

Effects of Water Chemistry and Watershed Characteristics on Populations of Trout in the Great Smoky Mountains National Park

R. Bruce Robinson, Ph.D., P.E.

Professor of Civil and Environmental Engineering

Karen Jackson, E.I.

Graduate Research Assistant

Department of Civil and Environmental Engineering
The University of Tennessee, Knoxville

Steve Moore

Supervisory Fishery Biologist

Matt Kulp

Fishery Biologist

Great Smoky Mountains National Park
Gatlinburg, TN

May 2006

**Report Prepared For:
The National Park Service**

Cooperative Agreement No.: 1443-CA-5460-98-006
Southern Appalachian Cooperative Ecosystem Studies
Unit CESU Host Cooperative Agreement
No. H5000 04 5040 Task Agreement No. J5460 05 0067

Abstract

The purpose of this study was to combine fish, water quality, and watershed databases in order to determine what relationships exist between trout biomass and base flow water quality in the Great Smoky Mountains National Park (GRSM). Quarterly base flow water quality data collected from 1993 to 2003 at 31 stream sites in the GRSM were used in step-wise multiple linear regression models to analyze brook and rainbow trout biomass (kg/ha). Stream samples were analyzed for pH, acid neutralizing capacity (ANC), conductivity, major cations, and major anions. The potential predictor variables included seasonality, basin characteristics, USGS stream flow data as surrogate hydrologic data, precipitation data, e.g. cumulative inches of rain on preceding days, and water quality data. Each of the predictor variables were found to be statistically significant ($p < 0.05$) influencing factors to trout biomass, particularly elevation, basin area, sulfate concentration, maximum stream flow, conductivity, ANC, and percent anakeesta geology.

Final correlation analysis, where zeros were assumed for biomass when there were no trout present, revealed that pH, ANC, conductivity, and sulfate are important predictors of trout biomass. Brook trout biomass was not significantly correlated with median pH or log (ANC). However, rainbow trout young-of-year and adult biomass had correlation coefficients of 0.514 and 0.504 respectively with median pH. Furthermore, rainbow trout young-of-year and adult biomass had correlation coefficients of 0.635 and 0.544 respectively with log (ANC). Brook trout young-of-year and adult biomass had correlation coefficients of -0.237 and -0.239 respectively with log (conductivity). Rainbow trout young-of-year and adult biomass had correlation coefficients of 0.613 and

0.368 respectively with log (conductivity). Lastly, both brook and adult rainbow trout biomass had significant negative correlations with sulfate concentrations. Brook trout young-of-year and adult biomass had correlation coefficients of -0.346 and -0.303 respectively with sulfate. Rainbow trout adult biomass had a correlation coefficient of -0.190 . Rainbow trout young-of-year biomass was not significantly correlated with sulfate concentrations.

Modeling revealed that brook trout biomass is most strongly related to elevation while rainbow trout biomass is related more to basin area. Elevation is positively correlated with brook trout biomass and accounts for 31% and 40% of the variability in brook trout young-of-year and adult biomass respectively. Similarly, basin area is positively correlated with rainbow trout biomass and accounts for 68% and 40% of the variability in rainbow trout young-of-year and adult biomass respectively. It is thought that basin area and elevation are possible surrogates for stream size. Elevation and basin area have a correlation coefficient of -0.4794 , meaning that large basin areas occur at lower elevations and higher elevations have smaller basin areas. Results also showed that young-of-year trout were negatively affected by increases in maximum stream flow and cumulative precipitation for the previous 90 days. Also results for adult trout biomass show a negative relationship with biomass of a competing trout species. Both trout species were negatively affected by increases in sulfate concentrations and percent anakeesta geology. The overall models for biomass produced r-squared values of 0.54 and 0.63 for brook trout young-of-year and adult respectively and values of 0.73 and 0.49 for rainbow trout young-of-year and adult respectively.

Based on the regression results, trout biomass decreases with increases in sulfate concentrations and percent anakeesta. Both of these variables can be linked to acidic stream conditions. Sites along Shutts Prong, Porters Creek, and Walker Camp Prong are at risk because total trout biomass at these locations is either zero or very small and they have greater than 90% anakeesta geology and/or elevated sulfate concentrations.

Brook trout biomass showed a significant positive relationship with elevation. This was expected since results from Baldigo and Lawrence (2001) showed that brook trout seem to be present in streams at high elevations with cold water, steep gradients, small channels, and fast water velocities. Furthermore, brook trout are most often found in small lakes and streams at high elevations which are most susceptible to acidic deposition (Turner et al. 1992). In the GRSM, brook trout are relegated to high elevation streams by historic logging and competition from exotic rainbow trout. Apparently due to competition, brook trout biomass was adversely affected by increases in rainbow trout biomass. Rainbow trout are larger than brook and therefore able to out-compete them for feeding territories. Larson and Moore (1985) found that in GRSM stream segments with similar physical characteristics rainbow trout have biomasses about 1.8 times greater than that of brook trout. Rainbow trout biomass showed a significant positive relationship with basin area, which is consistent with King's (1943) observation that rainbow trout are relatively larger and more active and therefore choose larger streams, other conditions being the same, than brook trout. Rainbow trout biomass also increases with increasing stream conductivity and ANC. Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. The negative relationships between young-of-year biomass and hydrologic

conditions can be explained by young-of-year trout being washed away by high flows and/or high flows often corresponding to decreases in stream pH and ANC (Latterell et al. 1998; Driscoll et al. 2001). Final correlation results also indicate that both brook and rainbow trout biomass decrease as the cumulative precipitation for the previous 90 and 180 days increases. This is consistent with results from Barnett (2003) that water quality conditions in the GRSM were adversely affected by increased stream flows, acid deposition and precipitation. Furthermore, negative correlations between sulfate concentrations and biomass give possible evidence to the problem of acid deposition. However, sulfate is also strongly correlated with anakeesta geology. Since this analysis does not consider storm event water quality, it is difficult to separate out the affects of acid deposition versus acidic geology in the GRSM.

Table of Contents

	Page
Chapter I. Introduction.....	1
Description of Study Area	1
Description of Parkwide Water Quality Monitoring	1
Description of Parkwide Trout Monitoring	2
Objectives	5
Chapter II. Literature Review	6
Factors Affecting Fish.....	6
Acidification and pH.....	7
Acidification Classification	8
Acidification Effects for Fish.....	9
Acid Sensitive Species.....	10
Acid Tolerant Species	11
Aluminum	12
Toxic Effects on Fish	12
Dissolved Organic Carbon.....	13
Calcium	14
Sulfate	14
Nitrate	15
Physical Habitat and Hydrologic Characteristics	16
Hydraulic Features	17
Geology	18
Physiographic Basin Characteristics.....	18
Trout in the Great Smoky Mountains	19
Southern Appalachian Brook Trout	20
Fish Kill at Beech Flats Creek	21
Summary	22
Chapter III. Methods	24
Introduction.....	24
Fish Data	24
Water Quality Data	27
Watershed Characteristics.....	27
Hydrologic Data.....	29
Statistical Analyses	30
Chapter IV. Results and Discussion.....	34
Young-of-year brook trout.....	46
Adult brook trout.....	49
Young-of-year rainbow trout	51
Adult rainbow trout.....	54
Conclusions.....	56
Chapter V. Conclusions	59
References.....	62
Appendix.....	68
Watershed Characteristics.....	69

Vegetation Groups	70
Residual Analysis.....	131
Outlier and Leverage Points Analysis.....	136

List of Tables

Table	Page
Table 1. List of co-located fish and water quality sites	25
Table 2. Water quality sample sites and descriptions	28
Table 3. Most significant chemistry variables with $p < 0.10$ (Pearson Correlation)	35
Table 4. Chemistry variables in order of descending correlation coefficient (Pearson Correlation)	36
Table 5. Most significant watershed characteristics (Pearson Correlation).....	38
Table 6. Significant geologies with $p < 0.10$ (Pearson Correlation).....	41
Table 7. Flow variables in order of descending correlation coefficient (Pearson Correlation)	41
Table 8. Precipitation variables in order of descending correlation coefficient (Pearson Correlation)	42
Table 9. Description of regression variables.....	43
Table 10. Model results for small stream sites	45
Table 11. Brook trout young-of-year biomass and water quality	49
Table 12. Brook trout adult biomass and water quality	51
Table 13. Rainbow trout young-of-year biomass and water quality	54
Table 14. Rainbow trout adult biomass and water quality.....	56
Table 15. Important predictor values for no-fish sites.....	58
Table A.16. Brook trout young-of-year biomass and water chemistry.....	74
Table A.17. Brook trout young-of-year biomass and flow variables	79
Table A.18. Brook trout young-of-year biomass and watershed characteristics	82
Table A.19. Brook trout young-of-year biomass and precipitation.....	84
Table A.20. Brook trout young-of-year biomass and geology	85
Table A.21. Brook trout adult biomass and water chemistry	87
Table A.22. Brook trout adult biomass and flow variables	91
Table A.23. Brook trout adult and watershed characteristics	93
Table A.24. Brook trout adult biomass and precipitation.....	95
Table A.25. Brook trout adult biomass and geology	96
Table A.26. Rainbow trout young-of-year biomass and water chemistry	98
Table A.27. Rainbow trout young-of-year biomass and flow variables	104
Table A.28. Rainbow trout young-of-year biomass and watershed characteristics.....	105
Table A.29. Rainbow trout young-of-year biomass and precipitation.....	107
Table A.30. Rainbow trout young-of-year biomass and geology	108
Table A.31. Rainbow trout adult biomass and water chemistry	110
Table A.32. Rainbow trout adult biomass and flow variables.....	116
Table A.33. Rainbow trout adult biomass and watershed characteristics.....	118
Table A.34. Rainbow trout adult biomass and precipitation	120
Table A.35. Rainbow trout adult biomass and geology.....	121
Table A.36. SPSS model summary for young-of-year brook trout biomass	123
Table A.37. SPSS coefficients for young-of-year brook trout biomass	124
Table A.38. SPSS model summary for adult brook trout biomass	125
Table A.39. SPSS coefficients for adult brook trout biomass	126

Table A.40. SPSS model summary for young-of-year rainbow trout biomass	127
Table A.41. SPSS coefficients for young-of-year rainbow trout biomass.....	128
Table A.42. SPSS model summary for adult rainbow trout biomass	129
Table A.43. SPSS coefficients for adult rainbow trout biomass.....	130
Table A.44. BKT YOY observations with large Cook's D.....	137
Table A.45. SPSS model summary for sulfate	138
Table A.46. SPSS coefficients for sulfate.....	139
Table A.47. SPSS model summary for log(conductivity)	140
Table A.48. SPSS coefficients for log(conductivity).....	141

List of Figures

Figure	Page
Figure 1. Location of 90 water quality monitoring sites sampled from 1993 to 2003	3
Figure 2. Distribution of trout streams in the Great Smoky Mountains National Park	4
Figure 3. Map of co-located water quality and trout monitoring sites.....	26
Figure 4. Plot of predicted versus actual brook trout young-of-year biomass values.....	46
Figure 5. Plot of predicted versus actual brook trout adult biomass values	50
Figure 6. Plot of predicted versus actual rainbow trout young-of-year biomass values...	52
Figure 7. Plot of predicted versus actual rainbow trout adult biomass values.....	55
Figure A.8. Normal probability plot for adult brook trout residuals	131
Figure A.9. Partial regression plot for young-of-year brook trout and elevation	134
Figure A.10. Partial regression plot for young-of-year brook trout and sulfate	134
Figure A.11. Partial regression plot for young-of-year brook trout and flow.....	135
Figure A.12. Partial regression plot for young-of-year brook trout and rainbow biomass	135
Figure A.13. Residual versus predicted young-of-year brook trout biomass	136

Chapter I. Introduction

Description of Study Area

The Great Smoky Mountains National Park (GRSM) is the second largest National Park in the Eastern United States, comprising about 220,000 hectares (850 square miles). The park receives approximately 10 million visitors per year; making it the most visited National Park.

There are more than 3000 kilometers (1860 miles) of headwater streams in the GRSM, which support a great number of fish species, amphibians, and benthic invertebrates, which the GRSM must protect from impairment. The GRSM also receives some of the highest acid depositional rates of any park in North America raising serious concerns for stream impairment because of the low acid neutralizing capacity of the GRSM geology (Shubzda et al. 1995).

The trout fisheries of the GRSM are considered some of the best in the Eastern United States. However, some of the streams that once supported native brook trout populations as recently as twenty years ago no longer do, and acid deposition is suspected to have contributed to their extirpation. The GRSM monitors both fish populations and water quality partly in order to develop long-term data to determine if water quality has an impact on fish. There are now enough data available for an initial assessment.

Description of Parkwide Water Quality Monitoring

Parkwide water quality monitoring began in 1993 and continues to the present. From 1993-1995, samples were collected at 367 sites semi-annually. In 1995, the number

of sites was reduced to 160 and collected on a monthly basis. In 1997, the number of sites was again reduced to 90 and collected quarterly. The number of sites was further reduced in 2004 to 35 sites sampled bimonthly and 10 sites biannually. Figure 1 is a map showing the locations of the ninety sampling sites. Analyses conducted for this thesis will utilize data from 31 of the ninety sites collected quarterly from 1993 to 2003 (Robinson et al. 2002).

Description of Parkwide Trout Monitoring

Parkwide trout monitoring began in 1986 and continues to the present. The National Park Service (NPS) samples about 24 streams a year on average with around 64 individual fish sites. Trout samples are collected in the summer and early fall (May to October) of each year using backpack electro fishing units. Fish are removed from a 100-meter representative section of stream by a standard three-pass removal-depletion sampling method (Trout Committee SD AFS 1992). Sampling areas can be calculated by multiplying the average stream width by the length of the representative section (100 meters). After removal, individual adult and young-of-year (YOY) trout are measured for total length (mm) and weight (g). A software program, which utilizes a maximum likelihood estimator, is used to generate population estimates based on the number of trout removed from a section of stream. Trout densities are then calculated as the population per unit area of stream (number of fish/ 100 m²). Trout biomass can also be calculated as the grams of fish per square meter of surface area of the reach. The values for biomass are usually reported in kilograms per hectare (kg/ha). Figure 2 is a map showing the locations of brook and rainbow trout streams in the GRSM. Analyses

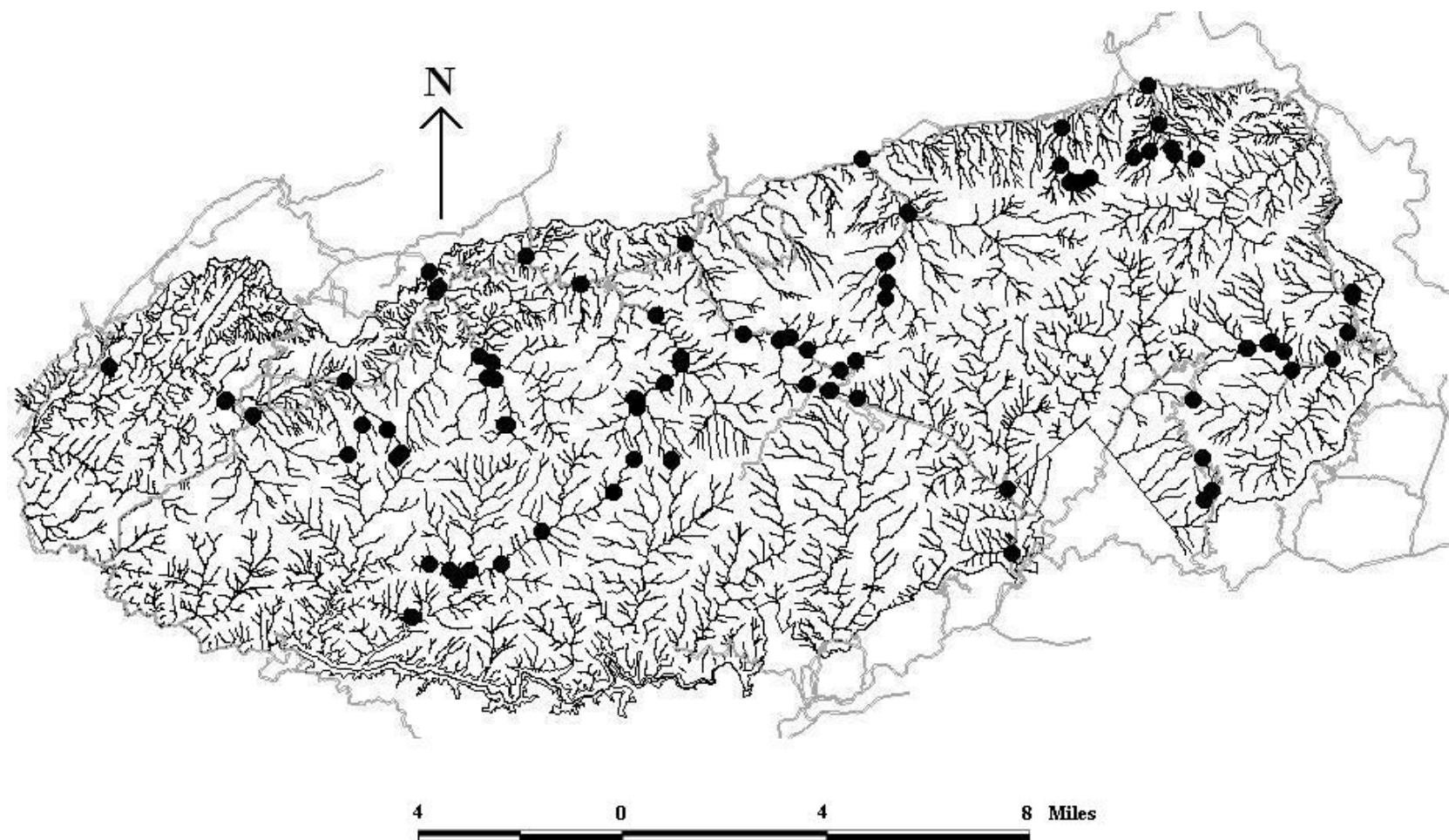


Figure 1. Location of 90 water quality monitoring sites sampled from 1993 to 2003

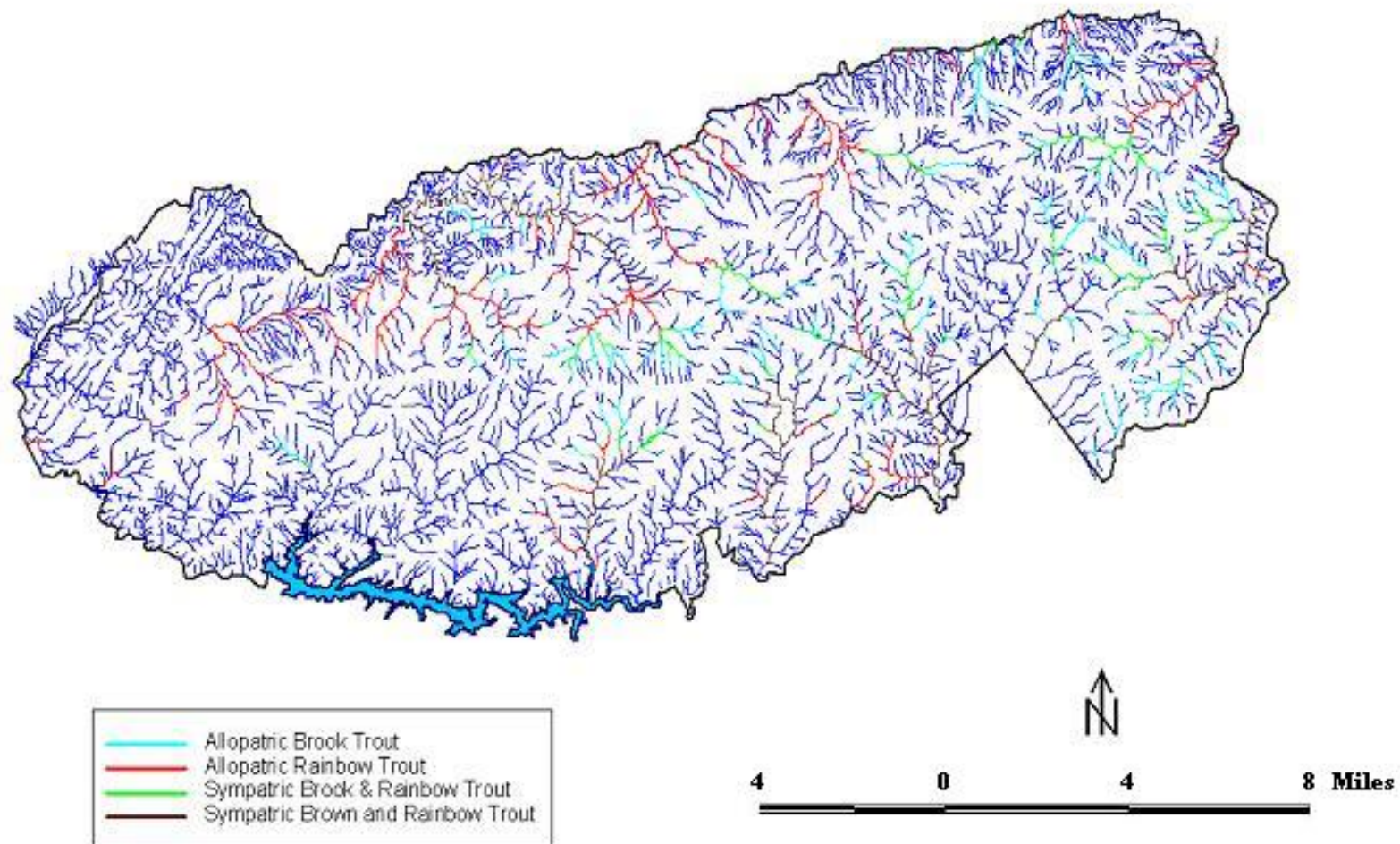


Figure 2. Distribution of trout streams in the Great Smoky Mountains National Park

conducted for this thesis utilized biomass data for brook and rainbow trout from 31 of these 64 sites collected from 1993 to 2003 (Moore and Kulp 2005).

Objectives

The goal of this research is to assess the relationship between water quality and trout biomass under base flow conditions and whether acid deposition has a discernable impact. This will include a review of previous literature on surface water quality and watershed conditions that affect trout populations. This work will assess in part if water quality has an affect on trout biomass by correlation analysis and by using step-wise multiple linear regression to model trout biomass as a function of water quality, watershed characteristics, and hydrologic data. The results assist the National Park Service in identifying areas of concern to trout populations based on water quality and watershed characteristics. Using correlation and regression analyses, the specific objectives of this thesis are as follows: 1) to identify environmental factors (water quality, hydrologic, and watershed characteristics) that are significantly correlated with trout biomass, 2) to develop a linear regression model for trout biomass as a function of the most significant environmental factors, and 3) to identify which environmental factors have the most impact on trout biomass and assess the impact on trout of water quality conditions related to acid deposition. The GRSM is one of the few places to date that have been able to perform this kind of analysis. The park's water quality and fish databases are unique due to the large number of sites and long period of record available.

Chapter II. Literature Review

Factors Affecting Fish

The streams within the boundaries of the Great Smoky Mountains National Park (GRSM) are home to three trout species (brook (*Salvelinus fontinalis*), brown (*Salmo trutta*), and rainbow (*Oncorhynchus mykiss*)) which are affected by a number of natural and anthropogenic factors. In general individual fish respond to a variety of factors including: stream chemistry, chemical inputs, physical habitat and hydrologic characteristics, physiographic basin characteristics, water temperature, recruitment success, rates of fishing and stocking, competition, predation, and the quality and quantity of food (Baldigo and Lawrence 2001). The following literature review identifies specific environmental factors that may limit the distribution of trout species and affect the composition of fish communities in the GRSM.

Stream chemistry, physical habitat and hydrologic characteristics, and recruitment success all play a major role in the population structure of trout. Water chemistry and toxicity vary with season and discharge. As a result, complex interactions among biotic and abiotic factors can increase or decrease the detrimental effects of toxic waters on fish (Baldigo and Murdoch 1997). Along with discharge, other chemical constituents like nitrate, sulfate, dissolved organic carbon (DOC), calcium, and magnesium can affect stream pH and the speciation of aluminum, which is toxic to fish (Baldigo and Lawrence 2000). Several studies done on freshwater fishes have found that acidity, calcium, and aluminum are the three key environmental factors in the survival and reproduction of fishes in water affected by acid deposition (Hunn 1985; Smith and Haines 1995). Furthermore, downstream movement of fish in response to episodic acidification may

explain the absence of fish in certain headwater streams (Baker et al. 1996). Although fish mortality is related to stream chemistry, it is thought that fish reproduction might be related to geomorphic process in the drainage basin (Lanka et al. 1987). Another reason for declines in fish populations is a failure to successfully recruit young of year fish into the local population.

Acidification and pH

Natural and anthropogenic factors can contribute to the patterns in stream pH. Kocovsky and Carline (2005) performed studies on Pennsylvania streams and found that natural factors affecting pH may include acidic soils and younger acid producing sandstones, which are dominant in headwater areas of the Appalachian Plateaus and Ridge and Valley provinces. Similarly, limestone deposits, which produce alkaline water, are common in valleys (Kocovsky and Carline 2005). Emissions from coal-fired power plants and automobiles cause sulfuric and nitric acids to form in the atmosphere. These acids then enter watersheds through wet or dry deposition and can lower the pH of streams. Episodic acidification is most common during seasons of high precipitation. During a study on the Neversink River in New York, Baldigo and Lawrence (2000) found that in the absence of acidic deposition, stream pH tends to decrease in the upstream direction as precipitation increases, temperature decreases and soils become shallower.

Acid neutralizing capacity (ANC) is often used to estimate the degree of a stream's acidification and remaining buffering capacity. This quantity represents the difference between the sum of base cation equivalent concentrations and the sum of

strong acid equivalents. In most natural waters, ANC can be defined by the following equation: $ANC = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$ (Jensen 2003). During a study of acid deposition in the Northeastern United States, Driscoll et al. (2001) found that depressions in stream ANC occur during acidic episodes and periods of high stream flow. Likewise, ANC values are usually at a maximum during summer base flow events (Driscoll et al. 2001). Similarly, in the Shenandoah National Park, Dennis et al. (1995) found that streams located in forested catchments with thin, base-poor soils often have negative acid neutralizing capacities.

Acidification Classification

The degree of stream acidification can be classified based on a number of parameters including: acid neutralizing capacity, pH, and aluminum concentration. Bulger et al. (1998) defined four acidification groups based on ANC from 5 years of quarterly water quality data collected from 60 Virginia streams. The four groups are defined as follows: 1) chronically acidic: $ANC < 0 \mu\text{eq/L}$, 2) episodically acidic: $0 < ANC < 20 \mu\text{eq/L}$, 3) transitional: $20 < ANC < 50 \mu\text{eq/L}$, 4) not acidic: $ANC > 50 \mu\text{eq/L}$. Bulger et al. (1995) also conducted a similar study in the Shenandoah National Park (SNP), which receives one of the highest rates of acid deposition of any U.S. National Park. Streams in the SNP range in acid neutralizing capacity (ANC) from 0 to 200 $\mu\text{eq/L}$. In 1995, 59% of the streams in the SNP were classified as “sensitive to acidification” which means they had ANC values less than 100 $\mu\text{eq/L}$ (MacAvoy and Bulger 1995). Likewise, Pinder and Morgan (1995) conducted a similar study in the Appalachian streams of Maryland. This study defined three ANC based sensitivity groups: 1)

extremely sensitive: $-100 < \text{ANC} < 50 \mu\text{eq/L}$, 2) sensitive: $50 < \text{ANC} < 200 \mu\text{eq/L}$, 3) insensitive: $\text{ANC} > 200 \mu\text{eq/L}$ (Pinder and Morgan 1995). Based on a sensitivity criterion of ANC less than $200 \mu\text{eq/L}$, survey analysts concluded that 52% of the streams sampled were sensitive to acidification. A study conducted by Baldigo and Lawrence (2000) on the Neversink River in New York classified the acidification of streams based upon ANC, pH, and aluminum concentrations. For the study, sites were grouped into four categories: minimally, moderately, strongly, and severely acidified. Minimally acidified sites were those having an ANC less than $46.4 \mu\text{eq/L}$, pH less than 6.31, and inorganic monomeric aluminum concentration between 0.21 and $0.29 \mu\text{mol/L}$. Moderately acidified sites had ANC values between 11.2 and $25.4 \mu\text{eq/L}$, pH values between 5.69 and 6.04, and aluminum concentrations between 0.21 and $1.16 \mu\text{mol/L}$. Strongly acidified sites were those having an ANC between -8.6 and $2.7 \mu\text{eq/L}$, pH between 4.97 and 5.39, and aluminum concentration between 1.54 and $3.71 \mu\text{mol/L}$. Lastly, severely acidified sites had ANC values between -27.7 and $-14.6 \mu\text{eq/L}$, pH values between 4.59 and 4.77, and aluminum concentrations between 5.47 and $9.74 \mu\text{mol/L}$ (Baldigo and Lawrence 2000).

Acidification Effects for Fish

Acidification can affect fish populations by a variety of mechanisms ranging from increased mortality and emigration to decreased food supplies (Baldigo and Lawrence 2001). According to a study done by Driscoll et al. (2001) on acid deposition in the northeastern United States, aquatic biota living in surface waters having a pH of less than 6, ANC less than $50 \mu\text{eq/L}$, or aluminum concentration greater than $2 \mu\text{mol/L}$ are at risk from surface water acidification. Similarly, Hunn et al. (1987) conducted a study on the

influence of pH and aluminum on developing brook trout in low calcium waters. The results of this study showed that fish exposed to a pH less than 5.5 had lethargic, uncoordinated swimming behavior. Hunn et al. (1987) also discovered that low pH interferes with ionic regulation in fish and can reduce their survival.

Ion-regulation in streams with low ANC can be more metabolically taxing for fish because of the steeper ion concentration gradients across which ions must be transported into body fluids (Dennis et al. 1995). During periods of heavy rain acute acidification can occur which may result in acute stress for fish. The duration and severity of acidic episodes are the most important factors influencing fish survival (Van Sickle et al. 1996). However, there is evidence of improved survival when fish become acclimated to acidic conditions prior to a more serious event. Fish in high elevation headwater streams are probably the most vulnerable to acidic events because ANC tends to increase with distance downstream (Pinder and Morgan 1995). Unless local areas of groundwater upwelling are present to provide refuge, fish often respond to acid episodes by emigrating downstream (Kocovsky and Carline 2005).

Acid Sensitive Species

Several species are sensitive to the negative effects of acidification including: brown trout, rainbow trout, longnose dace, slimy sculpin, mottled sculpin, minnows, darters and aquatic insects (Bulger et al. 1998). Within streams with acid neutralizing capacities of 0 to 20 $\mu\text{eq/L}$ species like longnose dace and mottled sculpin might be lost (Bulger et al. 1998). A study conducted by Dennis et al. (1995) in the Shenandoah National Park showed that the condition factor of blacknose dace could be used as an

indicator of environmental stress (Dennis et al. 1995). Dace in streams with low ANC and ionic strength had lower condition factors than dace in stream with higher ionic strength and ANC. Andersson and Andersson (1984) found that pH and alkalinity explained about 50% of the variability of brown trout densities in small acidic Swedish streams.

Acid Tolerant Species

Brook trout are native to eastern North America and are more tolerant to acidic conditions than brown or rainbow trout (Kocovsky and Carline 2005). Brook trout are most often found in small lakes and streams at high elevations, which are most susceptible to acidic deposition (Turner et al. 1992). Therefore establishing relationships among trout distributions and base flow pH has important implications for brook trout conservation (Kocovsky and Carline 2005). A study performed by Baldigo and Murdoch (1997) in the Catskill Mountains of New York showed that acidity was acutely toxic to brook trout in waters with a pH range of 3.5 to 4.5 (Note: Ramsey Prong in the GRSM had ten storm events in which the pH fell below 4.5 from June 2003 through May 2004). Furthermore acidity was a nonlethal inhibitor of growth at pH levels of 5 to 6 (Baldigo and Murdoch 1997). As with most fish, early life stages of brook trout are more acid sensitive than the older ones (Baldigo and Lawrence 2001). Turner et al. (1992) used a numerical model to predict trout levels in low-ANC eastern United States lakes and streams. The model was also used for predicting long-term changes in surface water chemistry caused by atmospheric sulfur deposition. Results from the study indicate that it

would take a 20 to 50% reduction in sulfur deposition in the southern United States in order to maintain 1990s ANC and brook trout levels after 50 years (Turner et al. 1992).

Aluminum

High concentrations of hydrogen ions and inorganic monomeric aluminum (Alim) are the main toxic agents responsible for fish mortality in low ionic strength acidic waters (Hesthagen et al. 1999). Alim is a reactive inorganic form of aluminum. The pH of stream water controls aluminum speciation and therefore Alim concentrations. The solubility of aluminum increases exponentially as pH falls below 5.6 with maximum toxicity occurring at about pH 5 (Bulger et al. 1998). During a study on brook trout in the Catskill Mountains of New York, Baldigo and Murdoch (1997) found that pH and aluminum concentrations are directly related to stream discharge. During spring time inorganic monomeric aluminum concentrations are much higher because of increased flows and acidity. Fish toxicity in acidic low ionic strength waters is possible when aluminum concentrations exceed 200 µg/L (Hunn et al. 1987). A study of long term trends in pH and aluminum in Scottish fresh waters showed that streams with mean aluminum concentrations less than 20 µg/L held sustainable trout populations while those with concentrations greater than 50 µg/L were without fish (McCartney et al. 2003).

Toxic Effects on Fish

During acidic conditions both pH and aluminum interfere with ion-regulation in fish (Dennis et al. 1995). The site of toxic action in fish is the gill. The gill is a complex organ, which is responsible for oxygen and carbon dioxide exchange. In addition, the gill helps maintain the proper salt and water balance within a fish's body. Fish constantly lose

small amounts of sodium and chloride from their blood by passive diffusion across the thin skin of the gills. This lost sodium and chloride is then replaced by an energy consumptive process using biochemical pumps in the gill membranes. These pumps transport sodium and chloride from a low concentration in the external stream water to a higher concentration in the blood. High concentrations of aluminum and low pH poison these biochemical pumps. As a result, when either or both of sodium and chloride concentrations fall more than 30% below normal, death occurs within hours (Bulger et al. 1998). Death can be attributed to a circulatory collapse, which is caused by an ionic imbalance.

Dissolved Organic Carbon

Surface water concentrations of inorganic monomeric aluminum are highly related to pH while organic monomeric aluminum concentrations are highly related to dissolved organic carbon (DOC) concentrations (Baldigo and Murdoch 1997). For salmonids, DOC has an ameliorating effect on the toxicity of aluminum (McCartney et al. 2003). When present in stream water, DOC complexes with inorganic aluminum in order to create organic monomeric aluminum, which is less toxic to fish. Concentrations of organic monomeric aluminum increase during fall due to high concentrations of DOC. While studying fresh water streams in Scotland, McCartney et al. (2003) noticed a nearly two-fold decline in the toxic form of aluminum when DOC was significantly increased. Similarly, in a study on brook trout in the Catskill Mountains of New York, Baldigo and Murdoch (1997) observed that DOC concentrations greater than 2 or 3 mg/l may significantly decrease the concentration of Alim. However, the protective effects of DOC

were most pronounced when concentrations were greater than 3.1 mg/l and water pH was between 5.2 and 5.6 (Baldigo and Murdoch 1997).

Calcium

Calcium plays an important role in fish health by reducing gill permeability and influencing the uptake of certain metals. In soft water, external calcium and internal levels of the hormone prolactin combine to control the permeability of the gill to water (Hunn 1985). As mentioned before, the gills of fish are involved in ionic regulation. Ionoregulatory failure is suggested as a key component in the toxic response of fish to acidic conditions. The presence of calcium in water reduces the permeability of fish gills to both hydrogen ions and sodium. A study performed by Hesthagen et al. (1999) on brown trout in Norway suggests that the threshold value at which calcium reduces gill membrane permeability is 1.0 mg/L. Note that in comparison, GRSM waters have a mean calcium concentration of 1.8 mg/L with a minimum of 0.58 mg/L and standard deviation of 3 mg/L. The response of fish to low pH has also been shown to be strongly influenced by the concentration of external calcium. Hardness metals like calcium also compete for interaction sites with toxic metal species like aluminum. Therefore calcium interacts with both pH and inorganic monomeric aluminum and moderates toxic effects. In soft acid waters, 3 mg/L of calcium can reduce the toxicity of aluminum to fish (Hunn 1985).

Sulfate

According to Driscoll et al. (2001) decades of atmospheric sulfur deposition have resulted in accumulation of sulfur in forest soils of the Northeastern United States, which is now gradually being released into surface waters. Emissions of SO₂ in the United

States are highest in the Midwest states clustered around the Ohio River Valley, including Tennessee. Also the unglaciated soils of the Southern Appalachians retain more sulfate than the glaciated soils found further north (Bulger et al. 1998). Long-term accumulation of sulfur in soils has been identified as a possible factor that may delay the recovery of certain watersheds from surface water acidification (Lawrence 2002). Although atmospheric emissions of SO₂ have been decreased due to Title IV of the Clean Air Act, depletion of base cations from soils will retard the recovery of forest ecosystems (Likens et al. 1996). Results from a study performed by Bulger et al. (1998) indicate that acidification of Virginia headwater streams is being driven by sulfate deposition. This particular study considered three alternate scenarios of sulfate deposition and the results for stream acidification associated with each. The three scenarios were defined as follows: 1) constant deposition at 1991 levels, 2) a 40% reduction from 1991 levels, 3) a 70% reduction from 1991 levels. Under the constant deposition scenario, the amount of streams that would be chronically acidic by the year 2041 increased from 6% to 35%. With the 40% reduction scenario, the amount of streams that would be chronically acidic by the year 2041 increased to 22%. Under the 70% reduction scenario the amount of chronically acidic streams would still be 11% by the year 2041 (Bulger et al. 1998).

Nitrate

In the past acid deposition was dominated by sulfur deposition, but recent research shows a growing importance of nitrogen deposition (Bulger et al. 1998). Unlike sulfur, nitrogen is an important and sometimes limiting plant nutrient. Stream nitrate concentrations are lowest in the summer due to the uptake of nitrogen by vegetation.

During fall and winter, stream nitrate increases due to increased flow and decreased plant activity. Likewise, maximum stream nitrate concentrations occur during spring snowmelt. In 1998 Tennessee was among the top ten states with the highest total nitrous oxide emissions in the U.S (Driscoll et al. 2001). These high emissions result primarily from electric utilities and heavy manufacturing in the region. Nitrate mobility is determined by biological controls in addition to deposition rates and soil properties (Webb et al. 2004). Atmospheric deposition of ammonium (NH_4) is derived from emissions of ammonia (NH_3), which result from agricultural activities, automobiles, and industrial processes (Driscoll et al. 2001). Ammonium can contribute to the acidification of soil and water if it is oxidized by soil microbes to nitrate. According to research conducted by Johnson (2002) at the University of Wisconsin, domestic brook trout experienced a significant increase in mortality when exposed to nitrate in both moderately hard and soft water. Therefore it does not appear that water hardness has any effect on the toxicity of nitrate. Johnson (2002) also concluded that concentrations of nitrate above 3 mg/L as nitrogen are considered elevated due to human activities. Note that in comparison, GRSM waters have a mean nitrate concentration of 0.30 mg/L as nitrogen with a maximum of 1.42 mg/L and a standard deviation of 0.25 mg/L.

Physical Habitat and Hydrologic Characteristics

Like water chemistry, physical habitat and hydrologic characteristics can affect the population structure of freshwater fish. In most studies channel, bank, riparian, hydrologic, and hydraulic features are characterized either by visual approximation or direct measurements. Platts (1979) found that as stream order increased, stream width,

depth, and percent rubble substrate increased. However the percent of pool habitats, channel gradient, and percent of gravel substrate decreased with increasing stream order (Lanka et al. 1987). A study conducted on trout in the North Fork Humboldt River Drainage in northeastern Nevada indicated that sites with trout had higher average flows, greater stream width, more rubble-boulder substrate, and more pools than sites without trout (Nelson et al. 1992). Kocovsky and Carline (2005) found that brook trout are superior competitors to rainbow trout in streams with low velocities that simulate pool habitat. Conversely, brook and rainbow trout appear to be equal competitors in high velocity streams that simulate riffle habitat (Kocovsky and Carline 2005). Low gradients and stable flows are common features of rivers with high brown trout and rainbow trout abundance (Jowett 1990). Overall brook trout seem to be present in streams at high elevations with cold water, steep gradients, small channels, and fast water velocities (Baldigo and Lawrence 2001).

Hydraulic Features

Displacement of young trout by high snowmelt runoff flows is a general mechanism that limits trout recruitment in mountainous regions (Latterell et al. 1998). There are five characteristics of flow, which potentially affect trout recruitment success: 1) magnitude, 2) duration, 3) frequency, 4) timing of peak flows, and 5) rate of change in flows. In a study of Colorado mountain streams, Latterell et al. (1998) used three flow variables to predict trout recruitment. A variable for annual maximum daily flow was chosen as a measure of peak flow magnitude. Next the mean of the highest 30 days of flow was used as a measure of both magnitude and duration of flow. The third flow

variable used was the number of days that flow equaled or exceeded a certain high flow benchmark. In this study the benchmark was chosen as the median 30-day maximum flow over the period of record for the gage (Latterell et al. 1998).

Geology

Bedrock geology can be an important factor for determining if a watershed is sensitive to acid deposition. Streams with carbonate as the dominant bedrock type in their catchments are not often susceptible to acidification. However, mountain streams are more sensitive due to a lower weathering rate and buffering capacity (Bulger et al. 1998). As a result of studies conducted in the Shenandoah National Park, MacAvoy and Bulger (1995) were able to classify bedrock types in order of increasing acid sensitivity. Catchments with basaltic bedrock were found to be the least sensitive to acidification, with ANC values greater than 75 $\mu\text{eq/L}$. Granitic catchments were intermediate in acid sensitivity with ANC values between 25 and 75 $\mu\text{eq/L}$. Lastly, streams draining catchments with sili-clastic bedrock were the most sensitive to acidification with ANC values less than 25 $\mu\text{eq/L}$ (MacAvoy and Bulger 1995).

Physiographic Basin Characteristics

Physiographic basin characteristics in mountainous landscapes like site elevation, watershed area, and stream gradient can be important factors for both fish and water quality. Several studies have found that the rates of acidic deposition tend to increase with increasing elevation (Baldigo and Lawrence 2000; Hesthagen et al. 1999). Furthermore, a study performed by Kocovsky and Carline (2005) on Pennsylvania streams showed that the proportion of brook trout increases with elevation. On average

stream slopes are highest in headwaters and lowest in downstream reaches. Lanka et al. (1987) found that in the Rocky Mountains small, gently sloping drainage basins produce the best trout habitat. Similarly, for Pennsylvania streams the proportion of a trout community composed of brook trout increases with stream slope (Kocovsky and Carline 2005).

Trout in the Great Smoky Mountains

In North America there are approximately 950 fish species of which about 485 are found in the southeast, and 350 are found in the Southern Appalachians south of the Roanoke and New Rivers (Bulger et al. 1998). Tennessee is the richest state for freshwater fish fauna in the United States with 307 species (Etnier and Starnes 1993). More specifically, Tennessee is home to three trout species: brook (native), brown (non native), and rainbow (non native). Brook trout are restricted to headwater streams because of historic land use and displacement by non-native trout. Native brook trout are also the most acid tolerant of the three trout species present in the Great Smoky Mountains National Park. Brown trout, which were introduced from Europe, are intermediate in acid tolerance. Rainbow trout are the most acid sensitive and were introduced from the western United States. Rainbow and brown trout occupy a position in the stream that is usually downstream of brook trout but have some overlapping ranges (King 1943). This is true for the Shenandoah National Park as well, where rainbow and brown trout have been successful at lower elevations (Bulger et al. 1998). Rainbow trout are relatively larger and more active and therefore choose larger streams, other conditions being the same, than brook trout (King 1943). King (1943) also found that rainbow trout

are migratory in nature and can reside most of the year in the main body of a stream where temperatures and food are better and move into headwater streams for spawning (Note: The GRSM has data that show rainbow are non-migratory). Brook trout have non-migratory habits and tend to restrict their range to the streams that satisfy their specific spawning requirements (King 1943). However, in the streams of the GRSM all three trout species (brook, rainbow, and brown) tend to be less migratory.

Southern Appalachian Brook Trout

Throughout the past century, Southern Appalachian headwater streams inhabited by native populations of brook trout have experienced a number of changes including: introduction of an exotic species (rainbow and brown trout), a decrease in pH due to acidic deposition, an increase in siltation and decrease in shade due to timber harvesting, and an increase in fishing pressure (Marschall and Crowder 1996). As a result of extensive logging prior to 1936, brook trout have disappeared from several low elevation and low gradient streams within the GRSM. Due to logging and increased fishing pressure brook trout streams have been closed to public fishing since the mid-1970s.

Early reductions in brook trout were attributed to logging and fishing pressure, but encroachment by exotic rainbow trout has been suspected as a major cause in later years (Larson and Moore 1985). In the GRSM, native brook trout must compete with exotic rainbow trout for feeding territories. It is often difficult for brook trout to compete with rainbow trout, which are much larger in size. Larson and Moore (1985) found that in GRSM stream segments with similar physical characteristics, allopatric brook trout and allopatric rainbow trout have similar numerical densities, but the average size of rainbow

trout is larger and rainbow trout have biomasses about 1.8 times greater than that of brook trout. Furthermore, studies by Moore et al. show that brook trout respond to experimental reductions of sympatric rainbow trout in park streams by increasing in abundance and biomass (Moore and Larson 1985).

Brook trout in the GRSM are more susceptible to the effects of acid deposition than rainbow trout because they have been relegated to high elevation streams. Barnett (2003) showed that stream pH in the GRSM decreased by 0.72 pH units for every 1000 meter increase in elevation. Results of laboratory experiments conducted by Marschall and Crowder (1996) on brook trout of the GRSM showed that egg to larva survival at pH 5.2 was 69% of survival at pH 6.5.

Fish Kill at Beech Flats Creek

Several streams in the GRSM, including Beech Flats Creek, are located near a geology formation called anakeesta. Anakeesta is a carbonaceous phyllite which is known to produce elevated concentrations of aluminum, manganese, and zinc when disturbed (Huckabee et al. 1975). In 1963 there was a fish kill in the GRSM after completion of a highway construction project near Beech Flats Creek. Trout and salamanders were killed in an area draining disturbed anakeesta over Beech Flats. Stream water near the fill had a pH of 4.5 and an alkalinity of 0.03 meq/L (Huckabee et al. 1975). Chemical analyses were performed on the stream water and revealed that it had increased concentrations of sulfate and metals. During the fish kill, a dense whitish to yellowish precipitate coated the streambed rocks for at least 2 kilometers downstream. Analysis of

the precipitate, using x ray diffraction and mass spectroscopy, showed mostly aluminum hydroxide complexes with some magnesium hydroxide complexes as well.

Summary

A review of previous literature on surface water quality and watershed conditions highlights the most important issues affecting trout populations of the GRSM. Acid neutralizing capacity (ANC) is often used to estimate the degree of a stream's acidification and remaining buffering capacity. Bulger et al. (1998) defined four acidification groups based on data collected from Virginia streams. The four groups are defined as follows: 1) chronically acidic: $ANC < 0 \mu\text{eq/L}$, 2) episodically acidic: $0 < ANC < 20 \mu\text{eq/L}$, 3) transitional: $20 < ANC < 50 \mu\text{eq/L}$, 4) not acidic: $ANC > 50 \mu\text{eq/L}$. By comparison, GRSM waters have a mean ANC of $70 \mu\text{eq/L}$ with a minimum of $-113 \mu\text{eq/L}$ and standard deviation of $155 \mu\text{eq/L}$.

High concentrations of hydrogen ions and inorganic monomeric aluminum (Alim) are the main toxic agents responsible for fish mortality in low ionic strength acidic waters (Hesthagen et al. 1999). A study performed by Baldigo and Murdoch (1997) in the Catskill Mountains of New York showed that acidity was acutely toxic to brook trout in waters with a pH range of 3.5 to 4.5. Furthermore acidity was a nonlethal inhibitor of growth at pH levels of 5 to 6 (Baldigo and Murdoch 1997). GRSM baseflow water quality samples have a mean pH of 6.23 with a minimum of 4.03 and standard deviation of 0.51. Calcium plays an important role in fish health by reducing gill permeability and influencing the uptake of certain metals, like aluminum. A study performed by Hesthagen et al. (1999) on brown trout in Norway suggests that the threshold value at which calcium

reduces gill membrane permeability is 1.0 mg/L. Note that in comparison, GRSM waters have a mean calcium concentration of 1.8 mg/L with a minimum of 0.58 mg/L and standard deviation of 3 mg/L.

Bedrock geology can be an important factor for determining if a watershed is sensitive to acid deposition. Due to underlying carbonate geology, GRSM streams within the Abrams Creek watershed are not susceptible to acidification. However, streams within the East Prong Little River, Middle Prong Little River, Middle Prong Little Pigeon River, West Prong Little Pigeon River, and Hazel Creek watersheds have an acidic geology called anakeesta, which is known to produce elevated concentrations of aluminum, manganese, and zinc when disturbed (Huckabee et al. 1975). In 1963 there was a fish kill in the GRSM when some anakeesta was disturbed by a highway construction project near Beech Flats Creek. Note that natural anakeesta slides have occurred in the headwaters of Walker Camp Prong and the upper ends of Alum Cave and NPS fish data show the loss of populations in these streams as a result.

Watershed characteristics are important factors for both brook and rainbow trout. Overall brook trout seem to be present in streams at high elevations with cold water, steep gradients, small channels, and fast water velocities (Baldigo and Lawrence 2001). Rainbow trout are relatively larger and more active and therefore prefer larger streams, other conditions being the same, than brook trout (King 1943). In the GRSM, rainbow trout cannot move into upstream areas because of steep gradients, natural barriers, and increased stream acidity.

Chapter III. Methods

Introduction

This chapter presents an overview of the water quality, watershed characteristics, hydrologic, and fish data collected for this thesis. Data have been collected for thirty-seven stream sites throughout the GRSM, which have been sampled for both fish and water quality. Table 1 lists the co-located fish and water quality sites and Figure 3 shows their location. All of the fish and water quality sites are located within 1000 feet of one another except for Site 74: Walker Camp Prong (1056 ft) and Site 150: Cataloochee Creek (1989 ft).

Fish Data

The analyses in this research utilize trout biomass data from thirty-seven sites within the GRSM, which are co-located for water quality. The data set includes samples collected from 1993 to 2003. All fish samples were collected between summer and early fall (May-October). Data were available for all three of the trout species present (brook, rainbow, and brown). However, only data for brook and rainbow trout were used in the analyses. The rationale is that brown trout are not as common in the GRSM as brook and rainbow. They are primarily found in larger streams at lower elevations. Furthermore, brown trout have more of an acid tolerance than rainbow trout. Three of the sites sampled had no fish present and are listed as follows: 1) Site 45: Shutts Prong, 2) Site 46: Porters Creek, and 3) Site 237: Walker Camp Prong.

Table 1. List of co-located fish and water quality sites

Water Quality Sites					Fish Sites			Distance (ft)	Elev. Diff. (ft)	Fish site's relative position to WQ site	Fish barriers below fish site
Site ID	SiteDescription	Elevation (ft)	UTM X	UTM Y	Elevation (ft)	UTM X	UTM Y				
1	Indian Camp at Old Settlers	2200	294112	3959340	2200	294024.65	3959100.54	254.89	0	Upstream	No
4	Lower Rock Creek	2080	300148	3959520	2120	300015.94	3959339.88	223.35	-40	Upstream	No
13	Little River at boundary	1100	254281	3950270	1100	254216.16	3950331.29	89.22	0	Downstream	No
20	Little River at Metcalf Bottoms	1700	260417	3951334	1700	260573.48	3950764.36	590.74	0	Upstream	Yes
34	Little River at Milsap Site	1960	263830	3949494	1980	264375.12	3949745.45	600.32	-20	Upstream	Yes
45	Shutts Prong upstream of confluents with Porters Creek	3200	282954	3948628	* No Fish at Site						
46	Porters Creek above Shutts Prong	2750	283078	3949670	* No Fish at Site						
47	Lower Cannon Creek	2400	282901	3950920	2420	282850.76	3950952.37	59.77	-20	Upstream	Yes
71	Road Prong above barrier cascade	3400	276295	3946000	3480	276476.38	3945834.38	245.62	-80	Upstream	Yes
74	Walker Camp Prong above Alum Cave Creek	3820	278028	3945370	4010	278784.84	3944633.72	1055.90	-190	Upstream	No
107	Indian Camp below Albright Grove	3040	294025	3957028	3010	293976.21	3957049.47	53.31	30	Downstream	No
114	Cosby Creek at log bridge	2510	301001	3958091	2600	301059.22	3957865.92	232.49	-90	Upstream	No
137	Upper Rock Creek (Cosby Creek)	2750	299580	3957849	2780	299579.64	3957803.94	45.06	-30	Upstream	No
142	Beech Creek above Lost Bottom Creek	3300	305727	3945447	3310	305692.52	3945453.61	35.11	-10	Upstream	Yes
143	Lost Bottom Creek (Cataloochee Creek)	3280	305779	3945513	3340	305622.04	3945656.97	212.99	-60	Upstream	Yes
147	Lower Cataloochee Creek	2460	312374	3948770	2440	312566.77	3948944.66	260.13	20	Downstream	No
149	Middle Cataloochee Creek at bridge	2550	312075	3946490	2650	312079.14	3946500.00	10.82	-100	Upstream	No
150	Cataloochee Creek below Caldwell Fork	2620	311140	3944770	2700	309185.31	3944401.29	1989.16	-80	Upstream	No
173	Mill Creek above Abrams Creek	1715	241439	3942129	1720	241607.57	3942053.01	184.91	-5	Upstream	No
174	Abrams Creek below Cades Cove	1715	241490	3942219	1715	242146.33	3942361.80	671.69	0	Upstream	No
186	Anthony Creek above Picnic Area	1965	248938	3943420	2000	249245.06	3943288.23	334.14	-35	Upstream	No
190	Thunderhead Prong at trail crossing	2120	257963	3943598	2100	258018.00	3943879.00	286.33	20	Downstream	No
191	Sams Creek (Middle Prong Little River)	3200	259185	3940688	3440	259468.62	3940280.29	496.66	-240	Upstream	Yes
192	Starkey Creek (Middle Prong Little River)	3200	259048	3940640	3200	259086.22	3940644.31	38.46	0	Upstream	Yes
214	Silers Creek (Little River)	3440	267355	3941710	3430	267375.07	3941773.73	66.82	10	Downstream	Yes
215	Ashe Camp Prong (Little River)	3380	267168	3942380	3440	267021.44	3942331.01	154.53	-60	Upstream	Yes
221	Hazel Creek above cascades	4000	265848	3936490	3950	265833.28	3936369.96	120.94	50	Downstream	Yes
237	Walker Camp Prong at last bridge	4520	281103	3944736	* No Fish at Site						
336	Flat Creek above falls (Bunches Creek)	4760	303075	3935992	4820	302972.15	3936189.84	222.98	-60	Upstream	Yes
337	Bunches Creek at Flat Creek Trail	4740	303536	3936519	4670	303563.00	3936302.65	218.03	70	Downstream	Yes
472	Sams Creek above Thunderhead Prong	2200	258365	3943535	2200	258364.97	3943535.47	0.47	0		Yes
473	West Prong Little Pigeon River across from Bearpen Prong	3630	276982	3946187	3620	277052.13	3945971.39	226.73	10	Downstream	No
484	Hazel Creek at Cold Spring Gap Trail	2475	258786	3931903	2420	258421.44	3932068.06	400.19	55	Downstream	No
485	Walker Creek above Hazel Creek Trail	2860	261409	3933962	2940	261167.90	3934383.32	485.43	-80	Upstream	No
488	Mill Creek at Pumphouse on Forge Creek Road	1790	243151	3941241	1790	243150.50	3941241.10	0.51	0		No
489	Abrams Creek 300 m below trailhead bridge	1710	241408	3942175	1710	241408.34	3942174.83	0.38	0		No
493	Palmer Creek at Davidson Branch Trail	2840	308073	3945282	2830	308072.65	3945282.39	0.52	10	Downstream	No

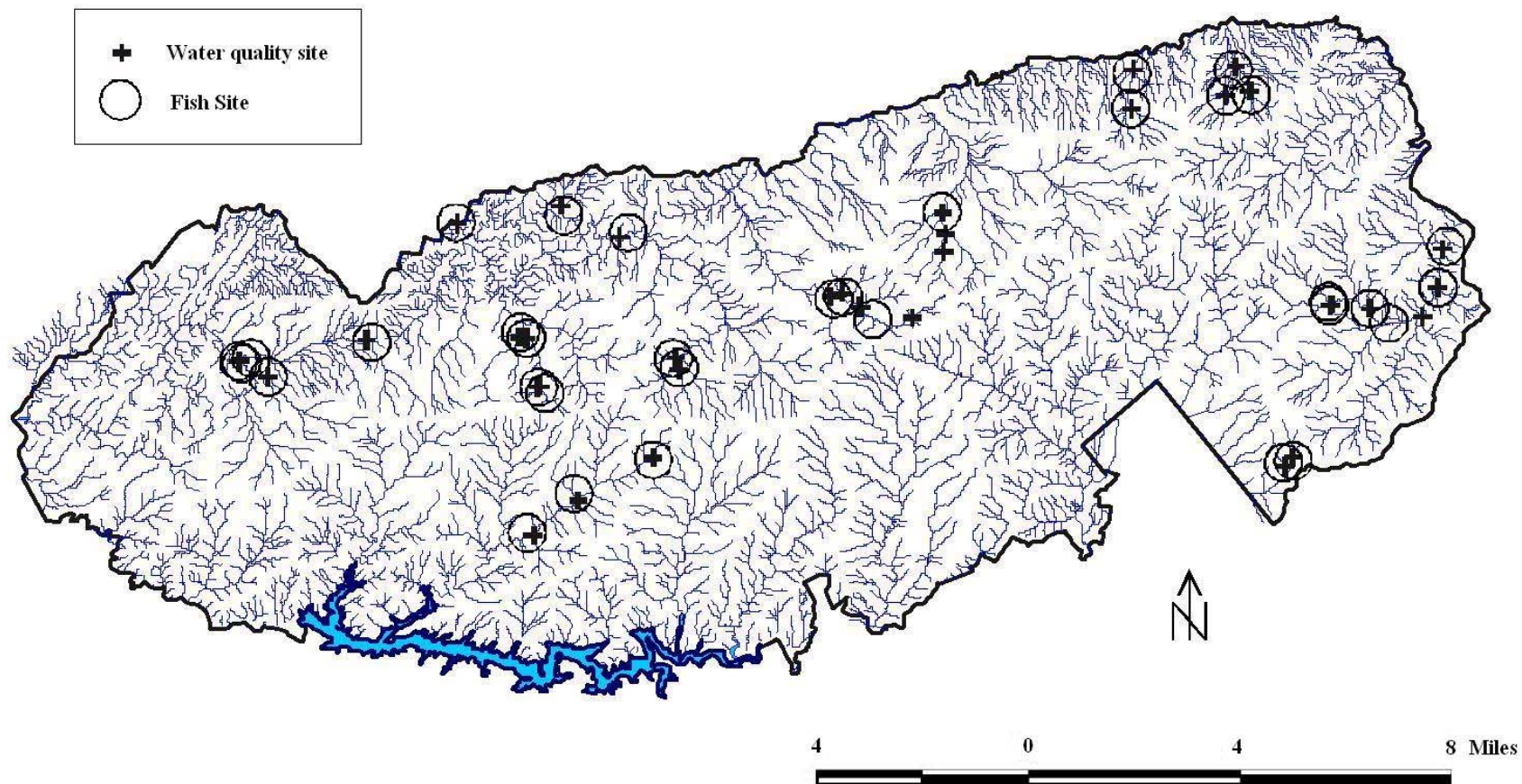


Figure 3. Map of co-located water quality and trout monitoring sites

Water Quality Data

The analyses in this research utilize the chemistry data of quarterly base flow grab samples from thirty-seven sites within the GRSM. The data set includes samples collected from 1993 to 2003. Table 2 lists sampling site locations and the watershed in which they are located. Each water sample collected was analyzed for the following water quality constituents: pH, acid neutralizing capacity (ANC), conductivity, nitrate, sulfate, chloride, sodium, potassium, and ammonium. A yearly median, maximum, and minimum value of each water quality constituent was calculated for every sampling site over the ten-year period of record. These values were calculated from quarterly grab samples taken within one year prior to the date of fish sampling. Regrettably, calcium and magnesium data were not available for January 1993 to March 2000.

Watershed Characteristics

Basin characteristics were determined for each quarterly water quality sampling site from previous work conducted by Harwell (2001). The data were collected either from digitized United States Geological Survey (USGS) quadrangle maps with a scale of 1:24,000 or from the National Park Service GIS database. The following is a list of the data collected for each sample site: elevation, basin area, average basin slope, channel slope, geology data, vegetation data, and disturbance history. For an extensive list of the watershed characteristics data collected for each sample site along with a description of the method used see the Appendix.

Table 2. Water quality sample sites and descriptions

Water Quality Sites		
Site ID	SiteDescription	Watershed
1	Indian Camp at Old Settlers	Indian Camp Creek
4	Lower Rock Creek	Cosby Creek
13	Little River at boundary	East Prong Little River
20	Little River at Metcalf Bottoms	East Prong Little River
34	Little River at Milsap Site	East Prong Little River
45	Shutts Prong upstream of confluents with Porters Creek	Middle Prong Little Pigeon River
46	Porters Creek above Shutts Prong	Middle Prong Little Pigeon River
47	Lower Cannon Creek	Middle Prong Little Pigeon River
71	Road Prong above barrier cascade	West Prong Little Pigeon River
74	Walker Camp Prong above Alum Cave Creek	West Prong Little Pigeon River
107	Indian Camp below Albright Grove	Indian Camp Creek
114	Cosby Creek at log bridge	Cosby Creek
137	Upper Rock Creek (Cosby Creek)	Cosby Creek
142	Beech Creek above Lost Bottom Creek	Cataloochee Creek
143	Lost Bottom Creek (Cataloochee Creek)	Cataloochee Creek
147	Lower Cataloochee Creek	Cataloochee Creek
149	Middle Cataloochee Creek at bridge	Cataloochee Creek
150	Cataloochee Creek below Caldwell Fork	Cataloochee Creek
173	Mill Creek above Abrams Creek	Abrams Creek
174	Abrams Creek below Cades Cove	Abrams Creek
186	Anthony Creek above Picnic Area	Abrams Creek
190	Thunderhead Prong at trail crossing	Middle Prong Little River
191	Sams Creek (Middle Prong Little River)	Middle Prong Little River
192	Starkey Creek (Middle Prong Little River)	Middle Prong Little River
214	Silers Creek (Little River)	East Prong Little River
215	Ashe Camp Prong (Little River)	East Prong Little River
221	Hazel Creek above cascades	Hazel Creek
237	Walker Camp Prong at last bridge	West Prong Little Pigeon River
336	Flat Creek above falls (Bunches Creek)	Bunches Creek
337	Bunches Creek at Flat Creek Trail	Bunches Creek
472	Sams Creek above Thunderhead Prong	Middle Prong Little River
473	West Prong Little Pigeon River across from Bearpen Prong	West Prong Little Pigeon River
484	Hazel Creek at Cold Spring Gap Trail	Hazel Creek
485	Walker Creek above Hazel Creek Trail	Hazel Creek
488	Mill Creek at Pumphouse on Forge Creek Road	Abrams Creek
489	Abrams Creek 300 m below trailhead bridge	Abrams Creek
493	Palmer Creek at Davidson Branch Trail	Cataloochee Creek

Hydrologic Data

Hydrologic variables were determined for each quarterly water quality sampling at each site from stream flow and precipitation data for the GRSM. This research included surrogate stream flow data from two USGS gaging stations for the statistical analyses because stream flow can have large impacts on trout populations. Although the effects are complex, drought will generally reduce the population and extreme spring flow events can harm young-of-year.

This data set included historical daily mean flow rates from January 1993 to December 2003. The two gaging stations, which provided stream flow data for the analyses, were Cataloochee Creek near Cataloochee, North Carolina (USGS#03460000) and Little River above Townsend, Tennessee (USGS#03497300). The Cataloochee station is located about five kilometers upstream from the boundary of the GRSM near Waterville Lake. Sampling site 147 is located on the opposite stream bank of the gaging station. The drainage area to the station is 12,742 hectares. The Little River gaging station is about 0.6 kilometers upstream from the Park boundary along State Road 73. The drainage area to the station is 27,454 hectares. The map straight-line distance between the two gaging stations is about 61.5 kilometers.

Daily mean flow rates from the two gaging stations were used to compute several flow variables. The ten flow variables calculated were from historical daily mean flows: 1) median spring flow (January to May), 2) maximum spring flow (January to May), 3) maximum yearly flow, 4) median yearly flow, 5) minimum yearly flow, 6) previous year maximum yearly flow, 7) previous year median yearly flow, 8) previous year minimum yearly flow, 9) number of flow days greater than 1000 cfs, and 10) number of flow days

less than 50 cfs. Yearly values were calculated for the calendar year of fish sampling. Previous year values were calculated for the calendar year prior to the date of fish sampling. For each site a set of weighted flow variables was computed based upon its distance from the gaging stations and which state it is located in (TN or NC). Sites that are in Tennessee use the corresponding Little River gage flows and sites in North Carolina use Cataloochee gage flows. The flows computed based upon distance used the following formula:

$$\text{Distance Wt. Flow} = \frac{(\text{Catl.Flow})(\text{Dist.toCatl.})^{-2} + (\text{L.RiverFlow})(\text{Dist.toL.River})^{-2}}{(\text{Dist.toCatl.})^{-2} + (\text{Dist.toL.River})^{-2}}.$$

The total weighted flows computed for each site were comprised of 50% flows determined by state (TN or NC) and 50% flows determined by distance.

Daily precipitation values obtained from the seven National Weather Service (NWS) weather stations were used to compute several precipitation variables. The NWS stations are located at the GRSM Park Headquarters, Cades Cove, Newfound Gap, Mount LeConte, Oconaluftee, Elkmont, and Look Rock. Cumulative precipitation values were obtained for each sampling location from the closest NWS weather station for 7, 30, 90, 180, 365, and 730 days prior to the date of fish sampling to account for antecedent conditions.

Statistical Analyses

Correlation analysis with SPSS (SPSS 1999) was used to determine if significant linear relationships exist between basin characteristics, median water quality constituent values, hydrologic data, and trout biomass. Correlation analysis was performed using both Kendall's Tau and Pearson's R. During this analysis, geology formations with zero

values for percent of the watershed were removed (i.e. Cochoran formation, Nichols shale, Nebo quartzite, Murray shale, Hesse quartzite, Wilhite formation, Wilhite formation course). Furthermore, some geology formations were excluded because they were present in small amounts within the contributing area to a few sample sites (i.e. Rich butt sandstone, Pigeon siltstone, Metadiorite, Wading branch formation). Three vegetation types were excluded because they are not common throughout the GRSM and there are only sparse data for these types: grape thicket, treeless, grassy bald. The vegetation type of pine oak was also excluded because when it is present within sampled basins, typically the coverage within the basin area is very small. Data for six large stream sites were removed from the database. These sites are from Cataloochee and Little River and have the following site numbers: 13, 20, 34, 147, 149, and 150. These sites were removed because they were both influential observations and outliers for the database, which is composed primarily of small streams. Trout biomass at these large stream sites seemed to be primarily a function of stream flow and not related to water chemistry or basin characteristics.

Stepwise multiple linear regression with SPSS (SPSS 1999) was used to develop models for estimating trout biomass as a function of observable water chemistry variables, precipitation, stream flow, and watershed characteristics. Independent variables entered the regression models if the probability of the partial F statistic was less than or equal to 0.05 and left if the partial F statistic was greater than or equal to 0.10. Only models with significance levels less than or equal to a p-value of 0.05 were considered. All independent variables in the models were significant at a p-value of 0.05.

Multicollinearity was addressed using the variance inflation factor (VIF) and informal multicollinearity diagnostics such as Spearman and Pearson bivariate correlations. A VIF value over 10 is frequently taken as an indication that multicollinearity may be unduly influencing the least square estimates (Helsel and Hirsch 1992; Neter et al. 1996). Independent variables with high multicollinearity were systematically removed from the models to produce the best adjusted r^2 values with minimal multicollinearity. Models with higher adjusted r^2 values explain more of the variability in the dependent variable and are therefore preferred assuming that other regression diagnostics are acceptable.

Influence of individual observations on the regression models were evaluated by evaluating each observation's Cook's D statistic and inspecting partial regression plots. Partial regression plots were useful for detecting influential data and can reveal nonlinearity (Fox 1997). Influence is defined as observations that have both high leverage and are large outliers (Helsel and Hirsch 1992). If inspection of partial regression plots showed an observation that had a relatively high Cook's D statistic also appeared as an outlier, then it was concluded that the observation was exerting a strong influence on the model. If removal of that observation could be well justified, then it was considered for removal from the analysis. If its removal improved the amount of variability explained by the model and the model adhered to the assumptions of regression, then it was removed.

Randomness of the residuals was checked using partial residual plots. Curvature and heteroscedasticity of the residuals were checked by plotting each of the independent variables. The points should be randomly distributed about the horizontal axis. Normality of the residuals was checked using the Shapiro-Wilk test and observation of the normal

probability plot. Partial regression or leverage plots were also observed to ensure a linear relationship exists between the independent variable and the dependent variable when the other independent variables have been accounted for. Residual analysis revealed unequal error variances and nonnormality of the error terms, which take the form of increasing skewness and increasing variability of the distribution of the error terms as the mean response increases. A transformation of the dependent variable is often used to remedy such departures from the linear regression model (Neter et al. 1996). However for this analysis a transformation was not used because of two reasons: 1) no physical reason could be found to make a transformation of biomass, 2) results from regression analysis would be difficult to interpret if a transformation of biomass was used. The reasonableness of predicted constituent values was also checked. The principle of parsimony was also used in the model selection process. This principle is used for choosing among models or theories and denotes that, everything else being equal, a simpler model is better (DeLurgio 1998). Therefore, the simplest model that explains a comparable amount of the variability and adheres to the assumptions of regression was chosen as the best model.

Chapter IV. Results and Discussion

Correlations among trout biomass and water chemistry, watershed characteristics, geology, flow, and precipitation variables were used to choose variables to include in stepwise regressions. These correlation tables can be found in the Appendix. Table 3 shows the most significant chemistry variables related to biomass ($p < 0.10$). Furthermore, Table 4 shows the chemistry variables in order of descending Pearson's correlation coefficient. Although the median values did not show up as the most significant chemistry variables in all cases, it was found that most of the chemistry variables were significantly correlated with the median values with a Pearson's correlation coefficient above 0.90. There were only two exceptions and those were minimum chloride and maximum ammonium. Thus median water chemistry values were used in regression analysis. Based on residual analyses, the following transformed water chemistry variables were also included in the stepwise regressions: $\log(\text{conductivity})$ and $\log(\text{ANC})$.

Results from Table 3 indicate that both brook and rainbow trout biomass increase with increasing stream pH. This result makes sense because low stream pH is indicative of acidic conditions that can be harmful to fish and other aquatic organisms. Hunn et al. (1987) discovered that low pH interferes with ionic regulation in fish and can reduce their survival. Stream pH also affects the speciation of aluminum, which is toxic to fish. Similarly, results in Table 3 show that trout biomass is positively correlated with ANC. ANC is often used to estimate the degree of a stream's acidification and remaining buffering capacity. Ionic regulation in streams with low ANC can be more metabolically taxing for fish because of the steeper ion concentration gradients across which ions must

Table 3. Most significant chemistry variables with p<0.10 (Pearson Correlation)

	Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
pH	<i>Minimum (0.369)</i>	<i>Minimum Spring (0.349)</i>	<i>LAG Median (0.577)</i>	<i>Maximum (0.607)</i>
ANC	<i>Minimum Spring (0.337)</i>	<i>Median Spring (0.380)</i>	<i>Minimum (0.533)</i>	<i>Minimum (0.765)</i>
Conductivity	<i>LAG Median (-0.318)</i>	<i>Median (-0.372)</i>	<i>Median (0.427)</i>	<i>Median Spring (0.705)</i>
Chloride			<i>Minimum (0.239)</i>	<i>Median (0.475)</i>
Nitrate			<i>Maximum Spring (-0.436)</i>	<i>Maximum (-0.392)</i>
Sulfate	<i>LAG Median (-0.451)</i>	<i>LAG Median (-0.479)</i>		<i>Maximum (-0.178)</i>
Anions	<i>Median Spring (-0.343)</i>	<i>LAG Median (-0.374)</i>	<i>Median Spring (-0.411)</i>	<i>Maximum Spring (-0.202)</i>
Sodium	<i>Maximum Spring (0.360)</i>	<i>Maximum Spring (0.434)</i>	<i>Median (0.482)</i>	<i>Minimum (0.608)</i>
Ammonium	<i>Maximum Spring (0.163)</i>		<i>Maximum (-0.167)</i>	
Potassium	<i>LAG Median (0.416)</i>	<i>Median Spring (0.450)</i>	<i>Median (0.604)</i>	<i>Median (0.595)</i>
Cations		<i>LAG Median (-0.212)</i>	<i>Minimum (0.504)</i>	<i>Minimum (0.767)</i>

Table 4. Chemistry variables in order of descending correlation coefficient (Pearson Correlation)

Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
<i>Sulfate</i> (-0.451)	<i>Sulfate</i> (-0.479)	<i>Potassium</i> (0.604)	<i>Cations</i> (0.767)
<i>Potassium</i> (0.416)	<i>Potassium</i> (0.450)	<i>pH</i> (0.577)	<i>ANC</i> (0.765)
<i>pH</i> (0.369)	<i>Sodium</i> (0.434)	<i>ANC</i> (0.533)	<i>Conductivity</i> (0.705)
<i>Sodium</i> (0.360)	<i>ANC</i> (0.380)	<i>Cations</i> (0.504)	<i>Sodium</i> (0.608)
<i>Anions</i> (-0.343)	<i>Anions</i> (-0.374)	<i>Sodium</i> (0.482)	<i>pH</i> (0.607)
<i>ANC</i> (0.337)	<i>Conductivity</i> (-0.372)	<i>Nitrate</i> (-0.436)	<i>Potassium</i> (0.595)
<i>Conductivity</i> (-0.318)	<i>pH</i> (0.349)	<i>Conductivity</i> (0.427)	<i>Chloride</i> (0.475)
<i>Ammonium</i> (0.163)	<i>Cations</i> (-0.212)	<i>Anions</i> (-0.411)	<i>Nitrate</i> (-0.392)
		<i>Chloride</i> (0.239)	<i>Anions</i> (-0.202)
		<i>Ammonium</i> (-0.167)	<i>Sulfate</i> (-0.178)

be transported into body fluids (Dennis et al. 1995). Therefore, it is logical that both brook and rainbow trout biomass increases with increases in ANC. The correlations between brook trout biomass and conductivity are negative and those between rainbow trout biomass and conductivity are positive. Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. Median conductivity also has a very strong positive correlation coefficient (0.97) with median ANC. The negative correlation between brook trout and conductivity could be related to its acid tolerance or may be an artifact of rainbow being present at lower elevations where conductivity is higher and brook at higher elevations where conductivity is lower. According to the correlation results, both brook and rainbow trout biomass decreases with increasing sulfate concentrations. This result was expected since a study performed by Bulger et al. (1998) indicated that acidification of Virginia headwater streams is being driven by sulfate deposition. Correlations between trout biomass and sodium and potassium were all positive. Therefore trout biomass appears to increase with increases in these cations. This result was also expected since sodium and potassium had correlation coefficients of 0.762 and 0.682 with pH respectively.

Table 5 shows the most significant watershed characteristics related to trout biomass. Correlation analysis revealed that basin area and stream miles were strongly correlated with a Pearson's coefficient of 0.993. To avoid collinearity problems stream miles was removed from the database. Basin area was chosen over stream miles because it has been related to water chemistry in past studies for the GRSM. Furthermore, heath

Table 5. Most significant watershed characteristics (Pearson Correlation)

Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
average basin slope (-0.597)	average basin slope (-0.593)	average basin slope (-0.552)	average basin slope (-0.517)
basin area (-0.258)	basin area (-0.240)	basin area (0.574)	basin area (0.804)
channel slope (-0.120)	channel slope (-0.233)	channel slope (-0.400)	channel slope (-0.429)
	cove hardwood (-0.069)	cove hardwood (-0.166)	
fish elevation (0.410)	fish elevation (0.401)	fish elevation (-0.340)	fish elevation (-0.521)
heath bald (-0.147)		heath bald (-0.108)	
heavy cut (0.382)	heavy cut (0.300)		heavy cut (-0.087)
	light cut (0.201)	light cut (0.361)	light cut (0.284)
mesic oak (0.253)	mesic oak (0.316)		mesic oak (-0.071)
mixed mesic hardwood (-0.131)	mixed mesic hardwood (-0.101)	mixed mesic hardwood (0.191)	
northern hardwood (0.357)	northern hardwood (0.258)	northern hardwood (-0.213)	northern hardwood (-0.426)
pine (-0.140)	pine (-0.071)	pine (0.368)	
selective cut (0.375)	selective cut (0.443)	selective cut (0.379)	selective cut (0.424)
settlement (0.210)	settlement (0.077)	settlement (0.281)	
spruce fir (-0.312)	spruce fir (-0.285)	spruce fir (-0.375)	spruce fir (-0.338)
tulip poplar (-0.296)		tulip poplar (0.060)	tulip poplar (0.307)
undisturbed (-0.487)	undisturbed (-0.504)	undisturbed (-0.500)	undisturbed (-0.361)
	xeric oak (0.113)	xeric oak (0.454)	

bald and cove hardwood were removed from the database because they were only present in two out of the four trout groups and had low correlation coefficients with biomass.

Correlation results show that brook trout biomass increases with increasing elevation and rainbow trout biomass decreases with increasing elevation. This result was expected since according to Turner et al. (1992) brook trout are most often found in small lakes and streams at high elevations, which are most susceptible to acidic deposition. In the GRSM, native brook trout have been displaced by rainbow trout and as a result relegated to headwater streams. Rainbow trout cannot move into upstream areas because of steep gradients and increased stream acidity. Similarly, brook trout biomass decreases with increasing basin area while rainbow trout increases with increasing basin area. Results from a study by King (1943) indicate that rainbow trout are larger and more active and therefore are present in larger streams, other conditions being the same, than brook trout. It is reasonable to believe that basin area is a surrogate for stream size since it is strongly correlated with stream miles. Correlations between brook trout and northern hardwood are negative and those between rainbow trout and northern hardwood are positive. A possible explanation for this could be that northern hardwood has a 0.592 correlation coefficient with elevation. Both brook and rainbow trout biomass have negative correlations with basin slope. This result seems logical for rainbow trout because they are generally present in the GRSM at low elevation low gradient streams. However, the negative correlation between brook trout biomass and basin slope could be confounded by the fact that basin slope has a correlation coefficient of 0.671 with sulfate. Likewise the negative relationship between brook trout biomass and spruce fir is probably confounded by the fact that spruce fir has a correlation coefficient of 0.687 with

anakeesta. According to the correlation results, trout biomass decreases as the percent of the contributing area that is undisturbed increases. Furthermore, percent undisturbed and sulfate have a correlation coefficient of 0.769. This result can be attributed to disturbed areas taking up more sulfate and nitrate.

Table 6 shows geology variables that are significantly related to trout biomass. Only geologies that were significant for at least two out of the four fish groups were included in stepwise regressions. Correlations in Table 6 show a negative relationship between trout biomass and anakeesta. Anakeesta is a geologic formation commonly found within the GRSM and contains pyrite (FeS_2). Whenever rock from this formation is disturbed a harmful chemical reaction takes place producing iron oxyhydroxide (FeOOH) and sulfuric acid (H_2SO_4). As expected, anakeesta has a correlation coefficient of 0.588 with sulfate.

Table 7 shows flow variables in order of descending correlation coefficient with trout biomass. Both brook trout and adult rainbow trout biomass decrease with increases in median yearly and maximum yearly stream flow. Possible reasons for this result include young-of-year trout can be washed away by high flows and high flows often correspond to decreases in stream pH and ANC (Latterell et al. 1998; Driscoll et al. 2001). Brook trout and adult rainbow trout biomass increase as the number of flow days less than 50 cfs increases. Less water means less stream surface area and therefore an increase in biomass initially. However, after an extended period of time there is a decline in biomass following drought conditions according to GRSM fisheries biologists.

Table 8 shows precipitation variables in order of descending correlation coefficient. The cumulative 90 and 180 day precipitation values will be included in

Table 6. Significant geologies with p<0.10 (Pearson Correlation)

Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
Anakeesta (-0.392)	Anakeesta (-0.248)	Anakeesta (-0.437)	Anakeesta (-0.350)
		Basement Complex (0.166)	
		Cades Sandstone (0.355)	Cades Sandstone (0.672)
		Elkmont Sandstone (0.186)	Elkmont Sandstone (0.487)
		Limestone (0.427)	Limestone (0.574)
		Longarm Quartzite (0.245)	
		Metcalf Phyllite (0.424)	Metcalf Phyllite (0.680)
		Roaringfork Sandstone (0.189)	
Thunderhead Sandstone (0.361)	Thunderhead Sandstone (0.266)	Thunderhead Sandstone (0.145)	Thunderhead Sandstone (-0.237)
Unnamed Sandstone (0.129)			

Table 7. Flow variables in order of descending correlation coefficient (Pearson Correlation)

Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
<i>Median Yearly (-0.315)</i>	<i>Median Yearly (-0.471)</i>	<i># Days < 50 cfs (0.236)</i>	<i>LAG Maximum (0.203)</i>
<i># Days < 50 cfs (0.297)</i>	<i>LAG Median (-0.386)</i>	<i>Maximum Yearly (-0.207)</i>	<i>LAG Median (0.198)</i>
<i>LAG Median (-0.262)</i>	<i>Maximum Yearly (-0.383)</i>	<i>LAG Median (0.193)</i>	<i>Median Yearly (0.185)</i>
<i>Maximum Yearly (-0.248)</i>	<i># Days < 50 cfs (0.373)</i>	<i>Median Yearly (-0.161)</i>	
<i>Minimum Yearly (-0.166)</i>	<i>LAG Maximum (-0.244)</i>		
<i>LAG Maximum (-0.166)</i>			

Table 8. Precipitation variables in order of descending correlation coefficient (Pearson Correlation)

Adult Brook Trout	YOY Brook Trout	Adult Rainbow Trout	YOY Rainbow Trout
Precip 90 (-0.362)	Precip 90 (-0.435)	Precip 730 (-0.333)	Precip 90 (-0.390)
Precip 30 (-0.310)	Precip 180 (-0.421)	Precip 90 (-0.265)	Precip 730 (-0.381)
Precip 180 (-0.310)	Precip 365 (-0.410)	Precip 180 (-0.239)	Precip 180 (-0.377)
Precip 365 (-0.267)	Precip 730 (-0.369)	Precip 365 (-0.231)	Precip 365 (-0.362)
Precip 730 (-0.247)	Precip 30 (-0.321)	Precip 30 (-0.132)	Precip 30 (-0.231)
Precip 7 (-0.153)	Precip 7 (-0.102)	Precip 7 (-0.132)	Precip 7 (0.016)

stepwise regressions since they seem to be the most strongly correlated with biomass. Correlation results indicate that both brook and rainbow trout biomass decrease as the cumulative precipitation for the previous 90 and 180 days increases. This is consistent with results from Barnett (2003) that water quality conditions in the GRSM were adversely affected by increased stream flows, acid deposition and precipitation. In this case, the previous 90 and 180 day precipitations have correlation coefficients of 0.409 and 0.490 with sulfate respectively. Table 9 lists all of the independent variables to be included in stepwise regressions.

Stepwise multiple linear regression with SPSS (SPSS, 1999) was used to develop models for estimating trout biomass as a function of water chemistry, watershed characteristics, and hydrologic data. The first model attempted was an all-inclusive regression equation which would model total biomass as a function of both numerical and

Table 9. Description of regression variables

Variable	Description
sine(q), cosine(q)	$\theta = 2\pi \cdot (\text{fraction of year})$, sine and cosine functions used to model seasonal fluctuations in water quality
Elevation (feet)	Elevation of sampling site in feet above MSL
Anakeesta	
Cades Sandstone	
Elkmont Sandstone	
Limestone	Percentage of contributing area (geology type)
Metcalf Phyllite	
Thunderhead Sandstone	
Closest Precipitation (90)	The cumulative precipitation at the closest NWS weather station to the sampling site in inches for 90 and 180 days prior to the day of sample collection
Closest Precipitation (180)	
Average Basin Slope (%)	Average land slope of the contributing area
Channel Slope (%)	The slope of the channel determined by the elevation difference between points
Undisturbed	
Settlement	
Selective Cut	Disturbance history data expressed as the percentage of the contributing area to the sample site with a certain type of historical land use
Heavy Cut	
Light Cut	
Spruce Fir	
Northern Hardwood	
Mesic Oak	
Mixed Mesic Hardwood	Vegetation data expressed as the percentage of the contributing area to the sample site covered by the vegetation type
Tulip Poplar	
Pine	
Xeric Oak	
Basin Area (mi ²)	Contributing area to the sample site determined from GIS database
Median Yearly Flow	
Previous Year Median Yearly Flow	
Number of flow days <50 cfs	Weighted flow from USGS gages for sampling date
Maximum Yearly Flow	
Previous Year Maximum Yearly Flow	
Median pH	
Median ANC	
Median Conductivity	
Median Chloride	
Median Nitrate	Data obtained for 30 small stream sites within the GRSM from the date of fish sampling
Median Sulfate	
Median Sodium	
Median Potassium	
Minimum Chloride	
Maximum Ammonium	

categorical variables. Categorical variables included age (young-of-year or adult) and species (brook or rainbow). This particular model became complicated due to the number of interaction terms required. With 41 independent variables (Table 9) and the associated interactions with age and species, the number of predictors for stepwise regression quickly rose to 124. As a result, this method of analysis was disregarded because too many predictors showed up in the final equation and interpretation of coefficients for interaction terms proved difficult.

For this study, separate regression models for adult and young-of-year brook and rainbow trout were prepared instead of the before mentioned all-inclusive regression equation. The SPSS output for these regression results can be found in the Appendix. This output includes the collinearity diagnostics discussed in the previous chapter. All of the models have variance inflation factors (VIF) less than 10, meaning multicollinearity does not appear to be influencing the least square estimates. Influence of individual observations on the regression models were evaluated by each observation's Cook's D statistic and inspecting partial regression plots. Furthermore, randomness of the residuals was also checked using partial residual plots. A discussion of these results can be found in the Appendix.

Table 10 presents the best model obtained for each trout biomass constituent as well as the adjusted r^2 and overall model p-value for data from the 31 small stream sampling sites within the GRSM. Adjusted r^2 values for rainbow trout biomass ranged from 0.491 to 0.733 for adult and young-of-year respectively. Adjusted r^2 value for brook trout biomass ranged from 0.544 to 0.627 for young-of-year and adult respectively.

Table 10. Model results for small stream sites

Constituent	Model	Adjusted r ²	Model p
YOY Brook Trout Biomass (kg/ha)	$-0.55 + (7.38\text{E-}04 \cdot \text{Elevation in feet}) + (7.89\text{E-}07 \cdot \text{Elevation}^2) + (-1.47\text{E-}02 \cdot \text{Median Sulfate in microeq/L}) + (-2.24\text{E-}02 \cdot \text{Rainbow trout biomass}) + (-1.86\text{E-}04 \cdot \text{Weighted Maximum Yearly Flow})$	0.544	0.000
Adult Brook Trout Biomass (kg/ha)	$-21.58 + (1.23\text{E-}02 \cdot \text{Elevation in feet}) + (6.62\text{E-}06 \cdot \text{Elevation}^2) + (-2.93\text{E-}01 \cdot \text{Rainbow trout biomass}) + (-1.51\text{E-}01 \cdot \% \text{ anakeesta})$	0.627	0.000
YOY Rainbow Trout Biomass (kg/ha)	$-1.99 + (2.13\text{E-}01 \cdot \text{Basin area in sq miles}) + (-4.28\text{E-}02 \cdot \text{Closest precipitation (90) in inches}) + (2.26 \cdot \text{Log(Conductivity in microS/cm)}) + (-7.27\text{E-}03 \cdot \% \text{ anakeesta}) + (-4.49\text{E-}01 \cdot \text{sine theta})$	0.733	0.000
Adult Rainbow Trout Biomass (kg/ha)	$3.13 + (7.28\text{E-}01 \cdot \text{Basin area in sq miles}) + (-1.04\text{E-}01 \cdot \text{Median Sulfate in microeq/L}) + (-1.98\text{E-}01 \cdot \text{Brook trout biomass}) + (6.03 \cdot \text{Log(ANC in microeq/L)})$	0.491	0.000

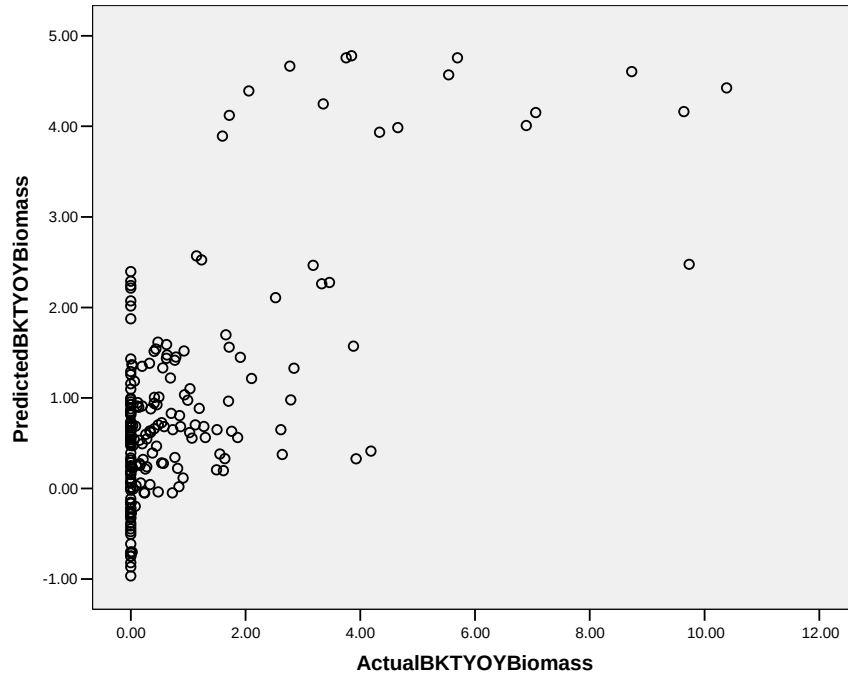


Figure 4. Plot of predicted versus actual brook trout young-of-year biomass values

Young-of-year brook trout

Figure 4 shows predicted versus actual values for the brook trout young-of-year biomass model. This figure shows a clustering of zeros on the y-axis, which lowers the model r^2 . These values are the result of brook trout being absent from certain streams and therefore zeros were put into the database for young-of-year brook trout biomass. These points were not deleted since absence of trout is considered important for this study.

The model in Table 10 shows that brook trout biomass increases with increases in elevation. Brook trout biomass increases at high elevation sites because that is where they have not been displaced by rainbow trout. If there were no rainbow trout present, brook trout would be present at lower elevations. An elevation² term was included in the

stepwise regression in order to allow a parabolic fit with elevation in case there is an optimum elevation range. However, it doesn't appear that an optimum range exists for brook trout young-of-year since both elevation and elevation² terms have positive coefficients. The regression model also shows that young-of-year biomass decreases with increases in sulfate. Anakeesta produces sulfate compounds when in contact with water, so one would expect higher surface water sulfate concentrations in areas with higher anakeesta content. Correlation analysis revealed that young-of-year brook trout biomass has a significant ($p = 0.038$) and Pearson's correlation coefficient of -0.134 with percent anakeesta geology. However, this variable did not enter the stepwise regression model because other variables, like sulfate, had stronger correlations with biomass. In order to clarify what influences sulfate, a stepwise regression with sulfate as the dependent variable against all of the variables that were not picked by the biomass model has been included in the Appendix. Results from this model show that anakeesta is the largest contributor to sulfate concentrations. Also increases in precipitation and conductivity result in higher sulfate values. It seems that sulfate also varies seasonally with the highest values occurring in the spring. Since highest stream flow and precipitation presumably occur in the spring, this is consistent with Barnett (2003) who found that sulfate concentrations increase with increasing Little River flow rate and increasing antecedent precipitation.

The regression model in Table 10 also indicates that brook trout biomass decreases with increases in rainbow trout biomass. This result supports the hypothesis of Larson and Moore (1985) that modern contraction of the brook's trout range is due to encroachment by rainbow trout. It is often difficult for brook trout to compete for feeding

territories with rainbow trout, which are much larger in size (Marschall and Crowder 1996). Larson and Moore (1985) found that in stream segments with similar physical characteristics rainbow trout have biomasses about 1.8 times greater than that of brook trout. In the GRSM, allopatric brook trout range has declined by almost 60% over the past 40 years while rainbow trout range has increased (Larson and Moore 1985).

Lastly brook trout young-of-year biomass tends to decrease with increases in maximum yearly stream flows. This decrease in biomass can be attributed to young trout being displaced by high stream flows or by water quality conditions which are adversely affected by increased stream flows (Latterell et al. 1998 and Driscoll et al. 2001). Results from Barnett (2003) also show that pH decreases with increases of flow at the Little River gaging station. This decrease in pH is indicative of precipitation events adding, releasing, and carrying acidic species to the surface waters. Indeed, 15-minute sonde data show one to two unit depressions in pH during storm events in the GRSM (Roby 2004). Thus changes in water chemistry caused by storm events can adversely affect young-of-year trout.

Table 11 shows correlations, where zeros were assumed for biomass when there were no trout present, between young-of-year brook trout biomass and pH, log(conductivity), and log(ANC). Brook trout young-of-year biomass is not significantly correlated with median pH or log(ANC). Brook trout young-of-year biomass is significantly negatively correlated with log(conductivity). Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. Paradoxically, conductivity also has a very strong positive correlation with ANC which would benefit trout, however this positive

Table 11. Brook trout young-of-year biomass and water quality

		Median pH	Log(Conductivity)	Log(ANC)
BKT YOY Biomass	Pearson Correlation	0.028	-0.237	0.006
	Sig. (2-tailed)	0.684	0.001	0.938
	N	207	207	198

correlation between ANC and conductivity is most likely influenced by the Abrams Creek watershed sites that are extreme outliers for ANC and by using Pearson correlation coefficients. The negative correlation between brook trout and conductivity is most likely an artifact that they occur in watersheds without high ANC where the conductivity is driven by acidic species. However, the log(conductivity) variable did not enter the stepwise regression model because other variables had stronger correlations with biomass.

In order to clarify what influences conductivity, a stepwise regression with log(conductivity) as the dependent variable against all of the variables that were not picked by the biomass model has been included in the Appendix. Results from this model show that limestone alone accounts for 77% of the variability in log(conductivity). This result is largely due to the serious leverage exerted by the Abrams Creek watershed. Sites in this watershed have high conductivities due to limestone geology. Also increases in sulfate, ANC, and basin area result in higher values for log (conductivity).

Adult brook trout

Figure 5 shows predicted versus actual values for the brook trout adult biomass model. This figure shows a clustering of zeros on the y-axis, which lower the model r^2 .

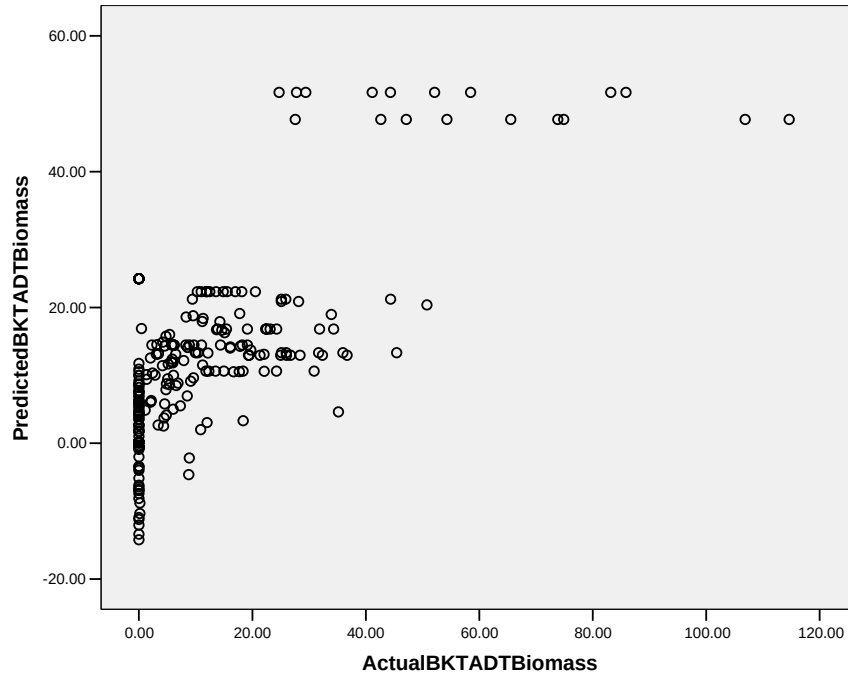


Figure 5. Plot of predicted versus actual brook trout adult biomass values

These values are the result of brook trout being absent from certain streams. For these cases zeros were put into the database for adult brook trout biomass. These points were not deleted since absence of trout is considered important for this study.

Brook trout adult biomass shows similar response to young-of-year with regards to elevation and rainbow trout biomass. Again this result demonstrates how brook trout have been displaced by rainbow trout and are relegated to headwater streams. Biomass increases with elevation and decreases with rainbow trout biomass. Brook trout adult biomass also decreases with increases in percent anakeesta geology. As discussed above, anakeesta can produce sulfate compounds. According to Harwell (2001), in the GRSM the spatial variability in sulfate concentrations are most likely due to anakeesta geology.

Correlation analysis revealed that adult brook trout biomass has a significant ($p = 0.000$) Pearson's correlation coefficient of -0.303 with median sulfate concentrations.

However, this variable did not enter the stepwise regression model because percent anakeesta was chosen instead. If anakeesta is not included as a predictor, stepwise regression would include sulfate in the model.

Table 12 shows correlations, where zeros were assumed for biomass when there were no trout present, between adult brook trout biomass and pH, log (conductivity), and log (ANC). Brook trout adult biomass is not significantly correlated with median pH or log (ANC). Brook trout adult biomass is significantly negatively correlated with log (conductivity) and the same discussion as above applies. However, the log (conductivity) variable did not enter the stepwise regression model because other variables had stronger correlations with biomass.

Young-of-year rainbow trout

Figure 6 shows predicted versus actual values for the rainbow trout young-of-year biomass model. This figure shows a clustering of zeros on the y-axis, which lower the model r^2 . These values are the result of rainbow trout being absent from certain streams. For these cases zeros were put into the database for young-of-year rainbow trout biomass.

Table 12. Brook trout adult biomass and water quality

		Median pH	Log(Conductivity)	Log(ANC)
BKT ADT Biomass	Pearson Correlation	0.040	-0.239	-0.035
	Sig. (2-tailed)	0.565	0.001	0.624
	N	207	207	198

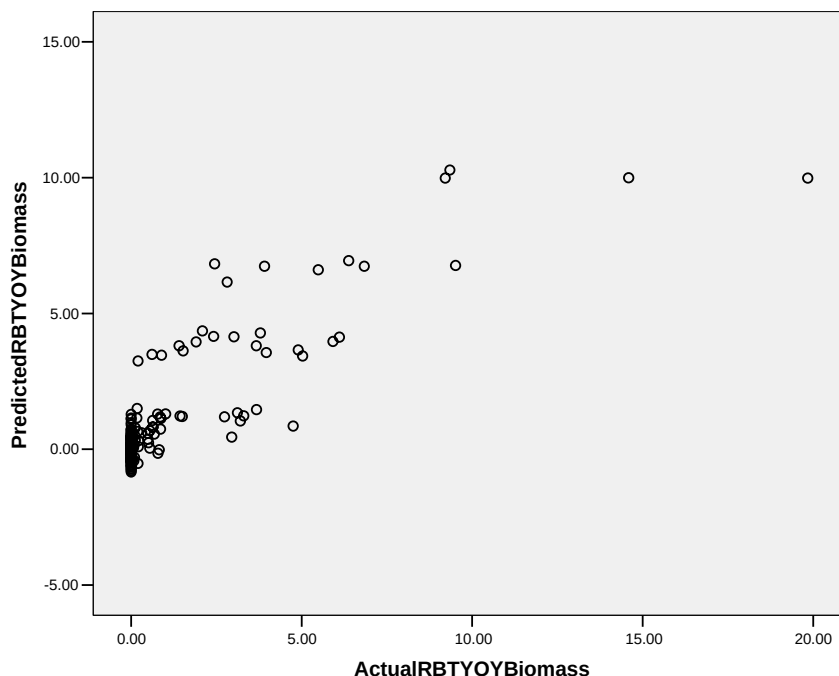


Figure 6. Plot of predicted versus actual rainbow trout young-of-year biomass values

These points were not deleted because absence of trout is considered important for this study.

The model in Table 10 shows that rainbow trout biomass increases with increases in basin area, which is what one would expect since rainbow trout are relatively large and therefore choose larger streams. Young-of-year biomass also decreases with increasing precipitation for the previous 90 days. This result is consistent with results from Barnett (2003) that base flow water quality conditions in the GRSM were adversely affected by increased stream flows, acid deposition and precipitation. During his study, Barnett found that base flow pH decreases with increasing flow at the Little River gaging station which is indicative of precipitation events adding, releasing, and carrying acid causing species to the surface waters. He also found that base flow pH decreases and sulfate increases

with increases in prior precipitation. For rainbow trout young-of-year biomass also increases with increases in conductivity. Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. It also has a very strong positive correlation with acid neutralizing capacity (ANC). Like adult brook trout, young-of-year rainbow trout are negatively affected by increases in percent anakeesta. Lastly, young-of-year rainbow trout biomass shows seasonality effects evidenced by the negative coefficient on sine (theta), where theta equals 2π times the fraction of year at the time of sample collection. The sine function gives positive values for the first half of the year (January 1 to June 30) and negative values for the last half (July 1 to December 31). Therefore the negative coefficient on sine theta means that young-of-year rainbow trout biomass is largest in the fall season and smallest in the spring. This result makes sense because rainbow trout spawn in the spring and young-of-year trout sampled in the fall have had all summer to gain biomass.

Table 13 shows correlations, where zeros were assumed for biomass when there were no trout present, between young-of-year rainbow trout biomass and pH, log (conductivity), and log (ANC). Rainbow trout biomass is significantly positively correlated with median pH. However, this variable was taken out of the stepwise regression model because when included it had a negative coefficient. Young-of-year biomass is also significantly positively correlated with log (conductivity). Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. Similarly, biomass is also positively correlated with log (ANC). However, the log (ANC) variable did not enter the stepwise

Table 13. Rainbow trout young-of-year biomass and water quality

		Median pH	Log(Conductivity)	Log(ANC)
RBT YOY Biomass	Pearson Correlation	0.514	0.613	0.635
	Sig. (2-tailed)	0.000	0.000	0.000
	N	207	207	198

regression model because other variables, like basin area, had stronger correlations with biomass.

Adult rainbow trout

Figure 7 shows predicted versus actual values for the rainbow trout adult biomass model. This figure shows a clustering of zeros on the y-axis, which lower the model r^2 . These values are the result of rainbow trout being absent from certain streams. For these cases zeros were put into the database for adult rainbow trout biomass. These points were not deleted because absence of trout is considered important for this study.

The model in Table 10 shows that rainbow trout biomass increases with increasing basin area and log (ANC). As mentioned before, the positive relationship between rainbow trout and ANC could be related to its low acid tolerance or may be an artifact of rainbow being present at lower elevations where ANC is higher and brook at higher elevations where ANC is lower. Similar to young-of-year brook trout, adult rainbow trout are negatively affected by increasing sulfate concentrations. Correlation analysis revealed that adult rainbow trout biomass has a significant ($p = 0.014$) Pearson's correlation coefficient of -0.159 with percent anakeesta geology. However, this variable

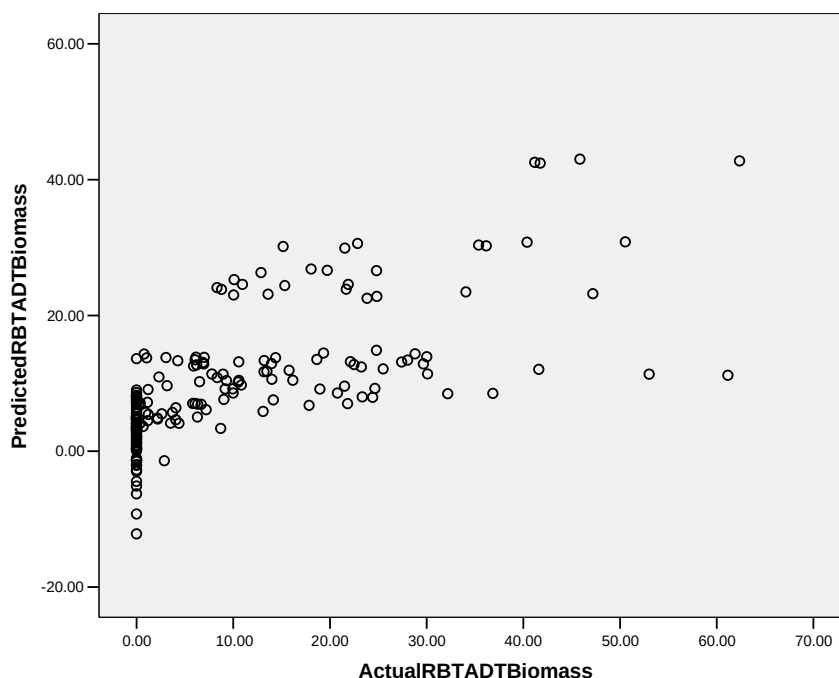


Figure 7. Plot of predicted versus actual rainbow trout adult biomass values

did not enter the stepwise regression model because other variables, like sulfate, had stronger correlations with biomass. The regression model shows that adult rainbow trout biomass decreases with increasing brook trout biomass. This negative relationship is the result of brook trout being displaced by rainbow trout and therefore relegated to headwater streams.

Table 14 shows correlations, where zeros were assumed for biomass when there were no trout present, between young-of-year rainbow trout biomass and pH, log (conductivity), and log (ANC). Rainbow trout biomass is significantly positively correlated with median pH. However, this variable did not enter the stepwise regression model because log (ANC) was chosen instead. If log (ANC) is not included as a predictor, stepwise regression would include median pH in the model. Adult biomass is also significantly positively correlated with log (conductivity). Conductivity is related to

Table 14. Rainbow trout adult biomass and water quality

		Median pH	Log(Conductivity)	Log(ANC)
RBT ADT Biomass	Pearson Correlation	0.504	0.368	0.544
	Sig. (2-tailed)	0.000	0.000	0.000
	N	207	207	198

the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water which should benefit fish. However, this variable did not enter the stepwise regression model because other variables, like log (ANC), had stronger correlations with biomass.

Conclusions

Relationships among trout biomass, watershed characteristics, water quality and hydrologic data for small streams of the GRSM were assessed with regression models. The regression models explained 54%, 63%, 73%, and 49% respectively of the variability in young-of-year brook trout, adult brook trout, young-of-year rainbow trout, and adult rainbow trout. Based on the regression results, trout biomass decreases with increases in sulfate concentrations and % anakeesta. Both of these variables can be linked to acidic stream conditions. Brook trout biomass showed a significant positive relationship with elevation. Results from Baldigo and Lawrence (2001) showed that brook trout seem to be present in streams at high elevations with cold water, steep gradients, small channels, and fast water velocities. In the GRSM, brook trout have been relegated to headwater streams by historic logging, exotic rainbow trout, and natural barriers which prevent upstream movement of rainbow. Due to competition, brook trout biomass was adversely affected by increases in rainbow trout biomass. Rainbow trout biomass showed a significant positive relationship with basin area that is consistent with King's (1943) observation that

rainbow trout are relatively larger and more active than brook trout and therefore present in larger streams. Rainbow trout biomass also showed a significant negative relationship with elevation. As a part of logging efforts, rainbow trout were first stocked around 1910 in park-area streams devoid of brook trout. Streams devoid of brook trout were generally located at low elevations and low gradients which were conducive to logging. Rainbow trout biomass also increases with increasing stream conductivity and ANC. Conductivity is related to the amount of ions (including calcium, magnesium, sodium, and potassium) found in a stream's water and is also strongly related to acid neutralizing capacity. In fact, for this data the Pearson correlation coefficient between median conductivity and median ANC is 0.972. The negative relationships between young-of-year biomass and hydrologic conditions and stream sulfate concentrations gives evidence to the problem of acid deposition/rain in the GRSM.

Three of the thirty one sites studied have no fish present (Site 45: Shutts Prong, Site 46: Porters Creek, and Site 237: Walker Camp Prong). From previous correlation analyses it is apparent that elevation, basin area, anakeesta, conductivity, sulfate, and ANC are all important predictors of trout biomass. Table 15 contains these predictor values for the three no-fish sites. Median elevation for all of the 31 sites sampled is 3010 feet. Therefore, only Site 237: Walker Camp Prong seems to have a relatively high elevation compared to other sites. Also median basin area for the 31 sites is 3.27 square miles. Compared to this value, sites 45 and 237 have relatively small basin areas. Median percent anakeesta geology for the sites sampled is 0.0. All three of the no-fish sites have high anakeesta compared to this value. Furthermore, median conductivity for the 31 sites is 13.90 $\mu\text{S}/\text{cm}$, median sulfate is 38.06 $\mu\text{eq}/\text{L}$, and median ANC is 36 $\mu\text{eq}/\text{L}$. All three

Table 15. Important predictor values for no-fish sites

Site	Elevation (feet)	Basin Area (sq. mi.)	% Anakeesta	Median Conductivity (microS/cm)	Median Sulfate (microeq/L)	Median ANC (microeq/L)
Site 45: Shutts Prong	3200	1.46	96.2	19.55	85.92	3.95
Site 46: Porters Creek	2750	3.35	75.2	16.75	68.60	5.14
Site 237: Walker Camp Prong	4520	1.66	100	19.61	72.20	-13.83

of the sites have relatively high conductivity, high sulfate, and low ANC. Therefore the fact that these sites have no fish present is most likely related to acid deposition and or acidic geology and not watershed characteristics like elevation and basin area.

Chapter V. Conclusions

The following observations and conclusions were made from the results presented in earlier chapters:

1. Brook trout biomass is positively related to elevation. Elevation accounts for 31% and 40% of the variability in brook trout young-of-year and adult biomass respectively. Rainbow trout biomass is significantly negatively correlated with elevation. This is most likely the result of brook trout being relegated to high elevation streams by historic logging and competition from exotic rainbow trout.
2. Rainbow trout biomass is positively related to basin area. Basin area accounts for 68% and 40% of the variability in rainbow trout young-of-year and adult biomass respectively. Brook trout biomass is significantly negatively correlated with basin area. Again this is most likely the result of brook trout being relegated to high elevation streams which have smaller basin areas and rainbow trout being present at low elevation streams which have larger basin areas.
3. It is thought that basin area and elevation are possible surrogates for stream size. Elevation and basin area have a significant correlation coefficient of -0.4794 , meaning that large basin areas occur at lower elevations and higher elevations have smaller basin areas.
4. Correlations and regressions performed on brook trout biomass yielded statistically significant decreasing trends with rainbow trout biomass.

5. Brook trout biomass is not significantly correlated with median pH or log (ANC).
Rainbow trout biomass is significantly positively correlated with median pH and log (ANC).
6. Brook trout biomass is significantly negatively correlated with log (conductivity).
This result is most likely an artifact of brook trout being present at higher elevations which have lower conductivities.
7. Correlations and regressions performed on brook and rainbow trout biomass yielded statistically significant decreasing trends with sulfate and anakeesta.
8. Correlations and regressions performed on young-of-year brook and rainbow trout biomass yielded statistically significant decreasing trends with cumulative precipitation and maximum stream flow.
9. The negative relationships between young-of-year biomass and hydrologic conditions and stream sulfate concentrations gives evidence to the problem of acid deposition/rain in the GRSM. However, sulfate is also strongly correlated with anakeesta geology. Since this analysis does not consider storm event water quality, it is difficult to separate out the effects of acid deposition versus acidic geology in the GRSM.
10. The following sites have no fish present and also have high sulfate concentrations (>80 $\mu\text{eq/L}$) and/or greater than 90% anakeesta geology and one could conclude that the absence of fish is related to acidic water quality:
 - a. Site 45: Shutts Prong upstream of confluents with Porters Creek (high sulfate and anakeesta)
 - b. Site 46: Porters Creek above Shutts Prong (high sulfate)

c. Site 237: Walker Camp Prong at last bridge (anakeesta)

11. The following sites are at risk because total trout biomass is very small, sulfate concentrations are relatively high ($>80 \mu\text{eq/L}$), and/or they have greater than 90% anakeesta geology :

a. Site 74: Walker Camp Prong above Alum Cave Creek (high sulfate and anakeesta)

b. Site 473: West Prong Little Pigeon River across from Bearpen Prong (high sulfate)

References

References

- American Fisheries Society Southern Division, Trout Committee. Standardized Sampling Guidelines for Wadeable Trout Streams. AFS (1992).
- An, Kwang-Guk; Park, Seok Soon; Shin, Joung-Yi. An evaluation of a river health using the index of biological integrity along with relations to chemical and habitat conditions. *Environment International* (2002), 28(5), 411-420. CODEN: ENVIDV ISSN:0160-4120. CAN 138:192531 AN 2002:790942 CAPLUS
- Baker, J.P.; Van Sickle, J.; Gagen, C.J.; DeWalle, D.R.; Sharpe, W.E.; Carline, R.F.; Baldigo, B.P.; Murdoch, P.S.; Bath, D.W.; Krester, W.A.; Simonin, H.A.; Wigington Jr., P.J. Episodic Acidification of Small Streams in the Northeastern United States: Effects on Fish Populations. *Ecological Applications* (1996), 6(2), 422-437.
- Baldigo, Barry P.; Murdoch, Peter S. Effect of stream acidification and inorganic aluminum on mortality of brook trout (*Salvelinus fontinalis*) in the Catskill Mountains, New York. *Canadian Journal of Fisheries and Aquatic Sciences* (1997), 54(3), 603-615. CODEN: CJFSDX ISSN:0706-652X. CAN 126:297294 AN 1997:319786 CAPLUS
- Baldigo, B.P.; Lawrence, G.B. Composition of Fish Communities in Relation to Stream Acidification and Habitat in the Neversink River, New York. *Transactions of the American Fisheries Society* (2000), 129, 60-76.
- Baldigo, Barry P.; Lawrence, Gregory B. Effects of Stream Acidification and Habitat on Fish Populations of a North American River. *Aquatic Sciences* (2001), 63, 196-222.
- Barnett, Thomas. Stream Water Quality Modeling in the Great Smoky Mountains National Park, M.S. Thesis, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, 2003.
- Beauchamp, J.J.; Christensen, S.W.; Smith, E.P. Selection of Factors Affecting the Presence of Brook Trout (*Salvelinus fontinalis*) in Adirondack Lakes: A Case Study. *Canadian Journal of Fisheries and Aquatic Sciences* (1992), 49, 597-608.
- Brown, D.J.A. The Effect of pH and Calcium on Fish and Fisheries. *Water, Air and Soil Pollution* (1982), 18, 343-351.
- Bulger, A.J.; Dolloff, C.A.; Cosby, B.J.; Eshleman, K.N.; Webb, J.R.; Galloway, J.N. The Shenandoah National Park: Fish in Sensitive Habitat (SNP:Fish) Project. *Water, Air and Soil Pollution* (1995), 85, 309-314.

- Bulger, Art; Cosby, Jack; Webb, Rick. Acid Rain: Current and Projected Status of Coldwater Fish Communities in the Southeastern US in the Context of Continued Acid Deposition. A Coldwater Conservation Fund Report. Trout Unlimited (1998).
- Dennis, T.E.; MacAvoy, S.E.; Steg, M.B.; Bulger, A.J. The Association of Water Chemistry Variables and Fish Condition in Streams of Shenandoah National Park (USA). *Water, Air and Soil Pollution* (1995), 85, 365-370.
- Driscoll, Charles T.; Lawrence, Gregory B.; Bulger, Arthur J.; Butler, Thomas J.; Cronan, Christopher S.; Eagar, Christopher; Lambert, Kathleen F.; Likens, Gene E., Stoddard, John L.; Weathers, Kathleen C. Acid Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. *BioScience* (2001), 51(3), 180-198.
- Etnier, David A.; Starnes, Wayne C. The Fishes of Tennessee. University of Tennessee Press, Knoxville, TN. 1993.
- Harriman, R.; Watt, A. W.; Christie, A. E. G.; Moore, D. W.; McCartney, A. G.; Taylor, E. M. Quantifying the effects of forestry practices on the recovery of upland streams and lochs from acidification. *Science of the Total Environment* (2003), 310(1-3), 101-111. CODEN: STENDL ISSN:0048-9697. CAN 139:201852 AN 2003:461482 CAPLUS
- Harwell, G. R., Water Quality Characteristics, Temporal Trends, and Influencing Factors for Selected Streams in the Great Smoky Mountains National Park, M.S. Thesis, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, 2001.
- Hesthagen, T.; Heggenes, J.; Larsen, B. M.; Berger, H. M.; Forseth, T. Effects of water chemistry and habitat on the density of young brown trout *Salmo trutta* in acidic streams. *Water, Air, and Soil Pollution* (1999), 112(1-2), 85-106. CODEN: WAPLAC ISSN:0049-6979. CAN 131:48896 AN 1999:367537 CAPLUS
- Huckabee, John W.; Goodyear, C. Phillip; Jones, Ronald D. Acid Rock in the Great Smokies: Unanticipated Impact on Aquatic Biota of Road Construction in Regions of Sulfide Mineralization. *Transactions of the American Fisheries Society* (1975), 4, 677-684.
- Hunn, J.B. Role of Calcium in Gill Function in Freshwater Fishes. *Comparative Biochemistry and Physiology* (1985), 82A(3), 543-547.
- Hunn, Joseph B.; Cleveland, Laverne; Little, Edward E. Influence of pH and Aluminum on Developing Brook Trout in a Low Calcium Water. *Environmental Pollution* (1987), 43, 63-73.

- Jensen, James N. *A Problem Solving Approach to Aquatic Chemistry*. John Wiley & Sons, Inc. New Jersey (2003).
- Johnson, Todd. Acute and Chronic Toxicity of Nitrate to Brook Trout (*Salvelinus fontinalis*) Embryos and Larvae. University of Wisconsin, Masters Thesis. (2002).
- Jowett, Ian G. Factors Related to the Distribution and Abundance of Brown and Rainbow Trout in New Zealand Clear-Water Rivers. *New Zealand Journal of Marine and Freshwater Research* (1990), 24, 429-440.
- King, Joseph E. Survival Time of Trout in Relation to Occurrence. *American Midland Naturalist* (1943), 29(3), 624-642.
- Kocovsky, Patrick M.; Carline, Robert F. Stream pH as an Abiotic Gradient Influencing Distributions of Trout in Pennsylvania Streams. *Transactions of the American Fisheries Society* (2005), 134, 1299-1312.
- Lanka, Robert P.; Hubert, Wayne A.; Wesche, Thomas A. Relations of Geomorphology to Stream Habitat and Trout Standing Stock in Small Rocky Mountain Streams. *Transactions of the American Fisheries Society* (1987), 116, 21-28.
- Larson, Gary L.; Moore, Stephen E. Encroachment of Exotic Rainbow Trout into Stream Populations of Native Brook Trout in the Southern Appalachian Mountains. *Transactions of the American Fisheries Society* (1985), 114, 195-203.
- Latterell, Joshua J.; Fausch, Kurt D.; Gowan, Charles; Riley, Stephen C. Relationship of Trout Recruitment to Snowmelt Runoff Flows and Adult Trout Abundance in Six Colorado Mountain Streams. *Rivers* (1998), 6, 240-250.
- Lawrence, G.B. Persistent Episodic Acidification of Streams Linked to Acid Rain Effects on Soil. *Atmospheric Environment* (2002), 36, 1589-1598.
- Likens, G. E.; Driscoll, C. T.; Buso, D. C. Long-term effects of acid rain: response and recovery of a forest ecosystem. *Science* (Washington, D. C.) (1996), 272(5259), 244-6. CODEN: SCIEAS ISSN:0036-8075. CAN 124:269661 AN 1996:226916 CAPLUS
- Luckenbach, T.; Tribskorn, R.; Muller, E.; Oberemm, A. Toxicity of waters from two streams to early life stages of brown trout (*Salmo trutta* f. *fario* L.), tested under semi-field conditions. *Chemosphere* (2001), 45(4-5), 571-579. CODEN: CSMHAF ISSN:0045-6535. CAN 135:314617 AN 2001:708561 CAPLUS
- MacAvoy, S.E.; Bulger, A.J. Survival of Brook Trout (*Salvelinus fontinalis*) Embryos and Fry in Streams of Different Acid Sensitivity in Shenandoah National Park, USA. *Water, Air and Soil Pollution* (1995), 85, 445-450.

- Marschall, Elizabeth A.; Crowder, Larry B. Assessing Population Responses to Multiple Anthropogenic Effects: A Case Study with Brook Trout. *Ecological Applications* (1996), 6(1), 152-167.
- McCartney, A. G.; Harriman, R.; Watt, A. W.; Moore, D. W.; Taylor, E. M.; Collen, P.; Keay, E. J. Long-term trends in pH, aluminum and dissolved organic carbon in Scottish fresh waters; implications for brown trout (*Salmo trutta*) survival. *Science of the Total Environment* (2003), 310(1-3), 133-141. CODEN: STENDL ISSN:0048-9697. CAN 139:201855 AN 2003:461485 CAPLUS
- Moore, Steve; Kulp, Matt. Great Smoky Mountains National Park Trout Data Base, Data Base Prepared by the U.S. National Park Service. 2005.
- Nelson, Rodger L.; Platts, William S.; Larsen, David P.; Jensen, Sherman E. Trout Distribution and Habitat in Relation to Geology and Geomorphology in the North Fork Humboldt River Drainage, Northeastern Nevada. *Transactions of the American Fisheries Society* (1992), 121(4), 405-426.
- Nielsen, Larry A.; Johnson, David L. Fisheries Techniques. *The American Fisheries Society* (1983), 293-298.
- Nislow, Keith H.; Lowe, Winsor H. Influences of Logging History and Stream pH on Brook Trout Abundance in First-Order Streams in New Hampshire. *American Fisheries Society* (2003), 132, 166-171.
- Pinder, Michael J.; Morgan II, Raymond P. Interactions of pH and Habitat on Cyprinid Distributions in Appalachian Streams of Maryland. *Transactions of the American Fisheries Society* (1995), 124, 94-102.
- Robinson, R.B., Smoot, J.L., Shubzda, J., Wood, M., Harwell, G., Barnett, T.W. Great Smoky Mountains National Park Stream Survey Water Quality Data Base, Data Base Prepared for the U.S. National Park Service, Knoxville, TN: Dept. Of Civil and Environmental Engineering, The University of Tennessee, April, 2002.
- Roby, J. Chad, Water Quality Characterization, Stormwater Analyses, and Statistical Modeling of Stream Water Quality in the Little Pigeon River Watershed of the Great Smoky Mountains National Park, M.S. Thesis, Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, 2004.
- Rosseland, B. O.; Henriksen, A. Acidification in Norway - loss of fish populations and the 1000-lake survey 1986. *Science of the Total Environment* (1990), 96(1-2), 45-56. CODEN: STENDL ISSN:0048-9697. CAN 113:120377 AN 1990:520377 CAPLUS

- Shubzda, J., Lindberg, S.E., Garten, C.T., and Nodvin, S.C. (1995). "Elevational Trends in the Fluxes of Sulphur and Nitrogen in Throughfall in the Southern Appalachian Mountains: Some Surprising Results." *Water, Air, and Soil Pollution*, 85, 2265-2270.
- Smith, Todd R.; Haines, Terry A. Mortality, Growth, Swimming Activity and Gill Morphology of Brook Trout (*Salvelinus fontinalis*) and Atlantic Salmon (*Salmo salar*) Exposed to Low pH With and Without Aluminum. *Environmental Pollution* (1995), 90(1), 33-40.
- Stoddard, J. L.; Jeffries, D. S.; Lukewolle, A.; Clair, T. A.; Dillon, P. J.; Driscoll, C. T.; Forsius, M.; Johannessen, M.; Kahl, J. S.; Kellogg, J. H.; Kemp, A.; Mannio, J.; Montelth, D. T.; Murdoch, P. S.; Patrick, S.; Rebsdorf, A.; Skjelkvile, B. L.; Stainton, M. P.; Traaen, T.; Van Dam, H.; Webster, K. E.; Wieting, J.; Wilander, A. Regional trends in aquatic recovery from acidification in North America and Europe. *Nature* (London) (1999), 401(6753), 575-578. CODEN: NATUAS ISSN:0028-0836. AN 1999:694483 CAPLUS
- Turner, R. S.; Ryan, P. F.; Marmorek, D. R.; Thornton, K. W.; Sullivan, T. J.; Baker, J. P.; Christensen, S. W.; Sale, M. J. Sensitivity to change for low-ANC eastern US lakes and streams and brook trout populations under alternative sulfate deposition scenarios. *Environmental Pollution* (Oxford, United Kingdom) (1992), 77(2-3), 269-77. CODEN: ENPOEK ISSN:0269-7491. CAN 117:76062 AN 1992:476062 CAPLUS
- Van Sickle, J.; Baker, J.P.; Simonin, H.A.; Baldigo, B.P.; Kretser, W.A.; Sharpe, W.E. Episodic Acidification of Small Streams in the Northeastern United States: Fish Mortality in Field Bioassays. *Ecological Applications* (1996), 6(2), 408-421.
- Van Sickle, J.; Wigington, P. J., Jr.; Church, M. R. Estimation of episodic stream acidification based on monthly or annual sampling. *Journal of the American Water Resources Association* (1997), 33(2), 359-366. CODEN: JWRAF5 CAN 126:333979 AN 1997:308958 CAPLUS
- Webb, James R.; Cosby, Bernard J.; Deviney, Frank A., Jr.; Galloway, James N.; Maben, Suzanne W.; Bulger, Arthur J. Are Brook Trout Streams in Western Virginia and Shenandoah National Park Recovering from Acidification? *Environmental Science and Technology* (2004), 38(15), 4091-4096. CODEN: ESTHAG ISSN:0013-936X. CAN 141:230055 AN 2004:528481 CAPLUS

Appendix

Appendix

Watershed Characteristics

The following is a list of the watershed characteristics data collected for each sample site along with a description of the method used.

- Elevation, in meters above mean sea level, is the elevation of the sample site. Sample sites are usually located at points along a stream where either roads or trails that appear on USGS 1:24,000 scale quadrangle maps intersect. For sampling sites that are not located at easily recognizable points on USGS quads, the sampling site location and elevation were estimated. All elevations are probably accurate to within 6.1 meters (20 feet) since contour intervals are 12.2 meters (40 feet).
- UTM X is the easting location of a sample site, in meters, using the North American datum of 1927 (NAD 27). Digitized USGS quadrangle maps provide UTM X and UTM Y when a location is selected.
- UTM Y is the northing location of a sample site, in meters, using NAD 27 as datum. See above for explanation of method.
- Basin area, in mi^2 , is the contributing area to the sample site determined from the GIS database.
- Average basin slope is the average land slope of the contributing area expressed as a percentage and determined from the GIS database.
- Channel slope, expressed as a percentage, is the slope of the channel determined by the elevation difference between points located 10 and 85 percent of the distance along the main stream channel from the sample site to the drainage basin divide, divided by 0.75 of the length of the main stream channel from the sample site to the drainage divide. This information was determined from the USGS 1:24,000 scale quadrangle maps (Choquette, 1988).
- Geology data are expressed as the percentage of the contributing area to the sample site covered by the different geology types in the GIS database. There are 21 different geology types including: Thunderhead Sandstone, Pigeon Siltstone, Roaring Fork Sandstone, Rich Butt Sandstone, Limestone, Cades Sandstone, Metcalf Phyllite, Elkmont Sandstone, Anakeesta, Unnamed sandstone, Metadiorite, Great Smoky Group, Basement complex, Longarm Quartzite, Wading Branch Formation, Cochoran Formation, Nichols Shale, Nebo Quartzite, Hesse Quartzite, Wilhite Formation, and Wilhite Formation Course. Geology data are available for all sites. The geology data in the GIS database are based upon work done in 1968 (King *et al*, 1968).
- Vegetation data are expressed as the percentage of the contributing area to the sample site covered by the different vegetation types. There are 13 different vegetation types including: Spruce Fir, Northern Hardwood, Cove Hardwood,

Mesic Oak, Mixed Mesic Hardwood, Tulip Poplar, Pine, Heath Bald, Xeric Oak, Pine-Oak, Grape Thicket, Treeless, and Grassy Bald. This information comes from the GIS database and is based upon work done in 1993 (MacKenzie, 1993).

- Disturbance history data are expressed as the percentage of the contributing area to the sample site with a certain type of historical land use. The types of disturbance histories include undisturbed, settlement, selective cut, heavy cut, and light cut. This information comes from the GIS database and is based upon work done in 1985 and 1988 (Pyle, 1985; Pyle, 1988).

Vegetation Groups

The different vegetation, or forest, types present in the GRSM occur in specific areas and, in most cases, the species which make up each forest type are unique. Mark MacKenzie's dissertation entitled 'The Vegetation of the Great Smoky Mountains National Park: Past, Present, and Future' provided the information on which species are included in each forest type and some habitat information. Additional habitat information for the different species was obtained from *The Audubon Society Field Guide to North American Trees, Eastern Edition*, 1980 (Little, 1980). The following defines each forest type:

- Spruce Fir
The Eastern Spruce (*Picea rubens*) often grows in pure stands in the rocky, high elevation (1,372-1,981 meters) soils of the GRSM.
- Northern Hardwood
Major species in this group include the American Beech (*Fagus grandifolia*) and the Sweet Birch (*Betula lenta*). Minor species include the Red Maple (*Acer rubrum*), Sugar Maple (*Acer saccharum*), and the Northern Red Oak (*Quercus rubra*). All of these species prefer the cool and moist conditions found at higher elevations. They generally occur at elevations above 1,075 meters and often in pure stands.
- Cove Hardwood
These forests generally do not have a single dominant species that occurs in pure stands like the Spruce Fir or the Northern Hardwood forests. However, major species in this group include White Basswood (*Tilia heterophylla*), Carolina Silverbell (*Halesia carolina*), Red Maple (*Acer rubrum*), Sugar Maple (*Acer saccharum*), Yellow Buckeye (*Aesculus octandra*), American Beech (*Fagus grandifolia*), Cucumber Magnolia

(*Magnolia acuminata*), Sweet Birch (*Betula lenta*), and Eastern Hemlock (*Tsuga canadensis*). Some of the species in this group are also found in the Northern Hardwood forest. However, when they occur in a Cove Hardwood forest, they are typically not pure stands. The elevation range for this type of forest is broad. Cucumber Magnolia and White Basswood trees are found in the lower elevations (about 60 meters) and other species are found at higher elevations. The Yellow Buckeye is found at elevations as high as 1,920 meters and the Eastern Hemlock as high as 1,524 meters. The Eastern Hemlock is the only species in this group that does occur in pure stands. All of the species in the Cove Hardwood forests prefer moist soil conditions. Moist soil conditions are found at the higher elevations and at lower elevations along streams and in ravines.

- Mesic Oak

Major species in these forests include Northern Red Oak (*Quercus rubra*), Chestnut Oak (*Quercus prinus*), and White Oak (*Quercus alba*). This forest can occur throughout the GRSM at almost any elevation. It is common on ridges and south facing slopes at higher elevations and ridges and side slopes at lower elevations. The trees in this forest often grow in pure stands.

- Mixed Mesic Hardwood

This forest type has no clear dominant species. It may contain any combination of the following: Oaks (*Quercus*), Elms such as the American Elm (*Ulmus americana*), Pines (*Pinus*), Hickories such as Bitternut Hickory (*Carya cordiformis*) and Pignut Hickory (*Carya glabra*), Tulip Poplar (*Liriodendron tulipifera*), Red Maple (*Acer rubrum*), Black Walnut (*Juglans nigra*), Sweetgum (*Liquidambar styraciflua*), Sycamore (*Platanus occidentalis*), and Black Locust (*Robinia pseudoacacia*). Some of these species, such as the Sweetgum, American Sycamore and Tulip Poplar, are found in areas that have been cleared in the last 80 years as a result of farming or logging operations. These areas are usually found at the lower elevations of the GRSM. The Mixed Mesic Hardwood forests are typically found at elevations less than 750 meters. Some of these species can be found at higher elevations.

- Tulip Poplar

The Tulip Poplar, mentioned as part of the Mixed Mesic Hardwood forests, also occurs frequently enough in stands within the GRSM to be classified as a unique forest type. The Tulip Poplar is usually found in coves and valleys with moist, well-drained soils at elevations from 300 meters to as high as 1,372 meters. Most of the stands are found at lower elevations that have been logged or farmed prior to establishment of the GRSM.

- Pine

Major species in the Pine forests include Pitch Pine (*Pinus rigida*), Table Mountain Pine (*Pinus pungens*), and Shortleaf Pine (*Pinus echinata*). Minor species include Eastern White Pine (*Pinus strobus*) and Virginia

Pine (*Pinus virginiana*). The Pine forests typically occur at the middle to lower elevations of the GRSM. They prefer well-drained soils such as sands and sandy loams. The Eastern White Pine can be found as high as 1,524 meters. The remainder of species in these forests is below 1,300 meters. The Virginia Pine is another species which tends to do well in areas that were farmed or logged prior to establishment of the GRSM.

- Heath Bald

The Heath Bald forests are dominated by evergreen ericaceous shrubs which form dense thickets in the understory of other mountain forests. Species within these forests include Mountain Laurel (*Kalmia latifolia*), Catawba Rhododendron (*Rhododendron catawbiense*), and Rosebay Rhododendron (*Rhododendron maximum*). These plants, especially the Mountain Laurel, prefer acidic soils. They are found over a broad elevation range but most are found at the middle to upper elevations (900 to 2,000 meters).

- Xeric Oak

Major species in this group include Scarlet Oak (*Quercus coccinea*), Chestnut Oak (*Quercus prinus*), Black Tupelo or Blackgum (*Nyssa sylvatica*), Sourwood (*Oxydendron arboreum*), and Black Locust (*Robinia pseudoacacia*). The trees in this forest can occur at high elevations in the GRSM but typically this forest occurs on ridges and slopes below 1,050 meters. These trees typically grow in mixed forests with other oaks or pines. The exception to this is the Chestnut Oak. As already mentioned, the Chestnut Oak often grows in pure stands. In this situation, it is part of what was classified as a Mesic Oak forest. The Chestnut Oak also occurs in Xeric Oak forests where it grows along with other species.

- Pine-Oak

This forest type contains an even mixture of pine and oak. It has the same site characteristics as the Pine forests. Species included in these forests can be any combination of the types typically found in the Pine forests or the Mesic Oak forests.

- Grape Thicket

These areas are composed of a number of different thicket forming *Vitis* species. They tend to occur in the low to middle elevations. Although they do represent a unique forest type within the GRSM, they are not very common. They represent only about 0.16% of the total area within the GRSM (MacKenzie, 1993).

- Treeless

The Treeless areas of the GRSM are those in which a major forest type does not exist, such as open fields within Cades Cove, or areas which are dominated by outcrops of rock formations, such as Anakeesta Formations found within the watersheds of the Middle Prong of the Little Pigeon River, the West Prong of the Little Pigeon River, and the upper portions of the Oconaluftee River near Beech Flats Creek. These areas only occupy about 0.68% of the GRSM (MacKenzie, 1993)

- Grassy Bald

These areas are found high on mountain tops above 1,525 meters. The Grassy Balds are dominated by mountain oat grass (*Danthonia compressa*) with only minor occurrences of trees. Although they represent a unique vegetation area within the GRSM, they only cover about 0.03% of the entire area (MacKenzie, 1993).

Table A.16. Brook trout young-of-year biomass and water chemistry

		BKT YOY Biomass	Median Sulfate	LAG Med Anions	Minimum Sulfate	Med Spring Sulfate	Median Anions	Min Spring Sulfate
LAG Median Sulfate	Pearson Correlation	-0.479	0.977	0.956	0.953	0.944	0.936	0.933
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	213	218	213	198	213	198
		BKT YOY Biomass	Min Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Median Anions	Med Spring Anions
Minimum Sulfate	Pearson Correlation	-0.475	0.981	0.967	0.966	0.953	0.940	0.926
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	213	194
		BKT YOY Biomass	Minimum Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Min Spring Anions	Median Anions
Min Spring Sulfate	Pearson Correlation	-0.475	0.981	0.976	0.958	0.933	0.931	0.931
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	198	218	194
		BKT YOY Biomass	Min Spring Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Anions	LAG Median Sulfate	Median Anions
Med Spring Sulfate	Pearson Correlation	-0.470	0.976	0.976	0.967	0.949	0.944	0.944
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	194	218	198	194
		BKT YOY Biomass	LAG Median Sulfate	Med Spring Sulfate	Minimum Sulfate	Median Anions	Min Spring Sulfate	Max Spring Sulfate
Median Sulfate	Pearson Correlation	-0.465	0.977	0.976	0.966	0.962	0.958	0.955
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	194	213	213	194	194
		BKT YOY Biomass	Median Potassium	Min Spring Potassium	Minimum Potassium	Maximum Potassium	LAG Med Potassium	Med Spring Sodium
Med Spring Potassium	Pearson Correlation	0.450	0.887	0.879	0.792	0.772	0.739	0.728
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	194	198	218
		BKT YOY Biomass	Med Spring Sodium	Maximum Sodium	Median Sodium	Min Spring Sodium	Med Spring Potassium	Median Potassium
Max Spring Sodium	Pearson Correlation	0.434	0.919	0.820	0.808	0.753	0.705	0.691
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	194	218	218	194
		BKT YOY Biomass	Min Spring Sodium	Max Spring Sodium	Median Sodium	Minimum Sodium	Maximum Sodium	Min Spring pH
Med Spring Sodium	Pearson Correlation	0.428	0.933	0.919	0.902	0.870	0.822	0.745
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	218	194	194	194	218
		BKT YOY Biomass	Maximum Anions	Max Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Max Spring Anions
Maximum Sulfate	Pearson Correlation	-0.424	0.920	0.916	0.904	0.895	0.881	0.866
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	194	194	213	213	194
		BKT YOY Biomass	Median Sulfate	Max Spring Anions	Minimum Sulfate	Median Anions	Maximum Sulfate	Med Spring Sulfate
Max Spring Sulfate	Pearson Correlation	-0.423	0.955	0.936	0.921	0.918	0.916	0.902
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	194	194	218

Table A.16. continued

		BKT YOY Biomass	Median Potassium	LAG Med Sodium	Minimum Potassium	Min Spring Potassium	Median Sodium	Med Spring Potassium
LAG Med Potassium	Pearson Correlation	0.411	0.885	0.827	0.809	0.745	0.742	0.739
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	213	218	213	198	213	198
		BKT YOY Biomass	Minimum Sodium	Med Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Potassium	Max Spring Sodium
Min Spring Sodium	Pearson Correlation	0.408	0.947	0.933	0.887	0.765	0.753	0.753
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	198	218	218
		BKT YOY Biomass	Minimum Potassium	Med Spring Potassium	Median Potassium	Min Spring Sodium	LAG Med Potassium	Med Spring Sodium
Min Spring Potassium	Pearson Correlation	0.404	0.881	0.879	0.878	0.753	0.745	0.739
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	218	198	218
		BKT YOY Biomass	Med Spring Potassium	LAG Med Potassium	Min Spring Potassium	Minimum Potassium	Median Sodium	Max Spring Potassium
Median Potassium	Pearson Correlation	0.403	0.887	0.885	0.878	0.864	0.780	0.764
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	213	194	213	213	194
		BKT YOY Biomass	Maximum Potassium	Median Potassium	Med Spring Potassium	Minimum Potassium	LAG Med Potassium	Min.pH
Max Spring Potassium	Pearson Correlation	0.396	0.786	0.764	0.666	0.639	0.628	0.526
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	194	218	194	198	194
		BKT YOY Biomass	Min Spring ANC	Minimum ANC	Median ANC	Max.TotalIC AAICPCat ions	MedSpringT otalCations	Min.TotalIC AAICPCat ions
Med Spring ANC	Pearson Correlation	0.380	0.990	0.989	0.979	0.974	0.971	0.970
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	194	194	218	194
		BKT YOY Biomass	Min Spring Sodium	Median Sodium	Med Spring Sodium	LAG Med Sodium	Minimum Potassium	Min Spring pH
Minimum Sodium	Pearson Correlation	0.377	0.947	0.883	0.870	0.843	0.797	0.752
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	213	194	213	213	194
		BKT YOY Biomass	Minimum ANC	Med Spring ANC	Median ANC	Min.TotalIC AAICPCat ions	MinSpringTo talCations	MedSpringT otalCations
Min Spring ANC	Pearson Correlation	0.376	0.998	0.990	0.971	0.965	0.961	0.958
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	194	194	218	218
		BKT YOY Biomass	Median Anions	LAG Median Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Sulfate	Med Spring Anions
LAG Med Anions	Pearson Correlation	-0.374	0.968	0.956	0.941	0.920	0.912	0.905
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	213	218	213	213	198	198
		BKT YOY Biomass	Maximum Cond	Max.TotalIC AAICPCat ions	MedianTotal Cations	Median ANC	Max Spring Cond	Med Spring Cond
MedianCond	Pearson Correlation	-0.372	0.976	0.974	0.972	0.972	0.960	0.958
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	213	213	194	194

Table A.16. continued

		BKT YOY Biomass	LAGMedTotalCations	LAG Med ANC	Maximum Cond	Max.TotalIC AAICPCations	Min Spring Cond	MedianTotalCations
LAG Median Cond	Pearson Correlation	-0.371	0.971	0.970	0.940	0.927	0.926	0.921
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	218	218	213	213	198	213
		BKT YOY Biomass	LAG Med Anions	Median Sulfate	Med Spring Anions	Med Spring Sulfate	Minimum Sulfate	LAG Median Sulfate
Median Anions	Pearson Correlation	-0.362	0.968	0.962	0.950	0.944	0.940	0.936
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	194	194	213	213
		BKT YOY Biomass	Min Spring ANC	Med Spring ANC	Min.TotalIC AAICPCations	MinSpringTotalCations	MedSpringTotalCations	Max Spring ANC
Minimum ANC	Pearson Correlation	0.357	0.998	0.989	0.970	0.961	0.959	0.957
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	194	194	194
		BKT YOY Biomass	Min Spring Anions	Median Anions	Med Spring Sulfate	Minimum Anions	Min Spring Sulfate	Minimum Sulfate
Med Spring Anions	Pearson Correlation	-0.354	0.959	0.950	0.949	0.935	0.930	0.926
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	218	194	218	194
		BKT YOY Biomass	Minimum Anions	Med Spring Anions	Min Spring Sulfate	Minimum Sulfate	Med Spring Sulfate	Median Anions
Min Spring Anions	Pearson Correlation	-0.351	0.962	0.959	0.931	0.914	0.904	0.900
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	194	218	218	194	218	194
		BKT YOY Biomass	Med Spring pH	Max Spring pH	Median pH	Min.pH	LAG Median pH	Max.pH
Min Spring pH	Pearson Correlation	0.349	0.980	0.921	0.917	0.915	0.855	0.842
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	218	194	194	198	194
		BKT YOY Biomass	Med Spring Cond	MinSpringTotalCations	Min.TotalIC AAICPCations	Minimum Cond	MedSpringTotalCations	MedianCond
Min Spring Cond	Pearson Correlation	-0.349	0.980	0.959	0.957	0.953	0.951	0.943
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	218	194	194	218	194
		BKT YOY Biomass	Max Spring Cond	Median ANC	Med Spring ANC	Max.ANCmeqL	Max.TotalIC AAICPCations	Minimum ANC
Max Spring ANC	Pearson Correlation	0.348	0.966	0.965	0.960	0.960	0.959	0.957
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	218	194	194	194
		BKT YOY Biomass	Min Spring Cond	MedSpringTotalCations	MaxSpringTotalCations	MinSpringTotalCations	Min.TotalIC AAICPCations	MedianTotalCations
Med Spring Cond	Pearson Correlation	-0.347	0.980	0.975	0.970	0.969	0.968	0.963
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	218	218	218	194	194
		BKT YOY Biomass	Min Spring Potassium	Median Potassium	LAG Med Potassium	Minimum Sodium	Med Spring Potassium	Median Sodium
Minimum Potassium	Pearson Correlation	0.347	0.881	0.864	0.809	0.797	0.792	0.755
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	213	213	213	194	213

Table A.16. continued

		BKT YOY Biomass	Max Spring Potassium	Med Spring Potassium	Median Potassium	LAG Med Potassium	Maximum Sodium	Minimum Potassium
Maximum Potassium	Pearson Correlation	0.344	0.786	0.772	0.726	0.671	0.648	0.611
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	213	213
		BKT YOY Biomass	Maximum Sulfate	Max Spring Anions	Med Spring Anions	Max Spring Sulfate	Median Anions	Med Spring Sulfate
Maximum Anions	Pearson Correlation	-0.334	0.920	0.917	0.881	0.869	0.867	0.864
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	194	194	194	213	194
		BKT YOY Biomass	Med Spring Sodium	Min Spring Sodium	Minimum Sodium	LAG Med Sodium	Maximum Sodium	Max Spring Sodium
Median Sodium	Pearson Correlation	0.332	0.902	0.887	0.883	0.866	0.819	0.808
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	213	194
		BKT YOY Biomass	Max Spring ANC	Median Cond	Med Spring Cond	Median Total Cations	Max. Total IC AAICPCations	Maximum Cond
Max Spring Cond	Pearson Correlation	-0.330	0.966	0.960	0.952	0.952	0.952	0.951
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	218	194	194	194
		BKT YOY Biomass	Max Spring Sulfate	Median Anions	Med Spring Anions	Maximum Anions	Median Sulfate	Med Spring Sulfate
Max Spring Anions	Pearson Correlation	-0.329	0.936	0.929	0.921	0.917	0.898	0.887
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	218	194	194	218
		BKT YOY Biomass	Min Spring pH	Med Spring pH	Median pH	LAG Median pH	Max Spring pH	Max. pH
Min. pH	Pearson Correlation	0.328	0.915	0.900	0.875	0.863	0.857	0.784
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	194	213
		BKT YOY Biomass	Max. Total IC AAICPCations	Median Cond	Max. ANC meq/L	Median ANC	Median Total Cations	Med Spring Cond
Maximum Cond	Pearson Correlation	-0.327	0.978	0.976	0.973	0.969	0.967	0.952
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	213	213	213	194
		BKT YOY Biomass	Min Spring Anions	Med Spring Anions	Minimum Sulfate	Min Spring Sulfate	Median Anions	Med Spring Sulfate
Minimum Anions	Pearson Correlation	-0.324	0.962	0.935	0.919	0.912	0.911	0.891
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	194	213	194
		BKT YOY Biomass	Min Spring pH	Max Spring pH	Median pH	Min. pH	LAG Median pH	Max. pH
Med Spring pH	Pearson Correlation	0.322	0.980	0.971	0.953	0.900	0.882	0.877
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	218	194	194	198	194
		BKT YOY Biomass	Median Sodium	Minimum Sodium	LAG Med Potassium	Min Spring Sodium	LAG Median pH	Maximum Sodium
LAG Med Sodium	Pearson Correlation	0.309	0.866	0.843	0.827	0.765	0.762	0.737
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	213	213	218	198	218	213
		BKT YOY Biomass	Min Spring Cond	Min. Total IC AAICPCations	Minimum ANC	Med Spring Cond	Min Spring Total Cations	Min Spring ANC
Minimum Cond	Pearson Correlation	-0.303	0.953	0.908	0.899	0.897	0.893	0.885
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	213	213	194	194	194

Table A.16. continued

		BKT YOY Biomass	Med Spring Sodium	Max Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Sodium	Median Potassium
Maximum Sodium	Pearson Correlation	0.296	0.822	0.820	0.819	0.737	0.732	0.680
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	194	213
		BKT YOY Biomass	Med Spring pH	Median pH	Min Spring pH	Max.pH	LAG Median pH	Min.pH
Max Spring pH	Pearson Correlation	0.285	0.971	0.952	0.921	0.890	0.884	0.857
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	161	218	194	218	194	198	194
		BKT YOY Biomass	Median pH	Max.pH	Max Spring pH	Med Spring pH	Min.pH	Min Spring pH
LAG Median pH	Pearson Correlation	0.270	0.942	0.892	0.884	0.882	0.863	0.855
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	213	213	198	198	213	198
		BKT YOY Biomass	LAGMedTot alCations	LAG Median Cond	Max.ANCme qL	Median ANC	Max.TotalIC AAICPCatio ns	Min Spring ANC
LAG Med ANC	Pearson Correlation	0.255	0.977	0.970	0.958	0.955	0.951	0.946
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	218	218	213	213	213	198
		BKT YOY Biomass	Max.ANCme qL	Max.TotalIC AAICPCatio ns	Med Spring ANC	MedianTotal Cations	MedianCond	Min Spring ANC
Median ANC	Pearson Correlation	0.217	0.983	0.981	0.979	0.977	0.972	0.971
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	194	213	213	194
		BKT YOY Biomass	LAG Med ANC	LAG Median Cond	Max.TotalIC AAICPCatio ns	MedianTotal Cations	Max.ANCme qL	Maximum Cond
LAGMedTotalCat ions	Pearson Correlation	-0.212	0.977	0.971	0.946	0.934	0.933	0.931
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000	0.000	0.000
	N	160	218	218	213	213	213	213
		BKT YOY Biomass	Med Spring pH	Max Spring pH	LAG Median pH	Max.pH	Min Spring pH	Min.pH
Median pH	Pearson Correlation	0.209	0.953	0.952	0.942	0.924	0.917	0.875
	Sig. (2-tailed)	0.009	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	194	194	213	213	194	213
		BKT YOY Biomass	Max.TotalIC AAICPCatio ns	Median ANC	MedianCond	MedSpringT otalCations	MinSpringTo talCations	Maximum Cond
MedianTotalCatio ns	Pearson Correlation	-0.208	0.987	0.977	0.972	0.969	0.968	0.967
	Sig. (2-tailed)	0.009	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	213	194	194	213
		BKT YOY Biomass	Median pH	LAG Median pH	Max Spring pH	Med Spring pH	Min Spring pH	Min.pH
Max.pH	Pearson Correlation	0.205	0.924	0.892	0.890	0.877	0.842	0.784
	Sig. (2-tailed)	0.010	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	194	194	194	213
		BKT YOY Biomass	MedianTotal Cations	Median ANC	Maximum Cond	Max.ANCme qL	Med Spring ANC	MedianCond
Max.TotalICAIC PCations	Pearson Correlation	-0.190	0.987	0.981	0.978	0.977	0.974	0.974
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000	0.000	0.000
	N	156	213	213	213	213	194	213

Table A.17. Brook trout young-of-year biomass and flow variables

		BKT YOY Biomass	Weighted Median	State # Flow Days > 1000 cfs	State Maximum	Weighted # Flow Days > 1000 cfs	Weighted Maximum
State Median	Pearson Correlation	-0.471	0.928	0.812	0.795	0.756	0.746
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	State Median	Distance Wt Median	Weighted # Flow Days > 1000 cfs	Weighted Maximum	Distance Wt Maximum
Weighted Median	Pearson Correlation	-0.423	0.928	0.901	0.801	0.789	0.755
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted # Flow Days > 1000 cfs	State Maximum	State Median Spring	Weighted Maximum	Weighted Median Spring
State # Flow Days > 1000 cfs	Pearson Correlation	-0.401	0.942	0.927	0.895	0.875	0.849
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	State # Flow Days > 1000 cfs	Weighted Maximum	Distance Wt # Flow Days > 1000 cfs	Weighted Median Spring	State Maximum
Weighted # Flow Days > 1000 cfs	Pearson Correlation	-0.393	0.942	0.920	0.904	0.878	0.877
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted LAG Median	State LAG Maximum	Weighted LAG Maximum	Distance Wt LAG Median	State Median
State LAG Median	Pearson Correlation	-0.386	0.925	0.762	0.707	0.664	0.619
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted Maximum	State # Flow Days > 1000 cfs	State Median Spring	Weighted # Flow Days > 1000 cfs	Weighted Median Spring
State Maximum	Pearson Correlation	-0.383	0.956	0.927	0.909	0.877	0.866
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted # Flow Days < 50 cfs	State Minimum	Weighted Minimum	Distance Wt # Flow Days < 50 cfs	Distance Wt Minimum
State # Flow Days < 50 cfs	Pearson Correlation	0.373	0.944	-0.818	-0.792	0.771	-0.724
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	State Maximum	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Weighted Median Spring	State # Flow Days > 1000 cfs
Weighted Maximum	Pearson Correlation	-0.359	0.956	0.929	0.920	0.891	0.875
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted Median Spring	State Maximum	State # Flow Days > 1000 cfs	Weighted Maximum	Weighted # Flow Days > 1000 cfs
State Median Spring	Pearson Correlation	-0.343	0.965	0.909	0.895	0.858	0.840
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	State LAG Median	Distance Wt LAG Median	Weighted LAG Maximum	Distance Wt LAG Maximum	State LAG Maximum
Weighted LAG Median	Pearson Correlation	-0.339	0.925	0.898	0.759	0.718	0.706
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	State Median Spring	Distance Wt Median Spring	Weighted Maximum	Weighted # Flow Days > 1000 cfs	State Maximum
Weighted Median Spring	Pearson Correlation	-0.324	0.965	0.940	0.891	0.878	0.866
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253

Table A.17. continued

		BKT YOY Biomass	State # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs	Weighted Minimum	Distance Wt Minimum	State Minimum
Weighted # Flow Days < 50 cfs	Pearson Correlation	0.310	0.944	0.938	-0.846	-0.829	-0.825
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Distance Wt Median Spring	Weighted Maximum	Distance Wt Median
Distance Wt # Flow Days > 1000 cfs	Pearson Correlation	-0.275	0.924	0.904	0.876	0.831	0.831
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted Maximum	Distance Wt # Flow Days > 1000 cfs	Distance Wt Median Spring	Weighted # Flow Days > 1000 cfs	Weighted Median Spring
Distance Wt Maximum	Pearson Correlation	-0.270	0.929	0.924	0.885	0.858	0.809
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted Median	Distance Wt # Flow Days > 1000 cfs	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Weighted Maximum
Distance Wt Median	Pearson Correlation	-0.268	0.901	0.831	0.809	0.707	0.695
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted LAG2 Minimum	Distance Wt LAG2 Minimum	State Maximum	Weighted Maximum	State Median Spring
State LAG2 Minimum	Pearson Correlation	-0.254	0.977	0.899	0.748	0.741	0.697
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted Median Spring	Distance Wt Maximum	Distance Wt # Flow Days > 1000 cfs	Weighted Maximum	Weighted # Flow Days > 1000 cfs
Distance Wt Median Spring	Pearson Correlation	-0.254	0.940	0.885	0.876	0.839	0.834
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
		BKT YOY Biomass	Weighted LAG Maximum	State Maximum Spring	Weighted Maximum Spring	State LAG Median	State LAG3 Minimum
State LAG Maximum	Pearson Correlation	-0.244	0.951	0.887	0.841	0.762	0.758
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	241
		BKT YOY Biomass	State LAG2 Minimum	Distance Wt LAG2 Minimum	Weighted Maximum	Distance Wt Maximum	State Maximum
Weighted LAG2 Minimum	Pearson Correlation	-0.243	0.977	0.971	0.748	0.707	0.706
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted Minimum	Distance Wt Minimum	Weighted # Flow Days < 50 cfs	State # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs
State Minimum	Pearson Correlation	-0.233	0.980	0.909	-0.825	-0.818	-0.733
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted LAG2 Minimum	State LAG2 Minimum	Distance Wt Maximum	Weighted Maximum Yearly	Distance Wt # Flow Days > 1000 cfs
Distance Wt LAG2 Minimum	Pearson Correlation	-0.212	0.971	0.899	0.744	0.715	0.663
	Sig. (2-tailed)	0.004	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			State Minimum	Distance Wt Minimum	Weighted # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs	State # Flow Days < 50 cfs
Weighted Minimum	Pearson Correlation	-0.206	0.980	0.974	-0.846	-0.801	-0.792
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253

Table A.17. continued

			Weighted # Flow Days < 50 cfs	Distance Wt Minimum	Weighted Minimum	State # Flow Days < 50 cfs	State Minimum
Distance Wt # Flow Days < 50 cfs	Pearson Correlation	0.200	0.938	-0.839	-0.801	0.771	-0.733
	Sig. (2-tailed)	0.006	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted LAG Median	Distance Wt LAG Maximum	Weighted LAG Maximum	State LAG Median	Distance Wt # Flow Days > 1000 cfs
Distance Wt LAG Median	Pearson Correlation	-0.200	0.898	0.792	0.676	0.664	0.662
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			State LAG Maximum	Distance Wt LAG Maximum	Weighted Maximum Spring	State Maximum Spring	Distance Wt Maximum Spring
Weighted LAG Maximum	Pearson Correlation	-0.197	0.951	0.921	0.866	0.830	0.814
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted Maximum Spring	State LAG Maximum	Weighted LAG Maximum	Distance Wt Maximum Spring	State LAG3 Minimum
State Maximum Spring	Pearson Correlation	-0.185	0.962	0.887	0.830	0.803	0.715
	Sig. (2-tailed)	0.012	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	241
			Weighted Minimum	State Minimum	Distance Wt # Flow Days < 50 cfs	Weighted # Flow Days < 50 cfs	Weighted Median Yearly
Distance Wt Minimum	Pearson Correlation	-0.162	0.974	0.909	-0.839	-0.829	0.643
	Sig. (2-tailed)	0.028	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted LAG4 Minimum	Distance Wt LAG4 Minimum	State Maximum Spring	Weighted Maximum Spring	State LAG Maximum
State LAG4 Minimum	Pearson Correlation	-0.142	0.979	0.907	0.334	0.329	0.318
	Sig. (2-tailed)	0.072	0.000	0.000	0.000	0.000	0.000
	N	162	225	225	225	225	225
			State Maximum Spring	Distance Wt Maximum Spring	Weighted LAG Maximum	State LAG Maximum	Distance Wt LAG Maximum
Weighted Maximum Spring	Pearson Correlation	-0.139	0.962	0.935	0.866	0.841	0.776
	Sig. (2-tailed)	0.059	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253
			Weighted LAG3 Minimum	Distance Wt LAG3 Minimum	State LAG Maximum	Weighted LAG Maximum	State Maximum Spring
State LAG3 Minimum	Pearson Correlation	-0.130	0.977	0.897	0.758	0.746	0.715
	Sig. (2-tailed)	0.086	0.000	0.000	0.000	0.000	0.000
	N	175	241	241	241	241	241
			Weighted LAG Minimum	Distance Wt LAG Minimum	State LAG Median	Weighted LAG Median	State Median Yearly
State LAG Minimum	Pearson Correlation	-0.129	0.978	0.903	0.610	0.593	0.485
	Sig. (2-tailed)	0.082	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253	253

Table A.18. Brook trout young-of-year biomass and watershed characteristics

		BKT YOY Biomass	Undisturbed	Selective cut	Channel slope	Cove hardwood
Average basin slope	Pearson Correlation	-0.593	0.724	-0.686	0.580	0.478
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Average basin slope	Selective cut	Mesic oak	Heavy cut
Undisturbed	Pearson Correlation	-0.504	0.724	-0.642	-0.636	-0.605
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Average basin slope	Undisturbed	Channel slope	Heathbald
Selective cut	Pearson Correlation	0.443	-0.686	-0.642	-0.556	-0.444
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Mixed mesic hardwood	Pine	Xeric oak	Grape thicket
Fish Elevation (ft)	Pearson Correlation	0.401	-0.815	-0.607	-0.586	-0.571
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Undisturbed	Heavy cut	Spruce fir	Cove hardwood
Mesic oak	Pearson Correlation	0.316	-0.636	0.568	-0.491	0.398
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Undisturbed	Mesic oak	Mixed mesic hardwood	Fish Elevation (ft)
Heavy cut	Pearson Correlation	0.300	-0.605	0.568	-0.391	0.340
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Basin Area (sqmi)	Xeric oak	Pine oak	Pine
Stream miles	Pearson Correlation	-0.243	0.993	0.764	0.746	0.740
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Undisturbed	Mesic oak	Fish Elevation (ft)	Selective cut
Spruce fir	Pearson Correlation	-0.285	0.525	-0.491	0.449	-0.433
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Tulip poplar	Fish Elevation (ft)	Grape thicket	Mixed mesic hardwood
Norther hardwood	Pearson Correlation	0.258	-0.570	0.562	-0.495	-0.462
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Stream miles	Xeric oak	Pine	Pine oak
Basin Area (sqmi)	Pearson Correlation	-0.240	0.993	0.736	0.715	0.710
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Average basin slope	Selective cut	Basin Area (sqmi)	Cove hardwood
Channel slope	Pearson Correlation	-0.233	0.580	-0.556	-0.541	0.535
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	184	253	253	253	253

Table A.18. continued

		BKT YOY Biomass	Undisturbed	Norther hardwood	Mesic oak	Stream miles
Light cut	Pearson Correlation	0.201	-0.447	-0.377	0.282	0.254
	Sig. (2-tailed)	0.006	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Xeric oak	Pine	Pine oak	Treeless
Grape thicket	Pearson Correlation	-0.155	0.892	0.777	0.770	0.688
	Sig. (2-tailed)	0.036	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Norther hardwood	Fish Elevation (ft)	Pine	Pine oak
Tulip poplar	Pearson Correlation	-0.129	-0.570	-0.554	0.468	0.462
	Sig. (2-tailed)	0.080	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Pine	Xeric oak	Treeless	Grape thicket
Pine oak	Pearson Correlation	0.122	0.970	0.929	0.809	0.770
	Sig. (2-tailed)	0.099	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Xeric oak	Pine oak	Pine	Stream miles
Treeless	Pearson Correlation	-0.117	0.814	0.809	0.744	0.728
	Sig. (2-tailed)	0.114	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Pine	Pine oak	Grape thicket	Treeless
Xeric oak	Pearson Correlation	0.113	0.933	0.929	0.892	0.814
	Sig. (2-tailed)	0.127	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Selective cut	Channel slope	Pine	Pine oak
Heathbald	Pearson Correlation	-0.108	-0.444	0.379	-0.346	-0.338
	Sig. (2-tailed)	0.145	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Fish Elevation (ft)	Pine	Pine oak	Xeric oak
Mixed mesic hardwood	Pearson Correlation	-0.101	-0.815	0.681	0.635	0.555
	Sig. (2-tailed)	0.172	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Grassybald	Undisturbed	Fish Elevation (ft)	Spruce fir
Settlement	Pearson Correlation	0.077	0.437	-0.365	-0.364	-0.350
	Sig. (2-tailed)	0.300	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Pine oak	Xeric oak	Grape thicket	Treeless
Pine	Pearson Correlation	-0.071	0.970	0.933	0.777	0.744
	Sig. (2-tailed)	0.335	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Pine oak	Pine	Xeric oak	Treeless
Cove hardwood	Pearson Correlation	-0.069	-0.629	-0.624	-0.596	-0.579
	Sig. (2-tailed)	0.355	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Pine	Pine oak	Mixed mesic hardwood	Xeric oak
Grassybald	Pearson Correlation	-0.050	0.594	0.579	0.461	0.456
	Sig. (2-tailed)	0.499	0.000	0.000	0.000	0.000
	N	184	253	253	253	253

Table A.19. Brook trout young-of-year biomass and precipitation

		BKT YOY Biomass	Weighted Precip90	Closest Precip180	Closest Precip30	Weighted Precip180
Closest Precip90	Pearson Correlation	-0.435	0.888	0.878	0.783	0.748
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	176	245	243	245	240
		BKT YOY Biomass	Weighted Precip180	Closest Precip90	Closest Precip365	Closest Precip730
Closest Precip180	Pearson Correlation	-0.421	0.883	0.878	0.838	0.833
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	240	243	243	233
		BKT YOY Biomass	Weighted Precip365	Closest Precip730	Closest Precip180	Weighted Precip730
Closest Precip365	Pearson Correlation	-0.410	0.861	0.853	0.838	0.730
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	235	233	243	222
		BKT YOY Biomass	Closest Precip90	Weighted Precip180	Closest Precip180	Weighted Precip365
Weighted Precip90	Pearson Correlation	-0.391	0.888	0.852	0.779	0.704
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	176	245	240	243	235
		BKT YOY Biomass	Closest Precip180	Weighted Precip730	Weighted Precip90	Weighted Precip365
Weighted Precip180	Pearson Correlation	-0.375	0.883	0.872	0.852	0.851
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	171	240	222	240	235
		BKT YOY Biomass	Weighted Precip730	Closest Precip365	Closest Precip180	Weighted Precip180
Closest Precip730	Pearson Correlation	-0.369	0.856	0.853	0.833	0.736
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	222	233	233	233
		BKT YOY Biomass	Closest Precip365	Weighted Precip730	Weighted Precip180	Closest Precip180
Weighted Precip365	Pearson Correlation	-0.370	0.861	0.860	0.851	0.748
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	169	235	222	235	235
		BKT YOY Biomass	Weighted Precip30	Closest Precip90	Closest Precip180	Weighted Precip90
Closest Precip30	Pearson Correlation	-0.321	0.866	0.783	0.614	0.576
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	176	245	245	243	245
		BKT YOY Biomass	Closest Precip30	Closest Precip90	Weighted Precip90	Closest Precip180
Weighted Precip30	Pearson Correlation	-0.309	0.866	0.693	0.677	0.578
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	176	245	245	245	243
		BKT YOY Biomass	Weighted Precip180	Weighted Precip365	Closest Precip730	Closest Precip180
Weighted Precip730	Pearson Correlation	-0.304	0.872	0.860	0.856	0.747
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	159	222	222	222	222
		BKT YOY Biomass	Weighted Precip7	Weighted Precip30	Closest Precip180	Closest Precip730
Closest Precip7	Pearson Correlation	-0.102	0.929	0.286	0.208	0.197
	Sig. (2-tailed)	0.180	0.000	0.000	0.001	0.003
	N	176	245	245	243	233
		BKT YOY Biomass	Closest Precip7	Weighted Precip30	Weighted Precip180	Weighted Precip90
Weighted Precip7	Pearson Correlation	-0.093	0.929	0.276	0.150	0.135
	Sig. (2-tailed)	0.221	0.000	0.000	0.020	0.035
	N	176	245	245	240	245

Table A.20. Brook trout young-of-year biomass and geology

		BKT YOY Biomass	Anakeesta	Elkmont sandstone	Cades sandstone	Metcalf phyllite
Thunderhead sandstone	Pearson Correlation	0.266	-0.613	-0.428	-0.357	-0.356
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone	Metcalf phyllite
Anakeesta	Pearson Correlation	-0.248	-0.613	-0.285	-0.234	-0.233
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Thunderhead sandstone	Great Smoky Group	Elkmont sandstone	Metcalf phyllite
Metadiorite	Pearson Correlation	-0.137	0.146	-0.091	-0.084	-0.069
	Sig. (2-tailed)	0.065	0.020	0.149	0.185	0.277
	N	184	253	253	253	253
		BKT YOY Biomass	Unnamed sandstone	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone
Great Smoky Group	Pearson Correlation	-0.098	0.892	-0.343	-0.138	-0.136
	Sig. (2-tailed)	0.187	0.000	0.000	0.029	0.031
	N	184	253	253	253	253
		BKT YOY Biomass	Pigeon siltstone	Roaringfork sandstone	Thunderhead sandstone	Anakeesta
Richbutt sandstone	Pearson Correlation	0.058	0.338	0.211	0.179	-0.174
	Sig. (2-tailed)	0.431	0.000	0.001	0.004	0.005
	N	184	253	253	253	253
		BKT YOY Biomass	Great Smoky Group	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone
Unnamed sandstone	Pearson Correlation	-0.041	0.892	-0.297	-0.110	-0.091
	Sig. (2-tailed)	0.584	0.000	0.000	0.080	0.150
	N	184	253	253	253	253
		BKT YOY Biomass	Richbutt sandstone	Thunderhead sandstone	Anakeesta	Great Smoky Group
Pigeon siltstone	Pearson Correlation	-0.035	0.338	0.302	-0.234	-0.138
	Sig. (2-tailed)	0.636	0.000	0.000	0.000	0.029
	N	184	253	253	253	253
		BKT YOY Biomass	Basement complex	Longarm quartzite	Anakeesta	Richbutt sandstone
Roaringfork sandstone	Pearson Correlation	0.006	0.962	0.781	-0.231	0.211
	Sig. (2-tailed)	0.936	0.000	0.000	0.000	0.001
	N	184	253	253	253	253
		BKT YOY Biomass	Roaringfork sandstone	Longarm quartzite	Anakeesta	Great Smoky Group
Basement complex	Pearson Correlation	0.001	0.962	0.649	-0.178	-0.105
	Sig. (2-tailed)	0.993	0.000	0.000	0.004	0.096
	N	184	253	253	253	253
		BKT YOY Biomass	Roaringfork sandstone	Basement complex	Anakeesta	Richbutt sandstone
Longarm quartzite	Pearson Correlation	0.001	0.781	0.649	-0.186	0.148
	Sig. (2-tailed)	0.993	0.000	0.000	0.003	0.018
	N	184	253	253	253	253
		BKT YOY Biomass	Metcalf phyllite	Limestone	Elkmont sandstone	Thunderhead sandstone
Cades sandstone	Pearson Correlation	.(a)	0.900	0.696	0.578	-0.357
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253

Table A.20. continued

		BKT YOY Biomass	Limestone	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Metcalf phyllite	Pearson Correlation	.(a)	0.930	0.900	0.536	-0.356
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Cades sandstone	Metcalf phyllite	Thunderhead sandstone	Limestone
Elkmont sandstone	Pearson Correlation	.(a)	0.578	0.536	-0.428	0.312
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Metcalf phyllite	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Limestone	Pearson Correlation	.(a)	0.930	0.696	0.312	-0.266
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	184	253	253	253	253
		BKT YOY Biomass	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone	Richbutt sandstone
Wadingbranch formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.
	N	184	253	253	253	253

Table A.21. Brook trout adult biomass and water chemistry

		BKT ADT Biomass	Median Sulfate	LAG Med Anions	Minimum Sulfate	Med Spring Sulfate	Median Anions
LAG Median Sulfate	Pearson Correlation	-0.451	0.977	0.956	0.953	0.944	0.936
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	213	218	213	198	213
		BKT ADT Biomass	Minimum Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Min Spring Anions
Min Spring Sulfate	Pearson Correlation	-0.450	0.981	0.976	0.958	0.933	0.931
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	198	218
		BKT ADT Biomass	Min Spring Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Anions	LAG Median Sulfate
Med Spring Sulfate	Pearson Correlation	-0.449	0.976	0.976	0.967	0.949	0.944
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	194	218	198
		BKT ADT Biomass	Min Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Median Anions
Minimum Sulfate	Pearson Correlation	-0.443	0.981	0.967	0.966	0.953	0.940
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	213
		BKT ADT Biomass	LAG Median Sulfate	Med Spring Sulfate	Minimum Sulfate	Median Anions	Min Spring Sulfate
Median Sulfate	Pearson Correlation	-0.440	0.977	0.976	0.966	0.962	0.958
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	194	213	213	194
		BKT ADT Biomass	Median Sulfate	Max Spring Anions	Minimum Sulfate	Median Anions	Maximum Sulfate
Max Spring Sulfate	Pearson Correlation	-0.418	0.955	0.936	0.921	0.918	0.916
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	194	194
		BKT ADT Biomass	Median Potassium	LAG Med Sodium	Minimum Potassium	Min Spring Potassium	Median Sodium
LAG Med Potassium	Pearson Correlation	0.416	0.885	0.827	0.809	0.745	0.742
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	213	218	213	198	213
		BKT ADT Biomass	Maximum Anions	Max Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate
Maximum Sulfate	Pearson Correlation	-0.413	0.920	0.916	0.904	0.895	0.881
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	194	194	213	213
		BKT ADT Biomass	Median Potassium	Min Spring Potassium	Minimum Potassium	Maximum Potassium	LAG Med Potassium
Med Spring Potassium	Pearson Correlation	0.407	0.887	0.879	0.792	0.772	0.739
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	194	198
		BKT ADT Biomass	Med Spring Potassium	LAG Med Potassium	Min Spring Potassium	Minimum Potassium	Median Sodium
Median Potassium	Pearson Correlation	0.380	0.887	0.885	0.878	0.864	0.780
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	213	194	213	213
		BKT ADT Biomass	Minimum Potassium	Med Spring Potassium	Median Potassium	Min Spring Sodium	LAG Med Potassium
Min Spring Potassium	Pearson Correlation	0.379	0.881	0.879	0.878	0.753	0.745
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	218	198
		BKT ADT Biomass	Min Spring pH	Med Spring pH	Median pH	LAG Median pH	Max Spring pH
Min.pH	Pearson Correlation	0.369	0.915	0.900	0.875	0.863	0.857
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	194

Table A.21. continued

		BKT ADT Biomass	Med Spring pH	Max Spring pH	Median pH	Min.pH	LAG Median pH
Min Spring pH	Pearson Correlation	0.366	0.980	0.921	0.917	0.915	0.855
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	194	194	198
		BKT ADT Biomass	Med Spring Sodium	Maximum Sodium	Median Sodium	Min Spring Sodium	Med Spring Potassium
Max Spring Sodium	Pearson Correlation	0.360	0.919	0.820	0.808	0.753	0.705
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	194	218	218
		BKT ADT Biomass	Min Spring pH	Max Spring pH	Median pH	Min.pH	LAG Median pH
Med Spring pH	Pearson Correlation	0.345	0.980	0.971	0.953	0.900	0.882
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	194	194	198
		BKT ADT Biomass	Min Spring Anions	Median Anions	Med Spring Sulfate	Minimum Anions	Min Spring Sulfate
Med Spring Anions	Pearson Correlation	-0.343	0.959	0.950	0.949	0.935	0.930
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	218	194	218
		BKT ADT Biomass	Max Spring Potassium	Med Spring Potassium	Median Potassium	LAG Med Potassium	Maximum Sodium
Maximum Potassium	Pearson Correlation	0.342	0.786	0.772	0.726	0.671	0.648
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	213
		BKT ADT Biomass	Maximum Potassium	Median Potassium	Med Spring Potassium	Minimum Potassium	LAG Med Potassium
Max Spring Potassium	Pearson Correlation	0.340	0.786	0.764	0.666	0.639	0.628
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	194	218	194	198
		BKT ADT Biomass	Minimum ANC	Med Spring ANC	Median ANC	Min.TotalICAAIC PCations	MinSpringTotal Cations
Min Spring ANC	Pearson Correlation	0.337	0.998	0.990	0.971	0.965	0.961
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	194	218
		BKT ADT Biomass	Min Spring ANC	Med Spring ANC	Min.TotalICAAI CPCations	MinSpringTotalCa tions	MedSpringTotal Cations
Minimum ANC	Pearson Correlation	0.337	0.998	0.989	0.970	0.961	0.959
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	194	194
		BKT ADT Biomass	Median Anions	LAG Median Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Sulfate
LAG Med Anions	Pearson Correlation	-0.332	0.968	0.956	0.941	0.920	0.912
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	213	218	213	213	198
		BKT ADT Biomass	Median pH	Max.pH	Max Spring pH	Med Spring pH	Min.pH
LAG Median pH	Pearson Correlation	0.331	0.942	0.892	0.884	0.882	0.863
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	213	213	198	198	213
		BKT ADT Biomass	Minimum Anions	Med Spring Anions	Min Spring Sulfate	Minimum Sulfate	Med Spring Sulfate
Min Spring Anions	Pearson Correlation	-0.329	0.962	0.959	0.931	0.914	0.904
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	218	194	218
		BKT ADT Biomass	Max Spring Sulfate	Median Anions	Med Spring Anions	Maximum Anions	Median Sulfate
Max Spring Anions	Pearson Correlation	-0.329	0.936	0.929	0.921	0.917	0.898
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	218	194	194
		BKT ADT Biomass	LAG Med Anions	Median Sulfate	Med Spring Anions	Med Spring Sulfate	Minimum Sulfate
Median Anions	Pearson Correlation	-0.321	0.968	0.962	0.950	0.944	0.940
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	213	194	194	213

Table A.21. continued

		BKT ADT Biomass	LAGMedTotalCations	LAG Med ANC	Maximum Cond	Max.TotalICAAIC PCations	Min Spring Cond
LAG Median Cond	Pearson Correlation	-0.318	0.971	0.970	0.940	0.927	0.926
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	213	213	198
		BKT ADT Biomass	Min Spring Sodium	Max Spring Sodium	Median Sodium	Minimum Sodium	Maximum Sodium
Med Spring Sodium	Pearson Correlation	0.316	0.933	0.919	0.902	0.870	0.822
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	194	194	194
		BKT ADT Biomass	Min Spring Potassium	Median Potassium	LAG Med Potassium	Minimum Sodium	Med Spring Potassium
Minimum Potassium	Pearson Correlation	0.314	0.881	0.864	0.809	0.797	0.792
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	213	213	213	194
		BKT ADT Biomass	Min Spring Cond	MedSpringTotalCations	MaxSpringTotalCations	MinSpringTotalCations	Min.TotalICAAIC PCations
Med Spring Cond	Pearson Correlation	-0.312	0.980	0.975	0.970	0.969	0.968
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	218	218	194
		BKT ADT Biomass	Minimum Sodium	Med Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Potassium
Min Spring Sodium	Pearson Correlation	0.310	0.947	0.933	0.887	0.765	0.753
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	194	218	194	198	218
		BKT ADT Biomass	Min Spring ANC	Minimum ANC	Median ANC	Max.TotalICAAIC PCations	MedSpringTotalCations
Med Spring ANC	Pearson Correlation	0.310	0.990	0.989	0.979	0.974	0.971
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	194	194	218
		BKT ADT Biomass	Min Spring Sodium	Median Sodium	Med Spring Sodium	LAG Med Sodium	Minimum Potassium
Minimum Sodium	Pearson Correlation	0.310	0.947	0.883	0.870	0.843	0.797
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	213	194	213	213
		BKT ADT Biomass	Max Spring ANC	MedianCond	Med Spring Cond	MedianTotalCations	Max.TotalICAAIC PCations
Max Spring Cond	Pearson Correlation	-0.309	0.966	0.960	0.952	0.952	0.952
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	218	194	194
		BKT ADT Biomass	Maximum Cond	Max.TotalICAAIC PCations	MedianTotalCations	Median ANC	Max Spring Cond
MedianCond	Pearson Correlation	-0.309	0.976	0.974	0.972	0.972	0.960
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	213	213	213	194
		BKT ADT Biomass	Med Spring pH	Median pH	Min Spring pH	Max.pH	LAG Median pH
Max Spring pH	Pearson Correlation	0.307	0.971	0.952	0.921	0.890	0.884
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	218	194	198
		BKT ADT Biomass	Maximum Sulfate	Max Spring Anions	Med Spring Anions	Max Spring Sulfate	Median Anions
Maximum Anions	Pearson Correlation	-0.299	0.920	0.917	0.881	0.869	0.867
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	194	194	194	213
		BKT ADT Biomass	Med Spring Cond	MinSpringTotalCations	Min.TotalICAAIC PCations	Minimum Cond	MedSpringTotalCations
Min Spring Cond	Pearson Correlation	-0.298	0.980	0.959	0.957	0.953	0.951
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	194	194	218
		BKT ADT Biomass	Med Spring Sodium	Min Spring Sodium	Minimum Sodium	LAG Med Sodium	Maximum Sodium
Median Sodium	Pearson Correlation	0.294	0.902	0.887	0.883	0.866	0.819
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	213

Table A.21. continued

		BKT ADT Biomass	Min Spring Anions	Med Spring Anions	Minimum Sulfate	Min Spring Sulfate	Median Anions
Minimum Anions	Pearson Correlation	-0.294	0.962	0.935	0.919	0.912	0.911
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	194	213
		BKT ADT Biomass	Max.TotalICAAI CPCations	MedianCond	Max.ANCmeqL	Median ANC	MedianTotalCations
Maximum Cond	Pearson Correlation	-0.286	0.978	0.976	0.973	0.969	0.967
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	159	213	213	213	213	213
		BKT ADT Biomass	Max Spring Cond	Median ANC	Med Spring ANC	Max.ANCmeqL	Max.TotalICAAI CPCations
Max Spring ANC	Pearson Correlation	0.284	0.966	0.965	0.960	0.960	0.959
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	218	194	218	194	194
		BKT ADT Biomass	Median Sodium	Minimum Sodium	LAG Med Potassium	Min Spring Sodium	LAG Median pH
LAG Med Sodium	Pearson Correlation	0.271	0.866	0.843	0.827	0.765	0.762
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	163	213	213	218	198	218
		BKT ADT Biomass	Med Spring pH	Max Spring pH	LAG Median pH	Max.pH	Min Spring pH
Median pH	Pearson Correlation	0.270	0.953	0.952	0.942	0.924	0.917
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	194
		BKT ADT Biomass	LAGMedTotalCations	LAG Median Cond	Max.ANCmeqL	Median ANC	Max.TotalICAAI CPCations
LAG Med ANC	Pearson Correlation	0.261	0.977	0.970	0.958	0.955	0.951
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000	0.000
	N	163	218	218	213	213	213
		BKT ADT Biomass	Median pH	LAG Median pH	Max Spring pH	Med Spring pH	Min Spring pH
Max.pH	Pearson Correlation	0.237	0.924	0.892	0.890	0.877	0.842
	Sig. (2-tailed)	0.003	0.000	0.000	0.000	0.000	0.000
	N	159	213	213	194	194	194
		BKT ADT Biomass	Max.ANCmeqL	Max.TotalICAAI CPCations	Med Spring ANC	MedianTotalCations	MedianCond
Median ANC	Pearson Correlation	0.219	0.983	0.981	0.979	0.977	0.972
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000	0.000
	N	159	213	213	194	213	213
		BKT ADT Biomass	Min Spring Cond	Min.TotalICAAI CPCations	Minimum ANC	Med Spring Cond	MinSpringTotalCations
Minimum Cond	Pearson Correlation	-0.214	0.953	0.908	0.899	0.897	0.893
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000	0.000
	N	159	194	213	213	194	194
		BKT ADT Biomass	Med Spring Sodium	Max Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Sodium
Maximum Sodium	Pearson Correlation	0.204	0.822	0.820	0.819	0.737	0.732
	Sig. (2-tailed)	0.010	0.000	0.000	0.000	0.000	0.000
	N	159	194	194	213	213	194
		BKT ADT Biomass	MedSpringAmmonium	Max.Ammonium meqL	MedianAmmonium	MinSpringAmmonium	MaxSpringChloride
Max Spring Ammonium	Pearson Correlation	0.163	0.842	0.742	0.290	0.244	0.193
	Sig. (2-tailed)	0.038	0.000	0.000	0.000	0.000	0.004
	N	163	218	194	194	218	218

Table A.22. Brook trout adult biomass and flow variables

		BKT ADT Biomass	Weighted Median Yearly	State # Flow Days > 1000 cfs	State Maximum Yearly	Weighted # Flow Days > 1000 cfs
State Median Yearly	Pearson Correlation	-0.315	0.928	0.812	0.795	0.756
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted # Flow Days < 50 cfs	State Minimum	Weighted Minimum	Distance Wt # Flow Days < 50 cfs
State # Flow Days < 50 cfs	Pearson Correlation	0.297	0.944	-0.818	-0.792	0.771
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State Median Yearly	Distance Wt Median	Weighted # Flow Days > 1000 cfs	Weighted Maximum Yearly
Weighted Median Yearly	Pearson Correlation	-0.279	0.928	0.901	0.801	0.789
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State # Flow Days > 1000 cfs	Weighted Maximum Yearly	Distance Wt # Flow Days > 1000 cfs	Weighted Spring
Weighted # Flow Days > 1000 cfs	Pearson Correlation	-0.275	0.942	0.920	0.904	0.878
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted # Flow Days > 1000 cfs	State Maximum Yearly	State Median Spring	Weighted Maximum Yearly
State # Flow Days > 1000 cfs	Pearson Correlation	-0.274	0.942	0.927	0.895	0.875
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted LAG Median	State LAG Maximum	Weighted LAG Maximum	Distance Wt LAG Median
State LAG Median	Pearson Correlation	-0.262	0.925	0.762	0.707	0.664
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs	Weighted Minimum	Distance Wt Minimum
Weighted # Flow Days < 50 cfs	Pearson Correlation	0.261	0.944	0.938	-0.846	-0.829
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Maximum Yearly	State # Flow Days > 1000 cfs	State Median Spring	Weighted # Flow Days > 1000 cfs
State Maximum Yearly	Pearson Correlation	-0.248	0.956	0.927	0.909	0.877
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Spring	State Maximum Yearly	State # Flow Days > 1000 cfs	Weighted Maximum Yearly
State Median Spring	Pearson Correlation	-0.233	0.965	0.909	0.895	0.858
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State Maximum Yearly	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Weighted Spring
Weighted Maximum Yearly	Pearson Correlation	-0.229	0.956	0.929	0.920	0.891
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State Median Spring	Distance Wt Spring	Weighted Maximum Yearly	Weighted # Flow Days > 1000 cfs
Weighted Spring	Pearson Correlation	-0.222	0.965	0.940	0.891	0.878
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State LAG Median	Distance Wt LAG Median	Weighted LAG Maximum	Distance Wt LAG Maximum
Weighted LAG Median	Pearson Correlation	-0.217	0.925	0.898	0.759	0.718
	Sig. (2-tailed)	0.003	0.000	0.000	0.000	0.000
	N	187	253	253	253	253

Table A.22. continued

		BKT ADT Biomass	Weighted # Flow Days < 50 cfs	Distance Wt Minimum	Weighted Minimum	State # Flow Days < 50 cfs
Distance Wt # Flow Days < 50 cfs	Pearson Correlation	0.185	0.938	-0.839	-0.801	0.771
	Sig. (2-tailed)	0.011	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Distance Wt Spring	Weighted Maximum Yearly
Distance Wt # Flow Days > 1000 cfs	Pearson Correlation	-0.182	0.924	0.904	0.876	0.831
	Sig. (2-tailed)	0.013	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Spring	Distance Wt Maximum	Distance Wt # Flow Days > 1000 cfs	Weighted Maximum Yearly
Distance Wt Spring	Pearson Correlation	-0.180	0.940	0.885	0.876	0.839
	Sig. (2-tailed)	0.014	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Median Yearly	Distance Wt # Flow Days > 1000 cfs	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs
Distance Wt Median	Pearson Correlation	-0.172	0.901	0.831	0.809	0.707
	Sig. (2-tailed)	0.019	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Maximum Yearly	Distance Wt # Flow Days > 1000 cfs	Distance Wt Spring	Weighted # Flow Days > 1000 cfs
Distance Wt Maximum	Pearson Correlation	-0.169	0.929	0.924	0.885	0.858
	Sig. (2-tailed)	0.021	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Minimum	Distance Wt Minimum	Weighted # Flow Days < 50 cfs	State # Flow Days < 50 cfs
State Minimum	Pearson Correlation	-0.166	0.980	0.909	-0.825	-0.818
	Sig. (2-tailed)	0.023	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted LAG Maximum	State Maximum Spring	Weighted Maximum Spring	State LAG Median
State LAG Maximum	Pearson Correlation	-0.166	0.951	0.887	0.841	0.762
	Sig. (2-tailed)	0.024	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Maximum Spring	State LAG Maximum	Weighted LAG Maximum	Distance Wt Maximum Spring
State Maximum Spring	Pearson Correlation	-0.164	0.962	0.887	0.830	0.803
	Sig. (2-tailed)	0.025	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State Minimum	Distance Wt Minimum	Weighted # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs
Weighted Minimum	Pearson Correlation	-0.150	0.980	0.974	-0.846	-0.801
	Sig. (2-tailed)	0.041	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State Maximum Spring	Distance Wt Maximum Spring	Weighted LAG Maximum	State LAG Maximum
Weighted Maximum Spring	Pearson Correlation	-0.145	0.962	0.935	0.866	0.841
	Sig. (2-tailed)	0.048	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	State LAG Maximum	Distance Wt LAG Maximum	Weighted Maximum Spring	State Maximum Spring
Weighted LAG Maximum	Pearson Correlation	-0.131	0.951	0.921	0.866	0.830
	Sig. (2-tailed)	0.074	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Weighted Minimum	State Minimum	Distance Wt # Flow Days < 50 cfs	Weighted # Flow Days < 50 cfs
Distance Wt Minimum	Pearson Correlation	-0.121	0.974	0.909	-0.839	-0.829
	Sig. (2-tailed)	0.099	0.000	0.000	0.000	0.000
	N	187	253	253	253	253

Table A.23. Brook trout adult and watershed characteristics

		BKT ADT Biomass	Undisturbed	Selective cut	Channel slope	Cove hardwood
Average basin slope	Pearson Correlation	-0.597	0.724	-0.686	0.580	0.478
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Average basin slope	Selective cut	Mesic oak	Heavy cut
Undisturbed	Pearson Correlation	-0.487	0.724	-0.642	-0.636	-0.605
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Mixed mesic hardwood	Pine	Xericoak	Grape thicket
Fish Elevation (ft)	Pearson Correlation	0.410	-0.815	-0.607	-0.586	-0.571
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Undisturbed	Mesic oak	Mixed mesic hardwood	Fish Elevation (ft)
Heavy cut	Pearson Correlation	0.382	-0.605	0.568	-0.391	0.340
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Average basin slope	Undisturbed	Channel slope	Heathbald
Selective cut	Pearson Correlation	0.375	-0.686	-0.642	-0.556	-0.444
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Tulip poplar	Fish Elevation (ft)	Grape thicket	Mixed mesic hardwood
Norther hardwood	Pearson Correlation	0.357	-0.570	0.562	-0.495	-0.462
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Undisturbed	Mesic oak	Fish Elevation (ft)	Selective cut
Spruce fir	Pearson Correlation	-0.312	0.525	-0.491	0.449	-0.433
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Norther hardwood	Fish Elevation (ft)	Pine	Pine oak
Tulip poplar	Pearson Correlation	-0.296	-0.570	-0.554	0.468	0.462
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Stream miles	Xericoak	Pine	Pine oak
Basin Area (sqmi)	Pearson Correlation	-0.258	0.993	0.736	0.715	0.710
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Undisturbed	Heavy cut	Spruce fir	Cove hardwood
Mesic oak	Pearson Correlation	0.253	-0.636	0.568	-0.491	0.398
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Basin Area (sqmi)	Xericoak	Pine oak	Pine
Stream miles	Pearson Correlation	-0.245	0.993	0.764	0.746	0.740
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Grassybald	Undisturbed	Fish Elevation (ft)	Spruce fir
Settlement	Pearson Correlation	0.210	0.437	-0.365	-0.364	-0.350
	Sig. (2-tailed)	0.004	0.000	0.000	0.000	0.000
	N	187	253	253	253	253

Table A.23. continued

		BKT ADT Biomass	Xericoak	Pine	Pine oak	Treeless
Grape thicket	Pearson Correlation	-0.205	0.892	0.777	0.770	0.688
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Xericoak	Pine oak	Pine	Stream miles
Treeless	Pearson Correlation	-0.205	0.814	0.809	0.744	0.728
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Pine	Xericoak	Treeless	Grape thicket
Pine oak	Pearson Correlation	0.167	0.970	0.929	0.809	0.770
	Sig. (2-tailed)	0.023	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Selective cut	Channel slope	Pine	Pine oak
Heathbald	Pearson Correlation	-0.147	-0.444	0.379	-0.346	-0.338
	Sig. (2-tailed)	0.044	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Pine	Pine oak	Mixed mesic hardwood	Xericoak
Grassybald	Pearson Correlation	0.146	0.594	0.579	0.461	0.456
	Sig. (2-tailed)	0.046	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Pine oak	Xericoak	Grape thicket	Treeless
Pine	Pearson Correlation	-0.140	0.970	0.933	0.777	0.744
	Sig. (2-tailed)	0.056	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Fish Elevation (ft)	Pine	Pine oak	Xericoak
Mixed mesic hardwood	Pearson Correlation	-0.131	-0.815	0.681	0.635	0.555
	Sig. (2-tailed)	0.074	0.000	0.000	0.000	0.000
	N	187	253	253	253	253
		BKT ADT Biomass	Average basin slope	Selective cut	Basin Area (sqmi)	Cove hardwood
Channel slope	Pearson Correlation	-0.120	0.580	-0.556	-0.541	0.535
	Sig. (2-tailed)	0.102	0.000	0.000	0.000	0.000
	N	187	253	253	253	253

Table A.24. Brook trout adult biomass and precipitation

		BKT ADT Biomass	Weighted Precip90	Closest Precip180	Closest Precip30	Weighted Precip180
Closest Precip90	Pearson Correlation	-0.362	0.888	0.878	0.783	0.748
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	179	245	243	245	240
		BKT ADT Biomass	Closest Precip90	Weighted Precip180	Closest Precip180	Weighted Precip365
Weighted Precip90	Pearson Correlation	-0.338	0.888	0.852	0.779	0.704
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	179	245	240	243	235
		BKT ADT Biomass	Closest Precip30	Closest Precip90	Weighted Precip90	Closest Precip180
Weighted Precip30	Pearson Correlation	-0.312	0.866	0.693	0.677	0.578
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	179	245	245	245	243
		BKT ADT Biomass	Weighted Precip30	Closest Precip90	Closest Precip180	Weighted Precip90
Closest Precip30	Pearson Correlation	-0.310	0.866	0.783	0.614	0.576
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	179	245	245	243	245
		BKT ADT Biomass	Weighted Precip180	Closest Precip90	Closest Precip365	Closest Precip730
Closest Precip180	Pearson Correlation	-0.310	0.883	0.878	0.838	0.833
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	177	240	243	243	233
		BKT ADT Biomass	Weighted Precip365	Closest Precip730	Closest Precip180	Weighted Precip730
Closest Precip365	Pearson Correlation	-0.267	0.861	0.853	0.838	0.730
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	177	235	233	243	222
		BKT ADT Biomass	Closest Precip180	Weighted Precip730	Weighted Precip90	Weighted Precip365
Weighted Precip180	Pearson Correlation	-0.251	0.883	0.872	0.852	0.851
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	174	240	222	240	235
		BKT ADT Biomass	Weighted Precip730	Closest Precip365	Closest Precip180	Weighted Precip180
Closest Precip730	Pearson Correlation	-0.247	0.856	0.853	0.833	0.736
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	170	222	233	233	233
		BKT ADT Biomass	Closest Precip365	Weighted Precip730	Weighted Precip180	Closest Precip180
Weighted Precip365	Pearson Correlation	-0.181	0.861	0.860	0.851	0.748
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000
	N	172	235	222	235	235
		BKT ADT Biomass	Weighted Precip180	Weighted Precip365	Closest Precip730	Closest Precip180
Weighted Precip730	Pearson Correlation	-0.172	0.872	0.860	0.856	0.747
	Sig. (2-tailed)	0.028	0.000	0.000	0.000	0.000
	N	162	222	222	222	222
		BKT ADT Biomass	Closest Precip7	Weighted Precip30	Weighted Precip180	Weighted Precip90
Weighted Precip7	Pearson Correlation	-0.160	0.929	0.276	0.150	0.135
	Sig. (2-tailed)	0.032	0.000	0.000	0.020	0.035
	N	179	245	245	240	245
		BKT ADT Biomass	Weighted Precip7	Weighted Precip30	Closest Precip180	Closest Precip730
Closest Precip7	Pearson Correlation	-0.153	0.929	0.286	0.208	0.197
	Sig. (2-tailed)	0.041	0.000	0.000	0.001	0.003
	N	179	245	245	243	233

Table A.25. Brook trout adult biomass and geology

		BKT ADT Biomass	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone	Metcalf phyllite	Cades sandstone
Anakeesta	Pearson Correlation	-0.392	-0.613	-0.285	-0.234	-0.233	-0.233
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253	253
		BKT ADT Biomass	Anakeesta	Elkmont sandstone	Cades sandstone	Metcalf phyllite	Great Smoky Group
Thunderhead sandstone	Pearson Correlation	0.361	-0.613	-0.428	-0.357	-0.356	-0.343
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253	253
		BKT ADT Biomass	Thunderhead sandstone	Great Smoky Group	Elkmont sandstone	Metcalf phyllite	Pigeon siltstone
Metadiorite	Pearson Correlation	-0.151	0.146	-0.091	-0.084	-0.069	-0.069
	Sig. (2-tailed)	0.039	0.020	0.149	0.185	0.277	0.276
	N	187	253	253	253	253	253
		BKT ADT Biomass	Great Smoky Group	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone	Cades sandstone
Unnamed sandstone	Pearson Correlation	0.129	0.892	-0.297	-0.110	-0.091	-0.090
	Sig. (2-tailed)	0.080	0.000	0.000	0.080	0.150	0.152
	N	187	253	253	253	253	253
		BKT ADT Biomass	Basement complex	Longarm quartzite	Anakeesta	Richbutt sandstone	Great Smoky Group
Roaringfork sandstone	Pearson Correlation	-0.101	0.962	0.781	-0.231	0.211	-0.136
	Sig. (2-tailed)	0.167	0.000	0.000	0.000	0.001	0.031
	N	187	253	253	253	253	253
		BKT ADT Biomass	Roaringfork sandstone	Longarm quartzite	Anakeesta	Great Smoky Group	Elkmont sandstone
Basement complex	Pearson Correlation	-0.101	0.962	0.649	-0.178	-0.105	-0.096
	Sig. (2-tailed)	0.168	0.000	0.000	0.004	0.096	0.127
	N	187	253	253	253	253	253
		BKT ADT Biomass	Roaringfork sandstone	Basement complex	Anakeesta	Richbutt sandstone	Great Smoky Group
Longarm quartzite	Pearson Correlation	-0.101	0.781	0.649	-0.186	0.148	-0.110
	Sig. (2-tailed)	0.168	0.000	0.000	0.003	0.018	0.082
	N	187	253	253	253	253	253
		BKT ADT Biomass	Richbutt sandstone	Thunderhead sandstone	Anakeesta	Great Smoky Group	Elkmont sandstone
Pigeon siltstone	Pearson Correlation	-0.080	0.338	0.302	-0.234	-0.138	-0.126
	Sig. (2-tailed)	0.279	0.000	0.000	0.000	0.029	0.045
	N	187	253	253	253	253	253
		BKT ADT Biomass	Unnamed sandstone	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone	Longarm quartzite
Great Smoky Group	Pearson Correlation	0.078	0.892	-0.343	-0.138	-0.136	-0.110
	Sig. (2-tailed)	0.290	0.000	0.000	0.029	0.031	0.082
	N	187	253	253	253	253	253
		BKT ADT Biomass	Pigeon siltstone	Roaringfork sandstone	Thunderhead sandstone	Anakeesta	Longarm quartzite
Richbutt sandstone	Pearson Correlation	0.032	0.338	0.211	0.179	-0.174	0.148
	Sig. (2-tailed)	0.661	0.000	0.001	0.004	0.005	0.018
	N	187	253	253	253	253	253

Table A.25. continued

		BKT ADT Biomass	Metcalf phyllite	Cades sandstone	Elkmont sandstone	Thunderhead sandstone	Anakeesta
Limestone	Pearson Correlation	.(a)	0.930	0.696	0.312	-0.266	-0.175
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.005
	N	187	253	253	253	253	253
		BKT ADT Biomass	Metcalf phyllite	Limestone	Elkmont sandstone	Thunderhead sandstone	Anakeesta
Cades sandstone	Pearson Correlation	.(a)	0.900	0.696	0.578	-0.357	-0.233
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253	253
		BKT ADT Biomass	Limestone	Cades sandstone	Elkmont sandstone	Thunderhead sandstone	Anakeesta
Metcalf phyllite	Pearson Correlation	.(a)	0.930	0.900	0.536	-0.356	-0.233
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253	253
		BKT ADT Biomass	Cades sandstone	Metcalf phyllite	Thunderhead sandstone	Limestone	Anakeesta
Elkmont sandstone	Pearson Correlation	.(a)	0.578	0.536	-0.428	0.312	-0.285
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	187	253	253	253	253	253
		BKT ADT Biomass	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone	Richbutt sandstone	Limestone
Wadingbranch formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.
	N	187	253	253	253	253	253

Table A.26. Rainbow trout young-of-year biomass and water chemistry

		RBT YOY Biomass	Minimum Spring Total Cations	Median Spring Total Cations	Maximum Spring Total Cations	Med Spring ANC
Minimum Total Cations	Pearson Correlation	0.767	0.994	0.987	0.973	0.970
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	194	194
		RBT YOY Biomass	Min Spring ANC	Med Spring ANC	Minimum Total Cations	Minimum Spring Total Cations
Minimum ANC	Pearson Correlation	0.765	0.998	0.989	0.970	0.961
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	194
		RBT YOY Biomass	Minimum Spring Total Cations	Maximum Spring Total Cations	Minimum Total Cations	Med Spring Cond
Median Spring Total Cations	Pearson Correlation	0.752	0.990	0.990	0.987	0.975
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	218
		RBT YOY Biomass	Minimum ANC	Med Spring ANC	Median ANC	Minimum Total Cations
Min Spring ANC	Pearson Correlation	0.750	0.998	0.990	0.971	0.965
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	194	194
		RBT YOY Biomass	Median Spring Total Cations	Minimum Total Cations	Minimum Spring Total Cations	Med Spring Cond
Maximum Spring Total Cations	Pearson Correlation	0.743	0.990	0.973	0.972	0.970
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	218	218
		RBT YOY Biomass	Minimum Total Cations	Median Spring Total Cations	Maximum Spring Total Cations	Med Spring Cond
Minimum Spring Total Cations	Pearson Correlation	0.742	0.994	0.990	0.972	0.969
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	218	218
		RBT YOY Biomass	Min Spring ANC	Minimum ANC	Median ANC	Max.TotalICAIC PCations
Med Spring ANC	Pearson Correlation	0.738	0.990	0.989	0.979	0.974
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	194	194
		RBT YOY Biomass	LAGMedTotalCati ons	LAG Median Cond	Max.ANCmeqL	Median ANC
LAG Med ANC	Pearson Correlation	0.710	0.977	0.970	0.958	0.955
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	218	218	213	213
		RBT YOY Biomass	Median ANC	Max.TotalICAICP Cations	Maximum Cond	Med Spring ANC
Max.ANCmeqL	Pearson Correlation	0.706	0.983	0.977	0.973	0.962
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	213	194
		RBT YOY Biomass	Min Spring Cond	Median Spring Total Cations	Maximum Spring Total Cations	Minimum Spring Total Cations
Med Spring Cond	Pearson Correlation	0.705	0.980	0.975	0.970	0.969
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	218	218
		RBT YOY Biomass	MedianTotalCation s	Median ANC	Maximum Cond	Max.ANCmeqL
Max.TotalICAIC PCations	Pearson Correlation	0.704	0.987	0.981	0.978	0.977
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	213	213

Table A.26. continued

		RBT YOY Biomass	Max.ANCmeqL	Max.TotalICAAICP Cations	Med Spring ANC	MedianTotalCation s
Median ANC	Pearson Correlation	0.695	0.983	0.981	0.979	0.977
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	194	213
		RBT YOY Biomass	Med Spring Cond	Minimum Spring Total Cations	Minimum Total Cations	Minimum Cond
Min Spring Cond	Pearson Correlation	0.693	0.980	0.959	0.957	0.953
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	Max.TotalICAAIC PCations	Median ANC	MedianCond	Median Spring Total Cations
MedianTotalCation s	Pearson Correlation	0.689	0.987	0.977	0.972	0.969
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	213	194
		RBT YOY Biomass	LAG Med ANC	LAG Median Cond	Max.TotalICAAI CPCations	MedianTotalCation s
LAGMedTotalCati ons	Pearson Correlation	0.681	0.977	0.971	0.946	0.934
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	218	218	213	213
		RBT YOY Biomass	Min Spring Cond	Minimum Total Cations	Minimum ANC	Med Spring Cond
Minimum Cond	Pearson Correlation	0.671	0.953	0.908	0.899	0.897
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	213	213	194
		RBT YOY Biomass	Max.TotalICAAIC PCations	MedianCond	Max.ANCmeqL	Median ANC
Maximum Cond	Pearson Correlation	0.667	0.978	0.976	0.973	0.969
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	213	213
		RBT YOY Biomass	Max Spring Cond	Median ANC	Med Spring ANC	Max.ANCmeqL
Max Spring ANC	Pearson Correlation	0.661	0.966	0.965	0.960	0.960
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	218	194
		RBT YOY Biomass	LAGMedTotalCati ons	LAG Med ANC	Maximum Cond	Max.TotalICAAIC PCations
LAG Median Cond	Pearson Correlation	0.657	0.971	0.970	0.940	0.927
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	218	218	213	213
		RBT YOY Biomass	Maximum Cond	Max.TotalICAAICP Cations	MedianTotalCatio ns	Median ANC
MedianCond	Pearson Correlation	0.634	0.976	0.974	0.972	0.972
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	213	213
		RBT YOY Biomass	Max Spring ANC	MedianCond	Med Spring Cond	MedianTotalCation s
Max Spring Cond	Pearson Correlation	0.624	0.966	0.960	0.952	0.952
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	218	194
		RBT YOY Biomass	Min Spring Sodium	Median Sodium	Med Spring Sodium	LAG Med Sodium
Minimum Sodium	Pearson Correlation	0.608	0.947	0.883	0.870	0.843
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	213	194	213
		RBT YOY Biomass	Median pH	LAG Median pH	Max Spring pH	Med Spring pH
Max.pH	Pearson Correlation	0.607	0.924	0.892	0.890	0.877
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	213	194	194

Table A.26. continued

		RBT YOY Biomass	Med Spring Sodium	Min Spring Sodium	Minimum Sodium	LAG Med Sodium
Median Sodium	Pearson Correlation	0.602	0.902	0.887	0.883	0.866
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	Med Spring Potassium	LAG Med Potassium	Min Spring Potassium	Minimum Potassium
Median Potassium	Pearson Correlation	0.595	0.887	0.885	0.878	0.864
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	213	194	213
		RBT YOY Biomass	Min Spring Sodium	Max Spring Sodium	Median Sodium	Minimum Sodium
Med Spring Sodium	Pearson Correlation	0.584	0.933	0.919	0.902	0.870
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	Median pH	Max.pH	Max Spring pH	Med Spring pH
LAG Median pH	Pearson Correlation	0.580	0.942	0.892	0.884	0.882
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	213	213	198	198
		RBT YOY Biomass	Median Sodium	Minimum Sodium	LAG Med Potassium	Min Spring Sodium
LAG Med Sodium	Pearson Correlation	0.577	0.866	0.843	0.827	0.765
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	213	213	218	198
		RBT YOY Biomass	Min Spring Potassium	Median Potassium	LAG Med Potassium	Minimum Sodium
Minimum Potassium	Pearson Correlation	0.559	0.881	0.864	0.809	0.797
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	213	213	213
		RBT YOY Biomass	Med Spring pH	Max Spring pH	LAG Median pH	Max.pH
Median pH	Pearson Correlation	0.558	0.953	0.952	0.942	0.924
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	Med Spring Sodium	Maximum Sodium	Median Sodium	Min Spring Sodium
Max Spring Sodium	Pearson Correlation	0.557	0.919	0.820	0.808	0.753
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	194	218
		RBT YOY Biomass	Minimum Sodium	Med Spring Sodium	Median Sodium	LAG Med Sodium
Min Spring Sodium	Pearson Correlation	0.554	0.947	0.933	0.887	0.765
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	194	198
		RBT YOY Biomass	Median Potassium	Min Spring Potassium	Minimum Potassium	Maximum Potassium
Med Spring Potassium	Pearson Correlation	0.548	0.887	0.879	0.792	0.772
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	194	194
		RBT YOY Biomass	Min Spring pH	Med Spring pH	Median pH	LAG Median pH
Min.pH	Pearson Correlation	0.545	0.915	0.900	0.875	0.863
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	Median Potassium	LAG Med Sodium	Minimum Potassium	Min Spring Potassium
LAG Med Potassium	Pearson Correlation	0.541	0.885	0.827	0.809	0.745
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	213	218	213	198

Table A.26. continued

		RBT YOY Biomass	Minimum Potassium	Med Spring Potassium	Median Potassium	Min Spring Sodium
Min Spring Potassium	Pearson Correlation	0.534	0.881	0.879	0.878	0.753
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	194	218
		RBT YOY Biomass	Med Spring pH	Median pH	Min Spring pH	Max.pH
Max Spring pH	Pearson Correlation	0.527	0.971	0.952	0.921	0.890
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	218	194
		RBT YOY Biomass	Max Spring Potassium	Med Spring Potassium	Median Potassium	LAG Med Potassium
Maximum Potassium	Pearson Correlation	0.524	0.786	0.772	0.726	0.671
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	Med Spring Sodium	Max Spring Sodium	Median Sodium	LAG Med Sodium
Maximum Sodium	Pearson Correlation	0.518	0.822	0.820	0.819	0.737
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	Min Spring pH	Max Spring pH	Median pH	Min.pH
Med Spring pH	Pearson Correlation	0.514	0.980	0.971	0.953	0.900
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	Med Spring pH	Max Spring pH	Median pH	Min.pH
Min Spring pH	Pearson Correlation	0.498	0.980	0.921	0.917	0.915
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	MinSpringChloride	MedSpringChloride	LAGMedChloride	Min.ChloridemeqL
MedianChloride	Pearson Correlation	0.475	0.671	0.670	0.598	0.563
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	MedianChloride	Min.ChloridemeqL	Med Spring Cond	Min Spring Cond
LAGMedChloride	Pearson Correlation	0.452	0.598	0.594	0.534	0.526
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	213	213	198	198
		RBT YOY Biomass	MinSpringChloride	LAGMedChloride	MedianChloride	Minimum Cond
Min.ChloridemeqL	Pearson Correlation	0.421	0.715	0.594	0.563	0.498
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	213	213	213
		RBT YOY Biomass	MaxSpringNitrate	MedSpringNitrate	MedianNitrate	LAGMedNitrate
Max.NitratemeqL	Pearson Correlation	-0.392	0.953	0.912	0.885	0.827
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	MedianNitrate	MedSpringNitrate	Min.NitratemeqL	Max.NitratemeqL
LAGMedNitrate	Pearson Correlation	-0.364	0.938	0.833	0.832	0.827
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	140	213	198	213	213

Table A.26. continued

		RBT YOY Biomass	LAGMedNitrate	MedSpringNitrate	MaxSpringNitrate	Max.NitratemeqL
MedianNitrate	Pearson Correlation	-0.362	0.938	0.934	0.908	0.885
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	135	213	194	194	213
		RBT YOY Biomass	MedSpringNitrate	Max.NitratemeqL	MedianNitrate	MinSpringNitrate
MaxSpringNitrate	Pearson Correlation	-0.354	0.958	0.953	0.908	0.833
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	194	218
		RBT YOY Biomass	MaxSpringNitrate	MinSpringNitrate	MedianNitrate	Max.NitratemeqL
MedSpringNitrate	Pearson Correlation	-0.347	0.958	0.941	0.934	0.912
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	Min.ChloridemeqL	MedSpringChloride	MedianChloride	Minimum Cond
MinSpringChloride	Pearson Correlation	0.347	0.715	0.712	0.671	0.414
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	218	194	194
		RBT YOY Biomass	MedSpringNitrate	Min.NitratemeqL	MedianNitrate	MaxSpringNitrate
MinSpringNitrate	Pearson Correlation	-0.324	0.941	0.873	0.865	0.833
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	218	194	194	218
		RBT YOY Biomass	Maximum Potassium	Median Potassium	Med Spring Potassium	Minimum Potassium
Max Spring Potassium	Pearson Correlation	0.297	0.786	0.764	0.666	0.639
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	145	194	194	218	194
		RBT YOY Biomass	MaxSpringChloride	MedSpringChloride	MedianChloride	Maximum Anions
Max.ChloridemeqL	Pearson Correlation	0.281	0.623	0.546	0.453	0.312
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	135	194	194	213	213
		RBT YOY Biomass	MinSpringNitrate	MedianNitrate	LAGMedNitrate	MedSpringNitrate
Min.NitratemeqL	Pearson Correlation	-0.277	0.873	0.867	0.832	0.829
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	135	194	213	213	194
		RBT YOY Biomass	MaxSpringChloride	MinSpringChloride	MedianChloride	Max.ChloridemeqL
MedSpringChloride	Pearson Correlation	0.269	0.879	0.712	0.670	0.546
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	145	218	218	194	194
		RBT YOY Biomass	Max Spring Sulfate	Median Anions	Med Spring Anions	Maximum Anions
Max Spring Anions	Pearson Correlation	-0.202	0.936	0.929	0.921	0.917
	Sig. (2-tailed)	0.015	0.000	0.000	0.000	0.000
	N	145	218	194	218	194
		RBT YOY Biomass	Min Spring Anions	Median Anions	Med Spring Sulfate	Minimum Anions
Med Spring Anions	Pearson Correlation	-0.197	0.959	0.950	0.949	0.935
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000
	N	145	218	194	218	194
		RBT YOY Biomass	Median Anions	LAG Median Sulfate	Median Sulfate	Minimum Sulfate
LAG Med Anions	Pearson Correlation	-0.192	0.968	0.956	0.941	0.920
	Sig. (2-tailed)	0.023	0.000	0.000	0.000	0.000
	N	140	213	218	213	213

Table A.26. continued

		RBT YOY Biomass	Minimum Anions	Med Spring Anions	Min Spring Sulfate	Minimum Sulfate
Min Spring Anions	Pearson Correlation	-0.188	0.962	0.959	0.931	0.914
	Sig. (2-tailed)	0.023	0.000	0.000	0.000	0.000
	N	145	194	218	218	194
		RBT YOY Biomass	LAG Med Anions	Median Sulfate	Med Spring Anions	Med Spring Sulfate
Median Anions	Pearson Correlation	-0.181	0.968	0.962	0.950	0.944
	Sig. (2-tailed)	0.036	0.000	0.000	0.000	0.000
	N	135	213	213	194	194
		RBT YOY Biomass	Maximum Anions	Max Spring Sulfate	Med Spring Sulfate	Median Sulfate
Maximum Sulfate	Pearson Correlation	-0.178	0.920	0.916	0.904	0.895
	Sig. (2-tailed)	0.039	0.000	0.000	0.000	0.000
	N	135	213	194	194	213
		RBT YOY Biomass	Median Sulfate	LAG Med Anions	Minimum Sulfate	Med Spring Sulfate
LAG Median Sulfate	Pearson Correlation	-0.172	0.977	0.956	0.953	0.944
	Sig. (2-tailed)	0.042	0.000	0.000	0.000	0.000
	N	140	213	218	213	198
		RBT YOY Biomass	Min Spring Anions	Med Spring Anions	Minimum Sulfate	Min Spring Sulfate
Minimum Anions	Pearson Correlation	-0.170	0.962	0.935	0.919	0.912
	Sig. (2-tailed)	0.049	0.000	0.000	0.000	0.000
	N	135	194	194	213	194
		RBT YOY Biomass	Min Spring Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Anions
Med Spring Sulfate	Pearson Correlation	-0.168	0.976	0.976	0.967	0.949
	Sig. (2-tailed)	0.044	0.000	0.000	0.000	0.000
	N	145	218	194	194	218
		RBT YOY Biomass	Minimum Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate
Min Spring Sulfate	Pearson Correlation	-0.166	0.981	0.976	0.958	0.933
	Sig. (2-tailed)	0.046	0.000	0.000	0.000	0.000
	N	145	194	218	194	198
		RBT YOY Biomass	Median Sulfate	Max Spring Anions	Minimum Sulfate	Median Anions
Max Spring Sulfate	Pearson Correlation	-0.164	0.955	0.936	0.921	0.918
	Sig. (2-tailed)	0.049	0.000	0.000	0.000	0.000
	N	145	194	218	194	194
		RBT YOY Biomass	LAG Median Sulfate	Med Spring Sulfate	Minimum Sulfate	Median Anions
Median Sulfate	Pearson Correlation	-0.162	0.977	0.976	0.966	0.962
	Sig. (2-tailed)	0.061	0.000	0.000	0.000	0.000
	N	135	213	194	213	213
		RBT YOY Biomass	MedSpringChloride	Max.ChloridemeqL	MedianChloride	MinSpringChloride
MaxSpringChloride	Pearson Correlation	0.155	0.879	0.623	0.509	0.395
	Sig. (2-tailed)	0.062	0.000	0.000	0.000	0.000
	N	145	218	194	194	218
		RBT YOY Biomass	Maximum Sulfate	Max Spring Anions	Med Spring Anions	Max Spring Sulfate
Maximum Anions	Pearson Correlation	-0.150	0.920	0.917	0.881	0.869
	Sig. (2-tailed)	0.082	0.000	0.000	0.000	0.000
	N	135	213	194	194	194
		RBT YOY Biomass	Min Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate
Minimum Sulfate	Pearson Correlation	-0.147	0.981	0.967	0.966	0.953
	Sig. (2-tailed)	0.089	0.000	0.000	0.000	0.000
	N	135	194	194	213	213

Table A.27. Rainbow trout young-of-year biomass and flow variables

		RBT YOY Biomass	Weighted LAG Maximum	Distance Wt Maximum Spring	Distance Wt LAG Median	Weighted Maximum Spring	State LAG Maximum
Distance Wt LAG Maximum	Pearson Correlation	0.203	0.921	0.862	0.792	0.776	0.755
	Sig. (2-tailed)	0.009	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253	253
		RBT YOY Biomass	Weighted LAG Median	Distance Wt LAG Maximum	Weighted LAG Maximum	State LAG Median	Distance Wt # Flow Days > 1000 cfs
Distance Wt LAG Median	Pearson Correlation	0.198	0.898	0.792	0.676	0.664	0.662
	Sig. (2-tailed)	0.010	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253	253
		RBT YOY Biomass	Weighted Median	Distance Wt # Flow Days > 1000 cfs	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs	Weighted Maximum
Distance Wt Median	Pearson Correlation	0.185	0.901	0.831	0.809	0.707	0.695
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253	253
		RBT YOY Biomass	Weighted LAG3 Minimum	State LAG3 Minimum	Distance Wt LAG Maximum	Weighted LAG Maximum	Distance Wt Maximum Spring
Distance Wt LAG3 Minimum	Pearson Correlation	0.182	0.971	0.897	0.747	0.731	0.671
	Sig. (2-tailed)	0.022	0.000	0.000	0.000	0.000	0.000
	N	158	241	241	241	241	241
		RBT YOY Biomass	Weighted Maximum Spring	Distance Wt LAG Maximum	Weighted LAG Maximum	State Maximum Spring	State LAG Maximum
Distance Wt Maximum Spring	Pearson Correlation	0.178	0.935	0.862	0.814	0.803	0.685
	Sig. (2-tailed)	0.021	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253	253
		RBT YOY Biomass	Weighted LAG4 Minimum	State LAG4 Minimum	Distance Wt Maximum Spring	Distance Wt LAG Maximum	Weighted Maximum Spring
Distance Wt LAG4 Minimum	Pearson Correlation	0.156	0.973	0.907	0.367	0.343	0.330
	Sig. (2-tailed)	0.062	0.000	0.000	0.000	0.000	0.000
	N	145	225	225	225	225	225
		RBT YOY Biomass	State LAG3 Minimum	Distance Wt LAG3 Minimum	Weighted LAG Maximum	State LAG Maximum	Distance Wt LAG Maximum
Weighted LAG3 Minimum	Pearson Correlation	0.148	0.977	0.971	0.759	0.720	0.702
	Sig. (2-tailed)	0.063	0.000	0.000	0.000	0.000	0.000
	N	158	241	241	241	241	241

Table A.28. Rainbow trout young-of-year biomass and watershed characteristics

		RBT YOY Biomass	Basin Area (sqmi)	Xeric oak	Pine oak	Pine
Stream miles	Pearson Correlation	0.812	0.993	0.764	0.746	0.740
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Stream miles	Xeric oak	Pine	Pine oak
Basin Area (sqmi)	Pearson Correlation	0.804	0.993	0.736	0.715	0.710
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Pine	Pine oak	Grape thicket	Treeless
Xeric oak	Pearson Correlation	0.717	0.933	0.929	0.892	0.814
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Pine oak	Xeric oak	Grape thicket	Treeless
Pine	Pearson Correlation	0.692	0.970	0.933	0.777	0.744
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Pine	Xeric oak	Treeless	Grape thicket
Pine oak	Pearson Correlation	0.681	0.970	0.929	0.809	0.770
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Xeric oak	Pine	Pine oak	Treeless
Grape thicket	Pearson Correlation	0.581	0.892	0.777	0.770	0.688
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Xeric oak	Pine oak	Pine	Stream miles
Treeless	Pearson Correlation	0.568	0.814	0.809	0.744	0.728
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Mixed mesic hardwood	Pine	Xeric oak	Grape thicket
Fish Elevation (ft)	Pearson Correlation	-0.521	-0.815	-0.607	-0.586	-0.571
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Average basin slope	Selective cut	Basin Area (sqmi)	Cove hardwood
Channel slope	Pearson Correlation	-0.429	0.580	-0.556	-0.541	0.535
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Undisturbed	Selective cut	Channel slope	Cove hardwood
Average basin slope	Pearson Correlation	-0.517	0.724	-0.686	0.580	0.478
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Fish Elevation (ft)	Pine	Pine oak	Xeric oak
Mixed mesic hardwood	Pearson Correlation	0.492	-0.815	0.681	0.635	0.555
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253

Table A.28. continued

		RBT YOY Biomass	Pine oak	Pine	Xeric oak	Treeless
Cove hardwood	Pearson Correlation	-0.443	-0.629	-0.624	-0.596	-0.579
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Tulip poplar	Fish Elevation (ft)	Grape thicket	Mixed mesic hardwood
Northern hardwood	Pearson Correlation	-0.426	-0.570	0.562	-0.495	-0.462
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Average basin slope	Undisturbed	Channel slope	Heathbald
Selective cut	Pearson Correlation	0.424	-0.686	-0.642	-0.556	-0.444
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Average basin slope	Selective cut	Mesic oak	Heavy cut
Undisturbed	Pearson Correlation	-0.361	0.724	-0.642	-0.636	-0.605
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Undisturbed	Mesic oak	Fish Elevation (ft)	Selective cut
Spruce fir	Pearson Correlation	-0.338	0.525	-0.491	0.449	-0.433
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Pine	Pine oak	Mixed mesic hardwood	Xeric oak
Grassybald	Pearson Correlation	0.322	0.594	0.579	0.461	0.456
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Grassybald	Undisturbed	Fish Elevation (ft)	Spruce fir
Settlement	Pearson Correlation	0.317	0.437	-0.365	-0.364	-0.350
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Northern hardwood	Fish Elevation (ft)	Pine	Pine oak
Tulip poplar	Pearson Correlation	0.307	-0.570	-0.554	0.468	0.462
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Undisturbed	Northern hardwood	Mesic oak	Stream miles
Light cut	Pearson Correlation	0.284	-0.447	-0.377	0.282	0.254
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Selective cut	Channel slope	Pine	Pine oak
Heathbald	Pearson Correlation	-0.253	-0.444	0.379	-0.346	-0.338
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Undisturbed	Mesic oak	Mixed mesic hardwood	Fish Elevation (ft)
Heavy cut	Pearson Correlation	-0.087	-0.605	0.568	-0.391	0.340
	Sig. (2-tailed)	0.261	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Undisturbed	Heavy cut	Spruce fir	Cove hardwood
Mesic oak	Pearson Correlation	-0.071	-0.636	0.568	-0.491	0.398
	Sig. (2-tailed)	0.363	0.000	0.000	0.000	0.000
	N	167	253	253	253	253

Table A.29. Rainbow trout young-of-year biomass and precipitation

		RBT YOY Biomass	Closest Precip90	Weighted Precip180	Closest Precip180	Weighted Precip365
Weighted Precip90	Pearson Correlation	-0.524	0.888	0.852	0.779	0.704
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	159	245	240	243	235
		RBT YOY Biomass	Closest Precip180	Weighted Precip730	Weighted Precip90	Weighted Precip365
Weighted Precip180	Pearson Correlation	-0.489	0.883	0.872	0.852	0.851
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	156	240	222	240	235
		RBT YOY Biomass	Weighted Precip180	Weighted Precip365	Closest Precip730	Closest Precip180
Weighted Precip730	Pearson Correlation	-0.474	0.872	0.860	0.856	0.747
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	142	222	222	222	222
		RBT YOY Biomass	Closest Precip365	Weighted Precip730	Weighted Precip180	Closest Precip180
Weighted Precip365	Pearson Correlation	-0.439	0.861	0.860	0.851	0.748
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	152	235	222	235	235
		RBT YOY Biomass	Weighted Precip90	Closest Precip180	Closest Precip30	Weighted Precip180
Closest Precip90	Pearson Correlation	-0.390	0.888	0.878	0.783	0.748
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	159	245	243	245	240
		RBT YOY Biomass	Closest Precip30	Closest Precip90	Weighted Precip90	Closest Precip180
Weighted Precip30	Pearson Correlation	-0.383	0.866	0.693	0.677	0.578
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	159	245	245	245	243
		RBT YOY Biomass	Weighted Precip730	Closest Precip365	Closest Precip180	Weighted Precip180
Closest Precip730	Pearson Correlation	-0.381	0.856	0.853	0.833	0.736
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	151	222	233	233	233
		RBT YOY Biomass	Weighted Precip180	Closest Precip90	Closest Precip365	Closest Precip730
Closest Precip180	Pearson Correlation	-0.377	0.883	0.878	0.838	0.833
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	158	240	243	243	233
		RBT YOY Biomass	Weighted Precip365	Closest Precip730	Closest Precip180	Weighted Precip730
Closest Precip365	Pearson Correlation	-0.362	0.861	0.853	0.838	0.730
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	158	235	233	243	222
		RBT YOY Biomass	Weighted Precip30	Closest Precip90	Closest Precip180	Weighted Precip90
Closest Precip30	Pearson Correlation	-0.231	0.866	0.783	0.614	0.576
	Sig. (2-tailed)	0.003	0.000	0.000	0.000	0.000
	N	159	245	245	243	245
		RBT YOY Biomass	Weighted Precip7	Weighted Precip30	Closest Precip180	Closest Precip730
Closest Precip7	Pearson Correlation	0.016	0.929	0.286	0.208	0.197
	Sig. (2-tailed)	0.839	0.000	0.000	0.001	0.003
	N	159	245	245	243	233
		RBT YOY Biomass	Closest Precip7	Weighted Precip30	Weighted Precip180	Weighted Precip90
Weighted Precip7	Pearson Correlation	-0.002	0.929	0.276	0.150	0.135
	Sig. (2-tailed)	0.978	0.000	0.000	0.020	0.035
	N	159	245	245	240	245

Table A.30. Rainbow trout young-of-year biomass and geology

		RBT YOY Biomass	Limestone	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Metcalf phyllite	Pearson Correlation	0.680	0.930	0.900	0.536	-0.356
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Metcalf phyllite	Limestone	Elkmont sandstone	Thunderhead sandstone
Cades sandstone	Pearson Correlation	0.672	0.900	0.696	0.578	-0.357
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Metcalf phyllite	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Limestone	Pearson Correlation	0.574	0.930	0.696	0.312	-0.266
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Cades sandstone	Metcalf phyllite	Thunderhead sandstone	Limestone
Elkmont sandstone	Pearson Correlation	0.487	0.578	0.536	-0.428	0.312
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone	Metcalf phyllite
Anakeesta	Pearson Correlation	-0.350	-0.613	-0.285	-0.234	-0.233
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Anakeesta	Elkmont sandstone	Cades sandstone	Metcalf phyllite
Thunderhead sandstone	Pearson Correlation	-0.237	-0.613	-0.428	-0.357	-0.356
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	0.000
	N	167	253	253	253	253
		RBT YOY Biomass	Richbutt sandstone	Thunderhead sandstone	Anakeesta	Great Smoky Group
Pigeon siltstone	Pearson Correlation	-0.124	0.338	0.302	-0.234	-0.138
	Sig. (2-tailed)	0.111	0.000	0.000	0.000	0.029
	N	167	253	253	253	253
		RBT YOY Biomass	Thunderhead sandstone	Great Smoky Group	Elkmont sandstone	Metcalf phyllite
Metadiorite	Pearson Correlation	-0.120	0.146	-0.091	-0.084	-0.069
	Sig. (2-tailed)	0.123	0.020	0.149	0.185	0.277
	N	167	253	253	253	253
		RBT YOY Biomass	Great Smoky Group	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone
Unnamed sandstone	Pearson Correlation	-0.114	0.892	-0.297	-0.110	-0.091
	Sig. (2-tailed)	0.141	0.000	0.000	0.080	0.150
	N	167	253	253	253	253
		RBT YOY Biomass	Roaringfork sandstone	Basement complex	Anakeesta	Richbutt sandstone
Longarm quartzite	Pearson Correlation	0.066	0.781	0.649	-0.186	0.148
	Sig. (2-tailed)	0.394	0.000	0.000	0.003	0.018
	N	167	253	253	253	253
		RBT YOY Biomass	Roaringfork sandstone	Longarm quartzite	Anakeesta	Great Smoky Group
Basement complex	Pearson Correlation	-0.054	0.962	0.649	-0.178	-0.105
	Sig. (2-tailed)	0.488	0.000	0.000	0.004	0.096
	N	167	253	253	253	253

Table A.30. continued

		RBT YOY Biomass	Basement complex	Longarm quartzite	Anakeesta	Richbutt sandstone
Roaringfork sandstone	Pearson Correlation	-0.036	0.962	0.781	-0.231	0.211
	Sig. (2-tailed)	0.643	0.000	0.000	0.000	0.001
	N	167	253	253	253	253
		RBT YOY Biomass	Pigeon siltstone	Roaringfork sandstone	Thunderhead sandstone	Anakeesta
Richbutt sandstone	Pearson Correlation	0.005	0.338	0.211	0.179	-0.174
	Sig. (2-tailed)	0.945	0.000	0.001	0.004	0.005
	N	167	253	253	253	253
		RBT YOY Biomass	Unnamed sandstone	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone
Great Smoky Group	Pearson Correlation	-0.002	0.892	-0.343	-0.138	-0.136
	Sig. (2-tailed)	0.975	0.000	0.000	0.029	0.031
	N	167	253	253	253	253
		RBT YOY Biomass	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone	Richbutt sandstone
Wadingbranc formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.
	N	167	253	253	253	253

Table A.31. Rainbow trout adult biomass and water chemistry

		RBT ADT Biomass	Med Spring Potassium	LAG Med Potassium	Min Spring Potassium	Minimum Potassium	Median Sodium	Max Spring Potassium
Median Potassium	Pearson Correlation	0.604	0.887	0.885	0.878	0.864	0.780	0.764
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	194	213	213	194
		RBT ADT Biomass	Median Potassium	LAG Med Sodium	Minimum Potassium	Min Spring Potassium	Median Sodium	Med Spring Potassium
LAG Med Potassium	Pearson Correlation	0.583	0.885	0.827	0.809	0.745	0.742	0.739
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	218	213	198	213	198
		RBT ADT Biomass	Median pH	Max.pH	Max Spring pH	Med Spring pH	Min.pH	Min Spring pH
LAG Median pH	Pearson Correlation	0.577	0.942	0.892	0.884	0.882	0.863	0.855
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	213	198	198	213	198
		RBT ADT Biomass	Min Spring pH	Med Spring pH	Median pH	LAG Median pH	Max Spring pH	Max.pH
Min.pH	Pearson Correlation	0.563	0.915	0.900	0.875	0.863	0.857	0.784
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	194	213
		RBT ADT Biomass	Med Spring pH	Max Spring pH	LAG Median pH	Max.pH	Min Spring pH	Min.pH
Median pH	Pearson Correlation	0.561	0.953	0.952	0.942	0.924	0.917	0.875
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	194	213
		RBT ADT Biomass	Median pH	LAG Median pH	Max Spring pH	Med Spring pH	Min Spring pH	Min.pH
Max.pH	Pearson Correlation	0.544	0.924	0.892	0.890	0.877	0.842	0.784
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	194	194	194	213
		RBT ADT Biomass	Min Spring pH	Max Spring pH	Median pH	Min.pH	LAG Median pH	Max.pH
Med Spring pH	Pearson Correlation	0.542	0.980	0.971	0.953	0.900	0.882	0.877
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	198	194
		RBT ADT Biomass	Med Spring pH	Median pH	Min Spring pH	Max.pH	LAG Median pH	Min.pH
Max Spring pH	Pearson Correlation	0.534	0.971	0.952	0.921	0.890	0.884	0.857
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	198	194
		RBT ADT Biomass	Min Spring ANC	Med Spring ANC	Min.TotalICAA ICPCations	MinSpringTota ICations	MedSpringTota ICations	Max Spring ANC
Minimum ANC	Pearson Correlation	0.533	0.998	0.989	0.970	0.961	0.959	0.957
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	194	194	194
		RBT ADT Biomass	Med Spring pH	Max Spring pH	Median pH	Min.pH	LAG Median pH	Max.pH
Min Spring pH	Pearson Correlation	0.529	0.980	0.921	0.917	0.915	0.855	0.842
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	198	194
		RBT ADT Biomass	Max Spring Potassium	Med Spring Potassium	Median Potassium	LAG Med Potassium	Maximum Sodium	Minimum Potassium
Maximum Potassium	Pearson Correlation	0.522	0.786	0.772	0.726	0.671	0.648	0.611
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	213	213
		RBT ADT Biomass	Min Spring Potassium	Median Potassium	LAG Med Potassium	Minimum Sodium	Med Spring Potassium	Median Sodium
Minimum Potassium	Pearson Correlation	0.511	0.881	0.864	0.809	0.797	0.792	0.755
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	213	213	194	213

Table A.31. continued

		RBT ADT Biomass	Max.ANCmeq L	Max.TotalICA AICPCations	Med Spring ANC	MedianTotalC ations	MedianCond	Min Spring ANC
Median ANC	Pearson Correlation	0.511	0.983	0.981	0.979	0.977	0.972	0.971
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	194	213	213	194
		RBT ADT Biomass	MinSpringTot alCations	MedSpringTota lCations	MaxSpringTota lCations	Med Spring ANC	Minimum ANC	Med Spring Cond
Min.TotalICA AICPCations	Pearson Correlation	0.504	0.994	0.987	0.973	0.970	0.970	0.968
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	194	194	213	194
		RBT ADT Biomass	Median ANC	Max.TotalICA AICPCations	Maximum Cond	Med Spring ANC	MedianTotalCa tions	Max Spring ANC
Max.ANCmeqL	Pearson Correlation	0.498	0.983	0.977	0.973	0.962	0.962	0.960
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	213	194	213	194
		RBT ADT Biomass	Median Potassium	Min Spring Potassium	Minimum Potassium	Maximum Potassium	LAG Med Potassium	Med Spring Sodium
Med Spring Potassium	Pearson Correlation	0.497	0.887	0.879	0.792	0.772	0.739	0.728
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	194	198	218
		RBT ADT Biomass	LAGMedTotal Cations	LAG Median Cond	Max.ANCmeqL	Median ANC	Max.TotalICA AICPCations	Min Spring ANC
LAG Med ANC	Pearson Correlation	0.495	0.977	0.970	0.958	0.955	0.951	0.946
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	218	218	213	213	213	198
		RBT ADT Biomass	Med Spring Sodium	Min Spring Sodium	Minimum Sodium	LAG Med Sodium	Maximum Sodium	Max Spring Sodium
Median Sodium	Pearson Correlation	0.482	0.902	0.887	0.883	0.866	0.819	0.808
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	213	194
		RBT ADT Biomass	MedianTotalC ations	Median ANC	Maximum Cond	Max.ANCmeq L	Med Spring ANC	MedianCond
Max.TotalICA AICPCations	Pearson Correlation	0.473	0.987	0.981	0.978	0.977	0.974	0.974
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	213	213	194	213
		RBT ADT Biomass	Median Sodium	Minimum Sodium	LAG Med Potassium	Min Spring Sodium	LAG Median pH	Maximum Sodium
LAG Med Sodium	Pearson Correlation	0.473	0.866	0.843	0.827	0.765	0.762	0.737
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	213	218	198	218	213
		RBT ADT Biomass	LAG Med ANC	LAG Median Cond	Max.TotalICA AICPCations	MedianTotalC ations	Max.ANCmeqL	Maximum Cond
LAGMedTotalC ations	Pearson Correlation	0.472	0.977	0.971	0.946	0.934	0.933	0.931
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	218	218	213	213	213	213
		RBT ADT Biomass	Min Spring ANC	Minimum ANC	Median ANC	Max.TotalICA AICPCations	MedSpringTota lCations	Min.TotalICA AICPCations
Med Spring ANC	Pearson Correlation	0.468	0.990	0.989	0.979	0.974	0.971	0.970
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	194	194	218	194
		RBT ADT Biomass	Max.TotalICA AICPCations	Median ANC	MedianCond	MedSpringTot alCations	MinSpringTota lCations	Maximum Cond
MedianTotalCati ons	Pearson Correlation	0.462	0.987	0.977	0.972	0.969	0.968	0.967
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	213	194	194	213
		RBT ADT Biomass	Minimum ANC	Med Spring ANC	Median ANC	Min.TotalICA AICPCations	MinSpringTota lCations	MedSpringTot alCations
Min Spring ANC	Pearson Correlation	0.460	0.998	0.990	0.971	0.965	0.961	0.958
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	194	218	218

Table A.31. continued

		RBT ADT Biomass	Minimum Potassium	Med Spring Potassium	Median Potassium	Min Spring Sodium	LAG Med Potassium	Med Spring Sodium
Min Spring Potassium	Pearson Correlation	0.448	0.881	0.879	0.878	0.753	0.745	0.739
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	218	198	218
		RBT ADT Biomass	Min Spring Sodium	Median Sodium	Med Spring Sodium	LAG Med Sodium	Minimum Potassium	Min Spring pH
Minimum Sodium	Pearson Correlation	0.440	0.947	0.883	0.870	0.843	0.797	0.752
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	194	213	213	194
		RBT ADT Biomass	MaxSpringNitr rate	MinSpringNitr ate	MedianNitr ate	Max.Nitrateme qL	LAGMedNitr ate	Min.Nitrateme qL
MaxSpringNitr ate	Pearson Correlation	-0.436	0.958	0.941	0.934	0.912	0.833	0.829
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	198	194
		RBT ADT Biomass	Max Spring Cond	Median ANC	Med Spring ANC	Max.ANCmeq L	Max.TotalICA AICPCations	Minimum ANC
Max Spring ANC	Pearson Correlation	0.431	0.966	0.965	0.960	0.960	0.959	0.957
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	194	194
		RBT ADT Biomass	Maximum Cond	Max.TotalICA AICPCations	MedianTotalCations	Median ANC	Max Spring Cond	Med Spring Cond
MedianCond	Pearson Correlation	0.427	0.976	0.974	0.972	0.972	0.960	0.958
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	213	213	194	194
		RBT ADT Biomass	MedianNitr ate	MedSpringNitr ate	Min.Nitrateme qL	Max.Nitrateme qL	MaxSpringNitr ate	LAG Med Anions
LAGMedNitr ate	Pearson Correlation	-0.426	0.938	0.833	0.832	0.827	0.826	0.790
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	198	213	213	198	218
		RBT ADT Biomass	MaxSpringNitr rate	MedSpringNitr ate	MedianNitr ate	LAGMedNitr ate	MinSpringNitr ate	Max Spring Anions
Max.Nitratemeq L	Pearson Correlation	-0.424	0.953	0.912	0.885	0.827	0.798	0.776
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	194	194
		RBT ADT Biomass	LAGMedNitr ate	MedSpringNitr ate	MaxSpringNitr ate	Max.Nitrateme qL	Min.Nitrateme qL	MinSpringNitr ate
MedianNitr ate	Pearson Correlation	-0.423	0.938	0.934	0.908	0.885	0.867	0.865
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	194	194	213	213	194
		RBT ADT Biomass	MaxSpringNitr rate	MinSpringNitr ate	MedianNitr ate	Max.Nitrateme qL	LAGMedNitr ate	Min.Nitrateme qL
MedSpringNitr ate	Pearson Correlation	-0.422	0.958	0.941	0.934	0.912	0.833	0.829
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	198	194
		RBT ADT Biomass	MinSpringTotalCations	MaxSpringTotalCations	Min.TotalICAA ICPCations	Med Spring Cond	Med Spring ANC	MedianTotalCations
MedSpringTotalCations	Pearson Correlation	0.422	0.990	0.990	0.987	0.975	0.971	0.969
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	218	218	194
		RBT ADT Biomass	MedSpringTotalCations	Min.TotalICAA ICPCations	MinSpringTotalCations	Med Spring Cond	Med Spring ANC	Max.TotalICA AICPCations
MaxSpringTotalCations	Pearson Correlation	0.418	0.990	0.973	0.972	0.970	0.968	0.959
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	218	218	194
		RBT ADT Biomass	Min.TotalICA AICPCations	MedSpringTotalCations	MaxSpringTotalCations	Med Spring Cond	MedianTotalCations	Med Spring ANC
MinSpringTotalCations	Pearson Correlation	0.414	0.994	0.990	0.972	0.969	0.968	0.966
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	218	218	194	218

Table A.31. continued

		RBT ADT Biomass	Min Spring Anions	Median Anions	Med Spring Sulfate	Minimum Anions	Min Spring Sulfate	Minimum Sulfate
Med Spring Anions	Pearson Correlation	-0.411	0.959	0.950	0.949	0.935	0.930	0.926
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	218	194
		RBT ADT Biomass	Max Spring Sulfate	Median Anions	Med Spring Anions	Maximum Anions	Median Sulfate	Med Spring Sulfate
Max Spring Anions	Pearson Correlation	-0.408	0.936	0.929	0.921	0.917	0.898	0.887
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	194	218
		RBT ADT Biomass	Min Spring Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Anions	LAG Median Sulfate	Median Anions
Med Spring Sulfate	Pearson Correlation	-0.405	0.976	0.976	0.967	0.949	0.944	0.944
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	194	218	198	194
		RBT ADT Biomass	Max.TotalICA AICPCations	MedianCond	Max.ANCmeqL	Median ANC	MedianTotalCa tions	Med Spring Cond
Maximum Cond	Pearson Correlation	0.405	0.978	0.976	0.973	0.969	0.967	0.952
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	213	213	213	194
			Med Spring Sodium	Max Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Sodium	Median Potassium
Maximum Sodium	Pearson Correlation	0.402	0.822	0.820	0.819	0.737	0.732	0.680
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	194	213
		RBT ADT Biomass	Median Sulfate	LAG Med Anions	Minimum Sulfate	Med Spring Sulfate	Median Anions	Min Spring Sulfate
LAG Median Sulfate	Pearson Correlation	-0.401	0.977	0.956	0.953	0.944	0.936	0.933
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	218	213	198	213	198
		RBT ADT Biomass	Median Anions	LAG Median Sulfate	Median Sulfate	Minimum Sulfate	Med Spring Sulfate	Med Spring Anions
LAG Med Anions	Pearson Correlation	-0.401	0.968	0.956	0.941	0.920	0.912	0.905
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	218	213	213	198	198
		RBT ADT Biomass	LAG Median Sulfate	Med Spring Sulfate	Minimum Sulfate	Median Anions	Min Spring Sulfate	Max Spring Sulfate
Median Sulfate	Pearson Correlation	-0.396	0.977	0.976	0.966	0.962	0.958	0.955
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	194	213	213	194	194
		RBT ADT Biomass	LAG Med Anions	Median Sulfate	Med Spring Anions	Med Spring Sulfate	Minimum Sulfate	LAG Median Sulfate
Median Anions	Pearson Correlation	-0.393	0.968	0.962	0.950	0.944	0.940	0.936
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	194	194	213	213
		RBT ADT Biomass	Minimum Anions	Med Spring Anions	Min Spring Sulfate	Minimum Sulfate	Med Spring Sulfate	Median Anions
Min Spring Anions	Pearson Correlation	-0.391	0.962	0.959	0.931	0.914	0.904	0.900
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	218	194	218	194
		RBT ADT Biomass	Median Sulfate	Max Spring Anions	Minimum Sulfate	Median Anions	Maximum Sulfate	Med Spring Sulfate
Max Spring Sulfate	Pearson Correlation	-0.390	0.955	0.936	0.921	0.918	0.916	0.902
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	194	194	218
		RBT ADT Biomass	Min Spring Sodium	Max Spring Sodium	Median Sodium	Minimum Sodium	Maximum Sodium	Min Spring pH
Med Spring Sodium	Pearson Correlation	0.390	0.933	0.919	0.902	0.870	0.822	0.745
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	194	218
		RBT ADT Biomass	Maximum Anions	Max Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Max Spring Anions
Maximum Sulfate	Pearson Correlation	-0.389	0.920	0.916	0.904	0.895	0.881	0.866
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	194	194	213	213	194

Table A.31. continued

		RBT ADT Biomass	Minimum Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Min Spring Anions	Median Anions
Min Spring Sulfate	Pearson Correlation	-0.385	0.981	0.976	0.958	0.933	0.931	0.931
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	198	218	194
		RBT ADT Biomass	Min Spring Cond	Min.TotalICAA ICPCations	Minimum ANC	Med Spring Cond	MinSpringTota ICations	Min Spring ANC
Minimum Cond	Pearson Correlation	0.381	0.953	0.908	0.899	0.897	0.893	0.885
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	213	194	194	194
		RBT ADT Biomass	LAGMedTotal Cations	LAG Med ANC	Maximum Cond	Max.TotalICA AICPCations	Min Spring Cond	MedianTotalC ations
LAG Median Cond	Pearson Correlation	0.380	0.971	0.970	0.940	0.927	0.926	0.921
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	218	218	213	213	198	213
		RBT ADT Biomass	MedSpringNitr rate	Min.Nitrateme qL	MedianNitrate	MaxSpringNitr ate	Max.Nitrateme qL	LAGMedNitr ate
MinSpringNitr ate	Pearson Correlation	-0.377	0.941	0.873	0.865	0.833	0.798	0.775
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	194	218	194	198
		RBT ADT Biomass	LAG Med Anions	Median Sulfate	Med Spring Anions	Med Spring Sulfate	Minimum Sulfate	LAG Median Sulfate
Maximum Anions	Pearson Correlation	-0.365	0.968	0.962	0.950	0.944	0.940	0.936
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	213	213	194	194	213	213
		RBT ADT Biomass	Minimum Sodium	Med Spring Sodium	Median Sodium	LAG Med Sodium	Min Spring Potassium	Max Spring Sodium
Min Spring Sodium	Pearson Correlation	0.365	0.947	0.933	0.887	0.765	0.753	0.753
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	218	194	198	218	218
		RBT ADT Biomass	Min Spring Sulfate	Med Spring Sulfate	Median Sulfate	LAG Median Sulfate	Median Anions	Med Spring Anions
Minimum Sulfate	Pearson Correlation	-0.353	0.981	0.967	0.966	0.953	0.940	0.926
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	213	194
		RBT ADT Biomass	Med Spring Sodium	Maximum Sodium	Median Sodium	Min Spring Sodium	Med Spring Potassium	Median Potassium
Max Spring Sodium	Pearson Correlation	0.350	0.919	0.820	0.808	0.753	0.705	0.691
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	194	218	218	194
		RBT ADT Biomass	Min Spring Anions	Med Spring Anions	Minimum Sulfate	Min Spring Sulfate	Median Anions	Med Spring Sulfate
Minimum Anions	Pearson Correlation	-0.339	0.962	0.935	0.919	0.912	0.911	0.891
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	194	213	194
		RBT ADT Biomass	Min Spring Cond	MedSpringTota ICations	MaxSpringTota ICations	MinSpringTota ICations	Min.TotalICAA ICPCations	MedianTotalC ations
Med Spring Cond	Pearson Correlation	0.339	0.980	0.975	0.970	0.969	0.968	0.963
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	218	218	194	194
		RBT ADT Biomass	MinSpringNitr ate	MedianNitrate	LAGMedNitr ate	MedSpringNitr ate	MaxSpringNitr ate	Minimum Anions
Min.Nitratemeq L	Pearson Correlation	-0.336	0.873	0.867	0.832	0.829	0.744	0.738
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	213	194	194	213

Table A.31. continued

		RBT ADT Biomass	Max Spring ANC	MedianCond	Med Spring Cond	MedianTotalC ations	Max.TotalICA AICPCations	Maximum Cond
Max Spring Cond	Pearson Correlation	0.322	0.966	0.960	0.952	0.952	0.952	0.951
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	194	194
		RBT ADT Biomass	Med Spring Cond	MinSpringTota ICations	Min.TotalICAA ICPCations	Minimum Cond	MedSpringTota ICations	MedianCond
Min Spring Cond	Pearson Correlation	0.315	0.980	0.959	0.957	0.953	0.951	0.943
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	218	194	194	218	194
		RBT ADT Biomass	Maximum Potassium	Median Potassium	Med Spring Potassium	Minimum Potassium	LAG Med Potassium	Min.pH
Max Spring Potassium	Pearson Correlation	0.289	0.786	0.764	0.666	0.639	0.628	0.526
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	194	194	218	194	198	194
		RBT ADT Biomass	MinSpringChl oride	LAGMedChlor ide	MedianChlorid e	Minimum Cond	Min Spring Cond	Min.TotalICA AICPCations
Min.Chlorideme qL	Pearson Correlation	0.239	0.715	0.594	0.563	0.498	0.457	0.456
	Sig. (2-tailed)	0.004	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	213	213	213	194	213
		RBT ADT Biomass	MedianChlori de	Min.Chlorideme qL	Med Spring Cond	Min Spring Cond	Minimum Cond	Min Spring ANC
LAGMedChlorid e	Pearson Correlation	0.203	0.598	0.594	0.534	0.526	0.519	0.517
	Sig. (2-tailed)	0.014	0.000	0.000	0.000	0.000	0.000	0.000
	N	147	213	213	198	198	213	198
		RBT ADT Biomass	MinSpringChl oride	MedSpringChl oride	LAGMedChlor ide	Min.Chlorideme qL	MaxSpringChl oride	Min Spring Cond
MedianChloride	Pearson Correlation	0.189	0.671	0.670	0.598	0.563	0.509	0.506
	Sig. (2-tailed)	0.024	0.000	0.000	0.000	0.000	0.000	0.000
	N	142	194	194	213	213	194	194
		RBT ADT Biomass	Max Spring Ammonium	MedSpringAm monium	MedianAmmon ium	MaxSpringChl oride	MinSpringAm monium	LAG Med Sodium
Max.Ammonium meqL	Pearson Correlation	-0.167	0.742	0.621	0.269	0.178	0.170	-0.163
	Sig. (2-tailed)	0.046	0.000	0.000	0.000	0.013	0.018	0.018
	N	142	194	194	213	194	194	213
		RBT ADT Biomass	MedSpringAm monium	Max.Ammoniu mmeqL	MedianAmmon ium	MinSpringAm monium	MaxSpringChl oride	MedSpringChl oride
Max Spring Ammonium	Pearson Correlation	-0.161	0.842	0.742	0.290	0.244	0.193	0.149
	Sig. (2-tailed)	0.048	0.000	0.000	0.000	0.000	0.004	0.028
	N	151	218	194	194	218	218	218
		RBT ADT Biomass	Max Spring Ammonium	Max.Ammoniu mmeqL	MinSpringAm monium	MedianAmmon ium	MedSpringChl oride	MaxSpringChl oride
MedSpringAmmon ium	Pearson Correlation	-0.154	0.842	0.621	0.441	0.344	0.262	0.257
	Sig. (2-tailed)	0.058	0.000	0.000	0.000	0.000	0.000	0.000
	N	151	218	194	218	194	218	218
		RBT ADT Biomass	LAGMedAmm onium	MedSpringAm monium	Max Spring Ammonium	Max.Ammoniu mmeqL	Minimum Sulfate	Minimum Anions
MedianAmmoni um	Pearson Correlation	-0.147	0.456	0.344	0.290	0.269	0.197	0.196
	Sig. (2-tailed)	0.081	0.000	0.000	0.000	0.000	0.004	0.004
	N	142	213	194	194	213	213	213

Table A.32. Rainbow trout adult biomass and flow variables

		RBT ADT Biomass	Weighted # Flow Days < 50 cfs	State Minimum	Weighted Minimum	Distance Wt # Flow Days < 50 cfs
State # Flow Days < 50 cfs	Pearson Correlation	0.236	0.944	-0.818	-0.792	0.771
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted Maximum	State # Flow Days > 1000 cfs	State Median Spring	Weighted # Flow Days > 1000 cfs
State Maximum	Pearson Correlation	-0.207	0.956	0.927	0.909	0.877
	Sig. (2-tailed)	0.006	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted LAG Median	Distance Wt LAG Maximum	Weighted LAG Maximum	State LAG Median
Distance Wt LAG Median	Pearson Correlation	0.193	0.898	0.792	0.676	0.664
	Sig. (2-tailed)	0.011	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted Median Spring	State Maximum	State # Flow Days > 1000 cfs	Weighted Maximum
State Median Spring	Pearson Correlation	-0.193	0.965	0.909	0.895	0.858
	Sig. (2-tailed)	0.011	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted Maximum Spring	State LAG Maximum	Weighted LAG Maximum	Distance Wt Maximum Spring
State Maximum Spring	Pearson Correlation	-0.192	0.962	0.887	0.830	0.803
	Sig. (2-tailed)	0.011	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted LAG Minimum	State LAG Minimum	Weighted LAG Median	Distance Wt LAG Median
Distance Wt LAG Minimum	Pearson Correlation	0.186	0.972	0.903	0.619	0.609
	Sig. (2-tailed)	0.014	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted # Flow Days > 1000 cfs	State Maximum	State Median Spring	Weighted Maximum
State # Flow Days > 1000 cfs	Pearson Correlation	-0.180	0.942	0.927	0.895	0.875
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Weighted Median	State # Flow Days > 1000 cfs	State Maximum	Weighted # Flow Days > 1000 cfs
State Median	Pearson Correlation	-0.161	0.928	0.812	0.795	0.756
	Sig. (2-tailed)	0.034	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	State # Flow Days < 50 cfs	Distance Wt # Flow Days < 50 cfs	Weighted Minimum	Distance Wt Minimum
Weighted # Flow Days < 50 cfs	Pearson Correlation	0.149	0.944	0.938	-0.846	-0.829
	Sig. (2-tailed)	0.049	0.000	0.000	0.000	0.000
	N	174	253	253	253	253

Table A.32. continued

		RBT ADT Biomass	State LAG Minimum	Distance Wt LAG Minimum	Weighted LAG Median	State LAG Median
Weighted LAG Minimum	Pearson Correlation	0.142	0.978	0.972	0.621	0.586
	Sig. (2-tailed)	0.062	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
			Weighted Minimum	Distance Wt Minimum	Weighted # Flow Days < 50 cfs	State # Flow Days < 50 cfs
State Minimum	Pearson Correlation	-0.141	0.980	0.909	-0.825	-0.818
	Sig. (2-tailed)	0.063	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
			State Maximum Spring	Distance Wt Maximum Spring	Weighted LAG Maximum	State LAG Maximum
Weighted Maximum Spring	Pearson Correlation	-0.127	0.962	0.935	0.866	0.841
	Sig. (2-tailed)	0.095	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
			Weighted Median Yearly	Distance Wt # Flow Days > 1000 cfs	Distance Wt Maximum	Weighted # Flow Days > 1000 cfs
Distance Wt Median	Pearson Correlation	0.126	0.901	0.831	0.809	0.707
	Sig. (2-tailed)	0.097	0.000	0.000	0.000	0.000
	N	174	253	253	253	253

Table A.33. Rainbow trout adult biomass and watershed characteristics

		RBT ADT Biomass	Basin Area (sqmi)	Xeric oak	Pine oak	Pine
Stream miles	Pearson Correlation	0.581	0.993	0.764	0.746	0.740
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Stream miles	Xeric oak	Pine	Pine oak
Basin Area (sqmi)	Pearson Correlation	0.574	0.993	0.736	0.715	0.710
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Undisturbed	Selective cut	Channel slope	Cove hardwood
Average basin slope	Pearson Correlation	-0.552	0.724	-0.686	0.580	0.478
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Average basin slope	Selective cut	Mesic oak	Heavy cut
Undisturbed	Pearson Correlation	-0.500	0.724	-0.642	-0.636	-0.605
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Pine	Pine oak	Grape thicket	Treeless
Xeric oak	Pearson Correlation	0.454	0.933	0.929	0.892	0.814
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Average basin slope	Selective cut	Basin Area (sqmi)	Cove hardwood
Channel slope	Pearson Correlation	-0.400	0.580	-0.556	-0.541	0.535
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Xeric oak	Pine oak	Pine	Stream miles
Treeless	Pearson Correlation	0.399	0.814	0.809	0.744	0.728
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Average basin slope	Undisturbed	Channel slope	Heathbald
Selective cut	Pearson Correlation	0.379	-0.686	-0.642	-0.556	-0.444
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Undisturbed	Northern hardwood	Mesic oak	Stream miles
Lightcut	Pearson Correlation	0.361	-0.447	-0.377	0.282	0.254
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Mixed mesic hardwood	Pine	Xeric oak	Grape thicket
Fish Elevation (ft)	Pearson Correlation	-0.340	-0.815	-0.607	-0.586	-0.571
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Grassybald	Undisturbed	Fish Elevation (ft)	Sprucefir
Settlement	Pearson Correlation	0.281	0.437	-0.365	-0.364	-0.350
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253

Table A.33. continued

		RBT ADT Biomass	Undisturbed	Mesic oak	Fish Elevation (ft)	Selective cut
Sprucefir	Pearson Correlation	-0.375	0.525	-0.491	0.449	-0.433
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Pine	Xeric oak	Treeless	Grape thicket
Pine oak	Pearson Correlation	0.372	0.970	0.929	0.809	0.770
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Pine oak	Xeric oak	Grape thicket	Treeless
Pine	Pearson Correlation	0.368	0.970	0.933	0.777	0.744
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Xeric oak	Pine	Pine oak	Treeless
Grape thicket	Pearson Correlation	0.352	0.892	0.777	0.770	0.688
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Undisturbed	Mesic oak	Mixed mesic hardwood	Fish Elevation (ft)
Heavy cut	Pearson Correlation	0.270	-0.605	0.568	-0.391	0.340
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Tulip poplar	Fish Elevation (ft)	Grape thicket	Mixed mesic hardwood
Northern hardwood	Pearson Correlation	-0.213	-0.570	0.562	-0.495	-0.462
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Fish Elevation (ft)	Pine	Pine oak	Xeric oak
Mixed mesic hardwood	Pearson Correlation	0.191	-0.815	0.681	0.635	0.555
	Sig. (2-tailed)	0.011	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Undisturbed	Heavy cut	Sprucefir	Cove hardwood
Mesic oak	Pearson Correlation	0.181	-0.636	0.568	-0.491	0.398
	Sig. (2-tailed)	0.017	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Pine oak	Pine	Xeric oak	Treeless
Cove hardwood	Pearson Correlation	-0.166	-0.629	-0.624	-0.596	-0.579
	Sig. (2-tailed)	0.028	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Pine	Pine oak	Mixed mesic hardwood	Xeric oak
Grassybald	Pearson Correlation	0.156	0.594	0.579	0.461	0.456
	Sig. (2-tailed)	0.040	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Selective cut	Channel slope	Pine	Pine oak
Heathbald	Pearson Correlation	-0.108	-0.444	0.379	-0.346	-0.338
	Sig. (2-tailed)	0.156	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Northern hardwood	Fish Elevation (ft)	Pine	Pine oak
Tulip poplar	Pearson Correlation	0.060	-0.570	-0.554	0.468	0.462
	Sig. (2-tailed)	0.429	0.000	0.000	0.000	0.000
	N	174	253	253	253	253

Table A.34. Rainbow trout adult biomass and precipitation

		RBT ADT Biomass	Weighted Precip730	Closest Precip365	Closest Precip180	Weighted Precip180
Closest Precip730	Pearson Correlation	-0.333	0.856	0.853	0.833	0.736
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	158	222	233	233	233
		RBT ADT Biomass	Closest Precip90	Weighted Precip180	Closest Precip180	Weighted Precip365
Weighted Precip90	Pearson Correlation	-0.299	0.888	0.852	0.779	0.704
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	166	245	240	243	235
		RBT ADT Biomass	Weighted Precip90	Closest Precip180	Closest Precip30	Weighted Precip180
Closest Precip90	Pearson Correlation	-0.265	0.888	0.878	0.783	0.748
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	166	245	243	245	240
		RBT ADT Biomass	Weighted Precip180	Closest Precip90	Closest Precip365	Closest Precip730
Closest Precip180	Pearson Correlation	-0.239	0.883	0.878	0.838	0.833
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	0.000
	N	165	240	243	243	233
		RBT ADT Biomass	Weighted Precip365	Closest Precip730	Closest Precip180	Weighted Precip730
Closest Precip365	Pearson Correlation	-0.231	0.861	0.853	0.838	0.730
	Sig. (2-tailed)	0.003	0.000	0.000	0.000	0.000
	N	165	235	233	243	222
		RBT ADT Biomass	Weighted Precip180	Weighted Precip365	Closest Precip730	Closest Precip180
Weighted Precip730	Pearson Correlation	-0.221	0.872	0.860	0.856	0.747
	Sig. (2-tailed)	0.007	0.000	0.000	0.000	0.000
	N	149	222	222	222	222
		RBT ADT Biomass	Closest Precip180	Weighted Precip730	Weighted Precip90	Weighted Precip365
Weighted Precip180	Pearson Correlation	-0.220	0.883	0.872	0.852	0.851
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000
	N	163	240	222	240	235
		RBT ADT Biomass	Closest Precip30	Closest Precip90	Weighted Precip90	Closest Precip180
Weighted Precip30	Pearson Correlation	-0.218	0.866	0.693	0.677	0.578
	Sig. (2-tailed)	0.005	0.000	0.000	0.000	0.000
	N	166	245	245	245	243
		RBT ADT Biomass	Closest Precip365	Weighted Precip730	Weighted Precip180	Closest Precip180
Weighted Precip365	Pearson Correlation	-0.144	0.861	0.860	0.851	0.748
	Sig. (2-tailed)	0.070	0.000	0.000	0.000	0.000
	N	159	235	222	235	235
		RBT ADT Biomass	Weighted Precip7	Weighted Precip30	Closest Precip180	Closest Precip730
Closest Precip7	Pearson Correlation	-0.132	0.929	0.286	0.208	0.197
	Sig. (2-tailed)	0.090	0.000	0.000	0.001	0.003
	N	166	245	245	243	233
		RBT ADT Biomass	Weighted Precip30	Closest Precip90	Closest Precip180	Weighted Precip90
Closest Precip30	Pearson Correlation	-0.132	0.866	0.783	0.614	0.576
	Sig. (2-tailed)	0.090	0.000	0.000	0.000	0.000
	N	166	245	245	243	245
		RBT ADT Biomass	Closest Precip7	Weighted Precip30	Weighted Precip180	Weighted Precip90
Weighted Precip7	Pearson Correlation	-0.098	0.929	0.276	0.150	0.135
	Sig. (2-tailed)	0.207	0.000	0.000	0.020	0.035
	N	166	245	245	240	245

Table A.35. Rainbow trout adult biomass and geology

		RBT ADT Biomass	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone	Metcalf phyllite
Anakeesta	Pearson Correlation	-0.437	-0.613	-0.285	-0.234	-0.233
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Metcalf phyllite	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Limestone	Pearson Correlation	0.427	0.930	0.696	0.312	-0.266
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Limestone	Cades sandstone	Elkmont sandstone	Thunderhead sandstone
Metcalf phyllite	Pearson Correlation	0.424	0.930	0.900	0.536	-0.356
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Metcalf phyllite	Limestone	Elkmont sandstone	Thunderhead sandstone
Cades sandstone	Pearson Correlation	0.355	0.900	0.696	0.578	-0.357
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Roaringfork sandstone	Basement complex	Anakeesta	Richbutt sandstone
Longarm quartzite	Pearson Correlation	0.245	0.781	0.649	-0.186	0.148
	Sig. (2-tailed)	0.001	0.000	0.000	0.003	0.018
	N	174	253	253	253	253
		RBT ADT Biomass	Richbutt sandstone	Thunderhead sandstone	Anakeesta	Great Smoky Group
Pigeon siltstone	Pearson Correlation	-0.200	0.338	0.302	-0.234	-0.138
	Sig. (2-tailed)	0.008	0.000	0.000	0.000	0.029
	N	174	253	253	253	253
		RBT ADT Biomass	Basement complex	Longarm quartzite	Anakeesta	Richbutt sandstone
Roaringfork sandstone	Pearson Correlation	0.189	0.962	0.781	-0.231	0.211
	Sig. (2-tailed)	0.012	0.000	0.000	0.000	0.001
	N	174	253	253	253	253
		RBT ADT Biomass	Cades sandstone	Metcalf phyllite	Thunderhead sandstone	Limestone
Elkmont sandstone	Pearson Correlation	0.186	0.578	0.536	-0.428	0.312
	Sig. (2-tailed)	0.014	0.000	0.000	0.000	0.000
	N	174	253	253	253	253
		RBT ADT Biomass	Roaringfork sandstone	Longarm quartzite	Anakeesta	Great Smoky Group
Basement complex	Pearson Correlation	0.166	0.962	0.649	-0.178	-0.105
	Sig. (2-tailed)	0.029	0.000	0.000	0.004	0.096
	N	174	253	253	253	253
		RBT ADT Biomass	Anakeesta	Elkmont sandstone	Cades sandstone	Metcalf phyllite
Thunderhead sandstone	Pearson Correlation	0.145	-0.613	-0.428	-0.357	-0.356
	Sig. (2-tailed)	0.056	0.000	0.000	0.000	0.000
	N	174	253	253	253	253

Table A.35. continued

		RBT ADT Biomass	Thunderhead sandstone	Great Smoky Group	Elkmont sandstone	Metcalf phyllite
Metadiorite	Pearson Correlation	0.139	0.146	-0.091	-0.084	-0.069
	Sig. (2-tailed)	0.068	0.020	0.149	0.185	0.277
	N	174	253	253	253	253
		RBT ADT Biomass	Great Smoky Group	Thunderhead sandstone	Elkmont sandstone	Pigeon siltstone
Unnamed sandstone	Pearson Correlation	-0.103	0.892	-0.297	-0.110	-0.091
	Sig. (2-tailed)	0.177	0.000	0.000	0.080	0.150
	N	174	253	253	253	253
		RBT ADT Biomass	Unnamed sandstone	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone
Great Smoky Group	Pearson Correlation	-0.065	0.892	-0.343	-0.138	-0.136
	Sig. (2-tailed)	0.391	0.000	0.000	0.029	0.031
	N	174	253	253	253	253
		RBT ADT Biomass	Pigeon siltstone	Roaringfork sandstone	Thunderhead sandstone	Anakeesta
Richbutt sandstone	Pearson Correlation	-0.035	0.338	0.211	0.179	-0.174
	Sig. (2-tailed)	0.644	0.000	0.001	0.004	0.005
	N	174	253	253	253	253
		RBT ADT Biomass	Thunderhead sandstone	Pigeon siltstone	Roaringfork sandstone	Richbutt sandstone
Wadingbranch formation	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.
	N	174	253	253	253	253

Table A.36. SPSS model summary for young-of-year brook trout biomass

Model Summary^f

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.557 ^a	.311	.307	1.49655	.311	88.367	1	196	.000
2	.688 ^b	.474	.468	1.31106	.163	60.382	1	195	.000
3	.713 ^c	.509	.501	1.26961	.035	13.941	1	194	.000
4	.733 ^d	.537	.527	1.23640	.028	11.563	1	193	.001
5	.745 ^e	.556	.544	1.21413	.019	8.145	1	192	.005

a. Predictors: (Constant), FishElevationft

b. Predictors: (Constant), FishElevationft, Elevation2

c. Predictors: (Constant), FishElevationft, Elevation2, MedianSulfate

d. Predictors: (Constant), FishElevationft, Elevation2, MedianSulfate, RBTTTotalBiomass

e. Predictors: (Constant), FishElevationft, Elevation2, MedianSulfate, RBTTTotalBiomass, WeightedMaxYearlyFlow

f. Dependent Variable: BKTYOYBiomass

Table A.37. SPSS coefficients for young-of-year brook trout biomass

Coefficients^a

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-2.6233	.394	-6.663	.000					
	FishElevationft	.0012	.000	9.400	.000	.557	.557	.557	1.000	1.000
2	(Constant)	-2.5639	.345	-7.432	.000					
	FishElevationft	.0010	.000	8.439	.000	.557	.517	.438	.937	1.067
	Elevation2	8.7E-007	.000	7.771	.000	.531	.486	.404	.937	1.067
3	(Constant)	-1.8961	.379	-5.004	.000					
	FishElevationft	.0010	.000	8.790	.000	.557	.534	.442	.937	1.068
	Elevation2	7.4E-007	.000	6.543	.000	.531	.425	.329	.854	1.172
	MedianSulfate	-.0155	.004	-3.734	.000	-.331	-.259	-.188	.908	1.102
4	(Constant)	-1.1135	.435	-2.560	.011					
	FishElevationft	.0008	.000	6.825	.000	.557	.441	.334	.778	1.286
	Elevation2	7.8E-007	.000	7.037	.000	.531	.452	.345	.844	1.185
	MedianSulfate	-.0176	.004	-4.292	.000	-.331	-.295	-.210	.888	1.126
	RBTTTotalBiomass	-.0225	.007	-3.401	.001	-.284	-.238	-.167	.812	1.231
5	(Constant)	-.5532	.470	-1.177	.241					
	FishElevationft	.0007	.000	6.167	.000	.557	.407	.297	.741	1.349
	Elevation2	7.9E-007	.000	7.233	.000	.531	.463	.348	.844	1.185
	MedianSulfate	-.0147	.004	-3.540	.001	-.331	-.248	-.170	.835	1.198
	RBTTTotalBiomass	-.0224	.007	-3.444	.001	-.284	-.241	-.166	.812	1.231
	WeightedMaxYearlyFlow	-.0002	.000	-2.854	.005	-.332	-.202	-.137	.880	1.137

a. Dependent Variable: BKTYOYBiomass

Table A.38. SPSS model summary for adult brook trout biomass

Model Summary^e

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.634 ^a	.402	.399	14.62843	.402	132.007	1	196	.000
2	.727 ^b	.528	.524	13.02969	.126	52.049	1	195	.000
3	.769 ^c	.591	.585	12.16038	.063	29.877	1	194	.000
4	.797 ^d	.635	.627	11.52163	.044	23.106	1	193	.000

a. Predictors: (Constant), FishElevationft

b. Predictors: (Constant), FishElevationft, Anakeesta

c. Predictors: (Constant), FishElevationft, Anakeesta, Elevation2

d. Predictors: (Constant), FishElevationft, Anakeesta, Elevation2, RBTTotalBiomass

e. Dependent Variable: ActualBKTADTBiomass

Table A.39. SPSS coefficients for adult brook trout biomass

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-29.573	3.848		-7.685	.000	-37.162	-21.984					
	FishElevationft	.014	.001	.634	11.489	.000	.012	.017	.634	.634	.634	1.000	1.000
2	(Constant)	-31.404	3.437		-9.137	.000	-38.183	-24.626					
	FishElevationft	.016	.001	.729	14.322	.000	.014	.019	.634	.716	.704	.934	1.071
	Anakeesta	-.189	.026	-.367	-7.215	.000	-.240	-.137	-.179	-.459	-.355	.934	1.071
3	(Constant)	-30.605	3.211		-9.531	.000	-36.938	-24.272					
	FishElevationft	.014	.001	.641	12.770	.000	.012	.017	.634	.676	.586	.837	1.195
	Anakeesta	-.148	.026	-.288	-5.805	.000	-.199	-.098	-.179	-.385	-.266	.855	1.170
	Elevation2	5.92E-006	.000	.271	5.466	.000	.000	.000	.491	.365	.251	.858	1.166
4	(Constant)	-21.581	3.575		-6.037	.000	-28.632	-14.530					
	FishElevationft	.012	.001	.545	10.583	.000	.010	.015	.634	.606	.460	.713	1.403
	Anakeesta	-.151	.024	-.294	-6.239	.000	-.199	-.103	-.179	-.410	-.271	.854	1.171
	Elevation2	6.62E-006	.000	.303	6.385	.000	.000	.000	.491	.418	.278	.841	1.189
	RBTTotalBiomass	-.293	.061	-.229	-4.807	.000	-.414	-.173	-.382	-.327	-.209	.830	1.205

a. Dependent Variable: ActualBKTADTBiomass

Table A.40. SPSS model summary for young-of-year rainbow trout biomass

Model Summary^f

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.825 ^a	.680	.678	1.36787	.680	416.167	1	196	.000
2	.839 ^b	.703	.700	1.32053	.023	15.305	1	195	.000
3	.848 ^c	.720	.715	1.28653	.017	11.441	1	194	.001
4	.856 ^d	.732	.727	1.25999	.013	9.260	1	193	.003
5	.860 ^e	.740	.733	1.24580	.007	5.423	1	192	.021

a. Predictors: (Constant), BasinAreaMi2

b. Predictors: (Constant), BasinAreaMi2, ClosestPrecip90

c. Predictors: (Constant), BasinAreaMi2, ClosestPrecip90, LogCond

d. Predictors: (Constant), BasinAreaMi2, ClosestPrecip90, LogCond, Anakeesta

e. Predictors: (Constant), BasinAreaMi2, ClosestPrecip90, LogCond, Anakeesta, sing

f. Dependent Variable: RBTYOYBiomass

Table A.41. SPSS coefficients for young-of-year rainbow trout biomass

Coefficients ^a											
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-.6140	.122		-5.022	.000					
	BasinAreaMi2	.2924	.014	.825	20.400	.000	.825	.825	.825	1.000	1.000
2	(Constant)	.4584	.298		1.536	.126					
	BasinAreaMi2	.2797	.014	.789	19.677	.000	.825	.816	.768	.948	1.055
	ClosestPrecip90	-.0519	.013	-.157	-3.912	.000	-.337	-.270	-.153	.948	1.055
3	(Constant)	-1.3956	.620		-2.249	.026					
	BasinAreaMi2	.2369	.019	.668	12.625	.000	.825	.672	.480	.516	1.937
	ClosestPrecip90	-.0587	.013	-.177	-4.489	.000	-.337	-.307	-.171	.925	1.081
	LogCond	1.8588	.550	.174	3.382	.001	.626	.236	.129	.544	1.839
4	(Constant)	-1.4640	.608		-2.408	.017					
	BasinAreaMi2	.2327	.018	.656	12.624	.000	.825	.673	.470	.513	1.948
	ClosestPrecip90	-.0528	.013	-.160	-4.077	.000	-.337	-.282	-.152	.904	1.106
	LogCond	1.9912	.540	.187	3.688	.000	.626	.257	.137	.540	1.851
	Anakeesta	-.0076	.002	-.115	-3.043	.003	-.181	-.214	-.113	.963	1.039
5	(Constant)	-1.9868	.642		-3.096	.002					
	BasinAreaMi2	.2128	.020	.600	10.579	.000	.825	.607	.389	.421	2.374
	ClosestPrecip90	-.0428	.014	-.129	-3.162	.002	-.337	-.223	-.116	.812	1.232
	LogCond	2.2571	.546	.212	4.134	.000	.626	.286	.152	.517	1.935
	Anakeesta	-.0073	.002	-.111	-2.943	.004	-.181	-.208	-.108	.960	1.042
	sinq	-.4485	.193	-.105	-2.329	.021	-.467	-.166	-.086	.668	1.498

a. Dependent Variable: RBTYOYBiomass

Table A.42. SPSS model summary for adult rainbow trout biomass

Model Summary^e

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.632 ^a	.399	.396	10.29073	.399	130.145	1	196	.000
2	.656 ^b	.431	.425	10.04122	.032	10.862	1	195	.001
3	.693 ^c	.480	.472	9.62559	.049	18.204	1	194	.000
4	.708 ^d	.501	.491	9.44684	.022	8.411	1	193	.004

a. Predictors: (Constant), BasinAreaMi2

b. Predictors: (Constant), BasinAreaMi2, BKTTTotalBiomass

c. Predictors: (Constant), BasinAreaMi2, BKTTTotalBiomass, MedianSulfate

d. Predictors: (Constant), BasinAreaMi2, BKTTTotalBiomass, MedianSulfate, LogANC

e. Dependent Variable: RBTADTBiomass

Table A.43. SPSS coefficients for adult rainbow trout biomass

Coefficients ^a													
		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	3.099	.920		3.369	.001	1.285	4.913					
	BasinAreaMi2	1.230	.108	.632	11.408	.000	1.018	1.443	.632	.632	.632	1.000	1.000
2	(Constant)	5.489	1.154		4.757	.000	3.213	7.765					
	BasinAreaMi2	1.105	.112	.567	9.872	.000	.884	1.325	.632	.577	.533	.884	1.131
	BKTTtotalBiomass	-.125	.038	-.189	-3.296	.001	-.200	-.050	-.382	-.230	-.178	.884	1.131
3	(Constant)	11.687	1.826		6.401	.000	8.086	15.289					
	BasinAreaMi2	1.055	.108	.542	9.779	.000	.842	1.268	.632	.575	.507	.874	1.144
	BKTTtotalBiomass	-.175	.038	-.265	-4.581	.000	-.250	-.100	-.382	-.312	-.237	.801	1.249
	MedianSulfate	-.135	.032	-.232	-4.267	.000	-.197	-.073	-.155	-.293	-.221	.906	1.104
4	(Constant)	3.132	3.452		.907	.365	-3.676	9.940					
	BasinAreaMi2	.728	.155	.374	4.699	.000	.422	1.033	.632	.320	.239	.409	2.446
	BKTTtotalBiomass	-.198	.038	-.300	-5.166	.000	-.273	-.122	-.382	-.349	-.263	.767	1.304
	MedianSulfate	-.104	.033	-.180	-3.189	.002	-.169	-.040	-.155	-.224	-.162	.813	1.230
	LogANC	6.026	2.078	.226	2.900	.004	1.928	10.125	.544	.204	.147	.426	2.348

a. Dependent Variable: RBTADTBiomass

Residual Analysis

For a linear regression model, the error terms are assumed to be independent normal random variables, with a mean of zero and constant variance. In order to check these assumptions, residual analysis must be performed. First the assumption of normality can be checked by preparing a normal probability plot of the residuals. A plot that is nearly linear suggests agreement with normality, whereas a plot that departs from linearity suggests that the errors are not normally distributed (Neter, 1996). A sample normal probability plot for the young-of-year brook trout model is shown in Figure A.8. The residuals deviate significantly from a straight line indicating lack of normality. The large number of outlying residuals points causes the tails to exhibit curvature. To further confirm this, a goodness of fit test was used. Normality was rejected at any reasonable confidence level ($p=0.001$).

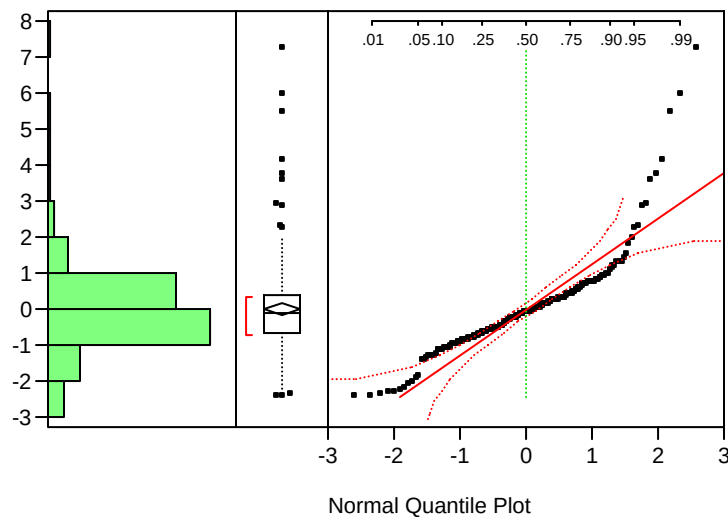


Figure A.8. Normal probability plot for adult brook trout residuals

Next, randomness of the residuals can be checked using partial residual plots. In this case, the residuals are plotted by each of the independent variables. The points on the plot should be randomly distributed about the horizontal axis with a proportionate amount above and below zero. Sample partial residual plots for the young-of-year brook trout model are shown in Figures A.9, 10, 11, and 12.

The residuals in Figure A.9 seem to be randomly scattered except for the a few large positive residuals in the upper portion of the plot. Some of these large residuals are from sites like Indian Camp and Cosby Creek that have relatively large brook trout biomass and low elevation (less than 2700 feet). The other problem residuals are from sites like Beech, Hazel, Flat, and Bunches Creek that have very large brook trout biomass and high elevations (greater than 3300 feet).

The residuals in Figure A.10 also seem to be randomly scattered with a few extremely large positive and negative residuals. The large positive residuals are from sites like Indian Camp, Cosby, Beech, Hazel, Flat, and Bunches Creek which have very high brook trout biomass and relatively low sulfate concentrations. The large negative residuals on the right side of Figure A.10 all come from Walker Camp Prong site number 237. This particular site has no fish present and relatively large sulfate concentrations.

The residuals in Figure A.11 also seem to be randomly scattered with a few extremely large positive and negative residuals. As before, the large positive residuals are from Indian Camp, Cosby, Hazel, Flat, and Bunches Creek which have large brook trout biomass. The large negative residuals are from site 237 which has no fish.

The residuals in Figure A.12 seem to be randomly scattered with the exception of a few extremely large positive residuals on the left side of the plot and a few small

residuals on the far right side. The large positive residuals on the left are from sites like Indian Camp, Cosby, Hazel, Flat, and Bunches Creek that have only brook trout present. The small residuals on the far right side of the plot are from sites like Abrams, Palmer, and Sam's Creek which have only rainbow trout present.

Lastly, plots of residuals versus predicted values can be visually inspected for curvature and heteroscedasticity. In other words, these plots are used to determine whether the variance of the error terms is constant. Again all plots should appear random with no patterns. Figure A. 13 is a sample plot of residual versus predicted values for the young-of-year brook trout model. The plot suggests that the larger brook trout biomass is, the more spread out the residuals area. Therefore, for this model the error variance is not constant. A transformation of the dependent variable is often used to remedy such departures from the linear regression model (Neter et al., 1996). However for this analysis a transformation was not used because of two reasons: 1) no physical reason could be found to make a transformation of biomass, 2) results from regression analysis would be difficult to interpret if a transformation of biomass was used.

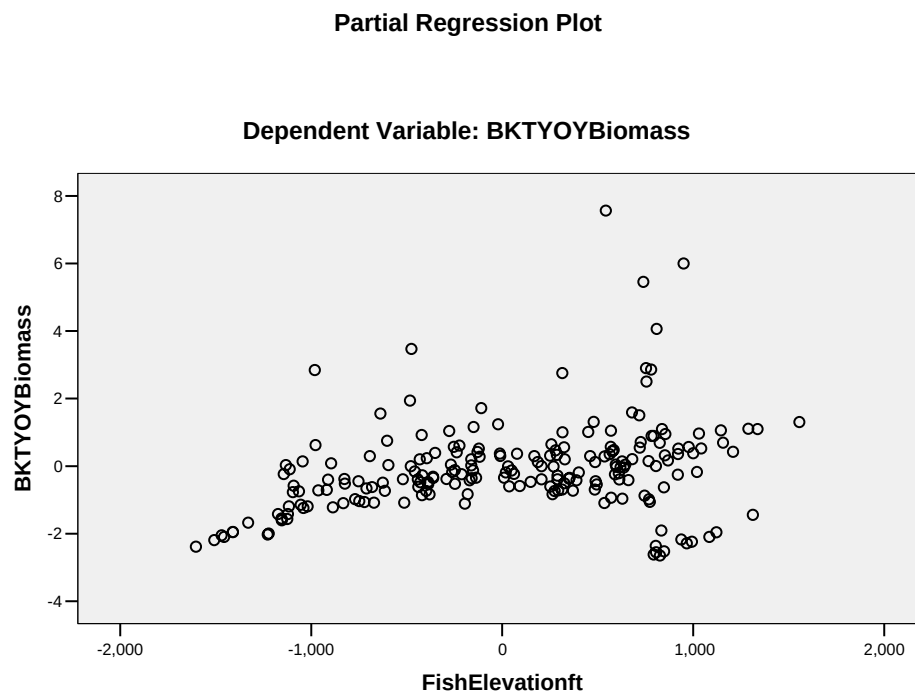


Figure A.9. Partial regression plot for young-of-year brook trout and elevation

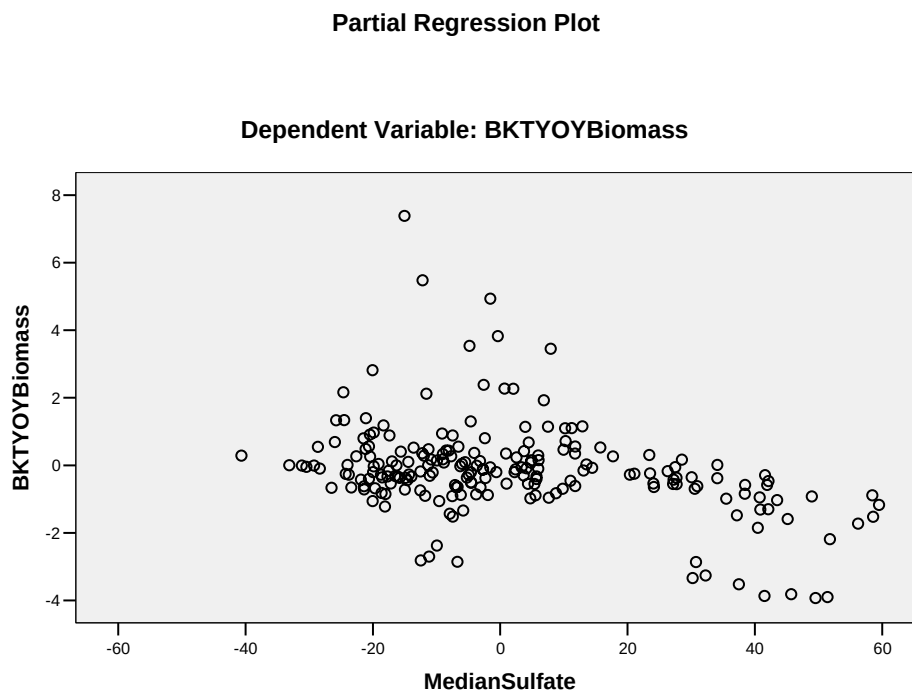


Figure A.10. Partial regression plot for young-of-year brook trout and sulfate

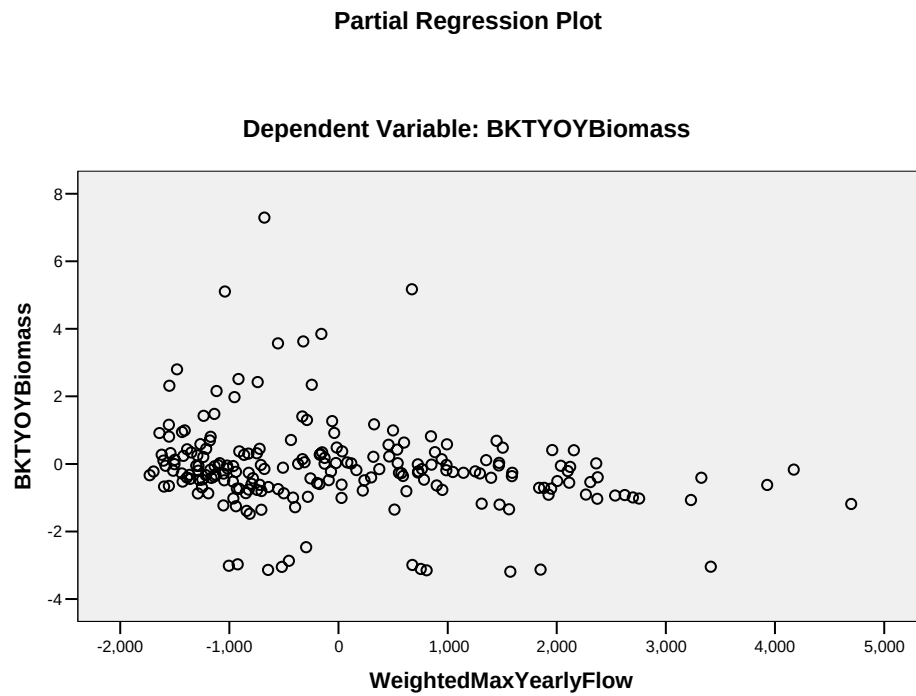


Figure A.11. Partial regression plot for young-of-year brook trout and flow

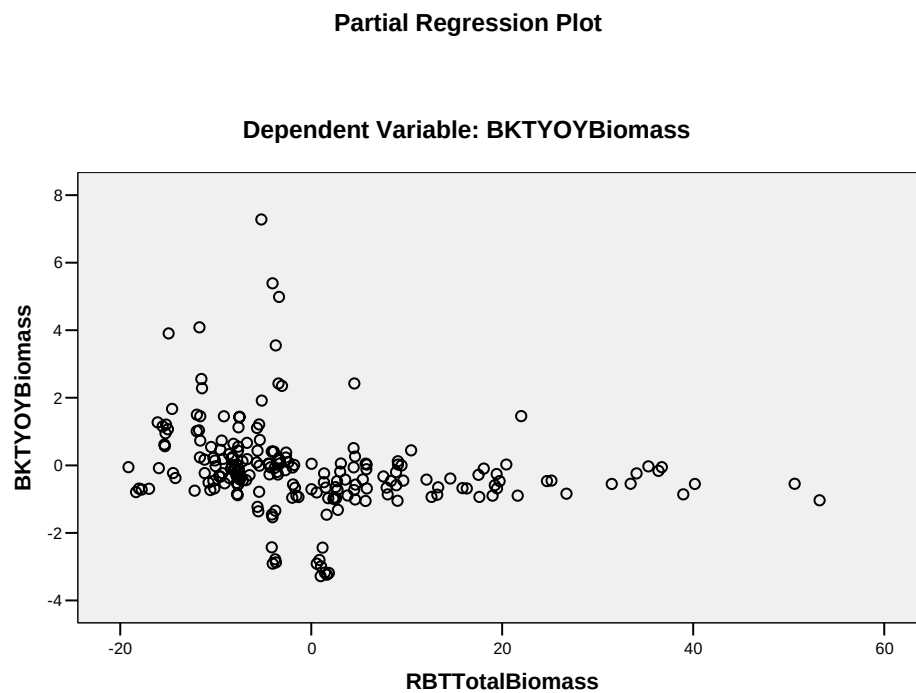


Figure A.12. Partial regression plot for young-of-year brook trout and rainbow biomass

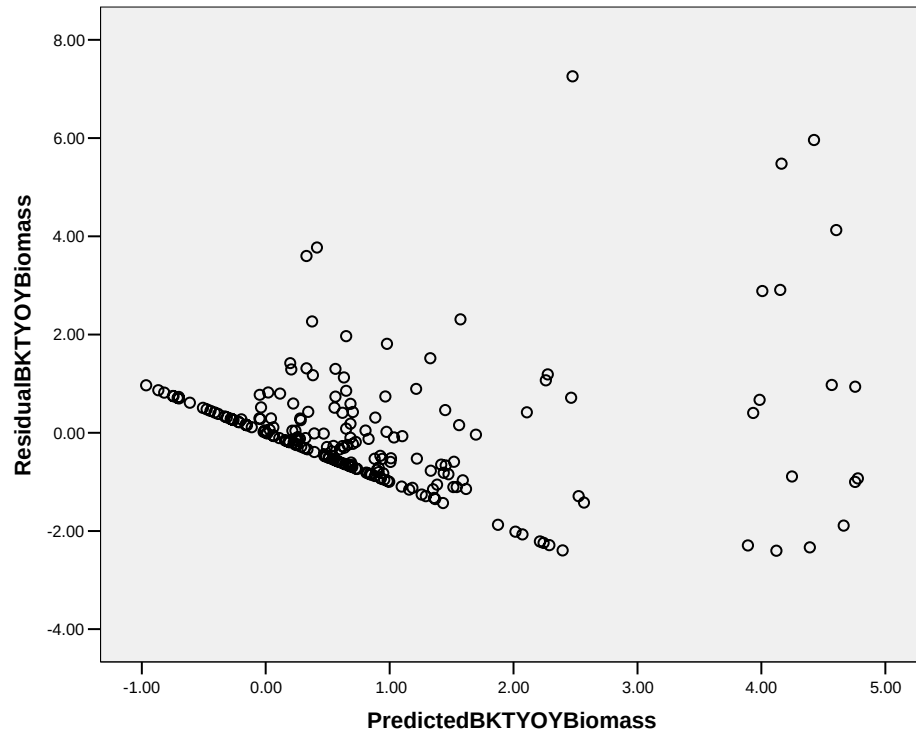


Figure A.13. Residual versus predicted young-of-year brook trout biomass

Outlier and Leverage Points Analysis

In addition to observations from partial regression plots, the influences of individual observations on the models selected by stepwise regression were evaluated by comparing each observation's Cook's D statistic. Influence is defined as observations which have both high leverage and large outliers (Helsel and Hirsch, 1992). These observations exert a strong influence on the regression model. A set value of the Cook's D statistic to measure influence was not used. Cook's D values for individual observations were observed and ones that appeared unreasonably large in comparison to other observations were noted.

Observations with relatively large Cook's D values in the young-of-year brook trout model are listed in Table A. 43. Observations for Indian Camp, Cosby, Hazel, Flat, and Bunches Creek also appear as outliers in the partial regression plots. All of these sites have only brook trout present. Site 237 appeared as an outlier in partial regression plots and has no fish present. Therefore it can be concluded that the observations in Table A.43 are exerting a strong influence on the model. However, removal of these observations cannot be justified because they appear to be valid points in the data set.

Table A.44. BKT YOY observations with large Cook's D

Site	Years
Site 1: Indian Camp at Old Settlers	1995
Site 114: Cosby Creek at log bridge	1997
Site 221: Hazel Creek above cascades	1999
Site 237: Walker Camp Prong at last bridge	1996-2003
Site 336: Flat Creek above falls	1996, 1998, 2000, 2003
Site 337: Bunches Creek at Flat Creek trail	1998, 2000-2003

Table A.45. SPSS model summary for sulfate

Model Summary^g

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.538 ^a	.290	.286	19.26181	.290	80.022	1	196	.000
2	.704 ^b	.496	.490	16.27728	.206	79.465	1	195	.000
3	.875 ^c	.765	.761	11.13613	.270	222.610	1	194	.000
4	.905 ^d	.818	.815	9.81821	.053	56.577	1	193	.000
5	.912 ^e	.831	.827	9.49517	.013	14.356	1	192	.000
6	.915 ^f	.837	.832	9.33980	.006	7.441	1	191	.007

a. Predictors: (Constant), Anakeesta

b. Predictors: (Constant), Anakeesta, Logcond

c. Predictors: (Constant), Anakeesta, Logcond, LogANC

d. Predictors: (Constant), Anakeesta, Logcond, LogANC, sinq

e. Predictors: (Constant), Anakeesta, Logcond, LogANC, sinq, ClosestPrecip180

f. Predictors: (Constant), Anakeesta, Logcond, LogANC, sinq, ClosestPrecip180, WeightedNumFlowDays50

g. Dependent Variable: MedianSulfate

Table A.46. SPSS coefficients for sulfate

Coefficients ^a												
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	30.906	1.635	18.903	.000	27.682	34.131					
	Anakeesta	.334	.037	8.945	.000	.261	.408	.538	.538	.538	1.000	1.000
2	(Constant)	-23.203	6.225	-3.727	.000	-35.480	-10.925					
	Anakeesta	.325	.032	10.291	.000	.263	.388	.538	.593	.523	.999	1.001
	Logcond	45.736	5.131	8.914	.000	35.617	55.854	.471	.538	.453	.999	1.001
3	(Constant)	-20.058	4.264	-4.704	.000	-28.468	-11.648					
	Anakeesta	.186	.024	7.897	.000	.140	.233	.538	.493	.275	.842	1.188
	Logcond	88.053	4.513	19.512	.000	79.152	96.953	.471	.814	.679	.604	1.655
	LogANC	-32.153	2.155	-14.920	.000	-36.403	-27.902	-.275	-.731	-.519	.550	1.818
4	(Constant)	-21.907	3.768	-5.815	.000	-29.338	-14.477					
	Anakeesta	.196	.021	9.415	.000	.155	.237	.538	.561	.289	.839	1.192
	Logcond	81.285	4.079	19.927	.000	73.239	89.330	.471	.820	.611	.575	1.739
	LogANC	-24.297	2.168	-11.207	.000	-28.573	-20.021	-.275	-.628	-.344	.423	2.367
	sinq	10.847	1.442	7.522	.000	8.003	13.692	.460	.476	.231	.739	1.352
5	(Constant)	-32.300	4.561	-7.082	.000	-41.296	-23.305					
	Anakeesta	.195	.020	9.680	.000	.155	.235	.538	.573	.287	.838	1.193
	Logcond	76.892	4.112	18.700	.000	68.782	85.002	.471	.803	.555	.529	1.889
	LogANC	-21.705	2.205	-9.841	.000	-26.055	-17.355	-.275	-.579	-.292	.382	2.619
	sinq	9.737	1.425	6.832	.000	6.926	12.548	.460	.442	.203	.708	1.412
	ClosestPrecip180	.291	.077	3.789	.000	.140	.443	.480	.264	.112	.752	1.331
6	(Constant)	-28.167	4.735	-5.949	.000	-37.507	-18.828					
	Anakeesta	.194	.020	9.810	.000	.155	.233	.538	.579	.286	.838	1.193
	Logcond	74.223	4.161	17.837	.000	66.015	82.430	.471	.790	.521	.500	2.000
	LogANC	-20.845	2.192	-9.509	.000	-25.169	-16.521	-.275	-.567	-.278	.374	2.674
	sinq	9.414	1.407	6.692	.000	6.639	12.189	.460	.436	.195	.703	1.422
	ClosestPrecip180	.312	.076	4.107	.000	.162	.462	.480	.285	.120	.744	1.344
	WeightedNum											
	FlowDays50	-.065	.024	-2.728	.007	-.113	-.018	-.286	-.194	-.080	.925	1.082

a. Dependent Variable: MedianSulfate

Table A.47. SPSS model summary for log(conductivity)

Model Summary^e

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.877 ^a	.768	.767	.10914	.768	649.912	1	196	.000
2	.955 ^b	.913	.912	.06706	.145	324.156	1	195	.000
3	.970 ^c	.942	.941	.05509	.029	94.903	1	194	.000
4	.975 ^d	.951	.950	.05057	.009	37.291	1	193	.000

a. Predictors: (Constant), Limestone

b. Predictors: (Constant), Limestone, MedianSulfate

c. Predictors: (Constant), Limestone, MedianSulfate, LogANC

d. Predictors: (Constant), Limestone, MedianSulfate, LogANC, BasinAreaMi2

e. Dependent Variable: Logcond

Table A.48. SPSS coefficients for log(conductivity)

Coefficients ^a													
		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	1.14012	.008		142.891	.000	1.124	1.156					
	Limestone	.04744	.002	.877	25.493	.000	.044	.051	.877	.877	.877	1.000	1.000
2	(Constant)	.99471	.009		105.285	.000	.976	1.013					
	Limestone	.04526	.001	.836	39.362	.000	.043	.048	.877	.942	.832	.989	1.011
	MedianSulfate	.00379	.000	.382	18.004	.000	.003	.004	.471	.790	.380	.989	1.011
3	(Constant)	.77285	.024		32.121	.000	.725	.820					
	Limestone	.03418	.001	.631	23.106	.000	.031	.037	.877	.856	.401	.403	2.479
	MedianSulfate	.00476	.000	.480	23.858	.000	.004	.005	.471	.864	.414	.744	1.343
	LogANC	.12546	.013	.275	9.742	.000	.100	.151	.589	.573	.169	.377	2.652
4	(Constant)	.81439	.023		35.244	.000	.769	.860					
	Limestone	.03234	.001	.597	23.253	.000	.030	.035	.877	.858	.370	.384	2.601
	MedianSulfate	.00457	.000	.461	24.635	.000	.004	.005	.471	.871	.392	.724	1.381
	LogANC	.08877	.013	.195	6.694	.000	.063	.115	.589	.434	.107	.300	3.338
	BasinAreaMi2	.00478	.001	.144	6.107	.000	.003	.006	.665	.402	.097	.459	2.180

a. Dependent Variable: Logcond