To the Graduate Council:

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and recommend its acceptance:

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(Original signatures are on file with official student records.)

Statistical Analyses on Legacy Data for the GRSM Stream Survey

A Thesis Presented for

The Master of Science

Degree

The University of Tennessee, Knoxville

Tim Pobst

May 2014

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I would like to thank... Dr. Schwartz, Keil Neff, Matt, and Steve Moore.

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Abstract

Abstract text goes here...

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Chapter 1

Introduction

Text and tables should show up.

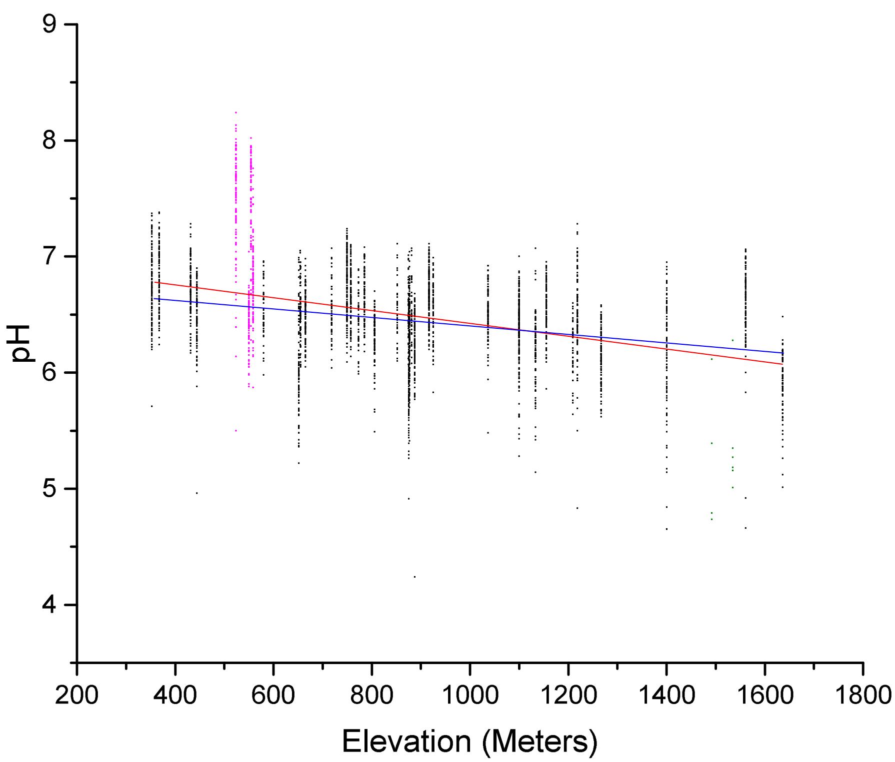

Figure 1.1: pH plotted vs. Elevation. With and without outliers.

Acid rain is believed to negatively affect The Great Smokey Mountain National Park

Acid Deposition, more commonly known as Acid Rain, is a constant problem for the i

Acid Deposition occurs when the emissions of sulfur oxides (SOx), and nitrogen oxi

Acid deposition greatly impacts surface water and the surrounding environment. The

Acidification of bodies of water can be either chronic or episodic. Chronic acidif

The Great Smoky Mountains National Park (GRSM) is located in the southern Appalach

In order to monitor acid deposition the park has a program called the Inventory an

Figure 1-1

This figure shows all pH data from 1993 to 2012 vs. Elevation (m). The red trend

Figure 1 is a graph of all measured pH values for Stream Survey between the years

In support of GRSM natural resource management, stream water quality has been moni

Table 1 shows the current historical elevation classes with the number of sites th

The National Park Service is currently developing a Vital Sign Monitoring Program

Objectives of this study were to:

\begin{itemize}

\item characterize time trends in stream pH and acidic anions among elevation ran

\item characterize sampling variance based on available water quality data, within

\end{itemize}

\begin{itemize}

\item Has stream pH and acid anion concentrations changed among three time periods

\begin{itemize}

\item ANOVA

\item Time trends

\end{itemize}

\item What is the statistical power for water quality parameters based on frequenc

```
\begin{itemize}

\item Post Hoc Analysis

\item A Priori Analysis

\end{itemize}

\end{itemize}

The thesis is organized into two separate chapters following the two above researc
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Chapter 2

Trend Analysis

2.1 Methods

2.1.1 Introduction

- Trend analysis for Stream Survey has been done before and reported in (Robinson et al., 2008) and the Biotics effects report (Meijun Cai, 2012)
- A trend analysis of the data collected through the Stream Survey can be used to help determine the water quality of the streams
- The most important trend is the trend for pH
- **Outline** The trend analysis will be conducted on Stream Survey data spanning the years 1993-2012 using the statistical program JMP for determining outliers and the statistical program SPSS for the actual trend analysis.

2.1.2 Body

- A trend analysis will answer the continuing question concerning the overall health of the park which is, "How are the streams doing?". More specifically "Is the pH trending towards a higher pH or a lower pH?"

Data

- The data comes from years of analyzing water samples collected through the Stream Survey and is tabulated into a running data set.
- A single trend line could be made to encompass all 20 years worth of water quality data, but this would make discovering the cause of the trends more difficult.
- Assuming ecosystems try to achieve equilibrium the change observed over all time should be zero.
- So in order to easier learn from this trend analysis, it will be logically broken up into smaller sets of years.
- Different sets may have different positive or negative trends for which separate hypothesis have been or can be formulated and tested in this trend analysis.
- The separate data sets are between time and between elevation classes. There were three different time sets created. The first time set covers the years 1993 to 2002, these are the same years analyzed in (Robinson et al., 2008). The remaining years were broken up at 2008, which was the year that the Kingston and Bull run power plants installed scrubbers onto their stacks. So with the six different elevation classes and the three different time sets there are eighteen different data sets that are analyzed in this paper.

Instruments

- done usisng statistical programs.
- Outliler determination and trend hypothesis.

Table 2.1: These elevation classes were created to add more weight to the higher elevations

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

- Plot pH on y-axis vs. all time. This visually represents that the slope does not equal zero. Check outliers in this plot. If they can be explained then fix or delete them.
- Plot pH on y-axis vs. elevation. Visually check for trend of decreasing pH as elevation increases.
- Plot pH vs. month. To check for seasonality.
- Outliers found include Abrams, Anakeesta sites, and storm flow. Abrams is consistently found as an out lier within GRSM water quality projects using stream survey data for statistical purposes. Abrams is located in the Cades Cove area of the park and sits in natural limestone bedrock. This limestone increases the ANC of the streams so much that many of the measured Abrams pH values are high enough to be outliers and are thrown out of the data.
- Water quality at sites 237 and 252 are heavily influenced by Anakeesta geology introduced into the streams through road cuts.
- Storm flow is also usually seen as an out lier in past GRSM water quality projects. Storms can bring high intensity rain fall which can very quickly raise the levels of nitrate and sulfate pollution in the streams. The runoff

can also carry any pollutants that have come to rest on vegetation or the ground. The lowered pH of the streams caused by the storm flow can cause leeching of the surrounding mineral geology in affected areas. Healthy streams can rebound to normal pH values, unhealthy streams can have lowered ANC due to the leaching. Measurements taken from storm flow can show uncharacteristically low pH values and high amounts of metals. In this way storm flow is sometimes considered an out lier. Much of the water quality data has been characterized as base flow and storm flow by Dr.Cai, but not all it. Water quality data after 2010 has not been characterized. Dismissing all of storm flow as an out lier is complicated by this lack of information. Either; storm flow and base flow would need to be determined for the 2011 and 2012 data,all of the 2011 and 2012 data could be left out, or 2011 and 2012 would need to be characterized as base flow or storm flow. Throwing out the years 2011 and 2012 would leave the last time set with only two years of data. The data was compared with and without storm flow observations. It was determined to manually select out lier storm flow observations. They can be removed on a case by case basis during the regression procedure.

  - review output for normality, heteroscedasticity, cook's D, DFBETAS, DFFITS.
  - Find proposed out lier in original data
  - Justify its removal, remove it and run the regression method again
  - The outputs will change every time an observation is removed.

- The variable selected through this process were used to create fixed models to be used while discovering the Julian Date coefficient for each water quality variable in each data set.

Table 2.2: 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)	$(.415 \times \text{Sum Base Cations}) + (-.185 \times SO_4) + (.595 \times \text{Conductivity}) + (-.102 \times NO_3) + (.019 \times \text{Julian Date}) + (.005 \times Cl) + (.005 \times \sin(\theta))$	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

- If the step-wise equation had at least one time variable in it(Julian date, $\sin(\theta), \cos(\theta)$) then the rest were added. This is presented in Table C.1.

- along with the step-wise regression method, another regression analysis was done using only time based variables. These are the Julian Date, $\sin(\theta)$, and $\cos(\theta)$ time variables. This method was used to find trends in the water quality variables that are related to time only.

- IBM's SPSS was used to conduct this trend analysis.

- These options were chosen for regression and assumptions for this procedure include.(from notebook and textbook)

2.2 Results

- In (Robinson et al., 2008) table 4 reports julian date coefficients for four water quality variables (pH, ANC, NO_3, SO_4) by each elevation band.

  - A similar layout was used in Table D.1 and Table D.2.
  - This was done for continuity and ease of comparison.

- The first trend analysis was completed using the step-wise method for choosing predictors and the results are presented in Table D.1

- The second trend analysis uses only time based variables as predictors and these results are presented in Table D.2

- Both tables are modeled after table 4 in (Robinson et al., 2008)

- Each table is further divided into three different time sets: 1993-2002, 2003-2008, 2009-2012.

- Each of these time sets are further divided into six elevation bands

- Each of elevation band has the results of four trend lines, one for each of the studied water quality variables (pH, ANC, NO_3, SO_4).

- Each trend line is represented by its Julian date coefficient, the r^2 value for the trend line, and it's statistical significance.

- 2 of the 72 trend lines in Table D.1 are insignificant. In contrast only 20 of the trend lines in Table D.2 are significant.

- Insignificance is determined by receiving a p-value greater than .05, the α of the trend line. A p-value greater than .05 rejects the hypothesis that $\beta \neq 0$. There is greater than a 5% chance that β=0. There is to much chance of no trend line for the scientific community.

- Repeat trends from previous thesis

- Compare to (Robinson et al., 2008), his trends are negative.

2.3 Discussion

- Why were the trends insignificant?
- Why are the water quality trends trending the way they are at separate time sets (discuss comparisons between sets in the ANOVA bonferoni section).
- How should the water quality variables have behaved based on known properties and (Robinson et al., 2008).
- Very generally speaking these results are different than (Robinson et al., 2008) predicted.
- Water quality will continue to get better.
  - because pollution is being regulated
- there are still unknowns and prediction is still hard.

Chapter 3

Means Comparison

3.1 Methods

3.1.1 Introduction

- In the year 2008 scrubbers were installed into the Bullrun and kingston power plants
- These scrubbers significantly reduced the amount of SO_4 emitted by the smoke stacks of the power plants by **how much**
- A the same time an obvious decrease in measured SO_4 was discovered in the Stream Survey samples (UTK, 2012).
- The amount of SO_4 in the streams is thought to be (correlated with?) to the pH index of the streams when the SO_4 goes up the pH goes down.
- The hypothesis is that of the three sets of data containing water quality measurements from 1993 to 2012, if the data is broken at 2002 and 2008, that because of the obvious measured decrease in SO_4, there will be an obvious difference of means in the sets before and after 2008.
- This can be tested using an Analysis of Variance procedure.

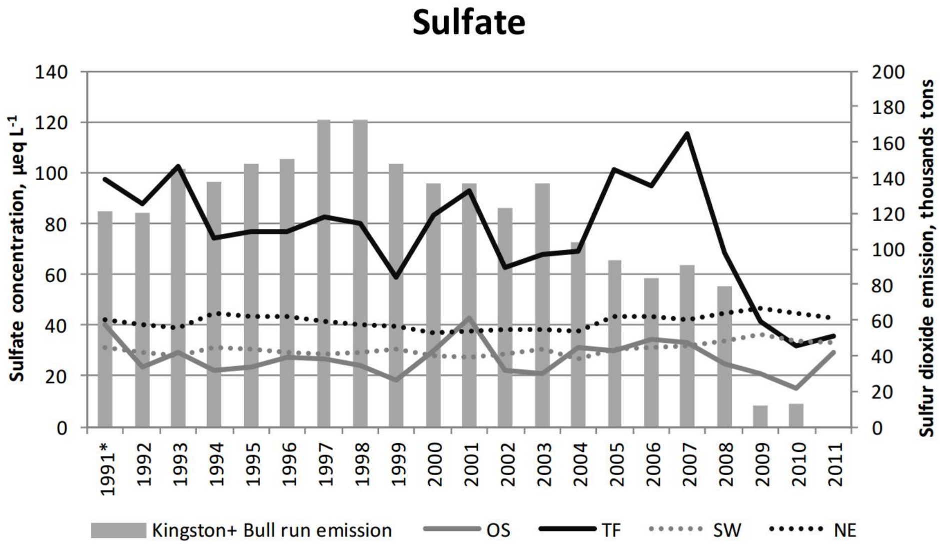


Figure 3.1: Sulfate emmisions of Kingstion and Bull run against those measured in Noland high elevation site.

- The data is only pH measurements for the three sets

Instruments

- The program used for this procedure was (probably SAS).
- Heterscedasticity can be a problem a brown-forsythe test was employed to test for this.
- If three groups are analyzed using ANOVA the only two outcomes may be "they are different" or "they are not different".
- If they are not different then the analysis of the data is over.
- If they are different then it would be nice to know which sets are different.

- This is accomplished with a Bonferoni analysis

3.1.2 Bonferoni Introduction

- Introduction from text book.
- rank-sum

instruments

- Bonferoni can output a graph presenting the means of each group in order to visually check for a difference in means. It will also output 95% confidence intervals between each pair of groups. This way definitive answers can be found for the question of "are they or are they not the same?"
- Bonferoni assumptions
- SAS

3.2 Results

- Background info?
- The output of the Bonferoni method includes 95% confidence intervals that represent definitive comparisons of the means of two groups of data. If the C.I. includes zero then the means are not statistically different.
- Table 3.1 reports the Bonferoni comparison means between the four water quality variables(pH, ANC, NO_3, SO_4) in one time set against the same water quality variable in another time set by elevation bands.

Table 3.1: Bonferoni comparisons between multiple groups

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	=	$\neq$	$\neq$	=	=	=	=	=	=	=	=	=

- There are three groups compared in Table 3.1, they are the three time sets: 93-02, 03-08, 09-12. The table uses = and $\neq$ to represent equality or inequality between the means of the groups compared.
- stuff from first draft
- the bonferoni analysis also outputs the results in figure form. These figures visually represent the group means and are presented in Figure **??** through Figure **??**.
- The negative trend of ANC is something to take note of.

3.3 Discussion

- Are these results a special case?
- Do these differences show up in other water quality analyses, not in the S.S.?
- What are the reasons that the means are higher or lower than expected?
- Differences between sets 2 and 3 were expected due to the scrubbers, did this occur?

- Why aren't the results as clear as the chart in the (Meijun Cai, 2012)?
  - probably math
- General hypothosis about what the results suggest
  - The results suggest that a larger difference is needed to see a sulfate difference between sets 2 and 3.

Chapter 4

Power Analysis

4.1 Methods

4.1.1 Introduction

Power is the likelihood of proving the hypothosis correct. The trend analysis preformed in chapter 2 is really a hypothesis test which comes with an inherent amount of error. It tests the hypothesis that a trend exists in the data which makes the null hypothesis one of no trend or a coefficient that equals zero. The error here is defined as type II error or β and can be seen in Table 4.1. β describes the failure to reject a false null hypothesis or in the case of this paper a failure to detect a trend in the data when there really is one. The opposite of β is the probability that a trend will be detected when it exists and is called the power of the test. A trend line with a power of 1.00 indicates a 100% chance that the calculated slope is not zero, a power of .50 means there is a 50% chance that the calculated slope might not exist. Power indicates the reliability of the trends which are important in determining the health of streams in the GRSM.

Power analysis refers to both post hoc and a priori analyses, in this paper both were completed with the help of the statistical program G*power. G*power is a free power analysis program written by four germen psychology professors and used by

Table 4.1: Hypothesis tests from Statistical Methods in Water Resources by theUSGS (Helsel and Hirsch, 1992).

	H_0 is true	H_00 is false
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**

many. It can compute both post hoc and a priori analysis for many different statistical tests (Faul et al., 2009), power analysis for regression was used here. All 144 trend lines from chapter 2 were evaluated using a post hoc analysis and a priori analysis was used to project the current stream survey program into the future.

The two different power analyses are two sides of the same coin and have many similarities, but different outcomes. The main objective of the post hoc analysis is to calculate the power of a given test, while the a priori analysis will calculate the number of observations for a chosen power. Unlike the trend analyses and mean comparisons of the first two chapters, the statistical program G*power requires only four inputs instead of whole data vectors. With post hoc analysis three of the these inputs are passed from the output of the trend analysis: number of observations (N), adjusted r^2 and number of predictors. The fourth input is ES or effect size which is calculated by G*power before the analysis, ES is described by Cohen as the probability to find a significant result (Cohen, 1992a). A priori analysis also requires an ES value but it is chosen, instead of calculated, along with the power. Just like the post hoc analysis the number of predictors is still needed for the a priori analysis and taken from the number of predictors given in the step-wise analysis from chapter 2

A post hoc analysis was preformed for both of the julian date coefficient tables from chapter 2, Table F.1 and Table F.2. In contrast to the post hoc analysis the a priori analysis only needs to be calculated for each of the four dependent variables.

This is because for each analysis the three inputs number of predictors, power, and ES remain the same for each variable. The front analysis is only for one chosen power and one chosen ES but G*power will create a power graph which plots each power and the number of observations it requires. But this is where the analysis in G*power ends and the results must be applied to the Stream Survey to get more specific results. This was accomplished in Excel, where the number of observations given by the power analysis were divided among the elevation bands. In this way elevation bands with many sites can be shown to contain more observations over time than necessary and elevation bands with lower amounts of sites are shown to need more observations for the same time period.

4.1.2 Procedures

Post hoc

The most popular power analysis methods originate from Jacob Cohen who outlined his approach in " A Power Primer" (Cohen, 1992a). Cohen displayed ways to calculate the power for eight different tests the last of which is the F test for multiple and multiple partial correlation, which can be used for regression. The different tests are represented by their differences in calculating ES. ES is the only input that needs to be calculated before the analysis can be completed, the other inputs come from the trend analysis. The equation for the ES of a regression model presented by Cohen is equal to the correlation coefficient divided by one minus the correlation coefficient.

$$ES = \frac{adj.r^2}{1 - adj.r^2} \tag{4.1}$$

This equation can be described as the ratio of explained to unexplained variation for the regression model. For the post hoc analysis this equation will be used to calculate a specific ES for each model presented in Table F.1 and Table F.2. The ES calculation is completed by G*power after inputing the correlation coefficient (adj. r^2). G*power uses ES along with the α (.05) used for the regression model, the number observations, and number of predictors in the model to output the power of the F test. This power will be between 0 and 1.00 and will be the power acquired by the models using past data and a calculated ES.

A priori

The a priori analysis is more conditional than the straight forward calculations for the post hoc analysis. Instead of outputting a power value like the post hoc analysis, G* power will compute the number of observations for a given scenario. The inputs for this analysis are α (.05), desired power, number of predictors, and ES. All of these inputs can be changed or manipulated based on the anticipated outcome. For this analysis the assumption was made that the same trend analysis as the one completed in chapter 2 would be attempted in the future. Based on this assumption the same step-wise equations constructed in Table 2.2 can be used to help chose the number of predictors and α.

The most encompassing way to present an a priori analysis is through a power graph. The power graphs plot power on the y-axis and number of observations on the x-axis. Using this as a tool a planner can choose a desired power and get the corresponding number of observations.

Choosing an ES value and desired power will be a matter of convention. To make choosing the ES value easier Cohen has defined small, medium, and large ES values for each of the eight tests described in Cohen (1992a). Concerning the multiple and multiple partial correlation test he decided on .02, .15, and .35 respectively. All of these ES values can be graphed in the power graphs by plotting different ES values as curves on the same plot. But in order to later determine more efficient site counts per elevation band a best ES value must be chosen. An ES value of .15 was settled upon after the power graphs for all three conventions per dependent variable were made. .02 was too small, requiring very high numbers of observations to reach a decent power. ES values of .35 can acquire small numbers of observations thus achieving a decent power level easier, but the smaller the ES the better. .15 is less than half of .35 so it minimizes the chances for insignificant results and the numbers of observations are reasonable to reach higher powers. If no argument can be made for any other desired power then Cohen suggests .80. This is chosen for its reasonable ratio of Type I error to Type II error which reflects their importance. If the power is .80 then $\beta = .20$ and $\alpha = .05$ and this makes the Type II error four times as likely as Type I error (Cohen, 1992b). These choices are presented in Table 4.2.

Table 4.2: 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

The a priori power analysis can be manipulated to calculate a number of sites per elevation band for the stream survey in the GRSM. First, samples per year per elevation band are counted for the 2012 year and will be represented by n. Next the results from Table 4.2 are divided by samples per year per elevation band to get the number of years it will take, at the 2012 sampling rate, to reach a power of .80.

$$yrs. = \frac{N_a}{n} \tag{4.2}$$

But, in order to get to the number of sites per elevation band required to reach a power of .80, the years will have to be held constant. If the future trend analysis is to be completed using the equation with only time variables (instead of the step-wise equations) then 77 samples will need to be collected in one year to reach a power of .80 according to Table 4.2. But if the future trend analysis is to be completed using the step-wise equations from Table 2.2 then at least 109 samples will need to be collected in one year to satisfy the requirements for ANC and NO_3. For the step-wise equations N will be rounded up to 110 and labeled N_b. These are presented in

Table 4.3: 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

Table 4.3, which has been calculated out to four years. So that instead of completing the trend analysis after one year, one could wait four years and only need to collect 28 samples per year. Subtracting the number of samples collected in one year per elevation band in 2012 from the number of samples needed to be collected per year to reach a power of .80 will provide the number of samples needed per elevation band to receive a power of .80 (N_c).

$$N_c = N_b - n \tag{4.3}$$

To get an estimation for the number of sites needed per elevation band to achieve a power of .80, the number of samples needed per elevation band to receive a power of .80 (N_c) were divided by six which is number of times each site is sampled per year.

$$\#Sites = \frac{N_c}{6} \tag{4.4}$$

4.2 Results

4.2.1 Post hoc

The results of the post hoc analysis on both trend analyses are reported in Table F.1 and Table F.2. They are broken into the four water quality variables (pH, ANC, NO_3, SO_4) and divided into the tree time sets (93-02, 03-08, 09-12), and then further divided into the six elevation classes. Each trend from chapter 2 is represented by its number of observations, the adjusted r^2, the calculated ES, and finally their observed power. Of the 72 lines evaluated for power in Table F.1 only eight of them were less than 1.00. And only two of the trend lines in Table F.1 were insignificant. One of the insignificant trends was the trend for Nitrate, set 3, class 5 , and along with insignificance the adjusted r^2 was negative and therefore the power could not be found. The other insignificant trend was pH, set 3, class 5 , which also received the lowest observed power of .28. In large dissimilarity from the step-wise trend models, 52 of the 72 trends from Table F.2 were insignificant. Of the 20 significant trends observed powers range from .26 to 1.00, 11 of them are above .80 and 2 are .99 or greater.

4.2.2 A priori

Power graphs

The traditional presentation for an a priori power analysis is the power graph. Here the powers are lie on the y-axis while the number of observations lie on the x-axis. Each of the water quality variables and the time model gets its own graph except for ANC and NO_3 which are the same because they contain the same number of predictors from the step-wise model. On each graph two curves are plotted representing an ES of either .15 or .35,they all rise from (0,0) asymptotically towards a power of 1.00. Despite the similar shapes the more predictors a model has the greater number of observations it requires to reach adequate powers, SO_4 requires almost 30 samples than the time model to reach a power of .80 with an ES of .15. The power graphs for pH, ANC and NO_3, SO_4, and Time are plotted in the appendices Figure G.1, Figure G.2, Figure G.3, andFigure G.4 respectively. And Table 4.4 was created for easier comparison.

This table shows the sample size values for both ES curves at a power of .80. Again all are similar except for the time graph, which has at least half as many predictors in its time trend equation as the others.

Table 4.4: Sample sizes at a power of .80

ES	0.15	0.35
pH	97	45
ANC and NO3	98	51
SO4	103	48
Time	76	35

A priori manipulation

In this section a scenario is presented in which the results of the a priori analysis are manipulated to achieve the number of sites required per elevation band to receive a power of .80.

Table 4.5: Years to acheive a power of .80

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

This scenario was followed through with both methods of trend lines. Table 4.5 records the six elevation bands along with the site numbers that belong to them. In the column labeled, current n per year, the amount of samples collected per elevation band in the year 2012 are tabulated. Then Using Equation 4.2 the number of years needed for each variable to reach a power of .80 is calculated. Looking at the table there are 26 samples collected in elevation band one in one year. In order to compute a trend line for pH using the same step-wise model from Table 2.2 that receives a power of .80, samples would need to be collected for 3.77 years before the trend line can be computed. The longest waiting period is for ANC or NO_3 at elevation class six which requires 9.08 years, presumably because they have the highest number of predictors and elevation class six contains only two sites.

Table 4.6: Necesary sites scenario for water quality variables

	#Samples required				# sites required			
Elevation Bands	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1	84	29	11	2	14	5	2	0
2	76	21	3	-7	13	4	0	-1
3	48	-7	-25	-35	8	-1	-4	-6
4	86	31	13	4	14	5	2	1
5	88	33	15	6	15	6	2	1
6	98	43	25	16	16	7	4	3

Table 4.7: Necesary sites scenario for time variables

	#Samples required				# sites required			
Elevation Bands	1 yr	2 yrs	3 yrs	4 yrs	1 yr	2 yrs	3 yrs	4 yrs
1	51	13	0	-7	9	2	0	-1
2	43	5	-8	-15	7	1	-1	-2
3	15	-24	-36	-43	3	-4	-6	-7
4	53	15	2	-5	9	2	0	-1
5	55	17	4	-3	9	3	1	0
6	65	27	14	7	11	4	2	1

Tables Table 4.6 and Table 4.7 correspond to the two trend models: step-wise and time. Both tables are broken down into two sides, the left side contains number of samples while the right side contains number of sites. Then each side is arranged by elevation band and calculated out to four years. Equation 4.3 is used to calculate the number of samples required and then these numbers are divided by six to get the number of sites. The numbers on the right side of the tables represent the change to the current number of sites in that elevation band required to achieve a power of .80 with an ES of .15 using the same models from chapter 2. In Table 4.6 for elevation class 3, 48 more samples need to be collected if a trend line for the water quality dependents with a power of .80 is to be created after one year. But if a trend line can wait to be created after two years, then there is a surplus of seven samples per year. If four years can be waited there is a surplus of 35 samples which on the right side of the table translates into a surplus of 6 whole site locations per year.

4.3 Discussion

4.3.1 Post hoc

Step-wise equations

By reviewing the results of the post hoc analysis after an a priori analysis has been completed it is easier to see why the results were outstanding for the step-wise equations and awful for the time based equations. Knowing that an a priori analysis on the step-wise equations will produce a requirement of 110 observations for a power of .80 and an ES of .15, Table 4.2, it can easily be seen that as the number of observations in Table F.1 decline from 110 the power also declines. In concert with the large number of observations, the observed ES values are very large compared to the chosen ES of .15 which coincides with the observed powers being close to 1.00. The large conventional ES given by Cohen is .35 and only 3 of the trend lines analyzed here were below that, all in pH. And because the ES is a ratio of the adjusted r^2 it declines as the r^2 does, the higher the r^2 the better.. But for a calculated ES of .15 the adjusted r^2 doesn't need to be very high. Such as the analyzed trend line for pH in time set 3 elevation class 5 has an adjusted r^2 of .158 and the ES is .19, which is larger than .15. Assuming that a power of .80 and an ES of .15 is ideal, then this post hoc analysis uses to many observations. One way to have less observations would be to use fewer years in the analysis. Another way would be to use less sites in the survey.

Time variable based equations

The two post hoc analyses on the two different models varied greatly. The differences in powers between the two post hoc analysis can not be the number of observations because the number of observations used in Table F.1 are the same as those Table F.2. The differences are between the adjusted r^2 values, which are very low for Table F.2, and leads to the low ES values. Overlooking the fact that most of the regression models for the time variable analysis are insignificant, most of the powers calculated in Table F.1 are not terrible. Of the 20 significant lines eleven have a power equal to or above .80.

4.3.2 A priori

The a priori power graphs themselves show every possible power and the number of observations needed to achieve it. But they are based on the specific step-wise equations that were created using this specific dataset. Because the step-wise process uses past data to create the equations, every time new data is added the equations could change. The a priori analysis assumes that these same equations, with the same number of variables, will be used to detect trends in the future. But even if the number of sites remain the same past this point, the data will still be different. And if the site numbers do change, such as more sites are added to the upper elevations and sites are removed from the lower elevations, then the step-wise equations are at greater risk of changing. Then if the number of predictors changes because the data changed then the a priori analysis in not applicable. A more static set of equations would ease this pressure.

These power graphs can still be used by managers and planners as an educated guess. After the number of observations for a desired power is determined from the graphs the observations can be placed into the survey with efficiency in mind. Each chosen power and ES value can represent a different scenario. One such scenario was carried out for a power of .80 and an ES of .15. Although any value in the power graphs can be chosen these values were chosen as the most efficient.

The results of this scenario can solve two concerns of the survey, the lack of high elevation sites and the lack of funding. By following the results in Table 4.6, waiting a minimum of four years before the next trend analysis can lead to the removal of two sites from the survey. And assuming that cost of the survey is related to the number of sites, then removing sites will save money. But removing two sites is just the sum difference of a redistribution suggested by the scenario. In fact one site should be removed from elevation class two and six from class three. One site each need to be added to classes five and six and three should be added to class six. There are too many sites in the lower elevation classes of two and three and not enough sites in the higher elevation classes of four, five, and six. A redistribution of sites is in order.

Bibliography

Bibliography

Cohen, J. (1992a). A power primer. *Psychological bulletin*, 112(1):155. 17, 18, 19

Cohen, J. (1992b). Statistical power analysis. *Current directions in psychological science*, 1(3):98–101. 20

Faul, F., Erdfelder, E., Buchner, A., and Lang, A.-G. (2009). Statistical power analyses using g* power 3.1: Tests for correlation and regression analyses. *Behavior research methods*, 41(4):1149–1160. 17

Helsel, D. R. and Hirsch, R. M. (1992). *Statistical methods in water resources*, volume 49. Elsevier. viii, 17

Meijun Cai, J. S. S. (2012). Biological effects of stream water quality on aquatic macroinvertebrates and fish communities within great smoky mountains national park. 4, 15

Robinson, R. B., Barnett, T. W., Harwell, G. R., Moore, S. E., Kulp, M., and Schwartz, J. S. (2008). ph and acid anion time trends in different elevation ranges in the great smoky mountains national park. *Journal of Environmental Engineering*, 134(9):800–808. 4, 5, 8, 9, 10

UTK (2012). 2011 water quality annual report. Technical report. 11

Appendix

Appendix A

A.1 Site Data

A.2 Site data

	Site ID	Site Description	Watershed
1	173	Mill Creek above Abrams Creek	Abrams
2	174	Abrams Creek below Cades Cove	Abrams
3	488	Mill Creek at Pumphouse on Forge Creek Road	Abrams
4	489	Abrams Creek 300 m below trailhead bridge	Abrams
5	142	Beech Creek above Lost Bottom Creek	Cataloochee
6	143	Lost Bottom Creek (Cataloochee Creek)	Cataloochee
7	144	Palmer Creek above Pretty Hollow Creek	Cataloochee
8	147	Lower Cataloochee Creek	Cataloochee
9	148	Lower Little Cataloochee Creek	Cataloochee
10	149	Middle Cataloochee Creek at bridge	Cataloochee
11	293	Rough Fork at Caldwell House	Cataloochee
12	493	Palmer Creek at Davidson Branch Trail	Cataloochee
13	4	Lower Rock Creek	Cosby
14	114	Cosby Creek at log bridge	Cosby
15	137	Upper Rock Creek (Cosby Creek)	Cosby
16	492	Camel Hump Creek off Low Gap Trail	Cosby
17	221	Hazel Creek above cascades	Hazel
18	224	Hazel Creek just below Proctor Creek Confluence	Hazel
19	310	Bone Valley Creek (Hazel Creek)	Hazel
20	311	Hazel Creek below Haw Gap Creek	Hazel
21	479	Hazel Creek at Campsite 86	Hazel
22	480	Haw Gap Creek at bridge near Campsite 84	Hazel
23	481	Little Fork above Sugar Fork Trail	Hazel
24	482	Sugar Fork above Little Fork	Hazel
25	483	Sugar Fork above Haw Gap Creek	Hazel
26	484	Hazel Creek at Cold Spring Gap Trail	Hazel
27	485	Walker Creek above Hazel Creek Trail	Hazel
28	13	Little River at boundary	Little
29	23	Lower Middle Prong Little River	Little
30	24	Lower West Prong Little River	Little
31	30	West Prong Little Pigeon at Headquarters	Little
32	66	West Prong Little Pigeon at Chimneys Picnic Area	Little
33	71	Road Prong above barrier cascade	Little
34	73	Walker Camp Prong above Road Prong	Little
35	74	Walker Camp Prong above Alum Cave Creek	Little
36	233	Walker Camp Prong above Alum Cave	Little
37	234	Upper Road Prong	Little
38	237	Walker Camp Prong at last bridge	Little
39	251	Beech Flats above US 441 loop	Oconaluftee
40	252	Beech Flats below roadcut	Oconaluftee
41	253	Beech Flats above roadcut	Oconaluftee
42	268	Oconaluftee River below Smokemont	Oconaluftee
43	270	Beech Flats at Kephart Footbridge	Oconaluftee

Table A.1: GRSM Stream Survey site descriptions

	Site ID	Elevation (ft)	Elevation (m)	slope	Latitude	Longitude	Historical Elevation Classes	New elevation classes
1	173	1715	522.73	35.68	35.59104	-83.85361	3	3
2	174	1715	522.73	10.27	35.59186	-83.85308	3	3
3	488	1790	545.59	4.04	35.58349	-83.83446	4	1
4	489	1710	521.21	32.78	35.59145	-83.85397	4	1
5	142	3300	1005.84	32.42	35.63565	-83.14537	5	2
6	143	3280	999.74	35.69	35.63625	-83.14481	6	2
7	144	2990	911.35	35.66	35.63900	-83.13078	5	2
8	147	2460	749.81	16.84	35.66688	-83.07277	4	3
9	148	2475	754.38	7.58	35.66913	-83.07283	4	3
10	149	2550	777.24	4.45	35.64627	-83.07554	5	3
11	293	2755	839.72	18.73	35.62442	-83.11391	5	4
12	493	2840	865.63	33.10	35.63462	-83.11943	6	6
13	4	2080	633.98	6.11	35.76133	-83.21044	3	1
14	114	2510	765.05	13.71	35.74863	-83.20066	5	2
15	137	2750	838.20	22.92	35.74616	-83.21630	5	2
16	492	2730	832.10	25.86	35.74457	-83.19876	5	6
17	221	4000	1219.20	30.02	35.54632	-83.58283	8	3
18	224	2999	914.00	17.92	35.53212	-83.62234	6	3
19	310	2240	682.75	19.63	35.49994	-83.68014	4	4
20	311	2155	656.84	26.20	35.49377	-83.68852	4	5
21	479	1740	530.35	39.70	35.47233	-83.71933	3	5
22	480	2201	671.00	10.07	35.49474	-83.68873	4	5
23	481	2540	774.19	30.90	35.50256	-83.70835	5	5
24	482	2540	774.19	38.66	35.50236	-83.70859	5	6
25	483	2320	707.14	34.29	35.49947	-83.69494	4	6
26	484	2475	754.38	9.11	35.50331	-83.65930	5	1
27	485	2860	871.73	5.17	35.52249	-83.63101	6	1
28	13	1100	335.28	44.21	35.66763	-83.71450	2	1
29	23	1150	350.52	5.96	35.65724	-83.70979	2	1
30	24	1150	350.52	31.60	35.65682	-83.71017	2	1
31	30	1430	435.86	2.17	35.68819	-83.53672	2	1
32	66	2680	816.86	17.92	35.63723	-83.49484	5	2
33	71	3400	1036.32	31.28	35.63440	-83.47032	6	2
34	73	3360	1024.13	28.98	35.63476	-83.46931	6	2
35	74	3820	1164.34	18.07	35.62912	-83.45102	7	2
36	233	4255	1296.92	21.86	35.61830	-83.42718	8	3
37	234	5000	1524.00	23.93	35.60975	-83.45043	10	3
38	237	4520	1377.70	30.21	35.62409	-83.41692	9	3
39	251	4010	1222.25	19.03	35.60226	-83.41533	8	3
40	252	4680	1426.46	33.32	35.60666	-83.43391	9	3
41	253	4760	1450.85	26.42	35.60682	-83.43510	9	3
42	268	2169	661.00	3.31	35.55293	-83.30937	4	4
43	270	2799	853.00	22.92	35.58641	-83.36400	5	4

Table A.2: Site Data

Appendix B

Descriptive Statistics

Table B.1: Descriptive statistics of Water Quality in the GRSM

Set	Class	pH				ANC meql				Nitrate meql				Sulfate meql			
		N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean	N	Minimum	Maximum	Mean
1993-2002																	
	1	327	4.96	7.90	6.57	327	-20.74	1534.47	149.76	275	0.00	49.94	12.04	325	12.32	85.01	36.09
	2	393	5.32	7.00	6.25	392	-7.43	182.95	40.75	377	1.37	73.76	26.62	390	0.00	159.51	51.68
	3	400	4.65	8.24	6.44	398	-19.97	1624.49	158.44	365	0.00	96.13	26.14	391	0.00	262.37	54.00
	4	121	6.18	7.11	6.50	120	24.45	178.00	75.84	105	2.16	28.29	11.90	119	12.34	77.74	25.16
	5	116	6.07	7.05	6.50	116	41.34	162.76	77.06	66	1.23	10.55	4.35	116	7.51	79.98	26.14
	6	110	5.77	7.06	6.41	110	15.64	165.02	68.01	81	1.56	60.46	21.13	110	14.71	61.16	28.35
2003-2008																	
	1	255	5.22	7.95	6.65	255	-37.09	1314.56	173.48	252	0.50	62.75	16.56	261	10.00	93.23	38.85
	2	289	4.83	7.07	6.32	289	-1.88	145.95	42.20	296	0.62	67.12	29.20	298	11.64	152.55	48.19
	3	299	4.65	8.10	6.55	299	-26.45	1591.06	172.82	297	0.13	95.72	27.69	308	10.44	490.01	54.25
	4	119	5.95	7.06	6.58	119	23.36	128.28	69.90	121	1.87	55.67	17.51	123	13.88	61.31	29.04
	5	35	5.98	7.03	6.50	35	36.37	115.80	77.84	30	1.45	26.48	7.59	37	12.18	117.46	30.54
	6	97	5.79	7.05	6.44	97	6.73	130.63	55.68	98	1.09	72.79	24.88	101	10.02	65.53	34.31
209-2012																	
	1	191	5.42	8.02	6.77	191	-0.02	1377.93	164.72	191	0.22	62.14	16.31	190	14.61	113.83	39.63
	2	212	4.91	7.28	6.47	212	-11.74	174.52	44.45	212	4.43	72.17	30.08	212	13.45	125.36	47.41
	3	228	4.73	7.96	6.68	228	-18.28	1535.69	160.14	228	1.04	72.16	26.23	228	13.59	317.63	58.15
	4	97	6.20	7.08	6.68	97	25.70	107.58	64.13	97	0.54	34.67	18.72	97	19.89	46.66	29.33
	5	29	6.30	7.11	6.77	29	40.10	115.94	73.55	29	0.21	83.68	6.44	29	16.78	109.18	36.16
	6	76	4.24	7.09	6.52	76	-3.92	114.28	46.15	76	0.16	79.04	32.17	76	15.72	63.32	37.05

Appendix C

Variable selection

Table C.1: List of variables used for step-wise variable selection. X's for variables selected by the step-wise method, O's if variable was added after the step-wise process.

		Dependents for step-wise regression			
Available Variables	comments	pH	ANC	NO_3	SO_4
pH	Dependent				
ANC	Dependent			X	X
NO_3	Dependent	X	X		X
SO_4	Dependent	X	X	X	
Julian Date			X	X	X
Month					
Year					
Julian Date Days	Seasonality	X			
$\sin(\theta)$	Seasonality	O	X	X	O
$\cos(\theta)$	Seasonality	X	O	X	O
Sum Base Cations			X	X	X
Conductivity			X	X	X
Chloride			X	X	
Elevation (m)					
Slope					
$\log_2$ (ANC)					
$\log_2$ (Base Cations)		X			
Number of predictors		6	8	8	7

Appendix D

Julian Date Coefficients

D.1 Step-wise Method

D.2 Temporal Variables

Table D.1: Time trend results for specific elevation classes using variables from step-wise regression. **Bold** results are insignificant.

Time set	Elevation class	Elevation range m (ft)	Number of sites	Julian date coefficient, eq/L or pH units (model adjusted r^2) (p-value)			
				pH	ANC	Nitrate	Sulfate
1993-2002	1	304.8-609.6	5	0.069	0.007	0.034	-0.096
		(1000-2000)		0.712	0.985	0.503	0.569
				0.000	0.000	0.000	0.000
	2	609.6-762	9	-0.091	-0.036	-0.037	0.019
		(2000-2500)		0.388	0.603	0.699	0.766
				0.000	0.000	0.000	0.000
	3	762-914.4	13	-0.010	0.008	-0.013	0.024
		(2500-3000)		0.693	0.971	0.359	0.590
				0.000	0.000	0.000	0.000
	4	914.4-1066.8	4	0.019	0.015	0.058	0.061
		(3500-3500)		0.205	0.709	0.410	0.402
				0.000	0.000	0.000	0.000
	5	1066.8-1371.6	4	-0.157	-0.082	0.288	-0.133
		(3500-4500)		0.165	0.760	0.328	0.566
				0.010	0.000	0.000	0.000
	6	1371.6<	2	0.218	0.067	-0.011	0.092
		(4500<)		0.505	0.802	0.871	0.716
				0.000	0.000	0.000	0.000
2003-2008	1	304.8-609.6	5	0.150	-0.004	0.038	0.039
		(1000-2000)		0.781	0.996	0.551	0.673
				0.000	0.000	0.000	0.000
	2	609.6-762	9	0.275	0.033	0.044	0.044
		(2000-2500)		0.348	0.779	0.816	0.893
				0.000	0.000	0.000	0.000
	3	762-914.4	13	0.156	0.005	0.072	0.034
		(2500-3000)		0.663	0.996	0.637	0.923
				0.000	0.000	0.000	0.000
	4	914.4-1066.8	4	0.249	-0.028	0.092	0.110
		(3500-3500)		0.400	0.779	0.405	0.343
				0.000	0.000	0.000	0.000
	5	1066.8-1371.6	4	0.137	-0.020	0.204	0.135
		(3500-4500)		0.300	0.739	0.562	0.884
				0.027	0.000	0.001	0.000
	6	1371.6<	2	0.359	0.127	0.074	0.161
		(4500<)		0.317	0.812	0.832	0.844
				0.000	0.000	0.000	0.000
2009-2012	1	304.8-609.6	5	0.106	-0.002	0.026	-0.052
		(1000-2000)		0.894	0.989	0.376	0.536
				0.000	0.000	0.000	0.000
	2	609.6-762	9	0.218	0.069	0.121	0.039
		(2000-2500)		0.606	0.862	0.735	0.887
				0.000	0.000	0.000	0.000
	3	762-914.4	13	0.056	0.007	0.019	0.050
		(2500-3000)		0.766	0.997	0.598	0.915
				0.000	0.000	0.000	0.000
	4	914.4-1066.8	4	0.413	-0.006	-0.013	-0.068
		(3500-3500)		0.593	0.772	0.635	0.529
				0.000	0.000	0.000	0.000
	5	1066.8-1371.6	4	**-0.115**	0.901	**0.098**	0.015
		(3500-4500)		**0.158**	0.540	**-0.272**	0.658
				0.130	0.001	**0.975**	0.000
	6	1371.6<	2	0.289	0.059	0.097	-0.059
		(4500<)		0.286	0.809	0.881	0.861
				0.000	0.000	0.000	0.000

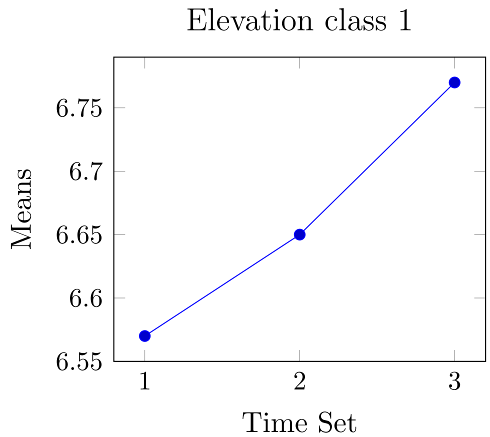
Table D.2: Time trend results for specific elevation classes using julian date, cosine(θ), and sine(θ) only. **Bold** results are insignificant.

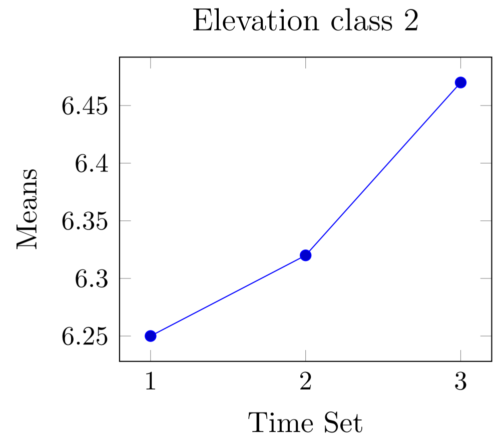
Time set	Elevation class	Elevation range m (ft)	Number of sites	Julian date coefficient, eq/L or pH units (model adjusted r^2) (p-value)			
				pH	ANC	Nitrate	Sulfate
1993-2002	1	304.8-609.6	5	**0.054**	**0.089**	-0.138	-0.190
		(1000-2000)		**0.047**	**0.024**	0.016	0.045
				0.321	**0.106**	0.022	0.001
	2	609.6-762	9	**-0.090**	**-0.060**	**-0.060**	**-0.075**
		(2000-2500)		**0.128**	**0.189**	**0.017**	**0.009**
				0.060	**0.195**	**0.248**	**0.142**
	3	762-914.4	13	**-0.012**	**-0.030**	**-0.048**	**-0.047**
		(2500-3000)		**0.013**	**0.000**	**-0.004**	**-0.004**
				0.817	**0.550**	**0.365**	**0.355**
	4	914.4-1066.8	4	**-0.047**	**-0.151**	**-0.009**	**0.095**
		(3500-3500)		**0.059**	**0.294**	**-0.027**	**-0.016**
				.597	**0.055**	**0.926**	**0.313**
	5	1066.8-1371.6	4	**-0.151**	-0.148	0.330	**0.092**
		(3500-4500)		**0.051**	0.381	0.120	**-0.010**
				.100	0.047	0.006	**0.331**
	6	1371.6<	2	**.156**	**-0.016**	**-0.208**	**-0.036**
		(4500<)		**.096**	**0.075**	**0.092**	**-0.009**
				.092	**0.863**	**0.058**	**0.707**
2003-2008	1	304.8-609.6)	5	.139	**0.009**	0.155	0.192
		(1000-2000		0.040	**0.001**	0.061	0.043
				0.025	**0.888**	0.012	0.002
	2	609.6-762	9	0.145	**-0.090**	0.178	0.138
		(2000-2500)		0.061	**0.081**	0.043	0.014
				0.012	**0.114**	0.002	0.017
	3	762-914.4	13	**0.103**	**-0.006**	**0.047**	**0.099**
		(2500-3000)		**0.020**	**-0.003**	**-0.003**	**0.006**
				0.075	**0.925**	**0.418**	**0.085**
	4	914.4-1066.8	4	0.235	**-0.029**	0.193	0.192
		(3500-3500)		0.148	**0.180**	0.086	0.023
				0.007	**0.728**	0.030	0.035
	5	1066.8-1371.6	4	**0.135**	**-0.112**	**-0.176**	**0.067**
		(3500-4500)		**-0.069**	**0.337**	**-0.082**	**-0.024**
				0.466	**0.443**	**0.401**	**0.701**
	6	1371.6<	2	0.204	**-0.108**	0.236	0.307
		(4500<)		0.081	**0.094**	0.046	0.074
				0.041	**0.274**	0.020	0.002
2009-2012	1	304.8-609.6	5	**0.111**	**0.026**	**-0.036**	**-0.092**
		(1000-2000)		**0.028**	**0.000**	**0.018**	**0.005**
				0.122	**0.718**	**0.619**	**0.207**
	2	609.6-762	9	0.141	**0.017**	**0.020**	**-0.062**
		(2000-2500)		0.052	**0.056**	**0.011**	**-0.010**
				0.037	**0.800**	**0.767**	**0.376**
	3	762-914.4	13	**-0.034**	**-0.027**	**-0.036**	**0.078**
		(2500-3000)		**-0.009**	**-0.002**	**-0.004**	**-0.007**
				0.611	**0.684**	**0.592**	**0.246**
	4	914.4-1066.8	4	0.405	**0.032**	**-0.067**	**-0.129**
		(3500-3500)		0.200	**0.161**	**-0.016**	**-0.011**
				0.000	**0.733**	**0.518**	**0.215**
	5	1066.8-1371.6	4	**-0.031**	0.891	**0.052**	**-0.414**
		(3500-4500)		**0.218**	0.466	**-0.039**	**-0.076**
				0.934	0.007	**0.904**	**0.347**
	6	1371.6<	2	0.264	**0.083**	**-0.021**	**-0.214**
		(4500<)		0.039	**0.058**	**-0.016**	**0.007**
				0.023	**0.462**	**0.859**	**0.068**

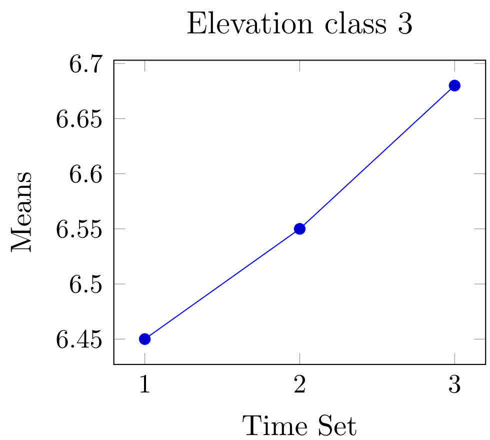
Appendix E

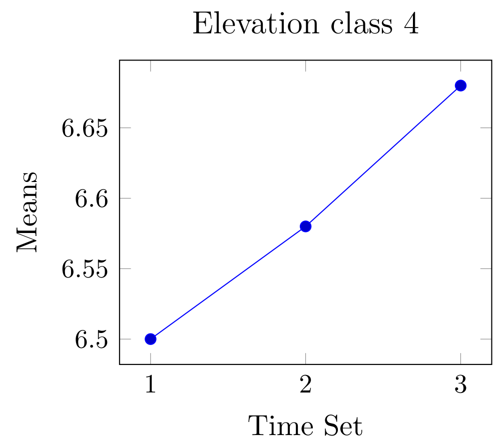
ANOVA/Bonferoni

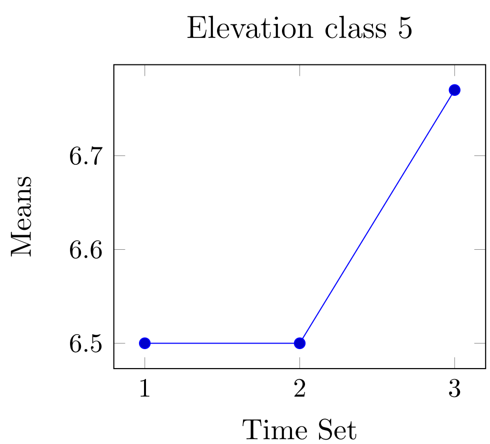
E.1 pH

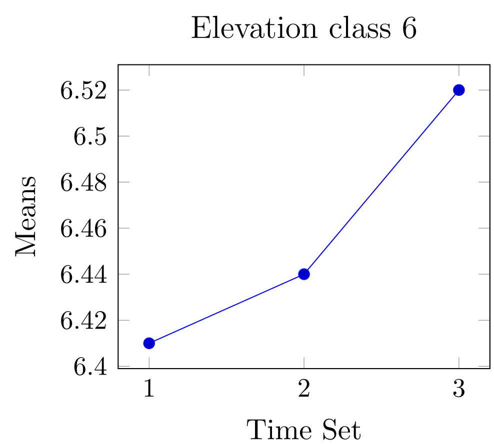

Elevation class 1
Means
6.75
6.7
6.65
6.6
6.55
1
2
3
Time Set


Elevation class 2
Means
6.45
6.4
6.35
6.3
6.25
1
2
3
Time Set

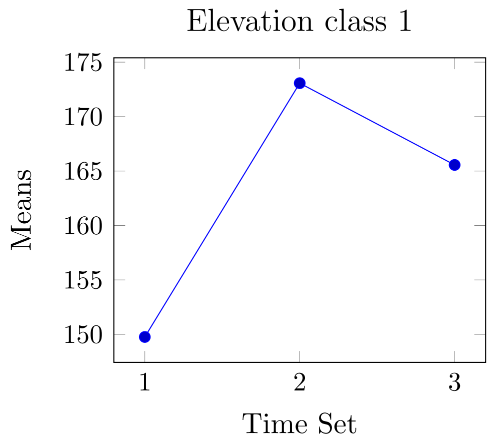

Elevation class 3
Means
6.7
6.65
6.6
6.55
6.5
6.45
1
2
3
Time Set

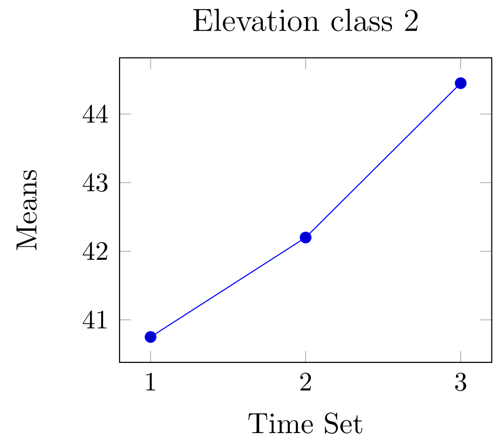

Elevation class 4
Means
6.65
6.6
6.55
6.5
1
2
3
Time Set

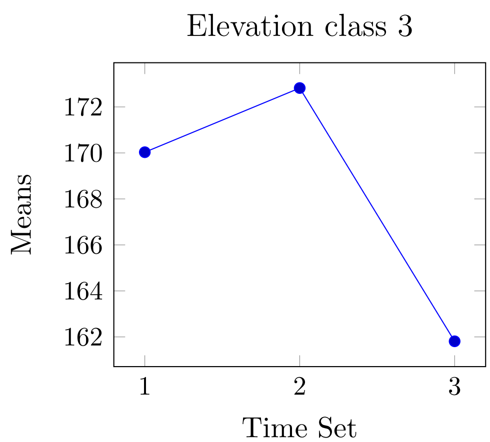

Elevation class 5
Means
6.7
6.6
6.5
1
2
3
Time Set

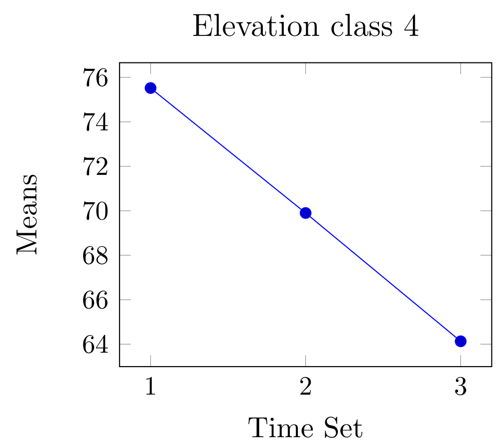

Elevation class 6
Means
6.52
6.5
6.48
6.46
6.44
6.42
6.4
1
2
3
Time Set

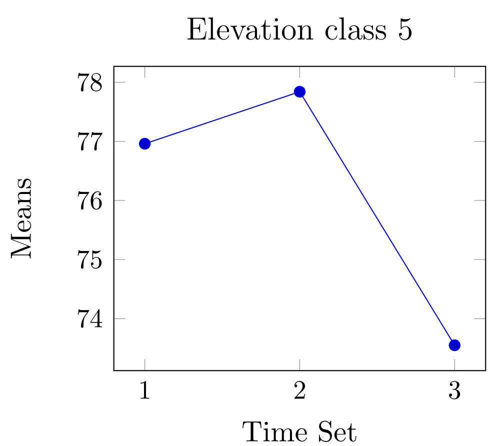
E.2 ANC

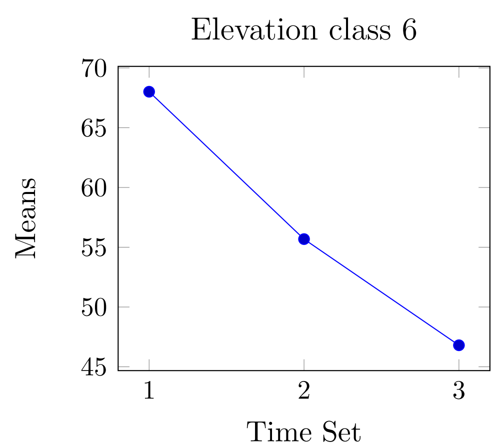

Elevation class 1
Means
175
170
165
160
155
150
1
2
3
Time Set


Elevation class 2
Means
44
43
42
41
1
2
3
Time Set

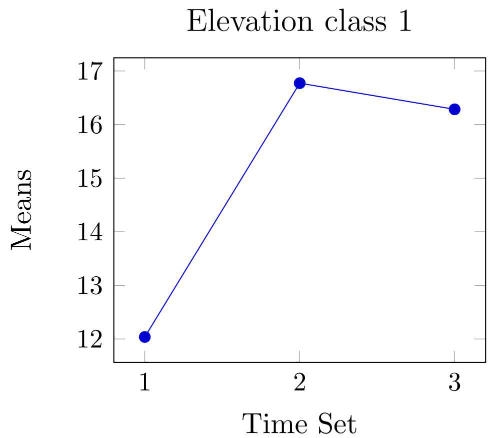

Elevation class 3
Means
172
170
168
166
164
162
1
2
3
Time Set

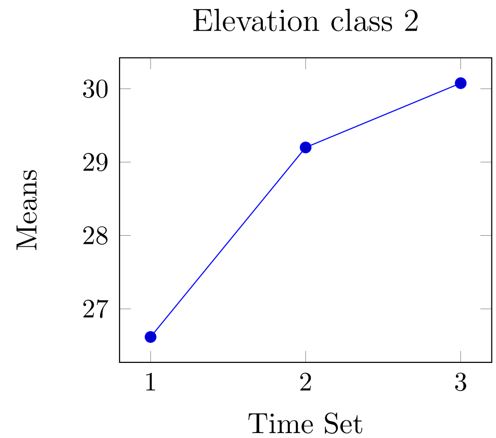

Elevation class 4
Means
76
74
72
70
68
66
64
1
2
3
Time Set

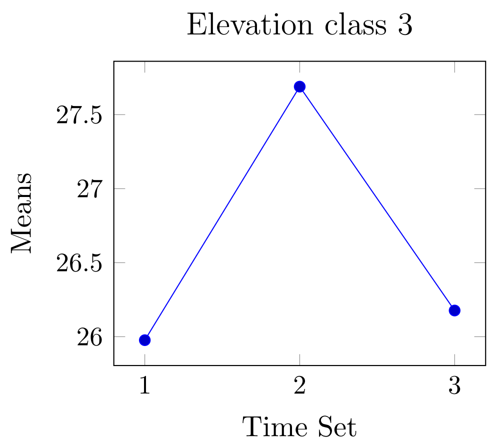

Elevation class 5
Means
78
77
76
75
74
1
2
3
Time Set

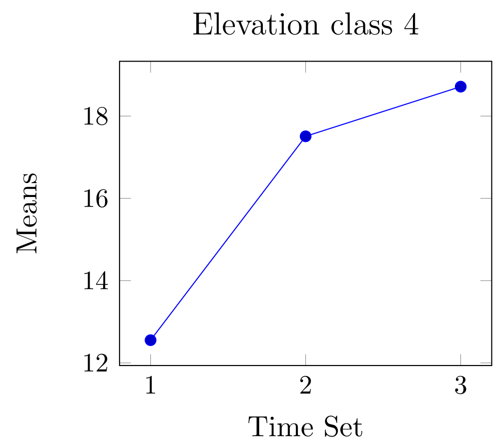

Elevation class 6
Means
70
65
60
55
50
45
1
2
3
Time Set

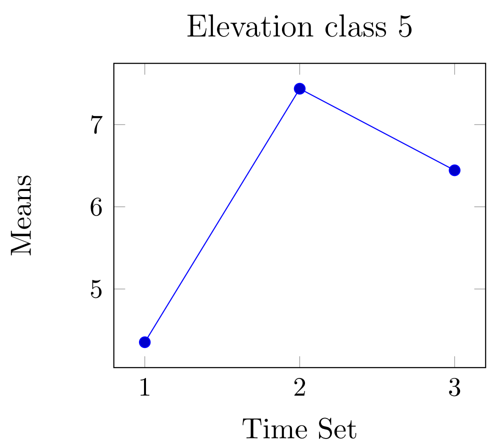
E.3 Nitrate

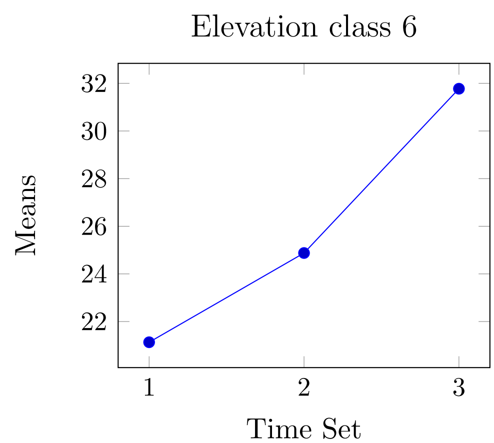

Elevation class 1
Means
17
16
15
14
13
12
1
2
3
Time Set


Elevation class 2
Means
30
29
28
27
1
2
3
Time Set

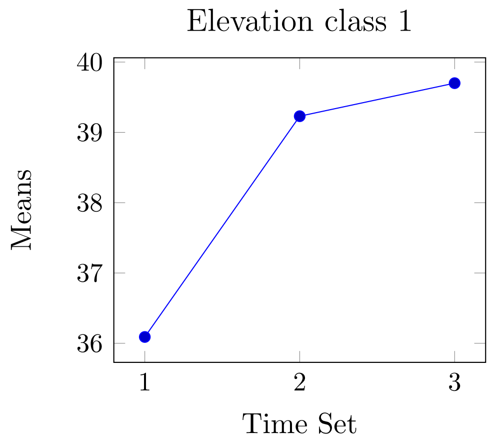

Elevation class 3
Means
27.5
27
26.5
26
1
2
3
Time Set

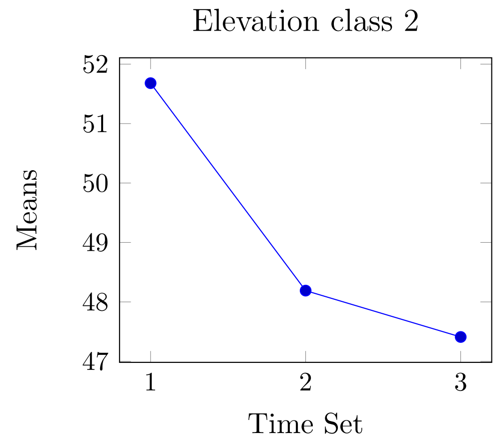

Elevation class 4
Means
18
16
14
12
1
2
3
Time Set

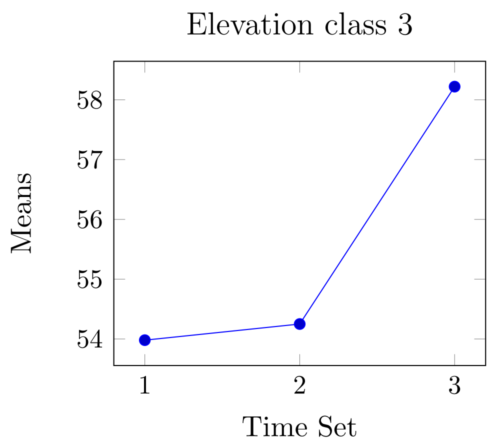

Elevation class 5
Means
7
6
5
1
2
3
Time Set

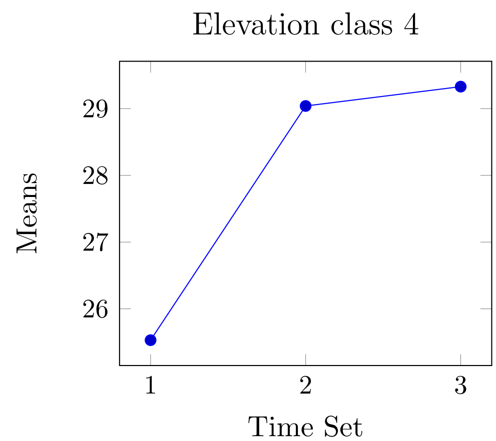

Elevation class 6
Means
32
30
28
26
24
22
1
2
3
Time Set

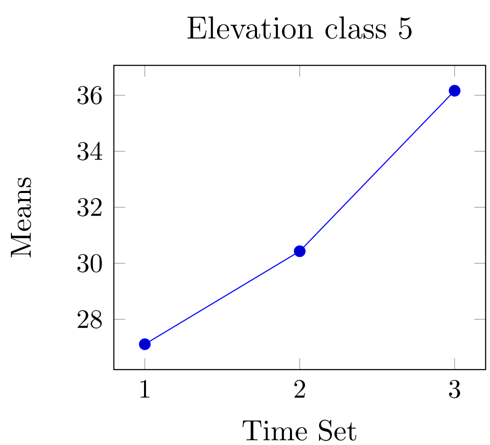
E.4 Sulfate

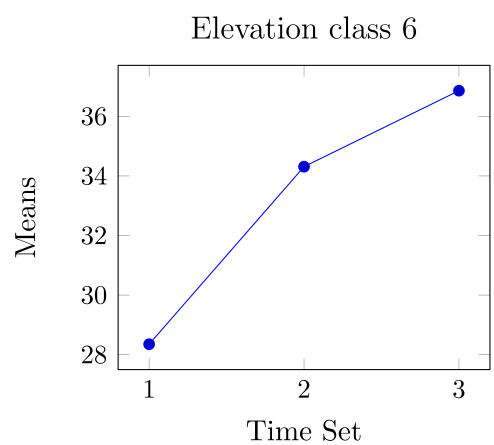

Elevation class 1
Means
Time Set
40
39
38
37
36
1
2
3


Elevation class 2
Means
Time Set
52
51
50
49
48
47
1
2
3


Elevation class 3
Means
Time Set
58
57
56
55
54
1
2
3


Elevation class 4
Means
Time Set
29
28
27
26
1
2
3


Elevation class 5
Means
Time Set
36
34
32
30
28
1
2
3


Elevation class 6
Means
Time Set
36
34
32
30
28
1
2
3

Appendix F

Post Hoc Power Analsysis

F.1 Step-Wise Variables

F.2 Temperol variables

Table F.1: Post hoc power analysis using G*power and a calculated ES, alpha is .05. **Bold** results are insignificant.

		pH				ANCmeqL				NitratemeqL				SulfatemeqL			
Set	Class	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power
1993-2002																	
	1	327	0.712	2.47	1.00	327	0.985	65.67	1.00	275	0.503	1.01	1.00	325	0.569	1.32	1.00
	2	393	0.388	0.63	1.00	392	0.603	1.52	1.00	377	0.699	2.32	1.00	390	0.766	3.27	1.00
	3	400	0.693	2.26	1.00	398	0.971	33.48	1.00	365	0.359	0.56	1.00	391	0.590	1.44	1.00
	4	121	0.205	0.26	0.99	120	0.709	2.44	1.00	105	0.410	0.69	1.00	119	0.402	0.67	1.00
	5	116	0.165	0.20	0.96	116	0.760	3.17	1.00	66	0.328	0.49	0.98	116	0.566	1.30	1.00
	6	110	0.505	1.02	1.00	110	0.802	4.05	1.00	81	0.871	6.75	1.00	110	0.716	2.52	1.00
2003-2008																	
	1	255	0.781	3.57	1.00	255	0.996	249.00	1.00	252	0.551	1.23	1.00	261	0.673	2.06	1.00
	2	289	0.348	0.53	1.00	289	0.779	3.52	1.00	296	0.816	4.43	1.00	298	0.893	8.35	1.00
	3	299	0.663	1.97	1.00	299	0.996	249.00	1.00	297	0.637	1.75	1.00	308	0.923	11.99	1.00
	4	119	0.400	0.67	1.00	119	0.779	3.52	1.00	121	0.405	0.68	1.00	123	0.343	0.52	1.00
	5	35	0.300	0.43	0.74	35	0.739	2.83	1.00	30	0.562	1.28	0.98	37	0.884	7.62	1.00
	6	97	0.317	0.46	1.00	97	0.812	4.32	1.00	98	0.832	4.95	1.00	101	0.844	5.41	1.00
2009-2012																	
	1	191	0.894	8.43	1.00	191	0.989	89.91	1.00	191	0.376	0.60	1.00	190	0.536	1.16	1.00
	2	212	0.606	1.54	1.00	212	0.862	6.25	1.00	212	0.735	2.77	1.00	212	0.887	7.85	1.00
	3	228	0.766	3.27	1.00	228	0.997	332.33	1.00	228	0.598	1.49	1.00	228	0.915	10.76	1.00
	4	97	0.593	1.46	1.00	97	0.772	3.39	1.00	97	0.635	1.74	1.00	97	0.529	1.12	1.00
	5	29	**0.158**	0.19	0.28	29	0.540	1.17	0.96	29	**-0.272**	NA	NA	29	0.658	1.92	1.00
	6	76	0.286	0.40	0.99	76	0.809	4.24	1.00	76	0.881	7.40	1.00	76	0.861	6.19	1.00

Table F.2: Post hoc power analysis using G*power a calculated ES, an alpha of .05 with the variables: sine(θ), cosine(θ), and julian date only. **Bold** results are insignificant.

		pH				ANCmeqL				NitratemeqL				SulfatemeqL			
Set	Class	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power	N	Adjusted r^2	Effect Size	Actual Power
1993-2002																	
	1	327	**0.047**	0.049	0.93	327	**0.024**	0.02	0.65	275	0.016	0.02	0.39	325	0.045	0.05	0.92
	2	393	**0.128**	0.15	1.00	392	**0.189**	0.23	1.00	377	**0.017**	0.02	0.55	390	**0.009**	0.01	0.32
	3	400	**0.013**	0.01	0.46	398	**0.000**	0.00	0.06	365	**-0.004**	NA	NA	391	**-0.004**	NA	NA
	4	121	**0.059**	0.06	0.61	120	**0.294**	0.42	1.00	105	**-0.027**	NA	NA	119	**-0.016**	NA	NA
	5	116	**0.051**	0.05	0.52	116	0.381	0.62	1.00	66	0.120	0.14	0.68	116	**-0.010**	NA	NA
	6	110	**0.096**	0.11	0.81	110	**0.075**	0.08	0.69	81	**0.092**	0.10	0.64	110	**-0.009**	NA	NA
2003-2008																	
	1	255	0.040	0.04	0.78	255	**0.001**	0.00	0.07	252	0.061	0.06	0.94	261	0.043	0.04	0.82
	2	289	0.061	0.06	0.96	289	**0.081**	0.09	0.99	296	0.043	0.04	0.87	298	0.014	0.01	0.37
	3	299	**0.020**	0.02	0.52	299	**-0.003**	NA	NA	297	**-0.003**	NA	NA	308	**0.006**	0.01	0.18
	4	119	0.148	0.17	0.97	119	**0.180**	0.22	0.99	121	0.086	0.09	0.80	123	0.023	0.02	0.26
	5	35	**-0.069**	NA	NA	35	**0.337**	0.51	0.93	30	**-0.082**	NA	NA	37	**-0.024**	NA	NA
	6	97	0.081	0.09	0.67	97	**0.094**	0.10	0.74	98	0.046	0.05	0.40	101	0.074	0.08	0.64
2009-2012																	
	1	191	**0.028**	0.03	0.47	191	**0.000**	0.00	0.05	191	**0.018**	0.02	0.31	190	**0.005**	0.01	0.11
	2	212	0.052	0.05	0.82	212	**0.056**	0.06	0.85	212	**0.011**	0.01	0.22	212	**-0.010**	NA	NA
	3	228	**-0.009**	NA	NA	228	**-0.002**	NA	NA	228	**-0.004**	NA	NA	228	**-0.007**	NA	NA
	4	97	0.200	0.25	0.99	97	**0.161**	0.19	0.96	97	**-0.016**	NA	NA	97	**-0.011**	NA	NA
	5	29	**0.218**	0.28	0.58	29	0.466	0.87	0.98	29	**-0.039**	NA	NA	29	**-0.076**	NA	NA
	6	76	0.039	0.04	0.27	76	**0.058**	0.06	0.39	76	**-0.016**	NA	NA	76	**0.007**	0.01	0.08

Appendix G

A priori analysis

G.1 Power graphs

G.1.1 pH

G.1.2 ANC and Nitrate

G.1.3 Sulfate

G.1.4 Time Variables

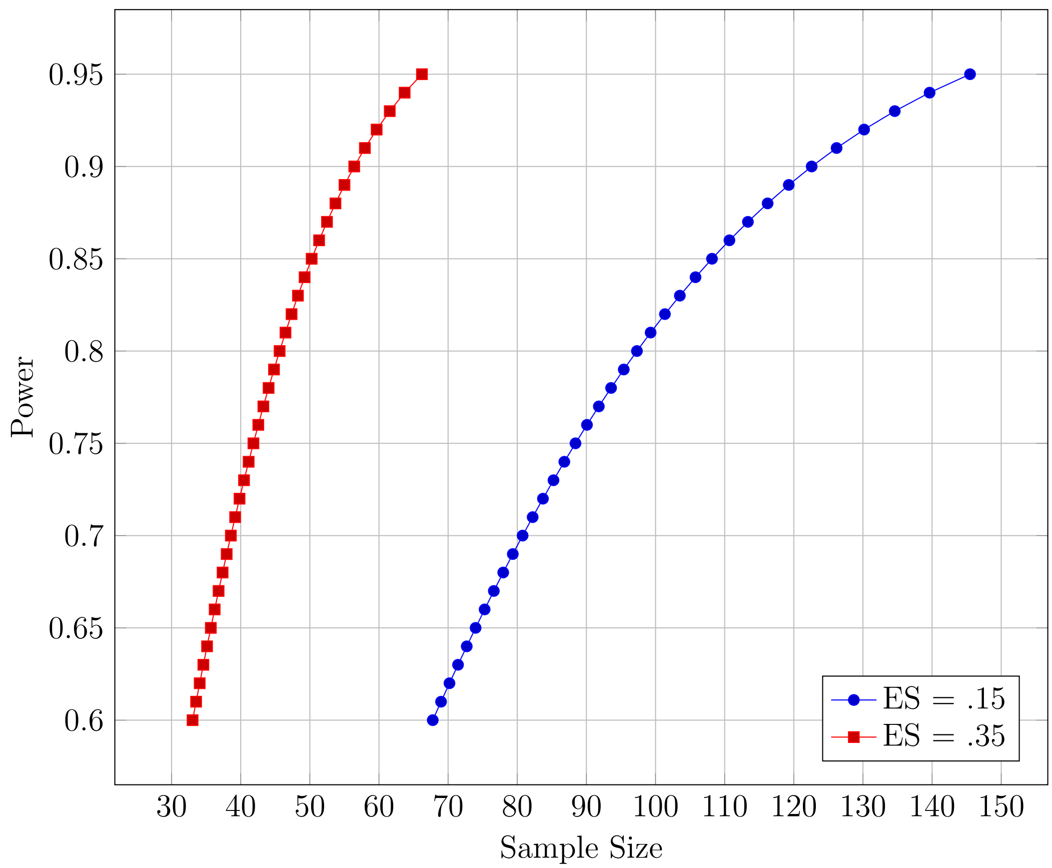


Figure G.1: pH Power Graph. The power is shown as a function of pH

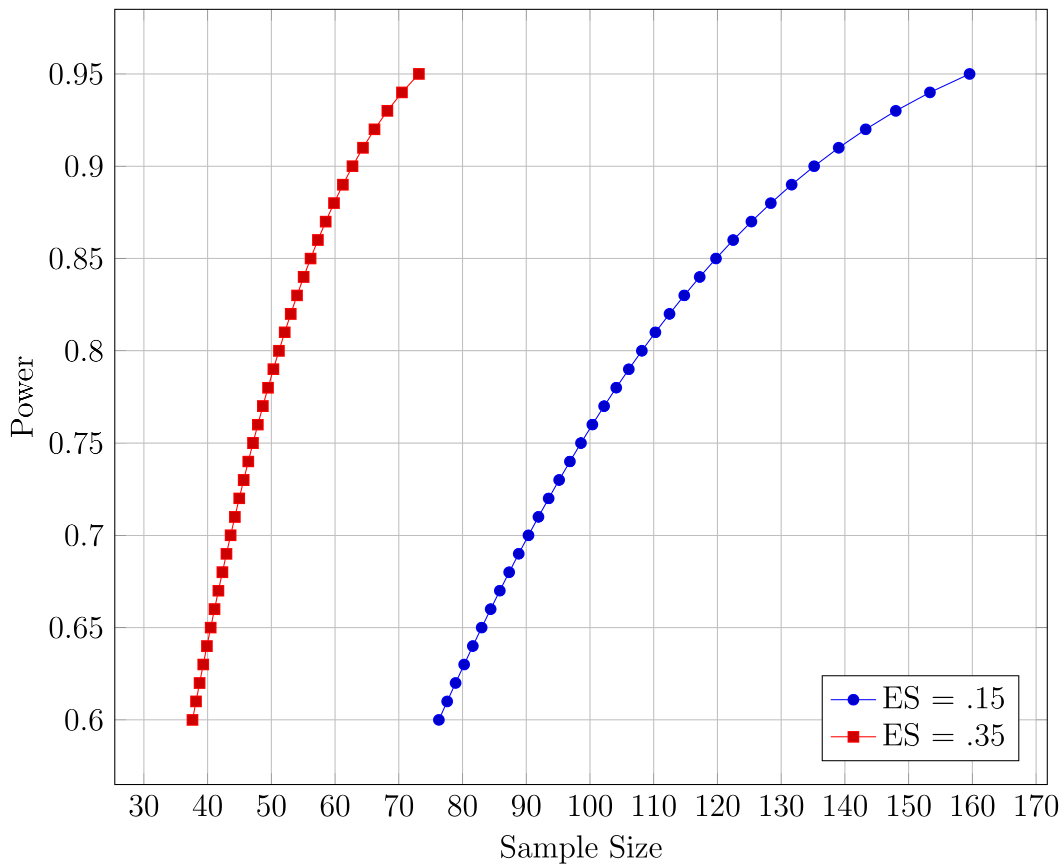


Figure G.2: ANC and Nitrate Power Graphs. The power graphs for ANC and Nitrate are the same because they both have the same number of predictors.

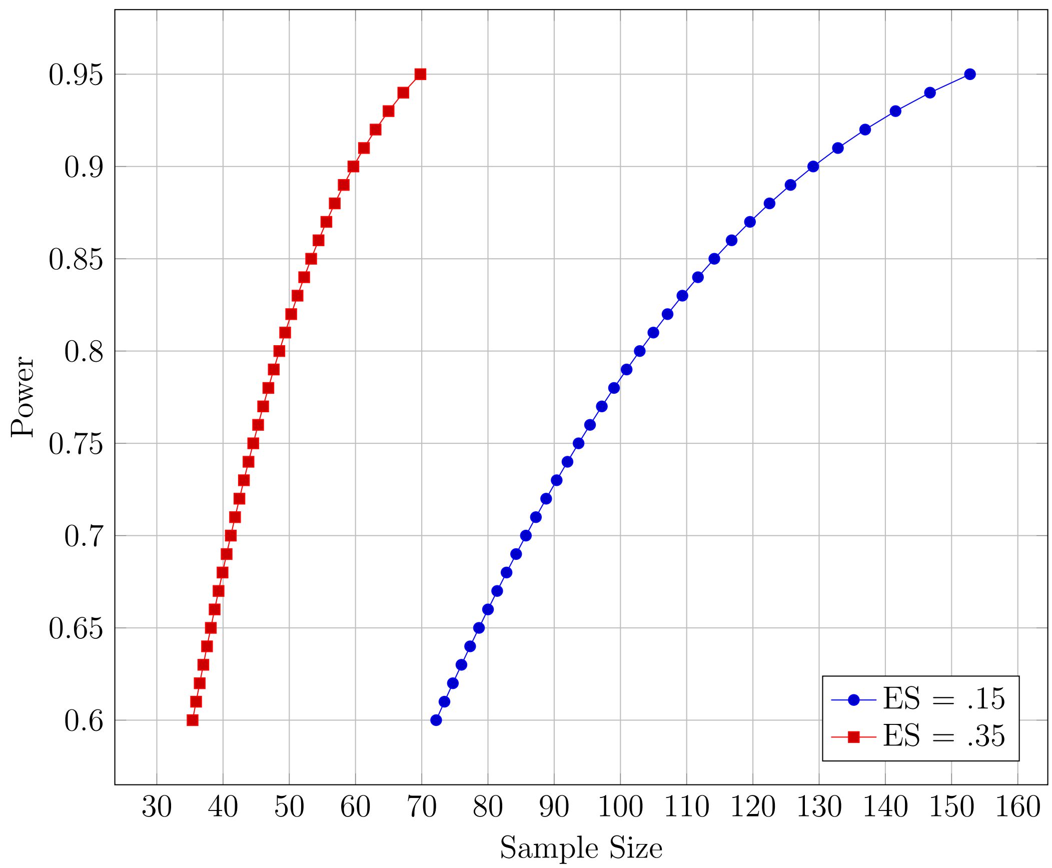


Figure G.3: Sulfate Power Graph

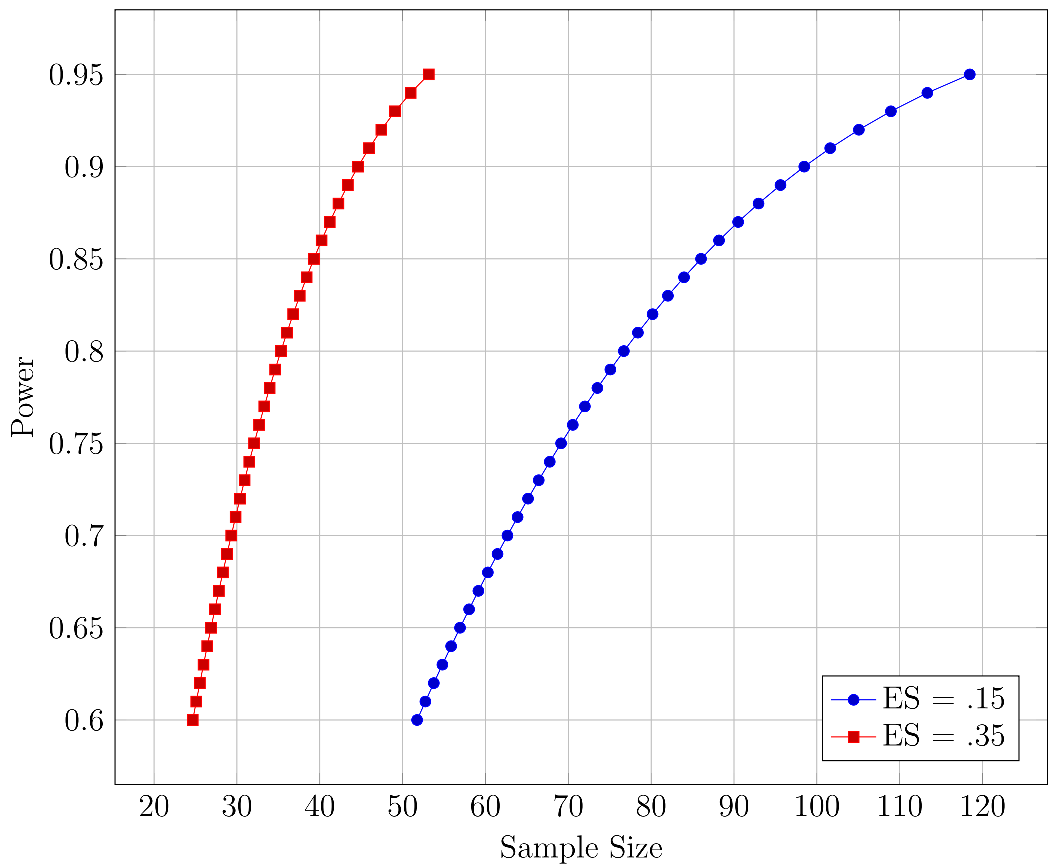


Figure G.4: Time Variables Power Graph

Vita

Tim Pobst was born in Nashville, TN on June 1st 1985 to George and Peggy Pobst. He graduated from Centennial High School near Franklin, TN and was accepted to the University of Tennessee immediately after. He was undecided for three years before deciding to try for a civil engineering degree and he finished it in spring of 2011. He stayed at the University of Tennessee to get a masters degree in environmental engineering under Dr. Schwartz.