Statistical Analyses on Legacy data of the GRSM Stream Survey

Time Trend Analysis, ANOVA, Power Analysis

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Contents

Study area

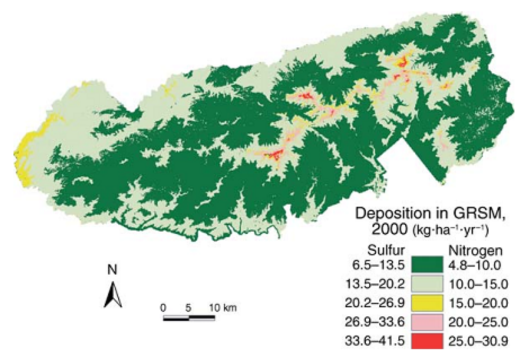
Description of study area

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

Acid Deposition and the GRSM

Affects and effects

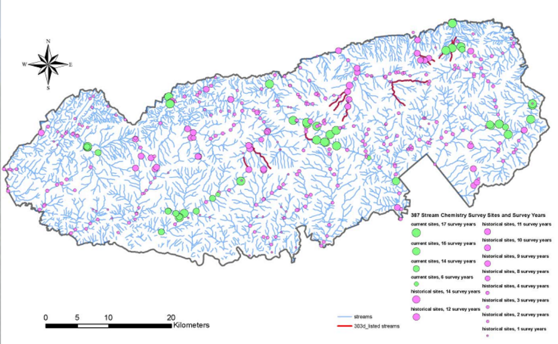
- Acid deposition negatively affects the park.
- Higher elevations are effected worse.



Database

Sites

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



Elevation Bands

Changes

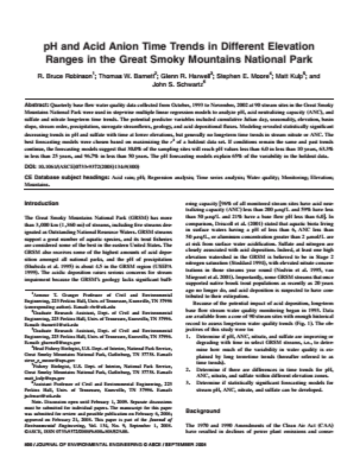
- 11 historical elevation bands
- re-organized into six more powerful bands

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

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

3 separate sets

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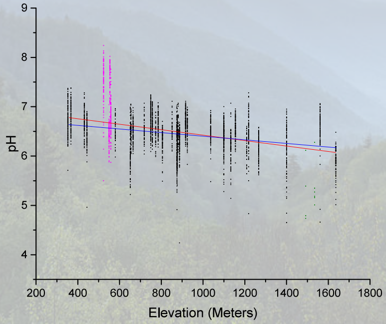
Data Smoothing

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

Determine statistical power for water quality parameters.

- 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 variables were computed for 67 sites for the years 1993 to 2009.

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

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- Predictions for stream pH

Biotics Effects report 2013

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Results

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

Stream Survey trend analysis history

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- 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.

Two equation methods

Table: Equations created through step-wise variable selection

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

Two equation methods

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

144 trends analyzed

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

144 trends analyzed

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- ANC increasing
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Time Variables

Only 20 of the 72 trends are significant

- pH increasing
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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

144 trends analyzed

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

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- pH increasing
- ANC increasing
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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

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- pH increasing
- ANC increasing
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Time Variables

Only 20 of the 72 trends are significant

- pH increasing
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- 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

144 trends analyzed

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

144 trends analyzed

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

144 trends analyzed

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

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

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

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Elevation Trend Results by comparison

Robinson 08

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

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

Pobst 14

- 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

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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

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 (37.371, 35.793, 29.715)
- pH is increasing while the sulfate trends are decreasing
- This combination could lead to sulfate desorption

Conclusions

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

Elevation class	Elevation range m (ft)	Number of sites	Julian date coefficient, μeq/L or pH units (model adjusted r^2) (p-value)			
			pH	ANC	Nitrate	Sulfate
1	304.8-609.6 (1000-2000)	5	0.106 0.894 0.000	-0.002 0.989 0.000	0.026 0.376 0.000	-0.052 0.536 0.000
2	609.6-762 (2000-2500)	9	0.218 0.606 0.000	0.069 0.862 0.000	0.121 0.735 0.000	0.039 0.887 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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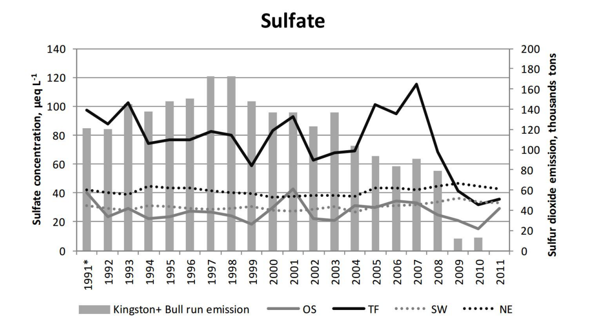
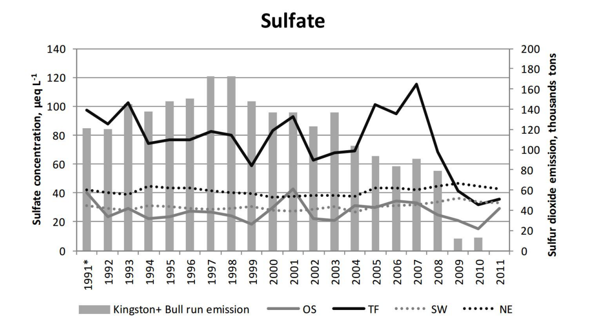
Hypothesis

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.



Method

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

Group Comparisons

pH

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

Elevation Classes	**pH**			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	$\neq$	$\neq$	$\neq$	=	=	=	$\neq$	=	=	=	=	=
2	=	=	=	=	$\neq$	=	$\neq$	$\neq$	=	$\neq$	$\neq$	=
3	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	$\neq$	$\neq$	=	=	=
4	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=
5	$\neq$	$\neq$	$\neq$	=	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	=
6	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=

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Elevation Classes	pH			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	≠	≠	≠	=	=	=	≠	=	=	=	=	=
2	=	=	=	=	≠	=	≠	≠	=	≠	≠	=
3	≠	≠	≠	=	≠	=	=	≠	≠	=	=	=
4	=	≠	≠	=	=	=	=	=	=	=	=	=
5	≠	≠	≠	=	≠	≠	≠	=	≠	=	=	=
6	=	≠	≠	=	=	=	=	=	=	=	=	=

Group Comparisons

ANC

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

Elevation Classes	pH			**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	≠	≠	≠	=	=	=	≠	=	=	=	=	=
2	=	=	=	=	≠	=	≠	≠	=	≠	≠	=
3	≠	≠	≠	=	≠	=	=	≠	≠	=	=	=
4	=	≠	≠	=	=	=	=	=	=	=	=	=
5	≠	≠	≠	=	≠	≠	≠	=	≠	=	=	=
6	=	≠	≠	=	=	=	=	=	=	=	=	=

Group Comparisons

ANC

- More equal than unequal groups
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Elevation Classes	pH			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	$\neq$	$\neq$	$\neq$	=	=	=	$\neq$	=	=	=	=	=
2	=	=	=	=	$\neq$	=	$\neq$	$\neq$	=	$\neq$	$\neq$	=
3	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	$\neq$	$\neq$	=	=	=
4	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=
5	$\neq$	$\neq$	$\neq$	=	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	=
6	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=

Group Comparisons

Nitrate

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

Elevation Classes	pH			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	≠	≠	≠	=	=	=	≠	=	=	=	=	=
2	=	=	=	=	≠	=	≠	≠	=	≠	≠	=
3	≠	≠	≠	=	≠	=	=	≠	≠	=	=	=
4	=	≠	≠	=	=	=	=	=	=	=	=	=
5	≠	≠	≠	=	≠	≠	≠	=	≠	=	=	=
6	=	≠	≠	=	=	=	=	=	=	=	=	=

Group Comparisons

Nitrate

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

Elevation Classes	pH			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	≠	≠	≠	=	=	=	≠	=	=	=	=	=
2	=	=	=	=	≠	=	≠	≠	=	≠	≠	=
3	≠	≠	≠	=	≠	=	=	≠	≠	=	=	=
4	=	≠	≠	=	=	=	=	=	=	=	=	=
5	≠	≠	≠	=	≠	≠	≠	=	≠	=	=	=
6	=	≠	≠	=	=	=	=	=	=	=	=	=

Group Comparisons

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	pH			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	$\neq$	$\neq$	$\neq$	=	=	=	$\neq$	=	=	=	=	=
2	=	=	=	=	$\neq$	=	$\neq$	$\neq$	=	$\neq$	$\neq$	=
3	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	$\neq$	$\neq$	=	=	=
4	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=
5	$\neq$	$\neq$	$\neq$	=	$\neq$	$\neq$	$\neq$	=	$\neq$	=	=	=
6	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=

Group Comparisons

Sulfate

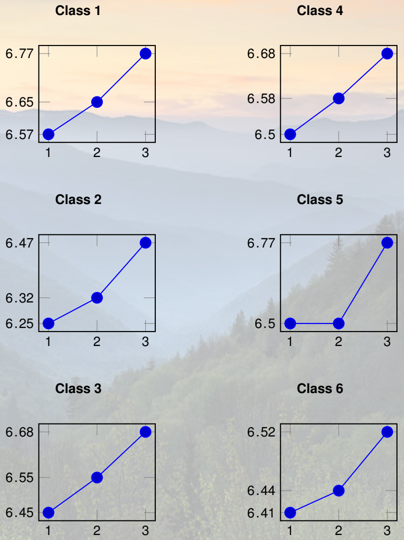
- All sets are equal for all classes except for comparisons in class 2
- All comparisons between sets 2 and 3 are equal

Elevation Classes	pH			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	≠	≠	≠	=	=	=	≠	=	=	=	=	=
2	=	=	=	=	≠	=	≠	≠	=	≠	≠	=
3	≠	≠	≠	=	≠	=	=	≠	≠	=	=	=
4	=	≠	≠	=	=	=	=	=	=	=	=	=
5	≠	≠	≠	=	≠	≠	≠	=	≠	=	=	=
6	=	≠	≠	=	=	=	=	=	=	=	=	=

Line graphs

pH

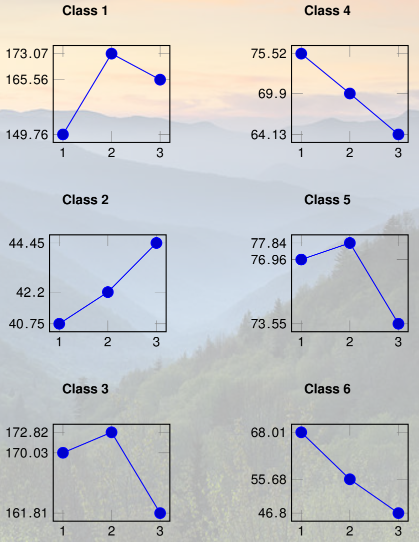
- Class 2 always contains the lowest pH mean instead of 6
- Class 3 belongs between 5 and 6



Line graphs

ANC μeqL^{-1}

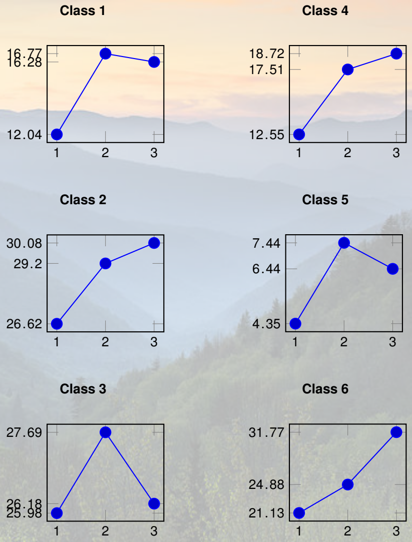
- All classes decrease from set 2 to 3 except for class 2, which is increasing
- Concentrations vary greatly across classes, classes 1 and 2 are more than double the others
- They are the lowest in class 2 which corresponds to the low pH values for class 2, but class 2 is also the only class that is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



Line graphs

Nitrate μeqL^{-1}

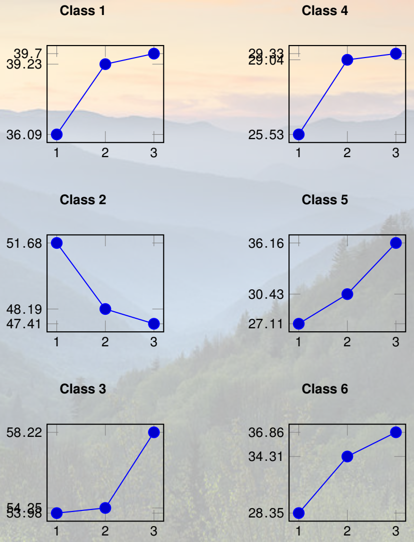
- The odd classes all have decreasing means from sets 2 to 3
- Classes 2 and 4 have mean values for set 3 that are greater than set 2, but the rate of change is decreasing
- Class 6 is always increasing



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



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

		Unknown True Situation	
		H_0 is true	H_0 is false
Decision	Fail to reject H_0	Correct decision Prob(correct decision) = 1-α	Type II error Prob(Type II error) = β
	Reject H_0	Type I error Prob (Type I error) = α **Significance level**	Correct decision Prob (correct decision) = 1-β **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

Methods: Cohen

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: $ES = \frac{adj.r^2}{1-adj.r^2}$

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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	327	0.985	65.67	1.00
	2	392	0.603	1.52	1.00
	3	398	0.971	33.48	1.00
	4	120	0.709	2.44	1.00
	5	116	0.760	3.17	1.00
	6	110	0.802	4.05	1.00
2003-2008	1	255	0.996	249.00	1.00
	2	289	0.779	3.52	1.00
	3	299	0.996	249.00	1.00
	4	119	0.779	3.52	1.00
	5	35	0.739	2.83	1.00
	6	97	0.812	4.32	1.00
2009-2012	1	191	0.989	89.91	1.00
	2	212	0.862	6.25	1.00
	3	228	0.997	332.33	1.00
	4	97	0.772	3.39	1.00
	5	29	0.540	1.17	**0.96**
	6	76	0.809	4.24	1.00

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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
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Table: Sulfate Step-Wise Post Hoc Power Analysis Results

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

Post Hoc

Step-wise equations

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

Time variables

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- 20 significant trends ranging from .26 to 1.00
  - 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	327	0.712	2.47	1.00
	2	393	0.388	0.63	1.00
	3	400	0.693	2.26	1.00
	4	121	0.205	0.26	**0.99**
	5	116	0.165	0.20	**0.96**
	6	110	0.505	1.02	1.00
2003-2008	1	255	0.781	3.57	1.00
	2	289	0.348	0.53	1.00
	3	299	0.663	1.97	1.00
	4	119	0.400	0.67	1.00
	5	35	0.300	0.43	**0.74**
	6	97	0.317	0.46	1.00
2009-2012	1	191	0.894	8.43	1.00
	2	212	0.606	1.54	1.00
	3	228	0.766	3.27	1.00
	4	97	0.593	1.46	1.00
	5	29	**0.158**	0.19	0.28
	6	76	0.286	0.40	**0.99**

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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	275	0.503	1.01	1.00
	2	377	0.699	2.32	1.00
	3	365	0.359	0.56	1.00
	4	105	0.410	0.69	1.00
	5	66	0.328	0.49	**0.98**
	6	81	0.871	6.75	1.00
2003-2008	1	252	0.551	1.23	1.00
	2	296	0.816	4.43	1.00
	3	297	0.637	1.75	1.00
	4	121	0.405	0.68	1.00
	5	30	0.562	1.28	**0.98**
	6	98	0.832	4.95	1.00
2009-2012	1	191	0.376	0.60	1.00
	2	212	0.735	2.77	1.00
	3	228	0.598	1.49	1.00
	4	97	0.635	1.74	1.00
	5	29	**-0.272**	NA	NA
	6	76	0.881	7.40	1.00

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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
1993-2002	1	327	**0.047**	0.049	0.93
	2	393	**0.128**	0.15	1.00
	3	400	**0.013**	0.01	0.46
	4	121	**0.059**	0.06	0.61
	5	116	**0.051**	0.05	0.52
	6	110	**0.096**	0.11	0.81
2003-2008	1	255	0.040	0.04	0.78
	2	289	0.061	0.06	**0.96**
	3	299	**0.020**	0.02	0.52
	4	119	0.148	0.17	**0.97**
	5	35	**-0.069**	NA	NA
	6	97	0.081	0.09	0.67
2009-2012	1	191	**0.028**	0.03	0.47
	2	212	0.052	0.05	**0.82**
	3	228	**-0.009**	NA	NA
	4	97	0.200	0.25	**0.99**
	5	29	**0.218**	0.28	0.58
	6	76	0.039	0.04	0.27

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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
1993-2002	1	325	0.045	0.05	**0.92**
	2	390	**0.009**	0.01	0.32
	3	391	**-0.004**	NA	NA
	4	119	**-0.016**	NA	NA
	5	116	**-0.010**	NA	NA
	6	110	**-0.009**	NA	NA
2003-2008	1	261	0.043	0.04	**0.82**
	2	298	0.014	0.01	0.37
	3	308	**0.006**	0.01	0.18
	4	123	0.023	0.02	0.26
	5	37	**-0.024**	NA	NA
	6	101	0.074	0.08	0.64
2009-2012	1	190	**0.005**	0.01	0.11
	2	212	**-0.010**	NA	NA
	3	228	**-0.007**	NA	NA
	4	97	**-0.011**	NA	NA
	5	29	**-0.076**	NA	NA
	6	76	**0.007**	0.01	0.08

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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	275	0.016	0.02	0.39
	2	377	**0.017**	0.02	0.55
	3	365	**-0.004**	NA	NA
	4	105	**-0.027**	NA	NA
	5	66	0.120	0.14	0.68
	6	81	**0.092**	0.10	0.64
2003-2008	1	252	0.061	0.06	**0.94**
	2	296	0.043	0.04	**0.87**
	3	297	**-0.003**	NA	NA
	4	121	0.086	0.09	**0.80**
	5	30	**-0.082**	NA	NA
	6	98	0.046	0.05	0.40
2009-2012	1	191	**0.018**	0.02	0.31
	2	212	**0.011**	0.01	0.22
	3	228	**-0.004**	NA	NA
	4	97	**-0.016**	NA	NA
	5	29	**-0.039**	NA	NA
	6	76	**-0.016**	NA	NA

Post Hoc

Step-wise equations

- 8 are less than 1.00
- 2 were insignificant
  1. pH set 3 class 5, lowest power of .28
  2. 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

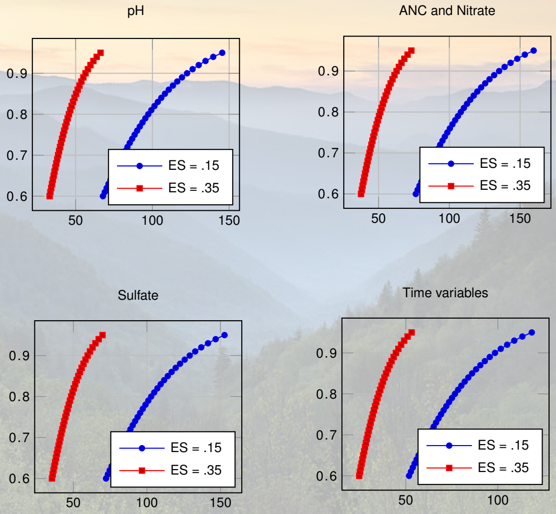
Table: ANC Time Variable Post Hoc Power Analysis Results

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

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



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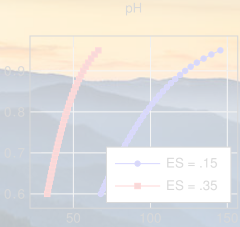

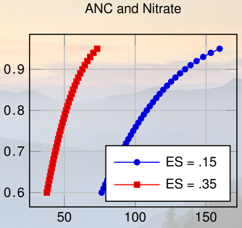

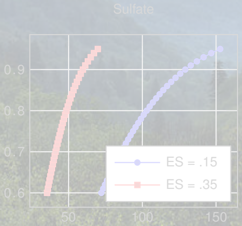

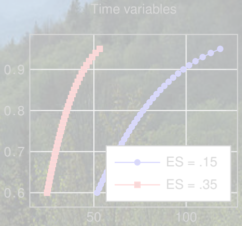

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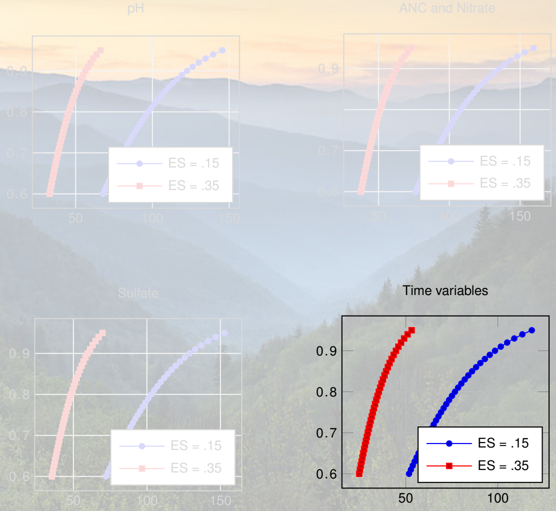

A priori

Power graphs

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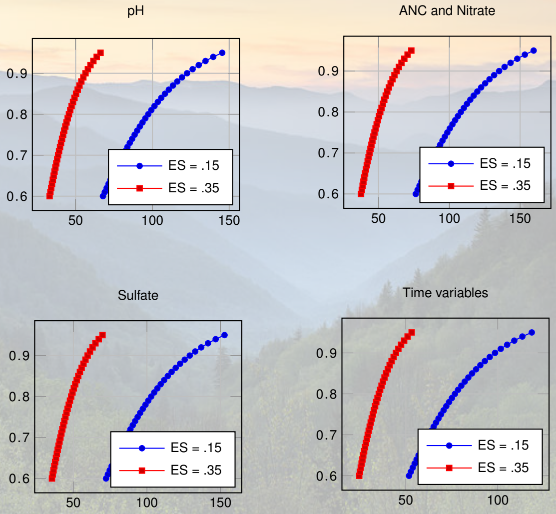

Cohen

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 $= 4\times$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
pH	6	98
ANC	8	109
Nitrate	8	109
Sulfate	7	103
Time	3	77

Current rates

Table: Years to achieve a power of .80

Elevation Bands	Site #	Current pH n/yr	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			
3	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224	62			
4	143, 142, 73, 71	24			
5	74, 221, 251, 233	22			
6	253, 234	12			

$$yrs. = \frac{N_a}{n}$$

Current rates

Table: Years to achieve a power of .80

Elevation Bands	Site #	N_a / Current n/yr	pH (98)	ANC NO_3 (109)	SO_4 (103)	Time variables (77)
1	13 ,23, 24, 30, 479	26				
2	4, 311, 268, 480, 310, 483, 147, 148, 484	34				
3	114, 481, 482, 149, 66, 492, 137, 293, 270, 493, 485, 144, 224	62				
4	143, 142, 73, 71	24				
5	74, 221, 251, 233	22				
6	253, 234	12				

$$yrs. = \frac{N_a}{n}$$

Current rates

Table: Years to achieve a power of .80

		N_a	98	109	103	77
Elevation Bands	Site #	Current n/yr	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

Trend analysis requirements

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)

Years	/1	/2	/3	/4
Water Quality Variables	110	55	37	28
Time Variables	77	39	26	19

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation Bands	#Samples required				# sites required			
	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1 2 3 4 5 6	$N_c = N_b - n$				$\#Sites = \frac{N_c}{6}$			

Necessary sites scenario for time variables

Elevation Bands	#Samples required				# sites required			
	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1 2 3 4 5 6	$N_c = N_b - n$				$\#Sites = \frac{N_c}{6}$			

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

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

Necessary sites scenario for time variables

Elevation Bands		#Samples required				# sites required			
	n	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
		77	39	26	19				
1	26								
2	34								
3	62	$N_c = N_b - n$				$\#Sites = \frac{N_c}{6}$			
4	24								
5	22								
6	12								

Trend analysis requirements per elevation band

Necessary sites scenario for water quality variables

Elevation Bands	n	#Samples required 1 yr 110	2 yrs 55	3 yrs 37	4 yrs 28	# sites required 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	24	86	31	13	4				
5	22	88	33	15	6				
6	12	98	43	25	16				

$$\#Sites = \frac{N_c}{6}$$

Necessary sites scenario for time variables

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

$$\#Sites = \frac{N_c}{6}$$

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	# sites required 1 yr	2 yrs	3 yrs	4 yrs
		110	55	37	28				
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

Necessary sites scenario for time variables

Elevation Bands	*n*	#Samples required 1 yr	2 yrs	3 yrs	4 yrs	# sites required 1 yr	2 yrs	3 yrs	4 yrs
		77	39	26	19				
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.

Summary

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

- Outlook
  - Elevation Bands
  - Effects of sulfate scrubbers

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