WATER QUALITY CHANGES ACROSS AN URBAN-RURAL LAND USE GRADIENT IN STREAMS OF THE WEST GEORGIA PIEDMONT

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WATER QUALITY CHANGES ACROSS AN URBAN-RURAL LAND USE GRADIENT IN STREAMS OF THE WEST GEORGIA PIEDMONT

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VITA

Jacqueline Fitzpatrick Crim, daughter of Sam and Kay Crim, was born August 18, 1982, in Atlanta, Georgia. She grew up in Daphne, Alabama, and graduated from Daphne High School as Valedictorian in 2000. She graduated *summa cum laude* with a Bachelor of Science degree in Environmental Science from Auburn University in May, 2004 and entered Graduate School at Auburn University in August 2004.

THESIS ABSTRACT

WATER QUALITY CHANGES ACROSS AN URBAN-RURAL LAND USE GRADIENT IN STREAMS OF THE WEST GEORGIA PIEDMONT

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Conversion of forested land to suburban and urbanized landscapes is occurring at extreme rates, especially in the Southeastern United States. Specifically, Georgia is ranked second in the total amount of land developed from 1992 to 1997 (NRCS 2007). To examine the effects of land use on water quality, eighteen small watersheds within the Middle Chattahoochee Watershed of western Georgia were chosen for investigation. Watersheds were selected to reflect an increasing impervious surface gradient and also to represent a wide array of land uses, including urban, developing, pastoral (primarily grazed pastures), mixed species forests (composed of deciduous and evergreen species), and pine forests (predominately composed of mixed pine species including some actively managed pine plantations). Grab samples were collected from May 2002 to January 2006 and analyzed for concentrations and yields of NO_3^-, Cl^-, SO_4^-, Na^+, NH_4^+, K^+, P, total dissolved and suspended solids, dissolved organic carbon, and fecal coliform counts. Hydrology was examined by installing *in situ* pressure transducers in each watershed and recording stage intervals every 15 minutes. In general, urban watersheds revealed higher concentrations and yields of total dissolved solids, Cl^-, SO_4^-, NH_4^+, K^+, dissolved organic carbon, and fecal coliforms than other land uses. All water quality parameters were positively correlated with % impervious surfaces and negatively so with % forest cover. Variation in yields of water quality parameters across years decreased with increasing forest cover. These results suggest that the amount of forest cover within a watershed is vital to protecting stream ecosystems. This study will help to clarify the effects of land development on the physicochemical and biological properties of stream water in the Georgia Piedmont.

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INTRODUCTION

Urban sprawl has become a nationwide phenomenon. In relative terms, most metro areas are consuming land for urban uses much faster than the population is growing, thus contributing to urban sprawl. Fulton *et al.* (2001) examined the consumption of land for urbanization in comparison to population growth for most metropolitan areas in the United States. Between 1982 and 1997, the amount of urbanized land in the U.S. increased by 47%, while the population only grew 17%. In the three five-year intervals within this time period, the nation's consumption of land for urban use increased (Figure 1) while the population density per urbanized acre declined.

Fulton *et al.* (2001) reported that metro areas nationwide are growing in different ways. There are many facets to sprawl, so land managers must take different approaches in dealing with its influence. For instance, the South consumed three times as much land as the West to accommodate population growth, with the West averaging 3.59 new residents for every new urbanized acre compared with only 1.37 for the South. Interestingly, although Atlanta, GA, had the largest absolute increase in urbanized land of any metro area nationwide, it is not as 'sprawling' as other Southeastern metro areas. For example, Atlanta had a 60% increase in population growth, but increased its urbanized land by 80% (Fulton *et al.* 2001). Contrastingly, Columbus, GA, a much smaller metropolitan area approximately 108 miles southwest of Atlanta, only exhibited an increase in population by 2.5%, but experienced a 53.4% increase in urbanized land

(Fulton *et al.* 2001). Urban land conversion is spreading faster than population growth in many areas (Alig *et al.* 2004). Relatively young metro areas such as Columbus are undergoing low-density development where land is converted to developed areas to support low population levels. In short, many people want the enjoyment of a yard with the convenience of a city, thus urban development is becoming increasingly spread out. Land consumption for urbanized uses can have serious ecological impacts, especially in regard to aquatic resources, thus Columbus, GA, presented an ideal location to study land use change influences on water quality.

Conversion of forested to developed land can have detrimental effects on stream ecosystem health. Urbanization is second only to agriculture as the leading cause of stream impairment, even though the total area of agricultural land is much greater than urban land area (USEPA 2000). According to this EPA report, the status of 23% of the nation's total rivers and streams was assessed in 1998, and approximately 291,263 miles (35%) were impaired and did not meet water quality standards. Of those miles, 120,513 (41%) were impaired by urbanization. Water quality management will become increasingly important as the human population continues to expand and the conversion of natural lands to urban areas increases.

Managing land use in a watershed, although rarely done, is crucial to protect drinking-water supplies, recreational resources, and stream ecosystem health. However, the effect of land use on streams is difficult to assess (Landers *et al.* 2002). From a land use perspective, agricultural activities have been identified as major sources of nonpoint source pollutants (sediments, animal wastes, nutrients, and pesticides) and are known to impact water quality. Urban areas are also key in generating large amounts of nonpoint source pollution from runoff and storm sewer discharge (Basnyat *et al.* 2000, USEPA 2000). Increased urbanization carries several environmental implications including, but not limited to, increased flows (Bledsoe and Watson 2001), nutrients (Zampella 1994, Emmerth and Bayne 1996, Rose 2002), heavy metals (Callender and Rice 2000), sediment (Finkenbine *et al.* 2000), and bacteria (Frick *et al.* 2001). Common nonpoint source pollutants persist in urban streams even during baseflow (Schiff and Benoit 2007). The environmental impacts of urbanization ultimately result in altered ecosystem function, such as increased leaf breakdown rates and decreased N and P retention (Meyer *et al.* 2005).

Hydrology

Impervious surfaces associated with urbanization represent one mechanism through which environmental impacts to stream ecosystems may occur. As development alters the natural landscape, the percentage of land covered by impervious surfaces increases. Impervious surfaces can cause serious hydrologic alterations. These surfaces prevent natural pollutant processing by decreasing infiltration and increasing surface runoff, which increases peak discharges and flood magnitudes (Dunne and Leopold 1978, Schoonover *et al.* 2006). The reduced infiltration may reduce groundwater recharge and lower water tables (Arnold and Gibbons 1996). The efficient delivery of water through stormwater drainage systems in urban areas results in large volumes of water entering streams over short periods of time (Walsh *et al.* 2005). Small streams are not equipped to handle such large water volumes of flow so, over time, the channels deepen. The elevated velocity and surface runoff increases erosion of stream banks (Finkenbine *et al.* 2000, Bledsoe and Watson 2001, Rosi-Marshall 2004). This disruption in the natural hydrologic regimes poses serious ecological consequences including loss of habitat from coarse woody debris reduction (Finkenbine *et al.* 2000) and sediment influxes.

Nutrients

Excessive nutrients in streams can cause diverse problems such as toxic algal blooms, loss of oxygen, fish kills, and loss of biodiversity. Nutrient inputs can include fertilizers, wastewater, animal wastes, leaky septic systems, combined sewer overflows, atmospheric deposition, and decomposition of organic matter. Urban and agricultural land uses are major nutrient contributors, especially in P and N (Carpenter *et al.* 1998, USEPA 2000, Tong and Chen 2002). Nitrogen and P at high concentrations accelerate eutrophication (Frick 1996, Freeman *et al.* 2007). High concentrations of NH_4^+ are toxic to aquatic life, while high NO_3^- concentrations are dangerous to humans and other animals (Frick 1998).

Phosphorus, N, and other nutrients have been observed at elevated levels in urban watersheds. Rose (2007) found that major ion concentrations increased with the degree of urbanization in the Chattahoochee River Basin during baseflow. A study in New Jersey found that concentrations of Ca, Mg, NO_3^-, NH_4^+, and P were positively correlated with a watershed disturbance gradient of increasing land use intensity and wastewater flow (Zampella 1994).

Headwater streams are critical to the supply, transport, and fate of water and solutes in watersheds (Alexander *et al.* 2007). Alteration of headwater streams disrupts the connectivity between uplands and downstream systems (Freeman *et al.* 2007). Land uses, such as urbanization, intensify the ecological effects of altering small streams by modifying runoff and nutrient loads, causing shifts in ecosystem structure and function downstream (Freeman *et al.* 2007). As N inputs to streams increase, streams often lose the capacity to retain and transform N, transporting inorganic N much farther with consequent increases in downstream eutrophication (Peterson *et al.* 2001). Small streams may be most important in regulating water chemistry in large drainages because of their large surface-to-volume ratios that favor rapid N uptake and processing (Peterson *et al.* 2001) and also because of their abundance (headwater streams comprise ~53% of the total United States stream length, excluding Alaska, Nadeau and Rains 2007). Yet small streams are endangered because they are the most vulnerable to disturbance (Peterson *et al.* 2001, Meyer *et al.* 2007). Restoration and preservation of small stream ecosystems should be a central focus of management strategies to ensure maximum N processing in watersheds, which, in turn, would improve the quality of water delivered to downstream waterbodies (Peterson *et al.* 2001).

Fecal Coliforms and *Escherichia coli*

Bacteria are one of the most common pollutants threatening the health of the nation's rivers and streams (USEPA 2000). The Chattahoochee River is one of Georgia's most utilized water resources, supplying drinking water and serving as a source for recreational activities. Fecal contamination is a central issue due to the high numbers of people using the river as a recreational resource and the potential sources of contamination such as nonpoint source runoff and wastewater effluent. In previous studies, both the Chattahoochee River and its tributaries have consistently exceeded the EPA's review criterion for fecal coliforms (Gregory and Frick 2001). Schoonover and Lockaby (2006) found higher concentrations of fecal coliforms in urban watersheds than watersheds with other predominant land uses during both baseflow and stormflow. High concentrations of fecal coliform bacteria have the potential to reduce the societal value of the Chattahoochee River by posing an increased risk of human exposure to harmful bacteria and associated adverse effects, including gastrointestinal diseases, hepatitis A, and typhoid fever, to name a few (Frick *et al.* 2001).

Despite a USEPA recommendation to change from using fecal coliforms to *Escherichia coli* (*E. coli*) or enterococci indicators, most states continue to use either fecal or total coliforms as indicators of potential illness-causing pathogens (USEPA 2002). *E. coli* and enterococci exhibit stronger correlations with swimming-associated illnesses; therefore, they are better indicators for predicting the presence of gastrointestinal illness-causing pathogens than fecal coliforms (USEPA 1986a). Fecal coliforms can be detected where fecal contamination is absent since the fecal coliform test also detects thermotolerant non-fecal coliform bacteria (Francy *et al.* 1993). This overestimation can lead to an inaccurate assessment of environmental risk. *E. coli* is the only member of the fecal coliform group that is exclusively fecal in origin and, thus, provides definitive evidence of fecal contamination (Rasmussen and Ziegler 2003).

Sources of fecal contamination include leaky sewer pipes, combined sewer overflows, and pet waste in urban areas, with livestock, agricultural runoff, and leaky septic tanks being major sources in rural areas. Forested watersheds typically have low fecal coliform counts, but counts can be highly variable and related to types of wildlife present (Shah *et al.* 2007). Concentrations can vary depending on the baseline bacteria already present in the streams, rainfall events, and die-off or multiplication within the water and sediments (Rasmussen and Ziegler 2003). Sediments may act as a reservoir of bacteria in streams (Davies *et al.* 1995). Sedimentation and adsorption can lead to higher concentrations of fecal bacteria in sediments than in the overlying water column (Burton *et al.* 1987, Lipp *et al.* 2001). Bacteria can survive and even thrive in sediments, causing concerns for potential resuspension into the water column if disturbed (Davies *et al.* 1995).

Sediment

Sediment is a major pollutant both for its effects on stream biota and because many other pollutants, such as heavy metals and nutrients, can attach to eroded soil particles (Arnold and Gibbons 1996, Callender and Rice 2000). Excessive total suspended solids (TSS) are a major cause of habitat degradation in streams (USEPA 2000). Channel erosion due to urbanization can become a predominant source of excess sediment to downstream reaches and result in degradation of biotic quality (Paul and Meyer 2001).

Construction sites are critical areas of concern for urban nonpoint source pollution. Increased stormwater runoff accelerates erosion, particularly during active construction, and causes scouring of stream channels resulting in much higher stream sediment loads (Landers *et al.* 2002). For example, erosion rates from developing watersheds may approach 50,000 mg/km/yr compared to 1,000-4,000 for agriculture and <100 for undisturbed forest (Carpenter *et al.* 1998). Eroded material contributes to sedimentation of water bodies as well as to eutrophication (Carpenter *et al.* 1998).

A study of three North Carolina Piedmont streams provides an example of the effects of land use on sediment yield. Suspended sediment yield was highest in the urban watershed (1320 kg/ha) and least in the forested watershed (291 kg/ha) (Lenat and Crawford 1994). As impervious surface area increases, infiltration decreases and there is a corresponding increase in surface runoff. Enhanced runoff, in turn, causes increased erosion, supplementing streams with high total suspended sediments (Arnold and Gibbons 1996).

Dissolved Organic Carbon

Dissolved organic carbon (DOC) serves as a bacterial energy source, transport of trace metals, and reduces ultraviolet light penetration (Evans *et al.* 2005). Headwater streams are important both as a source of DOC and to transport DOC downstream (Moore 2003). The transfer of DOC from terrestrial to aquatic systems forms a significant component of the global carbon cycle (Hope *et al.* 1994). Leaf litterfall is a major contributor to the amount of DOC in streams and disturbances of the riparian vegetation can modify organic inputs and their fate in streams (Pozo *et al.* 1997). Dissolved organic carbon inputs may be a result of runoff contributions from heavily forested watersheds (Cronan *et al.* 1999). However, urban areas can also significantly contribute to DOC increases in streams via wastewater treatment plant effluent and combined sewer overflow discharges, especially during storms (Paul and Meyer 2001). Barber *et al.* (2006) found an increase in DOC concentrations downstream from a wastewater treatment.

Conclusion

As the human population continues to increase, the challenge of balancing the expanding population against environmental degradation will become more pronounced. Continued land development presents many ecological concerns and the need for research concerning the implications of urbanization will only grow. There is no single solution to problems with urban sprawl and the amount and extent of sprawl varies depending on differences in physiography, climate, and development traits (Fulton *et al.* 2001, Alig *et al.* 2004), so it is important to examine urban impacts at a watershed level to determine management practices that maintain the structure and function of waterbodies. Research in small streams is essential for evaluation of cumulative effects of land-use practices from upland areas to downstream river systems because small streams can make up as much as 85% of the total stream distance within a watershed (Peterson *et al.* 2001). Much of the previous research regarding urbanization impacts on water quality in the Southeast have focused on large metropolitan areas, such as Atlanta, GA (Emmerth and Bayne 1996, Calhoun *et al.* 2001, Rose 2002, Meyer *et al.* 2005, Rose 2007). Urban tributaries and the Chattahoochee River downstream from Atlanta were among the most degraded sites evaluated by the National Water-Quality Assessment (NAWQA) program during 1992-1995 (Frick 1998). My study focuses on small watersheds in and surrounding Columbus, GA, a smaller metro area south of Atlanta, that has undergone rapid low-density development over the past 15 years. Therefore, I was able to characterize water quality of not only urbanized watersheds, but also for recently developed and natural landscapes.

Figure 1. Percent increases in land consumed for urban uses in the United States from 1982 to 1987, 1987 to 1992, and 1992 to 1997. Data from Fulton *et al.* (2001).

OBJECTIVES

The overall objective of my research was to examine the nutrient, hydrologic, and microbial changes in water quality across an urban-rural land use gradient in the Middle Chattahoochee River Watershed of west-central Georgia. Surface water quality parameters included concentrations and yields of NO_3^-, Cl^-, SO_4^-, Na^+, NH_4^+, K^+, P, DOC, TSS, TDS, fecal coliforms, and *E. coli*.

As part of his dissertation research, Schoonover (2005) examined 16 of the 18 watersheds investigated in my study from May 2002 to August 2004. In his study, Schoonover (2005), 1) developed regression models relating land cover to stream water nutrient and fecal coliform concentrations, 2) compared the nutrient and fecal coliform concentrations and loads of urban (>24% impervious surfaces) and non-urban (<5% impervious surfaces) watersheds during baseflow and stormflow, and 3) investigated relationships between hydrology and land use by quantifying flow frequency, flow magnitude, flow duration, and flow predictability and flashiness.

The aim of my research was to add to and complement the existing knowledge of water quality within these watersheds. I collected water samples from September 2004 to January 2006. Two additional watersheds (FR and BR) with mid-range impervious surface coverage (13% and 23%) were measured to improve the impervious surface gradient used in regression and correlation analyses. All of my analyses, except those pertaining to *E. coli*, were examined using the entire set of data (both Schoonover (2005) and mine) to strengthen the results. *E. coli* were only measured from May 2004 to January 2006.

My research complemented that of Schoonover's (2005) by 1) examining how concentrations and yields of water quality parameters differ between land uses (urban, developing, pastoral, pine forest, and mixed forest), 2) correlating water quality parameters and land cover percentages during baseflow, stormflow, and both flows combined to provide greater detail into land cover/water quality relationships, and 3) reexamining water quality regression models to determine any changes that might occur within the longer period of record.

In addition, I aimed to answer new questions about the water quality in these watersheds. As the study progressed, the combined influence of precipitation and land use on water quality became apparent. The interaction of terrestrial and aquatic phases is confounded by many factors. Land use practices, precipitation (particularly rainfall in my study), hydrology and geology all influence surface water chemistry. It is difficult to directly measure land use impacts when other variables cannot be controlled and do not remain constant. Changes in water quality may reflect changes in land use practices or could potentially be a product of changing weather patterns. Precipitation effects on water quality differ among land uses as rainfall is intercepted at differing rates and runoff varies. Precipitation variation has the potential to obscure the signature of land use/cover. Thus, most questions deal with variation in water quality parameters from hydrologic and discharge differences in land uses caused by precipitation patterns. Other questions deal with water quality guidelines and whether or not these watersheds are in compliance. The questions I examined were as follows: 1) Does water quality fluctuate across years and, if so, does land use have an influence on the fluctuations? I hypothesized that the variation in water quality parameters across years would increase along an increasing impervious surface gradient. 2) Will even a small increase in impervious surface (0-4%) cause a statistically significant increase in water quality concentrations and yields? I hypothesized that a small increase in impervious surface would increase water quality concentrations and yields. 3) Does land use affect the way water quality parameters respond to changes in stream discharge? That is, do the slopes of a water quality parameter versus discharge vary with land use? I hypothesized that urban watersheds would have the greatest water quality parameter response to discharge variation, followed by developing, pastoral, and forested watersheds. 4) How does land use influence P and N concentrations when compared to national P and N criteria? I hypothesized that watersheds with the most to least violations, respectively, would be pastoral, urban, developing, pine forest, and mixed forest. 5) How does land use impact fecal coliform violations of Georgia Department of Environmental Protection Division (GAEPD) guidelines and *E. coli* violations of United States Environmental Protection Agency (USEPA) guidelines? Furthermore, should it be recommended that GAEPD use *E. coli* as an indicator of fecal contamination instead of fecal coliforms? I hypothesized that the land uses with the most to least fecal coliform and *E.coli* violations would be as follows: urban>developing>pastoral>pine forest=mixed forest. 6) Does the influence of precipitation on water quality parameters differ with land use? I hypothesized that precipitation would show the strongest correlations with water quality parameters in urban watersheds followed by developing, pastoral, pine forest, and mixed forest.

STUDY AREA

Georgia is ranked second in the United States in total acres of land developed from 1992 to 1997 (NRCS 2007). West-central Georgia, primarily watersheds in Muscogee, Harris, and Meriwether counties, was chosen for study due to its rapidly expanding population in recent years, low-density development, and the potential to quantify land use influences on water quality with the availability of relatively small watersheds. Muscogee County is highly urbanized as a result of the city of Columbus, while Meriwether County is primarily rural and growth has been relatively stable over the last 10 years (Table 1). Harris County is predominately forested, but does, however, reflect developing land use as the city of Columbus continues to expand northward. Growth from Columbus occurs primarily in the northeast direction as a result of the Chattahoochee River to the west and Fort Benning Military Reservation to the southeast. Therefore, using these three counties, I was able to establish study sites across a land use gradient from urban to rural.

Eighteen subwatersheds of the Middle Chattahoochee Watershed in west-central Georgia, ranging in size from ~300 to 2500 ha, were selected for study (Figure 2). All watersheds reside within the Piedmont ecoregion. The area once consisted of primarily agricultural land uses but has mostly reverted to pine and hardwood forests, and more recently, to urban and suburban settlement (NARSAL 2007). Piedmont soils are generally fine-textured and highly erodable in many areas (NARSAL 2007). Stream channels and floodplains may still have large surpluses of sediment resulting from poor agriculture soil conservation practices in the early 1900s (Trimble 1974). The Southern Piedmont climate is temperate, humid, and rainfall is ~125 cm/yr with precipitation totals highest in the late winter and early spring with a secondary maximum of precipitation from summer thunderstorms in July (Franklin *et al.* 2002).

Impervious surface area was used as the primary measure of urbanization and is widely accepted as a means to quantify urbanization and relate it to water quality degradation (Arnold and Gibbons 1996). In order to examine urban influences on water quality, the watersheds were chosen to represent a gradient of impervious surfaces and also to reflect a range of primary land uses including pine forests (evergreen forests including some managed pine plantations), mixed forests (primarily undisturbed forests with deciduous and evergreen species), pastoral (primarily pasture used for grazing), developing (new subdivision and construction areas), and urban (established urban centers with >10% impervious surfaces). Land cover classification was generated using GIS and remote sensing techniques based on a Landsat TM aerial view from March, 2003. Land cover within each watershed was broken into % impervious surfaces, % evergreen forests, % mixed forests, % pasture, and % grasses in urban areas (Table 3). Watersheds were broken into land cover categories (urban, developing, pastoral, mixed forest, and pine forest) based on the dominant land use (what is occurring on the ground) and the dominant land cover (what is identified through classification) in that watershed (Table 2). One land cover was generally considered dominant. However, it should be noted that each land cover was present within the watershed so these categorical classifications are approximate. Greater detail of methods concerning land cover classification can be found in Lockaby *et al.* (2005).

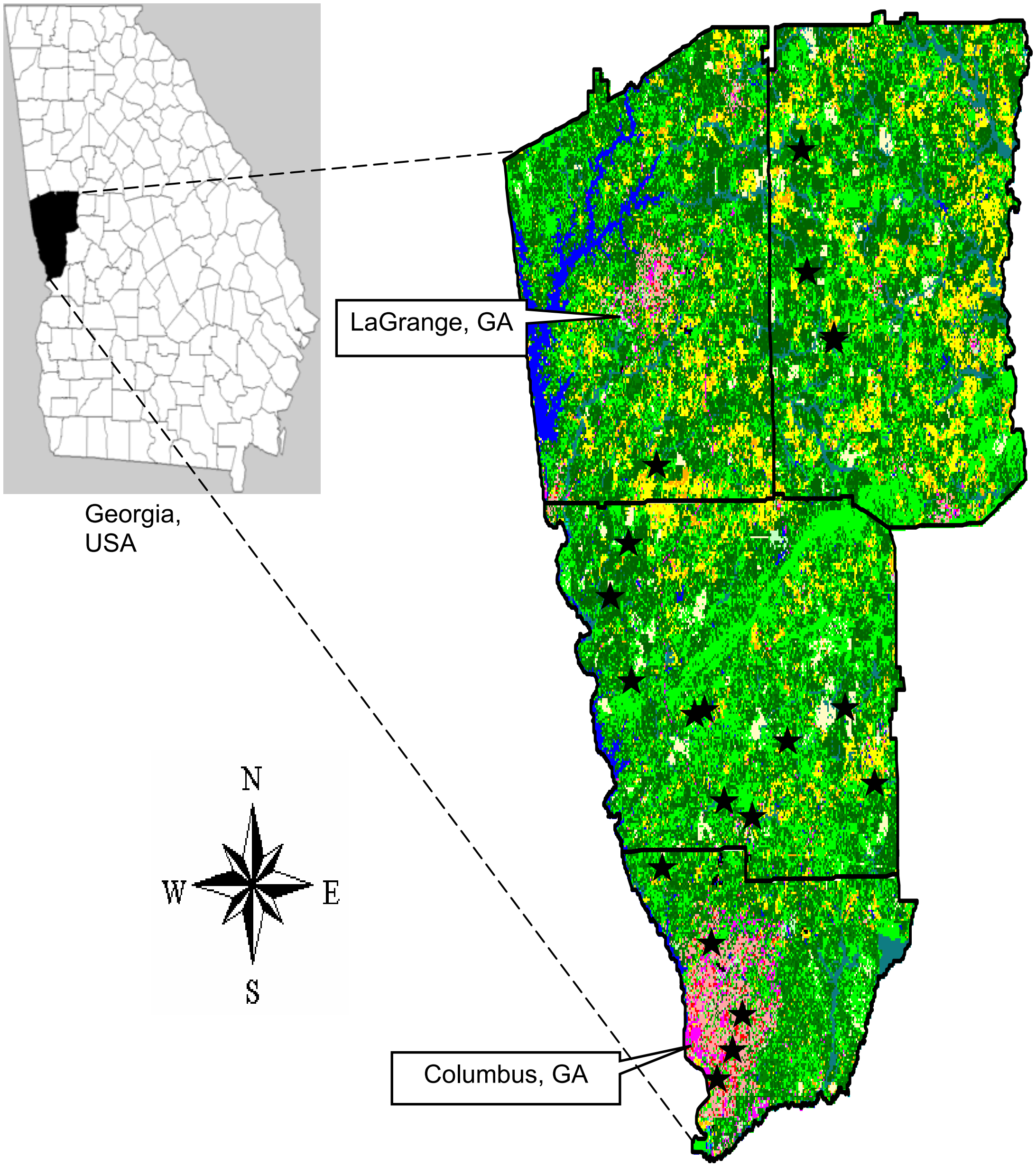

Figure 2. Map of study sites in west-central Georgia. Stars represent sampling points.

Table 1. Population statistics for Harris, Meriwether, and Muscogee counties and the state of Georgia (U.S. Census Bureau 2007).

County	Population, 2000	Population, 2005 estimate	Population, % change, April 1, 2000 to July 1, 2005	Population, % change, 1990 to 2000
Harris	23,695	27,779	17.2	33.2
Meriwether	22,534	22,919	1.7	0.55
Muscogee	186,291	185,271	-0.5	3.9
State of Georgia	8,186,453	9,072,576	10.8	26.4

Table 2. Land cover ranges for the 18 study watersheds. IS=impervious surface, EV=evergreen forest, MI=mixed forest, PA=pasture, UG=urban grass.

Category	%IS	%EV	%MI	%PA	%UG
Urban (5)	13.0-41.9	20.9-31.0	7.0-15.9	5.4-35.6	4.9-18.0
Developing (3)	1.8-3.4	37.3-41.2	22.8-35.4	16.3-25.5	0.6-2.2
Pastoral (4)	1.6-3.7	29.3-32.0	22.2-29.9	33.1-44.5	0.5-2.8
Pine Forest (4)	1.2-2.6	42.4-48.3	25.0-33.3	11.7-20.3	0.1-1.2
Mixed Forest (2)	1.2-1.9	41.6-48.1	28.2-37.1	13.0-18.4	0.2-0.8

Table 3. Land cover classification for the 18 study watersheds. ID=Watershed Identification, IS=impervious surface, EV=evergreen forest, MI=mixed forest, PA=pasture, UG=urban grass.

Land Use Category	ID	%IS	%EV	%MI	%PA	%UG
Mixed Forest	BLN	1.24	48.13	28.24	18.43	0.18
Urban	BR	23.00	29.00	14.00	10.91	16.06
Urban	BU1	41.94	20.89	12.34	5.44	17.61
Urban	BU2	24.93	30.49	15.88	7.56	17.99
Pine Forest	CB	1.53	48.31	32.99	11.74	0.09
Urban	FR	13.00	31.00	7.00	35.62	4.89
Pastoral	FS2	2.74	30.71	28.21	35.23	0.75
Pastoral	FS3	2.58	31.96	29.91	33.09	0.50
Pine Forest	HC	1.33	47.84	26.73	17.99	0.27
Pastoral	HC2	1.64	30.47	22.22	44.53	0.58
Pastoral	MU1	3.68	29.26	24.27	35.01	2.76
Pine Forest	MU2	2.57	42.39	24.98	14.47	1.20
Mixed Forest	MU3	1.88	41.55	37.06	12.97	0.79
Urban	RB	30.30	28.38	11.06	10.87	16.92
Developing	SB1	1.83	38.61	35.01	18.79	0.62
Developing	SB2	3.39	37.34	35.35	16.29	1.52
Developing	SB4	3.27	41.15	22.76	25.46	2.17
Pine Forest	SC	1.24	44.80	28.79	20.34	0.15

METHODS

Water Chemistry and Hydrologic Sampling

Nutrient and bacteriological water quality data were sampled from May 2002 to January 2006. Samples were collected bimonthly during the winter and spring months from November to March. These months are optimal for water chemistry sampling because of increased stream flow due to high precipitation and low evapotranspiration, thus, creating greater connectivity between the hydrologic and terrestrial regimes during this time (Lockaby *et al.* 1993). Sampling occurred monthly during the remainder of the year.

Grab samples were collected prior to other data collection to ensure no contamination would occur from persons wading in the stream. Before each collection, polypropylene bottles were conditioned by rinsing three times with stream water. Tissue culture flasks were used to detect low-level concentrations of cations and anions. These flasks were rinsed and filled with deionized water and then stored at 4˚C for at least 24 hours. During sampling, flasks were emptied and rinsed three times before taking a sample. Samples were kept on ice and then stored at 4˚C until analyzed.

Stream discharge was recorded to determine nutrient and sediment yields. This involved measuring depth and velocity along transects across the stream channel. Stream depth was measured every 10, 20, or 50 cm, depending upon stream width. Increments were chosen to provide a minimum of 10 readings. Velocity was then measured at the mid-point of each depth using a Marsh-McBirney flowmeter. Total stream discharge (Q) was calculated using the following equation: Q=Σ(width of each increment*mean depth of each increment*velocity of each increment) (Gore 1996). Nutrient and sediment yields were then calculated by multiplying concentration and discharge and dividing by watershed area.

InSitu pressure transducers (InSitu, Laramie, WY) were installed at each stream to quantify hydrology. These transducers were set to record stream stage levels at 15-minute intervals. Rating curves were created for each watershed to estimate discharge when it could not be measured manually. Schoonover *et al.* (2006) provided greater detail on transducer installation and rating curve establishment.

Laboratory Analyses

Water samples were analyzed within five days after collection. Anions and cations (NO_3^- , Cl^- , SO_4^-, Na^+, NH_4^+, K^+) were analyzed using the Dionex DX-120 ion chromatograph (Dionex Corporation, Sunnyvale, CA). Phosphorus was measured using the molybdate-blue method (Murphy and Riley 1962, Wantanabe and Olsen 1965). Total dissolved solids (TDS) were determined using a Fisher Accumet AB30 conductivity meter (Fisher Scientific, Pittsburgh, PA). Total suspended solids (TSS) were measured using filtration methods outlined by the Environmental Protection Agency (USEPA 1999). Dissolved organic carbon (DOC) was determined using a Rosemont DC80 organic carbon analyzer. Fecal coliform counts were determined using the filter membrane procedure described in American Public Health Association (1998).

Statistical Analyses

Statistical analyses were performed using SAS V.9.1 (SAS Institute 1999). All relationships were considered significant at α=0.05. In order to investigate whether or not water quality fluctuated across years, I examined the range of medians for each parameter measured across the three full years of data (2003-2005). Sixteen watersheds had three full years of water quality data (BR and FR did not and consequently were not used in this analysis). Yield data were used since yield/hectare provides a better comparison of data across watersheds by taking into account watershed area. Linear regression was used to examine the change in median range with respect to a forest cover gradient.

Significant differences in concentrations and yields of water quality parameters among land uses (i.e. urban, developing, pastoral, mixed forest, and pine forest) were obtained from NPAR1WAY Wilcoxin tests (Cody and Smith 2006). The Wilcoxin test is a nonparametric statistical test that should be used when the data are not normally distributed, which was the case in my dataset (Cody and Smith 2006). If the distribution of the data is in question, the Wilcoxin test can be used since it is almost as powerful as the t-test, its parametric equivalent (Cody and Smith 2006).

To provide greater detail into land cover/water quality relationships, Spearman rank correlations between concentrations and yields of water quality parameters and land cover percentages during baseflow, stormflow, and both flows combined were examined. Correlations between water quality concentrations and yields and land cover percentages were also examined between seasons to determine if the relationships differed between seasons. Spearman rank correlations were used to account for the non-normal distribution of water quality parameters (Helsel and Hirsch 2002, Shrestha and Kazama 2007).

It is generally accepted that water quality tends to decline around 10% impervious surface coverage within a watershed (Arnold and Gibbons 1996). I examined water quality concentrations along an impervious surface gradient using non-linear regression to determine if a threshold existed within the study watersheds. Non-linear was used because most concentrations of water quality variables increased and then leveled off as impervious surface increased. Before being used in regression, concentrations of water quality variables were log-transformed to meet normality assumptions (Helsel and Hirsch 2002, Cody and Smith 2006). Because I had many watersheds below the accepted threshold of 10% impervious surface, I also decided to determine if even a small increase in impervious surface (0-4%) influenced water quality concentrations by regressing each water quality concentration with % impervious surface.

Prediction models for each variable were determined by multiple regression analysis. Dependent variables (median concentrations of water quality parameters in each watershed) were log-transformed as needed to meet normality assumptions (Helsel and Hirsch 2002, Cody and Smith 2006). Independent variables were land cover percentages, i.e. impervious surfaces, pasture, mixed forest, evergreen forest, or total forest. The appropriate model was selected using the RSQUARE selection method (SAS Institute 1999). This method gives the R^2 value for every combination of independent variables. A high R^2 and low Mallow's Cp were used to select the appropriate model from the list (Cody and Smith 2006).

Land use was found to affect the hydrologic regimes of these watersheds (Schoonover *et al.* 2006). To examine if land use impacted stream chemistry responses to discharge variation, four watersheds were selected that were representative of a major land use category**,** i.e. urban, developing, pastoral, and forested. Concentrations of each water quality parameter were used as dependent variables and discharge as the independent variable. PROC GLM was used to identify significant differences between slopes between land uses (Cody and Smith 2006).

Daily precipitation data available from the National Climatic Data Center (NCDC 2005) were used for monthly, seasonal, and previous sample day precipitation estimates. Three sampling stations were chosen to represent the study area, Columbus Metropolitan Airport (#092166/93842), West Point (#099291), and Woodbury (#099506). All precipitation data used were averaged from these three stations. Precipitation influences on water quality variables were examined by correlating the variables with rainfall by dominant land use categories. I evaluated total monthly rainfall, sample day rainfall, previous day rainfall, previous day plus sample day rainfall, previous five-day rainfall total, and previous five-day plus sample day rainfall totals.

In the effort to examine land use impacts on fecal coliforms, I studied fecal coliform counts within each watershed by year. I categorized each year into supporting, partially supporting, or not supporting designated uses based on the percentage of fecal coliforms in water (GAEPD 2002). Designated uses are defined here as recreational waters. When samples are not adequate to obtain a monthly geometric mean, USEPA recommends a fecal coliform single sample criterion of 400 colonies/100mL. However, GAEPD uses the USEPA single sample criterion from May to October and a maximum criterion of 4000 colonies/100mL during the months of November to April (GAEPD 2002). I used the GAEPD guidelines for deciding if the watershed supported designated uses. Spearman rank correlations were also used to examine relationships between fecal coliform and *E. coli* and land use percentages.

I also examined the percentage of *E. coli* violations in each land use. The USEPA single sample primary contact recreational review criterion for *E. coli* is 576 colonies/100mL (USEPA 1986a). The single sample criterion was used because I did not have enough samples for the 30-day geometric mean criterion. The relationship between land cover percentages and % *E. coli* violations was examined using Pearson correlation coefficients. Pearson's test was appropriate here because the data were normally distributed as evidenced by a normal probability plot (Cody and Smith 2006).

E. coli to fecal coliform ratios (EC/FC) for each watershed were determined to investigate the question of which indicator, *E. coli* or fecal coliforms, provided a more reliable indicator of bacterial contamination in the study watersheds. Using the single sample criterions mentioned earlier for *E. coli* and fecal coliforms, a ratio of 576/400 (1.44) for May to October and 576/4000 (0.144) for November to April would be standard for these watersheds. However, a ratio greater than 1 should not be possible since all *E. coli* bacteria are fecal coliforms, but not all fecal coliforms are *E. coli*. Therefore, the November to April ratio was used as the standard for the whole year.

RESULTS AND DISCUSSION

Hydrology

Understanding watershed hydrology is critical to developing an understanding of the water chemistry within a particular watershed. An in-depth analysis of hydrology in these watersheds was discussed in Schoonover *et al.* (2006), describing the magnitude, duration, frequency, and flashiness of flows associated with these watersheds. They found that urban watersheds experienced more high flow pulses and peak discharges than other land uses. In addition, urban watersheds had little groundwater contributions and thus lower baseflows than watersheds with high vegetative cover. Hydrographs comparing the discharge distribution on an area basis with precipitation amounts are provided to give a broad overview of the hydrology in watersheds with differing land uses (Figures 3-5). The urban (Figure 3) watershed experienced more peak flows and greater flashiness than pastoral and forested watersheds. The high peak flows corresponded to rainfall events. Bare or impervious areas and a more developed stormwater drainage system produced greater volumes of high energy stormflow and reduced baseflow (Landers *et al.* 2002). Comparatively, the forested watershed was much more stable with little flashiness (Figure 5), likely from increased infiltration and plant uptake. The pastoral watershed also displayed a stable hydrograph (Figure 4). The stability of this watershed resulted from high and consistent groundwater inputs (Schoonover *et al.* 2006).

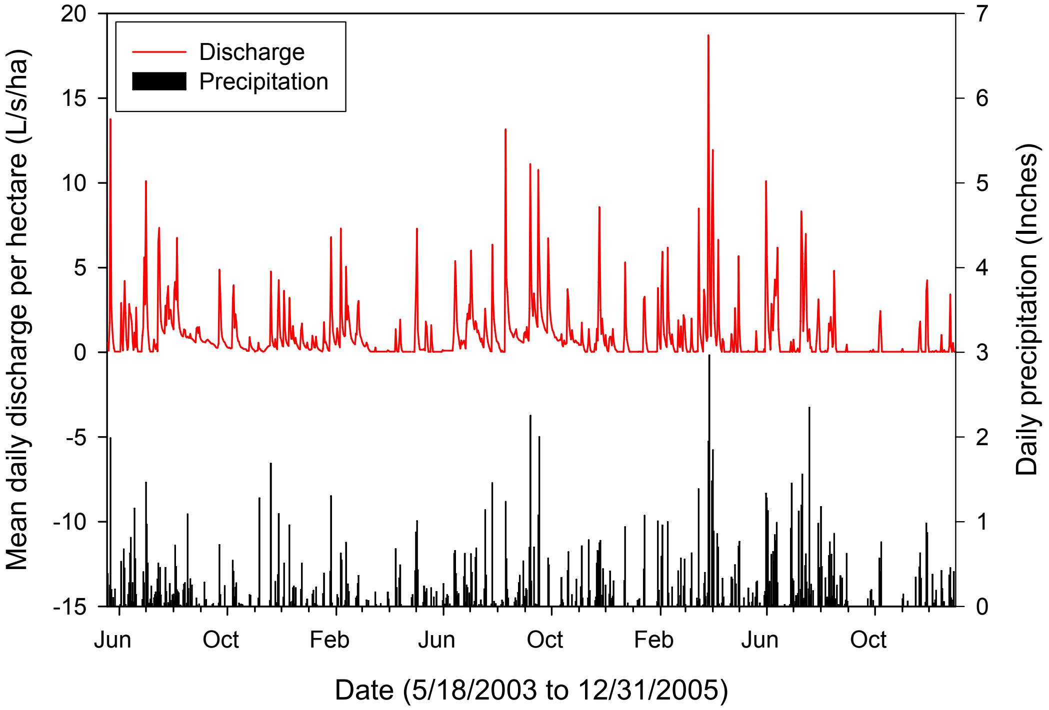

Figure 3. Hydrograph of RB, a representative urbanized watershed

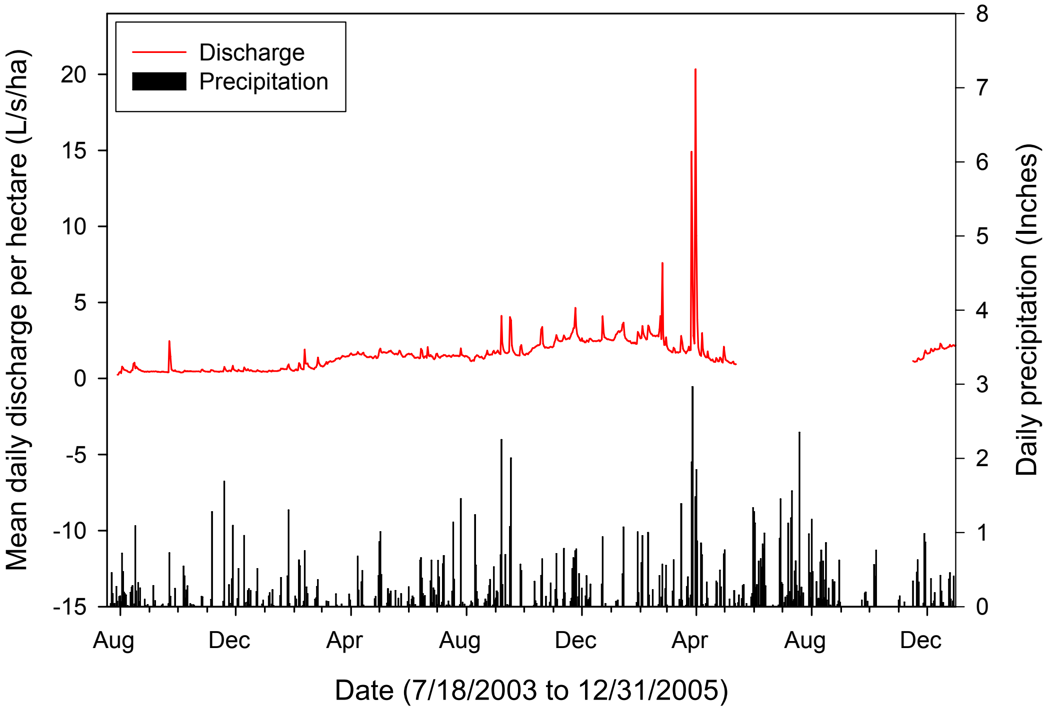

Figure 4. Hydrograph of FS2, a representative pastoral watershed.

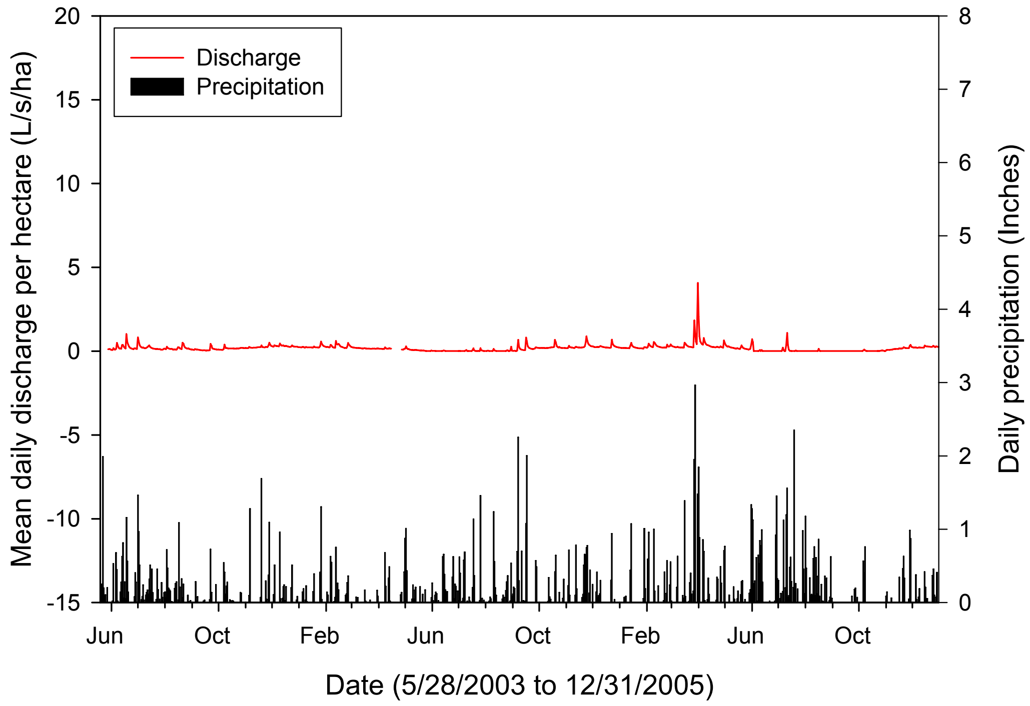

Figure 5. Hydrograph of BLN, a representative forested watershed.

Water Quality Fluctuations across Years

The three developing watersheds displayed the greatest median range over the three year time period for TDS, TSS, Cl^-, Na^+, K^+, DOC and P (Table 4). These watersheds could be considered the least stable in terms of active construction activity occurring within the watershed, therefore creating more variability across years. Urban watersheds had highest ranges in NO_3^-, SO_4^-, NH_4^+, and fecal coliforms (Table 4). Pastoral watersheds had low ranges compared to urban and developing watersheds, though P, NO_3^-, and NH_4^+ were higher than the forested watersheds (Table 4). The pine and mixed forest watersheds had relatively low ranges of most parameters, compared to urban and developing watersheds (Table 4). Higher DOC fluctuation in the pine forest compared to the mixed forest watersheds could be a result of forest clearing in the managed pine forest watersheds.

The median ranges of discharge, fecal coliform concentrations and yields of TDS, Cl^-, NO_3^-, SO_4^-, Na^+, and K^+ all were significantly related to % forest cover (Table 5). In general, watersheds with greater amounts of forest cover had less variability in medians across years for these parameters, as evidenced by a decline in median range as % forest cover increased (example, Figure 6). Developing and urban watersheds had greater variations in the range of median discharge across years (Table 4). These watersheds were less hydrologically stable and exhibited greater flashiness compared with watersheds with more forest cover (Schoonover *et al.* 2006). According to the examinations, the amount of forest cover within a watershed may contribute to the stability of many nutrients, sediment, and bacteria within flowing waters. The strongest relationship was between % forest cover and NO_3^- yield median ranges (Figure 6).

Watersheds with the lowest forest cover were located in Columbus, GA, the area with the highest amount of impervious surfaces and most urbanized landscapes. Nitrate yield medians varied greatest within these watersheds compared to watersheds with more forest cover located in less urbanized landscapes.

My original hypothesis was that variation in water quality parameters across years would increase across an increasing impervious surface gradient. However, once analyses began, it was clear that % forest cover provided a more accurate predictor for water quality variation than % impervious surface. Land use did influence water quality fluctuations across years. Urban and developing watersheds exhibited more variation than pastoral and forested watersheds. There was a significant decline in many water quality parameters (namely fecal coliform concentrations and yields of TDS, Cl^-, NO_3^-, SO_4^-, Na^+, and K^+) along an increasing forest cover gradient. It is likely that the way different land uses intercept precipitation and create varying hydrologic regimes is the real driver of water quality variation across years. Impervious surfaces decrease infiltration and deliver water along with nutrients, sediment, and bacteria to streams at a faster rate than forested watersheds, where water is intercepted and slowed before entering streams.

Table 4. 2003-2005 range of medians according to dominant land use within the watershed. Higher values imply greater variability in water quality parameters.

Variable	Urban	Developing	Pastoral	Pine Forest	Mixed Forest
TDS (g/d/ha)	214.61	558.97	66.65	75.70	113.81
TSS (g/d/ha)	23.03	26.50	19.07	23.20	14.59
Cl (g/d/ha)	27.06	59.40	4.47	6.97	7.09
NO_3 (g/d/ha)	10.68	5.38	5.73	3.97	1.60
SO_4 (g/d/ha)	34.17	18.71	2.68	9.41	2.43
Na (g/d/ha)	24.69	85.10	3.62	5.24	5.08
NH_4 (g/d/ha)	1.33	0.00	0.53	0.00	0.00
K (g/d/ha)	14.99	24.48	1.67	4.21	7.27
P (g/d/ha)	0.23	2.29	2.04	0.53	0.08
DOC (g/d/ha)	26.98	47.04	8.85	20.55	12.28
Fecal Coliforms (MPN/100mL)	980	145	151	81	210
Discharge (L/s)	82.44	142.60	56.50	23.17	17.71

Table 5. Water quality variables with significant relationships between median range and % forest cover. Relationships were significant at $p<0.05$.

Variable	R^2	p-value
TDS (g/d/ha)	0.38	0.0143
Cl (g/d/ha)	0.51	0.0029
NO_3 (g/d/ha)	0.81	<0.0001
SO_4 (g/d/ha)	0.54	0.0019
Na (g/d/ha)	0.47	0.0048
K (g/d/ha)	0.57	0.0014
Fecal Coliforms (MPN/100mL)	0.49	0.0043
Discharge (L/s)	0.30	0.0434

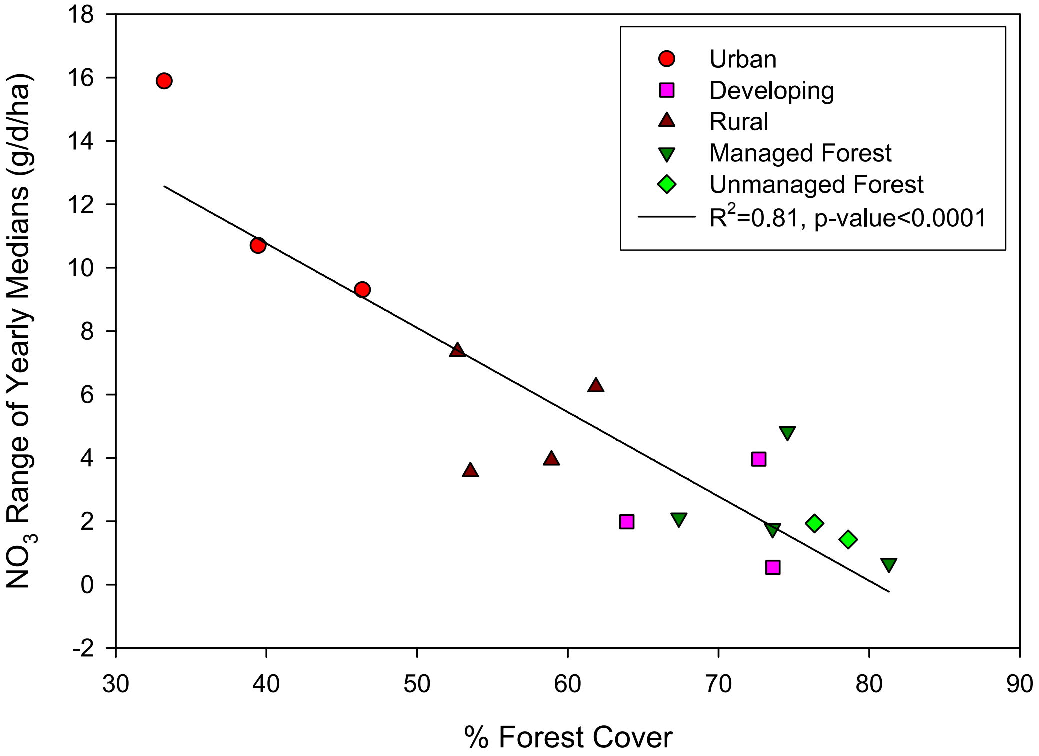

Figure 6. Nitrate yield median ranges for 2003-2005 across a forest cover gradient

Water Quality Differences between Land Use Categories

All watersheds contained a mosaic of land uses, but one land use in each watershed was considered dominant, allowing placement of each watershed into land use categories, i.e. urban, developing, pastoral, pine forest, or mixed forest (Table 2). The effect of the dominant land use on water quality cannot be truly isolated from the influences of any other land use within the watershed. However, in combination with other analyses, categorical comparisons may suggest general trends between water quality and land use.

Water quality parameters were examined across years according to the land use category (Table 6). Urban and developing watersheds reflected TDS concentrations that were higher and significantly different from all other watersheds (Figure 7). Total suspended solid concentrations were similar for all watersheds except mixed watersheds which exhibited a slightly lower, yet significant level (Figure 7). Areas with more human influences (urban, developing, and pastoral watersheds) had elevated Cl^- concentrations compared to forested watersheds (Table 6). Chloride concentrations were significantly greater in urban areas than all other land use categories likely from chlorination of drinking water (Figure 8). Developing and pastoral watersheds had higher Cl^- concentrations than predominantly forested areas (Figure 8). Sulfate concentrations were also highest in urbanized watersheds followed by developing, forested, and pastoral watersheds (Figure 8). Sodium concentrations in developing watersheds were significantly higher than those from all other watersheds (Figure 9). Urban areas had the second highest Na^+ concentrations and also were significantly different from all other land uses, while Na^+ was lowest and similar in pastoral and forested watersheds (Figure

9). Potassium concentrations were highest in urban watersheds followed by pastoral, pine forest, developing, and mixed forest watersheds (Figure 9). Median NO_3^- concentrations were significantly higher in pastoral watersheds than all other land uses (Figure 10). Urbanized areas had the next highest NO_3^- concentrations followed by pine forest, developing, and mixed forest watersheds (Figure 10). Ammonium concentrations were higher in urban watersheds than all other watersheds combined (Figure 10). Phosphorus concentrations were similar in urban, developing, pastoral, and pine forest watersheds (Figure 11). Phosphorus concentrations in mixed forest watersheds, however, were significantly lower than those in other land uses (Figure 11). Dissolved organic carbon concentrations were highest in urban and developing watersheds and were significantly different from all other categories (Figure 12). Pastoral watersheds had the next highest DOC concentrations followed by mixed and pine forest watersheds (Figure 12).

Most differences in daily yields (TDS, TSS, Cl^-, SO_4^-, Na^+, DOC, NO_3^-, and NH_4^+) across land use categories were similar to concentration results. However, median K^+ yields were highest in pastoral watersheds followed by urban areas, i.e. opposite from concentrations patterns (Table 6). Phosphorus yields were highest in pastoral watersheds and significantly different from all other land uses except developing (Table 6). The much higher standard errors in the urban and developing watersheds are also noteworthy (Table 6). These watersheds exhibited flashy hydrology and greater instability, leading to increased variation in nutrient and sediment yields as mentioned previously.

Similar to Frick *et al.* (1998) in a study of tributaries in the Apalachicola-Chattahoochee-Flint River Basin, pastoral sites had the highest concentrations and yields of NO_3^-, P, and TSS. They concluded the primary source of nutrients in those tributaries was poultry litter applied as fertilizer. Fertilizer is likely a key factor to nutrient enrichment in these pastoral watersheds. Frick *et al.* (1998) also found high nutrient yields in the urban and developing sites. They attributed high nutrients in urban sites to combined sewer overflows (CSOs). My urban sites also have a network of combined stormwater and wastewater sewers and near-stream manhole covers were commonly dislodged during large storm events, likely contributing to nutrient increases in these watersheds.

Schoonover and Lockaby (2006) found higher median concentrations of Cl^-, NO_3^-, SO_4^-, K^+, and DOC in urban watersheds (watersheds with >24% impervious surface) than non-urban watersheds (watersheds with <5% impervious surface) during both baseflow and stormflow. My results complemented Schoonover and Lockaby (2006) in that Cl^-, SO_4^-, K^+, and DOC concentrations were all higher in urban watersheds than the other land uses (Table 6). Schoonover and Lockaby (2006) also found elevated NO_3^-concentrations in pastoral watersheds (those with >24% grazed lands) than non-pastoral watersheds (those with <24% grazed lands. Similarly, my results indicated NO_3^- concentrations were highest in pastoral watersheds followed by urban watersheds (Figure 10). Schoonover and Lockaby (2006) suggest that NO_3^- is entering the pastoral streams through groundwater as evidenced by high baseflow contributions, while surface runoff and leaky sewage pipes are likely causes in urban areas.

It may be of value to note that those watersheds which displayed the most water quality fluctuations across years (urban and developing watersheds) (Table 4) also exhibited higher concentrations and yields (Table 6). Nitrate was the primary exception with yields highest in pastoral watersheds (Table 6), but more variable across years in urban watersheds (Table 4).

Table 6. Median values and standard errors of water quality parameters according to dominant land use present.

Variable	Urban		Developing		Pastoral		Pine Forest		Mixed Forest	
	Median	SE	Median	SE	Median	SE	Median	SE	Median	SE
Concentrations (mg/L)										
TDS	57.10	1.10	45.80	1.06	25.40	1.00	24.50	1.03	26.70	1.54
TSS	4.60	3.68	4.40	6.05	5.00	1.01	4.40	5.12	2.80	0.73
Cl	7.55	0.28	3.95	0.13	3.93	0.20	2.56	0.11	2.50	0.12
NO_3	1.75	0.10	0.27	0.03	2.90	0.16	0.46	0.05	0.24	0.02
SO_4	6.33	0.26	3.37	0.18	1.03	0.10	1.84	0.17	1.51	0.14
Na	5.82	0.28	6.78	0.32	3.11	0.21	3.28	0.24	3.85	0.36
NH_4	0.10	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00
K	3.17	0.11	1.87	0.08	2.25	0.11	1.89	0.08	1.76	0.08
P	0.10	0.01	0.11	0.02	0.11	0.01	0.10	0.01	0.08	0.02
DOC	5.94	0.29	5.49	0.34	3.38	0.33	2.89	0.25	4.63	0.46
Fecal Coliforms (MPN/100mL)	1200.00	821.95	236.00	88.73	147.00	62.58	134.00	55.80	132.00	72.63
Yields (g/d/ha)										
TDS	320.11	199.86	288.73	174.68	250.29	63.34	196.46	114.39	222.99	73.20
TSS	24.58	1593.02	25.47	1471.22	36.23	65.07	29.46	715.92	17.27	58.93
Cl	42.20	31.99	28.79	20.49	37.83	9.17	19.30	20.57	19.90	6.72
NO_3	9.88	10.83	2.21	3.08	22.55	6.81	3.48	3.67	1.81	1.29
SO_4	40.78	29.47	22.94	21.49	9.66	5.80	12.90	12.33	14.50	9.79
Na	33.92	14.84	46.53	23.23	31.65	7.20	26.73	14.39	31.35	9.95
NH_4	0.45	1.83	0.00	0.65	0.00	0.54	0.00	0.62	0.00	0.05
K	18.94	17.52	11.42	8.83	21.92	5.21	13.67	5.42	14.64	4.28
P	0.42	2.11	0.52	1.20	1.10	0.47	0.54	0.33	0.40	0.39
DOC	34.24	52.91	38.37	42.68	26.29	13.33	18.86	20.26	26.13	23.96

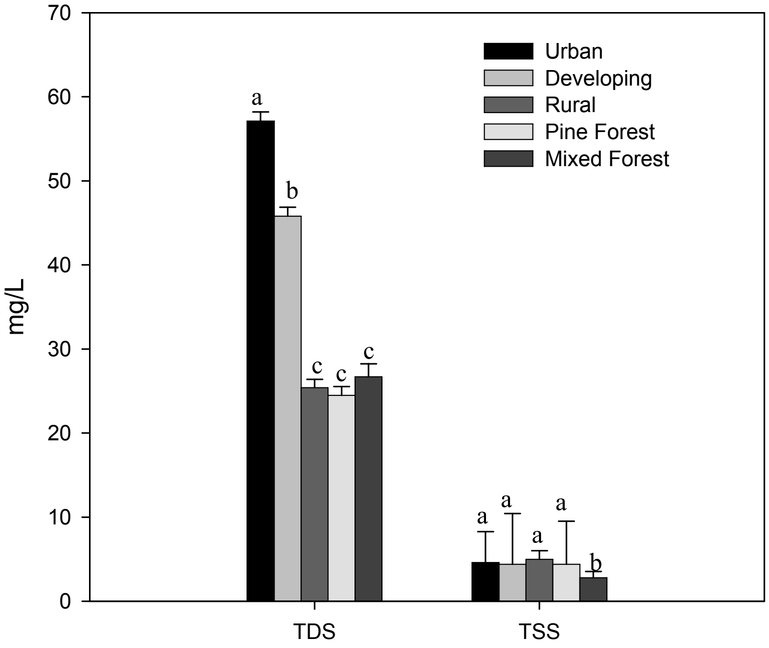

Figure 7. Land use comparisons for median TDS and TSS concentrations. Error bars represent standard errors. Significant differences at $p<0.05$ for each parameter are represented by different letters.

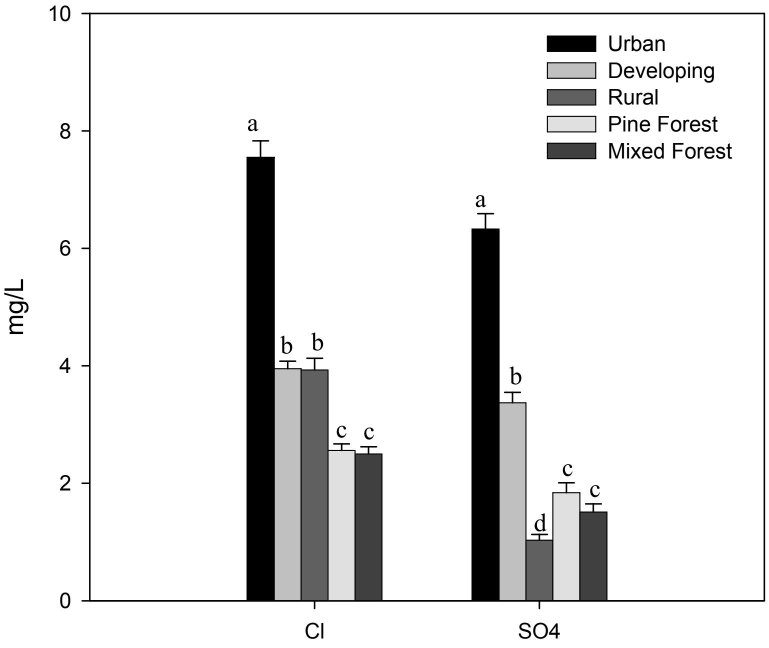

Figure 8. Land use comparisons for median Cl^- and SO_4^- concentrations. Error bars represent standard errors. Significant differences at $p<0.05$ for each parameter are represented by different letters.

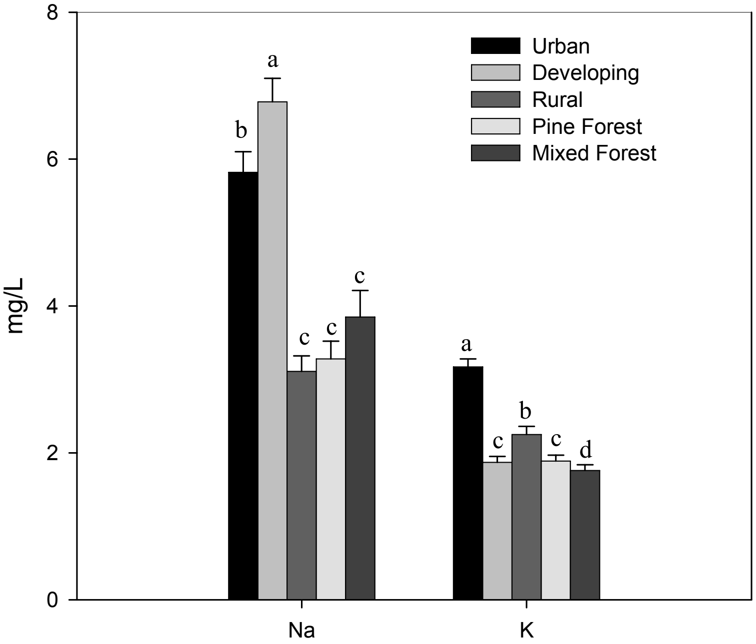

Figure 9. Land use comparisons for median Na^+ and K^+ concentrations. Errors bars represent standard errors. Significant differences at $p<0.05$ for each parameter are represented by different letters.

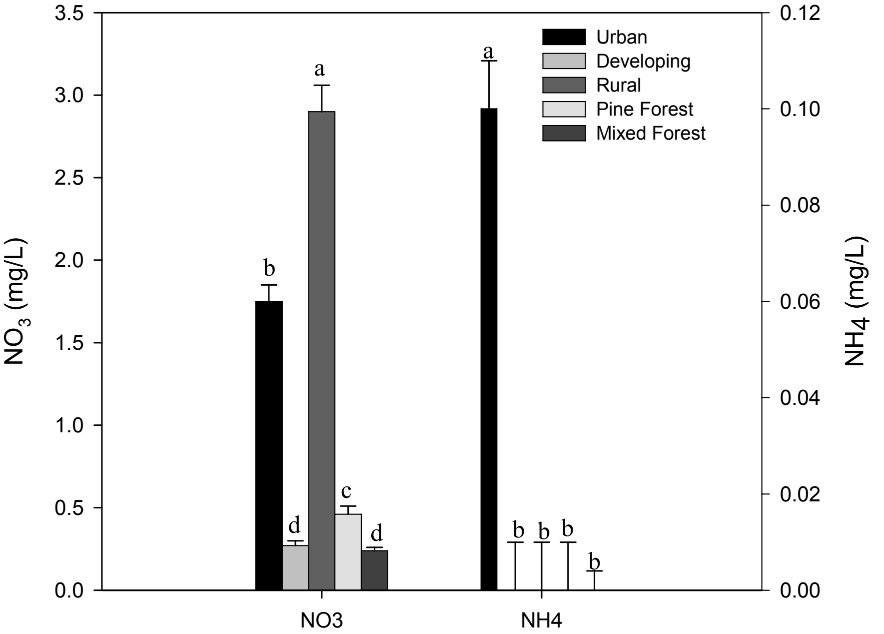

Figure 10. Land use comparisons for median NO_3^- and NH_4^+ concentrations. Error bars represent standard errors. Significant differences at $p<0.05$ for each parameter are represented by different letters.

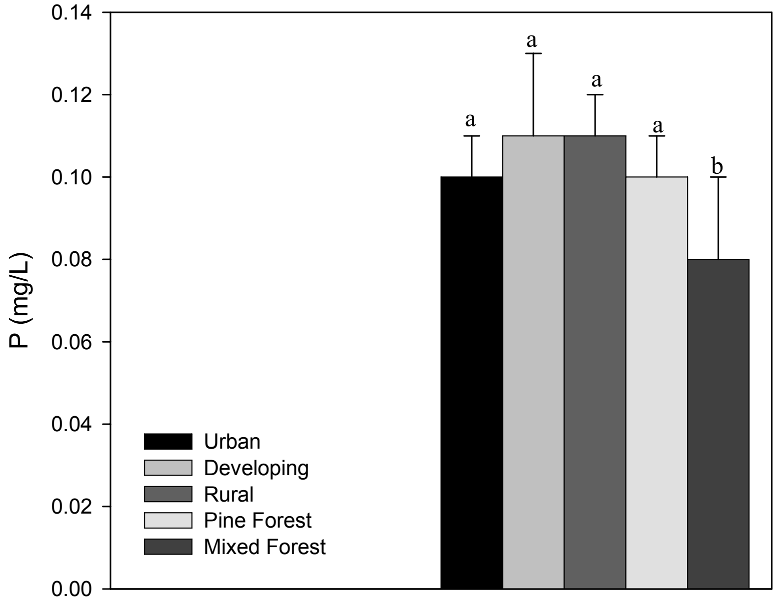

Figure 11. Land use comparisons for median total P concentrations. Error bars represent standard errors. Significant differences at $p<0.05$ are represented by different letters.

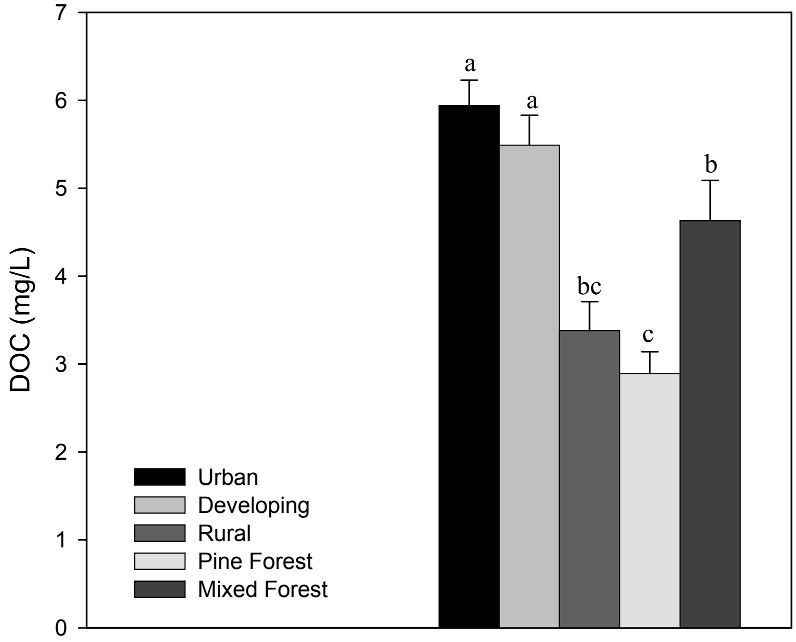

Figure 12. Land use comparisons for median DOC concentrations. Error bars represent standard errors. Significant differences at $p<0.05$ are represented by different letters.

Land Use and Water Quality Relationships

Relationships between land use/cover and water chemistry may change depending on what data are used to examine the relationships. Separating the samples into stormflow and baseflow reveals different relationships than when all flows are combined into one dataset. Spearman correlation coefficients between water quality parameters and land cover percentages are presented for all flows combined (Table 7) and for stormflow and baseflow separately (Table 8).

1. All Flows Combined

Concentrations of TDS were the only variable significantly correlated with all three land use percentage categories (Table 7). A positive relationship existed between TDS concentrations and % impervious surfaces, while forest and pasture revealed negative relationships (Table 7). A significant negative relationship existed between TSS concentrations and % forest cover (Table 7). Chloride, K^+, P, and fecal coliform concentrations all had strong positive relationships with % impervious surfaces and strong negative relationships with % forest cover (Table 7). Only % forest cover showed significant relationships with NO_3^- and NH_4^+ concentrations (negative) (Table 7). Sulfate concentrations had a strong positive relationship with % impervious surfaces and an equally strong negative relationship with % pasture (Table 7). Significant positive relationships existed between % impervious surfaces and Na^+ and DOC concentrations (Table 7).

Yield data revealed similar correlation results, with a few notable exceptions. Total suspended solids and P yields were significant and positively correlated with %

pasture (Table 7). Potassium and P yields were not significantly correlated with % impervious surfaces, unlike their concentration counterparts (Table 7).

When water quality concentrations and yields were correlated with % forest cover, all relationships were negative (Table 7). The opposite was true when concentrations and yields were correlated with % impervious surfaces (Table 7). These relationships reinforce the results found with the categorical analyses (Table 6). Watersheds in urbanized areas (those with large amounts of impervious surfaces) generally had higher concentrations and yields (Table 6) and reflected positive linear relationships across an increasing impervious surface gradient (Table 7). High nutrient concentrations in urbanized areas may be attributed to faulty sewer systems, nonpoint source pollution discharges, and lawn care fertilizers (USEPA 2000). Forested watersheds generally had lower concentrations and yields (Table 6) and consequently revealed negative linear relationships as forest cover increased (Table 7). Percent pasture revealed both negative and positive relationships with concentrations and yields of water quality variables, notably strong positive correlations with TSS and P yields (Table 7), likely reflecting fertilizer inputs and the binding capacity of P to sediment.

2. Baseflow and Stormflow Analyzed Separately

In general, the largest differences in land cover/water quality relationships between flows occurred as increased rainfall caused increased quickflow in areas with high amounts of impervious surfaces. More significant correlations between impervious surface and water quality parameters were revealed during stormflow than baseflow (Table 8). The amount of correlations with forest cover and pasture were similar in both flows, though they sometimes differed on which parameters were significant (Table 8).

Similar to the analyses using all flows, relationships were positive with impervious surface, negative with forest cover, and a mixture of both with pasture land (Table 8). There were, however, some differences in the nature of the relationships. Examining the relationships broken into different flows allows greater insight into potential causes of increased nutrients or sediment which, in turn, aides management of the watersheds. The relationship between impervious surface and NH_4^+ concentrations and yields was almost nonexistent during baseflow, but jumped to significantly positive during stormflow (Table 8). This is likely a result of problems associated with the sewer system as near-stream man-hole covers were commonly displaced during large storm events. Over-application of NH_4-based fertilizers on residential lawns could also be a source for NH_4^+ runoff during storms. Contrastingly, P concentrations were only significantly related to impervious surface during baseflow (Table 8).

Impervious surface and TSS yield relationships were only significant during stormflow, likely from increased surface runoff (Table 8). During baseflow, less interaction between the land and water likely resulted in low TSS concentrations for urban watersheds. Percent pasture revealed the significant positive correlations with TSS and P yields seen when both flows were combined (Table 7). However, here they are only seen during baseflow (Table 8). Two streams in this study were frequented by cattle, causing severe erosion to stream banks. Lenat and Crawford (1994) reported that average TSS concentrations were highest in an urban watershed followed by a pastoral and then a forested watershed during stormflow. However, during baseflow they found higher TSS concentrations at the agricultural site, perhaps reflecting a greater proportion of fine sediments in the agricultural watershed. While my median TSS concentrations did not follow this pattern, it is important to note that TSS yields were highest in the pastoral watersheds during baseflow (Table 9). Schoonover (2005) also suggests that the high baseflow contribution and sand-dominated substrate in these pastoral streams likely contribute to the continual bed movement within the stream channel.

In summary, concentrations and yields had positive correlations with % impervious surfaces during both baseflow and stormflow, but were more responsive during stormflow (Table 8). Relationships with % forest cover were negative in both flows, but generally stronger during stormflow (Table 8). Concentration and yield relationships with % pasture were a mix of positive and negative during baseflow and only negative during stormflow (Table 8). Positive relationships with pastoral land may be a result of the higher baseflow indices from groundwater inputs in these watersheds (Schoonover *et al.* 2006). So, forest cover > pastoral cover > impervious surface cover in terms of water quality protection, especially during rainfall events. In general, the more forested a watershed was, the less sediment and nutrients were contributed to the stream.

Table 7. Spearman correlation coefficients for water quality parameters and land cover percentages for both flows combined. Bold values are significant at $p < 0.05$.

Variable	**% Impervious Surface**	**% Forest**	**% Pasture**
Concentrations (mg/L)			
TDS	**0.77**	**-0.56**	**-0.57**
TSS	0.26	**-0.55**	0.30
Cl	**0.86**	**-0.83**	-0.30
NO_3	0.33	**-0.63**	0.21
SO_4	**0.63**	-0.42	**-0.68**
Na	**0.61**	-0.36	-0.43
NH_4	0.24	**-0.47**	0.16
K	**0.79**	**-0.84**	-0.23
P	**0.51**	**-0.65**	0.43
DOC	**0.56**	-0.23	-0.30
Fecal Coliforms (MPN/100mL)	**0.71**	**-0.65**	-0.34
Yields (g/d/ha)			
TDS	**0.83**	**-0.74**	-0.33
TSS	-0.01	-0.39	**0.59**
Cl	**0.78**	**-0.86**	-0.07
NO_3	0.22	**-0.57**	0.27
SO_4	**0.62**	-0.44	**-0.64**
Na	**0.52**	-0.25	-0.21
NH_4	0.16	-0.40	0.22
K	0.22	**-0.51**	0.24
P	0.29	**-0.54**	**0.55**
DOC	**0.61**	-0.42	0.01

Table 8. Spearman correlation coefficients between water quality parameters and land cover percentages for baseflow and stormflow. Bold values are significant at $p<0.05$. IS=impervious surface.

	Baseflow			**Stormflow**		
Variable	**% IS**	**% Forest**	**% Pasture**	**% IS**	**% Forest**	**% Pasture**
Concentrations (mg/L)						
TDS	**0.79**	**-0.54**	**-0.58**	**0.83**	**-0.63**	**-0.52**
TSS	0.22	**-0.51**	0.42	0.37	-0.24	-0.07
Cl	**0.89**	**-0.82**	-0.35	**0.86**	**-0.88**	-0.20
NO_3	0.24	**-0.59**	0.22	0.29	**-0.65**	0.18
SO_4	**0.65**	-0.39	**-0.69**	**0.74**	**-0.52**	**-0.60**
Na	**0.59**	-0.29	-0.45	**0.54**	-0.23	-0.28
NH_4	0.13	**-0.46**	0.30	**0.58**	**-0.72**	-0.24
K	**0.72**	**-0.78**	-0.28	**0.68**	**-0.85**	-0.14
P	**0.52**	**-0.73**	0.37	0.30	-0.03	**-0.48**
DOC	**0.67**	-0.32	-0.38	**0.50**	-0.09	-0.42
Fecal Coliforms (MPN/100mL)	**0.68**	**-0.62**	-0.38	**0.59**	**-0.47**	**-0.48**
Yields (g/d/ha)						
TDS	**0.71**	**-0.64**	-0.35	**0.60**	-0.36	**-0.57**
TSS	-0.08	-0.34	**0.62**	**0.47**	-0.20	-0.34
Cl	**0.63**	**-0.76**	-0.17	**0.63**	**-0.63**	-0.23
NO_3	0.18	**-0.55**	0.22	0.40	**-0.66**	0.04
SO_4	**0.49**	-0.27	**-0.75**	**0.62**	-0.36	**-0.57**
Na	**0.49**	-0.28	-0.17	**0.56**	-0.29	-0.43
NH_4	0.06	-0.39	0.36	**0.60**	**-0.71**	-0.26
K	0.07	-0.42	0.24	**0.48**	-0.39	-0.38
P	0.20	**-0.53**	**0.49**	0.30	0.04	-0.27
DOC	**0.82**	**-0.65**	-0.12	**0.55**	-0.19	-0.46

Table 9. Baseflow and stormflow median concentrations and yields of water quality variables by land use.

	Baseflow				**Stormflow**			
Variable	**Urban**	**Developing**	**Pastoral**	**Forest**	**Urban**	**Developing**	**Pastoral**	**Forest**
Concentrations (mg/L)								
TDS	60.20	50.80	25.58	23.73	40.70	30.45	24.55	21.30
TSS	4.30	3.20	3.90	3.38	21.90	21.30	11.40	10.75
Cl	7.64	3.97	3.92	2.44	4.78	3.25	3.57	2.04
NO_3	1.69	0.15	3.03	0.24	1.70	0.30	3.11	0.34
SO_4	5.44	3.40	0.90	1.77	5.41	4.15	1.65	2.54
Na	6.60	7.34	2.97	3.13	3.42	4.84	2.69	2.64
NH_4	0.08	0.00	0.06	0.00	0.23	0.00	0.07	0.02
K	3.15	1.92	2.30	1.91	2.39	1.73	2.02	1.65
P	0.10	0.09	0.12	0.08	0.13	0.13	0.08	0.14
DOC	5.54	4.79	2.31	2.23	6.51	8.42	1.89	2.88
Fecal Coliforms (MPN/100mL)	1500.00	212.00	114.00	112.00	2750.00	595.00	192.50	261.50
Yields (g/d/ha)								
TDS	263.96	177.06	224.17	171.19	2370.16	1657.19	812.31	998.20
TSS	19.78	17.68	28.18	18.26	1410.03	2173.88	429.92	583.72
Cl	37.26	18.42	33.34	15.23	257.94	164.29	146.02	78.92
NO_3	7.53	0.37	26.50	1.37	126.49	34.56	102.96	13.54
SO_4	28.84	10.36	7.76	10.95	365.37	203.77	73.70	103.64
Na	25.98	31.36	28.19	21.72	200.05	239.57	101.82	141.15
NH_4	0.27	0.00	0.36	0.00	15.91	0.00	1.94	0.40
K	14.24	9.16	18.25	11.56	165.24	93.55	91.96	74.53
P	0.52	0.27	0.83	0.36	3.77	9.26	3.53	4.72
DOC	27.27	23.78	21.32	15.27	426.00	396.36	68.43	158.29

Impervious Surface Influence on Water Quality

The average threshold of imperviousness at which water quality degradation first occurs has been suggested to be 10% (Arnold and Gibbons 1996, Bledsoe and Watson 2001). Using an urban intensity index (0-100, low to high urbanization) in a study of coastal New England streams, Coles *et al.* (2004) found that the greatest change in aquatic health occurred between low and moderate levels (0 to 35) of urban intensity (the degree of urban intensity was derived from land cover, infrastructure, and socioeconomic variables). They also found a threshold effect where the variable response no longer changed as urban intensity increased.

In the study watersheds, some water quality concentrations did show signs that a threshold may exist, and it was much lower than the expected 10% impervious surface. For example, Cl^- (Figure 13), SO_4^- (Figure 14), and TDS (Figure 15) concentrations showed an initial increase and then began to level-off as impervious surface increased to ~20%, with the inflection point or threshold seemingly within the very low impervious surface watersheds, likely around 3-5% impervious surface. Of the 11 water quality parameters measured, concentrations of TDS, Cl^-, SO_4^-, Na^+, K^+, and fecal coliforms showed a significant curvilinear trend (Table 10) with a sharp increase in concentration up to ~4% impervious surface, followed by a gradual increase at higher impervious surfaces. Phosphorus concentrations did not have a significant curvilinear relationship across the entire range of impervious surface (Figure 16). However, P concentrations rose to a maximum at 23% impervious surface and then dropped off. The relationship between P concentrations and impervious surface up to 23% was significant and followed the same curvilinear trend as the other water quality parameters, with the threshold around 3-5% impervious surface (Figure 17).

Because of this curvilinear trend and evidence of the impervious surface threshold likely existing below 5% (Figures 13-15), I also examined the relationships between concentrations and impervious surface only in watersheds with impervious surfaces between 0 and 4%. Concentrations of TDS, Cl^-, Na^+, P, and DOC all significantly increased between 0 and 4% impervious surface (Table 11). For example, Cl^- concentrations had an increasing linear relationship with low impervious surface levels (Figure 18).

I hypothesized that even a small increase in impervious surfaces (0-4%) would have a negative impact on stream water quality. Surprisingly, concentrations of TDS, Cl^-, SO_4^-, Na^+, K^+, and fecal coliforms all displayed curvilinear relationships with impervious surface in which the impervious surface threshold was around 3-5%, much lower than the generally accepted 10% threshold. In addition, concentrations of TDS, Cl^-, Na^+, P, and DOC did significantly increase as impervious surface increased from 0-4%. Therefore, even a small increase in impervious surface could impact stream water concentrations in these watersheds.

The relationship between imperviousness and water quality (either chemistry or biotic integrity) has been debated. Some reports have suggested a linear decline in biotic integrity with increasing impervious surface (Booth *et al.* 2004), while others have cited a linear decline with increasing effective impervious surface until a lower threshold is reached (Walsh *et al.* 2005). Regardless of the nature of threshold relationships, increasing urban density often drives declines in water quality (Arnold and Gibbons

1996, Paul and Meyer 2001, Booth *et al.* 2004, Walsh *et al.* 2005). Even small increases in imperviousness may have a negative impact on stream ecosystems (Coles *et al.* 2004). If a threshold does exist, it may differ among regions, types of development, and ecosystems, making it difficult to apply one model universally.

Table 10. Curvilinear relationships between water quality parameters and % impervious surfaces. Bold values represent significant relationships at $p<0.05$.

Variable (mg/L)	R^2	p-value
TDS	**0.56**	**0.0003**
TSS	0.09	0.2232
Cl	**0.77**	**<0.0001**
NO_3	0.03	0.5298
SO_4	**0.79**	**<0.0001**
Na	**0.23**	**0.0449**
NH_4	0.09	0.2242
P	0.18	0.0812
K	**0.64**	**<0.0001**
DOC	0.21	0.0582
Fecal Coliforms (MPN/100mL)	**0.46**	**0.0021**

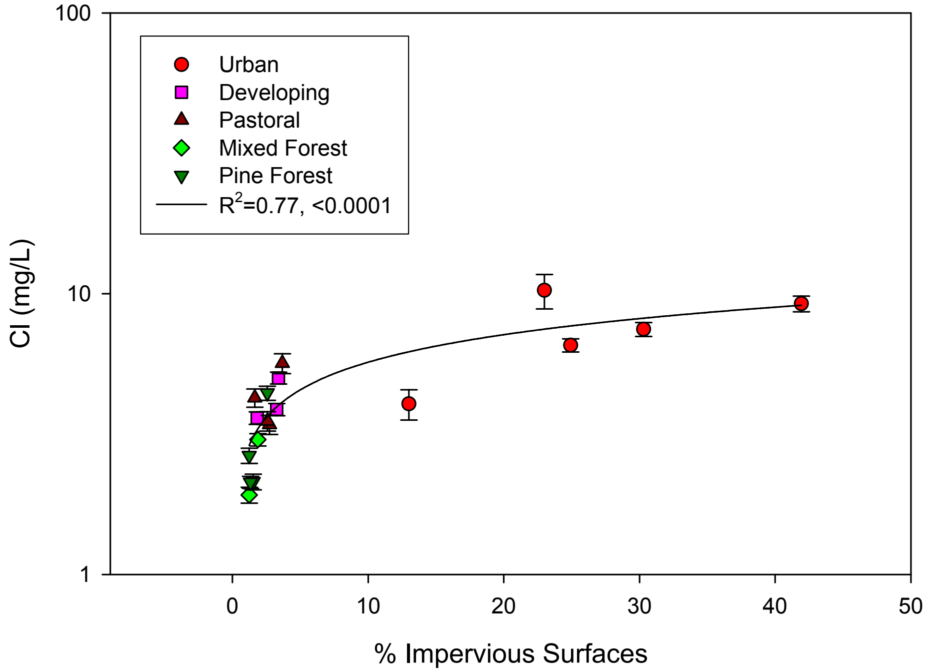

Figure 13. Median Cl concentrations ± standard errors along an impervious surface gradient. Relationship is significant at $p<0.05$.

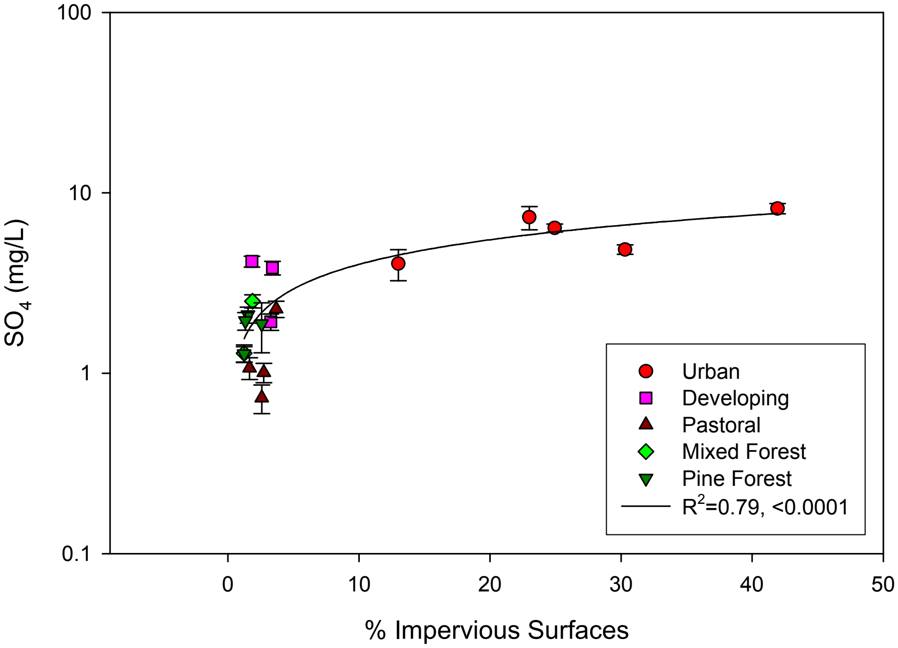

Figure 14. Median SO_4 concentrations ± standard errors along an impervious surface gradient. Relationship is significant at $p<0.05$.

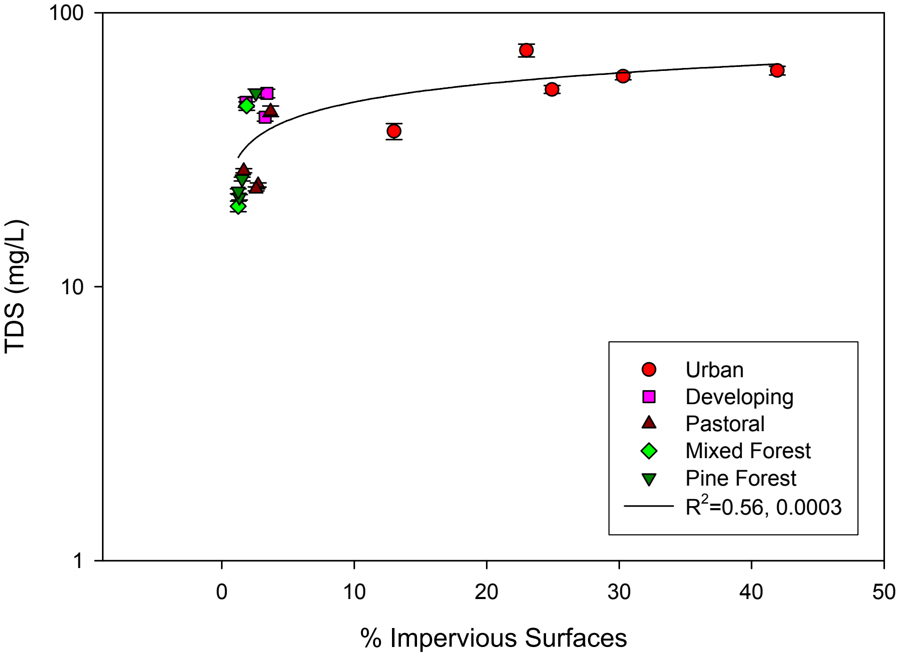

Figure 15. Median TSS concentrations ± standard errors along an impervious surface gradient. Relationship is significant at $p<0.05$.

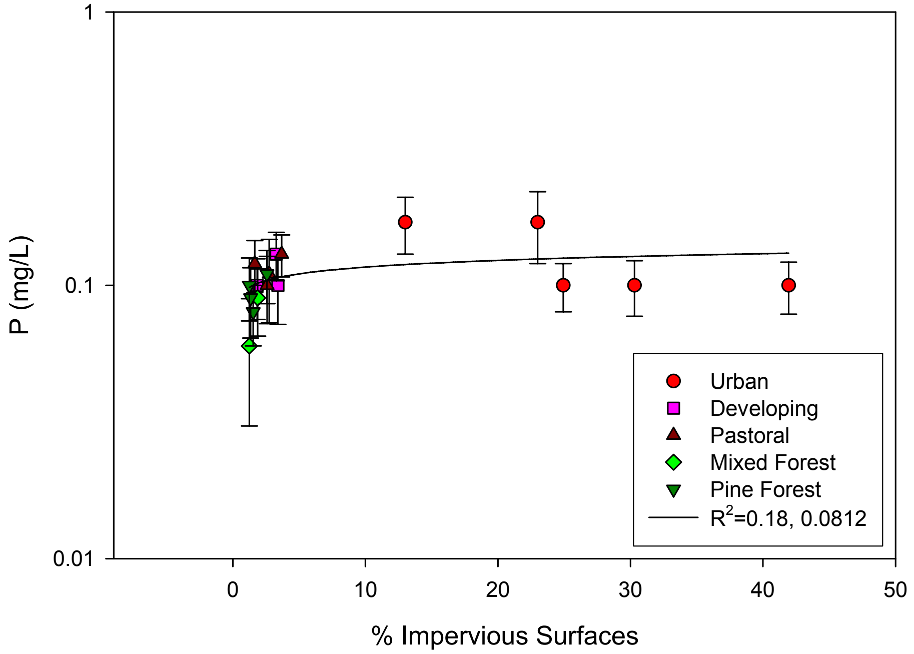

Figure 16. Median P concentrations ± standard errors along an impervious surface gradient. Relationship is significant at p<0.05.

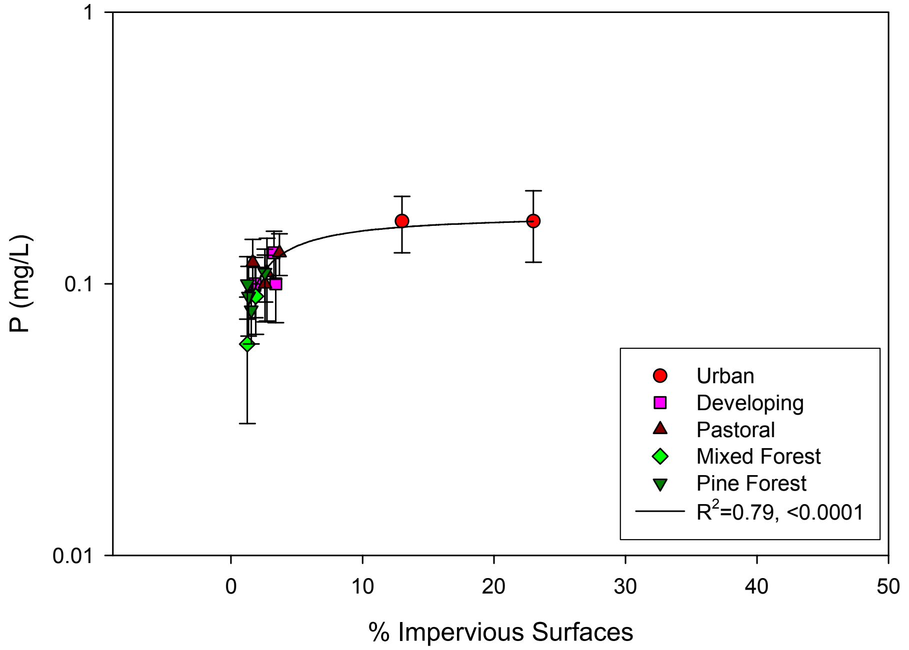

Figure 17. Median P concentrations ± standard errors along an impervious surface gradient ending at 23%. Relationship is significant at p<0.05.

Table 11. Linear relationships between water quality concentrations and low impervious surfaces (0-4%). Bold values represent significant relationships at $p<0.05$.

Variable (mg/L)	R^2	p-value
TDS	**0.37**	**0.029**
TSS	0.05	0.483
Cl	**0.67**	**0.0007**
NO_3	0.002	0.8992
SO_4	0.04	0.5232
Na	**0.36**	**0.0306**
NH_4	0.05	0.4643
P	**0.57**	**0.0044**
K	0.2	0.1247
DOC	**0.38**	**0.0246**
Fecal Coliforms (MPN/100mL)	0.07	0.3735

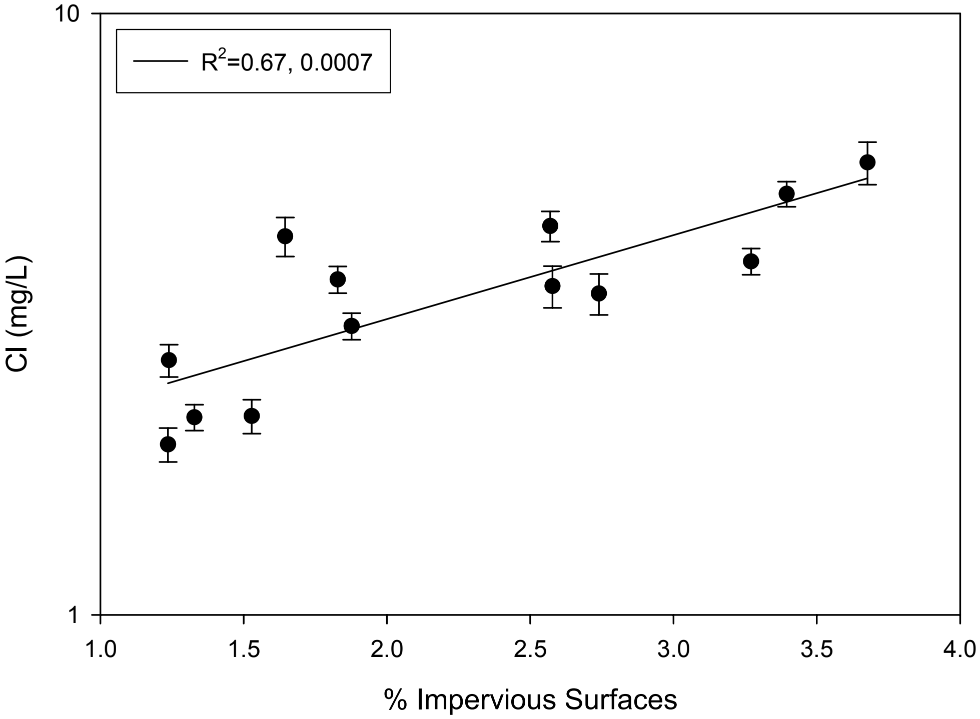

Figure 18. Median Cl concentrations ± standard errors along a low impervious surface gradient (0-4%). Relationship is significant at $p<0.05$.

Water Quality Prediction Models

Schoonover (2005) created prediction models for each water quality parameter based on data from 18 watersheds, 2 of which I did not sample, between May 2002 and August 2004. However, I chose to update the models based on additional sampling in the 16 watersheds, plus two watersheds with mid-range impervious surfaces, FR and BR (Table 3). Ammonium was the only parameter that did not display a significant regression model in both Schoonover (2005) (Table 13) and my analyses (Table 12). My models are similar to that of Schoonover (2005), but most R^2's are slightly higher (Tables 12 and 13). The longer dataset did change which parameters were selected in the models for NO_3^-, K^+, SO_4^-, and fecal coliforms, while all other models used the same independent variables (Tables 12 and 13). Also, Schoonover (2005) did not find a significant prediction equation for TSS (Table 13). In contrast, a significant equation for TSS concentrations was found using the combined dataset (Table 12). The length of a dataset can impact the strength of the model and the selection of independent variables within the model. Not only were the models strengthened from simply having more data points, but the availability of a longer dataset also captured more fluctuations in outside variables affecting water quality, such as precipitation events, which, in turn, likely aided in explaining more of the variability in the model.

The best prediction models for all parameters included all four land cover categories as independent variables with the exception of NO_3^- and K^+ (Table 12). Percent impervious surface and pasture created the strongest NO_3^- model (Table 12). Only evergreen and mixed forest percentages were included in the K^+ model (Table 12). It is interesting to note that SO_4^-, P, K^+ and fecal coliform models displayed models of similar strength when not separating the forest types, i.e. summing the evergreen and mixed forest percentages together instead of using them as separate independent variables (Table 12). Therefore, it may not be necessary to differentiate between forest types in order to predict those parameters.

Table 12. Multiple regression equations based on median concentrations for water quality parameters. IS=% Impervious Surfaces, EV=% Evergreen Forest, M=% Mixed Forest, AG=% Pasture, FOR=% Total Forest. *SO_4, P, K, and FC models change little when using % total forest instead of evergreen & mixed. Parameters were log-transformed to meet normality assumptions.

Parameter	Equation	R^2	p-value
TDS	y=-0.085(IS)-0.100(EV)-0.048(M)-0.074(AG)+10.711	0.81	0.0001
TSS	y=-0.065(IS)-0.040(EV)-0.072(M)-0.024(AG)+5.812	0.77	0.0004
Cl	y=-0.061(IS)-0.098(EV)-0.040(M)-0.052(AG)+7.554	0.93	<0.0001
NO_3	y=0.074(IS)+0.075(AG)-2.579	0.51	0.0049
SO_4	y=-0.053(IS)-0.075(EV)-0.050(M)-0.076(AG)+6.880	0.75	0.0006
Na	y=-0.112(IS)-0.118(EV)-0.056(M)-0.090(AG)+10.05	0.69	0.0026
P	y=-0.056(IS)-0.0.52(EV)-0.043(M)-0.027(AG)+1.745	0.74	0.0009
K	y=-0.013(EV)-0.013(M)+1.526	0.69	0.0002
DOC	y=-0.107(IS)-0.120(EV)-0.055(M)-0.085(AG)+9.749	0.51	0.0433
FC	y=-0.059(IS)-0.121(EV)-0.069(M)-0.082(AG)+13.891	0.70	0.0023
***SO_4**	y=-0.040(IS)-0.053(FOR)-0.066(AG)+5.845	0.74	0.0002
P	y=-0.051(IS)-0.044(FOR)-0.024(AG)+1.364	0.72	0.0003
K	y=-0.013(FOR)+1.527	0.69	<0.0001
FC	y=-0.032(IS)-0.075(FOR)-0.062(AG)+11.716	0.67	0.0010

Table 13. Schoonover (2005) multiple regression equations based on median concentrations for water quality parameters. IS=% Impervious Surfaces, EV=% Evergreen Forest, M=% Mixed Forest, AG=% Pasture. Parameters, except Na, were log-transformed to meet normality assumptions.

Parameter	Equation	R^2	p-value
TDS	y = -0.04(IS)-0.06(M)-0.09(EV)-0.06(Ag)+8.22	0.66	0.0052
TSS	not significant		
Cl	y = -0.04(IS)-0.06(M)-0.09(EV)-0.06(Ag)+8.22	0.83	<0.0001
NO_3	y = 0.25(IS)+0.19(M)+0.27(EV)+0.31(Ag)-24.90	0.63	0.0075
SO_4	y = 0.04(IS)-0.03(Ag)+1.19	0.60	0.0011
Na	y = -0.43(IS)-0.40(M)-0.69(EV)-0.57(Ag)+58.13	0.56	0.0211
P	y = -0.005(IS)-0.005(M)-0.005(EV)-0.004(Ag)+0.54	0.72	0.0014
K	y = 0.007(IS)-0.02(M)+1.21	0.77	<0.0001
DOC	y = -0.12(IS)-0.12(M)-0.18(EV)-0.14(Ag)+15.34	0.53	0.0333
FC	y = 0.06(IS)+4.85	0.69	<0.0001

Land Use Impacts on Stream Chemistry Responses to Discharge Variation

The urban watershed had the highest number of significant relationships between concentrations and discharge (TSS, TDS, Cl^-, SO_4^-, Na^+, K^+, NH_4^+, P, and fecal coliforms) (Table 14). In the developing watershed, concentrations of TSS, TDS, Cl^-, Na^+, K^+, DOC, and fecal coliforms were significantly related to changes in discharge (Table 14). Significant responses in the pastoral watershed were found for concentrations of TSS, TDS, Cl^-, SO_4^-, Na^+, and NO_3^- (Table 14). In the forested watershed, only Na^+ and K^+ showed significant relationships to discharge (Table 14).

The direction and slope of the response within each watershed were also examined. Concentrations of TDS, Cl^-, Na^+, and K^+ were negatively related to discharge variation, suggesting a dilution effect (Table 14). Total suspended solid concentrations were positively related to discharge, with the steepest increase in the developing watershed followed by the urban and pastoral watersheds (Table 14). Increases in TSS as discharge increased were likely from active construction sites in the developing and urban watersheds and erosion from cattle entering streams in the pastoral watershed. Ammonium, P, and fecal coliform concentrations were positively related to discharge in the urban watersheds (Table 14). Additions of these pollutants in the urban watershed as discharge increased may be a result of leaky sewer systems during storm events. Concentrations of DOC and fecal coliforms had positive relationships to discharge in the developing watershed (Table 14), also suggesting that sewer overflows may be a problem due to the variable hydrology of these streams during storms (Schoonover *et al.* 2006). In the pastoral watershed, NO_3^- and SO_4^- were not diluted with increased discharge, suggesting fertilizer runoff may contribute to increased nutrients (Table 14).

In comparing an urban and forested site, Clinton and Vose (2006) found that stream chemistry responses to variation in stream discharge were greatest at the urban site. In contrast to my study, they found a significant response in TSS, NO_3^-, and P with discharge variation at the forested site, although the urban site showed a greater slope coefficient. They also found that although concentrations were generally greatest at the urban site, the dilution effects of increased discharge were also greatest there. No discharge relationship was found with those three constituents at the forested site in my study (Table 14). However, a significant relationship and a dilution effect at the forested site were noted with Na^+ and K^+ two parameters which Clinton and Vose (2006) did not examine, though the negative slope was not significantly different from that of the other land uses (Table 14). Therefore, the land uses had similar declines in Na^+ and K^+ concentrations as discharge increased (Table 14). Also in contrast to Clinton and Vose (2006), an increasing response to discharge in P and NO_3^- concentrations was found at the urban site instead of a dilution effect. Total suspended solids in their study showed an increasing trend with discharge, with the steepest increase at the reference site. I also found an increasing TSS trend, but the steepest slope was in the developing watershed (Table 14), likely from active construction sites within the watershed.

My hypothesis was that the urban watershed would have the greatest water quality concentration response to changes in stream discharge, followed by developing, pastoral, and forested watersheds. The hypothesis was supported; however, the direction of the relationships differed with land use in many instances. Concentrations of TSS had the steepest increase with discharge in the developing watershed. Ammonium, P, and fecal coliform concentrations increased with discharge in the urban watersheds (Table 14).

Concentrations of DOC and fecal coliforms increased with discharge variation in the developing watershed (Table 14). Nitrate and SO_4^- concentrations had increasing trends with discharge in the pastoral watershed (Table 14). All other constituents were diluted as discharge increased (Table 14).

Table 14. Responses of concentrations of water quality variables to changes in stream discharge using regression. Significant differences between slopes of land uses at $p<0.05$ for each variable are represented by different letters; n.s.=not significant.

Variable	Land Use	Intercept	Slope	R^2	P-value
TSS	Urban	-0.413	0.024^a	0.88	<0.0001
	Developing	-16.675	0.100^b	0.49	<0.0001
	Pastoral	4.299	0.012^a	0.34	<0.0001
	Forested				n.s
TDS	Urban	61.494	-0.004^a	0.32	0.0001
	Developing	52.501	-0.015^b	0.54	<0.0001
	Pastoral	51.888	-0.023^b	0.40	<0.0001
	Forested				n.s
Cl	Urban	9.477	-0.001^a	0.17	0.0076
	Developing	4.037	-0.001^a	0.14	0.0145
	Pastoral				n.s.
	Forested				n.s
SO_4	Urban	8.972	-0.0005^a	0.10	0.0419
	Developing				n.s.
	Pastoral	1.844	0.002^b	0.21	0.0021
	Forested				n.s
Na	Urban	7.055	-0.0006^a	0.17	0.0077
	Developing	8.703	-0.003^b	0.25	0.0006
	Pastoral	8.201	-0.005^b	0.29	0.0002
	Forested	3.049	-0.007^{ab}	0.23	0.003
K	Urban	3.567	-0.0002^a	0.11	0.0334
	Developing	2.054	-0.0005^a	0.09	0.0472
	Pastoral				n.s.
	Forested	2.158	-0.005^a	0.2	0.005
NO_3	Urban				n.s.
	Developing				n.s.
	Pastoral	0.252	0.0002	0.10	0.0354
	Forested				n.s
NH_4	Urban	0.053	0.00002	0.15	0.0122
	Developing				n.s.
	Pastoral				n.s.
	Forested				n.s
P	Urban	0.130	0.00002	0.12	0.0248
	Developing				n.s.
	Pastoral				n.s.
	Forested				n.s
DOC	Urban				n.s.
	Developing	6.646	0.00231	0.13	0.0183
	Pastoral				n.s
	Forested				n.s
Fecal Coliforms	Urban	2694.750	0.629^a	0.15	0.0113
	Developing	355.500	0.968^a	0.24	0.001
	Pastoral				n.s.
	Forested				n.s

Land Use Influences on Phosphorus and Nitrogen

Nitrate is the only major nutrient for which a maximum contaminant level (10 mg/L) has been established by USEPA (1995) for drinking water. Drinking water with NO_3^- exceeding 10 mg/L poses the greatest health risk to infants from methemoglobinemia or "blue baby syndrome". In my study, only 2 of 807 samples tested had NO_3^- concentrations greater than 10 mg/L. Both were taken in predominately rural watersheds where the major land use was pasture. In a national examination of groundwater NO_3^-, Madison and Brunett (1985) defined NO_3-N concentrations of 3.1 to 10 mg/L as elevated concentrations indicative of human activities. In my study, developing and mixed forested watersheds had no samples within this range. Pine forested streams had 1 sample (0.53%) in this concentration range. Urban watersheds had the second highest number of samples with 17 (10%). Streams in largely pastoral watersheds had the highest number of samples with 72 (46%). Nitrate sources in urban and pastoral watersheds were likely K^+- NO_3^- and NH_4^+-NO_3^- fertilizers, cattle waste, and human sewage leaks.

No national criteria have been established for P. However, USEPA (1986b) recommends a surface water level of < 0.1 mg/L total P in order to control eutrophication in flowing waters. Over the course of this study, 54% (436 of 809) of samples exceeded this recommendation. In comparison, 40% of surface water samples taken from the Apalachicola-Chattahoochee-Flint River (ACF) basin from 1972-1990 were greater than the recommendation (Frick 1996). In my study, samples > 0.1 mg/L were predominantly in watersheds affected by human influence, including urban pressures and also management practices associated with pine plantations and pastoral land uses. The predominantly pastoral watersheds had the highest percentage of samples > 0.1 mg/L (i.e. 60%). The urban and developing watersheds surpassed the recommendation 58 and 56% of the time, respectively. Similarly, watersheds consisting largely of pine species exceeded the recommendation 52% of the time. Mixed watersheds, predominantly composed of mixed forest species, had the lowest percentage of exceedances with 42%. In general, the percentage of samples exceeding the P recommendation declined with increasing forest cover (Figure 19). This suggests that forest cover within a watershed may be critical in preventing the maximum contaminant level recommendation for P in streams. It may also be useful to examine the proximity of the forest cover to the streams.

Phosphorus can enter a stream in solution or bound to suspended sediment particles. I examined the relationship between P yields and total suspended sediment yields. There was a significant relationship when all data were used (p-value=0.0001, R^2=0.66), suggesting an increase in P inputs into the stream with increasing sediment yields. Separating the watersheds into major land use categories, I found the strongest relationship in the urban watersheds (R^2=0.93) followed by the developing (R^2=0.63), pastoral (R^2=0.37), and finally the forested watersheds (R^2=0.26). This is likely a result of higher ranges of TSS yields within the urban and developing streams. Phosphorus may be transported by means of sediment in urban and developing areas to a greater extent than other watersheds because of greater sediment fluxes into those streams. Sediment in urbanized areas often has an unobstructed pathway into stream systems because of less forest cover and reduced infiltration due to higher percentages of impervious surfaces. The urban watersheds had two large P fluxes (127 and 258 g/d/ha) corresponding with two extremely large sediment fluxes (135,000 and 173,000g/d/ha). Although pastoral watersheds had overall higher median TSS and P yields than urban areas (likely from sediment disturbance by cattle entering/exiting streams and increased fertilizer use), they did not experience high volume inputs. This is in contrast with the results from urban and developing watersheds and may reflect the increased velocity associated with storm flow events in the latter two categories. Pastoral watersheds had a maximum P and corresponding TSS yield of 46 and 5,000 g/d/ha, respectively.

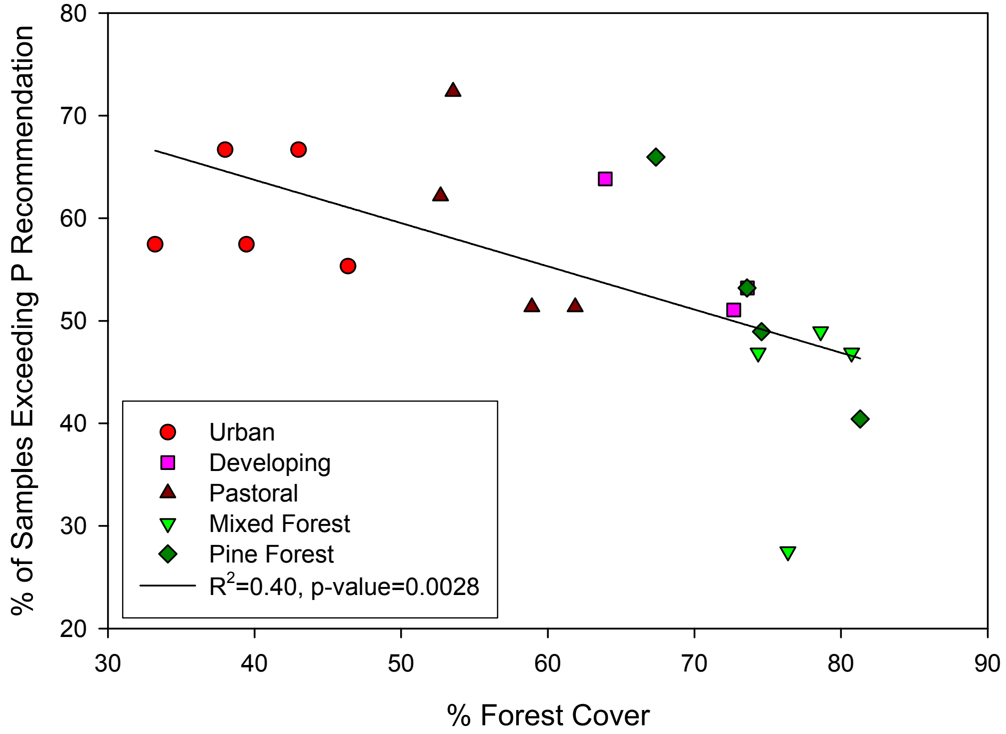

Figure 19. Percent of phosphorus samples exceeding USEPA recommendation (0.1mg/L) as related to % forest cover.

Land Use Impacts on Fecal Coliforms and *Escherichia coli*

Land use has the potential to influence the degree to which a watershed meets the GAEPD guidelines for supporting designated uses, in this case recreational. The majority of urban watersheds did not support designated uses (Table 15). In fact, two urban watersheds did not support designated uses three years in a row (Table 15). Mixed and pine forested watersheds fluctuated between supporting and partially supporting during the three years (Table 15). Pastoral watersheds usually supported or partially supported designated uses (Table 15). Only once did a predominately pastoral watershed not support designated uses (Table 15). Developing watersheds which had low amounts of impervious surfaces but active construction sites, displayed a mixture of all three designated use categories, with partially supporting the predominant category (Table 15).

In examining the relationships between concentrations of fecal coliforms and the percentage of land cover, a strong positive relationship with % impervious surfaces (R^2=0.71) and a strong negative relationship with % forest cover (R^2=-0.65) (Table 16) were found. There was no significant relationship between fecal coliform concentrations and the percentage of pastoral land (Table 16). These relationships may be a result of watershed hydrology. Schoonover and Lockaby (2006) found that fecal coliforms within these same urban and developing watersheds had a much greater response to storms than other watersheds, i.e. stormflow fecal coliform concentrations were much higher than baseflow concentrations. Fecal coliforms revealed stronger correlations with % impervious surface and % forest than *E. coli* (Table 16). *E. coli* did show a stronger negative correlation with % pastoral cover than fecal coliforms, though not significant (Table 16).

In a review of studies examining the health effects from exposure to recreational waters, 19 of 22 studies found the rate of certain gastrointestinal symptoms was significantly related to fecal indicator bacterial counts (Prüss 1998). In freshwaters, *E. coli* correlated better with health outcomes than fecal coliforms. In 1986, USEPA advocated states use *E. coli* or *enterococci* bacteria rather than fecal coliforms as indicators of fecal contamination for recreational waters. Rasmussen and Ziegler (2003) compared estimates of fecal coliform and *E. coli* in Kansas streams. They found that greater than half of the sampled streams could exceed USEPA *E. coli* criterion more often than the Kansas Department of Health and Environment (KDHE) fecal coliform criterion. While fecal coliform bacteria indicate the possible presence of pathogens associated with fecal contamination, *E. coli* presence is definitive evidence of fecal contamination from warm-blooded animals. It is the only member of the fecal coliform group that is exclusively fecal in origin.

Urban watersheds exhibited the highest median *E. coli* concentrations, ranging from 135 to 1255 MPN/100mL (Table 17). Values in developing watersheds ranged from 142 to 225 MPN/100mL (Table 17). Pastoral watersheds had median *E. coli* concentrations ranging from 56 to 206 MPN/100mL (Table 17). Watershed HC2, the pastoral watershed with the highest median and maximum concentration (Table 17), was a cattle pasture with no fences along the stream. Pine and mixed watersheds had median ranges of 94 to 169 MPN/100mL and 59 to 170 MPN/100mL, respectively (Table 17).

In examining how land use influences violations of *E. coli* review criterion, the four urban watersheds had the most violations, ranging from 13.6% to 66.7% of samples (Table 18). Developing watersheds followed with a range of 9.1% to 22.7% (Table 18).

Pastoral watershed violations ranged from 4.6% to 22.7% (Table 18). Pine and mixed watersheds had violations ranging from 4.6% to 13.6% and 9.1% to 13.6%, respectively (Table 18). The amount of impervious surface had a significant positive correlation (0.69) and the % of forest cover had a significant negative correlation (-0.60) with the % of *E. coli* violations within a watershed (Table 19). Therefore, the amount of impervious surface and forest cover within a watershed may impact the number of sampling days that exceed the review criterion for *E. coli* concentrations.

Examining *E. coli* to fecal coliform ratios (EC/FC) may show environmental agencies the importance of measuring *E. coli* concentrations in lieu of fecal coliform concentrations. Twelve of the sixteen watersheds had a median ratio greater than the review criterion ratio of 0.144 (Table 20). This means the *E. coli* criterion could potentially be exceeded while meeting the current fecal coliform criterion. Since *E. coli* has been shown to correlate more strongly with illness symptoms (Dufour and Cabelli 1984, Prüss 1998), health issues could result from humans in contact with the water even though the fecal coliform criterion is met.

Table 15. Fecal coliform violations for individual watersheds. no = not supporting designated uses, at least 26% of samples violate the review criterion. par = partially supporting designated uses, 11-25% of samples violate the review criterion. yes = supporting designated uses, 0-10% of samples violate the review criterion. . = no data or insufficient data. (number) = percentage of samples violating the review criterion. Review criterion: 400MPN/100mL from May-October, 4000MPN/100mL November-April. Violations existed when samples did not meet the review criterion. Based on the 2000-2001 Georgia Water Quality Report.

ID	Land Use	2003	2004	2005
BLN	**Mixed**	.	par (18)	yes (0)
BR	**Urban**	.	.	no (83)
BU1	**Urban**	no (62)	no (33)	no (62)
BU2	**Urban**	no (57)	no (47)	no (43)
CB	**Pine**	par (21)	par (12)	par (14)
FR	**Urban**	.	.	no (31)
FS2	**Pastoral**	.	yes (0)	yes (7)
FS3	**Pastoral**	.	par (18)	par (14)
HC	**Pine**	yes (0)	yes (0)	yes (7)
HC2	**Pastoral**	.	no (29)	par (21)
MU1	**Pastoral**	par (14)	yes (0)	yes (0)
MU2	**Pine**	yes (7)	yes (0)	yes (7)
MU3	**Mixed**	par (14)	par (20)	yes (7)
RB	**Urban**	no (36)	yes (7)	yes (0)
SB1	**Developing**	yes (7)	par (14)	no (29)
SB2	**Developing**	no (29)	par (14)	par (14)
SB4	**Developing**	par (14)	par (13)	yes (7)
SC	**Pine**	par (15)	yes (0)	yes (7)

Table 16. Spearman correlation coefficients between land cover percentages and *E. coli* and fecal coliform concentrations (p-value).

Land Cover	*Escherichia coli*	Fecal Coliforms
% Impervious Surface	**0.47 (0.05)**	**0.71 (0.001)**
% Forest	-0.35 (0.15)	**-0.65 (0.01)**
% Pasture	-0.46 (0.06)	-0.27 (0.27)

Table 17. Median, standard error, minimum and maximum *E. coli* concentrations for individual watersheds.

ID	Land Use	Median	Std Error	Min	Max
BLN	**Mixed**	59.00	57.30	0	1000
BR	**Urban**	1255.00	1019.45	97	12000
BU1	**Urban**	535.00	137.47	150	2725
BU2	**Urban**	611.50	155.90	12	2450
CB	**Pine**	169.50	109.56	0	2400
FR	**Urban**	180.00	123.70	58	1501
FS2	**Pastoral**	56.00	105.04	0	1844
FS3	**Pastoral**	103.50	101.83	0	2150
HC	**Pine**	124.00	86.17	0	1900
HC2	**Pastoral**	206.50	174.07	0	3900
MU1	**Pastoral**	73.50	60.83	0	1380
MU2	**Pine**	115.50	1334.98	0	29500
MU3	**Mixed**	170.50	119.75	0	2650
RB	**Urban**	135.00	86.43	18	1800
SB1	**Developing**	184.00	200.90	0	4025
SB2	**Developing**	225.00	1126.73	10	25000
SB4	**Developing**	142.50	222.39	12	5000
SC	**Pine**	94.50	78.51	0	1600

Table 18. Percent of samples violating the *E. coli* review criterion for individual watersheds. USEPA review criterion for *E. coli*: 576 colonies/100mL.

ID	Land Use	Samples	# of Violations	% Violated
BLN	**Mixed**	22	2	9.09
BR	**Urban**	12	8	66.67
BU1	**Urban**	22	11	50.00
BU2	**Urban**	22	11	50.00
CB	**Pine**	22	3	13.64
FR	**Urban**	12	4	33.33
FS2	**Pastoral**	22	3	13.64
FS3	**Pastoral**	22	3	13.64
HC	**Pine**	22	1	4.55
HC2	**Pastoral**	22	5	22.73
MU1	**Pastoral**	22	1	4.55
MU2	**Pine**	22	2	9.09
MU3	**Mixed**	22	3	13.64
RB	**Urban**	22	3	13.64
SB1	**Developing**	22	5	22.73
SB2	**Developing**	22	2	9.09
SB4	**Developing**	22	3	13.64
SC	**Pine**	22	2	9.09

Table 19. Pearson correlation coefficients between land cover percentages and % of samples violating *E. coli* review criterion (p-value). Bold values are significant at $p<0.05$.

Land Cover	% *E. coli* Violations
% Impervious Surfaces	**0.69 (0.0007)**
% Forest	**-0.60 (0.0054)**
% Pasture	-0.33 (0.1863)

Table 20. Ratio of *E. coli* to fecal coliform concentrations by watershed. Values in bold are > 0.144 (review criterion EC/FC ratio) indicating that the *E. coli* criterion could potentially be exceeded while meeting the current fecal coliform criterion.

ID	Land Use	Median	Std Error	Min	Max
BLN	**Mixed**	0.11	0.03	0.00	0.59
BR	**Urban**	**0.20**	0.06	0.08	0.78
BU1	**Urban**	0.12	0.05	0.04	1.00
BU2	**Urban**	**0.16**	0.02	0.02	0.37
CB	**Pine**	**0.17**	0.03	0.00	0.52
FR	**Urban**	**0.16**	0.05	0.02	0.47
FS2	**Pastoral**	0.11	0.04	0.00	0.69
FS3	**Pastoral**	0.12	0.06	0.00	1.00
HC	**Pine**	**0.25**	0.05	0.00	1.00
HC2	**Pastoral**	**0.21**	0.04	0.00	0.84
MU1	**Pastoral**	0.11	0.03	0.00	0.54
MU2	**Pine**	**0.15**	0.04	0.00	0.71
MU3	**Mixed**	**0.21**	0.05	0.00	1.00
RB	**Urban**	**0.19**	0.03	0.03	0.52
SB1	**Developing**	**0.19**	0.04	0.00	0.71
SB2	**Developing**	**0.20**	0.04	0.01	0.69
SB4	**Developing**	**0.19**	0.04	0.02	0.65
SC	**Pine**	0.14	0.06	0.00	1.00

Precipitation Impacts on Water Quality in Different Land Uses

When examining relationships between land cover and water quality parameters, rainfall distributions may explain some of the variability (Figure 20). Monthly rainfall rarely revealed the strongest relationships with water quality parameters. Therefore, it was important to examine precipitation patterns at a finer interval. Previous day rainfall proved to be most strongly related (i.e. the most significant correlations) to water quality parameters and thus, only results using previous day rainfall are discussed. Significant correlations between concentrations and yields of water quality parameters and previous day rainfall were the most numerous in the urban watersheds (Table 21). Urban watersheds are the most sensitive to rainfall because of low infiltration and high velocity inputs from pipes directly connected to streams. As expected, most concentrations declined as previous day rainfall increased (Table 21). Total dissolved solids, Cl^-, and Na^+ concentrations exhibited dilution effects in all land uses (Table 21). Sulfate concentrations were negatively correlated in the urban watersheds, but positively correlated in the pastoral and pine forested watersheds (Table 21).

Relationships between NO_3^- concentrations and rainfall were significant and positive in forested watersheds (Table 21), perhaps from N mineralization stimulation or leaky septic tanks. Urban watersheds had the only significant relationship (positive) between NH_4^+ concentrations and rainfall (Table 21). The increase in NH_4^+ in urban watersheds as rainfall increased was likely the result of leaky sewer systems, outflow from the combined sewer overflow system, and NH_4^+-based fertilizer runoff from residential lawns. Urban and developing watersheds had significant positive relationships between rainfall and DOC concentrations, also likely a result of leaky sewer systems (Table 21). Fecal coliform concentration relationships with rainfall were also positive for all land uses (Table 21). Total suspended solid concentration correlations with rainfall were positive in all land uses and surprisingly, mixed watersheds had the strongest correlations (Table 21). Total suspended solid concentrations exhibited a 0.58 correlation with previous day rainfall in mixed watersheds, the strongest of all watersheds (Table 21). Much of the suspended sediments in mixed forested watersheds are likely derived in-stream. The relationship may be a result of increased rainfall re-suspending in-stream sediment.

All significant yield relationships between water quality and rainfall were positive (Table 21), implying that concentrations did not decline in proportion to flow. Ammonium yield and rainfall correlations were stronger in urban watersheds than in other land uses (Table 21). The spike in NH_4^+ yields in the urban watersheds was likely a terrestrial source and related to sewer systems and fertilizer runoff, as previously mentioned.

I hypothesized that the influence of rainfall on water quality parameters would behave differently with land use. Specifically, rainfall would have the strongest correlations with water quality parameters in urban watersheds followed by developing, pastoral, pine forest, and mixed forest watersheds. Urban watersheds did have the most and generally strongest correlations between water quality variables and rainfall compared with other land uses as a result of increased quickflow over impervious surfaces. Also, NH_4^+ concentrations and yields only had positive relationships with rainfall in urban watersheds. However, developing, pastoral, and forested watersheds did not differ much in the number and type of correlations.

Table 21. Spearman correlation coefficients between water quality parameters and previous day rainfall. Bold values are significant at $p<0.05$.

Variable	**Urban**	**Developing**	**Pastoral**	**Pine Forest**	**Mixed Forest**
Concentrations (mg/L)					
TDS	**-0.575**	**-0.458**	-0.075	**-0.153**	-0.192
TSS	**0.469**	**0.539**	**0.294**	**0.354**	**0.584**
Cl	**-0.507**	**-0.418**	**-0.194**	**-0.186**	**-0.226**
NO_3	-0.024	-0.002	-0.049	0.121	**0.228**
SO_4	**-0.235**	0.106	**0.259**	**0.260**	0.202
Na	**-0.474**	**-0.496**	-0.132	**-0.190**	**-0.217**
NH_4	**0.212**	0.078	0.080	0.027	0.085
K	**-0.265**	-0.126	0.045	-0.121	-0.092
P	-0.089	0.007	-0.082	-0.101	-0.156
DOC	**0.248**	**0.312**	0.067	0.112	0.122
Fecal Coliforms (MPN/100mL)	**0.317**	**0.455**	**0.336**	**0.342**	**0.313**
Yields (g/d/ha)					
TDS	**0.539**	**0.502**	**0.322**	**0.405**	**0.418**
TSS	**0.553**	**0.562**	**0.332**	**0.473**	**0.577**
Cl	**0.493**	**0.477**	**0.289**	**0.377**	**0.435**
NO_3	**0.496**	**0.496**	**0.166**	**0.346**	**0.472**
SO_4	**0.513**	**0.459**	**0.313**	**0.431**	**0.444**
Na	**0.545**	**0.502**	**0.358**	**0.351**	**0.391**
NH_4	**0.413**	0.130	0.146	0.126	0.099
K	**0.609**	**0.542**	**0.420**	**0.427**	**0.483**
P	**0.186**	**0.297**	**0.196**	0.121	0.045
DOC	**0.593**	**0.512**	**0.286**	**0.384**	**0.365**

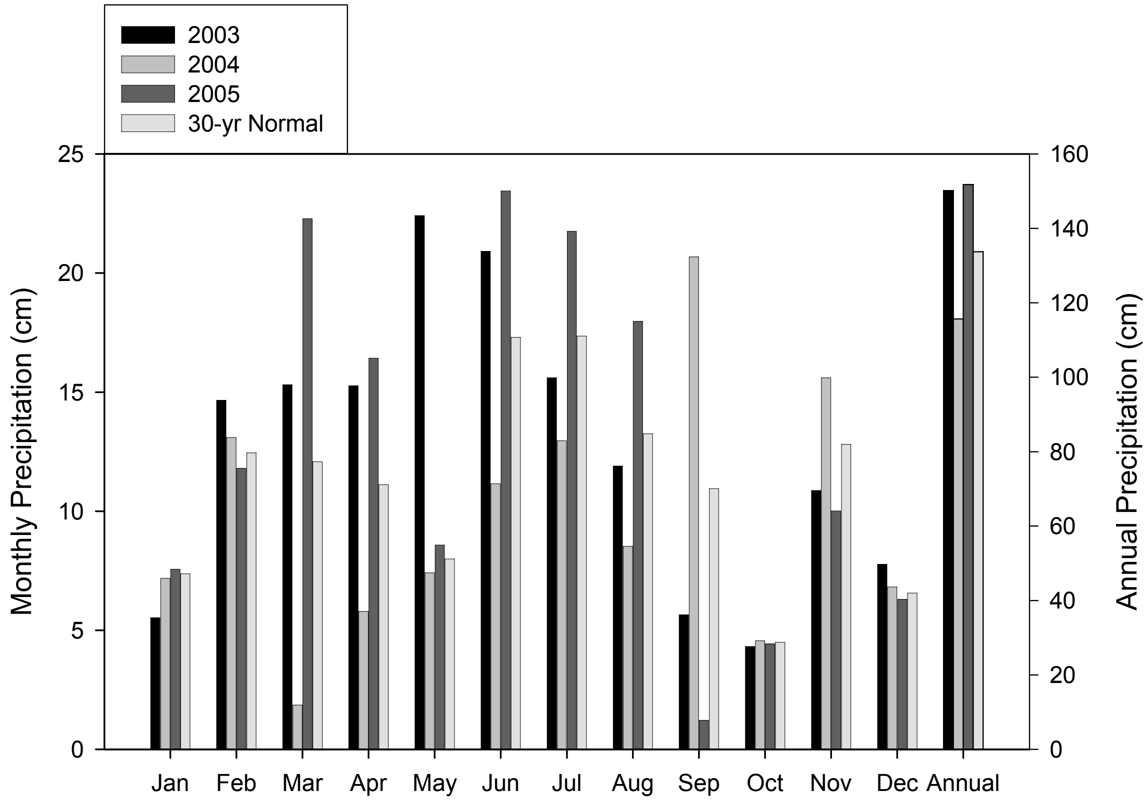

Figure 20. Monthly precipitation distribution.

Seasonal Trends between Water Quality and Land Use

Total dissolved solids, TSS, and K^+ concentrations revealed strongest relationships with % impervious surface (positive) and forest cover (negative) during the spring (Table 22). Chloride and Na^+ concentration relationships with land cover percentages were similar across seasons (Table 22). Nitrate concentrations had the strongest relationships with % impervious surface (positive), forest cover (negative), and pasture (positive) in the fall and winter (Table 22). Concentrations of SO_4^- revealed strong negative correlations with % pasture, with the highest in the fall (Table 22). Sulfate concentrations had the highest relationship with % impervious surface (positive) in the spring (Table 22). Ammonium concentrations displayed the strongest relationships in spring and summer with % impervious surface (positive) and % forest cover (negative) (Table 22). Concentrations of P had only one significant relationship, positive with % pasture in the summer (Table 22). Dissolved organic carbon concentrations had similar relationships with land cover among seasons, but was strongest with % impervious surface (positive) (Table 22). Fecal coliform concentrations were significant most often with all land uses in the winter and spring, with the strongest relationship occurring with % impervious surface in the winter (Table 22).

Examinations of yield relationships reveal that most correlations were highest in the winter and spring, especially in regard to % impervious surface (Table 22). Total dissolved solids and Cl^- yields were strongest in the winter, positive with % impervious surface and negative with % forest cover (Table 22). Total suspended solid yields were only significant with % impervious surface (positive) and forest cover (negative) in the spring (Table 22). Total suspended solid yields had a significant positive relationship with % pasture in the fall and winter (Table 22). Nitrate yields were only significant with % impervious surfaces in the spring (Table 22). Forest cover had a significant negative correlation with NO_3^- yields in all seasons, but was strongest in the winter (Table 22). Percent pasture revealed positive relationships with NO_3^- yields in the fall, winter, and summer (Table 22). Sulfate yields were significant (positive) with impervious surface in the winter and spring and negative with % pasture in the fall, winter, and summer (Table 22). Sodium yields were strongest with % impervious surface in the winter and spring (Table 22). Ammonium yields had the strongest relationships (negative) with % forest cover, significant in the spring, winter, and summer; positive relationships existed with impervious surface in the spring and summer (Table 22). Amount of forest cover exhibited the most relationships with K^+ yields, negative in the winter, spring, and summer (Table 22). Percent pasture had a positive correlation with K^+ yields in the fall (Table 22). Phosphorus yields were only significant in the fall and summer, both with % pastoral cover (Table 22). Dissolved organic carbon yields revealed a significant positive relationship with % impervious surface in the winter, spring, and summer (Table 22).

Few overall trends are seen from these data, though water quality relationships with % impervious surface were strongest during spring. Additional analyses are needed to draw conclusions about seasonal trends in water quality in relation to land use.

Table 22. Seasonal Spearman correlations between water quality variables and land use percentages. Bold values are significant at $p<0.05$. IS=% Impervious Surfaces, For=% Forest Cover, Ag=% Pasture.

		Fall			**Winter**			**Spring**			**Summer**	
Variable	**IS**	**For**	**Ag**	**IS**	**For**	**Ag**	**IS**	**For**	**Ag**	**IS**	**For**	**Ag**
Concentrations (mg/L)												
TDS	**0.67**	**-0.48**	**-0.41**	**0.72**	**-0.51**	**-0.57**	**0.80**	**-0.59**	**-0.46**	**0.68**	**-0.44**	**-0.42**
TSS	0.02	-0.28	0.17	0.14	**-0.33**	0.03	**0.42**	**-0.46**	0.09	-0.11	-0.08	0.24
Cl	**0.84**	**-0.85**	-0.17	**0.86**	**-0.84**	-0.25	**0.84**	**-0.88**	-0.19	**0.82**	**-0.89**	-0.16
NO_3	**0.33**	**-0.68**	**0.35**	**0.32**	**-0.69**	**0.30**	0.30	**-0.65**	0.16	0.22	**-0.57**	0.24
SO_4	0.27	-0.12	**-0.85**	**0.48**	-0.24	**-0.75**	**0.57**	**-0.36**	**-0.68**	**0.34**	-0.21	**-0.71**
Na	**0.59**	-0.28	**-0.41**	**0.57**	-0.25	**-0.36**	**0.61**	-0.30	-0.30	**0.46**	-0.14	-0.28
NH_4	0.04	-0.20	0.05	-0.03	**-0.35**	0.17	**0.38**	**-0.54**	-0.09	**0.44**	**-0.57**	0.13
K	**0.55**	**-0.60**	**-0.33**	**0.64**	**-0.73**	-0.22	**0.55**	**-0.74**	-0.23	**0.37**	**-0.46**	-0.27
P	0.11	-0.13	-0.04	0.23	-0.16	-0.02	0.18	0.01	0.19	0.07	-0.16	**0.37**
DOC	**0.46**	-0.23	**-0.36**	**0.57**	-0.27	-0.24	**0.59**	-0.28	-0.25	**0.60**	-0.29	**-0.39**
Fecal Coliforms (MPN/100mL)	**0.40**	-0.28	**-0.49**	**0.56**	**-0.38**	**-0.33**	**0.48**	**-0.35**	**-0.52**	**0.34**	**-0.44**	-0.28
Yields (g/d/ha)												
TDS	0.14	-0.29	0.23	**0.64**	**-0.52**	-0.18	**0.43**	**-0.37**	-0.11	**0.34**	**-0.34**	-0.10
TSS	-0.28	-0.12	**0.46**	-0.02	-0.22	**0.33**	**0.31**	**-0.35**	0.08	-0.12	-0.06	0.20
Cl	0.26	**-0.56**	**0.31**	**0.78**	**-0.88**	0.06	**0.48**	**-0.50**	-0.05	**0.34**	**-0.47**	0.05
NO_3	0.17	**-0.53**	**0.36**	0.24	**-0.66**	**0.36**	**0.31**	**-0.58**	0.12	0.10	**-0.42**	0.27
SO_4	0.22	**-0.38**	**-0.48**	**0.48**	-0.23	**-0.63**	**0.37**	-0.27	-0.29	0.21	-0.23	**-0.40**
Na	0.01	-0.10	0.25	**0.45**	-0.15	-0.13	**0.42**	-0.29	-0.04	**0.41**	**-0.34**	-0.06
NH_4	0.01	-0.18	0.10	-0.02	**-0.34**	0.24	**0.38**	**-0.52**	-0.10	**0.45**	**-0.56**	0.08
K	-0.21	-0.17	**0.47**	0.22	**-0.48**	0.18	0.28	**-0.36**	0.04	0.19	**-0.40**	0.11
P	-0.21	-0.08	**0.30**	0.03	-0.10	0.28	0.00	0.05	0.25	-0.03	-0.23	**0.39**
DOC	0.08	-0.14	0.12	**0.43**	-0.26	-0.04	**0.45**	-0.29	-0.09	**0.45**	**-0.35**	-0.27

CONCLUSIONS

Forests are critical to the proper function of watersheds. The amount of forest in a watershed is an important determinant of water quality and, thus, plays a major role in the stability of aquatic ecosystems. Hydrologically, urban and developing watersheds exhibited greater flashiness than other watersheds, with high peak flows corresponding to rainfall events. Forested watersheds exhibited a stable hydrologic regime and displayed seasonal patterns with higher discharges in the winter and spring from increased infiltration and reduced evaporation. Pastoral watersheds also displayed a stable hydrograph likely resulting from high and consistent groundwater inputs.

Urban and developing watersheds displayed the greatest instability in terms of water chemistry, as evidenced by greater fluctuations in water quality parameters across years. Developing watersheds had the greatest median fluctuations across years for TDS, TSS, Cl^-, Na^+, K^+, DOC, and P. These watersheds were undergoing active construction activity which may have stimulated variability. Urban watersheds had the highest median ranges concerning NO_3^-, SO_4^-, NH_4^+, and fecal coliforms. Large fluctuations of these constituents were likely from sewage effluent associated with large hydrologic variability.

In examining the median ranges of water quality parameters for individual watersheds with respect to % forest cover, the median variability of concentrations of fecal coliforms and yields of TDS, Cl^-, NO_3^-, SO_4^-, Na^+, and K^+ across years declined significantly as forest cover increased. In general, watersheds with greater amounts of forest cover had less variability in medians across years. The amount of forest cover within a watershed may contribute to the stability of many nutrients, sediment, and bacteria within flowing waters.

Although the effect of the dominant land use cannot truly be isolated from influences of other land uses, categorical analyses did suggest some general trends. Urban watersheds had elevated concentrations of many nutrients and fecal coliforms compared to other land uses. Ammonium concentrations were much higher in urban watersheds than all other land uses combined. Increased NH_4^+ and fecal coliform inputs were likely attributable to storm drainage problems. Pastoral watersheds had the highest concentrations and yields of NO_3^-, P, and TSS. Fertilizer and cattle wading in streams were likely causes. Land uses displaying the most variability in median ranges (i.e. urban and developing) also exhibited higher concentrations and yields. Nitrate was the exception with concentrations being highest in pastoral watersheds, but more variable across years in urban watersheds.

Concentrations and yields of water quality variables were positively correlated with % impervious surface and negatively correlated with % forest. Water quality variables revealed both positive and negative relationships with % pasture. Examining these relationships broken into different flow regimes (i.e. baseflow and stormflow) instead of combined flows allowed greater insight into potential sources of increased nutrients or sediment. For example, the relationship between impervious surface and NH_4^+ concentrations and yields was insignificant during baseflow, but was significantly positive during stormflow, suggesting problems with leaky sewer systems or fertilizer runoff in urbanized watersheds. Also, the positive correlations revealed between %

pasture and TSS and P yields during combined flows, were only seen during baseflow, suggesting high baseflow contributions to pastoral streams.

Even a small increase (0-4% impervious surfaces) in impervious surface was found to impact water quality concentrations. Relationships between impervious surface and many water quality concentrations, notably TDS, Cl^-, SO_4^-, Na^+, K^+, P, and fecal coliforms, revealed a curvilinear trend with an initial increase in concentration at low impervious surfaces followed by a gradual increase at higher impervious surfaces. Surprisingly, the impervious surface threshold was likely around 3-5% impervious surface, much lower than the generally accepted threshold of 10%. Additionally, concentrations of TDS, Cl^-, Na^+, P, and DOC significantly increased as impervious surface increased from 0-4%. Therefore, even a small amount of urban influence may have water quality consequences.

The linear relationship between yields of TSS and P was stronger in the urban and developing watersheds than other land uses. This may be a result of higher TSS yields within those streams. Phosphorus may be transported bound to sediment in urban and developing streams to a greater extent because of greater sediment fluxes into these streams. Although pastoral watersheds had overall higher median TSS and P yields, these watersheds did not exhibit high volume inputs. Furthermore, the % of samples exceeding the USEPA P recommendation declined with increasing forest cover. Therefore, forest cover within a watershed may also be critical to maintaining lower concentrations than the maximum contaminant level recommendation for P.

Urban watersheds consistently exceeded the USEPA review criterion for fecal coliforms. Fecal coliforms exhibited a strong positive relationship with impervious surfaces and a negative relationship with forest cover. Urban watersheds also had the highest concentrations and the most violations of the *E. coli* review criterion. The % of *E. coli* violations within each watershed was positively correlated with the amount of impervious surface in the watershed and negatively related to % forest cover. The land use in a watershed may impact the number of sampling days that exceed the *E. coli* review criterion. While many of the streams met the review criterion for fecal coliform for a given sampling date, the *E. coli* criterion was often not met, suggesting that regulatory agencies may need to reevaluate the methods used for illness indicators.

Precipitation effects on water quality differed by land uses. Water quality parameters in urban watersheds had the greatest correlations with rainfall, likely due to increased quickflow over impervious areas. Most of the relationships were evident when examining precipitation patterns at fine intervals before the sampling date, i.e. previous day rainfall. Wet weather events were responsible for the dilution or addition of many nutrient, sediment, and bacteria concentrations, especially within urban watersheds, and play a large role in the surface water chemistry within a watershed.

Because many watersheds contained a mosaic of land uses, it was difficult to pinpoint the influences on water quality of any one land use. As my results indicated, the amount and type of land use within a watershed play a vital role in protecting or degrading water quality within a watershed. Elevated nutrients in urban streams may reflect increased inputs and reduced removal rates. The amount of forest cover within a watershed is not only critical for filtering nutrients and sediment, but also for enhancing biotic uptake capacity by supplying organic matter (Meyer *et al.* 2005). Sound land management strategies protect the abiotic and biotic integrity of aquatic ecosystems and also reduce the cost of drinking water purification. This study revealed the important role forest cover plays in enhancing the quality of stream ecosystems in the Georgia Piedmont.

REFERENCES

Alexander, Richard B., Elizabeth W. Boyer, Richard A. Smith, Gregory E. Schwarz, and Richard B. Moore. 2007. The role of headwater streams in downstream water quality. Journal of the American Water Resources Association **43**:41-59.

Alig, Ralph J., Jeffrey D. Kline, and Mark Lichtenstein. 2004. Urbanization on the US landscape: looking ahead in the 21st century. Landscape And Urban Planning **69**:219.

American Public Health Association, American Water Works Association, and Water Environment Federation. 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. Eds. Lenore S. Clesceri, Arnold E. Greenberg, and Andrew D. Eaton. APHA, Washingtion, DC.

Arnold Jr., C. L., and C. J. Gibbons. 1996. Impervious surface coverage. Journal of the American Planning Association **62**:243-258.

Barber, L. B., S. F. Murphy, P. L. Verplanck, M. W. Sandstrom, H. E. Taylor, and E. T. Furlong. 2006. Chemical Loading into Surface Water along a Hydrological, Biogeochemical, and Land Use Gradient: A Holistic Watershed Approach. Environ. Sci. Technol. **40**:475-486.

Basnyat, P., L. Teeter, B. G. Lockaby, and K. Flynn. 2000. Land use characteristics and water quality: a methodology for valuing forested buffers. Environmental Management **26**:153-161.

Bledsoe, B. P., and C. C. Watson. 2001. Effects of urbanization on channel instability. Journal of the American Water Resources Association **37**:255-270.

Booth, D. B., J. R. Karr, S. Schauman, C. P. Konrad, S. A. Morley, M. G. Larson, and S. J. Burger. 2004. Reviving urban streams: Land use, hydrology, biology, and human behavior. Journal of the American Water Resources Association **40**:1351-1364.

Burton, G. A., D. Gunnison, and G. R. Lanza. 1987. Survival of pathogenic bacteria in various freshwater sediments. Applied and Environmental Microbiology **53**:633-638.

Calhoun, D. L., E. A. Frick, and G. R. Buell. 2001. Effects of urban development on nutrient loads and streamflow, Upper Chattahoochee River basin, Georgia, 1976-2001. Pages 39-42 *in* Kathryn J. Hatcher, editor. Proceedings of the 2001 Georgia Water Resources Conference. Institute of Ecology, The University of Georgia, Athens, Georgia, University of Georgia.

Callender, E., and K. C. Rice. 2000. The urban environmental gradient: anthropogenic influences on the spatial and temporal distributions of lead and zinc in sediments. Environmental Science & Technology **34**:232-238.

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications **8**:559-568.

Clinton, B. D., and J. M. Vose. 2006. Variation in stream water quality in an urban headwater stream in the southern Appalachians. Water, Air, and Soil Pollution **169**:331-353.

Cody, R. P., and J. K. Smith. 2006. Applied statistics and the SAS programming language. Fifth Edition. Pearson Prentice Hall, New Jersey.

Coles, J. F., T. F. Cuffney, G. McMahon, and K. M. Beaulieu. 2004. The effects of urbanization on the biological, physical, and chemical characteristics of coastal New England streams. U.S. Geological Survey Professional Paper 1695.

Cronan, C. S., J. T. Piampiano, and H. H. Patterson. 1999. Influence of land use and hydrology on exports of carbon and nitrogen in a Maine river basin. Journal of Environmental Quality **28**:953-961.

Davies, C. M., J. A. Long, M. Donald, and N. J. Ashbolt. 1995. Survival of fecal microorganisms in marine and freshwater sediments. Appl. Environ. Microbiol. **61**:1888-1896.

Dufour, A. P., and V. J. Cabelli. 1984. Health effects criteria for fresh recreational waters: Cincinnati, Ohio, USEPA, EPA **600/1-84-004**.

Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. New York: Freeman. 818pp.

Emmerth, P. P., and D. R. Bayne. 1996. Urban influence on phosphorus and sediment loading of West Point Lake, Georgia. Water Resources Bulletin **32**:145-154.

Evans, C. D., D. T. Monteith, and D. M. Cooper. 2005. Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts. Environmental Pollution **137**:55.

Finkenbine, J. K., J. W. Atwater, and D. S. Mavinic. 2000. Stream health after urbanization. Journal of the American Water Resources Association **36**:1149-1160.

Francy, D. S., D. N. Myers, and K. D. Metzker. 1993. *Escherichia coli* and fecal coliform bacteria as indicators of recreational water quality. USGS Water Resources Investigations Report **93-4083**.

Franklin, D. H., J. L. Steiner, M. L. Cabrera, and E. L. Usery. 2002. Distribution of inorganic nitrogen and phosphorous concentrations in stream flow of two southern piedmont watersheds. Journal of Environmental Quality **31**:1910-1917.

Freeman, Mary C., Catherine M. Pringle, and C. Rhett Jackson. 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales. Journal of the American Water Resources Association **43**:5-14.

Frick, E. A., Buell, G. R. and Hopkins, E. H. 1996. Nutrient sources and analysis of nutrient water-quality data, Apalachicola-Chattahoochee-Flint River Basin, Georgia, Alabama, and Florida, 1972-90. U.S. Geological Survey Water-Resources Investigations Report 96-4101.

Frick, E. A., A. K. Henderson, D. M. Moll, E. T. Furlong, and M. T. Meyer. 2001. Presence of pharmaceuticals in wastewater effluent and drinking water, metropolitan Atlanta, Georgia, July-September 1999. Pages 28 *in* Kathryn J. Hatcher, editor. Proceedings of the 2001 Georgia Water Resources Conference. Institute of Ecology, The University of Georgia, Athens, Georgia, University of Georgia.

Frick, E.A., Hippe, D.J., Buell, G.R., Couch, C.A., Hopkins, E.H., Wangsness, D.J., and Garrett, J.W. 1998. Water Quality in the Apalachicola-Chattahoochee-Flint River Basin, Georgia, Alabama, and Florida, 1992-1995. U.S. Geological Survey Circular 1164.

Fulton, W., R. Pendall, M. Nguyen, and A. Harrison. 2001. Who sprawls most? How growth patterns differ across the U.S. The Brookings Institution Survey Series, July 2001. Center on Urban & Metropolitan Policy, The Brookings Institution, Washington, DC.

GAEPD, DNR. 2002. Water quality in Georgia, 2000-2001. http://www.gaepd.org/Files_PDF/gaenviron/water_quality/305b00_rpt.pdf.

Gore, J. A. 1996. Discharge measurements and streamflow analysis. Pages 53-74 *in* F.R. Haur and G.A. Lamberti, editor. Methods in stream ecology. Academic Press, San Diego, CA.

Gregory, M. B., and E. A. Frick. 2001. Summary of fecal coliform bacteria concentrations in streams of the Chattahoochee River National Recreation Area, Metropolitan Atlanta, Georgia, May-October 1994 and 1995. Pages 83-86 *in* Kathryn J. Hatcher, editor. Proceedings of the 2001 Georgia Water Resources Conference. Institute of Ecology, The University of Georgia, Athens, Georgia, University of Georgia.

Helsel, D. R., and R. M. Hirsch. 2002. Statistical Methods in Water Resources. Techniques of Water Resources Investigations, Book 4, Chapter A3. U.S. Geological Survey. 522 pages.

Hope, D., M. F. Billett, and M. S. Cresser. 1994. A review of the export of carbon in river water: Fluxes and processes. Environmental Pollution **84**:301.

Landers, M. N., P. D. Ankcorn, K. W. McFadden, and M. B. Gregory. 2002. Does land use affect our streams? A watershed example from Gwinnett County, Georgia, 1998-2001. *in*. U.S. Geological Survey. Water-Resources Investigations Report 02-4281.

Lenat, D. R., and J. K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia **294**:185-199.

Lipp, E. K., R. Kurz, R. Vincent, C. Rodriguez-Palacios, S. R. Farrah, and J. B. Rose. 2001. The effects of seasonal variability and weather on microbial fecal pollution and enteric pathogens in a subtropical estuary. Estuaries **24**:266-276.

Lockaby, B. G., K. McNabb, and J. Hairston. 1993. Changes in groundwater nitrate levels along an agroforestry drainage continuum. In: Proceedings, Conference on Riparian Ecosystems in the Humid US: Functions, Values and Management. Atlanta, Georgia, pp. 412-417.

Lockaby, B. G., D. Zhang, J. McDaniel, H. Tian, and S. Pan. 2005. Interdisciplinary research at the Urban-Rural interface: The Westga project. Urban Ecosystems **8**:7-21.

Madison, R. J., and J. O. Brunett. 1985. Overview of the occurrence on nitrate in ground water in the United States, *in* National Water Summary 1984, hydrologic events, selected water-quality trends and ground-water resources: U.S. Geological Survey Water Supply Paper 2275.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society **24**:602-612.

Meyer, Judy L., David L. Strayer, J. Bruce Wallace, Sue L. Eggert, Gene S. Helfman, and Norman E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association **43**:86-103.

Moore, T.R. 2003. Dissolved organic carbon in a northern boreal landscape. Global Biogeochemical Cycles **17**:1109.

Murphy, J., and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytical Chemistry **27**:31-36.

Nadeau, Tracie-Lynn, and Mark Cable Rains. 2007. Hydrological connectivity between headwater streams and downstream waters: how science can inform policy. Journal of the American Water Resources Association **43**:118-133.

NARSAL. 2007. http://narsal.ecology.uga.edu/gap/georgia.html.

NRCS. 2007. http://www.nrcs.usda.gov/TECHNICAL/land/urban.html.

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics **32**:333-365.

Peterson, B. J., W. M. Wollheim, P. J. Mulholland, J. R. Webster, J. L. Meyer, J. L. Tank, E. Marti, W. B. Bowden, H. M. Valett, A. E. Hershey, W. H. McDowell, W. K. Dodds, S. K. Hamilton, S. Gregory, and D. D. Morrall. 2001. Control of nitrogen export from watersheds by headwater streams. Science **292**:86-90.

Pozo, J., E. Gonzalez, J. R. Diez, J. Molinero, and A. Elosegui. 1997. Inputs of particulate organic matter to streams with different riparian vegetation. Journal of the North American Benthological Society **16**:602-611.

Prüss, Annette. 1998. Review of epidemiological studies on health effects from exposure to recreational water. Int. J. Epidemiol. **27**:1-9.

Rasmussen, P. P., and A. C. Ziegler. 2003. Comparison and continuous estimates of fecal coliform and *escherichia coli* bacteria in selected Kansas streams, May 1999 through April 2002. Water-Resources Investigations Report **03-4056**.

Rose, S. 2002. Comparative major ion geochemistry of Piedmont streams in the Atlanta, Georgia region: possible effects of urbanization. Environmental Geology **42**:102-113.

Rose, Seth. 2007. The effects of urbanization on the hydrochemistry of base flow within the Chattahoochee River Basin (Georgia, USA). Journal of Hydrology **341**:42.

Rosi-Marshall, E. J. 2004. Decline in the quality of suspended fine particulate matter as a food resource for chironomids downstream of an urban area. Freshwater Biology **49**:515-525.

SAS Institute. 1999. SAS Version 9.1 for Windows. Cary, North Carolina.

Schiff, Roy, and Gaboury Benoit. 2007. Effects of Impervious Cover at Multiple Spatial Scales on Coastal Watershed Streams. Journal of the American Water Resources Association **43**:712-730.

Schoonover, J. E. 2005. Hydrology, water quality, and channel morphology across an urban-rural land use gradient in the Georgia Piedmont, USA. Auburn University, Auburn, Alabama.

Schoonover, J. E., and B. G. Lockaby. 2006. Land cover impacts on stream nutrients and fecal coliform in the lower Piedmont of West Georgia. Journal of Hydrology **331**:371-382.

Schoonover, J. E., B. G. Lockaby, and B. S. Helms. 2006. Impacts of land cover on stream hydrology in the west Georgia piedmont, USA. Journal of Environmental Quality **35**:2123-2131.

Shah, V. G., R. H. Dunstan, P. M. Geary, P. Coombes, T. K. Roberts, and T. Rothkirch. 2007. Comparisons of water quality parameters from diverse catchments during dry periods and following rain events. Water Research **In Press, Corrected Proof**.

Shrestha, S., and F. Kazama. 2007. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling & Software **22**:464.

Tong, S. T. Y., and W. Chen. 2002. Modeling the relationship between land use and surface water quality. Journal of Environmental Management **66**:377.

Trimble, S. W. 1974. Man-induced soil erosion on the Southern Piedmont: 1700-1970. Soil and Water Conservation Society of America. Ankeny, IA.

United States Census Bureau. 2007. http://quickfacts.census.gov/qfd/states/00000.html.

USEPA. 1986a. Ambient Water Quality Criteria for Bacteria - 1986. **EPA440/5-84-002**.

USEPA. 1986b. Quality criteria for water 1986. **EPA440/5-86-001**.

USEPA. 1995. Drinking water regulations and health advisories: Washington, D.C., U.S. Environmental Protection Agency, Office of Water.

USEPA. 1999. Standard operating procedure for the analysis of residue, non-filterable (suspended solids) water. Method 160.2NS. United States Environmental Protection Agency Region 5 Central Regional Laboratory. Chicago, IL.

USEPA. 2000. The quality of our nation's waters. **EPA 841-S-00-001**.

USEPA. 2002. Implementation Guidance for Ambient Water Quality Criteria for Bacteria. Draft **EPA-823-B-02-003**.

Walsh, C. J., T. D. Fletcher, and A. R. Ladson. 2005. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society **24**:690-705.

Wantanabe, F. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Science Society of America Journal **29**:677-678.

Zampella, R. A. 1994. Characterization of surface water quality along a watershed disturbance gradient. Water Resources Bulletin **30**:605-611.

APPENDICES

Appendix A. Urban watersheds: water quality variable correlations with rainfall. Bold values are significant at $p<0.05$.

Variable	**monthly rainfall**	**sample day rainfall**	**previous day rainfall**	**previous day plus sample day rainfall**	**previous 5 day rainfall**	**previous 5 day plus sample day rainfall**
Concentrations (mg/L)						
TDS	**-0.370**	**-0.177**	**-0.575**	**-0.447**	**-0.660**	**-0.629**
TSS	**0.209**	**0.219**	**0.469**	**0.407**	**0.304**	**0.302**
Cl	**-0.281**	-0.133	**-0.507**	**-0.418**	**-0.450**	**-0.428**
NO_3	0.152	-0.003	-0.024	-0.116	0.135	0.098
SO_4	0.008	-0.135	**-0.235**	**-0.240**	-0.112	-0.122
Na	**-0.335**	**-0.149**	**-0.474**	**-0.374**	**-0.494**	**-0.455**
NH_4	**0.194**	0.053	**0.212**	0.144	**0.252**	**0.211**
K	**-0.226**	-0.152	**-0.265**	**-0.216**	**-0.323**	**-0.302**
P	-0.014	0.013	-0.089	-0.031	-0.154	-0.097
DOC	**0.315**	**0.249**	**0.248**	**0.285**	-0.007	0.048
Fecal Coliforms	**0.209**	**0.333**	**0.317**	**0.364**	**0.160**	**0.225**
Yields (g/d/ha)						
TDS	**0.347**	**0.243**	**0.539**	**0.441**	**0.573**	**0.579**
TSS	**0.311**	**0.244**	**0.553**	**0.467**	**0.496**	**0.501**
Cl	**0.327**	**0.227**	**0.493**	**0.395**	**0.560**	**0.564**
NO_3	**0.368**	**0.228**	**0.496**	**0.382**	**0.588**	**0.574**
SO_4	**0.378**	**0.218**	**0.513**	**0.407**	**0.583**	**0.579**
Na	**0.322**	**0.256**	**0.545**	**0.444**	**0.592**	**0.607**
NH_4	**0.356**	**0.183**	**0.413**	**0.322**	**0.440**	**0.409**
K	**0.385**	**0.274**	**0.609**	**0.500**	**0.642**	**0.659**
P	0.161	0.098	**0.186**	0.155	**0.169**	**0.221**
DOC	**0.433**	**0.292**	**0.593**	**0.507**	**0.532**	**0.551**

Appendix B. Developing watersheds: water quality variable correlations with rainfall. Bold values are significant at $p<0.05$.

Variable	**monthly rainfall**	**sample day rainfall**	**previous day rainfall**	**previous day plus sample day rainfall**	**previous 5 day rainfall**	**previous 5 day plus sample day rainfall**
Concentrations (mg/L)						
TDS	**-0.407**	-0.163	**-0.458**	**-0.342**	**-0.556**	**-0.526**
TSS	**0.374**	**0.322**	**0.539**	**0.511**	**0.434**	**0.499**
Cl	**-0.373**	-0.163	**-0.418**	**-0.371**	**-0.337**	**-0.320**
NO_3	0.034	-0.041	-0.002	-0.018	0.026	-0.002
SO_4	0.176	-0.039	0.106	0.015	**0.249**	**0.219**
Na	**-0.421**	-0.189	**-0.496**	**-0.403**	**-0.478**	**-0.465**
NH_4	0.087	0.053	0.078	0.048	**0.257**	**0.244**
K	-0.201	-0.025	-0.126	-0.075	-0.193	-0.151
P	-0.016	0.150	0.007	0.077	-0.041	0.031
DOC	**0.364**	0.157	**0.312**	**0.283**	**0.215**	**0.255**
Fecal Coliforms	**0.269**	**0.351**	**0.455**	**0.542**	**0.295**	**0.393**
Yields (g/d/ha)						
TDS	**0.373**	**0.238**	**0.502**	**0.426**	**0.542**	**0.568**
TSS	**0.410**	**0.284**	**0.562**	**0.504**	**0.557**	**0.605**
Cl	**0.331**	**0.208**	**0.477**	**0.385**	**0.553**	**0.570**
NO_3	**0.376**	**0.212**	**0.496**	**0.411**	**0.529**	**0.535**
SO_4	**0.367**	0.184	**0.459**	**0.363**	**0.548**	**0.551**
Na	**0.350**	**0.220**	**0.502**	**0.409**	**0.571**	**0.594**
NH_4	0.134	0.096	0.130	0.094	**0.296**	**0.287**
K	**0.384**	**0.237**	**0.542**	**0.454**	**0.581**	**0.615**
P	**0.231**	**0.284**	**0.297**	**0.286**	**0.266**	**0.326**
DOC	**0.432**	**0.227**	**0.512**	**0.428**	**0.533**	**0.559**

Appendix C. Pastoral watersheds: water quality variable correlations with rainfall. Bold values are significant at $p<0.05$.

Variable	**monthly rainfall**	**sample day rainfall**	**previous day rainfall**	**previous day plus sample day rainfall**	**previous 5 day rainfall**	**previous 5 day plus sample day rainfall**
Concentrations (mg/L)						
TDS	0.002	0.033	-0.075	-0.037	-0.130	-0.108
TSS	0.150	**0.285**	**0.294**	**0.326**	0.129	**0.204**
Cl	-0.071	-0.043	**-0.194**	**-0.160**	-0.065	-0.057
NO_3	-0.011	-0.064	-0.049	-0.086	0.043	0.001
SO_4	**0.284**	0.113	**0.259**	**0.241**	**0.356**	**0.377**
Na	-0.056	-0.060	-0.132	-0.143	-0.140	-0.125
NH_4	0.107	0.061	0.080	0.075	0.146	0.128
K	0.067	**0.175**	0.045	0.105	-0.074	0.005
P	0.146	0.048	-0.082	-0.052	-0.094	-0.059
DOC	**0.208**	0.141	0.067	0.090	-0.052	-0.003
Fecal Coliforms	**0.256**	**0.510**	**0.336**	**0.472**	-0.026	0.119
Yields (g/d/ha)						
TDS	**0.223**	**0.207**	**0.322**	**0.327**	**0.316**	**0.367**
TSS	**0.175**	**0.260**	**0.332**	**0.352**	**0.225**	**0.300**
Cl	**0.203**	**0.192**	**0.289**	**0.289**	**0.333**	**0.383**
NO_3	0.055	0.028	**0.166**	0.139	**0.208**	**0.209**
SO_4	**0.223**	0.140	**0.313**	**0.294**	**0.368**	**0.400**
Na	**0.268**	**0.228**	**0.358**	**0.332**	**0.371**	**0.429**
NH_4	0.132	0.117	0.146	0.144	**0.180**	**0.174**
K	**0.310**	**0.309**	**0.420**	**0.423**	**0.365**	**0.450**
P	**0.237**	**0.207**	**0.196**	**0.205**	**0.158**	**0.207**
DOC	**0.286**	**0.213**	**0.286**	**0.292**	**0.224**	**0.289**

Appendix D. Pine forest watersheds: water quality variable correlations with rainfall. Bold values are significant at $p<0.05$.

Variable	monthly rainfall	sample day rainfall	previous day rainfall	previous day plus sample day rainfall	previous 5 day rainfall	previous 5 day plus sample day rainfall
Concentrations (mg/L)						
TDS	-0.125	-0.095	**-0.153**	-0.126	**-0.210**	**-0.203**
TSS	**0.268**	**0.311**	**0.354**	**0.398**	**0.302**	**0.375**
Cl	-0.070	-0.092	**-0.186**	**-0.188**	-0.101	-0.099
NO_3	0.126	0.044	0.121	0.078	**0.177**	**0.165**
SO_4	**0.278**	0.097	**0.260**	**0.186**	**0.342**	**0.336**
Na	**-0.163**	-0.134	**-0.190**	**-0.191**	**-0.164**	**-0.168**
NH_4	0.140	-0.042	0.027	-0.025	0.096	0.054
K	-0.122	0.017	-0.121	-0.060	**-0.165**	-0.120
P	-0.027	0.053	-0.101	-0.008	-0.072	-0.002
DOC	**0.220**	**0.210**	0.112	**0.178**	0.029	0.091
Fecal Coliforms	0.140	**0.446**	**0.342**	**0.483**	0.124	**0.231**
Yields (g/d/ha)						
TDS	**0.302**	**0.277**	**0.405**	**0.396**	**0.405**	**0.458**
TSS	**0.356**	**0.339**	**0.473**	**0.481**	**0.467**	**0.533**
Cl	**0.288**	**0.283**	**0.377**	**0.369**	**0.411**	**0.468**
NO_3	**0.265**	**0.187**	**0.346**	**0.294**	**0.388**	**0.391**
SO_4	**0.347**	**0.239**	**0.431**	**0.364**	**0.473**	**0.497**
Na	**0.239**	**0.233**	**0.351**	**0.325**	**0.398**	**0.442**
NH_4	**0.203**	0.036	0.126	0.072	**0.184**	**0.149**
K	**0.302**	**0.305**	**0.427**	**0.426**	**0.449**	**0.523**
P	0.108	0.141	0.121	**0.172**	0.129	**0.197**
DOC	**0.379**	**0.320**	**0.384**	**0.406**	**0.357**	**0.429**

Appendix E. Mixed forest watersheds: water quality variable correlations with rainfall. Bold values are significant at $p<0.05$.

Variable	**monthly rainfall**	**sample day rainfall**	**previous day rainfall**	**previous day plus sample day rainfall**	**previous 5 day rainfall**	**previous 5 day plus sample day rainfall**
Concentrations (mg/L)						
TDS	-0.159	-0.077	-0.192	-0.163	-0.184	-0.171
TSS	**0.334**	**0.331**	**0.584**	**0.546**	**0.333**	**0.392**
Cl	-0.108	-0.101	**-0.226**	**-0.227**	-0.070	-0.088
NO$_3$	**0.380**	-0.062	**0.228**	0.110	**0.481**	**0.404**
SO$_4$	**0.261**	-0.002	0.202	0.122	**0.358**	**0.339**
Na	-0.158	-0.105	**-0.217**	**-0.210**	**-0.216**	**-0.212**
NH$_4$	0.102	0.092	0.085	0.057	0.128	0.105
K	-0.113	-0.002	-0.092	-0.042	-0.181	-0.135
P	-0.022	-0.028	-0.156	-0.120	-0.133	-0.098
DOC	0.199	0.114	0.122	0.110	0.015	0.051
Fecal Coliforms	0.211	**0.331**	**0.313**	**0.342**	0.108	0.192
Yields (g/d/ha)						
TDS	0.210	0.173	**0.418**	**0.384**	**0.385**	**0.440**
TSS	**0.318**	**0.281**	**0.577**	**0.531**	**0.435**	**0.495**
Cl	**0.237**	**0.216**	**0.435**	**0.396**	**0.442**	**0.495**
NO$_3$	**0.345**	0.100	**0.472**	**0.364**	**0.590**	**0.562**
SO$_4$	**0.289**	0.177	**0.444**	**0.384**	**0.480**	**0.514**
Na	0.185	0.135	**0.391**	**0.332**	**0.383**	**0.427**
NH$_4$	0.112	0.101	0.099	0.070	0.134	0.111
K	**0.247**	**0.230**	**0.483**	**0.455**	**0.436**	**0.503**
P	0.071	0.027	0.045	0.037	0.049	0.088
DOC	**0.316**	0.180	**0.365**	**0.331**	**0.310**	**0.362**

Appendix F. Yearly medians and standard errors for urban watersheds.

Variable	2003		2004		2005		All Years	
	Median	SE	Median	SE	Median	SE	Median	SE
Concentrations (mg/L)								
TDS	52.65	1.93	59.10	1.39	57.30	2.27	57.10	1.10
TSS	5.00	11.58	3.20	0.94	6.60	1.23	4.60	3.68
Cl	6.36	0.45	7.73	0.24	7.78	0.69	7.55	0.28
NO_3	1.94	0.13	1.61	0.11	1.77	0.23	1.75	0.10
SO_4	6.49	0.40	6.08	0.28	6.49	0.60	6.33	0.26
Na	5.26	0.63	6.50	0.44	5.19	0.26	5.82	0.28
NH_4	0.15	0.02	0.00	0.02	0.10	0.02	0.10	0.01
K	3.15	0.18	3.67	0.21	2.83	0.09	3.17	0.11
P	0.10	0.02	0.10	0.02	0.14	0.02	0.10	0.01
DOC	5.45	0.22	6.53	0.58	5.82	0.50	5.94	0.29
Fecal Coliforms (MPN/100mL)	1200.00	1830.44	570.00	307.89	1550.00	1745.45	1200.00	821.95
Yields (g/d/ha)								
TDS	471.43	528.03	256.82	29.19	400.60	341.40	320.11	199.86
TSS	35.78	5160.88	15.59	6.60	38.62	139.55	24.58	1593.02
Cl	63.55	44.61	36.49	3.91	45.57	86.87	42.20	31.99
NO_3	17.71	20.99	7.03	1.46	11.23	25.78	9.88	10.83
SO_4	61.28	59.59	27.11	4.02	42.82	68.23	40.78	29.47
Na	56.40	34.63	31.71	3.46	33.60	30.38	33.92	14.84
NH_4	1.33	5.62	0.00	0.20	0.65	1.75	0.45	1.83
K	30.07	51.96	15.08	2.03	17.79	20.85	18.94	17.52
P	0.49	6.79	0.38	0.15	0.61	0.66	0.42	2.11
DOC	45.56	161.20	27.63	4.94	54.61	54.86	34.24	52.91
Q (L/s)	141.14	356.37	58.70	17.22	114.63	129.61	106.17	118.64

Appendix G. Yearly medians and standard errors for developing watersheds.

Variable	2003		2004		2005		All Years	
	Median	SE	Median	SE	Median	SE	Median	SE
Concentrations (mg/L)								
TDS	43.00	1.79	48.90	1.56	42.20	2.06	45.80	1.06
TSS	4.00	19.22	4.60	0.97	4.20	2.89	4.40	6.05
Cl	4.14	0.22	4.17	0.16	3.74	0.29	3.95	0.13
NO_3	0.18	0.04	0.21	0.05	0.44	0.06	0.27	0.03
SO_4	4.35	0.32	3.20	0.24	2.75	0.35	3.37	0.18
Na	6.30	0.60	7.56	0.62	6.26	0.24	6.78	0.32
NH_4	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01
K	1.97	0.12	1.95	0.19	1.70	0.05	1.87	0.08
P	0.09	0.01	0.08	0.03	0.19	0.02	0.11	0.02
DOC	5.64	0.39	5.64	0.72	5.21	0.50	5.49	0.34
Fecal Coliforms (MPN/100mL)	330.00	122.41	185.00	144.84	284.00	186.55	236.00	88.73
Yields (g/d/ha)								
TDS	214.12	398.20	233.16	104.55	773.09	347.09	288.73	174.68
TSS	19.30	4746.33	20.37	14.12	45.80	383.50	25.47	1471.22
Cl	24.51	41.53	24.81	8.70	83.91	46.00	28.79	20.49
NO_3	1.56	2.26	1.10	0.73	6.48	8.71	2.21	3.08
SO_4	25.30	38.34	17.40	6.44	36.11	52.07	22.94	21.49
Na	41.08	51.71	42.60	14.61	126.18	47.01	46.53	23.23
NH_4	0.00	0.34	0.00	0.12	0.00	1.93	0.00	0.65
K	10.16	19.99	9.28	5.35	33.76	17.84	11.42	8.83
P	0.20	3.18	0.26	1.48	2.49	1.38	0.52	1.20
DOC	26.82	93.32	26.76	28.49	73.80	88.26	38.37	42.68
Q (L/s)	110.84	135.62	92.83	22.13	235.43	103.42	126.62	56.35

Appendix H. Yearly medians and standard errors for pastoral watersheds.

Variable	**2003**		**2004**		**2005**		**All Years**	
	Median	**SE**	**Median**	**SE**	**Median**	**SE**	**Median**	**SE**
Concentrations (mg/L)								
TDS	26.80	1.87	25.30	1.53	24.90	1.73	25.40	1.00
TSS	4.70	1.47	4.65	0.91	5.20	2.27	5.00	1.01
Cl	3.68	0.23	3.73	0.13	4.18	0.45	3.93	0.20
NO_3	0.36	0.34	3.03	0.19	2.94	0.32	2.90	0.16
SO_4	0.96	0.31	0.90	0.09	1.40	0.17	1.03	0.10
Na	3.37	0.57	3.72	0.37	2.91	0.22	3.11	0.21
NH_4	0.04	0.02	0.00	0.01	0.00	0.01	0.00	0.01
K	2.13	0.18	2.35	0.20	2.23	0.13	2.25	0.11
P	0.10	0.02	0.10	0.02	0.17	0.02	0.11	0.01
DOC	6.22	0.91	3.78	0.55	2.70	0.40	3.38	0.33
Fecal Coliforms (MPN/100mL)	155.00	91.03	98.00	126.19	249.00	58.43	147.00	62.58
Yields (g/d/ha)								
TDS	240.41	91.12	236.21	22.79	302.86	151.73	250.29	63.34
TSS	33.97	82.61	32.15	18.33	51.22	160.83	36.23	65.07
Cl	37.46	10.35	36.30	3.97	40.77	21.87	37.83	9.17
NO_3	18.25	2.94	20.59	4.12	23.98	16.40	22.55	6.81
SO_4	9.20	15.50	8.65	2.45	11.33	12.56	9.66	5.80
Na	29.17	12.75	32.79	3.59	30.25	17.08	31.65	7.20
NH_4	0.53	0.42	0.00	0.21	0.00	1.37	0.00	0.54
K	20.74	8.45	22.41	2.75	22.00	12.28	21.92	5.21
P	0.89	0.93	0.70	0.34	2.74	1.05	1.10	0.47
DOC	22.53	51.65	25.60	4.55	31.38	24.47	26.29	13.33
Q (L/s)	144.68	57.24	88.18	15.49	120.05	103.53	114.72	42.26

Appendix I. Yearly medians and standard errors for pine forest watersheds.

Variable	2003		2004		2005		All Years	
	Median	SE	Median	SE	Median	SE	Median	SE
Concentrations (mg/L)								
TDS	24.00	1.70	24.70	1.88	25.05	1.71	24.50	1.03
TSS	4.00	16.66	4.40	0.58	5.40	1.50	4.40	5.12
Cl	2.65	0.14	2.42	0.14	2.53	0.27	2.56	0.11
NO_3	0.45	0.10	0.40	0.09	0.60	0.10	0.46	0.05
SO4	2.44	0.22	1.50	0.07	1.87	0.45	1.84	0.17
Na	3.30	0.44	3.61	0.49	2.82	0.26	3.28	0.24
NH_4	0.00	0.02	0.00	0.02	0.00	0.01	0.00	0.01
K	1.91	0.09	2.07	0.18	1.78	0.07	1.89	0.08
P	0.10	0.01	0.08	0.03	0.14	0.02	0.10	0.01
DOC	2.21	0.26	3.54	0.54	2.92	0.32	2.89	0.25
Fecal Coliforms (MPN/100mL)	103.00	102.38	110.00	102.20	184.00	82.61	134.00	55.80
Yields (g/d/ha)								
TDS	171.99	69.58	175.76	18.60	247.69	334.99	196.46	114.39
TSS	24.59	2366.48	25.11	8.59	47.79	62.77	29.46	715.92
Cl	18.23	7.18	16.89	2.04	23.86	61.60	19.30	20.57
NO_3	3.56	6.02	1.95	0.93	5.92	9.45	3.48	3.67
SO_4	19.83	13.76	10.42	1.21	14.98	34.55	12.90	12.33
Na	25.19	6.08	27.00	4.01	30.43	42.57	26.73	14.39
NH_4	0.00	0.49	0.00	0.12	0.00	1.83	0.00	0.62
K	13.13	8.73	12.76	3.18	16.97	13.68	13.67	5.42
P	0.40	0.62	0.40	0.30	0.93	0.75	0.54	0.33
DOC	13.25	36.74	18.29	4.72	33.80	50.95	18.86	20.26
Q (L/s)	59.58	35.24	51.16	4.90	74.33	65.33	60.63	24.74

Appendix J. Yearly medians and standard errors for mixed forest watersheds.

Variable	2003		2004		2005		All Years	
	Median	SE	Median	SE	Median	SE	Median	SE
Concentrations (mg/L)								
TDS	30.75	2.62	30.95	2.37	24.80	2.93	26.70	1.54
TSS	2.40	1.95	2.50	0.80	3.80	1.27	2.80	0.73
Cl	2.54	0.16	2.20	0.11	2.63	0.28	2.50	0.12
NO_3	0.21	0.02	0.25	0.04	0.29	0.05	0.24	0.02
SO_4	2.34	0.35	1.39	0.15	1.67	0.28	1.51	0.14
Na	4.49	0.74	4.73	0.66	2.78	0.46	3.85	0.36
NH_4	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
K	1.76	0.09	1.99	0.17	1.61	0.07	1.76	0.08
P	0.08	0.02	0.07	0.04	0.07	0.03	0.08	0.02
DOC	5.74	0.83	4.90	0.84	3.86	0.64	4.63	0.46
Fecal Coliforms (MPN/100mL)	310.00	88.75	100.00	162.13	132.00	71.92	132.00	72.63
Yields (g/d/ha)								
TDS	177.17	64.02	220.89	27.81	290.98	187.24	222.99	73.20
TSS	15.37	54.91	17.42	13.07	29.96	154.93	17.27	58.93
Cl	16.50	5.58	20.50	1.94	23.59	17.07	19.90	6.72
NO_3	1.58	0.52	1.69	0.46	3.18	3.33	1.81	1.29
SO4	14.13	10.79	14.34	2.08	16.56	25.00	14.50	9.79
Na	30.23	8.09	32.31	5.83	35.31	25.59	31.35	9.95
NH_4	0.00	0.05	0.00	0.00	0.00	0.14	0.00	0.05
K	11.34	3.35	14.21	2.77	18.61	10.80	14.64	4.28
P	0.40	0.41	0.39	0.51	0.32	0.89	0.40	0.39
DOC	17.71	31.37	24.62	8.24	29.99	61.06	26.13	23.96
Q (L/s)	49.02	32.70	45.08	7.54	62.79	87.97	49.02	33.82

Appendix K. Nutrient, sediment, and fecal coliform summaries for each of the 18 study watersheds.

Watershed ID: BLN
Watershed Area: 364 ha
Tributary Name: Blanton Creek
Number of Samples: 39

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	21.04	19.70	0.87	15.10	51.00
TSS	3.53	2.80	0.62	0.00	18.00
Cl	2.06	1.92	0.12	1.44	5.82
NO_3	0.28	0.26	0.04	0.00	1.20
SO_4	1.54	1.28	0.14	0.97	5.26
Na	2.69	2.61	0.09	1.48	4.33
NH_4	0.00	0.00	0.00	0.00	0.08
K	1.92	1.78	0.06	1.48	2.85
P	0.11	0.06	0.03	0.00	0.74
DOC	2.39	1.64	0.26	0.61	6.07
Fecal Coliforms (MPN/100mL)	254.74	84.00	74.52	4.00	2200.00
Yields (g/d/ha)					
TDS	264.25	201.66	31.52	73.00	868.04
TSS	50.61	22.99	11.82	0.00	383.21
Cl	25.55	19.90	3.17	6.30	108.01
NO_3	3.91	2.15	0.74	0.00	16.84
SO_4	21.39	12.61	3.42	3.48	89.59
Na	31.93	27.83	3.07	10.70	90.46
NH_4	0.02	0.00	0.02	0.00	0.82
K	22.83	18.82	2.34	7.84	70.88
P	1.25	0.44	0.38	0.00	13.38
DOC	26.98	21.36	3.77	4.98	129.24

Watershed ID: BR
Watershed Area: 471 ha
Tributary Name: Brookstone Creek
Number of Samples: 15

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	71.27	72.90	3.95	43.40	97.40
TSS	7.99	7.40	1.56	0.00	20.80
Cl	10.32	10.27	1.44	4.66	28.06
NO_3	1.91	1.47	0.36	1.18	6.52
SO_4	7.80	7.32	1.08	4.21	20.00
Na	9.29	10.46	0.76	4.38	15.11
NH_4	0.46	0.00	0.20	0.00	2.87
K	2.51	2.47	0.12	2.08	4.11
P	0.23	0.17	0.05	0.00	0.58
DOC	6.45	4.62	1.53	1.64	22.30
Fecal Coliforms (MPN/100mL)	8061.54	4200.00	2383.02	210.00	25000.00
Yields (g/d/ha)					
TDS	826.84	499.26	198.84	98.45	2612.68
TSS	161.29	25.22	63.55	0.00	776.27
Cl	129.79	59.66	46.76	14.17	737.17
NO_3	30.10	10.32	12.30	1.46	190.48
SO_4	137.35	40.47	54.62	4.79	828.59
Na	96.58	55.40	21.21	17.12	253.45
NH_4	8.57	0.00	3.17	0.00	41.06
K	34.73	15.47	10.17	3.08	136.89
P	1.93	1.15	0.55	0.00	7.92
DOC	100.15	31.67	36.31	2.99	539.67

Watershed ID: BU1
Watershed Area: 2548 ha
Tributary Name: Lindsay Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	59.47	61.60	2.18	21.60	83.20
TSS	17.54	3.50	8.06	0.00	357.00
Cl	8.99	9.13	0.58	1.66	26.71
NO_3	2.09	1.84	0.21	0.10	8.35
SO_4	8.55	8.23	0.51	2.43	27.49
Na	6.67	6.25	0.45	1.24	17.09
NH_4	0.07	0.00	0.02	0.00	0.51
K	3.47	3.15	0.15	2.11	6.10
P	0.14	0.10	0.02	0.00	0.59
DOC	6.96	5.56	0.49	2.94	15.60
Fecal Coliforms (MPN/100mL)	4040.24	2000.00	997.95	250.00	38000.00
Yields (g/d/ha)					
TDS	873.33	305.61	247.40	60.92	10471.81
TSS	4116.26	17.17	3677.83	0.00	173075.82
Cl	107.93	43.00	23.80	9.36	804.78
NO_3	45.13	11.16	13.74	0.08	539.10
SO_4	132.72	45.31	33.42	7.77	1180.02
Na	74.65	30.47	15.91	6.38	600.67
NH_4	4.94	0.00	3.30	0.00	153.68
K	60.99	16.46	22.38	3.16	1020.52
P	7.17	0.30	5.48	0.00	257.73
DOC	160.12	28.82	68.83	4.37	3161.91

Watershed ID: BU2
Watershed Area: 2469 ha
Tributary Name: Cooper Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	53.24	52.50	1.69	29.10	85.00
TSS	17.74	6.00	6.35	0.80	280.00
Cl	6.80	6.49	0.35	3.07	16.52
NO_3	1.86	1.68	0.14	0.88	6.78
SO_4	6.68	6.47	0.32	3.55	17.25
Na	5.47	4.86	0.36	2.41	14.45
NH_4	0.17	0.18	0.02	0.00	0.54
K	3.68	3.30	0.17	2.41	6.85
P	0.14	0.10	0.02	0.00	0.62
DOC	6.95	6.07	0.42	3.60	14.06
Fecal Coliforms (MPN/100mL)	5763.41	1700.00	2239.65	190.00	74000.00
Yields (g/d/ha)					
TDS	798.54	363.30	156.32	41.61	4165.97
TSS	1105.60	32.46	527.96	1.56	21162.27
Cl	98.39	46.63	19.00	4.25	565.44
NO_3	36.90	9.99	8.49	0.73	252.51
SO_4	114.01	42.62	23.41	2.77	609.22
Na	70.47	33.60	13.46	3.87	414.16
NH_4	4.71	1.19	1.22	0.00	28.72
K	57.33	21.34	12.85	2.18	441.85
P	3.27	0.58	1.26	0.00	44.71
DOC	131.41	36.34	31.39	2.97	991.64

Watershed ID: CB
Watershed Area: 897 ha
Tributary Name: Clines Branch
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	25.21	24.70	0.41	19.70	31.60
TSS	4.47	2.60	0.88	0.00	33.20
Cl	2.37	2.14	0.14	1.72	6.64
NO_3	0.14	0.07	0.03	0.00	1.13
SO_4	2.57	2.11	0.21	1.14	6.93
Na	3.89	3.48	0.19	2.40	8.40
NH_4	0.00	0.00	0.00	0.00	0.05
K	2.13	1.87	0.09	1.58	3.87
P	0.11	0.07	0.02	0.00	0.52
DOC	3.11	2.29	0.27	1.16	7.07
Fecal Coliforms (MPN/100mL)	443.33	180.00	124.98	18.00	4800.00
Yields (g/d/ha)					
TDS	253.51	148.60	45.61	0.00	1247.25
TSS	53.29	12.52	16.93	0.00	668.99
Cl	26.50	13.66	6.32	0.00	259.53
NO_3	1.97	0.41	1.00	0.00	45.62
SO_4	30.53	16.25	6.84	0.00	228.91
Na	34.90	22.79	5.67	0.00	162.30
NH_4	0.05	0.00	0.05	0.00	2.10
K	19.42	11.54	3.28	0.00	87.52
P	1.30	0.25	0.41	0.00	13.84
DOC	28.65	12.78	5.23	0.00	151.25

Watershed ID: FR
Watershed Area: 2396 ha
Tributary Name: Flat Rock Creek
Number of Samples: 15

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	37.65	36.90	2.46	25.40	55.60
TSS	15.55	11.20	2.68	5.00	33.40
Cl	4.61	4.05	0.50	2.13	9.08
NO_3	1.18	0.87	0.16	0.66	2.32
SO_4	4.90	4.05	0.79	2.30	14.02
Na	4.05	3.90	0.28	2.57	6.63
NH_4	0.13	0.12	0.03	0.00	0.40
K	2.35	2.22	0.10	1.84	3.29
P	0.18	0.17	0.04	0.00	0.58
DOC	5.23	4.75	0.51	3.25	11.11
Fecal Coliforms (MPN/100mL)	990.71	520.00	382.94	88.00	5300.00
Yields (g/d/ha)					
TDS	453.22	272.35	101.43	52.86	1469.45
TSS	287.57	98.77	114.15	5.70	1677.72
Cl	56.02	27.14	12.34	5.40	157.99
NO_3	14.92	9.70	3.45	1.21	42.05
SO_4	73.80	34.73	20.92	2.37	288.86
Na	48.07	27.17	10.45	6.30	148.91
NH_4	2.72	0.94	1.54	0.00	23.26
K	30.60	17.05	7.93	3.12	122.30
P	1.76	1.42	0.49	0.00	5.49
DOC	73.31	41.81	23.79	3.94	347.99

Watershed ID: FS2
Watershed Area: 1449 ha
Tributary Name: Wildcat Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	23.37	23.60	0.40	19.10	29.60
TSS	9.98	4.80	2.69	0.40	90.20
Cl	3.78	3.42	0.26	2.28	10.91
NO_3	2.90	2.85	0.17	1.41	8.02
SO_4	1.19	1.00	0.12	0.54	4.19
Na	3.11	2.82	0.15	1.84	5.81
NH_4	0.12	0.12	0.02	0.00	0.31
K	2.14	1.84	0.14	1.57	5.62
P	0.18	0.10	0.04	0.00	0.82
DOC	2.90	2.44	0.22	1.07	6.07
Fecal Coliforms (MPN/100mL)	370.67	130.00	125.51	16.00	4000.00
Yields (g/d/ha)					
TDS	622.40	234.48	206.45	88.23	6132.76
TSS	548.49	42.19	248.92	4.02	7137.90
Cl	88.30	35.04	27.28	11.66	819.27
NO_3	73.79	25.53	23.64	10.51	698.45
SO_4	41.96	10.17	15.06	2.07	377.66
Na	74.76	30.64	23.43	11.74	712.61
NH_4	4.98	1.07	2.08	0.00	59.76
K	52.96	18.48	15.96	7.69	442.92
P	4.56	1.08	1.68	0.00	46.59
DOC	72.32	25.77	21.41	6.22	560.54

Watershed ID: FS3
Watershed Area: 296 ha
Tributary Name: Wildcat Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	22.66	22.90	0.38	17.40	27.30
TSS	5.27	3.00	1.14	0.00	34.40
Cl	3.92	3.52	0.27	3.19	11.91
NO_3	3.44	3.20	0.23	1.62	10.06
SO_4	0.98	0.73	0.13	0.44	4.13
Na	3.00	2.71	0.14	2.11	5.35
NH_4	0.01	0.00	0.01	0.00	0.17
K	2.12	1.87	0.15	1.54	6.50
P	0.15	0.10	0.03	0.00	0.65
DOC	2.13	1.53	0.25	0.72	7.88
Fecal Coliforms (MPN/100mL)	395.17	124.00	102.55	28.00	3200.00
Yields (g/d/ha)					
TDS	322.94	237.76	55.85	114.86	1978.56
TSS	114.97	28.22	46.94	0.00	1519.53
Cl	53.08	36.14	8.85	17.78	293.70
NO_3	49.87	32.67	8.99	10.67	277.00
SO_4	15.70	7.09	3.59	2.34	83.87
Na	40.01	29.93	6.13	16.36	226.27
NH_4	0.20	0.00	0.11	0.00	3.37
K	28.23	19.78	4.26	10.62	146.02
P	1.80	1.07	0.30	0.00	6.60
DOC	25.47	19.52	3.18	4.99	79.93

Watershed ID: HC
Watershed Area: 665 ha
Tributary Name: House Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	21.73	21.50	0.48	13.80	32.80
TSS	18.02	5.00	8.63	1.00	405.00
Cl	2.33	2.13	0.10	1.60	5.81
NO_3	0.77	0.72	0.06	0.00	1.91
SO_4	2.43	1.94	0.21	1.01	8.13
Na	3.00	2.65	0.17	1.12	6.29
NH_4	0.05	0.00	0.01	0.00	0.42
K	2.16	1.85	0.12	1.44	4.94
P	0.14	0.09	0.03	0.00	0.86
DOC	3.21	2.23	0.29	1.38	8.58
Fecal Coliforms (MPN/100mL)	275.20	138.00	73.85	10.00	2800.00
Yields (g/d/ha)					
TDS	247.88	147.88	69.64	15.89	3366.58
TSS	1946.22	34.52	1799.49	1.49	84687.35
Cl	27.20	15.20	7.15	1.34	335.40
NO_3	13.89	5.25	6.40	0.00	303.62
SO_4	36.77	14.71	14.40	0.78	682.73
Na	27.75	22.94	4.96	2.61	234.20
NH_4	0.73	0.00	0.29	0.00	13.17
K	25.45	15.70	8.55	1.79	409.43
P	1.90	0.52	0.67	0.00	30.60
DOC	66.52	16.77	37.90	3.79	1794.95

Watershed ID: HC2
Watershed Area: 1395 ha
Tributary Name: House Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	26.75	26.60	0.45	20.90	30.80
TSS	11.81	7.80	2.69	2.40	98.60
Cl	4.70	4.27	0.31	3.20	13.23
NO_3	4.36	4.24	0.31	0.00	13.24
SO_4	1.36	1.07	0.14	0.65	4.56
Na	3.36	2.99	0.17	2.15	6.57
NH_4	0.11	0.12	0.02	0.00	0.27
K	2.93	2.55	0.19	2.11	7.66
P	0.16	0.12	0.03	0.00	0.65
DOC	2.65	2.03	0.25	1.09	6.70
Fecal Coliforms (MPN/100mL)	600.72	290.00	170.07	20.00	5700.00
Yields (g/d/ha)					
TDS	350.10	253.69	57.38	2.33	1476.81
TSS	172.13	56.39	48.44	3.24	1377.40
Cl	59.04	38.64	10.20	1.13	229.19
NO_3	57.65	36.95	10.66	0.00	254.78
SO_4	21.42	9.51	5.02	0.46	124.68
Na	41.16	29.19	6.24	0.23	145.08
NH_4	1.63	0.56	0.46	0.00	11.94
K	36.11	23.54	5.90	0.27	128.18
P	1.62	1.01	0.30	0.00	7.74
DOC	31.35	22.23	4.94	0.39	114.19

Watershed ID: MU1
Watershed Area: 1178 ha
Tributary Name: Ossahatchie Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	45.94	44.20	1.88	22.50	72.40
TSS	7.11	5.00	1.02	0.90	32.20
Cl	6.21	5.71	0.45	2.87	15.97
NO_3	0.31	0.27	0.04	0.00	1.07
SO_4	2.44	2.31	0.24	0.35	5.84
Na	6.97	6.19	0.47	3.27	17.32
NH_4	0.06	0.00	0.01	0.00	0.33
K	3.23	2.96	0.26	1.45	11.76
P	0.18	0.13	0.02	0.00	0.74
DOC	9.76	8.93	0.54	4.53	19.61
Fecal Coliforms (MPN/100mL)	314.68	130.00	86.38	24.00	3100.00
Yields (g/d/ha)					
TDS	624.69	340.12	112.14	15.56	3307.20
TSS	211.20	31.18	65.61	0.37	1929.20
Cl	88.89	49.31	18.25	1.03	654.61
NO_3	7.35	1.63	1.93	0.00	56.46
SO_4	59.72	21.47	13.42	0.09	355.35
Na	82.92	52.39	12.65	2.33	365.26
NH_4	1.13	0.00	0.50	0.00	21.00
K	48.10	22.10	10.10	0.77	291.17
P	2.84	1.10	0.69	0.00	22.16
DOC	173.64	82.84	36.40	1.32	1013.17

Watershed ID: MU2
Watershed Area: 606 ha
Tributary Name: Mulberry Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	51.31	51.30	1.78	28.20	76.30
TSS	6.55	4.80	0.74	0.60	23.40
Cl	4.70	4.48	0.25	2.21	11.98
NO_3	0.28	0.25	0.04	0.00	1.29
SO_4	2.67	1.89	0.57	0.58	27.56
Na	8.61	7.40	0.59	4.22	21.81
NH_4	0.09	0.00	0.02	0.00	0.66
K	2.51	2.00	0.25	1.27	12.28
P	0.16	0.11	0.02	0.00	0.77
DOC	6.53	4.63	0.70	2.05	21.41
Fecal Coliforms (MPN/100mL)	202.28	104.00	35.16	10.00	940.00
Yields (g/d/ha)					
TDS	1079.40	288.57	422.20	84.43	17867.27
TSS	193.15	26.11	67.56	3.01	1885.49
Cl	135.35	26.16	77.98	6.39	3650.67
NO_3	15.70	1.25	9.72	0.00	452.52
SO_4	95.31	11.58	43.70	0.71	1906.59
Na	148.10	44.05	53.53	14.28	2289.08
NH_4	3.53	0.00	2.29	0.00	105.05
K	50.49	12.20	17.20	3.00	681.02
P	2.69	0.54	0.92	0.00	30.55
DOC	158.26	26.18	64.71	4.00	2801.53

Watershed ID: MU3
Watershed Area: 1044 ha
Tributary Name: Turntime Branch
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	43.14	45.80	1.58	20.20	64.40
TSS	5.96	2.80	1.18	0.00	35.60
Cl	3.17	3.04	0.15	1.61	8.81
NO_3	0.26	0.23	0.03	0.00	0.92
SO_4	2.72	2.51	0.20	0.86	6.42
Na	7.06	6.19	0.49	2.60	17.19
NH_4	0.01	0.00	0.01	0.00	0.27
K	1.90	1.57	0.13	1.08	5.90
P	0.15	0.09	0.02	0.00	0.71
DOC	7.86	6.01	0.58	3.05	19.64
Fecal Coliforms (MPN/100mL)	446.86	243.00	114.75	20.00	4700.00
Yields (g/d/ha)					
TDS	556.55	259.89	126.92	4.40	3821.10
TSS	254.95	9.58	104.49	0.00	4076.20
Cl	47.92	19.59	11.69	0.29	310.75
NO_3	6.17	1.23	2.24	0.00	86.25
SO_4	59.57	16.56	17.13	0.09	524.35
Na	79.35	42.34	17.25	0.58	550.55
NH_4	0.14	0.00	0.09	0.00	3.95
K	28.09	9.03	7.51	0.13	224.42
P	2.16	0.37	0.63	0.00	23.19
DOC	152.15	36.07	41.53	0.25	1304.87

Watershed ID: RB
Watershed Area: 367 ha
Tributary Name: Roaring Branch
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	56.93	58.90	1.69	25.00	79.10
TSS	9.90	5.20	3.54	0.00	168.00
Cl	7.74	7.51	0.43	2.15	21.70
NO_3	1.89	1.77	0.13	0.79	5.38
SO_4	5.16	4.86	0.29	2.77	12.43
Na	7.48	6.50	0.54	1.67	18.91
NH_4	0.14	0.13	0.02	0.00	0.69
K	3.52	2.97	0.21	2.42	9.25
P	0.16	0.10	0.02	0.00	0.72
DOC	7.03	5.82	0.58	2.89	19.95
Fecal Coliforms (MPN/100mL)	632.51	290.00	181.16	12.00	7000.00
Yields (g/d/ha)					
TDS	1354.61	337.61	510.17	66.51	20165.97
TSS	3077.59	33.07	2880.13	0.00	135515.29
Cl	205.59	41.37	88.77	8.49	3757.86
NO_3	66.83	9.31	27.49	1.84	1044.24
SO_4	185.56	29.02	76.72	3.78	2755.37
Na	124.58	41.09	38.16	9.63	1344.67
NH_4	7.64	0.55	4.10	0.00	184.72
K	98.52	19.49	44.70	4.69	1969.81
P	4.19	0.62	2.70	0.00	127.26
DOC	260.38	37.80	136.36	6.60	6109.48

Watershed ID: SB1
Watershed Area: 2009 ha
Tributary Name: Schley Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	46.85	48.00	1.93	23.00	78.40
TSS	23.75	3.40	13.30	0.00	624.00
Cl	3.78	3.62	0.18	1.85	9.92
NO_3	0.20	0.13	0.04	0.00	1.52
SO_4	4.27	4.23	0.28	0.77	13.05
Na	7.63	6.83	0.51	2.77	19.53
NH_4	0.01	0.00	0.01	0.00	0.34
K	1.84	1.54	0.14	1.00	5.71
P	0.15	0.10	0.02	0.00	0.72
DOC	7.36	6.11	0.61	2.57	19.20
Fecal Coliforms (MPN/100mL)	754.32	180.00	198.49	30.00	5500.00
Yields (g/d/ha)					
TDS	541.15	236.79	102.25	12.40	3233.24
TSS	2130.54	25.87	1715.94	0.00	80701.75
Cl	51.82	19.60	11.77	0.94	435.22
NO_3	3.03	0.73	1.00	0.00	42.88
SO_4	80.95	25.90	19.74	0.20	696.44
Na	82.91	38.98	15.16	2.14	443.80
NH_4	0.01	0.00	0.01	0.00	0.24
K	23.91	7.79	5.73	0.53	199.56
P	3.11	0.36	1.02	0.00	38.44
DOC	168.87	38.25	48.69	0.71	1735.60

Watershed ID: SB2
Watershed Area: 634 ha
Tributary Name: Standing Boy Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	50.94	50.30	1.83	25.50	73.60
TSS	17.85	4.30	11.30	0.00	523.00
Cl	5.07	4.98	0.23	2.21	10.11
NO_3	0.28	0.18	0.04	0.00	1.23
SO_4	4.35	3.80	0.33	0.97	9.05
Na	8.95	7.26	0.68	3.47	26.26
NH_4	0.02	0.00	0.01	0.00	0.32
K	2.36	1.99	0.18	1.40	8.42
P	0.17	0.11	0.03	0.00	0.84
DOC	6.97	5.85	0.62	2.67	22.13
Fecal Coliforms (MPN/100mL)	522.47	280.00	117.96	28.00	4400.00
Yields (g/d/ha)					
TDS	1895.20	604.69	470.24	24.20	16503.16
TSS	4833.08	27.33	4007.07	0.00	184426.31
Cl	207.85	52.12	55.36	1.77	1736.36
NO_3	24.63	1.98	8.44	0.00	285.46
SO_4	203.31	43.38	56.57	0.89	1663.05
Na	269.69	80.95	61.13	3.57	2084.41
NH_4	2.29	0.00	1.82	0.00	82.63
K	90.80	20.53	22.63	1.02	742.29
P	10.24	0.85	3.19	0.00	126.19
DOC	386.78	58.16	109.28	2.10	3411.01

Watershed ID: SB4
Watershed Area: 2659 ha
Tributary Name: Standing Boy Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	41.53	41.70	1.36	21.30	75.10
TSS	16.03	5.80	3.98	0.50	150.40
Cl	4.16	3.88	0.19	2.12	9.53
NO_3	0.77	0.76	0.04	0.31	1.86
SO_4	2.32	1.93	0.20	0.81	6.07
Na	6.61	6.16	0.34	3.53	16.29
NH_4	0.09	0.00	0.02	0.00	0.39
K	2.05	1.91	0.07	1.56	3.62
P	0.18	0.13	0.03	0.00	0.74
DOC	6.55	5.05	0.52	2.44	19.04
Fecal Coliforms (MPN/100mL)	483.09	230.00	119.06	62.00	4300.00
Yields (g/d/ha)					
TDS	462.85	220.71	90.99	15.57	3007.18
TSS	776.65	25.47	401.95	0.56	17876.69
Cl	52.81	25.78	11.46	2.44	397.16
NO_3	10.07	4.19	2.38	0.19	69.27
SO_4	46.80	11.37	12.76	0.83	368.23
Na	72.37	38.80	15.59	5.95	627.59
NH_4	1.62	0.00	0.50	0.00	16.19
K	30.40	11.04	8.93	1.16	385.82
P	2.60	0.54	0.83	0.00	32.98
DOC	100.11	29.11	26.12	1.47	980.72

Watershed ID: SC
Watershed Area: 896 ha
Tributary Name: Sand Creek
Number of Samples: 57

Variable	Mean	Median	Standard Error	Minimum	Maximum
Concentrations (mg/L)					
TDS	22.63	22.50	0.45	16.00	31.40
TSS	25.33	5.60	18.06	1.30	855.00
Cl	2.92	2.65	0.16	1.84	7.62
NO_3	1.70	1.70	0.08	0.83	3.90
SO_4	1.54	1.27	0.12	0.63	4.11
Na	2.70	2.55	0.11	1.07	5.88
NH_4	0.12	0.11	0.02	0.00	0.34
K	2.02	1.82	0.08	1.58	3.95
P	0.15	0.10	0.03	0.00	0.87
DOC	2.79	2.04	0.33	0.90	10.80
Fecal Coliforms (MPN/100mL)	465.26	87.00	154.65	4.00	5300.00
Yields (g/d/ha)					
TDS	385.96	192.74	80.28	31.43	2170.62
TSS	2286.14	44.79	2137.26	3.34	100583.96
Cl	53.23	22.57	13.35	4.21	534.77
NO_3	33.26	13.06	7.77	2.87	213.20
SO_4	39.66	10.70	11.10	0.88	366.57
Na	41.67	23.17	7.87	4.33	230.64
NH_4	2.39	0.92	0.68	0.00	23.06
K	35.84	16.67	7.94	3.06	263.64
P	2.12	0.82	0.48	0.00	13.85
DOC	60.95	16.10	21.96	4.76	975.14