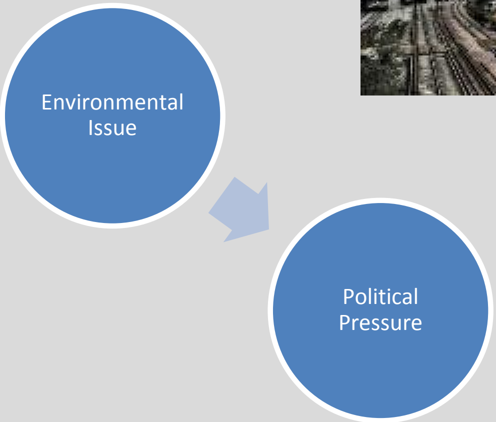
Revisiting Wisconsin’s Acid-Sensitive Lakes 30 years after Acid Rain Legislation

Lake Michigan from Sheboygan WI. *Photo by Lucius Clay*

Steve Greb and Katherine Webster
UW-Wisconsin Madison

Environmental Issue



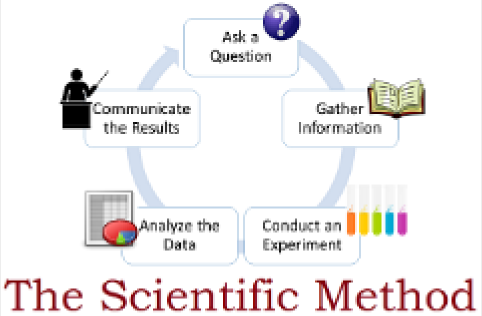
Environmental Issue

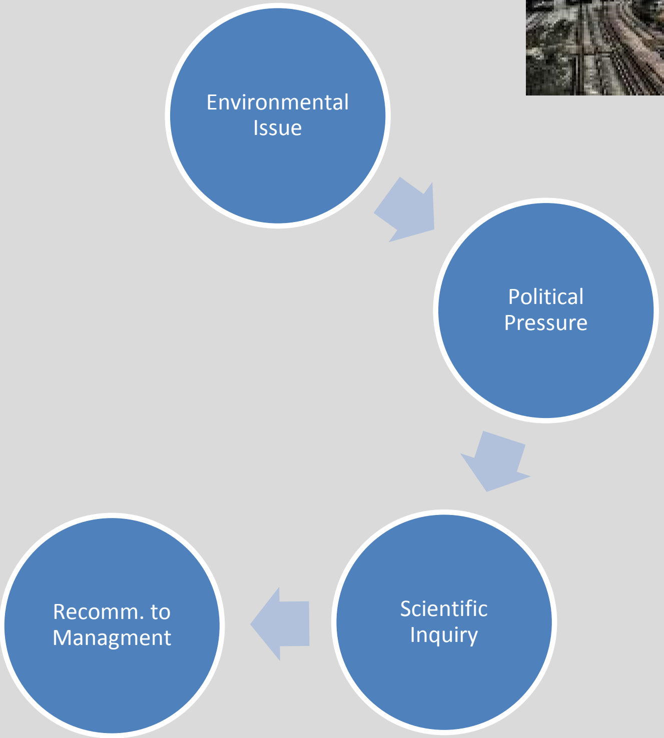
Political Pressure

Environmental Issue

Political Pressure

Scientific Inquiry





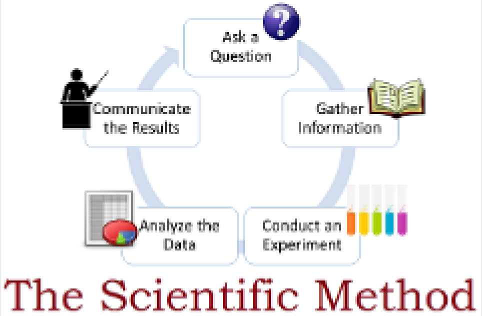
Environmental Issue

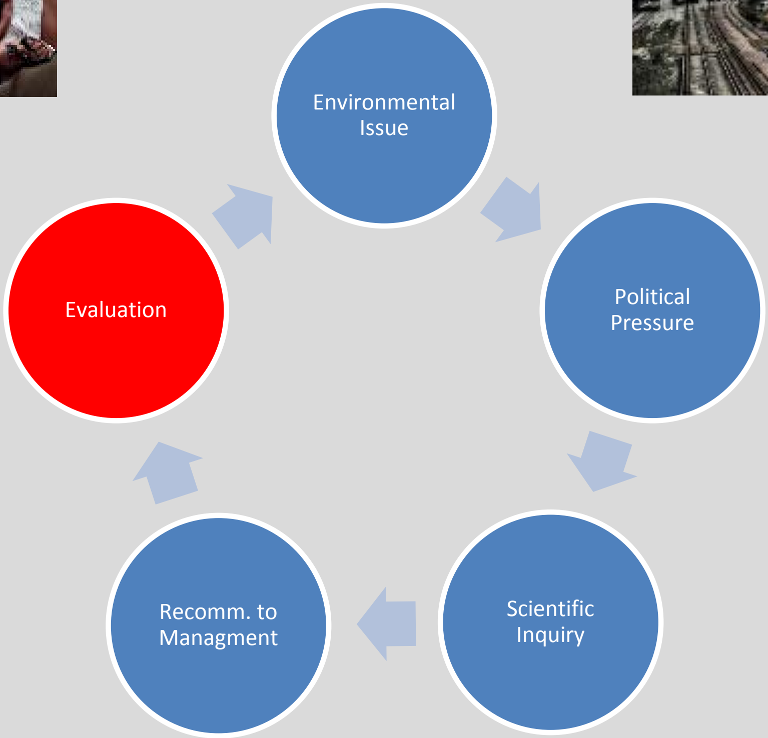
Political Pressure

Scientific Inquiry

Recomm. to Managment

WISCONSIN
DEPT. OF NATURAL RESOURCES





Environmental Issue

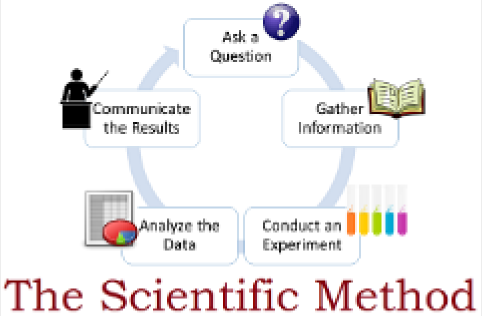
Political Pressure

Scientific Inquiry

Recomm. to Managment

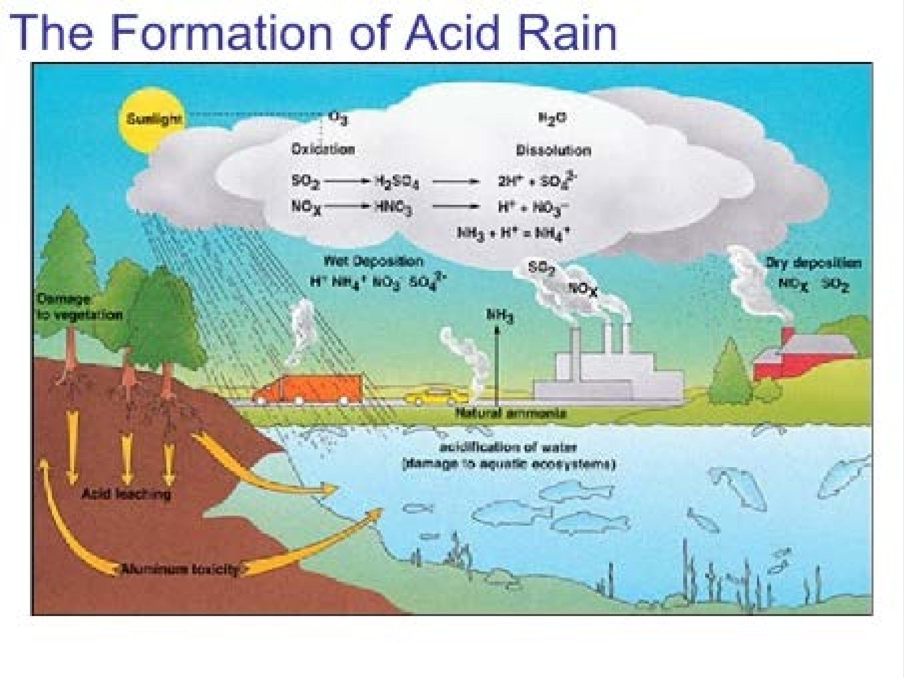
Evaluation

WISCONSIN
DEPT. OF NATURAL RESOURCES



Background

- Acid rain is caused primarily by emissions of sulfur dioxide and nitrogen oxides.
- Sulfur dioxide emissions come mostly from coal-fired power plants and pulp and paper mills.
- Nitrogen oxide emissions come mostly from coal-fired power plants, factories, motor vehicles and home furnaces.
- While in the air, sulfur dioxide and nitrogen oxides react with oxygen and moisture to form sulfuric acid, nitric acid and nitrous acid, which return to the land as precipitation through rain, snow or fog.



The former Pabst brewery in Milwaukee
Photo by Jeremey Jannene

Impacts of Acid Rain

Human health In the atmosphere, sulfate and nitrate aerosols increase morbidity and mortality from lung disorders, such as asthma and bronchitis, and impacts to the cardiovascular system.

Surface waters Acidic surface waters decrease the survivability of animal life in lakes and streams and in the more severe instances eliminate some or all types of fish and other organisms..

Forests Acid deposition contributes to forest degradation by impairing trees' growth and increasing their susceptibility to winter injury, insect infestation, and drought. It also causes leaching and depletion of natural nutrients in forest soil.

Impacts of Acid Rain

Materials Acid deposition contributes to the corrosion and deterioration of buildings, cultural objects, and cars, which decreases their value and increases costs of correcting and repairing damage.
Visibility In the atmosphere, sulfur dioxide and nitrogen oxides form sulfate and nitrate particles, which impair visibility and affect the enjoyment of national parks and other scenic views.

SOURCE: "Appendix I. Effect of Acid Rain on Human Health and Selected Ecosystems and Anticipated Recovery Benefits," in Acid Rain: Emissions Trends and Effects in the Eastern United States, U.S. General Accounting Office, March 2000, http://www.gao.gov/archive/2000/rc00047.pdf (accessed July 27, 2007)

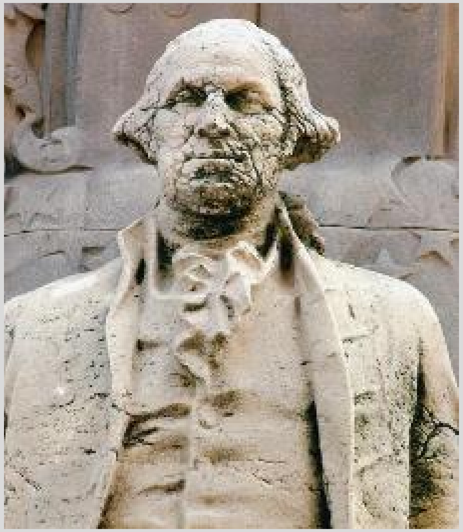


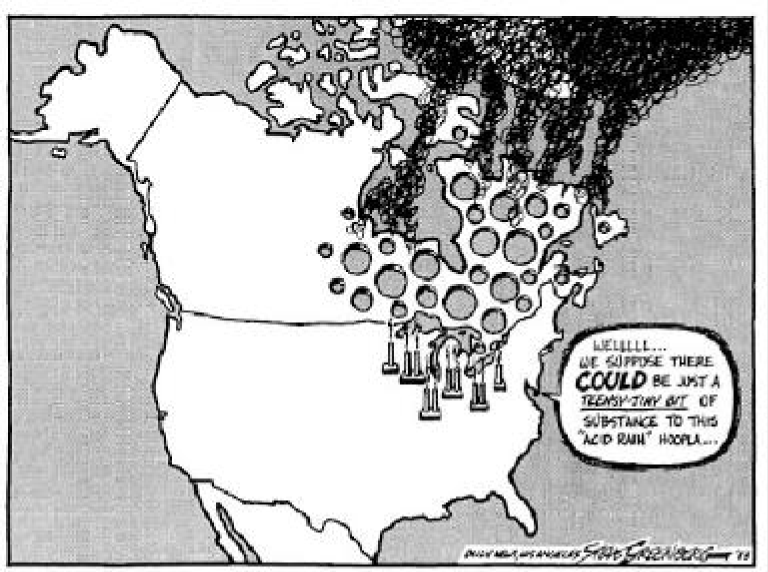
Photo by Spencer Platt

History

1970s- Acid rain started making worldwide news, thanks to research showing that acidic rainfall was damaging lakes, fisheries and forests in Europe and Canada.

1979- DNR tested lakes around Wisconsin and concluded that half of the northern lakes tested were vulnerable to damage from acid rain. Also damaging fish, forests, crops and even stone monuments around the state.

1986- Wisconsin acid rain legislation passed



Goals of Wisconsin Acid Rain Legislation

- Reduced acid rain and kept the pH of precipitation at least 4.7 across Wisconsin.

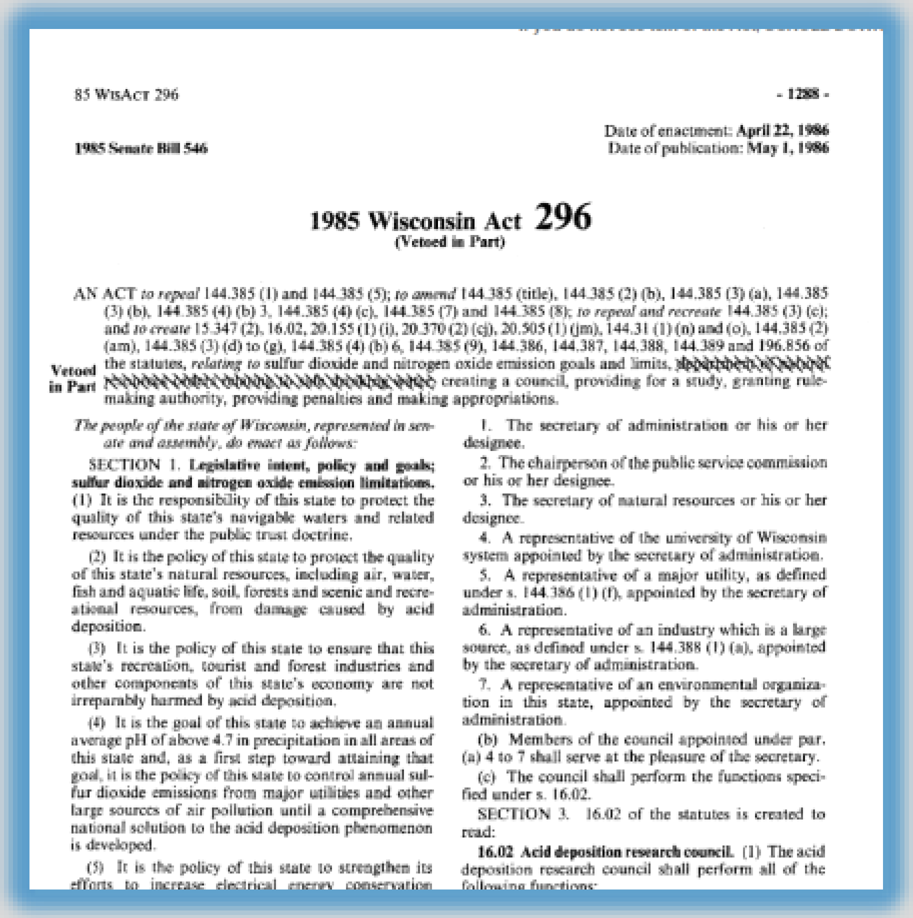
- Created standards for nitrogen oxide and sulfur dioxide emissions from different sources.

- Required the state's five major electric utilities to reduce their sulfur dioxide emissions to 50 percent of 1980 levels by 1993.

- Capped annual emissions from the state's five major electric utilities at 250,000 tons of sulfur dioxide beginning in 1993, and 135,000 tons of nitrogen oxides beginning in 1991.

- Kept sulfur dioxide emissions from all large sources in Wisconsin below 75,000 tons per year.

- Reduced average sulfur dioxide emissions to 1.5 pounds per million BTUs of heat produced by plants owned by Wisconsin companies



1985 Senate Bill 546

Date of enactment: **April 22, 1986**
Date of publication: **May 1, 1986**

1985 Wisconsin Act 296

(Vetoed in Part)

AN ACT *to repeal* 144.385 (1) and 144.385 (5); *to amend* 144.385 (title), 144.385 (2) (b), 144.385 (3) (a), 144.385 (3) (b), 144.385 (4) (b) 3, 144.385 (4) (c), 144.385 (7) and 144.385 (8); *to repeal and recreate* 144.385 (3) (c); and *to create* 15.347 (2), 16.02, 20.155 (1) (i), 20.370 (2) (cj), 20.505 (1) (jm), 144.31 (1) (n) and (o), 144.385 (2) (am), 144.385 (3) (d) to (g), 144.385 (4) (b) 6, 144.385 (9), 144.386, 144.387, 144.388, 144.389 and 196.856 of the statutes, *relating to* sulfur dioxide and nitrogen oxide emission goals and limits, [illegible] creating a council, providing for a study, granting rule-making authority, providing penalties and making appropriations.

Vetoed in Part

The people of the state of Wisconsin, represented in senate and assembly, do enact as follows:

SECTION 1. **Legislative intent, policy and goals; sulfur dioxide and nitrogen oxide emission limitations.** (1) It is the responsibility of this state to protect the quality of this state's navigable waters and related resources under the public trust doctrine.

(2) It is the policy of this state to protect the quality of this state's natural resources, including air, water, fish and aquatic life, soil, forests and scenic and recreational resources, from damage caused by acid deposition.

(3) It is the policy of this state to ensure that this state's recreation, tourist and forest industries and other components of this state's economy are not irreparably harmed by acid deposition.

(4) It is the goal of this state to achieve an annual average pH of above 4.7 in precipitation in all areas of this state and, as a first step toward attaining that goal, it is the policy of this state to control annual sulfur dioxide emissions from major utilities and other large sources of air pollution until a comprehensive national solution to the acid deposition phenomenon is developed.

(5) It is the policy of this state to strengthen its efforts to increase electrical energy conservation

1. The secretary of administration or his or her designee.
2. The chairperson of the public service commission or his or her designee.
3. The secretary of natural resources or his or her designee.
4. A representative of the university of Wisconsin system appointed by the secretary of administration.
5. A representative of a major utility, as defined under s. 144.386 (1) (f), appointed by the secretary of administration.
6. A representative of an industry which is a large source, as defined under s. 144.388 (1) (a), appointed by the secretary of administration.
7. A representative of an environmental organization in this state, appointed by the secretary of administration.

(b) Members of the council appointed under par. (a) 4 to 7 shall serve at the pleasure of the secretary.

(c) The council shall perform the functions specified under s. 16.02.

SECTION 3. 16.02 of the statutes is created to read:

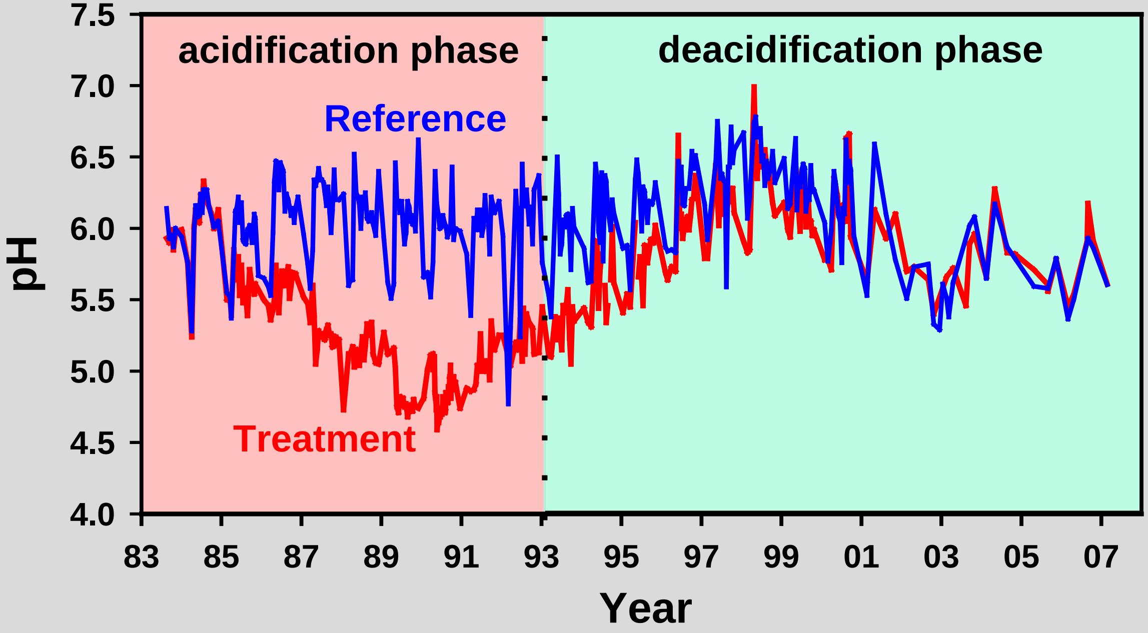
16.02 Acid deposition research council. (1) The acid deposition research council shall perform all of the following functions:

Acid Rain and Mercury deposition monitoring at Trout Lake

photos by Carl Watras

Experimental acidification and recovery of Little Rock Lake: 1984-2008

Little Rock Lake: acidified basin at top of picture



30¢ May 8, 1985 20 pages One Section Vol. 11, No. 50 30¢

WALLEYE STRE

WITH AN EYE ON THE NO

Karley Watras 1/86
Trout Lake Station
Rt 1, Box 71
Boulder Jct., WI 54512

Acidification Begins On Little Rock

The acidification of Little Rock Lake has begun. Researchers started last week on the crucial phase of the acidification project by applying acid to the north basin of this tiny lake. Thursday's application brought the pH of the north basin down to 5.5, this year's goal. The north basin is separated from the south basin by an impermeable barrier which was installed last year.

Next year the plan is to bring the north basin down even further - to 4.5, close to the area's rainfall of 4.3 ph.

Fifty three test wells located in a variety of positions around the lake, some positioned on the shoreline, some staggered thoughout the area, and some up to a mile away, to monitor any groundwater migration of the altered-ph water out of the north basin. These wells are monitored monthly year around.

November 1984 / $2.50

LIFE

BISECTING A LAKE FOR THE ACID TEST

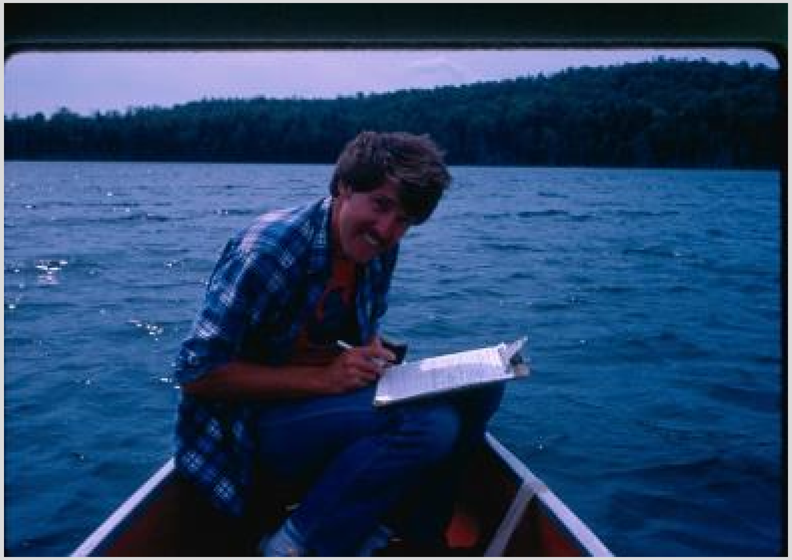
When acid rain falls on a watershed with alkaline soil, the acidity is neutralized, much as an indigestion tablet calms an acid stomach. But in less alkaline areas the precipitation, even if only mildly acidic, can chemically release toxic metals from the soil into streams and lakes. Poisons then work up the food chain from plants to animals. An estimated 10 percent of the 2,750 lakes in New York's Adirondack mountains can no longer support fish. The EPA has spent millions on lake studies, the most novel being the Wisconsin project shown here. Little Rock Lake has been divided by a waterproof fence, as if by the hand of Christo, to compare acidified with normal water. And though the only long-term answer is to check pollution at its source, researchers are treating damaged lakes with acid-reducing lime—or, in one case, with 14 fizzing tons of baking soda. ➸

Boats and scuba divers stretch a 230-foot plastic barrier across Wisconsin's 30-foot-deep Little Rock Lake. The northern half of the lake will be acidified with sulfuric acid, and its resulting ecosystem—from tiny plankton to bass and perch—compared with that of the unsullied southern half.

The Wisconsin Early Response Lakes (WERL) -1987
EPA Long-Term Monitoring (LTM) -1983

The goal of the acid-sensitive lake monitoring program is to quantify relationships between declining deposition rates of mineral acids which followed reductions in SO2 emissions, and the acid-base chemistry of sensitive lakes across the State. Chemical, hydrologic and deposition data will be incorporated into an evaluation of dose-response relationships, and consideration of time lags between emission reductions and lake responses

..with help from
many staff



Long-term lake chemistry changes to acid deposition; revisiting Wisconsin's Acid-Sensitive Lakes in 2016

Goal: Quantify changes and trends in acid-base chemistry of sensitive lakes in northern Wisconsin in the context of declining acid deposition rates

Work plan:

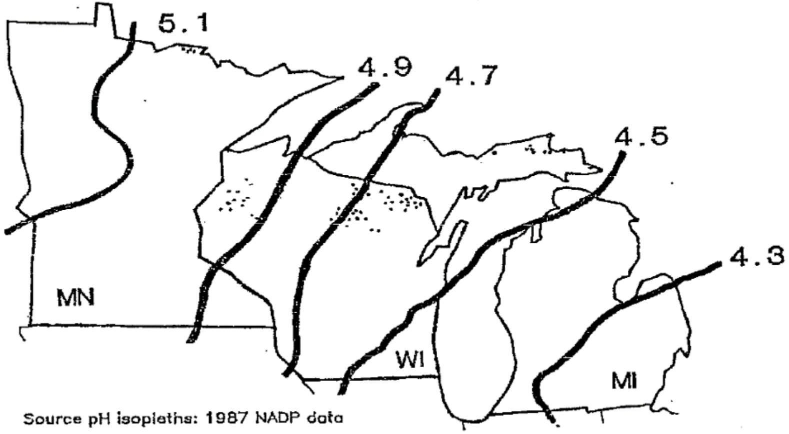
1. Retrieve all past archived data
2. Review methods and protocols
3. Select a subset of lakes (n=18)
4. Sample lakes during fall turnover in 2016
5. Present and publish findings of both past and current work

Three Stratums of lakes sampled

a. Stratum 1 Low ANC, low Color
b. Stratum 2- Low ANC, high Color
c. Stratum 3- Higher ANC, low Color

Webster

FIELD AND LABORATORY PROTOCOL:
LONG-TERM MONITORING (LTM) AND
WISCONSIN EARLY RESPONSE LAKES (WERL) PROGRAMS

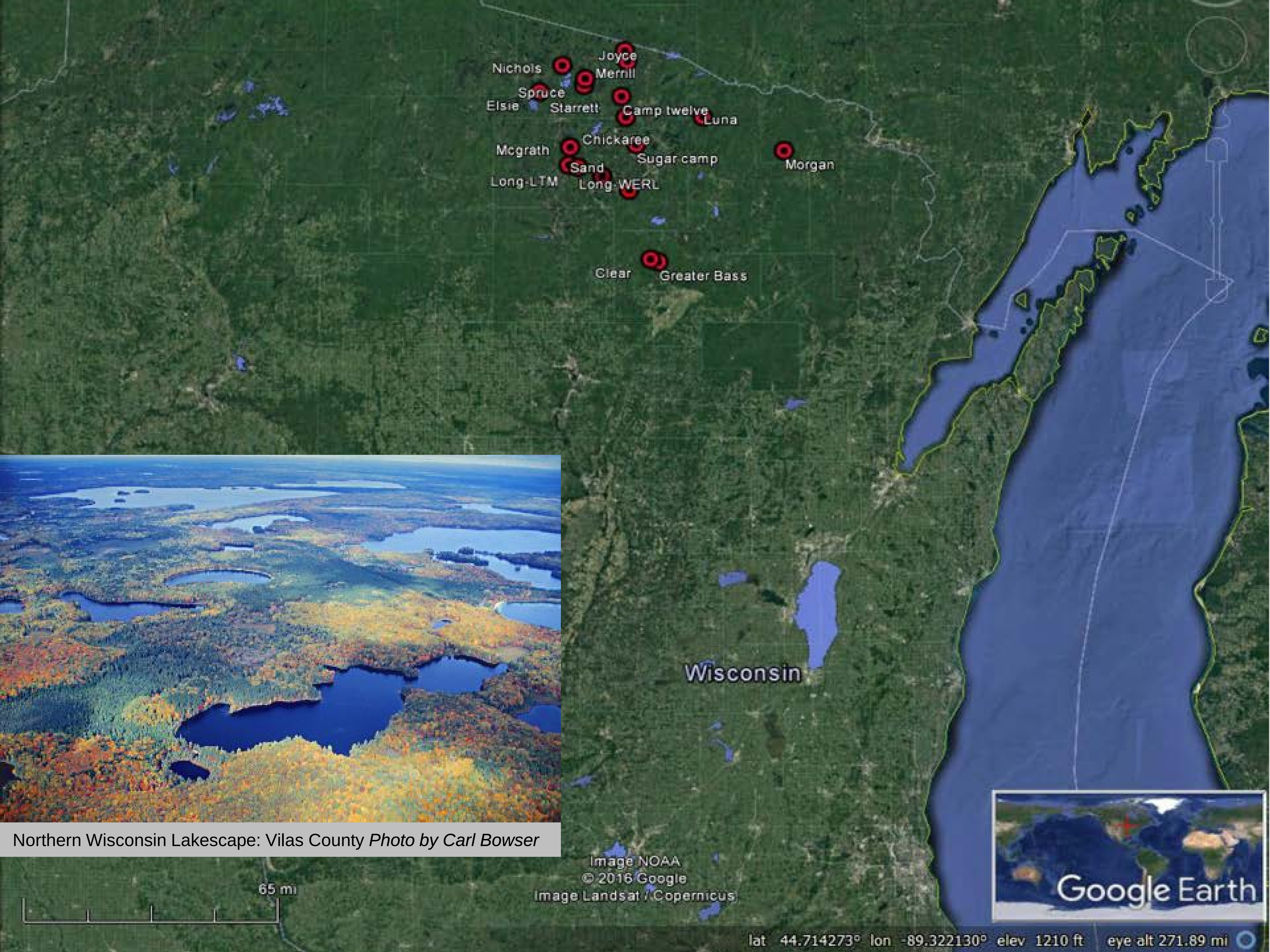


Source pH isopleths: 1987 NADP data

July 1991
Revised December 1993

Katherine E. Webster
Alistair P. Carr

Wisconsin Department of Natural Resources
Bureau of Research
1350 Femrite Drive
Monona WI 53716



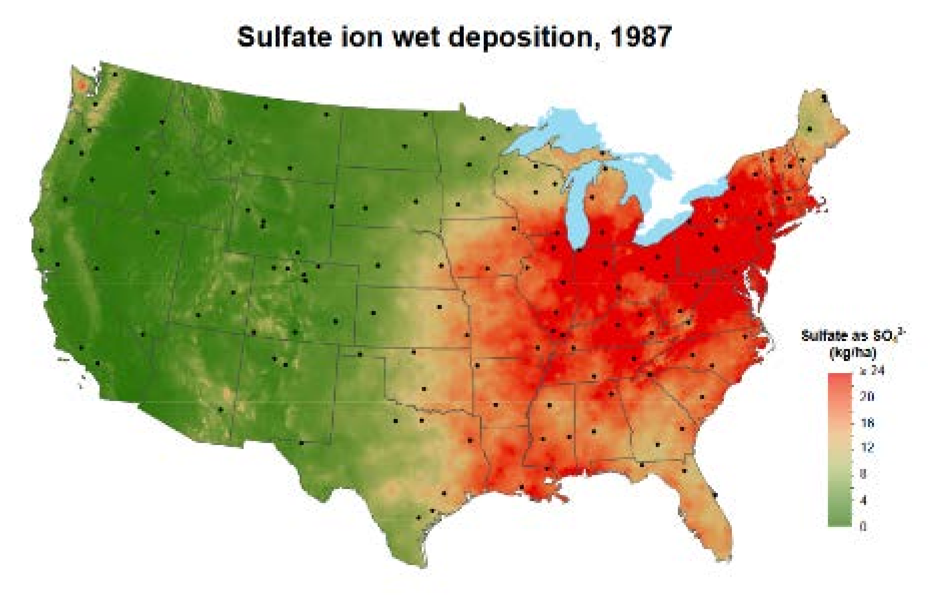
Northern Wisconsin Lakescape: Vilas County *Photo by Carl Bowser*

2016 Acid Rain Lakes Crew

Katie Hein Susan Knight Carol Warden Paul Garrison Steve Greb

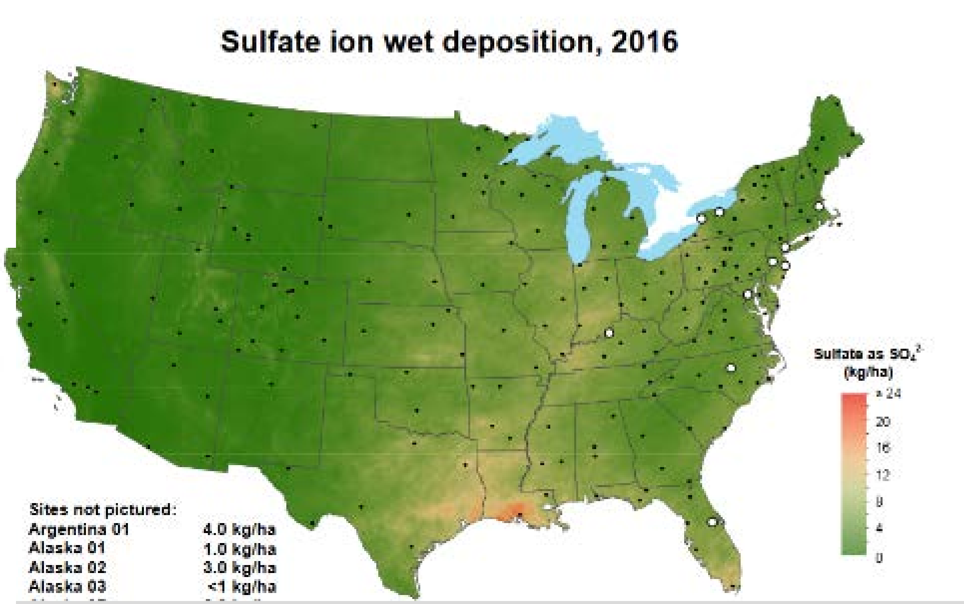
Lake Sampling 2016

Photos by Carol Warden and Susan Knight



Sulfate ion wet deposition, 1987

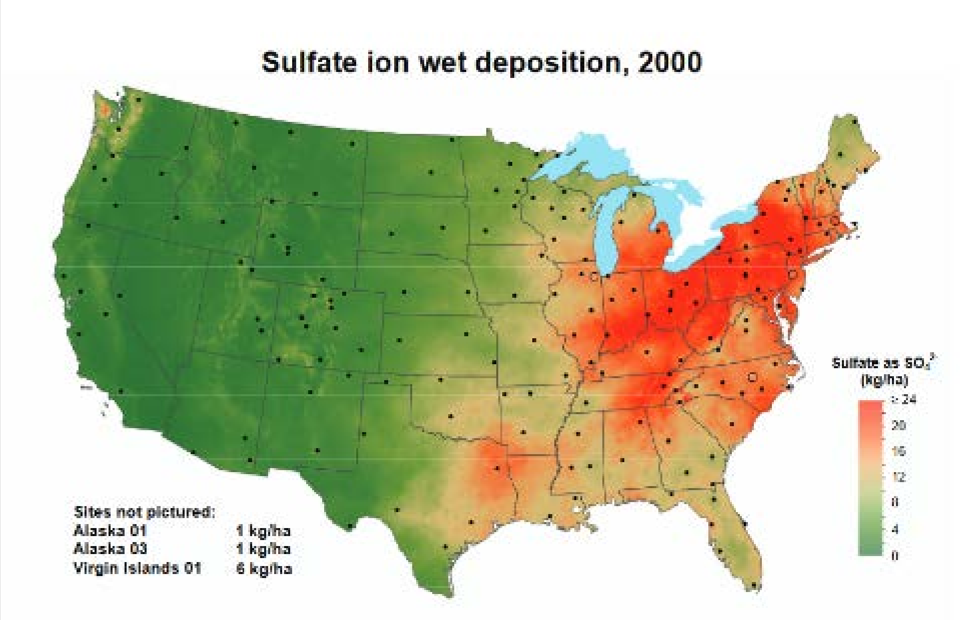
WOW!



Sulfate ion wet deposition, 2016

Sites not pictured:

Argentina 01	4.0 kg/ha
Alaska 01	1.0 kg/ha
Alaska 02	3.0 kg/ha
Alaska 03	<1 kg/ha

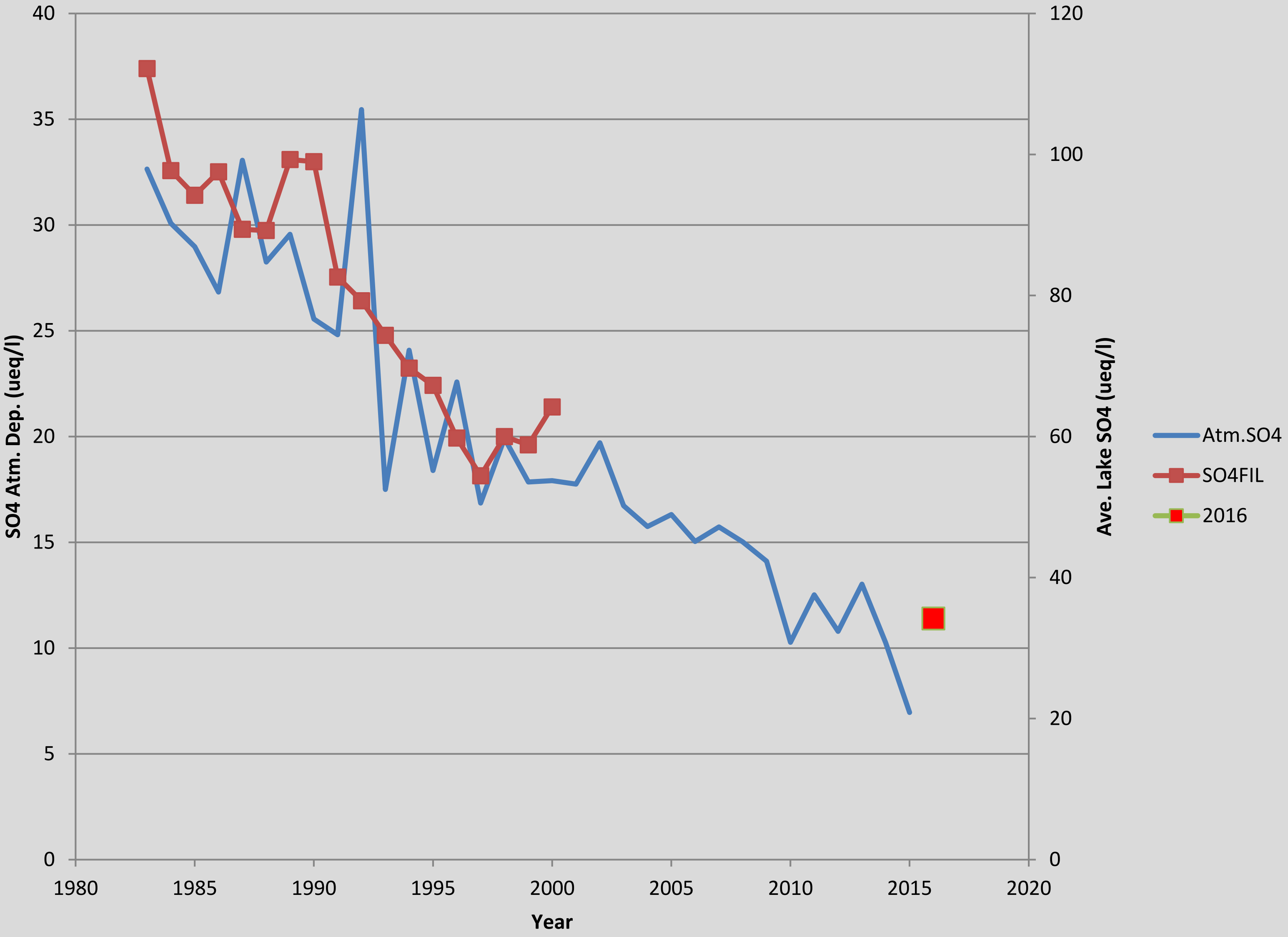


Sulfate ion wet deposition, 2000

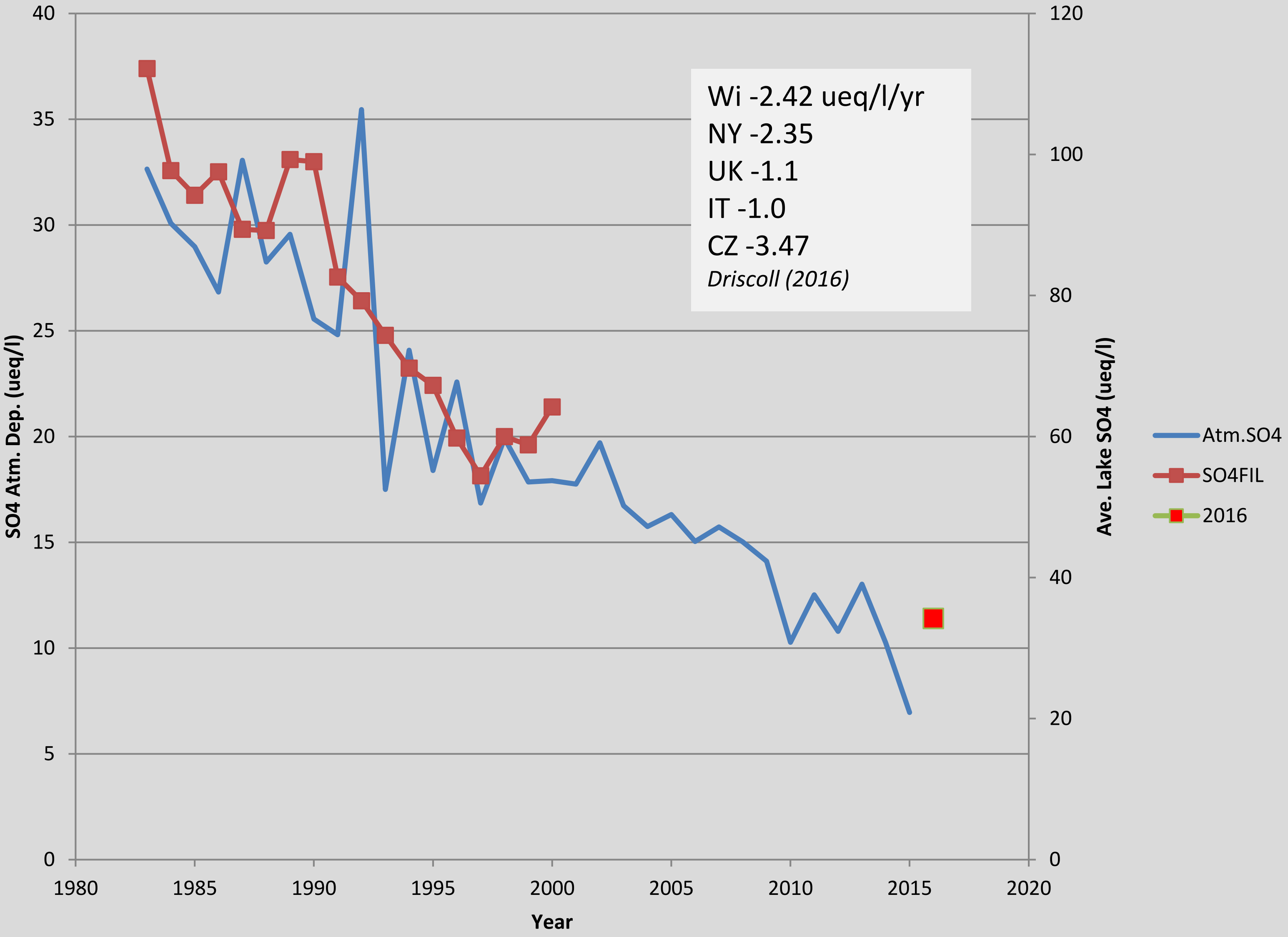
Sites not pictured:

Alaska 01	1 kg/ha
Alaska 03	1 kg/ha
Virgin Islands 01	6 kg/ha

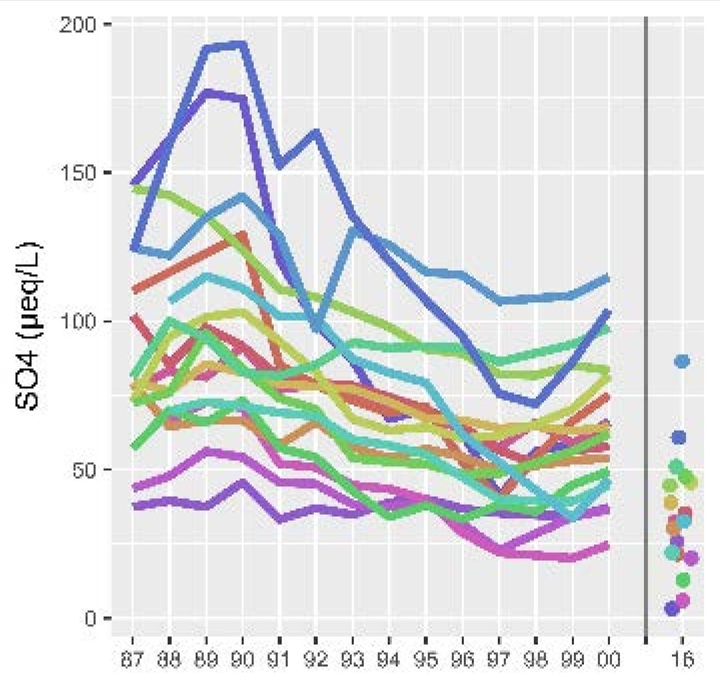
National Atmospheric Deposition Program (NRSP-3). 2018. NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706.



40
35
30
25
20
15
10
5
0
SO4 Atm. Dep. (ueq/l)
120
100
80
60
40
20
0
Ave. Lake SO4 (ueq/l)
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
Atm.SO4
SO4FIL
2016

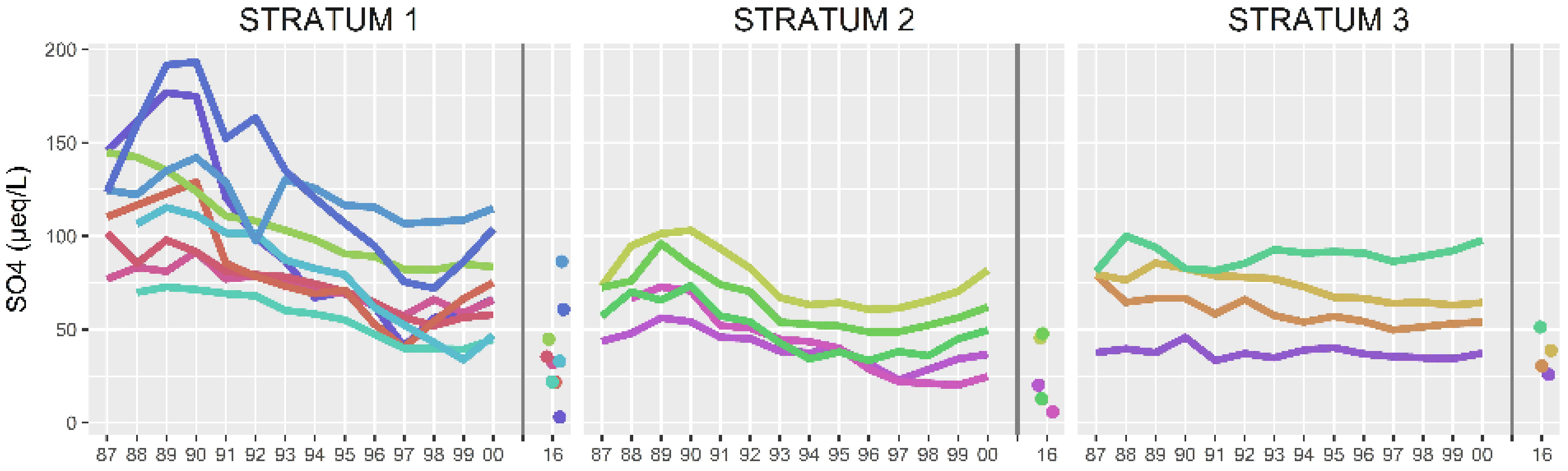


Wi -2.42 ueq/l/yr
NY -2.35
UK -1.1
IT -1.0
CZ -3.47
Driscoll (2016)

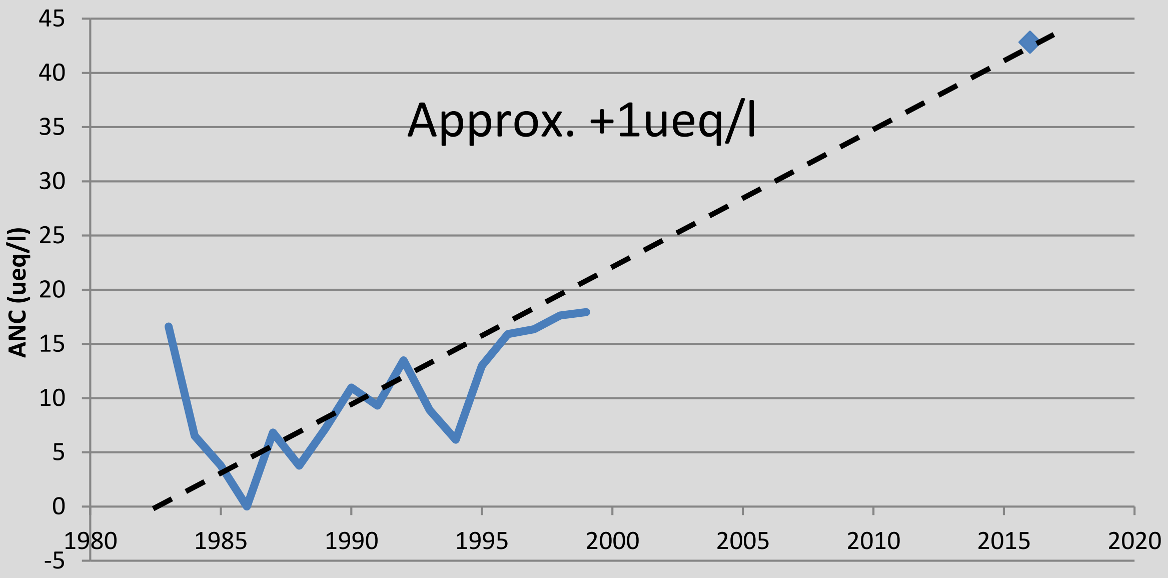


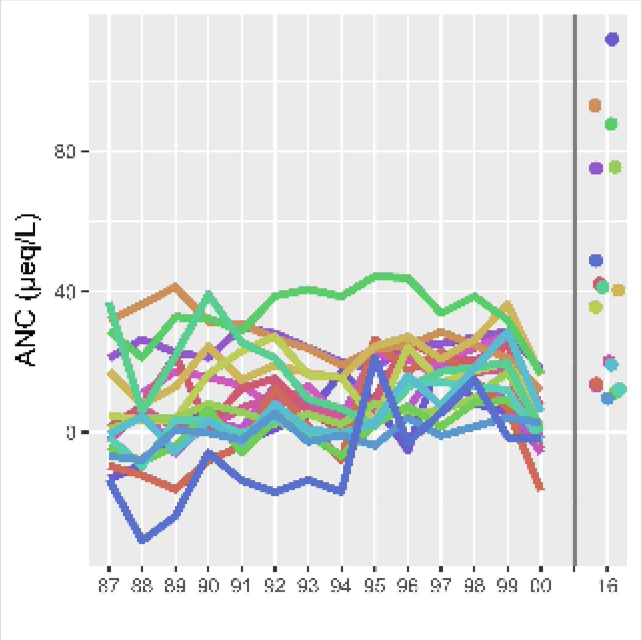
Sulfate Concentrations

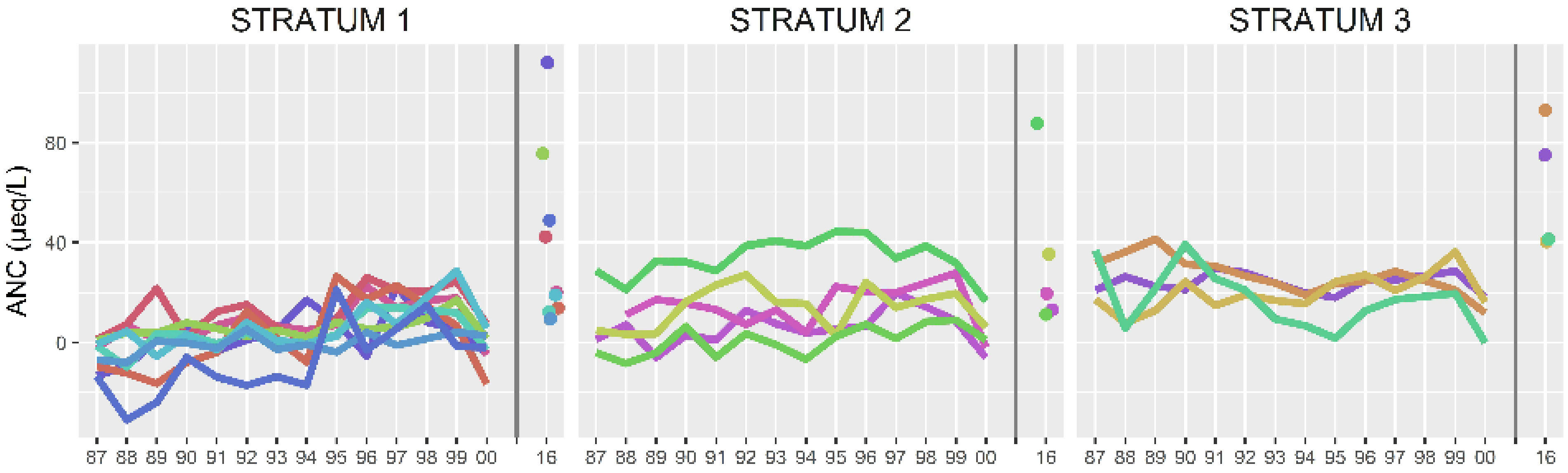
Stratum 1 Low ANC, low Color
Stratum 2- Low ANC, high Color
Stratum 3- Higher ANC, low Color

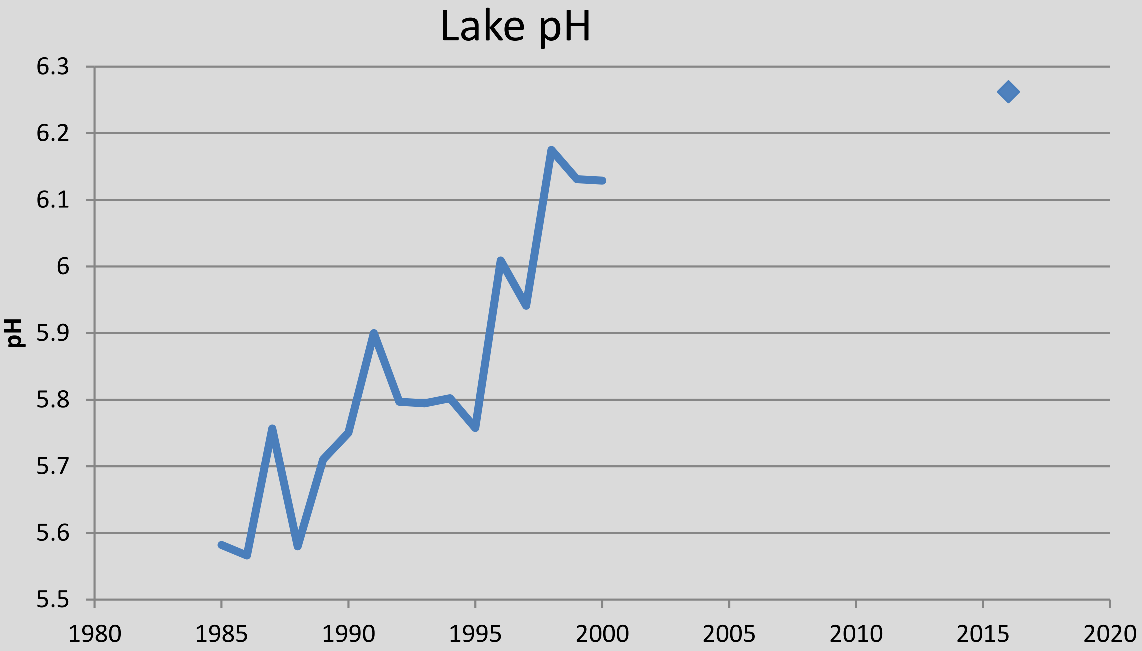


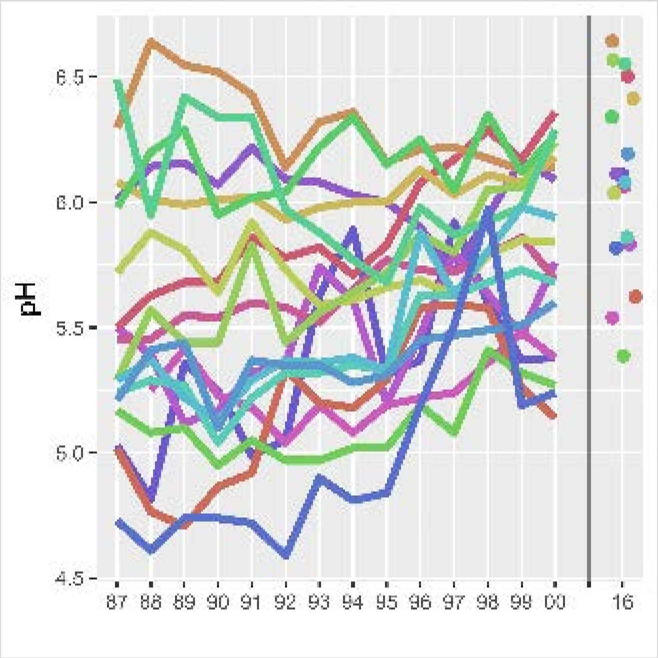
Acid Neutralizing Capacity








Lake pH
pH
6.3
6.2
6.1
6
5.9
5.8
5.7
5.6
5.5
1980
1985
1990
1995
2000
2005
2010
2015
2020


pH
6.5
6.0
5.5
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4.5
87
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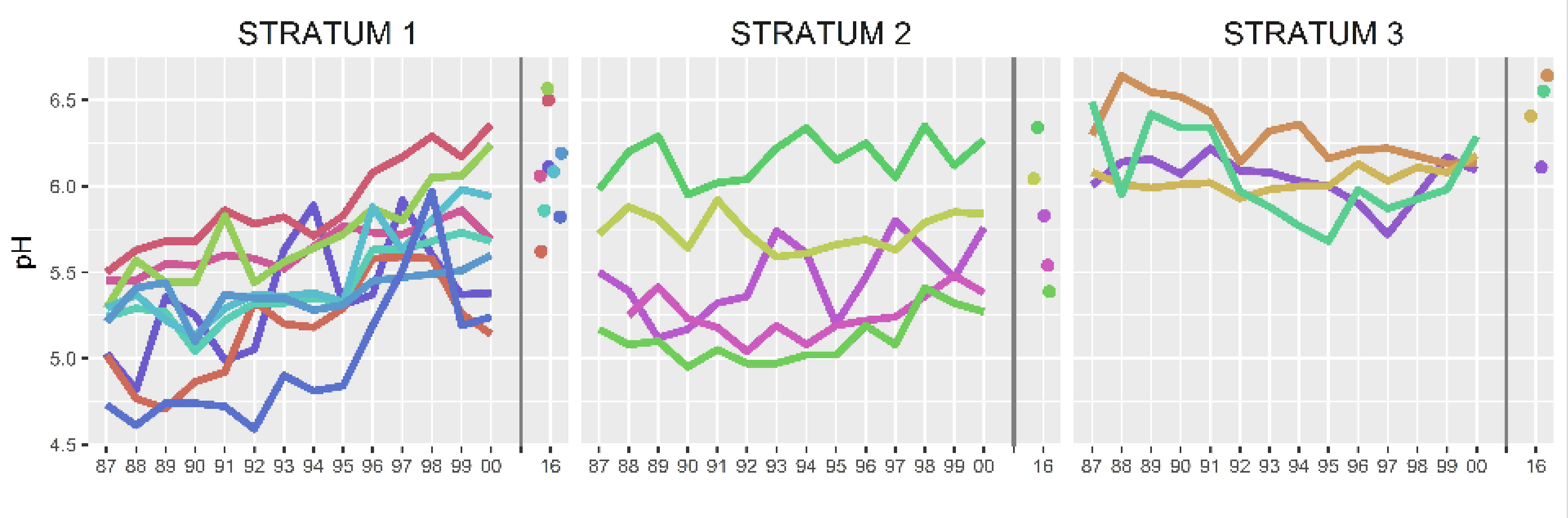
00
16


STRATUM 1
STRATUM 2
STRATUM 3
pH
6.5
6.0
5.5
5.0
4.5
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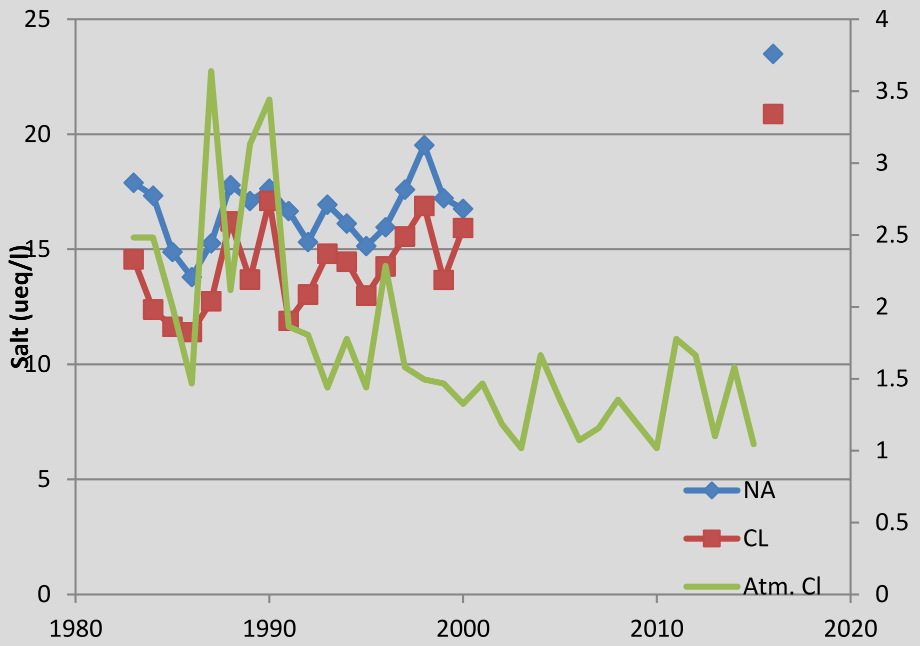
25
20
15
10
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0
Salt (ueq/l)
4
3.5
3
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2
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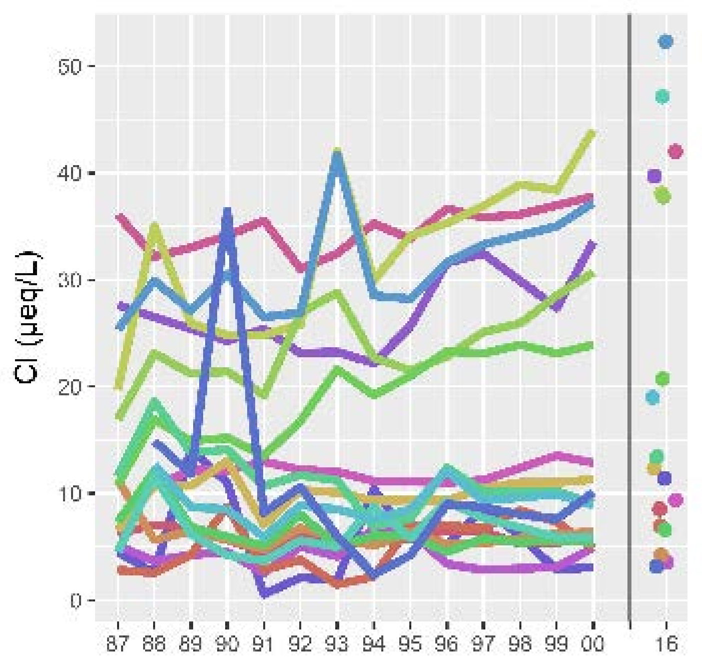
1
0.5
0
1980
1990
2000
2010
2020
NA
CL
Atm. Cl


50
40
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Cl (µeq/L)
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88
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92
93
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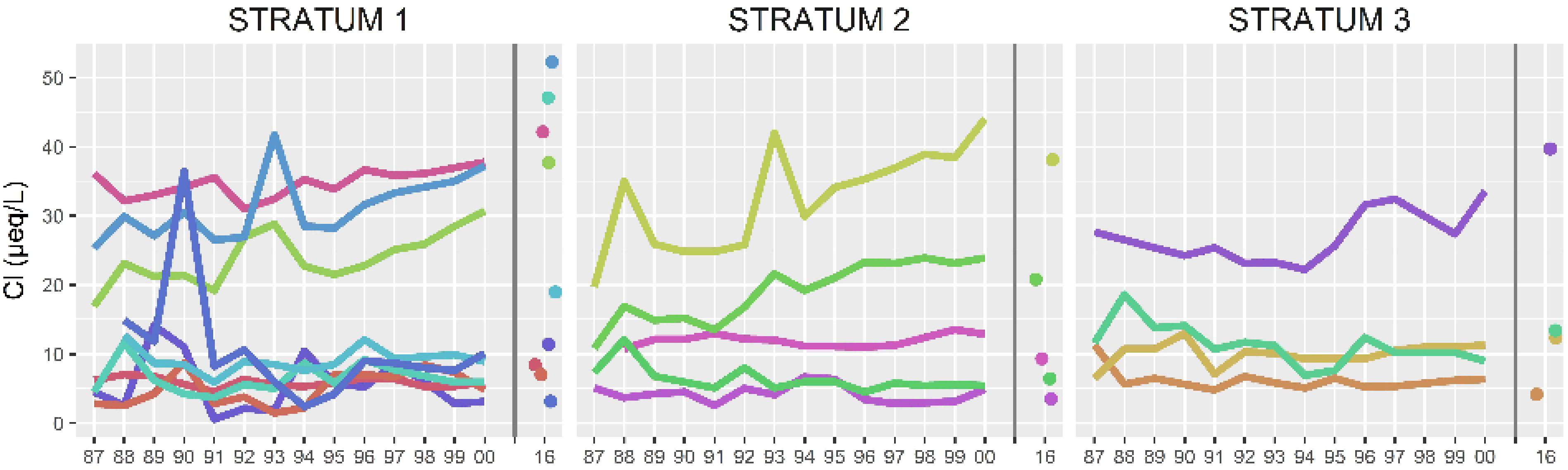
16


STRATUM 1
STRATUM 2
STRATUM 3
50
40
30
20
10
0
Cl (µeq/L)
87
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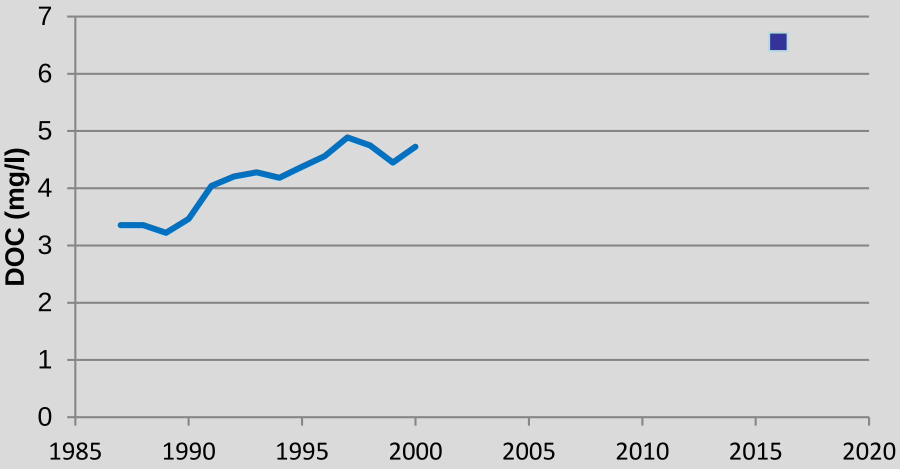
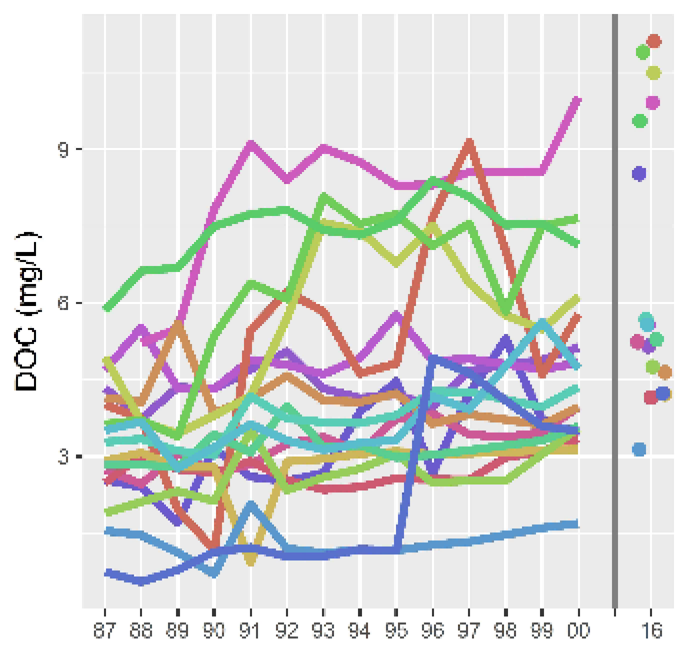
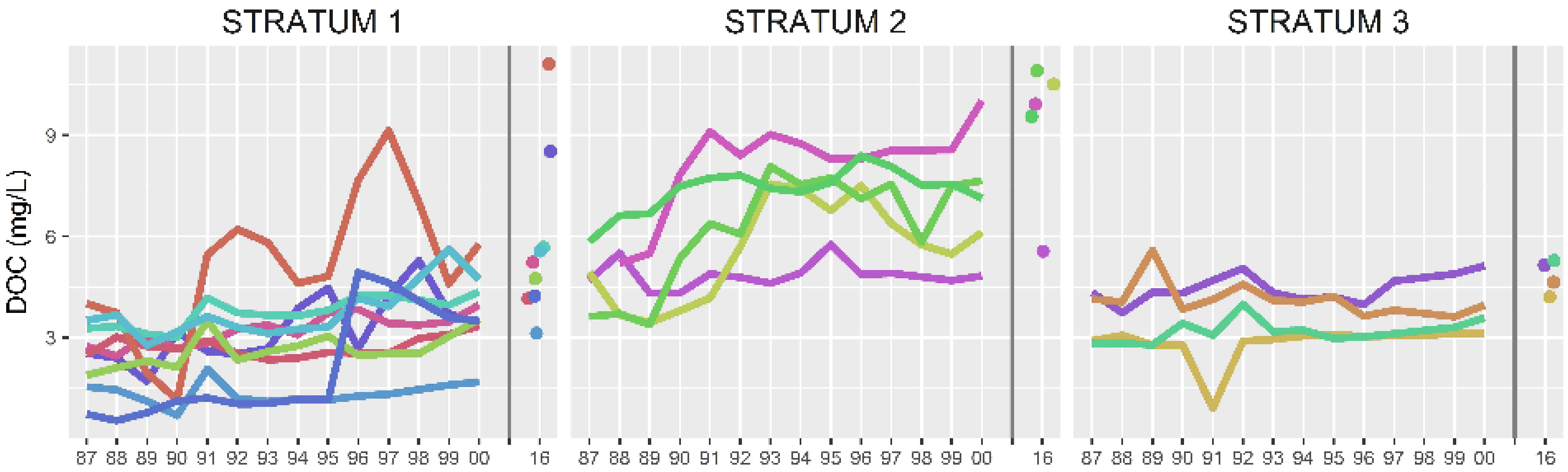
16

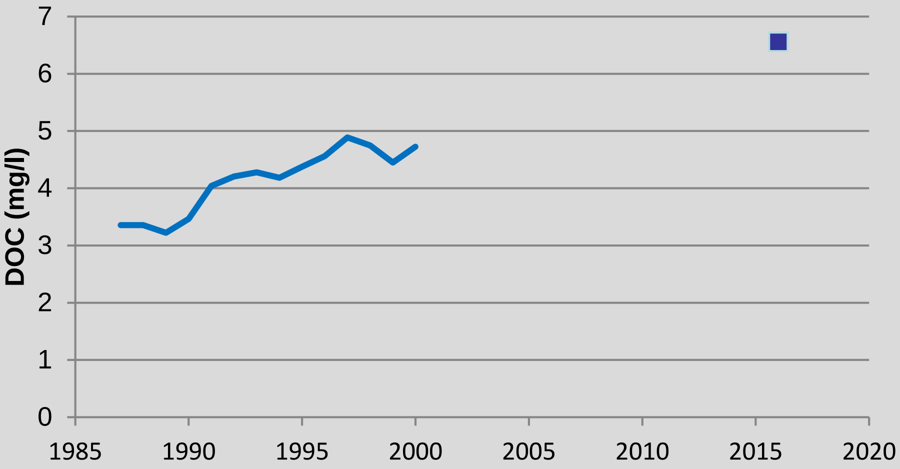
Dissolved Organic Carbon







Dissolved Organic Carbon

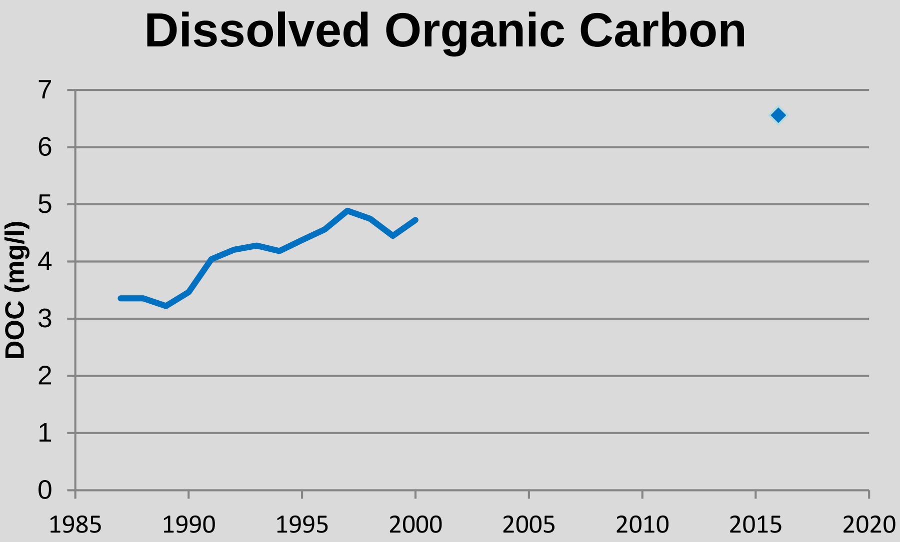


Possible explanations

- Changes in air temperature
- Increased precip.
- Land use changes
- Increased atm. CO_2
- Decreased atm. sulfur dep.
- Accum. atm. dep. N

Krause and Sucker (2016)

DOC: 13/18 Signif. Trend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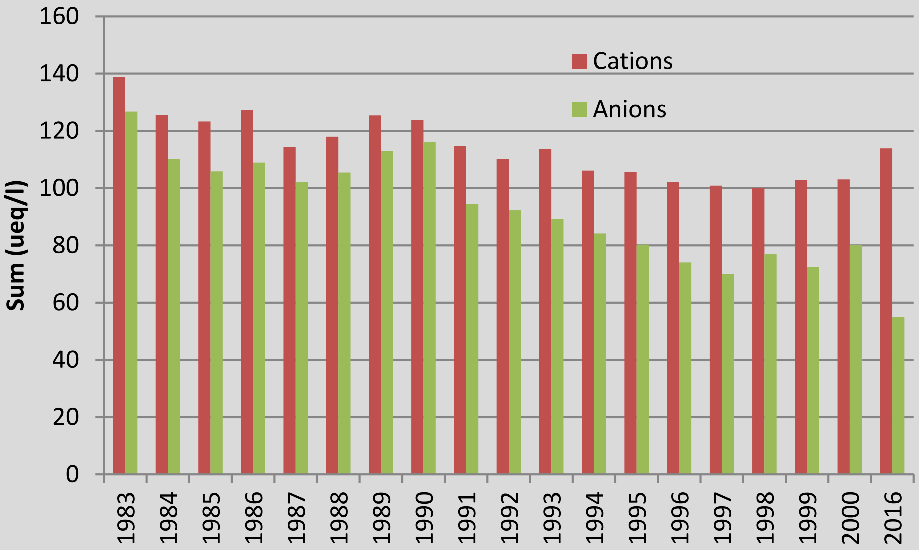
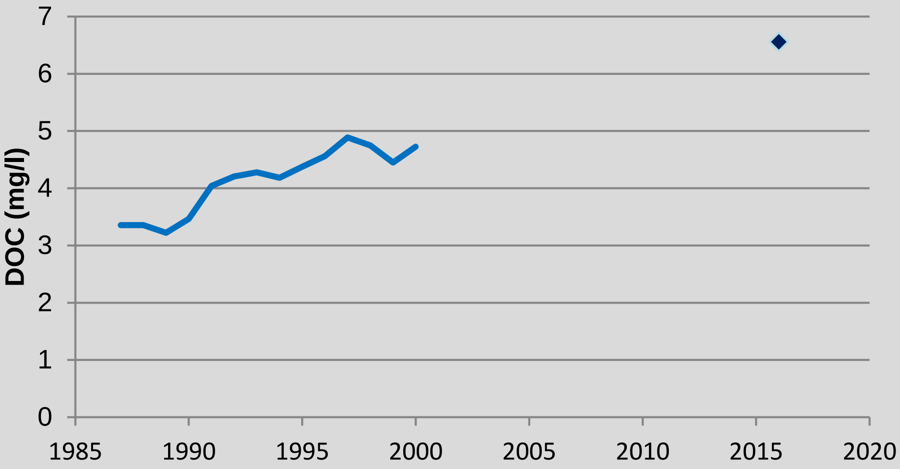
Krause and Sucker (2016)



Dissolved Organic Carbon



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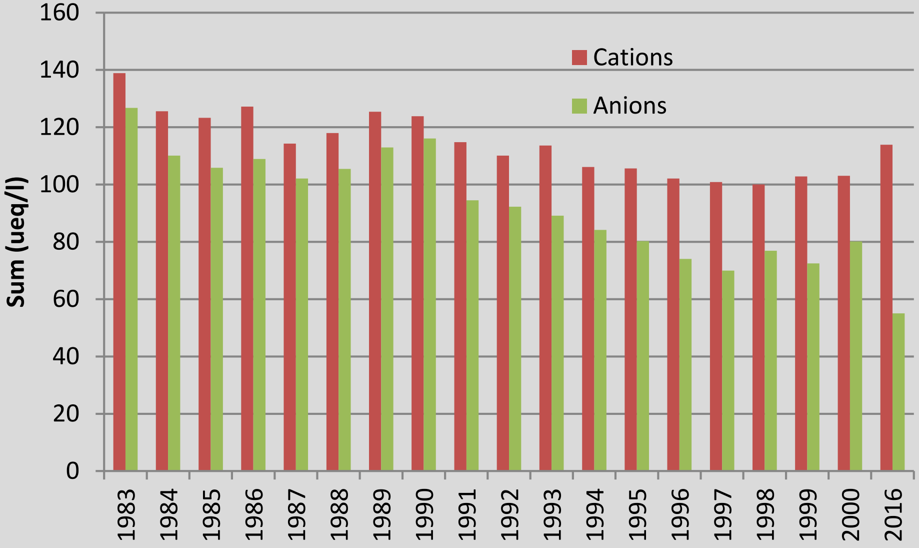
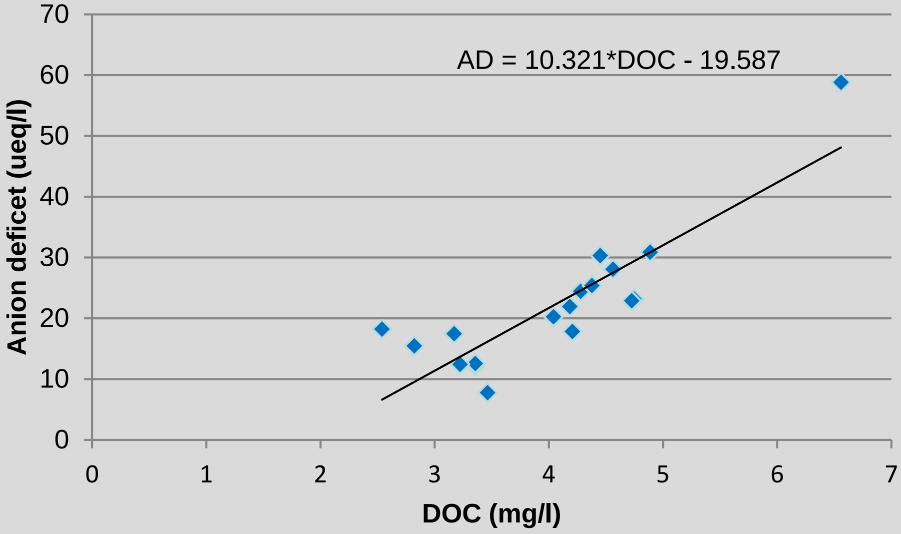
Krause and Sucker (2016)

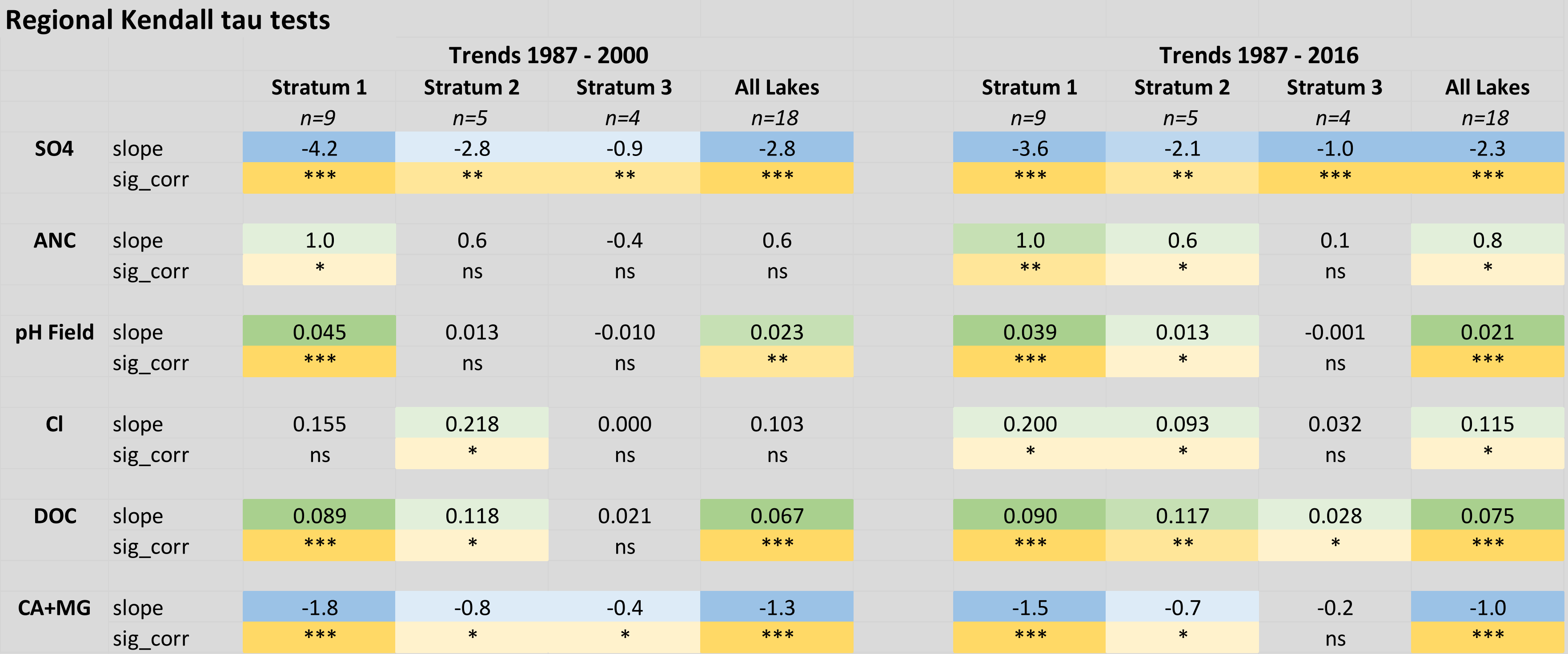




Results of regional Kendall tau trend test

(1987 – 2000 data and 1987 – 2016 data)

Str 1 -> low ANC, low Colour
Str 2 -> low ANC, high Colour
Str 3 -> higher ANC, low Colou



Regional Kendall tau tests

		Trends 1987 - 2000				**Trends 1987 - 2016**			
		Stratum 1	**Stratum 2**	**Stratum 3**	**All Lakes**	**Stratum 1**	**Stratum 2**	**Stratum 3**	**All Lakes**
		n=9	*n=5*	*n=4*	*n=18*	*n=9*	*n=5*	*n=4*	*n=18*
SO4	slope	-4.2	-2.8	-0.9	-2.8	-3.6	-2.1	-1.0	-2.3
	sig_corr	***	**	**	***	***	**	***	***
ANC	slope	1.0	0.6	-0.4	0.6	1.0	0.6	0.1	0.8
	sig_corr	*	ns	ns	ns	**	*	ns	*
pH Field	slope	0.045	0.013	-0.010	0.023	0.039	0.013	-0.001	0.021
	sig_corr	***	ns	ns	**	***	*	ns	***
Cl	slope	0.155	0.218	0.000	0.103	0.200	0.093	0.032	0.115
	sig_corr	ns	*	ns	ns	*	*	ns	*
DOC	slope	0.089	0.118	0.021	0.067	0.090	0.117	0.028	0.075
	sig_corr	***	*	ns	***	***	**	*	***
CA+MG	slope	-1.8	-0.8	-0.4	-1.3	-1.5	-0.7	-0.2	-1.0
	sig_corr	***	*	*	***	***	*	ns	***

Trends show:

- Stratum 1 lakes had strongest trends in ion concentration, pH, and DOC
- SO4 showed largest change (slope), followed by Ca+Mg; ANC trends weak
- pH and DOC increases strongest in Stratum 1
- Most acid sensitive lakes = Stratum 1 (as designed) and showed major changes over 3 decades
- Reductions in SO4 deposition reflected in declines in lake SO4 in all strata but other trends interact.

Summary

- Retrieved and reviewed past data sets
- Conducted field campaign on subset (n=18) of original lakes
- Lake responses differ depending on ambient lake chemistry
- Atmospheric acid concentrations strongly declining
- Concurrent decline in acid anions
- Small decline and stabilizing of base cation concentrations
- Slight increases of salt ions despite decrease in atmospheric concentrations
- Significant increase in DOC
- Caution when interpreting single point with large time gap.

WDNR photo

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