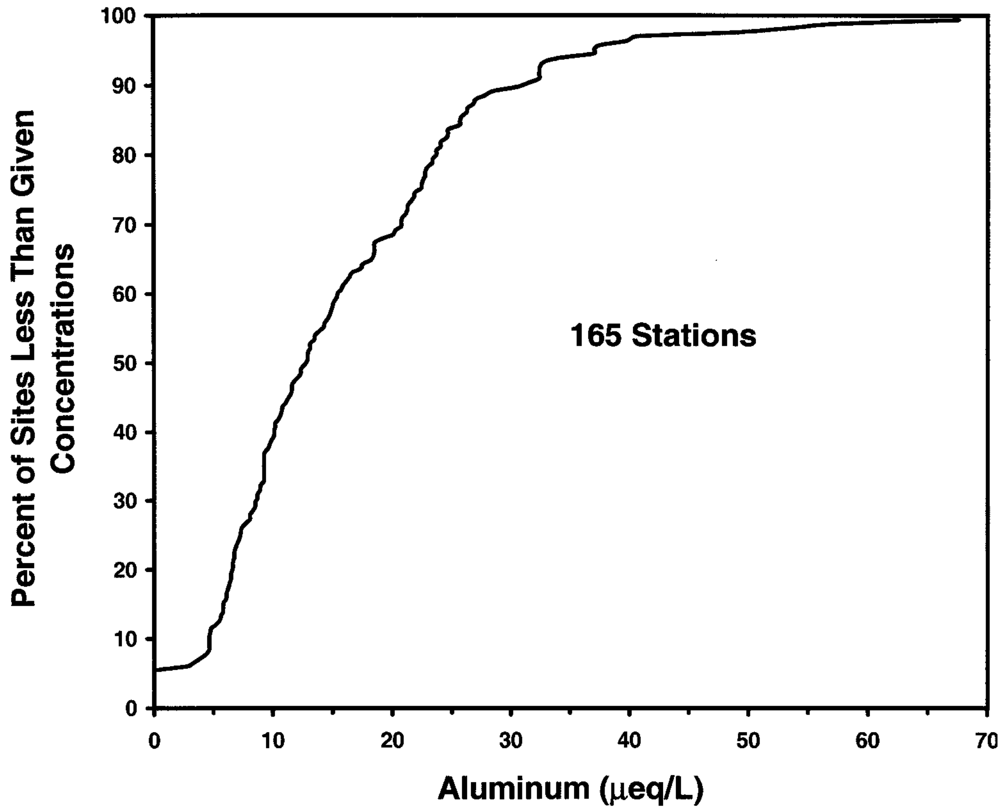
Cumulative Frequency Plots for pH, Potassium, Sodium, Magnesium, Aluminum, Chloride, Sulfate, and Nitrate



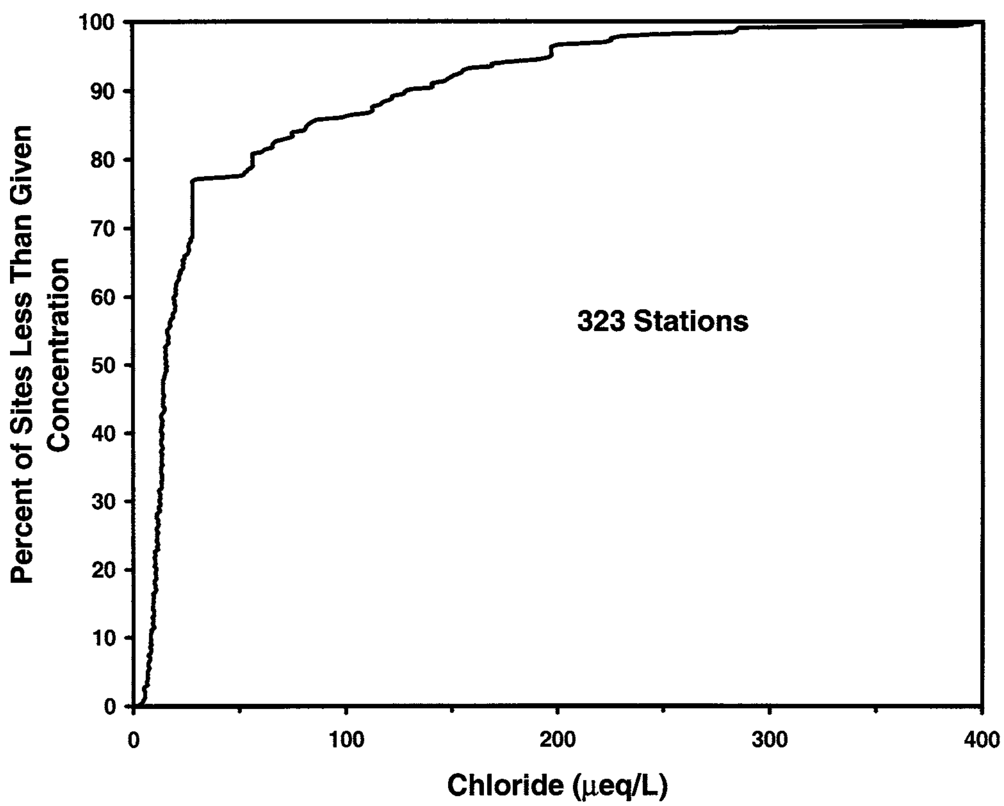




100
90
80
70
60
50
40
30
20
10
0
Percent of Sites Less Than Given Concentration
0
50
100
150
200
250
300
350
Sodium (μeq/L)
302 Stations

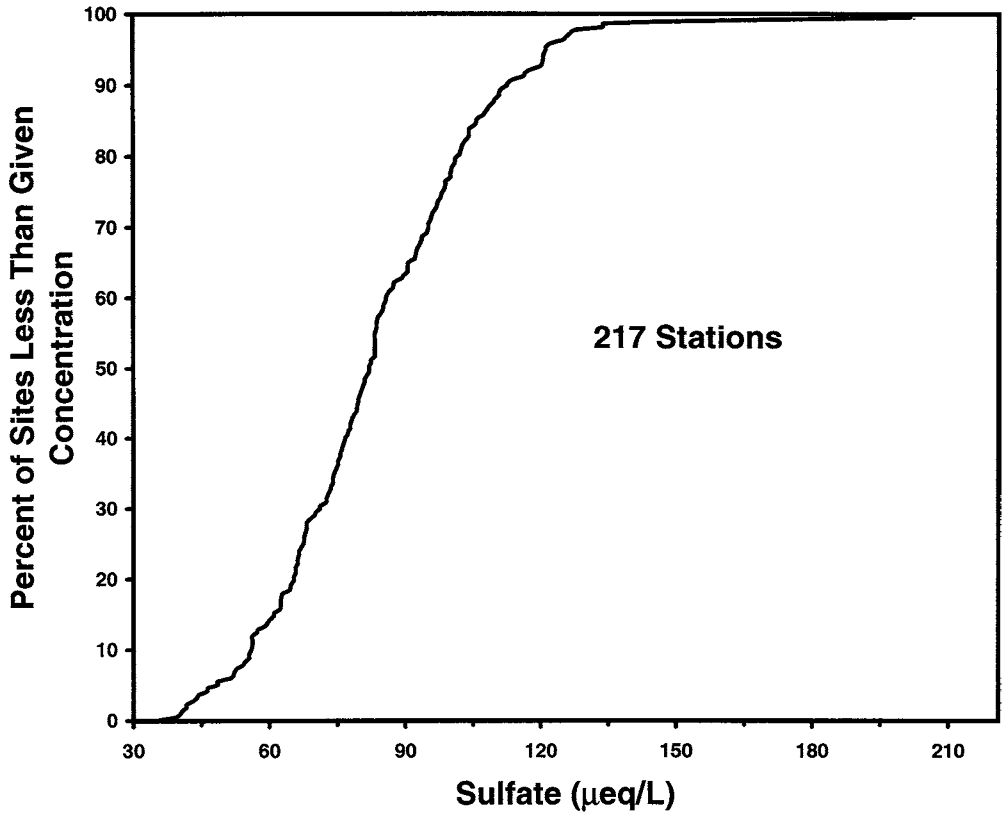

100
90
80
70
60
50
40
30
20
10
0
Percent of Sites Less Than Given Concentration
0
20
40
60
80
100
120
Magnesium (μeq/L)
301 Stations

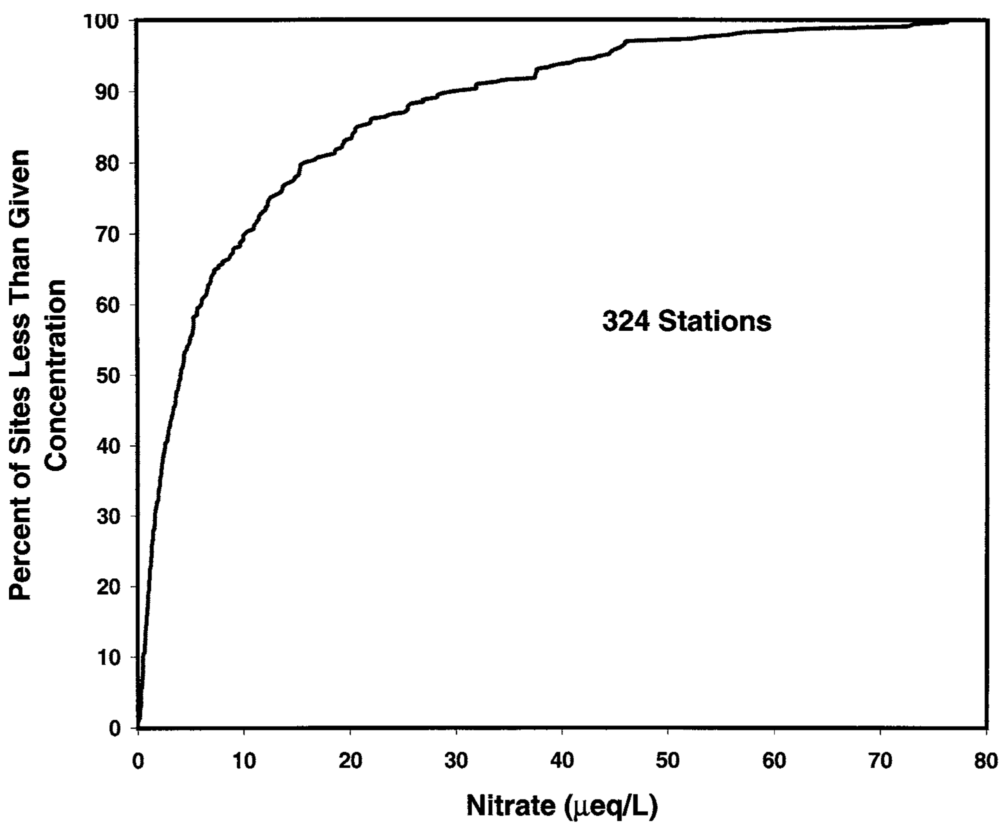


Percent of Sites Less Than Given Concentrations
100
90
80
70
60
50
40
30
20
10
0
165 Stations
0
10
20
30
40
50
60
70
Aluminum (μeq/L)

Percent of Sites Less Than Given Concentration
100
90
80
70
60
50
40
30
20
10
0
323 Stations
0
100
200
300
400
Chloride (μeq/L)


100
90
80
70
60
50
40
30
20
10
0
Percent of Sites Less Than Given Concentration
217 Stations
30
60
90
120
150
180
210
Sulfate (μeq/L)


100
90
80
70
60
50
40
30
20
10
0
Percent of Sites Less Than Given Concentration
324 Stations
0
10
20
30
40
50
60
70
80
Nitrate (μeq/L)

Hornbeck, James W.; Alexander, Michelle M.; Eagar, Christopher; Carlson, Joan Y.; Smith, Robert B. 2001. **Database for chemical contents of streams on the White Mountain National Forest.** Gen Tech. Rep. NE-282. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 12 p.

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**Keywords:** water quality, atmospheric deposition, pH, calcium, sulfate

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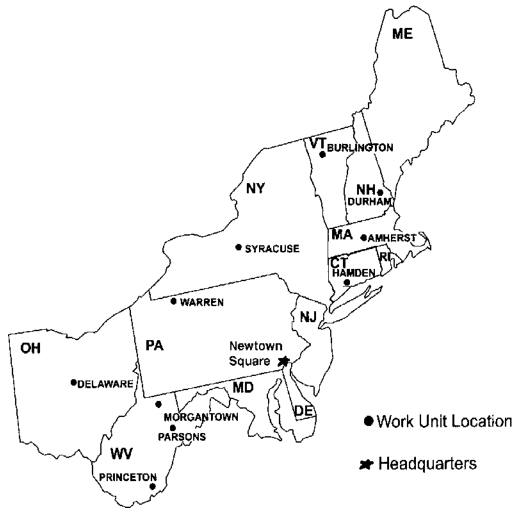


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