

To the Graduate Council:

I am submitting herewith a thesis written by Heather Melanie Hart entitled “Effect of Land Use on Total Suspended Solids and Turbidity in the Little River Watershed, Blount County, Tennessee”. I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Sciences.

Joanne Logan_____
Major Professor

We have read this thesis
and recommend its acceptance:

Paul Ayers_____

John Schwartz_____

Accepted for the council:

Anne Mayhew_____
Vice Chancellor and
Dean of Graduate Studies

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

Effect of Land Use on Total Suspended Solids and Turbidity
in the Little River Watershed, Blount County, Tennessee

A thesis presented for
the Master of Science Degree
The University of Tennessee, Knoxville

Heather Melanie Hart
August 2006

Dedication

I dedicate this thesis to my parents, Fred and Glenda Hart, who instilled in me the love of learning and the importance of a positive outlook. Their love, faith, and support have been a constant in my life. Through their encouragement and example, I have been able to achieve many of my goals and prepare myself for future challenges. I also dedicate this thesis to my sister, Christy, who has inspired me through her own achievements.

Acknowledgements

The author would like to acknowledge the following persons:

Dr. Joanne Logan, my major professor, for her positive attitude and encouragement. Under her guidance, I was able to finish my master's degree at the University of Tennessee.

Dr. Paul Ayers, committee member, for his willingness to share his insights and knowledge. His contribution has proved invaluable to the completion of this project.

Dr. John Schwartz, committee member, for his willingness to share his insights and knowledge. His contribution has proved invaluable to the completion of this project.

Galina Melnichenko, University of Tennessee, water quality scientist, whose patience, knowledge, and kindness made this project a great learning experience.

Tom McDonough, watershed representative with Tennessee Valley Authority, whose expertise was called upon on numerous occasions. Generosity of his time, guidance and equipment proved invaluable to the completion of this project.

Doyle Prince, manager of Maryville Water Treatment Plant, for his willingness to allow me to invade his office on numerous occasions to obtain historical data.

Jason Wight, Doctoral candidate, for his time and help with statistical analysis.

All my friends that I have had the pleasure of meeting in school and sharing great experiences with. I know that they have come into my life for a reason and I appreciate each one of them.

Abstract

The Little River (LR) originates in the Great Smoky Mountains National Park (GSMNP), providing drinking water to thousands of residents in Blount County as it makes its way to the Tennessee River. The upper reaches of the LR watershed have excellent water quality, qualifying it as a hydrologic benchmark river and outstanding national resource. A large outdoor recreation economy has grown dependent on the pristine land and water resources, including whitewater kayaking and rafting, cold and warm water fisheries, hiking, swimming and camping. However, in recent years there has been a documented overall decline in the biological diversity of the LR in the lower reaches outside of the GSMNP boundary, although the reasons are unknown. Sediment is suspected, since high levels can adversely affect water quality, creating an unsuitable habitat for plants and animals. Sediment is a non point source (NPS) pollutant, and is considered the primary cause of water impairment in the US, and especially Tennessee. Most watershed restoration planning, including the development of Total Maximum Daily Loads (TMDL) must address sediment pollution.

The objectives for this study were to analyze sediment by measuring 1) Total Suspended Solids (TSS) and turbidity in water collected after storm events, 2) quantify the relationship between TSS and turbidity, 3) examine land use effects on measured TSS, and 4) evaluate long term trends in turbidity data collected at the Maryville (Tennessee) Water Treatment Plant, located near the mouth of the LR. Nineteen single stage samplers were installed in May 2003 at 6 sites on the main

channel and near the mouths of 13 tributaries to collect storm event water samples. TSS was measured in mg L^{-1} using a filtration method, and turbidity in Nephelometric Turbidity Units (NTU) was measured with a turbidity meter. The drainage area of each sampling site was classified using a geographical information system (GIS) as either forest, urban, agriculture or mixed use, depending on the relative areas of each land use, and grouped according to percent imperviousness.

Results from 28 storm events from May 2003 to June 2004 showed a very wide range in TSS, from a low of less than 1 mg L^{-1} in the pristine upper reaches to a high of $11,108 \text{ mg L}^{-1}$ in one of the more impacted tributaries. The 13 tributaries had higher TSS than the 6 sites on main channel, yet the upper 4 sites on the main channel did not differ significantly from the lower 2 sites. Forested drainage areas had lower TSS than those that were classified as either agriculture or urban. With the exception of one agricultural drainage area, urban areas had higher TSS than agricultural areas. Since it was shown in this study that TSS and turbidity were highly correlated, turbidity data from 1990 – 2004 analyzed at the Maryville Water Treatment Plant was used as evidence of increasing TSS in the LR Watershed, especially in recent years and almost doubling since 2000. Increased development in urbanizing areas of the lower reaches and poor agricultural practices in other tributaries will continue to threaten the water quality of the LR, and must be taken into consideration in any watershed restoration planning.

Table of Contents

Introduction.....	1
Chapter 1 Literature Review.....	4
1.1 Water Quality and Total Maximum Daily Load.....	4
1.2 Non Point Source (NPS) Pollutants.....	5
1.2.1 Nutrients.....	6
1.2.2 Pathogens.....	9
1.2.3 Sediment.....	9
1.3 Watersheds and River Channel Processes.....	13
1.4 Land Use and Soil.....	18
1.5 Water Sampling for Sediment.....	21
1.6 Watershed Assessment Computer Models and GIS Applications.....	27
1.7 Best Management Practices to Control Sediment Pollution.....	28
Chapter 2 Methods and Materials.....	33
2.1 Study Area.....	33
2.1.1 Physiography and Geology.....	33
2.1.2 Soils.....	35
2.1.3 Land Use and Vegetation.....	36
2.2 Sample Collection.....	37
2.3 Site Selection.....	41
2.4 Laboratory Procedures.....	43
2.5 Turbidity Data from Maryville Water Treatment Plant.....	44
2.6 Statistical Analyses.....	45
2.7 Determination of Land Use Characteristics.....	48
Chapter 3 Results and Discussion.....	49
3.1 Comparisons of TSS and Turbidity.....	49
3.1.1 Geomean.....	49
3.1.2 TSS and Turbidity Comparisons.....	50
3.1.3 Main Channel TSS Concentration Comparisons.....	52
3.1.4 Tributary TSS Concentrations Versus Land Use Comparisons.....	53
3.2 Correlations.....	63
3.2.1 Maryville Water Treatment Plant.....	68
Conclusion and Recommendations.....	70
List of References.....	77
Appendices.....	90
Tables.....	91
Figures.....	103
Appendix Tables.....	120
Appendix Figures.....	129
Vita.....	131

List of Tables

Table 1. Environmental and engineering issues associated with sediment transport in rivers (Ongley, 1996).....	92
Table 2. Summary of characteristics for study streams.....	93
Table 3. Geomean of total suspended solids and turbidity for Little River watershed sampling sites.....	94
Table 4. Tests of normality determined by the Shapiro-Wilk test.....	95
Table 5. Descriptive statistics showing comparisons of TSS and turbidity for tributaries versus main channel sites in the Little River watershed.....	95
Table 6. Percentiles depicting the weighted average of the sampling sites TSS and turbidity.....	95
Table 7. Non-parametric test for the mean TSS and turbidity concentration for all sites.....	96
Table 8. Test for statistical significance of TSS and turbidity determined by Mann-Whitney test.....	96
Table 9. Nonparametric one-way ANOVA shows that the sites located in the forested upper reaches of the Little River watershed TSS concentrations compared to the sites in the lower reaches did not increase moving from upstream to downstream.....	96
Table 10. Nonparametric one-way ANOVA shows that the tributaries TSS concentrations are more impacted by agriculture than by forest.....	97
Table 11. Nonparametric one-way ANOVA shows that the tributaries TSS concentrations are more impacted by agriculture than by urban.....	97
Table 12. Land use percentages for combined sub-watersheds.....	98
Table 13. Imperviousness and dominant land use.....	100
Table 14. Pearson correlations that show the relationship between TSS and turbidity from the data collected over the sampling period is highly significant.....	102

Table A1. Little River watershed sites that had concentrations of TSS > 50 mg L ⁻¹	121
Table A2. Little River watershed sites TSS concentrations < 50 mg L ⁻¹ compared to other sites.....	123
Table A3. Descriptive statistics showing the minimum, maximum, mean and standard error for TSS and turbidity concentrations for each site.....	125

List of Figures

Figure 1. Little River watershed, Maryville Water Treatment Plant, tributaries and sampling sites in the 2003-2004 sediment study.....	104
Figure 2. Generalized geologic map of Tennessee (USGS, 2005).....	105
Figure 3. Soil Series (based on Tennessee STATSGO data) in Little River watershed. The section missing from the lower right corner of the map are soils from the Ramsey soil series (USDA, 1959).....	106
Figure 4. Land use in Little River watershed.....	107
Figure 5. Diagram of single stage sampler similar to one used in this study (Adapted from (IACWR, 1961)).....	108
Figure 6. Retrofitted bottle attached to the sampler.....	109
Figure 7. Sampling locations in the upper watershed study area showing TSS concentrations in relation to precipitation using rainfall data from Townsend.....	110
Figure 8. Sampling locations in the lower watershed study area showing TSS concentrations in relation to precipitation using rainfall data from McGhee Tyson airport.....	110
Figure 9. Correlation between geomean TSS concentration and imperviousness.....	111
Figure 10. Correlation between geomean TSS concentration and urban.....	111
Figure 11. Correlation between geomean TSS concentration and agriculture.....	112
Figure 12. Correlation between geomean TSS concentration and forest.....	112
Figure 13. Correlation between geomean TSS concentration and GSMNP.....	113
Figure 14. Pearson linear scatter plot showing the relationship between TSS and turbidity. The scatter plot appears to have few points when in reality there are several within the cluster, placed in behind each other.....	114
Figure 15. Comparisons of turbidity from Little River-2, Little River-3, and Ellejoy with Maryville Water Treatment Plant.....	115

Figure 16. Turbidity from Little River-2 compared to Maryville Water Treatment Plant.....	116
Figure 17. Turbidity from Little River-3 compared to Maryville Water Treatment Plant.....	116
Figure 18. Turbidity from Ellejoy compared to Maryville Water Treatment Plant.....	117
Figure 19. Maryville Water Treatment Plant turbidity data from 1990-2004 depicting seasonal data (Quarter 1:January, Febuary, March Quarter 2:April, May, June Quarter 3: July, August, September Quarter 4:October, November, December)...	118
Figure 20. Maryville Water Treatment Plant turbidity data reflecting the proportion of days in each quarter that are greater than 50 NTU for years 1990-2004.....	119
Figure A1. TSS geomean for Little River main channel sites from Little River-6 upstream to downstream Little River-1.....	130

Introduction

The Little River (LR) originates in the Great Smoky Mountains National Park (GSMNP), providing drinking water to thousands of residents in Blount County, Tennessee, as it makes its way to the Tennessee River. The upper reaches of the LR watershed have excellent water quality, qualifying it as a hydrologic benchmark river and outstanding national resource. A large outdoor recreation economy has grown dependent on the pristine land and water resources, including whitewater kayaking and rafting, cold and warm water fisheries, hiking, swimming and camping. However, in recent years there has been a documented overall decline in the biological diversity of the LR in the lower reaches outside of the GSMNP boundary, although the reasons are unknown (TDEC, 2005). Sediment, a non point source (NPS) pollutant, is suspected, since high levels can adversely affect water quality, creating an unsuitable habitat for plants and animals.

Studies have shown NPS to be the major cause of surface water quality degradation in many areas of the United States, surpassing point sources such as treated municipal and industrial wastewaters (Gilliland and Baxter-Potter, 1987; Driscoll, 1990). Although sediment suspended in the water naturally occurs in rivers as a result of stream bank erosion, high levels can directly impact aquatic organisms (Sigler et al., 1984), transform stream channels, contribute to flooding, and transport a large nutrient flux (Pickup, 1991). Large amounts of suspended sediment can lead to the deposition of sediment in the stream channel causing sedimentation of the waterbody (Lewis et al., 2001). Other sources of sediment are erosion from gravel

and dirt roads, soil erosion from agricultural areas, and erosion from development mainly in urban areas (Foster et al., 2002).

Land use impacts water quality throughout a watershed. A study conducted in North Carolina, (Lenat and Crawford, 1994) found that agricultural lands produced high nutrient concentrations in streams within close proximity. In another study of Coweeta creek in North Carolina, Bolstad and Swank (1997) observed that there were consistent changes in water quality associated with changes in land use. In the Midwest, a study conducted by Osborne and Wiley (1988) showed land use had a distinct overall and seasonal effect on stream water quality in an area with forest and urban development.

The LR supports several state and federally protected species including: endangered duskytail darter (federal and state listed) (USFWS, 1993a), fine-rayed pigtoe mussel (state listed) (USFWS, 2003), threatened snail darter (federal and state listed) and longhead darter (state listed) (USFWS, 1993). The primary threat to the integrity of the aquatic resources of the LR may be increased concentrations of suspended sediment contributing to sedimentation of the river. According to a Tennessee Valley Authority (TVA) study, the estimated soil loss for the LR Basin is 240,737 Mg per year, mostly due to agriculture (TVA, 2003). As development increases in the LR watershed and land use changes, so will imperviousness, initially resulting in greater sediment levels in the river.

An important measure of water quality is the amount of material suspended in the water (USGS, 2000a). Total Suspended Solids (TSS) is a concentration in mg L^{-1} that is equivalent to parts per million (ppm) and used interchangeably with suspended

sediment throughout this thesis. TSS includes organic and mineral particles that are transported in the water column and linked to land erosion and erosion of river channels. Turbidity is closely related to TSS and is a measure of the cloudiness of the water caused by suspended sediment particles (APHA, 1998).

For point source pollution, the highest concentrations are during low flow (Foster et al., 2002). The variability of the concentration in time and space are relatively simple to characterize, however, for NPS, the highest concentrations are at high flows (surface runoff events) and often 50% or more of the loads occur during 5% of the time (Thomas, 2003). During high flow events (storms), concentrations are highly variable. Currently, there is not any information available regarding TSS concentrations related to storm events for the LR.

The objectives of this study of sediment pollution in the LR Watershed were

1. Measure Total Suspended Solids (TSS) and turbidity in water samples collected after storm events from single stage samplers at 19 locations in the LR Watershed, including 6 sites along the main channel and the remaining sites near the mouths of 12 tributaries
2. Quantify the relationship between TSS and turbidity from these same samples
3. Examine land use effects on measured TSS at the 19 sites
4. Evaluate long term trends in turbidity data collected at the Maryville (Tennessee)

Water Treatment Plant, located near the mouth of the LR

Chapter 1 Literature Review

1.1 Water Quality and Total Maximum Daily Load

The Clean Water Act (CWA) instructs states to identify and report all polluted waters that do not comply with water quality standards initially established by the US Environmental Protection Agency (EPA) (Hession et al., 2000). The amended CWA of 1987 requires states to examine non point sources (NPS) of pollution (USEPA, 2001d). The CWA also requires that all states establish water quality standards, develop a list of impaired water bodies called the 303(d) list, and create Total Maximum Daily Loads (TMDL) for impaired waters (Hession et al., 2000). An impaired water body cannot support its designated use, while a threatened water body refers to a water body that could fail to support its use in the near future (Griffith et al., 1999).

A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards described by CWA (Hession et al., 2000). A TMDL facilitates the measures needed to improve water quality by allowing states to identify areas that need to reduce pollution concentrations, list polluted waters throughout the U.S., determine pollution sources and implement cleanup options (TDEC, 2004). Several factors are considered when developing a TMDL for each pollutant in a stream segment. These factors include waste load allocations for point sources contributing pollutants, identification of load allocations for nonpoint sources, background levels pertaining to the particular pollutant within a stream segment and inclusion of existing and future pollutant loadings (TDEC, 2004).

A margin of safety is also factored in that accounts for the unknown amount of a pollutant that may cause a water body to become impaired and the variability associated with natural background levels (USEPA, 2002c).

As part of the TMDL guidelines, states are required to produce a report every four years stating the water bodies that are polluted and when they will be cleaned up (USEPA, 2000a). The Water Pollution Control (WPC) division of Tennessee Department of Environment and Conservation (TDEC) publishes water quality data in a 305(b) report “The Status of Water Quality in Tennessee” every two years (TDEC, 2004). States are then given ten years to produce a cleanup schedule for impacted water bodies, and are granted a five year extension if needed. Polluted waters that are used for drinking supplies or provide critical habitat for endangered species must be given top priority. Failure to implement the TMDL requirements must be justified to the EPA as to why the steps are not necessary (USEPA, 2000a).

Many of groups of concerned citizens and environmental organizations have filed lawsuits against states for noncompliance with the CWA and with the EPA for no enforcement of the laws and regulations pertaining to the development of TMDLs (Leclair, 1997). Several states have had legal action brought against them because of their negligence to develop TMDLs (Leclair, 1997). The EPA will step in when states are not capable of developing water quality standards and TMDLs (Parry, 1998).

1.2 Non Point Source (NPS) Pollutants

Both point and NPS pollutants contribute to the degradation of water quality. Point source pollution may result from industrial and municipal discharges that are

conveyed by pipes, ditches, channels or other means of transport to a body of water (Foster et al., 2002). NPS pollution occurs when polluted runoff that enters a body of water is dispersed over a larger area and is not contributed from a specific point such as a pipe (Harbor, 1999). NPS for sediment include agriculture, construction sites and urban runoff. Most sediment in surface waters is derived from surface erosion and includes a mineral component from the erosion of bedrock, and an organic component from soil forming processes such as biological and microbiological production and decomposition (Madej, 2002). In addition, biological activity within the water body may add organic components (Guy, 1969).

Point source pollutants are responsible for approximately 10% of pollutants in waterways, while NPS contribute up to 43% of the pollutants causing impairment in the 303(d) listed waters (USEPA, 2000a). The main NPS pollutants of water bodies in the U.S. are nutrients, pathogens, and sediments (USEPA, 2002d). Several specific water quality issues in the U.S. such as NPS pollution assessment and the quantification of TMDLs for sediment and adsorbed pollutants may hinge directly on determining the sources of sediment delivered to streams. In Tennessee, NPS pollutants such as nutrients and sediment contribute greatly to the water impairment in Tennessee, with agriculture cited as the primary source (USEPA, 2001b).

1.2.1 Nutrients

Nutrients include nitrogen, phosphorus, algae, and aquatic weeds. Nutrient additions to waterways are mainly a result of human activities. Urban runoff, livestock operations, atmospheric deposition, untreated wastewater and treated

wastewater are sources of nitrogen and phosphorus additions to waterways (USEPA, 2002e). Nutrients attach to soil particles and are transported over land by storm water runoff to water bodies (Eghball and Gilley, 1999).

Nitrogen exists in several forms in the environment. The inorganic form of nitrogen (NH_4^+) (ammonium) can be adsorbed onto soil colloids, which accounts for some inorganic nitrogen movement into surface waters during storm events. NH_4^+ is transported with the eroded soil and can be released in the water. NH_4^+ undergoes nitrification to form nitrate and then can be assimilated by both plant and microbial organisms. Nitrate does not readily bind with soil or organic matter and may be leached through the unsaturated zone of soil (USEPA, 2002c).

High concentrations of NH_4^+ (ammonium), NO_2^- (nitrite), NO_3^- (nitrate) can have a significant impact on water quality by enhancing eutrophication. The process of eutrophication occurs when water bodies such as lakes, estuaries, slow moving streams or larger rivers receive excess nutrients that stimulate excessive plant growth (algae and other nuisance aquatic weeds) (USGS, 2000b). The additional plant growth, called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die. Aquatic organisms that use these forms of inorganic nitrogen release ammonia when they decompose. Cycling continues as these ammonia ions are converted into nitrate and nitrite and become available to aquatic organisms again. Sources of nitrogen that contaminate water are runoff from fertilizer applications to agricultural fields and residential

landscapes, leaking septic and sewer systems, animal inputs, and erosion of soil transported to water bodies (Stewart et al., 2001).

Phosphorus is found in rocks and phosphate deposits. Phosphorus is released from its source by weathering, leaching, erosion and mining. Phosphorus enters the environment through rainwater, plant residue, fertilizer additions, and animal wastes (USEPA, 2002e). Phosphorus exists in organic and inorganic states as either dissolved or solid form. Organic phosphorus occurs as dissolved or particulate form and exists in plant tissue, microbial tissue, and animal and municipal waste. Dissolved forms of inorganic phosphorus occur as H_2PO_4^- , HPO_4^{2-} , PO_4^{3-} , and particulate forms. Phosphorous in water can be adsorbed to sediments suspended in the water column or to substrate making it temporarily unavailable. Phosphorus can settle on the stream bottom and remain there until an increase in stream flow from a storm event or disturbance of the streambed causes it to be resuspended into the water column (Brady and Weil, 1999).

Movement of phosphorus from soils occurs in various forms and by different transport methods. Phosphorus in particulate form attached to soil particles is transported by erosion from surface runoff or wind (Tate et al., 1999). Dissolved inorganic phosphorus is removed by plant uptake or transported away from the soil by surface runoff (Sharpley and Withers, 1994). Phosphate rich soils tend to leach dissolved phosphorus and can enter ground water and subsurface flows eventually reaching surface waters (Cooke, 1998). Excess phosphorus additions can cause water

quality degradation by enhancing eutrophication (Correll, 1998). Increased levels of inorganic P can contribute to water quality impairment (Cooke, 1998).

1.2.2 Pathogens

Pathogens are disease-causing organisms such as bacteria or viruses that can pose a human health threat if ingested (USEPA, 2002b). *Cryptosporidium* is a waterborne pathogen that poses great health risks, even at low exposure (Gostin et al., 2000). Runoff from light rain has shown to carry relatively dense microbial populations because of the high proportion of finer textured soils (USDA, 1955). Storm events that transport high amounts of sediment often contain high concentrations of pathogenic bacteria (Giller and Malmqvist, 1998). The bacteria can attach to sediment particles and are transported through the watershed (Murdoch and Cheo, 1996).

1.2.3 Sediment

The United States Environmental Protection Service (USEPA) reports that 13% of all rivers and 40% of all impaired or threatened rivers are affected by sedimentation, resulting from increased suspended sediment concentrations in the water. Tennessee has 96,842 km of streams and rivers according to the EPA's National Hydrography Dataset (NHD) (USEPA, 2004). Of these, 9,242 km of rivers and streams are polluted. Historically, sediment has been one of the primary pollutants in Tennessee waterways.

Sediment includes turbidity, suspended particles, and siltation. Sediment is generally associated with land-disturbing activities such as agriculture and construction. Soil and rock transported from hill slopes and other land surfaces into rivers, streams, and lakes are the major sources of sediment in water bodies (Bryan, 2000). Sediment transport in rivers is associated with a wide variety of environmental and engineering issues listed in (Table 1) (Ongley, 1996). All tables and figures referenced are placed at the end of the document.

Most sediment is transported during peak flow events when it is carried as suspended load (Lee et al., 2002). Streams with high concentrations of total suspended solids (TSS) in studies have shown that TSS is highly variable and can be explained by seasonal differences to some degree (Riedel et al., 2003).

Extreme variability in sediment transport occurs because sediment transport is a dynamic phenomenon and measurement techniques are not fully representative of the ever-changing conditions that exist in river systems (Wohl, 1998). Imperviousness, particle size, sediment composition and monitoring technique all impact TSS concentration measurements representation. Hysteresis effects may also also cause a misrepresentation in data where the tendency for sediment concentration to have different values at identical stream discharges creates problems when trying to create a transport curve (Riedel et al., 2003).

Increased concentrations of suspended sediment in rivers and streams can have adverse impacts on the overall biological diversity of the water body (Berkman and Rabeni 1987, Carling and McCahon 1987). High sediment concentrations can cause the turbidity of the water to increase inhibiting the penetration of sunlight.

Turbidity is a measure of water clarity defined as how the suspended material in water decreases the passage of light through the water (USEPA, 2002a). This can affect water temperature, gas exchange, and decomposition rates, and photosynthetic processes (Davies-Colley et al., 1992). High flow rates associated with storm events are a factor that influences turbidity because fast running water can transport more particles and larger sized sediment (Black, 1991). Heavy rains can pick up sand, silt, clay and organic particles. Excess sediment additions degrade water quality by increasing nutrient levels, transporting metals and organics, and clogging gills of aquatic life (Denton et al., 2000). Suspended sediment in the water is a mode of transport for nutrients and high concentrations of TSS may cause outbreaks due to increased microorganism populations in the presence of excess nutrients in the waters (Mallin, 2000). Water treatment plants spend increasingly more money on treating sediment-laden waters (Dearmont et al., 1998). Other negative economic impacts include filling in of reservoirs, loss of navigation channels, and increased of flooding (Denton et al., 2000).

Metals carried in sediment can pose a serious health threat. The most common metals that impact Tennessee waters include copper, lead, iron, and manganese (TDEC, 2001). Elevated levels of zinc, mercury, and aluminum levels can also violate water quality standards. Toxicity to fish and aquatic life is the major concern regarding metal contamination and the danger that it poses to people who come in contact with the water or eat fish from the contaminated water body. Studies have shown that in most aquatic systems, the suspended sediment has a trace metal concentration that is much greater than the concentration dissolved in the water

column (Gibbs, 1977). Particle size is the most significant factor controlling sediment capacity for retaining trace metals according to (Jenne et al., 1980). According to Horowitz (1984), a significant correlation between decreasing grain size and increasing trace-metal concentrations is a result of both physical and chemical factors that are related to the large surface area per unit of fine particles (clays) compared to larger particles (silt and sand).

Organic contaminants carried in sediment can also have adverse effects on human health. These contaminants are man-made chemicals containing the element carbon and include PCB's, pesticides and dioxins. These substances are listed by the USEPA (1999) as priority pollutants. EPA classifies organic pollutants such as polychlorinated biphenyls (PCB's), chlordane, dichlorodiphenyltrichloroethane (DDT) and dioxin as probable human carcinogens (cancer causing agents). These substances can accumulate in sediment in streams and can pose a health threat to those who consume fish or shellfish. The lower reaches of the Little River near the mouth have contaminated sediment due to PCB accumulation resulting in fish advisories to be posted according to the 2004 303(d) list (USEPA, 2004).

A problem in identifying organic pollution is that the water quality criteria are often below current detection levels. Tennessee currently has no numeric organic sediment criteria. The detection of these substances is generally made either by fish tissue levels and/or by use of sediment screening values provided by the EPA (TDEC 2001). Exposure to these contaminants may cause the following health risks: increased cancer risk, nervous system effects, reproduction problems, liver or kidney problems, circulatory problems, and immune system problems (USEPA, 1999).

Sedimentation is also a concern due to possible profound effects on the morphology, hydrology, and biology of a body of water when increases from the natural sediment load or carrying capacity occur (Davis, 1976). Channelization, urban runoff, land development and contaminated sediments are other dominant sources of water quality degradation (Stone et al., 1995; USEPA, 2001b).

The term solids can be used to describe sediment, as well as mineral (calcium and magnesium) and organic matter in waters. Total solids refer to total sediments in surface waters. Total solids are measured without filtration of water samples. Total suspended solids refer to sediment that is suspended within the water column and can be filtered from the water sample. Dissolved solids can be defined as any mineral, organic, or sediment material that passes through a specified filter during analysis (Greenberg et al., 1992). There is currently no set standard for TSS, however there is a standard for total dissolved solids where these concentrations are not to exceed 500 mg L⁻¹ (TDEC, 2001).

1.3 Watersheds and River Channel Processes

A watershed within a larger basin is comprised of several smaller sub-watersheds that facilitate the drainage of water from the land area to streams, rivers, lakes and wetlands (TVA, 2003). The boundaries that make up a watershed reflect the topography formed by mountains, hills or ridgelines. The stream and river systems that drain the watershed tend to increase in size as the water moves downstream. Water that is transported as runoff moves across fields, pastures, forest, lawns and streets picking up pollutants that are carried into waterways (Batson et al., 1996).

River channels are dynamic natural systems that are continually changing (Wohl, 1998). Characterizing the dynamics of fluvial sediment sources over space and time is often critical in identifying human impacts on fluvial systems (Yeager et. al, 2005). Many processes influence channel characteristics within a watershed. These processes are ultimately controlled by geology and climate, which together determine regional topography, soil development, the growth of vegetation, and the land use practices of people living within the watershed (Wohl, 1998).

Pool and riffle sequences are found in mountain streams (Leopold, 1964). Pool, riffle and run sequences result from interactions between storage and transport of coarse sediment, and hydrological variances from channel bends, bedrock outcrops, and large organic debris. Suspended sediment concentration and flow measurements are affected by the conditions that exist at different positions within a pool/riffle/run sequence (Thomas and Lewis, 1995). High flow, geology, and large organic debris can affect suspended sediment measurements (Skinner, 2000).

Temporal and spatial variations in sediment concentrations can be associated with hydrologic variability reflecting variations in climate, geology, soils, imperviousness, basin scale, and sediment erosion and delivery processes (Walling and Moorehead, 1989). Topography, vegetation, and land-use will influence the characteristics of water and sediment yield from the hill slopes to the channel (Bryan, 2000). The movement of water and sediment along the channel will then depend on channel diagnostic features. Past research has shown that properties of the sediment particle size, shape, density, organic matter content, mineralogy and aggregate

stability are important in sediment delivery processes in non-point source pollution (Novotny and Chesters, 1989).

There are several processes that facilitate the movement of sediment down a hill slope and into a stream. Mass movements such as landslides occur when the hill slope has become unstable and shifts downhill. Sediment may also move as small individual particles or aggregates. Intense rainfall that does not infiltrate the soil as quickly creates thin sheets of flowing water across the slope, carrying sediment with it (Wohl, 1998). The water that runs along the surface of the soil may concentrate into rills and gullies where the water's erosive force is greatly increased in these small channels. This effect may be increased due to low vegetative cover. Sediment may also move gradually down slope due to freezing and thawing or wetting and drying cycles referred as soil creep. Transported sediment may enter a river channel and either immediately be deposited or move further downstream as suspended sediment (Bryan, 2000).

Hill slopes and channels are dynamic systems that constantly adjust in response to various types of disturbances that affect the amount of water and sediment transported to streams (Wohl, 1998). These disturbances include intense rainstorms, seasonal variability in precipitation, landslides, forest fires, logging, livestock grazing, crop growth, road construction and urbanization. These factors influence how precipitation falling on a hill slope is moved down that hill slope into a channel, and how that moving water carries sediment with it.

Movement of sediment from hill slopes and along channels becomes a water quality issue when it adversely impacts humans and the environment. Sediments

washed into streams from erosion and overland flow may be contaminated by materials that are toxic to humans and aquatic organisms (Yeager et al., 2005). These contaminants may be from agricultural fertilizers and pesticides or from construction activities. Water quality issues regarding suspended sediment in waters may result from processes that would occur in the absence of human activities, or may result directly from those activities. Human activities differ from natural disturbance in that human related disturbances are more likely to affect an entire watershed creating water quality issues through their cumulative impact (Wohl, 1998).

Several watershed studies that have addressed scale effects on sedimentation have emphasized the decreasing of specific sediment yield with increasing area as one proceeds downstream due to decrease in sediment delivery ratio with watershed size, opportunities for deposition increase downstream due to reduced river gradients, slopes, and decreased proportional spatial coverage of localized storms (Wolman and Schick, 1967; Walling, 1983; Jansson, 1998). Other studies have shown that for many temperate ecosystems that previously deposited sediment may be remobilized and actually increase specific sediment yields downstream (Meade, 1982; Ashmore, 1992). The degree of channel and slope erosion is important in the relationship between sediment yield and watershed area for river systems. Dedkov and Moszherin (1992) determined that where channel erosion is dominant, erosion rates would increase downstream, whereas in regions dominated by slope erosion (sheet and gully) the rates will decrease downstream. When erosion is concentrated in the steeper headwater areas within a watershed, the proportion of the mobilized sediment will be deposited during transport through the system.

Sediment transport is a direct function of water movement (Minshall et al., 1985). The turbulent forces in the water and the availability of sediment determine the amount and nature of suspended sediment in the water. The transport of sediment particles can be divided into relatively three categories: suspended material that includes (silt, clay and fine sand); the coarser bed load (sand, gravel, cobbles and boulders) and the saltation load (particles rolling along the bottom and resuspended) (Foster et al., 2002). The turbulent forces that cause sand to be lifted into suspension from the bed load tend to increase as discharge increases (Hillel, 1998). As a result, the concentration of sand is highest near the bed of a river and lowest near the surface. Only a small portion of clay and silt-sized particles ($<0.062\text{mm}$) that form the suspended load are contributed from river bed sediment. These fine particles that comprise a majority of the suspended load is eroded and carried to the river by overland flow during rainstorms. Fine sediment in water is more likely to be transported at or near stream velocity than sand sediment (Allen, 1985).

Sediment concentrations will vary over several hours during a storm event (Riedel et al., 2003). Typically, the sediment concentrations will increase up to a peak and then begin to decrease steadily over time. A storm event causes an increase in discharge and an associated increase in turbulence in a river. This turbulence can pick up particles from bed sediment and distribute them into suspension leading to high concentrations of suspended sediment in the water (Hillel, 1998). There is also sediment being washed into the river from overland flow that is being held in suspension. The initial increase and then eventual decrease of suspended sediment is because the quantity of sediment on a river bed, and which is introduced into the river

by erosion processes is limited and the amount of sediment available to be taken into suspension gradually diminishes during a storm event (Riedel et al., 2003).

Determination of potential sources and improved understanding of the dynamics of suspended sediments in river systems is a challenge but essential, due to the importance of effects in many fields of environmental science, including water quality (Swank et al., 2001), the fate and transport of pollutants (Batson et al., 1996) and ecological health and diversity (Ryan, 1991; Rice et al., 2001).

1.4 Land Use and Soil

Land use within a watershed impacts water quality by influencing additions of nonpoint source pollutants such as sediment and nutrients to waterways (Wolman and Schick, 1967). Studies have shown that sediments from different land use sources vary in the kind and amount of pollutants that are adsorbed to the particles and transported to rivers, stream, and lakes (Reidel and Vose, 2003; Sorens and Nelson, 2000; Wotling and Bouvier, 2002). The most widespread impacts of sediment are associated with the fines eroded from agricultural land (Walling and Moorehead, 1990). The loss of topsoil as a result of erosion is one of the most serious environmental problems today. Erosion of soil occurs naturally; however, poor agricultural practices increase the rate of soil loss and increases suspended sediment loads in freshwaters. Agricultural practices such as tillage can increase erosion by removing plant cover and leaving soil exposed (Stone et al., 1995).

Small streams, such as the tributaries of the Little River, are important hydrologic and biogeochemical elements in landscapes because they connect the

terrestrial environment with larger rivers. The concentrations of particulate and dissolved materials in small headwater streams, reflect the combined effects of the delivery of material from the watershed and processing of material that occurs within the stream channel (Minshall et al., 1985). Inputs of sediment, nutrients, and organic matter from terrestrial to aquatic ecosystems enter via small streams (Vannote et al., 1980). A study by Triska et al. (1984) determined that forested headwater streams often have steep gradients, channels shaded by trees, and inputs dominated by allochthonous materials. Many studies of small streams show that changes in land use, such as from forest to agricultural land, or major disturbance such as clear cutting, can dramatically alter the nature of particulate and dissolved material inputs to headwater streams (Dillon and Kirchner, 1975; Likens and Bowman, 1975; Correll et al., 1991; Cooke and Prepas, 1998).

Imperviousness has been found to be an indicator of land development impacts on water resources. These surfaces are areas that water cannot infiltrate into the soil and then percolate into the soil profile. Buildings, roads and parking lots are all examples of impervious surfaces. These surfaces collect and accumulate various pollutants that are washed from these surfaces in high concentrations to storm sewers that eventually lead to streams (TVA, 2003). Suspended sediment is not a problem on impervious surfaces but the large amount of water that runs off these surfaces can detach soil particles that are on adjacent pervious surfaces. This large amount of water that runs off tends to move over the pervious surface as well because the water cannot infiltrate the soil fast enough due to hydrologic conditions. As flow increases, the stream channel becomes unstable and may deepen and widen to carry the

increased flow (Wohl, 1998). This results in increased sediment loads and loss of aquatic and riparian habitat as soil and vegetation are scoured from the bottom and banks cave into the stream.

Soils are important in determining the potential sources of TSS because soil particle size influences sediment transport. The primary factors that determine whether soil particles are transported or deposited for a given flow condition is the sediment size distribution and the density of the sediment (Rhoton et al., 1982; Harmon and Meyer, 1989). Studies conducted by (Lee et al., 2002) show that the ability for suspended particles to carry contaminants that contribute to water pollution with the first flush of urban storm runoff show higher concentrations during later stages of a storm event. This is closely related to the particles specific surface area and largely dependent on the clay and silt content of the transported particles.

The suspended load comprised of silt, clay and fine sand particles are suspended in the water column due to the turbulence of the water (Dedkov and Moszherin, 1992). The suspended load includes silt and clay sized material (< 62 microns in particle diameter). The suspended load, referred to as “fine grained sediment”, usually results from erosion and surface runoff. In addition to silt and clay-sized particles, fine sand particles (>62 microns or greater) that may be in the suspended load are directly proportional to the turbulence and mainly originates from erosion of the bed and banks of the river (Bryan, 2000). The mineral fraction of the suspended sediment forms most of the transported load. Particle size based on the USDA classification is clay [<0.002 mm], silt [$.002-.05$ mm] and sand [$.05-2.0$ mm] (Foster, 2002). The distribution of primary particle sizes gives soil its texture. Soils

that are primarily clay are detached by raindrop impact when the force of raindrop impact overcomes the soil's internal bonding forces (Hillel, 1998). Clay is harder to detach than silt particles due to clay particles high cohesiveness. Silt particles are also detached by raindrop impact and easier to detach than clay because silt is not as cohesive as clay. Both clay and silt particles are easily transported by overland flow once detached and will stay suspended for lengthy amounts of time if the transport capacity of the water is greater than the sediment load it carries (Yoder, 2003).

The size and density of the sediment particles determines the sediment transport. Large particles, such as sand, are easily detached but tend to settle out quickly because sand is heavier than clay and silt particles. Although particles of sizes ranging from fine clay to cobbles and boulders may exist in a river, suspended load will rarely contain anything larger than coarse sand, and in many rivers 50-100 per cent of the suspended load will be composed only of silt and clay sized particles ($<.062\text{mm}$) (Buol et al., 1997).

1.5 Water Sampling for Sediment

Sampling of water to assess current water quality conditions to determine TMDLs requires surface grab samples or cross-sectional integrated flow composites. The EPA recommends that sampling in a representative area of the stream is suitable in assessment of water quality. Grab sampling methods have been used frequently by many state agencies due to lower cost, easy operation and less equipment needs (Skinner, 2000).

This method of sampling is typically for low flow events allowing the person collecting the sample to be able to wade out in a stream and collect the sample. Sediment concentrations are highest however, during and after a storm event due to erosion, surface runoff, high flow and turbulent waters carrying suspended material in the water column (Pickup, 1991). Tributaries contributing high amounts of sediment to main channels during storm events may not reflect high sediment concentrations during low flow sampling (Skinner, 2000). Studies have shown that timing and frequency of the sampling are very important in getting accurate assessments of the watershed (Riedel et al., 2003; Lee et al., 2002; Rinella et al., 2002; Madej, 2002). Sampling only during storm events or peak flows or conversely sampling only during low flows could lead to misinterpretation of the sediment interactions within the watershed (Tate et al., 1999).

TSS concentrations in previous studies have shown to be higher on the rising limb of the hydrograph versus the falling limb (Riedel et al., 2003). Samples taken during or immediately following storm events have shown to vary from samples collected prior to events (Skinner, 2000; Rinella et al., 2002; Graczyk et al., 1993).

One problem associated with sampling for suspended sediment is the distinction between bed and suspended load (Skinner, 2000). Suspended load primarily is considered to be that which is comprised of particles lifted upward from the momentum of turbulent eddies in the water. Suspended load may also be further divided into the wash load composed of particles that are held in suspension due to their small settling velocity (Skinner, 2000). This study considers the washload and

suspended load as one category. Bed load is comprised of all sediment that moves by sliding, rolling or saltating on or near the riverbed. During storm events, as the velocity of the moving water increases and the flow conditions change, sediment particles can interchange between the bed load and the suspended load (Hillel, 1998).

The suspended sediment sampler design has improved allowing for common problems such as sampling error associated with representative samples, handling, contamination and deployment of equipment at remote locations easier to combat (Skinner, 2000). These samplers are designed to obtain a representative volume of the water-sediment mixture moving in the stream in the vicinity of the sampler. Several versions of suspended sediment samplers exist, however the concept design is similar. The choice of which sampler type to use depends on the stream being monitored.

Depth integrating (DI) samplers collect representative samples from a stream vertical. These samplers have a streamlined appearance that encases a plastic or glass container fixed to an upstream-facing nozzle and downstream-facing air exhaust tube (IACWR, 1961). There are several advantages to using a DI sampler. These samplers have no moving parts and tend to last longer than other types of samplers due to less maintenance problems. The inflow rate of the sampler is isokinetic regardless of raising or lowering of the sampler through flowing water. A problem associated with these type samplers is that a fairly representative sample can only be collected up to a depth of around 4.6 m due to the compression of air trapped in the sample containers (Skinner, 2000).

The DH-59 and DH-76 (Hoskin Scientific) are lightweight samplers designed for use in shallow streams with flow velocities up to 1.5 (m/s). These samplers are used commonly in small to mid-size streams during normal flow and they are small, easy to transport, and durable (Edwards and Glysson, 1999). The D-74 and D-77 (Hoskin Scientific) are heavier samplers that are typically used in unwadeable streams that are not deeper than 4.6 m. The D-74 is designed to be suspended from a bridge crane or cableway utilizing a hanger bar and cable and reel system. The D-77 is designed differently than the D-74 excluding a head assembly that covers the mouth of the container at the point that the intake nozzle is located (Skinner, 2000).

Point Integrating (PI) Samplers allow for collection of suspended load for a small amount of time at a given depth. These samplers allow for collection of a more representative sample because the sample can be collected at any point from the surface to the stream bed. These samplers are suspended from a steel cable and can sample to a depth of 9.1 m. Some types of these samplers, such as the US P-61-A1, can sample to a depth of 54.9 m. The valve that allows intake and exhaust passages to be activated by the operator are controlled by an electric solenoid. A disadvantage of point integrators is that due to the moving parts there tends to be frequent maintenance and the solenoid can corrode preventing the valve from functioning properly (Skinner, 2000).

Pumping samplers allow for automated collection at remote sights. These samplers allow for several samples to be collected over a period of time such as storm duration (Foster et al., 2002). Automated sampling, which makes use of equipment programmed to collect samples in response to changes in stage and flow of a stream,

has been shown to be an effective method of sampling to describe the rapid changes in water quality (Graczyk, 1993). These samplers are very versatile, but have several disadvantages including high cost, potential battery failure and the poor correlation of fixed point samples and average concentrations of sand sized particles in cross sections for representation (Skinner, 2000).

Single stage samplers, as used in this study, are designed to obtain sediment samples from ephemeral streams that are in remote locations during peak flow periods (ICWR-SS, 1961). In cases where advance warning of a flood is not always sufficiently early for personnel and equipment to reach the site at the time samples are needed, especially for remote and flashy intermittent streams this sampler can be instrumental in obtaining samples where before samples may have been insufficient for storm events or seasons. These samplers are also used to sample perennial mountain streams. Rapid changes in stage due to a storm event make it impractical to use a depth integrated sampler. Single-stage samplers sample at a point in the stream where the intake nozzle is positioned into the current before a storm event occurs (Skinner, 2000).

Single stage samplers consist of a bottle sealed to a pair of inverted “U” shaped tubes, and is bolted to a post that is anchored at the sampling location. As the stage of the water level rises, the intake nozzle is covered and the bottle begins to fill by siphoning as the displaced air exhausts through the vent nozzle (ICWR-SS, 1961). The bottle will cease collecting a sample when the water rises in the upper tube and increases back pressure in the bottle. The sample is then collected after the flow

recedes. There are two types of single stage samplers, the US SS-59 (U-59) and US U-73 (Rickly Hydrological). The U-59 utilizes a pint milk bottle fitted with copper tubing anchored to a post at the location. The inside diameter air exhaust is 0.5(cm) and the inside diameter intake nozzle is 0.5(cm) or 0.6(cm). The copper tubing is inserted through a stopper in the mouth of the sample container. Single stage samplers have either a vertical or horizontal intake depending on the particle size of the sediment that is being collected (Skinner, 2000).

The U-73 sampler (Rickly Hydrological) is an updated version of the U-59 allowing for collection of samples during the rising and falling stage. The advantages of this updated version remove the former versions downfalls such as condensation in the sample container and a protective casing that prevents debris and trash from blocking the intake (Skinner, 2000). Sampling bottles can be mounted one above the other, to sample at different depths at the same location. This may be useful in streams with depths up to several feet. These samplers are simple and inexpensive to make, easy to operate and maintain, and cost effective to use at a large number of locations. The Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation (ICWR-SS) developed and tested siphon samplers under laboratory conditions and concluded that siphon samplers are able to collect a sample representative of near-surface water quality during rising stages. After several models of samplers were developed to collect representative samples for distinct ranges of stream velocity, water-surface surge, water temperature, and sediment size; the study concluded that siphon samplers are useful when sediment concentrations near the

surface are of value and sampling by other, possibly more accurate methods is not practical or feasible (ICWR-SS, 1961).

In a comparative study of siphon and automatic samplers, suspended sediment constituent concentrations in the paired samples were similar, but the ranges in values were slightly smaller in the samples collected with the automated sampler than those collected with the single stage sampler (USGS, 2000a). A pilot study conducted in Alaska testing single stage samplers for cost-effective methods of collecting suspended sediment found that they were sturdy and reliable for monitoring mountain streams (Rinella et al., 2002).

There are some disadvantages to using single stage samplers. Each sample is collected at a specific point below the water surface and fails to account for spatial variations in flow and concentration (Edwards and Glysson, 1999). These samplers may also leak around the seal allowing water to flow through the intake and out the exhaust tube. There are problems with debris that may lodge against the sampler during a storm potentially affecting the quality of the sample collected. Occasionally, during high flow storm events, samplers may be washed out completely requiring replacement (Skinner, 2002).

1.6 Watershed Assessment Computer Models and GIS applications

NPS pollution processes such as storm-water runoff are difficult to model due to their stochastic nature in both time and space domains (Corbitt, 1989). Modeling nonpoint source pollution requires organizing and processing large amounts of spatially referenced data that is difficult to implement without the aid of computer

automation. Geographic Information Systems (GIS) and Global Positioning Systems (GPS) have greatly advanced over the last 15 years and has gained widespread acceptance as a valuable tool because of its ability to carry out complex spatial operations and to link spatial and descriptive information (Sabins, 1997).

Assessment of the watershed as a whole rather than simple monitoring of the concentrations of pollutants in the waters is a growing trend (Chen et al., 1999). Wong (1998) used GIS applications to predict nonpoint source pollution potential from watersheds and found that urban land use (residential) produced the highest loading of pollutants.

TVA developed IPSI (Integrated Pollutant Source Identification), a geographic information system (GIS) database and analytic tool for Blount County and its associated watersheds (TVA, 2003). IPSI is used to estimate pollutant loads by source and watershed and to help plan and implement watershed restoration efforts. The information contained within this geographic database includes watershed features, such as land use, streambank erosion sites, livestock operations, and urban development areas that are known or suspected to be sources of non-point pollution (TVA, 2003).

1.7 Best Management Practices to Control Sediment Pollution

The inputs of nonpoint source pollutants to rivers, streams, and lakes may be reduced by the implementation of best management practices (BMP) in agricultural areas, forests, and urban lands. Soil and water conservation applications including no-till farming, pasture management, buffer zones, automatic livestock watering, and

nutrient and pesticide management can be effective in reducing the amount of suspended sediment and nutrients to streams (Sharpley and Withers, 1994).

No-till farming reduces surface runoff and erosion decreasing the amount of sediment and nutrients transported to surface waters compared to conventional farming. Studies have shown that concentrations of P and N associated with sediment transport are reduced significantly when no-till farming is practiced (Schreiber et al., 2001).

Pasture management combines several management practices aimed at balancing the production of forages and animal grazing needs. Overgrazing of pastures could result in surface runoff and soil erosion due to inadequate vegetative cover that helps reduce raindrop impact and promotes infiltration. Pasture rotation paired with alternative feed can help reduce impacts to overgrazed areas. Animal crossings at streams and fencing can be installed to keep animals out of the water therefore reducing sediment and nutrient inputs (Johnson, 2001). Limiting the animal access to rivers and streams can prevent bank destabilization and minimize the amount of waste directly entering the water, thus reducing nutrient and sediment inputs (Cooke, 1998).

Retaining a buffer zone near streams, rivers and lakes is an effective BMP that reduces sediment and nutrient inputs into water bodies by filtering out the sediment by allowing deposition to occur. Buffer zones consist of a variety of vegetation that occurs in strips adjacent to waterways intended to capture pollutants, such as pesticides, nutrients, or sediments, and stabilize streambanks (Foster, 2002). Buffers have the capacity to remove up to 50% or more of nutrients and pesticides, up

to 60% or more of certain pathogens and up to 75% or more of sediment (NRCS, 2000). Buffer strips are also effective in urban areas at reducing sediment and nutrient inputs based on studies by (Basnyat et al., 2000; Jordan et al., 1993).

Use of alternative water systems such as automatic watering pumps can improve water quality by keeping the animals out of the rivers and streams reducing the pollutant loadings (Johnson, 2001). Rotation or moving the water trough in pastures may also reduce surface runoff and erosion ensuring that the water source is on vegetated ground. Animals visiting the same water source in a pasture, wear the grass cover down increasing the chances for sediment transport due to surface runoff over the bare ground (Novotny and Chesters, 1989).

Management of nutrients and herbicides can benefit both the producer and water quality. Nutrient and herbicide management plans can be used to evaluate field conditions by considering inputs of all nutrient and herbicide sources, both man-made fertilizers and herbicides, as well as manure, along with nutrient outputs (Sharpley and Withers, 1994). By implementing an effective nutrient and herbicide management plan maximum productivity can be reached, cost can be reduced, and water quality can improve. Management of fertilizer application could help prevent nutrient loads to water bodies and be cost effective for crop producers. Yearly soil testing, applications of fertilizer at optimal conditions, and applying only the amount the crop needs could reduce the amount of fertilizer and nutrients that are available to enter surface and ground waters (Johnson, 2001).

Urban areas that contribute to nonpoint source pollution can also benefit from implementation of BMPs. In residential and commercial areas of land use there is an

increase in imperviousness due to sidewalks, parking lots, paved roads, housing and buildings (Bhaduri et al., 2000). Increased imperviousness allows for more storm water runoff due to the inability of rainwater to infiltrate into the ground naturally with a vegetative cover. A phenomenon occurs called first flush after a storm has begun where the concentration of pollutants is substantially higher than during later stages of a storm event (Lee et al., 2002).

The amount of pollutant concentrations from residential and industrial areas is extremely high during first flush, discharging an enormous quantity of pollutants into receiving waters (Lee and Bang, 2000). Many of these pollutants bind to soil that is delivered to streams from storm water runoff and are carried in many cases downstream due to the suspension of the sediment in the water. The reduction of impervious areas will also help control nonpoint source pollution by reducing the area from which water can runoff and increasing infiltration (Bhaduri et al., 2000).

Maintenance of lawns in urban areas can be a contributor of nonpoint source pollution due to excess fertilizers leaching through the soil or washing off during storm events and eventually carried to surface waters (Sims et al., 1994). Reduction in fertilizer application can reduce nitrogen and phosphorus inputs to streams in residential areas. Encouraging homeowners to adequately test their soils for proper amounts of fertilizer requirements, can prevent over application (Sharpley and Withers, 1994).

The practice of BMPs in forestry has been developed to lessen the impact of nonpoint source pollution. Proper management of road construction and maintenance is important in reducing nonpoint source pollution. Buffer zones should be installed

and maintained along streambanks to reduce sediment and nutrient loads (NRCS, 2000).

Chapter 2 Methods and Materials

2.1 Study Area

2.1.1 Physiography and Geology

The Little River (LR) is located in the Great Smoky Mountains National Park (GSMNP) in the Blue Ridge physiographic province in eastern TN. The LR is a northwest-flowing tributary of the Tennessee River and is a perennial stream. Mean monthly discharges measured at the USGS gauge in Townsend range from $3.5 \text{ m}^3\text{s}^{-1}$ during baseflow conditions in October to $14.7 \text{ m}^3\text{s}^{-1}$ during high flow in May (USGS, 2000a). The watershed area drains approximately 929 km^2 of mountainous terrain including parts of Blount, Knox, and Sevier Counties. Lower sections of the main channel and some tributaries are listed on the proposed 2004 303(d) list (TDEC, 2003).

The study area (Figure 1) encompasses the LR within Blount County and part of the Upper Tennessee River Basin. The elevation ranges from 400 m above sea level at the river mouth to above 2000 m at the headwaters. The summary of the characteristics for the 19 sampling sites show that several of the locations include impaired waters (Table 2).

The LR Watershed lies primarily within the Blue Ridge physiographic region with part of the county crossing into the Valley and Ridge physiographic region. The Great Valley section of the county is characterized by a lowland belt that has series of alternate linear ridges and valleys (USGS, 2000a). These ridges and valleys run in a southwest- northeast direction parallel to the Great Smoky Mountains. The relief is

prevailing rolling to hilly, although it ranges from nearly level to very steep. The elevation range between stream bottom and adjacent ridge crests are 50m to above 2000m. Sinkholes and caves are prevalent and areas with a majority of limestone bedrock exhibit karst relief (USGS, 2000). The part of Blount County that lies within the Blue Ridge physiographic region depicts rugged steep-walled, V-shaped valleys and narrow winding ridge crests and sharp peaks. The Little River from the National Park boundary to the headwaters is a benchmark river within ecoregion 66 (Blue Ridge) and 67 (Ridge and Valley) (TDEC, 2002).

The geology in the basin is predominantly metamorphosed sedimentary rocks of late Precambrian age (Figure 2). The dominant geologic units underlying the Little River Watershed consist of massive, thick-bedded feldspathic sandstones composed of plagioclase, detrital quartz, potassium feldspar and metamorphic biotite, muscovite, and chlorite (USGS, 2000). The rocks that comprise the geology of this area have been subjected to intense catastrophic events of the geologic past. This has resulted in extreme folding and faulting with beds inclined at high angles or entirely overturned. Differential geologic erosion of the limestones, dolomites, shales, and sandstones discern the succession of parallel ridges and valleys (USDA, 1969). The ridges in the Great Valley are underlain by low-grade dolomites, sandstones, and shales. High-grade limestones and interbedded limestones and shales underlay the valleys between the ridges (USGS, 2000). The geology influences the characteristics that contribute to the particle size of the suspended sediments that are transported through the watershed (Black, 1991).

2.1.2 Soils

The soils are primarily Inceptisols described as fairly deep, well-drained soils developed from residuum parent material (USDA, 1959). Data based on the soil survey for Blount County, Tennessee provided by the (USDA, 1959) gives a detailed map of the soils found in each sub-watershed within the Little River Watershed (Figure 3). The soils that are dominant around the LR-6 site outside of the GSMNP boundary and downstream including main channel sites LR-5, LR-4, LR-3 and tributaries Dry Branch, Hesse, Carr and Short Creeks are mainly from the Ramsey soil series. The soils mapped for this drainage area reflect rocky outcrops of slate or quartzite and silt loams occurring on steep to moderate slopes and loamy fine sands at the river bottoms (USDA, 1959).

The soils dominant in the locations surrounding LR-3, Ellejoy and Crooked Creek are categorized as Dandridge Whitesburg Hamblen series and are composed of shaly silt loams, and silt loams (alluvial) occurring on eroded moderate steep slopes and gentle slopes as well as river bottoms (USDA, 1959).

The soils dominant in the locations surrounding LR-2, Nails, Brown, and Pistol Creek-2 are categorized as Sequoia Litz Hamblen series and are composed of severely eroded silty clay and silty clay loams, shaly silty clay loams, and silt loams occurring on moderate and gentle slopes and along the river bottom (USDA, 1959). The soils dominant in the locations surrounding LR-1, Culton, Pistol Creek-1 and Stock are categorized as Dumnore Pace Greendale and Sequoia Litz Hamblen. These

soils are composed of silt loam, silty clay, silty clay loam, and shaly silty clay loams occurring on steep, moderate, and gentle slopes (USDA, 1959).

2.1.3 Land Use and Vegetation

Land use in the Little River Watershed (Figure 4) ranges from the forested headwaters in the upper watershed to agriculture and commercial/industrial in the lower watershed. Development is increasing rapidly in this area due to tourism and high population growth. Urban areas are concentrated around the cities of Maryville and Alcoa. The Little River watershed within Blount County boundaries general land use patterns by percent area is comprised of approximately 3% water and wetlands, 60% forest (25% in national park), 25% agriculture (pasture, cropland, livestock operations, dairy farms and horse farms), 4% commercial/industrial, and 10% residential according to the IPSI land use data (TVA, 2003).

Stream bank erosion within the Little River Watershed impacts approximately 100 miles of streams of approximately 980 total stream miles (TVA, 2003). Eleven percent of the streams within the study area have eroding banks. A large cause of stream bank degradation is the unrestricted access that livestock have to the streams within the study area.

The vegetation in the basin is comprised of hardwood-hemlock forests and includes yellow poplar, black locust, red maple, white oak, black oak, sweet birch, white pine, short leaf pine, pitch pine, dogwood, hemlock, and sumac. Areas with pasture consist of fescue (USDA, 1959).

2.2 Sample Collection

For this study, a retrofitted version of the U-59D (Figure 5) was installed at each sampling site to collect water/sediment mixture as the stream stage rises during a storm event and submerges the sampler. The components of the sampler consist of five basic parts:

- (1) A sample container consisting of a 250 ml wide mouth Nalgene bottle.
- (2) An air exhaust. A siphon-shaped copper tube with a smooth inside passage that is .47 cm in diameter. Used for venting the sample bottle.
- (3) An intake. A siphon-shaped tube having a smooth inside passage 3/16 inch in diameter at the nozzle and .47 cm diameter from the nozzle into the bottle. The intake was oriented in the horizontal position.
- (4) A bottle seal. A rubber stopper having two holes was used. It fit tightly in the top of the bottle and around the tubes.
- (5) An apparatus to secure it to. A metal sign post was used to secure the sampler to and then was anchored to an overhanging tree branch or rock.

The sampler works by collecting water through the intake nozzle as the stream surface rises to the elevation of the intake nozzle (ICWR-SS, 1961). When the water-surface elevation W reaches C, flow begins to run over the weir of the siphon, primes the siphon, and begins to fill the sample bottle under the head AC (Figure 5). Filling continues until the sample rises to F in the bottle, and water is forced up the air exhaust to the elevation W. The momentum of flow in the tubes causes a momentary rise above W in the air exhaust. Water drains out of the inner leg of the intake. When

the stream rises to D, air is trapped in the air exhaust. As long as sufficient air remains in the tubes, no flow can pass through to alter the original sample unless a differential head that exceeds the height of invert is built up. The influence of velocity and turbulence on the sample collected by the sampler may impact the results of the total suspended solid (TSS) data.

During and after a storm event the water level of the Little River and tributaries rises. In turbulent waters once the stream rises to the intake nozzle, the rise in the intake depends on the effective pressure at the nozzle. The static pressure in the water at the nozzle changes by transient dynamic pressure and velocity head. The position of the nozzle with respect to velocity influences whether the velocity head adds to or subtracts from the pressure. The ability of the sampler to function depends on pressures that are often highly variable.

When the sampler collects samples in turbulent flow conditions the intake nozzle may be submerged for a short amount of time as the turbulent water covers and uncovers the intake nozzle. The horizontal orientation of the nozzle allows for the collection of fine sediment and fine sands. In reference to the previous drawing (Figure 5) function of the sampler in turbulent flow is as follows: Collection of the sample begins when the pressure at the intake nozzle forces water up to C. Sampling will begin as soon as the intake is submerged if the intake points into the approaching flow and if the velocity head is greater than BC. Sampling will be intermittent if the surging water surface alternately covers and uncovers the intake nozzle. For the sampler to collect water continuously, BC should exceed the height of water surface surge plus velocity head. To maintain a sampling velocity in the intake, AC should

exceed the water-surface surge by a sufficient static head (5.08 cm). The height AB can be small or B can be below A. The sampler stops collecting the sample when the bottle is filled to the bottom of the air exhaust E, and the fluid is forced up the exhaust to the elevation that can be supported by the pressure at the intake nozzle.

The sampler always starts to fill under the head AC regardless of velocity and static head. Due to this, each sampler has a characteristic intake velocity. The characteristic velocity depends not only on the head AC but also on the following factors:

- (1) Temperature causes changes of a few percent in intake velocity.
- (2) Debris on the intake may cause abnormal intake velocities.

As the water level rises during and after a storm event, the bottle collects the sample until the bottle is full or the vent tube is covered with water. This method collects the sample as the river stage rises. A problem that may result is that the sampler may not actually collect the peak sediment concentration if it occurs after collection (Skinner, 2000). It is possible that the peak sediment concentrations may be even higher than what is actually collected if the peak concentration is missed.

Ideally, the accuracy for this sampler is based on the assumption that the sampler is at a depth where the concentration is representative of the suspended sediment in the vertical section, and samples on the rising stage of the river and tributaries (Skinner, 2000). This sampler preserves the sample until delivered to the laboratory and is economical to build and maintain. This sampler type was chosen because it can sample the water without needing immediate attention.

The sampler was checked after every storm event. In some cases, rather intense storms or storms of long duration prevented samples from being collected at some of the sites due to high water with fast moving current posing safety hazards. In these cases, the sample was collected 3-4 days after the event to allow the flood waters to subside.

The procedure for collecting the sample involved wading in some cases through the stream to the sampler location and then removing the PVC pipe lid off the apparatus that encases the sampler bottle (Figure 6). This bottle lifts out of the holding apparatus and then the bottle cap with the rubber stopper and copper tubing is removed. The bottle with the water-sediment mixture is capped off with a clean bottle cap that has been washed with soap and water for lab cleaning, labeled with the date and time, and then stored for transport back to the water quality lab for TSS analysis. The copper tubing and rubber stopper attached to the bottle cap that fits within the holding apparatus is rinsed on site with distilled water and the tubing blown out to ensure that there is no blockage preventing a new sample from being collected through the intake valve. This bottle was then replaced on the sampler apparatus with a clean bottle. The copper tubing intake and vent tubes were positioned for the next storm event. All of the sites were sampled on the same day after an event over several hours.

The timing of sample collection was determined by listening to the local televised weather cast and observation of Doppler radar over the internet as well as the USGS stream gage website. Since the study area covered a large expanse of acreage over several miles, rainfall varied over the Little River Watershed. Some sites

received high intensity rain events concentrated over a few acres while other areas for the same day had little or no rain. This affects the sample collection for tributaries that may not receive sufficient precipitation to raise the water level high enough to allow sample collection. Isolated storm events in the lower reaches of the watershed would raise gage height for tributaries and main channel locations in this area but sampling locations in the upper reaches would not have a sample because these sites were not affected by the event occurring in the lower reaches. After storms occurred, plans were made to go to the field at least within two days of the event.

2.3 Site Selection

The sites were chosen by observation of topography maps to determine where the tributaries suspected of high sediment contributions to the Little River converge and then ground truthed to determine the sampling site. Sampling sites were decided based on accessibility, proximity in the watershed based on land use, and safety. The samplers were placed with respect to the hydrologic conditions as far from the bank as possible and in a representative flow path.

The criteria used to determine the location of the samplers in the stream were based on parameters used by the U.S.G.S. (USEPA, 2005; NWQM, 2005). The samplers were placed when possible where the stream course was straight for approximately 91 m upstream and downstream of the site. This helps to ensure that the flow is fairly uniform across the channel width so that the suspended sediment sample collected by the sampler is representative of the conditions existing at the time of the high flow event. If placed in bends and meanders the sampler may collect

samples that reflect the flow patterns in relation to preferred pathways that sediment may follow giving unrealistic readings. It was important not to place the samplers near known subsurface or groundwater flow that could potentially bypass the site as this could cause unrepresentative samples.

Placement of the samplers was in the vicinity of a location not subject to scour and fill and free of aquatic plants. Site location was preferred where the banks of the stream channel were permanent, primarily free of brush and high enough to contain floods. The samplers were placed on a reach of channel that was between two confluent or tributary streams to avoid any possible impacts on the measurement of the suspended solids. The site had to be accessible for installation, operation, and maintenance of the sampling site. The selection of a sampler location was a compromise between these criteria.

Location of the sampler may affect the representative quality of the sample collected. Particle size distribution and the concentration will vary in the vertical section and across a river section. Since these samplers are fixed at one spot for each location, it is possible that the TSS concentrations may not be fully representative of the river cross section.

Sites in the upper half of the watershed included LR-6 (#17), Dry Branch (#16), Short Creek (#15), Carr Creek (#13), LR-5 (#14), LR-4 (#10), Hesse Creek (#12) and Reed Creek (#11). These sampling locations TSS concentrations were plotted with Townsend rainfall data (Figure 7). Sites in the lower half of the watershed included LR-3 (#8), Ellejoy Creek (#9), Crooked Creek (#7), LR-2 (#6), Nails Creek (#5), Brown Creek (#18), Pistol Creek-2 (#19), Culton Creek (#1), Pistol

Creek-1(#2), Little River-1(#4) and Stock Creek (#3) (Figure 12). These sampling locations TSS concentrations were plotted with rainfall data from McGhee Tyson airport (Figure 8).

2.4 Laboratory Procedures

Each 250 ml sample bottle was agitated by hand to thoroughly mix the sample. Suspended sediment samples were analyzed using the filtration method (ASTM, 2000), at the Department of Biosystems Engineering and Soil Science water quality lab located at the University of Tennessee, Knoxville. Samples were filtered using a vacuum suction and 45 μ m glass-fiber filters. Clean dried filters were oven dried at 103 to 105°C for 2 hours or until a constant weight was obtained to ensure that ambient moisture was not a source of systematic error. The filters were then placed in a dessicator until needed. Dried clean filters were weighed on a scientific scale and measurements recorded to the nearest milligram.

The filtering apparatus and filter were then assembled for vacuum suction of the samples. Each sample bottle was hand shaken for 2 minutes to agitate the sediment water mixture to ensure thorough mixing of the sample for good representation of the sample. A 25 ml sample from the original 250 ml bottle was then filtered and the filter transferred to an aluminum planchet. The filters were then dried according to procedures outlined in Standard Methods of Examination (ASTM, 2000), cooled in a dessicator for 15 minutes to balance temperature, and reweighed for their post filter weights to the nearest milligram. Total suspended sediment concentrations mg L⁻¹ were calculated for all sediment samples taken.

Turbidity in Nephelometric Turbidity Units (NTU) for each sample was measured in the laboratory using the nephelometric method with a turbidimeter. Turbidity instruments measure the average volume of light scattering over a defined angular range. Each sample was agitated and then poured into a 10-ml glass bottle for turbidity readings. Very dark samples were prepared by making a 1:10 dilution. The turbidimeter was calibrated to a standard sample of 10 NTU. The sample glass bottles were then placed in the turbidimeter and the measurement in nephelometric units was recorded. Each sample bottle was emptied after the analysis and cleansed with tap water and laboratory grade soap and then dried. These same bottles were reused for the next sample collection.

2.5 Turbidity Data from Maryville Water Treatment Plant

Daily turbidity data from Maryville Water Treatment Plant (MWTP) from 1990 to 2004 was also analyzed as part of this study. The MWTP is located near the mouth of the LR, downstream of most tributaries. Turbidity was used because MWTP did not have historical TSS data. Turbidity data collected by MWTP from the Little River was used to assess long-term trends in turbidity. Turbidity was measured in water samples collected directly from the Little River before the water was processed at the plant. The intake is located approximately 4 meters from the stream bank and approximately 3 meters from the stream bed. A sample line delivers water from the intake, before treatment, continually to the plant lab where samples were collected and tested every four hours.

2.6 Statistical Analyses

Geomeans were used instead of arithmetic means as natural phenomena such as water movement and concentrations associated with storm events are subject to spatial variation. Each data value is associated with a location in space and there is at least an implied connection between location and data value. Geometric means were used for TSS and turbidity concentrations as the measure of central tendency, due to the skewness of the data. The geomean uses multiplication rather than addition to summarize the data values for highly variable data. Sites were divided into those with TSS geomeans higher than 50 mg L^{-1} and those with TSS geomeans lower than this critical level. Since there is no standard for TSS concentrations in Tennessee, the level of 50 mg L^{-1} was used at a committee members suggestion. This number is used in discharge permits as a limit for source points. Since other studies have shown negative effects from increased TSS concentrations on aquatic organisms above 100 mg L^{-1} and found that the desirable concentration level to be below 25 mg L^{-1} for the least impact on aquatic organisms, a midpoint of 50 mg L^{-1} was used for this study (Reid and Anderson, 1998; FM, 2005). Ecoregion reference streams are preferable as a standard, however for ecoregions 66G, F, E and 67F and G that the Little River watershed boundaries cross, only low flow grab samples suspended residue data were available instead of storm event TSS. The use of 50 mg L^{-1} can be misleading as this concentration may be too high for in stream ambient conditions.

Descriptive statistics were used to show the minimum, maximum and geomean standard error for TSS and turbidity for the tributaries and main channel

sampling locations. Percentiles were used to report the frequency distribution of sampling sites for TSS and turbidity.

Tests of normality utilizing the Shapiro-Wilk test for TSS and turbidity data were run using only the storm event dates that had both TSS and turbidity available as it was determined that turbidity data be analyzed after the first several sampling collections took place. This is because the MWTP did not have historical TSS data available, only turbidity data. The Shapiro-Wilk test is designed to detect departures from normality without requiring that the mean or variance of the hypothesized normal distribution be specified in advance.

Non-parametric test were used due to the skewness of the distribution for TSS and turbidity. Test for statistical significance of TSS and turbidity main channel versus tributaries was determined by the Mann-Whitney U and Wilcoxon test. The Mann-Whitney U test assesses whether two sets of ranked scores are representative of the same population. The Wilcoxon test was used to compare the correlation of TSS and turbidity for possible differences.

Of the 19 sub-watersheds, six of the sampling locations were combined with other sub watersheds to allow for the upper reaches land use percentages to be factored in as they impact the TSS concentrations that contribute to sites downstream.

Nonparametric one way ANOVA was used to determine if there was an increase in the main channel TSS from upstream to downstream, to determine if TSS were higher in tributaries impacted by urban development and agriculture than those that are highly forested, and to determine if TSS were higher in tributaries impacted

by urban development than in streams with more agriculture. ANOVA was used because it allows the comparison of differences among many sample groups.

Daily rainfall amounts from Townsend, TN representing the upper reaches of the watershed and from Alcoa, TN representing the lower reaches of the watershed, (NOAA, 2005) were used to correlate rainfall during storms events and TSS using regression analysis. A “rainfall event” is defined as any occurrence of rain, preceded by 10 hours without precipitation that results in an accumulation of 0.10 inches or more (TDEC, 2004a). The period of time used was the rainfall event the day before the sampling occurred, however on some occasions it would be two days before the sampling occurred when stage height was too high to safely enter the water.

Correlations were used to evaluate the relationships between TSS and specific land use parameters such as percent imperviousness, agriculture, urban, forest and GSMNP. Correlations were used to evaluate the relationships between MWTP turbidity data and turbidity data from Little River-2 and 3 main channel sites and Ellejoy tributary.

Correlation between TSS and turbidity was used to quantify their relationship. If a highly positive correlation exists, it would allow for the extension of the MWTP turbidity data to draw conclusions about long-term trends in TSS.

For the MWTP turbidity data, Shewhart X $\bar{S}$ and P charts were used to determine if there was an increase of variability over time. The X chart plots the sample means in order to control the mean value of the turbidity variable. The S chart plots the sample standard deviations in order to control the variability of the turbidity variable. A control limit was set by years 1990-1994 mean turbidity values and then

compared to the subsequent years to determine if values fell outside of the upper and lower control limits. The P-chart control limits are based on binomial distribution of proportions. It was used to determine the proportion of days that turbidity was greater than 50 NTU for the historical data. Trends through time were determined to see if there was an auto correlation.

2.7 Determination of Land Use Characteristics

A GIS-based watershed delineation tool was used to digitize the drainage areas for each sampling point. IPSI (TVA, 2003) land use and imperviousness map layers were used to determine the total land area in each major land use type (residential, commercial, transportation and utilities, agriculture, forest, park, wetland, barren, disturbed, and water) and imperviousness level (grouped by 5 percentage points from 0% to 100%). Drainage areas were divided into 5 major classes – mostly forested, urbanized, agriculture, mixed, and National Park. Spatial Analysis was used to determine land use percentages and percent imperviousness for the 19 sub-watersheds.

Chapter 3 Results and Discussion

3.1 Comparison of TSS and turbidity

3.1.1. Geomean

The geometric mean for total suspended solids (TSS) and turbidity is shown for the 19 sampling sites within the Little River watershed (Table 3). 10 sites had TSS geomean concentrations for the sampling period greater than 50 mg L⁻¹ (Table A1). Sites 1, 2, 3, 5, 9, 13, 16, 17, 18, and 19 have higher concentrations of TSS compared to other sites. Of these sites, 2, 3, 5, 7, 9, 18, and 19 are listed on the 303(d) list of impaired streams. Carr Creek (#13), Ellejoy (#9), Nails (#5), Culton Creek (#1), Brown Creek (#18), Pistol Creek-1 (#2), Dry Branch (#16), Crooked (#7), Pistol-Creek-2 (#19) and Stock Creek (#3) had high TSS concentrations for several storm events throughout the sampling period. These 10 sites are tributaries of the Little River main channel. Culton Creek and Brown Creek are tributaries to Pistol Creek. Pistol Creek then empties into the Little River.

There were 9 sites that had TSS concentrations with a geomean less than 50 mg L⁻¹ over the sampling period. These were sites 4, 6, 8, 10, 11, 12, 14, 15, and 17 (Table A2). These include all the Little River main channel sites and Reed Creek (#11), Short Creek (#15), and Hesse Creek(#12). A majority of these sites were located on the Little River main channel. The lower TSS concentrations for the main channel sites may be attributed to the dilution effects of a larger body of water, where as the three tributaries were located in the more pristine upper reaches of the watershed.

Nails Creek (#5) had the highest TSS geomean for the sampling period with 826 mg L⁻¹. This creek also had the single highest maximum TSS concentration of all the sites with 11108 mg L⁻¹. Heavy agricultural use and urban development seen throughout Nails Creek sub-watershed is likely the cause of greater concentrations in TSS.

Little River-4 (#10) had the lowest geomean TSS concentration for the sampling period with 9 mg L⁻¹. This site's location within a forested area and adjacent to the GSMNP may contribute to the lower TSS concentrations.

3.1.2 TSS and Turbidity Comparisons

Nails Creek (#5) had the highest TSS measured for tributaries and main channel sites with a concentration of 11108 mg L⁻¹ and the highest turbidity concentration with 2000 NTU (Table A3). Little River-6 (#17) had the highest TSS measured for main channel sites with a concentration of 1574 mg L⁻¹. Little River-2 (#6) had the highest turbidity for main channel sites at 290 NTU. All of the sites sampled had a minimum concentration of 0 mg L⁻¹ for at least one storm event except for Culton Creek (#1) with a minimum of 24 mg L⁻¹ and Pistol Creek-2 (#19) with a minimum of 9.60 mg L⁻¹. A TSS concentration of 0 mg L⁻¹ occurred when TSS residue on the filter was minimal after processing and after drying was less than 1 mg L⁻¹. This may have occurred because the storm event did not flush out high concentrations of suspended sediment due to storm duration or intensity of the rain event. Distribution was not normal for TSS and turbidity concentrations as shown by the Shapiro-Wilk test of normality (Table 4). The concentrations for the tributaries

were higher than for the main channel for both TSS and turbidity over the sampling period (Table 5). The reason for this may be due to dilution effects that occur in the main channel because the volume of water is greater than what is in the tributaries. Effects of runoff from land use would have a greater impact on tributaries water quality due to the smaller volume of water compared to the main channel. Tributary conveyance of water with high TSS concentrations to the main channel may be the cause for deteriorating water quality in the Little River.

Percentiles representing the frequency of distribution for TSS and turbidity concentrations shows that approximately 25% of the samples collected had TSS concentrations of 14 mg L^{-1} or less (Table 6). Approximately 50% of the samples collected had TSS concentrations of 40 mg L^{-1} or less. This means that half of the samples had TSS concentrations exceeding 40 mg L^{-1} . Only 5% of the samples collected had TSS concentrations of 587 mg L^{-1} or more. Non-parametric tests were used due to the skewness of the distribution and the mean TSS and turbidity concentrations are shown in (Table 7). The Mann-Whitney U test showed that the two sets of ranks of turbidity and TSS grouped by main channel or tributaries represent a single population as the test found no significance (Table 8). The Wilcoxon test was used to compare for possible differences between the two correlated TSS and turbidity concentrations.

3.1.3 Main Channel TSS Concentration Comparisons

The TSS concentrations varied for each of the main channel sites for LR-1, LR-2, LR-3, LR-4, LR-5 and LR-6, however, the comparisons between the upper reaches and the lower reaches were not significant (Table 9). An increase in main channel TSS concentrations from upstream to downstream utilizing ANOVA one-way non-parametric showed that there was not a significant increase in TSS as one moves from the national park boundary at LR-6 downstream to the urban areas near Maryville at LR-1. This contradicts previous studies that show TSS and turbidity increased significantly from upstream to downstream (Bolstad and Swank, 1997).

The geomeans plotted over the sampling period for the main channel sites shows that the TSS levels are slightly elevated at LR-6 at the national park boundary and then drop off at LR-5 and then begin to rise steadily at LR-4, 3, and 2 and then begins to drop off at LR-1 (Figure A1). The reason for the elevated levels at the national park boundary may be attributed to the faster moving current over boulders that create scouring action resuspending bedload material and the amount of detritus material from plants and other organisms that are in the water. The sampler may be collecting the sample when the sediment plume that reaches the sampler is at higher concentrations versus samplers downstream that may be collecting the sample at a lower concentration. Possible explanation of the decrease in TSS at the downstream locations may be due to the change in river gradient near the downstream LR-2 and LR-1 sites as this section of the river compared to the upper reaches is not as steep and the current does not move as swiftly. The river at this point also widens compared

to the more narrow upper reaches of the main channel. The relatively flatter, slower moving current and wider river allow for suspended sediment to settle out more adequately compared to upstream.

3.1.4 Tributary TSS Concentrations Versus Land Use Comparisons

TSS concentrations were higher in areas sampled with agricultural land use than compared to areas sampled in forested areas (Table 10). Agriculture contributes to TSS concentrations through several avenues. Agriculture in close proximity to streams contributes to TSS concentrations by acting as a source for transport of sediment to streams by overland flow after storm events. Bare tilled fields with little or no vegetative cover are easily eroded by rainfall. Pastures and fields with cattle tend to contribute to nutrient enrichment of streams after storm events due to overland flow, especially in heavily overgrazed fields. Cattle with access to creeks stir up the sediments as they walk through and contribute to the amount of suspended sediment available for transport through the watershed. Forest is the most dominant land use in the watershed but does not impact the TSS concentrations as highly as agriculture land use does. Similar results were also found by (Thomas et al., 2003) among agriculture and forested land use in relation to TSS concentrations. The study investigated the influence of forest or pasture land use and stream size on particulate and dissolved material concentrations in streams during the dry and rainy season. The findings showed that the stream originating in pasture had higher concentrations of TSS than the stream originating in forest.

TSS concentrations were higher for agriculture versus urban land use (Table 11). Land associated with agriculture tends to be highly pervious allowing for adequate infiltration of water, whereas highly urbanized areas tend to have more impervious surfaces. Urbanized areas may contribute more water to streams due to runoff from paved surfaces, however there is less exposed soil compared to agricultural land use for potential sediment transport. Comparable results were found by (Dodds and Whiles, 2004) who examined patterns regarding land cover and suspended sediment quantity and quality in rivers. Their study showed that higher concentrations of TSS and turbidity were associated with agriculture than with urban land use.

Each sub-watershed and combined sub-watersheds land use percentages are shown in (Table 12). Imperviousness and dominant land use for each sub-watershed is listed in (Table 13). The main channel sites and Pistol-1 were grouped together with sub-watersheds in the upper reaches as their land use impacts the sampling locations downstream. Of the sub-watersheds with TSS concentrations above 50 mg L⁻¹ the dominant land use when compared to other land use for these sites was forest. Sub-watersheds representing streams found to have high concentrations of sediment over the sampling period had a high percentage of land use as forest 36% followed by urban 32%. Agriculture made up 26% and GSMNP 1% of the land use for sub-watersheds with TSS geomeans greater than 50 mg L⁻¹.

Nails Creek sub-watershed land use percentage shows that the dominant land uses are agriculture 41% (cropland and pasture) and forest 35%. Urban (residential and commercial) land use comprises 21% of the total sub-watershed area.

Approximately 7% of the sub-watershed is impervious. The remaining land use consists of rangeland and water. This sub-watershed had the highest percent agriculture as the dominant land use for all the sub-watersheds. This sub-watershed had the highest TSS concentration for the sampling period. This area has a large farming community. This sub-watershed through observation has many farms with cows grazing in pastures, with many pastures showing signs of heavy use and little vegetative cover. The sampling site was located downstream of a cow pasture where cattle would enter the stream despite attempts to keep the cattle out. The soils in this sub-watershed are severely eroding silty clays, silty clay loams and silt loams (USDA, 1959). This may contribute to the large TSS concentrations collected for the study.

Culton Creek sub-watershed land use percentage shows that the dominant land uses are urban 45% (commercial and industrial) and agriculture 36% (cropland and pasture). Approximately 16% of the sub-watershed is impervious. The remaining land use consists of forest, rangeland, wetlands and water. This sub-watershed is highly urbanized; however, also features agriculture lands that have cattle with heavy overgrazed pastures and stream access. The sampling site was located downstream of a cow pasture where cattle had been allowed previous recent access to the stream. Since this area is highly urbanized, this may contribute to large amounts of surface runoff due to the highly impervious surface conveying water with sediment and other pollutants into the stream. Large amounts of water entering the stream create strong currents that stir up the sediments already present. The soils present in this sub-

watershed are mainly silt loams, silty clay, and silty clay loams that are highly erodible (USDA, 1959).

Brown Creek sub-watershed land use percentage shows that the dominant land uses are urban 43% (commercial and residential) and agriculture 29% (cropland and pasture). Approximately 12% of the sub-watershed is impervious. The remaining 14 % land use consists of forest, barren and water. This sub-watershed is highly urbanized, creating conditions for less perviousness and therefore more storm runoff from streets and parking lots. Brown Creek and Culton Creek sub-watersheds are similar in land use characteristics, with Brown Creek having a greater percentage of urban land use and smaller percentage of agriculture.

Pistol Creek-1 sub-watershed land use percentage shows that the dominant land use is urban 84% (commercial and residential) followed by agriculture 9% (cropland and pasture). This site had the highest urban land use for all the sub-watersheds. Approximately 23% of the sub-watershed is impervious. The remaining land use is forest, rangeland and wetlands. This site when combined with the sub-watersheds upstream that contribute to the TSS and turbidity including Culton, PC-2 and Brown had combined urban land use percentage of 59%. This sub-watershed is highly urbanized in comparison to the other sub-watersheds with TSS greater than 50 mg L⁻¹. This site is located within a residential area, adjacent to Spring Brook Park in Alcoa. Upstream of this sampling location is dense residential and commercial land use. This watershed contains Culton Creek and Brown Creek tributaries to Pistol Creek that is a major tributary to the Little River below Little River-1. This site may be influenced by urban runoff conveying large amounts of water to the stream after a

storm event. The soils found in this sub-watershed are highly erodible silt loam, silty clay, silty clay loams, and shaly silty clay loams (USDA, 1959).

Ellejoy Creek sub-watershed land use percentage shows that the dominant land use is forest 51% followed by agriculture 41% (cropland and pasture). The agriculture is mainly pasture with some heavily overgrazed. Urban (residential) accounts for 6%. Approximately 3% of the sub watershed is impervious. The remaining is rangeland (brush and shrub) with minimal percentages of barren, water and wetlands. The barren area is disturbed lands with little or no vegetative cover. A large portion of this sub-watershed is forest. This area is also occupied with many farms that contain cattle. The land use upstream of this site consisted of pasture and forest.

Carr Creek sub-watershed land use percentage shows that the dominant land use is forest 90%. Agriculture comprises 8% and urban 2% with minimal percentages of barren and water land use. Approximately 2% of the sub-watershed is impervious. Agriculture consists mainly of pasture lands and one feedlot. The barren land use is strip mines and deep mines. This sampling site was located downstream of construction that was in process for the entire study period. Runoff from the development of the adjacent property for vacation cottages may have influenced the high TSS concentrations for this creek. The soils found in this sub-watershed reflect rocky outcrops of slate or quartzite and silt loams and loamy fine sands (USDA, 1959).

Crooked Creek sub-watershed land use percentage shows that the dominant land use is forest 47% with some harvested for timber followed by agriculture 25%

(cropland and pasture) and urban 19% (commercial and residential). Agriculture is mainly pasture with some croplands consisting of row crops. The remaining land use is rangeland (shrub and brush). Approximately 5% of the sub-watershed is impervious. Runoff from construction sites in the area for subdivision development located near the stream may have influenced the TSS concentrations. The soils found in this sub-watershed are composed of shaly silt loams, and alluvial silt loams (USDA, 1959).

Stock Creek sub-watershed land use percentage shows that the dominant land use is forest 71%, followed by agriculture 18% and urban 10%. Approximately 7% of the sub-watershed is impervious. Forested land use includes some harvested forest lands. Agriculture consists of mainly pastures with some heavily overgrazed. Urban is mainly commercial and residential with some utilities consisting of transmission line right of ways. The remaining 1% is rangeland (shrub and brush) with minimal barren and water land use. The barren land use consists of disturbed areas with little or no vegetative cover and strip mines, deep mines and quarries. Upstream of the site was mainly forest with some pasture. The soils found in this sub-watershed are highly erodible silt loams, silty clay and silt clay loams (USDA, 1959).

Pistol Creek-2 sub-watershed land use percentage shows that the dominant land use is urban 64% (commercial and residential) followed by agriculture 26% (cropland and pasture). Approximately 18% of the sub-watershed is impervious. Agriculture is mainly fair pasture lands with some areas heavily overgrazed. The remaining land use consists of forest 7% and rangeland 3% with a minimal percent of barren and water. The rangeland is shrub and brush with barren consisting of

disturbed areas with little or no vegetative cover. Immediately upstream from this site is developed residential and commercial areas while approximately three miles upstream land use is mainly pasture and forested areas. This section of Pistol Creek is the upper reaches of the Pistol Creek watershed. This site had lower TSS concentrations compared to the Pistol Creek-1 site located in Alcoa. The Pistol Creek-1 site concentrations may be influenced by urban runoff from the highly developed area upstream.

Dry Branch Creek sub-watershed land use percentage shows that the dominant land use is forest 69% and agriculture 17%. The GSMNP comprises 10% and the remaining land use consists of urban and water. Approximately 2% of the watershed is impervious. This sub-watershed had the lowest geomean TSS concentration of the sub-watersheds with TSS greater than 50 mg L^{-1} . This sampling site was located downstream of a construction site where a commercial development was being built. This may have contributed to the high TSS concentrations for the sampling period. The soils for this sub-watershed consist of silt loams and loamy fine sands at the river bottoms (USDA, 1959).

Sub-watersheds representing streams found to have lower concentrations of sediment over the sampling period, 50 mg L^{-1} or less, had a high percentage of forest 52% and GSMNP 18% land use. Agriculture accounted for 20% and urban for 9% land use. Most of the sub-watersheds falling in this category were sampling locations on the main channel of the Little River.

Reed Creek sub-watershed land use percentage consisted mainly of forest 93% followed by agriculture 6% and urban 1%. The percent imperviousness was

approximately 2%. The sampling site located near the mouth of Reed Creek was located in an area with residential homes. This site had the highest percentage of forest for all the sites sampled. Upstream of this site was mainly forested areas. This site had approximately the same land use percentages as Carr Creek sub-watershed that had more than double the amount of TSS as Reed Creek sub-watershed. These two sub-watersheds are similar in size and landform and may differ in concentrations due to the ongoing construction that occurred upstream of the Carr Creek sampling location. The soils found in this sub-watershed are silt loams to loamy fine sands (USDA, 1959).

Short Creek sub-watershed land use percentage consisted mainly of 72% forest followed by agriculture 17%. Urban land use accounted for 6% and GSMNP accounted for 4%. The percent imperviousness was approximately 3%. This site is comparable to the land use percentages for Dry Branch sub-watershed with less than half the TSS concentrations. The differences in concentrations may be contributed to the construction immediately upstream from the sampling site for Dry Branch creek. This sampling site was located near the mouth of Short Creek. The soils found in this sub-watershed are silt loams and loamy fine sands (USDA, 1959).

Hesse Creek sub-watershed land use percentage consisted mainly of GSMNP 54% followed by agriculture 39%. The remaining land use consisted of 5% urban and 1% forest and water. The percent imperviousness was approximately 1%. This creek is a tributary located in the upper reaches of the study area. The soils found in this sub-watershed are loams, fine sandy loams, and clay loams (USDA, 1959).

Little River-6 sub-watershed land use percentage consisted mainly of 100% GSMNP. The percent imperviousness was 0%. This site was located just outside of the National park boundary in the upper reaches of the Little River watershed study area. This site had a low TSS geomean for the sampling period compared to other sites. All the other sites in the study area were located downstream of Little River-6. Since this site is in an area with mostly forest and National park and virtually no agriculture and urban areas it was predicted that this site would have the lowest TSS compared to the other sites downstream that had larger percentages of other land use. This site had low TSS, however, on five of the 28 sampling events, concentrations from this site were higher than 500 mg L^{-1} . The sample collected at this site for those events had a large amount of sand and detritus in the sample container. The unusually high concentrations here may have been due to the organic debris and sampler location. For this site the sampler was fixed to a boulder in the water and may have collected large amounts of detritus materials in the sampler at high flow from scouring and the current picking up bed load material and resuspending it. The soils for this sub-watershed consisted of fine sandy loams, clay loams, and sandy loams (USDA, 1959).

Little River-5 sub-watershed land use percentages were combined with the land use of the sub-watersheds upstream that contributed water to the sampling point. This combined land use percentage consisted of 88% park, 8% forest, 2% agriculture 1% urban, and 1% water. The percent imperviousness was approximately less than half a percent. This site was located downstream of the site (Little River-6) immediately outside of the National Park. This site had low TSS concentrations. This

site compared to Little River-6 upstream did not have as many boulders and rocks that influenced the current possibly stirring up bed sediment. The soils for this sub-watershed consisted of fine sandy loams, clay loams, and sandy loams (USDA, 1959). Little River-4 sub-watershed land use percentages were combined with the land use of the sub-watersheds upstream that contributed water to the sampling point. This combined land use percentage shows that the dominant land use was park 74%, forest 21%, agriculture 4% and urban 1%. The percent imperviousness was less than 1%. This site had the lowest concentration of TSS of all the sites. It was located downstream of Little River-5. This site had less than 5% agriculture and urban land use. This site was not heavily influenced by urban runoff or agricultural runoff upstream. The soils found in this sub-watershed are loams and silt loams (USDA, 1959).

Little River-3 sub-watershed land use percentages were combined with the land use of the sub-watersheds upstream that contributed water to the sampling point. This combined land use percentage consisted mainly of park 64%, forest 29%, agriculture 5% and urban 2%. The percent imperviousness was approximately 1%. This site was not located in an area where heavy agricultural or urban land use was dominant upstream. The soils found in this sub-watershed are loams and silt loams (USDA, 1959).

Little River-2 sub-watershed land use percentages were combined with the land use of the sub-watersheds upstream that contributed water to the sampling point. This combined land use percentage consisted mainly of park 45%, forest 33%, and agriculture 15%. The remaining 7% consisted of 6% urban and 1% rangeland. The

percent imperviousness was approximately 2%. This site may have lower TSS compared to other sites with higher TSS because this site is in the lower reaches of the watershed where the river gradient is not as steep and the river is wider allowing for suspended sediment to settle out. The soils for this sub-watershed consisted of highly erodible silty clay and silty clay loams (USDA, 1959).

Little River-1 sub-watershed land use percentages were combined with the land use of the sub-watersheds upstream that contributed water to the sampling point. This combined land use percentage shows that the dominant land use was park 41%, forest 33% and agriculture 18%. Urban comprised 6% of the land use. The remaining land use consisted of 1% rangeland. The percent imperviousness was approximately 2%. This site had the highest percentage of agriculture for the main channel sites. This site was located downstream and was the last site on the main river channel. The river gradient in this sub-watershed is not as steep as the upper reaches and the water flow at this point does not move as swiftly as the land form flattens out and is wider compared to the upper main river channel that is more turbulent. Less flow and flatter gradient allows for suspended sediment to settle out faster rather than transporting it downstream. This sampler location may also have influenced the concentrations because it was placed on the outside bend of the river. The soils for this sub-watershed consisted mainly of fine sandy loams, loams, and silt loams (USDA, 1959).

3.2 Correlations

Correlations were made among TSS, rainfall, land use and turbidity with regression analysis. Correlations with TSS concentrations and rainfall showed a slight

positive correlation but weak linear association (Figure 7 and 8) for all sites. This is because rainfall is highly variable in space and time. This is in contrast to a study conducted by (Hollabaugh et al., 2002) examining the variations in water quality parameters in 38 streams in Georgia that showed a significant positive correlation for TSS and turbidity with rainfall.

Correlations were made among TSS geomean and specific landuse parameters. Correlations between imperviousness and TSS for each sub-watershed is shown in (Figure 9). The graph shows that there is a positive correlation .7059 between TSS and percent imperviousness within the watershed significant at 95% probability. The linear association is strong and shows that there is a moderate correlation between an increase of TSS concentrations and an increase in percent imperviousness. Imperviousness is primarily associated with urban land use. As imperviousness increases so does the level or concentration of the TSS variable. Similar results were found by Bolstad (1997) comparing building density and water quality variables who also found a positive correlation.

Correlation between percent urban land use and TSS showed a positive correlation .6739 significant at 95% probability (Figure 10). The linear association is strong with a moderate correlation between an increase in TSS concentrations and an increase in percent urban land use. As urban land use increased, TSS increased. This is not surprising as urban land use is associated with imperviousness and TSS correlation with imperviousness was significant. These results contrast findings in a study conducted by (Dodds and Whiles, 2004) that suggested urbanization leads to decreased sediment delivery to streams because there is more cover (pavement,

buildings) and bare soil is rare (e.g., lawns and paved areas cover soil and reduce erosion).

Correlation between percent agriculture and TSS concentrations showed a positive correlation .7236 significant at 95% probability (Figure 11). The linear association is strong with a high correlation between an increase in TSS concentrations and an increase in percent agriculture. Similar results were also found by (Dodds and Whiles, 2004). As agricultural land use increased, TSS concentrations increased. This means that a large percentage of TSS concentrations may be contributed from overland flow due to storm runoff from agricultural lands. Pastures, especially those that are heavily overgrazed may not allow adequate infiltration of water creating conditions for erosion and surface runoff. Tributaries in close proximity to farms, especially those that allow cattle access to streams may be impacted and have higher TSS concentrations than tributaries that flow through other types of land use.

Correlation between percent forest and TSS showed a negative correlation (Figure 12). The linear association is weak with a slight correlation between an increase in percent forested land use and decreased TSS. This means that TSS concentrations may not be impacted by forested land use as much as agriculture and urban land use. A negative correlation was found by (Dodds and Whiles, 2004) between forest and TSS, in contrast their negative correlation was significant and strongly correlated. Forest is a large percentage of the land use within the Little River watershed and therefore may contribute to the lower TSS concentrations of the

tributaries with large amounts of forested land use. As development increases in the Little River watershed and forest is reduced, TSS may increase.

Correlation between percent GSMNP and TSS concentrations showed a negative correlation -0.5512 significant at 95% probability (Figure 13). The linear association is strong with a moderate correlation between a decrease in TSS concentrations and increase in GSMNP land use. This means that as GSMNP land use increased that TSS concentrations decreased. The GSMNP is also largely forested but categorized separately as it is a managed area and not likely to change due to development and logging as forest would be impacted by.

Correlation between TSS concentrations and turbidity showed a significant positive correlation with a 99% confidence at the .01 probability level (Table 14). The linear association is strong with a high correlation between TSS and turbidity (Figure 14). This is useful because a high correlation between TSS and turbidity allows for TSS concentrations to be estimated from turbidity measurements. Turbidity is an acceptable indicator of TSS concentrations. Similar studies conducted examining TSS and turbidity dynamics (Lewis et al., 2001) showed that mean TSS and turbidity concentrations within two watersheds were significantly different and regression slopes for one watersheds TSS and turbidity indicated that a greater TSS concentration corresponds to a respective turbidity measurement. One watershed regression relationship of TSS and turbidity underestimated TSS concentrations by 1, 54, and 60% for turbidity measurements of 1, 100, 1,000 NTU respectively. Since a strong positive correlation was found between TSS and turbidity for the Little River watershed, this means that it would be feasible to monitor turbidity for the Little

River watershed instead of TSS because turbidity can be utilized as an effective and accurate indicator of TSS concentrations. Caution should be taken when applying turbidity as an indicator of TSS for other watersheds as the relationship between the two is site specific. This is supported by (Lewis et al., 2001) who found that similar turbidity values from two different tributary watersheds could indicate appreciably different TSS values. This is a result of differences in watershed geology, slope and aspect, soils, vegetation, and land use. Another study (Rinella et al., 2002) also showed that turbidity was significantly correlated with suspended sediment measurements.

Comparisons between turbidity from Maryville Water Treatment Plant and Little River-2 and Little River-3 main channel sites and Ellejoy tributary are shown in (Figure 15). Turbidity from MWTP and Little River-2 main channel site located downstream of the plant showed a positive correlation (Figure 16). Turbidity from MWTP and Little River-3 main channel site located upstream of the plant showed a positive correlation (Figure 17). This site was more strongly correlated than Little River-2 or Ellejoy. Turbidity from MWTP and Ellejoy tributary also showed a positive correlation (Figure 18). Ellejoy is more strongly correlated to MWTP turbidity than Little River-2. Ellejoy tributary empties into the Little River below Little River-3 site. Ellejoy has higher turbidity levels than Little River-2 and 3. Little River-3 had the lowest turbidity levels over the sampling period compared to Little River-2 and Ellejoy. Little River-2 had higher turbidity levels than Little-River-3. Little River-3 may be more strongly correlated to MWTP turbidity because the inputs of sediment from Ellejoy may have adequate time to settle back out before reaching

MWTP downstream. Little River-2 had increased levels of turbidity compared to Little River-3 and may be due to river channel dynamics influencing the sediment concentrations and turbidity levels. Another possible explanation for the variance in correlation would be placement of the intake at the MWTP that affects the water turbidity levels analyzed due to increased sediment concentrations and the particulate matter texture that comprises the sample collected. Since the intake is located 3.6 meters from the stream bank and approximately 1 meter from the stream bed then it is possible that the intake is collecting some resuspended bed sediment during high flow. The placement of the samplers for the study was located closer into the stream bank and not in the representative flow path of the river.

3.2.1 Maryville Water Treatment Plant

Turbidity values were compared over 14 year historical data from MWTP. The data shows that in the past few years there has been an increase in turbidity variability over time (Figure 19). The chart plots the log base¹⁰ turbidity values by quarter. The data for January-March 1990 is labeled 1990Q1, for April-June 1990 is labeled 1990Q2, for July-September 1990 is labeled 1990Q3, for October-December 1990 is labeled 1990Q4. High flow turbidity levels have nearly doubled since 2000 compared with levels observed in the 1990s. A proportion of the days in each quarter with respect to season are shown where turbidity values are greater than 50 NTU (Figure 20). The chart shows the average proportion of days that turbidity exceeds 50 NTU over a 14 year period with a higher proportion of days exceeding 50 NTU in 2002 to 2004 compared to previous years. Since turbidity and TSS have shown to be

highly correlated for this watershed, it is reasonable to expect that if the turbidity levels from MWTP has increased, especially over the last few years, that TSS concentrations are also increasing for the Little River and may continue to do so contributing to further degradation of the Little River.

Conclusion and Recommendations

The primary study objectives were met to determine TSS concentrations for 19 sites within the Little River Watershed for usefulness in creating a baseline and collecting land use information for further studies to be based on. The results provide a basis for additional study by determining that 1) single stage samplers can be a cost effective tool to successfully collect suspended sediment to determine streams with high concentrations for storm events over a given period, 2) the relationship between TSS and turbidity can be quantified, 3) land use is a major factor influencing the source and amount of sediments impacting water quality of the Little River Watershed and 3) trends over time are showing an increase of turbidity in the past few years suggesting that if current trends continue the sediment concentrations may continue to rise threatening the future of the Little River.

Comparisons of TSS geomean and turbidity for the sites sampled throughout the study area showed that Nails Creek (#5) had the highest TSS. This is most likely due to the heavy agricultural land use as this was determined to be the dominant land use for this sub-watershed and agriculture was shown to impact TSS more than forest or urban land use. Agriculture was also significantly correlated with an increase in TSS in tributaries as percent agriculture land use increased. Urban land use was also a large percentage of this sub-watershed and though urban did not impact TSS concentrations as greatly as agricultural land use, the correlation of increased TSS with an increase of percent urban land use was significant.

Comparisons of TSS geomean concentrations and turbidity of the sites sampled throughout the study area showed that Little River-4 (#10) had the lowest TSS and

Little River-6 (#17) and Little River-4 (#10) had the lowest turbidity. This is most likely due to the dominant forested land use for this sub-watershed and the sub-watershed upstream of this site that were either largely forest or GSMNP. TSS in tributaries were shown to not be significantly impacted by forest in comparison with agricultural and urban land use. An increase in percent forest land use showed a decrease in TSS. A strong association between an increase in GSMNP land use percentage and a decrease in TSS concentrations was also shown.

TSS concentrations were shown to be highly correlated with turbidity for this watershed. Overall, the tributaries were shown to have higher TSS than the main channel. The main channel did not have a significant increase of TSS moving from the upstream to downstream sites. This may be due to a bad sampler location for the upper LR-6 site outside of the GSMNP boundary that had higher than expected TSS concentrations due to scouring and resuspension of sediment bedload. The lower concentrations found at the downstream sites near LR-2 and LR-1 may be due to less steep river gradient and wider channels allowing for suspended sediment to settle out. Tributary conveyance of TSS to the main channel may contribute additional suspended sediment to the main channel but is not a significant source.

Forest is the dominant land use in the Little River Watershed study area followed by agriculture, urban, and GSMNP. For the ten sites sampled that were determined to have TSS over 50 mg L^{-1} for the study period the land use showed that 36% of these sub-watersheds had forest as the dominant land use followed by 32% urban, 26% agriculture and 1% GSMNP. For the nine sites sampled that were determined to have TSS less than 50 mg L^{-1} for the study period, the land use showed

that 43% of these sub-watersheds had forest as the dominant land use followed by 20% agriculture, 18% GSMNP and 9% urban.

Forested land use was dominant for all sites. Even though forest is the major land use, the highly pervious surface allows for infiltration of water rather than overland flow that would contribute to the transport of suspended sediment to the stream. TSS in tributaries were shown to be less impacted by forest land use than by agriculture and urban land use. Disturbed forest from logging, clearing for development and burning may contribute to higher TSS due to less vegetation creating conditions for more runoff across the land surface. For the sites with TSS greater than 50 mg L^{-1} , urban land use was the second dominant land use versus the sites with less than 50 mg L^{-1} TSS with agriculture as the second dominant land use. The smallest percentage of the worst sites land use was GSMNP while for the sites with lower TSS had urban as the smallest percentage of land use. The sites with greater than 50 mg L^{-1} have large percentages of both urban and agricultural land use that both have been shown to be highly correlated with an increase in TSS concentrations and a small percentage of GSMNP land use shown to be highly correlated with a decrease in TSS concentrations. The sites with less than 50 mg L^{-1} TSS concentrations have both agricultural land use shown to be highly correlated with an increase in TSS and GSMNP land use shown to be highly correlated with a decrease in TSS and a small percentage of urban land use.

The larger percentage of urban land use may be affecting the sub-watersheds with concentrations of 50 mg L^{-1} or higher. This may be attributed to a large amount of impervious surface for these sub-watersheds compared to the sub-watersheds with

less than 50 mg L⁻¹ TSS that have a smaller percentage of urban land use and smaller percentages of impervious surface. An increase in percent imperviousness was shown to highly correlate with an increase in TSS. An increase in urban land use was shown to correlate with an increase in TSS concentrations. The amount of impervious surfaces within the sub-watersheds with higher TSS may be conveying large amounts of water to the streams quickly creating higher flows with more turbulent waters creating conditions that may cause severe streambank erosion and channel erosion on highly erodible soils and also moving water over exposed soils transporting sediments and other pollutants to the streams. This may possibly be a factor since many of the sites are located in areas with high percentages of urban land use interspersed with agricultural areas.

Agricultural practices along the streams in the sub-watersheds of the Little River Watershed with TSS greater than 50 mg L⁻¹ contributed to the high concentrations of TSS and turbidity levels. Agriculture was shown to impact TSS concentrations significantly more than forest or urban land use. An increase in percent agriculture land use showed an increase in TSS. Riparian damage was seen though out the sub-watersheds sampled, especially in areas with cattle that had access to the water. Cattle contribute to the destabilization of stream banks and disturb the stream bed. Nails Creek (#5) had the highest TSS geomean for all sites sampled with 826 mg L⁻¹. This site was directly downstream of a pasture that had cattle access to the stream. Efforts had been made to keep the cattle out of the stream, but on more than one occasion, the cattle prevailed. Implementation of other BMPs, such as

concrete crossings, protected heavy use areas and buffer strips may help improve water quality.

Culton Creek (#1) also had high TSS and this may be due to cattle with access to the stream upstream of the sampling site. No observable efforts were made to keep the cattle out of this stream during the study period. Ellejoy Creek (#9) also was in a largely agricultural area with many farms adjacent to the stream. No cattle were observed entering the stream during the study period.

Implementation of BMPs on farms throughout the Little River watershed may help improve water quality. Focusing on farms with pastures that run along the streams or have cattle with access to the stream would be a first step.

Culton Creek (#1), Brown Creek (#18), Crooked Creek (#7), Pistol Creek-1 (#2) and 2 (#19) are all sub-watershed sites with high urban land use and high imperviousness. These sites had high TSS concentrations over the sampling period. These sites also had a large percentage of agriculture. Creating more riparian buffers around these streams and less zoning for development of the land along the stream could reduce impacts to water quality in these urban areas.

Stock Creek (#3) and Dry Branch (#16) both had large amount of either forest or agriculture. Both of these sites elevated TSS concentrations may be due to construction activities present throughout the study period. Implementation and maintenance of erosion control structures such as silt fences and check dams at the construction sites may help reduce TSS.

Since TSS and turbidity were shown to be highly correlated and turbidity increases over time were shown from the historical MWTP data it is conceivable that

TSS concentrations are also increasing in the Little River. Since percent agriculture and urban land use are both dominant in addition to forest land use and have been shown to highly correlate with an increase in TSS concentrations, a reduction in percent agriculture and urban land use with more emphasis in creating greenways and conserving more forested areas may help to reduce the inputs of suspended sediment to the Little River due to overland flow from stormwater runoff. Since reducing urban land use is not practical, implementing BMPs is crucial to conservation of soil and water resources.

Recommendations for other studies would include measuring flow to determine discharge for storm events, to plot TSS concentrations and determine sediment load, staff gauges installed at the sampling site to measure gauge height and create flow duration curves to look at TSS trends over time, particle size analysis to determine what fraction of sand, silt or clay is comprising the sample collected, lateral profiling of the tributaries and main channel to determine shifts in the stream bed due to sedimentation and different methods of collecting storm event samples for comparison. Determining sediment load would allow for an estimate of how many tons of sediment are being flushed through the watershed. Particle size analysis would help determine where sediment sources are in relation to the soils that are dominant within a watershed and would further support effects from particular land use types. Comparing different methods of collecting storm event samples would allow for comparisons among TSS concentrations collected to help determine how representative particular methods are of TSS concentrations within the river and watershed.

In response to concerns about water quality in the Little River, local, state, and federal agencies and private organizations are working together to improve and protect it. This study collecting stormwater total suspended solids (TSS) and turbidity samples will provide environmental indicators to measure success in reducing sediment loads. Post initiative stormwater samples will be collected in 2007. The goal is a 25% reduction in TSS and turbidity levels. Funding through various grants is necessary in order to continue monitoring and evaluating the Little River Watershed, and to provide an outreach program to inform and encourage landowners about improving water quality and implementing BMPs.

List of References

ADEC (Alaska Department of Environment and Conservation). 2002. Granite Creek TMDL Summary. Division of Air and Water Quality.

Allen, J.R.L. 1985. Principles of Physical Sedimentology: London, George Allen and Unwin. 120-131.

APHA. 1998. American Public Health Association.
<http://www.apha.org/journal/toc.htm>

Aschmann, S.G., D.P. Anderson, R.J. Croft, and E.A. Cassell. 1999. Using a watershed nutrient dynamics model, WEND, to address watershed-scale nutrient management challenges. Journal of Soil Water Conservation. Fourth quarter. 630-635.

Ashmore, P. 1992. Sediment delivery in large prairie river basins, western Canada. International Association of Hydrological Sciences Publication 210: 423-432.

Arnwine, D.H., J.I. Broach, L.K. Cartwright, and G.M. Denton. 2000. Tennessee Ecoregion Project. TDEC, Division of Water Pollution Control, Nashville, TN.

ASTM. 2000. D 3977-97, Standard test method for determining sediment concentration in water samples, annual book of standards. Water and Environmental Technology. 11(2): 389-394.

Basnyat, P., L.D. Teeter, B.G. Lockaby and K.M. Flynn. 2000. The use of remote sensing and GIS in watershed level analyses of nonpoint source pollution problems. Forest Ecology Management. 128: 65-73.

Batson, V., Bertsch, P., and B. Herbert. 1996. Transport of anthropogenic uranium from sediments to surface waters during episodic storm events. Journal of Environmental Quality. 25: 1129-1137.

Berkman, H.E. and C.F. Rabeni. 1987. Effects of siltation on stream fish communities. Environmental Biology of Fishes. 18: 285-294.

Bhaduri, B., J. Harbor, B. Engel, and M. Grove. 2000. Assessing watershed scale, long-term hydrologic impacts of land-use change using a GIS-NPS model. Environmental Manage. 26(6): 643-658.

Black, Peter E. 1991. Watershed Hydrology. Prentice Hall. New Jersey. 1-408.

Bolstad, P.V. and W.T. Swank. 1997. Cumulative impacts of land use on water quality in a southern Appalachian watershed. Journal of the American Water Resources Association 33(3): 519-534.

Brady, N.C. and R.R. Weil (Editors). 1999. The Nature and Properties of Soils, 12th ed. Prentice Hall Publishing. Upper Saddle, NJ.

Bryan, Rorke B. 2000. Soil Erodibility and Processes of water erosion on a hillslope. *Geomorphology*. 32(3-4): 1-40.

Buffleben, M.S., Nix, D., Ouyang, X., Ruth, E., Stenstrom, M.K. and I.H. Suffet. 2000. Evaluation of non-point source runoff on suspended solids that enter Santa Monica Bay. American Society of Civil Engineers-Water Resources Division. Symposia-Urban Runoff Water Quality-Impacts, Runoff and Control Strategies. 1-10.

Buol, S.W., Hole, F.D., McCracken, R.J. and Southard, R.J. 1997. Soil genesis and classification 4th ed. Iowa State University Press. Ames, Iowa.

Carling, P.A. and C.P. McMahon. 1987. Natural siltation of brown trout spawning gravels during low-flow conditions. Plenum Press, New York. 229-244.

Carling, P.A. and C.P. Mc Cahon. 1987. Natural siltation of brown trout spawning gravels during low flow conditions. *Advances in Ecology*. Plenum Press, New York. 229-244.

Chen, C.W., J. Herr, L. Ziemelis, R.A. Goldstein, and L. Olmstead. 1999. Decision support system for total maximum daily load. *Journal Environmental Engineering.-ASCE*. July: 653-659.

Cooke, S.E., and E.E. Prepas. 1998. Stream phosphorus and nitrogen export from agricultural and forested watersheds on the Boreal Plain. *Canadian Journal of Fisheries* 55: 2292-2299.

Corbitt, R.A. 1989. *Standard Handbook of Environmental Engineering*. McCraw-Hill, Inc., New York, New York.

Correll, D.L. 1998. The role of phosphorous in the eutrophication of receiving waters: A review. *Journal Environmental Quality*. 27 (2):261-266.

Correll, D.L., Jordan, T.E. and D.E. Weller. 1991. Nutrient Flux in a landscape: Effects of coastal landuse and terrestrial community mosaic on nutrient transport to coastal waters. *Estuaries* 15: 431-442.

Davies-Colley, R.J., C.W. Hickey and J.M. Quinn. 1992. Effects of clay discharges on streams. *Hydrobiologia* 248: 215-234.

Dearmont, D., B.A. McCarl, and D.A. Tolman. 1998. Costs of water treatment due to diminished water quality: A case study in Texas. *Water Resources* 34 (4): 849-854.

Dedkov, A.P. and V.T. Moszherin. 1992. Erosion and sediment yield in mountain areas of the world. International Association of Hydrological Sciences Publication. 209: 29-36.

Denton, G.M., A.D. Vann, and S.H. Wang. 2000. The Status of Water Quality in Tennessee: 2000 305(b) Report. TDEC, Division of Water Pollution Control. Nashville, TN.

Dillon, P.J. and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. *Water Research* 9: 135-148.

Dodds, W.K. and M.R. Whiles. 2004. Quality and quantity of suspended particles in rivers: Continent scale patterns in the United States. *Environmental Management* 33 (3): 355-367.

Driscoll, E.D., Shelley, P.E., and Strecker, E.W. 1990. "Pollutant loadings and impacts from stormwater runoff, Vol. 3". Analytical Investigation and Res. Rep. FHWA-RD-88-008, Fed. Highway Administration., Washington, D.C.

Edwards, T.K. and G.D. Glysson. 1988. Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report. 86-531.

Edwards, T.K. and G.D. Glysson. 1999. Field methods for measurement of fluvial sediment. Techniques of Water-Resources Investigations of the U.S. Geological Survey. Book 3, Applications of Hydraulics.

Eghball, B. and J.E. Gilley. 1999. Phosphorus and nitrogen in runoff following beef cattle manure and compost application. *Journal Environmental Quality* 28: 1201-1210.

Foster, G.R., Renard, K.G. and Toy, T.J. 2002. Soil Erosion, Processes, Prediction, Measurement and Control. John Wiley and Sons, Inc., New York. 1-295.

FM River Water Quality. 2005.

<http://www.undeerc.org/watman/FMRiver/PPTV/waterrating.asp>

Gibbs, R. 1977. Transport phases of transition metals in the Amazon and Yukon Rivers. *U.S. Geological Society of America Bulletin* 88: 829-843.

Giller, P.S. and Malmqvist, Bjorn. 1998. The Biology of streams and rivers. Oxford University Press.

Gilliland, M.W., and Baxter-Potter, W. 1987. "A geographic information system to predict non-point source pollution potential." *Water Resources*. 23 (2), 281-291.

Greenburg, A.E., L.S. Clesceri and A.D. Eaton (Editors). 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Association. Washington, D.C.

Glover, T. 1996. Livestock manure: foe or fertilizer? Economic Research Service, USDA. Agricultural Outlook.

Gosselink, J.G., G.P. Schaffer, L.C. Lee, D.M. Burdick, D.L. Childers, N.C. Leibowitz, S.C. Hamilton, R. Bouman, D. Cushman, S. Fields, M. Koch, and J.M. Visser. 1990. Landscape Conservation in a forested wetland watershed: can we manage cumulative impacts? *Bioscience* 40: 588-600.

Gostin, L.O., Z. Lazzarini, V.S. Neslund, and M.T. Osterholm. 2000. Water quality laws and waterborne diseases: *Cryptosporidium* and other emerging pathogens. *American Journal Public Health*. 90 (6): 847-853.

Griffith, G.E., J.M. Omernik, and A.J. Woods. 1999. Ecoregions, watersheds, basins, and HUCs: how state and federal agencies frame water quality. *J. Soil Water Conservation*. Fourth quarter. 666-677.

Graczyk, D.J., J.F. Walker, S.R. Greb and D.W. Owens. 1993. Evaluation of non-point contamination, Wisconsin-selected data for 1992 water year: U.S. Geological Survey Open-File Report 93-630. 48.

Guy, H.P. 1969. Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations. 5 (1): 5-58.

Harbor, Jon. 1999. Engineering geomorphology at the cutting edge of land disturbance: erosion and sediment control on construction sites. 31(1-4): 247-263.

Harmon, W.C. and L.D. Meyer. 1989. A new method for evaluating particle size distribution and aggregated portion of eroded sediment. *Transactions of the ASAE*. 32: 89-96.

Hession, W.C., M. McBride, and M. Bennett. 2000. Statewide nonpoint source pollution assessment methodology. *J. Water Res. Pl-ASCE*. May/June: 146-155.

Heidel, S.G. 1956. The progressive lag of sediment concentration with flood waves: *Transactions of the American Geophysical Union*. 37 (1): 56-66.

Hillel, Daniel. 1998. *Environmental Soil Physics*. Academic Press. San Diego, California. 1-706.

Hollabaugh, C.L., R.R. Harris, J.D. Congleton, R.L. Kath, J.K. Bartley and J.A. Waters. 2002. Paper No. 4-0 North Central Section (36th) and Southeastern Section (51st), GSA Joint Annual Meeting (April 5, 2002).

Horowitz, A. 1984. A primer on trace metal-sediment chemistry. Geological Survey Open-File Report 84-709.

Hoskin Scientific Manual

<http://ehoskin.xplorex.com/page120.htm>

ICWR-SS. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation. 1961. The single-stage sampler for suspended-sediment: Minneapolis, Minnesota, St. Anthony Falls Hydraulics Laboratory, Report 13. 15-105

Jansson, M.B. 1998. A global survey of sediment yield. *Geografiska Annaler*. 70a (1-2):81-98.

Jenne, E., Kennedy, V. Burchard, J. and J. Ball. 1980. Sediment collection and processing for selective extration and for total metals analysis. Ann Arbor Science Publishers, Ann Arbor, MI. 2: 169-189.

Jordan, T.E., D.L. Correll, W.T. Weller. 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. *Journal of Environmental Quality* 22:467-473.

Johnson, T. 2001. Conservation Practices for the Farms and Forests of Tennessee. Tennessee Department of Agriculture. Nashville, TN.

Leblanc, R.T., R.D. Brown, and J.E. Fitzgibbon. 1997. Modeling the effects of land use change on the water temperature in unregulated urban streams. *Journal of environmental management*. 49: 445-469.

Leclair, V. 1997. Courts push states, EPA to create TMDL water programs. *Environmental Science Technol.* 31 (4): 178A-179A

Lee, J.H., K.W. Bang, L.H. Ketchum, Jr., J.S. Choe and M.J. Yu. 2002. First flush analysis of urban storm runoff. *The Science of the Total Environment*. 293 (1-3): 163-175.

Lee, J.H. and K.W. Bang. 2000. Characterization of urban stormwater runoff. *Water Resources*. 34: 1773-1780.

Leopold, L.B. 1964. *Fluvial processes in geomorphology*. San Francisco: W.H. Freeman and Company.

Lenat, D.R. and J.K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia*. 294(3): 185-2000.

Lewis, David., K.W. Tate, R.A. Dahlgren and J. Newell. 2002. Turbidity and total suspended solid concentration dynamics in streamflow from California Oak Woodland watersheds. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184. 107-118.

Lewis, D.J., K.W. Tate, J.M. Harper, J. Price. 2001. Survey identifies sediment sources in North Coast rangelands. *California Agriculture* 55(4): 32-38.

Likens, G.E. and F.H. Bormann. 1975. Nutrient-hydrologic interactions. Hasler A.D. (ed.), *Coupling of land and water systems*. Springer-Verlag, NY. 1-63.

Madej, Mary Ann. 2002. The contribution of suspended organic sediments to turbidity and sediment flux. Turbidity and other sediment surrogates workshop, April 30-May 2, 2002, Reno, Nevada.

Mallin, M.A. 2000. Impacts of industrial animal production on rivers and estuaries. *American Science*. 88:26-37.

Mast, M.A. 1999. Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the eastern U.S. 1963-95. U.S. Geological Survey Circular 1173-A, 1-16.

Meade, R.H. 1982. Sources, sinks and storage of river sediment in the Atlantic drainage of the United States. *The journal of geology*. 90: 235-252.

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Bruns and J.R. Sedell. 1985. Developments in stream ecosystem theory. *Canadian Journal of Fisheries*. 42: 1045-1055.

Mueller, David K. and Dennis R. Hesel. 2001. Nitrients in the nation's waters-too much of a good thing? USGS NAWQA Circular 1136. U.S. Geological Survey. <http://water.usgs.gov/nawqa/circ-1136/h3.html>

Murdoch T. and M. Cheo. 1996. The streamkeeper's field guide. Adopt-A-Stream Foundation.

Natural Resource Conservation Service. 2000. Buffer strips: common sense conservation. <http://www.nhq.nrcs.usda.gov/CCS/Anchor-WhatBuffer>

National Oceanic Atmospheric Administration. 2003. Preliminary Local Climatological Data. <http://www.srh.noaa.gov/mrx/climdata/TYSLCDJUN2003.txt>

NWQM. 2005. National Water Quality Monitoring Council. www.acwi.gov/monitoring

Novotny V. and G. Chesters. 1989. Delivery of sediment and pollutants from non-point sources: a water quality perspective. *Journal of Soil and Water Conservation*. 44 (6): 568-576.

Ongley, E. 1996. *Water Quality Monitoring-A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*.
http://www.who.int/docstore/water_sanitation_health/wqmonitor

Osborne, L.L. and M.J. Wiley. 1988. Empirical relationships between land use cover patterns and stream water quality in an agricultural watershed. *Journal of Environmental Management* 26:9-27.

Packman, James. 2001. Center for streamside studies. *Streamside Runoff*. Newsletter. Vol. 13. No.2.

Parry, R. 1998. Agricultural phosphorus and water quality: a U.S. Environmental Protection Agency perspective. *J. Environmental Quality*. 27:258-261.

Pickup, G. 1991. Event frequency and landscape stability on the floodplain systems of arid central Australia. *Quaternary Science Review*. 10, 463-473.

Reid, S.M., and Anderson, P.G., 1998. Suspended Sediment and Turbidity Criteria associated with Instream Construction Activity: Assessment of Biological Relevance,”. Golder Associates for Interstate Natural Gas Association of America. 1-109. *American Fisheries Society* vol. 113: 142-150

Rhoton, F.E., Meyer, L.D. and F.D. Whisler. 1982. A laboratory method for predicting the size distribution of sediment from surface soils. *Soil Science Society America Journal*. 46: 1259-1263.

Ribaudo, M. and P. Kuch. 1999. The Clean Water Action Plan: New directions or going in circles? *American Journal Agricultural Ecology* 81 (5): 1205-1209.

Rice, S., Greenwood, M. and C. Joyce. 2001. Tributaries, sediment sources, and the longitudinal organization of macroinvertebrate fauna along river systems. *Canadian Journal Fisheries Aquatics*. 58(4): 824-840.

Rickly Hydrological Company
<http://www.rickly.com/ss/singlestage.htm>

Riedel, Mark S., J.M. Vose and P.V. Bolstad. 2003. Characterizing hysteretic water quality in Southern Appalachian streams. *USDA Forest Service, Coweeta Hydrologic Laboratory*. 2-6.

- Rinella, Daniel., Prussian, A., Major, E. 2002. A pilot study using biomonitoring to determine effectiveness of forest road stream crossing best management practices. Alaska Department of Natural Resources. 1-22.
- Ryan, P. 1991. Environmental effects of sediment on New Zealand streams: a review. New Zealand Journal Freshwater Resources. 25: 207-221.
- Sabins Jr., F. 1997. Remote Sensing, Principles and Interpretation. 2nd edition., W.H. Freeman and Company, San Francisco CA.
- Schreiber J.D., R.A. Rebich, C.M. Cooper. 2001. Dynamics of diffuse pollution from US southern watersheds. Water Resorces. 35 (10): 2534-2542.
- Sharpley, A. and P. Withers. 1994. The environmentally-sound management of agricultural phosphorus. Fert. Res. 39 (2): 133-146.f
- Sidle, R.C. and J.W. Hornbeck, 1991. Cumulative effects: A broader approach to water quality research. J. Soil Water Conservation. 46: 268-271.
- Sigler, J.W., T.C. Bjornn, F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113: 142-150.
- Sims, J.T., A.C. Edwards, O.F. Schoumans, and R.R. Simard. 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. Journal of environmental quality. 29: 60-71.
- Skinner, John. 2000. Federal Interagency Sedimentation Project. A study of methods used in measurement and analysis of sediment load in reservoirs. 2-28.
- Stewart, J.C., A.T. Lemley, S.I. Hogan, R.A. Weimiller, and A.G. Hornsby. 2001. Water testing and interpretation: the secondary drinking water standards. University of Florida Extension, Institute of Food and Agricultural Sciences. Gainesville, FL.
- Stone, K.C., P.G. Hunt, S.W. Coffey, and T.A. Matheny. 1995. Water quality status of a USDA water quality demonstration project in the Eastern Coastal Plain. J. Soil and Water Cons. 50 (5): 567-572.
- Swank, W., Vose, J. and K. Elliot. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecology Management. 143: 163-178.
- Tate, K.W., R.A. Dahlgren, M.J. Singer, B. Allen-Diaz, and E.R. Atwill. 1999. Timing, frequency of sampling affects accuracy of water-quality monitoring. California. Agr. 53 (6): 44-48.

TDEC (Tennessee Department of Environment and Conservation). 2000. Water Quality 303 (D) report

www.state.tn.us/environment/wpc/

TDEC, 2005. General Water Quality Criteria

www.state.tn.us/environment/wpc/tmdl198.htm

TDEC. 2004. 305(B). Report The status of water quality in Tennessee.

<http://www.state.tn.us/environment/wpc/publications>

TDEC. 2004a. Permit Effluent Limitations and Standards.

<http://www.state.tn.us/environment/wpc/publications>

TDEC (Tennessee Department of Environment and Conservation). 2003. Water Quality 303 (D) report

www.state.tn.us/environment/wpc/

TDEC. 2001. Water pollution control fishing advisories, posted lakes and streams.

<http://www.state.tn.us/environment/wpc/advisory.htm>

TDEC. 1998a. Tennessee river assessment summary report.

<http://www.state.tn.us/environment/riv/how.htm>

TDEC. 1998b. Agreement between U.S. Environmental Protection Agency, region 4 and Tennessee Department of Environment Conservation Division of Water Pollution Control regarding the implementation of Section 303(d) of the Clean Water Act.

www.state.tn.us/environment/wpc/tmdl198.htm.

TVA (Tennessee Valley Authority). 2003. Blount County and Little River Basin Non-point Source Pollution Inventories and Pollutant Load Estimates. Little Tennessee Watershed Team.

Thomas, R.B., and J. Lewis. 1995. An evaluation of flow stratified sampling for estimating suspended sediment loads. *Journal of Hydrobiology*. 170:27-45.

Thomas, S.M., Neill, C., Deegan, L., Krusche, A.V., Ballester, V.M., and R.L. Victoria. 2003. Influences of land use and stream size on particulate and dissolved materials in a small Amazonian stream network. *Biogeochemistry* 68: 135-151.

Tong, Susanna and Wenli Chen. 2002. Modeling the relationship between land use and surface water quality. *Journal of environmental management*. 66: 377-393.

Triska, F.J., Sendell, J.R., Cromack K. Jr., Gregory S.V. and F.M. McCorison. 1984. Nitrogen budget for a small coniferous forest stream. *Ecological Monographs* 54: 119-140.

USDA. (United States Department of Agriculture). 1955. The Yearbook of Agriculture 84th Congress, 1st session, House Document No. 32.

USDA. (United States Department of Agriculture). 1969. Soil Conservation Service. Blount County Survey.

USEPA. 2005. EPA monitoring and assessing water quality.
www.epa.gov/owow/monitoring/monintr.html

USEPA. 2004. Atlas of America's polluted water's: EPA 840-B-00-002, Office of water, USEPA, Washington, DC.

USEPA. 2002a. The quality of our Nation's water.
<http://www.epa.gov/305b/sum1.html>

USEPA. 2002b. Current drinking water standards.
<http://www.epa.gov/safewater/mcl.html>

USEPA. 2002c. Protocol for developing nutrient TMDLs.
<http://www.epa.gov/owow/tmdl/nutrient/intro.html>

USEPA. 2002d. 1998 Section 303(d) list fact sheet for Tennessee.
http://oaspub.epa.gov/waters/state_rept.control?p_state=TN

USEPA. 2002e. Nutrients and water quality.
<http://www.epa.gov/owow/tmdl/nutrient/wat-qual.html>

USEPA. 2001a. BASINS, version 3 Fact Sheet.
<http://www.epa.gov/OST/BASINS>

USEPA. 2001b. 1998 Section 303(d) List Fact Sheet: Tennessee
<http://www.epa.gov/OWOW/tmdl/states/tnfact.html>

USEPA. 2001c. National Pollutant Discharge Elimination System Permit Program.
<http://cfpub.epa.gov/npdes/index.cfm>

USEPA. 2001d. Overview of current Total Maximum Daily Load-TMDL-Program and Regulations. EPA841-F-00-009.
<http://www.epa.gov/owow/tmdl/overviewfs.html>

USEPA. 2000a. Final TMDL Rule: fulfilling the goals of the Clean Water Act. EPA 841-F-00-008.

<http://www.epa.gov/owow/tmdl/finalrule/factsheet1.html>

USEPA. 2000b. Animal feeding operations-water quality impacts.
<http://www.epa.gov/r5water/npdestek/npdcafowaterqualimpacts.htm>

USEPA. 1999. Drinking water and health: what you need to know. EPA 816-K-99-001.
<http://www.epa.gov/safewater/dwhealth.html>

USEPA. 1998. Watershed Protection: a statewide approach. EPA841-R-95-004.
<http://www.epa.gov/OWOW/watershed/wacademy/its/statewid/chaptr1.htm>

USEPA. 1997. Pointer No. 8. Managing nonpoint source pollution from forestry.
<http://www.epa.gov/owow/nps/facts/point8.htm>

USFWS. 1993. U.S. Fish and wildlife service division of endangered species. April 27.
<http://www.fws.gov/endangered/i/e/sae32.html>

USFWS. 1993a. Endangered and threatened wildlife and plants; determination of the duskytail darter (*Etheostoma caeruleum*) to be an endangered species. Federal Register vol. 58 (79): 25758-25763.

USFWS. 2003. Endangered and threatened wildlife and plants. Finerayed pigtoe mussel. Statelisted vol. 68 (103): 32078-32080.

USGS, 2006. National Water Information System for retrieval of Alcoa Streamflow on 2006-02-26.
http://nwis.waterdata.usgs.gov/tn/nwis/discharge?site_no=03498850&agency_cd=USGS

USGS, 2000a. Sources, instream transport, and trends of nitrogen, phosphorus, and sediment in the Lower Tennessee River Basin, 1980-96.
<http://water.usgs.gov/pubs/wri/wri994139/text/abstract.html>.

USGS, 2000b. Comparison of water-quality samples collected by siphon samplers and automatic samplers in Wisconsin. USGS Fact Sheet FS-067-00.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Walling, D.E. 1983. The sediment delivery problem. Journal of Hydrology. 65: 209-237.

Walling, D.E. and P.W. Moorehead. 1989. The particle size characteristics of fluvial suspended sediment: An overview. Hydrobiologia. 176/177: 125-149.

Wohl, Ellen. 1998. Inheriting our past: river sediment sources and sediment hazards in Colorado. Colorado Water Resources Research Institute. No. 7.

Wolman, M.G. and A.P. Schick. 1967. Effects of construction on fluvial sediment: urban and suburban areas of Maryland. *Water Resources Research*. 6: 1312-1326.

Wood, P.J., and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21: 203-217.

Wong, K.M., Strecker, E.W., and M.K. Stenstrom. 1998. GIS to estimate storm-water pollutant mass loadings. *Journal of Environmental Engineering*. August:737-745.

Wotling, G. and C. Bouvier. 2002. Impact of urbanization on suspended sediment and organic matter fluxes from small catchments in Tahiti. *Hydrological Processes*. 16:1745-1756.

Yeager, K.M., Santschi, P.H., Phillips, J.D. and B.E. Herbert. 2005. Suspended sediment sources and tributary effects in the lower reaches of a coastal plain stream as indicated by radionuclides, Loco Bayou, Texas. *Environmental Geology* 47: 382-395.

Ziemer, R.R., J. Lewis, R.M. Rice, and T.E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. *Journal Environmental Quality* 20: 36-42.

Appendices

Tables

Table 1. Environmental and engineering issues associated with sediment transport in rivers (Ongley, 1996).

Sediment Size	Environmental Issues	Associated engineering issues
Silts and clays	Erosion, especially loss of topsoil in agricultural areas; gullyng	
	High sediment loads to reservoirs	Reservoir siltation
	Chemical transport of nutrients, metals, and chlorinated organic compounds	Drinking Water Supply
	Accumulation of contaminants in organisms at the bottom of the food chain	
	Silting of fish spawning beds and disturbance of habitats (by erosion or siltation)	
Sand	River bed and bank erosion	River channel deposition: navigation problems
	River bed and bank erosion	Sedimentation in reservoirs
	Habitat disturbance	
Gravel	Channel instability when dredged or aggregate	Instability of river channel leads to problems of navigation and flood control
	Habitat disturbance	

Table 2. Summary of characteristics for study streams.

Stream	303(d) status	Drainage Area (km ²)	Elevation Range (m)	Latitude	Longitude
Little River-6 (#17)	Unlisted	274	400-2000	N35°39.36	W83°42.36
Dry Branch (#16)	Unlisted	5	400-2000	N35°40.48	W83°45.00
Little River-5 (#14)	Unlisted	36	400-800	N35°40.48	W83°47.24
Carr Creek (#13)	Unlisted	17	400-800	N35°40.48	W83°47.23
Short Creek (#15)	Impaired	24	400-800	N35°40.48	W83°47.22
Little River-4 (#10)	Unlisted	10	400-800	N35°42.00	W83°48.00
Hesse Creek (#12)	Unlisted	66	400-600	N35°42.36	W83°49.12
Reed Creek (#11)	Unlisted	31	400-800	N35°43.48	W83°48.36
Ellejoy Creek (#9)	Impaired	98	300-600	N35°46.12	W83°51.00
Little River-3 (#8)	Unlisted	28	300-400	N35°46.12	W83°51.36
Crooked Creek (#7)	Impaired	60	300-400	N35°46.12	W83°52.48
Little River-2 (#6)	Unlisted	30	300-400	N35°48.00	W83°53.24
Nails Creek (#5)	Impaired	37	300-400	N35°48.36	W83°52.48
Little River-1 (#4)	Threatened	21	300-400	N35°49.12	W83°55.48
Brown Creek (#18)	Impaired	9	300-400	N35°45.00	W83°57.00
Pistol Creek-2 (#19)	Impaired	13	300-400	N35°47.24	W83°58.12
Culton Creek (#1)	Unlisted	31	300-400	N35°46.48	W84°00.00
Pistol Creek-1 (#2)	Impaired	21	300-400	N35°44.24	W83°55.48
Stock Creek (#3)	Impaired	44	300-400	N35°52.48	W83°54.00

Table 3. Geomean of total suspended solids and turbidity for Little River watershed sampling sites.

Sampling Sites	TSS (mg L ⁻¹)*	Turbidity NTU*
Little River-6 (#17)	13	6
Dry Branch (#16)	52	44
Little River-5 (#14)	10	7
Carr Creek (#13)	69	81
Short Creek (#15)	23	12
Little River-4 (#10)	9	6
Hesse Creek (#12)	22	19
Reed Creek (#11)	31	29
Ellejoy (#9)	89	41
Little River-3 (#8)	20	21
Crooked Creek (#7)	56	34
Little River-2 (#6)	41	31
Nails (#5)	826	173
Little River-1 (#4)	11	13
Brown Creek (#18)	133	64
Pistol Creek-2 (#19)	55	52
Culton Creek (#1)	172	138
Pistol Creek-1 (#2)	101	65
Stock Creek(#3)	56	34

*TSS and turbidity values are geomeans.

Table 4. Tests of normality determined by the Shapiro-Wilk test.

	Statistic	df	Sig.
TSS	.356	337	.000
Turbidity	.444	337	.000

Table 5. Descriptive statistics showing comparisons of TSS and turbidity for tributaries versus main channel sites in the Little River watershed.

Site		N Statistic	Min Statistic	Max Statistic	Mean Statistic	Std. Error
Tributaries	TSS	358	0	11108	241	45
	Turbidity	231	.05	2000	102	11
Main Channel	TSS	167	0	1574	66	17
	Turbidity	107	.25	290	30	5

Table 6. Percentiles depicting the weighted average of the sampling sites TSS and turbidity.

		5	10	25	50	75	90	95
Wtd.* Avg.	TSS	3	5	14	40	123	281	587
	Turbidity	1	3	11	42	82	206	255

*Weighted Average

Table 7. Non-parametric test for the mean TSS and turbidity concentration for all sites.

	N	Mean	Std. Dev.	Min	Max
Turbidity	338	80	148	.05	2000
TSS	525	186	731	0	11108
Site	551	.32	.465	0	1

Table 8. Test for statistical significance of TSS and turbidity determined by Mann-Whitney test.

	Turbidity	TSS
Mann-Whitney U	5648	16212
Wilcoxon W	11426	30240
Z	-8.032	-8.451
Asymp. Sig. (2-tailed)	.000	.000

a. Grouping Variable: Location

Table 9. Nonparametric one-way ANOVA shows that the sites located in the forested upper reaches of the Little River watershed TSS concentrations compared to the sites in the lower reaches did not increase moving from upstream to downstream.

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Among	1	21664	21664	0.4064	0.5247 NS
Within	159	8475089	53302		

NS-Not Significant

Table 10. Nonparametric one-way ANOVA shows that the tributaries TSS concentrations are more impacted by agriculture than by forest.

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Among	1	450224	450224	10.6248	0.0013***
Within	234	9915737	42375		

***Significant

Table 11. Nonparametric one-way ANOVA shows that the tributaries TSS concentrations are more impacted by agriculture than by urban.

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Among	1	13950856	13950856	10.8201	0.0012***
Within	186	239818133	1289344		

***Significant

Table 12. Land use percentages for combined sub-watersheds.

Comb. Sub-WS		U	Ag	R	F	B	W	P
Culton	Culton	45	36	6	11	0	2	0
Pistol 1, Culton, Pistol 2, Brown	Pistol 1	59	26	4	8	1	1	0
Stock	Stock	22	24	2	52	0	0	0
All- Culton, Pistol, Brown, Stock	LR 1	6	18	1	33	0	0	41
Nails	Nails	21	41	3	35	0	0	0
All- Culton, Pistol, Brown, Stock, LR 1, Nails	LR 2	5	15	0	33	0	1	45
Crooked	Crooked	18	35	1	45	0	1	0
LR3, LR4, LR5, LR6, Reed, Dry Branch, Short, Hesse	LR3	2	5	0	29	0	0	64
Ellejoy	Ellejoy	6	41	1	50	0	1	0
LR4, LR5, LR6, Reed, Dry Branch, Short	LR4	1	4	0	21	0	0	74
Reed	Reed	1	6	0	93	0	0	0
Hesse	Hesse	2	6	0	39	0	0	54
Carr	Carr	2	8	0	90	0	0	0

U-Urban Ag-Agriculture R-Range F-Forest W-Water B-Barren P-Park

Table 12. Continued

		U	Ag	R	F	B	W	P
Comb. Sub-WS								
LR5, LR6, Dry Branch	LR5	1	2	0	8	0	0	88
Short	Short	6	17	0	72	0	1	4
Dry Branch	Dry Branch	3	17	0	69	0	0	10
LR6	LR6	0	0	0	0	0	0	100
Brown	Brown	43	29	4	14	9	1	0
Pistol 2	Pistol 2	63	26	3	7	0	0	0
U-Urban Ag-Agriculture R-Range F-Forest B-Barren Wt-Wetland P-Park								

Table 13. Imperviousness and dominant land use

Combined Sub-WS		Impervious	Land Use	Impervious	TSS mg l ⁻¹
Culton	Culton	15.93	Urban	High	172
Pistol 1, Culton, Pistol 2, Stock	Pistol 1	22.62	Urban	High	101
	Stock	7.08	Mixed	Medium	56
All-Culton, Pistol, Brown, Nails	LR 1	2.18		Low	11
	Nails	6.52	Ag	Medium	
All-Culton, Pistol, Brown, Crooked	LR 2	1.88		Low	41
	Crooked	5.14	Ag	Medium	56
LR3, LR4, LR5, LR6, Reed, Dry Ellejoy	LR3	0.86		Low	20
	Ellejoy	2.63	Ag	Low	89
LR4, LR5, LR6, Reed, Dry Reed	LR4	0.66		Low	9
	Reed	1.38	Forest	Low	31
Hesse	Hesse	0.82	Forest	Low	22
Carr	Carr	1.81	Forest	Low	69
LR5, LR6, Dry Branch Short	LR5	0.40		Low	10
	Short	2.89	Forest	Low	23

Table 13. Continued

Combined Sub-WS		Impervious	Land Use	Impervious	TSS mg L ⁻¹
Dry Branch	Dry Branch	1.74	Forest	Low	52
LR6	LR6	0.00	Park	Low	13
Brown	Brown	12.34	Urban	High	133
Pistol 2	Pistol 2	18.09	Urban	High	55

Table 14. Pearson correlations that show the relationship between TSS and Turbidity from the data collected over the sampling period is highly significant.

		TSS	Turbidity
TSS	Pearson Correlation	1	.876**
	Sig. (2-tailed)		.000
	N	525	337

** . Correlation is significant at the 0.01 level (2-tailed).

Figures

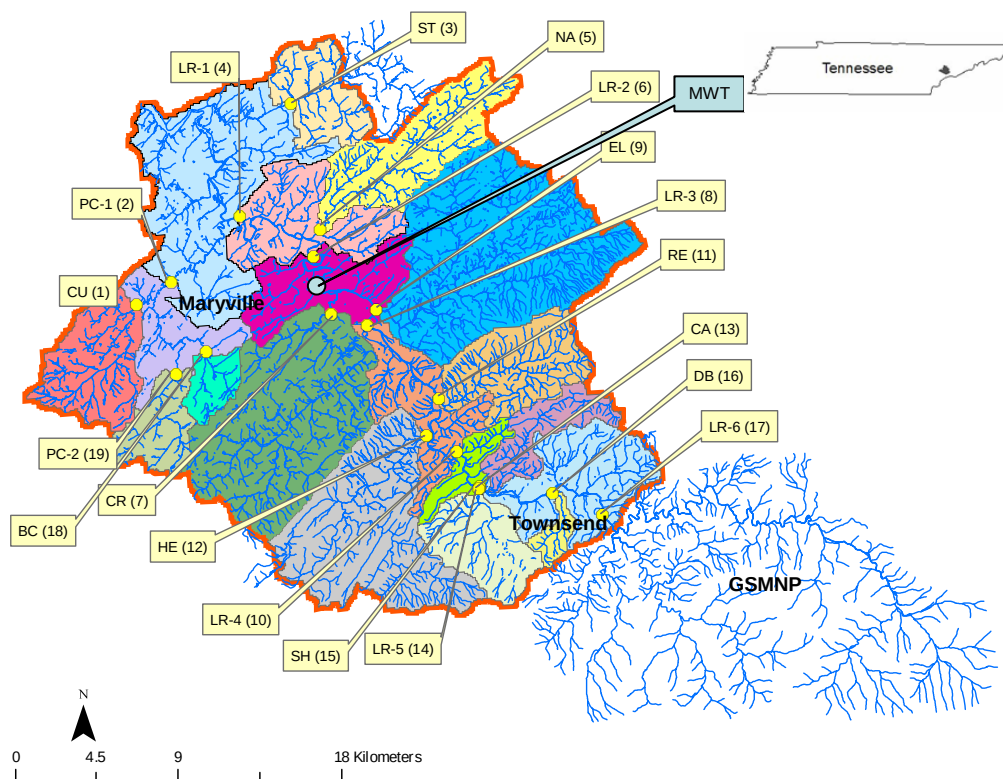
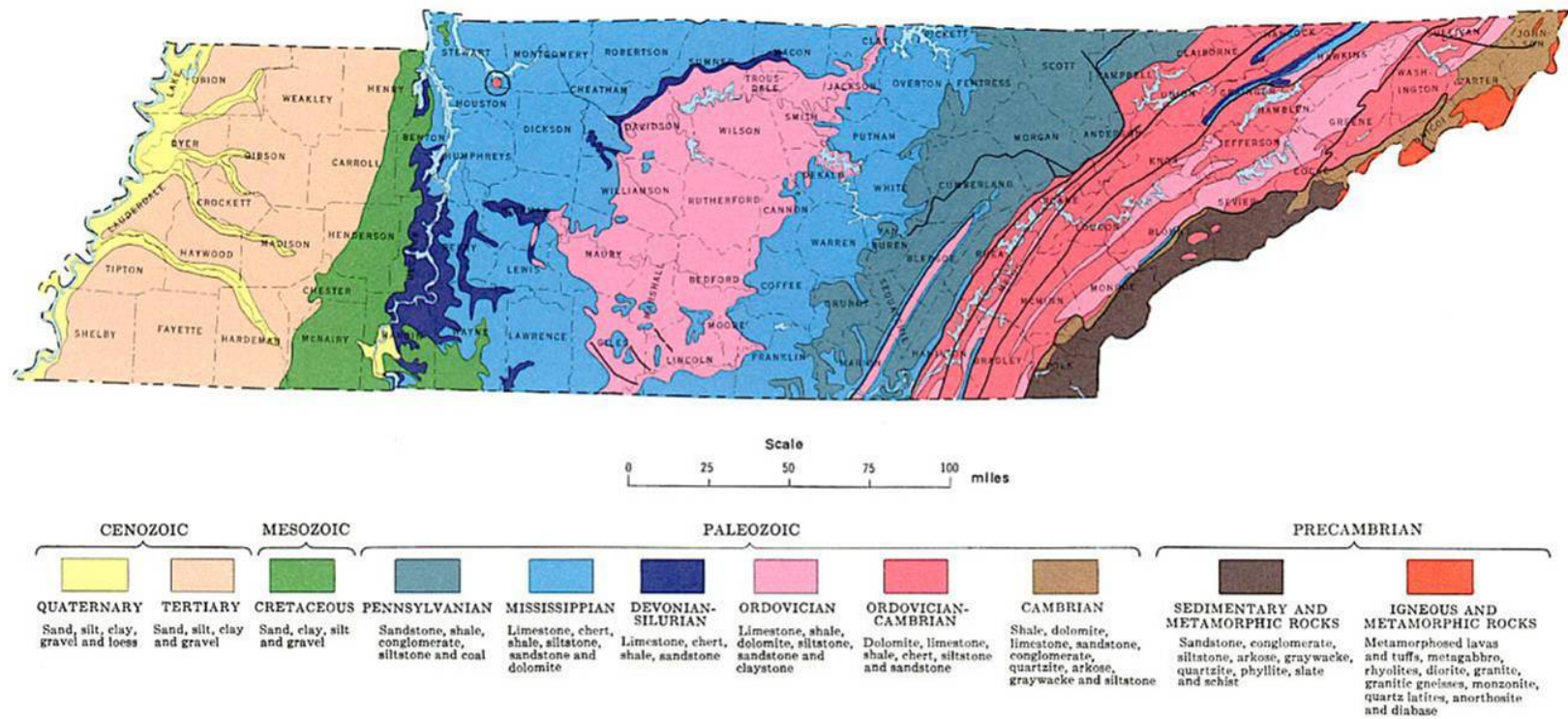


Figure 1. Little River watershed, Maryville Water Treatment Plant, tributaries and sampling sites in the 2003-2004 sediment study.



GENERALIZED GEOLOGIC MAP OF TENNESSEE

Figure 2. Generalized geologic map of Tennessee (USGS, 2005).

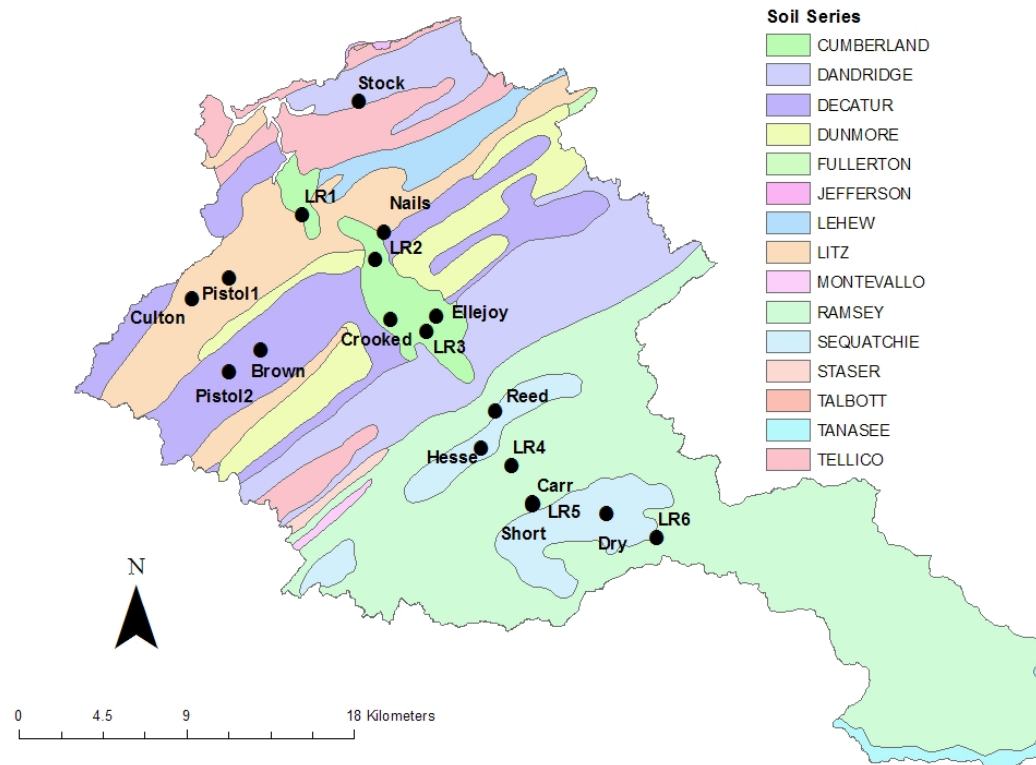


Figure 3. Soil Series (based on Tennessee STATSGO data) in Little River watershed. The section missing from the lower right corner of the map are soils from the Ramsey soil series (USDA, 1959).

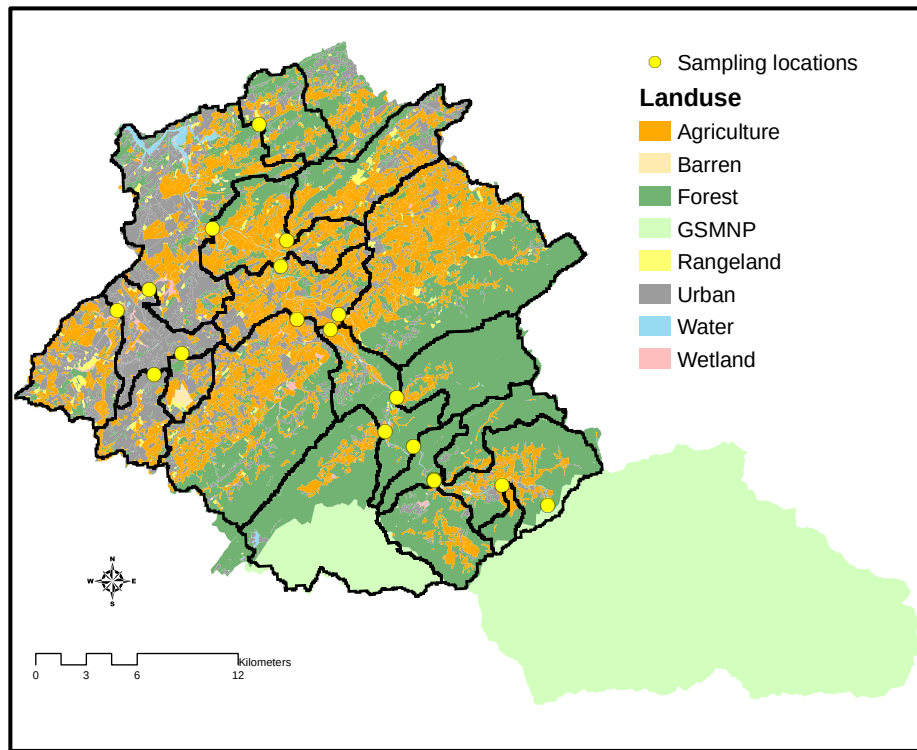


Figure 4. Land use in Little River watershed.

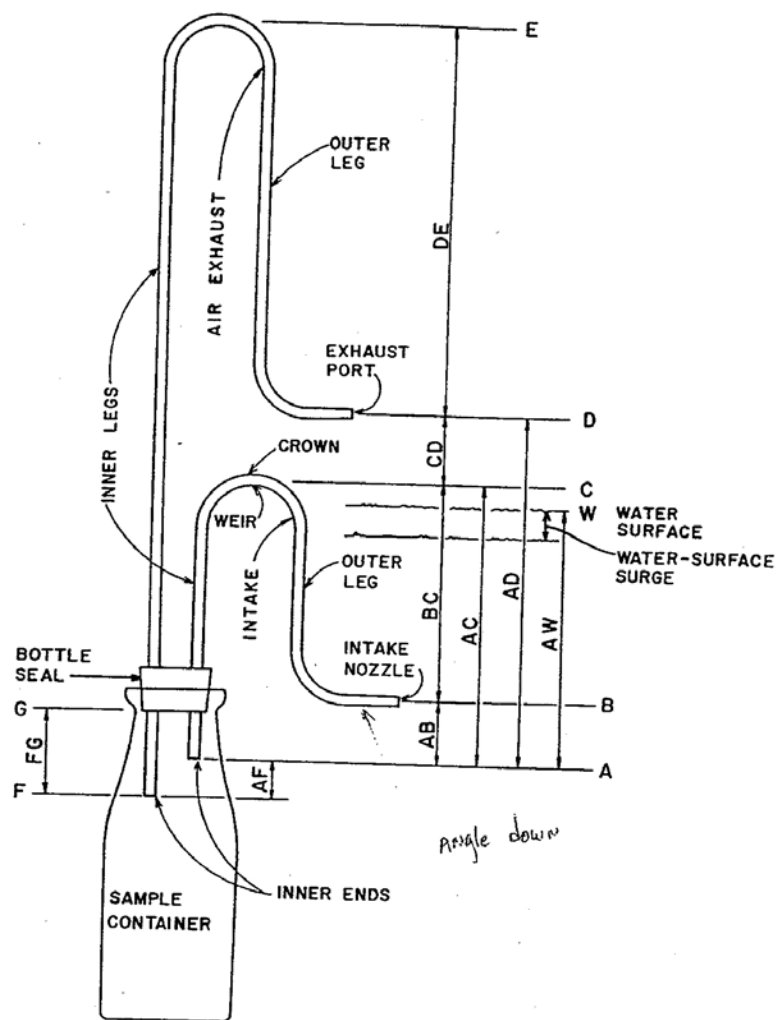


Figure 5. Diagram of single stage sampler similar to one used in this study (Adapted from (IACWR, 1961).



Figure 6. Retrofitted bottle attached to the sampler

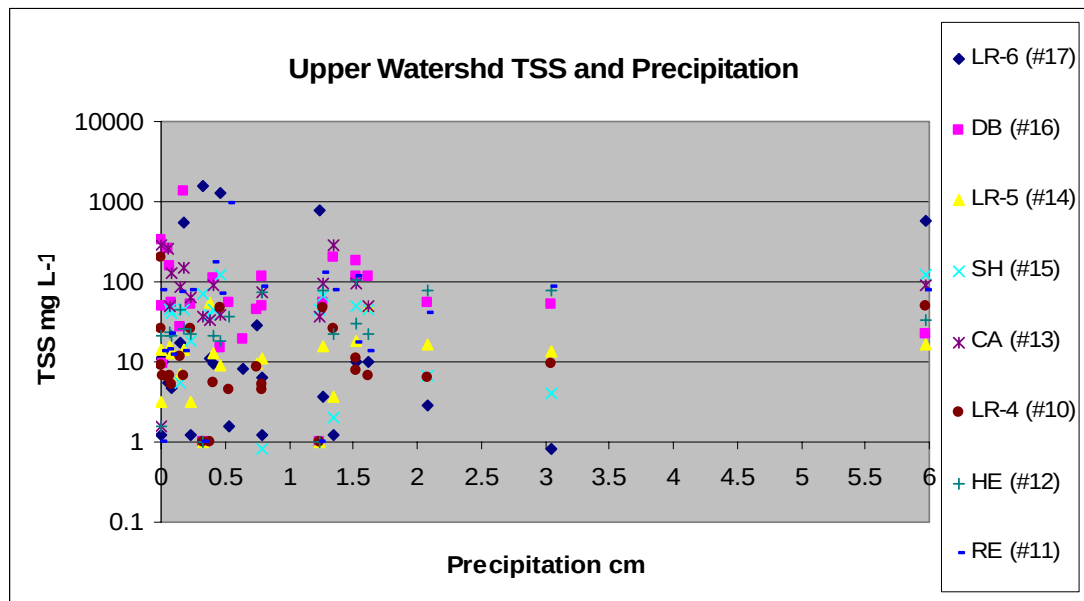


Figure 7. Sampling locations in the upper watershed study area showing TSS concentrations in relation to precipitation using rainfall data from Townsend.

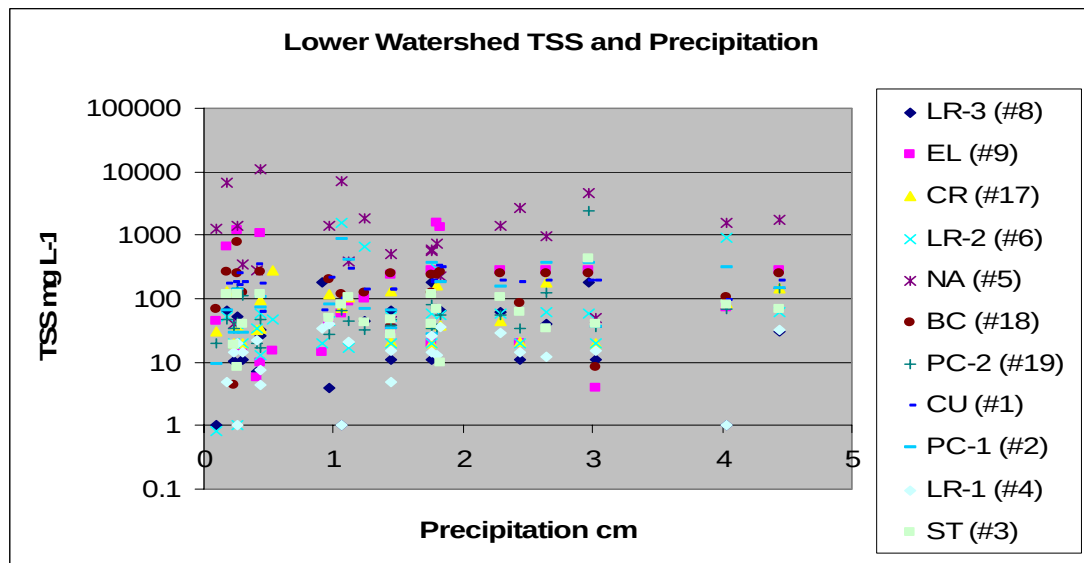


Figure 8. Sampling locations in the lower watershed study area showing TSS concentrations in relation to precipitation using rainfall data from McGhee Tyson airport.

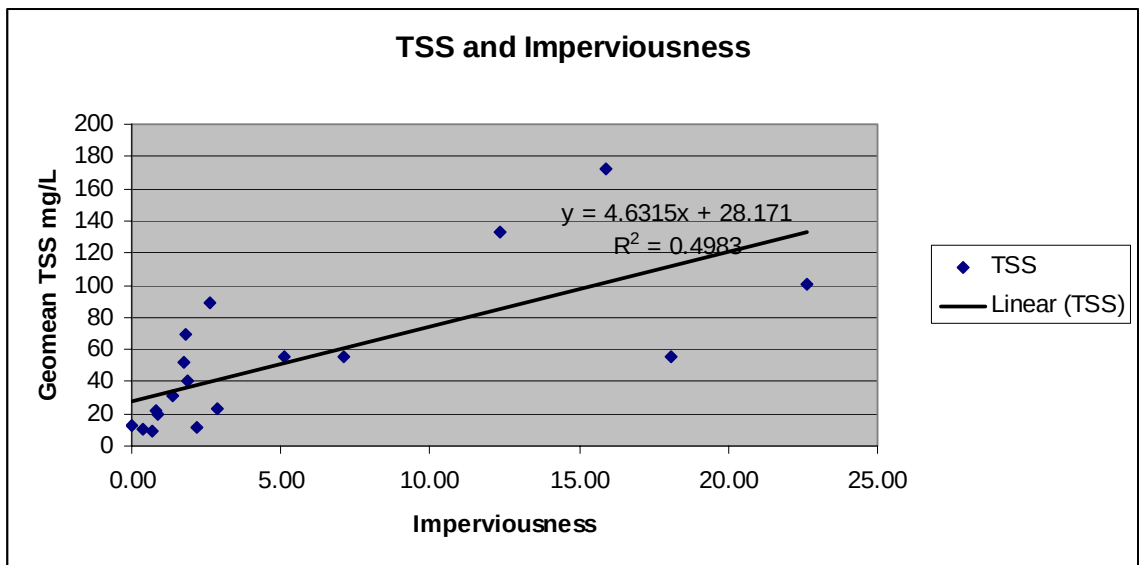


Figure 9. Correlation between geomean TSS concentration and imperviousness.

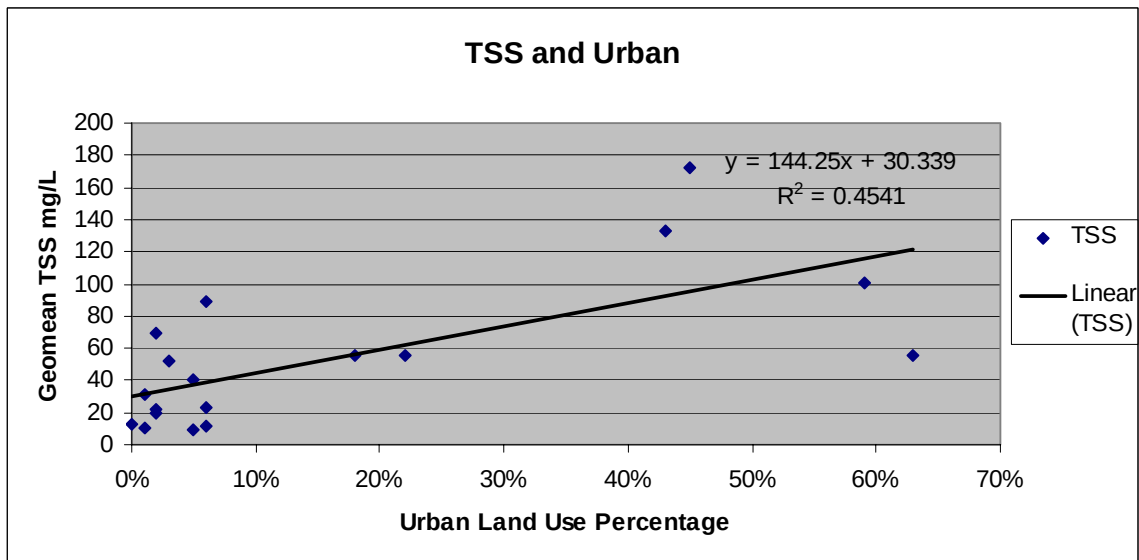


Figure 10. Correlation between geomean TSS concentration and urban.

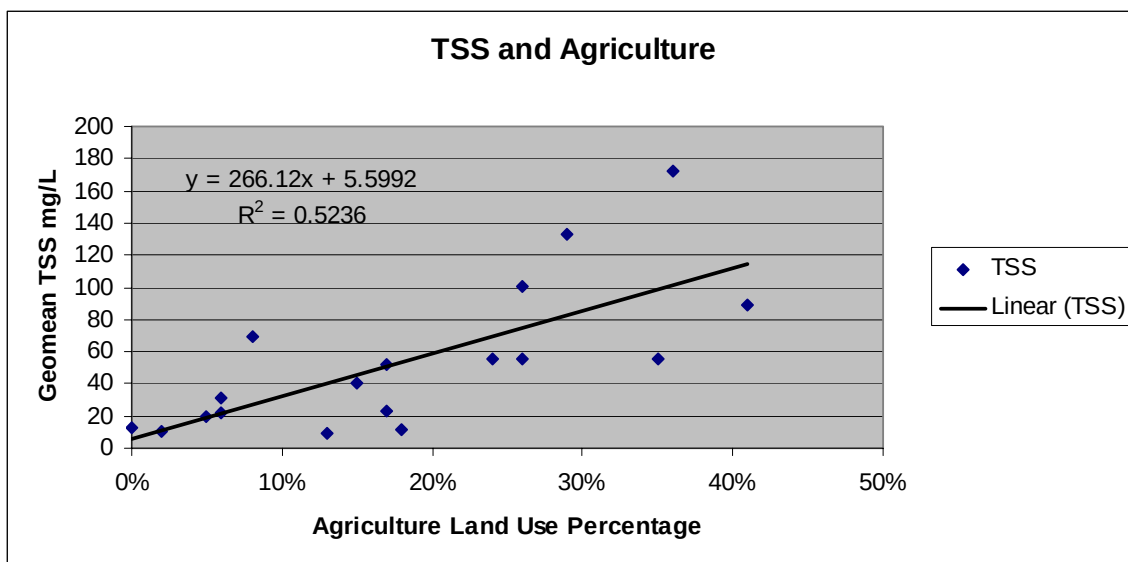


Figure 11. Correlation between geomean TSS concentration and agriculture.

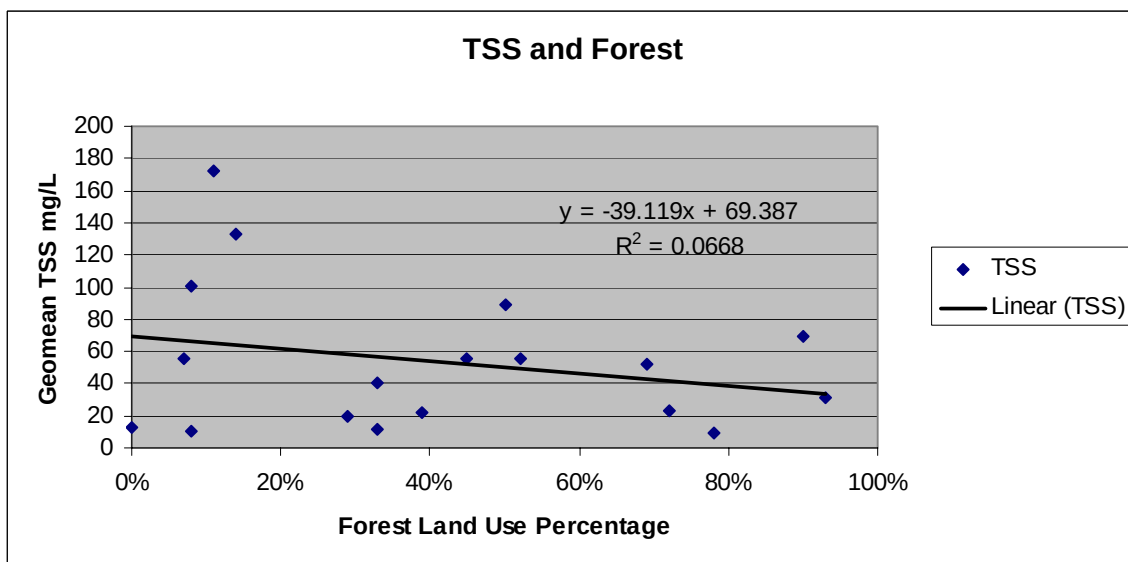


Figure 12. Correlation between geomean TSS concentration and forest.

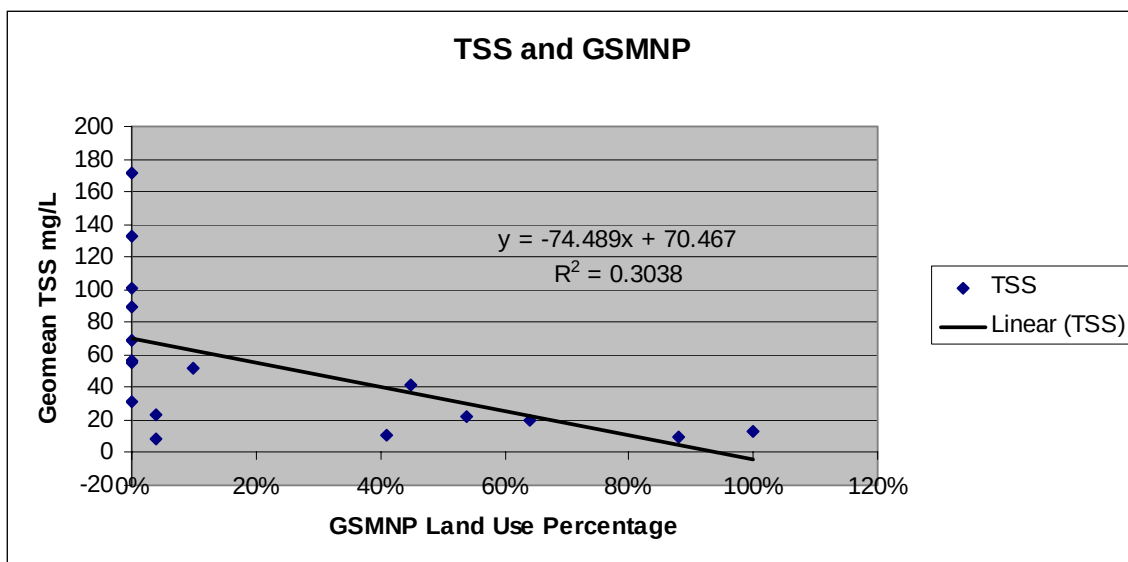
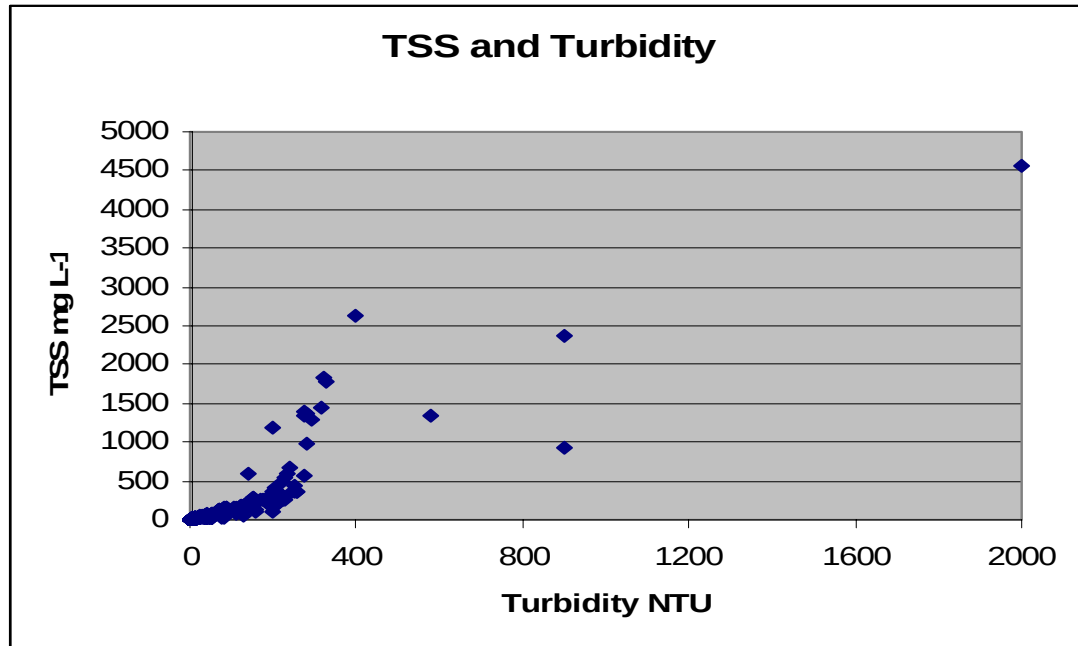


Figure 13. Correlation between geomean TSS concentration and GSMNP.



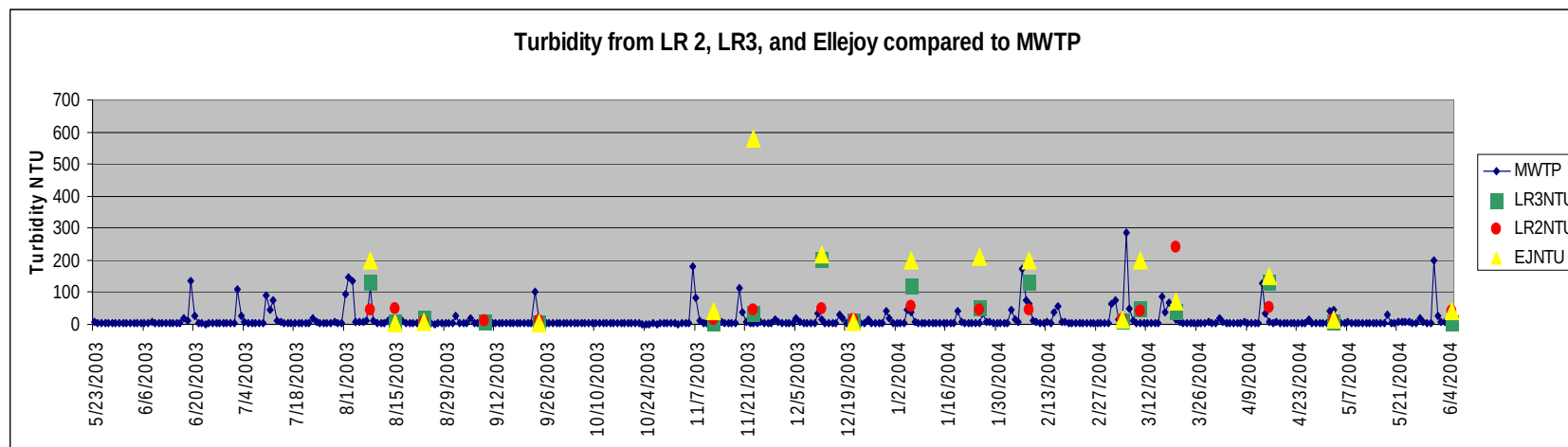


Figure 15. Comparisons of turbidity from Little River-2, Little River-3, and Ellejy with Maryville Water Treatment Plant.

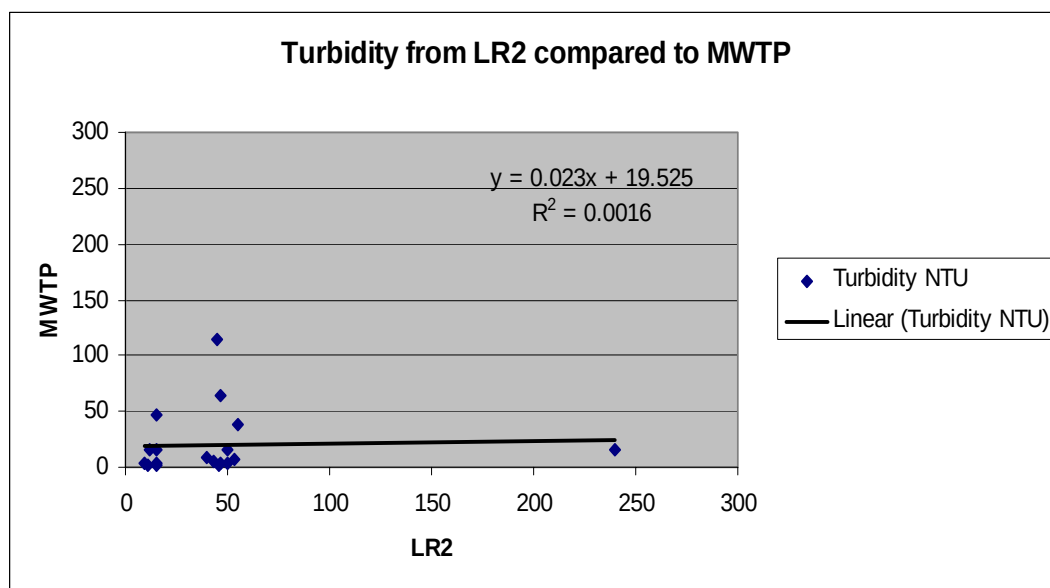


Figure 16. Turbidity from Little River-2 compared to Maryville Water Treatment Plant.

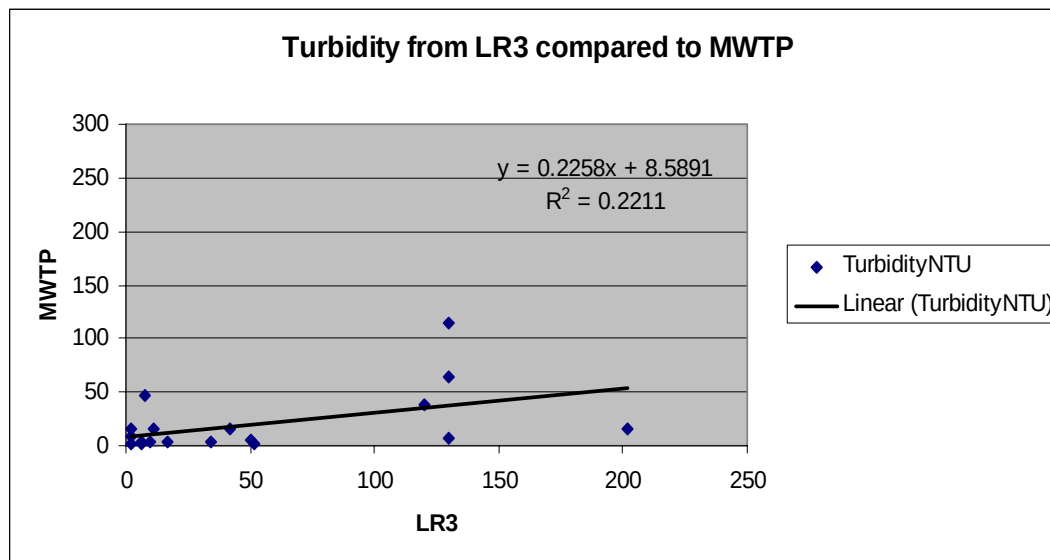


Figure 17. Turbidity from Little River-3 compared to Maryville Water Treatment Plant.

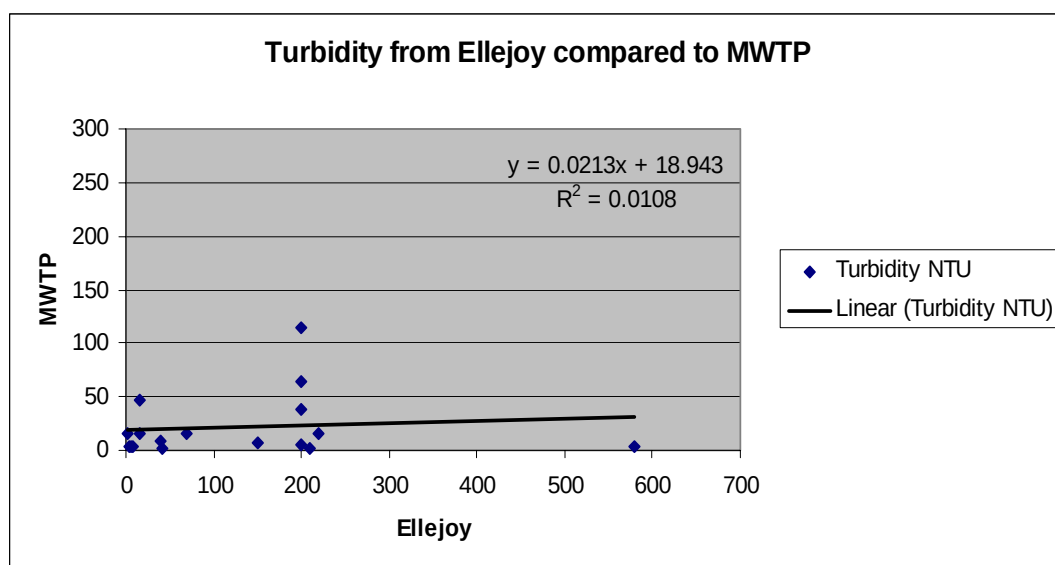


Figure 18. Turbidity from Ellejoy compared to Maryville Water Treatment Plant.

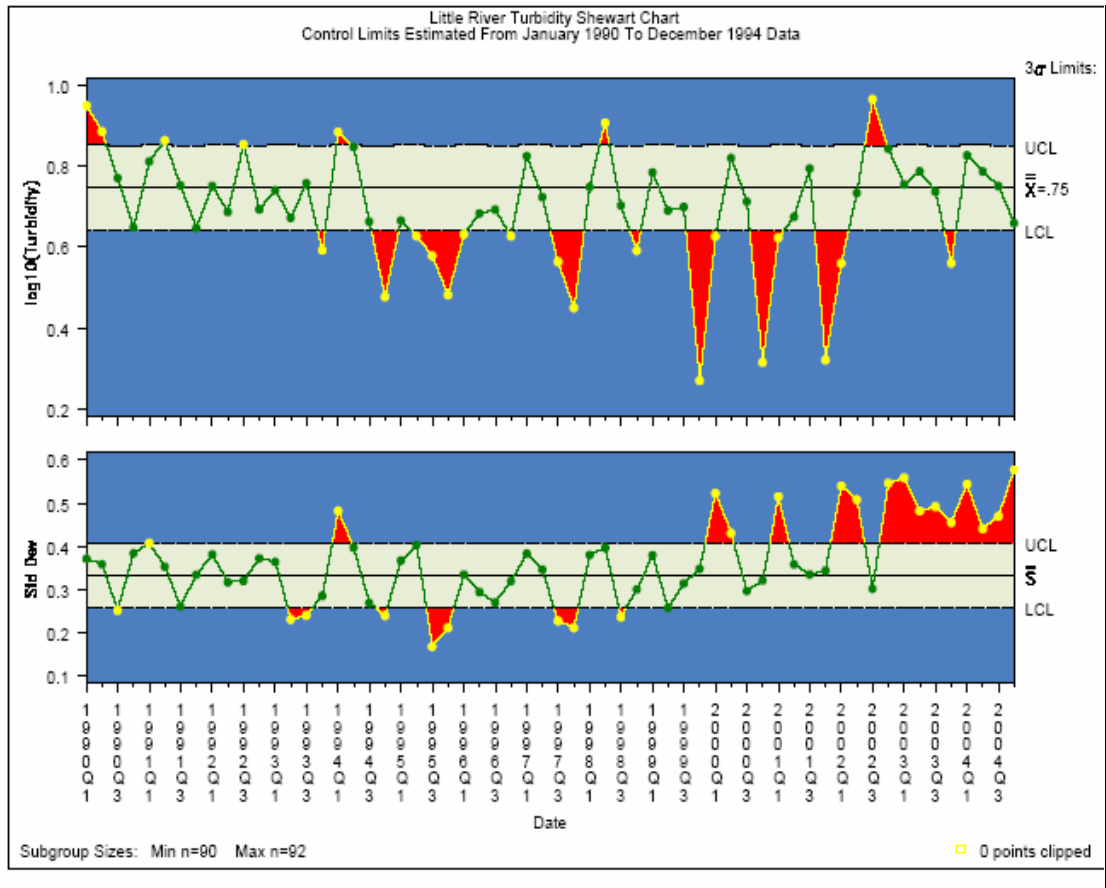


Figure 19. Maryville Water Treatment Plant turbidity data from 1990-2004 depicting seasonal data (Quarter 1:January, February, March Quarter 2:April, May, June Quarter 3: July, August, September Quarter 4:October, November, December).

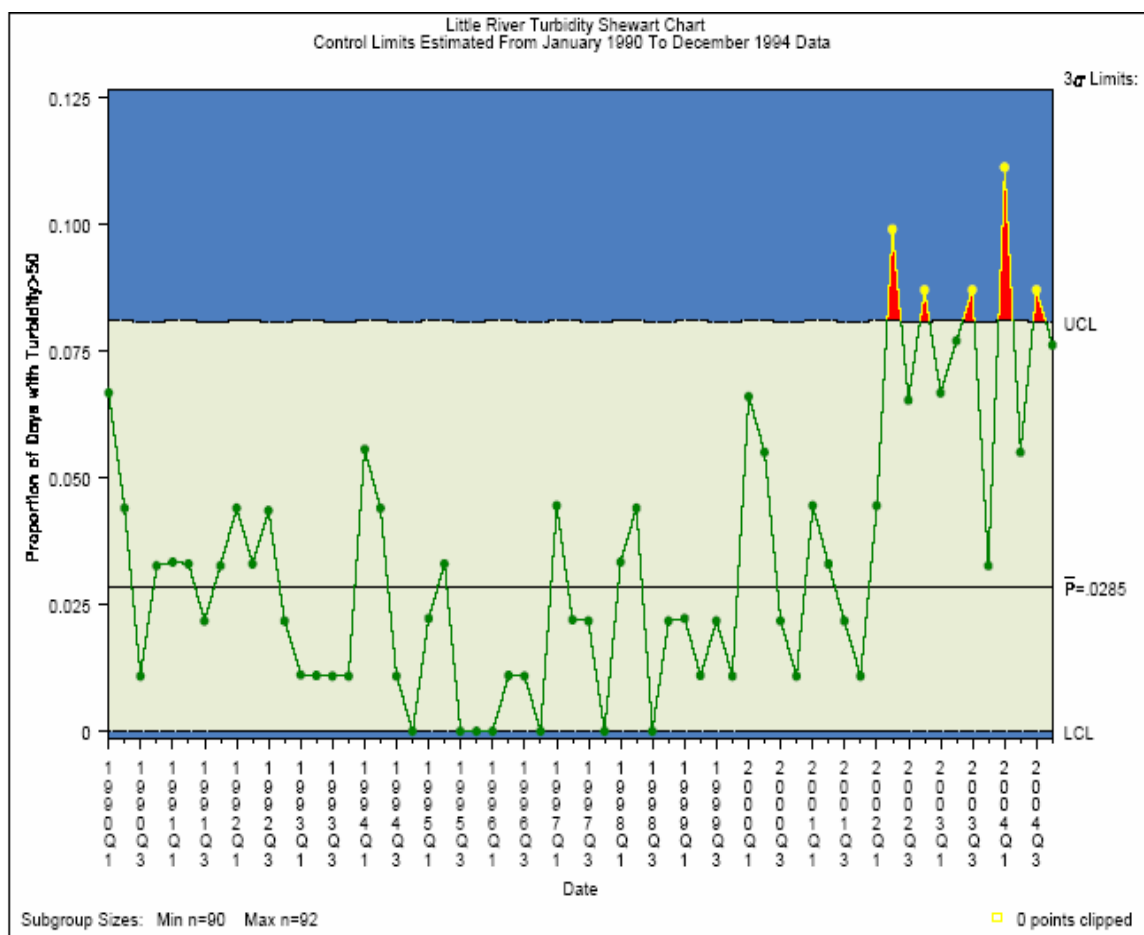


Figure 20. Maryville Water Treatment Plant turbidity data reflecting the proportion of days in each quarter that are greater than 50 NTU for years 1990-2004.

Appendix Tables

Table A1. Little River watershed sites that had concentrations of TSS>50 mg L⁻¹

Sampling Date	Carr (13)	Ellejoy (9)	Nails (5)	Brown (18)	Culton (1)	Pistol Creek-1(2)
5/27/2003	*	44	1263	70	*	9
5/30/2003	*	15	*	*	*	*
6/11/2003	32	14	*	*	64	*
6/19/2003	*	*	*	760	159	*
7/5/2003	36	60	7173	118	99	882
7/11/2003	38	74	1553	108	96	312
7/18/2003	290	1075	11108	265	176	105
7/25/2003	*	88	394	*	292	400
8/4/2003	*	1554	746	241	333	*
8/8/2003	*	282	4574	247	192	361
8/15/2003	253	6	282	*	355	*
8/23/2003	2	10	*	*	62	72
8/29/2003	290	675	6620	265	176	65
9/9/2003	*	*	40	4	178	28
9/24/2003	50	4	48	8	186	36
11/12/2003	94	32	44	36	138	34
11/23/2003	89	1341	220	257	315	176
12/12/2003	74	280	574	243	188	357
12/21/2003	50	16	353	124	178	28
1/6/2004	96	284	974	249	194	363
1/25/2004	62	235	498	246	136	65
2/8/2004	*	284	1775	249	194	142
3/5/2004	89	20	596	124	177	28
3/10/2004	38	1180	1432	252	246	136
3/20/2004	128	100	1840	124	137	67
4/15/2004	*	281	1372	245	190	157
5/3/2004	153	20	2638	84	178	*
6/5/2004	88	44	1404	198	214	81
Geomean	69	89	826	133	172	101

Table A1. Continued

Sampling Dates	Pistol Creek-2 (19)	Dry Branch (16)	Crooked Creek (7)	Stock Creek (3)
5/27/2003	20	49	30.4	*
5/30/2003	*	19	278	*
6/11/2003	*	*	*	*
6/19/2003	145	178	*	116
7/5/2003	64	1	73	80
7/11/2003	69	1	85	79
7/18/2003	46	336	94	120
7/25/2003	44	46	108	107
8/4/2003	34	115	158	70
8/8/2003	2365	54	*	427
8/15/2003	20	263	32	*
8/23/2003	17	*	33	*
8/29/2003	46	204	134	120
9/9/2003	34	9	20	18
9/24/2003	36	159	20	40
11/12/2003	38	119	21	48
11/23/2003	56	22	39	10
12/12/2003	81	50	40	115
12/21/2003	114	115	20	40
1/6/2004	125	56	184	34
1/25/2004	46	51	134	28
2/8/2004	146	54	144	69
3/5/2004	33	112	20	39
3/10/2004	43	15	38	8
3/20/2004	33	55	*	41
4/15/2004	56	52	44	106
5/3/2004	34	1348	21	60
6/5/2004	28	28	120	48
Geomean	55	52	56	56

*Sample not collected due to low stage.

Table A2. Little River watershed sites TSS concentrations <50 mg L⁻¹ compared to other sites.

Sampling Date	Little River-6 (#17)	Short Creek (#15)	Little River-5 (#14)	Hesse Creek (#12)	Reed Creek (#11)
5/27/2003	*	*	*	2	1
5/30/2003	8	*	*	*	*
6/11/2003	11	39	54	*	*
6/19/2003	*	*	*	104	115
7/5/2003	1574	71	1	1	1
7/11/2003	765	46	1	1	1
7/18/2003	1	*	3	22	76
7/25/2003	29	*	10	*	*
8/4/2003	6	*	*	*	*
8/8/2003	2	*	*	37	928
8/15/2003	6	*	*	*	14
8/23/2003	11	*	14	*	*
8/29/2003	1	2	4	22	76
9/9/2003	10	*	*	*	13
9/24/2003	14	46	16	24	22
11/12/2003	10	50	18	30	17
11/23/2003	586	122	17	33	76
12/12/2003	1	0.8	11	73	84
12/21/2003	10	46	50	22	13
1/6/2004	4	68	16	79	130
1/25/2004	1	18	3.2	22	76
2/8/2004	3	7	17	79	40
3/5/2004	10	45	13	21	172
3/10/2004	1297	121	9	18	69
3/20/2004	5	40	13	20	12
4/15/2004	0.8	4	14	76	88
5/3/2004	541	46	14	26	14
6/5/2004	18	6	7	44	74
Geomean	13	23	10	22	31

*Sample not collected due to low stage

Table A2. Continued

Sampling Dates	Little River-4 (#10) TSS mg/L	Little River-3 (#8) TSS mg/L	Little River-2 (#6) TSS mg/L	Little River-1 (#4) TSS mg/L
5/27/2003	206	1	0.8	*
5/30/2003	*	*	48	*
6/11/2003	1	181	20	34
6/19/2003	8	*	1	1
7/5/2003	1	1	1544	1
7/11/2003	1	1	900	1
7/18/2003	26	26	57	4.4
7/25/2003	9	*	16	21
8/4/2003	5	*	291	13
8/8/2003	4	182	59	*
8/15/2003	6	7.2	35	22
8/23/2003	9	32	13	8
8/29/2003	25.6	66	53	5
9/9/2003	6	11	20	14
9/24/2003	7	11	20	15
11/12/2003	11	11	20	15
11/23/2003	50	64	54	36
12/12/2003	4	178	59	26
12/21/2003	7	11	20	14
1/6/2004	46	39	61	12
1/25/2004	26	66	53	5
2/8/2004	6	31	60	32
3/5/2004	6	11	20	14
3/10/2004	47	54	40	20
3/20/2004	5	44	660	*
4/15/2004	10	60	57	29
5/3/2004	7	11	20	14
6/5/2004	12	4	44	40
Geomean	9	20	41	11

Table A3. Descriptive statistics showing the minimum, maximum, mean and standard error for TSS and turbidity concentrations for each site.

Site		N	Min	Max	Mean	Std.
		Stat	Stat	Stat	Stat	Stat
LR-6 (17)	TSS	29	0	1574	166	405
	Turbidity	18	.50	290	41	86
	Valid N (listwise)	18				
Dry Branch (16)	TSS	28	0	1348	122	255
	Turbidity	17	1.2	272	68	63
	Valid N (listwise)	17				
Short Creek (15)	TSS	27	0	122	29	38
	Turbidity	18	.50	75	28	25
	Valid N (listwise)	18				

Table A3. Continued

Site		N	Min	Max	Mean	Std.
		Stat	Stat	Stat	Stat	Stat
Little River-5 (14)	TSS	27	0	54	6	23
	Turbidity	18	.25	45	10	9
	Valid N (listwise)	18				
Carr Creek (13)	TSS	26	0	358	105	112
	Turbidity	18	2	210	111	66
	Valid N (listwise)	17				
Little River-4 (10)	TSS	28	0	206	14	44
	Turbidity	18	1	48	12	15
	Valid N (listwise)	18				
Hesse Creek (12)	TSS	28	0	104	18	31
	Turbidity	18	.45	82	33	26
	Valid N (listwise)	18				
Reed Creek (11)	TSS	28	0	928	72	176
	Turbidity	18	.05	900	97	206
	Valid N (listwise)	18				

Table A3. Continued

Site		N	Min	Max	Mean	Std.
		Stat	Stat	Stat	Stat	Stat
Little River-3 (8)	TSS	28	0	184	47	70
	Turbidity	18	2	202	53	61
	Valid N (listwise)	18				
Ellejoy (9)	TSS	29	0	1554	274	444
	Turbidity	18	2	580	120	145
	Valid N (listwise)	18				
Crooked Creek (7)	TSS	28	0	765	95	148
	Turbidity	17	15	125	44	33
	Valid N (listwise)	17				
Little River-2 (6)	TSS	29	0	1544	143	336
	Turbidity	18	9	240	45	52
	Valid N (listwise)	18				
Nails (5)	TSS	28	0	11108	1696	2620
	Turbidity	18	8	2000	312	437
	Valid N (listwise)	18				

Table A3. continued

Site		N	Min	Max	Mean	Std.
		Stat	Stat	Stat	Stat	Stat
Little River-1 (4)	TSS	26	0	59	9	31
	Turbidity	17	.50	50	19	14
	Valid N (listwise)	17				
Brown Creek (18)	TSS	28	0	760	161	158
	Turbidity	18	3	230	120	87
	Valid N (listwise)	18				
Pistol Creek-2 (19)	TSS	28	10	2365	136	438
	Turbidity	18	11	900	100	202
	Valid N (listwise)					
Culton Creek (1)	TSS	27	24	355	181	79
	Turbidity	18	32	220	151	55
	Valid N (listwise)	18				
Pistol Creek-1 (2)	TSS	27	0	882	145	197
	Turbidity	17	12	260	96	87
	Valid N (listwise)	17				
Stock Creek (3)	TSS	26	0	427	67	87
	Turbidity	18	6	250	51	55
	Valid N (listwise)	18				

Appendix Figures

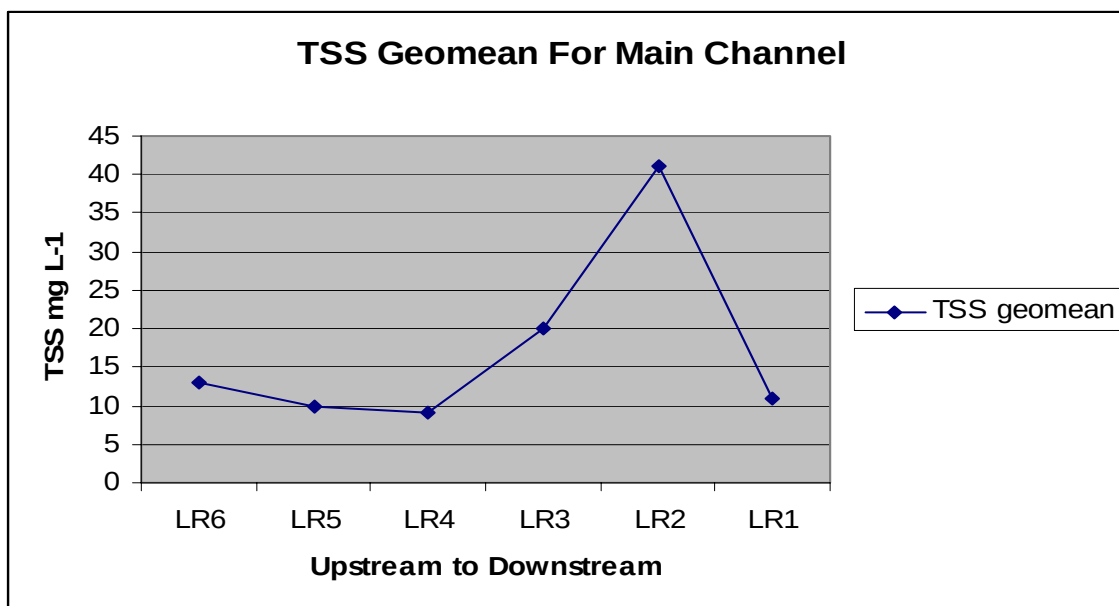


Figure A1. TSS geomean for Little River main channel sites from Little River-6 upstream to downstream Little River-1.

Vita

Heather Melanie Hart was born in Knoxville, Tennessee in 1973. She received her Bachelors of Science degree in Plant and Soil Science at the University of Tennessee, Knoxville. She received her Masters of Science degree in Environmental and Soil Science August of 2006. She has plans to continue investigating soil and water quality. Her plans include working with other organizations to help monitor impaired streams and educate the public about the quality of streams in their area.