BASEFLOW TURBIDITY OF TRIBUTARIES TO THE UPPER LITTLE TENNESSEE RIVER, NORTH CAROLINA AND GEORGIA

by

LESLIE ANN MARTIN

(Under the Direction of David S. Leigh)

ABSTRACT

Turbidity levels at baseflow conditions were examined in relation to a gradient of land use/land cover types, topography, and stream density in 30 drainage basins within the upper Little Tennessee River watershed. Baseflow turbidity at each site was sampled on 11 separate occasions between November 2006 and May 2007. Relationships between baseflow turbidity and 27 independent variables were explored through correlation, linear regression and forward stepwise multiple regression. The watershed variables could be reduced to three components which explained 73% of the variance in baseflow turbidity, with pasture land cover demonstrating the greatest effect. A better understanding of the relationship between basin-scale land use and baseflow turbidity is essential to providing specific guidance on drainage basin alterations most detrimental to stream quality.

INDEX WORDS: baseflow, turbidity, suspended sediment, land use, land cover, Blue Ridge, Little Tennessee River

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RIVER BASIN, NORTH CAROLINA AND GEORGIA

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LESLIE ANN MARTIN

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LESLIE MARTIN

Major Professor: David S. Leigh

Committee: George Brook
Rhett Jackson

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

To my parents, Jayne and Gerry Martin, for providing unconditional and unflinching support to me for 26 years and counting.

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CHAPTER ONE

INTRODUCTION

Stream water quality is affected by the land use/land cover (LULC) of its drainage basin. Land use involving the removal or alteration of basin vegetation typically results in decreased infiltration and increased surface runoff (Dunne and Leopold, 1978; Knighton, 1998), which generally is linked to higher levels of sediment input to streams. Turbidity is the cloudiness of water, usually caused by suspended sediment. An increase in the turbidity level of a stream decreases its visual water quality, which in turn affects many environmental components including aquatic life (Zamor and Grossman, 2007; Walters et al., 2003; Sutherland et al., 2002; Walters et al., 2001; Meyer et al., 1999; Sutherland et al., 1999). By blocking sunlight penetration, chronically high turbidity can reduce photosynthesis, thus reducing the primary productivity of a fluvial system. In very turbid waters, sight feeders (i.e. most fish) cannot find their food. In addition, chronically high sediment levels can abrade gills or block gill function.

In general, increases in turbidity are associated with increased land disturbances from agriculture and urbanization (Galbraith and Burns, 2006; Roy et al., 2003; Walters et al., 2003; Lougheed et al., 2001). Soil erosion on cultivated land commonly is the most important contributor of sediment to fluvial systems (Walling and Fang, 2003; Meade et al., 1990). Timber harvesting, mining activities, animal grazing and second home and road construction are other anthropogenic factors that increase the sediment load of streams (Meade et al., 1990). In fact, Goudie (1981) argued that the greatest effect mankind has had on water quality is their contribution to levels of suspended sediment in streams. It is vital to understand the various contributors of turbidity, so that changes in water quality due to modified land use can be predicted and realistically modeled.

Objectives and Hypotheses

The primary objective of this study is to examine turbidity levels, as well as levels of total suspended solids (TSS), at baseflow conditions in relation to a gradient of LULC types in stream basins of the upper Little Tennessee River basin. The comparison of basins containing a wide variety of LULC types will allow for relationships between LULC classes and baseflow turbidity to be identified and for cause and effect relationships between LULC and baseflow turbidity to be inferred. In addition to studying the effects of LULC, this study incorporates other independent variables in an attempt to relate aspects of drainage basin topography, size, and stream density to baseflow NTU.

During rainless periods, the water that sustains streamflow is termed baseflow. Rainwater that percolates to the groundwater and reaches the stream gradually and over longer periods of time than stormflow constitutes baseflow (Dunne and Leopold, 1978). Sediment sources during baseflow differ from those of stormflow. During storms, overland runoff pulses large amounts of sediment into streams whereas baseflow turbidity is more indicative of chronic sedimentation or disturbance in the stream channel. The negative effects of turbidity can be withstood by biological communities for short periods of time. Therefore, if turbidity levels are high only during storms, then stream biota will not be significantly impacted. Turbidity levels become a concern when they are constantly elevated during normal baseflow conditions. The use of stormflow as a proxy for comparing streams is difficult, as flood discharges ideally must be sampled at the same point on a flood hydrograph. However, comparative sampling is easily facilitated during baseflow conditions. Thus, this study focuses on baseflow turbidity, in contrast to stormflow, because high baseflow turbidity levels denote a departure from the natural condition and will identify streams suffering from persistent sediment disturbance (Walters et al., 2003; TAG, 2002; Meyer et al., 1999).

A secondary objective of this study is to augment the existing relationship between NTU and TSS measurements that has been established for the Blue Ridge physiographic province (Sutherland et al., 1999). An established correlation between the two is important to monitor stream health, as NTU measurements are less costly and less time consuming than TSS measurements.

In regard to the research objectives, this study hypothesizes that higher turbidity values will accompany the conversion of forested LULC to developed LULC in a drainage basin (e.g. Price and Leigh, 2006a; Roy et al., 2003; Walters et al., 2003; Sutherland et al., 2002) and that baseflow turbidity will increase with the percentage of pasture and agricultural LULC in a drainage basin (e.g. Galbraith and Burns, 2006; Lougheed et al., 2001). This study hypothesizes that streams of longer length possess a higher chance of becoming turbid, and therefore expects drainage basin size, drainage density and length of watercourse to play a role in the variation of baseflow turbidity (e.g. Bolstad and Swank, 1997; Swank and Bolstad 1994; Simmons, 1993). Because turbidity is known to correlate with stream discharge, the results of this study are hypothesized to demonstrate this correlation (e.g. Lewis et al., 2002; Sutherland et al., 2002; Knighton, 1998).

CHAPTER TWO

BACKGROUND

Turbidity is a measurement of water clarity, measured as the amount of light that is scattered and absorbed as it passes through a water sample. The standard units for expressing turbidity are nephelometric turbidity units (NTU), thereby constituting an index of light scattering by suspended particles. However, turbidity can be measured in a variety of ways and there are many unresolved issues concerning the collection of turbidity data. For example, the use of different measurement methods may not give comparable results, and the instrumentation and methods are not standardized. These technological differences indicate that turbidity is not an absolute value, but a value representing a semi-quantitative measurement that can yield different readings based on the method and materials used (Ankcorn, 2003; Gray and Glysson, 2002; Ziegler, 2002).

Total suspended solids (TSS) are used to express water quality as a concentration (weight of solids/volume of water; mg/L) of mineral and organic sediment. This measurement typically is based on a 200-1000 mL volume of a stream water sample, determined by filtration. It specifically excludes dissolved solids in the reported value.

Turbidity measurements are commonly utilized as proxies for TSS. Turbidity is less expensive and more easily measured than TSS and studies have documented a strong relationship between the two measurements (Ankcorn, 2003; Holliday, et al., 2003; Christensen, et al., 2002; Lewis, 2002; Gippel, 1995). Turbidity is a useful measure when examining the relationship between suspended sediment and aquatic life because the quality and quantity of underwater light directly affect important animal behaviors such as foraging, hunting, and predator avoidance of fishes. Visual clarity has been found to be strongly related to NTU, but less strongly related to suspended sediment (Davies-Colley and Close, 1990). Therefore, in some instances, measuring the optical attributes of suspended sediment, or turbidity, is more applicable than the measurement of its mass concentration (Davies-Colley and Smith, 2001). In fact, the Georgia Board of Regents' Scientific Panel (1995) changed the preferred regulatory method for measuring the influence of sediment on water quality from TSS to NTU, concluding that turbidity measured in NTUs provides a more effective and cost efficient method of monitoring water quality than measuring TSS in mg/L.

However, while a relationship can be established between turbidity and TSS, the dynamics of this relationship are functions of watershed-specific factors and temporal trends across seasons (Lewis et al., 2002; Barnes et al., 1997), which can change spatially and temporally due to variations in sediment composition and stream energy (Rasmussen, 1995). Similar turbidity values from two different tributary watersheds could indicate appreciably different TSS values (Lewis et al., 2002). The amount of light scattered or absorbed in a water sample is a function of the size, shape, surface characteristics, and quantity of particles within the sample (Clifford et al., 1995; Gippel, 1995; Orbeco Analytical Systems, Inc., no date).

Particles of organic material strongly absorb incident light. Therefore, the organic material present in a water sample will prevent a significant portion of incident light from reaching the detecting system, resulting in an artificially high turbidity value. Organic sediments remain in suspension longer than do similarly-sized inorganic components, contributing more to turbidity. Thus, an increased proportion of suspended organic sediments would be expected to decrease primary production in fish assemblages. The separation of suspended load material into organic and inorganic fractions will provide a greater resolution of physical and biological conditions of watersheds than is currently being provided (Madej et al., 2002).

In general, baseflow NTU has been found to underestimate TSS, largely because of the operational differences between the two techniques. Suspended sediment concentrations are based on the total dry mass of sediment that is retained on a 0.7 micron glass-fiber filter after all water has passed through the filter. In contrast, NTU is based on the passage of light through the suspended sediment in a glass vial. After introducing a sample into the glass vial, sand and coarse silt particles, along with coarse organic particles, settle to the bottom of the vial and are not measured by the beam of light. Consequently, NTU measurements can be used to estimate sediment concentrations for fine soil fractions, but underestimates the total sediment concentration when sand-size fractions are present (Holliday et al., 2003; TAG, 2002). Fortunately for this study, there is a low likelihood that sand is transported under the slow flow velocities that typically characterize baseflow conditions.

To better represent water quality and sediment transport, the watershed-specific nature of turbidity and TSS relationships must be understood. In order for turbidity to serve as a surrogate for TSS, a numerically defined relationship for predicting TSS as a function of turbidity must be developed from data sets with paired measurements of the two parameters. This relationship should be established with data collected across a full range of streamflows to represent the seasonal and flow variability of TSS and turbidity (Lewis et al., 2002; Pavanelli and Pagliarani, 2002).

Literature Review

Barnes et al. (1997) revealed that when TSS data are plotted against corresponding NTU values, most points from the Blue Ridge province fall either on or below the 1:1 line, suggesting that NTU underestimates TSS. More recent studies found a strong correlation between NTU and TSS measurements for NTU values < 900, suggesting that NTU is a good indicator of TSS levels (Meyer et al., 1999; Sutherland et al., 1999). In fact, Sutherland et al. (1999) developed a regression equation ($r^2 = 0.93, n=106$) to convert NTU to its equivalent TSS units for Blue Ridge streams:

Equation 2.1 $$\mathrm{Log}_{10}\,\mathrm{TSS} = -0.059 + 1.118\,\mathrm{Log}_{10}\,\mathrm{NTU}$$

The Federal government has not yet established regulatory limits for turbidity or TSS. However, the Georgia Erosion and Sedimentation Act (ESCA) of 1975 (O.C.G.A. Section 12-7-1) attempts to establish and implement a statewide program to protect waters of the state from excess erosion and sedimentation that can occur during land disturbing activities. The ESCA requires that runoff from construction sites not cause an increase in turbidity of more than 25 NTU in receiving streams supporting warm water fisheries or more than 10 NTU for trout streams (O.C.G.A. Section 12-7-6(a)(2)). The Georgia Board of Regents scientific panel recommends an average instream turbidity standard of 25 NTU for trout and fishing streams, with an allowance for precipitation in excess of a 10-year event (TAG, 2002). The state of North Carolina has created regulatory limits for erosion control as well, wherein trout streams should have a turbidity limit of 10 NTU, while non-trout streams should not have a turbidity level over 50 NTU. Table 2.1 displays regulatory limits established in southeastern states (TAG, 2002).

Water clarity plays an important role in biological and ecological systems. Hence, NTU is a useful indicator of potential habitat degradation. Studies have documented the negative impact of turbidity on the species-rich streams of the Blue Ridge Mountains (Sutherland et al., 2002; Meyer et al., 1999). Meyer et al. (1999) observed that significant changes in fish assemblages occurred at baseflow turbidities between 10 and 15 NTU in the Blue Ridge physiographic province. Their study proposed standards that would protect fishes so that baseflow turbidity values in stream water should not exceed 15 NTU, and baseflow turbidity should only exceed 10 NTU in one out of five stream water samples. Meyer et al. (1999) assert that baseflow turbidity values in excess of these values threaten the integrity of southern Appalachian fish assemblages. Sutherland et al. (2002) identified the relative abundance of reproductive guilds as a predictor of impacts resulting from excessive sediment. At disturbed sites, where sediment transport was highest and silt/sand habitat was abundant, there was a decrease in fishes requiring clean riffle habitat for spawning. Upon analyzing fish biotic integrity in the Etowah River basin, Walters et al. (2001) found that NTU was negatively correlated with an index of biotic integrity (IBI), which assigns scores based on high quality, regional reference sites. Results indicate a linear decline in biotic integrity begins around 5 NTU. At levels greater than 10 NTU, IBI scores were consistently low, indicative of a significant negative impact to fish assemblages (Walters et al., 2001). These results were supported by a more recent study conducted in the Etowah River Basin which found baseflow NTU to be a statistically significant predictor of fish assemblage richness and abundance (Walters et al., 2003).

High suspended sediment levels in streams have detrimental effects beyond stream biota. For example, sedimentation can cause increased flooding, necessitate channel dredging and result in loss of reservoir storage. Suspended sediment can also degrade recreational uses of water, such as swimming, and reduces boating safety due to low visibility and inability to detect underwater hazards. Additionally, high levels of sediment in fluvial systems reduce the efficiency and increase the cost of drinking water purification (TAG, 2002; Pimentel et al., 1995).

In addition to altering the physical elements of a stream ecosystem, anthropogenic disturbance of a basin's landscape influences the biological elements of stream ecosystems. Variation in the structure of fish, invertebrate and algal assemblages is directly related to human-induced alterations of the landscape. In Southern Appalachian streams, biological assemblages have been found to differ structurally with respect to watershed LULC (Scott et al., 2002; Burcher and Benfield, 2006). Changes in the landscape associated with urbanization, such as increasing impervious cover and decreasing forested cover, are good predictors of community impairment and a decrease in biological integrity (Burcher and Benfield, 2006; Roy et al., 2003; Kennan and Ayers, 2002; Paul and Meyer, 2001; Sponseller, et al., 2001; Jones et al., 1999; Booth and Jackson, 1997). For example, results of a study conducted by Jones et al. (1999) signify riparian forest removal in excess of 1-3 km will have substantial detrimental effects on fish assemblages. Sponseller et al. (2001) also documents a decline in stream habitat and biological assemblages as the extent of agricultural land increases within catchments. The pesticides and other harmful fertilizer chemicals often used on agricultural lands may be partially responsible for the alteration of habitat quality (Pimental et al., 1995). In sum, the percent of forest cover in a watershed is positively related to the health and condition of aquatic communities. Anthropogenic alterations of the landscape due to urban, suburban, and agricultural development have been consistently linked to the deterioration of aquatic assemblage structure, thus contributing to the degradation of stream habitat and biota.

Baseflow turbidity and TSS levels in streams have been shown to be a function of land surface characteristics and land use activities. Both NTU and TSS are positively related to the percentage of pasture and agricultural land cover in a drainage basin and negatively to the percentage of indigenous forest cover (Galbraith and Burns, 2006; Lougheed et al., 2001). Various studies conducted in the Appalachian Highlands demonstrate that urban land cover is positively related to stream turbidity levels (Roy et al., 2003; Walters et al., 2003). In addition, work in the upper Little Tennessee River determined that streams draining less forested basins demonstrate significantly higher levels of baseflow TSS and/or turbidity than streams draining more forested basins (Price and Leigh, 2006a; Price and Leigh, 2006b; Scott et al., 2002; Sutherland et al., 2002).

Human-induced changes in LULC modify the physical landscape, thereby altering fluxes of water and sediment through the networks of stream channels. Subsequently, modification of the stream habitat induces significant changes in ecological processes and biological communities. Many areas within the Blue Ridge physiographic province are rapidly undergoing development. Few studies to determine the fluvial effects of urbanization have been conducted in the Southern Appalachian region, even though urbanization is increasing. Recently, however, the Environmental Protection Agency mandated that states develop plans to restore water quality in streams failing to meet criteria appropriate for their designated uses, which has increased the interest of fluvial geomorphology studies in the study area (Price and Leigh, 2006a; Price and Leigh, 2006b; Harden, 2004; Sutherland et al., 2002; Simmons, 1993). Quantifying and understanding how LULC affects water quality and stream processes is essential for determining how humans can minimize their impacts on stream ecosystems.

Table 2.1. Regulatory limits for erosion control in five Southeastern states, USA (TAG, 2002).

State	Limit
Alabama	Background + 50 NTU
Florida	Background + 29 NTU
Georgia	Trout streams: Background[1] + 10 NTU Non-trout streams: Background[1] + 25 NTU
North Carolina	Trout streams: 10 NTU Non-trout streams: 50 NTU
South Carolina	Background + 10%

[1]Background baseflow levels for the Blue Ridge province of Georgia are less than four NTU (Alhadeff and Landers, 2005).

CHAPTER THREE

STUDY AREA

Description

The upper Little Tennessee River basin, which flows northward into western North Carolina from northeastern Georgia, drains into Lake Fontana and is located in the Southern Blue Ridge physiographic province (Figure 3.1). The sub-basins sampled in this study are contained upstream of the upper Little Tennessee River's confluence with Iotla Creek, below Franklin, NC, and are within a drainage area of 863 km^2 (Table 3.1 & Figure 3.2). The study area includes parts of two states; northeast Georgia (Rabun County) and western North Carolina (Macon County). The center of the study area is located approximately at latitude N 35°07'05" and longitude W 83°20'39". Altitudes in the upper Little Tennessee River basin upstream of Iotla Creek range from 573 meters to 1650 meters above sea level (Figure 3.3 & Table 3.2). The average elevation within the study area is 874 meters above sea level. Please refer to Figures 3.4 a-b for representative photographs of the study area.

The regional climate is classified as having cool summers, mild winters, and adequate rainfall during all seasons, with a mean annual temperature of 13˚C (Collins, 2008). Overall, the Blue Ridge physiographic province experiences a great variation in precipitation, as the mountainous topography can drastically affect rainfall amounts in the space of a few kilometers. Annual precipitation is high, with an average of 178 cm at lower elevations to over 250 cm on upper slopes. The region has no pronounced rainy or dry seasons. Snow typically contributes less than 2 percent to total precipitation (Collins, 2008).

Due to the mountainous terrain of the study area, stream gradients are steep. The fast-flowing streams of this physiographic province are capable of transporting tremendous quantities of sediment. However, the amount of sediment supplied to these streams is considerably less than their carrying capacity. Channel degradation and migration are prevented in most steep mountain streams by natural rock outcrops and streambed armoring, which minimizes sediment contribution from the channel itself (Simmons, 1993).

The landscape within the study area has experienced various anthropogenic disturbances. Humans first arrived in Southern Appalachians around 12,000 years ago (Yarnell, 1998). Prior to the arrival of European settlers in the 1700s, North Carolina was almost totally forested and erosion was minimal. "Accounts by early explorers, historians, and geologists attest to the purity and clarity of the State's streams, even during storm runoff. As pristine forests fell to the settlers' axes, these once-clear streams ran muddy" (Simmons, 1993, p. 10). The region experienced dramatic and widespread land use change when logging activities peaked during the late 1800s and early 1900s. These exploitative land uses led to the federal purchase of land in the 1930s to create national forests in the eastern United States. Extensive public land holdings in the national forests are now covered with secondary forests dating from the early 1900s (Harden, 2004). Primarily because of the area’s population increase (Figure 3.5), significant changes in the privately owned landscape are underway. Much of the privately owned land has recently undergone suburban development, resulting in a rapid increase in residential and commercial development throughout the study area. “Sediment is the biggest threat to water quality in the [Little Tennessee River] basin” (Burgess, 2002, p 4). Historically, most of the eroded soil came from fields, pastures and dirt roads. However, in the past 20 years, a growing population and increased development for homes and driveways have increased sediment delivery to streams (Burgess, 2002).

Because the Little Tennessee River is a mountainous river, its tributaries typically have relatively steep gradients and riffle/pool habitats capable of supporting trout populations (The North Carolina Center for Geographic Information and Analysis, 2006; Georgia DNR, 2004; North Carolina Division of Water Quality, 2000). The Little Tennessee River also supports a large variety of other aquatic species and is widely known for its diversity of freshwater fishes and mussels, including 174 species of fish and 85 species of mussels (Hampson et al., 2000). Unfortunately, the overall diversity of these populations is slowly declining. Twenty-five of these mussel species are no longer found in the basin, mostly due to habitat destruction associated with reservoir impoundment. Eleven such species are believed to now be extinct (Hampson et al., 2000).

Many areas within the basin are currently facing development and urbanization. Fortunately, a substantial portion of the basin is located in the Nantahala and Chattahoochee National Forests, where development has been restricted since the 1930s. The presence of both protected and unprotected areas within the upper Little Tennessee River basin has resulted in a wide range of LULC in its tributaries. The development of a somewhat continuous LULC gradient provides the opportunity to assess stream response to a variety of LULC levels.

Site Selection and Physical Characteristics

Within the upper Little Tennessee River watershed, 30 sub-basins draining different levels of anthropogenic land cover were studied (Figure 3.6 and Table 3.4). The sampled basins are located nearby the Coweeta Long Term Ecological Research (LTER) facility at the U.S.D.A.

Forest Service Coweeta Hydrologic Research Laboratory near Otto, North Carolina. This study investigated turbidity on a small regional scale, consequently minimizing variability in the data attributed to natural factors such as climate, geology, elevation and suspended sediment particle composition traits. Small streams are most likely to reflect the land-use signature (Allen, 2004). Thus, low order tributaries draining between 2.70 and 18.07 km² were selected for sampling. All sampling locations were chosen at bridge crossings to maximize accessibility. Efforts were made to best represent the complete range of LULC found in the study area. The universal transverse Mercator (UTM) coordinates, bridge crossing road name, description of the sampling location in reference to the bridge crossing, and elevation of each sample location can be found in Appendix A.

A variety of basin parameters were calculated for use as independent variables in statistical correlations and regression models (Table 3.4). Boundaries of all 30 watersheds were delineated using standard GIS methods. The watershed delineation process involved the use of the Basin1 extension of ESRI ArcView® 3.3 (Petras, 2000) and a digital elevation model (DEM) with a resolution of 10 meter grid cells (U.S. Geological Survey, available from seamless.usgs.gov), which was corrected for sinks. The percentage of different land cover types present in each basin was calculated using Erdas Imagine® software. Land cover data grids acquired from the National Land Cover Database (NLCD), produced by the U. S. Geological Survey (USGS) for the year 2001, were clipped to each drainage basin. The dataset contains 21 different land cover classifications at a spatial resolution of 30 meters (USGS, 2001). Detailed descriptions of each land cover category, as defined by the USGS, can be found in Appendix B. The percentage of each land cover classification type in each basin was determined by dividing the number of cells defined in a classification category by the total number of cells contained in that basin. The Basin1 extension was employed to calculate numerous parameters for each basin: area, perimeter, average basin slope, average elevation, standard deviation of elevations, length of the longest watercourse, relative longest watercourse, and equivalent length of the basin. These, along with other physical basin characteristics, can be found in Table 3.5.

Please note that the most recent land cover data available was utilized in basin LULC percentage calculations. The USGS land cover classification was performed for the year 2001, yet the data collection for this study occurred in late 2006 and early 2007. The time lag between the land cover classification and the data collection could potentially be problematic. Although this study does not suspect that LULC has significantly changed in these five years, future development of this research should examine LULC more closely. One method of testing the accuracy of the 2001 land cover data is to obtain aerial imagery of the study area for late 2006 or early 2007, manually measure the percentage of each land cover category in the studied basins and assess the correlation between the two land cover datasets. Occasionally, the Coweeta LTER generates new land cover datasets for the study area, which can be compared against the 2001 USGS land cover data as well as used to update the LULC percentages for each drainage basin.

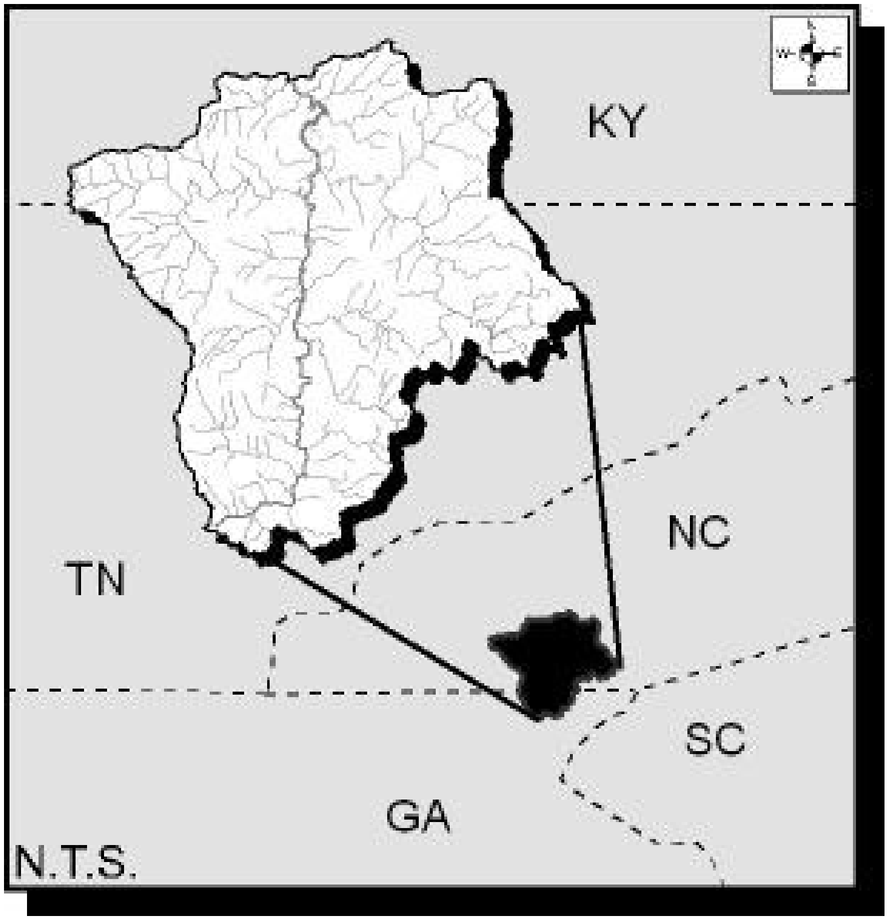

Figure 3.1. Study area: the upper Little Tennessee River basin.

Table 3.1. Land cover of the upper Little Tennessee River basin, upstream of Iotla Creek.

LULC type	%	Area (km²)
Open water	0.10	0.88
Developed- open space	7.05	60.82
Developed- low intensity	0.79	6.79
Developed- medium	0.21	1.82
Developed- high intensity	0.04	0.30
Barren land	0.11	0.96
Deciduous forest	74.53	642.83
Evergreen forest	2.63	22.70
Mixed forest	1.67	14.41
Shrub / scrub	1.63	14.05
Grassland / herbaceous	1.34	11.55
Pasture / hay	9.31	80.27
Cultivated crops	0.47	4.01
Woody wetlands	0.13	1.14

Land cover classification provided by the NLCD (USGS, 2001).

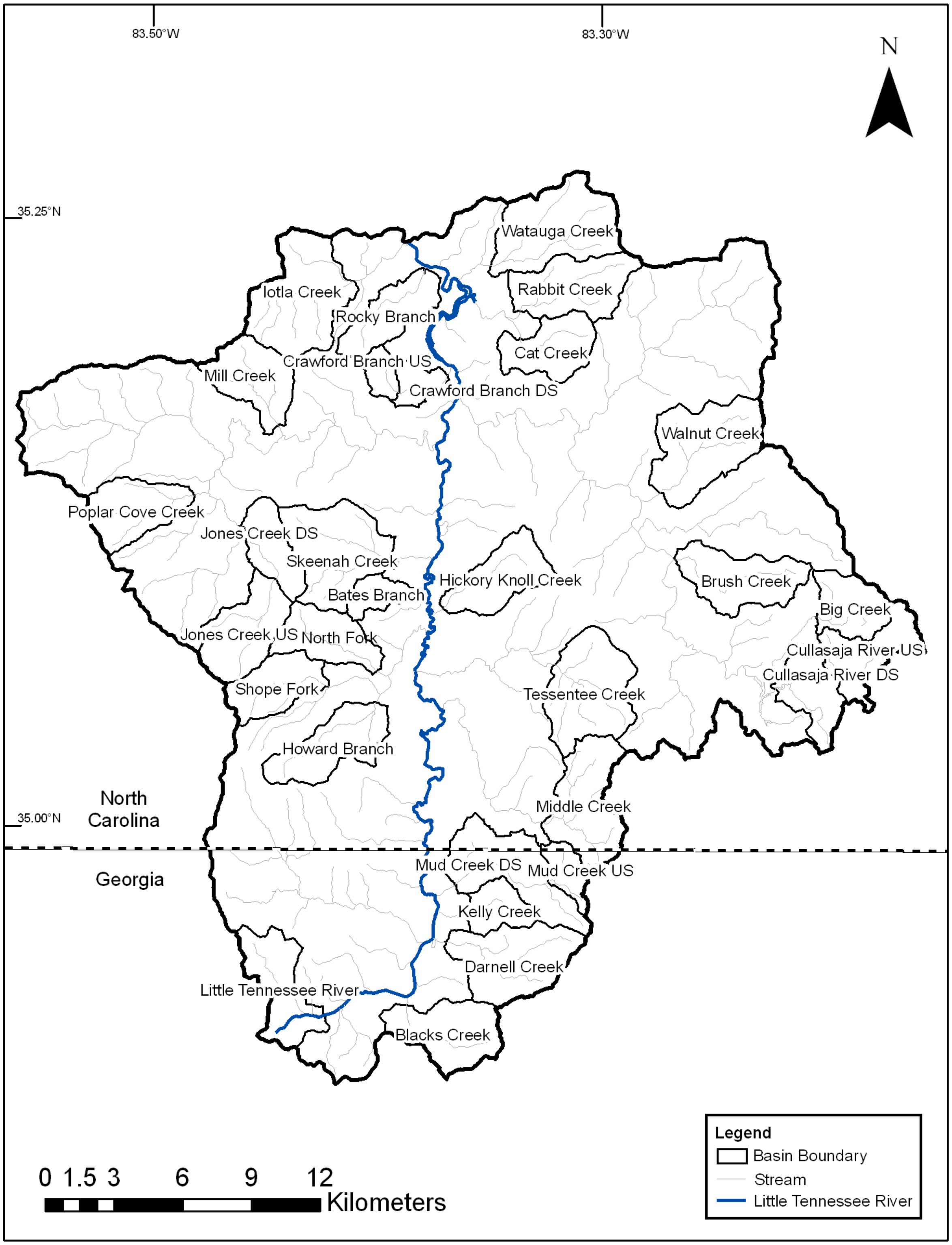

Figure 3.2. Thirty sub-basins within the upper Little Tennessee River watershed were selected for this study. The drainage basins of Crawford Branch, Cullasaja River, Jones Creek and Mud Creek were sampled at two different locations. The downstream sampling location is abbreviated as DS and the upstream sampling location is abbreviated as US.

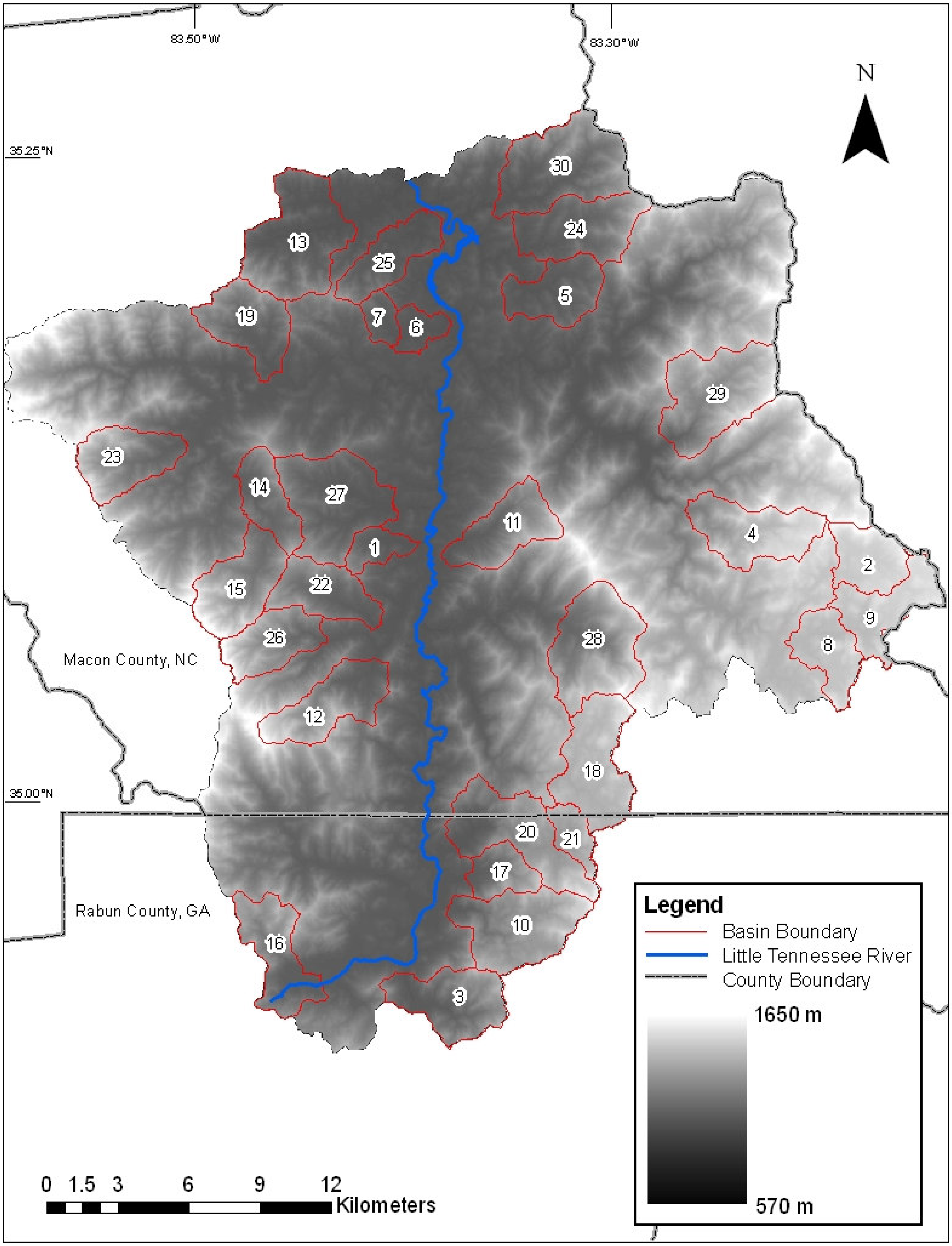

Figure 3.3. Elevations of the Little Tennessee River basin, upstream of Iotla Creek (USGS DEM). Basin names that correspond to each number can be found in Table 3.2.

Table 3.2. Basin name key for Figures 3.3 and 3.5.

1. Bates Branch	11. Hickory Knoll Creek	21. Mud Creek upstream
2. Big Creek	12. Howard Branch	22. North Fork
3. Blacks Creek	13. Iotla Creek	23. Poplar Cove Creek
4. Brush Creek	14. Jones Creek downstream	24. Rabbit Creek
5. Cat Creek	15. Jones Creek upstream	25. Rocky Branch
6. Crawford Branch downstream	16. Little Tennessee River	26. Shope Fork
7. Crawford Branch upstream	17. Kelly Creek	27. Skeenah Creek
8. Cullasaja River downstream	18. Middle Creek	28. Tessentee Creek
9. Cullasaja River upstream	19. Mill Creek	29. Walnut Creek
10. Darnell Creek	20. Mud Creek downstream	30. Watauga Creek

Figure 3.4a. Representative stream reach photograph, taken at Walnut Creek.

Figure 3.4b. Representative photograph of study area landscape (source: Ralph Preston).

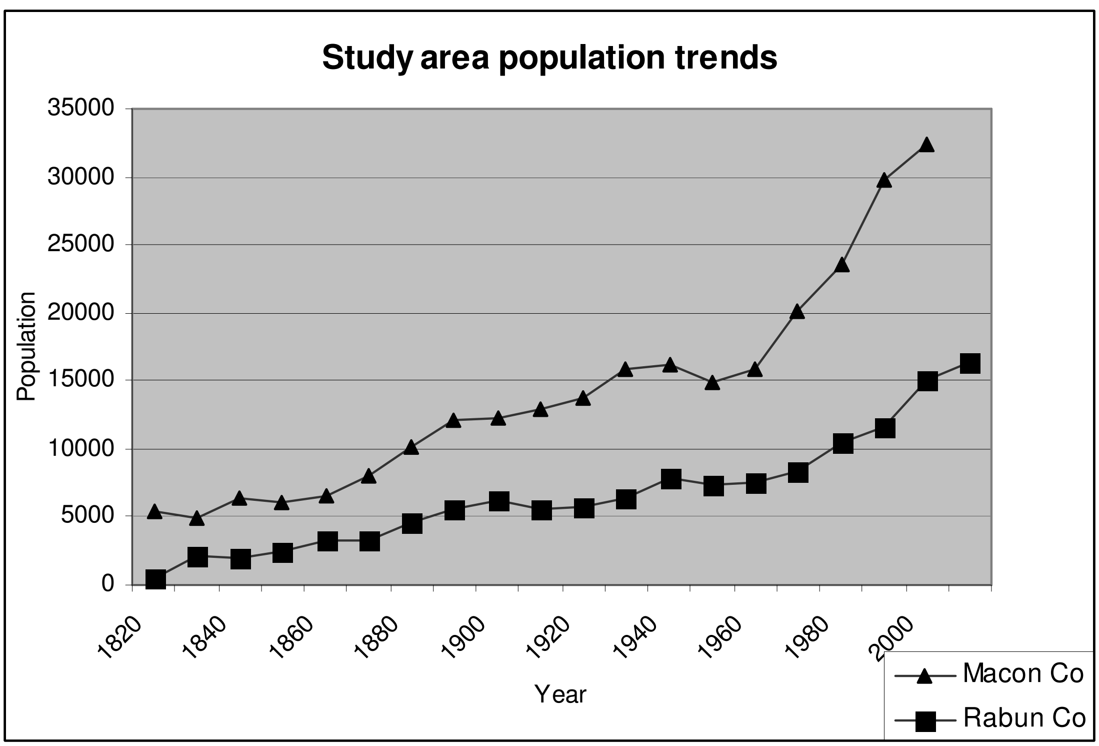

Figure 3.5. Macon County, North Carolina and Rabun County, Georgia population trends, 1820 – 2000. Population levels for 2006 are estimated (U.S. Census Bureau).

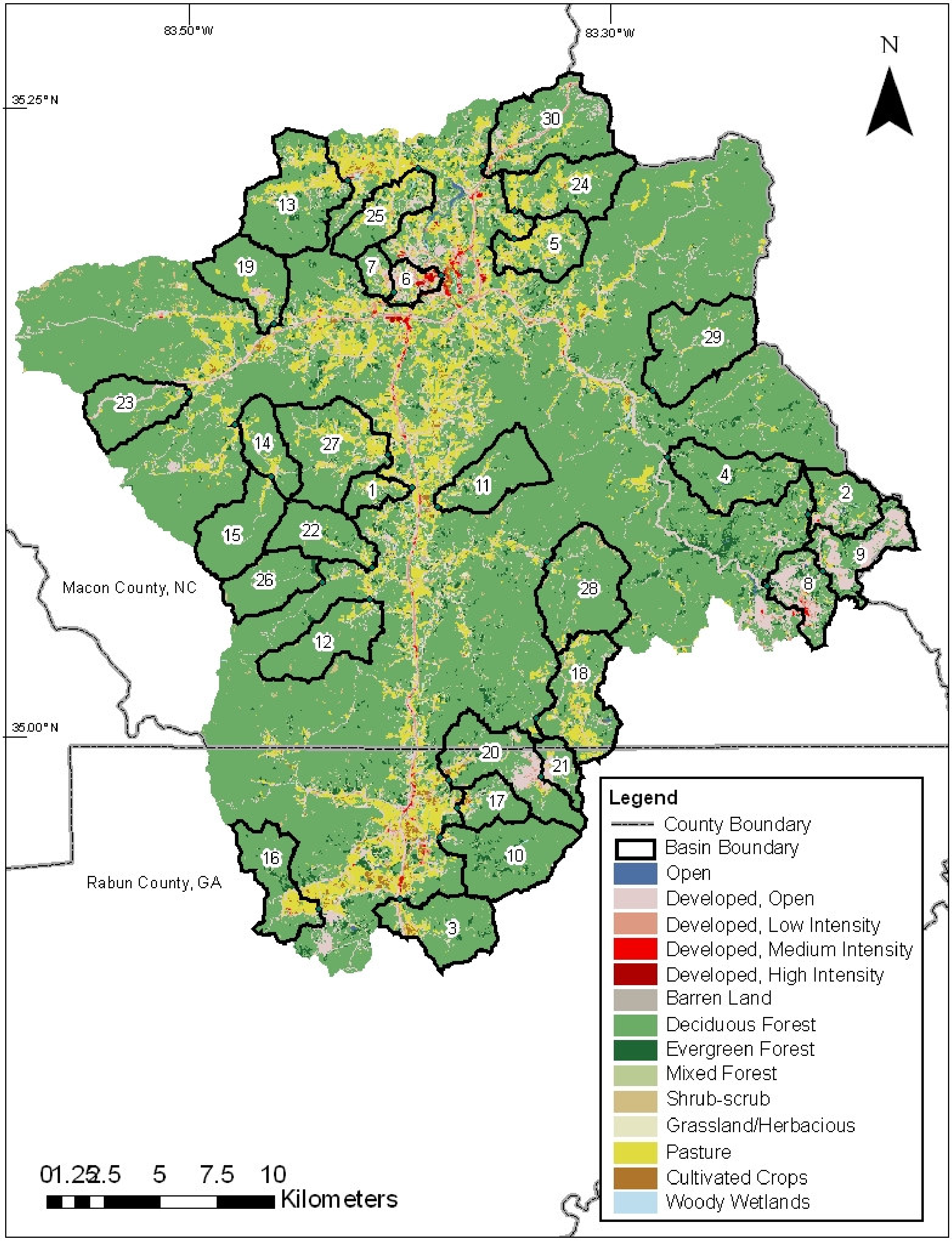

Figure 3.6. Land use/land cover of the Little Tennessee River basin, upstream of Iotla Creek, 2001. The basin names corresponing to each number can be found in Table 3.2.

Table 3.3. Basin LULC (%) (page 1 of 2).

Basin	Dev_ open	Dev_ low	Dev_ med	Barren	Forest _d	Forest _e	Forest _mix	Water
1. Bates Branch	5.24	0.00	0.00	0.00	73.63	2.70	2.00	0.00
2. Big Creek	13.16	1.10	0.23	0.46	68.56	5.05	3.63	0.27
3. Blacks Creek	3.06	0.83	0.06	0.00	83.16	2.15	2.62	0.00
4. Brush Creek	1.39	0.00	0.00	0.00	86.07	5.28	3.71	0.16
5. Cat Creek	7.77	0.00	0.00	0.13	56.30	3.45	2.66	0.00
6. Crawford Branch DS	29.61	9.13	4.05	0.00	37.13	2.08	1.21	0.00
7. Crawford Branch upstream	23.49	2.66	0.00	0.00	58.89	1.12	1.73	0.00
8. Cullasaja River downstream	39.99	3.27	0.84	0.09	43.57	6.63	2.19	0.32
9. Cullasaja River upstream	43.22	2.09	0.15	0.08	43.14	5.59	1.93	0.28
10. Darnell Creek	0.95	0.00	0.00	0.00	90.57	4.81	2.26	0.00
11. Hickory Knoll Creek	3.03	0.00	0.00	0.00	86.97	1.63	1.96	0.00
12. Howard Branch	2.10	0.00	0.00	0.00	91.98	0.30	0.25	0.00
13. Iotla Creek	4.86	0.00	0.00	0.18	70.88	4.60	1.94	0.00
14. Jones Creek downstream	2.15	0.00	0.00	0.00	91.32	0.37	0.24	0.00
15. Jones Creek upstream	1.43	0.00	0.00	0.00	95.99	0.01	0.18	0.00
16. Little Tennessee River	3.96	0.26	0.11	0.00	78.41	3.55	1.71	0.00
17. Kelly Creek	7.29	0.56	0.22	0.41	80.26	1.26	1.48	0.00
18. Middle Creek	6.84	0.24	0.00	0.45	63.87	1.69	1.46	0.55
19. Mill Creek	4.99	0.60	0.00	0.11	84.79	1.36	0.69	0.05
20. Mud Creek downstream	15.94	1.90	0.08	0.43	72.66	1.56	1.12	0.05
21. Mud Creek upstream	17.81	0.84	0.02	0.00	72.62	0.33	0.94	0.26
22. North Fork	1.58	0.00	0.00	0.00	88.37	2.37	0.55	0.00
23. Poplar Cove Creek	6.39	0.51	0.00	0.00	88.17	0.17	0.18	0.00
24. Rabbit Creek	4.01	0.00	0.00	0.00	72.73	1.90	1.73	0.00
25. Rocky Branch	9.75	0.36	0.00	0.14	57.68	4.21	2.46	0.00
26. Shope Fork	1.66	0.00	0.00	0.00	94.52	1.93	0.66	0.00
27. Skeenah Creek	5.33	0.10	0.00	0.03	73.68	1.47	1.21	0.05
28. Tessentee Creek	1.65	0.00	0.00	0.41	89.39	0.87	2.46	0.00
29. Walnut Creek	3.13	0.00	0.00	0.00	92.96	0.41	1.14	0.00
30. Watauga Creek	11.03	2.07	0.08	0.13	72.46	2.57	2.06	0.00

Table 3.3. Basin LULC (%) (page 2 of 2).

Basin	Shrub scrub	Grass	Pasture	Crop	Woody wet	Pasture +Grass	Dev_ total	Forest _total
1. Bates Branch	1.32	2.20	12.73	0.00	0.17	14.93	5.24	78.33
2. Big Creek	2.37	0.75	4.04	0.11	0.26	4.79	14.50	77.25
3. Blacks Creek	0.61	1.09	5.51	0.91	0.00	6.6	3.95	87.93
4. Brush Creek	0.58	0.12	2.65	0.00	0.03	2.77	1.39	95.06
5. Cat Creek	3.03	2.67	23.64	0.36	0.00	26.31	7.77	62.41
6. Crawford Branch DS	1.51	1.55	12.50	0.00	0.00	14.05	44.02	40.42
7. Crawford Branch upstream	1.38	0.61	10.11	0.00	0.00	10.72	26.16	61.75
8. Cullasaja River downstream	0.48	0.43	2.03	0.03	0.05	2.46	44.19	52.38
9. Cullasaja River upstream	0.61	0.27	2.56	0.00	0.08	2.83	45.46	50.65
10. Darnell Creek	0.36	0.24	0.46	0.09	0.26	0.7	0.95	97.64
11. Hickory Knoll Creek	1.45	1.10	3.84	0.03	0.00	4.94	3.03	90.56
12. Howard Branch	1.91	0.80	2.67	0.00	0.00	3.47	2.10	92.52
13. Iotla Creek	1.79	1.41	14.03	0.28	0.03	15.44	4.86	77.43
14. Jones Creek downstream	0.50	0.71	4.69	0.00	0.00	5.4	2.15	91.94
15. Jones Creek upstream	0.29	0.27	1.82	0.00	0.00	2.09	1.43	96.18
16. Little Tennessee River	1.16	0.17	10.20	0.48	0.00	10.37	4.32	83.67
17. Kelly Creek	0.48	0.48	5.88	1.22	0.46	6.36	8.08	83.00
18. Middle Creek	3.56	1.69	19.19	0.37	0.09	20.88	7.08	67.02
19. Mill Creek	0.37	0.47	6.47	0.00	0.11	6.94	5.59	86.84
20. Mud Creek downstream	0.50	0.56	4.55	0.58	0.06	5.11	17.93	75.34
21. Mud Creek upstream	0.82	0.54	5.63	0.05	0.14	6.17	18.68	73.89
22. North Fork	0.71	3.17	3.17	0.00	0.10	6.34	1.58	91.28
23. Poplar Cove Creek	1.28	0.28	2.91	0.00	0.09	3.19	6.90	88.53
24. Rabbit Creek	1.80	1.06	16.42	0.36	0.00	17.48	4.01	76.36
25. Rocky Branch	1.91	3.77	19.19	0.04	0.48	22.96	10.12	64.35
26. Shope Fork	0.85	0.00	0.37	0.00	0.00	0.37	1.66	97.11
27. Skeenah Creek	1.91	2.44	13.44	0.25	0.09	15.88	5.43	76.35
28. Tessentee Creek	3.06	0.40	1.69	0.06	0.00	2.09	1.65	92.73
29. Walnut Creek	1.15	0.06	1.14	0.00	0.00	1.2	3.13	94.51
30. Watauga Creek	1.30	0.88	7.13	0.28	0.00	8.01	13.18	77.09

Table 3.4. Variable abbreviations and definitions.

Variable	Definition
Avg	arithmetic average of NTU samples (n=11)
Median	median of NTU samples (n=11)
Geomean	geometric mean of NTU samples (n=11)
Stand_dev	arithmetic standard deviation of NTU samples (n=11)
CV	coefficient of variation (standard deviation / arithmetic mean)
Range	range of NTU samples (95^{th}-5^{th} percentile, n=11)
Area	basin area (km^2)
Perimeter	basin perimeter (km)
Basin _slope	mean basin slope (%), calculated using basin pixel elevation values
Elevation	mean basin elevation (m), calculated using basin pixel elevation values
El_stdev	standard deviation of basin elevations
L	length of the longest watercourse (km), calculated as the distance from the pour point along the longest watercourse to the basin boundary.
Le	equivalent length of basin (km), calculated as the longer side of rectangle which has the same area and perimeter as the basin. (P+(P^2-16*A)^0.5)/4
Lr	relative longest watercourse length ($Lr = L / Area^{0.5}$) Large values indicate an elongated basin or meandering river.
Dev_open	developed land cover in basin - open (%)
Dev_low	developed land cover in basin - low intensity (%)
Dev_med	developed land cover in basin - medium intensity (%)
Barren	barren land cover in basin (%)
Forest_d	deciduous forested land cover in basin (%)
Forest_e	evergreen forested land cover in basin (%)
Forest_mix	mixed forested land cover in basin (%)
Water	water land cover in basin (%)
Shrubscrub	shrubscrub land cover in basin (%)
Grass	grass land cover in basin (%)
Pasture	pasture land cover in basin (%)
Crop	crop land cover in basin (%)
Woodywet	woody wetland cover in basin (%)
Pasture+Grass	pasture and grass land cover in basin, calculated as the sum of pasture and grass land cover percentages (%)
Dev_total	total developed land in basin, calculated as the sum of all developed land percentages (%)
Forest_total	total forested land in basin, calculated as the sum of all forested land percentages (%)
Relief_ratio	ratio of the total relief of a basin to the total length of stream (km/km)
Drain_dens	ratio of the sum of all stream lengths in basin to the basin area (km/km^2)
Stream_slope	mean stream slope, calculated as (elevation at 0.85L – elevation at 0.1L) / (0.75L)

Table 3.5. Basin physical parameters.

Basin	Area (km^2)	Perimeter (km)	Basin slope (%)	Elevation (m)	El_stdev	L (km)	Le (km)	Lr	Relief ratio (km/km)	Drain dens (km/km^2)	Stream slope (km/km)	Total relief (m)
1. Bates Creek	3.48	9.22	26.57	721	82.97	4.25	3.65	2.27	0.09	3.87	0.05	370
2. Big Creek	7.49	12.97	21.07	1249	61.43	4.32	4.98	1.58	0.08	4.01	0.01	359
3. Blacks Creek	11.31	16.09	37.00	827	118.81	6.63	6.23	1.97	0.08	3.74	0.04	516
4. Brush Creek	11.4	17.25	33.62	1137	124.4	8.34	6.99	2.47	0.07	3.61	0.06	586
5. Cat Creek	8.68	14.13	24.23	705	49.2	4.43	5.48	1.5	0.06	3.67	0.02	276
6. Crawford Branch downstream	5.85	12.08	17.05	672	44.25	5.45	4.83	2.25	0.05	3.62	0.01	260
7. Crawford Branch upstream	2.7	7.03	23.7	701	47.74	2.72	2.38	1.65	0.09	3.58	0.02	246
8. Cullasaja River downstream	17.13	27.55	19.19	1204	52.16	8.92	12.4	2.15	0.03	3.69	0.01	284
9. Cullasaja River upstream	9.43	20.34	18.92	1225	50.18	6.04	9.13	1.96	0.04	3.60	0.02	268
10. Darnell Creek	14.49	18.06	34.29	976	132.25	8.34	6.94	2.19	0.09	3.89	0.06	762
11. Hickory Knoll Creek	9.74	14.95	39.8	872	149.87	7.05	5.8	2.26	0.10	4.19	0.06	718
12. Howard Branch	10.75	16.69	42.44	927	194.19	6.96	6.75	2.12	0.12	4.03	0.08	854
13. Iotla Creek	17.07	19.24	30.79	730	102.41	6.51	7.27	1.57	0.08	3.92	0.03	546
14. Jones Creek downstream	18.07	22.55	41.87	938	185.04	9.59	9.34	2.25	0.09	4.19	0.04	853
15. Jones Creek upstream	11.16	14.88	46.23	1018	184.89	6.03	5.36	1.8	0.13	4.22	0.08	803
16. Little Tennessee River	10.3	18.71	34.47	865	131.94	6.49	8.08	2.02	0.08	3.96	0.05	502
17. Kelly Creek	5.16	10.14	39.36	875	136.46	4.23	3.66	1.86	0.14	3.81	0.09	598
18. Middle Creek	13.37	19.38	20.96	1135	58.51	6.52	8.02	1.78	0.07	3.72	0.02	440
19. Mill Creek	9.99	14.68	35.64	803	112.78	6.26	5.53	1.66	0.08	3.64	0.04	520
20. Mud Creek downstream	17.95	23.23	30.47	949	164.47	8.76	9.78	2.06	0.09	4.06	0.07	791
21. Mud Creek upstream	3.71	9.81	25.63	1062	66.29	2.91	3.97	1.51	0.11	4.11	0.06	316
22. North Fork	8.8	14.59	32.79	824	115.99	6.26	5.77	2.11	0.08	4.12	0.05	480
23. Poplar Cove Creek	9.72	13.45	41.86	946	171.86	5.82	4.62	1.86	0.13	4.05	0.06	736
24. Rocky Branch	8.21	14.97	23.59	688	71.38	6.36	6.15	2.22	0.06	3.95	0.01	402
25. Rabbit Creek	12.12	17.33	31.55	788	133.02	6.84	6.91	1.96	0.11	3.70	0.05	717
26. Shope Fork	8.58	13.53	49.58	995	185.48	5.64	5.07	1.92	0.16	3.98	0.09	913
27. Skeenah Creek	15.79	19.4	27.73	744	91.8	6.13	7.63	1.54	0.08	3.97	0.02	486
28. Tessentee Creek	15.47	17.81	39.47	1005	163.74	5.84	6.54	1.48	0.13	3.89	0.10	748
29. Walnut Creek	15.88	18.67	40.04	1029	141.85	7.27	7.09	1.82	0.12	4.23	0.05	839
30. Watauga Creek	16.72	19.65	38.44	812	122.87	7.51	7.63	1.83	0.08	3.97	0.03	619

CHAPTER FOUR

METHODOLOGY

Field Sampling

All sampling occurred during baseflow conditions, which has been found to be a useful indicator of potential stream degradation (Price and Leigh, 2006a; Walters et al., 2003; Sutherland et al., 2002; TAG, 2002; Meyer et al., 1999). For this study, baseflow conditions were defined by the lack of runoff-generating precipitation over the preceding 48 hours. The National Weather Service Southeast River Forecast Center website, which depicts radar derived accumulated precipitation estimates for the preceding 48 hours, was checked prior to any sampling (http://www.srh.noaa.gov/alr/qpfvsmap.shtml). Additionally, to assure that the streams sampled had returned to baseflow after a rainfall event, the USGS real-time hydrograph of Cartoogechaye Creek (USGS station number 03500240, http://waterdata.usgs.gov/nc/nwis/uv/?site_no=03500240&PARAmeter_cd=00065,0006) near Franklin, NC was examined to confirm that the recession limbs of storm hydrographs had become relatively flat. The Cartoogechaye Creek is located within the study area and drains 187 km^2. Therefore, this USGS gaging station was determined an adequate proxy of baseflow conditions for the smaller streams sampled, as they typically would have returned to baseflow prior to Cartoogechaye Creek. Each stream was sampled on 11 separate occasions from late November 2006 through early May 2007. Each set of samples was gathered in a one or two day period to ensure a synoptic look at turbidity conditions. Figures 4.1 a-g display daily precipitation totals for the study area, obtained from the Georgia Automated Environmental

Monitoring Network-Rabun County Unit weather station. Daily precipitation totals appear in blue and the days in which sampling took place are marked in red.

In a stream cross section, concentrations of suspended sediment vary laterally and vertically with time and flow conditions. Suspended sediment concentrations in streams are generally highest near the thalweg, where flow velocities and turbulence are usually greatest, and decrease laterally toward the stream banks. Thus, depth-integrated sampling was utilized to account for the heterogeneity of the distributions of water velocity and suspended-sediment concentrations. Two samples of the water column were collected at each sampling location with a hand-held DH-48 depth-integrated sampler at 2 equal intervals of stream width and immediately analyzed using an Orbeco-Hellige© Model 966 portable turbidimeter. The NTU of the two samples were averaged to determine the baseflow turbidity. It should be noted that the entire water column is not sampled. The intake nozzle stops its downward descent through the water column at 6 cm above the bottom of the stream; therefore, each vertical sampling transit has an unmeasured zone of this distance above the streambed. The unmeasured part constitutes primarily the bedload discharge and only a very small percentage of the suspended-sediment discharge.

Prior to each day of sample collection, a calibration confirmation was performed against a 40.0 NTU standard made with styrene divinylbenzene spheres in an aqueous solution, which meets USEPA regulations. The variability of the turbidimeter was tested using a 4.0 NTU sample, created by dispersing 40 mg of silt plus clay in 1L of distilled water. Replicate analysis performed 30 times showed that the turbidity meter's 5 second reading is most appropriate; as it corresponds closest to the actual value and it has the lowest standard deviation and coefficient of variation (Table 4.1). Therefore, the 5 second turbidity reading was used in the data analysis.

To demonstrate the correlation between TSS and NTU, grab samples were collected twice at each sample location to analyze TSS content. Baseflow discharge was measured on two occasions at an optimal transect across each stream. One discharge measurement was taken during a relatively dry period and the other during a relatively wet period to estimate the range of baseflow values of each stream sampled. Discharge was calculated by the velocity-area method from cross-sectional dimensions and velocity measurements at 0.6 depth taken at a minimum of 10 intervals of stream width. Velocity was measured using a Marsh-McBirney© Flowmate Model 2000 electromagnetic flow meter. Stream water stage, measured by means of a stadia rod and a predetermined stage marker, was recorded for all samples collected to identify temporal differences in water heights. A two-point stage versus discharge linear regression equation was used to estimate the baseflow discharge for each sample within the narrow range of stages observed during sample collections (Appendix C).

Laboratory Analysis

Samples collected for the purpose of TSS analysis were refrigerated prior to analysis and measured within one week of collection. The samples were analyzed in the University of Georgia's Geomorphology Laboratory by using the filtration method outlined by the U. S. EPA (U. S. EPA, 1983). Briefly, TSS determinations were made by measuring the weight of dry solid material remaining after vacuum filtration of a known sample volume. Samples were filtered through a Whatman® 934-AH glass microfibre filter (0.7 micron nominal mesh diameter) and weighed on an Ohaus® Explorer balance. For this study, two sampling occasions also were analyzed for TSS concentrations to compare with the NTU values. The presence of biological material in the watershed can alter the correlation between turbidity and TSS. To account for this, the samples were burned at 550°C in a Thermolyne® 62700 muffle furnace and reweighed (to 0.0001g) to calculate the amount of organic material present in the samples.

Statistical Analysis

A combination of univariate and multivariate approaches were used to statistically evaluate the effects of a basin's physical characteristics on turbidity. First, univariate procedures were used to assess the normality, skewness, and kurtosis of all explanatory variables prior to multivariate analyses. Assumptions commonly associated with multivariate procedures are that the samples have normal distributions and that within-group covariatiation is equal. The Shapiro-Wilks test was applied to check basin parameters for normality. The 'sktest' function in Intercooled Stata® 8.0 was applied to the parameters to test for skewness and kurtosis. Normalization of the variables for which one or more basins were non-normally distributed was attempted utilizing both nonstandard and standard transformations ($\log_{10}$, natural log, reciprocal, or square root). The Box-Cox transformation was able to normalize all 14 parameters deviating from model assumptions, and was therefore applied for its effectiveness. In the Box-Cox transformation equation (Equation 4.1), Y is the response variable and λ is the transformation parameter. Table 4.2 lists the transformation parameter for each variable requiring transformation. The Box-Cox transformation was implemented using Intercooled Stata® 8.0. The arcsin square root transformation was applied to drainage basin LULC percentage data before analyses were run to minimize bounding limitations imposed by the proportion range from 0 to 1 (Equation 4.2). In this equation, the # symbol represents the percentage of a LULC in a drainage basin.

Equation 4.1. $$T(Y) = ((Y^{\lambda}) - 1) / \lambda$$

Equation 4.2. $$\text{Arcsine} \sqrt{(\# / 100)}$$

Predictive models utilized in this study include correlation, linear regression and stepwise multiple regression. All correlations were measured using the Pearson product-moment correlation coefficient. A correlation matrix was created to identify the variables that have statistically significant relationships with each other. Correlation was also utilized to compare concentrations of organic solids (mg/L) to LULC. A sediment rating curve, or a two point linear regression between water stage and discharge (m^3/s), was generated for each stream. The resulting linear regression equations were used to calculate the discharge associated with each turbidity sample. Discharge values were normalized in terms of standard deviation units relative to the mean value at each site and entered into a correlation matrix with NTU to evaluate basin-specific relationships between discharge and the dependent variable. All normalized discharge values and corresponding NTU values were combined into a single dataset and correlation was performed to compare the overall relationship between discharge and NTU in the whole study area. Linear regression was used to analyze the relationship between NTU and TSS and derive an equation relating the two. Forward stepwise multiple regression was used to identify a combination of independent variables having the greatest effect on NTU. In a forward stepwise multiple regression analysis, the number of predictors and their order of entry are both decided by statistical criteria. The process begins with an empty model and an independent variable is allowed entry based on the degree to which it correlates to the dependent variable. Independent variables not admitted into the equation do not make a contribution that is statistically significant at a predetermined level. The probability for entry applied to all stepwise regression models was a p value less than 0.10. Separate analysis of the response for each independent variable cannot replace multiple regression, especially if some variables are correlated or if interaction exists. In these situations, variables that are complementary in explanatory power could provide erroneous conclusions if they are assessed separately. By regressing three to five explanatory variables to estimate the value of the response variable, the errors in prediction are limited and, at the same time, a large proportion of the variance in the response variable can be accounted for. Forward stepwise multiple regression was performed using Intercooled Stata® 8.0.

A methodological approach was employed in selecting the sets of independent variables to be analyzed by stepwise multiple regression. First, the 27 independent variables under consideration were trimmed down by subjecting numerous groups of randomly selected independent variables (n = 8+) to the stepwise multiple regression process and eliminating those variables never allowed entry into a model. Table 4.3 lists the variables consistently allowed entry into the preliminary stepwise regression models alongside each variable's correlation with the dependent variable. Next, the between-variable correlations were assessed to select sets of variables that would minimize multicollinearity in a regression model, as strongly correlated independent variables (those having an r value higher than 0.70) can be problematic when analyzed together by multiple regression (Table 4.4). From these results, four sets of independent variables were selected for multiple regression analysis against NTU.

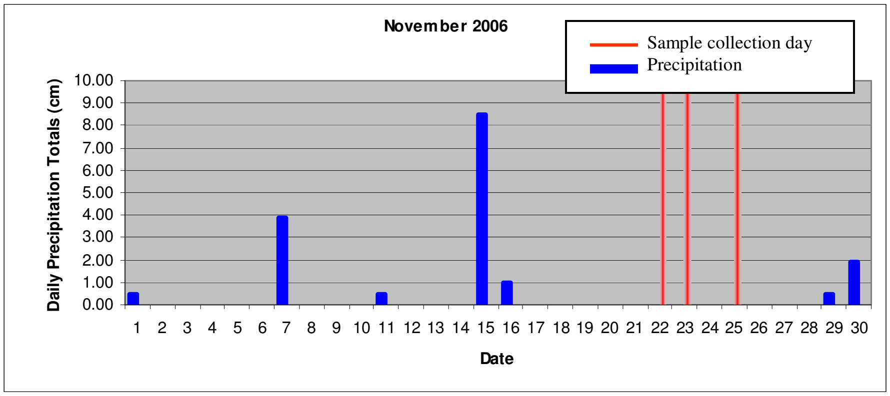

Figure 4.1a. Daily precipitation totals for the month of November 2006. November 22nd and 23rd constitute one sample occasion.

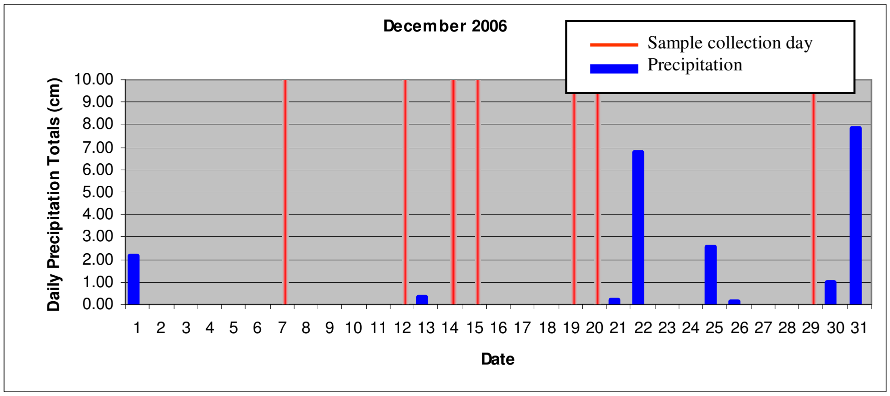

Figure 4.1b. Daily precipitation totals for the month of December 2006. December 19th and 20th constitute one sample occasion.

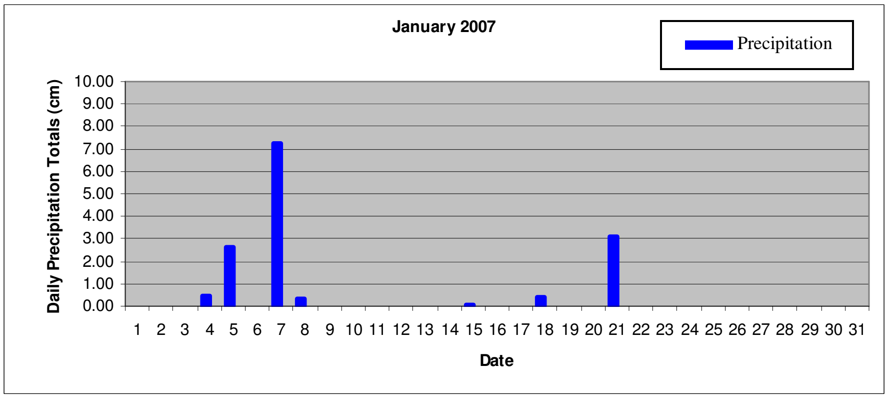

Figure 4.1c. Daily precipitation totals for the month of January 2007.

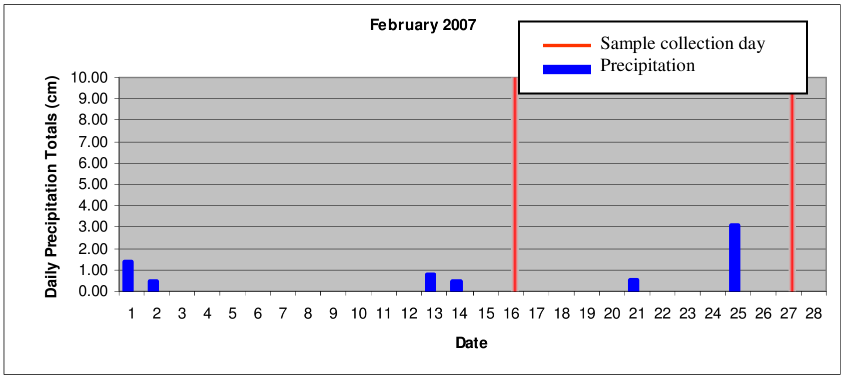

Figure 4.1d. Daily precipitation totals for the month of February 2007.

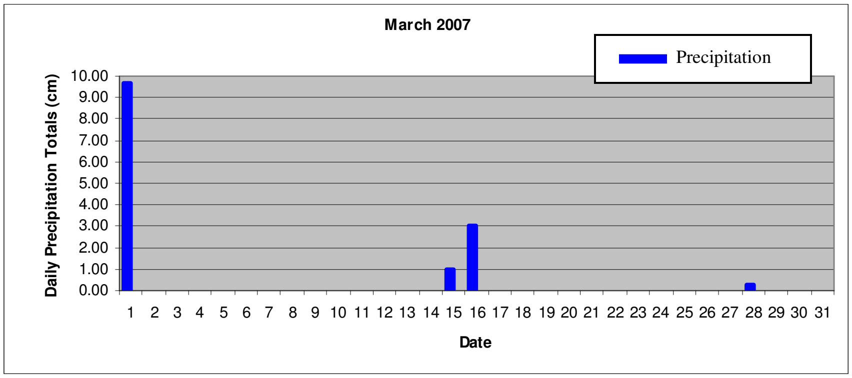

Figure 4.1e. Daily precipitation totals for the month of March 2007.

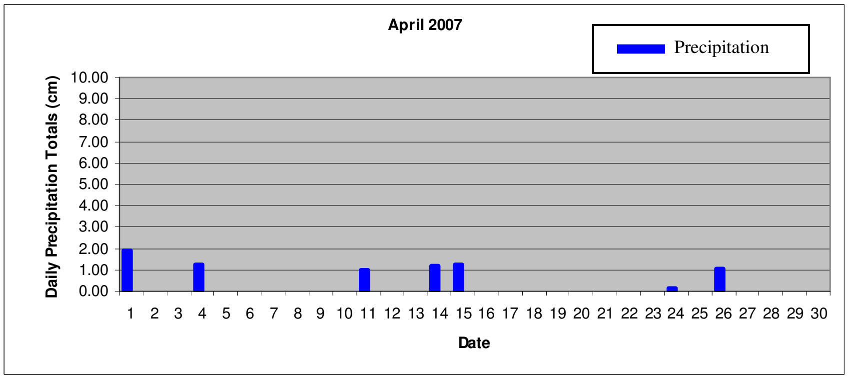

Figure 4.1f. Daily precipitation totals for the month of April 2007.

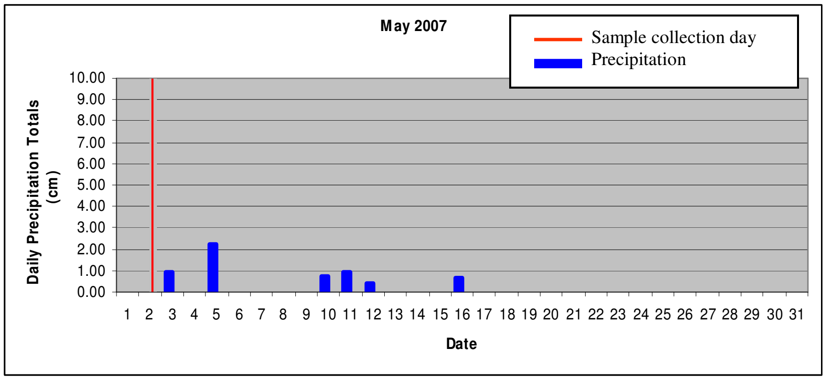

Figure 4.1g. Daily precipitation totals for the month of May 2007.

Table 4.1. Results from the replicate analysis of turbidimeter (n = 30).

Parameter	5 sec	10 sec	15 sec
Mean	3.5	3.2	2.9
Standard deviation	0.33	0.49	0.44
Coefficient of variation	0.09	0.15	0.15

Table 4.2. Box-Cox transformation parameter (λ).

Variable	Λ
Avg	-0.343306
Median	-0.005528
Geomean	-0.203068
Standard_dev	-0.4838762
CV	-0.133814
Range	-0.556844
Water	0.8257047
Dev_open	-0.430951
Dev_low	-0.035508
Dev_med	-0.564694
Barren	0.5595579
Crop	0.3161878
Woodywet	-0.1771666
Dev_total	-0.435064

Table 4.3. Independent variables exhibiting a statistically significant correlation with the geometric mean of NTU.

Parameter	Correlation coefficient (r)
Pasture	0.75
Pasture+Grass	0.72
Elevation	-0.63
Forest_d	-0.56
Dev_total	0.55
Forest_total	-0.55
Dev_open	0.54
Grass	0.51
Crop	0.39
Basin_slope	-0.36

A 0.05 level of significance for a two tailed test yields a critical value of 0.361 (n = 30). A 0.01 level of significance for a two tailed test yields a critical value of 0.463 (n = 30).

Table 4.5. Correlations between the independent variables exhibiting statistically significant correlation with NTU.

	Basin slope	Elevation	Dev open	Forest d	Grass	Pasture	Crop	Pasture +Grass	Dev total	Forest total
Basin_slope	1.00									
Elevation	-0.02	1.00								
Dev_open	**-0.74**	-0.01	1.00							
Forest_d	**0.91**	0.10	**-0.86**	1.00						
Grass	-0.45	-0.58	0.19	-0.40	1.00					
Pasture	-0.52	-0.60	0.40	-0.57	**0.73**	1.00				
Crop	0.30	-0.34	-0.04	0.13	-0.02	0.32	1.00			
Pasture+Grass	-0.53	-0.63	0.36	-0.55	**0.85**	**0.98**	0.25	1.00		
Dev_total	**-0.73**	-0.02	**1.00**	**-0.86**	0.19	0.40	0.00	0.36	1.00	
Forest_total	**0.74**	0.18	**-0.87**	**0.85**	-0.37	-0.54	0.01	-0.52	**-0.87**	1.00

Correlation coefficients (r) above 0.70 are shown in bold (n = 30).

CHAPTER FIVE

RESULTS

Descriptive statistics of turbidity were generated for each of the 30 basins and for each of the 11 sampling occasions (Tables 5.1 & 5.2). Sampled turbidities ranged from 0.55 NTU to 32.6 NTU in the 330 samples taken from 30 streams. Median turbidities in each stream ranged from 0.78 NTU to 6.22 NTU and average turbidities varied from 1.15 NTU to 9.41 NTU. Some streams exhibited little temporal variation in turbidity, with standard deviations as low as 0.49, while others showed high baseflow variation with standard deviations as high as 11.5. Correlation identified statistically significant relationships between the dependent and independent variables (Table 5.3). Correlations between all of the independent variables analyzed in this study are listed in Appendix D. To determine which of the dependent variables would be most representative for use in correlation and regression analysis, the relationships between the dependent and the independent variables were ranked using correlation coefficients. The geometric mean of NTU has the greatest number of highest ranked correlations; therefore, the geometric mean was utilized as the dependent variable in correlation matrices and regression models. Bivariate plots relating each independent variable to the geometric mean of NTU can be found in Appendix E.

Correlations between LULC categories and organic solids indicate that the relationship of organic solids to both *grass* and *woodywetland* is statistically significant at the 0.05 level and the relationship of organic solids to *water* is statistically significant the 0.01 level (Table 5.4).

Woodywetland and *water* are both negatively correlated with organic solids while *grass* and organic solids have a positive correlation.

The correlation between NTU and normalized baseflow discharge was calculated at the basin-specific level as well as for the study area as a whole (Table 5.5). The cross-section at which turbidity was measured at the Crawford Branch downstream sampling location was unavoidably altered during the course of the sampling period, rendering the stage marker ineffective in measuring water stage. Therefore, the Crawford Branch downstream basin was removed from the discharge analysis. Of the 29 basins, only two exhibited a statistically significant correlation between NTU and normalized discharge at the 0.01 level and three had statistically significant correlation at the 0.05 level (n = 11). The correlation between all of the normalized discharge values combined and the corresponding NTU measurements yielded a coefficient value of 0.1154 (n = 318). Additionally, correlation was performed on non-normalized discharges and their corresponding NTU measure, resulting in a coefficient value of -0.1936 (n = 318). Therefore, these results indicate that baseflow NTU (of all the sites as a group) does not vary as a function of water discharge in this study.

The relationship between NTU and TSS data collected in this study was developed by regressing paired measurements of the two parameters. Statistically, the NTU and TSS data collected in this study do not adhere to a normal distribution and a Log_{10} transformation on the data produced a pure error lack of fit. Thus, regression was performed on linear datasets simply to illustrate the overall close correspondence between NTU and TSS (Figure 5.1). Although the NTU values analyzed by regression were less than 35, only two values are in the 20-35 range. If the range of values is limited to 20 NTU, then an exponential rise to a maximum in the range of

10-15 NTU is apparent, which indicates that increases in the 10-15 NTU range are not matched by increases in TSS.

Four sets of independent variables were selected for forward stepwise multiple regression analysis against NTU. These variable groups, along with the partial R^2 and partial adjusted R^2 of each variable allowed entry into each stepwise regression model, can be found in Tables 5.6 a-d. *Pasture* was the first variable granted entry into all four of the stepwise models. Independent variables are allowed entry based on their degree of correlation to the dependent variable; therefore, *pasture* LULC has the greatest influence over NTU, determining 56 percent of the variation in NTU. When *pasture* is combined with *elevation* and a developed LULC class (*dev_total* or *dev_open*), then approximately 73% of the variation in the geometric mean of NTU is explained. *Elevation* contributes about 10% to this explanation and developed LULC (*dev_total* or *dev_open*) contributes about 7% (Tables 5.6 a-b). The models incorporating forested LULC classes (*forest_total* or *forest_d*) instead of developed LULC are less successful (Tables 5.8 c-d), only accounting for 66-68% of the variation in the dependent variable. *Elevation* and *forest_total* are each responsible for 5% and *forest_d* being responsible for around 7% of this variation. These models thus suggest that certain categories of developed LULC (*dev_total* or *dev_open*) play a more significant role than do certain categories of forested LULC (*forest_total* or *forest_d*) in explaining the variation in the geometric mean of NTU.

Table 5.1. NTU statistics of each basin (n = 11).

Basin	Avg	Median	Geo Mean	Stand Dev	CV	Range
Bates Branch	3.20	2.68	3.00	1.43	0.45	3.56
Big Creek	1.88	1.14	1.42	2.09	1.11	4.47
Blacks Creek	2.58	2.28	2.47	0.89	0.35	2.48
Brush Creek	1.15	0.89	0.99	0.90	0.78	1.86
Cat Creek	5.83	5.18	5.46	2.49	0.43	6.68
Crawford Branch downstream	5.56	5.06	5.42	1.36	0.24	3.78
Crawford Branch upstream	3.02	2.53	2.81	1.45	0.48	3.55
Cullasaja River downstream	2.74	2.53	2.56	1.13	0.41	3.06
Cullasaja River upstream	2.20	1.57	1.91	1.47	0.67	3.88
Darnell Creek	1.35	1.02	1.18	0.98	0.73	1.97
Hickory Knoll Branch	3.54	2.71	3.11	2.59	0.73	5.16
Howard Branch	1.63	1.22	1.49	0.81	0.50	1.95
Iotla Creek	6.71	5.84	6.26	3.09	0.46	8.05
Jones Creek downstream	1.72	1.36	1.53	1.07	0.62	2.68
Jones Creek upstream	1.46	1.56	1.38	0.49	0.34	1.35
Little Tennessee River	4.75	4.16	4.53	1.77	0.37	4.36
Kelly Creek	8.09	4.07	5.76	9.20	1.14	21.79
Middle Creek	2.36	2.27	2.32	0.54	0.23	1.42
Mill Creek	2.47	2.45	2.38	0.69	0.28	1.96
Mud Creek downstream	5.66	4.53	5.13	3.13	0.55	7.29
Mud Creek upstream	2.84	1.94	2.28	2.39	0.84	6.03
North Fork	1.72	1.33	1.61	0.77	0.45	2.00
Poplar Cove Creek	2.13	1.69	1.90	1.24	0.58	3.15
Rabbit Creek	8.51	4.44	5.99	11.50	1.35	21.64
Rocky Branch	9.41	6.22	7.84	7.42	0.79	18.21
Shope Fork	1.17	0.78	1.01	0.75	0.64	1.83
Skeenah Creek	3.28	2.80	3.12	1.28	0.39	3.07
Tessentee Creek	1.99	1.55	1.76	1.43	0.72	2.81
Walnut Creek	2.95	1.75	2.13	3.71	1.26	7.21
Watauga Creek	4.97	4.24	4.67	2.23	0.45	4.81

Table 5.2. NTU statistics of each sample collection date (n = 30).

Parameter	Nov. 22	Nov. 25	Dec. 7	Dec. 12	Dec. 14	Dec. 15	Dec. 19	Dec. 29	Feb. 16	Feb. 27	May 2
Avg	3.19	2.71	2.88	2.24	2.73	2.68	3.40	2.73	2.78	4.64	9.21
Median	2.46	2.30	2.23	1.74	2.03	2.28	2.21	2.41	2.26	3.89	6.88
Geomean	2.35	2.28	2.35	1.82	2.23	2.29	2.26	2.41	2.44	3.78	7.15
Stand_dev	3.17	1.61	1.85	1.40	1.77	1.50	5.67	1.42	1.49	3.09	8.44
CV	0.99	0.59	0.64	0.63	0.65	0.56	1.67	0.52	0.54	0.67	0.92
Range	5.48	4.62	5.40	3.80	5.08	4.65	4.55	4.26	4.76	8.66	21.01

Table 5.3. Correlation coefficients between the dependent and independent variables.

Variable	Avg	Median	Geomean	Stand_dev	CV	Range
Area	-0.06	0.00	-0.04	-0.06	-0.04	-0.10
Perimeter	-0.04	0.02	-0.02	-0.07	-0.09	-0.09
Basin_slope	-0.35	**-0.36**	**-0.36**	-0.19	0.20	-0.24
Elevation	***-0.58***	***-0.63***	***-0.63***	-0.28	0.27	-0.33
El_stdev	-0.34	-0.36	-0.35	-0.17	0.22	-0.23
L	-0.18	-0.12	-0.15	-0.15	-0.03	-0.20
Le	-0.01	0.04	0.01	-0.06	-0.10	-0.06
Lr	-0.15	-0.13	-0.12	-0.09	0.02	-0.12
Dev_open	***0.55***	***0.53***	***0.54***	**0.39**	-0.12	***0.48***
Dev_low	0.03	0.04	0.03	0.09	-0.03	0.12
Dev_med	0.15	0.22	0.19	-0.10	-0.34	-0.16
Barren	-0.07	-0.18	-0.13	0.12	0.34	0.05
Forest_d	***-0.54***	***-0.56***	***-0.56***	-0.32	0.23	**-0.39**
Forest_e	0.13	0.15	0.15	0.18	0.02	0.17
Forest_mix	0.24	0.22	0.23	**0.38**	0.22	0.33
Water	0.07	**0.03**	0.10	0.06	0.02	0.04
Shrubscrub	0.29	0.27	0.29	0.21	-0.04	0.19
Grass	***0.47***	***0.51***	***0.51***	0.18	-0.28	0.23
Pasture	***0.71***	***0.76***	***0.75***	0.34	-0.30	**0.40**
Crop	**0.38**	**0.37**	**0.39**	0.06	-0.22	0.11
Woodywet	0.23	0.07	0.16	**0.38**	**0.44**	0.35
Pasture+Grass	***0.68***	***0.74***	***0.72***	0.31	-0.31	**0.38**
Dev_total	***0.56***	***0.53***	***0.55***	**0.38**	-0.14	***0.47***
Forest_total	***-0.53***	***-0.55***	***-0.55***	-0.20	0.34	-0.31
Relief_ratio	-0.11	-0.10	-0.10	0.02	0.09	-0.06
Drain_dens	0.26	0.30	0.29	0.13	-0.15	0.13
Stream_slope	-0.04	0.00	-0.01	-0.03	-0.06	-0.11

A 0.05 level of significance for a two tailed test yields a critical value of 0.361 (n = 30). A 0.01 level of significance for a two tailed test yields a critical value of 0.463 (n = 30). Those correlation coefficients significant at the 0.05 level are bold. Those correlation coefficients significant at the 0.01 level are bold and italicized.

Table 5.4. Correlations between LULC categories and organic solids (mg/L).

LULC type	Correlation coefficient (r)
Dev_open	-0.11
Dev_low	-0.1
Dev_med	0.03
Barren	-0.17
Forest_d	-0.04
Forest_e	0.09
Forest_mix	0.13
Water	***-0.78***
Shrubscrub	0.36
Grass	**0.51**
Pasture	0.21
Crop	-0.41
Woodywet	**-0.5**
Pasture+Grass	0.31
Dev_total	-0.11
Forest_total	0.02

A 0.05 level of significance for a two tailed test yields a critical value of 0.413 (n = 22). A 0.01 level of significance for a two tailed test yields a critical value of 0.526 (n = 22). The two correlation coefficients significant at the 0.05 level are bold. The correlation coefficient significant at the 0.01 level are bold and italicized. The organic solids dataset was normalized using a Log_{10} transformation.

Table 5.5. Correlations between basin-specific NTU and normalized discharge.

Basin	Correlation Coefficient (r)	Minimum Discharge (m^3/s)	Maximum Discharge (m^3/s)	Range (m^3/s)	Average Discharge (m^3/s)	Standard Deviation of Discharge
Bates Branch	-0.05	0.0468	0.0476	0.0008	0.047	0.0002
Big Creek	0.49	0.2668	0.2924	0.0256	0.284	0.0068
Blacks Creek	***0.75***	0.1702	0.1803	0.0101	0.173	0.0030
Brush Creek	0.48	0.2128	0.2214	0.0085	0.217	0.0028
Cat Creek	-0.51	0.0779	0.0793	0.0014	0.079	0.0004
Crawford Branch upstream	0.04	0.0599	0.0613	0.0014	0.061	0.0003
Cullasaja River downstream	**0.73**	0.4756	0.5163	0.0407	0.490	0.0112
Cullasaja River upstream	0.53	0.2674	0.2998	0.0324	0.281	0.0101
Darnell Creek	0.12	0.2912	0.2940	0.0027	0.292	0.0007
Hickory Knoll Creek	-0.28	0.1333	0.1364	0.0031	0.134	0.0009
Howard Branch	***0.74***	0.1992	0.2073	0.0081	0.200	0.0024
Iotla Creek	**0.71**	0.2112	0.2290	0.0178	0.218	0.0045
Jones Creek downstream	0.24	0.4019	0.4048	0.0029	0.403	0.0009
Jones Creek upstream	-0.09	0.2416	0.2434	0.0018	0.243	0.0006
Little Tennessee River	0.49	0.2280	0.2330	0.0050	0.230	0.0016
Kelly Creek	-0.10	0.0735	0.0738	0.0003	0.074	0.0001
Middle Creek	0.26	0.4062	0.4093	0.0031	0.409	0.0010
Mill Creek	0.50	0.0722	0.0993	0.0271	0.082	0.0094
Mud Creek downstream	0.28	0.3286	0.3349	0.0063	0.331	0.0019
Mud Creek upstream	0.45	0.1514	0.1639	0.0125	0.160	0.0034
North Fork	0.33	0.1796	0.1871	0.0075	0.181	0.0021
Poplar Cove Creek	-0.24	0.1251	0.1809	0.0559	0.131	0.0165
Rabbit Creek	0.25	0.1179	0.1203	0.0024	0.119	0.0009
Rocky Branch	0.14	0.0772	0.0792	0.0019	0.078	0.0004
Shope Fork	0.27	0.1486	0.1579	0.0092	0.153	0.0025
Skeenah Creek	0.25	0.2498	0.2517	0.0019	0.251	0.0006
Tessentee Creek	***0.75***	0.2158	0.2171	0.0013	0.216	0.0004
Walnut Creek	0.17	0.1626	0.1634	0.0008	0.210	0.0058
Watauga Creek	0.13	0.2050	0.2263	0.0213	0.163	0.0002

A 0.05 level of significance for a two tailed test yields a critical value of 0.602 (n = 11). A 0.01 level of significance for a two tailed test yields a critical value of 0.735 (n = 11). The three correlation coefficients significant at the 0.01 level are bold italicized. The two correlation coefficients significant at the 0.05 level are bold. Please note the table displays actual discharge values. Discharge values analyzed by correlation were normalized in terms of standard deviation units relative to the mean value at each site.

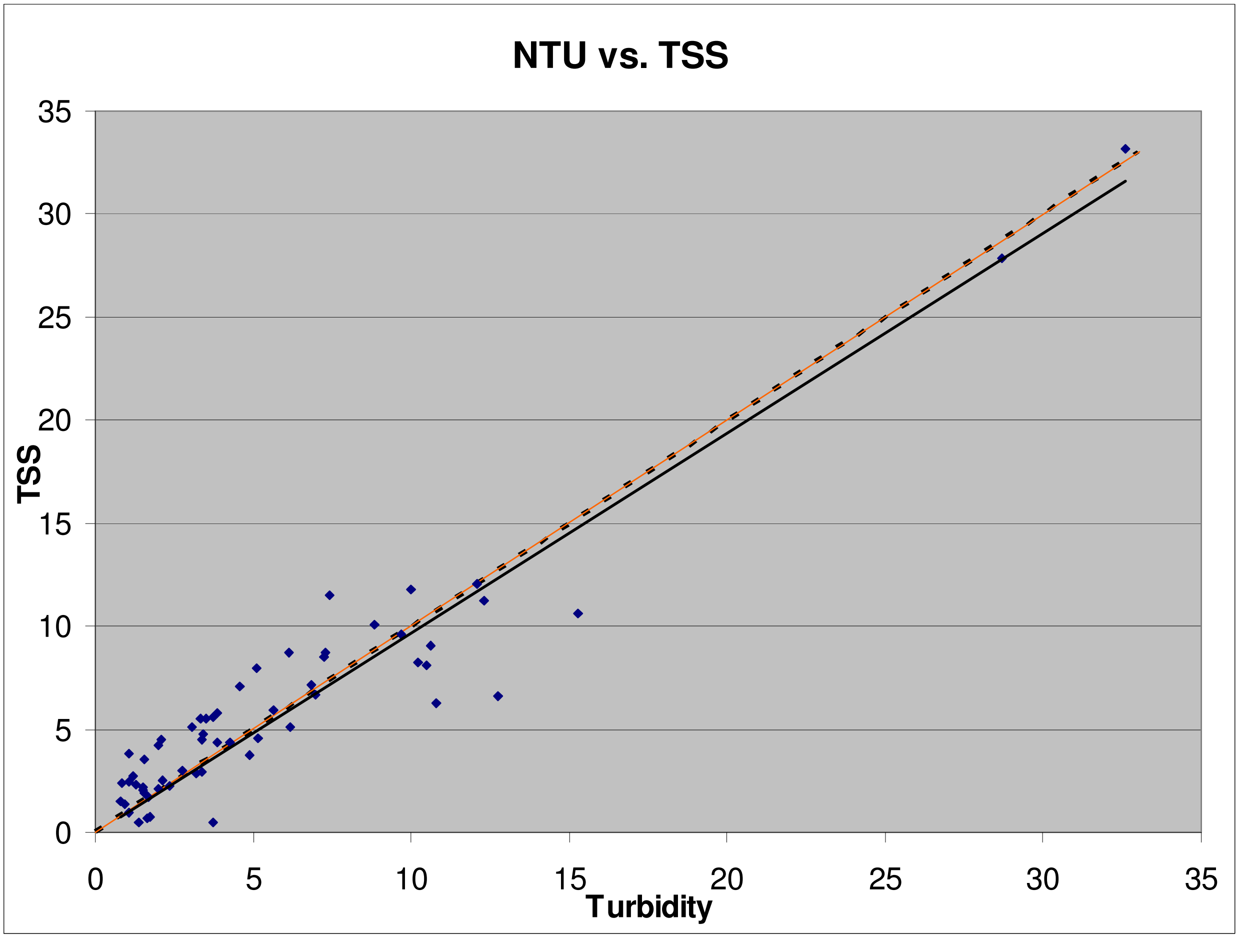

Figure 5.1. The regression of NTU against TSS from all study basins combined for NTU values < 35 is shown as the solid black line. The regression equation is: TSS = 1.5227 + 0.7448 * NTU ($r^2 = 0.73$, n = 59). The data collected in this study do not exhibit a normal distribution yet a Log_{10} transformation produces a pure error lack of fit. Therefore, regression was performed on linear datasets. The dashed black line represents the 1:1 line and the orange line represents the regression equation found by Sutherland et al. (1999).

Tables 5.6 a-d. Partial R^2 and partial adjusted R^2 of model variables.

a.

Variable	Partial R^2	Partial Adjusted R^2
Pasture (+)	0.56	0.54
Dev_total (+)	0.077	0.065
Elevation (-)	0.102	0.099
SUM	0.7344	0.7037

b.

Variable	Partial R^2	Partial Adjusted R^2
Pasture (+)	0.56	0.54
Dv_open(+)	0.074	0.062
Elevation (-)	0.106	0.102
SUM	0.735	0.7045

c.

Variable	Partial R^2	Partial Adjusted R^2
Pasture (+)	0.56	0.54
Elevation (-)	0.055	0.037
Forest_total (-)	0.049	0.038
SUM	0.664	0.615

d.

Variable	Partial R^2	Partial Adjusted R^2
Pasture (+)	0.56	0.54
Elevation (-)	0.05	0.037
Forest_d (-)	0.072	0.064
SUM	0.68	0.64

CHAPTER SIX

DISCUSSION

Both North Carolina and Georgia have created regulatory turbidity limits for erosion control (see Table 2.1). North Carolina requires that turbidity levels be less than 50 NTU in non-trout streams and less than 10 NTU in trout streams. Georgia requires that turbidity levels be less than a pre-established background level + 25 NTU in non-trout streams and less than the background level + 10 NTU in trout streams (TAG, 2002). Background baseflow levels for the Blue Ridge province of Georgia have been found to be less than four NTU (Alahadell and Landers, 2005). All streams sampled for turbidity in this study are trout streams (The North Carolina Center for Geographic Information and Analysis, 2006; Georgia DNR, 2004). Of the 133 turbidity samples collected in both states, twelve violated the North Carolina state turbidity regulation and eight violated the Georgia state turbidity regulation (Table 6.1). The majority of these violations occurred in the spring (May 2 sampling), suggesting that turbidity is, in fact, subject to temporal trends across seasons (Lewis et al., 2002; Pavanelli and Pagliarani, 2002). However, only one of the eleven sampling rounds occurred in the spring, which limits the strength of this conclusion. A possible explanation for elevated NTU on May 2nd could be the general increase in agricultural activities that occur in spring, including riparian cultivation and frequent vehicular crossings in streams. Another theory is that spring may coincide with higher productivitiy levels in soils. The possible increased input of dissolved organics into the stream could explain the elevated NTU values in May. Higher levels of organics in the stream result in higher levels of algae, thus raising turbidity levels at baseflow.

Of the fifteen LULC types analyzed, *grass, water* and *woodywetland* were the only variables having a statistically significant correlation with suspended organic solid levels. The positive ($p = 0.05$) relationship between *grass* and organic solids possibly can be attributed to grass clippings. The overland flow of grass-covered land can result in a higher delivery of organics to the stream. *Water* and organic solids have a negative relationship ($p = 0.01$). The USGS land cover classification of *water* includes standing water and farm ponds that act as sediment traps, and therefore, keep organics from flowing downstream. The *woodywetland* land use category contains the presence of soil or substrate that is periodically saturated with or covered with water. This standing water also traps organics from flowing downstream, and therefore, may help to explain the negative relationship of *woodywetland* with organic solids ($p = 0.05$).

Turbidity is known to correlate with stream discharge both at-a-station and in the downstream direction (Lewis et al., 2002; Knighton, 1998). In the upper Little Tennessee River basin, a strong correlation has been found between turbidity and discharge when data collection encompasses both stormflow and baseflow (Sutherland et al., 2002). Results from this study indicate that the NTU of all basins combined does not vary as a function of *baseflow* water discharge. Of all the basins combined, the lowest discharge sampled was 0.0468 m^3/s (at the Bates Branch basin) and the highest sampled was 0.516 m^3/s (at the Cullasaja River downstream basin), resulting in a range of 0.4692 m^3/s ($n = 318$). A positive correlation between discharge and NTU at all sites combined is expected upon sampling a wider range of stream discharges. This study analyzed the correlation between NTU and normalized discharge at each individual basin as well. At the basin-specific level, the Cullasaja River downstream and Iotla Creek basins exhibited a statistically significant correlation between NTU and normalized discharge at the

0.05 level and the Howard Branch, Blacks Creek and Tessentee Creek basins demonstrated a statistically significant correlation between NTU and normalized discharge at the 0.01 level. Basin size and stream discharge may be partially responsible for these results. The average discharge calculated at each of the aforementioned five basins is within the upper fifty percent of all sampled basins. These same five basins are also in the upper fifty percent of size as well, because streams draining larger areas are subject to more variability in their discharge. The analysis of larger discharge ranges at each basin is more likely to result in a correlation with NTU. An increase in human activity is hypothesized to play a role in explaining the significant correlation at the five basins.

Turbidity is proven to have a cumulative effect. Correlation analysis performed on data collected by Simmons (1993) in the Blue Ridge province during the years of 1970-1979 statistically supports the correlation between drainage basin size and turbidity. ($p = 0.01$, $n = 28$). Bolstad and Swank (1997) and Swank and Bolstad (1994) observed baseflow turbidity at five points along Coweeta Creek, located within the upper Little Tennessee River basin. The downstream rates of turbidity increased by 0.08 to 0.61 NTU/building/100ha. These studies establish that downstream changes in LULC are accompanied by consistent, cumulative increases in turbidity in the Blue Ridge physiographic province, and this is consistent with the studies mentioned above that show correlation between discharge and NTU in the downstream direction (Lewis et al., 2002; Knighton, 1998). This study hypothesized that longer streams possess a higher chance of becoming turbid; thus, drainage basin size, drainage density and length of watercourse were expected to exhibit a strong positive correlation with baseflow turbidity. However, none of these parameters had a demonstrable impact on NTU in this study during November 2006 to May 2007. Although size attributes were not found to be significantly correlated with NTU in this study, the non-nested and spatially-distributed nature of the different sized watersheds probably confounded the relationship. Thus, cumulative effects probably are much more noticible within an individual drainage network with nested watersheds.

Barnes et al. (1997) observed that, although a strong correlation exists between the two measurements, NTU very slightly underestimates TSS in the Blue Ridge physiographic province. Sutherland et al. (1999) further defined the strong correlation between the two parameters in the Blue Ridge province. Although the TSS and NTU data collected in this study support the overall close correspondence, it appears that, upon the examination of Figure 5.1, if the range of NTU values is limited to 20, then an exponential rise to a maximum in the range of 10-15 NTU occurs (see Figure 5.1). This indicates that increases between 10-15 NTU are not matched by increases in TSS, which may be due, at least in part, to organic solids contributing to NTU, but not significantly to TSS. Since measures of turbidity are based on the passage of light through suspended sediment and particles of organic material absorb incident light, the presence of organic material in a water sample can result in an artificially high turbidity value (Madej et al., 2002). Although this study compared the correlation between NTU and TSS for NTU values <35, no data was collected in the range of 12-25 NTU. The two baseflow turbidity measurements greater than 25 NTU were deemed abnormal occurrences, as all drainage basins in this study yielded arithmetic average turbidities less than 10 NTU (n = 11). Because these two NTU measures greatly deviated from normal conditions, a phenomenon other than an increase in organic solids is expected to be responsible for these extreme values.

Sutherland et al. (1999) has further defined the strong correlation between the two measurements in the Blue Ridge province. Upon the regression of NTU against TSS, Sutherland et al. (1999) generated an r^2 value of 0.93. (n = 106). The regression of NTU against TSS for this study generated an r^2 value of 0.73 (n = 59), affirming the strong correlation between the two measurements (Equation 6.1). Sutherland et al. (1999) developed a regression equation to convert Log_{10} NTU to its equivalent Log_{10} TSS units for Blue Ridge streams (see Equation 2.1). Differences in these two equations can be attributed to the different ranges of turbidity values analyzed by the two studies. Sutherland et al. (1999) compared NTU values of less than 900, while this study compared NTU values of less than 35 to allow for a higher resolution on low range values. Other differences between these two studies include the fact that Sutherland et al. (1999) analyzed a total of 106 data points and measured turbidity with a Hach© Model 2100P turbidimeter whereas this study analyzed a total of 59 data points and measured turbidity with a Orbeco-Hellige© Model 966 turbidimeter.

Equation 6.1. $$TSS = 1.5227 + (0.7448 * NTU)$$

Baseflow turbidity and TSS levels in streams have been shown to be a function of land surface characteristics and land use activities. This study supports others (Price and Leigh, 2006a; Galbraith and Burns, 2006; Sutherland et al., 2002; Lougheed et al., 2001; Bolstad and Swank, 1997) by demonstrating that baseflow NTU is positively related to the percentage of pasture and agricultural land cover in a drainage basin and negatively to the percentage of indigenous forest cover. The results of this study also support those of Roy et al. (2003) and Walters et al. (2003) suggesting that urban land cover is positively related to baseflow stream turbidity levels. Previous work conducted in the upper Little Tennessee River determined streams draining less forested basins demonstrated significantly higher levels of baseflow turbidity than streams draining more forested basins. Upon analyzing four streams in the upper Little Tennessee River basin, both Price and Leigh (2006b) and Sutherland et al. (2002) observed the means of baseflow NTU in two disturbed streams as approximately triple that of two reference streams.

This study found the amount of *pasture* LULC present in a drainage basin explains 56% of the variation in NTU. It is known that animals grazing in pastures adjacent to streams can have a major impact on the quality of water in a drainage basin, principally through fecal contamination and the disturbance of watercourses and surrounding land (Line, 2003; Davies-Colley and Nagels, 2001; Quinn et al., 1998). For example, turbidity levels downstream of cattle wading in a stream have been shown to increase dramatically from less than 10 to 50-250 NTU (Quinn et al., 1998). The installation of livestock exclusion fencing on cattle-grazed land result in statistically significant decreases stream turbidity and suspended sediment levels (Line, 2003). Such downstream effects have a significant impact on water quality and potentially on animal productivity. Higher stream turbidity levels are inevitable where animals can wander freely into the water. Although this study demonstrates that the percentage of *pasture* LULC present in a drainage basin largely affects the turbidity of a stream, the amount and effect of *pasture* present in the riparian zone remains unanswered by this study. Furthermore, while instream animal activity associated with pastureland is an obvious source of baseflow turbidity, other associations with *pasture* LULC (e.g. vehicular crossings in streams and recreational activities) are not well understood. It is clear that *pastur*e is a good proxy for land cover types that favor sediment inputs to baseflow, but the exact mechanisms and processes are not well understood. Thus, further research is needed to determine the overall processes and effects of *pasture* LULC and its effect on turbidity in the Blue Ridge Mountains.

The independent variable *elevation* is allowed entry into all four forward stepwise regression models and thus plays a significant role in determining the variation in the geometric mean of NTU. Figures 6.1 and 6.2 indicate that higher elevated *pasture* generates less turbidity. Because *pasture* LULC is managed differently at various elevations, *pasture* at higher elevations may have fewer livestock grazing than at lower elevations. Less animal activity occurring on higher elevated *pasture* LULC would result in a lower stream turbidity.

The independent variables *dev_open* and *dev_total* were identified to be good predictors of NTU as well. These two LULC types capture the influence of bare ground on baseflow turbidity. The lack of deep-rooted vegetation in a stream basin results in higher erosion rates, increasing the amount of sediment in a stream. The anthropogenic activities associated with developing land include various construction practices, which can also increase sediment levels in streams, especially when construction is occurring in the riparian zone. Although *pasture* is the variable that demonstrates the greatest effect on baseflow turbidity, Figures 6.3 and 6.4 illustrate that *elevation* and developed LULC influence NTU as well. The scatter of points is tighter in Figure 6.3 than 6.4, indicating an improvement in regression model performance when *pasture* is combined with *elevation* and *dev_open.*

Table 6.1. Turbidity violations of state regulations.

Basin	Nov 22	Dec 19	Feb 22	May 5
Cat Creek	5.81	3.75	8.79	**12.01**
Hickory Knoll Creek	2.75	3.11	3.78	**11.25**
Iotla Creek	6.41	5.14	9.83	**14.90**
Kelly Creek	3.97	**32.60**	5.56	**18.45**
Mud Creek downstream	6.00	3.05	**14.19**	7.00
Rabbit Creek	6.00	3.76	8.20	**42.95**
Rocky Branch	**17.35**	5.88	**10.18**	**29.00**
Walnut Creek	2.48	2.41	2.69	**14.03**
Watauga Creek	4.15	3.62	5.32	**11.39**

Turbidity was sampled on eleven separate occasions from November 2006 to May 2007. One or more basins exhibited a turbidity value above the state regulatory level on four different sampling dates. The twelve turbidity violations are in listed in bold. Mud Creek DS and Kelly Creek have the majority of their drainage basins in Georgia and the other seven basins are in North Carolina.

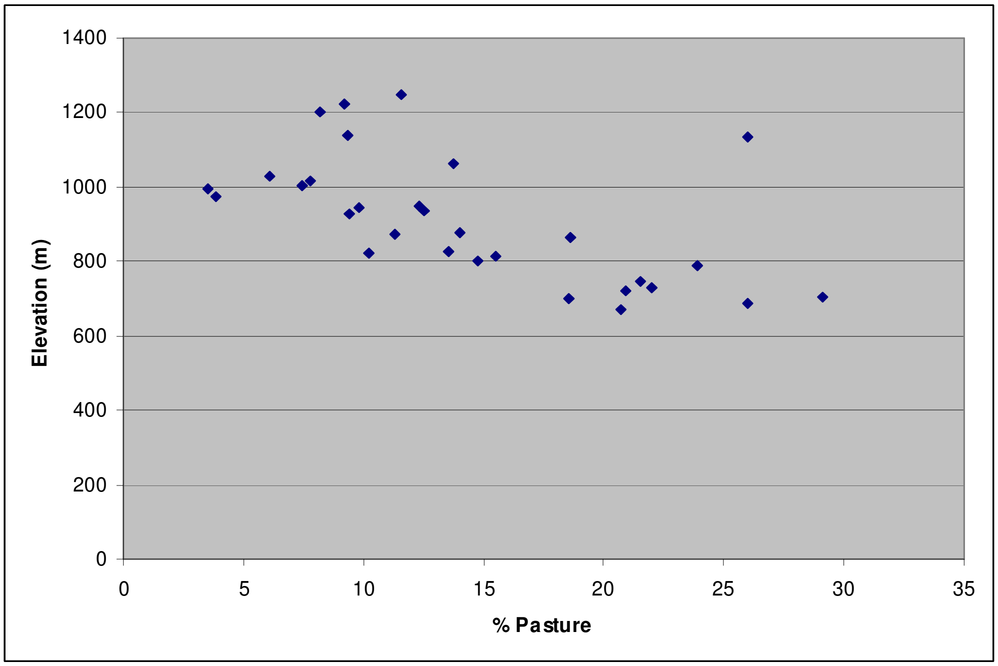

Figure 6.1. *Pasture* LULC plotted against *elevation* (m). The percentage of *pasture* LULC has undergone arcsin square root transformation.

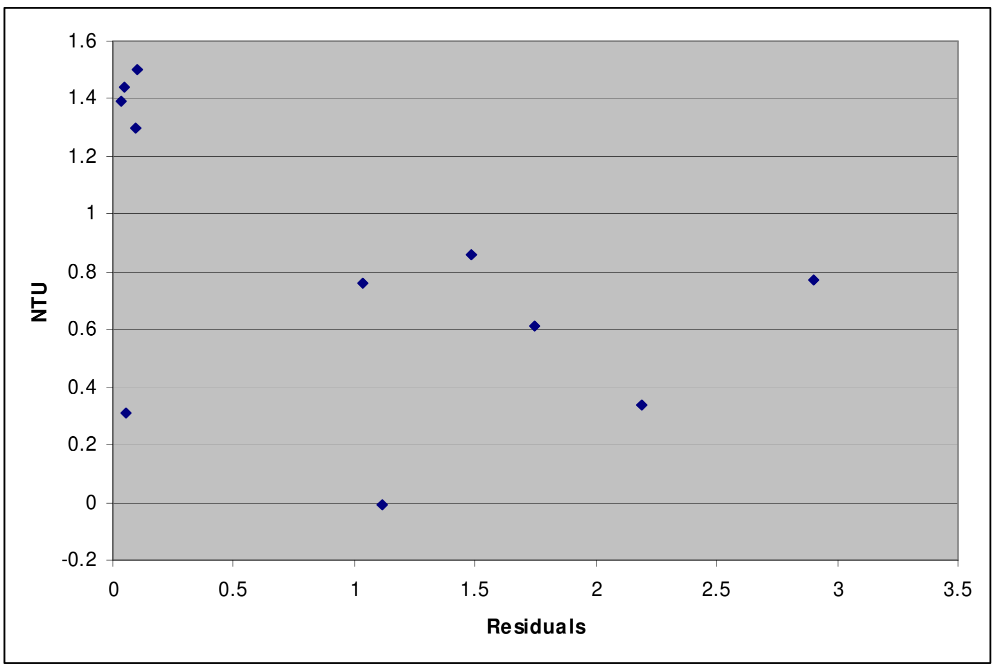

Figure 6.2. The positive residuals from the regression of *pasture* and *elevation* plotted against NTU. The residuals are generating relatively less turbidity, demonstrating that the independent variable *elevation* is an interactive term. The geometric mean of NTU was normalized using the Box-Cox transformation.

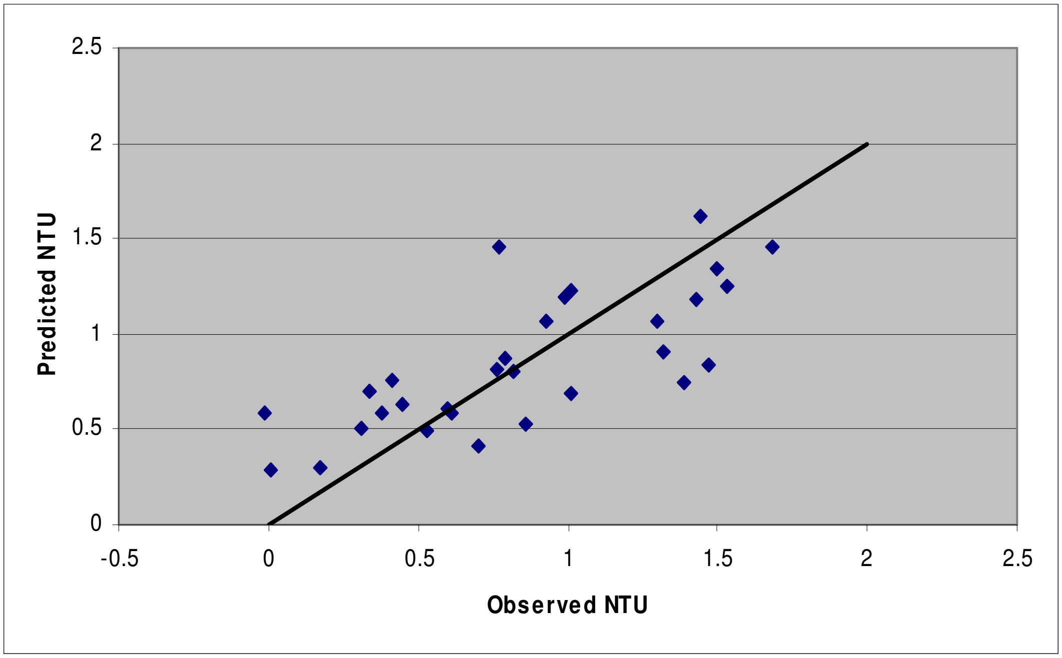

Figure 6.3. Observed vs. predicted NTU values resulting from the regression of *pasture* and the geometric mean of NTU. The geometric mean of NTU was normalized using the Box-Cox transformation**.**

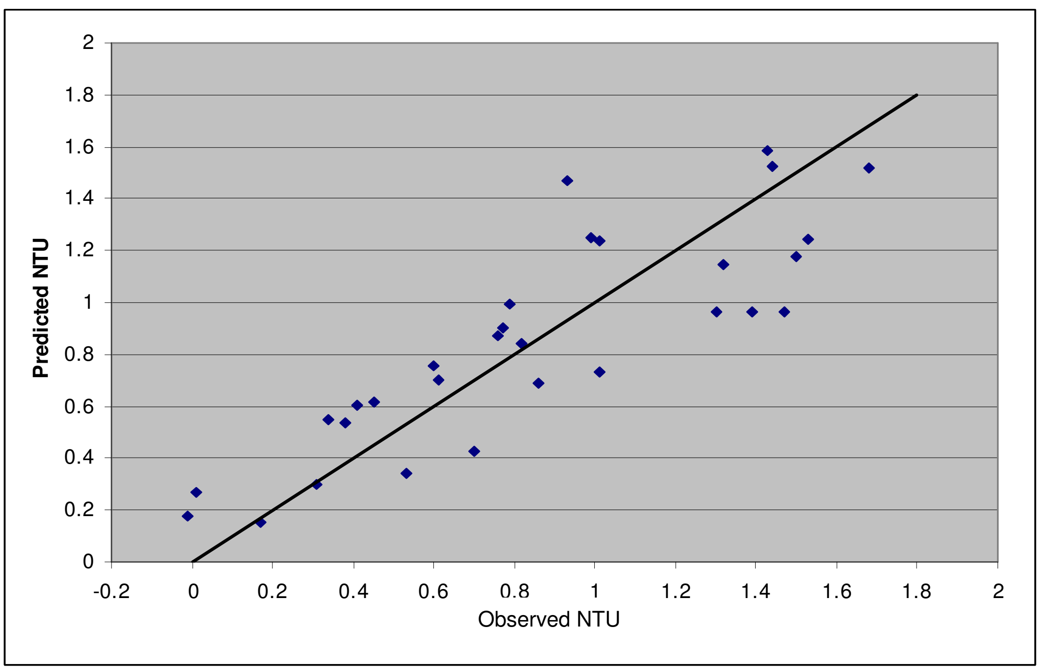

Figure 6.4. Observed vs. predicted NTU values resulting from the best fit regression model of *pasture, dev_open,* and *elevation*. The geometric mean of NTU was normalized using the Box-Cox transformation.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

This study demonstrates that the different types of LULC present in a drainage basin are statistically related to variability in baseflow turbidity. In general, anthropogenic disturbance of the natural landscape causes an increase in stream baseflow turbidity. In the absence of human impacts, the LULC within the study area region would be very nearly 100% forested (Yarnell, 1998). Baseflow NTU is negatively related to the percentage of forest LULC present in a drainage basin ($p = 0.01$). Forested land within the studied basins that has undergone the conversion to *pasture, grass* and developed LULC exhibit a positive correlation to baseflow NTU, and thus negatively effect stream water quality ($p = 0.01$). These landscape indicators can provide a suitable proxy for the biotic quality of streams, and they can be used to help manage, restore, and predict degraded and impaired stream conditions that result from urban growth, agriculture and other changes in LULC.

From the analysis of 27 independent variables, *pasture* LULC was identified as the primary correlate of differences in baseflow NTU. Stepwise multiple regression allowed for the isolation of differences in the percentage of *pasture* present in a drainage basin and its effect on baseflow water quality, revealing that *pasture* is responsible for 56% of the variation in the geometric mean of NTU. When *pasture* is combined with *elevation* and a developed LULC class (*dev_total* or *dev_open*), 73% of the variation in NTU is explained. Models incorporating *pasture*, *elevation,* and a forested LULC class (*forest_total* or *forest_d*) are less successful, only accounting for 66-68% of the variation in the dependent variable and thus suggesting that developed LULC plays a more significant role than does forested LULC in explaining the variation in the geometric mean of NTU. Contrary to hypotheses, baseflow turbidity did not demonstrate significant correlations with drainage basin size, drainage density or length of watercourse, although analyzing a larger range of these parameters in nested watersheds may be required to trigger a response in NTU.

This study supports the strong correlation found to exist between NTU and TSS measurements. Although NTU is a good indicator of suspended sediment levels, the data collected in this study yield a regression line which falls below the 1:1 line, suggesting that NTU slightly underestimates TSS in the Blue Ridge province. This study also indicates that increases between 10-15 NTU are not matched by increases in TSS, which may be due, at least in part, to organic solids contributing to NTU but not significantly to TSS. Because resource managers sometimes rely on turbidity measurements rather than TSS, it is important to understand the relationship between the two.

By linking LULC with stream water quality, this study enhances the understanding of how LULC affects the streams of the Blue Ridge province, thereby improving existing knowledge of the factors controlling regional stream turbidity. A better understanding of this relationship is needed in order to provide specific guidance on which LULC changes would be protective of aquatic life in the study area. Research of this type is essential in linking conservation ecology and sustainable development through regulation in order to reduce the amount of suspended sediment entering Blue Ridge streams.

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APPENDIX A

LOCATION AND PHYSICAL CHARACTERISTICS OF SUB-BASIN TURBIDITY SAMPLING SITES

Table A.1. Location and physical characteristics of sub-basin turbidity sampling sites (page 1 of 2).

BASIN	X	Y	Bridge crossing road name	Sample location in reference to bridge crossing	Basin outlet elevation (m)
Bates Branch	282380.7	3886584	Addington Bridge Rd.	10 ft. upstream of bridge edge	620
Big Creek	299786.3	3885401	Nc -1538	2 ft. upstream of bridge edge	1170
Blacks Creek	281914	3868420	Yorkhouse Rd.	3 m. upstream of bridge edge	648
Brush Creek	293610.8	3887930	Hwy 64	12 m. upstream of bridge edge	822
Cat Creek	286851.5	3897526	Cat Creek Rd.	3 ft. downstream of tunnel edge	628
Crawford Branch downstream	283665.2	3895942	Derby St.	11 ft. downstream of tunnel edge	617
Crawford Branch upstream	281572.9	3895171	Old Murphy Rd.	15 ft. upstream of bridge edge	631
Cullasaja River downstream	298010.9	3882240	Hwy 64	3 m. downstream of bridge support posts	1112
Cullasaja River upstream	300473.8	3882894	Hwy 64	4 m. upstream from concrete posts	1127
Darnell Creek	283638.6	3871172	Kelly’s Creek Rd.	6 ft. upstream from bridge posts	651
Hickory Knoll Creek	283478.3	3885762	Hickory Knoll Rd.	2 ft. upstream of front of bridge poles	629
Howard Branch	280533.2	3881666	Coweeta Lab Rd.	Directly under middle of bridge	647
Iotla Creek	279582.7	3900092	Airport Rd.	Directly under downstream side of bridge	614
Jones Creek downstream	274620.4	3889346	W. Old Murphy Rd.	4 ft. downstream from bridge edge	677
Jones Creek upstream	276198.9	3887042	Allison Watts Rd.	Directly under upstream side of bridge	728
Little Tennessee River	278277.6	3867943	Wolf Fork Church Rd.	12 ft. downstream from bridge edge	658
Kelly Creek	284331.1	3872423	Kelly’s Creek Rd.	10 m. downstream from bridge poles	651
Middle Creek	287855	3876437	NC State Route 106	Directly under middle of bridge	1028
Mill Creek	276287.6	3893746	Wayah Rd.	Directly under downstream side of bridge	641
Mud Creek downstream	283997.6	3873701	Kelly’s Creek Rd.	12 m. downstream concrete structure	642
Mud Creek upstream	288083.9	3873815	Sky Valley Way	3 ft. upstream from metal tunnel edge	954
North Fork	280595.7	3883045	Hickory Knoll Rd.	Directly under downstream side of bridge	644
Poplar Cove Creek	272586.5	3890732	Crawford Rd.	4 ft. upstream from bridge edge	670
Rabbit Creek	286842	3898755	Rabbit Creek Rd.	Directly under upstream bridge edge	629
Rocky Branch	282677.3	3900597	Riverbend Rd.	3 ft. downstream from bridge edge	604
Shope Fork	278485.9	3882385	Coweeta Lab Rd.	1 ft. from upstream from bridge edge	679

Table A.1. Location and physical characteristics of sub-basin turbidity sampling sites (page 2 of 2).

BASIN	X	Y	Bridge crossing road name	Sample location in reference to bridge crossing	Basin outlet elevation (m)
Skeenah Creek	281452.5	3888042	Addington Bridge Rd.	Directly under middle of bridge	627
Tessenntee Creek	288399.6	3883319	Nc 1636	5 ft. downstream from metal tunnel edge	707
Walnut Creek	292942.4	3890811	Walnut Creek Rd.	Directly under downstream edge of bridge	665
Watauga Creek	285608.3	3900757	Sanderstown Rd.	2 m. upstream from portion of concrete	619

APPENDIX B

USGS NATIONAL LAND COVER DATA CLASSIFICATION DESCRIPTIONS (2001)

Open Water - All areas of open water, generally with less than 25% cover or vegetation or soil

Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes

Developed, Low Intensity -Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Grassland/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

Woody Wetlands - Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

APPENDIX C

WATER STAGE AND DISCHARGE DATA

Table C.1. Stage height recordings and discharge data for each sample occasion (page 1 of 2).

Basin	Nov 22		Nov 25		Dec 7		Dec 12		Dec 14	
	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)
Bates Branch	1.42	0.0468	1.44	0.0471	1.45	0.0472	1.44	0.0471	1.48	0.0476
Big Creek	1.41	0.2668	1.52	0.2840	1.49	0.2785	1.52	0.2846	1.52	0.2843
Blacks Creek	1.08	0.1705	1.09	0.1711	1.08	0.1702	1.09	0.1711	1.10	0.1717
Brush Creek	1.35	0.2147	1.36	0.2164	1.34	0.2128	1.36	0.2171	1.36	0.2171
Cat Creek	2.00	0.0784	2.05	0.0790	2.00	0.0784	2.05	0.0790	2.02	0.0786
Crawford Branch upstream	1.20	0.0599	1.24	0.0609	1.23	0.0606	1.24	0.0608	1.24	0.0609
Cullasaja River downstream	1.29	0.4831	1.30	0.4865	1.27	0.4756	1.32	0.4926	1.32	0.4926
Cullasaja River upstream	1.37	0.2686	1.42	0.2838	1.40	0.2777	1.41	0.2807	1.42	0.2838
Darnell Creek	1.06	0.2920	1.05	0.2917	1.03	0.2912	1.05	0.2916	1.05	0.2916
Hickory Knoll Creek	1.91	0.1348	1.94	0.1364	1.91	0.1346	1.88	0.1333	1.89	0.1337
Howard Branch	1.02	0.1994	1.04	0.2008	1.02	0.1994	1.03	0.1997	1.02	0.1994
Iotla Creek	1.82	0.2112	1.86	0.2130	1.96	0.2171	1.95	0.2164	1.97	0.2173
Jones Creek downstream	1.51	0.4037	1.50	0.4035	1.47	0.4019	1.53	0.4048	1.50	0.4035
Jones Creek upstream	1.40	0.2432	1.39	0.2425	1.38	0.2418	1.40	0.2429	1.39	0.2425
Little Tennessee River	1.41	0.2285	1.42	0.2296	1.41	0.2285	1.42	0.2296	1.43	0.2309
Kelly Creek	1.26	0.0735	1.27	0.0736	1.27	0.0736	1.26	0.0735	1.26	0.0735
Middle Creek	1.39	0.4062	1.45	0.4093	1.43	0.4080	1.44	0.4088	1.45	0.4092
Mill Creek	1.23	0.0974	1.13	0.0906	1.00	0.0818	0.96	0.0788	0.95	0.0784
Mud Creek downstream	1.17	0.3326	1.18	0.3334	1.13	0.3294	1.14	0.3302	1.15	0.3312
Mud Creek upstream	1.17	0.1514	1.33	0.1610	N/A	N/A	1.32	0.1605	1.33	0.1608
North Fork	1.90	0.1811	1.91	0.1818	1.89	0.1803	1.89	0.1803	1.89	0.1799
Poplar Cove Creek	1.95	0.1809	1.13	0.1257	1.15	0.1271	1.15	0.1271	1.14	0.1266
Rabbit Creek	1.40	0.1179	1.40	0.1179	1.43	0.1195	1.44	0.1202	1.44	0.1200
Rocky Branch	1.60	0.0783	1.36	0.0772	1.61	0.0783	1.61	0.0783	1.60	0.0783
Shope Fork	1.07	0.1579	1.05	0.1548	1.04	0.1525	1.04	0.1525	1.03	0.1514
Skeenah Creek	1.79	0.2507	1.78	0.2511	1.79	0.2507	1.82	0.2498	1.82	0.2499
Tessentee Creek	1.32	0.2162	1.32	0.2162	1.31	0.2158	1.32	0.2162	1.32	0.2162
Walnut Creek	1.56	0.2050	1.58	0.2065	1.61	0.2084	1.63	0.2099	1.63	0.2104
Watauga Creek	1.39	0.1626	1.40	0.1629	1.40	0.1630	1.42	0.1634	1.40	0.1629

Water stage at the Mud Creek upstream sampling station was unable to be measured on December 7, 2006 due to a maintence crew working near the marker.

Table C.1. Stage height recordings and discharge data for each sample occasion (page 2 of 2).

Basin	Dec 15		Dec 19		Dec 29		Feb 16		Feb 27		May 2	
	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)	Stage (m)	Discharge (m/s)
Bates Branch	1.44	0.0471	1.45	0.0472	1.44	0.0471	1.44	0.0471	1.43	0.0470	1.45	0.0472
Big Creek	1.53	0.2852	1.54	0.2863	1.50	0.2809	1.55	0.2888	1.55	0.2888	1.57	0.2924
Blacks Creek	1.10	0.1717	1.14	0.1740	1.12	0.1726	1.15	0.1747	1.16	0.1754	1.25	0.1803
Brush Creek	1.36	0.2164	1.38	0.2190	1.35	0.2144	1.39	0.2210	1.38	0.2200	1.39	0.2214
Cat Creek	2.02	0.0786	2.08	0.0793	2.02	0.0786	1.99	0.0782	1.95	0.0779	2.00	0.0784
Crawford Branch US	1.24	0.0609	1.26	0.0613	1.24	0.0608	1.24	0.0609	1.24	0.0610	1.23	0.0608
Cullasaja River DS	1.32	0.4946	1.33	0.4966	1.27	0.4756	1.31	0.4895	1.32	0.4922	1.39	0.5163
Cullasaja River US	1.45	0.2925	1.42	0.2838	1.37	0.2674	1.37	0.2686	1.42	0.2844	1.47	0.2998
Darnell Creek	1.05	0.2916	1.04	0.2915	1.15	0.2940	1.05	0.2918	1.04	0.2916	1.07	0.2922
Hickory Knoll Creek	1.90	0.1343	1.90	0.1345	1.88	0.1333	1.88	0.1333	1.89	0.1338	1.88	0.1334
Howard Branch	1.03	0.1999	1.04	0.2008	1.02	0.1992	1.02	0.1994	1.02	0.1994	1.13	0.2073
Iotla Creek	1.96	0.2171	1.99	0.2184	1.96	0.2172	2.01	0.2190	1.99	0.2182	2.26	0.2290
Jones Creek DS	1.49	0.4027	1.52	0.4045	1.48	0.4024	1.50	0.4036	1.50	0.4035	1.52	0.4042
Jones Creek US	1.40	0.2434	1.40	0.2434	1.38	0.2421	1.39	0.2422	1.38	0.2420	1.38	0.2416
L. Tennessee River	1.43	0.2308	1.44	0.2315	1.41	0.2280	1.42	0.2292	1.41	0.2281	1.45	0.2330
Kelly Creek	1.26	0.0735	1.26	0.0735	1.26	0.0735	1.26	0.0735	1.29	0.0738	1.25	0.0735
Middle Creek	1.44	0.4088	1.45	0.4093	1.42	0.4078	1.42	0.4075	1.45	0.4092	1.45	0.4093
Mill Creek	0.93	0.0769	0.92	0.0764	0.86	0.0722	0.95	0.0785	0.87	0.0730	1.26	0.0993
Mud Creek DS	1.14	0.3302	1.14	0.3302	1.12	0.3286	1.17	0.3326	1.15	0.3310	1.20	0.3349
Mud Creek US	1.34	0.1615	1.34	0.1613	1.30	0.1593	1.31	0.1599	1.37	0.1634	1.38	0.1639
North Fork	1.90	0.1807	1.89	0.1799	1.90	0.1810	1.89	0.1803	1.98	0.1871	1.88	0.1796
Poplar Cove Creek	1.15	0.1268	1.16	0.1278	1.13	0.1257	1.14	0.1264	1.13	0.1258	1.12	0.1251
Rabbit Creek	1.44	0.1201	1.44	0.1200	1.44	0.1200	1.42	0.1190	1.42	0.1192	1.44	0.1203
Rocky Branch	1.61	0.0783	1.62	0.0784	1.61	0.0783	1.61	0.0783	1.81	0.0792	1.62	0.0784
Shope Fork	1.04	0.1528	1.05	0.1540	1.01	0.1486	1.04	0.1534	1.03	0.1520	1.06	0.1563
Skeenah Creek	1.77	0.2513	1.81	0.2501	1.80	0.2505	1.80	0.2506	1.76	0.2517	1.79	0.2507
Tessentee Creek	1.33	0.2163	1.35	0.2167	1.32	0.2161	1.33	0.2164	1.34	0.2166	1.36	0.2171
Walnut Creek	1.61	0.2084	1.63	0.2102	1.57	0.2056	1.64	0.2108	1.85	0.2263	1.66	0.2124
Watauga Creek	1.41	0.1632	1.41	0.1633	1.40	0.1628	1.40	0.1629	1.40	0.1628	1.41	0.1631

US is an abbreviation for upstream. DS is an abbreviation for downstream.

APPENDIX D

CORRELATIONS BETWEEN INDEPENDENT VARIABLES

Table D.1. Correlation coefficients between independent variables (page 1 of 2).

Variable	Area (km^2)	Perimeter (km)	Basin slope (%)	Elevation (m)	El_stdev	L (km)	Le (km)	Lr	Relief ratio (km/km)	Drain dens (km/km^2)	Stream slope (km/km)
Forest_d	0.20	-0.05	***0.91***	0.10	***0.87***	0.23	-0.16	0.05	0.33	0.18	***0.78***
Forest_e	0.06	0.27	**-0.56**	0.11	***-0.55***	0.17	0.34	0.24	-0.04	-0.14	**-0.39**
Forest_mix	-0.03	0.04	***-0.48***	0.07	***-0.53***	-0.06	0.07	0.00	-0.01	-0.33	**-0.37**
Shrubscrub	-0.04	-0.12	-0.30	-0.18	-0.29	-0.31	-0.14	**-0.40**	0.04	0.00	-0.35
Grass	-0.14	-0.13	**-0.45**	***-0.58***	**-0.45**	-0.17	-0.11	-0.01	**0.39**	-0.20	**-0.41**
Pasture	-0.19	-0.17	***-0.52***	***-0.60***	***-0.54***	-0.30	-0.13	-0.20	0.29	-0.20	***-0.55***
Water	-0.27	0.02	***-0.77***	***0.81***	***-0.76***	-0.20	0.10	0.05	***-0.85***	0.06	***-0.62***
Dev_open	-0.24	-0.03	***-0.74***	-0.01	***-0.70***	-0.33	0.07	-0.20	**-0.44**	-0.08	***-0.69***
Dev_low	-0.13	-0.02	**-0.37**	0.08	-0.31	0.03	0.03	**0.40**	-0.35	-0.21	-0.11
Dev_med	0.04	0.17	***-0.50***	-0.07	**-0.38**	0.24	0.19	***0.65***	-0.15	-0.12	**-0.36**
Barren	-0.14	-0.28	0.20	0.34	**0.38**	-0.19	-0.29	-0.06	-0.23	0.26	**0.40**
Crop	0.01	-0.08	0.30	-0.34	0.26	-0.08	-0.11	-0.15	0.29	-0.24	0.24
Woodywetland	***-0.61***	***-0.59***	0.04	-0.19	-0.06	***-0.49***	***-0.55***	-0.01	0.14	**0.43**	-0.09
Pasture+Grass	-0.18	-0.17	***-0.53***	***-0.63***	***-0.55***	-0.28	-0.13	-0.15	-0.21	0.16	0.01
Dev_total	-0.24	-0.03	***-0.72***	-0.02	***-0.70***	-0.33	0.07	-0.20	**-0.44**	-0.08	-0.68
Forest_total	0.25	0.06	***0.74***	0.18	***0.67***	0.33	-0.04	0.16	**0.37**	0.07	0.67

A 0.05 level of significance (p) for a two tailed test yields a 0.361 critical value of r (n=30). A 0.01 level of significance (p) for a two tailed test yields a 0.463 critical value of r (n=30). Those correlation coefficients significant at the 0.05 level are bold. Those correlation coefficients significant at the 0.01 level are bold italicized.

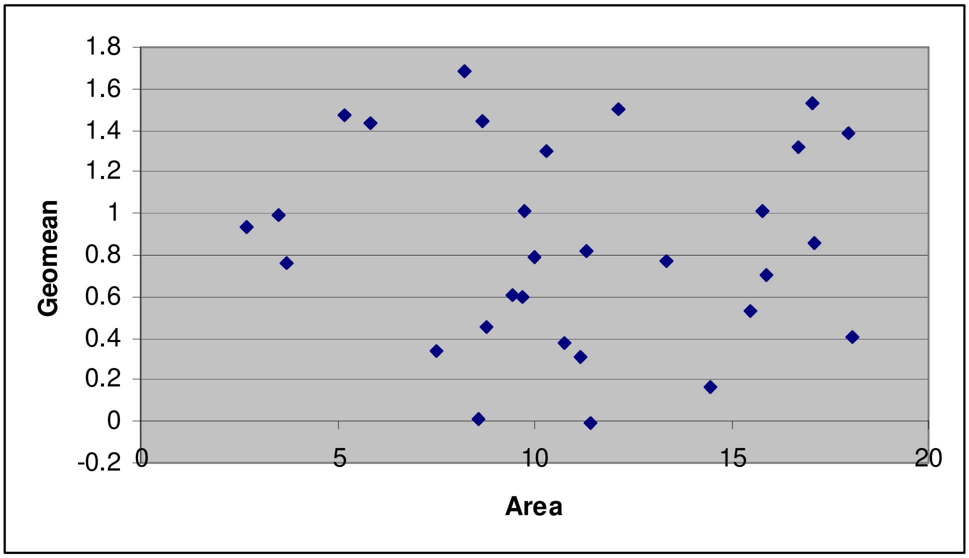
Table D.1. Correlation coefficients between independent variables (page 2 of 2).

Variable	Forest d	Forest e	Forest mix	Shrub scrub	Grass	Pasture	Water	Dev open	Dev low	Dev med	Barren	Crop	Woody wetland	Pasture +Grass	Dev total
Forest_e	***-0.54***														
Forest_mix	**-0.45**	***0.76***													
Shrubscrub	-0.27	0.04	0.29												
Grass	**-0.4**	0.17	0.15	**0.46**											
Pasture	***-0.57***	0.17	0.25	***0.57***	***0.73***										
Water	***-0.57***	0.31	**0.36**	***0.47***	-0.03	0.09									
Dev_open	***-0.86***	0.24	0.21	0.14	0.19	**0.4**	0.29								
Dev_low	***-0.59***	0.23	0.16	-0.33	-0.28	**-0.41**	0.18	***0.75***							
Dev_med	***-0.67***	***0.55***	0.19	0.21	0.25	0.11	0.26	**0.39**	***0.57***						
Barren	**0.37**	-0.31	0.2	0.24	-0.26	-0.16	0.36	-0.24	0.12	-0.2					
Crop	0.12	-0.2	-0.21	-0.11	-0.02	0.32	**-0.38**	-0.04	-0.21	-0.07	0.3				
Woodywetland	0.09	-0.18	0.03	0.05	0.23	0.09	0.09	0.02	-0.29	-0.1	0.27	-0.02			
Pasture+Grass	***-0.55***	0.18	0.23	***0.57***	***0.85***	***0.98***	0.22	0.36	**-0.39**	0.17	-0.19	0.25	0.14		
Dev_total	***-0.86***	0.24	0.2	0.13	0.19	**0.39**	0.29	***1.0***	***0.8***	**0.42**	-0.23	0.00	0.02	0.36	
Forest_total	***0.85***	-0.04	0.03	-0.24	**-0.37**	***-0.54***	-0.36	***-0.87***	***-0.55***	***-0.47***	**0.41**	0.01	0.02	***-0.52***	***-0.87***

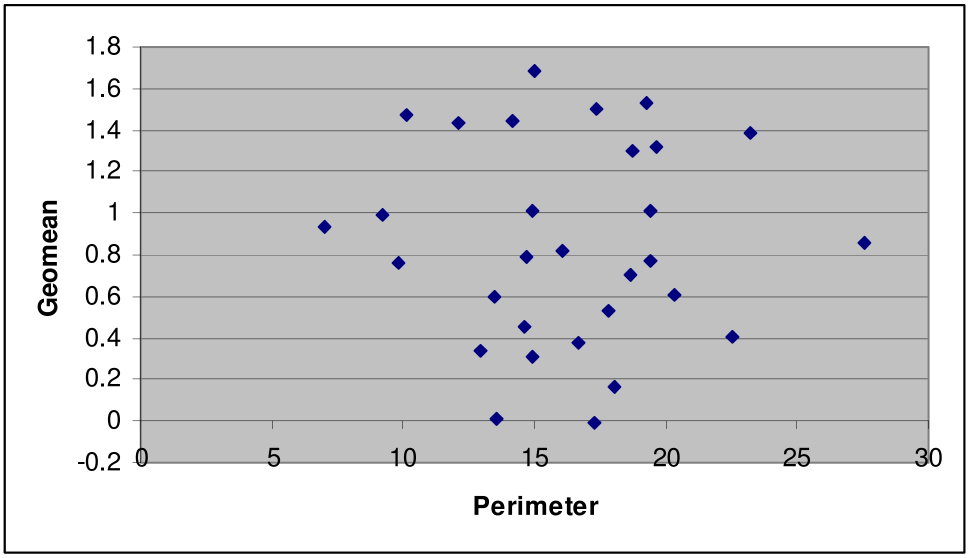
A 0.05 level of significance (p) for a two tailed test yields a 0.361 critical value of r (n=30). A .01 level of significance (p) for a two tailed test yields a 0.463 critical value of r (n=30). Those correlation coefficients significant at the 0.05 level are bold. Those correlation coefficients significant at the 0.01 level are bold italicized.

APPENDIX E

BIVARIATE PLOTS DEPICTING NTU AGAINST EACH INDEPENDENT VARIABLE



Pearson’s r correlation coefficient = -0.04



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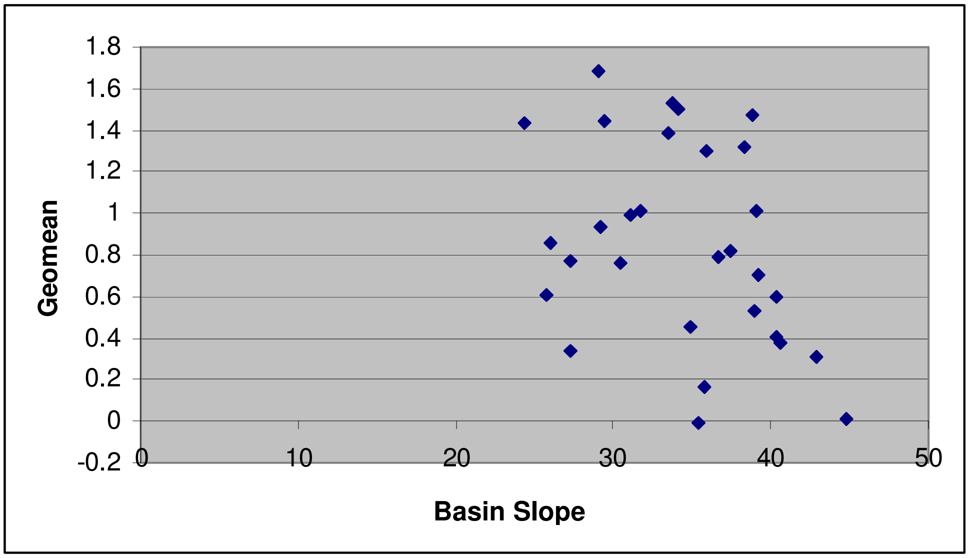

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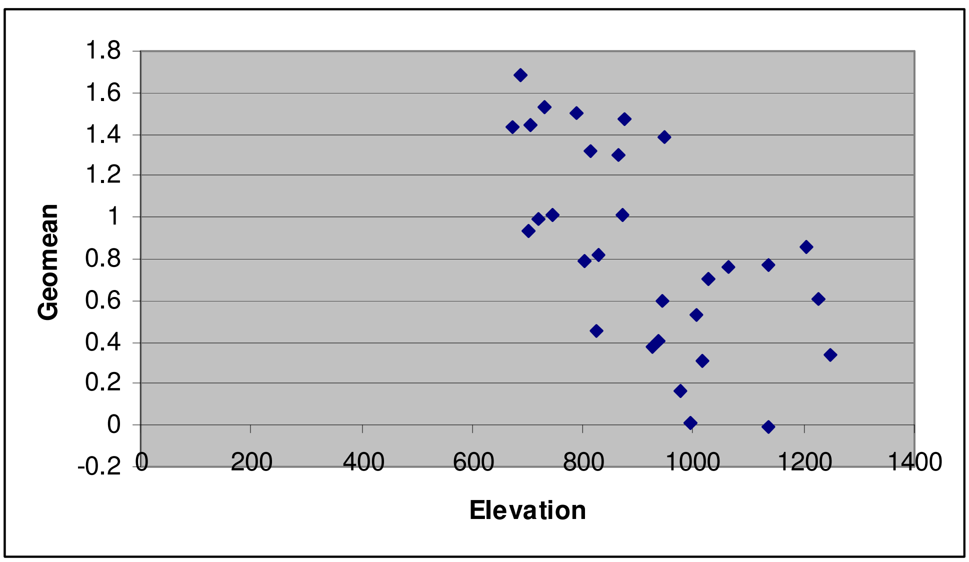

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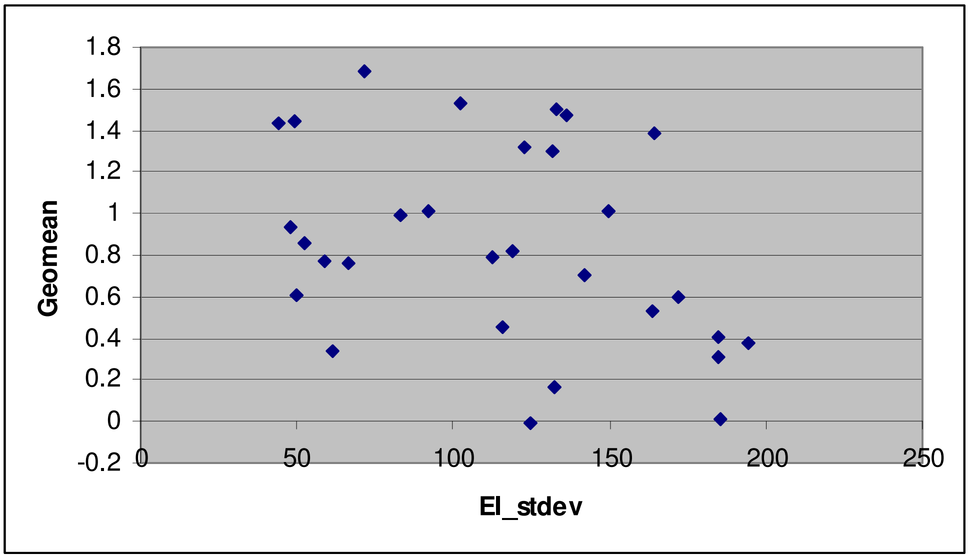

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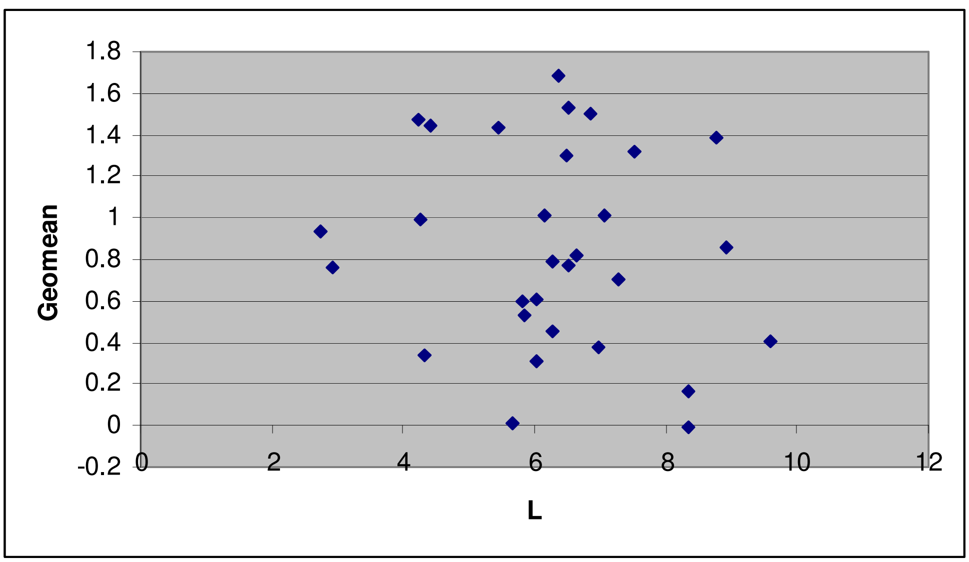

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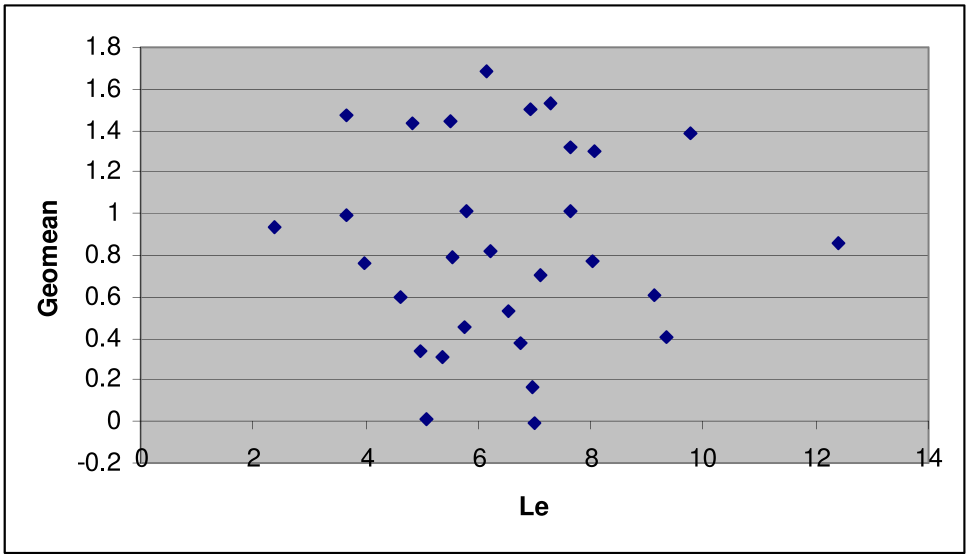

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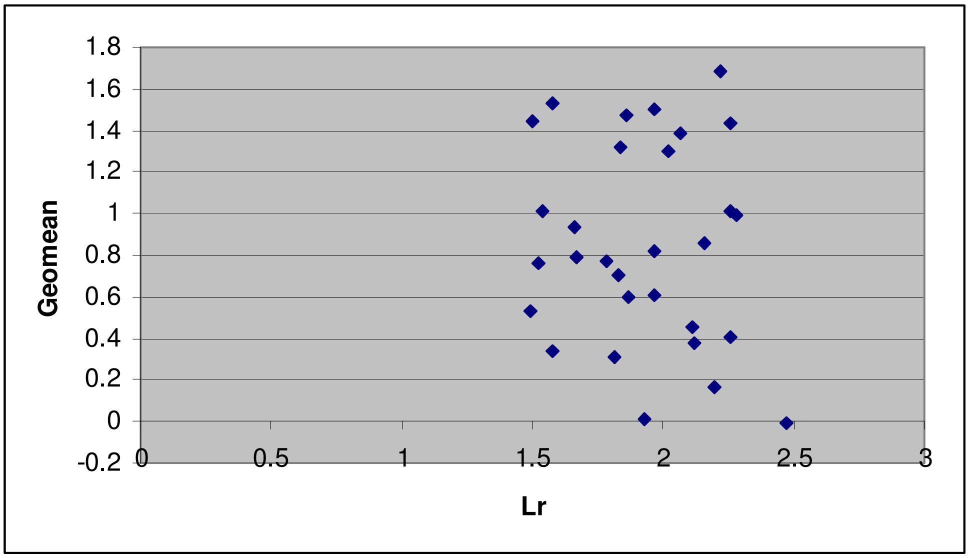

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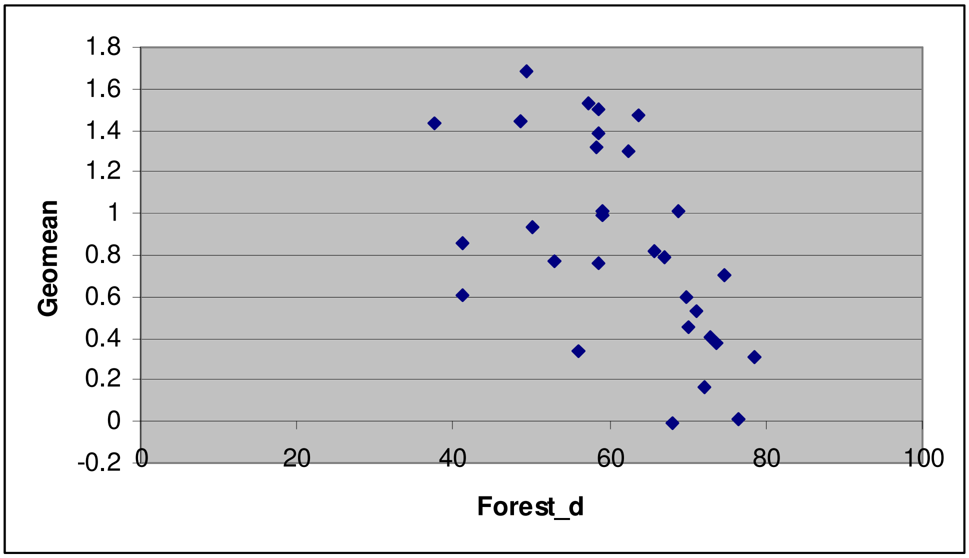
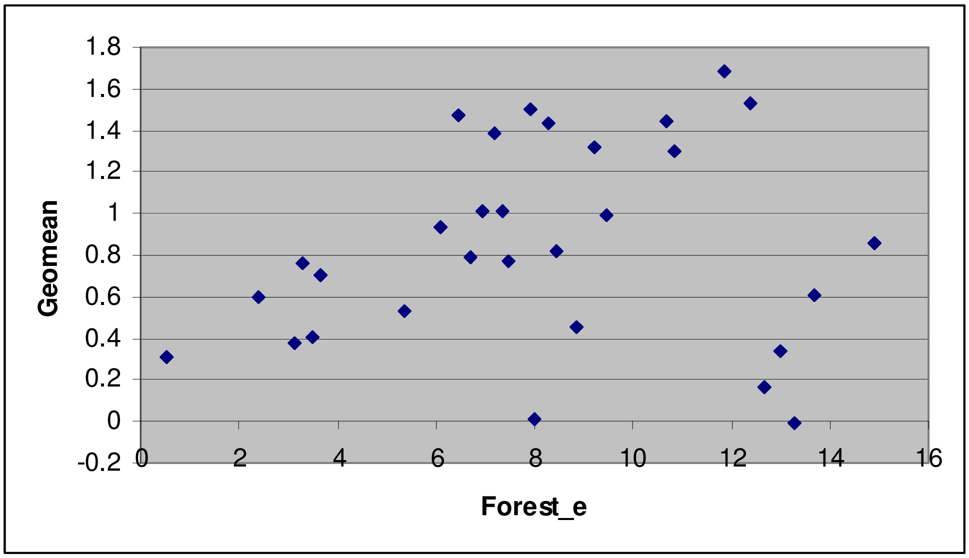
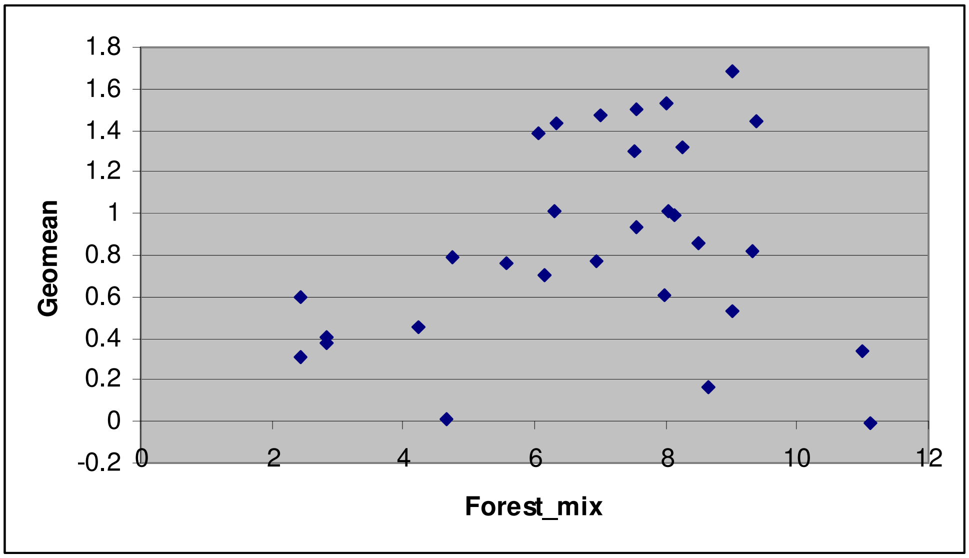


Pearson's r correlation coefficient = -0.56



Pearson's r correlation coefficient = 0.15



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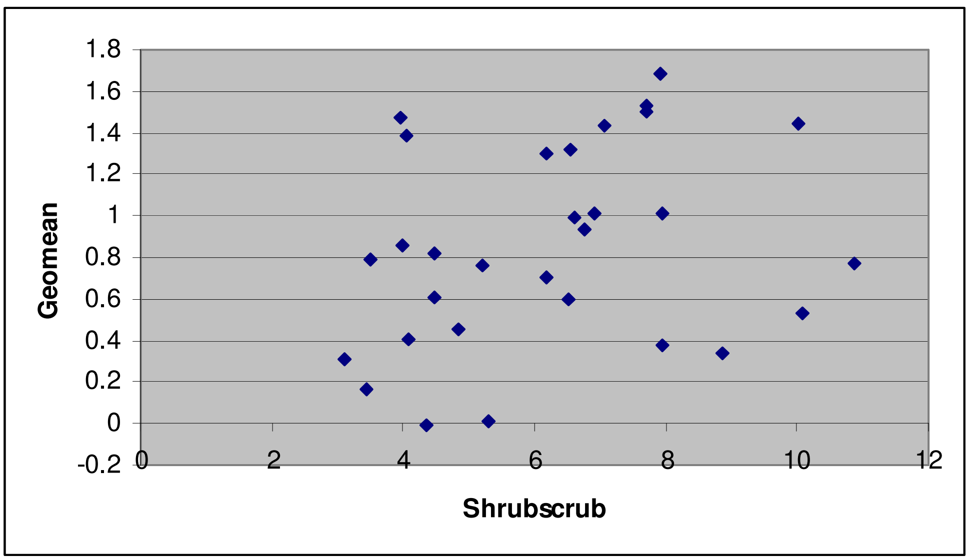

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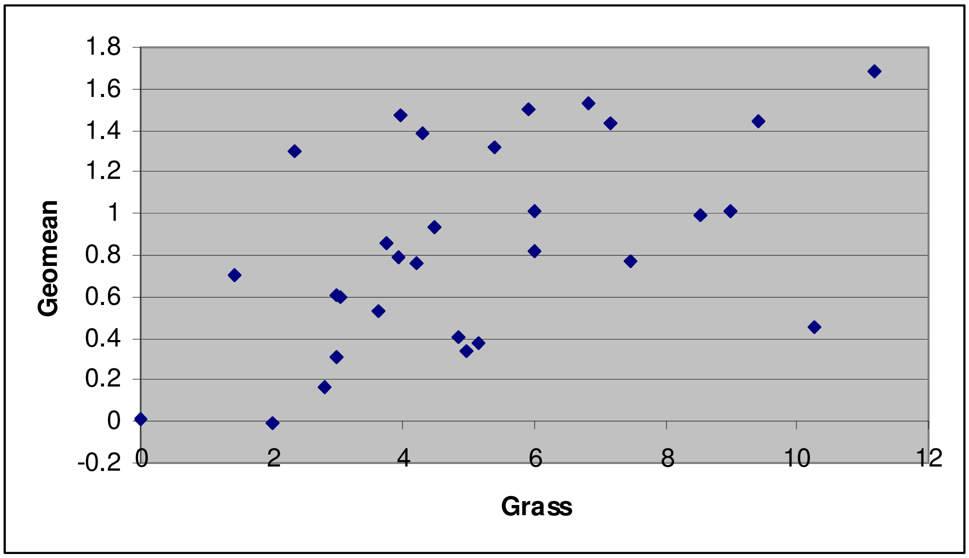
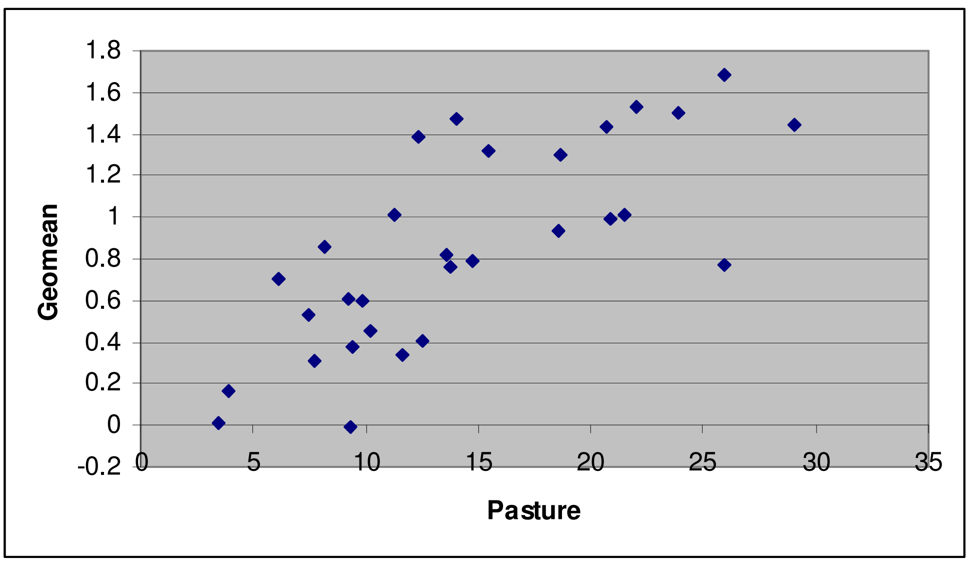
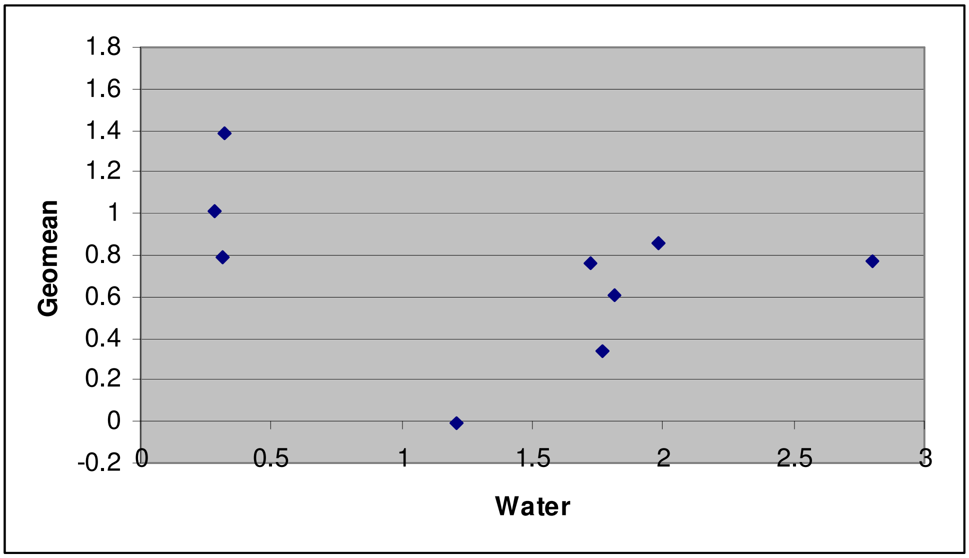


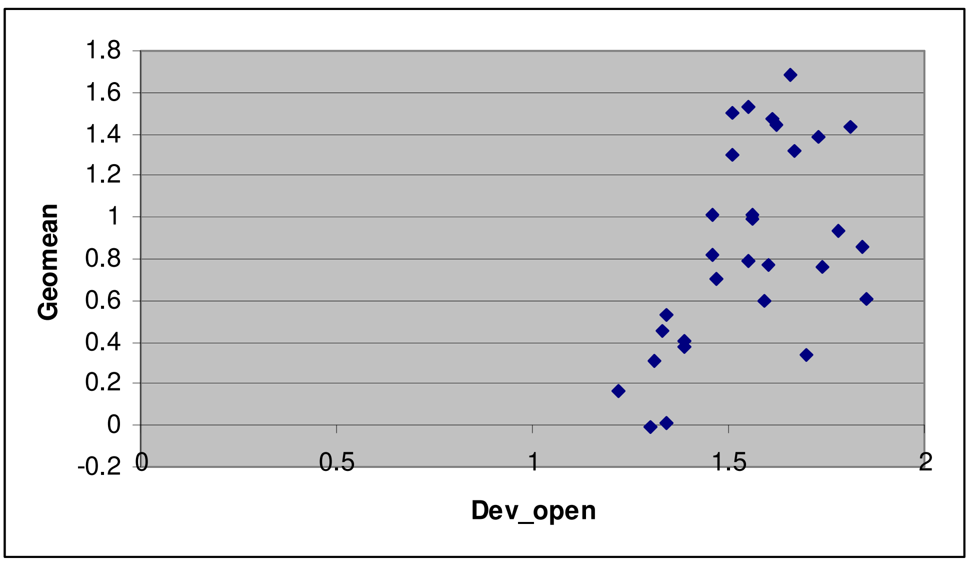
Pearson's r correlation coefficient = 0.51



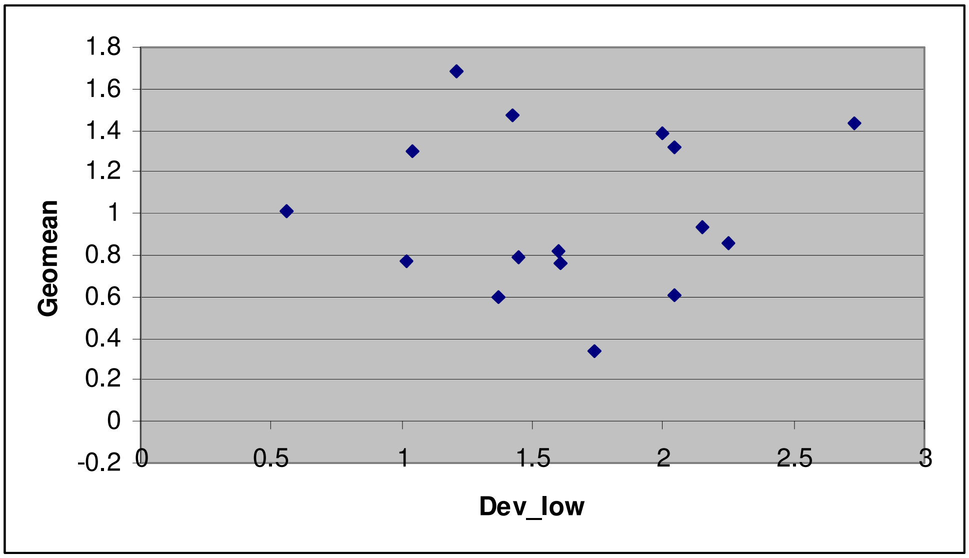
Pearson's r correlation coefficient = 0.75



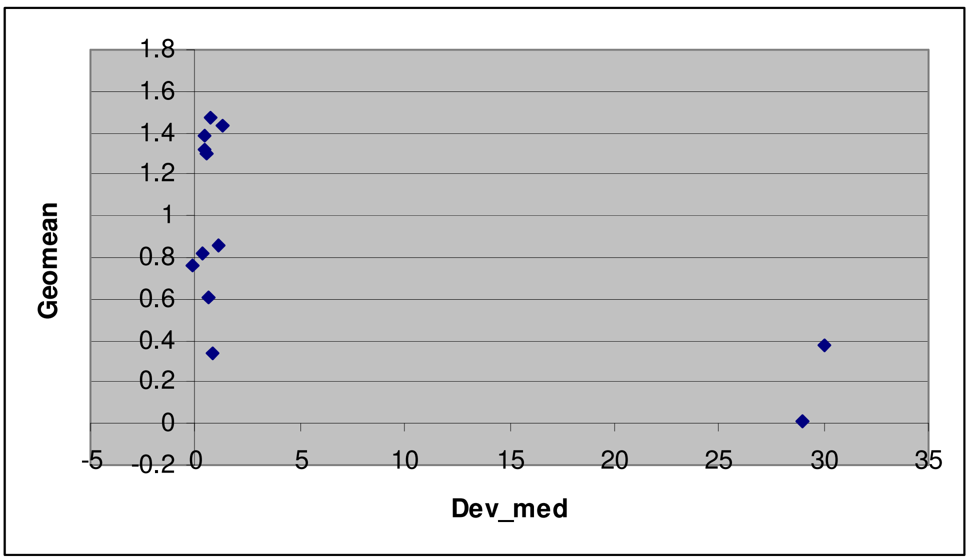
Pearson's r correlation coefficient = -0.36



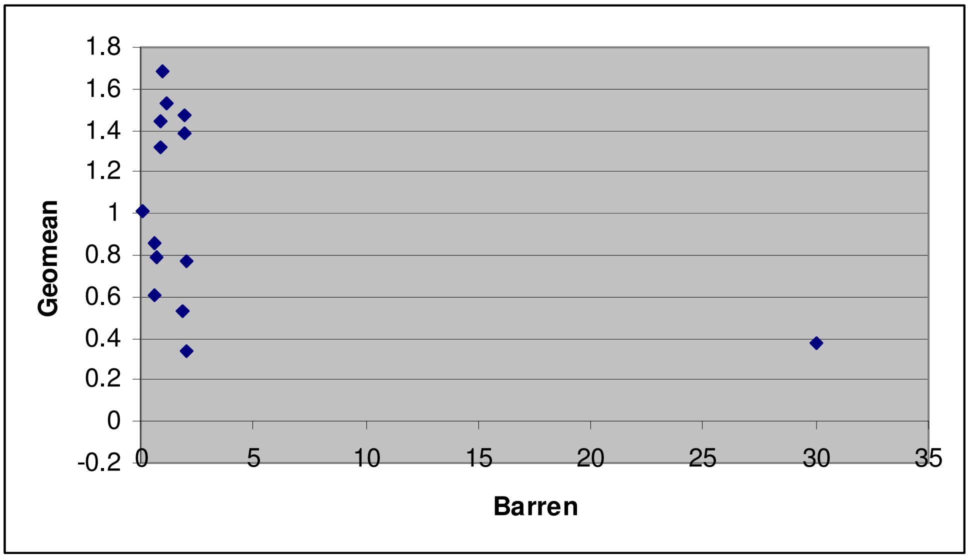
Pearson's r correlation coefficient = 0.54



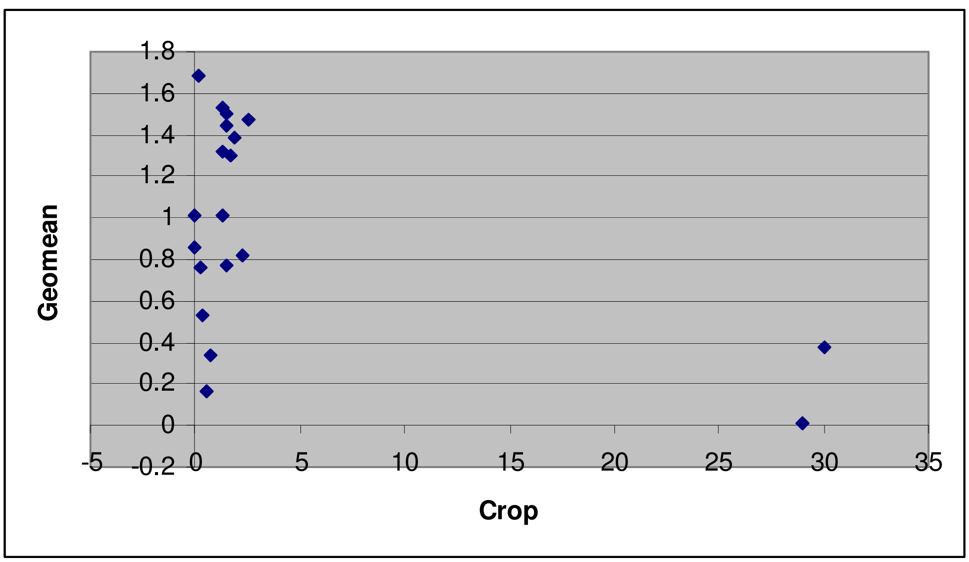
Pearson's r correlation coefficient = 0.03



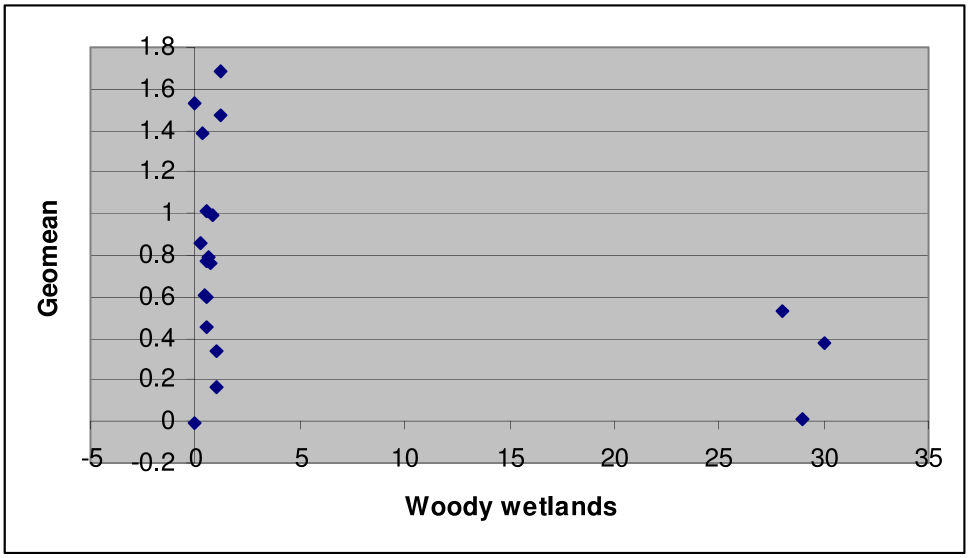
Pearson's r correlation coefficient = 0.19



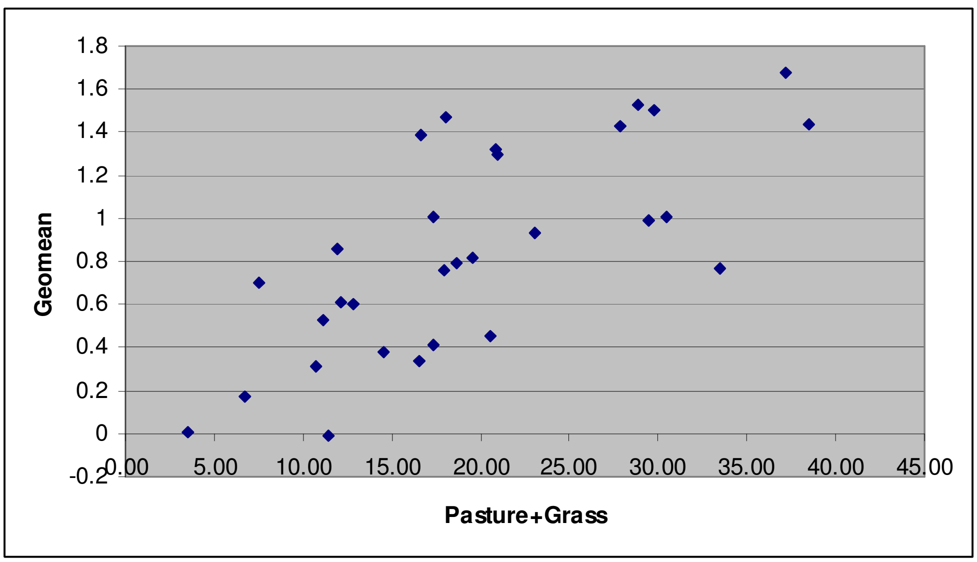
Pearson's r correlation coefficient = -0.13



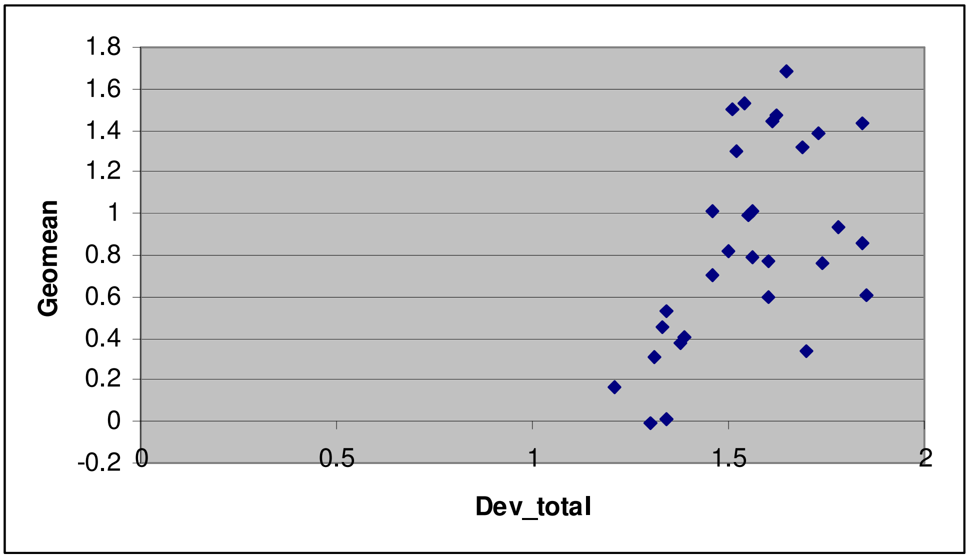
Pearson's r correlation coefficient = 0.39



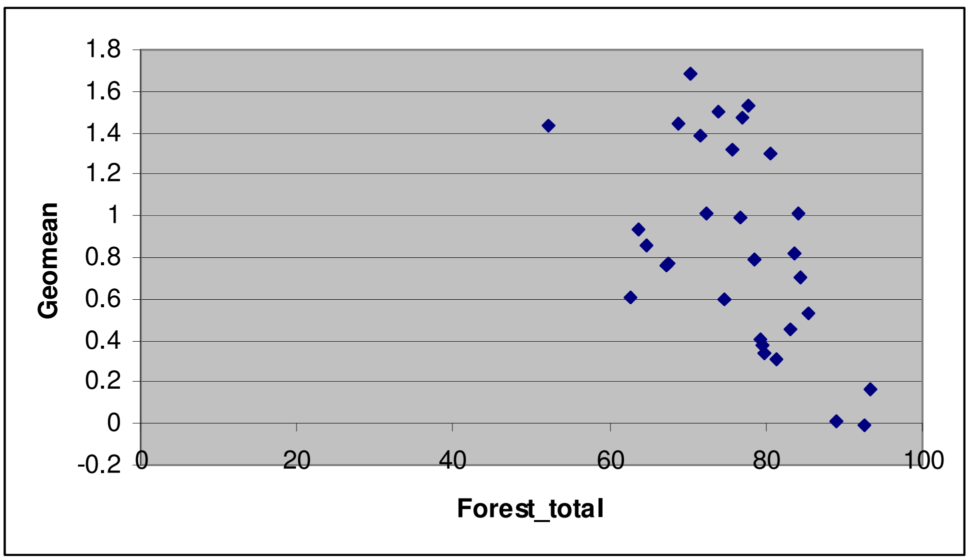
Pearson's r correlation coefficient = 0.16



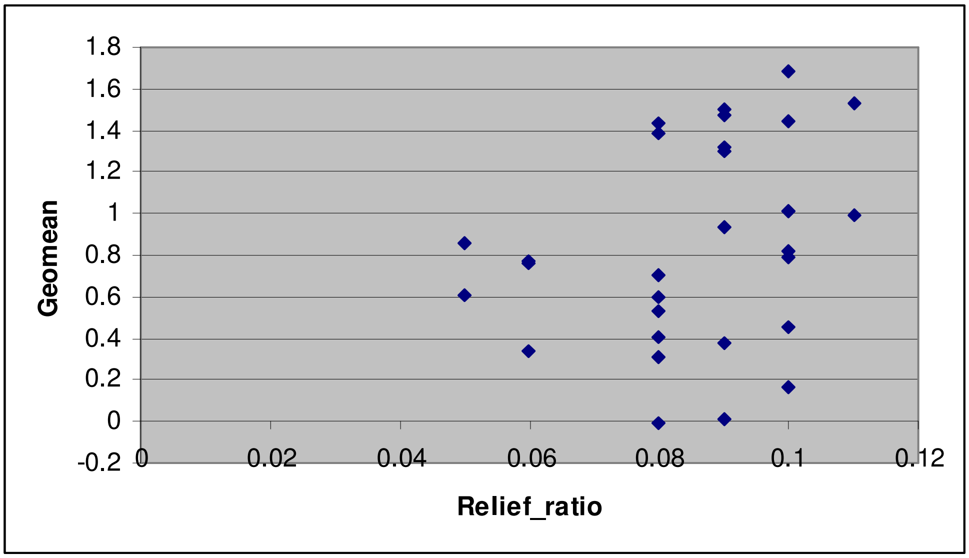
Pearson's r correlation coefficient = 0.52



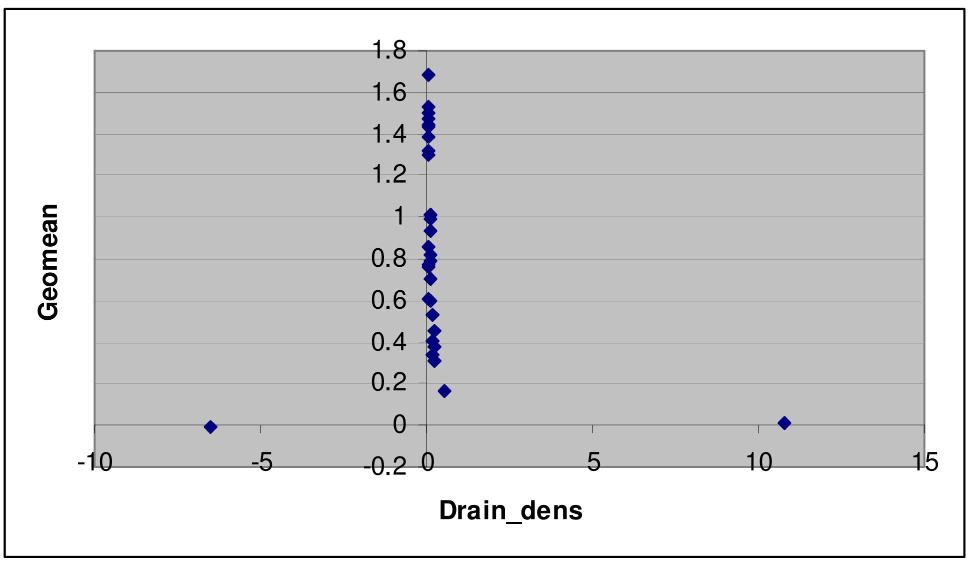
Pearson's r correlation coefficient = 0.55



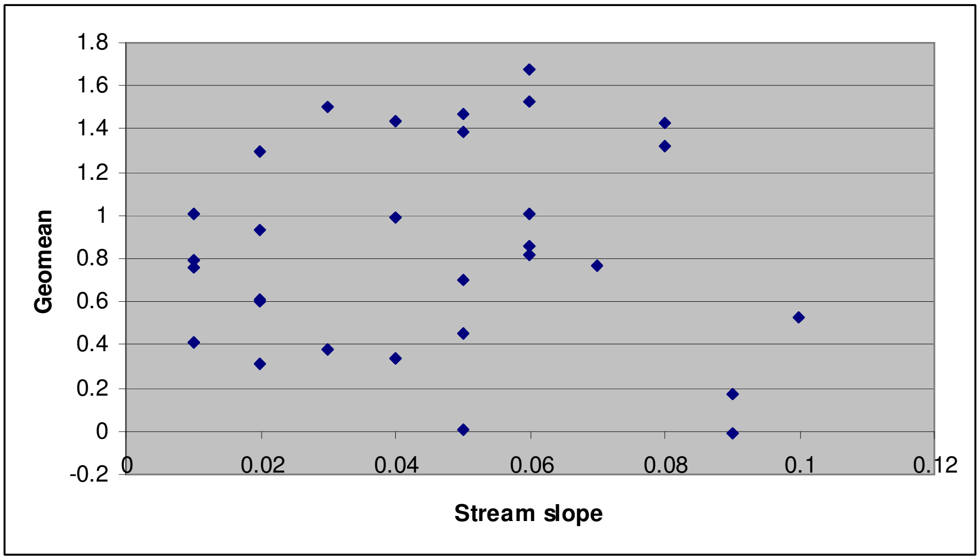
Pearson's r correlation coefficient = -0.54



Pearson's r correlation coefficient = 0.29



Pearson's r correlation coefficient = -0.13



Pearson's r correlation coefficient = .0002