Statistical Analyses on Legacy data of the GRSM Stream Survey

Time Trend Analysis, ANOVA, Power Analysis

Tim Pobst

Department of Civil and Environmental Engineering
University of Tennessee

March 12, 2014

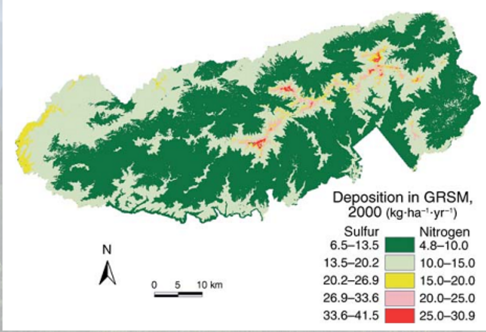
Contents

Description of study area

- Straddles the border of Tennessee and North Carolina
- Diverse wildlife, plant life, and fisheries.

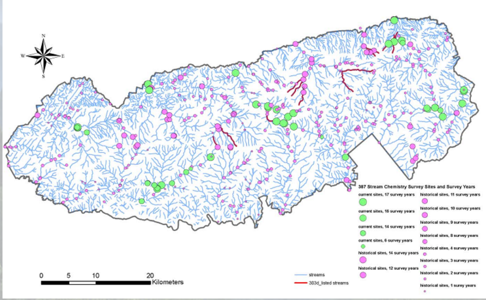
Acid Deposition and the GRSM

- Acid deposition negatively affects the park.
- Higher elevations are effected worse.



Database

- 1993 - ?
- The number of sites monitored has decreased over the years



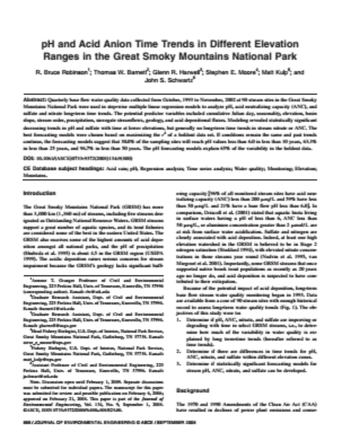
Elevation Bands

- 11 historical elevation bands
- re-organized into six more powerful bands

Elevation Classes	Meters (Feet)	n	Site #
1	304.8-609.6 (1000-2000)	5	13 ,23, 24, 30, 479
2	609.6-762 (2000-2500)	9	4, 311, 268, 480, 310, 483, 147, 148, 484
3	762-914.4 (2500-3000)	13	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224
4	914.4-1066.8 (3000-3500)	4	143, 142, 73, 71
5	1066.8-1371.6 (3500-4500)	4	74, 221, 251, 233
6	1371.6 $<$ (4500 $<$)	2	253, 234

Time sets

1. 1993-2002: The years previously studied by Dr. Robinson
2. 2003-2008: Up to 2008, the year Kingston and Bull-run installed sulfate scrubbers
3. 2009-2012: After the scrubbers were installed up to the most recent data available



pH and Acid Anion Time Trends in Different Elevation Ranges in the Great Smoky Mountains National Park

R. Bruce Robinson[1]; Thomas W. Barnett[2]; Glenn R. Harwell[3]; Stephen E. Moore[4]; Matt Kulp[5]; and John S. Schwartz[6]

Introduction

Background

Time sets

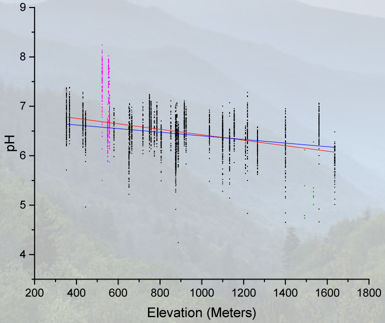
1. 1993-2002: The years previously studied by Dr. Robinson
2. 2003-2008: Up to 2008, the year Kingston and Bull-run installed sulfate scrubbers
3. 2009-2012: After the scrubbers were installed up to the most recent data available

Time sets

1. 1993-2002: The years previously studied by Dr. Robinson
2. 2003-2008: Up to 2008, the year Kingston and Bull-run installed sulfate scrubbers
3. 2009-2012: After the scrubbers were installed up to the most recent data available

Data Smoothing

- Outliers and Influential observations
- Removed Abrams and sites associated with Anakesta



Objectives

One

Determine conditions of stream pH and acidic anions within elevation bands.

- Time trends
- Means Comparisons

Two

Determine statistical power for water quality parameters.

- Post Hoc Analysis
- A priori Analysis

Objectives

One

Determine conditions of stream pH and acidic anions within elevation bands.

- Time trends
- Means Comparisons

Two

Determine statistical power for water quality parameters.

- Post Hoc Analysis
- A priori Analysis

Objectives

One

Determine conditions of stream pH and acidic anions within elevation bands.

- Time trends
- Means Comparisons

Two

Determine statistical power for water quality parameters.

- Post Hoc Analysis
- A priori Analysis

Objectives

One

Determine conditions of stream pH and acidic anions within elevation bands.

- Time trends
- Means Comparisons

Two

Determine statistical power for water quality parameters.

- Post Hoc Analysis
- A priori Analysis

Stream Survey trend analysis history

Robinson 2008

- Time trends for water quality variables were computed for 90 sites in 10 elevation bands for the years 1993 to 2002.
- Predictions for stream pH

Results

pH is decreasing at at rate of -0.0127 to -0.0260 pH units/year for Elevation Classes 2-6.

Biotics Effects report 2013

- Time trends for water quality variables were computed for 67 sites for the years 1993 to 2009.

Stream Survey trend analysis history

Robinson 2008

- Time trends for water quality variables were computed for 90 sites in 10 elevation bands for the years 1993 to 2002.
- Predictions for stream pH

Biotics Effects report 2013

- Time trends for water quality variables were computed for 67 sites for the years 1993 to 2009.

Results

pH will reach a deadly 5.0 in 9.4 years in elevation class 6 (914-1067m)

Stream Survey trend analysis history

Robinson 2008

- Time trends for water quality variables were computed for 90 sites in 10 elevation bands for the years 1993 to 2002.
- Predictions for stream pH

Biotics Effects report 2013

- Time trends for water quality variables were computed for 67 sites for the years 1993 to 2009.

Results

- Most showed no trend
- 22 showed an increase in pH
- Only 2 showed a decrease

Two equation methods

Step-wise: $Y = \beta_0 + \beta_1 T + \beta_2 X + \beta_n X + \epsilon$

- Multi-step process of adding and removing variables
- A variable with an F test statistic of .05 or higher can enter but would be removed if it exceeded .10.
- If any of the time variables were chosen by the step-wise method, the others were forced in.

Time Variables: $Y = \beta_0 + \beta_1 JulianDate + \beta_2 \sin(\theta) + \beta_3 \cos(\theta) + \epsilon$

- Remove the confusion caused by extra non-time based variables
- Inherently weaker because time doesn't explain all the variation of the dependent variables.

Step-wise equations

Dependent (n)	Model	Adjusted r^2	Model p
pH (3116)	$.673 \times \log_2(\text{Sum Base Cations}) + (-.368 \times NO_3) + (.262 \times \text{Julian Day}) + (-.266 \times SO_4) + (-.050 \times \cos(\theta))$	0.630	<0.001
ANC (3116)	$(.415 \times \text{Sum Base Cations}) + (-.185 \times SO_4) + (.595 \times \text{Conductivity}) + (-.102 \times NO_3) + (.019 \times \text{Julian Date}) + (.005 \times Cl) + (.005 \times \sin(\theta))$	0.984	0.049
NO_3 (3116)	$(-.295 \times SO_4) + (-3.183 \times ANC) + (2.19 \times \text{Conductivity}) + (.923 \times \text{Sum Base Cations}) + (.120 \times \text{Julian Date}) + (.051 \times Cl) + (.047 \times \sin(\theta)) + (.031 \times \cos(\theta))$	0.498	0.017
SO_4 (3116)	$(-.166 \times NO_3) + (2.318 \times \text{Conductivity}) + (-3.229 \times ANC) + (1.033 \times \text{Sum Base Cations}) + (.042 \times \text{Julian Date})$	0.720	<0.001

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- pH is negative in only 3 significant lines, all in the 93'-02' time set, in elevation classes 2, 3, and 5
- Overall pH is increasing over time

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Eleven positive trends ranging from 0.005 to 0.901 μeqL^{-1}
- Seven negative trends ranging from -0.002 to -0.082 μeqL^{-1}
- Overall ANC is increasing over time

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Trends for time set 1 are half positive and half negative
- Trends in set 2 are all positive, from 0.038 to 0.204 μeqL^{-1}
- There is only one decreasing trend in set3, class 4 (-0.013 μeqL^{-1})
- Overall nitrate is increasing over time

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- All trends are positive in set 2, ranging from 0.034 to 0.161 μeqL^{-1}
- Trends in set 3, classes 1, 3, and 6 are negative
- Trends are increasing from set 1 to set 2, but decreasing from set 2 to set 3

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Set 1 contains 0 significant lines and together sets 2 and 3 are half insignificant
- Other than prevalent insignificance, the trends for the time variables are similar to those of the the step-wise equations
- Overall pH is slowly increasing over time

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Only 2 of the 24 trends are significant
- Set 1, class 5 has a decreasing trend of -0.148 μeqL^{-1}
- Set 3, class 5 has a increasing trend of 0.891 μeqL^{-1}
- Overall ANC is increasing over time

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Only 6 of the 24 trends are significant, 2 in set 1, 4 in set 2, 0 in set 3
- Ever trend is increasing except set 1, class 1, which is -0.138 μeqL^{-1}
- The increasing trends range from 0.155 $\mu eq/L$ to 0.330 μeqL^{-1}
- Overall nitrate is increasing over time
- The trends are decreasing from set 2 to 3, but all of set 3 is insignificant

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate decreasing

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Trend Results

- Only 5 of the 24 trends are significant, 1 in set 1, 4 in set 2, 0 in set 3
- Ever trend is increasing except set 1, class 1, which is -0.190 μeqL^{-1}
- The increasing trends range from 0.138 μeqL^{-1} to 0.307 μeqL^{-1}
- Overall sulfate is increasing over time
- The trends are decreasing from set 2 to 3, but all of set 3 is insignificant

Elevation Trends

- pH and ANC decrease as elevation increases
- Nitrate, sulfate, and SBC all increase as elevation increases
- Except for SBC all elevational trends decrease over time

Table: Dependents regressed against elevation.

set	Dependent	n	slope	r^2	per +1000m
1	pH	1357	.000	.173	-0.411
	ANC	1354	-.056	.199	-56.227
	NO_3^-	1161	.032	.372	32.211
	SO_4^{2-}	1343	.037	.108	37.371
	SBC	1358	.013	.005	13.065
2	pH	997	.000	.094	-0.391
	ANC	997	-.051	.157	-50.970
	NO_3^-	995	.031	.307	30.677
	SO_4^{2-}	1029	.036	.098	35.793
	SBC	1031	.016	.009	15.537
3	pH	757	.000	.061	-0.286
	ANC	757	-.036	.087	-35.689
	NO_3^-	757	.026	.195	25.924
	SO_4^{2-}	757	.030	.101	29.715
	SBC	757	.020	.014	19.905

Table: Dependents regressed against elevation.

set	Dependent	n	slope	r^2	per +1000m
1	pH	1357	.000	.173	-0.411
	ANC	1354	-.056	.199	-56.227
	NO_3^-	1161	.032	.372	32.211
	SO_4^{2-}	1343	.037	.108	37.371
	SBC	1358	.013	.005	13.065
2	pH	997	.000	.094	-0.391
	ANC	997	-.051	.157	-50.970
	NO_3^-	995	.031	.307	30.677
	SO_4^{2-}	1029	.036	.098	35.793
	SBC	1031	.016	.009	15.537
3	pH	757	.000	.061	-0.286
	ANC	757	-.036	.087	-35.689
	NO_3^-	757	.026	.195	25.924
	SO_4^{2-}	757	.030	.101	29.715
	SBC	757	.020	.014	19.905

Elevation Trends

- pH and ANC decrease as elevation increases
- Nitrate, sulfate, and SBC all increase as elevation increases
- Except for SBC all elevational trends decrease over time

Elevation Trends

- pH and ANC decrease as elevation increases
- Nitrate, sulfate, and SBC all increase as elevation increases
- Except for SBC all elevational trends decrease over time

Table: Dependents regressed against elevation.

set	Dependent	n	slope	r^2	per +1000m
1	pH	1357	.000	.173	-0.411
	ANC	1354	-.056	.199	-56.227
	NO_3^-	1161	.032	.372	32.211
	SO_4^{2-}	1343	.037	.108	37.371
	SBC	1358	.013	.005	13.065
2	pH	997	.000	.094	-0.391
	ANC	997	-.051	.157	-50.970
	NO_3^-	995	.031	.307	30.677
	SO_4^{2-}	1029	.036	.098	35.793
	SBC	1031	.016	.009	15.537
3	pH	757	.000	.061	-0.286
	ANC	757	-.036	.087	-35.689
	NO_3^-	757	.026	.195	25.924
	SO_4^{2-}	757	.030	.101	29.715
	SBC	757	.020	.014	19.905

Data differences

Robinson 08

- 90 sites
- 11 elevation classes
- 1993 - 2002, 10 years
- includes Abrams and sites 237 and 252

Schwartz 13

- 67 sites
- 11 elevation classes
- 1993 - 2009, 17 years

Pobst 14

- 43 sites
- 6 elevation classes
- set 1: 10 years
- set 2: 6 years
- set 3: 4 years
- removed Abrams and sites 237 and 252

Results by comparison

Schwartz 13

- pH decreased -1.056 pH units per 1000 m gain
- ANC decreased -117.909 μeqL^{-1} per 1000 m gain
- insignificant negative trend for sulfate

Pobst 14

- pH decreased -0.0286 pH units per 1000 m gain
- ANC decreased -35.689 μeqL^{-1} per 1000 m gain
- Positive sulfate elevational trends decrease over time

Conclusions on Sulfate

sulfate desorption is of greater concern than pH levels in the park

- Lack of trend found in the Biotics effects report were attributed to high elevation soil adsorption of depsotional sulfate
- Sulfate will remain absorbed to soil particles as long as soil water chemistry remains high in sulfate concentration and low in pH
- Over time most sulfate concentrations are increasing but in set 3: classes 1, 4, and 6 have negative trends
- The elevation trend is decreasing over time
- The combination of these trends support desorption of sulfate into the streams bringing the elevation trend to equilibrium

- ANOVA/Bonferroni
- Discussion

- ANOVA/Bonferroni
- Discussion

- ANOVA/Bonferroni
- Discussion

- Power Analysis
- Post Hoc
- A priori
- Manipulation

- Power Analysis
- Post Hoc
- A priori
- Manipulation

- Power Analysis
- Post Hoc
- A priori
- Manipulation

- Power Analysis
- Post Hoc
- A priori
- Manipulation

- Power Analysis
- Post Hoc
- A priori
- Manipulation

Summary

- Water Quality is getting better
- Sulfate sequestration is supported
- The power of the time trends are excelent
- Power analysis can help re-distribute sites

- Outlook
    - Elevation Bands
    - Effects of sulfate scrubbers

Summary

- Water Quality is getting better
- Sulfate sequestration is supported
- The power of the time trends are excelent
- Power analysis can help re-distribute sites

- Outlook
  - Elevation Bands
  - Effects of sulfate scrubbers

Summary

- Water Quality is getting better
- Sulfate sequestration is supported
- The power of the time trends are excelent
- Power analysis can help re-distribute sites

- Outlook
  - Elevation Bands
  - Effects of sulfate scrubbers

Summary

- Water Quality is getting better
- Sulfate sequestration is supported
- The power of the time trends are excelent
- Power analysis can help re-distribute sites

- Outlook
  - Elevation Bands
  - Effects of sulfate scrubbers

Summary

- Water Quality is getting better
- Sulfate sequestration is supported
- The power of the time trends are excelent
- Power analysis can help re-distribute sites

- Outlook
  - Elevation Bands
  - Effects of sulfate scrubbers