Introduction

Statistical Analyses on Legacy data of the GRSM Stream Survey

Time Trend Analysis, ANOVA, Power Analysis

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Introduction

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 - Power Analysis
 - Results
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 - Discussion

Great Smoky Mountains

Introduction

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Study area

Description of study area

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



Great Smoky Mountains

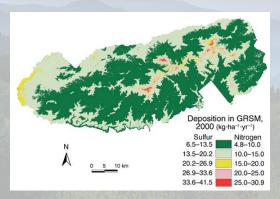
Introduction

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Acid Deposition and the GRSM

Affects and effects

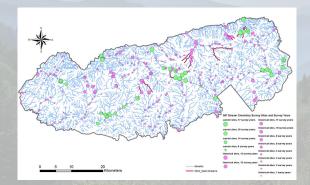
- Acid deposition negatively affects the park.
- Higher elevations are effected worse.



Database

Sites

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



Elevation Bands

Changes

- 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

3 separate sets

- 1993-2002: The years previously studied by Dr. Robinson
- 2003-2008: Up to 2008, the year Kingston and Bull-run installed sulfate scrubbers
- 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'; Thomas W. Barneti'; Glenn R. Harwyd'; Siephen E. Moore'; Matt Kulp'; and

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CSI Database subject headings: And rain; pil, Represion analysis; Time union analysis; Water quality; Mentering; Elevation, Mountains.

Introduction

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Brosse of the potential impact of acid deposition, long-term have fine stream water quality membring larges in 1995, Data are creatable from a core of Wistersen sizes with energy histories, record to assers, long-term water quality towals (Fig. 1). The obpositions of this study was in:

1. Determine of plf., NNC, minute, and suffair are improving or

- Determine of pill, ANC, which, and willist are importing or depending with time in solve! GOM diseases, i.e., to determine how much of the torishibity in water quisity is explained by long investince heads (hereafter relieved to as time threads).
- Determine of three are differences in time treats for pH, ANC, which, and stillate within different elevation irone.
 Determine of statistically eignificant formacting models for virus pH, ANC, which, and stillate can be developed.

Background

The 1970 and 1990 Assendments of the Clean Air Act (CAA) have resulted in declines of press plant emissions and conse-

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Time Sets

Stream Survey

3 separate sets

- 1993-2002: The years previously studied by Dr. Robinson
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- 2009-2012: After the scrubbers were installed up to the most recent data available



Time Sets

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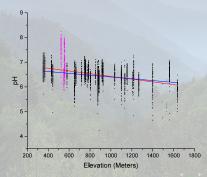
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- 2009-2012: After the scrubbers were installed up to the most recent data available



Data Smoothing

Outliers and Influential observations

- Influential observations are studied
 - Removed Abrams and sites associated with Anakesta
 - Others are reviewed individually
 - Outliers remain



Objectives

One

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

- Time trends
- Means Comparisons

Two

- Post Hoc Analysis
- A priori Analysis

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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

Results

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

Stream Survey trend analysis history

Robinson 2008

- Time trends for water quality
- Predictions for stream pH

Biotics Effects report 2013

Time trends for water quality

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



Introduction 0000000 Regression

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: $Y = \beta_0 + \beta_1 JulianDate + \beta_2 \sin(\theta) + \beta_3 \cos(\theta) + \beta_3 \sin(\theta) + \beta_4 \sin(\theta) + \beta_5 \cos(\theta) + \beta_5 \sin(\theta) + \beta_5 \sin(\theta) + \beta_5 \cos(\theta) + \beta_5 \sin(\theta) + \beta_5 \cos(\theta) + \beta_5 \sin(\theta) + \beta_5 \cos(\theta) +$

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

Two equation methods

Table: Equations created through step-wise variable selection

Dependent (n)	Model	Adjusted r ²	Model p
pH (3116)	$.673 \times \log_2(\text{Sum Base Cations}) + (368 \times \text{NO}_3) + (.262 \times \text{Julian Day}) + (266 \times \text{SO}_4) + (950 \times \cos(\theta))$	0.630	<0.001
ANC (3116)	(.415 × Sum Base Cations) + (185 × SO ₄) + (.595 × Conductivity) + (102 × NO ₃) + (.019 × Julian Date) + (.005 × Cl) + (.005 × $\sin(\theta)$)	0.984	0.049
NO ₃ (3116)	$(295 \times SO_4) + (-3.183 \times ANC) + (2.19 \times Conductivity) + (.923 \times Sum Base Cations) + (.120 \times Julian Date) + (.051 \times Cl) + (.047 \times sin(\theta)) + (.031 \times cos(\theta))$	0.498	0.017
SO ₄ (3116)	$\begin{array}{l} (166\times \mathrm{NO_3}) + (2.318\times \mathrm{Conductivity}) + \\ (-3.229\times \mathrm{ANC}) + (1.033\times \mathrm{Sum\ Base\ Cations}) + (.042\times \mathrm{Julian\ Date}) \end{array}$	0.720	<0.001

Two equation methods

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

- 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.
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Time Variables: $Y = \beta_0 + \beta_1$ Julian Date $+ \beta_2 \sin(\theta) + \beta_3 \cos(\theta) + \epsilon$

- 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

Results

- pH increasing
- ANG increasing
- Nitrate increasing
- 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

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

Step-wise equations

- pH increasing
- ANC increasing
- Nitrate increasing
- Sulfate

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

- 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

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

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

Step-wise equations

Results

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

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

- 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

- 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

Results

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

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

- 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 μegL⁻¹
- Overall ANC is increasing over time

Step-wise equations

Results

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

Time Variables

Only 20 of the 72 trends are significant

- pH increasing
- ANC increasing
- Nitrate
- Sulfate

- 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 μ eq L^{-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

- 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 μ eqL⁻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

Table: Dependents regressed against elevation.

Three 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

	set	Dependent	n	slope	r ²	per +1000m
	1	pH ANC NO ₃ SO ₄ ²⁻ SBC	1357 1354 1161 1343 1358	.000 056 .032 .037 .013	.173 .199 .372 .108 .005	-0.411 -56.227 32.211 37.371 13.065
	2	pH ANC NO ₃ SO ₄ ²⁻ SBC	997 997 995 1029 1031	.000 051 .031 .036 .016	.094 .157 .307 .098 .009	-0.391 -50.970 30.677 35.793 15.537
	3	pH ANC NO ₃ SO ₄ ² SBC	757 757 757 757 757 757	.000 036 .026 .030 .020	.061 .087 .195 .101 .014	-0.286 -35.689 25.924 29.715 19.905

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Elevation trends

Table: Dependents regressed against elevation.

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- Nitrate, sulfate, and SBC all increase as elevation increases
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	set	Dependent	n	slope	r ²	per +1000m
	1	pH ANC	1357 1354	.000 056	.173 .199	-0.411 -56.227
		NO ₃	1161	.032	.372	32.211
		SO ₄ ² - SBC	1343 1358	.037 .013	.108 .005	37.371 13.065
	2	pH ANC	997 997	.000 051	.094	-0.391 -50.970
		NO ₃	995	.031	.307	30.677
		SO ₄ ² - SBC	1029 1031	.036	.098	35.793 15.537
	3	pH ANC NO ₃ SO ₄	757 757 757 757	.000 036 .026	.061 .087 .195 .101	-0.286 -35.689 25.924 29.715
		SBC	757	.020	.014	19.905

Elevation Trend Results by comparison

Robinson 08

- pH decreases
 -0.72 pH units
 per 1000 m gain
- Elevation not a predictor for any other dependen

Schwartz 13

- pH decreases
 -1.056 pH units
 per 1000 m gain
- ANC decreases

 -117.909 μeqL⁻¹
 per 1000 m gain
- Insignificant negative trend for sulfate

- pH decreases
 -0.0286 pH units
 per 1000 m gain
- ANC decreases -35.689 μeqL⁻¹ per 1000 m gain
- Positive sulfate elevational trends decrease over time

Robinson 08

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Results

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 -0.72 pH units
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 - ANC decreases
 -35.689 μeqL⁻¹
 per 1000 m gain
- Positive sulfate elevational trends decrease over time

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

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

Conclusions

Sulfate

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

- Over time most sulfate trends are positive but in set 3: classes 1, 4, and 6 have negative trends (-0.052, -0.068, -0.059)
- The elevation trend is decreasing over the three time sets

Table: Julian date coefficients from step-wise regression for set 3.

Elevation class	Elevation range m (ft)	Number of sites		e coefficien r ²) (p-value	t, μ eq/L or pH	units (model
	• ,		pH	ANC	Nitrate	Sulfate
1	304.8-609.6 (1000-2000)	5	0.106 0.894	-0.002 0.989	0.026 0.376	-0.052 0.536
	(2000)		0.000	0.000	0.000	0.000
2	609.6-762 (2000-2500)	9	0.218 0.606	0.069 0.862	0.121 0.735	0.039 0.887
			0.000	0.000	0.000	0.000
3	762-914.4 (2500-3000)	13	0.056 0.766 0.000	0.007 0.997 0.000	0.019 0.598 0.000	0.050 0.915 0.000
4	914.4-1066.8 (3500-3500)	4	0.413 0.593 0.000	-0.006 0.772 0.000	-0.013 0.635 0.000	-0.068 0.529 0.000
5	1066.8-1371.6 (3500-4500)	4	-0.115 0.158 0.130	0.901 0.540 0.001	0.098 -0.272 0.975	0.015 0.658 0.000
6	1371.6< (4500 <)	2	0.289 0.286 0.000	0.059 0.809 0.000	0.097 0.881 0.000	-0.059 0.861 0.000

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 4, and 6 have negative trends (-0.052, -0.068, -0.059)
- The elevation trend is decreasing over the three time sets (37.371, 35.793, 29.715)
- pH is increasing while the sulfate trends are decreasing
- This combination could lead to sulfate desorption

Table: Dependents regressed against elevation.

set	Dependent	n	slope	r ²	per +1000m
1	рН	1357	.000	.173	-0.411
	ANC	1354	056	.199	-56.227
	NO ₃	1161	.032	.372	32.211
	SO ₄	1343	.037	.108	37.371
	SBĊ	1358	.013	.005	13.065
2	рН	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
	SBČ	1031	.016	.009	15.537
3	рН	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
	SBČ	757	.020	.014	19.905

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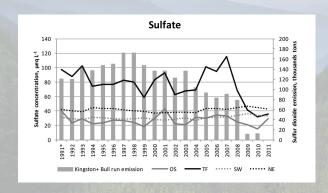
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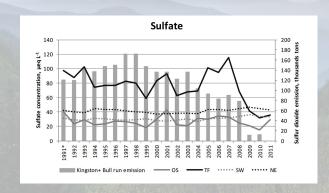
Hypothesis

Is there a correlation between the decrease in Noland Divide TF sulfate concentrations and the decrease of sulfur dioxide emissions from Kingston and Bull run power plant emissions due to the installation of scrubbers in 2008?



Hypothesis

If there is a correlation between the decrease of sulfate concentrations and lowered sulfur dioxide emissions, then time sets 2 and 3 will not be statistically equal.



Bonferroni

- The three time sets will be tested against each other for sameness
- With more than 2 groups ANOVA cannot say which groups are the same or not the same
- The Bonferroni method can achieve this
 - It will compare all time sets with each other in pairs (1:2, 1:3, 2:3)
 - SPSS multiplies the p-value of the least significant differences (LSD) by the number of tests
 - Insignificant comparisons are considered statistically equal

рН

• pH comparisons are more unequal than any other dependent

ANOVA

More inequalities versus set 3 than any other

Elevation Classes		рН			ANC			Nitrate			Sulfate	1
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	=	#	#	=	= 0	=	7	=	=	70.16	31=	T = 1
2	=	=	=	=	#	=	#	#	=	#	#	=
3	#	#	#	=	≠	=	=	\neq	#	=	=	=
4	=	#	#	=	=	=	= ±	=01	=	=	=	=
5	#	#	#	=	#	#	#	=	#	=	=	=
6	=	#	#	=	=	=	=	=	=	=	=	=

рΗ

- pH comparisons are more unequal than any other dependent
- More inequalities versus set 3 than any other

Elevation Classes		рН			ANC			Nitrate			Sulfate	*
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	<i>≠</i>	<i>≠</i>	#	=	= 1	=	<i>≠</i>	=	=	36.46	S =	T =
2	=	=	=	=	≠	=	#	≠	=	#	#	=
3	#	#	#	=	≠	=	=	#	#	=	=	=
4	= 4	#	#	=	=	=	= =	=00	=	=	=	=
5	#	<i>≠</i>	#	=	#	#	+	=.	#	=	=	=
6	=	<i>≠</i>	#	=	200=a	=	=	=	=	=	15=2	=

ANC

- More equal than unequal groups
- Sets 1 and 2 are always equal, not so with set 3

Elevation Classes		рН			ANC			Nitrate			Sulfate	100
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	<i>≠</i>	#	#	=	= 1	=	7	=	=	The safe	S =)	=
2	=	=	=	=	≠	=	#	#	=	#	#	=
3	#	#	#	=	≠	=	=	#	#	=	=	=
4	=	#	#	=	=	=	= =	=01	=	=	=	=
5	#	<i>≠</i>	#	=	#	#	+	=	#	=	=	=
6	=	<i>≠</i>	<i>≠</i>	=	=	=	=	=	=	=	=	=

ANOVA 00000

ANC

- More equal than unequal groups
- Sets 1 and 2 are always equal, not so with set 3

Elevation Classes		рН			ANC			Nitrate			Sulfate	*
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	<i>≠</i>	+	#	=	= 1	=	7	=	=	The safe	S =)	=
2	=	=	=	=	≠	=	#	#	=	#	#	=
3	#	#	+	=	\neq	=	=	\neq	#	=	=	=
4	=	#	#	=	=	=	= =	=01	=	=	=	=
5	#	<i>≠</i>	#	=	#	#	+	=	#	=	=	=
6	=	<i>≠</i>	<i>≠</i>	=	=	=	=	=	=	=	=	=

ANOVA

Nitrate

- Classes 4 and 6 are equal across all time sets
- Difference in means seems to move up in elevation

Elevation Classes		рН			ANC			Nitrate			Sulfate	100
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	<i>≠</i>	+	#	=	=	=	7	=	=	The sale	S = 1	=
2	=	=	=	=	#	=	\neq	≠	= 1	#	#	=
3	#	#	#	=	#	=	=	≠	#	=	=	=
4	=	#	#	=	=	=	= +	=00	=	=	=	=
5	#	<i>≠</i>	#	=	#	#	#	=	#	=	=	=
6	=	<i>≠</i>	<i>≠</i>	=	=	=	-	=	=	=	=	=

ANOVA

Nitrate

- Classes 4 and 6 are equal across all time sets
- Difference in means seems to move up in elevation

Elevation Classes		рН			ANC			Nitrate			Sulfate	1
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	¥	#	#	=	=	=	≠	=	=	7k.ud	3 (=)	=
2	=	=	=	=	#	=	#	#	=	#	#	=
3	#	#	#	=	#	=	=	<i>≠</i>	#	=	=	=
4	=	#	#	=	=	=	= =	=00	= 4	=	=	=
5	#	<i>≠</i>	#	=	#	#	#	=	#	=	=	=
6	=	*	· +	=	=	=	-	=	=	=	=	=

Sulfate

- All sets are equal for all classes except for comparisons in class 2
- All comparisons between sets 2 and 3 are equal

Elevation Classes		рН			ANC			Nitrate			Sulfate	
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	#	+	#	=	=	=	<i>≠</i>	=	=	- Lud	S = 1	-
2	=	=	=	=	#	=	#	#	=	#	≠	=
3	#	#	#	=	#	=	=	#	#	=	=	=
4	=	#	#	=	=	=	= =	= 01	=	=	=	=
5	#	<i>≠</i>	#	=	#	#	#	=	#	= 1	=	=
6	=	#	#	=	=	=	=	=	=	=	=	=

Sulfate

- All sets are equal for all classes except for comparisons in class 2
- All comparisons between sets 2 and 3 are equal

Elevation Classes		рН			ANC			Nitrate			Sulfate	1
	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3	1-2	1-3	2-3
1	<i>≠</i>	+	+	=	=	=	<i>≠</i>	=	=	76.44	=	=
2	=	=	=	=	#	=	\neq	\neq	=	#	#	=
3	#	#	+	=	<i>≠</i>	=	=	#	#	=	=	=
4	=	#	+	=	=	=	= =	=	=	=	=	=
5	#	<i>≠</i>	+	=	<i>≠</i>	#	+	=	#	=	in Ex	=
6	=	*	*	=	=	=	=	=	=	= "	0 = 2	=

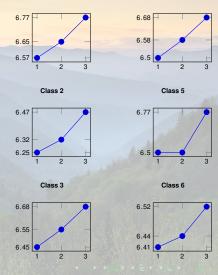
Class 1

Class 4

Line graphs

рН

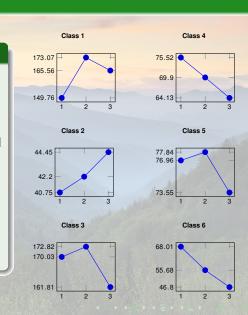
- Class 2 always contains the lowest pH mean instead of 6
- Class 3 belongs between 5 and 6



Line graphs

ANC μ egL $^{-1}$

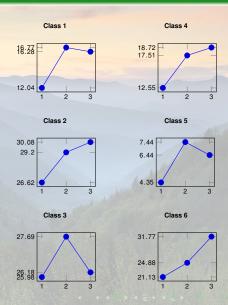
- All classes decrease from set 2 to 3 except for class 2, which is increasing
- Concentrations vary greatly across classes, classes 1 and 2 are more than double the others
- They are the lowest in class 2 which corresponds to the low pH values for class 2, but class 2 is also the only class that is increasing



Line graphs

Nitrate μeqL^{-1}

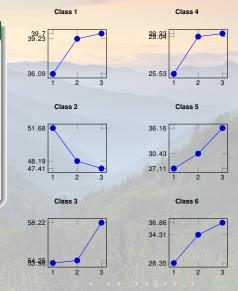
- The odd classes all have decreasing means from sets 2 to 3
- Classes 2 and 4 have mean values for set 3 that are greater than set 2, but the rate of change is decreasing
- Class 6 is always increasing



Line graphs

Sulfate μeqL^{-1}

- Set 3 means are greater than set 2 means in all but class 2
- In classes 1, 4, and 6 the rate of change is decreasing
- Concentrations seem to be increasing across the sets in classes 3 and 5
- Class 2 has a decreasing decreasing trend



Discussion and Conclusions

Introduction

Conclusions

Sulfate

- No evidence in support of a decrease in stream sulfate caused by decrease of sulfur dioxide emissions
- If sulfate is being sequestered, it may need to be depleted before a trend can be noticed

Introduction

Power Analysis

- The power of a test to correctly reject the null hypothesis
- Commonly used to determine number of observations required for a desired power
- Post-hoc analysis is used when the test is already completed
- A Priori analysis is used when planning a new test

		Unkn	own True Situation
		H ₀ is true	H ₀ is false
Decision	Fail to reject H ₀	Correct decision Prob(correct decision) = $1-\alpha$	Type II error Prob(Type II error) = β
0	Reject H ₀	Type I error Prob (Type I error) = α Significance level	Correct decision Prob (correct decision) = $1-\beta$ Power

Two Analyses

Post Hoc "after this"

- Preformed on all trend lines found in the trend analysis
- Reports the power and ES of the current stream survey
- Requires number of predictors, adjusted r^2 , α and N values as input
- Calculates 144 ES values and 144 powers for each of the 144 trend lines

A Priori "from the earlier

- Used to find # of observations for each water quality variable
- Requires choosing desired powers and ES values (a scenario)
- Requires proposed number of predictors as input
- Calculates *N* for each the four dependent variables
- And presents a power graph for all powers and their N values

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- Calculates N for each the four dependent variables
- And presents a power graph for all powers and their N values

Power Analysis

Effect Size

- Differentiates between tests using Effect Size (ES)
- Cohen describes it as the probability of finding a significant result
- ES is like a lens that an analyst looks at the regression line through to see a "trend"
- Regression: $ES = \frac{adj.r^2}{1-adi.r^2}$

Results

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
 - pH set 3 class 5, lowest power of .28
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

- 52 of the 72 trends were insignificant
- 20 significant trends ranging from .26 to 1.00
 - 11 of them are greater than .80
 - 2 are greater than .99

Table: ANC Step-Wise Post Hoc Power Analysis Results

Set	Class	N	Adjusted r ²	Effect Size	Actual Power
1993-2002	1 2 3 4 5 6	327 392 398 120 116 110	0.985 0.603 0.971 0.709 0.760 0.802	65.67 1.52 33.48 2.44 3.17 4.05	1.00 1.00 1.00 1.00 1.00 1.00
2003-2008	1 2 3 4 5 6	255 289 299 119 35 97	0.996 0.779 0.996 0.779 0.739 0.812	249.00 3.52 249.00 3.52 2.83 4.32	1.00 1.00 1.00 1.00 1.00
2009-2012	1 2 3 4 5 6	191 212 228 97 29 76	0.989 0.862 0.997 0.772 0.540 0.809	89.91 6.25 332.33 3.39 1.17 4.24	1.00 1.00 1.00 1.00 0.96 1.00

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Table: Sulfate Step-Wise Post Hoc Power Analysis Results

Se	et Class	N	Adjusted r ²	Effect Size	Actual Power
1993-2002	1 2 3 4 5	325 390 391 119 116 110	0.569 0.766 0.590 0.402 0.566 0.716	1.32 3.27 1.44 0.67 1.30 2.52	1.00 1.00 1.00 1.00 1.00
2003-2008	1 2 3 4 5 6	261 298 308 123 37 101	0.673 0.893 0.923 0.343 0.884 0.844	2.06 8.35 11.99 0.52 7.62 5.41	1.00 1.00 1.00 1.00 1.00 1.00
2009-2012	1 2 3 4 5 6	190 212 228 97 29 76	0.536 0.887 0.915 0.529 0.658 0.861	1.16 7.85 10.76 1.12 1.92 6.19	1.00 1.00 1.00 1.00 1.00 1.00

Post Hoc

Step-wise equations

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 - pH set 3 class 5, lowest power of .28
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Time variables

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 - 11 of them are greater than .80
 - 2 are greater than 99

Table: pH Step-Wise Post Hoc Power Analysis Results

Set	Class	N	Adjusted r ²	Effect Size	Actual Power
1993-2002	1 2 3 4 5	327 393 400 121 116	0.712 0.388 0.693 0.205 0.165	2.47 0.63 2.26 0.26 0.20	1.00 1.00 1.00 0.99 0.96
2003-2008	1 2 3 4 5 6	255 289 299 119 35 97	0.505 0.781 0.348 0.663 0.400 0.300 0.317	3.57 0.53 1.97 0.67 0.43 0.46	1.00 1.00 1.00 1.00 1.00 0.74 1.00
2009-2012	1 2 3 4 5 6	191 212 228 97 29 76	0.894 0.606 0.766 0.593 0.158 0.286	8.43 1.54 3.27 1.46 0.19 0.40	1.00 1.00 1.00 1.00 0.28 0.99

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
 - pH set 3 class 5, lowest power of .28
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

- 52 of the 72 trends were insignificant
- 20 significant trends ranging from .26 to 1.00
 - 11 of them are greater than .80
 - 2 are greater than .99

Table: Nitrate Step-Wise Post Hoc Power Analysis Results

	Set	Class	N	Adjusted r ²	Effect Size	Actual Power
	1993-2002	1 2 3 4 5 6	275 377 365 105 66 81	0.503 0.699 0.359 0.410 0.328 0.871	1.01 2.32 0.56 0.69 0.49 6.75	1.00 1.00 1.00 1.00 0.98 1.00
	2003-2008	1 2 3 4 5 6	252 296 297 121 30 98	0.551 0.816 0.637 0.405 0.562 0.832	1.23 4.43 1.75 0.68 1.28 4.95	1.00 1.00 1.00 1.00 0.98 1.00
	2009-2012	1 2 3 4 5 6	191 212 228 97 29 76	0.376 0.735 0.598 0.635 -0.272 0.881	0.60 2.77 1.49 1.74 NA 7.40	1.00 1.00 1.00 1.00 NA 1.00

Post Hoc

Introduction

Results

Step-wise equations

- 8 are less than 1.0
- 2 were insignificant
 - pH set 3 class 5, lowest power of .28
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

- 52 of the 72 trends were insignificant
- 20 significant trends ranging from .26 to 1.00
 - 11 of them are greater than .80
 - 2 are greater than 99

Table: pH Time Variable Post Hoc Power Analysis Results

Set	Class	N	Adjusted r ²	Effect Size	Actual Power
	1	327	0.047	0.049	0.93
00	2	393	0.128	0.15	1.00
Ķ	3	400	0.013	0.01	0.46
1993-2002	4	121	0.059	0.06	0.61
9	5	116	0.051	0.05	0.52
	6	110	0.096	0.11	0.81
	1	255	0.040	0.04	0.78
8	2	289	0.061	0.06	0.96
2003-2008	3	299	0.020	0.02	0.52
8	4	119	0.148	0.17	0.97
20	5	35	-0.069	NA	NA
	6	97	0.081	0.09	0.67
	1	191	0.028	0.03	0.47
12	2	212	0.052	0.05	0.82
2009-2012	3	228	-0.009	NA	NA
-60	4	97	0.200	0.25	0.99
20	5	29	0.218	0.28	0.58
	6	76	0.039	0.04	0.27
77 T T T T T T T		Name and Address	and the second	AND RESIDENCE	A STATE OF THE PARTY OF THE PARTY.

Results

Step-wise equations

- 8 are less than 1.0
- 2 were insignificant
 - pH set 3 class 5, lowest
 power of 28
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

- 52 of the 72 trends were insignificant
- 20 significant trends ranging from .26 to 1.00
 - 11 of them are greater than .80
 - 2 are greater than .99

Table: Sulfate Time Variable Post Hoc Power Analysis Results

Set	Class	N	Adjusted r ²	Effect Size	Actual Power
	1	325	0.045	0.05	0.92
00	2	390	0.009	0.01	0.32
-5	3	391	-0.004	NA	NA
1993-2002	4	119	-0.016	NA	NA
19	5	116	-0.010	NA	NA
	6	110	-0.009	NA	NA
	1	261	0.043	0.04	0.82
2003-2008	2	298	0.014	0.01	0.37
-50	3	308	0.006	0.01	0.18
03	4	123	0.023	0.02	0.26
20	5	37	-0.024	NA	NA
	6	101	0.074	0.08	0.64
	1	190	0.005	0.01	0.11
12	2	212	-0.010	NA	NA
-50	3	228	-0.007	NA	NA
2009-2012	4	97	-0.011	NA	NA
20	5	29	-0.076	NA	NA
	6	76	0.007	0.01	0.08

Post Hoc

Step-wise equations

- 8 are less than 1.0
- 2 were insignificant
 - pH set 3 class 5, lowest
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

- 52 of the 72 trends were insignificant
- 20 significant trends ranging from .26 to 1.00
 - 11 of them are greater than
 80
 - 2 are greater than .99

Table: Nitrate Time Variable Post Hoc Power Analysis Results

Set	Class	N	Adjusted r ²	Effect Size	Actual Power
1993-2002	1 2 3 4 5	275 377 365 105 66 81	0.016 0.017 -0.004 -0.027 0.120 0.092	0.02 0.02 NA NA 0.14	0.39 0.55 NA NA 0.68 0.64
2003-2008	1 2 3 4 5 6	252 296 297 121 30 98	0.061 0.043 -0.003 0.086 -0.082 0.046	0.06 0.04 NA 0.09 NA 0.05	0.94 0.87 NA 0.80 NA 0.40
2009-2012	1 2 3 4 5 6	191 212 228 97 29 76	0.018 0.011 -0.004 -0.016 -0.039 -0.016	0.02 0.01 NA NA NA NA	0.31 0.22 NA NA NA

Post Hoc

Step-wise equations

- 8 are less than 1.0
- 2 were insignificant
 - pH set 3 class 5, lowest
 power of 28
 - Nitrate set 3 class 5, adjusted $r^2 = -0.272$

Time variables

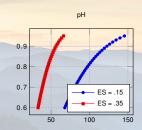
- 52 of the 72 trends were insignificant
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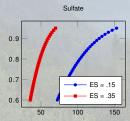
Table: ANC Time Variable Post Hoc Power Analysis Results

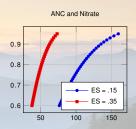
	Set	Class	N	Adjusted r ²	Effect Size	Actual Power
	1993-2002	1 2 3 4 5 6	327 392 398 120 116 110	0.024 0.189 0.000 0.294 0.381 0.075	0.02 0.23 0.00 0.42 0.62 0.08	0.65 1.00 0.06 1.00 1.00 0.69
	2003-2008	1 2 3 4 5 6	255 289 299 119 35 97	0.001 0.081 -0.003 0.180 0.337 0.094	0.00 0.09 NA 0.22 0.51 0.10	0.07 0.99 NA 0.99 0.93 0.74
	2009-2012	1 2 3 4 5 6	191 212 228 97 29 76	0.000 0.056 -0.002 0.161 0.466 0.058	0.00 0.06 NA 0.19 0.87 0.06	0.05 0.85 NA 0.96 0.98 0.39

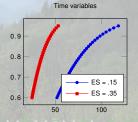
Power graphs

- Graphs look very similar
- ANC and Nitrate are the same graphs
- Time variable graph requires less observations to achieve similar powers
- Power graphs can be useful for planning





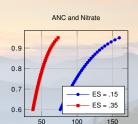


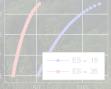


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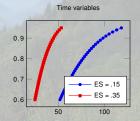
Results

Power graphs

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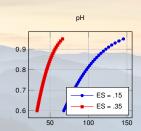


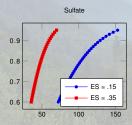


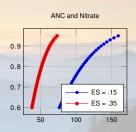
A priori

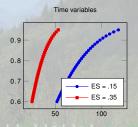
Power graphs

- Graphs look very similar
- ANC and Nitrate are the same graphs
- Time variable graph requires less observations to achieve similar powers
- Power graphs can be useful for planning









Cohen

Introduction

Manipulation

Conventions

- Small (.02), medium (.15), and large (.35) ES values
- Choose an ES of .15 and a power of .80 for a priori analysis
 - .02 made N very large, .15 is the smallest acceptable "window"
 - when power=.80, $\beta=$.20 and usually $\alpha=$.05, making Type II error = 4×Type I error

Optimal scenario

Table: A priori calculation in G*power when alpha, ES, and power are set to .05, .15, and .80 respectively.

Number of predictors	N _a
6	98
8	109
8	109
7	103
3	77
	6 8 8 7

Manipulation

Table: Years to achieve a power of .80

Elevation Bands	on Site #	Current pH n/yr	ANC NO₃	SO ₄	Time variables
1	13 ,23, 24, 30, 479	26			
2	4, 311, 268, 480, 310, 483, 147, 148, 484	34	VKO		Na
3	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224	62	yrs.	-	\overline{n}
4	143, 142, 73, 71	24			
5	74, 221, 251, 233	22			
6	253, 234	12			

Current rates

Manipulation

Table: Years to achieve a power of .80

1			Na	98	109	103	77
	Elevation Bands	on Site #	Current n/yr	рН	ANC NO ₃	SO ₄	Time variables
	1	13 ,23, 24, 30, 479	26				
	2	4, 311, 268, 480, 310, 483, 147, 148, 484	34	14	ırc		Na
	3	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224	62	y	rs.	Ass	n
	4	143, 142, 73, 71	24				
	5	74, 221, 251, 233	22				
	6	253, 234	12				

Current rates

Manipulation

Table: Years to achieve a power of .80

		N _a	98	109	103	77
Elevation Bands	on Site #	Curre n/yr	nt pH	ANC NO ₃	SO ₄	Time variables
1	13 ,23, 24, 30, 479	26	3.77	4.19	3.96	2.96
2	4, 311, 268, 480, 310, 483, 147, 148, 484	34	2.88	3.21	3.03	2.26
3	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224	62	1.58	1.76	1.66	1.24
4	143, 142, 73, 71	24	4.08	4.54	4.29	3.21
5	74, 221, 251, 233	22	4.45	4.95	4.68	3.50
6	253, 234	12	8.17	9.08	8.58	6.42

Introduction

Manipulation

Grab samples are not separate for each water quality variable. 110 will be used as the number of samples to collect to achieve a power of .80 in all dependents and 77 will be used as the number of samples to collect for time variable equations.

Table: Samples/year to achieve a power .80 (N_b)

The same of the sa				the co
Years	/1	/2	/3	/4
Water Quality Variables	110	55	37	28
Time Variables	77	39	26	19

Introduction

Manipulation

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation	#Sample	s require	ed	# sites required			
Bands	1 yr 2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1							
2							
3	$N_c =$	M.	n		#Site	·c _ /	V_c
4	IV _C —	IND —	11		# One	S — -	6
5							
6							

Elevation		#Sample	s require	ed				
Bands	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1				1 21	1 3			
2								
3		$N_c =$	M	n		II Cita	. 1	V _C
4		V _C =	IND -	П		#Site	s = -	6
5								
6								

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation Bands	n	#Samples required 1 yr 2 yrs 3 yrs 4 yrs 110 55 37 28	# sites required 1 yr 2 yrs 3 yrs 4 yrs
1 2 3 4 5	26 34 62 24 22 12	$N_c = N_b - n$	$\#Sites = rac{N_c}{6}$

Elevation		#Samples required	# sites required
Bands	n	1 yr 2 yrs 3 yrs 4 yr 77 39 26 19	yrs 1 yr 2 yrs 3 yrs 4 yrs
1	26		
2	34		
3	62	$N_c = N_b - n$	4 Sitos - No
4	24	$N_C - N_b - H$	$\#Sites = \frac{N_c}{6}$
5	22		
6	12		

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation			#Sample	s require	ed	# sites required
Bands	n	1 yr 110	2 yrs 55	3 yrs 37	4 yrs 28	1 yr 2 yrs 3 yrs 4 yrs
1	26	84	29	11	2	
2	34	76	21	3	-7	
3	62	48	-7	-25	-35	4 Sitos - No
4	24	86	31	13	4	$\#Sites = \frac{N_c}{6}$
5	22	88	33	15	6	
6	12	98	43	25	16	

Elevation		#Samples required					# sites required			
Bands	n	1 yr	2 yrs 39	3 yrs 26	4 yrs 19	1 yr	2 yrs	3 yrs	4 yrs	
1	26	51	13	0	-7	11.375	1 32			
2	34	43	5	-8	-15					
3	62	15	-24	-36	-43		II Cita	- 1	Vc	
4	24	53	15	2	-5		#Site	s = -	6	
5	22	55	17	4	-3					
6	12	65	27	14	7					

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation			#Sample	s require	ed	# sites required				
Bands	n	1 yr 110	2 yrs 55	3 yrs 37	4 yrs 28	1 yr	2 yrs	3 yrs	4 yrs	
1	26	84	29	11	2	14	5	2	0	
2	34	76	21	3	-7	13	4	0	-1	
3	62	48	-7	-25	-35	8	-1	-4	-6	
4	24	86	31	13	4	14	5	2	1	
5	22	88	33	15	6	15	6	2	1	
6	12	98	43	25	16	16	7	4	3	

Elevation Bands	#Samples required					# sites required				
	n	1 yr 77	2 yrs 39	3 yrs 26	4 yrs 19	1 yr	2 yrs	3 yrs	4 yrs	
1	26	51	13	0	-7	9	2	0	-1	
2	34	43	5	-8	-15	7	1	-1	-2	
3	62	15	-24	-36	-43	3	-4	-6	-7	
4	24	53	15	2	-5	9	2	0	-1	
5	22	55	17	4	-3	9	3	1	0	
6	12	65	27	14	7	11	4	2	1	

Conclusions

Step-wise

- ES values are large
- Large ES values make it easier to find trends

Time variables

- What is the power of an insignificant trend line?
- Disregarding insignificance results were similar to the step-wise results

Manipulation

Manipulation is a house of cards.

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

- Outlook
 - Elevation Bands
 - Effects of sulfate scrubbers

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