HYDROLOGY, WATER QUALITY, AND CHANNEL MORPHOLOGY ACROSS AN URBAN-RURAL LAND USE GRADIENT IN THE GEORGIA PIEDMONT, USA

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HYDROLOGY, WATER QUALITY, AND CHANNEL MORPHOLOGY ACROSS AN URBAN-RURAL LAND USE GRADIENT IN THE GEORGIA PIEDMONT, USA

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DISSERTATION ABSTRACT

HYDROLOGY, WATER QUALITY, AND CHANNEL MORPHOLOGY ACROSS AN URBAN-RURAL LAND USE GRADIENT IN THE GEORGIA PIEDMONT, USA

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The southeastern United States is experiencing rapid urban development. Consequently, Georgia's streams have been threatened by hydrologic alteration, nutrient and bacteriological impairment, and channel morphometry changes from extensive development and from other land use activities such as livestock grazing and silvicultural practices. A study was performed to assess the above activities across an urban to rural land use gradient within 24 west Georgia watersheds ranging in size from 500-2500 ha that were drained by 1st, 2nd, and 3rd order streams. Dominant land covers in the study watersheds included: urban, developing, pasture, managed forest, and unmanaged forest.

Stream hydrology was continuously monitored in 18 watersheds from 29 July 2003 to 23 September 2004 using InSitu pressure transducers. Dependent variables were estimated from the discharge data and placed into four categories, including flow frequency (i.e., the number of times a predetermined discharge threshold is exceeded), flow magnitude (i.e., maximum and minimum flows), flow duration (i.e., the amount of time discharge was above or below a predetermined threshold), and flow predictability and flashiness. Fine resolution data (i.e., 15-min interval) was also compared to daily discharge data to determine if resolution affected how streams were classified hydrologically. Urban watersheds experienced flashy discharges during storm events, whereas pastoral and forested watersheds showed more stable hydrographs. Flow frequency variables were most tightly correlated to land cover. Further, stream hydrology response variables were explained similarly with both the 15-minute and daily data resolutions.

A two-phase study approach was used to investigate differences in stream water nutrient and bacteriological loading across the land use gradient. During phase 1, nutrient and biological data were collected within 18 watersheds, and data were used to generate regression models between land cover and the nutrient/biological parameters. Results from the phase 1 suggested nutrient and fecal coliform concentrations within watersheds having >5% impervious surface often exceeded those levels in nonurban watersheds during both base flow and storm flow. During phase 2 of the study, regression models were tested based on data from 6 new watersheds with representative land use/cover patterns for the area.

To assess sediment movement and channel morphometry, 18 study watersheds were monitored. Biweekly grab samples and stacked-pole samplers were used to determine instream concentrations of total suspended solids (TSS) and total dissolved solids (TDS) during both base flow and storm flow. Multiple headwater cross-sections and sediment grids were measured routinely and following storm events to assess streambed stability. Higher TSS loads were present in nonurban watersheds during baseflow conditions. However, during stormflow, TSS loads dramatically increased within watersheds having >5% impervious surface cover and watersheds with intensive silviculture. Stream cross-sections and grids suggest that urban and pastoral streams had unstable stream channels, where fill and scour were common.

To further explore sediment movement within study watersheds, sediment source tracking techniques were performed in 8 of the west Georgia streams. Fe in TSS samples from 2 flooding regimes was used to track sediment origin. Artificial flooding was used to develop a signature of Fe concentrations for in channel sources of sediment, and natural flooding was characterized and compared to in channel signatures. Urban and unmanaged forest streams received sediment inputs from terrestrial sources, whereas developing, pasture, and managed forests were dominated by instream sources of sediment.

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CHAPTER 1

1.1 INTRODUCTION

Urbanization is an invasive, rapidly expanding land use pattern in the United States. Much of the U.S. has rapidly undergone conversion of forested land to urban and/or residential uses (Figure 1) (USDA, NRCS 2004). The southeastern U.S. has been particularly vulnerable to land conversion, with Texas, Georgia, and Florida leading the U.S. in land development between 1982 and 1997 (USDA, NRCS 2004). With population growth rates continuing to increase (US Census Bureau 2005), the relationships among the growing human population, urban sprawl, and forest and agricultural land conversion will likely continue. Demographic trends also suggest that humans have an increasing tendency to cluster into urban areas (United Nations 2002), which can result in increased stress on the environment due to increased impervious surfaces and associated pollutants. Consequently, population growth has increased pressures on an already diminishing natural resource.

As a result of land use conversion, urban sprawl also threatens water resources. In 1998, the USEPA's water quality report to Congress indicated that 291,000 miles of rivers and streams did not meet water quality standards (USEPA 2000). They also reported that 12% of the ocean's assessed shorelines were considered polluted. Pollutant sources were primarily from urban runoff, storm sewers, and land disposal of waste, which cause increased bacteria, turbidity, and nutrient levels along the ocean shorelines (USEPA 2000).

A major impact of urbanization is reflected in the hydrological response to increased impervious surfaces within a watershed (Dunne and Leopold 1978, Imbe et al. 1997, Finkenbine et al. 2000, Lee and Bang 2000, Bledsoe and Watson 2001, Paul and Meyer 2001, Rose and Peters 2001, Brezonik and Stadelmann 2002). Impervious surfaces can be defined as any material that prevents water infiltration into soil (Arnold et al. 1996), and therefore, increases overland flow and causes quicker pulses in storm hydrographs (Hirsch et al. 1990). To support the increases in flow volume, a stream must undergo geomorphic change that, in turn, increases channel erosion (Arnold et al. 1982, Gregory et al. 1992). In many regions, impervious surface coverage >10% of a watershed's area can cause stream degradation (Schueler 1995, Bledsoe and Watson 2001), with degradation increasing as proportions of impervious surface increase. Other problems associated with urban development include increased export of sediment (Wolman 1967, Walling and Gregory 1970, Waller and Hart 1986, Wahl et al. 1997), heavy metals (Callender and Rice 2000, Hunter et al. 1979, Norman 1991), nutrients (Emmerth and Bayne 1996, Herlihy et al. 1998, Lee and Bang 2000, Rose 2002), and bacteria (Gregory and Frick 2000). Thus, with increasing urban development, and specifically increasing proportions of impervious surface within watersheds, southeastern cities can expect increased flooding, channel degradation, and water quality impairment in their streams and reservoirs.

Southeastern U.S. streams and rivers offer prime examples of water quality impairment from urbanization and land conversion. As an example, Atlanta, Georgia, is a large metropolitan area that has been intensively studied for impacts on water quality. Receiving waters from Atlanta have been monitored for fecal coliform (Gregory and

Frick 2000), major ions (Rose 2002), P, and sediment (Emmerth and Bayne 1996), hydrologic modification (Rose and Peters 2001, Rose 2003), and heavy metals (Callender and Rice 2000). Each of these studies reported major impairments of water quality that could be related to urbanization. On a smaller scale, Columbus, Georgia has also undergone urban expansion and is continuing to rapidly develop. The Columbus Water Works (2001) reported that streamwater pollutant yields of fecal coliform, biological oxygen demand (BOD), TSS, and NH_3-N were generally higher in urbanized watersheds than rural watersheds. Many of these previous reports have sampled relatively large watersheds (i.e., >50,000 ha), a spatial scale at which water quality linkages with land use/cover can be obscure. Hence, our investigations concentrated on much smaller watersheds (i.e., <2500 ha) where relationships among water quality impairment and land use/cover maybe more easily detected. Smaller watersheds also provide more realistic sizes at which land management (i.e., city vs. county level) decisions are made. Further, in addition to meeting the need for new research in unique environments, this investigation took place in the Piedmont physiographic province of the Southeast, which has experienced the most extreme urban development in the U.S. (NRCS 2004).

Increased inputs of any of the above stressors may lead to degraded water quality, decreased biological habitat, low aesthetic quality, human health hazards, or loss of recreational opportunity. Consequently, a multiple-year study was performed to assess changes in hydrology, water quality, and sedimentation across an urban to rural gradient near Columbus, Georgia. Columbus provided an ideal location for this study because of its rapid rate of development. The primary focus of this research was to elucidate and quantify the effects of urbanization on hydrology, physicochemical and biological water quality, and channel morphometry of 1 to 3^{rd} order streams across an urban-rural gradient.

The primary objectives of this study were:

1. Assessment of hydrologic parameters across a land use gradient and comparison of two sampling resolutions in terms of accuracy of stream hydrologic characterization.
2. Development of predictive models for nutrient, sediment, and fecal coliform that can aid in the prevention of water quality impairment under various land use scenarios for the Piedmont physiographic region of the southeastern U.S.
3. Comparison of land uses in terms of stream channel stability and sediment transport during baseflow and stormflow conditions.
4. Determination of sediment origin (i.e., whether terrestrial or in-stream).

1.2 GENERAL OUTLINE

The following report is separated into four major topics: stream hydrology, chemical and bacteriological water quality, sediment transport and channel morphometry, and sediment origin, with each topic comprising an individual chapter. Chapter two describes the effects of land use on various flow variables that have been demonstrated to be important biological indicators of anthropogenic disturbance (Richter et al. 1996, Clausen and Biggs 2000). Response variables were divided into the following 5 flow categories: magnitude, frequency, duration, flashiness and stability, and baseflow. The response variables were compared among streams draining different land uses and used to evaluate 2 different scales of flow measurement in terms of stream hydrologic characterization. This assessment provides key information that can directly and indirectly influence fish and macroinvertebrate assemblages, channel stability, nutrient and sediment transport, and provides insight to time sampling scale issues dealing with hydrologic characterization.

Chapter 3 compares streamwater nutrient concentrations and loads among 24 watersheds with contrasting land use during both baseflow and stormflow conditions. Additionally, fecal coliform concentration, an important indicator of sewage and animal waste contamination, was also compared among the land uses. Regression models were developed based on land use percentages and tested for their predictive ability in determining nutrient and fecal coliform concentrations in 6 test watersheds. Various land use change scenarios were explored to provide land managers with information for predicting the effects of land use conversion on water quality within the Middle Chattahoochee Watershed.

In order to adapt to increases in stream discharges discussed in Chapter 2, a stream channel must undergo geomorphic change that subsequently leads to channel erosion (Arnold et al., 1982; Gregory et al., 1992, Walters et al. 2003). Changes in channel morphometry and increases in sediment transport can be a source of physical disturbance on stream biota. Thus, a detailed analysis of channel stability, in terms of scour and fill, and sediment movement across the land use gradient was conducted to elucidate factors that may influence stream biotic assemblages. Stability results also provide information to sediment origin, which is discussed in the fourth chapter.

Sediment has been deemed as one of the top two impairments to streams and lakes in the US (USEPA, 2000). A key question associated with sedimentation relates to whether sediment sources are terrestrial or in-stream. One of the growing concerns with the role of suspended sediment in streams, rivers, and lakes is transport of sediment-associated nutrients and contaminants, specifically, P, heavy metals, and PCBs (Owens et al. 2001). These chemical and physical properties of sediment are also influenced by its source (Carter et al. 2003). Thus, knowledge of sediment origin allows land managers to concentrate financial resources and restoration efforts in the most susceptible areas to erosion and contaminant loading potential. Chapter 5 describes an assessment of two source-tracking methods used to identify sediment sources across an urban-rural land use gradient.

Chapter 6 presents a synthesis of the findings from each of the previous chapters. Management implications and recommendations for future research in urban and rural environments also were discussed. The overall goal of this research was to provide essential information to land managers that can be used for the management and ecologically sound development of watersheds across an urban-rural land use gradient in the Piedmont and other similar physiographic provinces in the Southeast.

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Figure 1.

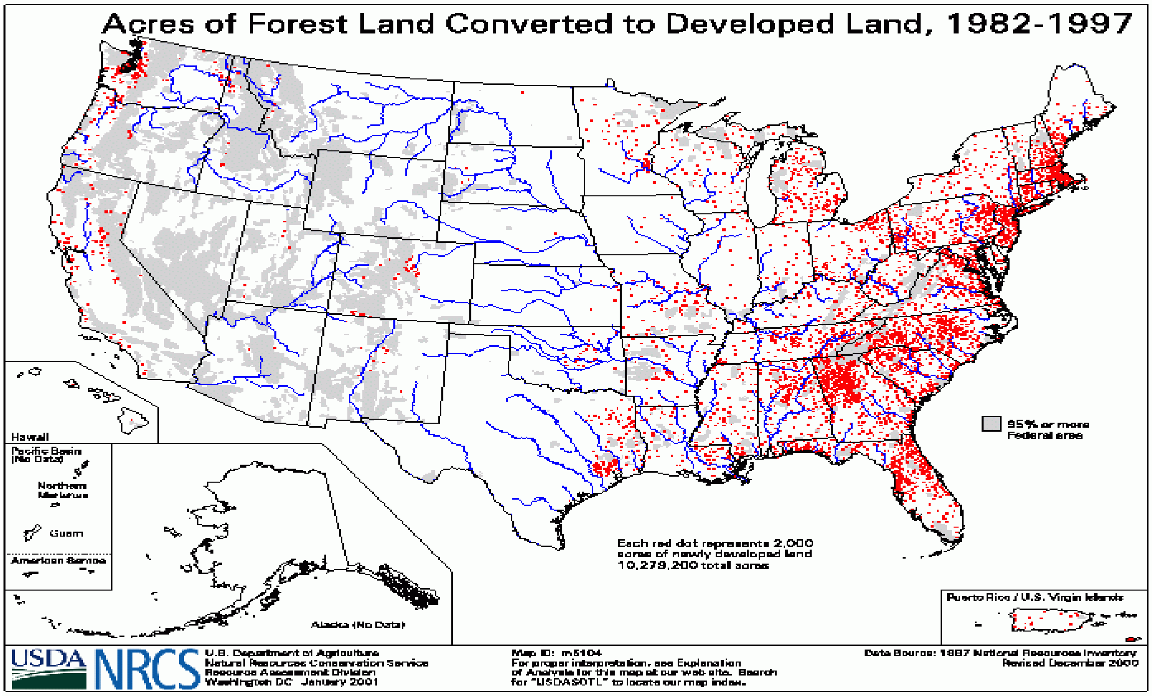

*Figure from http//:www.nrcs.usda.gov/technical/nri_data.html

CHAPTER 2

2. Hydrology of Perennial Streams Across an Urban-Rural Gradient in western Georgia, USA.

2.1 ABSTRACT

The southeastern United States is experiencing rapid urban development. Consequently, Georgia's streams are experiencing hydrologic alterations from extensive development and from other land use activities such as livestock grazing and silviculture. A study was performed to assess stream hydrology within 18 watersheds ranging from 500-2500 ha. Study streams were 1st, 2nd or, 3rd order and hydrology was continuously monitored from 29 July 2003 to 23 September 2004 using InSitu pressure transducers. Rating curves between stream stage (i.e., water depth) and discharge were developed for each stream by correlating biweekly discharge measurements and stage data. Dependent variables were calculated from discharge data and placed into 4 categories: flow frequency (i.e., the number of times a predetermined discharge threshold is exceeded), flow magnitude (i.e., maximum and minimum flows), flow duration (i.e., the amount of time discharge was above or below a predetermined threshold), and flow predictability and flashiness. Fine resolution data (i.e., 15-min interval) was also compared to daily discharge data to determine if resolution affected how streams were classified hydrologically. Urban watersheds experienced flashy discharges during storm events, whereas pastoral and forested watersheds showed more stable hydrographs. Also, in comparison to all other flow variables, flow frequency measures were most tightly

correlated to land cover. Further, the stream hydrology was explained similarly with both the 15-min and daily data resolutions.

2.2 INTRODUCTION

Land use/ land cover plays a crucial role in driving hydrological processes within watersheds. Vegetation removal, which reduces evapotranspiration, can cause increased overland flow and groundwater inputs into streams (Maidment 1992). Silvicultural and agricultural activities that alter dominant vegetation communities within a watershed may also influence streamflow generation (Bormann et al. 1999, Xu et al. 2002). Perhaps the most prominent land use affecting hydrology is urban development (Dunne and Leopold 1978, Imbe et al. 1997, Finkenbine et al. 2000, Lee and Bang 2000, Bledsoe and Watson 2001, Rose and Peters 2001, Brezonik and Stadelmann 2002).

Studies have shown that increases in a watershed's proportion of impervious surface (IS) to greater than 10 percent may significantly impact stream hydrology (Hammer 1972, Hollis 1975). Hydrological effects of increased IS typically result in elevated quickflow generation and produce both high magnitudes and early peaks in storm hydrographs (Hirsch et al. 1990, Smith and Ward 1998). These alterations in hydrology can have dramatic effects on ecological processes within stream ecosystems (Paul and Meyer 2001). The impacts of IS on large order (e.g., >3rd order) streams are well documented, although fewer studies have assessed hydrological impacts from land use change in low-order streams (Simmons and Reynolds 1982, Ferguson and Suckling 1990, Richter et al. 1997, Stewart et al. 1999, Frick and Buell 1999, Rose and Peters 2001, Rose 2002).

Five important flow variables that affect ecological processes within streams have been shown to be influenced by IS: *flow magnitude* (amount of discharge), *flow frequency* (number of times a magnitude is exceeded), *flow duration* (the amount of time a discharge is exceeded), *flow timing or predictability* (overall variability of flows, coefficient of variation), and *flashiness* (rate of change of discharge) (Richter et al. 1996, Poff et al. 1997, and Clausen and Biggs 2000, McMahon et al. 2003). Typically, streams with increasing IS result in higher magnitudes and shorter return intervals of high flows and streams also generally display shorter duration flows with high flashiness (Paul and Meyer 2001).

The southeastern US is clearly affected with rapid population growth as well as the conversion of land uses (US Census Bureau; Census, 2000; Infoplease: US Population by Region, 1990-2002). The rapidly growing city of Columbus, Georgia offered an excellent opportunity to explore the effects of land development on hydrology, and the high abundance of relatively small watersheds with a variety of rather homogenous land uses. Columbus is also in a much smaller city compared to those that many studies have investigated (e.g., Atlanta, GA, Phoenix, AZ, Portland, OR, and Baltimore, MD). Because of their vast number compared to larger metropolitan areas, smaller cities should be deemed as critical areas to investigate and manage to help alleviate the impacts of urban expansion on lotic ecosystems.

In this paper the effects of land use on hydrology of low-order streams across an urban-rural gradient were investigated. The objectives of this study were two-fold. First, the effects of land use on an array of hydrologic measures were assessed. Specifically, the effects of land use on flow duration, frequency, magnitude, variability, and baseflow were examined. Secondly, stage levels were recorded at two time intervals (15-min and daily) to allow comparisons between the sampling resolutions for their ability to characterize the stream hydrology among multiple land uses. The above objectives were investigated using data collected from 18 streams in which the watersheds were dominated by urban, developing, pastoral, unmanaged, or managed forest land covers.

2.3 METHODS

2.3.1 Study Area

The southern extent of the study area is within Columbus, Georgia (N 32 30.658 W84 52.484) and extends northward to LaGrange, Georgia (N33 02.475 W85 .02.045) (Figure 1). All watersheds ranged in size from 300-2500 ha and are sub-basins of the Middle Chattahoochee Watershed within the Piedmont physiographic province. According to Strahler's stream classification system, the study streams ranged from 1st to 3rd order (Strahler 1952).

Dominant land uses within the study area were classified as unmanaged forest, managed forest, urban, developing, and pastoral (Table 1). One-meter aerial photographs were taken during leaf-off in March 2003 to facilitate land use classification. The first effort in the 1-m image analyses was to generate an IS percentage for each watershed. IS is a widely accepted and reliable indicator of urbanization and its impacts on natural resources, particularly for water resources (Schueler 1995, Arnold and Gibbons 1996). The remaining land classes were then digitized using both unsupervised and supervised classification methods. The image processing methods used in this assessment are described in detail by Lockaby et al. (2005).

Elevation ranges of the Piedmont are between 152 to 457 m above mean sea level and the topography is gently rolling to steep. Udults dominate the area, which have clayey or loamy subsoil, a thermic temperature regime, a udic moisture regime, and a kaolinitic or mixed mineralogy. The soils are underlain by acid crystalline and metamorphic rocks. Historical cotton farming has eroded approximately 18 cm of the topsoil in many localities, leaving clayey subsoil exposed (Trimble 1974). Stream channel substrates were predominantly composed of unconsolidated materials in size classes <2mm.

Forest cover types within the study area range from intensively managed pine plantations to bottomland hardwood forests. Many of the uplands are either in pasture, which is used for grazing or growing hay, or in pine plantations. Plantations are both non-industrial privately owned and industry owned lands under several management prescriptions. Loblolly pine (*Pinus taeda* L.) is the predominate species that is commercially harvested and exists in various harvesting stages (i.e., mature, clearcut, thinned, or planted). Many of the watershed lowlands have intact riparian corridors composed of bottomland hardwoods such as sweetgum (*Liquidambar styraciflua* L.), oaks (*Quercus spp.*), tulip poplar (*Liriodendron tulipifera* L.), and magnolias (*Magnolia spp.*).

2.3.2 Field Methods

Eighteen watersheds were instrumented with InSitu, MiniTroll®, pressure transducers to record stream stage at fixed sampling locations near the point of outflow from the watersheds (InSitu Corp., Boulder, CO). Pressure transducers were housed in 10 cm, schedule 40 PVC pipe, which were perforated along the portion extending into the stream. The PVC tubes served as temporary stilling wells, prevented damage to the units, and provided a stable water surface to increase accuracy of stage readings. Pressure transducers were programmed to record a stage reading at 15-min intervals, which allowed for detailed storm hydrographs. The period of record was from 29 July 2003 through 23 September 2004.

Stream stage readings were correlated with discharge readings that were measured during all seasons of the year and at various stages. Coinciding with water chemistry sampling (Chapter 3), stream discharge was measured biweekly during the winter and monthly through the remainder of the year (Schoonover 2005). To ensure that rating curves were represented at a variety of stages, discharge was also recorded during several high flow events. Streams that were unsafe to sample during extreme flows were measured for morphometry characteristics at baseflow near the gauging stations and the data were used to calculate discharge utilizing Manning's equation (Maidment 1992). Instantaneous discharge was determined by measuring the velocity and cross-sectional areas of subsections across the stream channel. Generally, at least 20 subsections were measured across the stream channel, which complies with USGS stream gauging guidelines (Rantz 1982). A Marsh-McBirney® flowmeter was used to measure the velocity within each subsection. The mean velocity (typically, measured below the streams surface at 60 % of the total depth) at each subsection or point was multiplied by an area equal to the product of the depth at that point and a width equal to one-half the distance of the preceding and following points. The resulting products were then summed to obtain total discharge (Equation 1).

Equation 1:
Discharge, $m^3 s^{-1}$ (Q) = $\sum$ (Sub-section Width i, m) (Sub-section Depth $_i$, m) (Sub-section velocity $_i$, m s^{-1})

Daily precipitation data available from the National Climatic Data Center (NCDC, Ashville, North Carolina) was used to calculate runoff coefficients. Four NCDC stations were monitored to ensure that sufficient coverage was available across the study area. Weather stations used in this study were located at the Columbus Metropolitan Airport (#092166/93842), Mulberry Grove (096148), West Point (099291), and Woodbury (099506) (Figure 1). Historical monthly averages were based on the Columbus, West Point, and Woodbury stations; Mulberry Grove was excluded due to its recent installation (1997), whereas the others had historic data from 1948, 1931, and 1931, respectively.

2.3.3 Indicators of Hydrologic Alteration

Software developed by the Nature Conservancy, Indicators of Hydrologic Alteration (IHA), was used to analyze daily median flows. Daily median flow values were calculated from the 15-min discharge collected from the 18 watersheds. The IHA software analyzes data based on complete water years, and in cases where missing values are present, IHA interpolates data based on measured values. The data interpolation used in the software has applicability in data sets that cover multiple years. However, numerous interpolations increase the potential for error with smaller data sets such as in our study. To circumvent this problem, we analyzed one complete year beginning on 29 July 2003, thus only “real” (i.e., measured) values were used in IHA computations.

2.3.4 Data Analysis

Rating curves for stage/discharge relationships were developed using Table Curve 2D software based on the 15-min discharge data (Systat Software, Point Richmond, California). Table Curve is designed to create the best equation to explain the correlation between the data. A logistic dose response equation was the simplest equation that accurately explained the rating curve data of all streams, without over-fitting the data while maintaining a high r^2 (0.95-0.99) (Equation 2).

Equation 2: $y = a + b / (1 + (x / c)^d)$

where:

x=discharge ($m^3 s^{-1}$)

y=stage (ft)

Hydrograph analyses were performed using SAS software (version 8 1999, SAS Institute, Cary, North Carolina). Hydrology data were separated into five categories: baseflow, magnitude, frequency, duration, and predictability, and flashiness. Thirty-two hydrologic variables were calculated for each stream (listed in Table 2). Dependent variables (i.e., hydrologic parameters) were tested among land uses (independent variables) using Kruskal-Wallace tests (α=0.05). Nonnormal dependent variables were log-transformed to meet assumptions of normality before performing analyses (Sokal and Rohlf 2000).

2.3.4.1 *Baseflow Hydrology*

Baseflow was predicted for each stream using a 5-day smoothed minima technique (Gustard 1992). A brief outline of the baseflow separation method follows:

1. Mean daily flow data was divided into non-overlapping blocks of 5 days and then determine the minimum flow for each block.
2. The minimum flow value was multiplied by 0.9. If the product is less than both the previous 5-day block minima and next 5-day block minima then the value was used as an estimate of baseflow. The latter was performed for each 5-day block.
3. A daily value of baseflow was estimated for the entire data set using linear interpolation between each predicted baseflow.
4. If the actual observed flows were lower than predicted flows, then the baseflow estimate was equal to the observed flow.

Predicted baseflow values were then summed and divided by the sum of the observed values, resulting in an estimate of baseflow index (BI). BI is the proportion of water contributing to a stream as groundwater inputs vs. surface runoff, where high BI values indicate significant groundwater inputs (stable hydrographs) and low values indicate higher surface water inputs (flashy flows). Previous investigations have shown BI to be less variable than other low flow variables (Gustard 1992).

2.3.4.2 *IHA analyses*

IHA software offers user-defined thresholds for identifying criteria for extreme low flows, high flow pulses, and large- and small-flood events. For the following analyses, extreme low flows were defined as those that fell below the lowest 10% of flows for the entire sampling period. High flow pulses were initiated when the flow increased by >25% per day or exceeded 75% of all flows for the period of record. A high-flow pulse ended once the flow decreased by <10% per day or to a value <50% of all daily flows. Small- and large-flood events were identified as the flows in which high flow pulses had a recurrence interval of at least 2 and 10 years, respectively. IHA calculated 32 parameters that were organized into five groups: 1) magnitude, 2) magnitude and duration of annual extreme conditions, 3) timing of annual extreme conditions, 4) frequency and duration of high- and low-flow pulses, and 5) rate and frequency of flow change (Richter et al. 1996). Individual parameters of IHA are discussed in detail by Richer et al. (1996 and 1997).

2.4 RESULTS AND DISCUSSION

2.4.1 Precipitation

The 30-yr average rainfall total was 132 cm yr^{-1} for western Georgia, and fell predominantly as rain (NCDC, 2004). In 2003, annual rainfall was 23.3 cm above average, whereas in 2004 the annual rainfall was 5.5 cm below normal. In 2003, most above average rainfall fell between February and August, with the remainder of the year being below average. In 2004, the late winter and early spring (i.e., January through May) had below average precipitation totals whereas the early fall (specifically September) experienced higher rainfall than average.

2.4.2 Stormflow Hydrology

Flow magnitude, frequency, duration, and flashiness variables calculated from the high-resolution data (i.e., 15-min intervals) are summarized and defined in Table 2. The number of readings in which particular magnitudes (i.e., the frequency variables) were exceeded was considerably higher in urban watersheds than watersheds with other land uses. Specifically, the 3xMed, 5xMed, 7xMed, >95th, and >99th variables were higher in the urban watersheds. Additionally, when both the urban and developing land-use categories were combined and compared to other land uses there were significant differences among the 5 aforementioned variables, with the exception of the >95th. Urban watersheds also experienced the highest peak discharges for magnitude (L s^{-1}) as well as for magnitude on an area basis (L $s^{-1}ha^{-1}$) (Table 3). However, duration of flows above the magnitude was similar to, or lower than, other land uses.

Watersheds dominated by forestland (both managed and unmanaged combined), without an urban component, have significantly lower mean discharges per area ($p=0.0452$) as well as lower maximum discharges ($p=0.0184$). Forested watersheds also had significantly lower minimum flows, suggesting that evapotranspiration may contribute to lower stream discharges. Median flows were negatively correlated with the % of unmanaged forest cover in watersheds (Figure 2).

Watersheds with large proportions of pasture (i.e., >30%) had higher BI than other land uses, suggesting that groundwater inputs provide a significant input to stream recharge. Infiltration rates greatly depend on soil condition and soils with dense grass cover have been shown to promote homogeneous infiltration and storage of soil waters (Williamson et al. 2004). Grasses also produce dense rooting networks deep into soil layers, which affect infiltration capacities and in drying soils uniformly (through evapotranspiration), thus facilitating soils ability for high infiltration and runoff storage during subsequent events (Hino et al. 1987). High infiltration would also explain the significant groundwater contribution to streamflow generation (i.e., high BI). Streams draining pastureland also rarely exceeded the 5x and 7x median flows, which resulted in stable hydrographs throughout the study period.

Table 4 shows Pearson's correlation coefficients for the significant relationships between land use and the hydrology variables. Watersheds with IS of >20 % were positively correlated with flow frequency variables, whereas forested areas were generally negatively correlated with frequency variables. The higher flow frequencies and flow magnitudes in the urban watersheds resulted from high runoff volumes and fast conveyance of water by impervious surfaces such as parking lots, rooftops, driveways, and sidewalks (Carter 1961, Leopold 1968, Tourbier and Westmacott 1981). In contrast, forested watersheds typically show greater infiltration capacities, which ultimately lead to longer lag times between rainfall and increases in stream flow.

Several approaches are commonly used to estimate runoff generation and lag times for different land cover types, including the rational method, Soil Conservation Service (SCS) method, and runoff coefficients (Kirpich 1940, SCS 1972, Ward et al. 1980). Runoff coefficients (C) were calculated for the three urban watersheds in this study because of their close proximity to one of the rainfall stations; remaining watersheds were not located close enough to NCDC rainfall stations to calculate reliable C values. C values for the urban watersheds were 0.69, 0.65, and >1.0. The urban watershed with the C value >1 indicated that streamflow generation was > precipitation volume; streamflow was likely elevated here because discharge originated from sources other than rainfall, such as leaky sewage pipes, septic drain fields, or excessive landscape irrigation (Ferguson and Suckling 1990). C values reported by Erie and Niagara Regional Planning Board (1981) ranged from 0.47 to 0.69 for high-density residential areas, and up to 0.90 in industrial areas. The American Society of Civil Engineers and Water Pollution Control Federation report similar C values, up to 0.95 in downtown urban areas (Maidment 1992). However, C values reported by Rose and Peters (2001) for Peachtree Creek near Atlanta, Georgia were considerably < those measured in downtown Columbus, Georgia. Differences in effective impervious surfaces (i.e., those sources of discharge directly connected to streams by pipes) (Booth and Jackson 1997) may have been higher in Columbus watersheds.

2.4.3 Baseflow Hydrology

Median base flow ranged from 7.6 L s^{-1} in unmanaged forested watersheds to 208.8 L s^{-1} in pastoral watersheds. Median base flow in pastoral watersheds was significantly higher than watersheds with other dominant land uses (p=0.0445). High base flow in the pastoral watersheds was likely due to the high infiltration capacities of pastures, which may lead to groundwater recharge. Additionally, the lack of forest cover may reduce high transpiration losses by woody vegetation (Whitehead and Robinson 1993). Baseflow levels of urban streams have been reported as being lower than in rural areas due to the high impervious surface coverage, which reduces infiltration, and sanitary sewerage (Sulam and Ku 1977, Simmons and Reynolds 1982). Figure 3 shows that groundwater inputs likely contribute to streamflow generation in both managed and unmanaged forested watersheds throughout the year, as opposed to urban and developing watersheds where, possibly because of lower evapotranspiration, discharge did not increase during the winter. However, baseflow levels were maintained throughout the year in urban streams, perhaps low flows may be supplemented by leaky sewage pipes, septic drainage, or excess irrigation (Simmons and Reynolds 1982, Ferguson and Suckling 1990).

BI for each land use is illustrated in Figure 5 and exhibited relatively tight correlations with several hydrologic parameters. BI is highest in pastoral and forested streams; however, MU2, a managed forest stream, and MU1 and FS3, which are pastoral streams do not follow the trend. MU2 was recently clearcut, which would likely reduce evapotranspiration and potentially lead to higher overland flow input, thus ultimately reducing the BI. For the two pastoral streams, the cause of the lower BI (~0.30) was not identifiable. Figures 6 and 7 illustrate the relationships between BI and CV and the number of times the 7xMedian flow was exceeded. Watersheds with high BIs showed greater flow stability (i.e. lower %CVs) whereas watersheds with low BIs showed higher peak discharges and higher occurrences of flows exceeding greater magnitudes. Jordan et al. (1997) found similar trends in baseflow; watersheds with low BIs were clearly dominated by brief high discharge episodes, and watersheds having high BIs experienced more constant flows through time. In this study, the relationship between land use and BI was explained by the following model (r^2=0.51, p=0.0156):

$$BI = -0.42(\log IS) - 1.63\,(\log Forest) - 0.26\,(\log Pasture) + 8.44$$

2.4.4 IHA Analysis

IHA software calculated hydrologic parameters based on daily median flow values. Urban watersheds (>5% IS) were compared to watersheds with little urban development (Table 5). IHA group 2 variables (i.e., magnitude variables) included both maximum and minimum flow values. Urban watersheds had both the highest 1-day and 90-day minimum flows. Minimum flows from the high-resolution data were not significantly different among land use classes. However, low flows in the forested watersheds were significantly lower than those for other land uses, likely because of transpiration losses during the summer months (Whitehead and Robinson 1993). Both low- and high-pulse counts and rise and fall rates were highest in urban watersheds, suggesting that urban streams experience not only high spate flows, but also rapid hydrograph rise and fall. Forested land use percentages within the watersheds were negatively correlated (-0.52, p=.0336) with the number of high pulses, reiterating stability of stream flows in forested watersheds. The pulsing signatures of the study streams are shown Figures 3 and 4. Both figures revealed significant groundwater inputs, as base flow, contributed to stream discharge. The November to April increase in base flow discharge coincides with the leaf-off period, which likely indicated reduced plant transpiration.

Parameters tested in the high-resolution data set and those for the IHA software were not identical. However, the five dominant flow categories showed general trends between the two methods. Both the IHA and the high-resolution data showed higher magnitude flows, frequency of flows, and higher flashiness in urban watersheds than watersheds with <5% IS coverage. The two methods appear to show similar annual trends among lands uses. However, if analysis of individual storm hydrographs is deemed critical, then the high-resolution has greater utility in characterizing individual storm hydrographs.

2.4.5 Daily Median Flows

With the exception of 2 streams, daily median flows were significantly correlated across watersheds. The two non-correlated watersheds were pastoral, with one stream exhibiting very stable flows throughout the sampling period while the other displayed high sustained daily median flows. The high-flow watershed (FS2) also had a C-value >1.0, suggesting that a non precipitation source supplemented discharge. Spring (i.e., groundwater upwelling) inputs have been observed along the stream (personal observation) and likely contribute to the elevated C-value and median flows.

Median daily flows in the urban watersheds were tightly correlated with one another (r = 0.83-0.92, p=<0.0001). The tight relationship likely exists because of their close proximity as well as the high percentages of impervious surfaces, which can promote similar runoff timing among the watersheds.

2.5 SUMMARY AND CONCLUSIONS

This paper addressed how hydrologic variables related to land use within 18 watersheds draining the Piedmont of western Georgia. Thirty two variables that characterized the magnitude, duration, frequency, and flashiness of flows were calculated for each watershed. Two scales of flow measurement were also compared (a high-resolution, 15-min interval discharge data set vs. daily discharge) in terms of their utility for assessing stream hydrology. In both the high- and low-resolution data sets, flow frequency variables were most tightly related to land use. High flow pulses and elevated peak discharges were more frequent in urban watersheds (>5% IS) than any other land use, and baseflow (i.e., groundwater) inputs in urban streams were lower than other watersheds. Annual hydrographs in urban streams illustrated that baseflow discharge deviated little between growing and dormant seasons, suggesting that vegetation had minor to no effect on groundwater contributions to streamflow. Also, BIs suggested that quickflow contributed up to 90% of the flow reaching urban streams and between 65-90% of flow in streams associated with developing watersheds. Conversely, watersheds with high forest or grass cover had higher contributions from groundwater inputs. Furthermore, the proportion of unmanaged forest within the watersheds was negatively correlated with stream discharge.

Runoff coefficients were similar to the ranges reported for residential and commercial areas by the American Society of Civil Engineers and the Water Pollution Control Federation. However, measured runoff coefficients were considerably higher than those reported near downtown Atlanta, Georgia, perhaps due to greater proportions of effective impervious surfaces.

Hydrologic parameters identified in this study are critical for characterizing habitat quality for many aquatic fish and macroinvertebrate species. Study streams experiencing flashy flows and increased flow frequency have experienced shifts from intolerant species (e.g., those representing EPT taxa) towards more tolerant species (e.g., Chironomidae and Oligochaete worms) (Helms 2005, unpublished data). Thus, the preservation of land cover types such as forests and grasses are important when managing watersheds for flood prevention and the maintenance of habitat stability within streams.

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Table 1. Land use ranges within the 18 study watersheds of western Georgia. Numbers in parentheses represent the number of watersheds in each category.

	Land Use (%)			
	Urban	**Evergreen**	**Deciduous**	**Grazing**
Urban (3)	24.9-41.9	20.9-30.5	11.1-15.9	14.8-24.9
Developing (3)	1.8-3.4	37.3-41.2	22.8-35.4	19.9-20.3
Pasture (4)	1.6-3.7	29.3-32.8	22.2-29.9	33.2-44.0
Managed (4)	1.2-2.6	42.4-48.3	25.0-33.0	13.0-20.8
Unmanaged (4)	1.2-2.3	36.4-48.1	28.2-37.9	13.2-19.8

Table 2. Hydrology variables separated by dominant land use categories within each west Georgia study watershed.

		Land Use Category				
Variable ID	**Description**	**Urban N=3**	**Developing n=3**	**Pasture n=4**	**Managed n=4**	**Un-managed n=4**
Area (ha)	Watershed Area	1794.3	1767.3	1079.5	719.0	757.0
Magnitude						
Mean	Average discharge (L s^{-1})	420.3	206.7	441.8	120.7	91.7
Med	Median discharge (L s^{-1})	181.0	49.1	319.0	62.9	27.7
Max	Maximum discharge (L s^{-1})	23216.7	16166.7	9975.0	4911.0	4169.7
Min	Minimum discharge (L s^{-1})	15.4	1.1	89.6	0.7	0.0
Mean_ha	Average discharge (L s^{-1})/ watershed area	0.2	0.1	0.4	0.2	0.1
Med_ha	Median discharge (L s^{-1})/ watershed area	0.1	0.0	0.4	0.1	0.1
Max_ha	Maximum discharge (L s^{-1})/ watershed area	12.9	9.1	9.2	6.8	5.5
Min_ha	Minimum discharge (L s^{-1})/ watershed area	0.0	0.0	0.1	0.0	0.0
Frequency (# times exceeded threshold)						
3xMed	# of times discharge exceeded 3x median flow	58	37	25	23	27
5xMed	# of times discharge exceeded 5x median flow	52	34	20	18	20
7xMed	# of times discharge exceeded 7x median flow	45	31	17	16	17
>75th	# of times discharge exceeded 75th percentile	64	50	69	51	55
>95th	# of times discharge exceeded 95th percentile	47	25	34	22	21
>99th	# of times discharge exceeded 99th percentile	20	12	11	9	10
Duration (# of hours spent above threshold)						
>3xMed_d	Hours discharge was >3x median flow	1916.3	2763.0	1446.3	1403.3	2431.3
>5xMed_d	Hours discharge was >5x median flow	1186.0	2133.3	572.8	1162.3	1597.0

>7xMed_d	Hours discharge was >7x median flow	786.3	1763.0	273.5	981.7	1201.0
Predictability and Flashiness						
C.V.	% Coefficient of Variation	204	313	203	256	221
Inc1h100	# of events discharge increases by 100% within 1 hr	65	35	29	31	37
Inc1h1000	# of events discharge increases by 1000% within 1 hr	17	15	11	9	20
Inc1h5000	# of events discharge increases by 5000% within 1 hr	6	9	8	3	15
Inc3h100	# of events discharge increases by 100% within 3 hr	71	38	34	41	40
Inc3h1000	# of events discharge increases by 1000% within 3 hr	22	20	15	12	21
Inc3h5000	# of events discharge increases by 5000% within 3 hr	8	12	9	7	17
Dec1h100	# of events discharge decreases by 100% within 1 hr	31	24	21	19	36
Dec1h1000	# of events discharge decreases by 1000% within 1 hr	6	10	11	6	19
Dec1h5000	# of events discharge decreases by 5000% within 1 hr	1	3	7	2	11
Dec3h100	# of events discharge decreases by 100% within 3 hr	55	34	29	29	39
Dec3h1000	# of events discharge decreases by 1000% within 3 hr	10	13	12	8	23
Dec3h5000	# of events discharge decreases by 5000% within 3 hr	4	5	8	5	16
Baseflow (L s^{-1})						
Mean_bf	Average baseflow	69.7	40.3	333.5	45.3	26.7
Med_bf	Median baseflow	50.7	23.8	208.8	44.0	7.6
BI	Baseflow index (sum of predicted baseflow/ sum of observed flow)	0.16	0.11	0.54	0.42	0.43

Table 3. Land use comparisons with flow variables calculated from high-resolution (15-min intervals) discharge data. Table includes significant variables only.

Land use comparison	**Variable**	**Variable Description**	**P**
Unmanaged forest < Other land uses combined	Max_ha	Maximum discharge ($L\ s^{-1}$)/ watershed area	0.0399
Urban and developing < Other land uses combined	BI	Baseflow index	0.0021
Urban and developing > Other land uses combined	>99th	# of times the discharge exceeds 99th percentile	0.0258
Urban and developing > Other land uses combined	>3x Med	Hours the discharge is >3x median flow	0.0155
Urban and developing > Other land uses combined	>5x Med	Hours the discharge is >5x median flow	0.0043
Urban and developing > Other land uses combined	>7x Med	Hours the discharge is >7x median flow	0.0064
Urban and developing > Other land uses combined	Max_ha	Maximum discharge ($L\ s^{-1}$)/ watershed area	0.0274
Unmanaged and managed forest < Other land uses combined	>5x Med	Hours the discharge is >5x median flow	0.0597
Unmanaged and managed forest < Other land uses combined	>7x Med	Hours the discharge is >7x median flow	0.0596
Unmanaged and managed forest < Other land uses combined	Mean_ha	Average discharge ($L\ s^{-1}$)/ watershed area	0.0452
Unmanaged and managed forest < Other land uses combined	Max_ha	Maximum discharge ($L\ s^{-1}$)/ watershed area	0.0184
Unmanaged and managed forest < Other land uses combined	Min_ha	Minimum discharge ($L\ s^{-1}$)/ watershed area	0.0292
Pasture > Other land uses combined	BI	Baseflow index	0.0496
Pasture < Other land uses combined	>5x Med	Hours the discharge is >5x median flow	0.0399
Pasture < Other land uses combined	>7x Med	Hours the discharge is >7x median flow	0.0399

Table 4. Pearson's correlation coefficients (r) for high-resolution hydrology variables (15 min intervals) versus the dominant land use within 18 west Georgia streams.

Variable	Variable Description	IS[†]	Managed Forest	Unmanaged Forest	Pasture	Forest Types Combined
Max	Maximum discharge ($L\ s^{-1}$)	0.66**	-0.64**	-0.47*	0.20	-0.61**
Max_ha	Maximum discharge ($L\ s^{-1}$)/ watershed area	0.54*	-0.45	-0.46*	0.15	-0.49*
3xMed	Hours discharge is >3x median flow	0.65**	-0.43	-0.26	-0.20	-0.34
5xMed	Hours discharge is >5x median flow	0.64**	-0.52*	-0.34	-0.03	-0.48*
7xMed	Hours discharge is >7x median flow	0.57**	-0.47*	-0.35	0.04	-0.40
>95th	# of times discharge exceeded 95th percentile	0.52*	-0.46*	-0.36	0.16	-0.43
>99th	# of times discharge exceeded 99th percentile	0.60**	-0.41	-0.54*	0.15	-0.50*

* α=0.05,

** α=0.01

[†] Impervious surface

Table 5. Results from the Indicators of Hydrologic Alteration software for 18 streams across an urban-rural land use gradient in western Georgia. Data are based on daily median flows.

	<5% IS*	>5% IS	P
Constancy/Predictability	0.33	0.16	0.0087
IHA Group 2			
1-day maximum (L s^{-1} ha^{-1})	1.28	1.63	0.0486
90-day minimum (L s^{-1} ha^{-1})	0.01	0.07	0.0220
IHA Group 4			
High pulse count (#)	14	26	0.0085
Low pulse count (#)	0	18	0.0078
IHA Group 5			
Fall rate (L s^{-1} ha^{-1})	-0.01	-0.03	0.0164
Rise rate (L s^{-1} ha^{-1})	0.02	0.04	0.0377
EFC Parameters			
Small flood fall rate (L s^{-1} ha^{-1})	-0.05	-0.2	0.0188
Small flood rise rate (L s^{-1} ha^{-1})	0.15	1.63	0.0099
Small flood pulse (L s^{-1} ha^{-1})	1.23	1.63	0.0339
High flow fall rate (L s^{-1} ha^{-1})	-0.03	-0.09	0.0188
High flow frequency (#)	17	29	0.0044
High flow pulse (L s^{-1} ha^{-1})	0.14	0.44	0.0188

[†] Environmental flow components

* Impervious surface

Figure 1. Locations of study watersheds (depicted by polygons) within the Middle Chattahoochee Watershed of west Georgia. Stars represent rainfall stations used in the study.

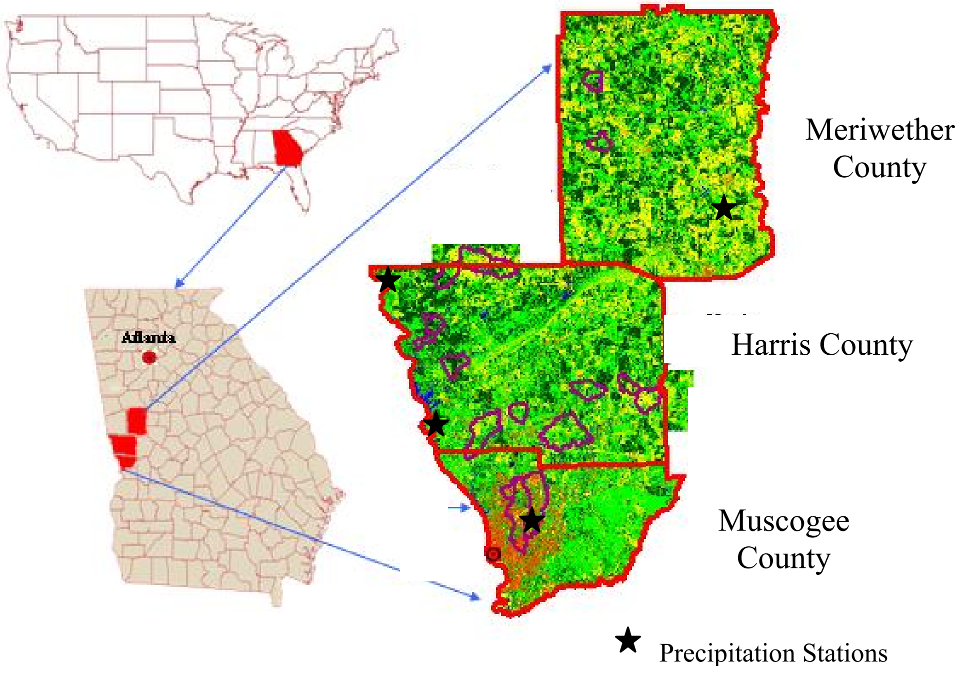


Figure 2. Mean (±1SE) stream discharge relationships with percent unmanaged forest in west Georgia watersheds.

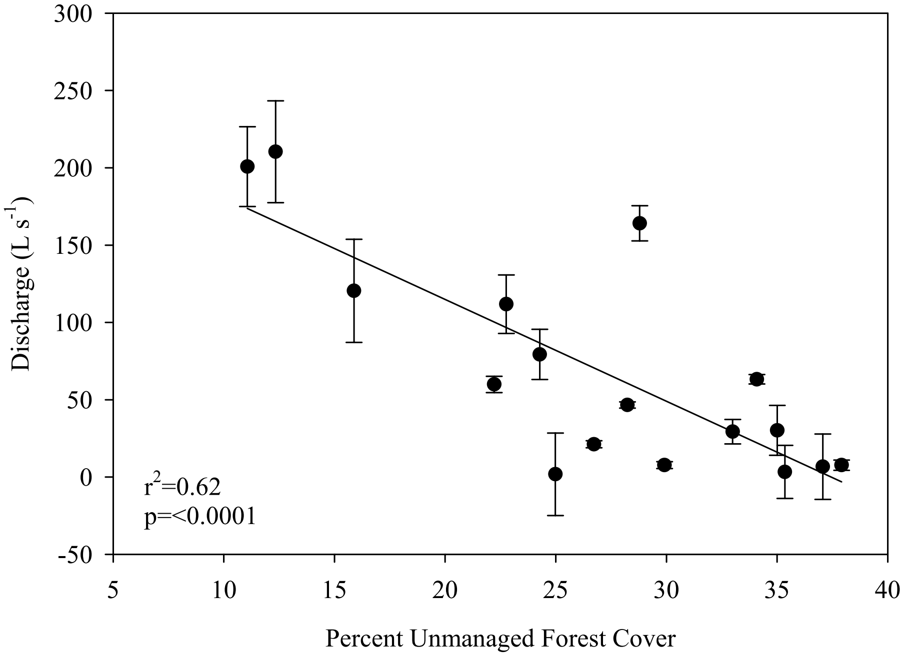


Figure 3A. Annual hydrograph and baseflow estimation for a stream draining a watershed dominated by unmanaged forest cover.

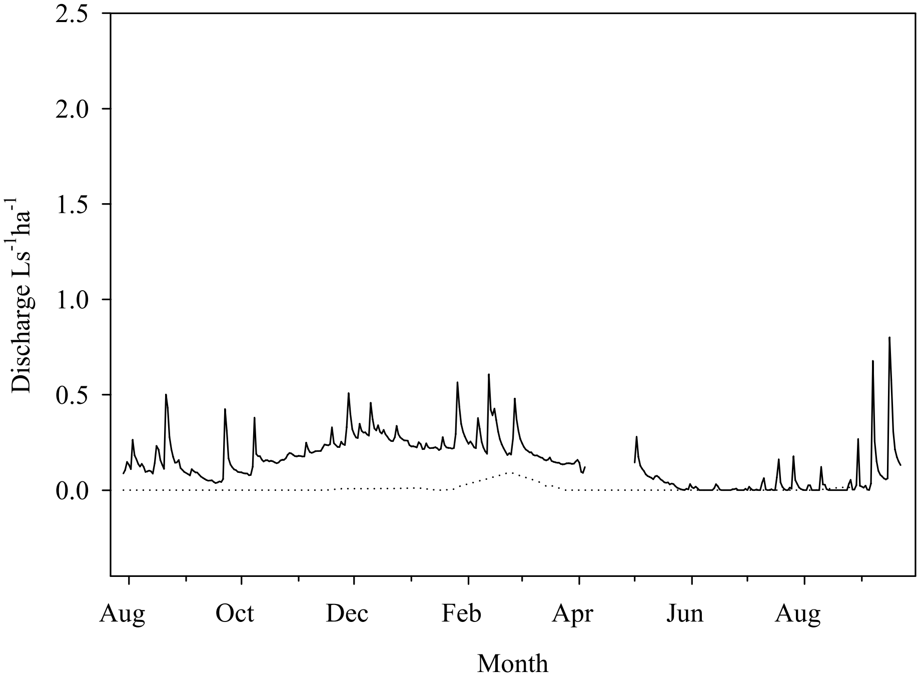


Figure 3B. Annual hydrograph and baseflow estimation for a stream draining a watershed dominated by managed forest cover.

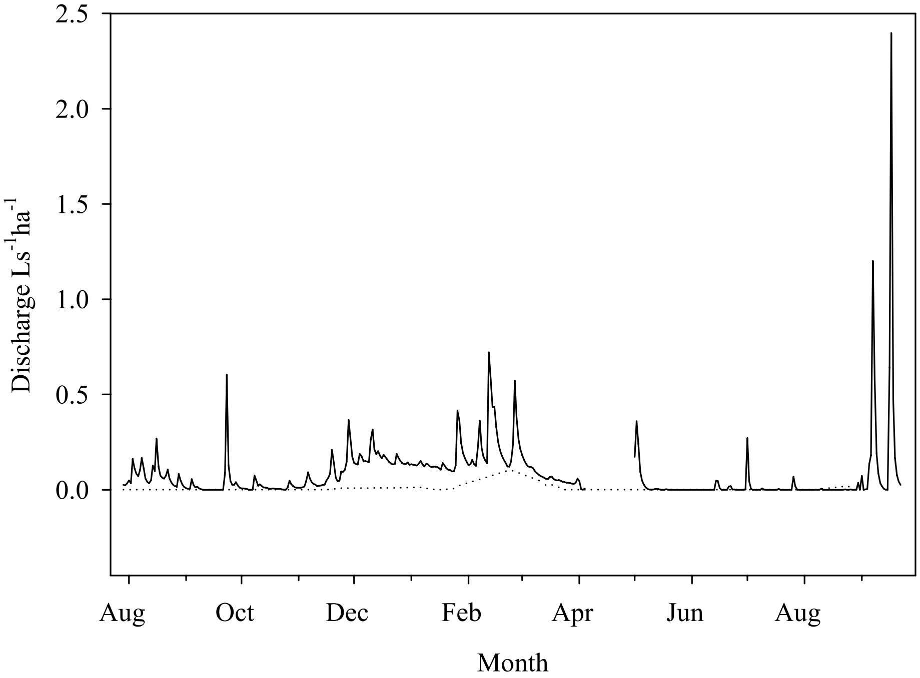


Figure 4A. Annual hydrograph and baseflow estimation stream draining a developing watershed (subdivisions and new development were common).

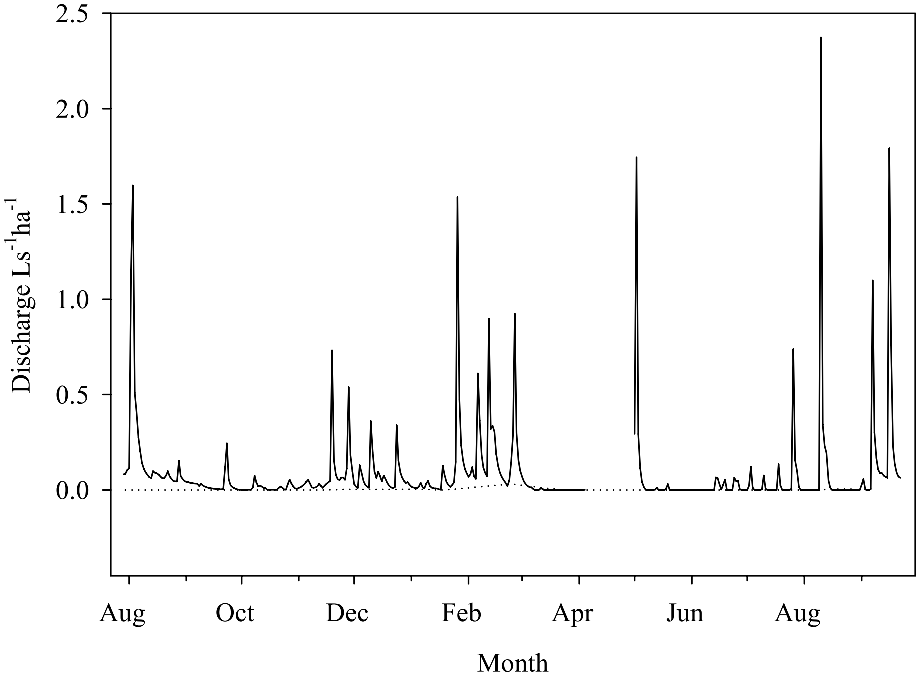


Figure 4B. Annual hydrograph and baseflow estimation for a stream draining a watershed with 25% impervious surface coverage.

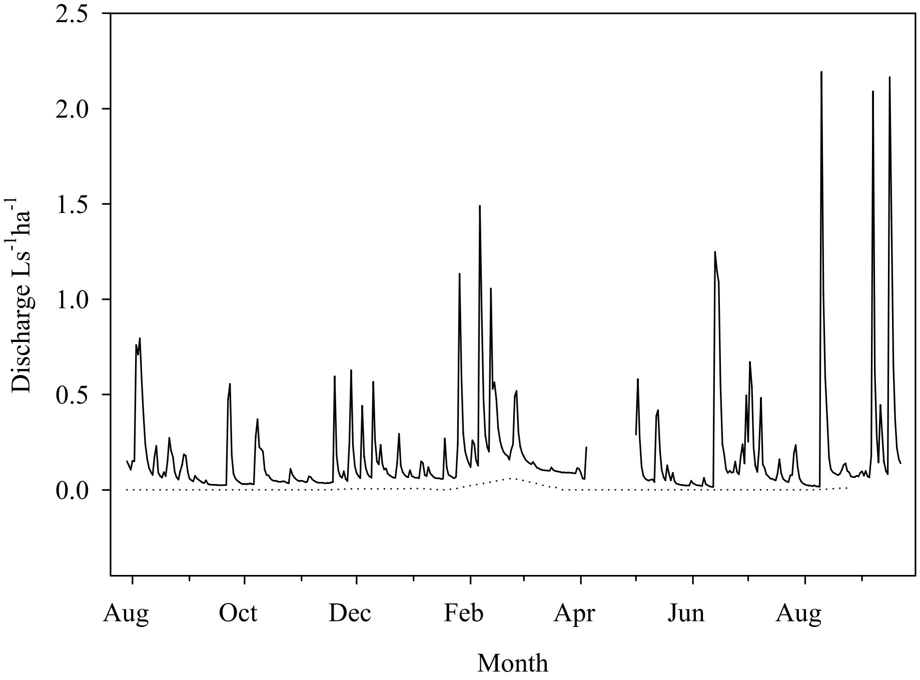


Figure 5. Baseflow indices for 18 streams in western Georgia.

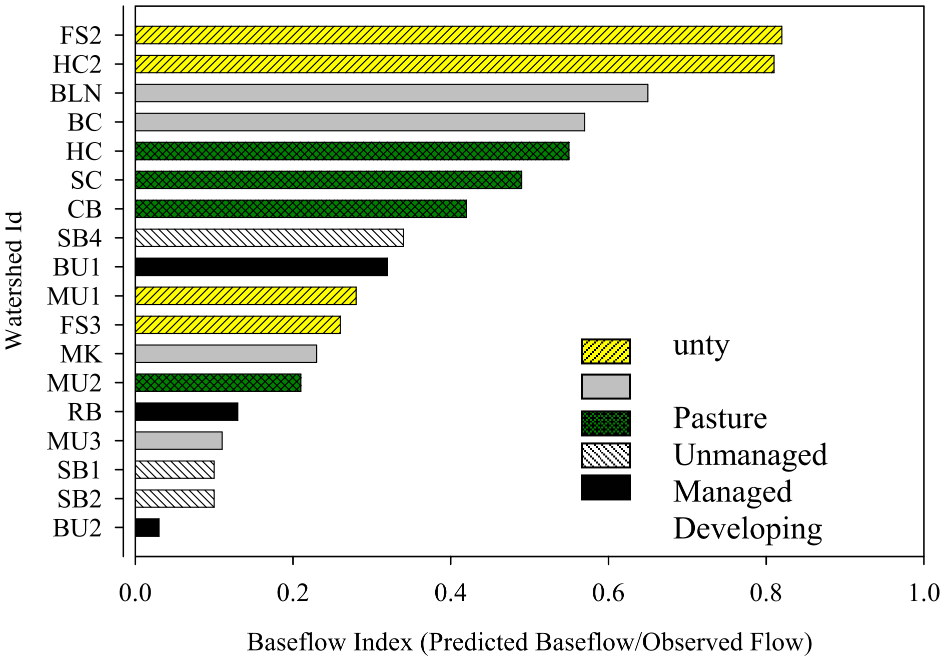


Figure 6. Baseflow index plotted against the coefficient of variation (%) for stream discharge in 18 west Georgia streams.

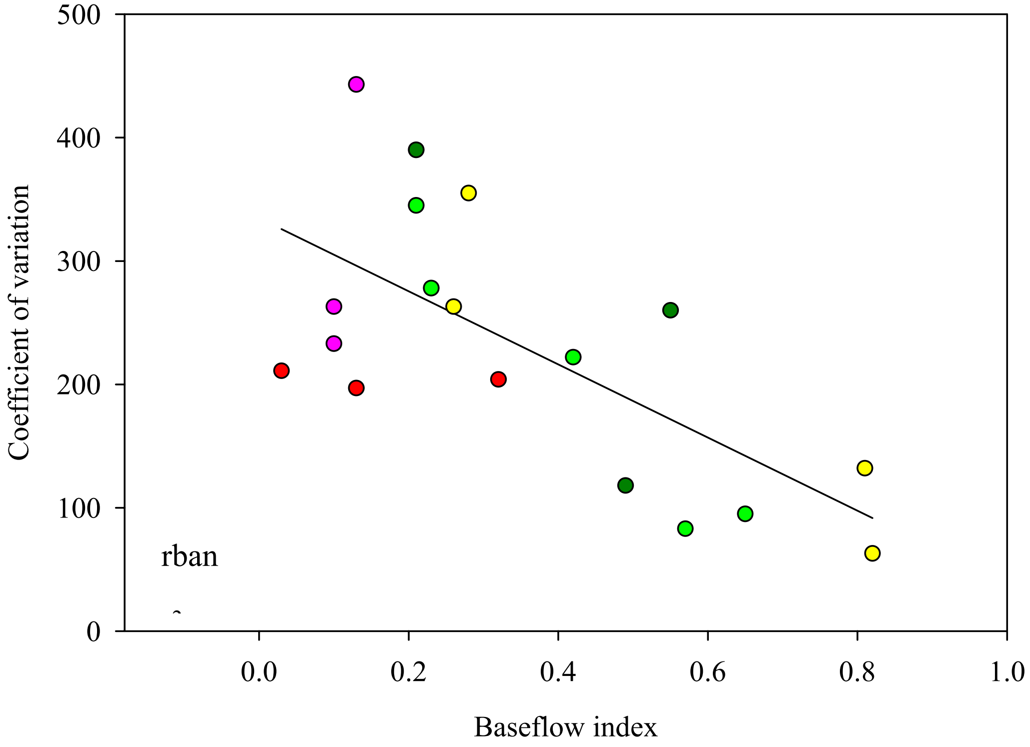
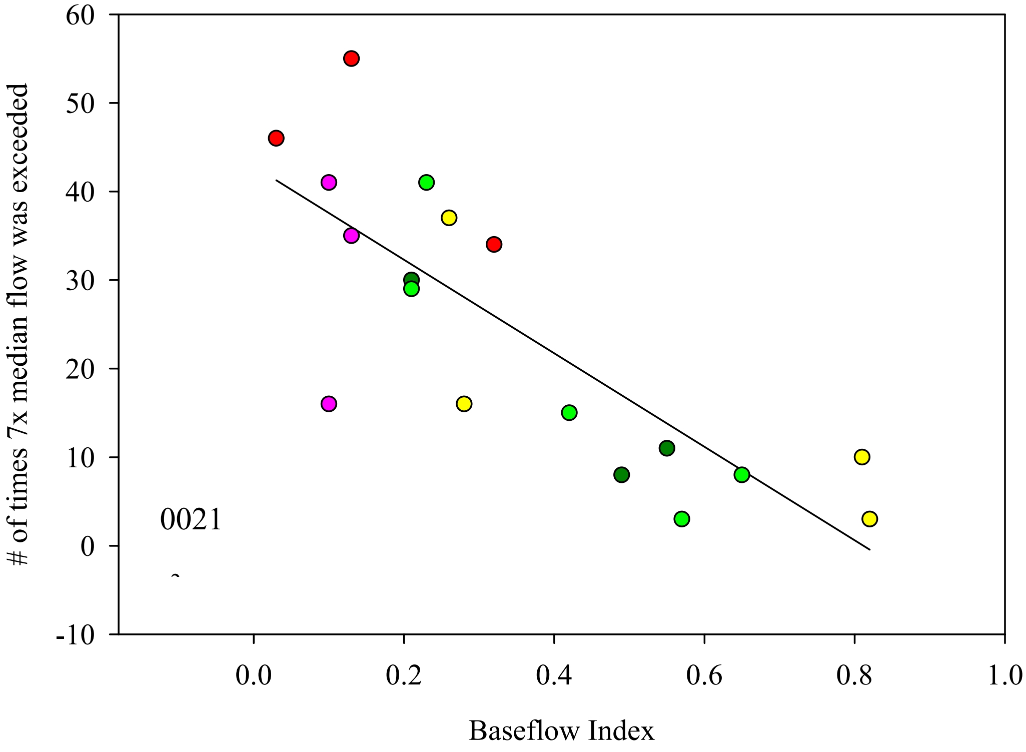


Figure 7. Relationship between baseflow index and the number of times that the 7x median flow was exceeded in 18 west Georgia streams.



CHAPTER 3

3. Changes in Nutrient and Bacteriological Properties of Stream Water Across an Urban-Rural Gradient in Western Georgia

3.1 ABSTRACT

The Middle Chattahoochee River Watershed in western Georgia is undergoing rapid urban development. Between 2000 and 2003, counties within the Chattahoochee drainage have experienced up to 13.7% increases in population growth, and nearly all the Georgia counties within the drainage showed a positive growth increase during this time (US Census Bureau 2005). Consequently, west Georgia's water quality is threatened by extensive development as well as other land uses such as livestock grazing. Maintenance of stream water quality, as land development occurs, is critical for the protection of drinking water and biotic integrity. A 2-phase, watershed-scale study was established to develop relationships among land cover and water quality within western Georgia. During phase 1, nutrient and biological data were collected within 18 sub-watersheds, ranging in size from 500-2500 ha and reflecting an urban-rural gradient in land cover. Data were used to generate regression models between land cover and the streamwater nutrient/biological parameters. Nutrient and fecal coliform concentrations within watersheds having >5% impervious surface often exceeded those in nonurban watersheds during both baseflow and stormflow. Fecal coliform bacteria in urbanized areas often exceeded the US EPA's review criterion for recreational waters. During phase 2, regression models were tested based on data from 6 newly chosen watersheds with

similar land use/cover patterns. Most nutrients and fecal coliform concentrations were accurately estimated using the land cover prediction models generated in phase 2.

3.2 INTRODUCTION

Urbanization is an invasive and rapidly expanding land use pattern in the United States. The southeastern U.S. has been particularly vulnerable to land use conversion, with Texas, Georgia, and Florida leading the U.S. in land development between 1982 and 1997 (USDA-NRCS 2004). With the continuation of escalating population rates the relationship between the human population growth and forest land loss through conversion will likely continue and the demand on an already diminishing natural resource will persist. Hence, methods for forecasting the impacts of land use change in areas susceptible to urbanization are critically important to ensure that land managers and policy makers have the information necessary to make ecologically sound decisions.

In addition to land use conversion, urban sprawl will continue to threaten water resources. In 1998, the US EPA's water quality report to Congress indicated that 291,000 miles of rivers and streams do not meet water quality standards (US EPA 2000). The dominant pollutant sources were urban runoff, storm sewers, and land disposal of waste, which increased bacteria, turbidity, and nutrients in receiving streams (US EPA 2000). Additional, potential problems associated with urban development include increased sediment loadings (Walling and Gregory 1970, Waller and Hart 1986, Wahl et al. 1997), heavy metals (Hunter et al. 1979, Norman 1991, Callender and Rice 2000), nutrients (Emmerth and Bayne 1996, Herlihy et al. 1998, Lee and Bang 2000, Rose 2002), and bacteria (Gregory and Frick 2000).

Investigations of streams and rivers draining the Piedmont physiographic region of the southeastern U.S. have reported that urbanization and land use conversion threaten water quality. Drainage basins near Atlanta, Georgia, have been monitored for concentrations of fecal coliform (Gregory and Frick 2000), major ions (Rose 2002), and phosphorus and sediment (Emmerth and Bayne 1996). Each of these studies reported significant impairments in water quality that was related to urban development.

Landscapes in or near the city of Columbus, Georgia, also in the Piedmont, have undergone extensive urbanization and continue to rapidly develop, particularly in the last decade. Urban development near the city of Columbus is much less expansive than large metro centers such as Atlanta, and consequently, the area surrounding Columbus offers an opportunity to examine water quality influenced by recent development. Further, Columbus's population and land area, as opposed to Atlanta, is more common within the US. Nutrient and bacteriological data are available for the Columbus area (Columbus Water Works 2001), but were collected in relatively large watersheds (~50,000 ha) with a wide array of land covers. This research concentrates on relatively small watersheds (~500-2500 ha) in which relationships between water quality and land cover can be more easily elucidated.

Increased urban pollutants can lead to degraded water quality, poor biological habitat, low aesthetic quality, health hazards, or decreased recreation. To fully understand landscape level nonpoint source pollution, one must understand how particular land covers influence water quality as well as the interactions between multiple land covers within a single watershed. A key question here involves the extent that urbanization affects nutrient and biological aspects of stream health. Because of reduced infiltration and the reduction of soil and water interactions, I hypothesized that water quality will be degraded to a greater extent in watersheds with >5% impervious surfaces compared to all other land covers. This assessment will assist land use planners and environmental managers in estimating potential nutrient- and sediment-related impacts of development within the Piedmont and similar physiographic regions.

3.3 STUDY AREA

A 3-county study area (Muscogee, Harris, and Meriwether) was selected in west-central Georgia to include a gradient in land use/cover from urban to rural. The city of Columbus occupied the most of Muscogee County, which was the most highly urbanized county. The Chattahoochee River, to the west, and Ft. Benning Military Reservation, to the south and east, channeled the development near Columbus to the northeast into southern Harris County, which reflected the transition from rural to urban. Harris County also experienced the highest population growth (33% increase) (U.S. Census Bureau 2005), and consequently urban development during the study period. The northernmost county, Meriwether County, was classified as rural and was characterized by a mosaic of forest and pasture land covers across the landscape. Row crop agriculture was uncommon within the study watersheds. Twenty-four tributaries within the Middle Chattahoochee River Watershed were sampled for an array of streamwater nutrients and fecal coliform bacteria. Detailed methodology for site selection and land cover classification were reported by Lockaby et al. (2005). All watersheds were located within the Piedmont physiographic province north of Columbus, Georgia (Figure 1).

Elevation ranges of the Piedmont are between 152 to 457 meters above sea level (30 to 90 m locally) and the topography is gently rolling to steep. Soils are dominated by udults, which have clayey or loamy subsoil and a kaolinitic or mixed mineralogy (USFS 2005). The soils are underlain by acid crystalline and metamorphic rocks and are typically acidic and low in N and P. Historical cotton farming has eroded 18 cm of the topsoil in many localities, leaving clayey subsoil exposed, and subsequently filling many of the old channels with alluvium (Trimble 1974).

Stream channels selected in this study were predominantly composed of unconsolidated materials in size classes <2mm diameter, while some of the urban channels had coarser substrates (i.e. >2 mm) including both natural and anthropogenic materials (i.e., gravel, rip rap, and/or concrete). Basin circularity ranged from 0.31 to 0.63 and channel slopes were between 0.02 and 0.3%. Further, the deeply incised urban channels lack a tight connection with their floodplains and connectivity within the developing watersheds is declining as well. In contrast, the less-incised forested and pastoral streams retain their floodplain connectivity with overbank flows occurring annually to biennially.

3.4 METHODS

The study was divided into 2 phases. During phase 1, 18 watersheds were sampled for streamwater nutrient and fecal coliform concentrations. Streams for phase 1 ranged in size from 1st to 3rd order (Strahler 1952), and were selected based to reflect an urban-rural land cover gradient. Data from the 18 watersheds were used to generate multiple regression models between land cover and selected water quality parameters (Table 1). The second phase involved sampling 6 additional watersheds that were used to test the prediction models.

3.4.1 Water Collection and Analysis

Water-quality parameters were sampled biweekly in 18 watersheds during winter and spring (Nov.-Mar.) between 1 May 2002 and 3 August 2004, whereas monthly samples were collected during the remaining months. Winter and spring coincides with lower levels of vegetative evapotranspiration, resulting in greater hydrologic connectivity between aquatic and terrestrial systems (Lockaby et al., 1993). This sampling regime has been used successfully in studying relationships between water quality and land cover/use (Basnyat et al., 2000). To test the water quality predictive models (base on land cover) generated from the original 18 watersheds, 6 additional watersheds were selected and monitored from 2 May 2002 thru 6 May 2003 using the same sampling regime as the phase 1 study.

Sampling locations were identified and fixed near the outlet of each watershed. Polypropylene bottles were used for sample collection. Bottles were pre-washed and rinsed with deionized water, and rinsed again three times with stream water from the sampling sites before samples were collected. Pre-rinsed, 200ml tissue culture flasks also were used to sample for all cations and anions to ensure detection of low-level concentrations. Grab samples were collected following guidelines from Lurry and Kolbe (2000). Samples were kept on ice and then refrigerated at 4^{o} C until analyzed. A report from Swank and Crossley (1988) showed that grab sample estimates were within 1 to 5% of the values from proportional sampling techniques (i.e., those integrating baseflow and stormflow).

At each site, stream discharge was recorded with each grab sample to allow for determination of nutrient loads. Discharge was determined by measuring the velocity and cross-sectional areas of sub-sections across the stream channel. Generally, at least 20 sub-sections, at 0.1, 0.2, or 0.5 m intervals depending on channel width, were measured perpendicular to the stream channel according to Rantz (1982). A Marsh-McBirney Flo-Mate 2000® (Marsh-McBirney 1990) was used to measure the velocity within each subsection.

Stream stage was also monitored throughout the study period in the 18 original watersheds and discharge-stage rating curves were developed for each stream. Stream stage was recorded using InSitu MiniTroll® (InSitu, Laramie, Wyoming) pressure transducers that were housed within stilling wells at the fixed sampling locations. Hydrological data for the streams are discussed in more detail by Schoonover et al. (2005).

Grab samples were analyzed within 48 hr of collection for nutrients. Anions and cations (NO_3^-, Cl^-, SO_4^{2-}, Na^+, NH_4^+, and K^+) were analyzed using a DX-120 Ion Chromatograph (Dionex, Sunnyvale, California). Total P was measured using the molybdate-blue method (Murphy and Riley 1962, Watanabe and Olsen 1965). Dissolved organic carbon (DOC) analysis was performed using a Rosemont DC80 organic carbon analyzer. Fecal coliform (FC) colonies were isolated on sterilized, nitrocellulose membrane filters (0.47 um pore size, 47mm diameter, Millipore Corporation, Billerica, Massachusetts) following APHA (1998). Fecal coliform samples were filtered and placed on agar plates within 6 hr of collection, samples were incubated in a water bath at 44.5°C for 24±2hr.

Daily precipitation data available from the National Climatic Data Center (NCDC, Ashville, NC) were used for seasonal precipitation estimates. Three sampling stations across the study area were monitored to ensure that sufficient coverage was available. Weather stations used in this study were located at the Columbus Metropolitan Airport (#092166/93842) and at the towns of West Point (099291), and Woodbury (099506). The 30-yr rainfall averages were based on the Columbus, West Point, and Woodbury stations, where historic data from 1948-, 1931-, and 1931-present were available, respectively

3.4.2 Statistical Analyses

Five dominant land cover categories were determined from <1 m aerial photographs; these included: unmanaged forests (dominated by mixed hardwood stands), managed forests (silviculturally managed systems), pasture (cattle grazing and/or forage production), developing, and urban. The developing land cover was separated from the other cover types by evidence of subdivisions and active construction sites. Land cover (i.e., managed and unmanaged forest, pasture, impervious surface) proportions were independent variables and the nutrient and bacteriological parameters were the response variables in analyses. In some of the following analyses, individual land cover classes were treated as categorical variables, and it should be noted that multiple land covers were present within all watersheds and interactions may be unaccounted for in the particular tests. The land use categories are identified in Table 1. Additional categories (e.g., urban and nonurban, pastoral and nonpastoral) were tested when clear breaks in land use separated the categories. For example, urban and nonurban and pastoral and nonpastoral were separated at impervious surface levels of 5% and pasture proportions of 25%, respectively.

Data from phase 1 and 2 were compared using a nonparametric Kruskal-Wallis test. This distribution-free analysis was also used for comparisons among land covers. MAXR regression was used to develop regression models between land cover variables and abiotic and bacteriological parameters. When dependent variables were not normally distributed according to Anderson-Darling tests (SAS Institute 2004), they were $\log_{10}$-transformed before being used in regression or correlation analyses. Regression models were created using the median annual concentrations of streamwater nutrient and bacterial concentrations from the 18 original watersheds sampled for two years. Models were tested for accuracy using median concentrations from six additional watersheds that were sampled for 1 year.

MAXR regression was used to ensure that any possible combination of predictor variables could be incorporated into model development. MAXR selects the one-variable model with the highest r^2, followed by the best two-variable model, etc., until a full model (i.e., all independent variables included) is estimated (Cody and Smith 1997). R^2 and Mallow's Cp (the total square errors, which indicates lack of fit) were assessed in the final outputs, in which, a high r^2 and a low Cp indicate the best predictive models (Yu, 2000). Models are tested in a stepwise process; therefore, the models can range in the number of predictor variables in the final model. SAS Version 8 software was used for all statistical analyses (SAS Institute, 1999).

3.5 RESULTS AND DISCUSSION

Precipitation was slightly lower than the 30-yr average for the 3 county study area during both years (Figure 2). Seasonal variation between years 1 and 2 was low; although, across all land covers combined, stream discharge was significantly higher during year 2 ($p=0.0071$). Higher discharges were recorded during the spring and summer, which coincided with the timing of slightly higher rainfall amounts in year 2.

Median annual streamwater nutrient concentrations were higher during year 1, which is likely due to a concentration effect from the lower discharge. Higher chloride concentrations, which is a conservative tracer, also supported the evidence of concentration during year 1 ($p<0.0001$). However, with the increased discharge during the second year, the nutrient loads were not significantly different between the years. Annual trends for nutrients and their relationship to land cover were similar during both years, thus the two annual datasets were combined. The observed nutrient and fecal coliform trends were also similar to the preliminary investigation of the watersheds (Schoonover 2005).

3.5.1 Nutrients

Median concentrations of Cl^-, NO_3^-, SO_4^{2-}, and K^+ were higher during both baseflow and stormflow in watersheds with >5% impervious surface (IS) (i.e., urbanized watersheds) cover compared with all other land covers combined (Table 2). The urbanized watersheds also had greater Na^+ concentrations during baseflow and higher NH_4^+ concentrations during stormflow. At the Hubbard Brook Experimental Forest, Na^+ concentrations were predictably diluted as stream flow increased (Likens et al. 1967), which was similar to the effect observed in watersheds with urban and to a lesser extent in watersheds with <5% IS. In contrast, the increase in NH_4^+ concentrations during storm flow in urban streams is likely due to increased inputs of sewage effluent and/or lawn/garden fertilizers. In nonurban watersheds all nutrient concentrations were lower during storm flow than base flow, due to dilution, with the exception of SO_4^{2-}. Rose

(2002) reported the same trend with SO_4^{2-} in Piedmont watersheds near Atlanta, Georgia where desorption of sulfate from shallow soil horizons was assumed to be the contributor during stormflow. Sulfate concentrations did not increase in urban storm flow, but remained higher than non urban concentrations. Overall trends for anion and total P concentrations during base flow followed the same trend that emerged during a preliminary investigation of the west Georgia streams, where $Cl^- > SO_4^{2-} > NO_3^- >$ total P (Schoonover et al. 2005). Cation concentrations were ranked in the following order: $Na^+ > K^+ > NH_4^+$.

In urbanized (i.e., >5% IS) streams, NO_3^-, NH_4^+, and fecal coliform (FC) concentrations all increased during stormflow (Table 2), an effect that may be attributed to septic drain fields, dysfunctional sewage lines, combined sewer overflows (CSOs) inputs, and/or pet waste. A study of urban streams in the Northeast U.S. showed that elevated N was more prevalent in watersheds with septic tank systems rather than sewered watersheds (Steffy and Kilham 2004). However, in aging cities like Columbus, the condition of the sewer systems, the carrying capacity of drainage pipes, and CSOs are all factors that can potentially influence stream inputs. In southern Columbus, near-stream manhole covers on sewage lines were commonly displaced following large rainfall events (personal observation), causing direct inputs of untreated sewage to the streams.

DOC concentrations were also significantly higher in watersheds with >5% IS, which also may reflect inputs of sewage. Elevated DOC concentrations could also potentially originate from other anthropogenic sources, such as grass clippings or other organic yard waste. Residential areas were typically mowed weekly from spring to fall, and occurrence of yard wastes disposed directly into stream channels or gullies was common (personal observation). Additionally, increased nutrient inputs in urban streams could lead to increased autochthonous production of DOC concentrations (Parks and Baker 1997).

Nitrate concentrations were elevated in both urban (i.e., >5% IS) and pastoral (i.e., >25% grazed) watersheds. However, the transport paths were likely different in the two streams. Baseflow indices (BI) were calculated for each watershed and are listed in table 4. A thorough discussion of BI calculations was presented in the previous chapter (Chapter 2). High baseflow indices suggest significant streamflow contribution from groundwater, whereas watersheds with low baseflow indices are predominantly recharged from surface runoff inputs (Gustard 1992, Jordan et al. 1997, Schoonover et al. 2005). Thus, in pastoral watersheds, mobile ions (e.g., NO_3^-) likely enter the stream through groundwater while in urban watersheds evidence suggests that NO_3^- reached the streams via surface runoff or by sources such as leaky pipes or CSOs.

Nutrient loads followed a nearly identical pattern as the concentration data, except that Na^+ was highest in urban streams during both base flow and storm flow. NH_4^+ loads were higher in watersheds with >5% IS during storm flow, which suggests that an outside source may contribute during elevated flows. Again, sewage effluent overflows or leakages were potential sources during wet weather conditions in urban streams.

3.5.2 Fecal Coliform

Kruskal-Wallace tests showed fecal coliform concentrations were highest in streams with >5% IS during both baseflow ($p<0.0001$) conditions and stormflow ($p<0.0001$) (Figure 3). Furthermore, urban streams exceeded the US EPA's review criterion (400 Most Probable Number, MPN) during both flow conditions. Across all flows, fecal coliform was positively correlated (r=0.85, p=<0.0001) with the proportion of impervious surfaces in the watersheds. Median concentrations were below the review criterion for all other land covers. Similarly, the Columbus Water Works reported much higher fecal coliform concentrations in Columbus, Georgia as opposed to rural areas. Fecal coliform counts of 25,000 MPN $100ml^{-1}$ were reported in urban streams during stormflow (Columbus Water Works 2001). Also within the Chattahoochee watershed, an investigation by Gregory and Frick (2000) reported that 27-100% of the samples collected from 22 tributaries to the Chattahoochee River near Atlanta, Georgia exceeded the USEPA review criterion for fecal coliforms. Tufford and Marshall (2002) reported that highest fecal coliform concentrations occurred in sub basins with the greatest proportions of commercial and mixed urban land use/cover in the Piedmont.

Streams with high proportions of unmanaged forests and low IS (i.e. <5%) may reflect an estimate of natural wildlife fecal coliform inputs to streams. However, in this study, in streams draining watersheds dominated by managed forest had fecal coliform concentrations slightly lower than those of unmanaged, forest-dominated watersheds during stormflow (p=0.0219), but not base flow (p=0.0956). This relationship could potentially result from habitat diversity differences among the forest types or may be influenced by sources that were not evident in the mixed land use watersheds. In our study area, managed forests were represented by monocultures of pine trees, predominantly loblolly (*Pinus taeda* L.). Even-aged pine plantations have reduced instand structural diversity, subsequently leading lower habitat diversity resulting from low vertical stratification, which may ultimately reduce species richness and diversity

(Marion et al. 2002). Negative correlations exist between fecal coliform and the proportions of unmanaged (r=-0.62, p=0.0068) and managed forest (r=-0.59, p=0.0100) land covers in the watersheds.

Many of the streams in the heavily grazed watersheds (i.e., >25%) were freely accessed by cattle and fecal material was common in and near the stream channels (personal observation). Surprisingly, exception for a few extreme events, these streams did not maintain high fecal coliform concentrations. Schoonover et al. (2005) reported that hydrology of pasture watersheds was dominated by groundwater inputs; thus, surface runoff inputs may have been of insufficient volume and/or energy to transport fecal coliform bacteria from the pastures to the streams. Coliform bacteria have also been reported to preferentially bind with sediment, thus the dense grasses may have facilitated bacterial settling in the terrestrial environments (Schillinger and Gannon 1982). Moreover, bacterial settling in stream beds of the pastoral channels is most likely a result of the stream's stable- and baseflow-dominated discharges (Chapter 2), which would present lower shear stresses and minor sediment entrainment.

Fecal coliform varied seasonally with air temperature (Figure 4). From October thru March, fecal coliform counts were suppressed whereas in summer counts became elevated. Wang et al. (2002) reported that terrestrial fecal coliform mortality/growth was more influenced by temperature than moisture. Specifically, three temperature treatments showed that fecal coliform counts were highest at 27°C, followed by 4°C, and then 41°C. Also, fecal bacteria were found within the 4°C and 27°C samples for 103 days (Wang et al. 2002).

3.5.3 Predictive Models

Predictive equations for nutrients and fecal coliform are presented in Table 5. For NH_4^+, no significant prediction equation was developed. To broaden the applicability of the models, hydrology data were not included, thus allowing greater utility in land use decision making processes (i.e., by not requiring pre-collected streamflow data). Data used in the equations were collected from 18 watersheds between 2 May 2002 and 3 August 2004. To test the accuracy of the models, 6 additional watersheds from diverse land cover compositions were sampled for 1yr between 22 May 2002 and 6 May 2003 (Table 6).

Ninety-five percent confidence intervals were calculated for each parameter based on the difference between measured and predicted values (Table 5). According to the confidence intervals, most parameters, except for DOC and FC, were underestimated by the prediction equations. FC was overestimated in all watersheds except FS1, which was dominated by pasture, and WC, which was a highly urbanized (49% IS) watershed. Similarly, NO_3^- was overestimated in 4 watersheds, except for FS1 and WC. Trends in the data suggest that watersheds with one dominating land cover (such as, pasture and impervious surface) underestimate parameters that are commonly associated with those land covers. For example, high NO_3^- and FC are commonly associated with cattle grazing and urban development, and both were underestimated in the urban and pastoral test watersheds. In fact, all parameters, except DOC, were underestimated in these two watersheds.

The measured median concentrations for test watersheds are presented in Table 7. Weracoba Creek (WC) is an urban watershed (49% IS) and had considerably higher nutrient and FC concentrations than the other 5 watersheds, which followed the same trend as the original 18 watersheds. Both the unmanaged and managed forest-dominated watersheds (BSB, FPWB, FS5, and FS6) had low levels of NO_3^-, NH_4^+, and fecal coliform, whereas FS1, a heavily grazed watershed, had intermediate levels of nutrients and fecal contamination.

To further explore the effects of land use/cover change on water quality, 6 theoretical land cover scenarios were developed based on current and historical land use/cover change patterns in west Georgia (land cover proportions for each scenario are presented in Table 8). IS ranged from 1.24 and 41.94% in the original 18 watersheds; however, watersheds having proportions between 4 and 24% were not well-represented; thus, scenarios 1 and 2 filled the gap in impervious cover data. Land cover scenarios 3-6 predict the effects of further urban development on water quality (land cover percentages for each scenario are presented in Table 8). The foundation for the development of scenarios 3-6 originates from research by Zhang et al. (2005), where an extensive study on historical land cover change was conducted on the 3 county study area of west Georgia. Their results indicated that between 1974 and 2002, urban land cover increased by more than 380%, with ~63% of the new urban areas being converted from forest land. Further, they found that crop land was reduced by 59% during the 28 yr period, which was typically converted back to forest cover. The total forested area changed very little during the time period due to the counteractive effects between cropland abandonment and urbanization; however, spatial distributions may have changed notably. Their findings did not differentiate between unmanaged and managed forests, but according to the 2003 land cover trends it appears that plantation forests (i.e., managed) may be more resistant to development than natural forests (i.e., unmanaged). In further support for the land use scenario development, the Southern Forest Resource Assessment projects that urbanization will continue over the next 3-4 decades and that rising timber prices may drive agricultural land uses towards timber production (Wear and Greis 2002).

Predictions for nutrient and fecal coliform concentrations are reported in Table 8. Cl^-, NO_3^-, and FC concentrations are predicted to increase as urban development increases. Between 10 and 20% IS, FC concentrations exceeded the US EPA review criterion of 400 MPN 100 ml^{-1}. Pastoral land cover was correlated with NO_3^- and total P concentrations, thus the levels decreased as IS increased. NO_3^- levels peaked in scenario 2, which had 32.5% pasture and 20 IS. NO_3^- concentrations were predicted to exceed the drinking water standard (45 mgL^{-1}) when the proportion of pasture in watersheds reaches 70% and all other land covers are equal (i.e., 10% each).

The use of predictive equations allows city planners to model various scenarios of landscape alterations and observe the effects on water quality. One potential limitation of this method would be the presence of point-source-pollutants (PSP) or combined sewer overflows (CSOs). For instance, in Weracoba Creek (WC) the predictive models estimated NO_3^- concentrations to be 0.55 mgL^{-1}, and actual measured values were 7.65 mgL^{-1}. WC includes the older, industrial portion of Columbus, Ga. that was drained by a CSO network and had three industrial stormwater permits issued for discharge into the stream as of 6/7/2000 (Environmental Protection Division of Georgia Department of Natural Resources 2005). Thus, the potential for erroneous estimates of nutrients and bacteriological concentrations under such scenarios is highly probable; however, difficult to model due to the variability among pollutants associated with different contributors of PSPs.

3.6 CONCLUSIONS

The above discussion recognizes pervasive impacts of urban development on streamwater quality in terms of nutrient and fecal contamination. Streams with >5% IS were subjected to higher concentrations and loads during both base flow and storm flow for fecal coliform and for most macro nutrients. Fecal coliform counts exceeded the US EPA's review criterion during both baseflow and stormflow. Perhaps, our sampling techniques (grab samples near mid water column) did not capture a true estimate of fecal contamination in other watersheds. Streams with fine channel substrates may induce high fecal coliform binding and settling, thus a sampling technique that involves collecting an additional bed sample for fecal coliform analysis may offer a greater awareness to fecal contamination.

Clean water not only reduces the cost of water purification for consumptive uses, but serves as a crucial habitat for many aquatic species. Also, streams draining residential areas and urban parks attract children, making human health risks a significant concern. Thus, establishment of predictive models based on land cover for bacteria and nutrient water quality indicators is essential for planning and policy decisions in areas subject to urban development. Moreover, fecal coliform prediction provides an indication of the potential health risks posed by excess contamination. Hence, the development of location-specific predictive models is critical to achieve sound land development decisions designed to protect water quality.

Individual land covers were treated as categorical variables for a subset of analyses in this study. Thus, it is important to reiterate that the watersheds were composed of a variety of land covers, and that complex interactions of land cover types can be undetected in the categorical analyses. In situations where clear categorical separations were not evident (e.g., using five separate land cover classes), results may be subject to errors that cannot be accounted for. Furthermore, if PSPs were discharged into any of the streams, my categorical results could potentially be invalid. Even though categorical separations were based on clearly defined breaks in land cover proportions, it is important to be aware that the categorical analyses should be interpreted with the aforementioned limitations in mind.

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Table 1. Land cover ranges within 18 watersheds of western Georgia. Numbers in parentheses represent the number of watersheds in each category.

Digitized Land Cover Ranges	**Land Cover Category**				
	Urban (3)	**Developing (3)**	**Pasture (4)**	**Managed (4)**	**Unmanaged (4)**
Impervious Surfaces	24.9-41.9	1.8-3.4	1.6-3.7	1.2-2.6	1.2-2.3
Evergreen Forest	20.9-30.5	37.3-41.2	29.3-32.8	42.4-48.31	36.4-48.1
Deciduous Forest	11.1-15.9	22.8-35.4	22.2-29.9	25.0-33.0	28.2-37.9
Grass	14.8-24.9	19.9-20.3	33.2-44.0	13.0-20.8	13.2-19.8

Table 2. Median concentration data (mg L^{-1}) for streamwater nutrients, dissolved organic carbon (DOC), and fecal coliform (FC) in 18 west Georgia watersheds.

	Base flow (mg L^{-1})				**Storm flow (mg L^{-1})**			
	<5% IS[††], (n=182)		**>5% IS, (n=43)**		**<5% IS, (n=198)**		**>5% IS, (n=43)**	
	Median	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**
Cl^-	3.43	0.13	**9.46**	0.40	2.87	0.09	**6.30**	0.32
NO_3^-	0.61	0.09	**1.64**	0.16	0.36	0.07	**1.93**	0.14
SO_4^{2-}	1.58	0.20	**8.04**	0.58	2.15	0.13	**6.86**	0.42
Na^+	6.4	0.67	**10.01**	1.01	5.14	0.22	5.17	0.56
NH_4^+	0.00	0.02	0.00	0.03	0.00	0.01	**0.15**	0.02
K^+	2.45	0.21	**4.24**	0.51	1.80	0.05	**3.28**	0.40
Total P	0.08	0.00	0.09	0.01	0.08	0.00	0.09	0.01
DOC	2.44	0.27	**4.73**	0.47	3.64	0.22	**5.52**	0.20
FC*	120	28	**430**	134	167	54	**1600**	561

Significance was tested using nonparametric statistics (Kruskal-Wallis).

* Measured in most probable number per 100 milliliters (MPN 100ml^{-1})

† Statistical differences (α=0.05) are represented by bold numbers, tests were within similar flow regimes (i.e., base flow or storm flow).

†† Impervious surface

Table 3. Median load data (g d^{-1} ha^{-1}) for streamwater nutrients and dissolved organic carbon (DOC) in 18 west Georgia watersheds.

	Base flow (g d^{-1} ha^{-1})				**Storm flow (g d^{-1} ha^{-1})**			
	<5% IS[††], (n=182)		**>5% IS, (n=43)**		**<5% IS, (n=198)**		**>5% IS, (n=43)**	
	Median	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**
Cl^-	15.46	1.13	**30.03**	3.54	24.77	2.89	**76.44**	17.68
NO_3^-	1.55	1.07	**5.66**	1.44	3.12	1.55	**17.34**	6.93
SO_4^{2-}	7.01	0.78	**22.70**	3.23	17.53	4.16	**68.03**	23.04
Na^+	27.00	1.80	**31.81**	5.56	38.54	4.07	**57.15**	19.02
NH_4^+	0.00	0.07	0.00	0.13	0.00	0.11	**2.03**	0.78
K^+	11.82	0.70	**14.95**	2.75	13.81	1.95	**35.18**	14.90
Total P	0.20	0.03	0.25	0.03	0.43	0.19	0.59	1.26
DOC	11.06	1.00	**15.96**	1.86	22.31	10.35	**51.19**	27.93

Significance was tested using nonparametric statistics (Kruskal-Wallis).

† Statistical differences (α=0.05) are represented by bold numbers, tests were within similar flow regimes (i.e., base flow or storm flow)

†† Impervious surface

Table 4. Baseflow index and median nitrate concentration for 18 streams draining the Piedmont of west Georgia.

Watershed ID	**Dominate Land Cover**	**NO_3^- (mg L^{-1})**	**Baseflow Index**[†]
BU1	Urban	1.99	0.32
BU2	Urban	1.61	0.03
RB	Urban	1.74	0.13
SB1	Developing	0.14	0.13
SB2	Developing	0.10	0.10
SB4	Developing	0.79	0.10
FS2	Pasture	3.02	0.82
FS3	Pasture	3.21	0.26
HC2	Pasture	4.59	0.81
MU1	Pasture	0.17	0.28
CB	Managed Forest	0.08	0.42
HC	Managed Forest	0.63	0.55
MU2	Managed Forest	0.10	0.21
SC	Managed Forest	1.72	0.49
BC	Unmanaged Forest	0.76	0.57
BLN	Unmanaged Forest	0.28	0.65
MK	Unmanaged Forest	0.56	0.23
MU3	Unmanaged Forest	0.22	0.21

[†] Base flow index is a measure of groundwater contribution into stream (∑ predicted baseflow/ ∑ observed baseflow)

Table 5. Multiple regression models based on median streamwater concentrations (mg L^{-1}) for nutrients, and DOC, and MPN $100ml^{-1}$ for FC) during all flows, dependent variables were log-transformed to meet normality assumptions.

Parameter	**Prediction Equation**†	**r^2**	***p*-value**	**95 % Confidence Interval**
log Cl^-	y = -0.04(IS)-0.06(M)-0.09(E)-0.06(Ag)+8.22	0.83	<0.0001	-1.82 to 0.80
log NO_3^-	y = 0.25(IS)+0.19(M)+0.27(E)+0.31(Ag)-24.90	0.63	0.0075	-4.69 to 2.03
log SO_4^{2-}	y = 0.04(IS)-0.03(Ag)+1.19	0.60	0.0011	-3.59 to 0.68
Na^+	y = -0.43(IS)-0.40(M)-0.69(E)-0.57(Ag)+58.13	0.56	0.0211	-11.51 to -1.37
log K^+	y = 0.007(IS)-0.02(M)+1.21	0.77	<0.0001	-3.51 to 0.12
Total P	y = -0.005(IS)-0.005(M)-0.005(E)-0.004(Ag)+0.54	0.72	0.0014	-0.03 to -0.01
log DOC	y = -0.12(IS)-0.12(M)-0.18(E)-0.14(Ag)+15.34	0.53	0.0333	-3.34 to 4.35
log FC	y = 0.06(IS)+4.85	0.69	<0.0001	-80.90 to 88.67

† IS = % Impervious surface, M = % Mixed forest, E = % Evergreen forest, Ag = % Pasture.

†† 95% confidence limits represent the difference between the measured and predicted values from the six newly chosen watersheds. Confidence values for nutrients are reported in mg L^{-1} and MPN $100ml^{-1}$ for FC.

Table 6. Land cover percentages of 6 west Georgia watersheds used to test the regression models presented in table 5.

ID	Impervious	Evergreen	Deciduous	Grazing
BSB	1.7	47.4	36.3	14.0
FPWB	1.0	40.3	36.9	19.9
FS1	2.5	32.8	29.0	33.2
FS5	1.2	46.3	36.1	15.2
FS6	0.7	48.0	24.7	24.8
WC	49.5	22.2	10.2	12.9

Table 7. Median streamwater nutrient concentrations for the 6 watersheds used to test predictive models.

ID→	**BSB**		**FPWB**		**FS1**		**FS5**		**FS6**		**WC**	
Parameter	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**
Cl^-	2.40	0.44	2.78	0.24	4.34	0.36	2.51	0.19	2.76	0.29	20.46	1.95
NO_3^-	0.00	0.03	0.39	0.06	4.42	0.28	0.82	0.16	0.32	0.09	7.65	0.64
SO_4^{2-}	1.77	0.09	1.96	0.11	1.50	0.10	3.95	0.50	3.93	1.15	21.1	1.65
Na^+	5.19	0.93	8.34	1.47	6.85	1.23	7.25	1.67	8.74	1.71	25.67	3.63
NH_4^+	0.00	0.00	0.00	0.00	0.05	0.07	0.27	0.06	0.14	0.06	2.19	0.35
K^+	3.29	0.49	3.88	0.88	3.68	0.84	1.98	0.7	1.64	0.52	8.45	1.74
Total P	0.08	0.02	0.08	0.02	0.10	0.02	0.10	0.02	0.09	0.01	0.11	0.02
DOC	1.25	0.32	1.41	0.20	1.67	0.13	3.42	0.37	5.11	0.41	3.86	0.58
FC	80.00	60.02	120.00	74.06	285.00	74.08	84.00	40.18	60.00	81.27	2530.00	656.21

Table 8. Predicted water quality of 6 theoretical land use/cover scenarios based on current and historical land use change trends.

Scenario	**Managed Forest**	**Unmanaged Forest**	**Pasture**	**Impervious Surface**	**Chloride**	**Nitrate**	**Sulfate**	**Total P**	**Fecal Coliform**
1	30	25	35	10	5.31[†]	2.46	1.72	0.08	232.76[††]
2	30	22.5	32.5	20	5.18	7.03	2.76	0.05	424.11
3	10	10	20	60	22.65	2.46	19.89	0.05	4675.07
4	7	13	10	70	25.28	1.72	40.04	0.05	8518.54
5	5	10	5	80	33.78	1.35	69.41	0.04	15521.79
6	2.5	5	2.5	90	47.94	1.22	111.61	0.04	28282.54

[†] Concentrations (mg L^{-1})

[††] MPN 100ml^{-1}

Figure 1. Study locations in west Georgia, USA. Polygons represent the watersheds under investigation.

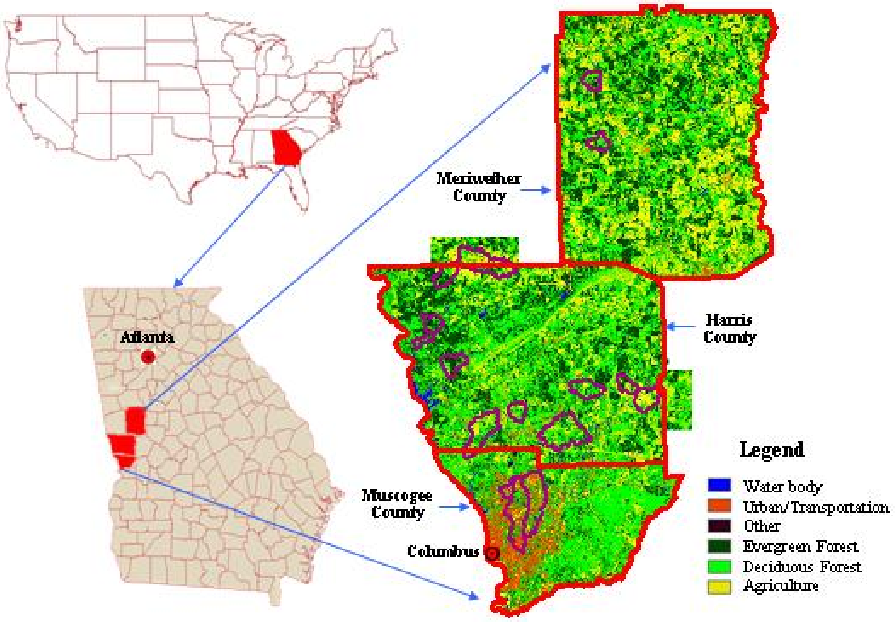


Figure 2. Seasonal precipitation data during the study period in west Georgia. Mean values were calculated from 4 long-term rainfall stations distributed throughout the study area.

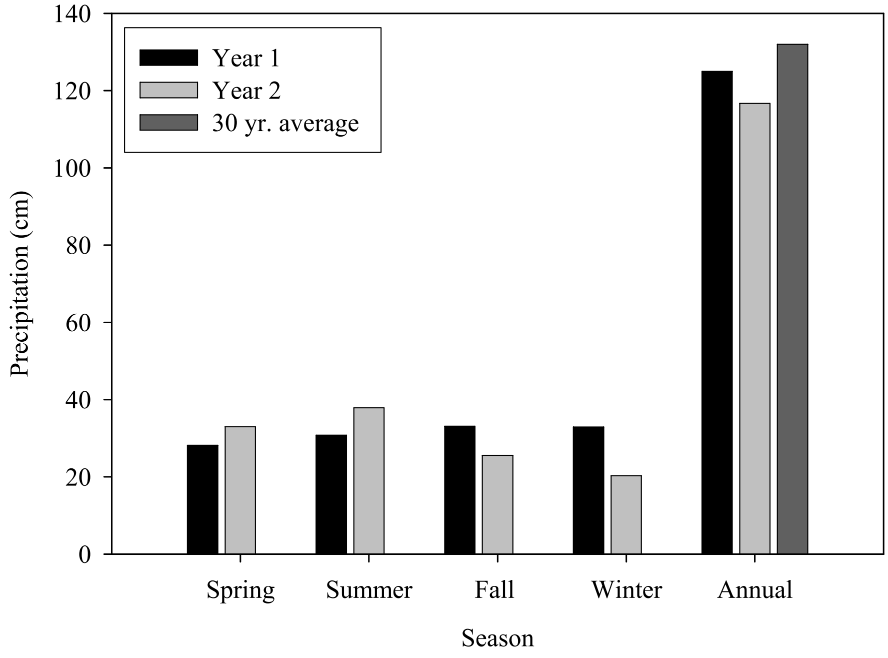


Figure 3. Median (±1SE) fecal coliform concentrations for 18 streams draining the Piedmont of west Georgia.

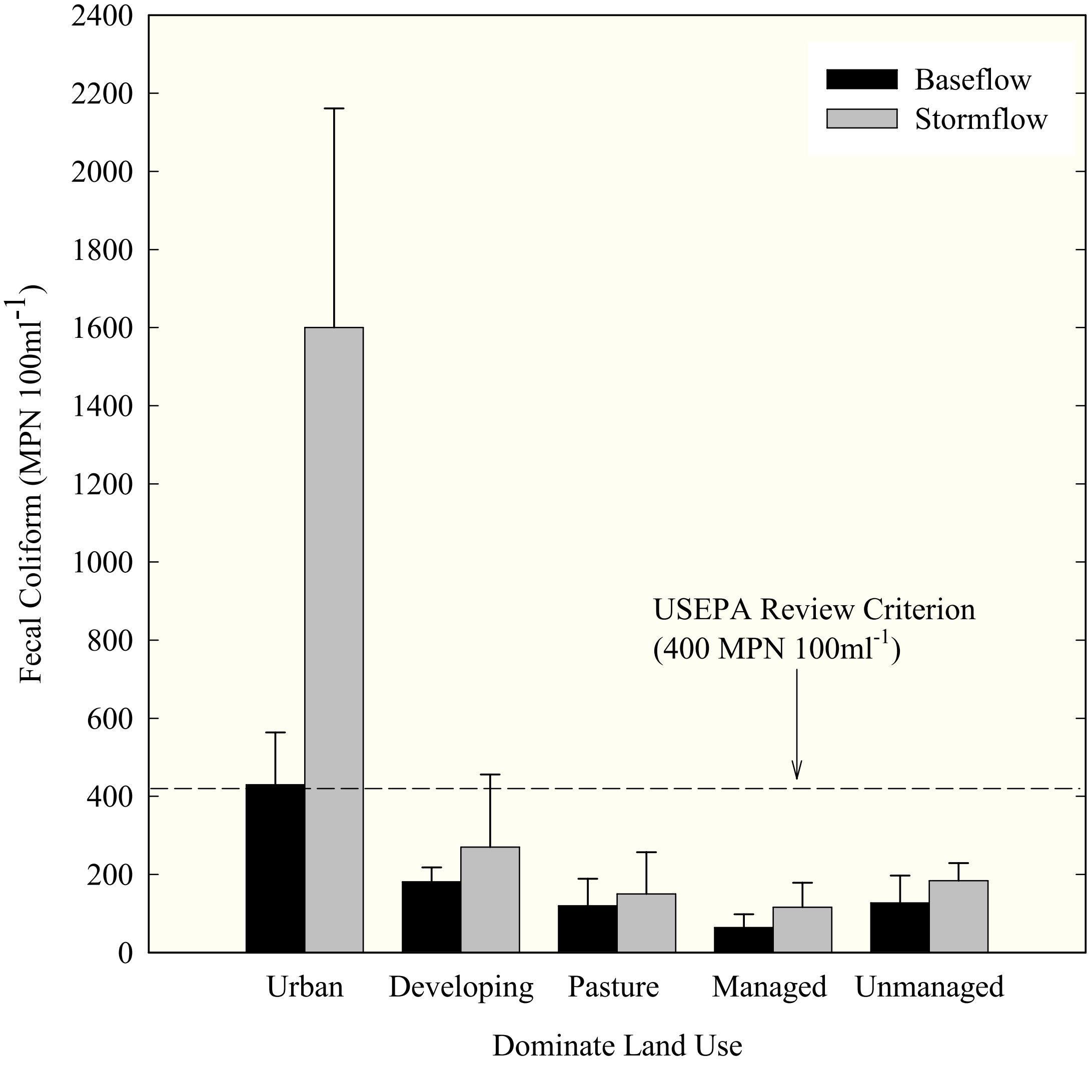
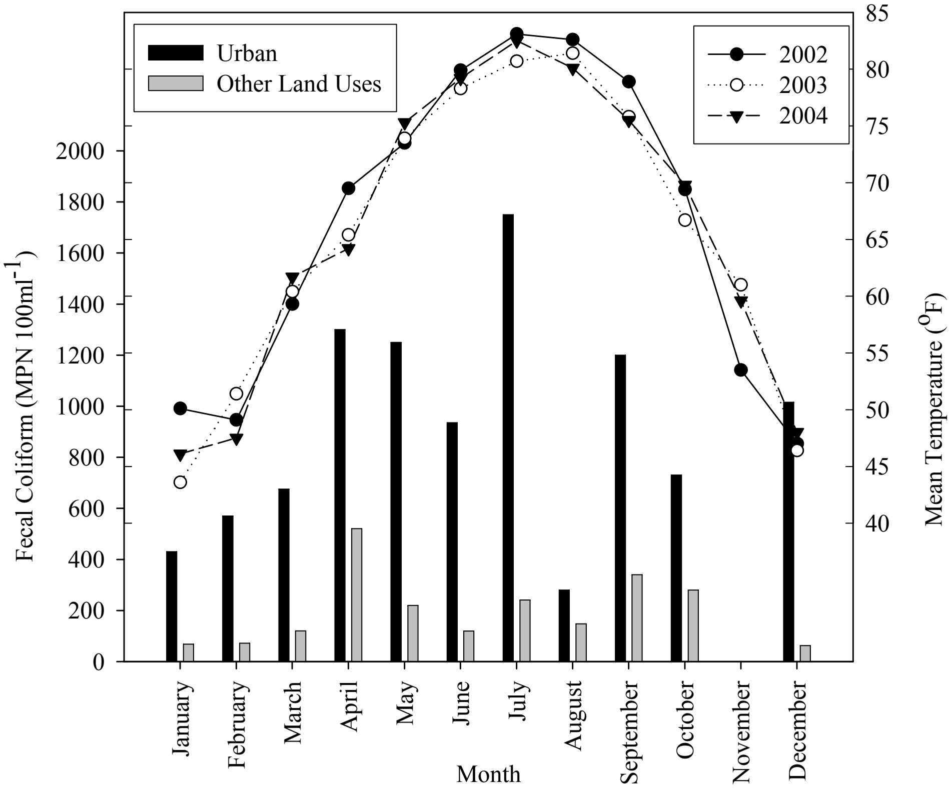


Figure 4. Monthly fecal coliform counts (bars) of urban watersheds vs. all other land uses combined in relation to mean annual air temperature (trend lines).



CHAPTER 4

4. Channel Morphology and Sediment Movement.

4.1 ABSTRACT

Urbanization is common across much of the U.S.; however, the Southeast, including the Georgia Piedmont, is developing much faster than other regions of the U.S. (USDA, NRCS 2004). Consequently, water resources in the Middle Chattahoochee Watershed of western Georgia are threatened by increased sedimentation and hydrological alteration from extensive development as well as from other land uses such as livestock grazing and silviculture. A 2 yr study was developed to assess sediment movement and hydrology within 18 watersheds across a land use gradient. Watersheds ranged in size from 500-2500 ha and each was instrumented with stream stage monitoring equipment. Biweekly grab samples and stacked-pole samplers were used to determine instream total suspended solid (TSS) and total dissolved solid (TDS) concentrations during both base flow and storm flow. Multiple headwater cross-sections and sediment grids were measured routinely and following storm events to assess streambed stability. Higher TSS loads were present in nonurban watersheds during baseflow conditions. However, during stormflow, TSS loads dramatically increased within watersheds having >5% impervious surface cover and watersheds that have experienced intensive silviculture. In urban watersheds an initial flush during storm events was evident with stacked-pole data, where peak TSS loads occurred at ~1 m stage

during storm events. Furthermore, stream cross-sections and grids suggest that urban and pastoral streams have highly unstable stream channels, with fill and scour being common.

4.2 INTRODUCTION

Urban sprawl and land use conversion threaten streams throughout the US. Anthropogenic influences such as channelization, forest clearing, and impervious surface construction have detrimental impacts on streams and their associated flood plains such as flooding, channel widening, and sedimentation. Schueler (1995) reported stream degradation occurring with as little as a 10% increase in impervious surfaces. Direct effects from impervious surfaces such as increased sediment delivery to streams, decreased channel stability, and hydrological alteration can negatively affect biotic habitat and species.

Many investigations relating the effects of land use on channel stability and sedimentation have used historical comparisons of cross-sections, hydraulic geometry measurements, detailed field surveys, or measurements from topographic maps (Gregory et al. 1992). These investigations have importance for historical and point assessments. However, assessment impacts of stream biota and their habitats require finer sampling resolution. The importance of spate flow events on biotic integrity can be high (Clausen and Biggs 2000, Helms et al. 2005). Stream organisms can be displaced, injured, or killed during spate flow events and the substrates they utilize as habitat can be buried or scoured (Power and Stewart 1987).

The southeastern US is particularly vulnerable to sedimentation and channel instability issues from ever-increasing urban development and the residual alluvium present from the cotton farming era (Trimble 1974). Investigations of humid regions of the U.S. have reported that channel instability and reduction in biotic integrity are evident at impervious surface levels as low as 10 to 20 % (Booth and Reinalt 1993, Schueler 1995). Metropolitan areas such as Atlanta, Georgia, and on a smaller scale, Columbus, Georgia, have increased impervious surfaces to greater than 50% of the total land cover in many watersheds, and such disturbances threaten the sustainability of fishes, invertebrates, reptiles, and amphibians within the lower Piedmont physiographic province. The city of Columbus, Georgia offered a unique opportunity to investigate the effects of land use on channel stability and sediment transport in the Piedmont physiographic province. Columbus is bordered on the west by the Chattahoochee River (also the Georgia/Alabama state boundary) and on the south and southeast by the U.S. Army's Ft. Benning installation, and consequently, urban development has been constrained to a northeastern direction, thus creating a gradient from urban to rural land uses. Additionally, the Columbus is mid-sized, and thus is closer in population size to most U.S. cities, as opposed to large metropolitan areas (e.g. Atlanta, Georgia).

This assessment investigates the effects of land use on channel stability and sediment transport. A primary objective was to provide a morphological assessment based on channel changes during individual storm events and quarter-annual cross-sectional measurements. Additionally, total suspended solids and total dissolved solids were sampled routinely and during storm events to compare concentrations and loads across an array of land use/covers.

4.3 METHODS

4.3.1 Study Area

The study area spanned 3 counties and an array of land uses and population densities (Figure 1) (Lockaby et al. 2005). The city of Columbus (N32.51130 W84.87499) covers most of Muscogee County, which was the southernmost and most highly urbanized county in this study. Harris County reflects the transition from urban to rural and has experienced urban encroachment stemming from the city of Columbus. The northernmost county, Meriwether County, was classified as rural with a mosaic of forest and pasture land uses. Row crop agriculture was uncommon within the study watersheds. Watersheds were drained by 1st to 3rd order streams and ranged in size from ~500-2500 ha (Strahler, 1952).

High-resolution (1 m) aerial photographs were taken in March (leaf-off) of 2003 and used to delineate land use/land cover within the study watersheds. Five dominant land use categories were determined from the aerial photographs: *unmanaged forests* (dominated by mixed hardwood stands), *managed forests* (dominated by pine plantations under various silvicultural prescriptions), *pasture* (grazed by cattle), *developing* (new urban development), and *urban* (Columbus, GA) (Table 1). Developing land use was separated from the other land uses by the evidence of subdivisions and construction areas. Detailed methodology for site selection and land use classification is reported by Lockaby et al. (2005).

The 3-county study area lies within the Piedmont physiographic province in western Georgia. The Piedmont lies along the eastern face of the Appalachian Mountains and ranges in elevation from ~152 to 457 meters above mean sea level, with local relief ranging from 30 to 90 m (USFS 2005). The area has gently rolling to steep topography, a long growing season, and abundant precipitation generally falling as rain. Soils are underlain by acid crystalline and metamorphic rocks. Ultisols dominate the area, which have clayey or loamy subsoil and a kaolinitic or mixed mineralogy (USFS 2005). Prior to 1700, erosion was negligible in the Piedmont. However, historical cotton farming has eroded an average of 18 cm of topsoil between the 1800 and 1900s leaving clayey subsoil exposed and filling stream channels with alluvium (Trimble 1974). Stream channels with exposed granite bedrock substrates were avoided to reduce the variation in total dissolved solids, total suspended solids, channel stability, and habit requirements for stream biota among the watersheds (Schoonover et al. 2005, Helms et. al. 2005).

4.3.2 TSS

Total suspended solids (TSS) were measured within streams emanating from watersheds containing an array of land uses. Grab samples were collected every two weeks between November and March and monthly thereafter at fixed sampling stations near the watershed outlets. Samples were collected between 1 May 2002 and 3 August 2004. This sampling regime allows for more intensive sampling during the seasons that coincide with lower levels of vegetative evapotranspiration, thus resulting in greater hydrologic connectivity between aquatic and terrestrial systems (Lockaby et al., 1993). Samples were transported to Auburn University Laboratories for TSS analyses. TSS was determined by a vacuum filtration method outlined by the EPA (1999).

In addition to grab samples, study watersheds were instrumented with stacked-pole water samplers to collect TSS at various stream stages (Van Lear 1997). Sampler fabrication involved fastening bottles to a metal fence post at incremental (30 cm) distances vertically along the pole. Two pieces of copper tubing, ~6 mm in diameter, were inserted into a rubber stopper; one was bent and oriented to allow water intake and the other air expulsion. The design allowed for point samples to be collected during the rising limb of storm events at 30 cm intervals (Figure 2). Water samples were collected from the stacked-pole samplers following storm events of large enough size to increase stream stage by ~30-cm (i.e., the location of the lower bottle, #1). Samplers were installed at the same locations that grab samples were collected. Bottle numbers were positioned in reference to baseflow for each stream, where bottle #1 was 30 cm above baseflow level and each additional bottle was incrementally spaced higher at 30 cm intervals. Stage elevations where samples were retained were known, and discharge-stage rating curves were previously developed for each stream to allow for load calculations for all storm events (Chapter 2).

4.3.3 Geomorphological Analyses

Channel morphometry measurements were recorded within the headwater reaches of each of the 18 watersheds. Three cross-sectional depth measurements were recorded for each stream and remeasured every three months. Measurements were confined to straight channel reaches in run habitats to avoid overestimates of channel scour. Rebar was installed on each streambank in stable locations to permanently mark the measurement locations. Streambed elevations were measured using a surveying level at 1-m intervals perpendicular to the channel, beginning at the left bank (facing downstream).

A detailed grid analysis was also performed for 10 of the watersheds. Two streams from each of the 5 dominant land uses (i.e., urban, developing, managed forest, unmanaged forest, and pasture) were sampled. Like cross-sections, three grids were measured in straight reaches and confined to runs in each stream. Each grid consisted of 5 transects perpendicular to the channel and were measured at 1-m intervals (Figure 3). Grids were resurveyed following significant storm events (>2.5 cm of rainfall) to determine scour and fill volumes. A transit and level were used to ensure accurate elevations of each grid point. In contrast to the cross-sections, the grids were measured near the watershed outlets. Benchmark elevations were established and measured each sampling period to account for changes in equipment setup.

Streambed substrate was classified for each stream using dry-sieving techniques where size classes were characterized according to the USDA guidelines (Soil Survey Division Staff 1993). Three sediment cores were randomly located within the grid sections to allow comparison of distributions of coarse and fine materials within the stream channels and to offer insight to the mechanisms (e.g., critical tractive force/competence) leading to fill and scour of the stream beds (Leopold et al. 1995). Stream channels without grid sections were also characterized by 3 random samples collected within straight channel reaches.

4.3.4 Statistical Analyses

Five dominant land cover categories were determined from sub-meter aerial photographs; these included: unmanaged forests (dominated by mixed hardwood stands), managed forests (silviculturally managed systems), pasture (cattle grazing and/or forage production), developing, and urban. The developing land cover was separated from other land covers by evidence of subdivisions and active construction sites. In the following analyses, land cover (i.e., managed and unmanaged forest, pasture, impervious surface) proportions were independent variables and the nutrient and biological parameters were the response, or dependent, variables. In a subset of the following analyses, individual land cover classes were analyzed as categorical treatments, and it is necessary to note that multiple land covers were present within all watersheds (Table 1) and consequently, experimental units were not completely homogeneous.

Nonparametric Kruskal-Wallis tests were used to compare TSS and TDS (dependent variables) concentrations and loads among land use types (independent variables). The distribution-free analysis was used to compare urban (i.e., >5% impervious surfaces) and nonurban (i.e., <5% impervious surfaces) watersheds. MAXR regression was used to examine relationships between land use variables and TSS and TDS (Cody and Smith 1997). Regression model development is described in more detail by Schoonover et al. (2005). Land use separations were tested using general linear models with least significant differences for mean separation. To meet normality assumptions, dependent variables were log-transformed to fit the normal distribution (Sokal and Rohlf 2000). A probability level of $\alpha=0.05$ was used for all statistical tests, and SAS Version 8 software was used for all analyses (SAS Institute 1999).

4.4 RESULTS AND DISCUSSION

4.4.1 TDS and TSS

TDS and TSS concentrations and loads for both base flow and storm flow are listed in Table 2. During baseflow and stormflow, TDS concentrations and loads were approximately two times higher ($p<0.0001$) in urbanized watersheds (IS >5%) than all other land uses combined. Crippen (1967) reported that dissolved solids increased tenfold following suburban development. Anthropogenic influences, such as urbanization, have been shown to increase TDS levels in receiving waters (Knighton 1984). TSS concentrations were not different among land uses although median TSS loads were higher in nonurban watersheds during baseflow conditions. The elevated TSS loads are likely attributable to differences in stream substrate sizes (Figure 4). The median TDS and TSS values for the test watersheds are given in Figure 5. Critical sheer stress is higher for larger particles of sediment (Leopold et al. 1995), thus more energy is required to entrain the larger substrates in urban streams. Channel substrates in urban watersheds were >60% coarse materials (i.e., > 1mm in size), which required ~2X as much energy to entrain particles compared to nonurban substrates, which were predominately <1mm in size (see Leopold et al. 1995).

TDS concentration was significantly explained by the following equation (r^2=0.66, p=0.0052) derived from MAXR analysis:

Equation 1: $\log TDS = -0.06\,(IS)-0.07(M)-0.11(E)-0.09(P)+12.04$

where: IS = Impervious surface

D = % of watershed as mixed forest (unmanaged forest)

E = % of watershed as evergreen forest (managed forest)

P = % of watershed as pasture

The above equation was validated for predictive accuracy based on land use composition from 6 test watersheds (Table 3). Ninety-five percent confidence intervals for the prediction error were -13.82 to 4.11. Thus, TDS concentrations were generally underestimated in the test watersheds, but provided a range that would be of sufficient accuracy to produce useful for water quality estimates. TSS concentrations were not explained by a significant land use based prediction equation. Further, TSS concentrations were not significantly correlated with hydrology variables or substrate size classes.

4.4.2 Storm Sampling

Although there were no significant differences in sediment loads among the land uses, during stormflow, a trend in TSS loads developed within urban watersheds. As stream stage rose, TSS loads peaked at ~1 m stage, and then declined in subsequent samples (Table 4). This trend was not observed in any other land use category, and was likely attributable to high proportions of impervious surfaces (i.e., >30%) in urban watersheds. Additionally, the urban and developing watersheds had higher numbers of samples collected at both 30 cm ($p=0.0386$) and 90 cm stages ($p=0.00343$) than all other land cover types. Impervious surfaces contribute copious volumes of quick flow (overland flow) to receiving waters and thus respond quickly to rainfall events (Arnold and Gibbons 1996, Schoonover et al. 2005). Impervious surfaces such as roads, rooftops, parking lots, and sidewalks were likely quickly washed of sediment and debris that contributed to the TSS loads, and initial flushing of these surfaces support the observed trend. Furthermore, the increased discharges could also entrain bed load and result in increased TSS. Once stages reached ~1m in urban streams, the data suggest that the contributing runoff was much cleaner (i.e., lower TSS) than during the earlier stages of runoff events.

The rapid increase in pollutant loads followed by subsequent dilution has been commonly observed in urban channels and was described as the “first flush phenomenon” (Deletic 1998, Lee et al. 2002, Soller et al. 2005). However, this phenomenon is not always evident for all watersheds or pollutants. For example, Walling and Gregory

(1970) reported increases in suspended sediment concentrations from 2 to 10 times greater in areas undergoing construction than undisturbed conditions, although sediment concentrations were highest near the hydrograph peak. Chang et al. (1990) summarized the first flush phenomenon in over 160 storm events from 7 monitoring stations, reporting that the phenomenon best describes streams with >30% impervious surfaces, but is much less pronounced at lower levels of impervious surface.

Streams draining areas with high impervious surfaces displayed frequent stage levels of 30 and 60 cm (Table 4). The total number of events that bottles at stages levels between 30-90 cm filled was positively correlated with the frequency that stream discharges exceed 3x-, 5x-, and 7x-median flow (r=0.54, p=0.04; r=0.68, p=0.01; r=0.64, p=0.01, respectively). A hydrological assessment of these streams showed that flashy stream responses were correlated with the proportion of impervious surface coverage within the study watersheds (Schoonover et al. 2005).

Watersheds with high intensive silviculture had the highest loads of TSS in the stacked-pole samplers. As stream stages rose, TSS loads increased considerably throughout the events. The trend in managed forest watersheds was much different than urban watersheds that were diluted as stage increased beyond the first flush effect. The data suggest that terrestrial inputs of sediment are the probable source for the elevated loads. Managed forests were in various stages of their rotations, such as, recently clearcut or planted, while others were near maturity. Logging decks, skid trails, and access roads were common in the most areas. Studies have reported high sediment losses associated with unpaved forest roads (50-90 t $ha^{-1}yr^{-1}$), skid trails and logging decks (25 and 101 t $ha^{-1}yr^{-1}$, respectively), and harvesting (39% increase of TSS compared with unmanaged natural forest) (Grayson et al. 1993, Stott et al. 2001, Walbrink et al. 2002). In the Piedmont of Georgia, Hewlett (1979) attributed 90% of the mass loss of sediment to poor harvesting practices, such as poorly designed roads and land disturbance by equipment.

Pastoral and unmanaged forests had much lower load increases than other watersheds. However, these land cover/uses still displayed increasing trends in TSS production during runoff events (Table 4). TSS loads in developing watersheds were slightly higher than all other land uses for the first 3 stage levels. Developing watersheds also experienced flashy responses to rain events (Chapter 2), which potentially entrained bed sediments during the initial runoff period. The primary difference between the urban and developing channels was the substrate size. Extensive scour in the lower reaches of the urban channels has led to coarser, more resistant substrates than in the developing watersheds. It is likely that the finer substrates in the developing watersheds were entrained during the flow pulses in response to rainfall, which ultimately produced higher TSS loads.

Event mean concentrations (EMCs) (Novotny 1993) for TSS were calculated for each watershed. No significant correlations between EMC and any of the land uses were significant. However, dominant land uses were significantly different in terms of categorical data (p=0.0082) (Figure 6). Pastured watersheds contributed the lowest median EMC TSS compared with all other land uses. Developing, unmanaged forest, managed forests, and urban watersheds were not significantly different from each another.

Observed EMCs in urban watersheds were considerably higher (474 vs 69-101 mgL^{-1}) than those of residential and commercial uses reported by the EPA (1983) in nationwide urban runoff program (NURP) sites. However, differences may be an artifact of the diversity of locations throughout the U.S.

4.4.3 Cross-section Morphometry

Fill, scour, and streambed stability were assessed using stream cross-section measurements at three month intervals (Tables 5 and 6). Two stream sampling locations were lost during the study and, as a result, data are based on 16 watersheds. Fill and scour were calculated taking the average of positive and negative changes along a cross-section transect. During the first sampling period (i.e., 10 January 2003 to 16 May 2003), streams draining managed forests experienced greater channel scour than both urban and unmanaged forest land uses (Table 5). No other significant differences were observed for individual sampling periods or the overall mean, median, or range values. However, between the date of cross-section installation (i.e., initial sampling date) and the final sample date, pastoral and managed forests experienced greater scour than the other land uses. On average, no land use was subjected to net accumulation of sediments in the headwater reaches, which suggests that channel erosion may be greater than terrestrial inputs.

Streambed stability was much more variable among land uses than estimates of channel scour and fill. Data in Table 6 were derived from the absolute value of the observed changes, which gave an overall estimate of habitat stability. Both scour and fill are important variable in terms of biotic health and survivability, thus these data were computed to serve as an indicator of biotic stress among land uses (Helms et al. 2005). In the west Georgia study watersheds, Helms (2005) has documented increases in tolerant species (e.g., Chironomidae) in streams having low bed stability (unpublished data). These data suggest that unmanaged forests and developing watersheds were the most stable systems during each of the individual sampling periods, overall, and between the initial and final measurements. Pasture and urban watersheds had the lowest stability during the first half of 2003 and during the overall study period. As the proportion of pasture increased in a catchment, the habitat stability decreased (Figure 7). Watersheds dominated by managed forests experienced intermediate disturbance levels in terms of habitat stability.

Stream substrate sizes were correlated with habitat stability. For example, as the amount of particles between 0.5 and 1.0 mm increased, the stability suggested a weak but, nonsignificant trend (r=-0.47, p=0.0683). Pasture and managed forest streams had a large proportion of sediments in this size-class. Conversely, particle sizes greater than >2 mm were positively correlated with increased stability (r=0.58, p=0.0177), which were more common in developing and unmanaged forest watersheds. Urban streams also had a large proportion of coarse materials; however, the stream discharges were much flashier, greater in magnitude, and occurred more frequently in urban systems (Schoonover et al. 2005), thus the critical shear stresses of the materials were more easily exceeded during stormflow.

4.4.4 Streambed Grid Analysis

Ten stream channels were sampled using grid sections near the watershed outlets and findings were summarized in table 7. Similar to the cross-sections, data were analyzed by overall change (cm^3) and the absolute value of overall change ($\left| cm^3 \right|$).

Data suggest that urban, developing, and pastoral streams are scouring, whereas, the two forest types are filling or remaining relatively stable. The absolute values of change also support the trend, whereas urban and developing watersheds have the lowest stability in terms of volume change.

Data from the headwater cross-sections and the grids suggest that the unmanaged forests have stable stream channels. However, the cross-sections in developing watersheds were stable as well, but the grids were not. Headwater sections, where cross-section measurements were recorded, in developing streams were commonly above the development areas (i.e., subdivisions), thus the streams were less susceptible to sedimentation and hydrologic alterations from development. The headwater reaches of developing watersheds closely resemble those of unmanaged forests despite the downstream differences.

Pastoral watersheds were unstable according to both the cross-section and the grid data. In both instances, scour was high and overall habitat stability was low. Hydrology was also monitored throughout the study, and baseflow values were at least 4 times higher in pasture watersheds than any other land use (Schoonover et al. 2005). A combination of high base flow and a sand-dominated substrate likely result in the high continual bed movement within the channels. Pool habitats are typically short-lived in pastoral streams due to the constant substrate movement, and they generally form as a result of channel debris, such as rootwads or other coarse woody debris (personal observation). Within the pasture-dominated watersheds, baseflow appears to contribute sufficient discharge to serve as the channel forming discharge, and is particularly important to habitat stability.

Land use legacies such as historical cotton farming may partially explain the observed stability trends (Harding et al. 1998). Channel substrate was likely influenced by historic land uses across the landscape; however, the impacts were likely more evident in particular streams. For example, pastoral stream substrates were likely composed of the topsoil that eroded during the intensive farming era, whereas urban channels, due to the high impervious surfaces, have flushed the historic sediments downstream with present-day high energy flows. Thus, further investigations on historic land use legacies combined with present day land use interactions could offer greater insight to observed channel stability in the Piedmont physiographic province.

4.5 CONCLUSIONS

Although there was a considerable degree of variation, land use was related to sediment movement and stream channel stability. Historic land use and altered hydrology from contemporary land use are the most probable influences on channel substrate, which appeared to directly impact bed stability. Contemporary land uses also explained 66% of the variation in TDS concentrations, but did not explain TSS.

Stream stability in the Piedmont physiographic province was variable across the land use gradient in west Georgia. Physical stream habitats were continually changing in urban, developing, and pastoral landscapes and, thus, organisms could potentially be subjected to stresses or replacement by species with greater tolerance to habitat modification (Helms 2005, unpublished data). However, shifts towards more tolerant species (e.g., Chironomidae) have already occurred in streams that experienced low bed stability, which could have been additionally influenced by historical sedimentation from farming. Thus, stabilization efforts may only be beneficial to streams with contemporary land uses (e.g., urbanization) that are impacting species diversity or richness. Perhaps, biotic sustainability and diversification in historically disturbed streams would be directly benefited by establishing stream habitats that resemble predisturbed streams. Consequently, restoration and management efforts must consider historic as well as current stream conditions and objectives or goals could be based on stabilizing current conditions or reestablishing past streams characteristics.

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Table 1. Land use ranges within 18 study watersheds surveyed in west Georgia. Numbers in parentheses represent the number of watersheds in each category.

Digitized Land Use Ranges	**Land Use Category**				
	Urban (3)*	**Developing (3)**	**Pasture (2)**	**Managed (4)**	**Unmanaged (4)**
Impervious	24.9-41.9	1.8-3.4	2.5-3.5	1.2-2.6	1.2-2.3
Evergreen	20.9-30.5	37.3-41.2	29.3-32.8	42.4-48.3	36.4-48.1
Deciduous	11.1-15.9	22.8-35.4	24.3-29.0	25.0-33.0	28.2-37.9
Grazing	14.8-24.9	19.9-20.3	33.2-36.8	13.0-20.8	13.2-19.8

Table 2. Median concentration (mg L^{-1}) and load data (g d^{-1} ha^{-1}) for total dissolved solids (TDS) and total suspended solids (TSS) in 18 west Georgia watersheds.

	Baseflow (mg L^{-1})				**Stormflow (mg L^{-1})**			
	<5% IS, (n=182)		**>5% IS, (n=43)**		**<5% IS, (n=198)**		**>5% IS, (n=43)**	
	Median	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**
	-----------------------Concentration (mg L^{-1})-------------------------							
TDS	29.45	1.27	**62.80**†	1.26	29.20	0.90	**51.70**	1.30
TSS	3.50	0.24	2.80	0.43	5.30	0.96	6.00	4.35
	--------------------------Load (g d^{-1} ha^{-1})----------------------------							
TDS	138.84	8.15	**194.87†**	24.39	237.79	25.72	**555.69**	135.71
TSS	**13.29**	2.90	6.50	2.69	35.49	55.14	59.83	357.07

Significance was tested using nonparametric statistics (Kruskal-Wallis).
†Statistical differences (α=0.05) are represented by bold numbers, tests were within similar flow regimes (i.e., baseflow or stormflow).

Table 3. Land use percentage of the 6 test watersheds used to validate the TDS predictive model.

ID	Impervious	Evergreen	Deciduous	Grazing
BSB	1.7	47.4	36.3	14.0
FPWB	1.0	40.3	36.9	19.9
FS1	2.5	32.8	29.0	33.2
FS5	1.2	46.3	36.1	15.2
FS6	0.7	48.0	24.7	24.8
WC	49.5	22.2	10.2	12.9

Table 4. Stacked-pole TSS loads (tons $ha^{-1}yr^{-1}$) across the 5 dominant land uses in west Georgia, USA.

Bottle Stage Level (cm)	**Urban (3)**†	**Developing (3)**	**Pasture (2)**	**Pine (4)**	**Mixed (4)**
30	10.60 (33) ††	27.25 (20)	3.05 (10)	8.50 (9)	18.60 (9)
60	38.65 (24)	44.15 (14)	6.25 (10)	12.40 (7)	22.90 (5)
90	50.30 (10)	77.70 (9)	8.35 (4)	13.20 (5)	75.80 (5)
120	261.00 (7)	125.30 (5)	30.00 (3)	353.90 (3)	138.80 (5)
150	148.85 (2)	175.10 (2)	112.70 (1)	707.70 (2)	75.10 (3)
180	74.30 (2)	-	130.40 (1)	-	168.30 (3)
210	-	-	-	-	124.10 (1)

† Number of watersheds sampled in the land use category

†† Number in parenthesis represents the number of samples collected at the respective bottle location (Stage levels are in relation to average baseflow).

Table 5. Mean (±1SE) change in cross-section depth (cm) by dominant land use. Positive and negative numbers represent fill and scour, respectively.

Parameter			**Land Use**		
	Urban	**Developing**	**Pasture**	**Managed**	**Unmanaged**
1/10/03 – 5/16/03[†]	-0.76 ± 0.85 a[††]	.	.	-7.68 ± 1.86 b	-0.70 ± 0.85 a
5/16/03 – 7/29/03	-1.55 ± 0.76 a	0.85 ± 0.52 a	-1.28 ± 1.58 a	-0.55 ± 0.73 a	-0.64 ± 0.76 a
7/29/03 – 1/12/04	-0.24 ± 0.94 a	0.15 ± 0.76 a	1.13 ± 2.23 a	0.18 ± 0.79 a	-1.68 ± 0.94 a
1/12/04 – 3/18/04	-0.88 ± 0.73 a	-1.89 ± 0.82 a	-2.01 ± 0.94 a	-0.88 ± 0.88 a	1.04 ± 0.73 a
3/18/04 – 6/9/04	1.49 ± 0.49 a	0.00 ± 0.61 a	1.01 ± 0.64 a	0.64 ± 0.64 a	0.76 ± 0.49 a
Mean	-0.79 ± 0.24 a	-0.24 ± 0.12 a	-0.40 ± 0.91 a	-0.91 ± 0.40 a	-0.21 ± 0.24 a
Median	-0.55 ± 0.21 a	0.00 ± 0.18 a	-0.70 ± 0.94 a	-0.91 ± 0.40 a	-0.37 ± 0.21 a
Range	11.49 ± 1.40 a	11.09 ± 1.34 a	11.40 ± 2.53 a	15.03 ± 1.58 a	11.13 ± 1.40 a
Max. Fill	39.32	29.87	43.59	50.60	29.57
Max Scour	-36.88	-37.80	-27.74	-63.09	-35.36
1/10/03 – 6/9/04	0.00 ± 1.10 a	-0.09 ± 0.61 a	-4.75 ± 2.41 b	-4.39 ± 1.10 b	-2.26 ± 0.85 a

[†] Average scour (-) or fill (+) for sampling period.

[††] Within rows, different letter represent significant differences ($\alpha = 0.05$).

Table 6. Absolute values for mean depth changes (cm) of cross-sections, numbers represent the amount of overall stability (i.e., scour/fill) within streams.

Parameter	**Land Use**				
	Urban	**Developing**	**Pasture**	**Managed**	**Unmanaged**
1/10/03 – 5/16/03[†]	1.74 ± 0.37 b[††]	.	.	9.20 ± 1.71 a	3.63 ± 0.61 b
5/16/03 – 7/29/03	5.67 ± 0.70 a	3.26 ± 0.40 bc	6.80 ± 1.13 a	4.72 ± 0.55 b	3.93 ± 0.61 c
7/29/03 – 1/12/04	4.45 ± 0.64 a	3.93 ± 0.64 a	6.86 ± 1.83 a	4.48 ± 0.64 a	4.48 ± 0.82 a
1/12/04 – 3/18/04	3.35 ± 0.34 a	4.05 ± 0.70 a	3.47 ± 0.76 a	4.30 ± 0.79 a	3.20 ± 0.67 a
3/18/04 – 6/9/04	3.66 ± 0.52 a	3.23 ± 0.52 a	2.16 ± 0.46 a	2.77 ± 0.58 a	2.41 ± 0.43 a
Mean	2.07 ± 0.21 a	0.76 ± 0.12 c	2.99 ± 0.76 a	1.77 ± 0.37 b	1.25 ± 0.21 bc
Median	2.16 ± 0.21 b	0.91 ± 0.15 c	3.38 ± 0.76 a	1.71 ± 0.37 b	1.22 ± 0.18 c
1/10/03 – 6/9/04	7.32 ± 0.76 b	3.72 ± 0.46 c	12.53 ± 1.46 a	6.61 ± 0.94 b	4.54 ± 0.70 bc

[†] Average scour (-) or fill (+) for sampling period.

[††] Within rows, different letter represent significant differences (α = 0.05).

Table 7. Summary of streambed grid cross-sections for 10 watersheds from each dominant land use.

Parameter	Change vs Stability			Land Use		
		Urban (2)[†]	Developing (2)	Pasture (2)	Managed (2)	Unmanaged (2)
Average	Change (cm^3)	-849±1342 a[††]	-2117±1273 a	-3223±1216 b	-746±708 c	1754±1130 c
	Absolute change	40352±964 a	39947±907 a	29776±822 b	20676±507 b	16589±817 b
Median	Change (cm^3)	-2500	-1250	-2500	0	-1250
	Absolute change	26250	25000	21250	12500	10000
Maximum	Change (cm^3)	200000	197500	110000	98750	13750
	Absolute change	200000	200000	110000	100000	93750
Coefficient of Variation	Change (cm^3)	-6830	-2686	-1246	-3968	1363
	Absolute change	103	101	91	102	104

[†] Number in parenthesis represents the number of watersheds sampled.

[††] Within rows, different letter represent significant differences (α = 0.05).

Figure 1. Study locations in western Georgia, USA. Polygons represent sampled watersheds.

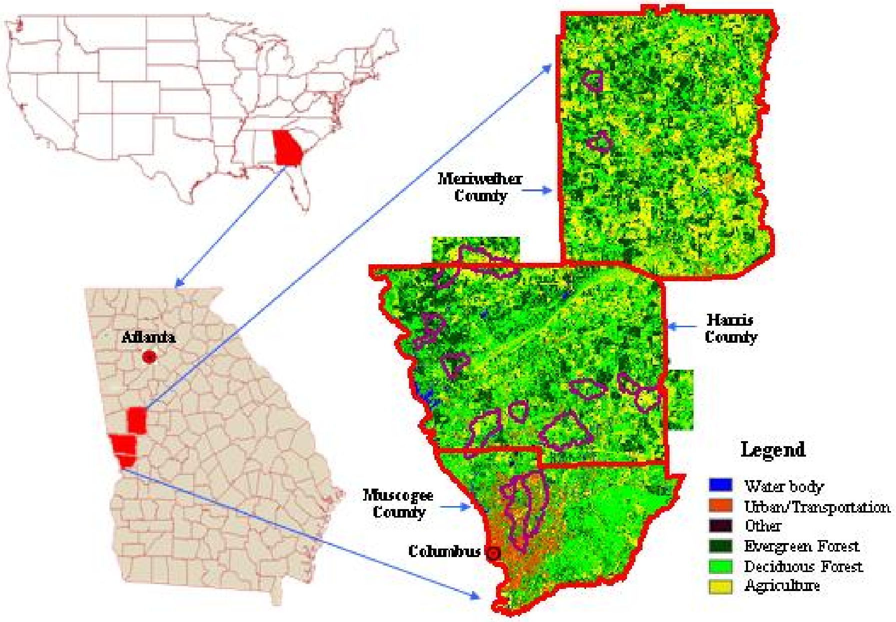


Figure 2. Photograph of the stacked-pole sampler design used for stormflow sampling.

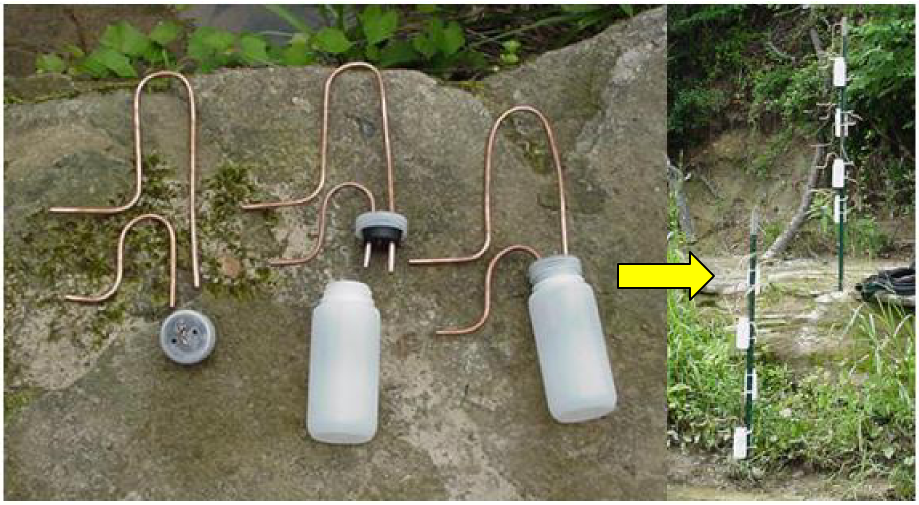


Figure 3. Example grid layout for each stream section; 3 grids per stream were established in run habitats and sampled before and after storm events.

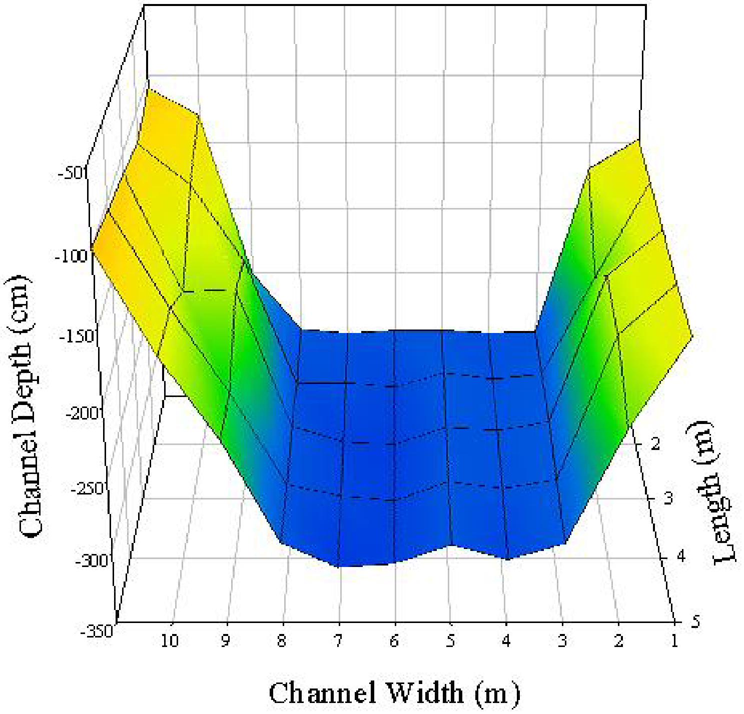


Figure 4. Particle size distribution for streambed substrate in 18 stream channels by dominant land use. Size classes were based on the USDA soil classification system.

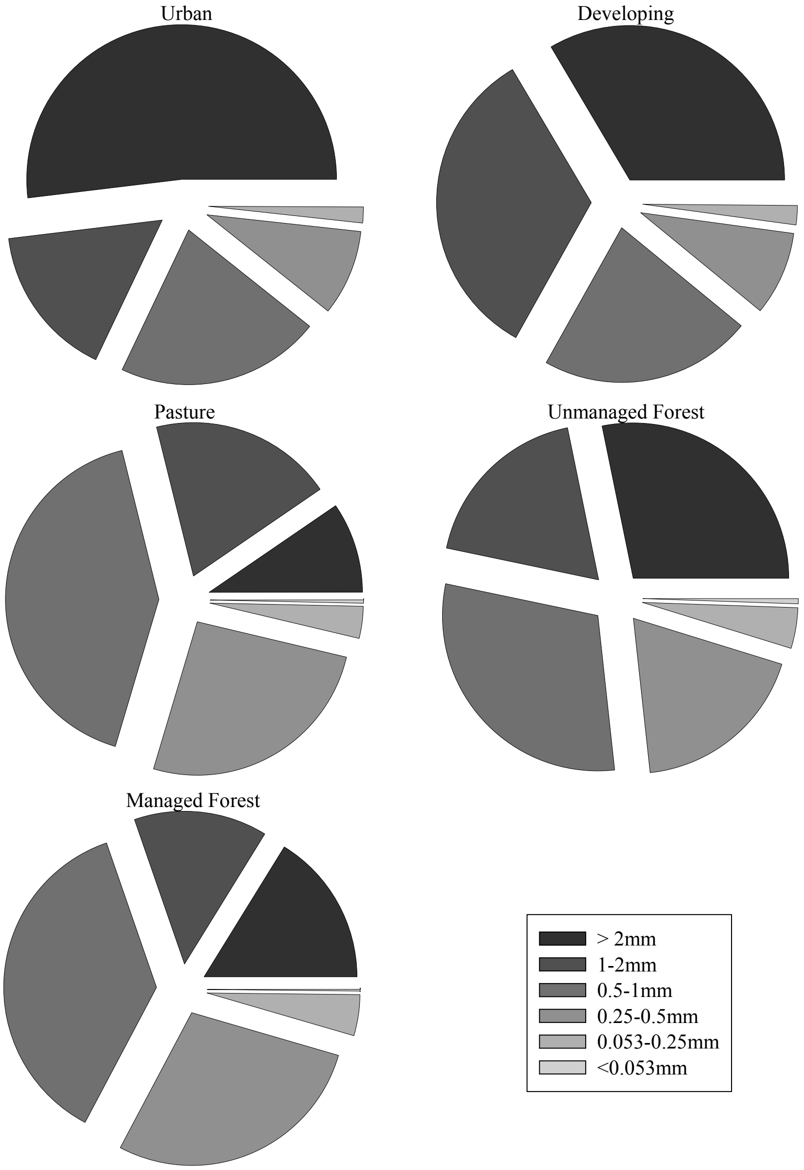


Figure 5. Median TDS and TSS (mg L^{-1}) concentrations in the 6 west Georgia test watersheds used to test the predictive models.

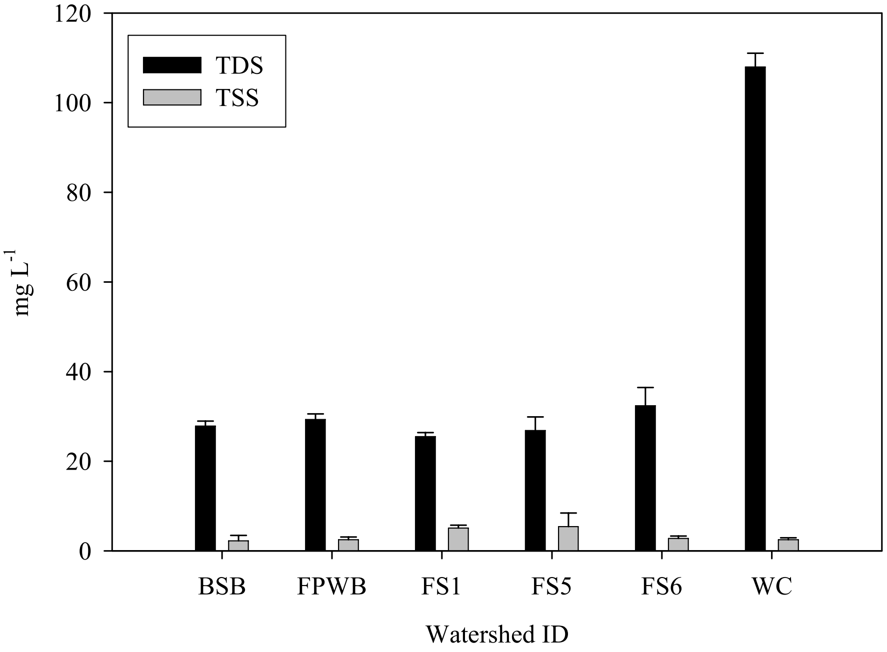


Figure 6. Median (±1SE) TSS event mean concentrations (EMC) for stacked-pole samplers in 18 west Georgia streams. Different letters represent statistical differences at α=0.05. An ANOVA with LSD means separation procedure was used on log-transformed EMCs.

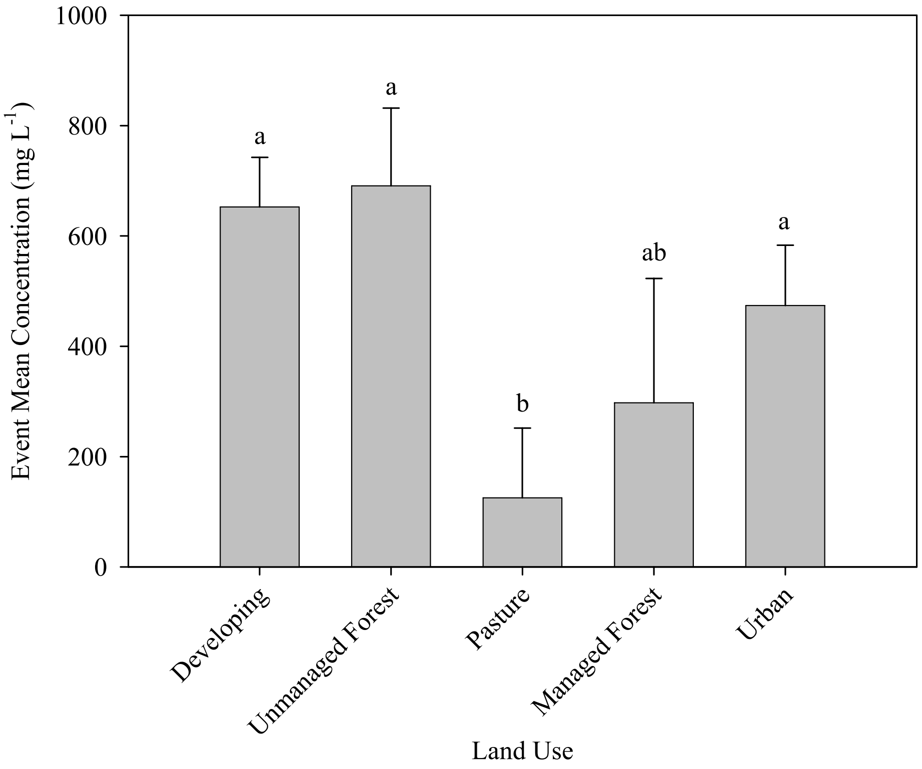
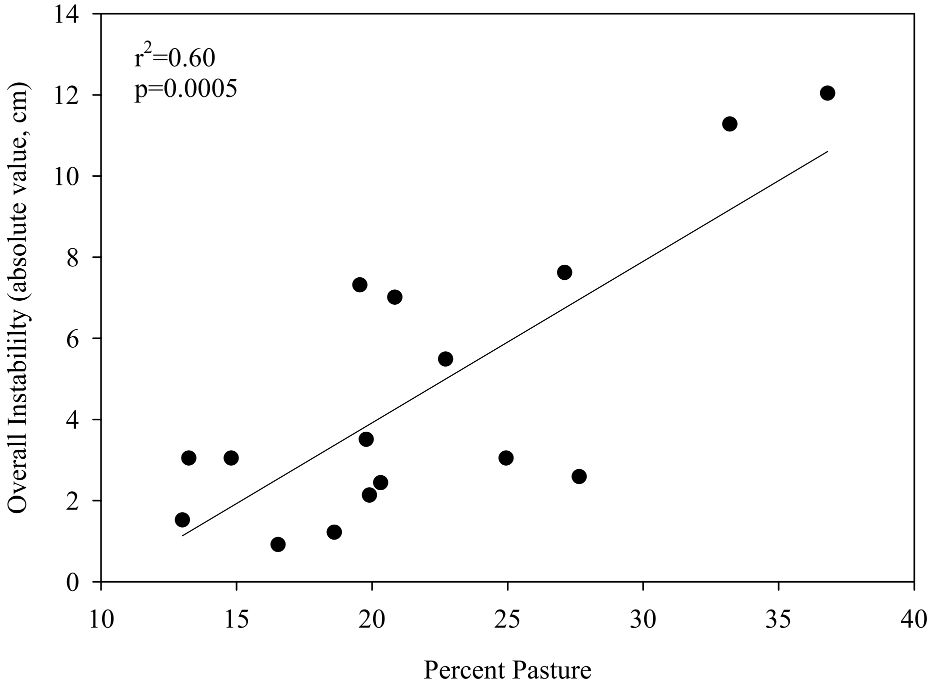


Figure 7. Median value of overall change (absolute value) from cross-sections for 16 stream channels in west Georgia, USA.



CHAPTER 5

5. Sediment Origin: Terrestrial vs. In-Stream

5.1 ABSTRACT

Sedimentation is one of the leading water quality concerns in streams of the United States. Both the direct and indirect (e.g., pollutant binding and transport) effects of sedimentation have led to increased environmental awareness. In order to identify the potential sources of sediment in a number of west Georgia Piedmont streams, we analyzed extractable Fe in total suspended solid samples from two flooding regimes. Specifically, artificially flooding the channel was used to develop instream signatures of sediment, while natural flooding and associated sediments were characterized and compared to in-stream signatures. Streams draining urban, developing, pasture, managed forest, and unmanaged forest subwatersheds were sampled. Higher Fe-oxalate: Fe-citrate dithionite (Fe_{ox}: Fe_{DCB}) ratios during artificial flows (urban = 0.60 and unmanaged forest = 0.14) than natural stormflows (urban = 0.08 and unmanaged forest = 0.03) suggested that crystalline sources of Fe were transported to the stream during natural rainfall in watersheds dominated by urban and unmanaged forest land covers. The Fe_{ox}: Fe_{DCB} ratios suggested that urban and unmanaged forest streams received sediment inputs from terrestrial sources in this region, whereas developing, pasture, and managed forests were dominated by instream sources of sediment. In managed forest watersheds, poorly crystalline forms of Fe were evident during artificial flows, whereas crystalline forms of Fe were more prevalent during natural storm flow. Construction, impervious surfaces,

and channel bank erosion likely contributed the sources of terrestrial sediment in urban watersheds, whereas wildlife activity, which may promote stream bank erosion, potentially provided a terrestrial source of sediment in unmanaged forest systems; however, the factors producing the terrestrial inputs (i.e., impervious surfaces and wildlife activity) in the aforementioned land covers were not measured. This investigation presents techniques that may have applicability to regions of the U.S. with soils having large quantities of Fe oxides, which ultimately may assist in sediment source tracking.

5.2 INTRODUCTION

Land use conversion influences sediment movement through fluvial systems. Alteration of forested to urbanized landscapes often results in increased sediment inputs into streams, which occurs predominately in two phases that have been outlined by Finkenbine et al. (2000). In the first phase, during watershed urbanization (i.e., clearing and construction), stream channels become conduits for fine sediments originating from terrestrial sources (Wolman and Schick 1967), and entrained sediments are transported downstream or settle and become stored as alluvium. Previous studies indicate that over half of the sediment reaching a stream is stored as alluvium (Trimble 1983, USDA 1985, 1986, Phillips 1986). The second phase of sedimentation occurs following development, where impervious surfaces (IS) often cover >50% of the land area within a watershed. Such large increases in IS often lead to higher peak flows and more frequent bankfull discharges, thus stimulating channel bed and bank erosion (Finkenbine et al. 2000, Paul and Meyer 2001). According to the two aforementioned phases of sedimentation, the sediment sources are directly related to terrestrial processes. However, channel redistribution and storage of sediments are also sources of in-stream suspended sediment (Peart, 1980 Walling et al 2003).

To determine sediment origin, an array of sediment tracking (i.e., “fingerprinting”) techniques have been developed. Fingerprinting examples include the use of sediment color (Grimshaw and Lewin 1980, Phillips and Marion 2001), mineralogy (Klages ad Hsieh 1975), radiometry (Murray et al. 1993), physical/chemical properties (Peart and Walling 1986), and isotopic (e.g., strontium) (Douglas et al. 1995) analyses. Typically, these methods are regionally or locally specific; e.g., areas that experienced fallout radionuclides (Walling and Woodward 1992, Wallbrink et al. 1998) or that have unique soil characteristics such as color or iron content (Grimshaw and Lewin 1980, Phillips and Marion 2001).

Phillips and Marion (2001) investigated sediment residence times in the eastern Pineywoods region of the Texas Coastal Plain, and noted that the Fe-rich soils offered a unique opportunity to use Fe oxidation states (as depicted by Munsell color notation) to distinguish between old and new sediment. In their assessment, Munsell color of sediments was used to differentiate between oxidized and reduced sediment, which provided an estimate of sediment residence times. Although innovative, this colorimetric approach can be affected by factors other than Fe oxide mineralogy. Thus, I propose to quantitatively and qualitatively characterize Fe oxides directly as a potential source tracking mineral in Georgia’s Fe-rich Piedmont physiographic province. In our investigation, total suspended solid (TSS) samples were analyzed using preferential Fe extractions for the characterization of Fe forms and differential x-ray diffraction (DXRD) was used to identify Fe oxides.

Applications for selective Fe extraction and DXRD have been shown by Hillier (2001) and Collins and Walling (2002). These studies showed the potential of x-ray diffraction (XRD) for evaluating mineralogy between sediment derived from stormflow versus baseflow, and both oxalate and dithionite-extractable Fe (Fe_{ox} and Fe_{DCB}, respectively) have been useful in sediment fingerprinting techniques. In this study, the two aforementioned laboratory techniques were used to analyze total suspended solids (TSS) collected from natural and artificial flood events, and differentiate between terrestrial and instream sediment. Specifically, DRXD and Fe extraction were used to analyze Fe forms in TSS from natural versus simulated flood events.

The focus of this study is to determine whether TSS is originating from terrestrial or instream sources across an array of land uses/covers. Specific land covers include <u>urban</u>, <u>developing</u>, <u>pastoral</u> (grazed by cattle or hay land), <u>intensively managed forest</u> (predominantly loblolly pine plantations, *Pinus taeda* L.), and <u>unmanaged forest</u>. The objectives of this study were twofold. First, 8 watersheds were compared to determine if the application of the above techniques can differentiate between terrestrial and in-stream sediment. Second, the impacts of land use/cover to sedimentation were compared based on sediment origin results.

Flooding regimes, whether artificial or natural, were expected to generate TSS that included Fe in different forms. I hypothesized that instream sources of sediment will include greater quantities of the less crystalline forms of Fe (e.g., ferrihydrite), whereas terrestrial sediments are expected to be dominated by more crystalline forms of Fe such as goethite and hematite. Furthermore, Fe extraction was performed to separate amorphous vs. crystalline forms of Fe, and to determine differences in total extractable

Fe quantities. Extraction with acid ammonium oxalate can be used to estimate the poorly crystalline fraction of Fe oxides in soils (see Schwertmann and Fischer 1973), and dithionite-citrate-bicarbonate (DCB) extracts all free Fe forms (i.e., organically bound, poorly crystalline, and crystalline). Iron form is generally related to its oxidation state, where crystalline forms are generally more oxidized than poorly crystalline forms of Fe oxides (e.g., ferrihydrite) (Schwertmann and Fischer 1973). Thus, I hypothesize that TSS originating from terrestrial sources will exhibit a low ratio of Fe_{ox}: Fe_{DCB}, whereas TSS originating from instream sources will have higher concentrations of poorly crystalline Fe (i.e., Fe_{ox}) and thus, a higher Fe_{ox}: Fe_{DCB} ratio. Further, sediment originating from in-stream sources was expected to have lower proportions of Fe_{DCB} due to Fe reduction and solubilization.

5.3 METHODS

5.3.1 Study Sites

All watersheds are drainage units within the Middle Chattahoochee Watershed. Eight intermittent streams were selected for this investigation and each were headwater tributaries to intensively monitored watersheds (Schoonover 2005). Watersheds were selected based on current land use, and were in headwater areas that had drainage areas between ~20 and 430 ha in size. The sampling of small headwater streams ensured that artificial discharge could significantly increase the current streamflow to maximize bed substrate entrainment. Small catchments also allowed for sampling of streams draining more homogeneous land uses/covers. The streams were within 100 km of the city of Columbus, GA in the Piedmont province of the southeastern United States (Figure 1) and the specific coordinates (utm zone 16N) for individual stream sampling locations are presented in Table 1. Water sampling locations were located at the watershed outlets.

Elevation ranges from 152 to 457 meters above mean sea level in the Piedmont, and local relief ranges from 30 to 90 m with a gently rolling to steep topography. The dominate soil order in the study area is Ultisols, which typically have clayey or loamy subsoils and a kaolinitic mineralogy (Soil Survey Staff 2003). Upland soils are typically red in color, acidic, and rich in Fe oxides (Parker and Beck 2003). The most common Fe oxides are generally goethite (α-FeOOH) and hematite (Fe_2O_3), which imparts brown to red subsoil colors (Shaw 2001). Other forms of Fe oxides in the Piedmont include the poorly crystalline ferrihydrite (Fe_5HO_8 $4H_2O$), which commonly as an orange flocculent occurs in slow moving streams and drainage ditches, and lepidocrocite (γ-FeOOH), which typically exist as orange concentrations within poorly drained soils. Over most of the Piedmont region, historical cotton farming has eroded ~18 cm of topsoil exposing clayey subsoils and filling alluvial valleys with sediment (Trimble 1974).

5.3.2 Land Classification

In March or 2003, true color (i.e., 3-band) aerial photographs were taken of the study watersheds. The photographs coincided with periods of leaf-off to aid in the differentiation between hardwood and evergreen forest types. All impervious surfaces and water bodies were manually digitized to reduce errors in classification. The remaining land cover classes were classified using a hybrid unsupervised/supervised classification technique, which exploited the strengths of each, and was classified similarly to the Anderson Classification Scheme (Myeong et al. 2001, Lockaby et al. 2005). Ground truthing to verify land cover classes was performed to ensure the accuracy of classification. Details for the image processing methods are explained by Lockaby et al. (2005) and the overall classification accuracy was 91% for all land covers combined.

Intermittent channels were selected based on the dominant land use within each watershed, and thus were separated into land use categories. The watersheds were small enough size to drain primarily a single land use. However, they often contained inclusions of several land cover classes. For example, the developing watersheds drained newly developed subdivisions, and the urban watershed streams drained residential neighborhoods with high impervious surface (IS) coverage. In this example, both watersheds had a primary land use of urban development, but watersheds (i.e., according to the land cover classification) may have high proportions of land cover classes other than impervious surfaces. Thus, it is important to note that several land covers make up an individual land use category, and potential confounding among the land cover types on sediment movement is possible.

5.3.3 Field Methods

5.3.3.1 *Artificial Event*

Generation of artificial streamflow was accomplished by flooding intermittent channels with 1500 L of water. Elevated inchannel flow, without terrestrial inputs, allowed for the development of instream sediment signatures based on Fe oxide characteristics. Water samples were collected at 2 established stations (sites A and B), which were 10 m apart. The water tank was placed 10 m upstream of site A, and 20 m upstream of site B (Figure 2). The initial water release from the tank was considered the beginning of a flow event, and the entire event lasted approximately 8 min. Water from the tank was directly released into the stream channels using a flexible hose fitted with a deflector, which reduced substrate disturbance. TSS samples were collected in pre-washed/rinsed, 1 L HDPE bottles before the flow event was initiated and at 1-min intervals following the beginning of the flow event. TSS samples were collected at each preestablished sampling location (i.e., site A and site B). Stream discharge was also recorded before and after the artificial event at both sampling locations using a Marsh McBirney® flow meter (Rantz 1982).

5.3.3.2 *Natural Event*

The first natural storm event following artificial flooding was sampled to characterize Fe in TSS, which would allow for comparison to the signature developed during artificial events. Six 1-L bottles were filled with stream water and discharge was measured at each of the pre-established sampling locations (i.e., sites A and B) during the rainfall event. Sampling occurred during the rain event and water samples were collected during the rising limb or near the peak of the discharge event. Samples were cooled (~ 4 ^{o}C) and transported for analysis.

5.3.4 Laboratory Methods

5.3.4.1 TSS and Fe Extraction

TSS concentrations were calculated for each sample collected at 1-min. intervals for sites A and B during the artificial flow. The natural event samples were analyzed for TSS using a volume composited sample (6 individual 1 L bottles). Further, to ensure sufficient sediment was available for Fe analyses, water samples for the artificial event were composited by time (8-minute sampling period) for sites A and B. TSS concentrations were determined using vacuum filtration procedures outlined by the US

EPA (1999), and loads (kg ha^{-1} day^{-1}) were calculated by multiplying concentration data (mg L^{-1}) by stream discharge measurements (L s^{-1}).

5.3.4.2 *Fe Extraction and Differential X-ray Diffraction*

Sediment samples were compared between flow events (i.e., artificial vs. natural) based on their mineralogical characteristics using differential x-ray techniques and Fe extraction. Suspended sediment samples were flocculated using $MgCl_2$ (solid), allowed to settle for 24hr, and the supernatant was removed by siphoning. Organic matter (OM) was then removed using 30% H_2O_2 in a NaOAc buffer solution adjusted to pH 5 (Jackson 1969). Once OM was removed, the samples were then washed with DI water, an ethanol and water (50:50) solution, and by a final washing with pure ethanol to remove salts. Following washing, the samples were shaken overnight with 1 M Na_2CO_3 to disperse the soil particles. The soils were then wet-sieved to separate coarse (i.e., >53μm diameter) from fine particles (<53 μm). The samples then underwent dialysis to remove excess salts, and samples were freeze-dried and weighed prior to XRD analyses.

The identification of TSS Fe oxide minerals was performed using differential x-ray diffraction (DXRD) (Schulze 1981). Untreated TSS samples were divided to allow DXRD analyses for samples with: 1) Fe_{ox} removed, and 2) Fe_{DCB} removed. The first step in DXRD was to generate an x-ray pattern for the untreated TSS samples. X-ray patterns were produced by analyzing randomly oriented powder mounts using a Siemen’s D5000 x-ray diffractometer. All pre- and post –treatment samples were scanned from 2 to 40° 2θ in 0.02° steps at 10 sec per step. After scanning, half of the original untreated sample was treated with acid ammonium oxalate (in the dark) to extract poorly crystalline Fe oxides (Schwertmann 1964). The remaining half of the untreated sample was treated with dithionate-citrate-bicarbonate (DCB) to extract both poorly crystalline and crystalline Fe oxides (Mehra and Jackson 1960). Following the extractions, Fe was quantified using Atomic Absorption Spectroscopy (AAS) and treated TSS samples were subsequently x-rayed using above procedures.

The XRD output from the two extraction procedures were subtracted from the untreated samples and assessed for any changes in the mass absorption coefficient. Changes in the mass absorption coefficient may occur due to increased concentration of minerals following dissolution, and then removal of free Fe, thus affecting XRD intensities (Schulze 1994). K values (scale factor for intensity increases) were calculated using trial-and-error subtractions (Schulze 1981). The following relationship defines the relationship between the treated and untreated samples:

$$\mathrm{A}i - k\mathrm{B}i = \mathrm{C}i$$

where Ai and Bi are the counts at angle i in patterns of the untreated and treated samples, respectively, Ci represents the subtracted spectra, and k is the scale factor. The pattern produced by the difference between patterns A and B, yield pattern C (the differential XRD pattern). Thus, pattern C is composed only of Fe oxides, and peak locations can be used for Fe oxide identification.

5.3.5 Statistical Analyses

Significant differences in extractable Fe among land uses were calculated using ANOVA in SAS (SAS Institute 1999). Land use categories were independent variables and total suspended solids (TSS), discharge, and extractable Fe quantities were dependent variables. Significance levels for all statistical tests were α=0.05. Pearson linear correlation coefficients were used to test for significant relationships among dependent variables.

5.4 RESULTS AND DISCUSSION

5.4.1 Land Classification

Land cover was divided into 5 dominant classes for the 8 west GA watersheds used in this study (Table 1). Watersheds identified as BU1 and BU2 were classified as urban watersheds because of their high proportions of impervious surface (i.e., >10%). Within watersheds draining urban and residential landscapes (BU1, BU2, SB1, and SB4), ground truthing verified that the areas classified as grass were predominantly urban lawns, whereas grass in the remaining watersheds was pasture and hay land, and to a much lesser extent residential turf. Further, ground verification proved that the land cover classified as “other” was dominated by exposed bare ground. In the urban and developing watersheds, bare ground represented housing development, and in the managed forest watershed bare ground was a result of clearcut harvesting.

5.4.2 TSS and Discharge

Stream discharge was significantly higher during natural storms than the artificial flooding for all land uses except unmanaged forest (Figure 3). High evapotranspiration in the unmanaged forest watershed likely caused the lower observed stream discharges during the natural storm event (Bosch and Hewlett 1982). Further, increased infiltration and high water storage capacities are generally associated with mature forests (Fisher and Binkley 2000), which may also lead to the lower observed stream flows within the unmanaged forest streams. Managed forests likely did not follow the same trend as unmanaged forests because of the patches of clearcut forest within the watershed, which could promote elevated overland flow volumes. With the exception of urban channels, discharge was higher during natural flows for most streams, and total suspended solid (TSS) concentrations were not significantly different among the 2 flooding types for any of the land cover types (Figure 4). Urban streams (i.e. >5 % IS) had significantly higher TSS concentrations ($p=0.0005$) during the artificial events than natural events, which was likely due to the first flush phenomenon that is commonly associated with urban streams (Deletic 1998, Lee et al. 2002, Soller et al. 2005, Schoonover et al. 2005). Increased flows during the artificial event potentially entrained solids that previously settled due to low velocities or were associated with adjacent bed/bank sediments during the initial stage increase. Natural storms were sampled during the rising limb or near peak flow during the rainfall event to attempt to capture runoff during the greatest hydrologic connectivity between the stream and the terrestrial system. The collection schedule prevented sampling during the first flush of storm events, thus a combination of the first flush and dilution of TSS was likely in the urban channels (Schoonover 2005).

Averaged TSS concentrations, by land use, collected during the artificial flow are shown in Figure 5. Pasture and managed forest streams had the highest TSS concentrations, which appear to peak early in the flood event. Urban, developing, and unmanaged forest streams had relatively uniform TSS concentrations throughout the events and concentrations were also low in magnitude. TSS concentrations declined in the latter part of the artificial flood events in all streams, suggesting the first flush phenomenon may be common across all land uses in small watersheds.

5.4.3 Extractable Iron

Extractable Fe and Fe_{ox}:Fe_{DCB} ratios in TSS collected during artificial flow were used to develop the signature (i.e., fingerprint) for in-stream sources of sediment. In both urban and unmanaged forest streams the Fe_{ox}: Fe_{DCB} ratios were significantly higher during artificial flows versus natural flow (p=0.0117 and p=0.0050, respectively) (Figure 6), which is either due to increases in the proportion of Fe_{ox} or decreases in the proportion of Fe_{DCB} in the TSS. High Fe_{ox} proportions during the artificial flow were expected because oxalate extracts poorly crystalline forms of Fe, which is likely of higher proportion in stream environments. Rhoton et al. (2002) suggest that Fe_{ox}: Fe_{DCB} ratios greater than 0.50 indicated the presence of ferrihydrite, which was the case in our urban and managed forest streams. Further, Shaw (2001) reported low Fe_{ox}: Fe_{DCB} ratios (0.02 to 0.09) for highly weathered upland ultisols of the Piedmont region, thus low Fe_{ox}: Fe_{DCB} ratios in TSS may suggest contributions from terrestrial sources of sediment. In urban streams the ratio was significantly lower during natural flows (<0.50), possibly suggesting that there was little in-stream contribution of Fe and increased terrestrial inputs during natural stormflow. Moreover, the Fe_{ox}: Fe_{DCB} ratios decreased from 0.60 to 0.08 in the urban streams and from 0.14 to 0.03 in the unmanaged forest streams between the artificial and natural flows, and the ratios for natural storm events (i.e., 0.08 and 0.03) fall within the range of Fe_{ox}: Fe_{DCB} ratios for terrestrial uplands (0.02 to 0.09) (Shaw 2001). Conversely, the managed forest streams Fe_{ox}: Fe_{DCB} ratios did not significantly deviate between the flow regimes, suggesting similar sources of sediment. Further, higher proportions of Fe_{DCB} were evident during natural flows in urban and unmanaged streams, suggesting the presence of more crystalline forms of Fe. Terrestrial inputs of sediment appeared to be common in both urban and unmanaged forest watersheds during natural flows because the channels transported TSS enriched with greater proportions of crystalline Fe. In contrast, developing, pastoral, and managed forest's Fe_{ox}: Fe_{DCB} ratios did not differ significantly during natural flows compared to the artificial flows, suggesting that in-stream redistribution or scour was the dominant source of sediment.

Potential terrestrial sources of sediment in urban landscapes are ubiquitous, and the prevailing transport mechanism is likely overland flow runoff draining impervious surfaces. Impervious surfaces, such as, roads, rooftops, sidewalks, and parking lots impede water infiltration, which increases surface runoff volumes and velocities (Schueler 1995). Higher runoff velocities can facilitate soil erosion from bare ground and transport sediments over the impervious surfaces. Additionally, impervious surfaces often accumulate dust and other particles associated with urban landscapes (Schueler 1995). In contrast, terrestrial sources of sediment in unmanaged forest streams could potentially be related to the amount of land disturbance by wildlife activity, for example, white-tailed deer (*Odocoileus virginianus*). In the unmanaged forest areas (predominately mixed-hardwoods) heavily used white-tailed deer stream crossings were common. In West Virginia streams, researchers recognized that white-tailed deer stream crossings were a dominant sediment source, particularly in watersheds subject to little human disturbance (Edwards 2005, personal communication). Additionally, a case study in rural New Zealand suggested that deer can cause more damage to waterways (i.e., through trampling of streams margins and vegetative removal) than any farm animal (Ministry of the Environment 2001). However, both the urban and unmanaged forest streams transported low sediment loads compared to those of developing, pastoral, and managed systems. In urban streams, low TSS load may be an artifact of the first flush phenomenon, in which the majority of sediments are transported during early stages of storm hydrographs. Also, previous morphometry analyses of headwater reaches within the same watersheds showed that the unmanaged streams had stable headwater channels compared to other land uses, which supports the observed low in-stream contribution of sediment (Schoonover 2005).

Streambed stability also plays an important role in the observed trends. For example, Fe_{ox}: Fe_{DCB} ratios suggest that pastoral streams are dominated by in-stream sources of sediment; previous investigations of perennial pastoral channels in the west Georgia study area reported that pastoral channels experienced low bed stability (Schoonover 2005). Moreover, as the amount of pasture land cover increased, the channel stability decreased (Schoonover 2005). Pasture substrates were predominately composed of fine sands (0.5 – 1.0 mm) that proved to be highly mobile with high baseflow discharges. Furthermore, stability data for developing watersheds suggested that channel scour was evident, which also suggests that in-stream sediment sources would be probable. Conversely, managed watersheds were relatively stable in their lower reaches according to the morphometry study; however, active headcut migration was observed in channel reaches upstream of TSS sampling locations (Schoonover 2005). The headcut movement was a potential source for the in stream signature of sediment, and even though the uplands in the managed systems were disturbed by silviculture practices, riparian buffers were retained along the stream margins, which may have provided protection to the channels from terrestrial inputs of sediment.

During artificial flow, urban streams exhibited higher Fe_{ox} and Fe_{DCB} percentages than all other land uses (Table 2). Furthermore, the urban Fe_{ox} and Fe_{DCB} percentages were also higher during artificial vs. natural stormflow. TSS in the unmanaged forest stream also had a higher percentage of Fe_{ox} during artificial flow, which suggests that the in-stream signature was composed of a greater proportion of poorly crystalline forms of Fe.

Linear correlation and multiple regression analyses were performed for all response and independent variables. Correlation between land cover proportions and response variables were not significant, with the exception of a positive correlation between % evergreen vs. % Fe_{DCB} during natural flow (r=.71, p=0.05), which may be a result of high TSS concentrations during natural stormflow in the managed systems. Perhaps, the lack of additional significant trends may have been due to the relatively small sample sizes. Furthermore, previous research has suggested that spatial arrangements of landscape patches in small watersheds (i.e., 1-10 km^2) may play a critical role in the predictive power of ecological response variables (Strayer et al. 2003).

5.4.4 Differential X-ray Diffraction

Differential x-ray diffraction was used to qualitatively describe the Fe oxide minerals present within the TSS samples. DXRD patterns for both artificial and natural events are illustrated in Figures 7 through 10. The x-ray patterns were generated from TSS samples collected from a stream draining predominantly managed forest land cover (MU2), and the stream had relatively high percentages of Fe compared to other streams. Although the extraction treatments and small TSS quantities potentially reduced the peak intensities of Fe to levels near the detection limits, the Fe percentages (4.42-5.86 % Fe_{ox}

and 6.32-8.32% Fe_{DCB}) produced several identifiable x-ray peaks (Figures 7-10). During the artificial flow event, sites A and B produced peaks for ferrihydrite, and site A showed evidence that either hematite or goethite was present (Figures 7 and 8). Conversely, during the natural flow events crystalline forms of Fe (hematite or goethite) were more prevalent than the poorly crystalline forms (Figures 9 and 10). However, ferrihydrite was still evident in the x-ray patterns at site A during the natural flows, which supports the findings from the Fe extraction data where in-streams sources of sediment were likely in managed forests (Figure 9). Furthermore, these data also support our hypothesis that in-stream sources of sediment are predominately composed of poorly crystalline forms of Fe (e.g., ferrihydrite).

Low TSS weights (0.18-3.7 g, before being divided) reduced the effectiveness of the DXRD approach. Schulze (1981) showed that the presence of around 2% of Fe_{DCB} as goethite, hematite, or both can be detected by DXRD, and at 5% or more Fe_{DCB}, DXRD patterns can be used to characterize ratios of goethite: hematite. According to the oxalate and Fe_{DCB} extractions, Fe percentages (Fe_{ox}: 2.10±0.47, Fe_{DCB}7.7±0.57) were near the detection limits necessary for thorough characterization and Fe speciation. Moreover, the Fe_{ox} and Fe_{DCB} extraction treatments could have potentially reduced the relative intensities of the peaks in the DXRD patterns (Schulze 1981).

5.5 CONCLUSIONS

This study assessed methods of sediment source tracking based on free Fe characteristics in total suspended sediment samples. Data suggest that both urban and unmanaged forest landscapes produced higher terrestrial inputs of sediment than all other land uses where in-stream redistribution of sediment appeared to be the dominate mode of sediment transport. Although sediment inputs to streams were relatively low, the potential mechanisms of terrestrial transport were via impervious surfaces and white-tailed deer trails, respectively; however, these disturbances (i.e., impervious surfaces and white-tailed deer) contributing terrestrial inputs of sediment are speculative.

Possible limitations to this work include the sampling of a single artificial and natural storm event and the use of categorical data. However, the unique application of using Fe and two flooding regimes provides a foundation for the advancement of sediment source tracking methodologies. Future applications of these methods should be based on a more rigorous sampling regime, where natural events are sampled multiple times during each event. Ideally, automated samplers could be used to ensure that the first flush of the event was captured and to allow comparisons of rising vs. falling limb contributions of sediment. Additionally, seasonal variation in sediment sources and transport mechanisms are probable. Thus, a seasonal sampling effort could be used to characterize sediment transport through time.

Individual land covers were treated as categorical variables for a subset of analyses in this study. Thus, it is important to reiterate that the watersheds were composed of various land covers, and that complex interactions of land cover types can be undetected in categorical analyses. In situations where clear categorical separations were not evident (e.g., using five separate land cover classes), results may be subject to errors that cannot be accounted for. Even though we attempted to base our categorical separations on clearly defined breaks in land cover proportions, it is important to interpret these data with the aforementioned limitations in mind.

Sediment source tracking is critical for effective management of stream ecosystems. Knowledge of sediment sources will allow land managers to effectively develop restoration designs and to direct economic resources to areas that are most susceptible to erosion. Furthermore, sediment source tracking techniques are unique to each physiographic region, thus, the development of innovative tracking techniques in other regions would benefit the future of sediment management.

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Table 1. Land cover classification and location for eight watersheds in west Georgia. Numbers represent the proportion of each land cover within the watersheds, and letters denote the land cover class assignments within watersheds.

Land Cover	**-------------------------------Watershed ID-------------------------------**							
	BU1	**BU2**	**SB1**	**SB4**	**HC2**	**MU1**	**MU2**	**BC**
Impervious	37.1	17.3	2.8	3.7	7.9	1.7	3.5	2.6
Evergreen	23.9	33.8	33.6	54.4	10.9	12.2	40.0	47.9
Deciduous	13.5	19.8	33.3	18.7	26.9	14.9	26.0	33.8
Grass/Pasture	23.4	22.8	22.8	20.8	51.4	66.2	17.9	13.4
Water	0.8	1.1	3.7	1.3	1.5	4.1	0.8	0.5
Other	1.3	5.2	3.9	0.9	1.5	0.9	11.8	1.7
Land Use Category	U[†]	U	D	D	P	P	MF	UF
Coordinates (utm zone16)	16N693752 3600311	16N695190 3603990	16N686662 3611495	16N699429 3613371	16N688928 3636884	16N713391 3617635	16N710223 3620023	16N705813 3658107

[†] U=Urban, D=Developing, P=Pasture, MF=Managed Forest, and UF=Unmanaged Forest.

Table 2. Average percent Fe (±1SE) calculated from Fe_{ox} and Fe_{DCB} extractions during artificial and natural flow regimes in 8 Piedmont watersheds of west Georgia.

Land Use	Flow	Artificial (%)	Natural (%)
Urban	Oxalate	**6.68**[†]±1.81	0.41±0.14
	DCB	**10.92**±1.74	4.74±0.90
Developing	Oxalate	0.38±0.11	0.19±0.11
	DCB	4.16±1.04	2.13±0.08
Pasture	Oxalate	2.19±0.34	2.03±0.43
	DCB	6.98±2.20	6.55±0.83
Managed Forest	Oxalate	4.42±1.68	5.86±0.49
	DCB	6.32±2.41	8.32±0.15
Unmanaged Forest	Oxalate	**0.69**±0.05	0.16±0.02
	DCB	5.02±0.10	4.98±0.00

[†]Within rows significantly higher values are illustrated in bold.

Figure 1. Stream locations across a 3-county land use gradient in west Georgia, USA. Streams drained the Piedmont province and were tributaries to the Chattahoochee River.

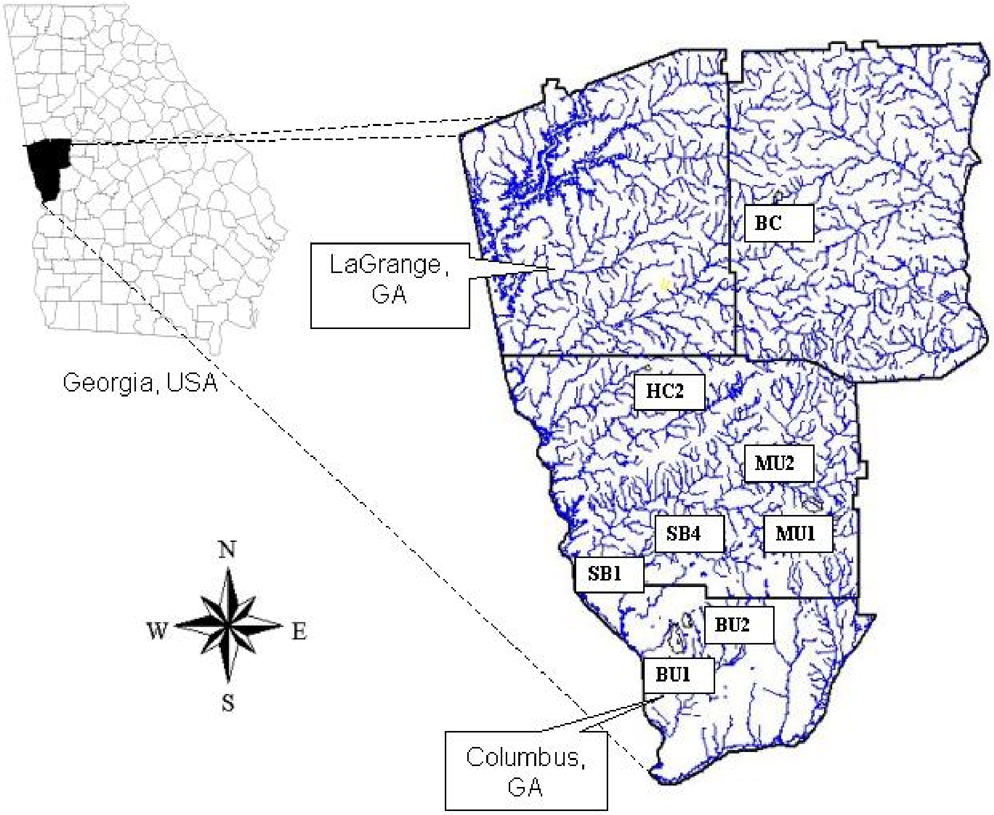

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Figure 2. Study design for artificial flow and layout of sampling stations; the same sampling locations (i.e., sites A and B) were used for natural storm event sampling.

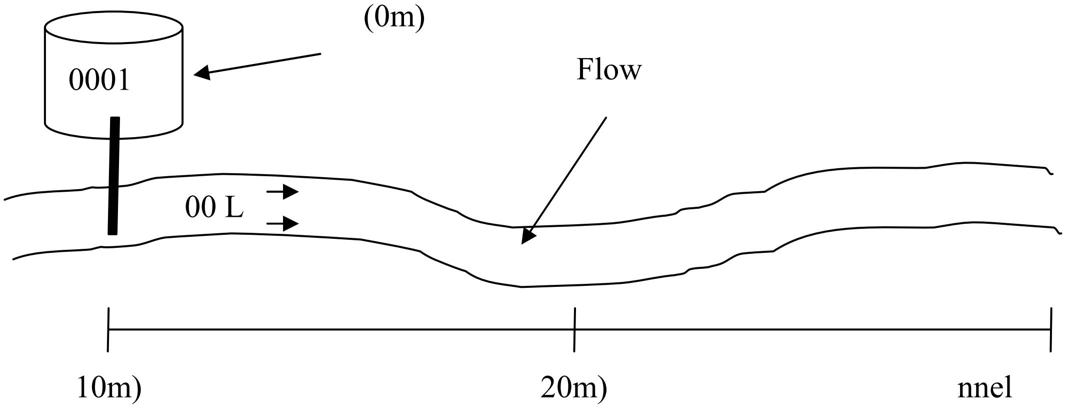


Figure 3. Mean (±1SE) stream discharge (L s^{-1}) during artificial and natural stormflow for 8 Piedmont streams across a land use gradient in west Georgia.

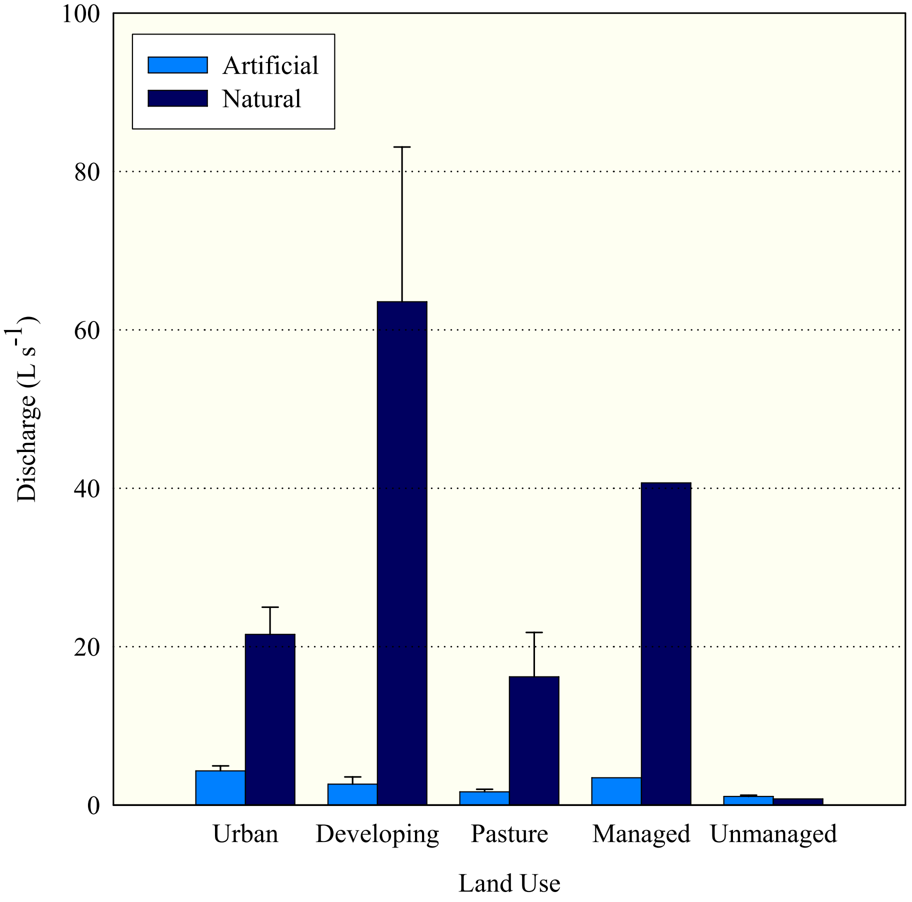


Figure 4. Total suspended solid (TSS) concentrations (mg L^{-1}) and loads (kg ha^{-1} day^{-1}) for 8 watersheds across an urban-rural gradient in west Georgia.

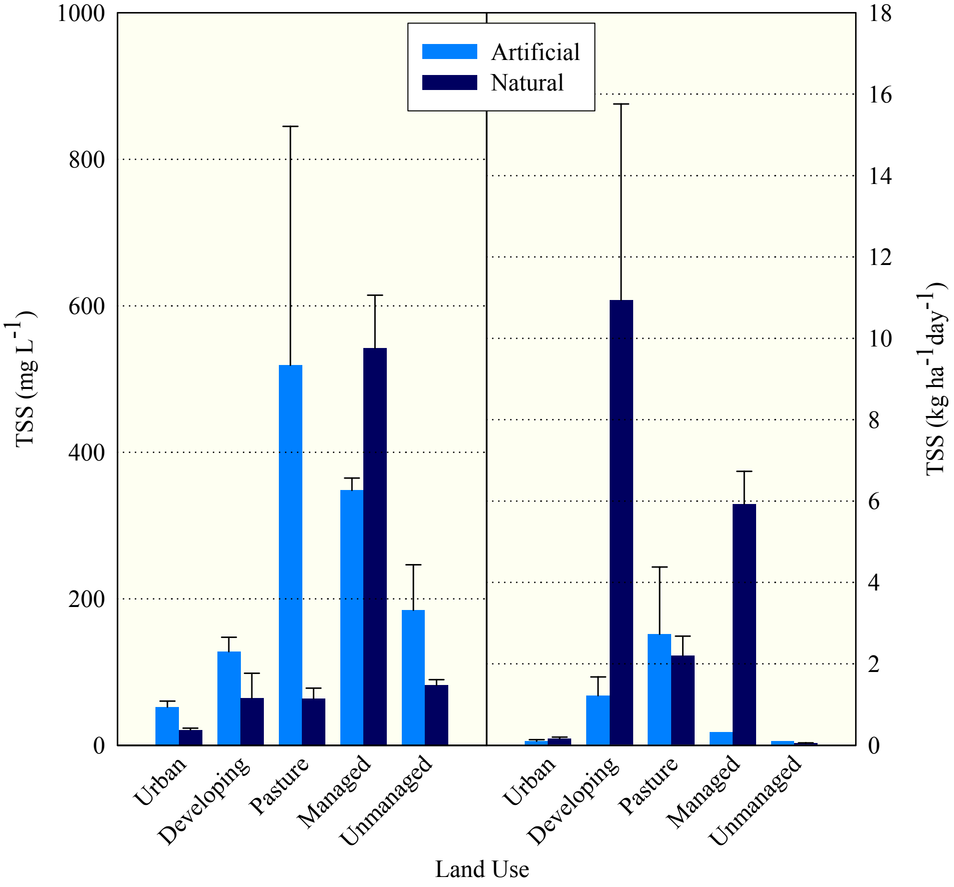


Figure 5. TSS concentrations (mg L^{-1}) (averaged for sites A and B) for 8 watersheds during artificial flood events in west Georgia. Time zero represents the concentration of TSS when the initial pulse of discharge reaches the respective site, and subsequent collection times were at 1-minute intervals after the time zero collection.

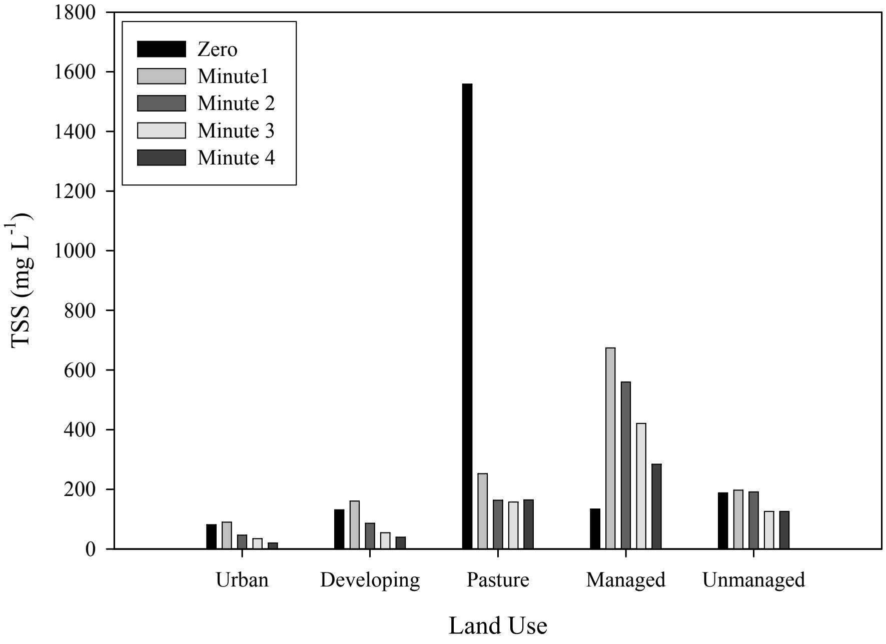
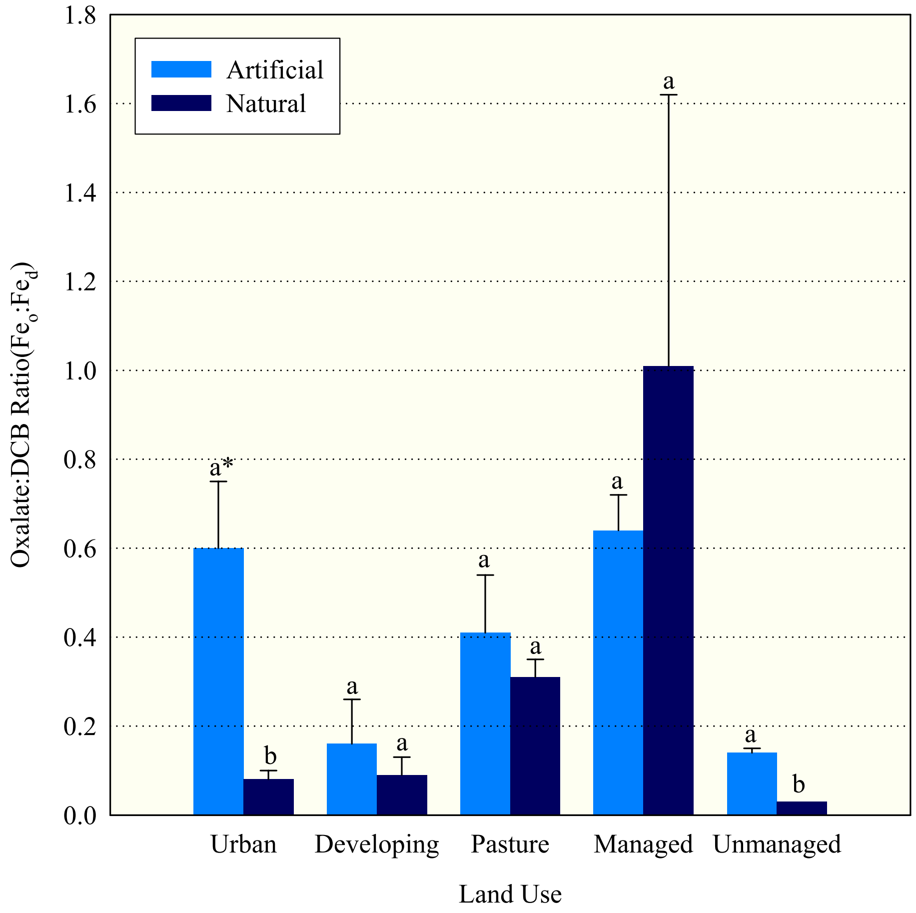


Figure 6. Mean (±1SE) Fe_{ox}: Fe_{DCB} ratios of TSS samples across a land use gradient in 8 Piedmont streams of west Georgia.



*Within land use, different letters represent significant differences at α=0.05.

Figure 7. XRD patterns for TSS samples collected during the artificial flood event from site A in watershed MU2 (Go=goethite, He=hematite, Fh=ferrihydrite). X-ray patterns were developed using the fine soil fraction (i.e., <53µm).

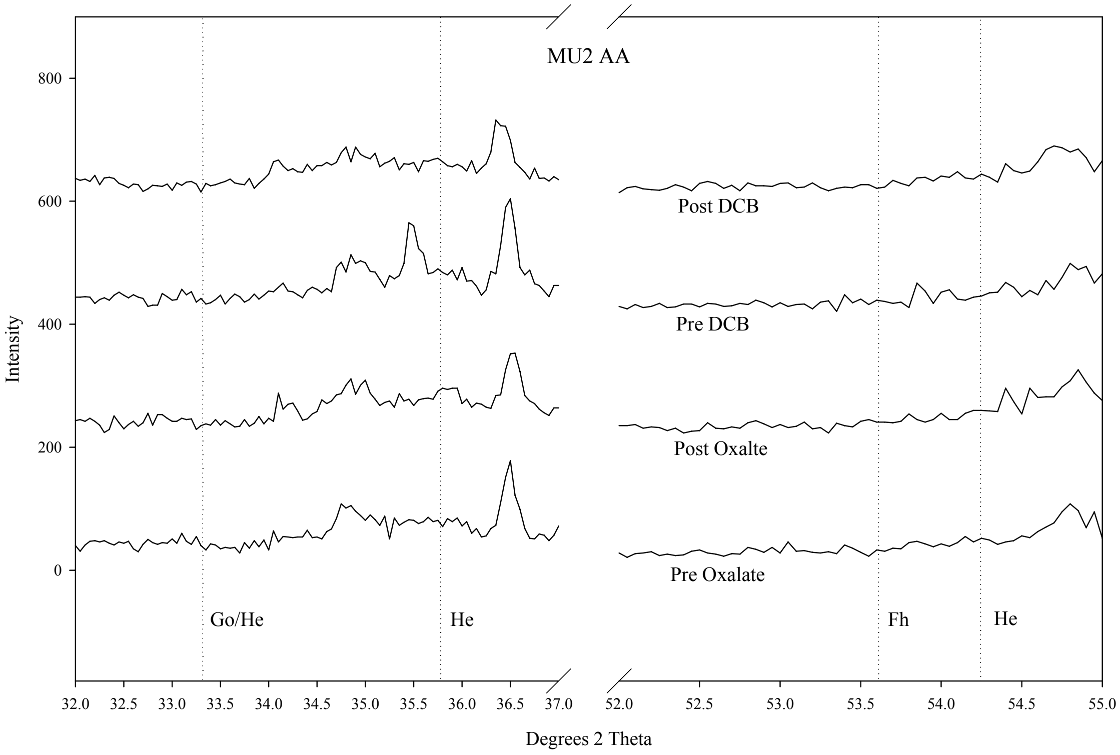


Figure 8. XRD patterns for TSS samples collected during the artificial flood event from site B in watershed MU2 (Go=goethite, He=hematite, Fh=ferrihydrite). X-ray patterns were developed using the fine soil fraction (i.e., <53μm).

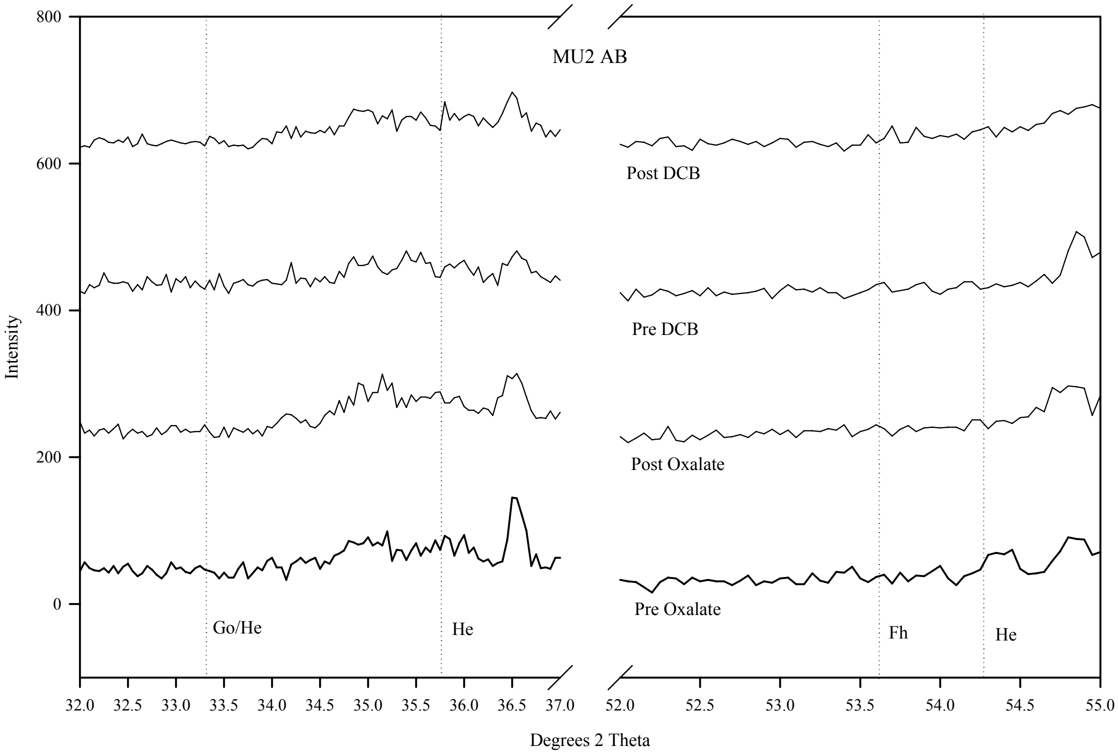


Figure 9. XRD patterns for TSS samples collected during the natural flood event from site A in watershed MU2 (Go=goethite, He=hematite, Fh=ferrihydrite). X-ray patterns were developed using the fine soil fraction (i.e., <53µm).

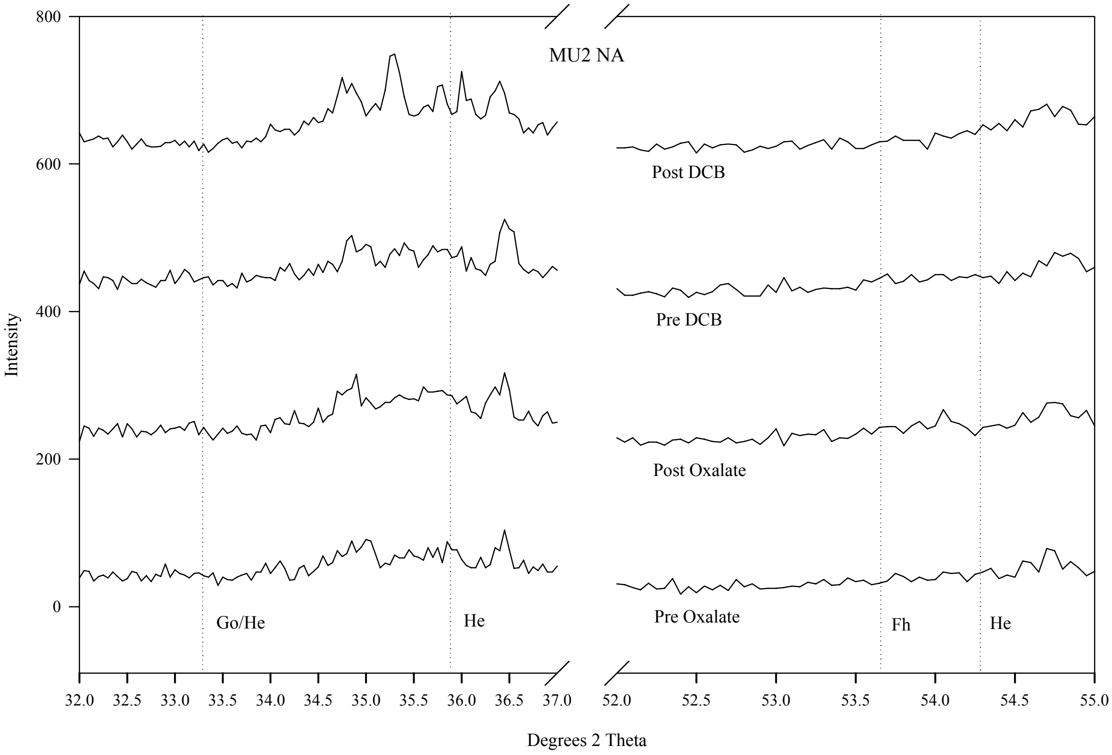
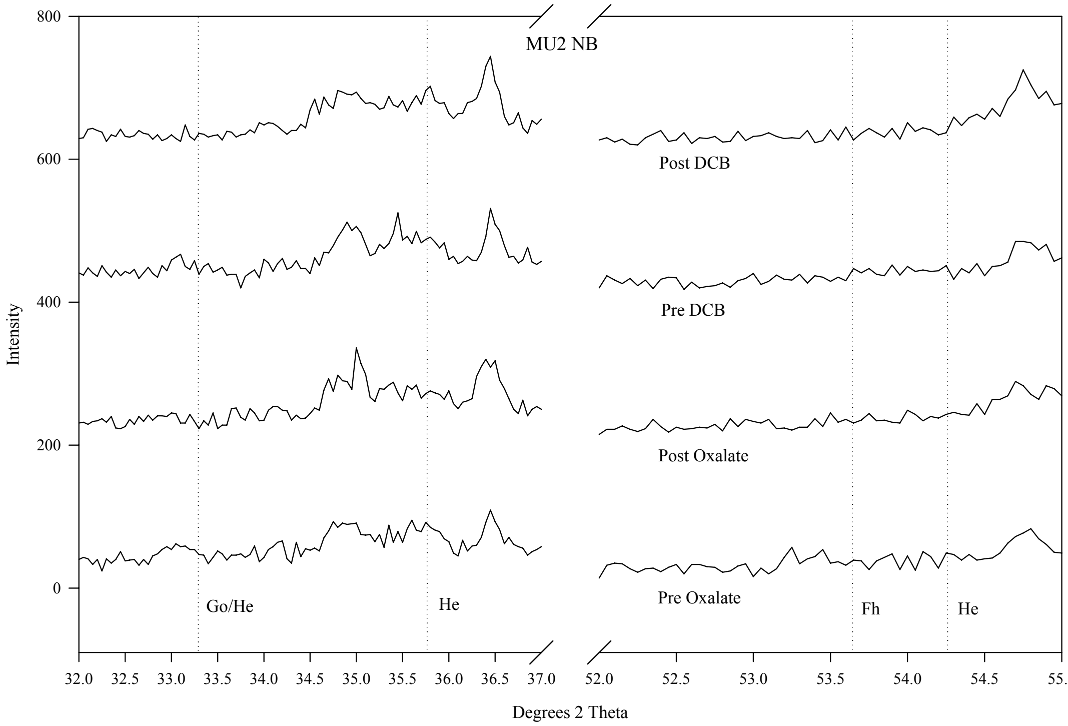


Figure 10. XRD patterns for TSS samples collected during the natural flood event from site B in watershed MU2 (Go=goethite, He=hematite, Fh=ferrihydrite). X-ray patterns were developed using the fine soil fraction (i.e., <53µm).



CHAPTER 6

6. Project Summary

6.1 SIGNIFICANT FINDINGS

The investigations described here indicate the following key changes associated with urban sprawl in the Georgia Piedmont:

6.1.1 Hydrology

- High flow pulses and elevated peak discharge were far more frequent in urban watersheds (>20% impervious surface) than any other land use, and baseflow (i.e., groundwater) inputs in urban streams were reduced.

- Both high and low resolution stream discharge data adequately characterized the hydrologic nature of the streams.

- Overland flow (i.e., quickflow) contributed as much as 90% of the flow reaching the urban streams and between 65 and 90% of flow in streams associated with developing catchments.

- Watersheds with high proportions of forest or grass cover had much higher groundwater contribution to streamflow.

- Runoff coefficients ranged from 0.65 to >1.0 and were similar to the ranges reported for residential and commercial areas elsewhere.

6.1.2 Nutrients and Fecal Coliform

- Streams with >5% IS were subjected to higher nutrient and fecal coliform concentrations and loads during both baseflow and stormflow.

- Theoretical prediction scenarios of land use change suggest that dramatic increases in fecal coliform, chloride, and sulfate concentrations will be evident with increasing urban development.

- Fecal coliform counts exceeded the US EPA’s review criterion during both baseflow and stormflow in urban streams.

- Fecal coliform counts were likely influenced by substrate size classes due to fecal coliform and sediment binding with finer soil particles.

6.1.3 Channel Morphometry and Sediment

- Although there was a considerable degree of variation, land use appeared to be related to sediment movement and channel stability, where stream habitats were continually changing in urban, developing, and pastoral landscapes due to scour and fill.

- Historic land use and altered hydrology from contemporary land uses were the most probable influences on channel substrate, which appeared to directly impact bed stability.

- Contemporary land uses also explained 66% of the variation in TDS concentrations, but was not significantly correlated to TSS.

6.1.4 Sediment Origin

- Sediment originated from terrestrial sources in urban and unmanaged forest watersheds, while developing, pastoral, and managed watersheds were dominated by in-stream sources of sediment.

- Terrestrial inputs of sediment were low in unmanaged forest watersheds, and wildlife activity was likely the main cause.

6.2 SYNTHESIS

Hydrologic and geomorphic parameters identified in this study are critical for the survival and habitat quality for many aquatic species of fishes and macroinvertebrates, and these parameters appeared to be intimately linked with land cover. Thus, the maintenance of land cover types such as forests and grasses are important when managing watersheds for flood prevention and the maintenance of habitat stability within streams. Although stream stability in the Piedmont physiographic province was variable across the land use gradient in west Georgia, stream habitats were continually changing in urban, developing, and pastoral landscapes and, as a result, organisms could potentially be subjected to stresses or replacement by species with greater tolerances to habitat modification. Stream organisms not only had to contend with physical stresses imposed upon them by fluctuating hydrology and channel modification, but they also were subjected to impaired water quality in many streams. Specifically, in streams with >5% impervious surface, fecal coliform counts were elevated and the risk of bacterial infections, which could ultimately lead to lesions and/or tumors, threatened fish inhabiting the streams (Helms et al. 2005).

The ramifications of urban development are far-reaching beyond the organisms living within the streams. Protection of clean water not only reduces the cost of water purification for consumptive uses, but also serves as a recreational opportunity for humans. Streams draining residential areas attract young children and adults, which make human health risks a critical concern. Thus, the establishment of prediction models based on land cover and water quality indicators is imperative for planning and policy decisions in areas subject to urban development or land use change. Moreover, fecal coliform prediction provides an indication of the potential health risks associated with excess bacterial exposure. Hence, location-specific predictive models are critical to achieve sound land development decisions for the protection of water quality.

Lastly, knowledge of sediment origin is fundamental in land use decision making processes. Results suggested that both urban and unmanaged forest land covers were the dominant contributors of terrestrial sediments. The potential for sediment to bind pollutants makes the terrestrial input of urban sediment a major concern to the health of receiving waters. This is because PCBs, heavy metals, fecal coliform, and phosphorus have high potential as sediment-bound threats to urban streams. Thus, in urban landscapes, the implementation of sediment controls, whether through the creation of detention ponds, riparian buffers, or the use of mechanical removal of sediments, are key to the sustainability of urban streams. Other land uses, such as active urban development, in-stream revetments may offer more protection in the stabilization of stream channels.

6.3 FUTURE DIRECTIONS

Several of the previous chapters have mentioned that historical land use may have a significant role in many of the observed processes. For example, the present-day land use in a watershed may be classified as stable (e.g., unmanaged forest), while the streams draining the area show signs of sediment impairment, but in actuality the sediment degradation may be a result of historical erosion due to cotton farming that occurred 200 yrs prior. Thus, the recognition of the effects of land use legacies can aid in the clarification of anomalies observed in present-day stream ecosystems.

The impacts of the land use disturbances are cumulative and can involve a broad range of disciplines. Thus, interdisciplinary approaches and goals have gained popularity and should continue to be implemented in the integration processes across individual disciplines. Utilizing interdisciplinary approaches, researchers can identify socioeconomic and policy dynamics that drive land use change, while others identify ecological effects that subsequently follow the land use alteration. This holistic approach, with strong internal linkages, can provide direct applicability to land management processes and offer much greater insight to serious issues facing society today (i.e., urbanization).

7. APPENDICES

Appendix A: Land use percentages for all 24 watersheds. Percentages based on 1 m aerial photographs taken March 10, 2003.

ID	Evergreen	Deciduous	Pasture	Impervious	Water	Other	Total
BC	46.64	34.08	13.24	2.29	0.69	3.07	100.00
BLN	48.13	28.24	18.61	1.24	0.00	3.79	100.00
BSB	47.38	36.27	14.04	1.67	0.03	0.61	100.00
BU1	20.89	12.34	22.71	41.94	0.71	1.41	100.00
BU2	30.49	15.88	24.94	24.93	1.63	2.11	100.00
CB	48.31	32.99	13.00	1.53	0.38	3.78	100.00
FPWB	40.26	36.92	19.86	1.00	1.18	0.78	100.00
FS1	32.82	29.03	33.20	2.46	1.30	1.18	100.00
FS2	30.71	28.21	35.79	2.74	1.51	1.05	100.00
FS3	31.96	29.91	33.91	2.58	0.62	1.02	100.00
FS5	46.25	36.05	15.18	1.16	0.44	0.92	100.00
FS6	48.01	24.66	24.82	0.70	0.55	1.26	100.00
HC	47.84	26.73	19.55	1.33	0.68	3.87	100.00
HC2	30.47	22.22	43.95	1.64	0.76	0.96	100.00
MK	36.44	37.91	19.78	2.27	0.58	3.02	100.00
MU1	29.26	24.27	36.80	3.68	4.12	1.86	100.00
MU2	42.39	24.98	16.53	2.57	1.05	12.48	100.00
MU3	41.55	3706	14.80	1.88	0.86	3.85	100.00
RB	28.38	11.06	27.10	30.30	1.62	1.53	100.00
SB1	38.61	35.01	20.32	1.83	0.73	3.51	100.00
SB2	37.34	35.35	19.90	3.39	1.26	2.76	100.00
SB4	41.15	22.76	27.64	3.27	1.91	3.26	100.00
SC	44.80	28.79	20.84	1.24	0.71	3.62	100.00
WC	22.18	10.18	12.92	49.48	0.05	5.19	100.00

Appendix B: Pearson correlation coefficients for stream discharge among 18 watersheds in west Georgia.

ID	**Distance (km)†**	**Bearing**	**precip**	**BC**	**BLN**	**BU1**	**BU2**
			0.3632	1.0000	0.8089	0.5122	0.4321
BC	**31.5**	**10**	<.0001	.	<.0001	<.0001	<.0001
			0.4009	0.8089	1.0000	0.4478	0.3780
BLN	**21.3**	**267**	<.0001	<.0001	.	<.0001	<.0001
			0.6245	0.5122	0.4478	1.0000	0.9154
BU1	**34.1**	**191**	<.0001	<.0001	<.0001	.	<.0001
			0.6025	0.4321	0.3780	0.9154	1.0000
BU2	**30.7**	**188**	<.0001	<.0001	<.0001	<.0001	.
			0.4923	0.6846	0.6453	0.5438	0.5142
CB	**18.3**	**262**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.1253	-0.0403	-0.3134	0.3124	0.2737
FS2	**18.3**	**315**	0.0129	0.4243	<.0001	<.0001	<.0001
			0.1864	0.1324	0.1497	0.1679	0.1431
FS3	**19**	**318**	0.0002	0.0083	0.0028	0.0008	0.0043
			0.3919	0.2829	0.4457	0.3614	0.3450
HC	**21.5**	**283**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.2030	0.0080	0.2686	0.0448	0.0639
HC2	**17.3**	**300**	<.0001	0.8743	<.0001	0.3744	0.2048
			0.5224	0.6238	0.6637	0.5682	0.5151
MK	**42.4**	**7**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.5901	0.5964	0.5258	0.7155	0.6396
MU1	**17.7**	**130**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.5142	0.4743	0.4146	0.5683	0.5335
MU2	**10.9**	**118**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.5620	0.5474	0.4807	0.7549	0.7081
MU3	**7.8**	**165**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.6147	0.3722	0.3311	0.8994	0.8307
RB	**25.5**	**199**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.6380	0.4768	0.5312	0.7532	0.7301
SB1	**22.9**	**218**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.5051	0.6097	0.5140	0.7229	0.7268
SB2	**14.2**	**209**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.5002	0.5778	0.4451	0.8477	0.8002
SB4	**14.4**	**188**	<.0001	<.0001	<.0001	<.0001	<.0001
			0.4502	0.8034	0.7207	0.6160	0.5158
SC	**21.2**	**298**	<.0001	<.0001	<.0001	<.0001	<.0001

†Distances and bearings are in relation to the city of Hamilton, Georgia.

Appendix B. Continued

ID	CB	FS2	FS3	HC	HC2	MK	MU1
	0.68456	-0.0403	0.1324	0.2829	0.0080	0.6238	0.5964
BC	<.0001	0.4243	0.0083	<.0001	0.8743	<.0001	<.0001
	0.64532	-0.3134	0.1497	0.4457	0.2686	0.6637	0.5258
BLN	<.0001	<.0001	0.0028	<.0001	<.0001	<.0001	<.0001
	0.54379	0.31238	0.1679	0.3614	0.0448	0.5682	0.7155
BU1	<.0001	<.0001	0.0008	<.0001	0.3744	<.0001	<.0001
	0.51418	0.27371	0.1431	0.3450	0.0639	0.5151	0.6396
BU2	<.0001	<.0001	0.0043	<.0001	0.2048	<.0001	<.0001
	1	0.20511	0.0742	0.4536	0.0774	0.5988	0.7988
CB	.	<.0001	0.1403	<.0001	0.1244	<.0001	<.0001
	0.20511	1	-0.2115	-0.2642	-0.6406	-0.1186	0.2885
FS2	<.0001	.	<.0001	<.0001	<.0001	0.0182	<.0001
	0.07424	-0.2115	1.0000	0.4443	0.3808	0.1962	0.1850
FS3	0.1403	<.0001	.	<.0001	<.0001	<.0001	0.0002
	0.45355	-0.2642	0.4443	1.0000	0.7817	0.4001	0.4363
HC	<.0001	<.0001	<.0001	.	<.0001	<.0001	<.0001
	0.07743	-0.6406	0.3808	0.7817	1.0000	0.2505	0.0737
HC2	0.1244	<.0001	<.0001	<.0001	.	<.0001	0.1463
	0.59882	-0.1186	0.1962	0.4001	0.2505	1.0000	0.6520
MK	<.0001	0.0182	<.0001	<.0001	<.0001	.	<.0001
	0.7988	0.28851	0.1850	0.4363	0.0737	0.6520	1.0000
MU1	<.0001	<.0001	0.0002	<.0001	0.1463	<.0001	.
	0.8993	0.32944	0.0947	0.4007	0.0397	0.5703	0.8449
MU2	<.0001	<.0001	0.0617	<.0001	0.4342	<.0001	<.0001
	0.81193	0.28454	0.1880	0.4214	0.0632	0.6128	0.8909
MU3	<.0001	<.0001	0.0002	<.0001	0.2102	<.0001	<.0001
	0.44525	0.32915	0.1799	0.3535	0.0772	0.4424	0.6419
RB	<.0001	<.0001	0.0003	<.0001	0.1257	<.0001	<.0001
	0.58056	0.16032	0.2395	0.4369	0.1763	0.5084	0.7191
SB1	<.0001	0.0014	<.0001	<.0001	0.0004	<.0001	<.0001
	0.68374	0.23586	0.1249	0.3093	0.0061	0.6350	0.8359
SB2	<.0001	<.0001	0.0129	<.0001	0.9045	<.0001	<.0001
	0.65972	0.32896	0.1228	0.2833	-0.0602	0.5700	0.7829
SB4	<.0001	<.0001	0.0145	<.0001	0.2329	<.0001	<.0001
	0.78122	0.31242	0.0210	0.2601	-0.0795	0.5748	0.6980
SC	<.0001	<.0001	0.6913	<.0001	0.1334	<.0001	<.0001

Appendix. B. Continued.

ID	MU2	MU3	RB	SB1	SB2	SB4	SC
BC	0.47433	0.54744	0.3722	0.4768	0.6097	0.5778	0.8034
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
BLN	0.41457	0.48073	0.3311	0.5312	0.5140	0.4451	0.7207
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
BU1	0.56828	0.75489	0.8994	0.7532	0.7229	0.8477	0.6160
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
BU2	0.53354	0.70807	0.8307	0.7301	0.7268	0.8002	0.5158
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CB	0.8993	0.81193	0.4453	0.5806	0.6837	0.6597	0.7812
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
FS2	0.32944	0.28454	0.3292	0.1603	0.2359	0.3290	0.3124
	<.0001	<.0001	<.0001	0.0014	<.0001	<.0001	<.0001
FS3	0.0947	0.18801	0.1799	0.2395	0.1249	0.1228	0.0210
	0.0617	0.0002	0.0003	<.0001	0.0129	0.0145	0.6913
HC	0.40069	0.42141	0.3535	0.4369	0.3093	0.2833	0.2601
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
HC2	0.03971	0.06319	0.0772	0.1763	0.0061	-0.0602	-0.0795
	0.4342	0.2102	0.1257	0.0004	0.9045	0.2329	0.1334
MK	0.57026	0.61279	0.4424	0.5084	0.6350	0.5700	0.5748
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
MU1	0.84487	0.89089	0.6419	0.7191	0.8359	0.7829	0.6980
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
MU2	1	0.86397	0.4825	0.5413	0.6785	0.6869	0.6594
	.	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
MU3	0.86397	1	0.6471	0.7268	0.8066	0.8518	0.7069
	<.0001	.	<.0001	<.0001	<.0001	<.0001	<.0001
RB	0.48246	0.64711	1.0000	0.7876	0.6347	0.7532	0.4654
	<.0001	<.0001	.	<.0001	<.0001	<.0001	<.0001
SB1	0.54127	0.72684	0.7876	1.0000	0.7236	0.7347	0.5516
	<.0001	<.0001	<.0001	.	<.0001	<.0001	<.0001
SB2	0.67852	0.8066	0.6347	0.7236	1.0000	0.8965	0.6643
	<.0001	<.0001	<.0001	<.0001	.	<.0001	<.0001
SB4	0.6869	0.85179	0.7532	0.7347	0.8965	1.0000	0.6909
	<.0001	<.0001	<.0001	<.0001	<.0001	.	<.0001
SC	0.65938	0.70689	0.4654	0.5516	0.6643	0.6909	1.0000
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	.

Appendix C: Nutrient summaries and watershed descriptions for each individual watershed sampled in west Georgia.

Watershed ID: BC
Watershed Area: 647 ha
Tributary Name: Beech Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 703868 3657575
Number of Samples: 32
Median Baseflow: 31 Ls^{-1}
Baseflow Index: 0.57

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
---------------------Concentration Data (mg L^{-1}) ---------------------						
TDS	29.28	28.6	0.96	41.20	19.30	27.32-31.25
TSS	10.66	6.8	3.20	93.40	1.60	4.10-17.22
Cl^-	2.14	1.85	0.11	3.67	1.59	1.91-2.37
NO_3^-	0.80	0.76	0.06	1.61	0.16	0.68-0.92
SO_4^{2-}	1.53	1.46	0.11	2.90	0.66	1.30-1.77
Na^+	5.91	4.68	0.67	17.75	2.33	4.52-7.29
NH_4^+	0.02	0.00	0.01	0.26	0.00	0.00-0.05
K^+	1.99	1.57	0.22	6.22	0.95	1.54-2.44
Total P	0.08	0.06	0.01	0.22	0.00	0.05-0.10
DOC	2.29	2.08	0.23	6.85	1.09	1.81-2.77
FC	356.93	184.00	92.96	2500.00	18.00	165.83-548.02
------------------------Load Data (g $L^{-1}ha^{-1}$)------------------------						
TDS	340.55	253.05	253.05	1426.90	99.631	231.18-449.93
TSS	370.79	39.33	39.33	6730.95	5.98	0.00-857.92
Cl^-	26.14	18.26	18.26	127.63	4.39	16.38-35.91
NO_3^-	9.83	7.26	7.26	30.97	0.75	5.60-14.07
SO_4^{2-}	25.23	12.19	12.19	194.36	1.64	10.09-40.37
Na^+	57.25	50.33	50.33	167.99	11.87	43.09-71.41
NH_4^+	0.18	0.00	0.00	2.15	0.00	0.00-0.39
K^+	20.49	16.81	16.81	76.97	4.54	14.21-26.78
Total P	1.31	0.46	0.46	11.3	0.00	0.32-2.30
DOC	31.36	17.29	17.29	215.48	5.04	14.26-48.46

Watershed ID: BLN
Watershed Area: 364 ha
Tributary Name: Blanton Creek
Stream Order (Strahler): 1
UTM Zone 16 Coordinates: 16 N 677570 3625622
Number of Samples: 18
Median Baseflow: 21 Ls^{-1}
Baseflow Index: 0.65

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	19.68	19.50	0.51	26.30	17.30	18.59-20.78
TSS	3.56	2.70	0.96	16.80	0.80	1.51-5.61
Cl^-	1.91	1.93	0.02	2.06	1.79	1.87-1.95
NO_3^-	0.27	0.28	0.04	0.57	0.00	0.19-0.35
SO_4^{2-}	1.28	1.28	0.04	1.70	1.02	1.18-1.37
Na^+	2.82	2.57	0.14	4.33	2.24	2.52-3.13
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	1.88	1.81	0.07	2.41	1.49	1.72-2.03
Total P	0.07	0.06	0.01	0.20	0.00	0.04-0.10
DOC	1.64	1.43	0.23	4.85	0.95	1.15-2.13
FC	305.38	84.00	139.37	2200.00	4.00	8.32-602.43
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	198.09	179.41	26.40	536.42	66.11	141.82-254.37
TSS	29.01	24.42	5.15	89.35	7.75	18.03-39.98
Cl^-	18.94	18.56	1.98	39.55	5.71	14.73-23.15
NO_3^-	2.61	2.18	0.49	8.61	0.00	1.56-3.65
SO_4^{2-}	13.16	12.21	1.83	34.71	3.15	9.25-17.06
Na^+	26.99	26.87	2.39	45.63	9.69	21.89-32.08
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	17.83	17.72	1.43	30.92	7.1	14.78-20.88
Total P	0.69	0.48	0.17	2.38	0.00	0.33-1.05
DOC	14.70	14.42	1.50	29.71	6.64	11.49-17.90

Watershed ID: BSB
Watershed Area: 697 ha
Tributary Name: Blue Springs Branch
Stream Order (Strahler): 1
UTM Zone 16 Coordinates: 16 N 690427 3621407
Number of Samples: 15
Median Baseflow: na
Baseflow Index: na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	26.63	27.60	1.16	36.60	21.60	26.15-31.11
TSS	12.43	2.50	8.83	135.00	0.50	0.00-31.37
Cl^-	3.30	2.40	0.42	7.53	1.96	2.41-4.20
NO_3^-	0.09	0.00	0.03	0.29	0.00	0.02-0.15
SO_4^{2-}	1.67	1.76	0.08	2.03	1.13	1.49-1.84
Na^+	5.24	5.17	0.89	13.10	1.90	3.32-7.16
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	3.26	3.06	0.47	7.55	1.36	2.25-4.27
Total P	0.10	0.08	0.02	0.35	0.00	0.05-0.16
DOC	2.10	1.26	0.41	6.11	0.64	1.22-2.99
FC	370.39	100	193.83	2600.00	12.00	0.00-792.7
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	318.48	201.46	99.05	1593.70	50.62	106.05-530.92
TSS	708.35	9.23	661.32	9960.65	3.46	0.00-2126.74
Cl^-	31.35	20.12	9.31	153.91	5.92	11.38-51.32
NO_3^-	1.50	0.00	1.10	16.68	0.00	0.00-3.87
SO_4^{2-}	20.50	9.73	7.45	119.09	2.48	4.53-36.47
Na^+	39.4	33.36	7.89	139.82	6.94	22.47-56.32
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	27.83	19.19	7.89	133.10	4.94	10.9-44.76
Total P	2.36	0.64	1.69	25.9	0.00	0.00-5.99
DOC	46.02	11.23	29.25	450.52	1.71	0.00-108.74

Watershed ID: BU1
Watershed Area: 2546 ha
Tributary Name: Lindsay Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 693323 3592891
Number of Samples: 32
Median Baseflow: 144 Ls^{-1}
Baseflow Index: 0.32

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	59.12	61.10	2.46	81.7	30.6	54.07-64.18
TSS	11.51	2.80	5.53	118.20	0.00	0.14-22.87
Cl^-	9.60	9.60	0.62	15.74	3.44	8.34-10.87
NO_3^-	2.14	1.99	0.25	4.17	0.24	1.64-2.65
SO_4^{2-}	9.58	9.21	0.61	16.38	4.11	8.34-10.83
Na^+	8.96	7.27	1.11	29.88	3.21	6.69-11.23
NH_4^+	0.06	0.00	0.03	0.51	0.00	0.01-0.11
K^+	4.48	3.18	0.47	10.78	2.47	3.52-5.45
Total P	0.10	0.09	0.01	0.31	0.01	0.07-0.13
DOC	5.92	5.54	0.43	11.82	2.94	5.04-6.79
FC	2984.78	1800.00	821.40	17000.00	430	1281.31-4688.26
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	515.25	305.61	110.33	2092.87	60.92	288.47-742.03
TSS	484.17	15.13	306.37	6173.15	0.00	0.00-1113.93
Cl^-	74.65	45.32	14.50	273.30	9.36	44.85-104.45
NO_3^-	26.09	11.16	7.08	142.07	0.25	11.53-40.65
SO_4^{2-}	87.14	45.99	20.58	394.35	8.03	44.83-129.45
Na^+	62.51	36.73	12.64	292.07	7.37	36.52-88.49
NH_4^+	1.25	0.00	0.54	12.36	0.00	0.13-2.36
K^+	39.42	18.26	10.39	229.48	3.87	18.07-60.78
Total P	1.76	0.30	0.82	17.08	0.02	0.07-3.45
DOC	67.59	21.52	20.2	421.53	6.36	26.07-109.10

Watershed ID: BU2
Watershed Area: 2469 ha
Tributary Name: Cooper Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 695222 3595956
Number of Samples: 32
Median Baseflow: 0.37 Ls^{-1}
Baseflow Index: 0.03

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	53.51	52.65	1.73	70.20	29.10	49.97-57.04
TSS	12.98	5.10	4.16	106.20	1.80	4.48-21.49
Cl^-	7.29	6.94	0.43	12.39	3.07	6.41-8.17
NO_3^-	1.71	1.61	0.14	4.39	0.12	1.42-2.00
SO_4^{2-}	8.00	7.42	0.62	19.9	3.55	6.73-9.26
Na^+	7.93	5.31	0.88	19.74	2.98	6.13-9.73
NH_4^+	0.21	0.19	0.04	1.15	0.00	0.12-0.30
K^+	5.43	3.72	0.61	13.86	2.44	4.18-6.67
Total P	0.11	0.09	0.01	0.34	0.00	0.08-0.13
DOC	5.74	5.49	0.30	10.79	3.60	5.13-6.34
FC	2265.85	1550.00	467.34	8000.00	146.00	1303.34-3228.35
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	718.61	323.31	181.28	3783.90	7.01	347.85-1089.36
TSS	743.18	25.70	444.95	10038.59	0.45	0.00-1653.21
Cl^-	94.21	41.57	23.79	483.93	1.06	45.56-142.85
NO_3^-	26.07	9.75	7.92	171.86	0.08	9.87-42.27
SO_4^{2-}	110.43	41.91	29.17	542.38	1.12	50.77-170.09
Na^+	89.89	38.04	25.93	641.64	1.10	36.86-142.92
NH_4^+	3.06	0.91	1.03	27.05	0.00	0.96-5.17
K^+	67.52	26.95	20.21	441.85	0.95	26.18-108.86
Total P	3.05	0.36	1.67	44.71	0.00	0.00-6.48
DOC	102.96	30.19	37.51	991.64	0.62	26.24-179.68

Watershed ID: CB
Watershed Area: 897 ha
Tributary Name: Clines Branch
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 680997 362509
Number of Samples: 32
Median Baseflow: 1.8 Ls^{-1}
Baseflow Index: 0.42

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	25.32	24.60	0.67	37.00	20.30	23.96-26.68
TSS	2.95	2.20	0.54	13.00	0.00	1.84-4.06
Cl^-	2.36	2.15	0.09	3.86	1.96	2.18-2.53
NO_3^-	0.13	0.08	0.03	0.54	0.00	0.07-0.18
SO_4^{2-}	3.27	2.41	0.38	9.15	1.15	2.49-4.05
Na^+	5.53	3.57	0.67	16.19	2.40	4.16-6.89
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	3.08	1.96	0.43	10.81	1.58	2.20-3.96
Total P	0.07	0.07	0.01	0.18	0.00	0.05-0.09
DOC	2.28	1.83	0.20	6.58	1.16	1.88-2.69
FC	332.74	188.00	111.81	3000.00	18.00	102.92-562.56
-------------------------Load Data (g L^{-1}ha^{-1})-------------------------						
TDS	127.55	116.93	19.55	519.34	4.45	87.51-167.60
TSS	22.06	8.32	10.59	312.56	0.00	0.37-43.75
Cl^-	11.89	10.38	1.83	48.11	0.55	8.14-15.63
NO_3^-	0.50	0.23	0.13	2.60	0.00	0.24-0.75
SO_4^{2-}	16.57	11.91	3.33	92.59	0.37	9.75-23.39
Na^+	20.55	18.19	2.29	57.78	2.09	15.86-25.24
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	10.72	10.19	1.33	38.71	1.40	7.99-13.45
Total P	0.31	0.20	0.06	0.91	0.00	0.19-0.42
DOC	12.23	8.50	3.19	95.33	0.24	5.68-18.77

Watershed ID: FPWB
Watershed Area: 489 ha
Tributary Name: Five Points West Branch
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 689255 3621326
Number of Samples: 15
Median Baseflow: na
Baseflow Index: na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	31.14	29.35	1.26	39.20	23.80	28.42-33.86
TSS	2.45	2.15	0.59	8.20	0.00	1.19-3.71
Cl^-	3.19	2.81	0.24	4.45	2.13	2.68-3.71
NO_3^-	0.35	0.37	0.06	0.88	0.00	0.22-0.48
SO_4^{2-}	1.86	1.93	0.10	2.35	1.14	1.64-2.09
Na^+	8.72	8.49	1.37	18.12	3.17	5.76-11.67
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	4.81	4.34	0.82	10.36	1.89	3.05-6.57
Total P	0.10	0.09	0.02	0.24	0.00	0.05-0.15
DOC	1.76	1.52	0.19	3.32	0.85	1.35-2.16
FC	419.08	144.50	200.89	2500.00	40.00	0.00-861.24
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	159.22	114.91	35.90	469.14	6.58	81.67-236.77
TSS	19.15	7.7	9.69	139.89	0.00	0.00-40.08
Cl^-	14.67	11.32	3.05	40.91	0.74	8.09-21.25
NO_3^-	1.68	1.54	0.43	5.54	0.00	0.74-2.62
SO_4^{2-}	10.86	7.20	3.06	40.16	0.29	4.25-17.47
Na^+	31.71	31.55	5.06	75.23	1.81	20.78-42.64
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00-0.00
K^+	17.79	15.60	2.90	41.71	0.81	11.52-24.05
Total P	0.51	0.29	0.18	1.95	0.00	0.12-0.90
DOC	11.65	5.63	4.09	56.6	0.23	2.82-20.48

Watershed ID: FS1
Watershed Area: 2420 ha
Tributary Name: Wildcat Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 684091 3641414
Number of Samples: 15
Median Baseflow: na
Baseflow Index: na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	26.14	25.80	0.89	32.1	19.00	24.26-28.03
TSS	11.03	5.40	4.11	73.6	2.00	2.31-19.75
Cl^-	4.77	4.26	0.36	7.05	2.61	4.01-5.52
NO_3^-	4.29	4.24	0.29	6.83	1.75	3.67-4.91
SO_4^{2-}	1.60	1.61	0.09	2.18	0.85	1.40-1.79
Na^+	6.60	6.79	1.07	14.47	2.70	4.34-8.85
NH_4^+	0.18	0.11	0.06	0.74	0.00	0.06-0.31
K^+	4.49	3.63	0.71	10.23	1.72	2.98-6.00
Total P	0.10	0.11	0.02	0.24	0.00	0.07-0.14
DOC	1.90	1.91	0.19	4.31	1.02	1.49-2.31
FC	1649.4	430.00	977.96	15000.00	70.00	0.00-3746.92
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	246.93	204.06	53.77	843.06	30.77	132.94-360.92
TSS	251.85	45.70	189.51	3265.74	2.40	0.00-653.61
Cl^-	39.33	33.02	7.41	115.59	5.56	23.63-55.03
NO_3^-	37.26	37.90	6.45	79.04	3.48	23.60-50.93
SO_4^{2-}	17.85	10.82	5.24	85.02	1.36	6.75-28.95
Na^+	41.01	40.02	6.52	122.86	6.64	27.20-54.83
NH_4^+	1.00	0.67	0.35	5.68	0.00	0.26-1.74
K^+	29.98	24.55	6.83	129.70	5.09	15.5-44.45
Total P	1.40	0.48	0.64	10.73	0.00	0.04-2.76
DOC	24.92	9.63	10.92	191.24	2.05	1.76-48.07

Watershed ID: FS2
Watershed Area: 1449 ha
Tributary Name: Wildcat Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 685946 3639085
Number of Samples: 15
Median Baseflow: 730 Ls^{-1}
Baseflow Index: 0.82

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	22.29	22.10	0.54	26.40	19.10	21.12-23.46
TSS	5.64	5.00	0.79	10.80	0.40	3.95-7.33
Cl^-	3.43	3.42	0.03	3.66	3.27	3.37-3.49
NO_3^-	2.87	3.02	0.11	3.32	1.77	2.63-3.11
SO_4^{2-}	0.99	0.98	0.07	1.58	0.62	0.84-1.14
Na^+	3.38	2.91	0.28	5.81	2.46	2.79-3.97
NH_4^+	0.14	0.14	0.03	0.31	0.00	0.08-0.20
K^+	2.22	1.97	0.26	5.62	1.57	1.66-2.79
Total P	0.07	0.08	0.01	0.17	0.00	0.04-0.10
DOC	2.22	2.06	0.22	4.80	1.48	1.75-2.70
FC	167.20	140.00	24.68	390.00	24.00	114.27-220.13
------------------------Load Data (g $L^{-1}ha^{-1}$)------------------------						
TDS	233.89	224.29	20.10	367.45		190.78-276.99
TSS	64.70	54.52	12.33	160.02	88.24	38.26-91.13
Cl^-	36.56	35.28	3.40	62.86	4.02	29.26-43.86
NO_3^-	31.18	28.69	3.55	56.45	11.66	23.56-38.80
SO_4^{2-}	11.46	10.21	1.86	29.11	10.52	7.47-15.44
Na^+	34.01	32.05	2.76	58.28	2.07	28.08-39.94
NH_4^+	1.48	1.44	0.35	4.25	11.74	0.74-2.23
K^+	22.05	19.87	1.94	39.34	0.00	17.89-26.20
Total P	0.75	0.67	0.15	1.96	7.69	0.44-1.07
DOC	21.84	22.01	1.66	30.54	0.00	18.27-25.40

Watershed ID: FS3
Watershed Area: 296 ha
Tributary Name: Wildcat Creek
Stream Order (Strahler): 1
UTM Zone 16 Coordinates: 16 N 685956 3640196
Number of Samples: 15
Median Baseflow: 2 Ls^{-1}
Baseflow Index: 0.26

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
			----------------------Concentration Data (mg L^{-1}) ----------------------			
TDS	20.99	20.90	0.50	26.00	18.80	19.92-22.07
TSS	4.40	3.20	1.01	15.80	0.40	2.24-6.56
Cl^-	3.44	3.45	0.04	3.74	3.24	3.37-3.52
NO_3^-	3.22	3.21	0.12	3.94	2.22	2.95-3.49
SO_4^{2-}	0.73	0.71	0.06	1.21	0.44	0.61-0.86
Na^+	3.19	2.68	0.25	5.35	2.28	2.65-3.73
NH_4^+	0.02	0.00	0.01	0.17	0.00	0.00-0.05
K^+	2.09	1.89	0.16	3.69	1.55	1.74-2.43
Total P	0.06	0.06	0.01	0.11	0.00	0.04-0.08
DOC	1.59	1.48	0.18	3.76	0.97	1.19-1.98
FC	357.6	120.00	132.76	1800.00	28.00	72.86-642.34
			-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------			
TDS	228.43	218.35	24.37	452.08	114.86	176.17-280.70
TSS	56.29	29.55	18.13	264.09	4.20	17.4-95.19
Cl^-	37.31	36.08	3.69	65.05	17.78	29.41-45.22
NO_3^-	35.26	32.89	3.98	68.53	15.28	26.71-43.80
SO_4^{2-}	8.69	7.07	1.49	20.99	2.64	5.49-11.89
Na^+	32.30	29.44	2.31	49.44	16.36	27.35-37.26
NH_4^+	0.18	0.00	0.14	1.91	0.00	0.00-0.47
K^+	21.06	20.43	1.33	28.85	11.82	18.22-23.91
Total P	0.65	0.44	0.13	1.56	0.00	0.37-0.93
DOC	16.92	11.96	2.41	39.45	6.73	11.76-22.08

Watershed ID: FS5
Watershed Area: 1183 ha
Tributary Name: Flat Shoals Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 707467 3652031
Number of Samples: 15
Median Baseflow: na
Baseflow Index: na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	32.88	28.20	3.48	63.80	15.80	25.42-40.34
TSS	11.15	5.50	4.43	63.00	0.00	1.65-20.66
Cl^-	2.82	2.59	0.23	4.68	1.38	2.33-3.30
NO_3^-	1.02	0.96	0.13	1.94	0.26	0.74-1.30
SO_4^{2-}	5.82	4.05	1.20	20.54	1.89	3.25-8.40
Na^+	7.81	7.45	1.42	19.88	1.21	4.77-10.86
NH_4^+	0.29	0.27	0.05	0.79	0.09	0.18-0.40
K^+	3.29	2.01	0.63	8.27	0.98	1.93-4.65
Total P	0.12	0.11	0.02	0.31	0.01	0.07-0.17
DOC	4.27	3.70	0.49	9.66	2.21	3.21-5.33
FC	800.38	120.00	390.17	4600.00	12.00	0.00-1650.5
------------------------Load Data (g $L^{-1}ha^{-1}$)------------------------						
TDS	204.93	133.84	68.93	1021.58	9.01	56.01-353.85
TSS	166.93	17.38	132.31	1880.84	0.00	0.00-452.77
Cl^-	19.11	12.52	6.31	92.13	0.55	5.48-32.74
NO_3^-	6.70	3.03	2.30	29.93	0.24	1.72-11.67
SO_4^{2-}	34.77	20.34	12.22	180.45	0.55	8.37-61.17
Na^+	35.88	34.36	8.59	106.31	2.11	17.32-54.44
NH_4^+	1.62	1.35	0.42	4.91	0.06	0.70-2.53
K^+	14.35	10.88	3.89	51.27	1.21	5.96-22.75
Total P	0.78	0.30	0.37	5.36	0.03	0.00-1.57
DOC	35.90	14.55	17.13	250.86	0.61	0.00-72.89

Watershed ID: FS6
Watershed Area: 922 ha
Tributary Name: Flat Shoals Creek
Stream Order (Strahler):2
UTM Zone 16 Coordinates: 16 N 707446 3651910
Number of Samples: 15
Median Baseflow: na
Baseflow Index:na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	36.68	32.40	5.01	85.50	17.70	27.94-49.42
TSS	4.18	2.80	1.28	21.00	0.50	1.44-6.92
Cl^-	3.52	2.76	0.87	15.01	1.05	1.66-5.38
NO_3^-	0.39	0.32	0.08	1.28	0.08	0.22-0.56
SO_4^{2-}	5.54	3.93	1.19	18.50	1.46	2.98-8.09
Na^+	8.50	8.74	1.57	20.45	1.28	5.14-11.86
NH_4^+	0.21	0.15	0.06	0.64	0.00	0.09-0.33
K^+	2.69	1.64	0.56	7.30	0.74	1.48-3.9
Total P	0.10	0.10	0.01	0.17	0.00	0.07-0.12
DOC	5.55	5.51	0.43	8.90	3.19	4.62-6.48
FC	648.23	90.00	338.28	4000.00	8.00	0.00-1385.28
-------------------------Load Data (g $^{-1}$)-------------------------						
TDS	268.17	144.19	97.75	1418.11	1.08	56.98-479.35
TSS	51.02	11.06	33.86	487.28	0.06	0.00-124.17
Cl^-	22.00	15.47	7.74	114.20	0.04	5.28-38.73
NO_3^-	3.52	1.03	2.07	29.67	0.02	0.00-7.99
SO_4^{2-}	37.80	22.89	14.25	209.59	0.12	7.02-68.58
Na^+	43.53	39.12	11.41	140.62	0.39	18.8-68.18
NH_4^+	1.32	0.02	0.70	8.43	0.00	0.00-2.83
K^+	13.84	9.67	4.52	57.16	0.09	4.07-23.60
Total P	0.84	0.38	0.30	3.78	0.00	0.19-1.48
DOC	51.77	19.87	23.66	344.16	0.17	0.66-102.89

Watershed ID: HC
Watershed Area: 655 ha
Tributary Name: House Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 678141 3630775
Number of Samples: 32
Median Baseflow: 17 Ls^{-1}
Baseflow Index: 0.55

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	22.26	20.70	0.73	32.80	16.30	20.77-23.75
TSS	6.34	4.65	1.75	52.00	0.50	2.75-9.93
Cl^-	2.41	2.16	0.11	4.30	1.77	2.18-2.64
NO_3^-	0.81	0.63	0.10	2.15	0.07	0.61-1.02
SO_4^{2-}	2.85	2.35	0.31	8.13	1.14	2.21-3.49
Na^+	4.36	2.75	0.59	13.37	2.23	3.15-5.57
NH_4^+	0.08	0.03	0.02	0.42	0.00	0.04-0.12
K^+	2.92	1.93	0.40	10.37	1.44	2.10-3.74
Total P	0.06	0.07	0.01	0.15	0.00	0.05-0.08
DOC	2.18	2.03	0.17	5.90	1.38	1.82-2.54
FC	110.19	79.00	18.56	390.00	10.00	71.98-148.41
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	151.56	136.31	22.16	575.52	4.95	106.08-197.03
TSS	100.25	27.94	64.64	1836.01	0.09	0.00-232.88
Cl^-	16.26	13.63	2.40	62.46	0.57	11.34-21.18
NO_3^-	6.42	3.49	1.40	27.15	0.11	3.55-9.29
SO_4^{2-}	20.50	15.97	3.51	87.28	0.52	13.29-27.70
Na^+	22.57	21.22	3.21	95.97	0.95	15.98-29.15
NH_4^+	0.48	0.01	0.14	2.70	0.00	0.20-0.77
K^+	15.37	12.44	2.72	82.66	0.94	9.79-20.95
Total P	0.56	0.33	0.19	5.11	0.00	0.18-0.94
DOC	15.85	10.84	3.76	107.97	0.35	8.12-23.57

Watershed ID: HC2
Watershed Area: 1395 ha
Tributary Name: House Creek
Stream Order (Strahler): 3
UTM Zone 16 Coordinates: 16 N 683811 3634666
Number of Samples: 15
Median Baseflow: 44 Ls^{-1}
Baseflow Index: 0.81

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	25.53	25.70	0.58	29.2	20.90	24.29-26.76
TSS	8.44	7.80	1.43	25.4	3.00	5.38-11.51
Cl^-	4.20	4.18	0.04	4.51	3.96	4.11-4.29
NO_3^-	4.45	4.59	0.16	5.19	2.94	4.10-4.80
SO_4^{2-}	1.08	1.07	0.08	1.81	0.70	0.91-1.25
Na^+	3.60	2.92	0.31	6.57	2.62	2.93-4.27
NH_4^+	0.16	0.20	0.02	0.27	0.00	0.11-0.21
K^+	2.89	2.42	0.23	5.12	2.11	2.39-3.40
Total P	0.07	0.08	0.01	0.16	0.00	0.04-0.10
DOC	1.87	1.75	0.19	4.30	1.09	1.45-2.28
FC	524.67	270.00	166.24	2300.00	60.00	168.12-881.21
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	294.16	235.56	60.15	1080.56	83.65	165.15-423.17
TSS	88.15	66.24	15.75	230.33	26.48	54.38-121.93
Cl^-	51.28	36.56	13.16	229.19	12.92	23.05-79.50
NO_3^-	55.37	41.12	14.87	254.78	14.87	23.48-87.26
SO_4^{2-}	15.83	9.51	5.73	93.37	2.11	3.54-28.13
Na^+	39.19	32.92	7.69	140.83	10.38	22.70-55.67
NH_4^+	2.14	1.86	0.74	11.94	0.00	0.55-3.74
K^+	31.54	26.57	6.56	120.57	10.84	17.47-45.61
Total P	0.64	0.61	0.13	1.41	0.00	0.35-0.92
DOC	20.53	15.39	4.37	77.45	8.02	11.16-29.89

Watershed ID: MK
Watershed Area: 663 ha
Tributary Name: McKoon Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 703701 3668559
Number of Samples: 32
Median Baseflow: 0.25 L s^{-1}
Baseflow Index: 0.23

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	28.06	27.70	0.72	37.40	20.40	26.58-29.53
TSS	11.73	7.40	3.03	83.00	1.50	5.53-17.94
Cl^-	2.34	2.18	0.10	4.00	1.65	2.13-2.56
NO_3^-	0.63	0.56	0.05	1.22	0.28	0.52-0.74
SO_4^{2-}	1.16	1.11	0.09	2.52	0.39	0.98-1.34
Na^+	7.26	4.46	0.95	22.44	2.94	5.31-9.22
NH_4^+	0.07	0.00	0.02	0.33	0.00	0.03-0.11
K^+	2.14	1.40	0.31	8.52	1.05	1.51-2.76
Total P	0.08	0.08	0.01	0.19	0.00	0.06-0.10
DOC	2.36	2.18	0.23	7.39	0.81	1.89-2.83
FC	228.54	165.00	41.34	872.00	20.00	143.72-313.35
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	245.32	212.24	32.68	868.36	48.13	178.39-312.26
TSS	228.53	61.65	117.86	3231.99	3.65	0.00-469.95
Cl^-	20.44	17.01	2.87	78.50	3.70	14.56-26.32
NO_3^-	6.61	4.35	1.57	43.92	0.70	3.40-9.82
SO_4^{2-}	13.55	7.73	3.67	98.13	0.86	6.02-21.07
Na^+	50.11	44.15	5.27	131.26	12.68	39.31-60.91
NH_4^+	0.63	0.00	0.22	4.48	0.00	0.18-1.07
K^+	15.74	12.23	2.21	57.99	2.78	11.22-20.26
Total P	0.74	0.48	0.18	4.03	0.00	0.38-1.11
DOC	25.25	16.81	6.74	171.49	3.56	11.43-39.07

Watershed ID: MU1
Watershed Area: 1178 ha
Tributary Name: Ossahatchie Creek
Stream Order (Strahler): 3
UTM Zone 16 Coordinates: 16 N 712939 3615237
Number of Samples: 32
Median Baseflow: 29 Ls^{-1}
Baseflow Index: 0.28

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	43.18	39.75	2.78	85.20	22.50	37.48-48.87
TSS	7.83	5.90	1.31	32.20	2.00	5.14-10.51
Cl^-	5.08	4.70	0.38	12.15	2.87	4.31-5.85
NO_3^-	0.23	0.17	0.03	0.64	0.05	0.17-0.28
SO_4^{2-}	2.80	2.18	0.54	14.99	0.38	1.70-3.90
Na^+	9.38	6.28	1.60	37.82	3.27	6.09-12.67
NH_4^+	0.16	0.00	0.06	1.40	0.00	0.04-0.27
K^+	3.38	2.28	0.52	12.86	1.45	2.31-4.45
Total P	0.12	0.12	0.01	0.37	0.00	0.09-0.15
DOC	9.89	9.42	0.60	18.18	5.41	8.66-11.13
FC	271.92	128.00	99.38	2400.00	32.00	66.33-477.50
-------------------------Load Data (g L^{-1}ha^{-1})-------------------------						
TDS	475.07	316.92	89.88	1763.06	6.09	290.65-659.48
TSS	197.55	33.73	77.00	1744.89	0.22	39.56-355.55
Cl^-	59.61	45.86	10.91	224.65	0.68	37.21-82.00
NO_3^-	4.27	1.11	1.14	18.48	0.06	1.92-6.61
SO_4^{2-}	50.71	19.71	14.54	355.35	0.14	20.88-80.54
Na^+	76.09	65.41	12.18	256.31	3.18	51.11-101.07
NH_4^+	0.97	0.00	0.39	7.97	0.00	0.17-1.78
K^+	35.54	23.84	8.20	190.02	0.77	18.73-52.36
Total P	2.34	0.56	0.87	19.23	0.00	0.55-4.13
DOC	159.42	69.09	47.03	1013.17	1.37	62.92-255.92

Watershed ID: MU2
Watershed Area: 606 ha
Tributary Name: Mulberry Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 708913 3621461
Number of Samples: 32
Median Baseflow: 18 Ls^{-1}
Baseflow Index: 0.21

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	51.69	49.50	2.94	106.00	28.2	45.67-57.71
TSS	6.89	6.00	0.88	23.4	0.00	5.08-8.70
Cl^-	4.77	4.62	0.26	9.21	2.21	4.23-5.30
NO_3^-	0.16	0.10	0.03	0.66	0.00	0.09-0.22
SO_4^{2-}	2.83	2.03	0.50	12.42	0.58	1.80-3.85
Na^+	12.18	7.96	1.76	44.53	4.22	8.57-15.80
NH_4^+	0.22	0.00	0.07	1.29	0.00	0.08-0.36
K^+	3.24	2.31	0.47	12.14	1.54	2.27-4.20
Total P	0.10	0.10	0.01	0.26	0.00	0.07-0.12
DOC	5.15	4.63	0.51	16.89	2.23	4.11-6.20
FC	193.46	93.00	52.02	1064.00	10.00	86.33-300.59
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	306.67	223.09	48.15	1097.01	18.40	208.04-405.30
TSS	63.52	22.21	21.05	451.32	0.00	20.4-106.64
Cl^-	27.58	23.33	4.00	81.79	2.30	19.38-35.78
NO_3^-	2.18	0.29	0.79	16.24	0.00	0.55-3.81
SO_4^{2-}	20.71	8.84	5.32	95.44	0.71	9.81-31.6
Na^+	55.33	44.05	7.67	207.2	9.44	39.62-71.04
NH_4^+	0.65	0.00	0.20	3.33	0.00	0.24-1.06
K^+	17.37	11.1	4.01	113.16	3.00	9.16-25.57
Total P	0.91	0.36	0.36	9.65	0.01	0.17-1.64
DOC	40.46	20.39	12.00	289.33	0.78	15.88-65.03

Watershed ID: MU3
Watershed Area: 1044 ha
Tributary Name: Turntime Branch
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 701261 3618978
Number of Samples: 32
Median Baseflow: 0.04 Ls^{-1}
Baseflow Index: 0.21

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	42.04	41.80	1.58	56.20	23.20	38.8-45.28
TSS	3.99	2.00	1.16	30.60	0.00	1.61-6.37
Cl^-	3.13	3.07	0.12	5.25	1.97	2.88-3.38
NO_3^-	0.22	0.22	0.02	0.60	0.00	0.17-0.27
SO_4^{2-}	3.16	3.31	0.25	5.43	1.20	2.65-3.67
Na^+	9.15	6.23	1.15	28.13	2.81	6.79-11.51
NH_4^+	0.02	0.00	0.01	0.27	0.00	0.00-0.04
K^+	2.68	1.80	0.48	13.17	1.08	1.68-3.67
Total P	0.08	0.07	0.01	0.21	0.00	0.05-0.10
DOC	7.00	5.83	0.63	19.64	3.51	5.71-8.30
FC	258.04	211.00	45.79	980.00	20.00	163.54-352.54
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	274.37	198.01	49.23	1020.56	2.09	173.36-375.35
TSS	77.25	8.64	38.10	903.65	0.00	0.00-155.44
Cl^-	21.93	14.04	4.26	85.43	0.17	13.19-30.67
NO_3^-	1.68	1.02	0.38	7.32	0.00	0.89-2.47
SO_4^{2-}	28.58	14.15	7.68	140.47	0.21	12.82-44.34
Na^+	43.85	40.34	6.22	138.47	0.42	31.08-56.62
NH_4^+	0.03	0.00	0.03	0.88	0.00	0.00-0.10
K^+	12.58	8.38	2.50	57.66	0.25	7.46-17.70
Total P	0.72	0.32	0.28	6.10	0.00	0.13-1.30
DOC	65.87	22.55	21.71	488.18	0.44	21.34-110.41

Watershed ID: RB
Watershed Area: 367
Tributary Name: Roaring Branch
Stream Order (Strahler): 1
UTM Zone 16 Coordinates: 16 N 691357 3602110
Number of Samples: 32
Median Baseflow: 7.8 Ls^{-1}
Baseflow Index: 0.13

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	57.98	58.90	1.75	77.40	35.60	54.40-61.56
TSS	5.18	3.50	0.89	22.20	0.00	3.36-7.00
Cl^-	8.12	7.80	0.47	15.32	4.74	7.16-9.07
NO_3^-	1.84	1.74	0.14	3.43	0.79	1.56-2.12
SO_4^{2-}	5.89	5.55	0.45	12.81	2.92	4.96-6.82
Na^+	10.39	7.06	1.32	32.51	3.97	7.69-13.08
NH_4^+	0.18	0.17	0.03	0.41	0.00	0.13-0.23
K^+	4.82	3.22	0.59	16.66	2.44	3.61-6.04
Total P	0.08	0.08	0.01	0.26	0.00	0.06-0.11
DOC	5.42	4.87	0.57	19.95	2.89	4.26-6.58
FC	428.26	330.00	82.84	2000.00	12.00	257.97-598.55
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	440.46	324.25	76.56	1704.81	81.65	283.63-597.29
TSS	71.82	13.85	28.96	759.98	0.00	12.50-131.14
Cl^-	57.29	41.60	8.47	184.21	8.49	39.93-74.64
NO_3^-	18.15	8.31	4.70	117.56	1.90	8.53-27.77
SO_4^{2-}	52.69	31.18	13.20	353.32	3.79	25.65-79.73
Na^+	63.19	52.70	10.16	235.62	9.63	42.38-83.99
NH_4^+	1.57	0.70	0.42	9.22	0.00	0.70-2.44
K^+	33.16	22.32	6.54	152.82	4.70	19.76-46.55
Total P	0.96	0.38	0.39	8.87	0.00	0.16-1.76
DOC	47.03	27.63	11.44	230.97	6.69	23.59-70.47

Watershed ID: SB1
Watershed Area: 2009 ha
Tributary Name: Schley Creek
Stream Order (Strahler): 3
UTM Zone 16 Coordinates: 16 N 685293 3608160
Number of Samples: 32
Median Baseflow: 0.05 Ls^{-1}
Baseflow Index: 0.13

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	45.93	48.90	1.92	65.10	23.70	42.00-49.87
TSS	6.68	3.20	1.89	50.40	0.00	2.80-10.56
Cl^-	3.87	3.86	0.18	6.09	1.89	3.51-4.24
NO_3^-	0.16	0.14	0.02	0.42	0.00	0.12-0.19
SO_4^{2-}	4.59	4.50	0.29	8.95	2.09	4.00-5.18
Na^+	10.14	7.17	1.23	31.33	3.83	7.62-12.66
NH_4^+	0.01	0.00	0.01	0.34	0.00	0.00-0.04
K^+	2.82	1.90	0.46	10.71	1.00	1.87-3.77
Total P	0.07	0.08	0.01	0.20	0.00	0.05-0.09
DOC	6.05	4.96	0.63	19.20	2.57	4.76-7.34
FC	656.48	152.00	346.79	8660.00	30.00	0.00-1372.22
------------------------Load Data (g $L^{-1}ha^{-1}$)------------------------						
TDS	365.40	189.03	95.31	1884.40	1.83	170.18-560.63
TSS	232.02	17.98	138.76	3782.79	0.00	0.00-516.25
Cl^-	33.05	16.61	8.96	198.05	0.18	14.70-51.40
NO_3^-	1.47	0.51	0.48	11.52	0.00	0.49-2.45
SO_4^{2-}	51.69	17.95	15.55	314.90	0.12	19.83-83.55
Na^+	63.84	29.59	17.92	443.80	1.01	27.14-100.55
NH_4^+	0.01	0.00	0.01	0.24	0.00	0.00-0.03
K^+	16.84	6.91	5.51	144.03	0.33	5.56-28.11
Total P	1.17	0.18	0.57	13.88	0.00	0.00-2.34
DOC	90.37	18.99	36.77	778.32	0.19	15.05-165.69

Watershed ID: SB2
Watershed Area: 634
Tributary Name: Standing Boy Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 692405 3613831
Number of Samples: 32
Median Baseflow: 3.3 Ls^{-1}
Baseflow Index: 0.10

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	56.12	57.90	2.25	77.30	30.40	51.5-60.73
TSS	3.50	3.70	0.39	7.80	0.00	2.71-4.30
Cl^-	5.88	5.57	0.32	11.55	2.65	5.21-6.54
NO_3^-	0.12	0.10	0.02	0.30	0.00	0.08-0.15
SO_4^{2-}	5.82	5.68	0.49	14.80	2.38	4.82-6.83
Na^+	12.87	9.14	1.74	40.44	4.42	9.31-16.43
NH_4^+	0.03	0.00	0.02	0.32	0.00	0.00-0.06
K^+	3.30	2.30	0.48	11.41	1.40	2.33-4.28
Total P	0.07	0.07	0.01	0.20	0.00	0.05-0.09
DOC	6.06	4.61	0.72	22.13	2.84	4.59-7.53
FC	370.68	260.00	58.00	1000.00	28.00	250.98-490.38
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	281.80	163.79	65.33	1315.62	0.34	147.75-415.85
TSS	31.02	7.95	12.59	328.91	0.00	5.19-56.86
Cl^-	30.32	15.84	6.72	144.40	0.02	16.54-44.11
NO_3^-	1.09	0.21	0.38	7.88	0.00	0.31-1.86
SO_4^{2-}	38.44	19.16	10.28	217.47	0.02	17.34-59.55
Na^+	49.49	32.97	11.95	302.33	0.18	24.98-73.99
NH_4^+	0.01	0.00	0.01	0.28	0.00	0.00-0.04
K^+	13.19	7.57	4.03	106.55	0.06	4.93-21.46
Total P	0.60	0.15	0.31	8.52	0.00	0.00-1.25
DOC	46.99	11.19	18.27	397.02	0.02	9.51-84.47

Watershed ID: SB4
Watershed Area: 2659
Tributary Name: Standing Boy Creek
Stream Order (Strahler): 3
UTM Zone 16 Coordinates: 16 N 697366 3612240
Number of Samples: 32
Median Baseflow: 68 Ls^{-1}
Baseflow Index: 0.10

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	45.62	42.50	2.60	86.20	21.30	40.31-50.92
TSS	10.25	5.00	3.43	89.00	0.00	3.24-17.25
Cl^-	4.74	4.19	0.26	8.22	3.03	4.22-5.27
NO_3^-	0.73	0.79	0.04	1.18	0.20	0.64-0.82
SO_4^{2-}	3.07	2.39	0.47	14.56	0.82	2.11-4.04
Na^+	11.68	7.02	1.77	42.94	3.53	8.07-15.29
NH_4^+	0.22	0.00	0.07	1.33	0.00	0.09-0.36
K^+	3.58	1.96	0.59	15.14	1.56	2.38-4.78
Total P	0.09	0.10	0.01	0.19	0.00	0.07-0.11
DOC	6.11	5.02	0.55	19.04	3.65	4.99-7.24
FC	302.07	228.00	53.94	1300.00	28.00	191.21-412.94
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	237.83	141.18	62.99	1878.15	1.64	109.19-366.48
TSS	264.80	14.76	196.66	6056.35	0.00	0.00-666.44
Cl^-	27.22	17.11	7.37	220.68	0.14	12.17-42.26
NO_3^-	5.34	2.67	2.19	69.27	0.00	0.86-9.82
SO_4^{2-}	25.66	8.16	11.04	340.65	0.02	3.12-48.20
Na^+	42.39	27.54	8.47	240.49	0.35	25.09-59.69
NH_4^+	0.71	0.00	0.25	5.10	0.00	0.19-1.23
K^+	14.74	8.08	4.24	129.77	0.13	6.07-23.41
Total P	0.70	0.17	0.35	10.65	0.00	0.00-1.41
DOC	45.52	18.21	18.67	571.34	0.11	7.38-83.66

Watershed ID: SC
Watershed Area: 896.41 ha
Tributary Name: Sand Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 680233 3635938
Number of Samples: 32
Median Baseflow: 97 Ls^{-1}
Baseflow Index: 0.49

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	23.16	22.00	0.72	33.70	17.10	21.70-24.63
TSS	5.71	4.45	0.87	25.60	1.50	3.93-7.49
Cl^-	3.09	2.70	0.18	6.30	2.04	2.73-3.46
NO_3^-	1.65	1.72	0.08	2.19	0.68	1.49-1.81
SO_4^{2-}	1.57	1.42	0.14	4.03	0.63	1.28-1.86
Na^+	4.13	2.84	0.55	13.74	2.19	3.00-5.26
NH_4^+	0.16	0.14	0.02	0.45	0.00	0.12-0.21
K^+	2.85	1.99	0.39	11.38	1.58	2.06-3.65
Total P	0.07	0.07	0.01	0.16	0.00	0.05-0.09
DOC	1.95	1.51	0.32	10.80	0.90	1.29-2.62
FC	195.50	70.00	76.35	2100.00	4.00	38.84-352.16
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	178.28	161.16	22.47	507.23	19.43	132.31-224.24
TSS	65.45	23.83	25.00	759.36	3.24	14.32-116.58
Cl^-	22.30	19.56	2.82	61.29	4.08	16.53-28.07
NO_3^-	14.18	11.72	2.02	38.69	0.62	10.05-18.30
SO_4^{2-}	14.07	9.24	2.72	52.09	0.88	8.51-19.63
Na^+	25.01	23.92	3.07	93.53	4.33	18.72-31.29
NH_4^+	1.41	0.97	0.28	6.94	0.00	0.83-1.99
K^+	17.90	16.20	2.66	83.74	3.06	12.46-23.35
Total P	0.62	0.37	0.17	4.78	0.00	0.28-0.96
DOC	14.47	12.00	2.92	85.10	1.17	8.51-20.43

Watershed ID: WC
Watershed Area: 2193 ha
Tributary Name: Weracoba Creek
Stream Order (Strahler): 2
UTM Zone 16 Coordinates: 16 N 691980 3590902
Number of Samples: 14
Median Baseflow: na
Baseflow Index: na

Parameter	Mean	Median	Standard Error	Max	Min	95 % CI
----------------------Concentration Data (mg L^{-1}) ----------------------						
TDS	91.23	89.80	5.46	104.00	81.30	73.84-108.61
TSS	2.60	2.00	0.84	5.00	1.40	0.00-5.27
Cl^-	13.09	13.00	1.66	16.90	9.44	7.80-18.37
NO_3^-	4.63	4.75	0.44	5.45	3.58	3.23-6.03
SO_4^{2-}	17.15	18.93	1.93	19.35	11.37	11.01-23.28
Na^+	17.55	13.98	6.43	35.57	6.66	0.00-38.01
NH_4^+	1.78	1.61	0.54	3.10	0.79	0.06-3.49
K^+	9.97	6.72	4.29	22.43	3.99	0.00-23.62
Total P	0.15	0.15	0.03	0.21	0.09	0.06-0.24
DOC	6.32	5.80	1.15	9.38	4.29	2.66-9.97
FC	8633.33	5400.00	4219.14	17000.00	3500.00	0.00-26786.81
-------------------------Load Data (g $L^{-1}ha^{-1}$)-------------------------						
TDS	506.47	309.47	224.75	1175.92	231.03	0.00-1221.74
TSS	21.71	5.96	16.39	70.84	4.07	0.00-73.87
Cl^-	65.70	49.10	23.09	133.74	30.88	0.00-139.17
NO_3^-	28.69	15.36	15.33	74.32	9.70	0.00-77.47
SO_4^{2-}	105.25	59.65	55.65	270.86	30.83	0.00-282.36
Na^+	69.08	72.27	15.50	96.45	35.31	19.75-118.40
NH_4^+	7.33	7.33	1.64	11.19	3.48	2.12-12.54
K^+	39.54	40.74	11.22	60.81	15.88	3.85-75.23
Total P	0.94	0.48	0.54	2.54	0.26	0.00-2.65
DOC	37.62	21.64	19.57	95.58	11.64	0.00-99.90

Appendix D: Example load calculation. Conversion of mg L^{-1} to g $day^{-1}ha^{-1}$.

Given:

Concentration: 5 mgL^{-1}

Discharge: 50 $Lsec^{-1}$

Watershed Area: 1000 ha

Solution:

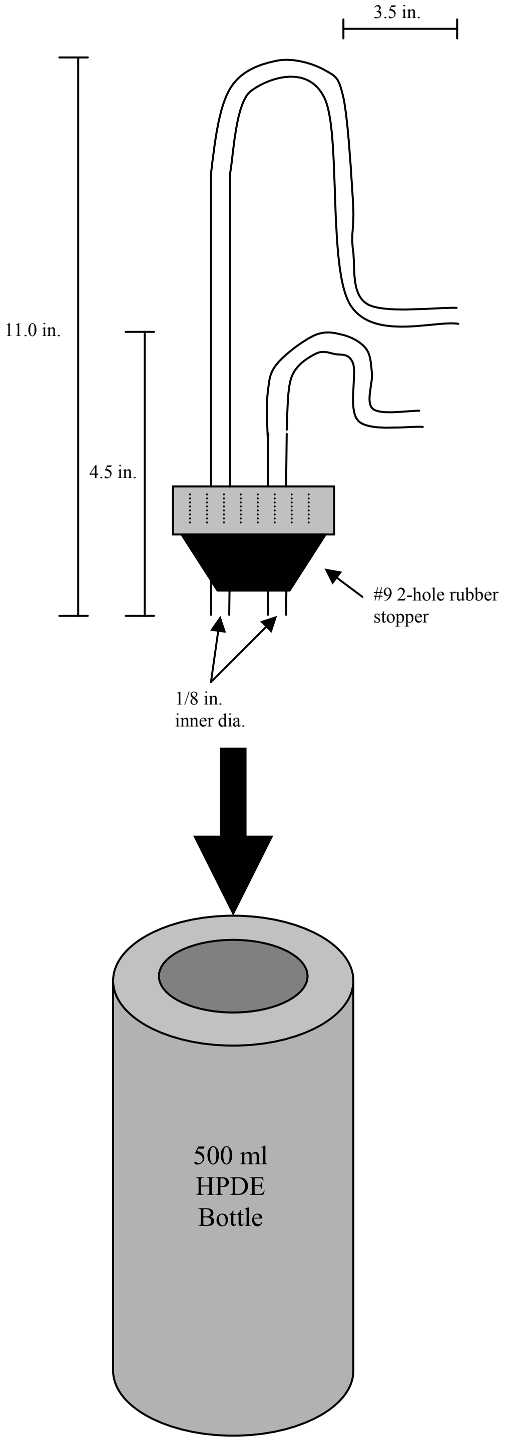
$(5\ mgL^{-1})(50Lsec^{-1}) = 250\ mg\ sec^{-1}$

$(250\ mg\ sec^{-1})(86400\ sec\ day^{-1}) = 21600000\ mg\ day^{-1}$

$(21600000\ mg\ day^{-1}) / (1000) = 21600\ g\ day^{-1}$

$(21600\ g\ day^{-1}) / (1000\ ha) =$ **$21.6\ g\ day^{-1}\ ha^{-1}$**

Appendix E: Schematic detailing fabrication measurements used for stacked-pole samplers.



1. Copper tubes are 22 in. (56 cm) and 11 in. (28 cm) in total length.

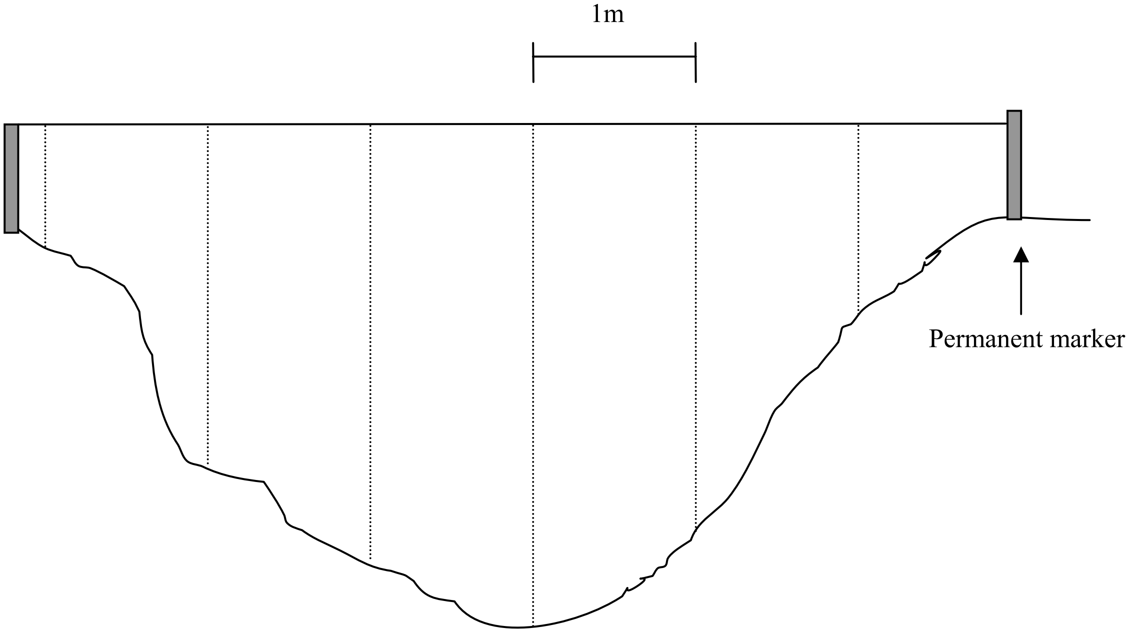
2. Rubber stopper is fastened to bottle cap using with 14ga. copper wire. Wire was passed through two pre-drilled holes in the cap and stopper, and then twist to secure.

3. The bottle cap (with stopper) were then screwed on to the bottle as normal.

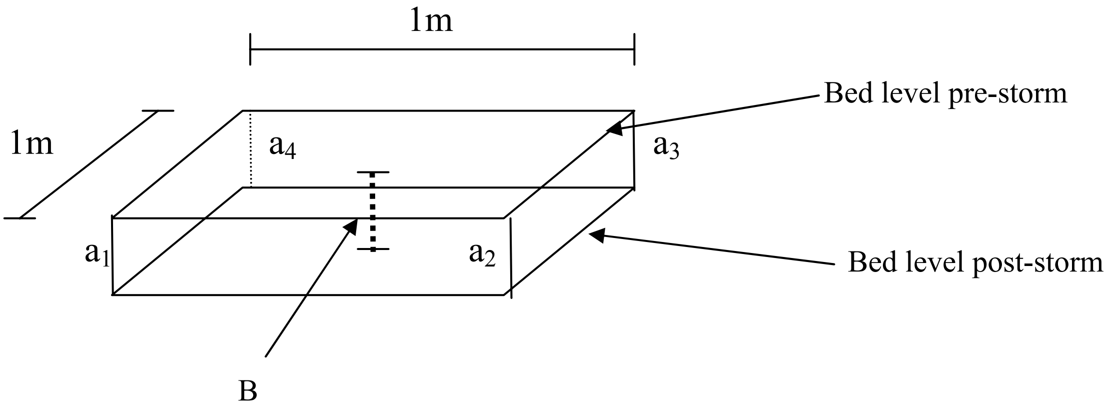
4. Copper tubes were then inserted into the cap through two additional pre-drilled ¼ in.(6.35 mm) holes.

5. Finished samplers were fastened to poles in streams using 14ga. copper wire and copper tubes were faced in the up-stream direction.

Appendix F: Example cross-section measurement. Cross-sections were sampled every three months between 10 January 2003 to 9 June 2004.



Appendix G: Example calculation of grid square volume change for channel fill and scour estimates.



$B = \sum (a_1 + a_2 + a_3 + a_4) / 4$ (measurements in cm)

(B cm)(100 cm)(100 cm) = cm^3 of change between pre to post storm

Note: positive volume change is a result of net channel fill and negative change is net scour