Spring 5-9-2015

The Effects of Urbanization on Baseflow over Time: An Analysis of Changing Watersheds and Stream Flow Response in Georgia

Emily B. Furtsch
Georgia State University

THE EFFECTS OF URBANIZATION ON BASEFLOW OVER TIME: AN ANALYSIS OF CHANGING WATERSHEDS AND STREAM FLOW RESPONSE IN GEORGIA

By

EMILY FURTSCH

Under the Direction of Katie Price, PhD

ABSTRACT

This study examines the relationship between baseflow and urbanization over time with the help of spatial analysis using Geographic Information Systems. The urbanization parameters used were population and urban land use. Five urban and three non-urban streams were chosen for analysis in the state of Georgia. Four percentile baseflows for each stream were identified and analyzed for trends over time. A correlation analysis was also run to determine how baseflow varies as a function of urbanization. According to the trend analysis, the baseflows over time were considered stable or had no statistically significant trend. The correlation analysis between baseflow and urbanization revealed some scattered relationships though a general conclusion cannot be drawn. The simplicity of the study may have contributed to not capturing all of the baseflow changes with the urbanization parameters.

INDEX WORDS: Urbanization, Baseflow, Stream flow, GIS, Spatial Analysis, Change Over Time

The Effects of Urbanization On Baseflow Over Time: An Analysis of Changing Watersheds and Stream Flow Response in Georgia

by

Emily Furtsch

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in the College of Arts and Sciences

Georgia State University

2015

The Effects of Urbanization On Baseflow Over Time: An Analysis of Changing Watersheds and Stream Flow Response in Georgia

by

Emily Furtsch

Committee Chair: Katie Price

Committee: Dajun Dai

Daniel Deocampo

Electronic Version Approved:

Office of Graduate Studies

College of Arts and Sciences

Georgia State University

May 2015

DEDICATION

This work is dedicated to my ever-supportive husband Trent Furtsch and my children. I can't thank you enough for your abounding patience and support. Without you guys, I couldn't have completed any of this. Thank you. I love you.

ACKNOWLEDGEMENTS

I would like to thank Dr. Katie Price for your eloquent explanations, guidance and willingness to take over! Dr. Seth Rose, thank you for your guidance through my research. I would also like to acknowledge Joseph Hurley. I thoroughly enjoyed working with you and the experience I gained is price-less. Thank you for helping me search for my data and allowing me time and space to work on my re-search.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Approximately fifty percent of the world's population resides in an urban setting (Cohen, 2003). The Southeastern United States, especially the Atlanta area, has experienced a drastic population increase since 1950. Perlman, in 2011, found the population of the Atlanta metropolitan area increased three-fold from a population of about 1 million people in 1950 to over 3 million currently and still rising (Perlman, 2011). As of 2013 the Atlanta Metropolitan Statistical Area, as defined by the U.S. Census Bureau had an estimated population of 5,522,942 (www.census.gov, 7/23/14). With increasing population, there has been a change in land cover. There was a 79% increase (21 million acres) in developed land from 1982 to 2007 in the Southern United States (USDA, 2009). Urbanization leads to increased impervious surface coverage (Foster, et. al, 1998).

Research on the effects of urbanization and stream flow response has produced a greater understanding of the complex hydrological processes and subsequent responses. Runoff from impervious cover, disconnection of streams from floodplains, and removal of vegetation have created urban streams that are more like drainage pipes than unique ecosystems (O'Driscoll et al., 2010). It is generally agreed that urbanization affects stream flow five ways: degradation of water quality from effluent discharges, increased surface runoff from higher proportions of precipitation, decreased lag time between precipitation and runoff due to alterations of natural pathways, decreased baseflow due to reduced contributions from groundwater storage, and increased the magnitude of peak flows (Shaw, 1994).

Specifically, the effects of urbanization on underlying groundwater systems are seen in two ways: by radically changing the patterns and rates of aquifer recharge and by affecting the quality of the groundwater (Foster, et. al, 1996). With less groundwater recharge, there is a lowering of the water table and a decrease in baseflow. According to O'Driscoll, et al. (2010), baseflow as a percent of annual stream flow has been shown to decrease in urban streams. In contrast, peak flows are 30-100% greater in urbanized streams than in less urbanized streams (Rose and Peters, 2001).

1.1 Purpose of the Study

The effects of urbanization on stream flow have been studied rather thoroughly, but less so with the element of time over large watershed areas. This study hopes to expand upon the research already conducted on the effects of urbanization on stream flow by incorporating a spatial analysis of collected stream flow data and comparing changes over time in baseflow and urbanization. Due to a lack of historical stream gauge data in most areas, studies have been limited in their change over time results. Hirpa et al.'s (2010) work on temporal river flow fluctuations with respect to watersheds in the Flint River Basin in Georgia shows long-memory stream flow fluctuations that increase with increasing watershed area. Their work shows a relationship between large watersheds and more persistent stream flow fluctuations, meaning high intensity peak flows (i.e., flows with larger peak values) are more likely to be followed by more high intensity peak flows and vice versa, but short-memory precipitation and hydrograph transfer are not enough to account for the long-memory river flow (Hirpa et al., 2010).

1.2 Expected Results

While GIS, temporal and spatial analyses have been used to examine land use change, peak flow changes, and hydrological effects of urbanization, fewer studies have been done that incorporate a GIS spatial analysis of large watersheds over time to examine the effects of urbanization on baseflow. Gregory and Calhoun (2007) have indicated that temporally extensive data might reveal a low-flow signature related to increasing watershed urbanization in Southeastern streams. This study seeks to examine thoroughly the effects of historic and present urbanization of a watershed on the baseflow of streams in the Southeastern region of the United States. It is expected to achieve a better understanding of the relationship between urbanization and baseflow and to explore the possibility of urban recharge within that setting.

1.3 Significance

According to the U.S. EPA (2011), we all live in a watershed, which is an area that drains to a stream or lake or other common waterway, and individual actions can affect the watershed. Because individual actions affect watersheds, it is important to understand how urbanization of a watershed affects stream flow over time through a thorough spatial analysis. Even more important, is understanding how the urbanization of a watershed affects baseflow; this is the background water supply to these urban areas. Baseflow is generally the main water source for a population. If urbanization is affecting the amount of available water, it is important to understand this relationship.

Populations are growing. They are not only growing, but they are becoming increasingly urban. From 2000 to 2030 there is a projected increase in population of 2.2 billion. Of that 2.2-billion, 2.1 billion will be in urban areas. Of that 2.1 billion, all but 0.1 billion will be in developing countries (Cohen, 2003). It is necessary to determine the effects of urbanization on groundwater levels as our world is becoming increasingly urbanized. The need to examine water supply is pertinent so that future development and urbanization can be done consciously.

This study undertakes the charge to exam the relationship between base flow and urbanization over time through a spatial analysis using GIS. By examining watersheds across the Southeastern United States, it is hoped to find spatial patterns and insight into this complex hydrological relationship. Through identification of patterns, it is hoped that future urbanization can be done in a sustainable manner.

1.4 Background

Urbanization is not a single condition, but a series of actions that lead to recognizable landscape forms and, in turn, to changes in stream conditions (Konrad and Booth, 2005). Urbanization can be defined as a loss of vegetation, loss of soil to increased impervious surfaces and routing of storm water runoff directly to streams (Rose and Peters, 2001). Urbanization comes with an expansion of TIA (total impervious area) in the form of parking lots, rooftops, roads and lawns. With increased TIA comes a reduction in infiltration and surface storage of precipitation as well as increased surface water runoff (Arnold and Gibbons, 1996). Smucygz (2010) defines urbanization using population statistics and the percent impervious surface area at the basin-level. Other studies generalize urbanization as being human-induced land cover change (Poelmans, et. al, 2011; Guo, et. al, 2008; Schoonover, et. al, 2006).

No matter how urbanization is defined, it affects stream flow. The effects of urbanization on a stream have been studied in a variety of ways. Low density development in an urbanized setting is shown to have the greatest hydrological impact due to highest per capita impervious area. In the Roanoke River Basin in the Appalachian region of Virginia a 12% watershed decline in groundwater recharge was found with low density development with the highest per capita TIA (Bosch, et. al, 2003).

Urbanization, with increased impervious surface cover (TIA), causes degradation of water quality, increased runoff, decreased lag time in catchment response to precipitation, increased magnitude of peak flows, and decreased low flow (Shaw, 1994; Brezonik and Stadelmann, 2002). Smucygz, et. al, (2010) confirmed this widely accepted view that higher degrees of urbanization leads to higher runoff volumes when she found that median yearly runoff volume increased with increasing degrees of urbanization in three Chattahoochee River Subbasins in Georgia over a 44-year period (Smucygz, et al., 2010; Sauer et al., 1983; Walsh et al., 2005; Gregory, 2006). Runoff volume has been correlated most highly with total precipitation and the size of the drainage area (Brezonik and Stadelmann, 2002). although, it is still debatable as to whether urbanization or topography plays a larger role in that average annual runoff (Rose and Peters, 2001; Sun, et al., 2002; Smucygz, 2010).

Increased imperviousness leads to increased runoff volumes, which, in turn, leads to increased peak flows (Rose and Peters, 2001; Smucygz, et. al, 2010). Urbanization elevates a watershed's peak flow rates and the annual discharge volumes (Boggs and Sun, 2011). Rose and Peters, (2001) found that peak flows increased between 30 to 100% in urbanized watersheds. An increased loss of precipitation to runoff (rather than infiltration) leads to increased peak flow (storm flow) and decreased baseflow. In the inner coastal plain streams of North Carolina, storm water accounted for more than half of event discharge in urbanized watersheds, where storm water was only about a quarter of event discharge in rural areas (DeLoatch, et al., 2008).

Guo, et al., found, in 2008, that climate change (i.e., increased precipitation) in the Poyang Lake region of China was the biggest driver for annual stream flow changes. In Belgium, it was found that climate change is the main source of uncertainty affecting future peak flows in already urbanized areas, but land cover change is the largest driver of flood extent (Poelmans, et al., 2011).

Higher peak flow rates are also, in part, from decreased evapotranspiration rates as well as increased runoff from increased TIA (Boggs and Sun, 2011; Rose and Peters, 2001; Guo, et al., 2008). Long term trends in annual evapo-transpiration rates showed significant decreases in watersheds with a 0-58% urbanization between 1920 and 1990 in the eastern United States. At 100% urbanization, annual evapo-transpiration is predicted to decrease 22 cm (Dow and DeWalle, 2000).

As urban development increases, streams develop flashier hydrographs with characteristically higher flows for shorter durations. A flashier hydrograph means that the magnitude of the peak flows is greater and the lag time to get to these peak levels is decreased. Decreased lag time means that the water from precipitation reaches the stream faster. This leads to increased peak flows and a lower minimum due to a faster recession. This is collectively termed flashy discharge. These effects are greatest in the fall season when the Southeastern United States is typically in a low flow period. (Gregory and Calhoun, 2007).

Urbanized streams typically have flashy discharge compared to the more forested streams that have a less flashy hydrograph (Schoonover, et al., 2005; DeLoatch, et al., 2008). Flashy discharges are associated with increased flooding in urban areas (Guo, et al., 2008). It takes less time for water to reach flood conditions due to decreased lag time and higher magnitude peak flows.

Urbanized streams often see a significant increase in peak flow, but a decrease in the baseflow. Baseflow recession constants, used to show declining rate of baseflow, are 35-45% lower in urban streams (Rose and Peters, 2001). Increased TIA leads to decreased infiltration rates, decreasing the re-charge of groundwater and decreasing baseflow. Low flow in Peachtree Creek, an urbanized stream, is 25-35% less than other streams possibly as a result of less infiltration (Rose and Peters, 2001). Urban streams see a shift from baseflow dependence to storm water dependence (DeLoatch, et al., 2008). A study of lakes in two rapidly urbanizing watersheds in Pasco County, Florida revealed that baseflow de-creases with urbanization, but the presence of adjacent wetlands can offset the reduction in baseflow (Paynter, et. al, 2011).

Most hydrologists agree that most baseflow originates by saturated flow from groundwater storage and long-term baseflow rates are indicators of basin-wide groundwater recharge rates (Meyer, 2005). Rose and Peters (2001) found that urban wells showed a notable decline in water levels because of decreased groundwater recharge as a result of increased imperviousness and greater loss of precipi-tation as runoff. Low flow is decreased due to a reduction in groundwater recharge contributions (Shaw, 1994). Direct human interferences, such as water withdrawals and return flows, can affect the baseflow recession process (Wang and Cai, 2009). DeLoatch, et. al, (2008) found that disruptions in baseflow/groundwater interaction from increased imperviousness has altered recharge, runoff and channel erosion processes.

Wang and Cai (2009) argue that land cover changes (an indirect human interference) affect peak flow, but that direct human interference is the main cause of baseflow recession in urbanized streams. In the Northeast United States a reduction in the baseflow to total stream flow ratio in East Meadow Brook located in Hempstead, New York was recognized to be a result of accompanying urbanization of the watershed in the 1950s and 1960s (Sawyer, 1963; Seaburn, 1969). Meyer (2005) states that baseflow rates in urban streams can be altered from predevelopment rates by changes in water management and land use accompanying urbanization. In Nassau County, New York, the local water-table elevation and total stream flow in urban streams declined as a result of increased use of a sewer system (Franke, 1968; Sulam, 1979).

Although it has been found that infiltration of precipitation is lowered in areas with impermeable surface coverage and therefore groundwater recharge has decreased, it has also been found that other sources of water infiltration are present with increased urbanization. A case study in Austin, Texas found that groundwater is recharged despite impervious surface coverage, but it is recharged from leaky sewers and irrigation return flows (Garcia-Fresca and Sharp, 2005). In Austin, Texas 12% of water flowing to Barton Springs during low rainfall years was from leaky utility system recharge. The same was found in the Edward aquifer in San Antonio, Texas where 30% of annual recharge was from leaky water and sewage infrastructure (Lorenzo-Rigney and Sharpe, 1999; Sharp, et. al, 2006). Gregory and Calhoun (2007) found that urbanization does not lead to a higher frequency of lower flows in more urban streams, though they recognized that other studies have found this to be true and that limited availability of data may have caused their results to differ.

Channel incision along with decreased infiltration from increased imperviousness decreases recharge and causes a decline in groundwater level in floodplains of urban streams (DeLoatch, et. al, 2008). If groundwater and, subsequently, the water table are lowered due to decreased infiltration from increased impervious and increased channelization, baseflow will be decreased. In a study on peak flow, Smucygz, et. al, (2010) found that increased peak flow causes increased channel erosion and incision. Gregory and Calhoun (2007) found that flashier stream flow conditions leads to accelerated rates of bank erosion and streambed coarsening, though they suggest these conditions are more akin to former row-crop land conditions. Groundwater levels are much deeper in urban areas because the streams are incised or channelized from the increased peak flow. In some cases channel incision disconnected the stream from the aquifer system by down cutting into an impermeable layer (DeLoatch, et. al, 2007).

A study in northeastern Illinois found there was no significant trend in mean annual baseflows in three urban streams, but there were statistically significant upward trends in median annual baseflow characterized with increased lower baseflow rates (Meyer, 2005). Meyer (2005) states that the low permeability of the near-surface materials in the watersheds could explain why his results are in contrast to other studies that have shown decreases in baseflow.

Spatial scale, as well as urbanization, plays a role in stream flow variability (McBride and Booth, 2005). In large watersheds, it takes longer for baseflow to be affected by urban land changes. Hirpa, et. al, (2010) showed that the watershed size affects long-memory stream flow. The effects of urbanization are delayed for large watershed areas and they also have a stronger long memory than small streams that comes from baseflow rather than precipitation (Hirpa, et. al, 2010). Hirpa, et. al, (2010) also showed that river flow fluctuations decrease with watershed area.

Spatial analysis with GIS has been used to study the effects of urbanization and stream flow, but most of it has been aimed at examining peak flow changes or general land cover changes. In Thailand, GIS and remote sensing were used over a 15-year period to determine peak flow changes that subsequently caused flooding in central-northern area (Petchprayoon, et. al, 2010). Time series with satellite imagery has been used in the Atlanta, Georgia metropolitan area to determine land use change over 25 years, but a hydrological element was not included in the study (Yang and Lo, 2002). Moglen and Beighley used GIS in 2004 for spatially explicit time series of land use in an urban watershed in order create modeling for the prediction of peak discharge. Their scheme predicts discharge throughout a large watershed, rather than at a single outlet giving a large spatial scale and GIS analysis of stream flow, but it was for peak flow rather than low flow (Moglen and Beighley, 2004).

While GIS, temporal and spatial analyses have been used to examine land use change, peak flow changes, and hydrological effects of urbanization, there lacks a clear study that incorporates a GIS spatial analysis of large watersheds over time to examine the effects of urbanization on baseflow. Gregory and Calhoun (2007) have indicated that temporally extensive data might reveal a low-flow signature related to increasing watershed urbanization in Southeastern streams. This study seeks to examine thoroughly, through spatial analysis, the effects of historic, present (and future urbanization) of a watershed on the baseflow of streams in the Southeastern region of the United States.

METHODS

This study examined the impact of urbanization on baseflow over time. In particular, it offers a quantitative look at stream flow changes over time, comparing urbanized versus non-urbanized streams. A spatial analysis and comparison of basins was also utilized to define urbanization and which parameters may or may not cause changes to stream flow. In order to effectively answer this question, multiple data sets for Geographic Information Systems (GIS) and stream-gaged data were collected and analyzed including stream discharge from 1987 until 2010, land use change shapefiles, and population statistics for this time period.

Stream data were collected for 5 urbanized and 3 non-urbanized streams in the state of Georgia from USGS stream gage data. The urbanized streams were chosen based on proximity to a major metropolitan area as well as on background knowledge of urban growth in the Atlanta Metropolitan Area. A prior study to determine urban versus non-urban revealed significant growth from 1990 to 2010 within the areas surrounding each urbanized stream. The non-urbanized streams, historically, have less population growth and are out of the major Atlanta Metropolitan Area. Upon examination of the non-urban streams, the urban land use is significantly less than the urban land use in the urbanized streams and therefore confirmed non-urban status. Because the non-urban are not necessarily rural, a non-urban designation was given. All streams were also chosen because of the historical data available.

Although baseflow analysis is the main objective of this particular study, data on storm flow, baseflow and mean flow were collected. The 5th, 10th, 25th, and 50th percentile streamflow were used for analysis. By limiting the study to these lower percentile flows, the scope and data allow for a more comprehensive representation of baseflow values that includes median flows. The 5th- to 10th-percentile flows represent an approximate threshold of streambed stability for many river channels (e.g., Helley 1969; Milhous 1973; Pickup and Warner 1976; Andrews 1984; Sidle 1988; Carling 1988; Konrad et al. 2002; Konrad and Booth, 2005). In addition to the 5th and 10th percentile flows, the 25th and 50th percentile flows were also examined in order to gain more insight into streamflow trends. This gives a better perspective of the data and allows a more enhanced comparative analysis between urbanized and non-urbanized streams.

The watershed size and characteristics were also collected and assessed through the USGS. In order to compare urbanized and non-urbanized, the watershed characteristics must be taken into account for a more accurate analysis and comparison.

The GIS data needed for this study relate to urbanization and land use change. Several parameters were used to analyze urbanization and its effects on baseflow. These parameters include population, watershed area, high-intensity urban land cover, low-intensity urban land cover, and total urban land cover. All of these were assessed individually with their change over time within the basin area.

One of the parameters used to define urbanization is population in each watershed from U.S. Census data. Smugycz, et. al, (2010) used population census data and landsat images in order to quantify urbanization. Similarly, this study uses population data from the U.S. Census Bureau from 1985 until 2013 and land-use raster files from UGA Natural Resources Spatial Analysis Lab for the years 1974 to 2008.

GIS raster files (converted from landsat images) were acquired from the University of Georgia Natural Resources Spatial Analysis Lab for the years 1974 until 2008 in order to compare the percent urban land use changes over time. Yang and Lo, 2002, used a time series with land use change over a

25-year period for the Atlanta area. They found that from 1973 until 1998 there was a 350,000 acre loss of forest area for 13 of Atlanta's metropolitan counties. Those losses were replaced by low density residential areas (termed suburbs by Lo). Since 1973 suburban low-density residential areas has doubled to nearly 670,000 acres (Yang and Lo, 2002). The raster land use files from UGA were used to determine the urban land use in each watershed.

This study is limited by the amount of data that are widely available for all years within all parameters. It is the goal of this study to eliminate as many gaps as possible, but, due to its reliance on historical data and past surveillance, there were inherent gaps of information in the data. The analysis recognizes and takes into consideration any missing data. Using similar data between these various areas and with the extensive parameter sets, the analysis is scientifically sound despite any such gaps. By using multiple data sets there should be an accurate representation of all parameters.

A map of the watershed basins in Georgia including all of the urbanized and non-urbanized streams was created in ArcGIS. The urbanization parameters were added to the map in order to create a spatial analysis of the change over time in relation to each and then separate maps for each watershed were made to accurately display parameters within the context of the watershed. Gradients in population change over time and land use change were created and added as layers to the map to better correlate visually how changes over time to a basin affect the baseflow of the indicated streams. To analyze the stream flow changes over time, this study took the 5th, 10th, 25th, and 50th percentile flows (representing baseflow) for each year for the period of 1987 until 2010 (in accordance with the last set of Census Population data) and determined how it varies as a function of each urbanization parameter similar to previous studies (e.g., Helley 1969; Milhous 1973; Pickup and Warner 1976; Andrews 1984; Sidle 1988; Carling 1988; Konrad et al. 2002; Konrad and Booth, 2005). An analysis of the different percentile flows was examined to see how they vary as a function of population (by both county and by Census Tract). Lastly, total percent urban land use was assessed and the percentile flows were analyzed to determine how they vary as a function of the percent urbanization in general.

1.5 Research Design

Eight streams were chosen in Georgia and used to create watershed delineations (see Table 2.1). These streams were chosen because they represent various amounts of urbanization and can therefore give a more accurate representation of the effects of urbanization on baseflow. Five of the eight are considered urbanized with varying degrees of urbanization over the period of study. The remaining three were chosen because they are mostly non-urbanized and can help provide act as control streams showing contrast to the urbanized streams therefore making clear the effects of urbanization on streamflow. All eight streams, with their varying degrees of urbanization or non-urbanization, were also chosen because they had similar data availability. They all had historically consistent stream gage data without any gaps in years of collection.

The first is USGS site number 02336300 at Peachtree Creek in Atlanta, GA. It is a historically urbanized stream that runs through the city of Atlanta and especially the Buckhead area. The second urbanized stream is USGS 02335870 at Sope Creek near Marietta, GA. The third urbanized stream chosen for analysis is located in Suwanee, Georgia. It is USGS site number 02334885 at Suwanee Creek. USGS site number 02204070 at South River at Klondike Road near Lithonia, GA, is the fourth urbanized stream chosen for watershed delineation and analysis. The last urbanized stream chosen is USGS site number 02335700 at Big Creek near alpharetta, GA in Fulton County (waterdata.usgs.gov, 2012).

The sixth stream, a non-urbanized stream, chosen is USGS site number 2344700 at Line Creek near Senoia, Georgia. Though not considered urbanized, its proximity to Peachtree City allows an analysis of a historically non-urbanized stream with exposure to urbanization giving a variation of degree of non-urbanized. The seventh stream chosen, a non-urbanized stream, is USGS site number 2337500 at Snake Creek near Whitesburg, Georgia. The eighth and last stream, a non-urbanized stream, chosen is USGS site number 2193340 at Kettle Creek near Washington, Georgia (waterdata.usgs.gov, 2012).

Table 0.1 Streams Studied

Eight streams (five urbanized and three non-urbanized) were used to analyze the effects of urbanization on baseflow over time (waterdata.usgs.gov, 2012).

Study No.	State	Stream Name	USGS Gage No.	Basin (mi^2)	City	County	XY Coordinates
URBANIZED							
1	GA	Peachtree Creek	2336300	86.8	Atlanta	FULTON	Latitude 33°49'10", Longitude 84°24'28" (NAD 83)
2	GA	Sope Creek	2335870	30.7	Marietta	COBB	Latitude 33°57'14", Longitude 84°26'36" (NAD 83)
3	GA	Suwanee Creek	2334885	47.0	Atlanta northern suburbs	GWINNETT	Latitude 34°01'56", Longitude 84°05'22" (NAD27)
4	GA	South River	2204070	182	Litho-nia/suburban Atlanta	DEKALB	Latitude 33°37'47", Longitude 84°07'43" (NAD27)
5	GA	Big Creek	2335700	72	Alpharetta	FULTON	Latitude 34°03'02", Longitude 84°16'10" (NAD83)
NON URBANIZED							
6	GA	Line Creek near Senoia	2344700	101	Senoia	COWETA	Latitude 33°19'09", Longitude 84°31'20" (NAD 83)
7	GA	Snake Creek near Whitesburg	2337500	35.5	Whitesburg	CARROLL	Latitude 33°31'46", Longitude 84°55'42" (NAD27)
8	GA	Kettle Creek near Washing-ton	2193340	33.9	Washington	WILKES	Latitude 33°40'57", Longitude 82°51'29" (NAD27)

1.5.1 Data

In order to complete this study, a digital elevation model (DEM) valid for all eight streams was required. The DEM covering the entire state of Georgia was converted into digital elevation rasters. A stream shapefile for each of the afore-named streams was necessary as well.

A DEM for the state of Georgia was attained from the Atlanta Regional Commission. Seven of the stream shapefiles, extracted from the Rivers & Streams shapefile from the GA Dept. of Transportation and provided by the Atlanta Regional Commission, were added to an initial map in ArcMap. The eighth stream shapefile for Kettle Creek was created by extracting the data from a U.S. Census Bureau's TIGER/Line shapefile and adding back as a separate layer. Lastly, a all-encompassing watershed HUC file from USGS (www.usgs.gov) for Georgia was added.

Stream flow data were available at USGS real-time water data website (waterdata.usgs.gov). After selecting the eight stream sites by number, the latitudinal and longitudinal location of each stream (at the stream gage) was acquired.

Shapefiles with population for 2010 were acquired from US Census Bureau Census Tracts. Shapefiles with population data by Census Tracts for 1980, 1990, 2000 were ordered and downloaded from Minnesota Population Center National Historic Geographic Information System with a grant from National Science Foundation for National Historic Geographic Information System incorporating all available aggregate census information for the US between 1790 and 2000. Land Cover Changes raster files were acquired from Natural Resources Spatial Analysis Lab from UGA College of Agricultural and Environmental Sciences (www.narsal.uga.edu/glut, 6/13/14).

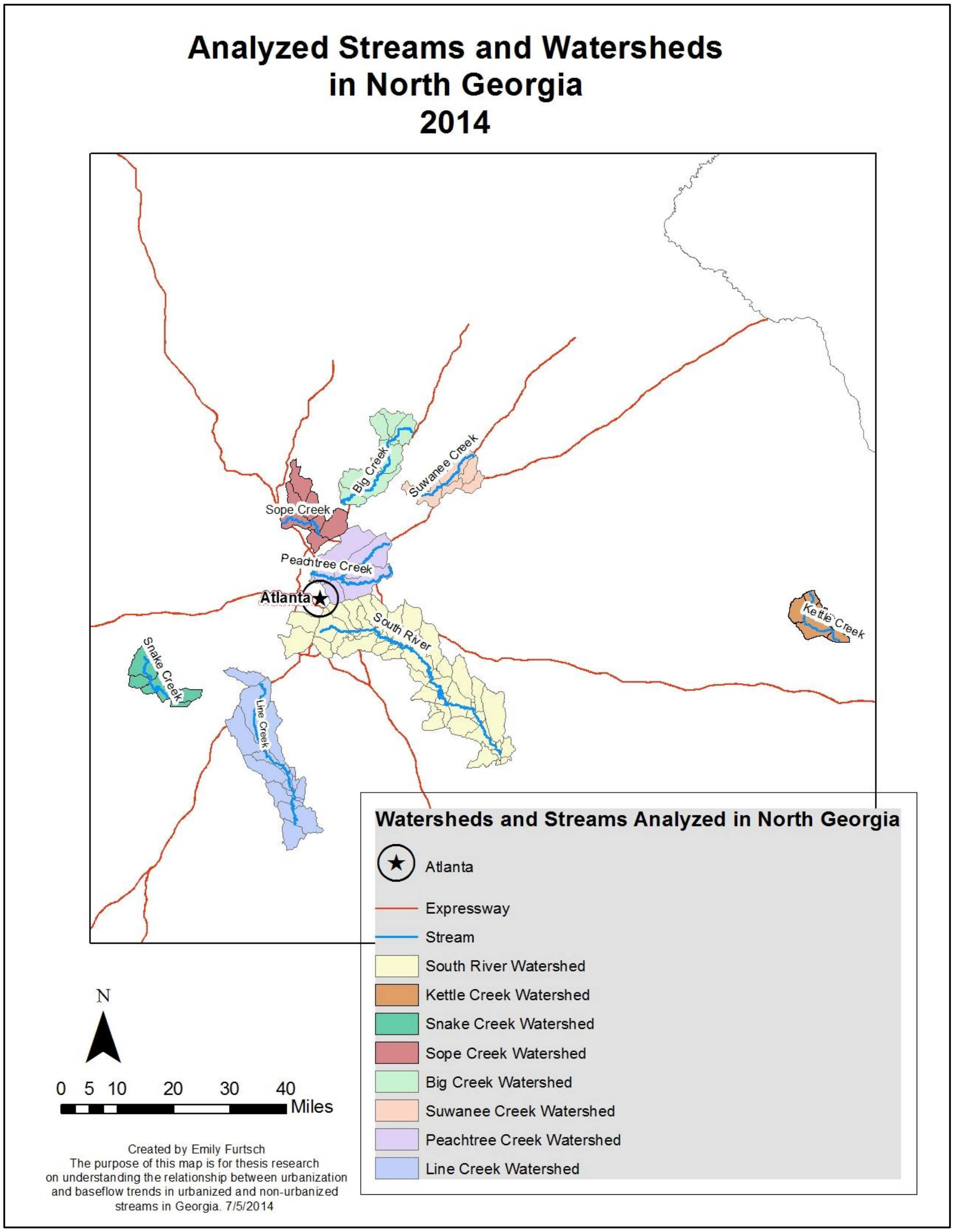

Figure 1.5.1 Delineated Watersheds.

This map shows the location of the eight streams within their delineated watersheds. The city of Atlanta and major highways are also shown for location reference.

1.6 Experiment

1.6.1 Watershed Delineation and GIS Methods

There are many methods for data organization and watershed delineation: in his 2008 study Ribeiro, et. al (2008) implemented a set of topologically based data sets in ArcInfo to run large watershed data sets. This decreased the processing time and allowed for easier delineation of the watersheds. It also allowed organization and extraction of information for the data sets to run more smoothly. Similarly, the WinBasin analysis system appears to be another approach to more quickly and systematically delineating watersheds. It automatically calculates depression-less flow directions, delineates watersheds/sub-watersheds, extracts realistic drainage networks, and calculates geomorphological indices and hydrological responses from DEMs then exports this information as vectors for GIS software (Lin, et. al, 2008). Unfortunately, due to limited software availability these techniques will not be as useful for the range of this particular study though they seem ideal for future methodological resources.

With the time and scope of this project, the focus was on using ArcGIS techniques to complete the watershed delineation and then complete analysis of urbanization parameters with streamflow data. There are six steps to delineate a watershed in ArcGIS. First the DEMs have to be filled to eliminate any void or bad pixels by assigning these pixels the lowest elevation value of the neighbors to fill the hole. This is to help ensure a more accurate flow direction and clears up any sinks or depressions that might cause inaccurate flow direction determination.

The second step is to determine the flow direction with a D8 algorithm. This calculates the difference in elevations to see where the deepest areas are located in the DEM. Flow direction is in the direction of the steepest distance-weighted gradient. The D8 method uses data from the 8 nearest neighbors of a center pixel. This information will be created as a raster.

The third step is to create a flow accumulation raster based on the flow direction raster. Stream channels and ridgelines are determined through this GIS Spatial Analysis technique. The elevation data of the flow are used to determine where flow will accumulate from surrounding areas/flow lines.

The next step is the creation of a stream network by defining a flow accumulation threshold. A moderate size is needed to have the best results. Having a low value will result in a denser network of streams that may make it harder to analyze fully. An accumulation value of about 4000 pixels was used for the basin-wide watershed delineation. In this step a stream network is created based on topological data. The topology helps to create stream flow lines by giving each portion of the stream network an assigned value. The values show how many streams are flowing into each branch and the place where the flow is most collected. This is the main stream.

The sixth step is the creation of a source raster from the stream network raster and the flow direction raster. This source raster is then used to delineate the watersheds.

Data were downloaded and converted in ArcView from e00 files. The DEM 2500 file was added to the map. Then a temporary flow direction raster was made to find sinks using flow direction tool. The sink tool was used with the temp flow raster to find sinks. Those sinks were filled with the sink tool. Using the filled raster, a flow direction raster was created. That flow direction raster was used in the flow accumulation tool to create a flow accumulation raster. From there a threshold of 1000 streams inflowing into the accumulation raster was created making a new raster called Net. Using the stream link tool, the flow direction was linked with the net raster and a source output raster was created. Using the source output raster and the flow direction raster, the watersheds were delineated. Peachtree Creek was selected from the rivers and streams shapefile from the ARC data and then exported to create a new shapefile for that specific stream. That shapefile was added back to the map. The watershed raster for all of Georgia was converted from a raster file to a polygon file so individual subwatersheds could be selected using the polygon selection method. Based on the location of Peachtree Creek and its subsidiaries as indicated by the source layer, the watershed polygon layer was selected and the appropriate polygons were highlighted. That was exported to a new polygon layer for that particular watershed, then extracted by mask using the watersheds raster and the exported watershed polygon data. I repeated these steps for the remaining seven watersheds.

1.6.2 Stream Methods

Daily stream discharge data were downloaded from USGS (www.waterdata.usgs.gov) from April 1986 to April 2014 for all eight streams. The year 1986 was chosen because it is the earliest year that Kettle Creek had daily streamflow records, but the year 1986 was later eliminated for better accuracy because records only dated back to April 1986 giving only a partial view of the year. For the same reason, all 2014 data were eliminated from research. Because population data were limited to 2010 (the last Census during this period of study), stream data after 2010 were also eliminated for better correlation analysis.

Daily stream data was provided in discharge values but were needed to be in the form of runoff (mm/year) for analysis. Discharge values, provided in cubic feet per second, were converted into runoff by dividing by the total watershed area (converted into mm^2) for each watershed and converted into mm/yr.

$$\text{Runoff} = Q/A, \text{ where } Q = \text{discharge and } A = \text{area}$$

The scope of this study is to understand baseflow trends so the next step was to identify and separate the low flows of the year. The daily runoff values were organized by year and assigned a rank from lowest flow to highest flow and normalized to percentile. The 5th, 10th, 25th and 50th (lowest) percentile flows for each year for each stream were identified for baseflow trend analysis. In order to cover a broader range and to give a great perspective, the study was extended to the yearly 25th and 50th percentile flows as well as the normally accepted 5th and 10th percentile flows.

1.6.3 Rainfall Resolution

To account for rainfall, averaged annual precipitation data were gathered through the National Weather Service NOAA website for each watershed for every year over the scope of this project (http://www.nws.noaa.gov, 8/1/14). Because of the limited historical data available and overlapping HUC watershed areas, some of the same precipitation data were used for different delineated watersheds. Proximity and data availability were used to make the best judgment on which precipitation gage to use (See Figure 2.2). Precipitation data from the Cumming 1 Ene, GA gage were used for both Big Creek and Suwanee Creek. The Atlanta Bolton, GA gage was used for both Peachtree Creek and Sope Creek. The Atlanta International Airport gage was used for South River and Line Creek. The Washington 2 Ese, GA gage was used for Kettle Creek normalization and the Carrollton station was used for Snake Creek. In order to account for the rainfall, each percentile runoff was divided by rainfall to normalize the baseflow values. This rainfall coefficient can be used as a baseflow proxy and will henceforth be called baseflow for the purposes of this project.

Then each percentile flow for each stream was plotted against time for visual trends. A Mann-Kendall statistical analysis was performed on all percentiles of all streams in order to assess more accurate statistical. The Mann-Kendall test is a nonparametric statistical analysis useful in identifying long-term trends. Each percentile flow for each stream from the years 1987-2010 was then plotted as a function of the percent urban land cover parameters as well as the percent population parameters. Statistically, a correlation analysis was performed with each urbanization parameter with each set of percentile flows (1987-2010) for all eight streams. For example, A correlation analysis was run with the 5th percentile flows from 1987 to 2010 and the population data, then it was run three more times with each urban land use parameter. This was done for the 10th, 25th, and 50th percentile flows from 1987-2010 for each stream.

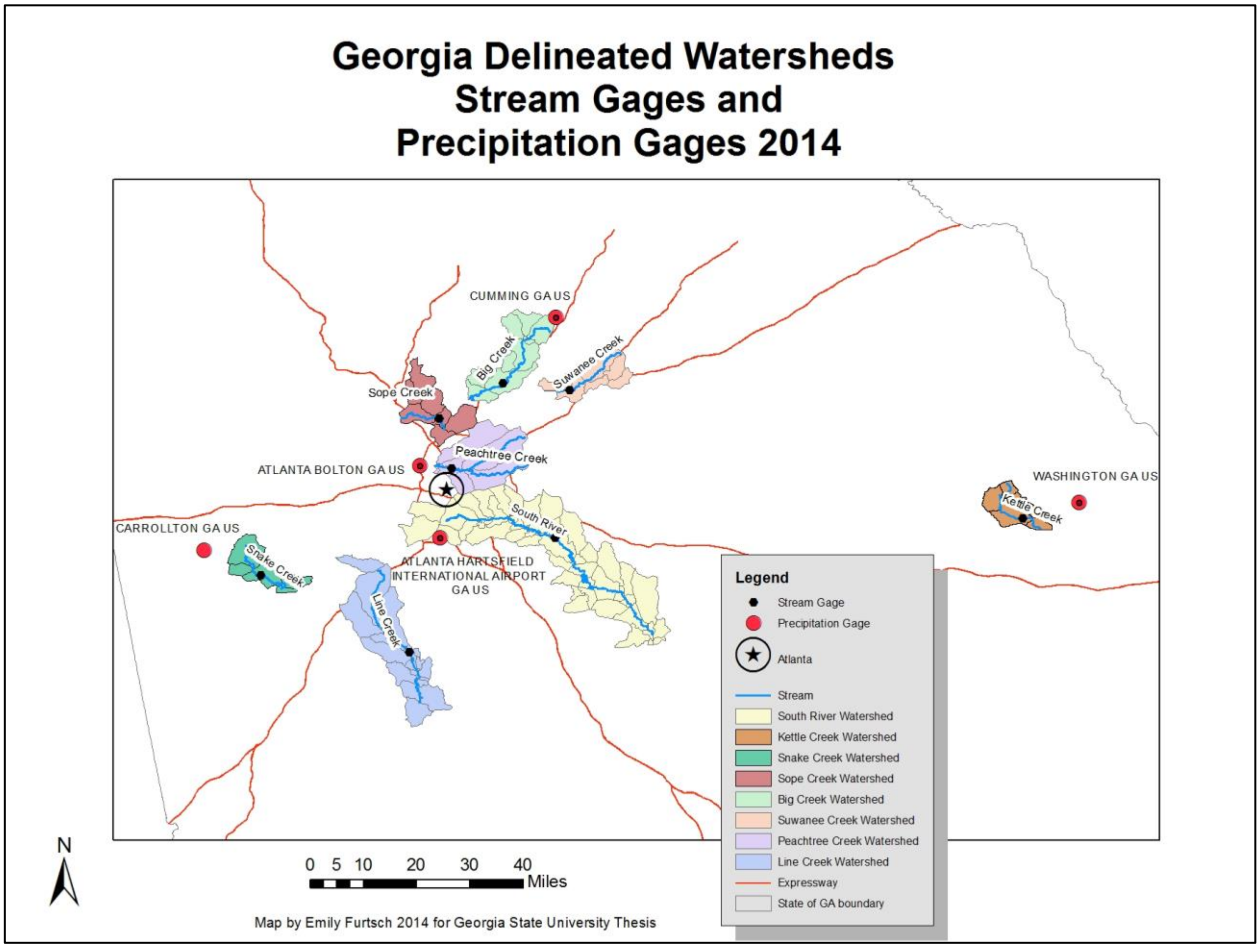

Figure 1.6.1 Stream and Precipitation Gages.

Precipitation gages used are shown within proximity to delineated watersheds in Georgia.

1.6.4 Urbanization Parameter Measurements

Smucygz (2010) uses population statistics and the percent impervious surface area at the basin-level to define urbanization. Other studies generalize urbanization as being land cover change (Poelmans, et. al, 2011; Guo, et. al, 2008; Schoonover, et. al, 2006). According to Jarnagin (2006) a direct and quantifiable result of urbanization is the transformation of natural land cover to impervious surfaces, which include roads, rooftops, parking lots, driveways and sidewalks.

Population growth is one of the most obvious and greatest drivers in land cover change including increased imperviousness. The environmental impact to an area from urbanization can be seen through a rewritten version of the Ecological Footprint Equation (Jarnagin, 2006):

Environmental Impact = Population * (Consumption/Efficiency)

This equation shows, quantifiably, that there are magnifiers and modifiers from population growth that affect the environment. Every person has a minimum requirement for space, food, water, and air and land use will change in association with those requirements. More people need more resources which, in turn, results in a greater conversion of natural land-cover to a human-altered land-cover or to a more intensive use of existing land cover that has already been altered (Jarnagin, 2006).

This particular study, like Smucygz (2010), used spatial analysis to evaluate both changes in urban land use and population to understand the degree of urbanization then relate that, statistically, to historical stream data. Multiple GIS layers were downloaded from a variety of sources, but the most suitable used were from Atlanta Regional Commission, US Census Bureau, University of Georgia's Natural Resources Spatial Analysis Lab and Minnesota Population Center National Historic Geographic Information System. All urbanization parameters (land use raster files and population shapefiles) were added by year to each delineated watershed. A map was made of each parameter for each year of data availability. For the population maps and analysis, Census data tables for 1980, 1990, and 2000 were added and joined to the respective shapefiles through the ArcGIS join function. The 2010 TIGER shapefile already had Census population data in the attribute table. The shapefiles were clipped using the ArcMap clip tool within the delineated watershed. The population data were displayed from the joined attribute table. Since the population census tracts change over time, it is difficult to visually assess the change in time that is occurring because larger census tracts are broken down into smaller census tracts within the watershed areas from 1980 to 2000. The only two maps with the same census tracts are the population maps for 2000 and 2010. Because, visually, they don't provide much, the maps have not been included, but the data collected from them were used for analysis with the streams.

Land Use Trends shapefiles for 1974, 1985, 1991, 2001, 2005, and 2008 were downloaded from the University of Georgia's Natural Resources Spatial Analysis Lab (narsal.uga.edu) and added to a map with all of the delineated watersheds in ArcGIS. The 1974 land use trend was selected and used in order to establish the degree of urbanization already present within each watershed. The land use raster files already had appropriate data within the attribute table. Land use was selected and displayed for each land use map. According to UGA's Natural Resources Spatial Analysis Lab (NARSAL), low-intensity urban land use is defined as "single family dwellings, recreational areas, cemeteries, playing fields, campus-like institutions, parks, and schools" (narsal.uga.edu/glut/classdescriptions/, 6/5/2014). High-intensity urban land use is defined as "multi-family dwellings, commercial/industrial areas, prisons, speedways, junkyards, confined animal operations, transportation, roads, railroads, airports and runways, and utility swaths" (narsal.uga.edu/glut/classdescriptions, 6/5/2014).

The clip tool was used to isolate and define the land use trends for each year within the boundaries of each watershed. A Count Attributes was created for each year for each watershed to understand the total amount of each land use. The rows with unique identifiers of 22 and 24 represent low intensity urban land use and high intensity urban land use, respectively. Those values were isolated and recorded with the watershed area used to define each clip. A percent low intensity urban land use, high intensity urban land use and total urban land use were calculated for all watersheds and all years and recorded in a spreadsheet. A Mann-Kendall test was performed on each of the land cover data sets for each stream to determine any trends.

Population by Census Tract was collected for years 1980, 1990, 2000 and 2010 from the U.S. Census Bureau (www.census.gov). Census Tract shapefiles were downloaded from the U.S. Census Bureau as well as from Minnesota Population Center National Historic Geographic Information System (www.nhgis.org) and were added to the watersheds map in ArcMap. The shapefiles were lacking population information within the attribute table, so an accompanying table with population was also ordered and downloaded from the Minnesota Population Center's National Historic Geographic Information System. The data files were converted into dbf data tables suitable for ArcMap. The table and shapefiles attribute tables were put together using a join by attribute.

In ArcMap, the Census Tract shapefiles were clipped using the watershed delineations. Population data for all Census Tracts within the watershed were collected and summed up from the attribute table. The population by Census Tract within the watershed was plotted against the runoff for each percentile for each stream. A Mann-Kendall test was run on the population data set for each watershed to identify any long-term trends in population. Then a correlation analysis was used to determine any correlation between population growth and baseflow.

Individual maps of each stream were created displaying the watershed delineations and stream flow accumulations, land use trends by year and population data by year.

After initial review of the results, it seemed that additional statistical analysis was needed to further understand the relationships. Because the parameter data are limited in the scope of availability relative to stream discharge data, parameter data was interpolated between years of available data. With the additional interpolated values, the linear correlation was run with a one-to-one relationship with the stream discharge values for each percentile.

Population data was interpolated from 1980 to 1990, from 1990 to 2000, and from 2000 to 2010. A correlation analysis was run on all of the population values from 1987 to 2010 and stream discharge data from 1987 to 2010. Similarly, land use change data was interpolated for additional statistical strength. A correlation analysis was run for each urban land use parameter (total, high-intensity, and low-intensity) with the stream discharge from 1987 to 2008. Because the latest land use data point is 2008, the correlation stopped at that year. These correlation analyses were done for each percentile flow for each stream.

RESULTS

1.7 Urban

1.7.1 Peachtree Creek

A Mann-Kendall statistical analysis revealed no trend in the baseflows across all four percentiles with a confidence interval of 95%. Population by Census tract, total urban land use, and high-intensity urban land use are all increasing according to the Mann-Kendall trend analysis. Low-intensity urban land use was the only parameter to show no trend. The analysis revealed a correlation between high-intensity urban land use and the 5th, 10th, and 25thth percentile baseflow (Table 3.1, 3.2, 3.4). There were no correlations between the 50th percentile flow and any of the parameters.

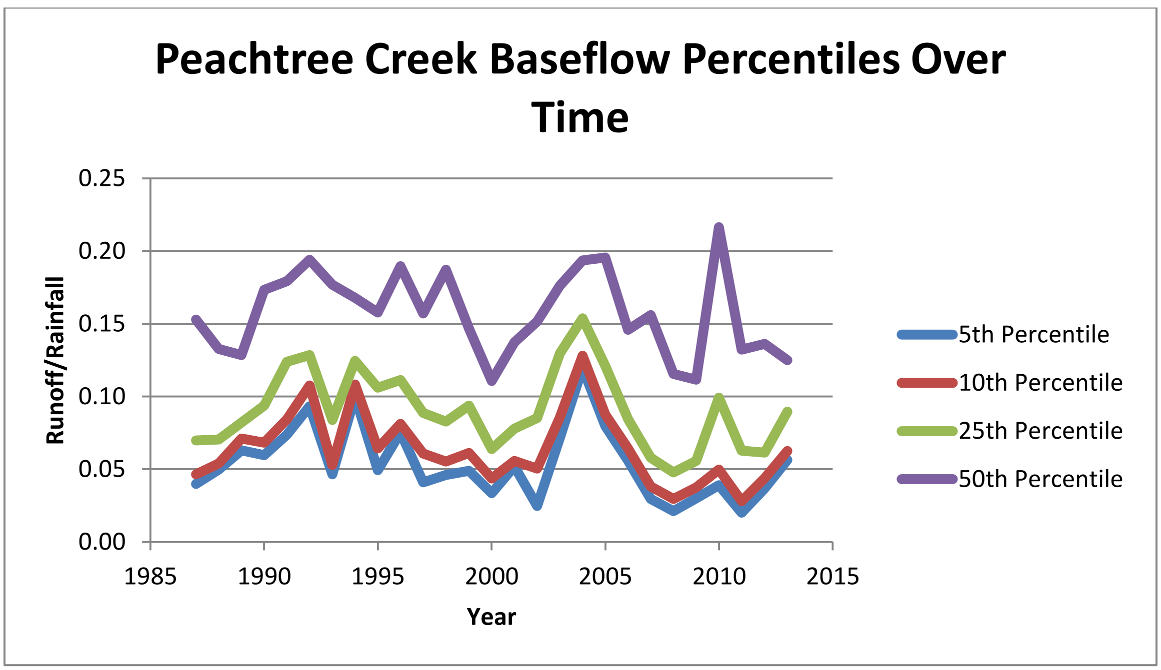

Figure 1.7.1 Peachtree Creek Baseflows
The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Peachtree Creek, an urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical.

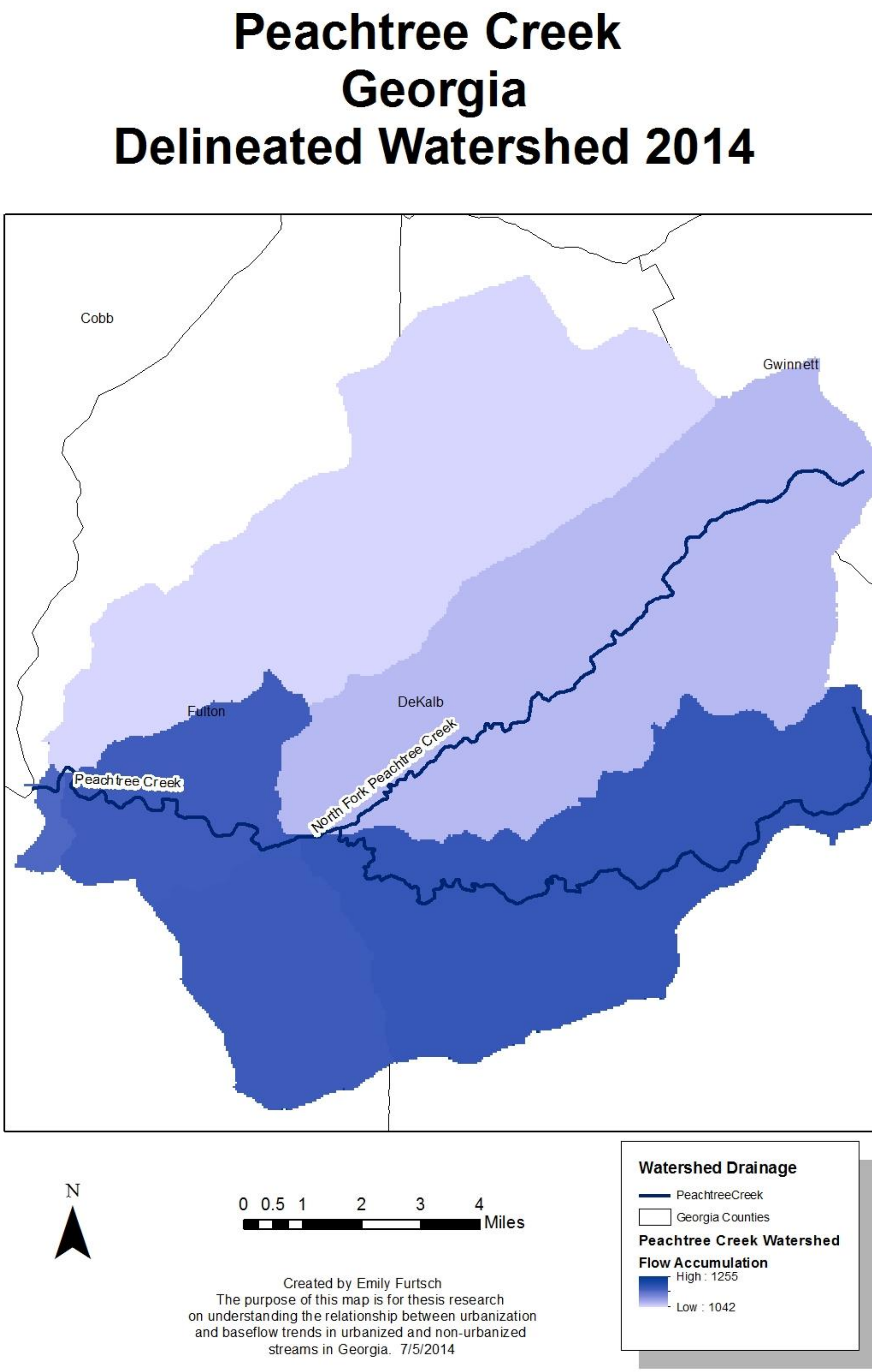

Figure 1.7.2 Peachtree Creek Watershed

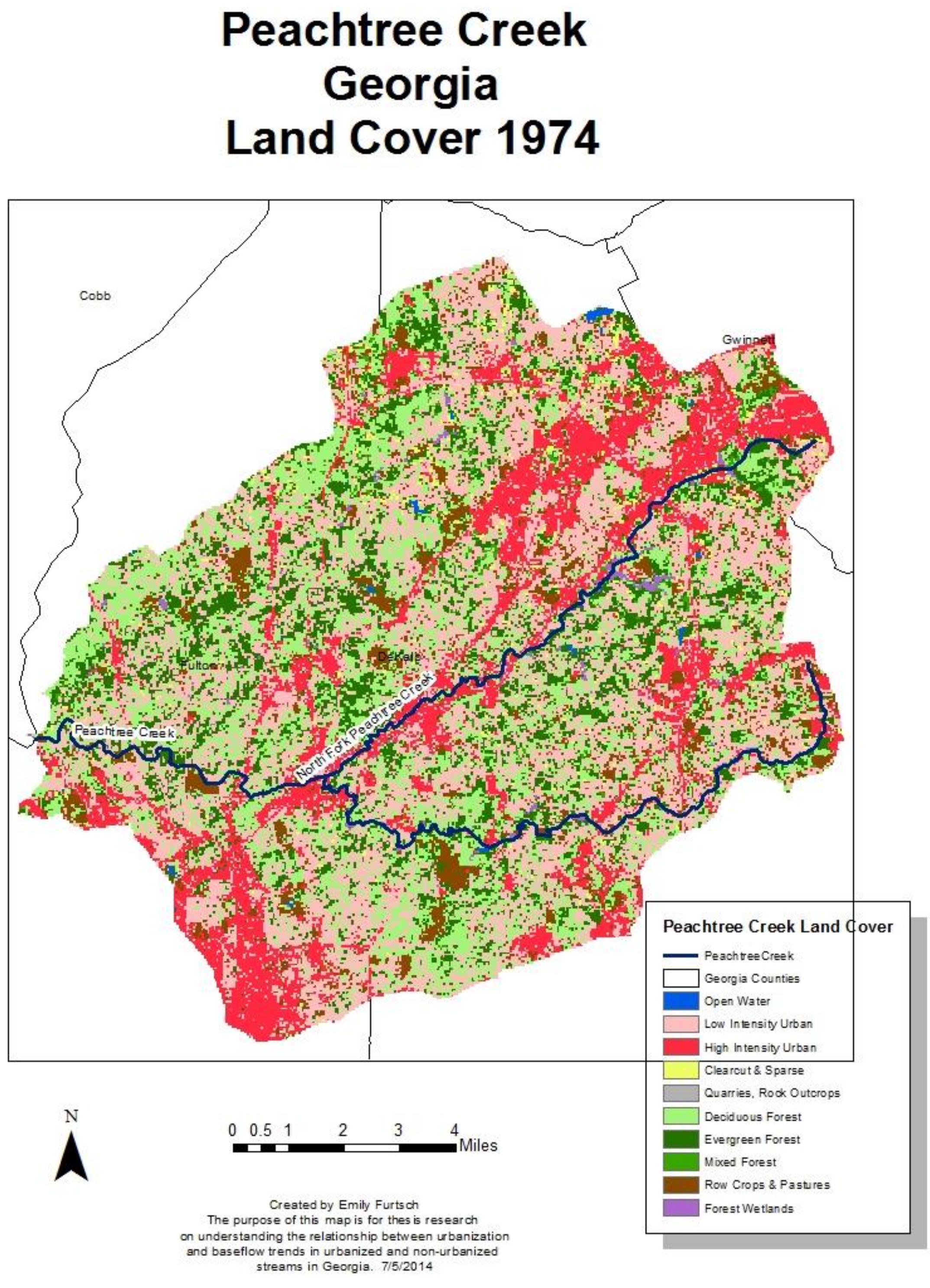

Figure 1.7.3 Peachtree Creek 1974 Land Cover

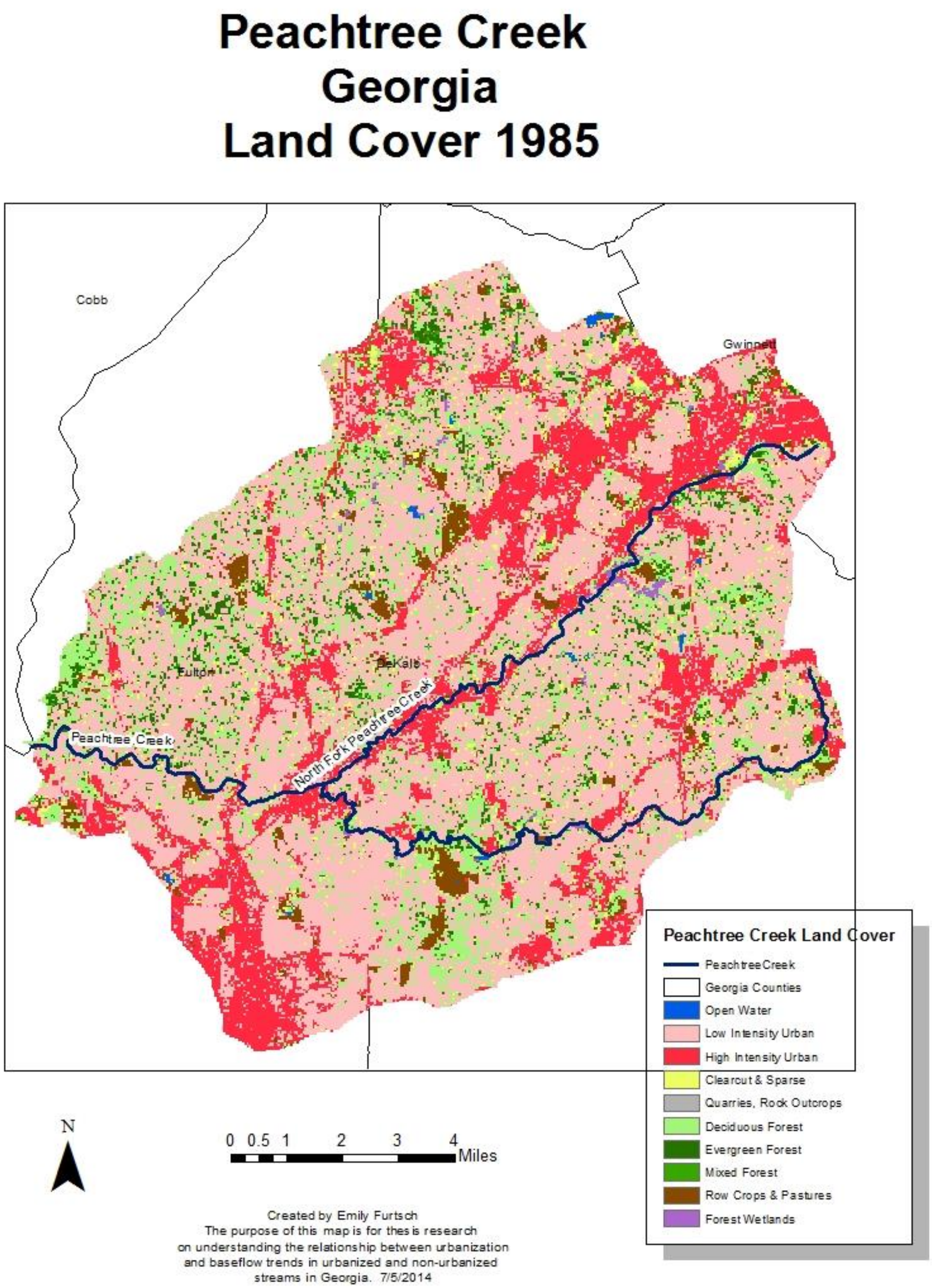

Figure 1.7.4 Peachtree Creek 1985 Land Cover

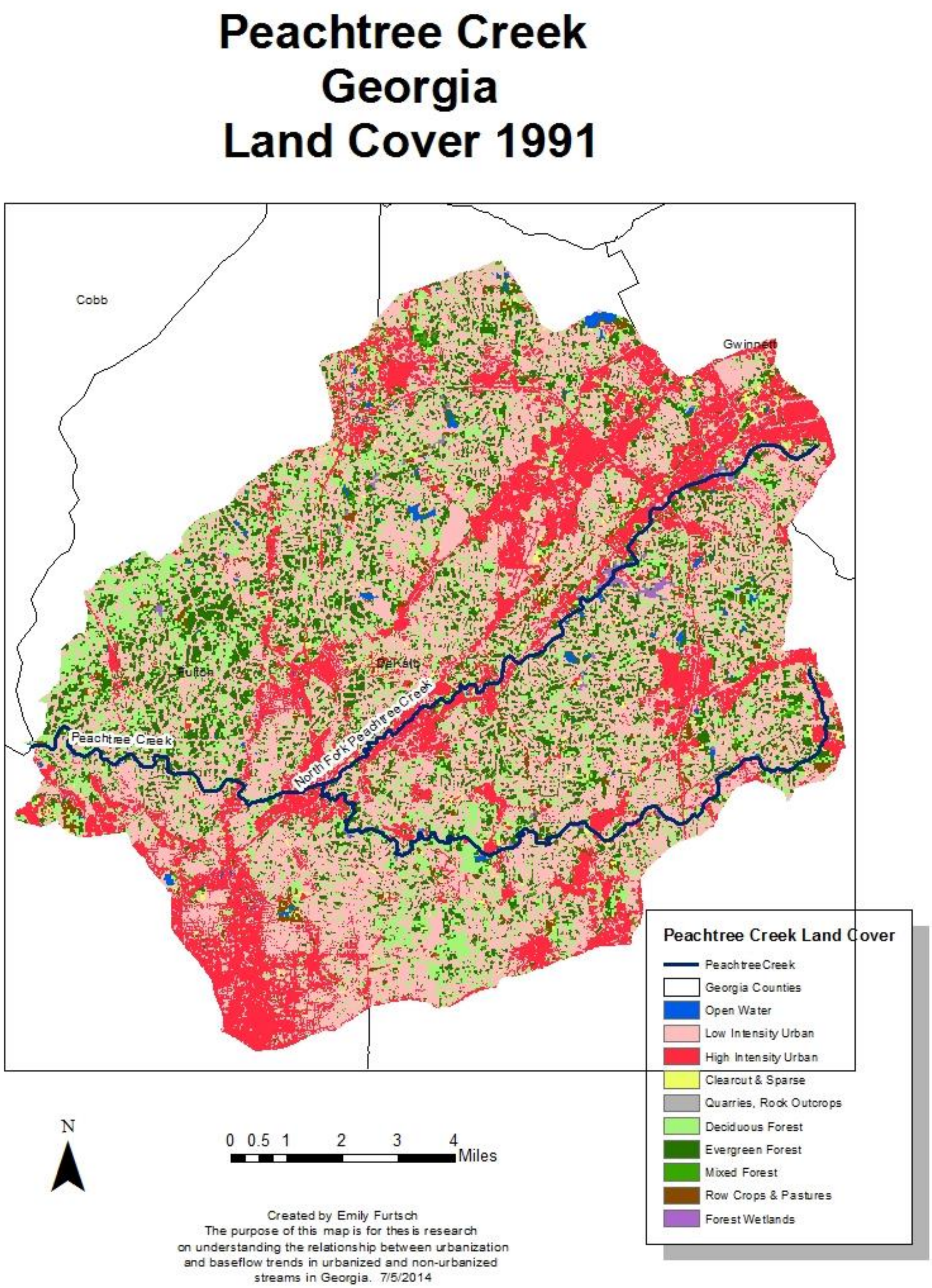

Figure 1.7.5 Peachtree Creek 1991 Land Cover

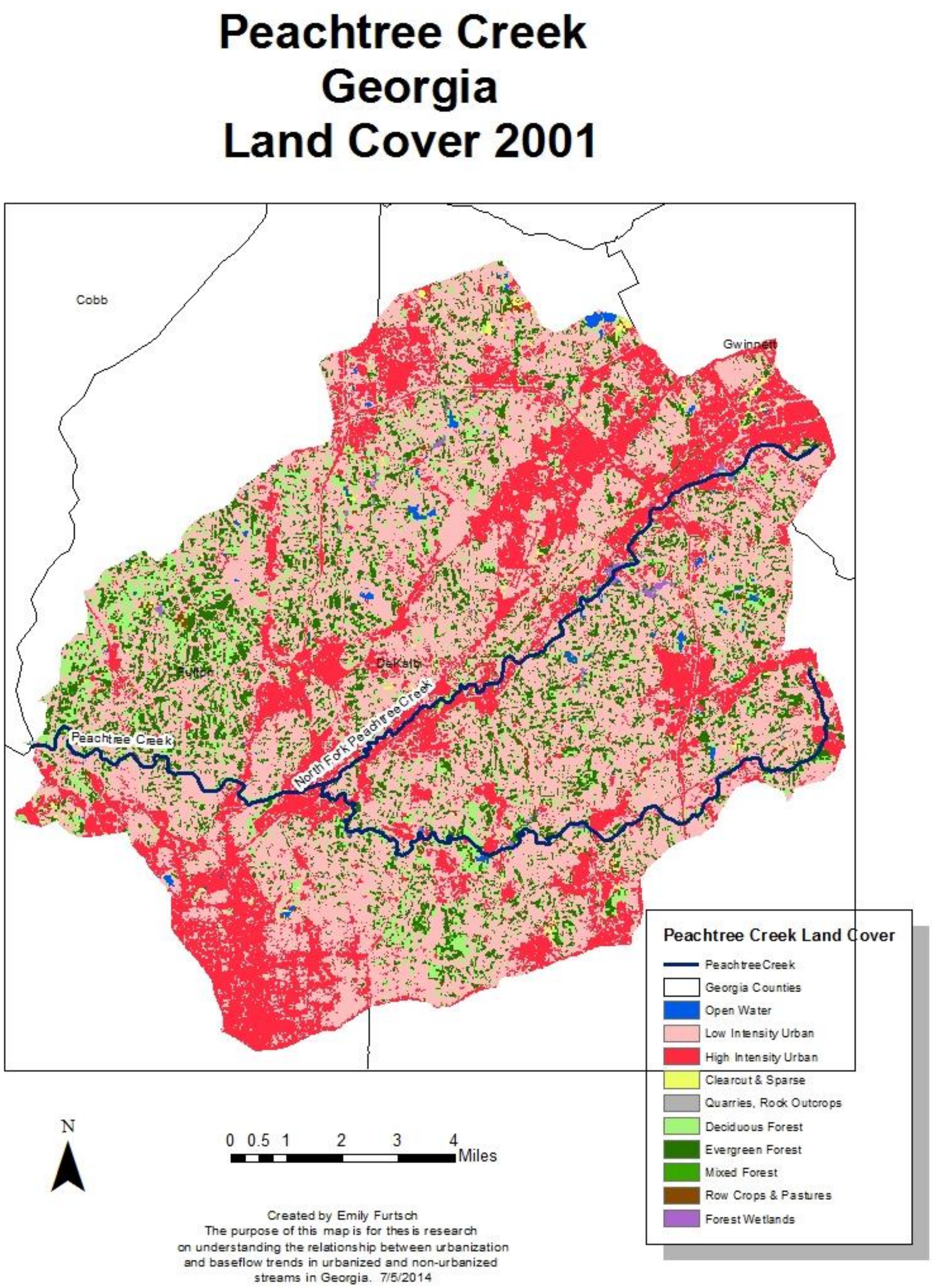

Figure 1.7.6 Peachtree Creek 2001 Land Cover

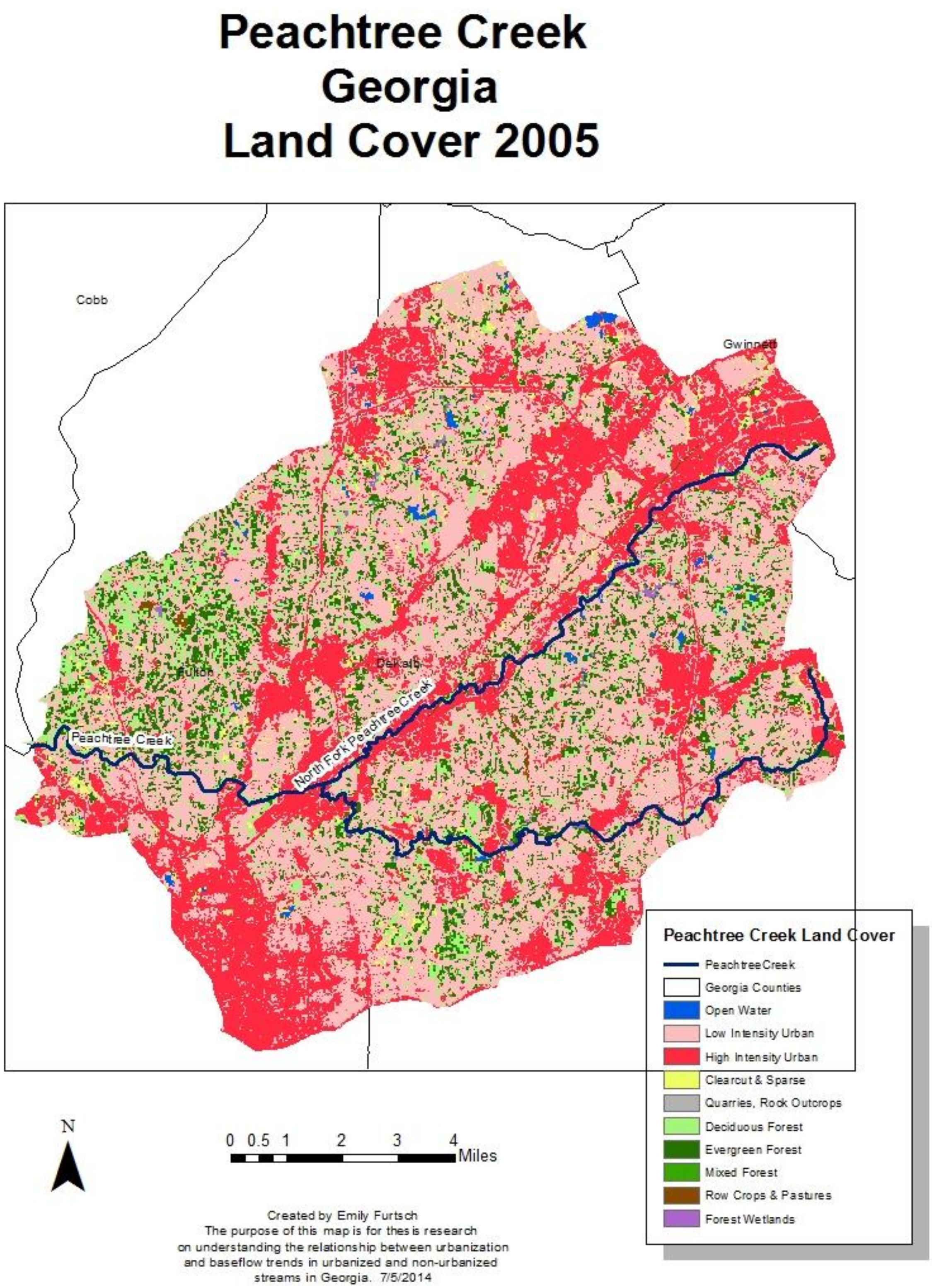

Figure 1.7.7 Peachtree Creek 2005 Land Cover

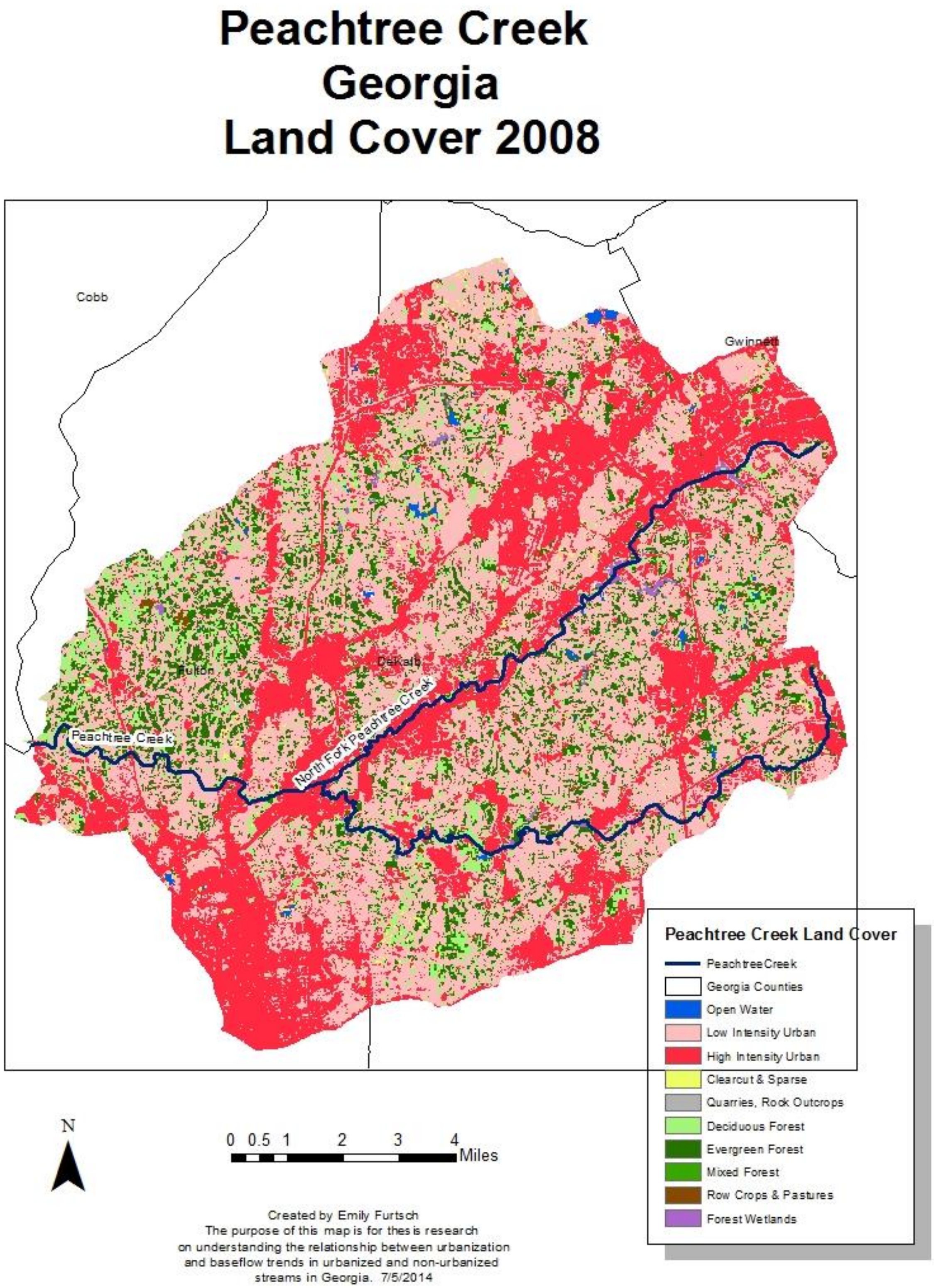

Figure 1.7.8 Peachtree Creek 2008 Land Cover

1.7.2 South River

The Mann-Kendall test results show all four baseflow percentiles had no trend (Table 3.1). The trend test revealed total urban land use, high-intensity land use, and low-intensity land use are all increasing. No trend was found for population by Census tract.

The correlation analysis results for the 5th percentile stream flow found a correlation between baseflow and population by Census tract, total urban land use, and low intensity urban land use (Table 3.1). Population by Census tract and the 5th percentile flow had the strongest correlation with an r value of 0.98 and a p value of 0.02036. The 10th percentile baseflow had a correlation with all parameters (Table 3.2). The population parameter had the strongest correlation with an r value of 0.96. In the 25th percentile a correlation was found between the baseflow and all of the parameters (Table 3.3). Population by Census tract had the strongest positive correlation with an r value of 0.98 and a p value of 0.02379. The 50th percentile baseflow showed no correlation with any of the parameters (Table 3.4). The null hypothesis was not rejected in any of the 50th percentile correlation analyses.

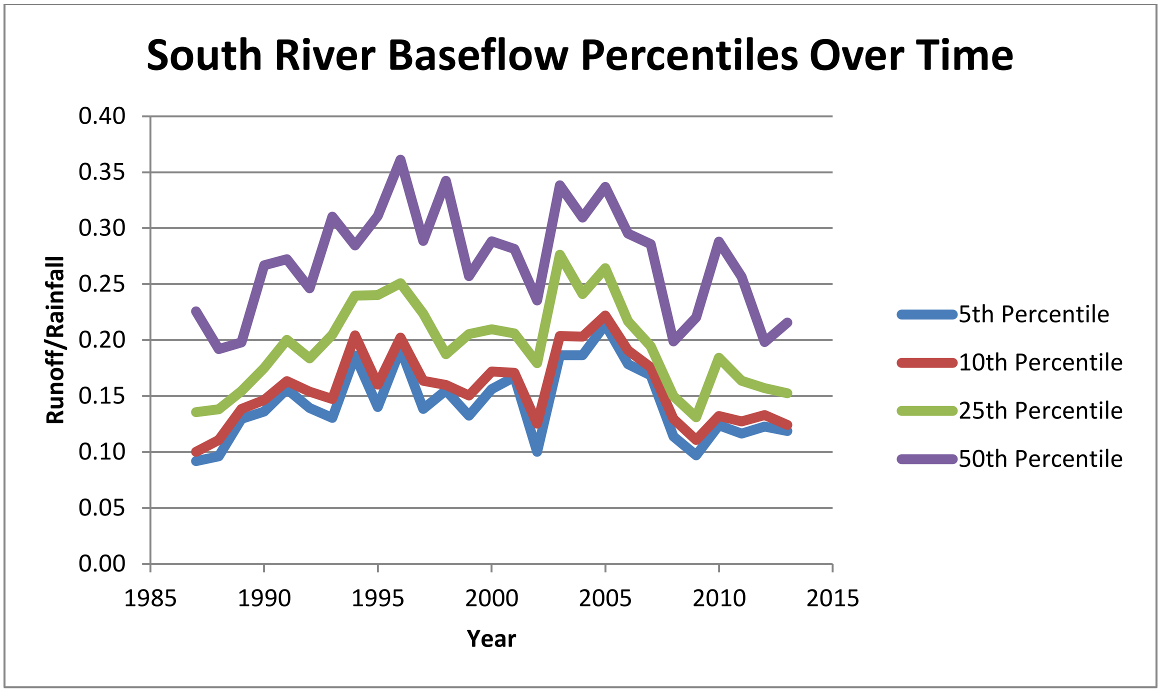

Figure 1.7.9 South River Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for South River, an urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis.

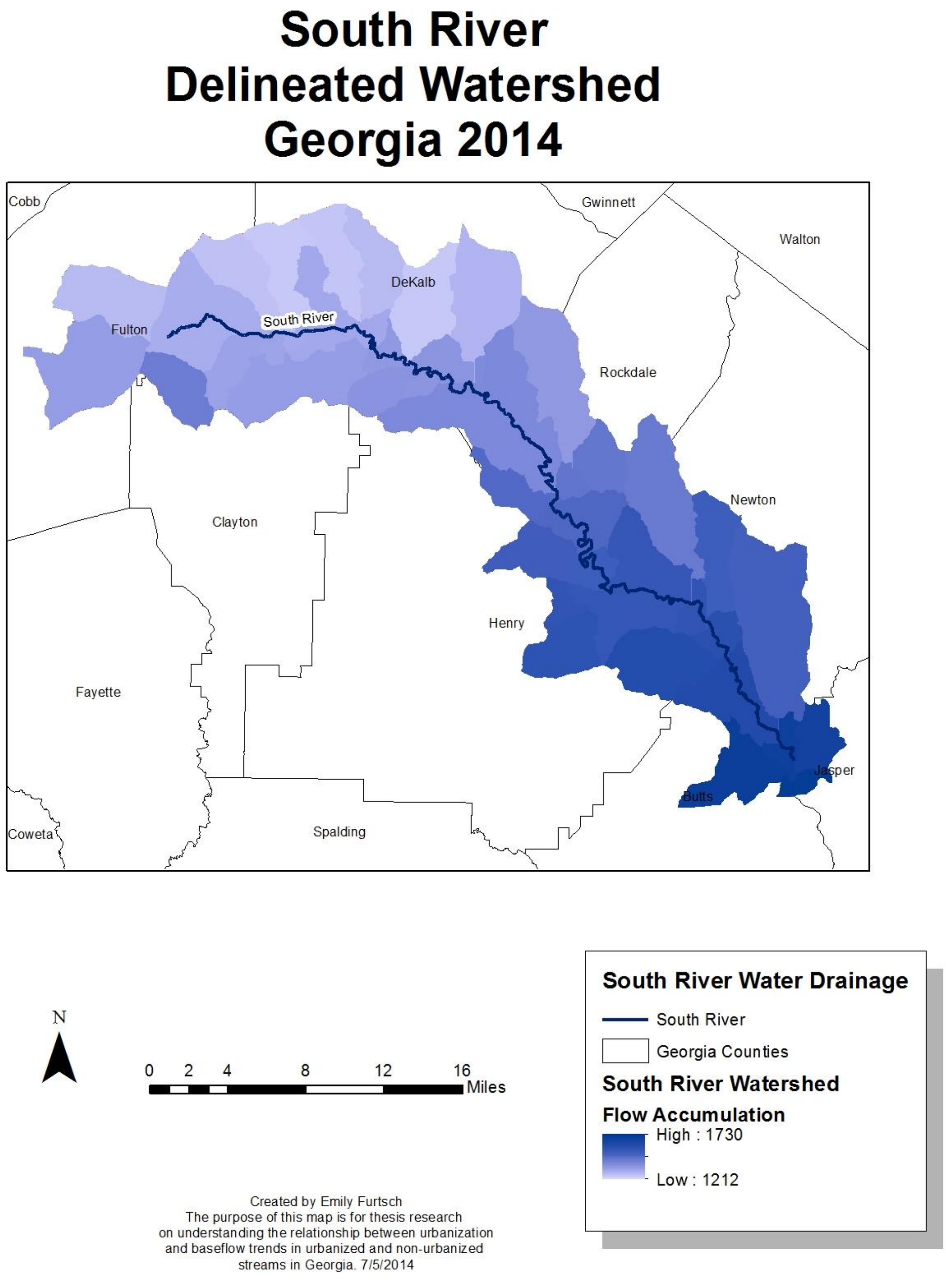

Figure 1.7.10 South River Watershed

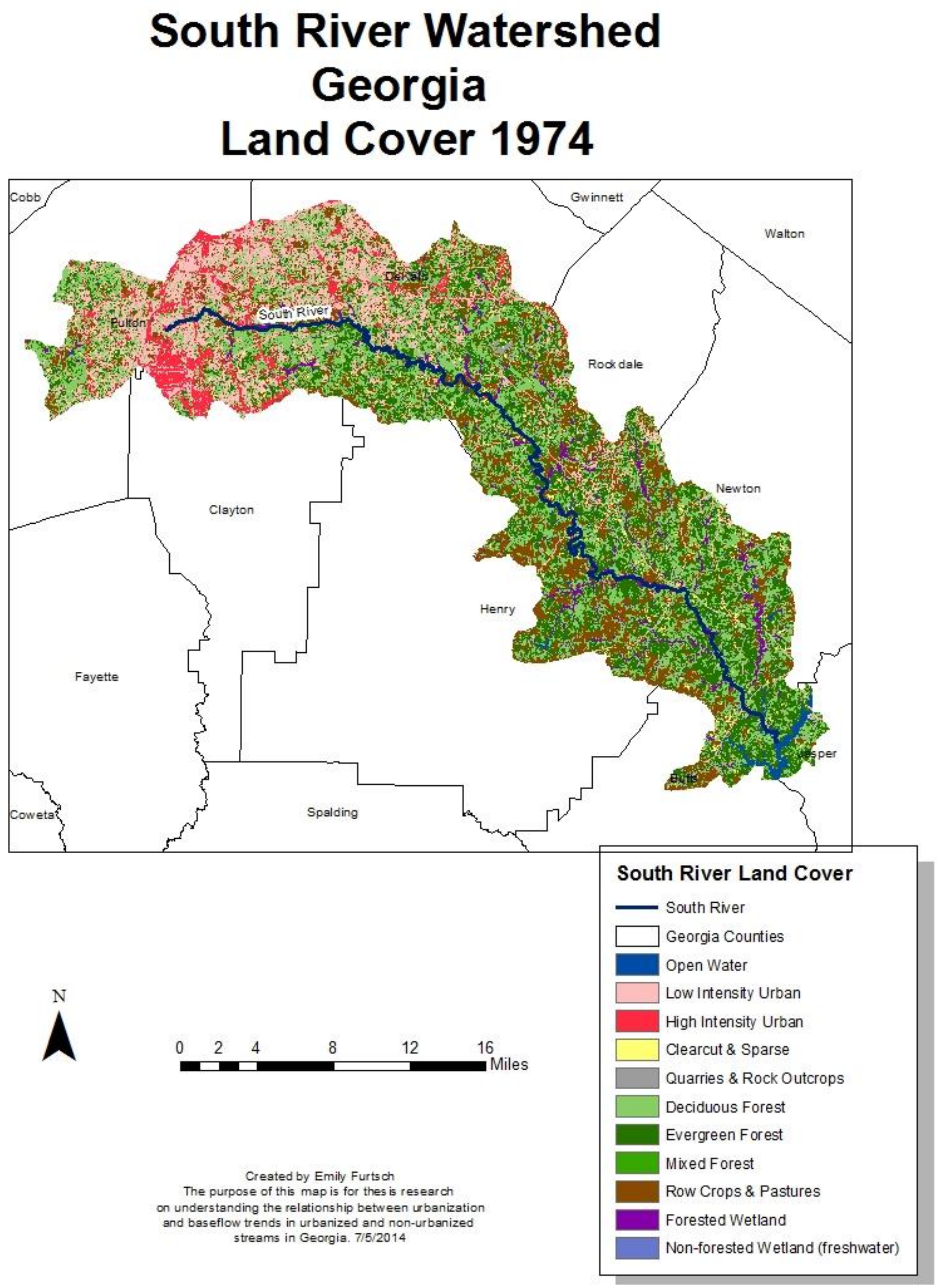

Figure 1.7.11 South River 1974 Land Cover

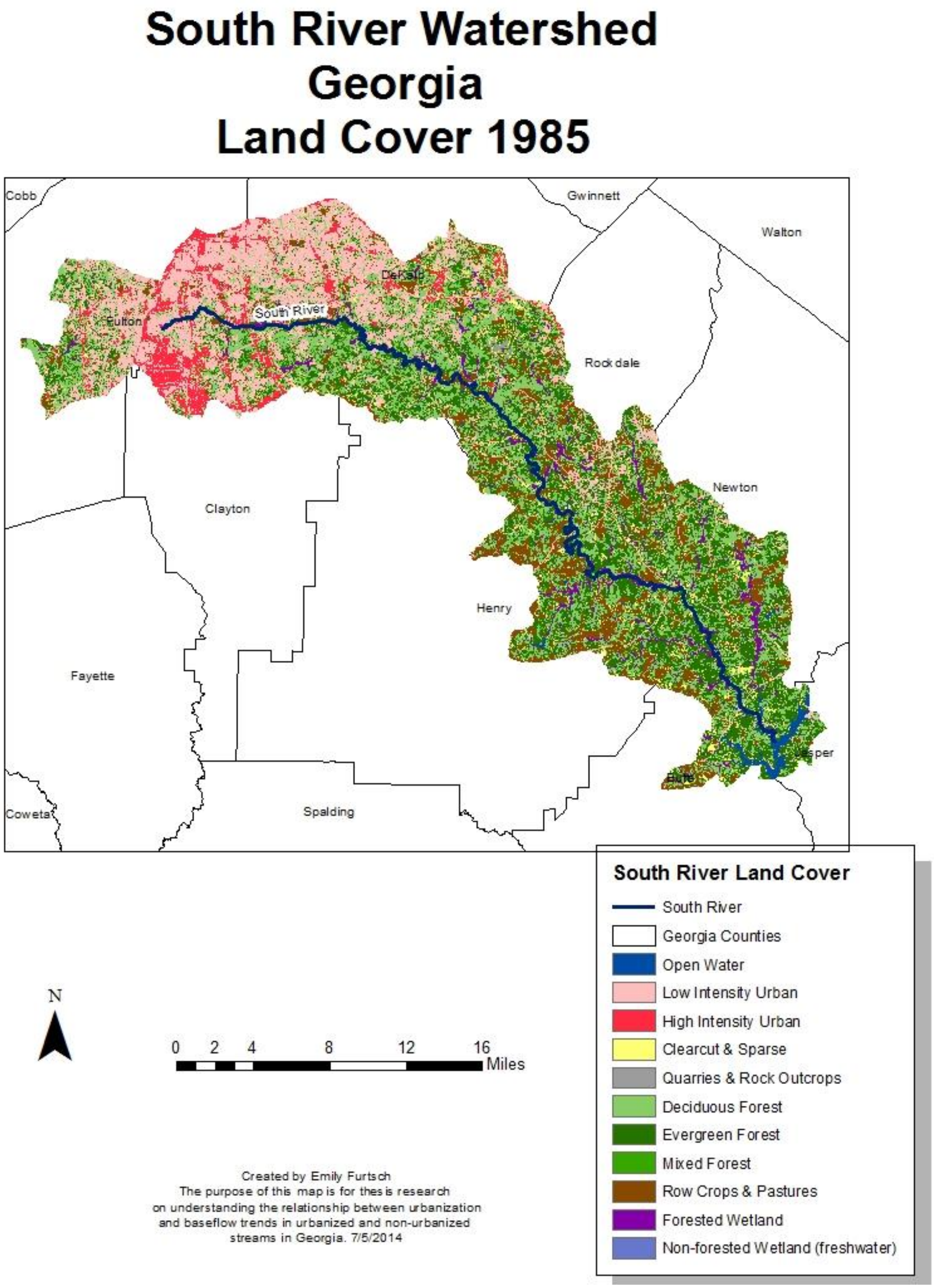

Figure 1.7.12 South River 1985 Land Cover

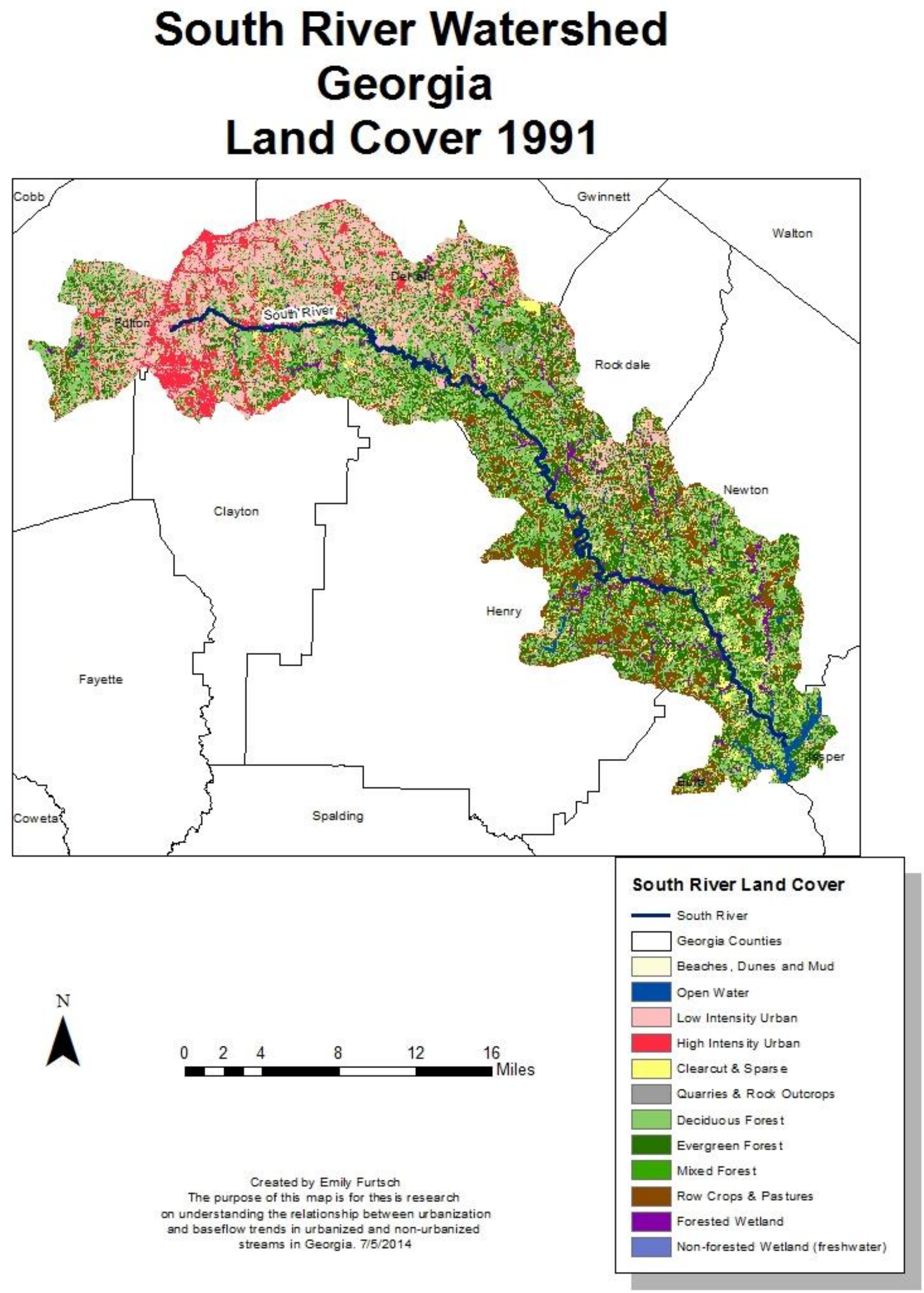

Figure 1.7.13 South River 1991 Land Cover

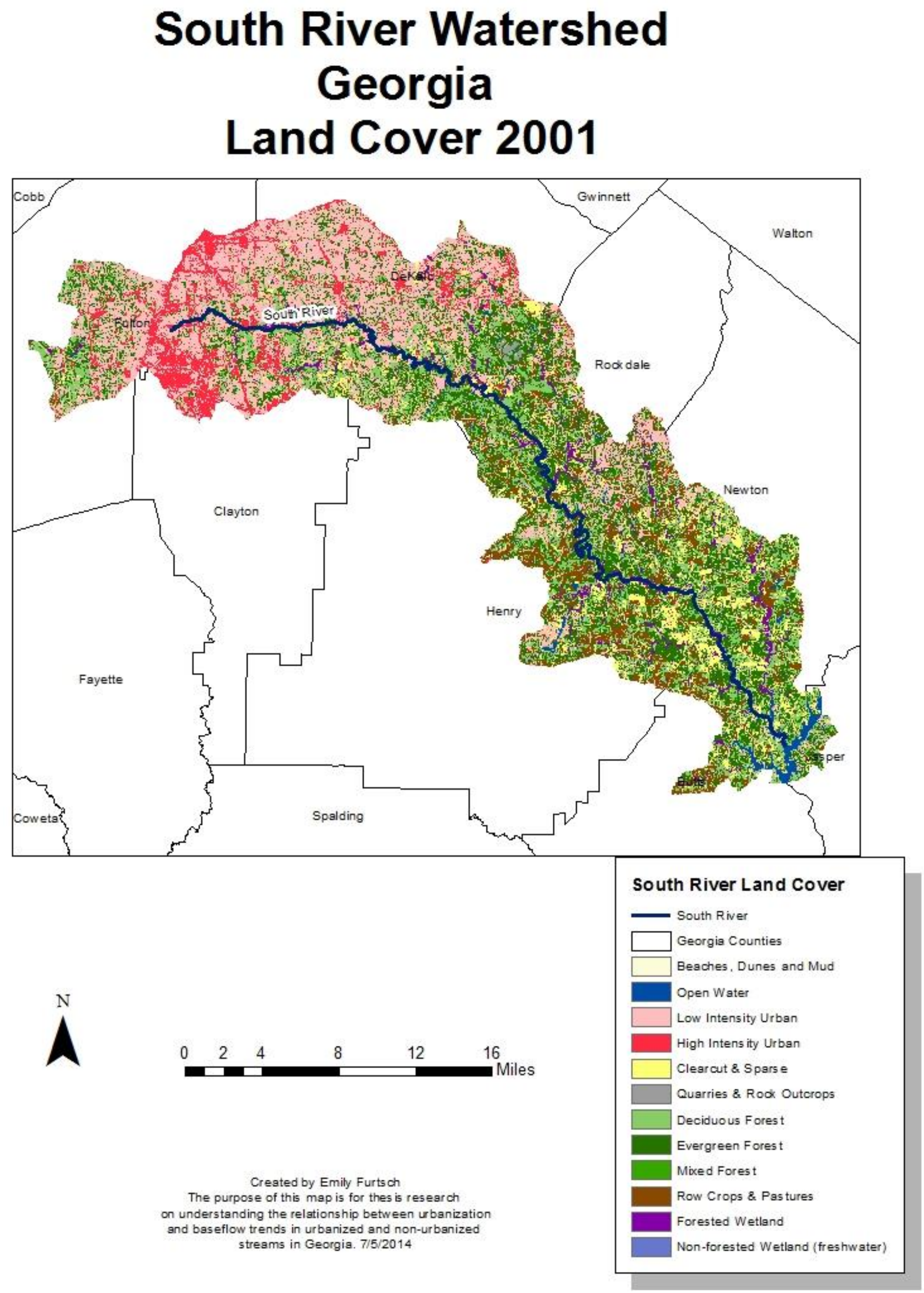

Figure 1.7.14 South River 2001 Land Cover

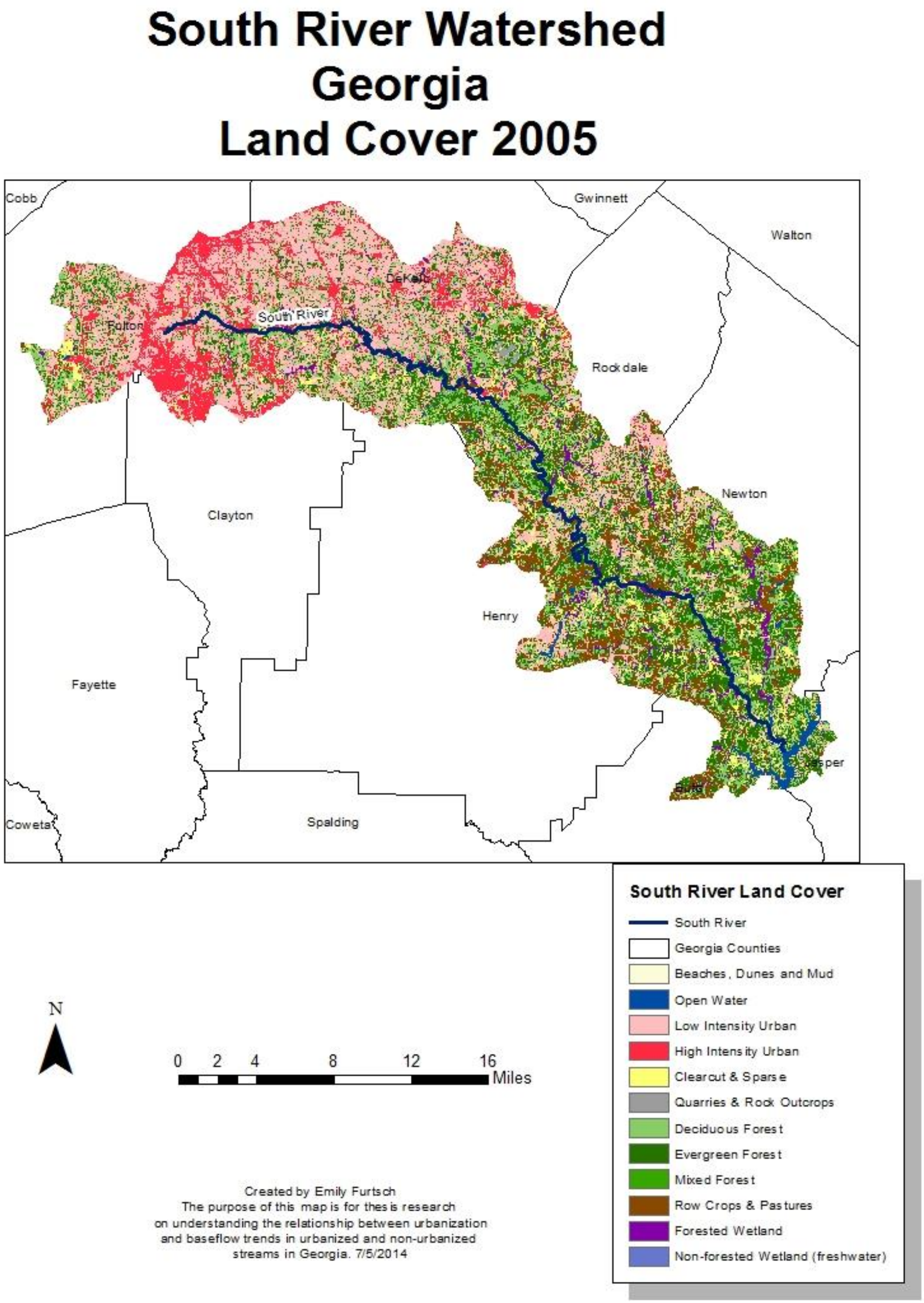

Figure 1.7.15 South River 2005 Land Cover

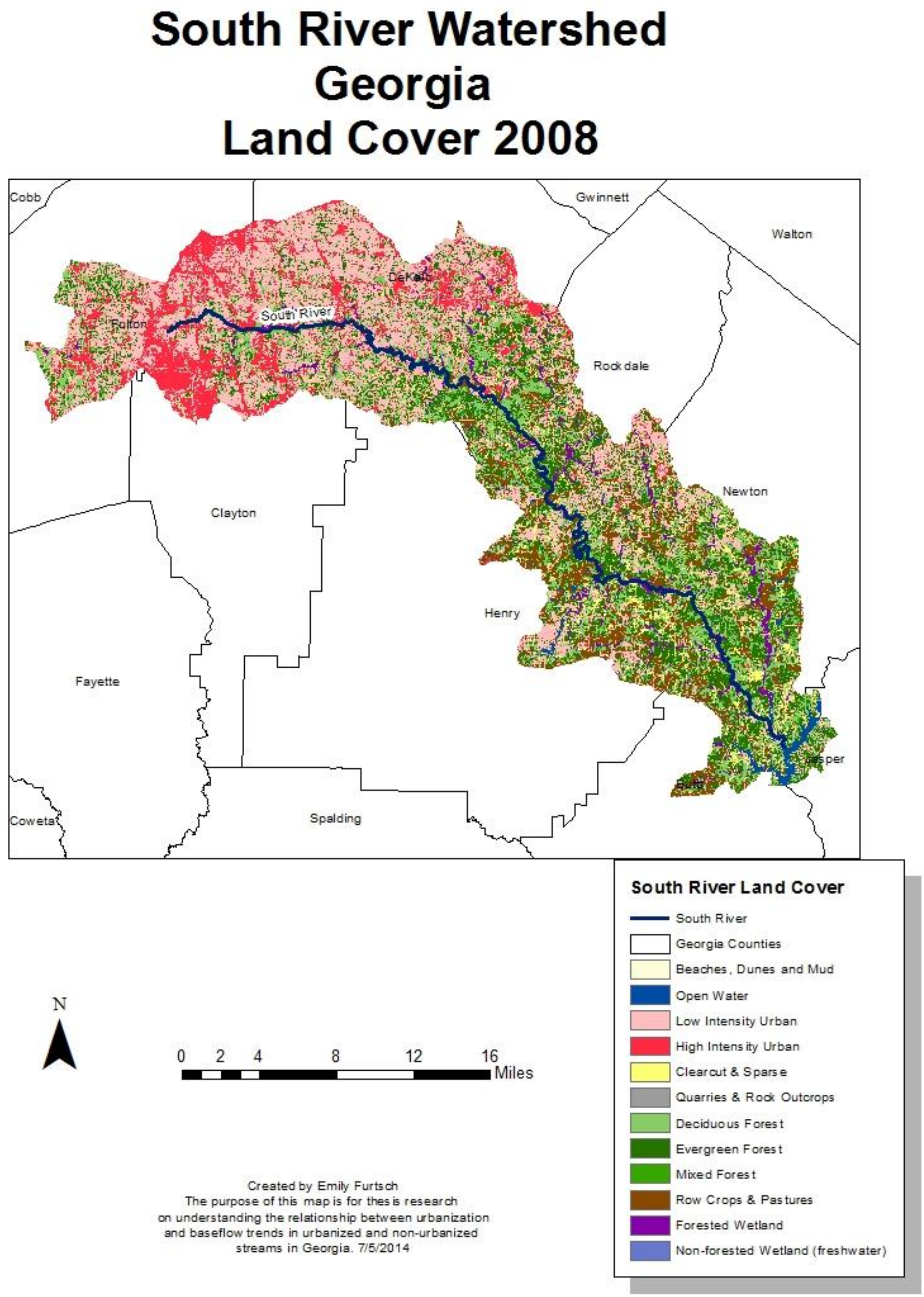

Figure 1.7.16 South River 2008 Land Cover

1.7.3 Suwanee Creek

A Mann-Kendall trend analysis on the parameters showed all four parameters were increasing with confidence factors between 95.8% to 99.9%. A Mann-Kendall trend analysis found that Suwanee Creek baseflow trends were stable in the 5th, 10th, and 25th percentile, but no trend in the 50th percentile (Tables 3.1-3.4).

Correlation analysis revealed a correlation between the 5th percentile baseflow and three urbanization parameters (population by Census Tract, total urban land use and low-intensity urban land use) (Table 3.1). The 10th percentile baseflow had a positive correlation with population by Census tract (Tables 3.1 and 3.2). There was no correlation between any of the parameters and the 25th percentile. A correlation was found between 50th percentile baseflow and all parameters (Table 3.3 and 3.4). The strongest relationship was with population by Census tract.

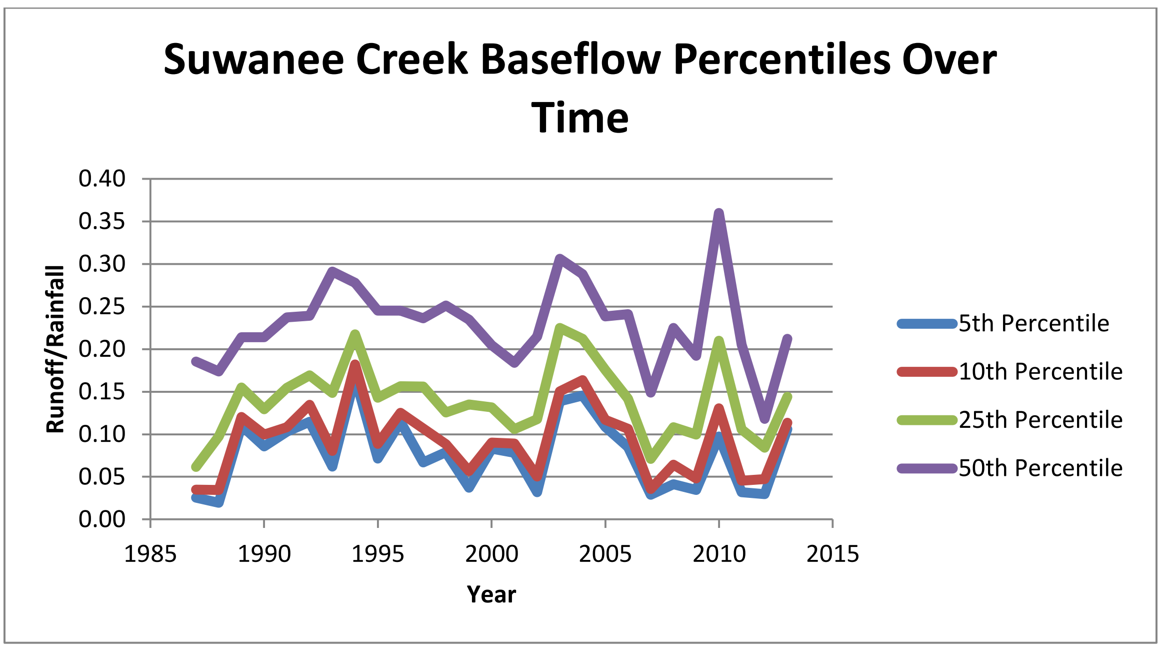

Figure 1.7.17 Suwanee Creek Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Suwanee Creek, an urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis.

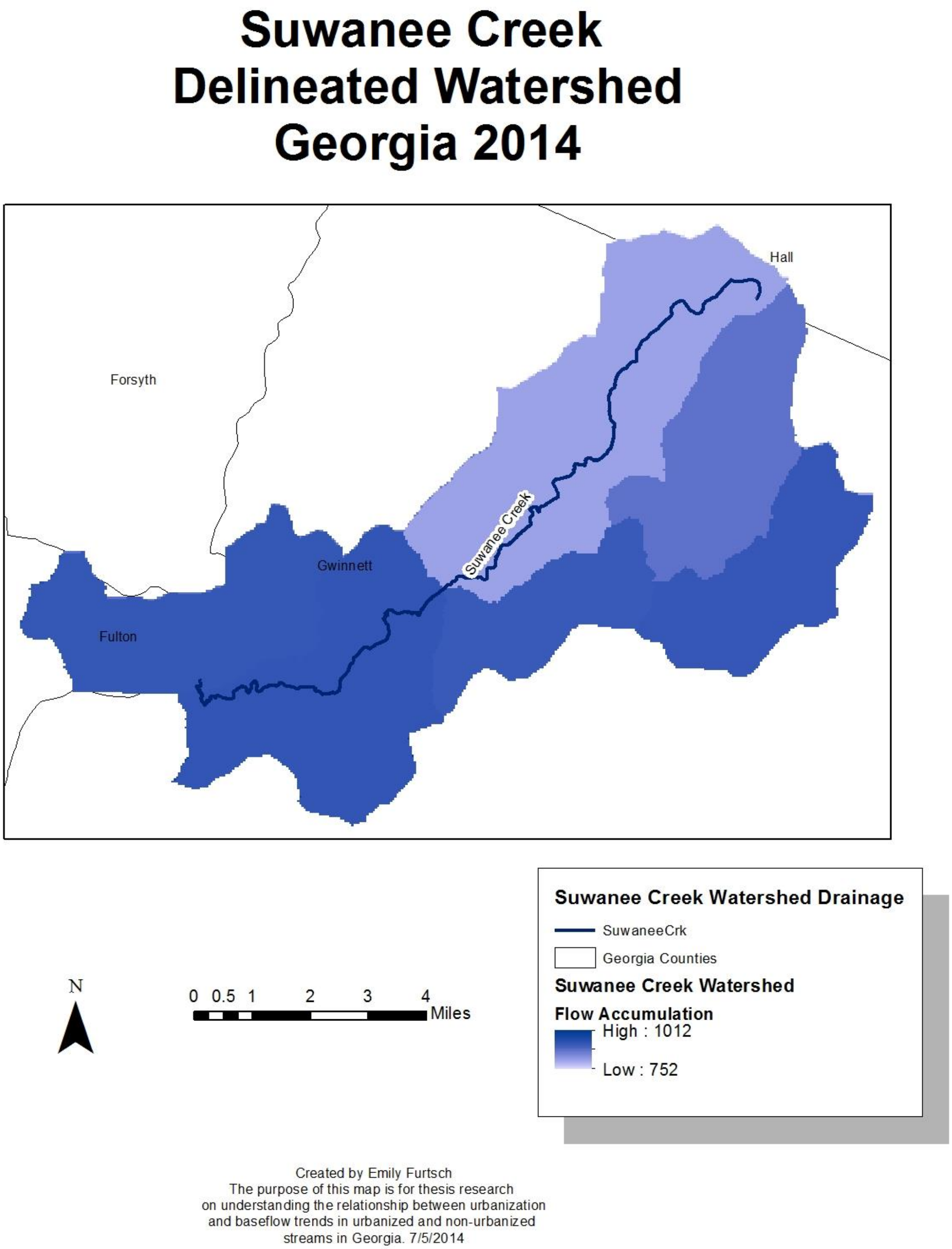

Figure 1.7.18 Suwanee Creek Watershed

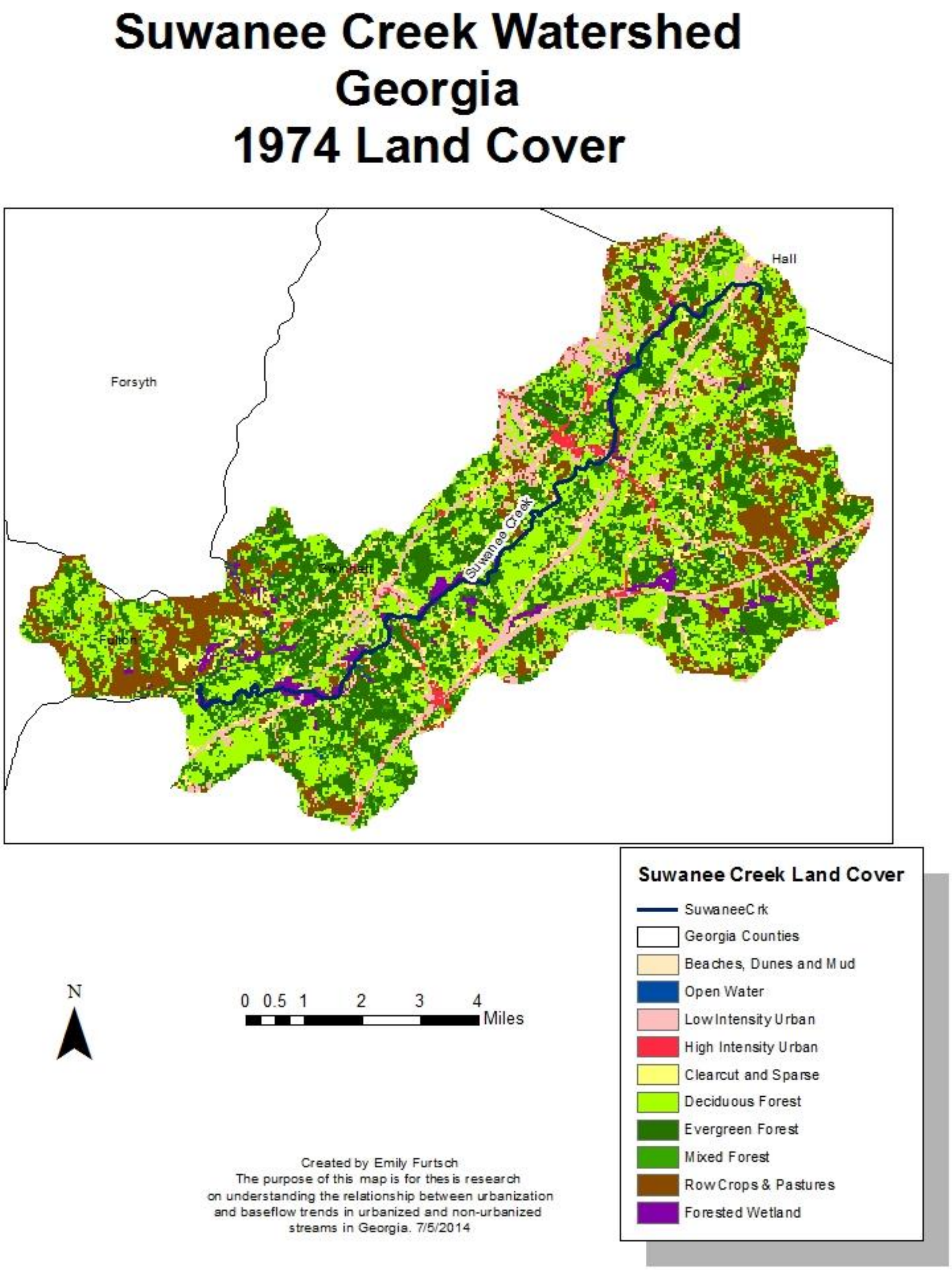

Figure 1.7.19 Suwanee Creek 1974 Land Cover

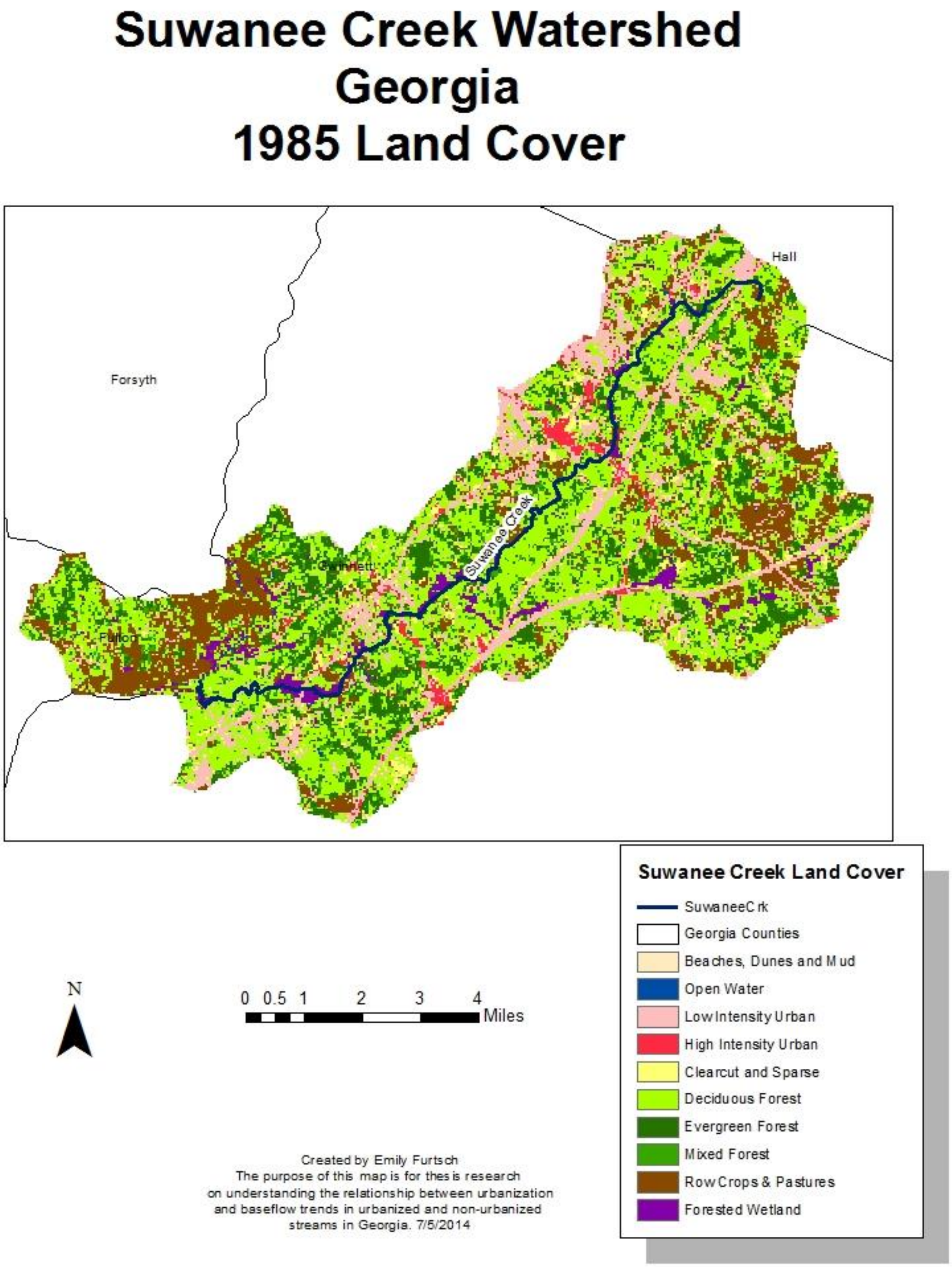

Figure 1.7.20 Suwanee Creek 1985 Land Cover

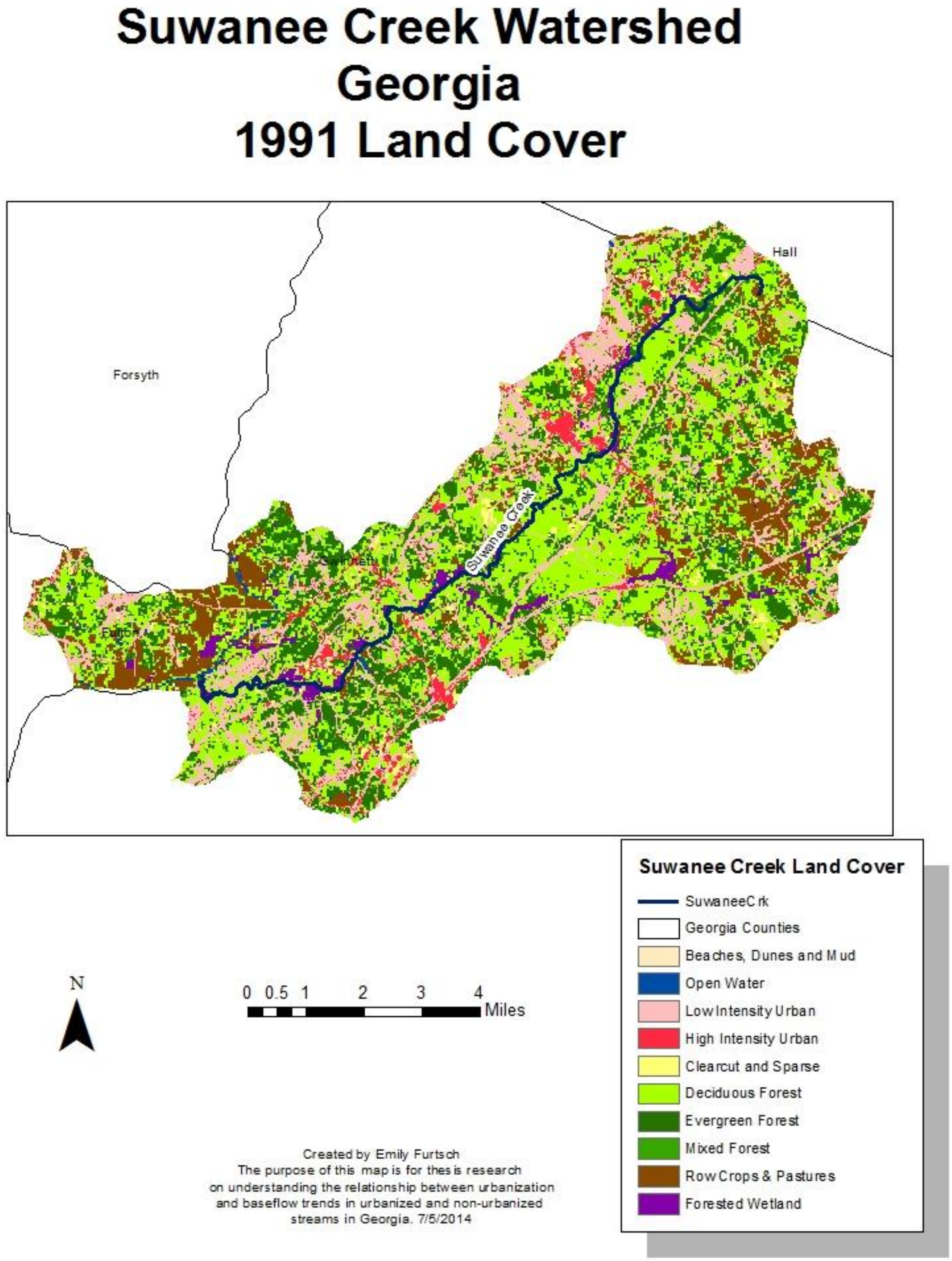

Figure 1.7.21 Suwanee Creek 1991 Land Cover

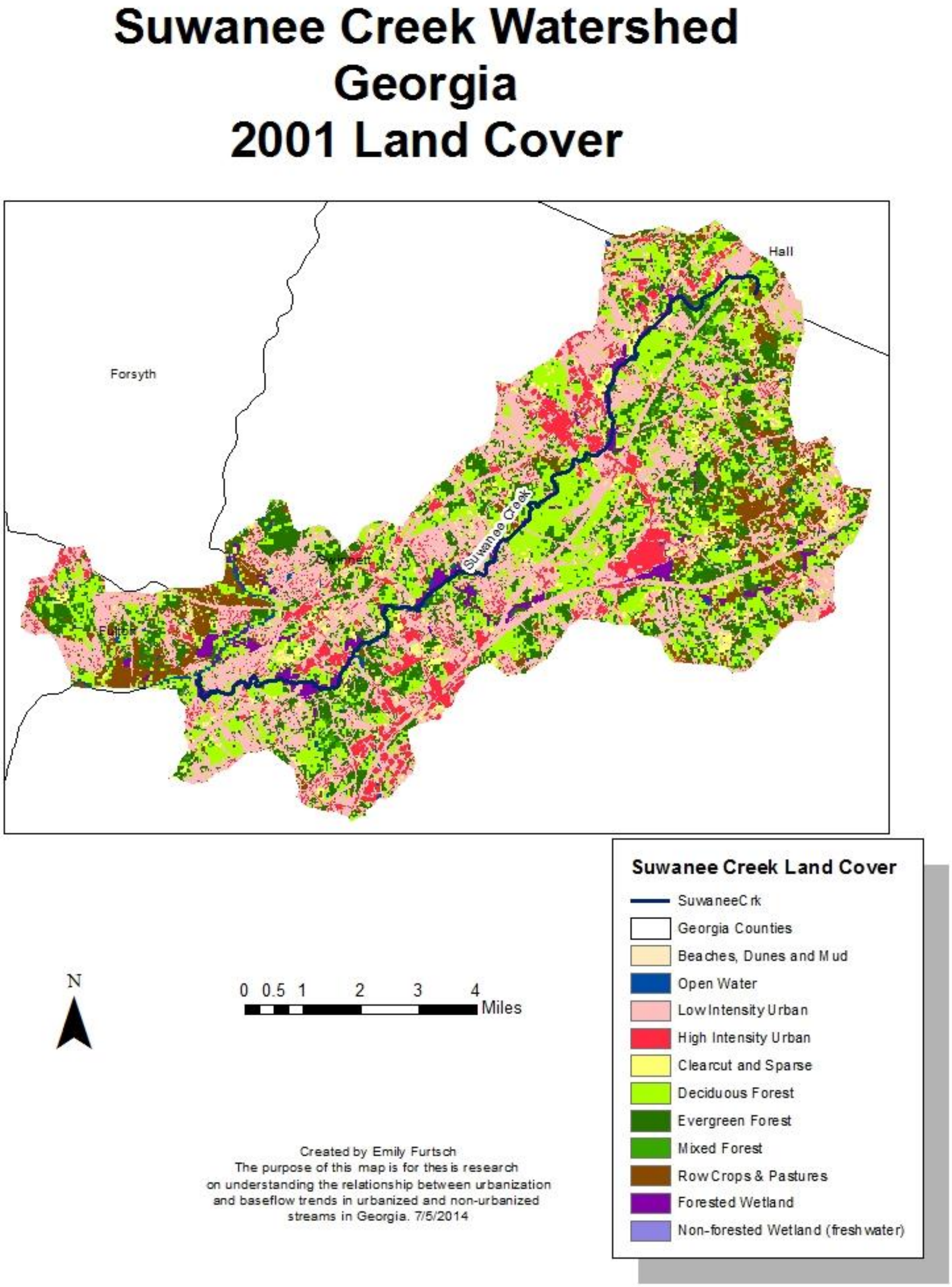

Figure 1.7.22 Suwanee Creek 2001 Land Cover

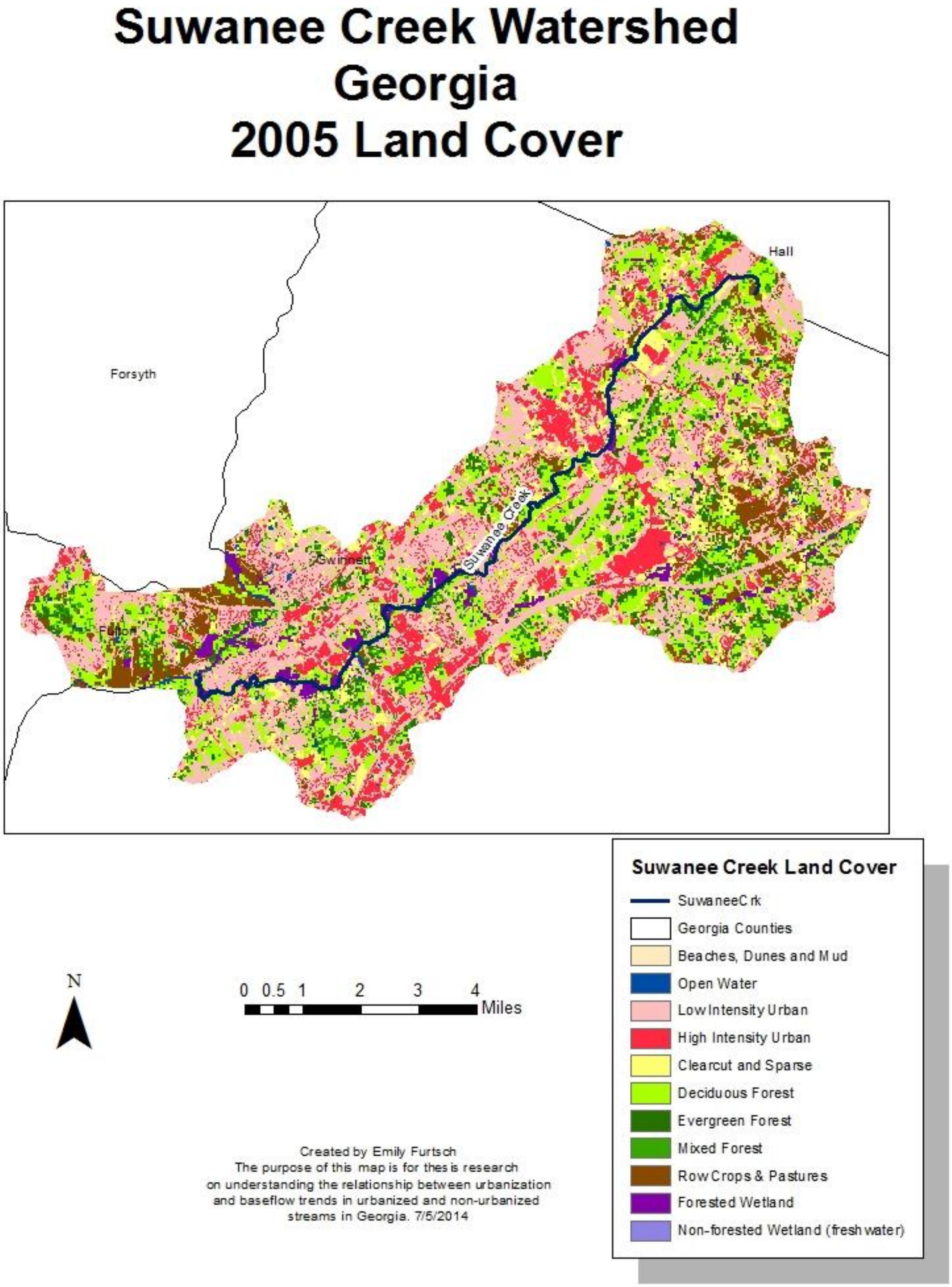

Figure 1.7.23 Suwanee Creek 2005 Land Cover

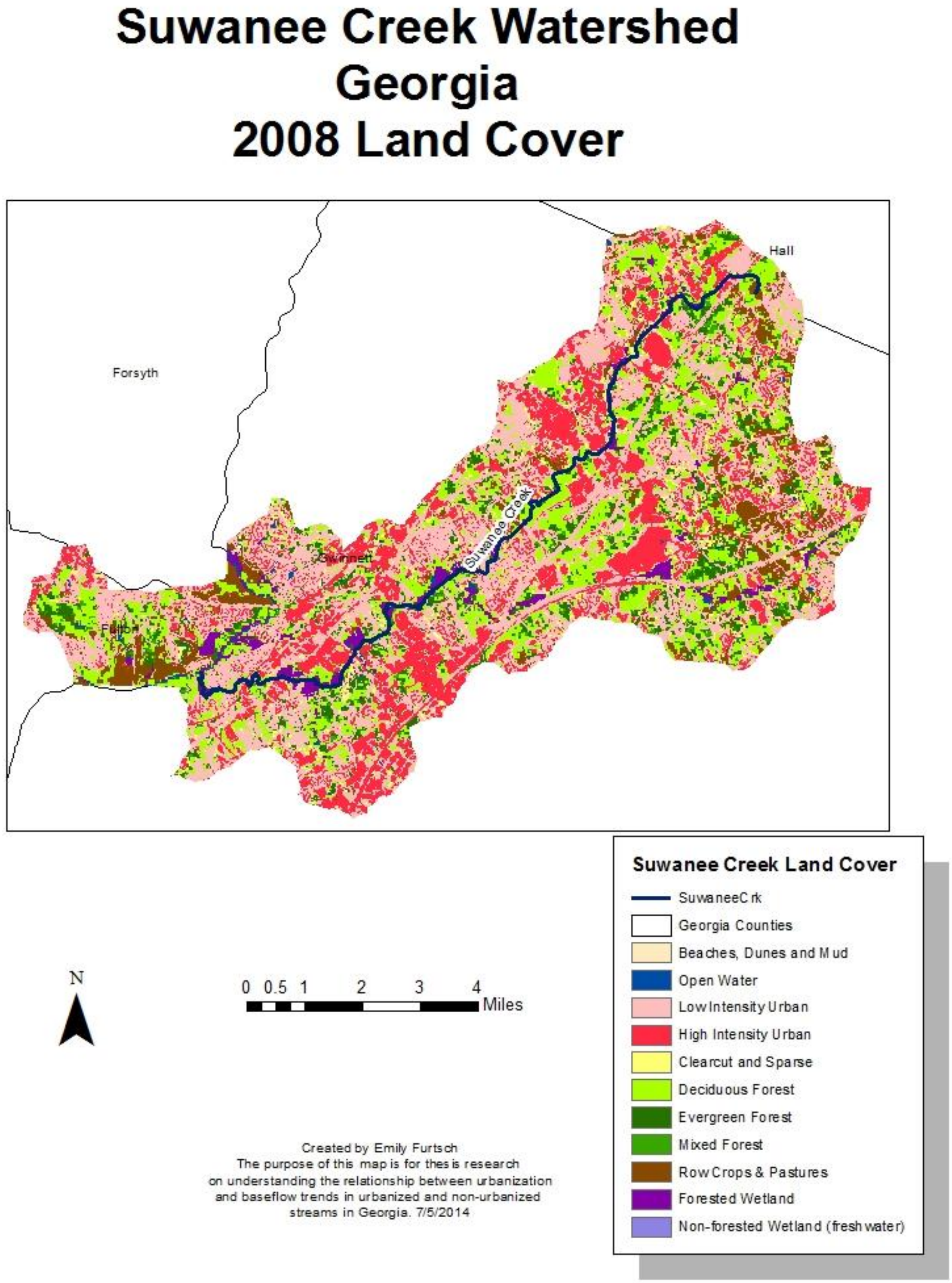

Figure 1.7.24 Suwanee Creek 2008 Land Cover

1.7.4 Big Creek

The Mann-Kendall test for population indicates that there is an overall increasing trend from 1980-2010 for both Census tract. All three urban land use parameters (low-intensity, high-intensity, and total urban) are increasing as well. The Mann-Kendall test found that baseflow in the 5th, 10th, 25th and 50th percentiles is stable (Tables 3.1-3.4).

The correlation analysis results showed no correlation between 5th and 50th percentile baseflows and the urbanization parameters (Table 3.1 and 3.4). The 10th percentile flows rejected the null hypothesis and a correlation was observed between total urbanization (Table 3.2). In the 25th percentile the null hypothesis was rejected with all parameters; the strongest relationship observed was with population by Census tract (Table 3.3).

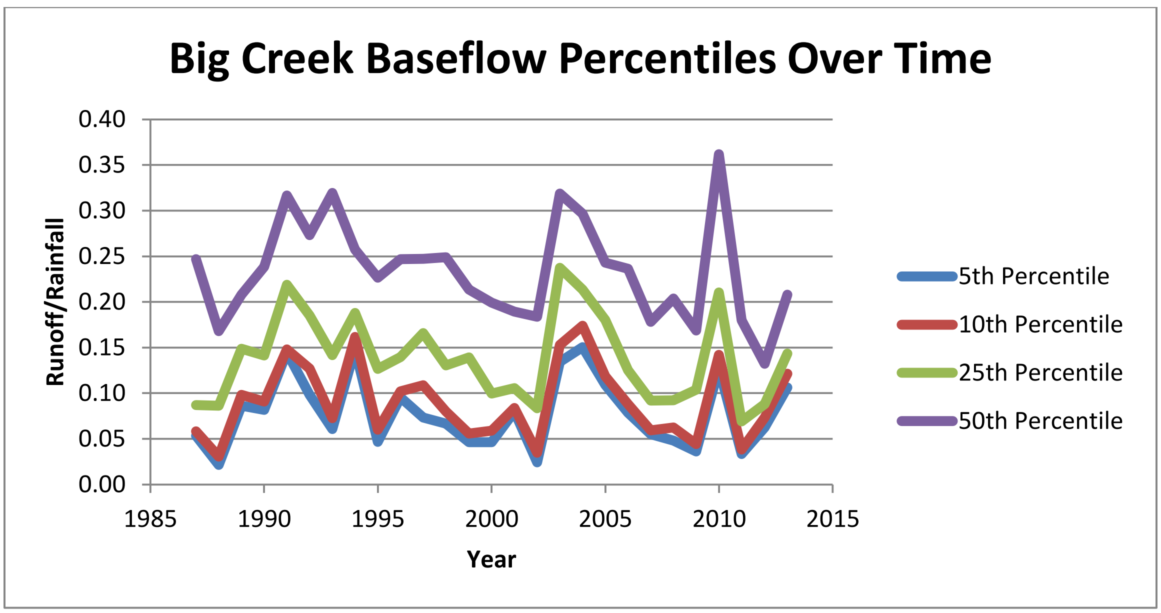

Figure 1.7.25 Big Creek Baseflows
The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Big Creek, an urbanized stream, plotted over time. No clear discernible pattern is visible without further statistical analysis.

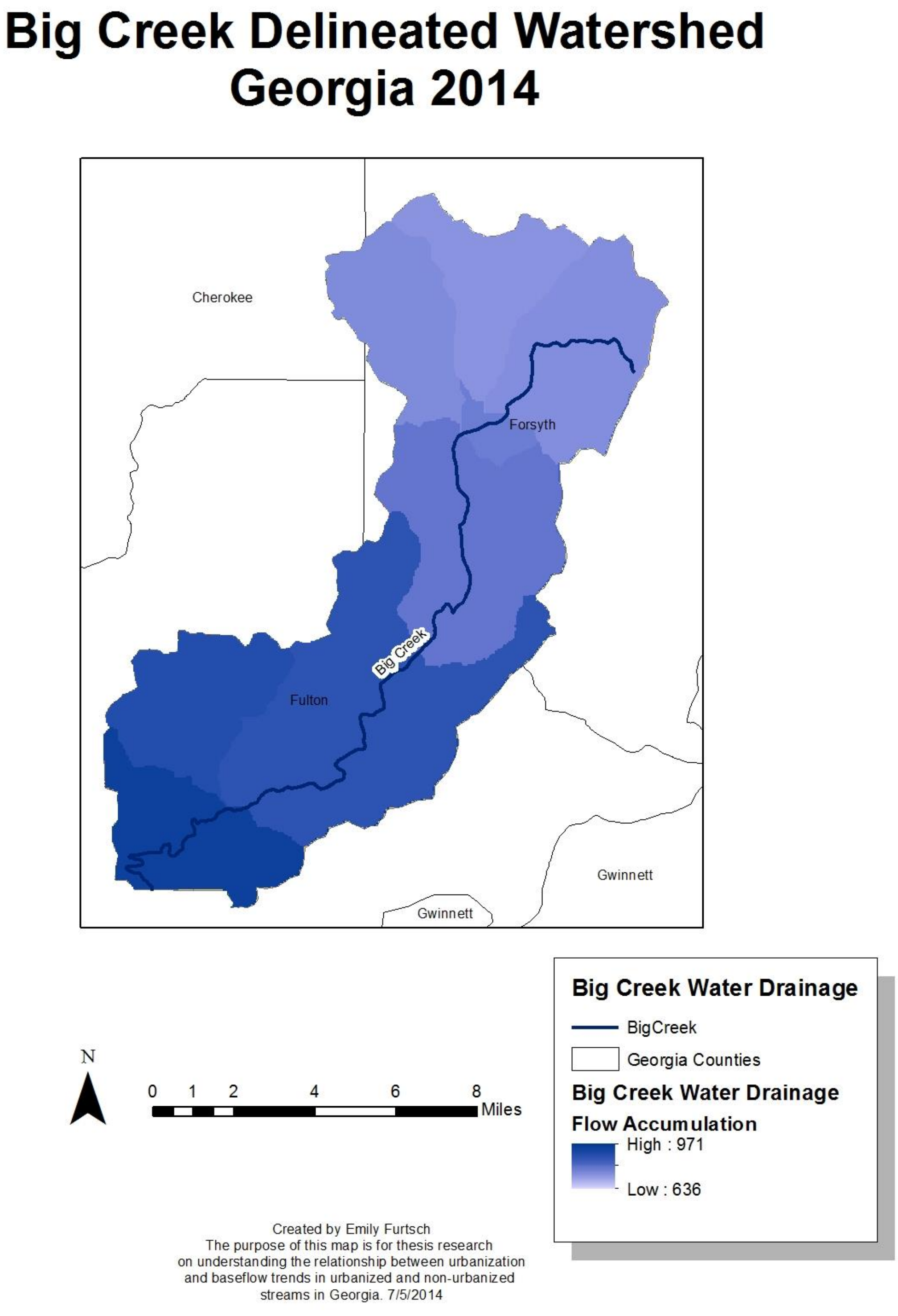

Figure 1.7.26 Big Creek Watershed

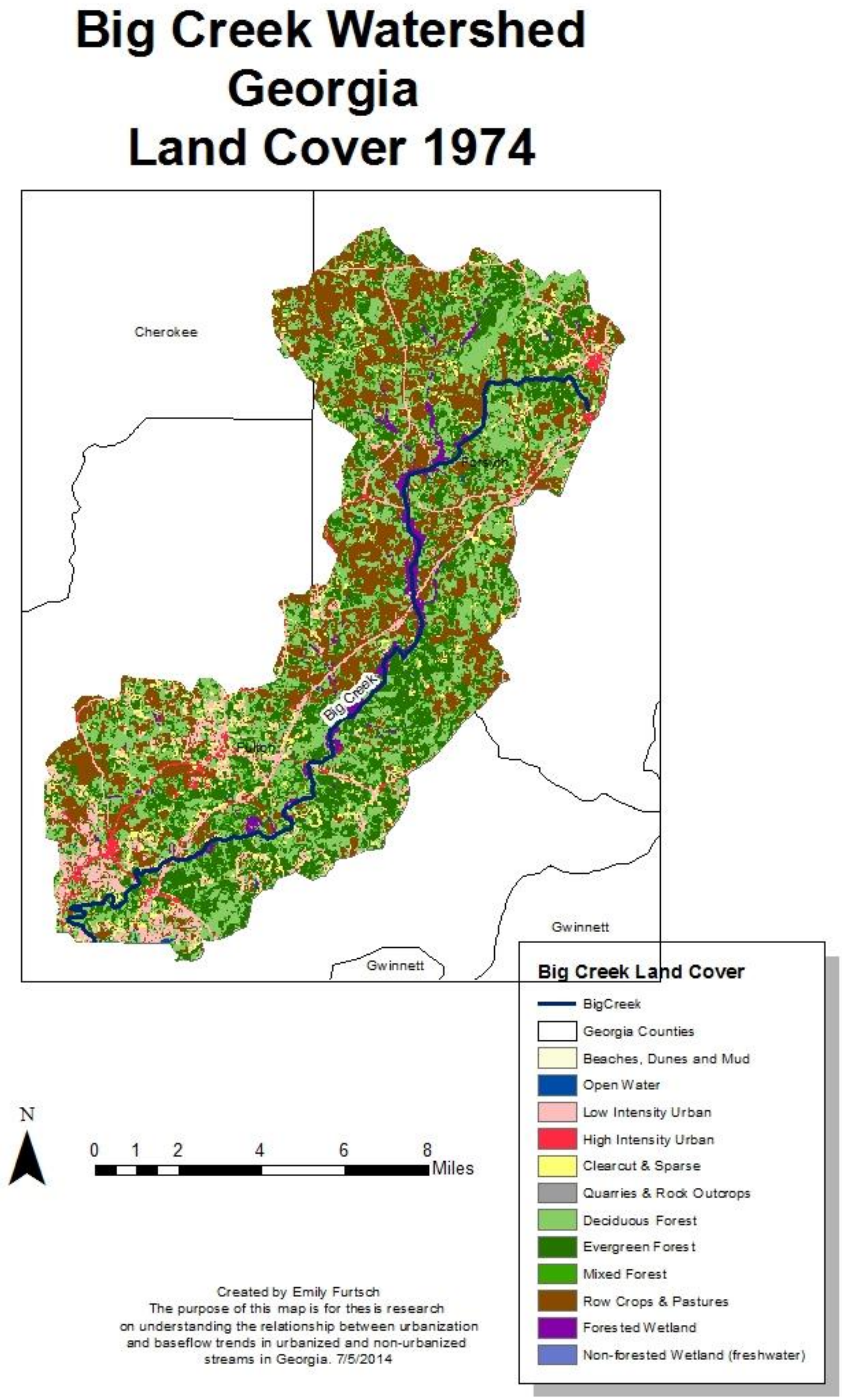

Figure 1.7.27 Big Creek 1974 Land Cover

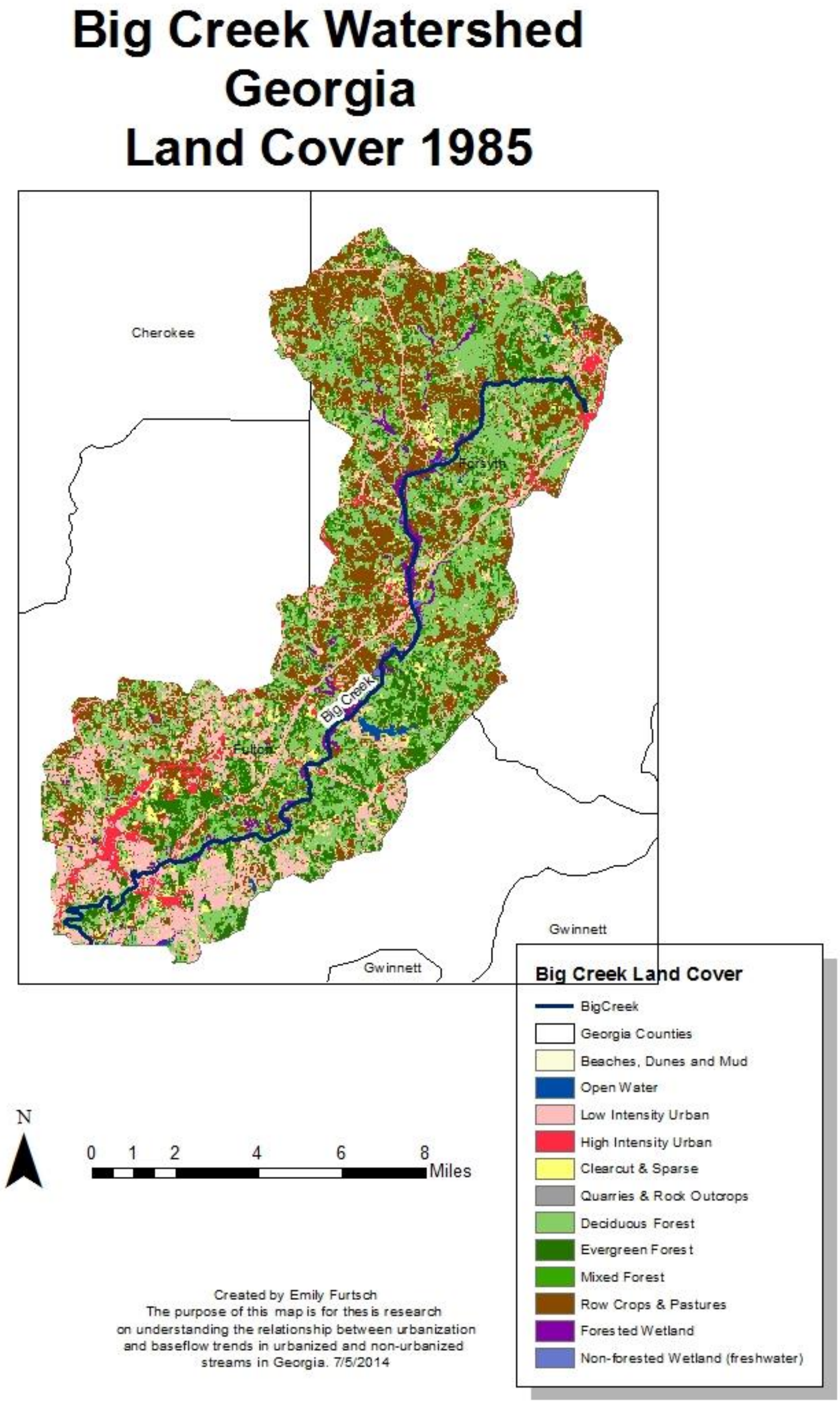

Figure 1.7.28 Big Creek 1985 Land Cover

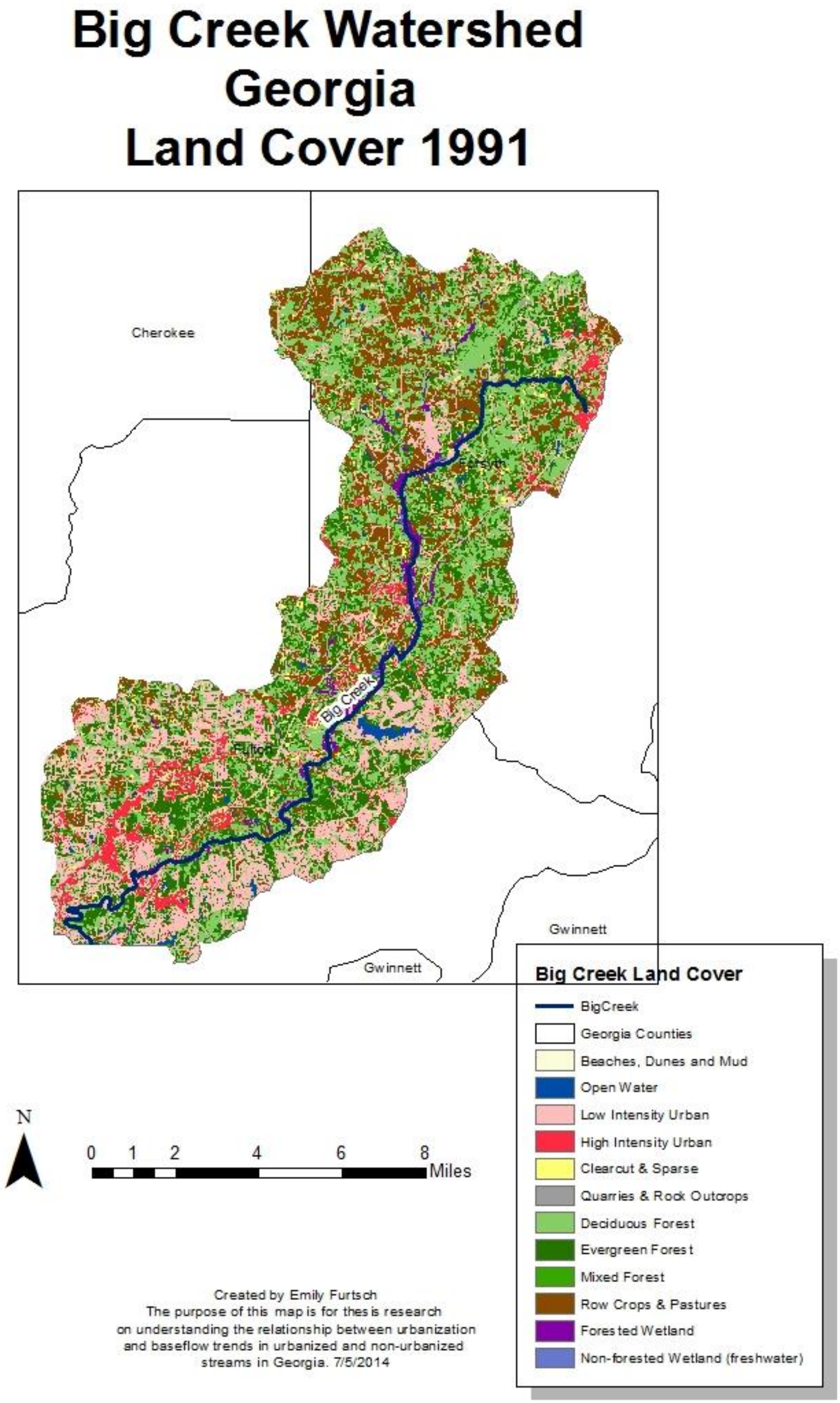

Figure 1.7.29 Big Creek 1991 Land Cover

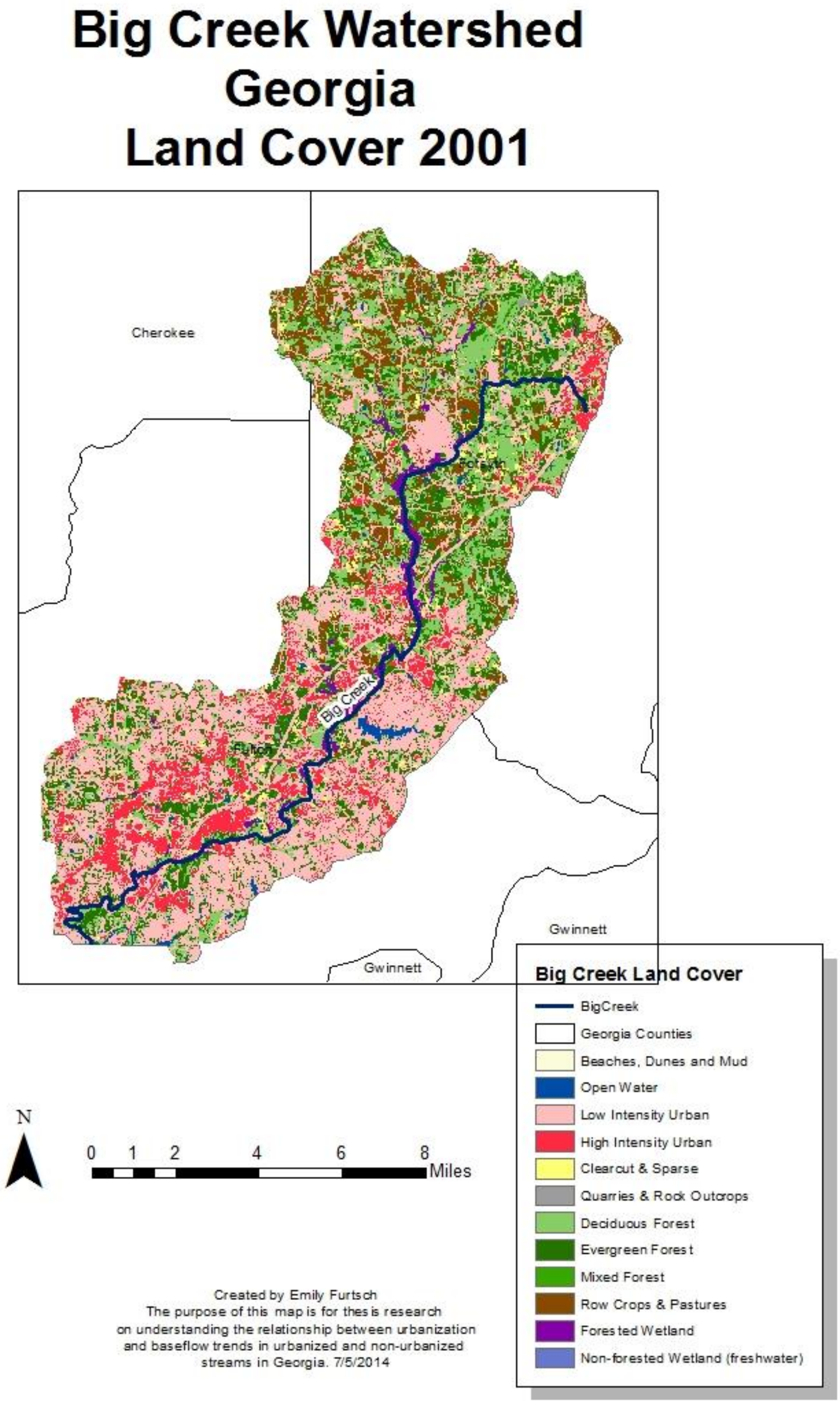

Figure 1.7.30 Big Creek 2001 Land Cover

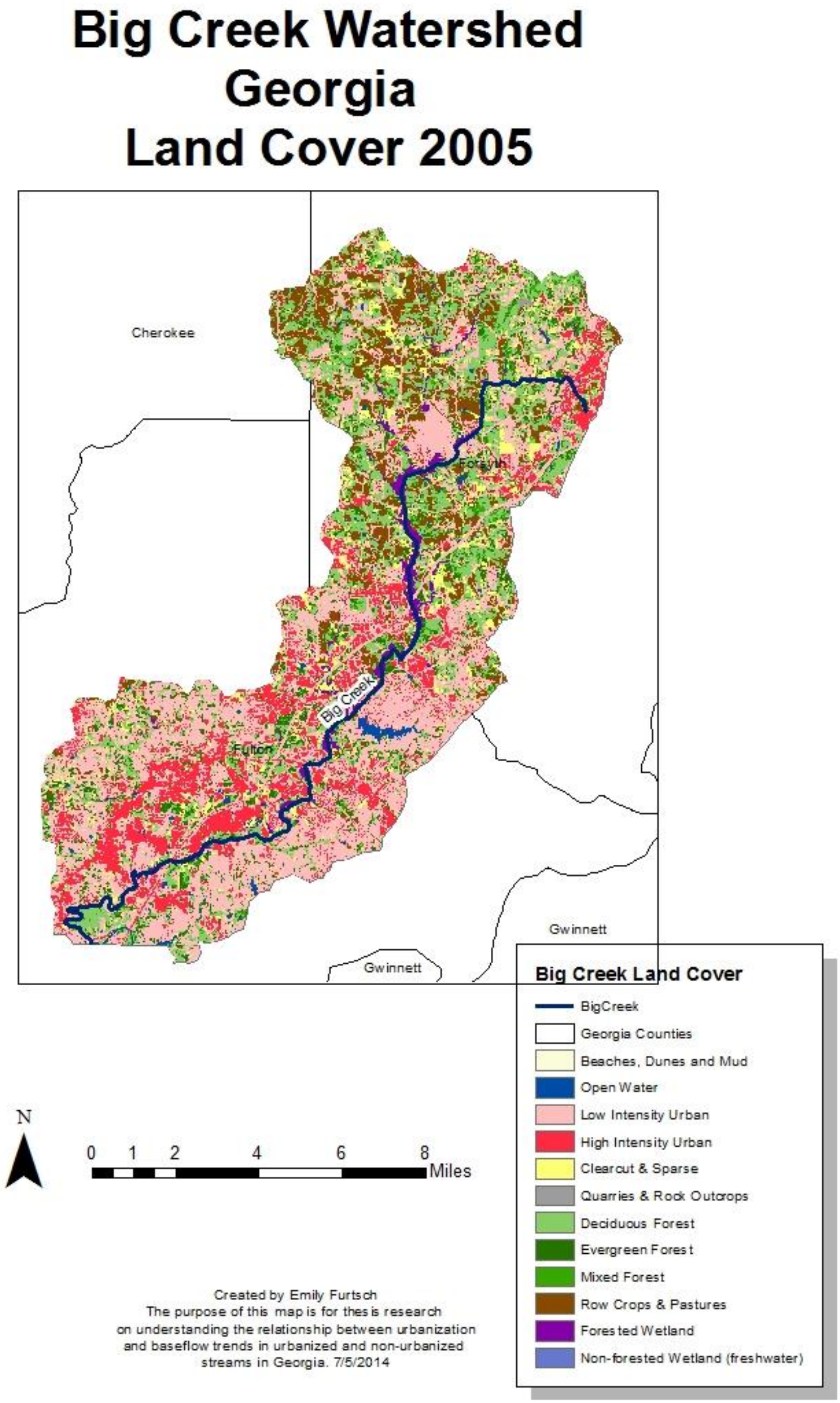

Figure 1.7.31 Big Creek 2005 Land Cover

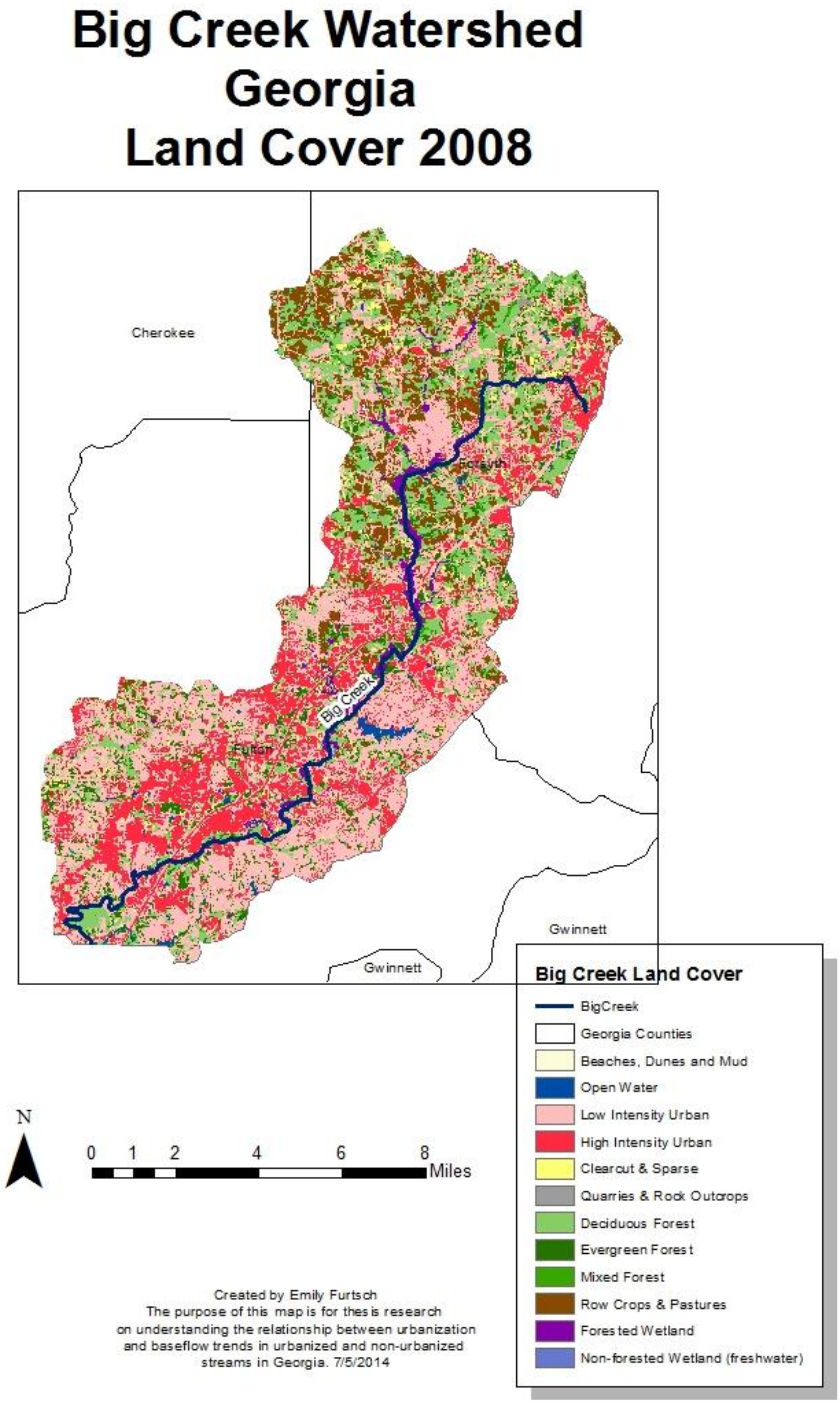

Figure 1.7.32 Big Creek 2008 Land Cover

1.7.5 Sope Creek

A Mann-Kendall trend analysis revealed that all four urbanization parameters were increasing. A Mann-Kendall analysis on the baseflow found no trend over time for all four percentile flows (Tables 3.1-3.4).

The correlation analysis results revealed no correlation between any of the parameters and any of the baseflow percentiles except in the 50th percentile. The 50th percentile had positive correlation with high-intensity urban land use, though the relationship was moderate (84%). The null hypothesis was not rejected for any of the other parameters across all of the percentiles (Tables 3.1-3.4).

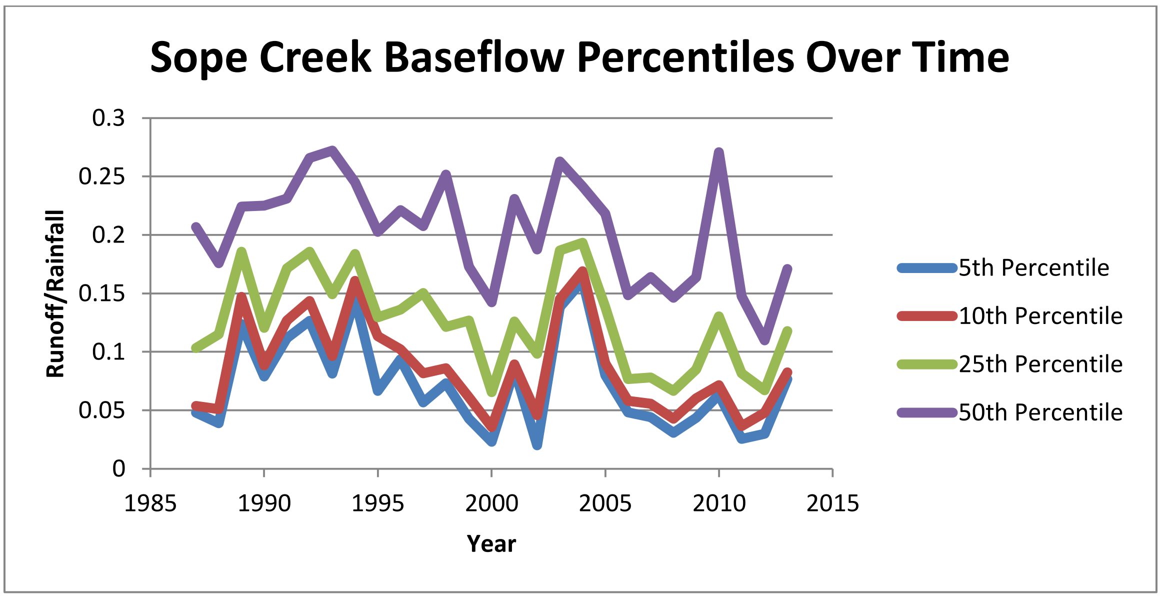

Figure 1.7.33 Sope Creek Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Sope Creek, an urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis.

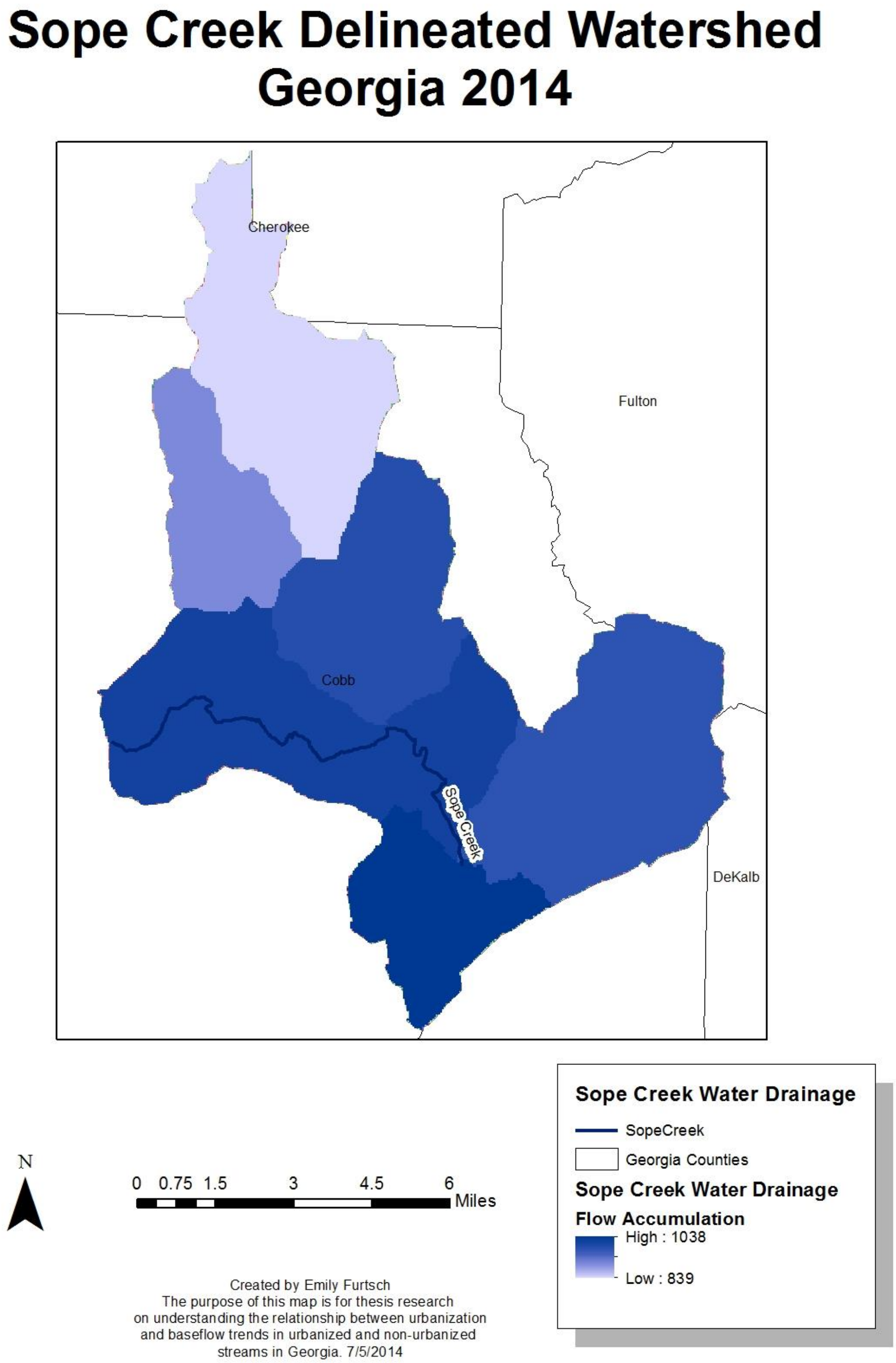

Figure 1.7.34 Sope Creek Watershed

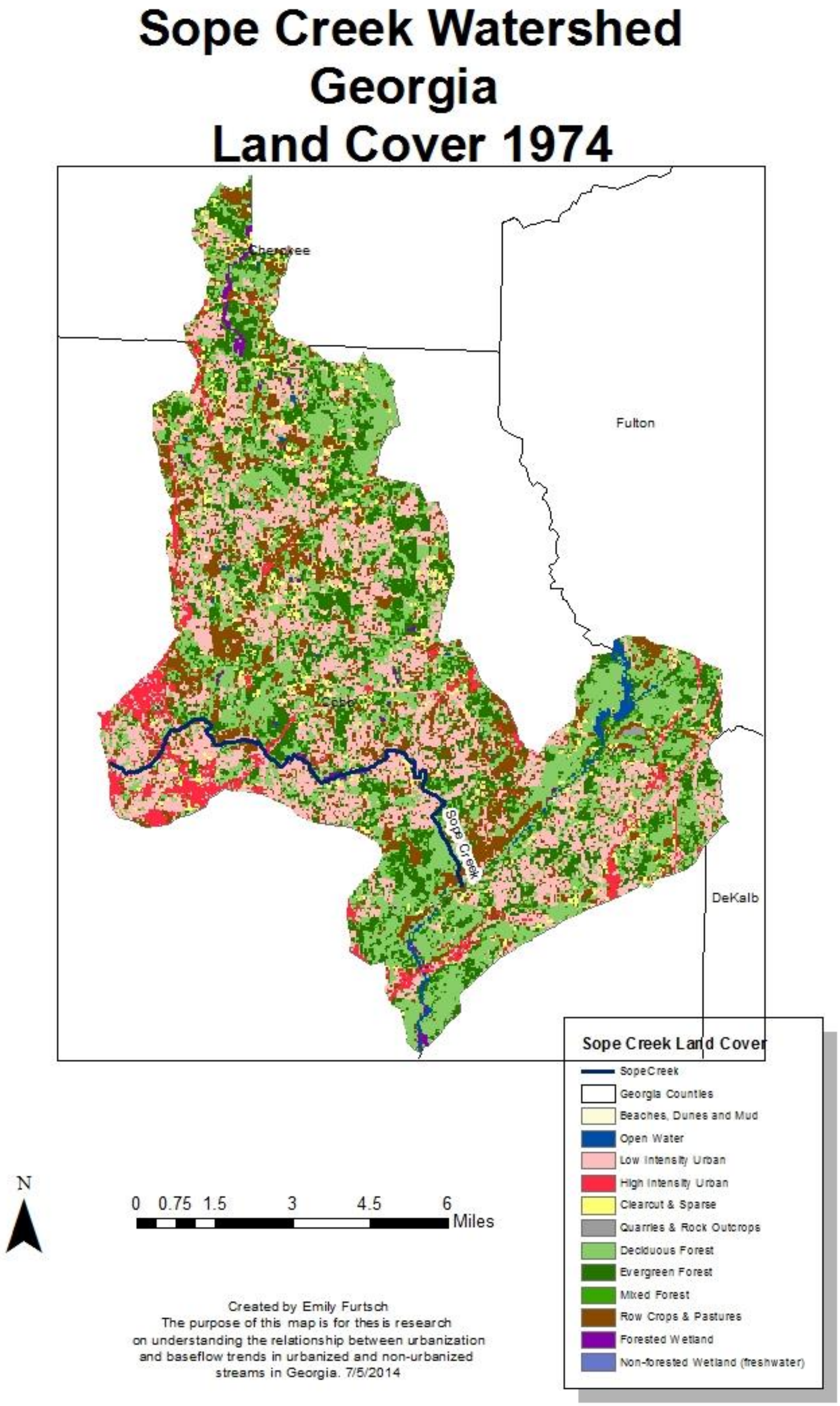

Figure 1.7.35 Sope Creek 1974 Land Cover

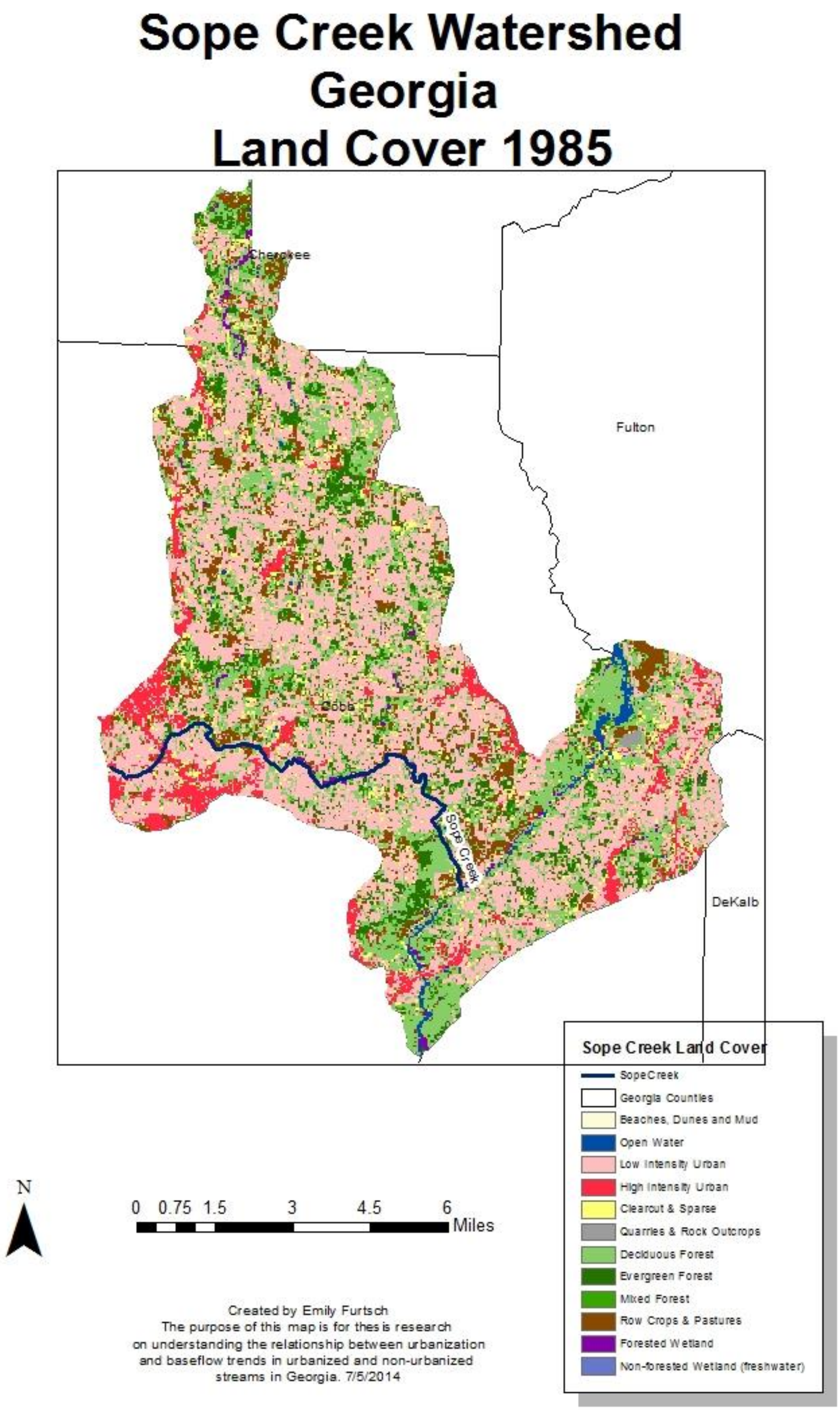

Figure 1.7.36 Sope Creek 1985 Land Cover

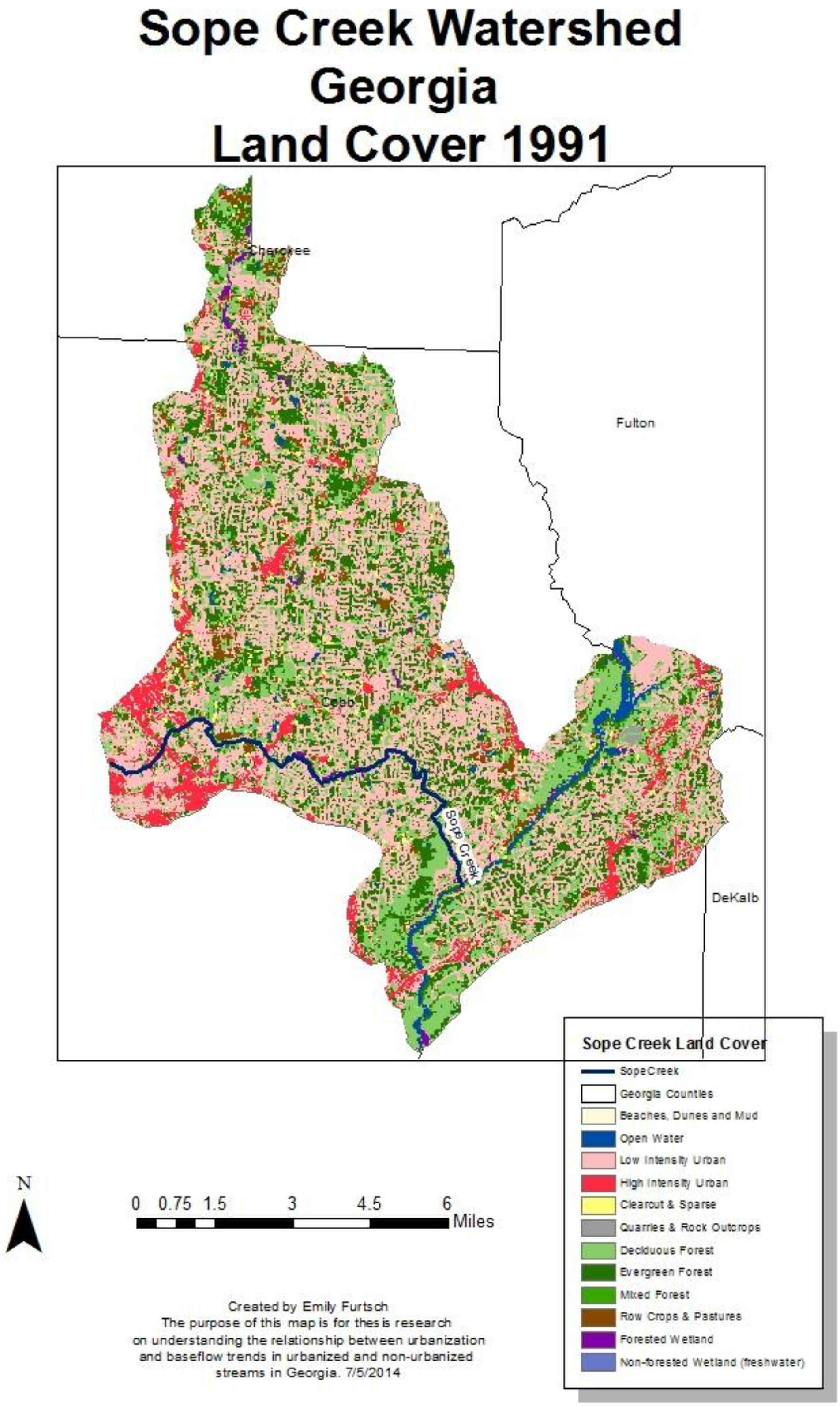

Figure 1.7.37 Sope Creek 1991 Land Cover

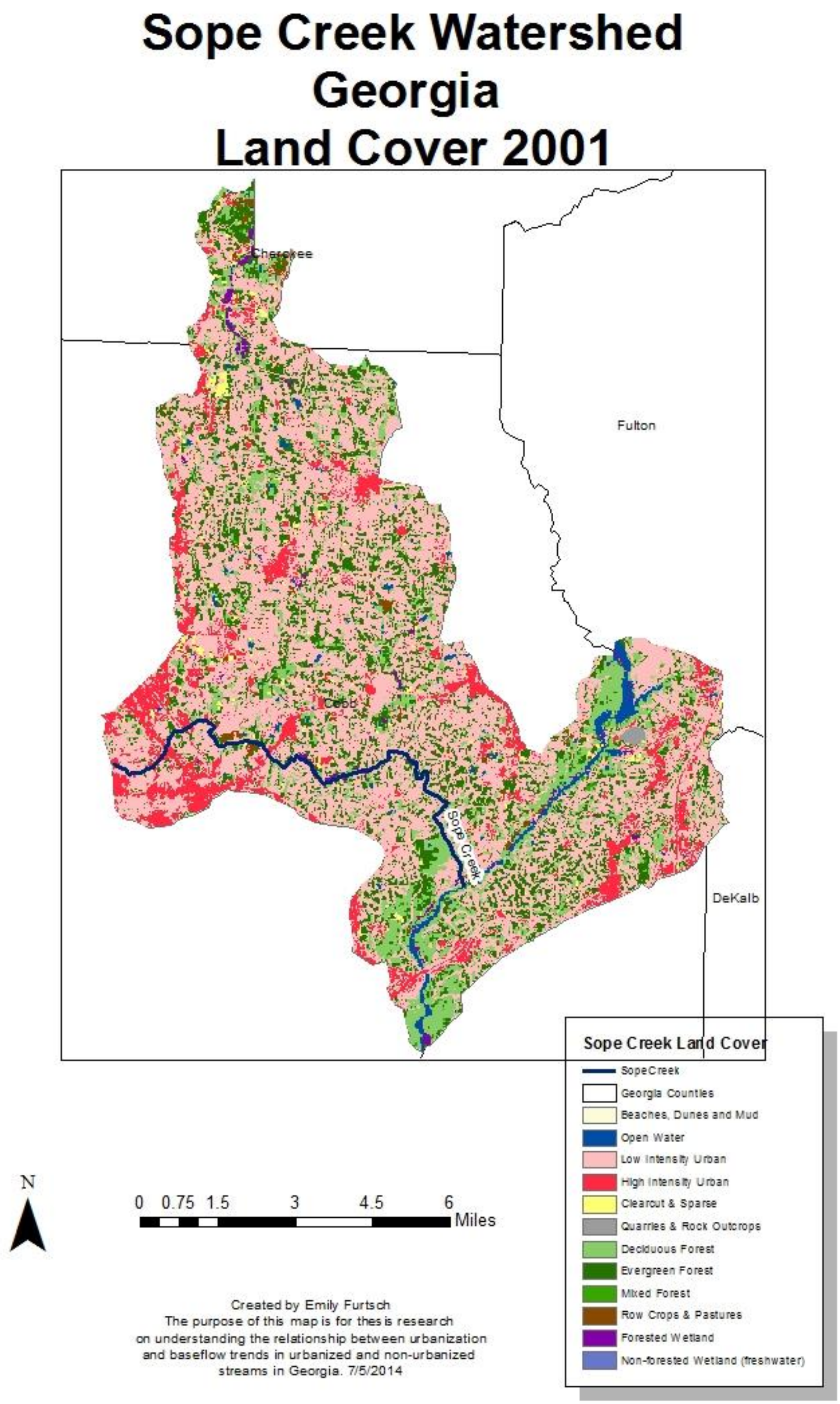

Figure 1.7.38 Sope Creek 2001 Land Cover

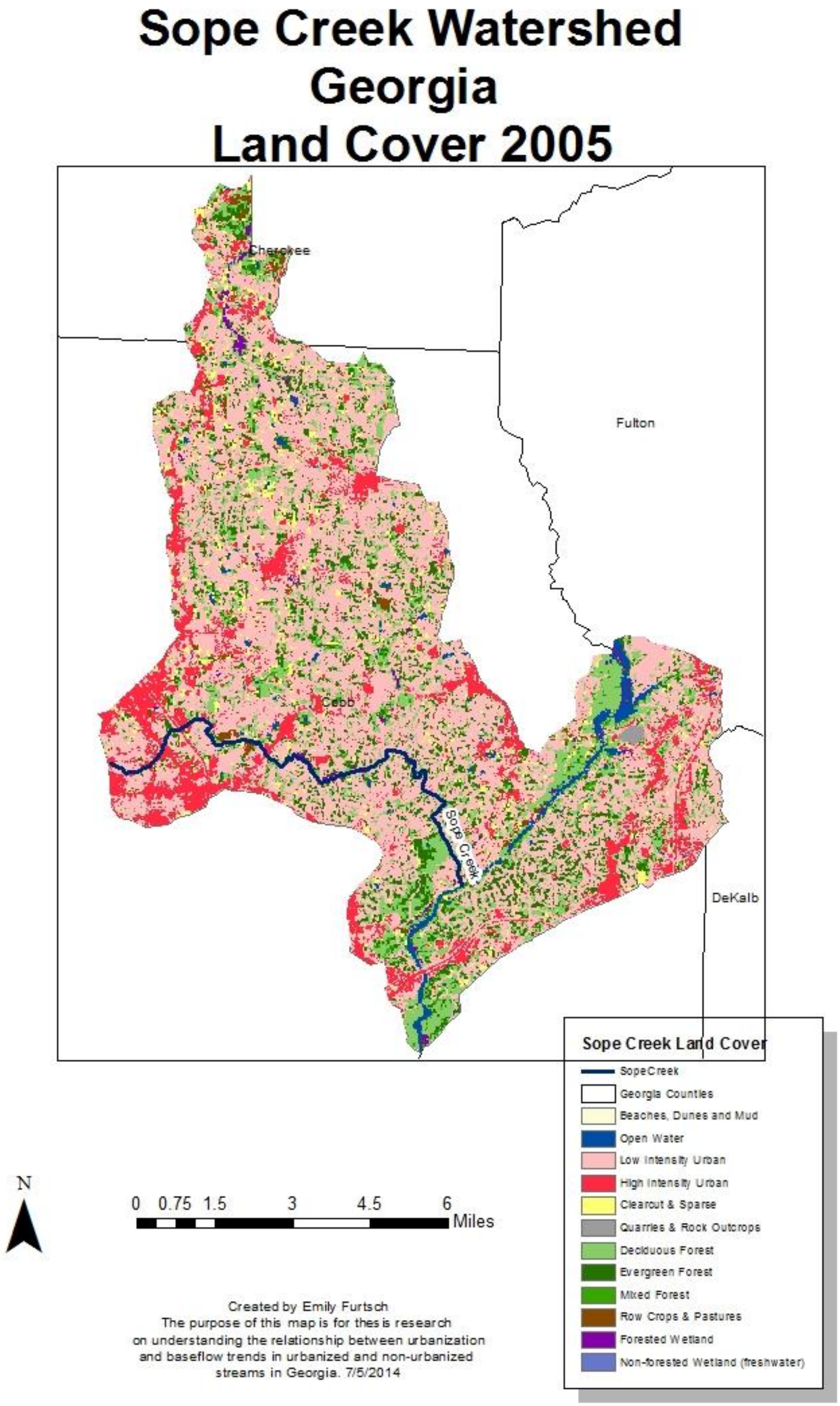

Figure 1.7.39 Sope Creek 2005 Land Cover

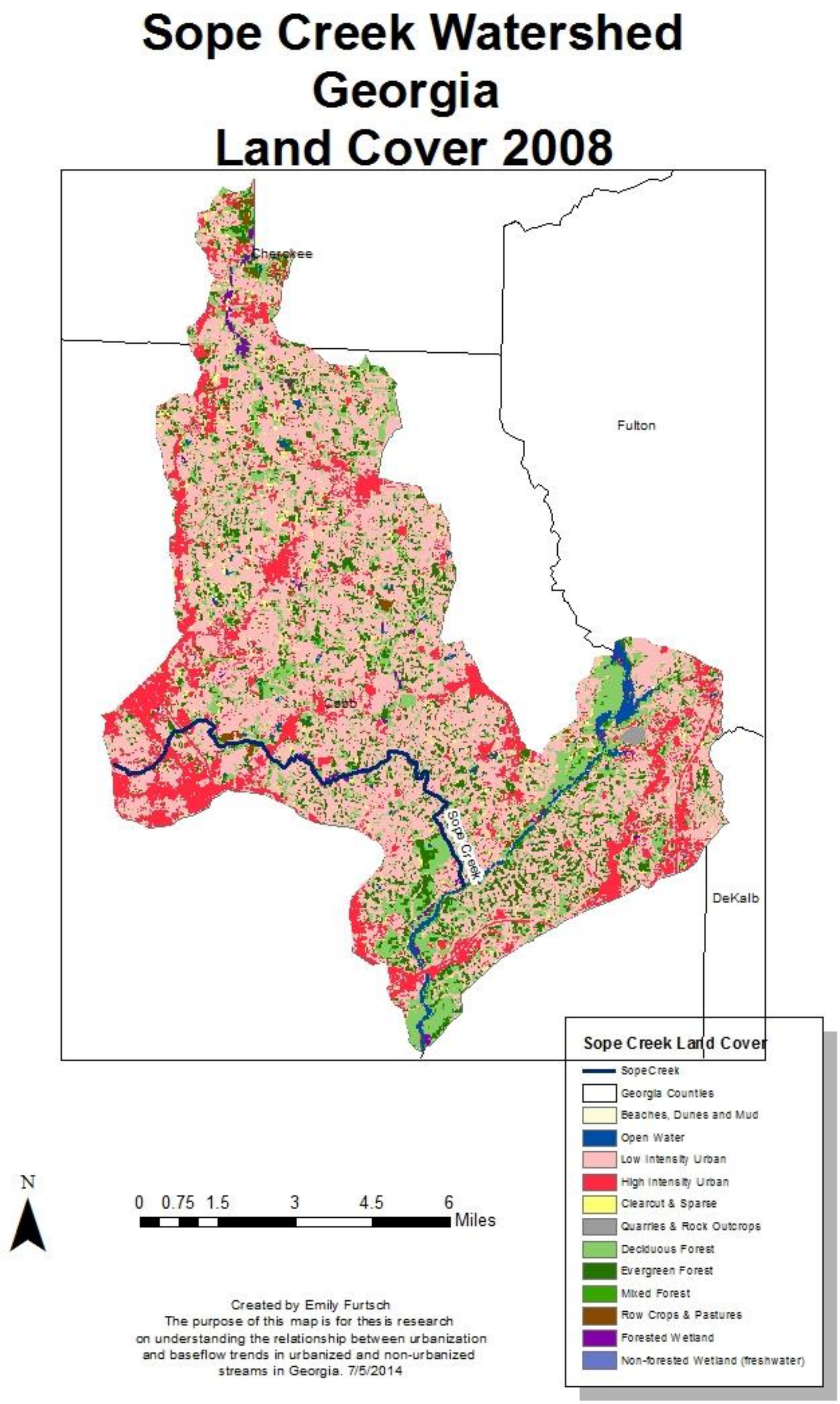

Figure 1.7.40 Sope Creek 2008 Land Cover

1.8 Non-Urbanized

1.8.1 Line Creek

The Mann-Kendall test for Line Creek baseflow found no trend over time across all percentiles (Tables 3.1-3.4). Population by Census tract had no trend (with an 83.3% confidence). The three urban land use parameters were found to be increasing with a confidence of 99.9%.

At a 95% confidence level the correlation analysis results rejected the null hypothesis in the 50th percentile for all three urban land use parameters (Table 3.4). There was no correlation found between the 5th, 10th, and 25th percentiles and any of the urbanization parameters.

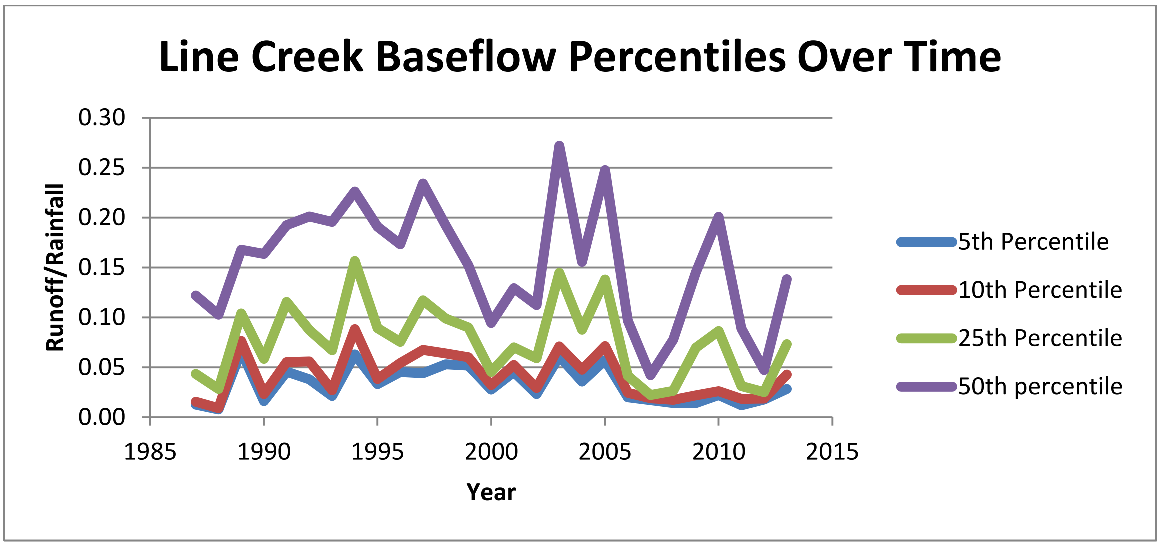

Figure 1.8.1 Line Creek Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Line Creek, a non-urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis.

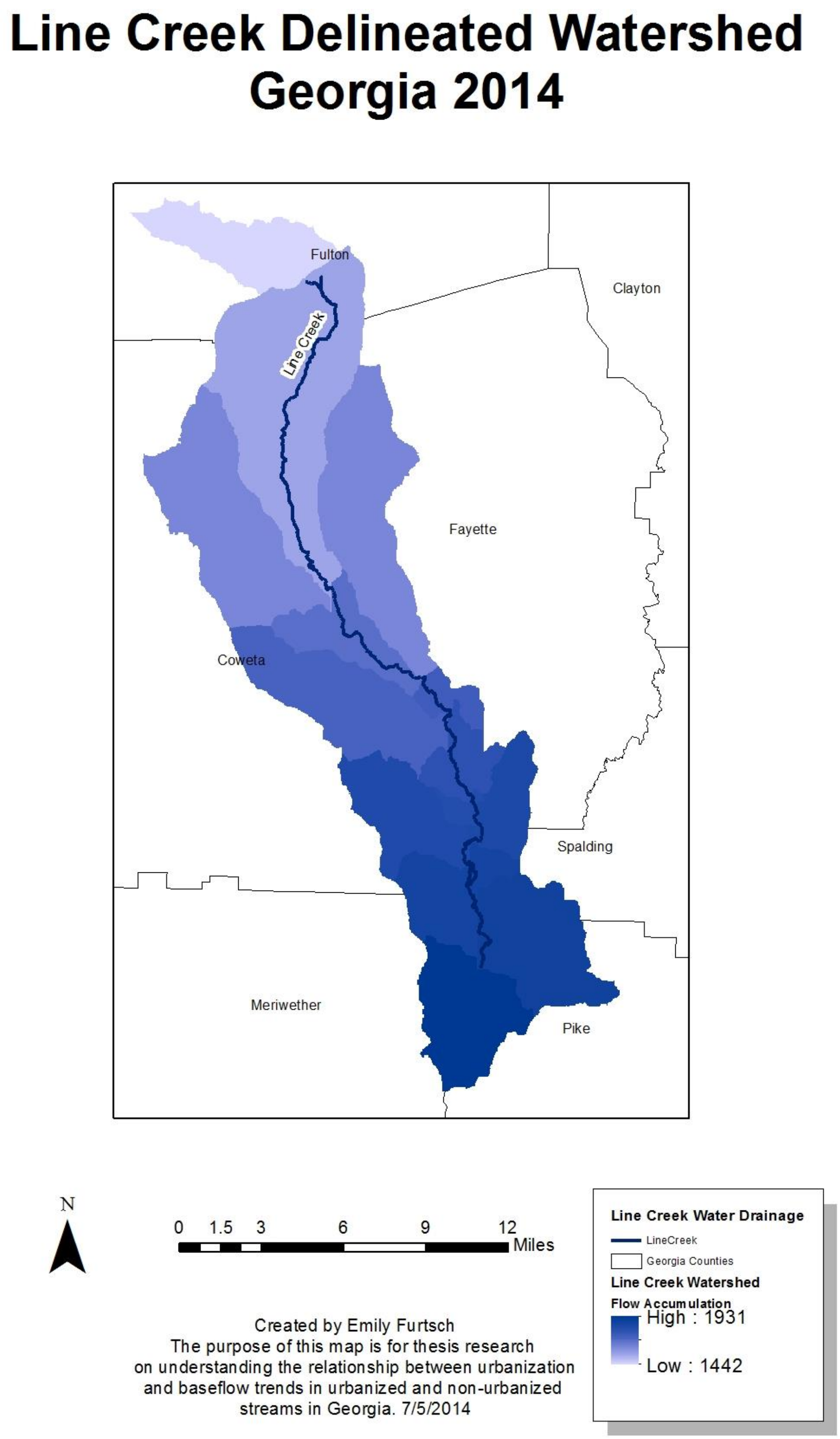

Figure 1.8.2 Line Creek Watershed

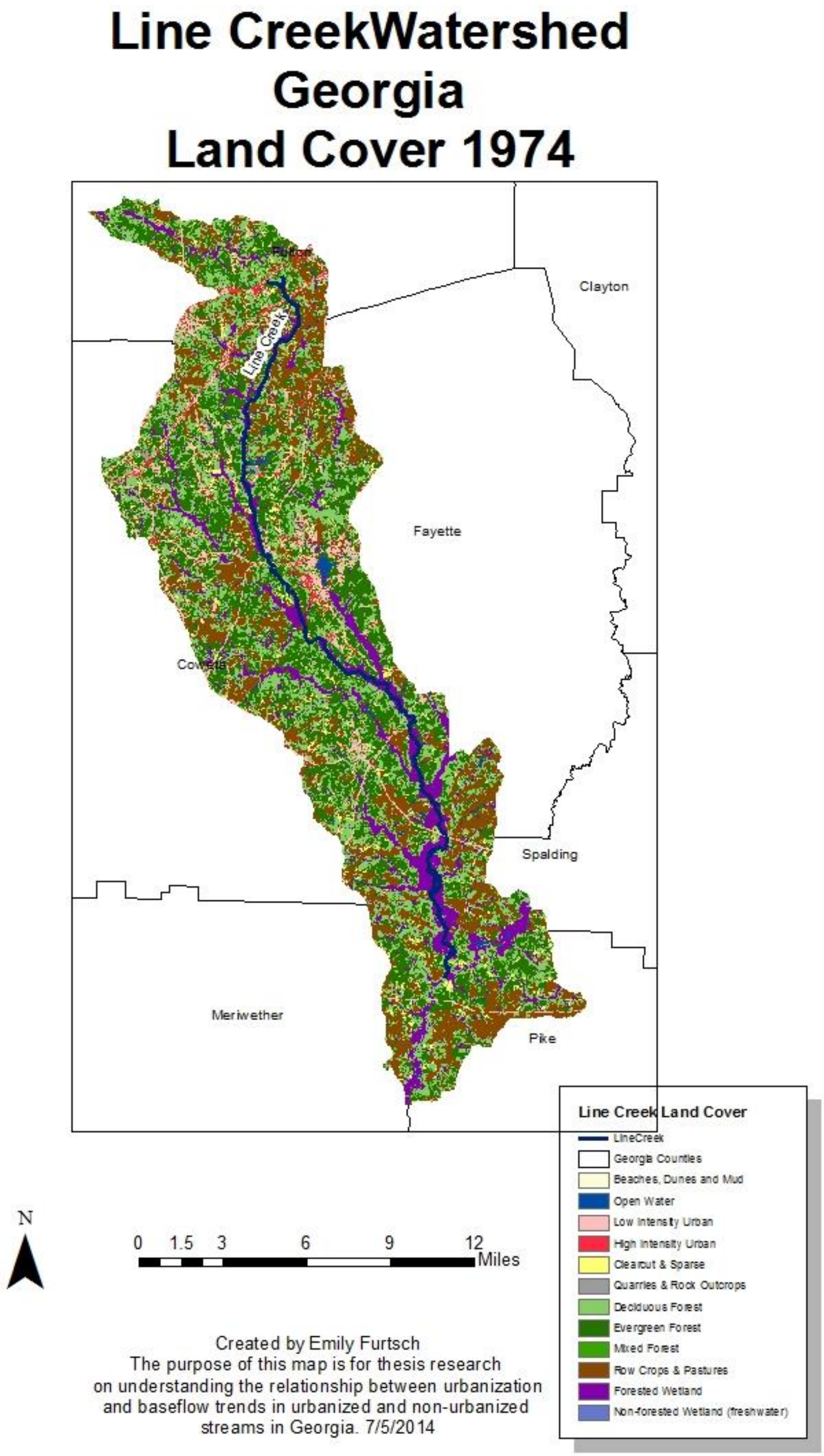

Figure 1.8.3 Line Creek 1974 Land Cover

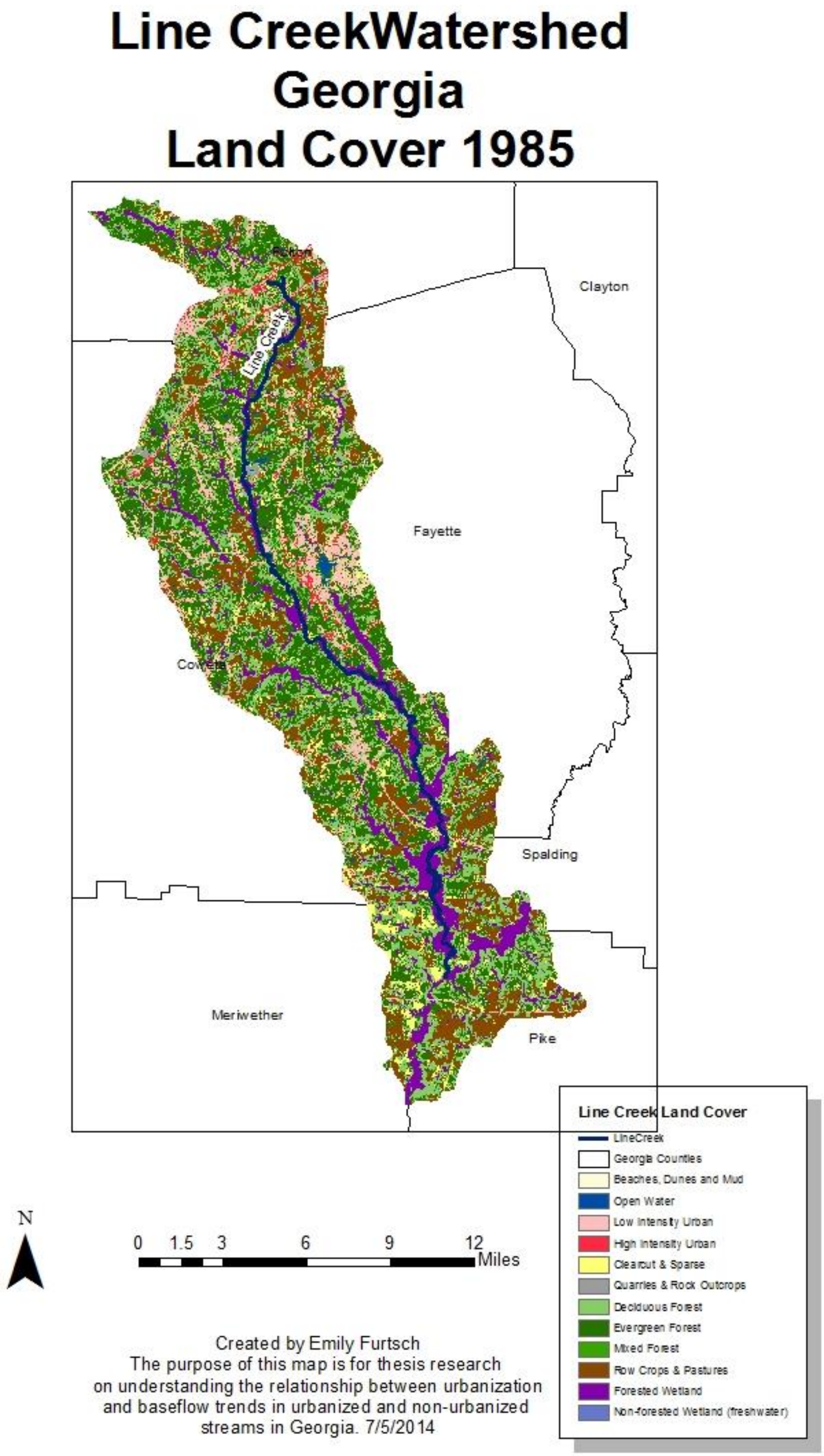

Figure 1.8.4 Line Creek 1985 Land Cover

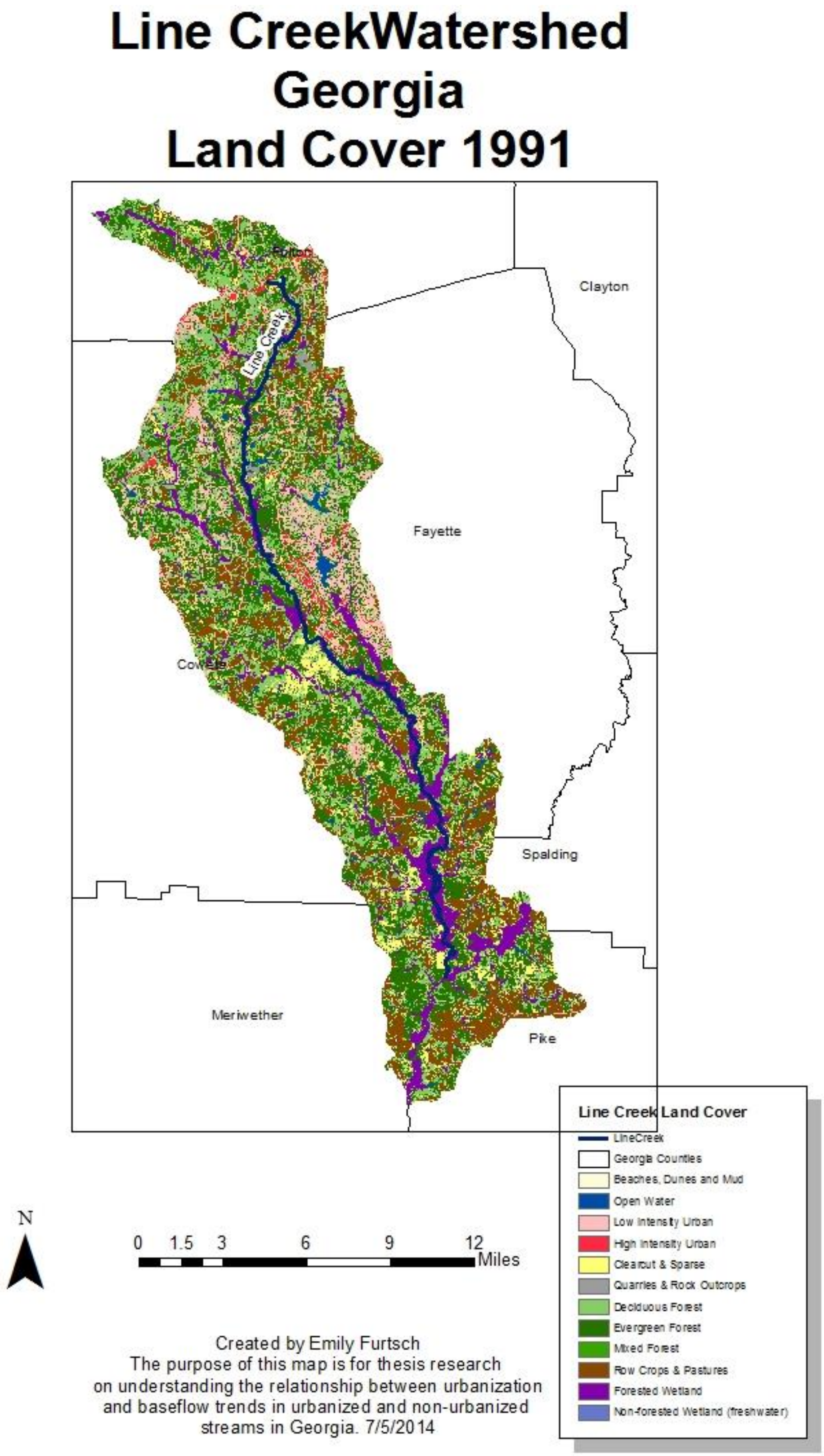

Figure 1.8.5 Line Creek 1991 Land Cover

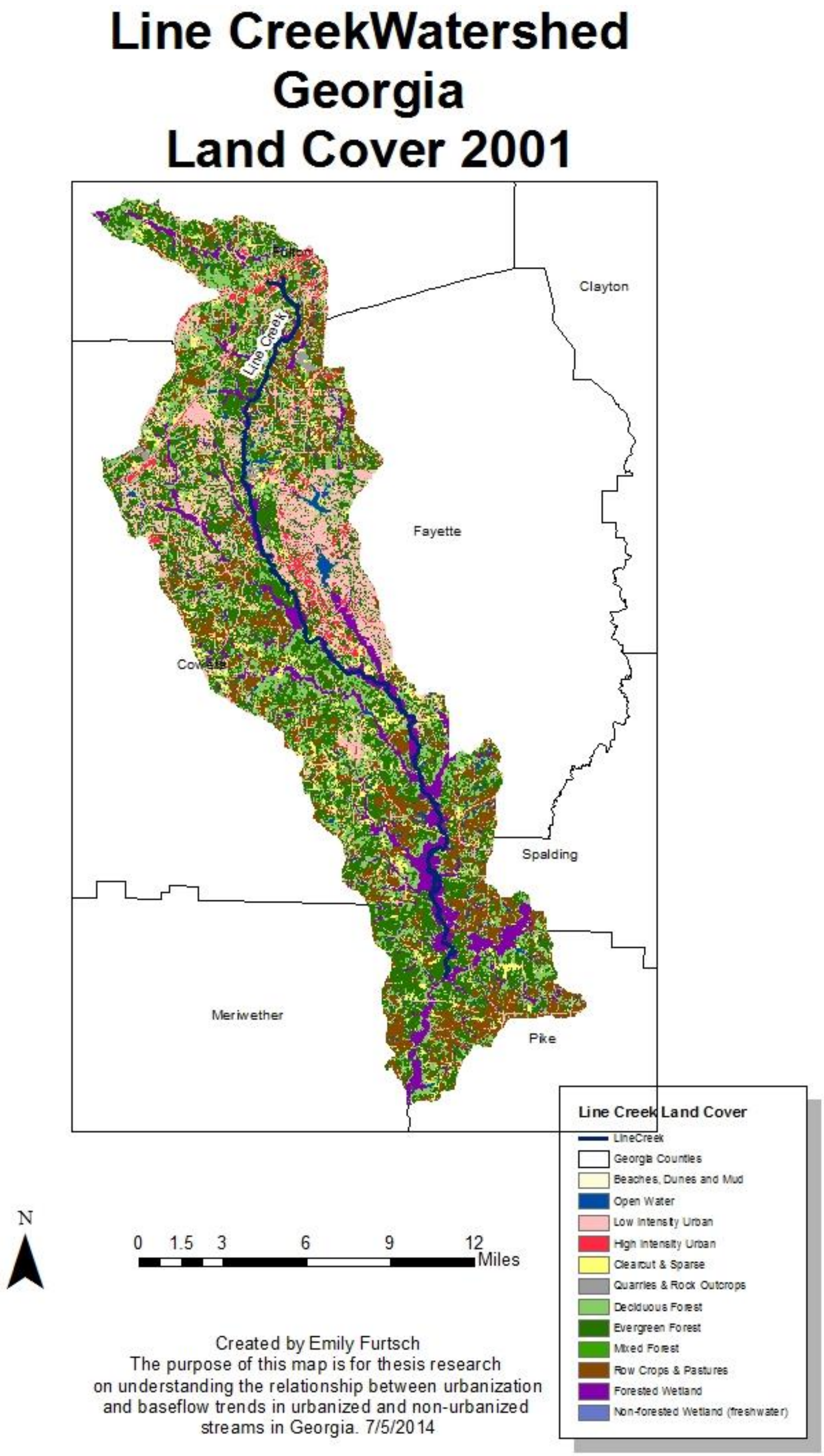

Figure 1.8.6 Line Creek 2001 Land Cover

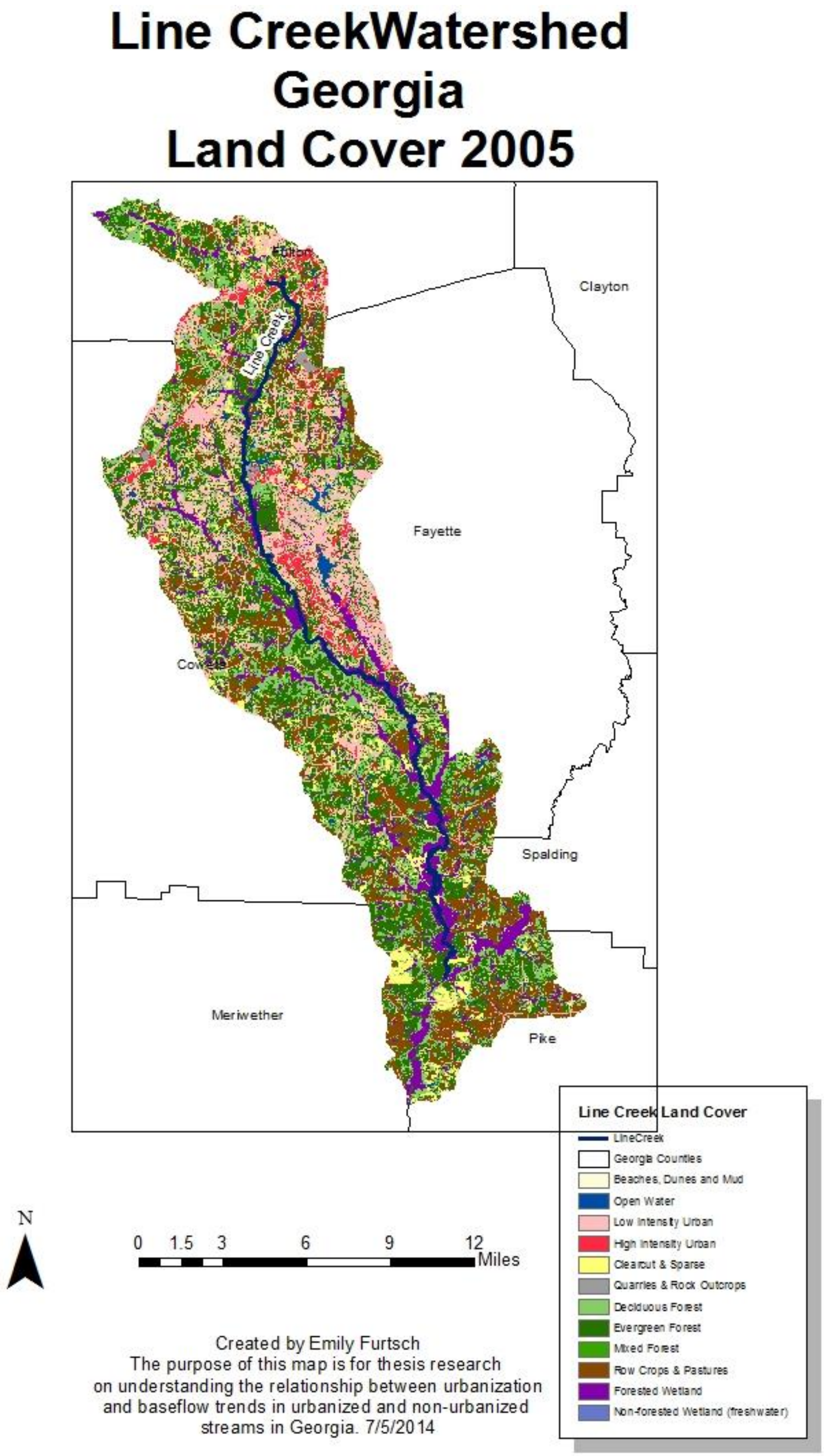

Figure 1.8.7 Line Creek 2001 Land Cover

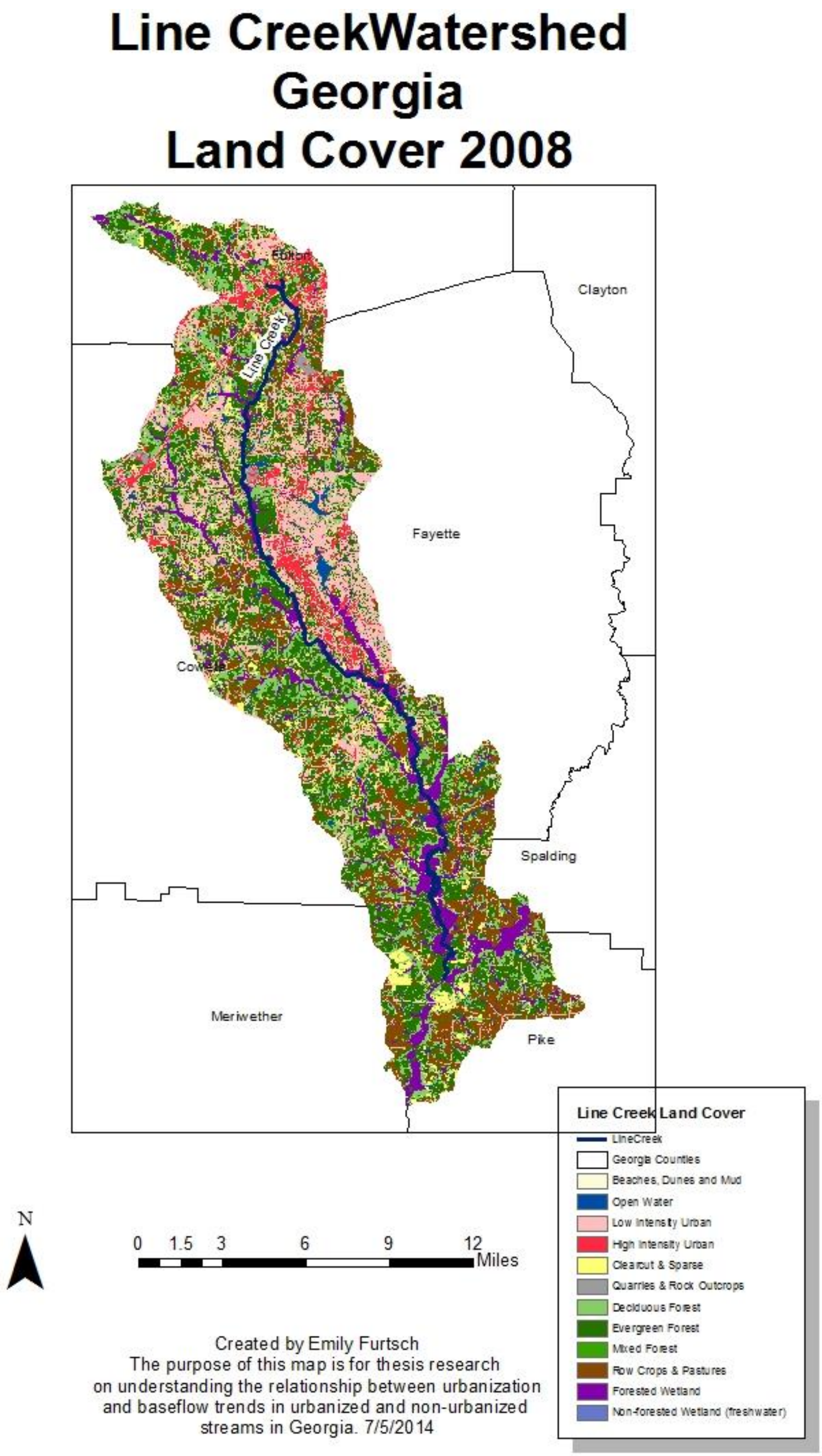

Figure 1.8.8 Line Creek 2008 Land Cover

1.8.2 Snake Creek

All four urbanization parameters were found to have an increasing trend after running the Mann-Kendall test. A trend analysis of Snake Creek baseflows found all four percentiles to have no statistically discernible trend (Tables 3.1-3.4).

After running the correlation analysis for all percentiles of run off against all parameters, the null hypothesis was not rejected at the 95% confidence level for any of the parameters (Tables 3.1-3.4).

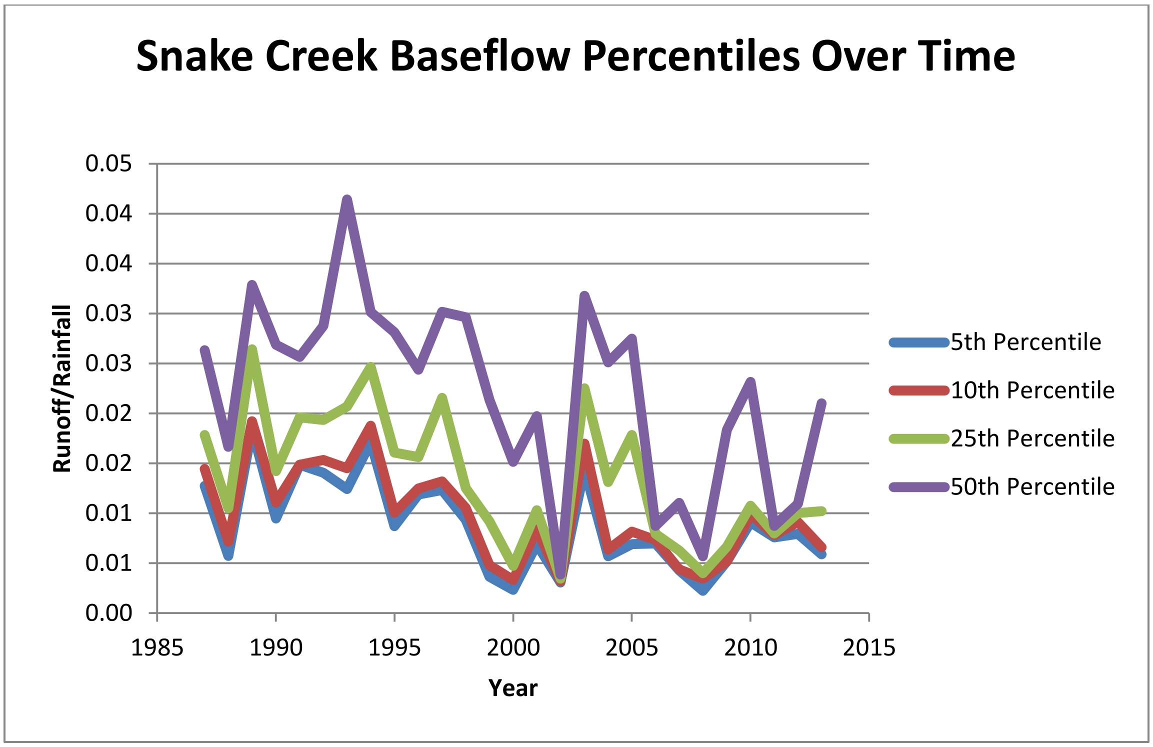

Figure 1.8.9 Snake Creek Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Snake Creek, a non-urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis though initial glance would indicate a decrease in flows.

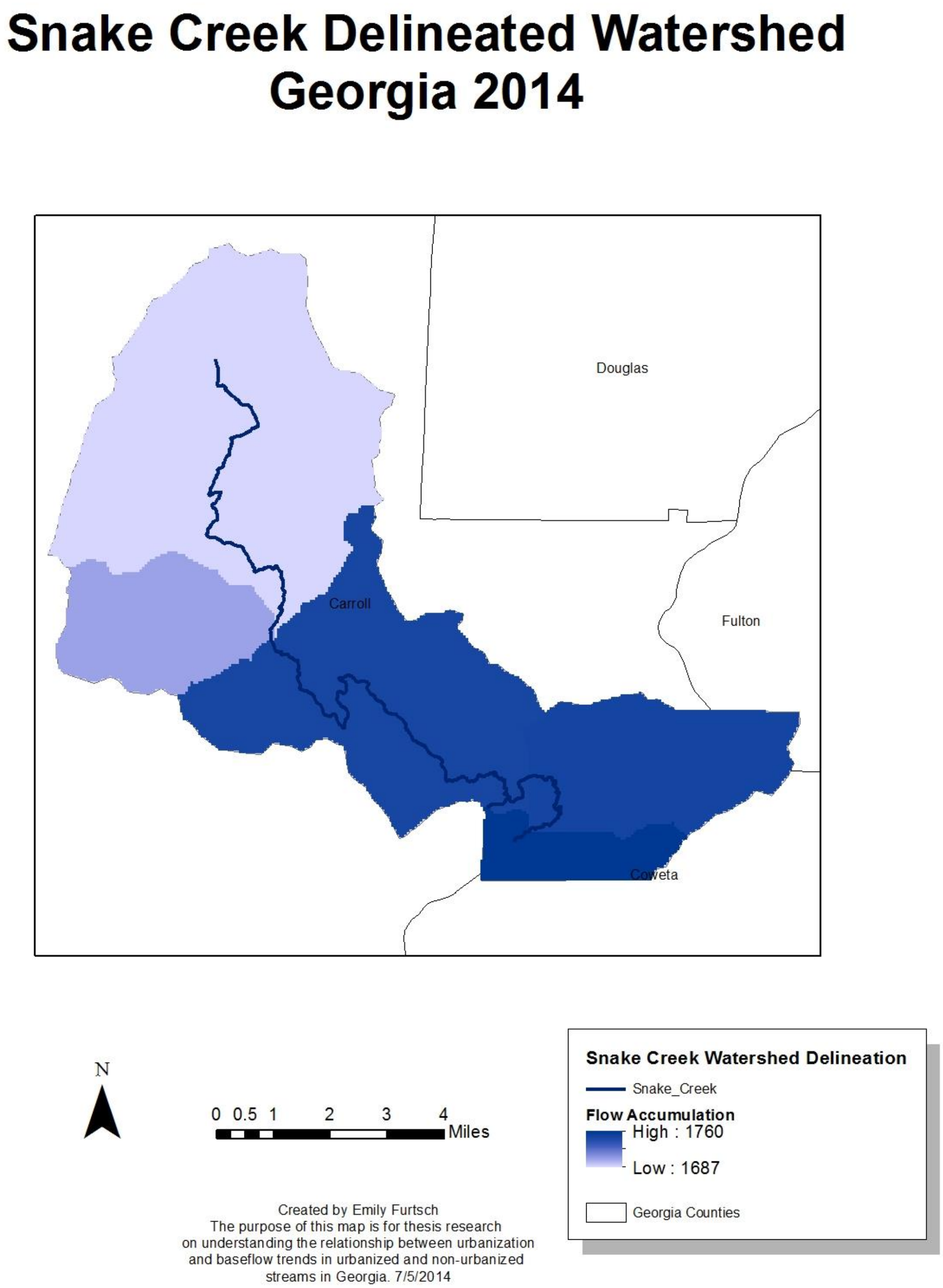

Figure 1.8.10 Snake Creek Watershed

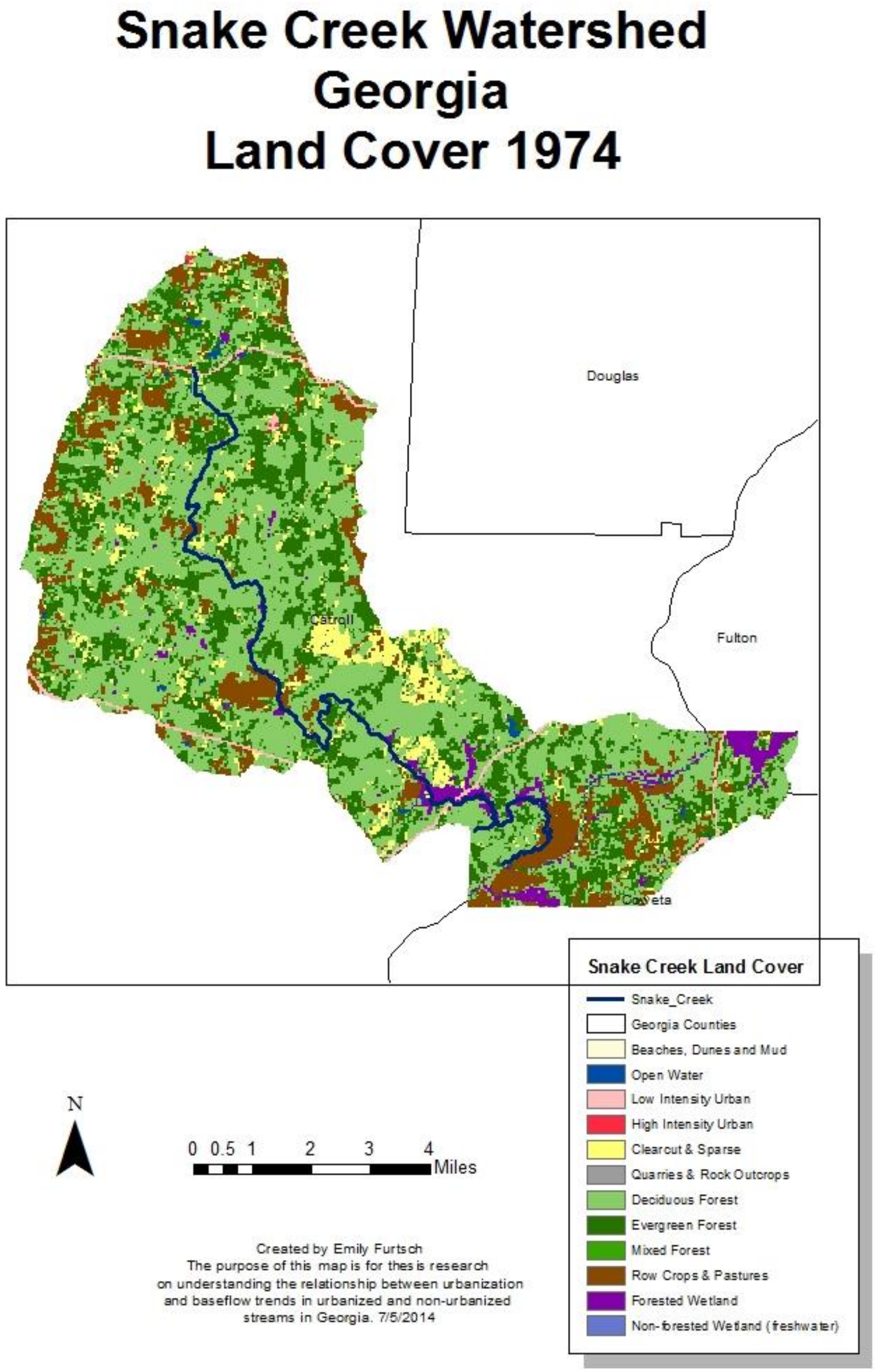

Figure 1.8.11 Snake Creek 1974 Land Cover

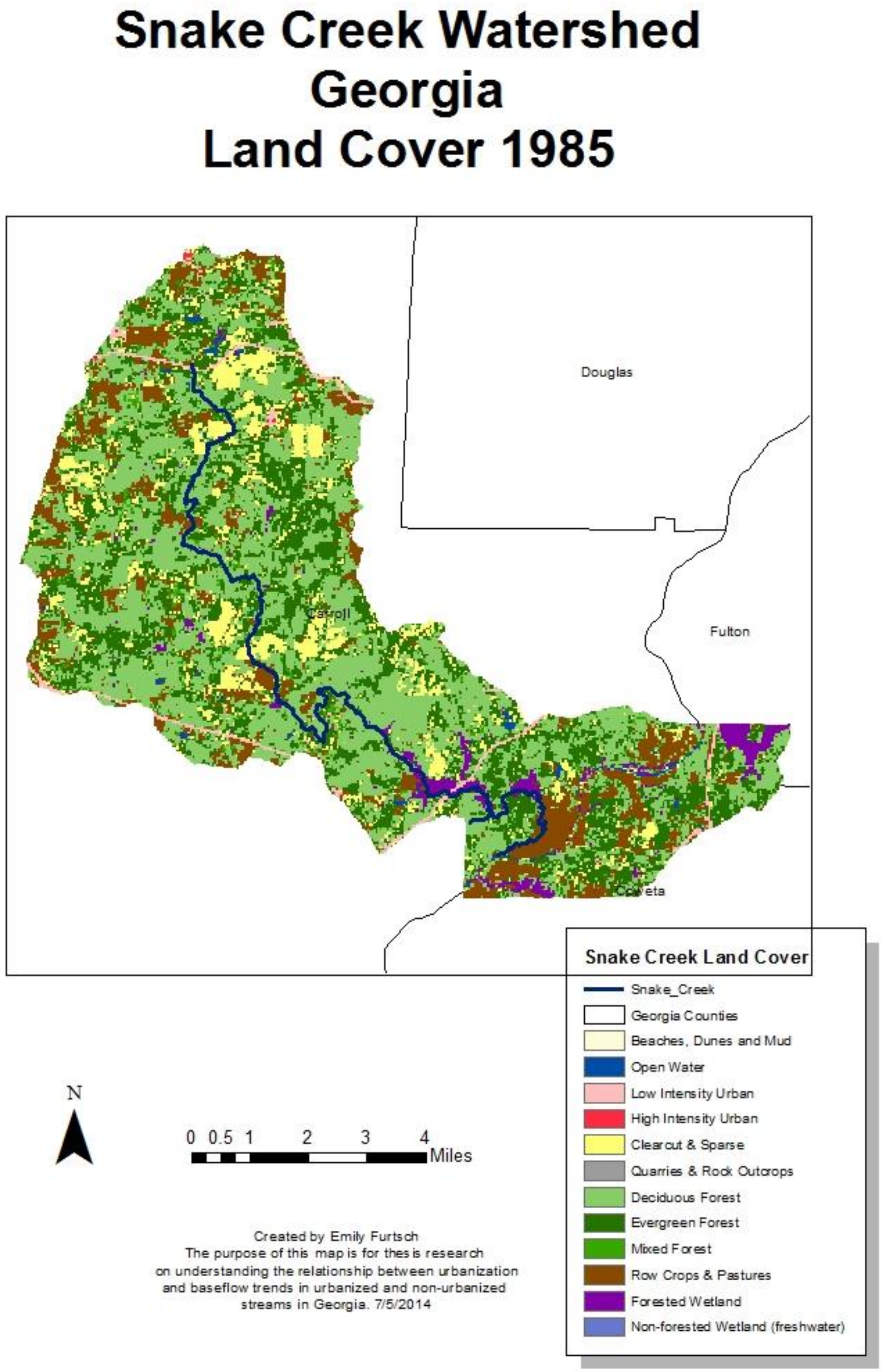

Figure 1.8.12 Snake Creek 1985 Land Cover

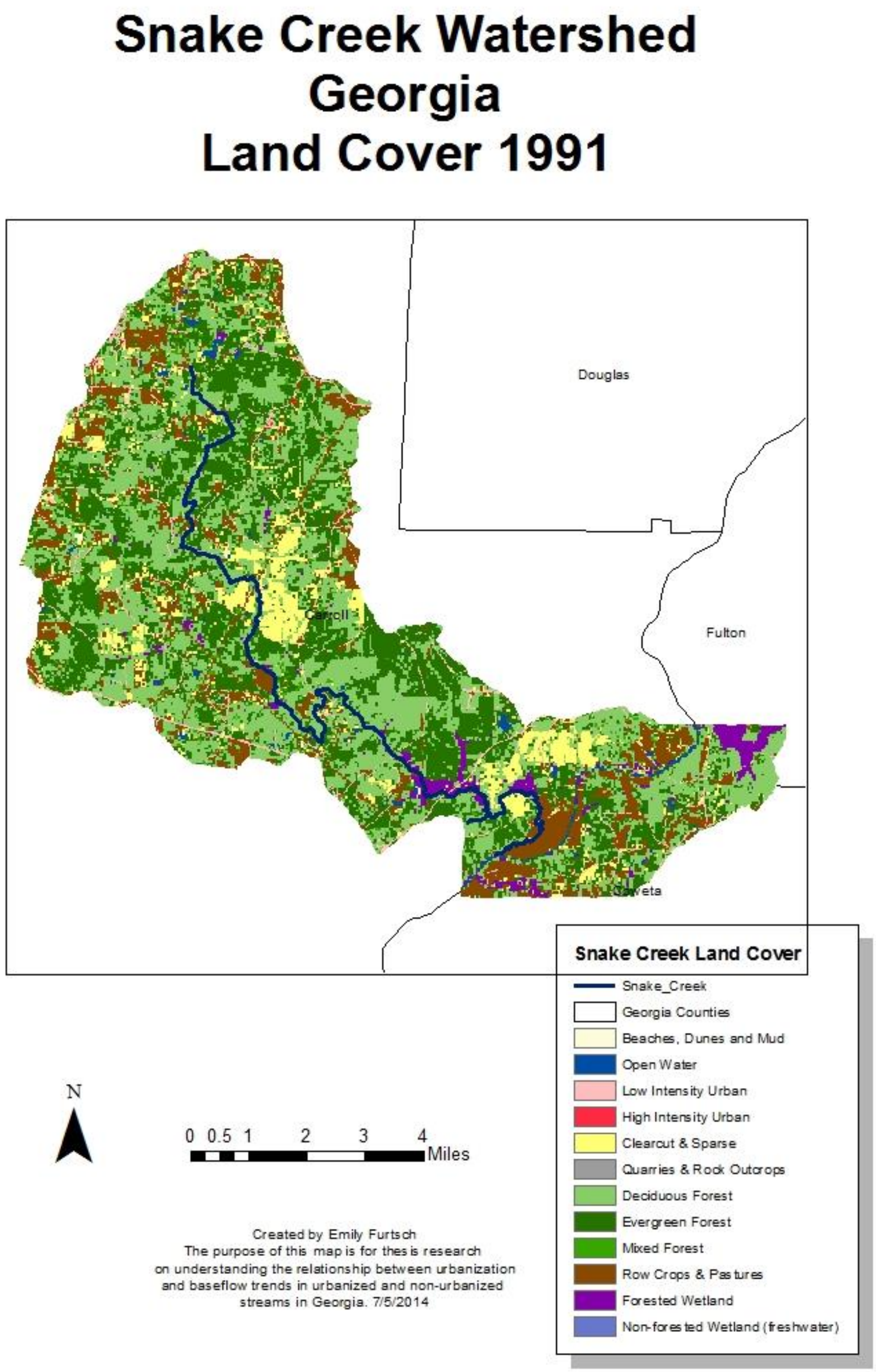

Figure 1.8.13 Snake Creek 1991 Land Cover

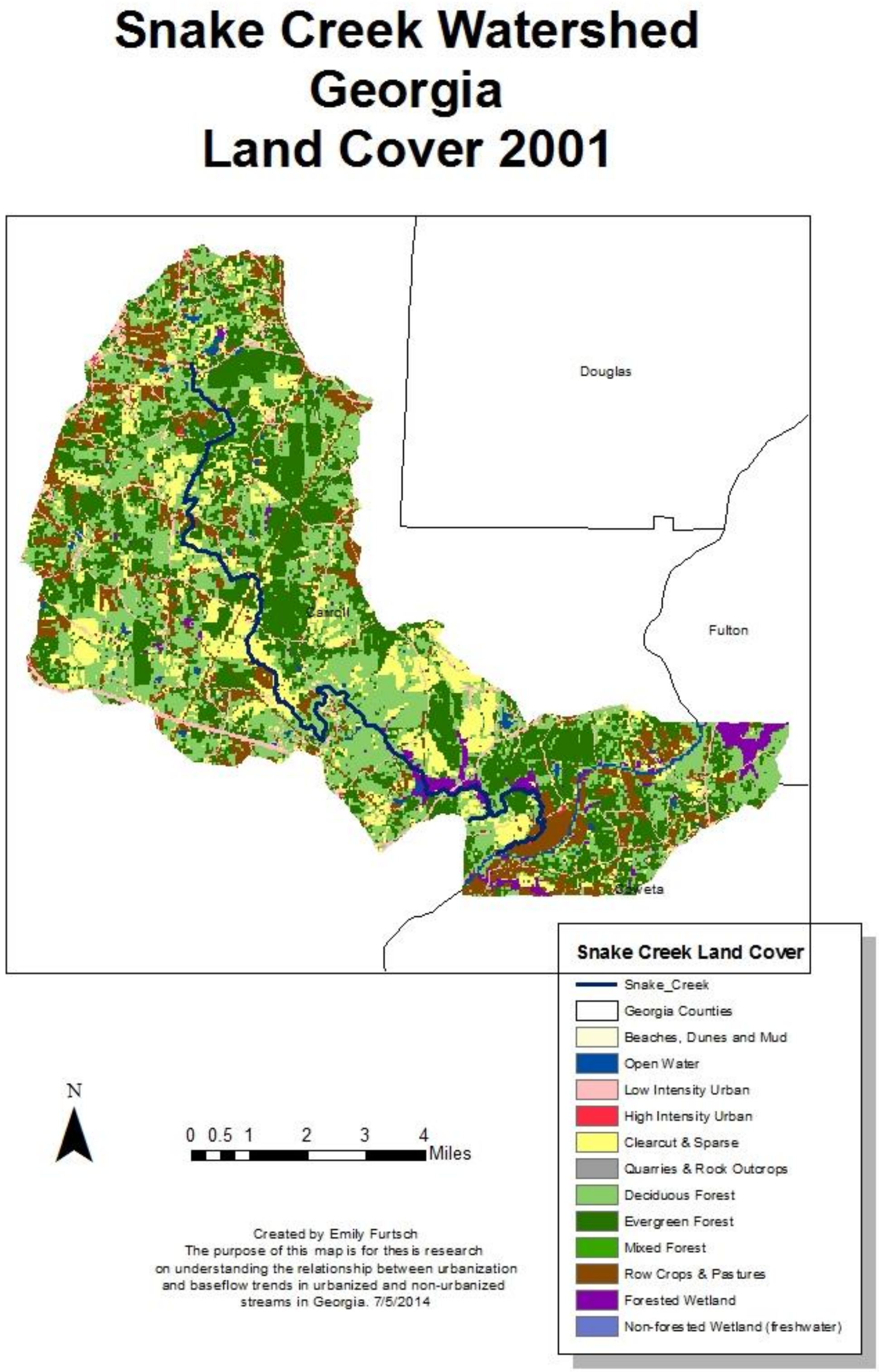

Figure 1.8.14 Snake Creek 2001 Land Cover

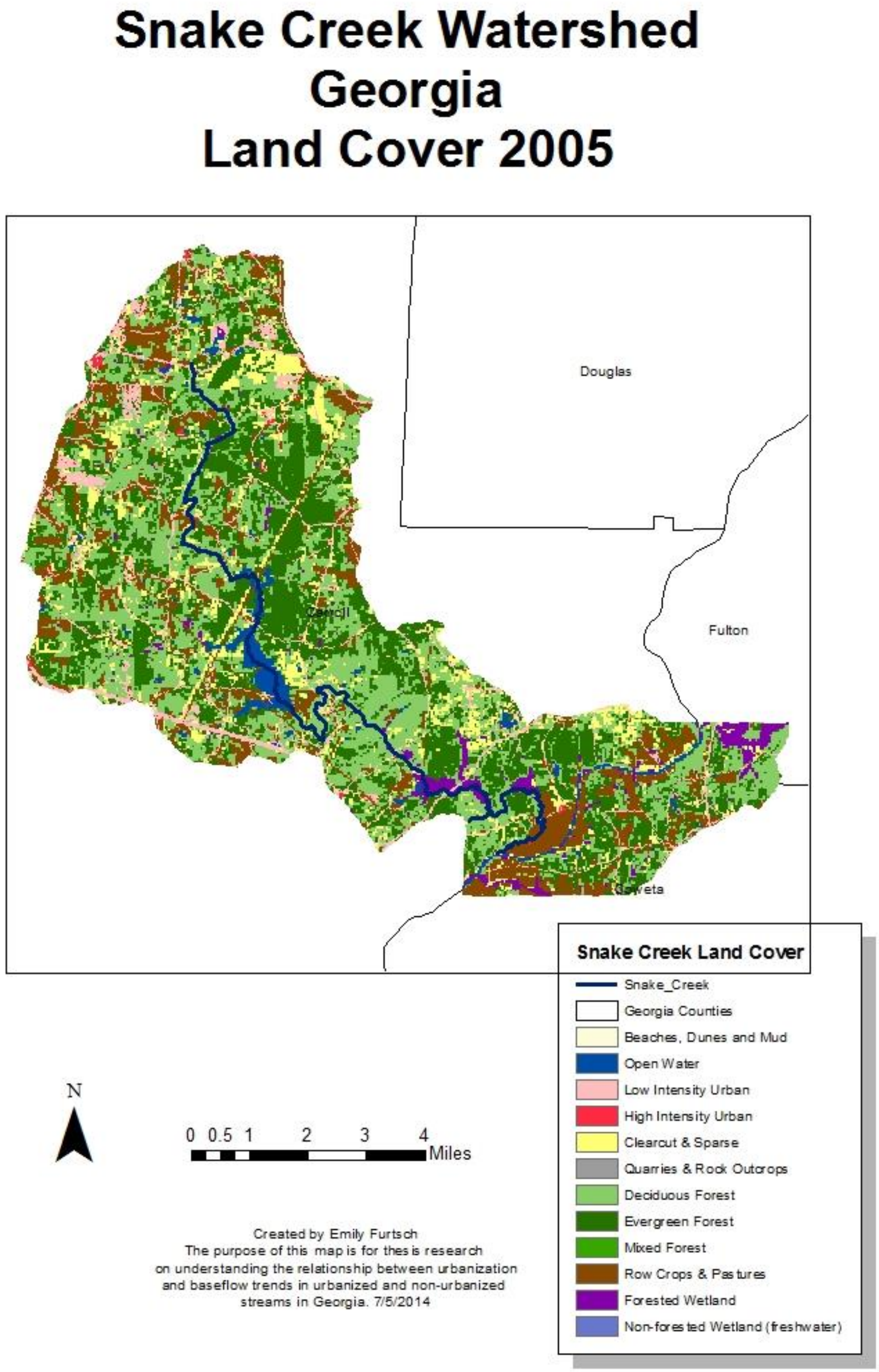

Figure 1.8.15 Snake Creek 2005 Land Cover

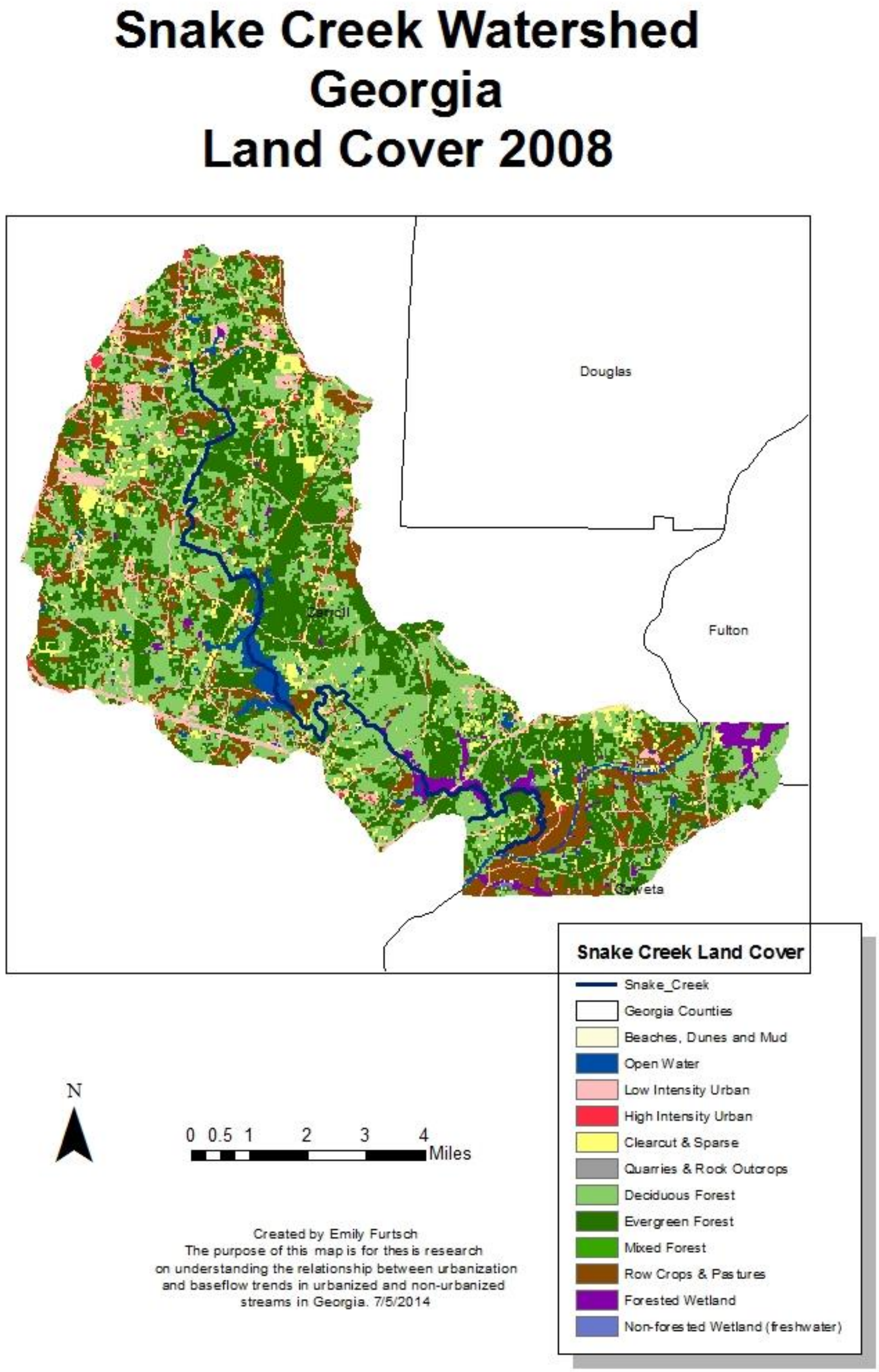

Figure 1.8.16 Snake Creek 2008 Land Cover

1.8.3 Kettle Creek

The Mann-Kendall test for run off in Kettle Creek found no trend across all four percentiles of baseflow (Tables 3.1-3.4). A trend analysis on the urbanization parameters found population by Census tract was both stable, while all urban land use parameters had an increasing trend (Table 2.2.3).

There was one correlation found between the 25th percentile low flows and high-intensity urban land use over time (Tables 3.1-3.4). There were no other correlations across the percentiles and parameters.

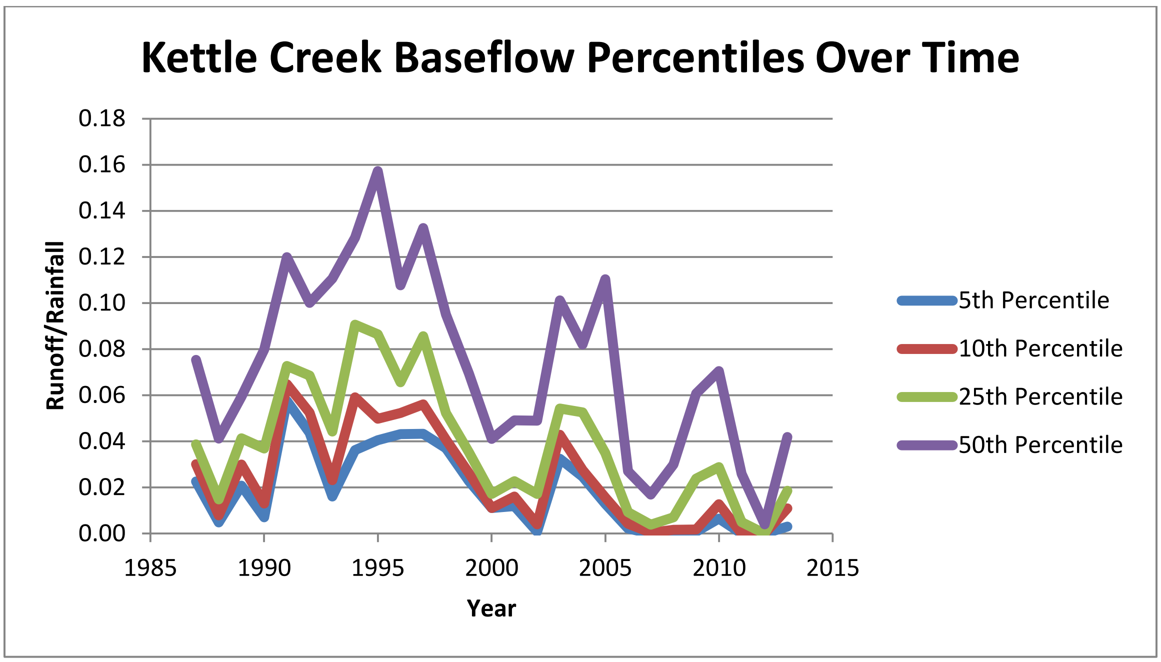

Figure 1.8.17 Kettle Creek Baseflows

The 5th, 10th, 25th and 50th percentile low flows per year calculated from daily flows for Kettle Creek, a non-urbanized stream, plotted over time. No clear discernible pattern is visible across all percentiles without further statistical analysis though initial glance would indicate a decrease in run off.

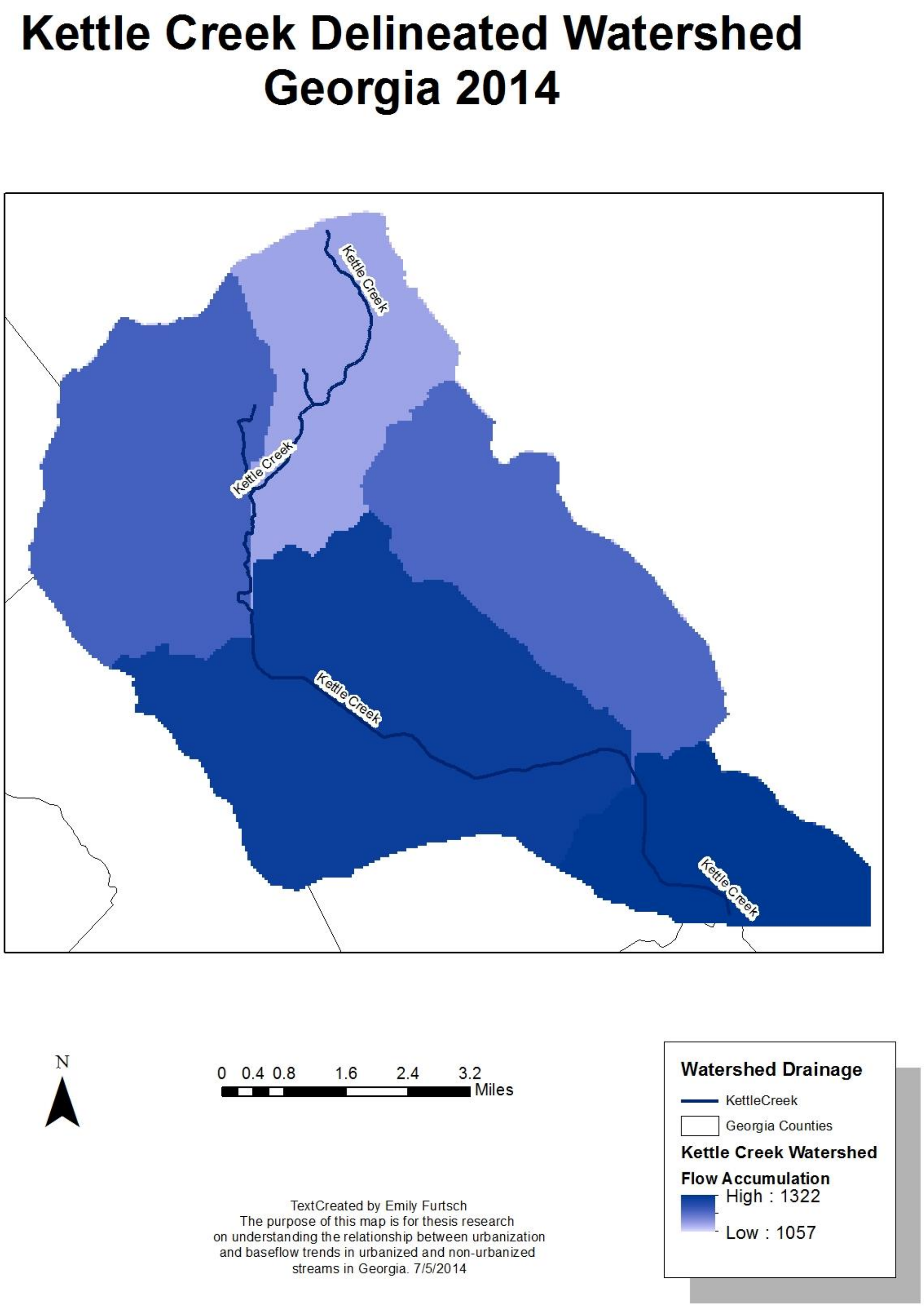

Figure 1.8.18 Kettle Creek Watershed

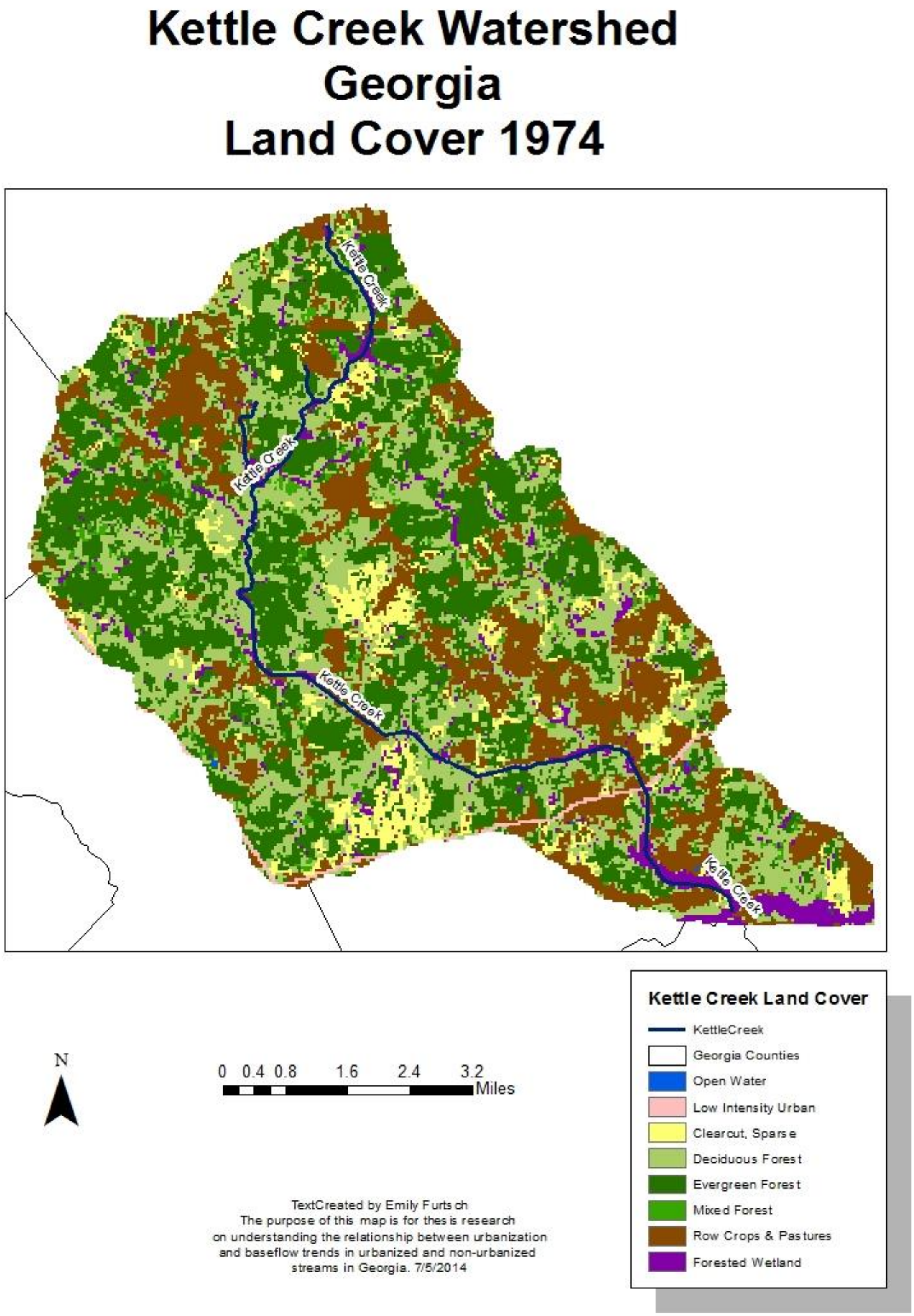

Figure 1.8.19 Kettle Creek 1974 Land Cover

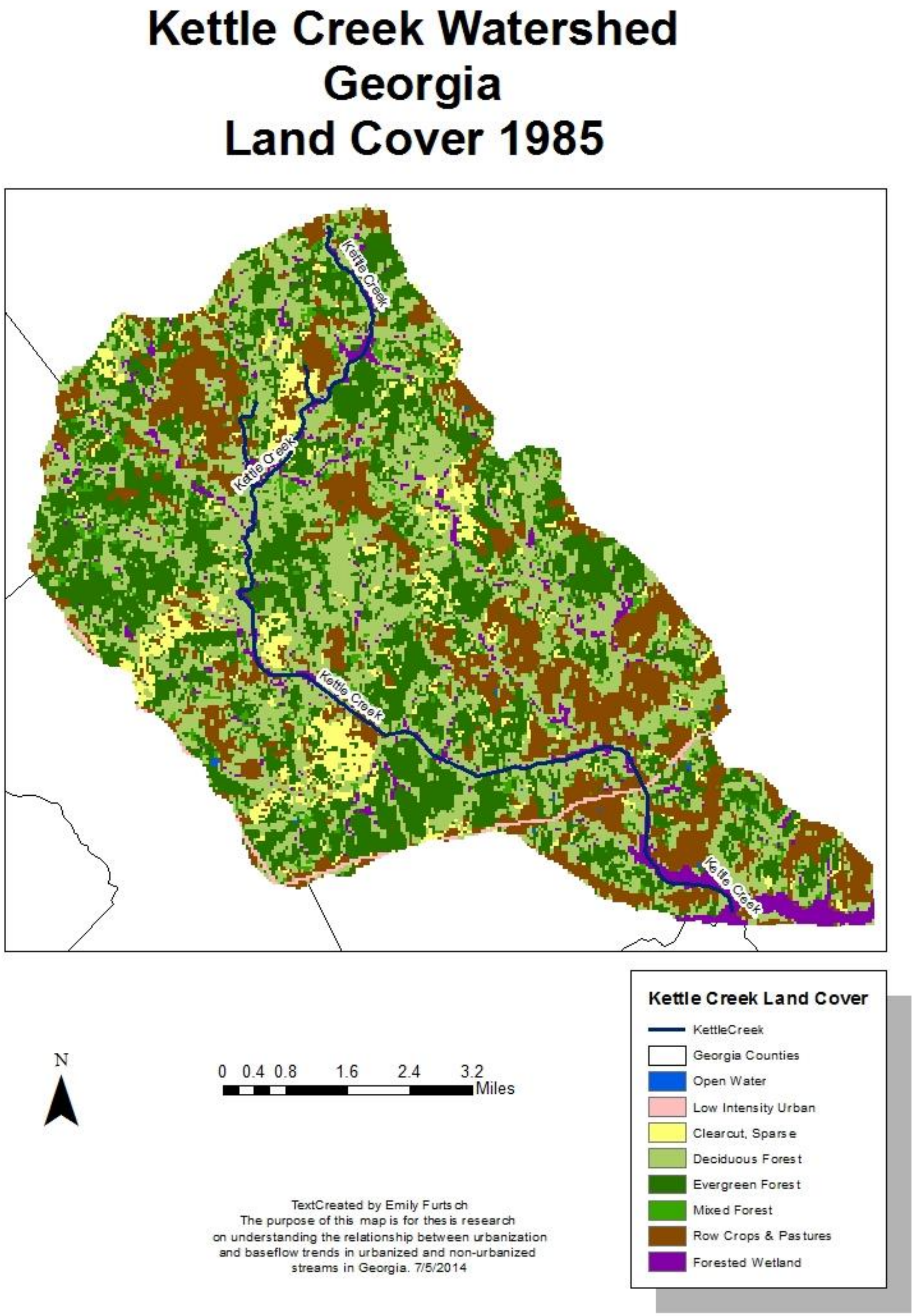

Figure 1.8.20 Kettle Creek 1985 Land Cover

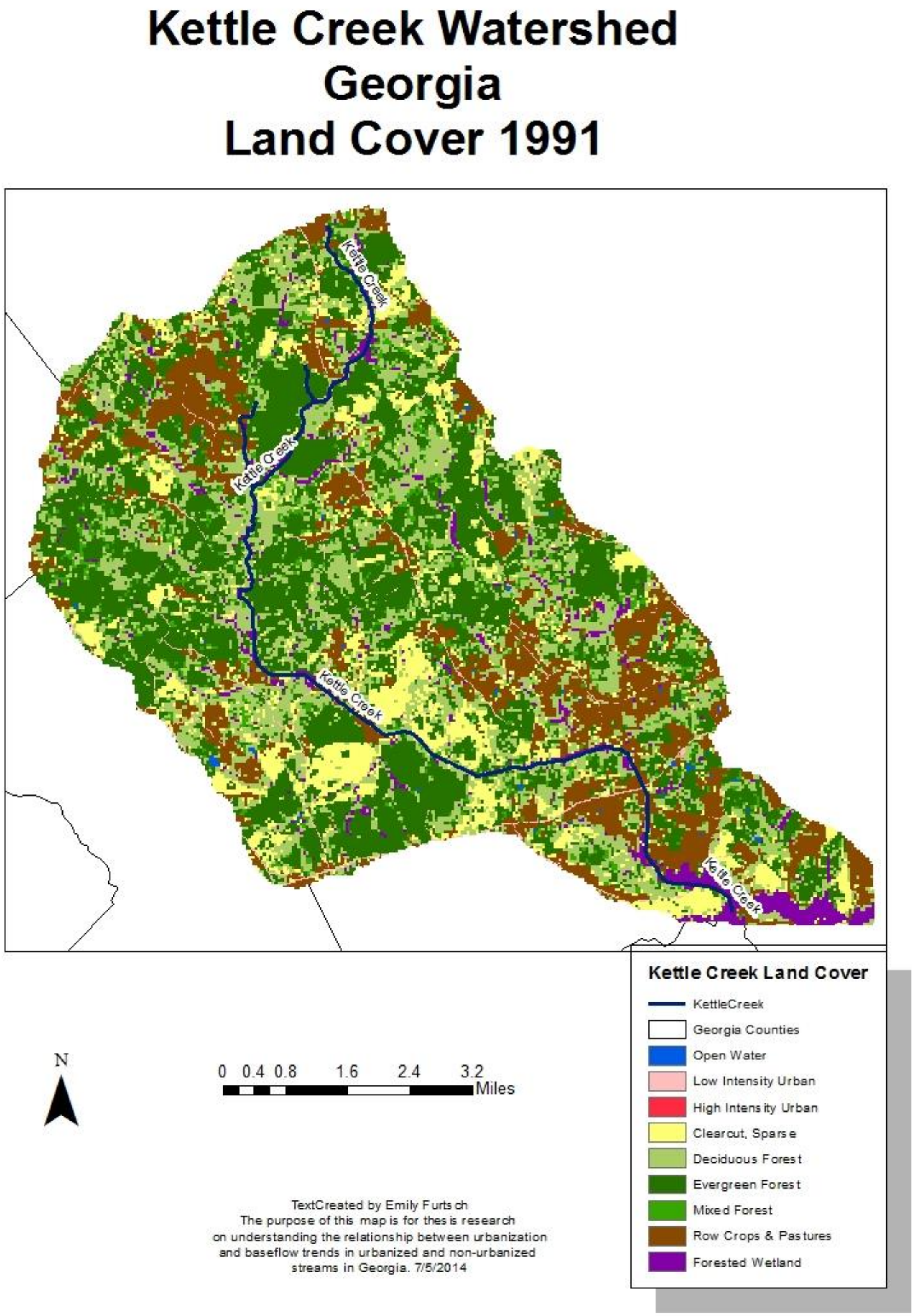

Figure 1.8.21 Kettle Creek 1991 Land Cover

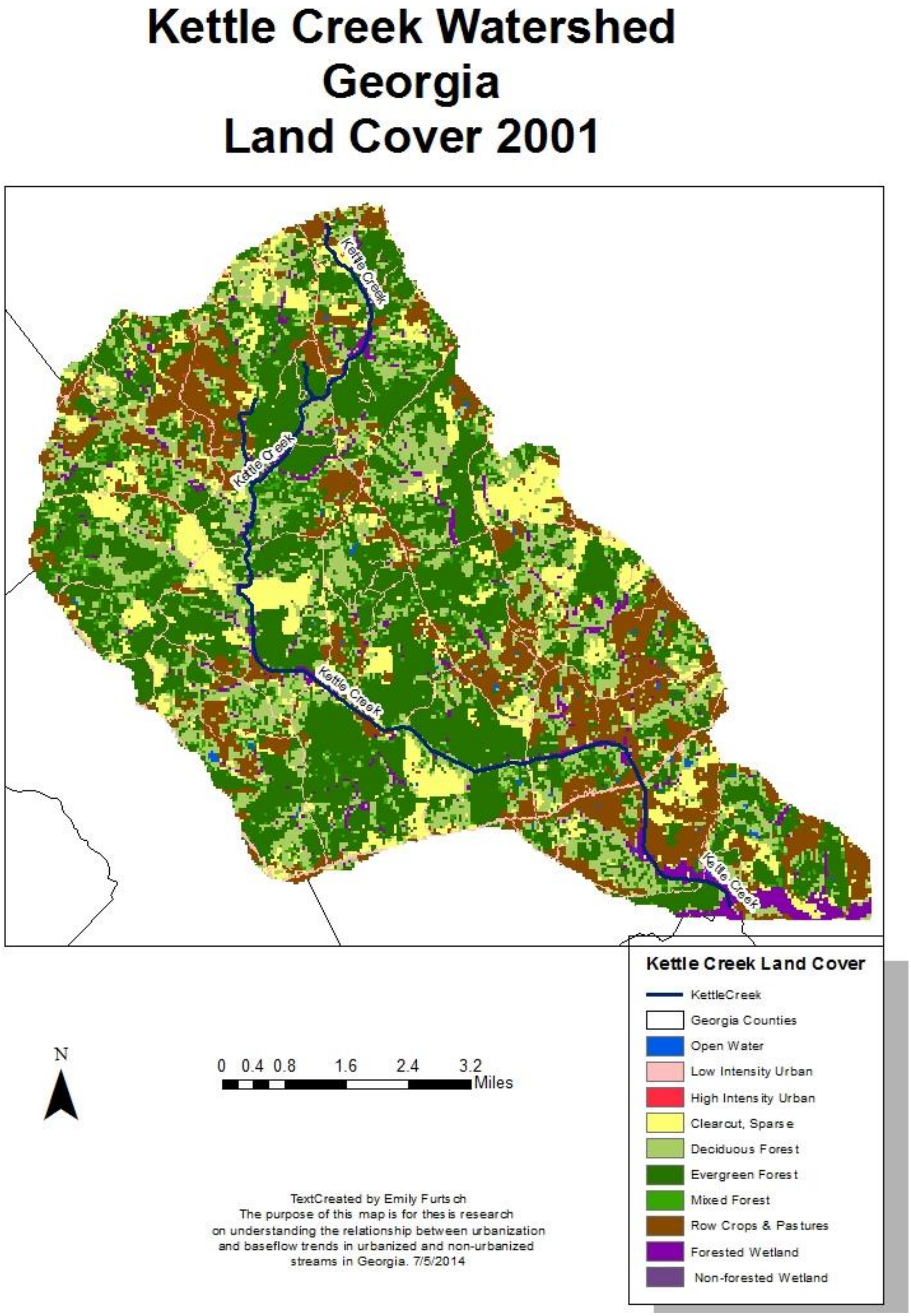

Figure 1.8.22 Kettle Creek 2001 Land Cover

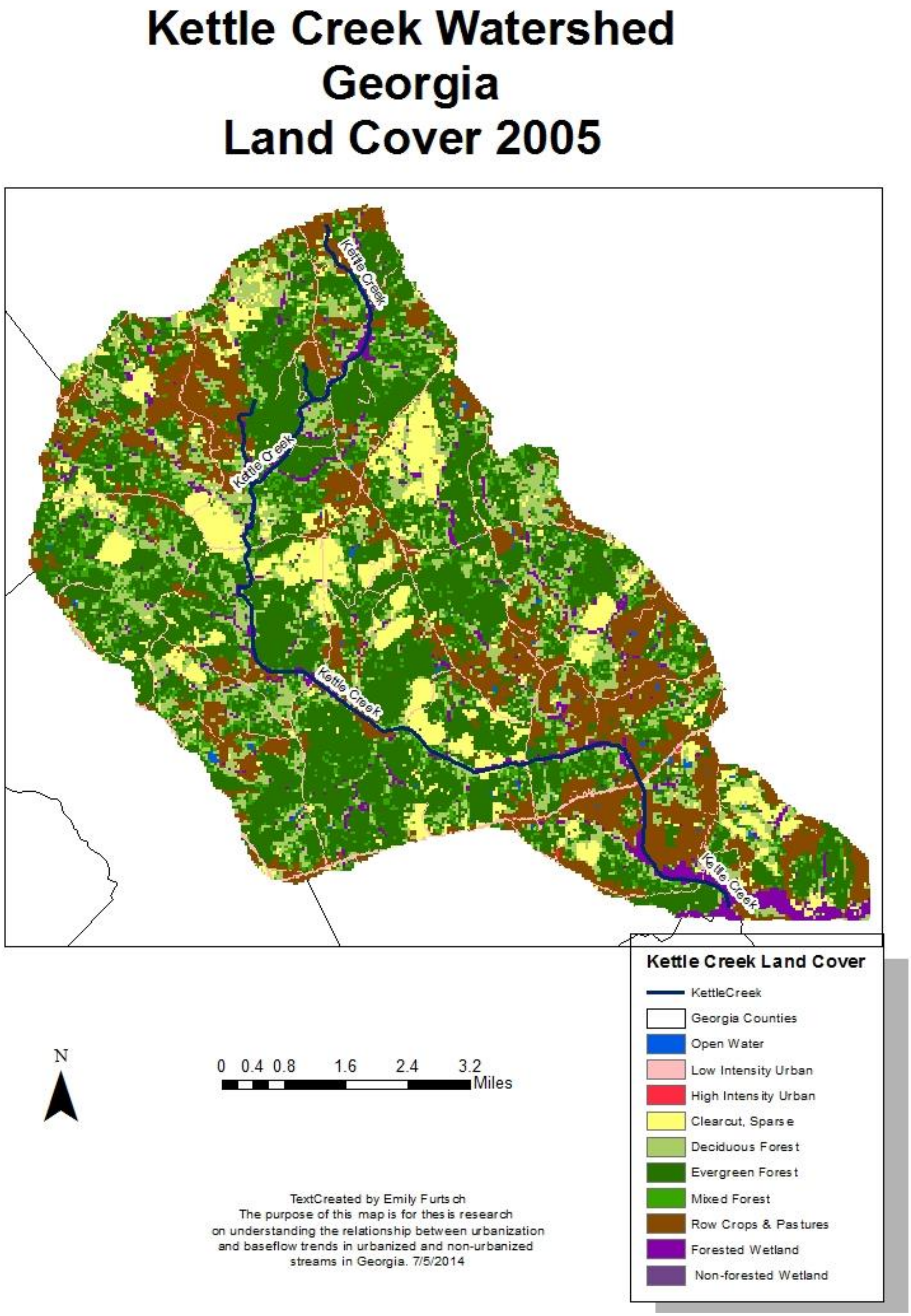

Figure 1.8.23 Kettle Creek 2005 Land Cover

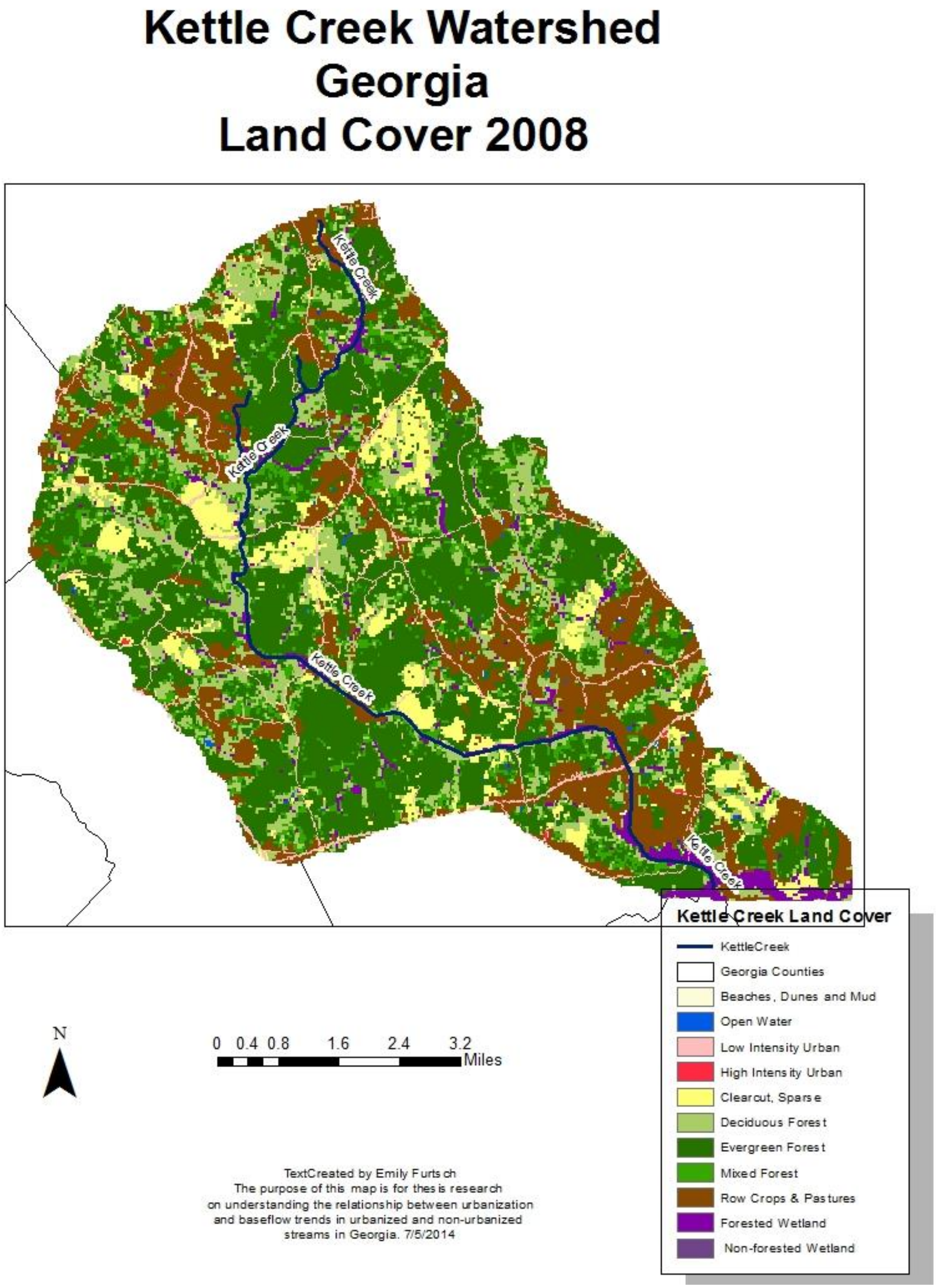

Figure 1.8.24 Kettle Creek 2008 Land Cover

Table 0.1 Statistical Analysis Results Table

Fifth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses. Only Peachtree Creek shows a correlation between High Intensity Urban Land Use and the 5th Percentile baseflow.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 5th	Total Urban vs 5th	HI Urban vs 5th	LI Urban vs 5th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	Yes; R=0.96, P=0.0025	No
2	Sope Creek	No Trend	No	No	No	No
3	Suwanee Creek	Stable	Yes; R=0.96, P=0.04133	Yes; R=0.87, P=0.02507	No	Yes; R=0.87, P=0.02489
4	South River	No Trend	Yes; R=0.98, P=0.02036	Yes; R=0.86, P=0.002598	No	Yes; R=0.88, P=0.02134
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	No	No	No	No
8	Kettle Creek near Washington	No Trend	No	No	No	No

Table 0.2 Statistical Analysis Results Table

Tenth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 10^{th}	Total Urban vs 10^{th}	HI Urban vs 10^{th}	LI Urban vs 10th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	Yes; R=0.93; P=0.0021	No
2	Sope Creek	No Trend	No	No	No	No
3	Suwanee Creek	Stable	Yes; R=0.97; P=0.02857	No	No	No
4	South River	No Trend	Yes; R=0.96; P=0.03585	Yes; R=0.91; P=0.01108	Yes; R=0.84; P=0.03572	Yes; R=0.92; P=0.0089
5	Big Creek	No Trend	No	Yes; R=0.82; P=0.04366	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	No	No	No	No
8	Kettle Creek near Washing-ton	No Trend	No	No	No	No

Table 0.3 Statistical Analysis Results Table

Twenty-fifth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses

Study No.	**Stream Name**	**Mann-Kendall Trend**	**Pop CT vs 25th**	**Total Urban vs 25th**	**HI Urban vs 25th**	**LI Urban vs 25th**
URBANIZED						
1	Peachtree Creek	No Trend	Yes; R=0.97; P=0.02621	No	Yes; R=0.98; P=0.00072	No
2	Sope Creek	No Trend	No	No	No	No
3	Suwanee Creek	Stable	No	No	No	No
4	South River	No Trend	Yes; R=0.98; P=0.02379	Yes; R=0.94; P=0.0059	Yes; R=0.88; P=0.01993	Yes; R=0.94; P=0.00568
5	Big Creek	No Trend	Yes; R=0.86; P=0.02637	Yes; R=0.87; P=0.02272	Yes; R=0.83; P=0.04008	Yes; R=0.85; P=0.03222
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	No	No	No	No
8	Kettle Creek near Washington	No Trend	No	No	Yes; R=0.81; P=0.04934	No

Table 0.4 Statistical Analysis Results Table

Fiftieth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 50th	Total Urban vs 50th	HI Urban vs 50th	LI Urban vs 50th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	No	No
2	Sope Creek	No Trend	No	No	Yes; R=0.84; P=0.0349	No
3	Suwanee Creek	No Trend	Yes; R=0.96; P=0.04162	Yes; R=0.90; P=0.01426	Yes; R=0.85; P=0.03007	Yes; R=0.88; P=0.02107
4	South River	No Trend	No	No	No	No
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	Yes; R=0.90; P=0.01368	Yes; R=0.85; P=0.03394	Yes; R=0.90; P=0.01398
7	Snake Creek near Whitesburg	No Trend	No	No	No	No
8	Kettle Creek near Washing-ton	No Trend	No	No	No	No

Table 0.5 Interpolated Data Statistical Analysis Results

Fifth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses between stream discharge and interpolated data.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 5^{th}	Total Urban vs 5^{th}	HI Urban vs 5^{th}	LI Urban vs 5^{th}
URBANIZED						
1	Peachtree Creek	No Trend	No	No	No	No
2	Sope Creek	No Trend	No	No	No	No
3	Suwanee Creek	Stable	No	No	No	No
4	South River	No Trend	No	Yes; r=0.42281; p=0.04994	No	Yes; r=0.43844; p=0.04124
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	Yes; r=0.5776; p=0.00312	Yes; r=0.60723; p=0.00273	Yes; r=0.60579; p=0.00281	Yes; r=0.60622; p=0.00278
8	Kettle Creek near Washing-ton	No Trend	No	No	yes; r=0.51398; p=0.01441	No

Table 0.6 Interpolated Data Statistical Analysis Results

Tenth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses between stream discharge and interpolated data.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 10th	Total Urban vs 10th	HI Urban vs 10th	LI Urban vs 10th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	No	No
2	Sope Creek	No Trend	No	No	No	No
3	Suwanee Creek	Stable	No	No	No	No
4	South River	No Trend	No	Yes; r=0.44734; p=0.03684	No	Yes; r=0.46848; p=0.02787
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	Yes; r=0.60356; p=0.00294	Yes; r=0.61409; p=0.00236	Yes; r=0.6127; p=0.00243	Yes; r=0.61307; p=0.00241
8	Kettle Creek near Washing-ton	No Trend	No	No	No	No

Table 0.7 Interpolated Data Statistical Analysis Results

Twenty-fifth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses between stream discharge and interpolated data.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 25th	Total Urban vs 25th	HI Urban vs 25th	LI Urban vs 25th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	No	No
2	Sope Creek	No Trend	No	No	Yes; r=0.44203; p=0.03942	No
3	Suwanee Creek	Stable	No	No	No	No
4	South River	No Trend	No	No	No	No
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	Yes; r=0.56753; p=0.00382	Yes; r=0.54574; p=0.00861	Yes; r=0.55124; p=0.00783	Yes; r=0.54447; p=0.0088
8	Kettle Creek near Washington	No Trend	No	No	Yes; r=0.54157; p=0.00924	No

Table 0.8 Interpolated Data Statistical Analysis Results

Fiftieth Percentile Statistical Results for all streams showing Mann Kendall Trend and Correlation Analyses between stream discharge and interpolated data.

Study No.	Stream Name	Mann-Kendall Trend	Pop CT vs 50th	Total Urban vs 50th	HI Urban vs 50th	LI Urban vs 50th
URBANIZED						
1	Peachtree Creek	No Trend	No	No	No	No
2	Sope Creek	No Trend	No	No	Yes; r=0.46699; p=0.02844	No
3	Suwanee Creek	No Trend	No	No	No	No
4	South River	No Trend	No	No	No	No
5	Big Creek	No Trend	No	No	No	No
NON URBANIZED						
6	Line Creek near Senoia	No Trend	No	No	No	No
7	Snake Creek near Whitesburg	No Trend	Yes; r=0.48805; p=0.01554	Yes; r=0.54329; p=0.00897	Yes; r=0.59556; p=0.00345	Yes; r=0.53954; p=0.00956
8	Kettle Creek near Washing-ton	No Trend	No	No	Yes; r=0.49968; p=0.01789	No

Table 0.9 Urban Land Cover 1974-2008

The table displays, in percent values, the percent of urban land cover for each class of urbanization within the eight designated watersheds.

Watershed	Landcover Class	1974	1985	1991	2001	2005	2008	Total Change
LINE CREEK	Low Intensity Urban	5.08	7.15	9.88	14.75	16.48	17.70	12.63
	High Intensity Urban	0.78	1.00	1.16	2.02	3.16	4.38	3.60
	TOTAL URBAN	5.86	8.15	11.05	16.77	19.64	22.08	16.23
SOUTH RIVER	Low Intensity Urban	15.36	20.20	20.51	27.63	29.66	30.62	15.26
	High Intensity Urban	4.64	5.13	5.79	7.25	9.50	11.34	6.71
	TOTAL URBAN	19.99	25.33	26.30	34.88	39.16	41.96	21.97
SUWANEE CREEK	Low Intensity Urban	7.86	13.63	18.44	34.50	36.28	36.78	28.92
	High Intensity Urban	1.25	1.80	2.99	7.70	12.67	20.50	19.25
	TOTAL URBAN	9.11	15.43	21.43	42.20	48.95	57.29	48.17
PEACHTREE CREEK	Low Intensity Urban	35.45	54.44	45.50	53.57	50.61	47.88	12.43
	High Intensity Urban	15.82	18.07	20.01	23.60	27.50	31.20	15.38
	TOTAL URBAN	51.27	72.51	65.51	77.17	78.12	79.09	27.82
BIG CREEK	Low Intensity Urban	7.44	16.16	22.21	37.85	38.26	38.44	31.00
	High Intensity Urban	1.50	2.93	4.40	9.96	13.29	18.80	17.31
	TOTAL URBAN	8.93	19.09	26.61	47.80	51.55	57.24	48.30
KETTLE CREEK	Low Intensity Urban	0.60	0.62	1.30	2.84	2.82	3.10	2.50
	High Intensity Urban	0.00	0.00	0.00	0.03	0.05	0.08	0.08
	TOTAL URBAN	0.60	0.62	1.30	2.87	2.87	3.18	2.58
SNAKE CREEK	Low Intensity Urban	1.43	1.74	3.27	5.67	6.79	7.55	6.12
	High Intensity Urban	0.05	0.06	0.06	0.16	0.26	0.33	0.28
	TOTAL URBAN	1.48	1.80	3.33	5.84	7.05	7.88	6.40
SOPE CREEK	Low Intensity Urban	25.81	44.06	42.17	55.46	54.99	54.66	28.85
	High Intensity Urban	4.16	6.16	6.71	9.49	11.81	14.49	10.34
	TOTAL URBAN	29.96	50.22	48.88	64.95	66.80	69.15	39.19

1.9 Additional Statistical Results

In the urbanized streams, the correlation analyses with the additional interpolated data reduced the amount of relationships between the urbanization parameters and each stream for each percentile flow (see Tables 3.5-3.8). Even though there are fewer correlations, the ones that are found seem to be positive relationships and scattered. The p-values for those relationships are all within a 95% confidence level, but the r values are all below 50%. This means that though there are statistically strong correlations, the parameters are only accounting for less than 50% of the changes in stream discharge over the period of study.

In the non-urbanized streams, the correlation analysis reduced the relationship between Line Creek and the parameters, but introduced a statistically strong positive correlation between Snake Creek and all four urbanization parameters. As well as one additional correlation between high-intensity land use and Kettle Creek in the 50th percentile flows. Again, the parameters only account for, at most, just over 60% of the change in stream discharge. The p-values are well within the 95% confidence interval indicating that the relationship is strong (ranging from p = 0.00236 to p = 0.01789).

1.10 Discussion

All five of the urbanized stream baseflows over time were found to be statistically stable or have no trend across all four percentiles. Suwanee Creek was stable across the three lowest flows, but had no trend in the 50th percentile. Visually there was also no obvious trend in any of the five urbanized streams.

The lowest flow, the 5th percentile, had a few correlations in the urbanized streams. There was a correlation found between Peachtree Creek and high intensity urban land use. With a historically urbanized watershed basin that runs through Atlanta (in particular Buckhead), this correlation with high intensity urban land use (consisting of central business districts, multi-family housing, commercial, institutional and industrial uses, and high impervious surface areas) makes sense. These are likely the newest types of development over the time period of this study. It would lead to the conclusion that high intensity land use could lead to effects on the lowest baseflow percentiles especially since this correlation continues into the 10th and 25th percentile baseflows as well.

Two other streams in the 5th percentile had a correlation with three other parameters. South River, a stream with no trend, had a correlation with population by Census tract (a parameter that also had no trend in the Mann-Kendall analysis), total urban land use, and low-intensity urban land use. The strongest relationship was with the population by Census tract. Suwanee Creek also had a relationship with population by Census Tract, total urban land use, and low-intensity urban land use. Again, population by Census Tract had the strongest relationship of the three parameters (r=0.96).

In the 10th percentile baseflows, four out of the five urbanized streams (Peachtree Creek, Suwanee Creek, South River, and Big Creek) saw correlations with at least one parameter. Population by Census tract and 10th percentile flow had a correlation in both Suwanee Creek and South River. Total percent urban land use and flows for both South River and Big Creek had positive correlations. The historically urbanized Peachtree Creek (51.27% urban land cover already by 1974, see Table 3.5) had a correlation with the high-intensity urban land use as did South River. Lastly, South River had a correlation with low-intensity urban land use and 10th percentile flows. South River baseflow over time had a positive correlation with all four urbanization parameters with the population parameter having the strongest relationship with the low flow.

Sope Creek and Suwanee Creek showed no correlation with any of the urbanization parameters and their 25th percentile flows. The 25th percentile baseflow for South River had a correlation with all four urbanization parameters with the strongest being with population by Census tract (r= 0.97). The 25th percentile for Big Creek had correlations between all of the urban land use parameters and population by Census tract. Again, population by Census tract had the strongest correlation (r=0.97). Peachtree Creek had a correlation again with the high-intensity urban land use and the 25th percentile flows as well as with population by Census Tract. Big Creek 25th percentile flows over time had a moderate correlation with population by Census Tract and all three urban land use parameters.

In the 50th percentile flows for the urbanized streams only Suwanee and Sope Creeks had any correlations with the urbanization parameters. The linear correlation revealed a relationship between the 50th percentile baseflows for Suwanee Creek and all three urban land-use parameters as well as population by Census tract. Population by Census tract had the strongest relationship (r=0.96). Sope Creek 50th percentile flows had a relationship with high-intensity urban land use.

All three non-urbanized streams had no trend statistically across all four percentile flows. They all had increasing urbanization parameters meaning these non-urbanized streams are becoming more urbanized with time though none was more than 25% urbanized as of 2008. Line Creek increased from having a total urban land use of 5.86% to only 22.08% but it was the highest of the three. Kettle Creek was only 3.18% urban land use as of 2008 and Snake Creek only had 7.88% total urban land use. In contrast in 2008 the urbanized stream with the lowest total urban land use was South River and it had almost 42% urban land use (almost double that of Line Creek). There were no correlations between any of the urbanization parameters for the 5th and 10th percentile flows for all three non-urbanized streams. In the 25th percentile flows for non-urbanized streams, only Kettle Creek baseflow had a relationship with an urbanization parameter. A correlation was found between high-intensity urban land use and the 25th percentile baseflow over time for Kettle Creek though the relationship was only moderate (r=0.81). In the larger 50th baseflow percentile Line Creek had a correlation with total urban land use, high-intensity urban land use, and low-intensity urban land use. Kettle Creek and Snake Creek 50th percentile baseflows did not show any relationship with any urbanization parameter.

It was expected that the baseflow trends would be found to be decreasing, especially in the suburban streams where urban land use increases were relatively large and population changes were greater. Based on the statistical trend analysis on the streams though, the urbanized stream flows don’t seem to have any general trends across the different percentile flows. All five were stable or had no trend across all four percentile flows. Suwanee Creek remained stable except in the 50th percentile where it had no trend. Sope Creek had the least correlations across the percentile with only a moderate correlation between 50th percentile flows and high-intensity urban land use.

The Mann-Kendall trend analysis revealed that most of the urbanization parameters were increasing while the urban streams remained stable or without any noticeable trend. Future research could be aimed at attaining a deeper understanding of each of the baseflows in each watershed and their changing nature. It was expected, based on previous studies discussed previously showing a relationship between streamflow and increasing urbanization, that this study would find a negative correlation between urbanization parameters and baseflow. All correlations that were found were positive correlations which would mean an increase in the urbanization parameters for this study leads to an increase in baseflow or even possibiy an increase in baseflow stability where correlations were found. This is the opposite of the expected results. In general though, no real trends can be observed across the baseflows of the streams in this study and the urbanization parameters. Further research is needed to understand why some streams had positive correlations between baseflows and the different parameters but others did not. The non-urbanized streams had no correlations in the lower percentile baseflows. In the 50th percentile flows for Line Creek a positive correlation was found with urban land use parameters. The baseflows for all three non-urbanized streams statistically showed no trend. Further research is needed to understand each of the complex relationship between the specific baseflows for each stream with positive correlations with urbanization parameters.

It is possible that because of the limited scope of urbanization parameter data relative to the baseflow percentile data, the results are exaggerated. Population from Census data values only has four available values (1980, 1990, 2000, 2010) due to the timeline of Census data. Land use data were only available for six years (1974, 1985, 1991, 2001, 2005, and 2008) while stream percentile data were available annually from 1987 to 2010. It is harder to establish trends and correlations that are reliable with data that have such drastic differences in availability. A linear correlation requires a minimum of four values, but gives greater accuracy with more values. Since the population only had four values, the accuracy could be compromised especially when analyzed with extensive amount of baseflow values. With only six values total, the same problem presents itself in a linear correlation between land use and stream baseflow. Given the historical data, it is assumed, that the baseflow trends are accurate, therefore further research is needed, to understand the correlations that were found and why they exist.

1.10.1 Discussion on Additional Statistical Analyses with Interpolated Data

The additional analyses done for each percentile stream correlated against each interpolated parameter again showed scattered results. The correlations that were made only accounted for a relatively small percentile of changes making clear that there must be something else going on to account for the baseflow value changes over time. The simplicity of the study is a major contributing factor to such result. There is no perfect urbanization proxy and each proxy accounts for only a portion of urbanization that occurs. Though, as seen in Snake Creek (Tables 3.5-3.8), the r values are similar across all of the parameters, meaning that the parameters themselves (i.e., population and land use changes) are closely related and do work successfully as a proxy for at least a portion of urbanization.

The scattered results are indicative of the fact that there is some relationship between these urbanization proxies and stream flow, though that relationship is clearly convoluted and needs a much more thorough analysis to be understood. These results draw into question, what is being missed and what else could be contributing that is a part of the urbanization schema. Ideas such as water relocation need to be taken into account. Though it goes beyond the reach of this particular study, future studies could endeavor to find out where water is being withdrawn for an entire population’s use (including commercial, industrial, well, personal, etc.) and if that water would then be returned, in the form of leaky infrastructure, watering of lawns, etc., to a different watershed. Also to be considered for future studies is the actual percent imperviousness changes and the one-to-one relationship with baseflow.

The parameters used for the study work, as mentioned previously, as a proxy, but a longer, more in-depth study could calculate, more accurately, by choosing a smaller set of data (i.e., two percentiles for only 3-4 streams).

The most interesting point to all of the statistical results, both with interpolated data and without, is the results in the higher median baseflows. The extreme ends of stream flow (both 5th baseflow and 95th peak flow) will usually be the first to respond to changes, generally speaking, but when correlations are found within the median flows, as is found in this study, a relationship is clearly occurring between urbanization and baseflow. Something about urbanization is changing the watershed and subsequently the stream flow. As seen in these results, these relationships seem to be positive, another surprising result.

Other things to consider and that the statistical correlations show, is that this is a very intricate web of relationships. Urbanization doesn't affect just stream flow, or, in particular baseflow. It affects, as shown in many studies aforementioned, many parts of the web from evapotranspiration to precipitation to the landscape. Recently, Diem (2013) found that precipitation actually rebounded and increased from the 1970s in the Atlanta area when air pollution was decreased due to the Clean Air Act. Increased precipitation could recharge groundwater and therefore increase baseflow. Though this study aimed to account for rainfall and normalized accordingly, it is possible that the rainfall data used was not as accurate as desired. The gages used for this study were not perfectly aligned with the streams with which they were associated for normalization due to limited consistent historical precipitation gage data. In addition, this study did not take into account evapo-transpiration. Evapo-transpiration rates, as mentioned earlier, according to multiple studies have been found to decrease with urbanization (Boggs and Sun, 2011; Rose and Peters, 2001; Guo, et al., 2008). In eastern United States, watersheds with 0-58% urbanization between 1920-1990 showed decreases in evapo-transpiration. At 100% urbanization, annual evapo-transpiration is predicted to decrease 22 cm (Dow and DeWalle, 2000). All of these factors, and many not mentioned that occur with increasing urbanization, come into play and could be affecting baseflow trends and correlations.

Regardless of the relationships, a major finding from this study is the clear lack of a trend in urbanizing watersheds. It was expected, based on previous studies, that stream flow, including baseflow, decrease with increasing urbanization. This study clearly shows increasing urbanization through urbanization factors population and land use change and even shows some correlations are occurring and accounting for some baseflow changes. In general, though, the expected results of a negative correlation (a decreasing baseflow with increasing urbanization) were definitely not found in the statistical analysis. The streams had no visible decreasing trend across all percentiles and any relationships found with urbanization parameters were positive. Other factors such as water relocation, well water use, leaky infrastructures, landscaping (watering of lawns, golf courses, etc.), increased precipitation, decreased evapo-transpiration rates and other factors could be causing the trends to defy the expected results.

Population is increasing. As population increases, further studies are necessary to understand more precisely how baseflow is affected by urbanization and what other factors are coming into play. The annual rate of increase of urban population over the next 30 years is 1.8%. The urban population of developing regions is projected to grow rapidly as people migrate from rural to existing urban areas and transform rural settlements into cities (Cohen, 2003). With population growth comes land use change and consumption changes. With increasing urban population growth, urbanization will only continue to occur. This study has brought to light there are correlations between urbanization and baseflow, though those correlations are scattered and only account for a percent of the stream flow changes. The relationship seen in the correlation analyses in this study proved to be positive. Future studies could find out the implications of a positive correlation between baseflow and urbanization as well as why this may be occurring.

SUMMARY AND CONCLUSIONS

This study examined the relationship between urbanization, as defined by population and urban land use, and baseflow run off trends from 1987 to 2010. Eight different streams, five urbanized and three non-urbanized, in the state of Georgia were chosen for examination. Population was determined by Census tract within the delineated watershed. Urban land use was divided into three categories, total urban land use, high-intensity land use, and low-intensity land use. By subdividing the parameters, it was hoped to achieve a more thorough and accurate assessment of factors that may affect baseflow trends, if there are trends.

The existence of a trend in the baseflows, or lack thereof, was established and documented in the results section. The eight streams had no consistent set of relationships associated with urbanization. There are a few exceptions that will be discussed further, but urbanized streams were found to be stable or without a trend across all percentiles, non-urbanized streams were found to be without a statistical trend as well. The statistical analyses with the interpolated data produced inconsistent correlations across the stream percentiles as well, though Snake Creek baseflows appeared to have statiscally strong relationships across all percentiles with all of the urbanization parameters.

Low flows for Line Creek, a non-urbanized stream, located near Senoia, Georgia had no trend across all percentiles of baseflow. The other two non-urbanized streams, Kettle Creek and Snake Creek, also had no statistical trend for the baseflow. Upon examination of the location of Line Creek, it is possible that the presence of Peachtree City, an urbanized area within the vicinity of the stream could have affected it to behave more like an urbanized stream. The area also had the greatest increase in population and urban land use when compared with the other non-urbanized streams.

The urbanized streams had baseflows that were stable or exhibited no trend across all percentile flows. Sope Creek had only one correlations between its baseflows and the urbanization parameters and it was in the 50th percentile flow, a greater volume of water and probably least representative of low-flow overall. It is possible that the presence of the Chattahoochee National Forest surrounding a portion of the stream gave the stream a buffer from increased urbanization surrounding it.

When comparing these results with Mann-Kendall trend analysis on the parameters, it was thought that there should be a negative correlation between the trends in general, but the linear correlation does not support these findings. Any correlations that were found in the analyses were positive correlations with a p-value < 0.95.

Seven of the eight streams had, in at least one percentile, a correlation between baseflow trends and an increasing trend of at least one of the three urban land uses. In the correlation analyses with interpolated data only four out of eight streams had, in at least one percentile, a correlation between urbanization parameters and baseflow. In the original correlation analysis, Peachtree Creek had a correlation between three of the four percentile baseflows and the high intensity urban. This makes sense because Peachtree Creek has been urbanized for long enough that low-intensity urban land cover would have slowed down or stabilized, leaving room for only high-intensity urbanization, but a positive correlation was not expected. According to the majority of studies, there should have been a negative correlation, but with Peachtree Creek, with heavy urbanization in place and still continuing, there was a positive correlation between increased urbanization and baseflow.

Suwanee Creek is increasing in urbanization across all parameters, but the baseflow is considered stable across most percentiles and there are two positive correlations with that stable flow. In the 50th percentile flow where there is no trend in the baseflow, a positive correlation was found with all urban land use parameters as well as population by Census tract. In all but the 25th percentile there was a correlation between baseflow over time and population by Census Tract, which could mean that there is a relationship between increasing baseflow and increasing population. But, according to the trend analysis, even though population and urban land cover are increasing, baseflows are remaining stable.

This could lend to the argument that increasing population could lead to stabilized baseflows. An explanation could be that there is a delay in stream response to urbanization due to watershed size as Hirpa, et. al (2010) found, but a further analysis of the watershed size relative to their definition of a larger watershed would need to be done to ascertain. The correlation analyses with interpolated data displayed no relationship between any of the urbanization parameters and any of the percentile flows.

Big Creek saw all of its urbanization parameters increasing. There was a moderate correlation between the 10th percentile and total urban land use. The 25th percentile baseflows saw correlation with total urban land use, low-density urban land use, high-density urban land use, and population by Census tract. All parameters are increasing for Big Creek, but the baseflow, across the three lowest percentiles is considered stable. The linear correlation shows that there is a positive correlation between 10th and 25th percentile baseflows and increased urbanization as defined by urban land use. Correlation analyses with interpolated data show no relationship with any urbanization parameter with any of the percentile flows.

Sope Creek's parameters are all increasing while the baseflows have no observable trend over time. The linear correlation reveals there are no correlations between any urbanization factors and baseflow in the three lowest flows, but the 50th percentile flow over time has a relationship with high intensity urbanization. In the correlation analyses with interpolated data, the 25th percentile flow also had a strong statistical relationship with high intensity urbanization.

All of the parameters for urbanization in the Line Creek watershed, a non-urban stream, were increasing except population by census tract (even though there was an increase of over 10,000 from ~7,100 to ~17,800 over the course of this study period). There was only a correlation between the 50th percentile flows and the all three urban land use cover parameters. The 50th percentile baseflows are extending the reach and definition of baseflow beyond the normally accepted values of 5th and 10th percentile flows and can be considered median flows. It is more unlikely to see changes in the median flows, therefore it's interesting to note that there are correlations that are found within those flows solely. These results could also be its proximity to Peachtree City. Line Creek had no trend quantitatively for the baseflows over time across all percentiles.   In the correlation analyses with interpolated data there were no relationships with any of the urbanization parameters across all percentile baseflows.

Snake Creek, a non-urban stream, saw all of the urbanization parameters increasing, but no trend over time in the baseflows across all four percentiles. The correlation analysis found no correlation between baseflow and urbanization parameters though. There could be a delay in urbanization and affect on stream baseflow or there could be a baseline of urbanization to be met before effects can be seen.   However, after interpolating the parameter data, all four percentile baseflows had a statistically strong relationship with all four urbanization parameters.

Lastly Kettle Creek's population was stable, but all urban land use was increasing. Kettle Creek baseflow trends across all percentiles had no statistical trend over time. Yet there was no correlation between any of the parameters and baseflow except in the 25th percentile low flow where a correlation was seen with high intensity land use. Again, the same reasoning aforementioned for Snake Creek could come into play: time and a baseline urbanization before low flows are affected. The statistical analyses on the interpolated data produced two more relationships with both the 5th and 50th percentile flows and high-intensity urban land use. The correlations in the median baseflows may be indicative of the fact that there are truly changes to stream flow that can be accounted for by the urbanization parameters.

All creeks saw urbanization increasing in some manner or another, yet the correlations were scattered and seemed to point more toward a positive relationship. All five urbanized streams either had no statistical trend over time or were considered stable. Further analysis needs to be done to determine the rate at which baseflows are affected by urbanization and by the rate of urbanization (i.e., is there an immediate stream response and then flows stabilize or vice versa). The non-urbanized streams that had a correlation with an urbanization parameter could be evaluated in future years for continuing changes to establish, more firmly, the effects of urbanization and the timeline for those effects. A future study could break down the land use in a more detailed way to examine whether increased lawn space, reduced old forest coverage, increased recreational green space and other urban green space contribute to baseflow while decreased TIA may still decrease baseflow as other studies have found. A more time-intensive and detailed study could further expand upon the idea of how urbanization in changing the landscape, may just be rerouting water through artificial pathways including concrete drains, increased residential and commercial lawn space (therefore increased watering), recreational greenways (i.e., golf, parks, etc.) and even leaky infrastructure. It could also investigate the possibility that water being drawn from one watershed for public and private use is being added back into the water budget of another watershed through some of the aforementioned routes. Another interesting urbanization parameter that could be considered is that of drainage ditches and artificial lakes where water is collected. These stored water systems could be either enhancing the leaking of water or inhibiting the natural movement of water by changing the evapo-transpiration water return to a given watershed. This in turn could be affecting precipitation.

There are many factors in the natural system that are disrupted and even rerouted in an urbanized water setting. It is difficult, with the scope of a study, to take into account all of these factors. This study, in particular, was limited by its simplicity in urbanization proxies. Because this study attempted to determine if a particular type of urban land use change (high-intensity versus low-intensity versus just total urban land use) would have a stronger correlation, the design was kept simple. There was no clear relationship that was stronger than another urbanization parameter, rather they all seemed to go hand in hand indicating that the parameters used are effective as a proxy for a portion of urbanization.

If a trend had to be drawn based on the results of this study, there are more instances lending to the belief that with time, increasing urbanization can lead to stabilized baseflows. Though that trend cannot be drawn conclusively and further research would be needed to make that assertion with confidence. It is not clear whether the initial effects of urbanization are greater and it becomes more stable thus giving a statistical result of no trend or stable. Though there appears to be a relationship between urbanization and baseflow over time, that relationship and the nature of which parameter might have the greatest effect is also not clear without further research that goes beyond the scope of this study. Future studies could also break down the historical baseflow over smaller time frames to examine statistically for any small trends that may occur over smaller periods of time, but are lost in the bigger picture examination. If that produced any trends, it would be interesting to see if and when the watershed begins to be affected after the start of urbanization. This could lead to an understanding of what exactly is the lag-time for reaction and what are the trends when seen over shorter periods of time compared to a large-scale time period. It would also be beneficial to examine the historical urbanization and stream data for even earlier dates especially for streams such as Peachtree Creek and South River. This might provide greater understanding of the initial reaction of stream flow to increased urbanization.

REFERENCES

Administration, N. O. a. A. Annual Climatological Summary. http://www.ncdc.noaa.gov/ (accessed 08/01/2014)

Agency, U. S. E. P. 2011. Watersheds. http://water.epa.gov/type/watersheds/index.cfm.

Agriculture., U. S. D. o. 2009. *Summary Report: 2007 National Resources Inventory*. 123. Natural Resources Conservation Service: Washington, D.C., USA, Center for Survey Statistics and Methodology: Iowa State University, Ames, IA, USA.

Andrews, E. D. (1984) Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. *Geological Society of America Bulletin,* 95**,** 371-378.

Arnold, C. L. & C. J. Gibbons (1996) Impervious surface coverage - The emergence of a key environmental indicator. *Journal of the American Planning Association,* 62**,** 243-258.

Barney, C. (2004) Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts. *World Development,* 32**,** 23-51.

Boggs, J. L. & G. Sun (2011) Urbanization alters watershed hydrology in the Piedmont of North Carolina. *Ecohydrology,* 4**,** 256-264.

Bosch, D. J., V. K. Lohani, R. L. Dymond, D. F. Kibler & K. Stephenson (2003) Hydrological and fiscal impacts of residential development: Virginia case study. *Journal of Water Resources Planning and Management-Asce,* 129**,** 107-114.

Brezonik, P. L. & T. H. Stadelmann (2002) Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. *Water Research,* 36**,** 1743-1757.

Bureau, U.S. Census, "U.S. Census Bureau", U.S. Department of Commerce http://www.census.gov (first accessed 2-21-2012).

Carling, P. (1988) The concept of dominant discharge applied to two gravel-bed streams in relation to channel stability thresholds. *Earth Surface Processes and Landforms,* 13**,** 355-367.

Chebud, Y. & A. Melesse (2011) Operational Prediction of Groundwater Fluctuation in South Florida using Sequence Based Markovian Stochastic Model. *Water Resources Management,* 25**,** 2279-2294.

Chin, A. (2006a) Urban transformation of river landscapes in a global context. *Geomorphology,* 79**,** 460-487.

--- (2006b) Urban transformation of river landscapes in a global context. *Geomorphology,* 79**,** 460-487.

Cohen, J. E. (2003) Human Population: The Next Half Century. *Science,* 302**,** 1172-1175.

DeLoatch, J. P., M. A. O'Driscoll, M. M. Brinson & E. C. Hardison (2007) Groundwater hydrology of low-order coastal plain streams across an urban land-use gradient. *Abstracts with Programs - Geological Society of America,* 39**,** 319-319.

--- (2008) Urban land-use effects on stream-groundwater interactions along inner coastal plain streams, NC. *Abstracts with Programs - Geological Society of America,* 40**,** 385-385.

Commission, A. R. GIS Data and Maps. http://www.atlantaregional.com/info-center/gis-data-maps (accessed 11-22-2011).

Diem, J.E**.** 2013. The 1970 Clean Air Act and termination of rainfall suppression in a U.S. urban area. Atmospheric Environment, 75:141-146.

Doll, B. A., D. E. Wise-Frederick, C. M. Buckner, S. D. Wilkerson, W. A. Harman, R. E. Smith & J. Spooner (2002) Hydraulic geometry relationships for urban streams throughout the piedmont of North Carolina. *Journal of the American Water Resources Association,* 38**,** 641-651.

Dow, C. L. & D. R. DeWalle (2000) Trends in evaporation and Bowen ratio on urbanizing watersheds in eastern United States. *Water Resources Research,* 36**,** 1835-1843.

Foster, S. (2006) Groundwater - sustainability issues and governance needs. *Episodes,* 29**,** 238-243.

Foster, S., A. Lawrence & B. Morris. 1998. Groundwater in urban development: assessing management needs and formulating policy strategies. In *World Bank technical paper; no. WTP 390*. World Bank.

Foster, S. S. D., A. R. Lawrence & B. L. Morris. 1996. Urban groundwater resource management; priorities for developing cities. 106-113. United Kingdom: E & FN Spon : London, United Kingdom.

Franke, O. L. 1968. Double-mass-curve analysis of the effects of sewering on ground-water levels on Long Island, New York. B205-b209. United States: U. S. Geological Survey : Reston, VA, United States.

Galster, J. C., F. J. Pazzaglia, B. R. Hargreaves, D. P. Morris, S. C. Peters & R. N. Weisman (2006) Effects of urbanization on watershed hydrology; the scaling of discharge with drainage area. *Geology [Boulder],* 34**,** 713-716.

Garcia-Fresca, B. 2006. Urban-enhanced groundwater recharge: review and case study of Austin, Texas, USA. In *Urban Groundwater, Meeting the Challenge. International Association of Hydrogeologists Selected Papers,* ed. K. W. F. E. Howard, 3-18. Longdon, UK: Taylor & Francis.

Garcia-Fresca, B. & J. M. Sharp, Jr. (2005) Hydrogeologic considerations of urban development; urban-induced recharge. *Reviews in Engineering Geology,* 16**,** 123-136.

Gong, Y. W., Z. Y. Shen, R. M. Liu, X. J. Wang, and T. Chen. "Effect of Watershed Subdivision on Swat Modeling with Consideration of Parameter Uncertainty." *Journal of Hydrologic Engineering* 15, no. 12 (2010): 1070-1074.

Grable, J. L. & C. P. Harden (2006) Geomorphic response of an Appalachian Valley and Ridge stream to urbanization. *Earth Surface Processes and Landforms,* 31**,** 1707-1720.

Graf, W. L. (1999) Dam nation; a geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research,* 35**,** 1305-1312.
--- (2006) Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology,* 79**,** 336-360.

Graniel, C. E., L. B. Morris & J. J. Carrillo-Rivera (1999) Effects of urbanization on groundwater resources of Merida, Yucatan, Mexico. *Environmental Geology,* 37**,** 303-312.

Gregory, K. J., G. Benito, R. Dikau, V. Golosov, A. J. J. Jones, M. G. Macklin, A. J. Parsons, D. G. Passmore, J. Poesen, L. Starkel & D. E. Walling (2006) Past hydrological events related to understanding global change; an ICSU research project. *Catena [Giessen],* 66**,** 2-13.

Gregory, M. B. & W. L. Bryant (2003) Effects of urbanization on stream ecosystems in the Piedmont ecoregion of Georgia and alabama; a study design. *Proceedings - Georgia Water Resources Conference,* 2003.

Gregory, M. B. & D. L. Calhoun. 2007. Physical, Chemical, and Biological Responses of Streams to Increasing Watershed Urbanization in the Piedmont Ecoregion of Georgia and alabama, 2003. In *U.S. Geological Survey Scientific Investigations Report 2006-5101-B*. U.S. Geological Survey.

Guo, H., Q. Hu & T. Jiang (2008) Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang Lake basin, China. *Journal of Hydrology,* 355**,** 106-122.

Hardison, E. C., M. A. O'Driscoll, J. P. DeLoatch, R. J. Howard & M. M. Brinson (2009) Urban Land Use, Channel Incision, and Water Table Decline along Coastal Plain Streams, North Carolina(1). *Journal of the American Water Resources Association,* 45**,** 1032-1046.

Hawley, R. J. & B. P. Bledsoe (2011) How do flow peaks and durations change in suburbanizing semi-arid watersheds? A southern California case study. *Journal of Hydrology,* 405**,** 69-82.

Helley, E. J. 1969. Field measurement of the initiation of large bed particle motion in Blue Creek near Klamath, California. United States: U. S. Geological Survey : Reston, VA, United States.

Hirpa, F. A., M. Gebremichael & T. M. Over (2010) River flow fluctuation analysis: Effect of watershed area. *Water Resources Research,* 46.

Hirsch, R. M., J. F. Walker, J. C. Day & R. Kallio. 1990. The influence of man on hydrologic systems The geology of North America. 329-359. United States: Geol. Soc. Am. : Boulder, CO, United States.

Hollenhorst, T. P., T. N. Brown, L. B. Johnson, J. J. H. Ciborowski, and G. E. Host. "Methods for Generating Multi-Scale Watershed Delineations for Indicator Development in Great Lake Coastal Ecosystems." *Journal of Great Lakes Research* 33, (2007): 13-26.

Holmes, K. L., and P. C. Goebel. "A Functional Approach to Riparian Area Delineation Using Geospatial Methods." *Journal of Forestry* 109, no. 4 (2011): 233-241.

Jana, R., T. V. Reshmidevi, P. S. Arun, and T. I. Eldho. "An Enhanced Technique in Construction of the

Discrete Drainage Network from Low-Resolution Spatial Database." *Computers & Geosciences* 33, no. 6 (2007): 717-727.

Juracek, K. E. (2004) Historical channel-bed elevation change as a result of multiple disturbances, Soldier Creek, Kansas. *Physical Geography,* 25**,** 269-290.

Kang, R. S. & R. A. Marston (2006) Geomorphic effects of rural-to-urban land use conversion on three streams in the Central Redbed Plains of Oklahoma. *Geomorphology,* 79**,** 488-506.

Khan, H. H., A. Khan, S. Ahmed & J. Perrin (2011) GIS-based impact assessment of land-use changes on groundwater quality: study from a rapidly urbanizing region of South India. *Environmental Earth Sciences,* 63**,** 1289-1302.

Kini, Y. Y., K. K. Lee & I. H. Sung (2001) Urbanization and the groundwater budget, metropolitan Seoul area, Korea. *Hydrogeology Journal,* 9**,** 401-412.

Konrad, C. P. & D. B. Booth. 2002. Hydrologic trends associated with urban development for selected streams in the Puget Sound basin, western Washington. United States: U. S. Geological Survey : [Reston, VA], United States.

---. 2005. Hydrologic Changes in Urban Streams and Their Ecological Significance. In *American Fisheries Society Symposium*, 157–177. American Fisheries Society.

Lab, U. o. G. s. N. R. S. A. Georgia Land Use Trends. http://narsal.uga.edu (accessed 6-13-2014).

Leopold, L. B. 1968. Hydrology for urban land planning; a guidebook on the hydrologic effects of urban land use.

--- (1973) River Channel Change with Time; An Example. *Geological Society of America Bulletin,* 84**,** 1845-1860.

Lerner, D. N. (2002) Identifying and quantifying urban recharge; a review. *Hydrogeology Journal,* 10**,** 143-152.

Lin, W. T., W. C. Chou, C. Y. Lin, P. H. Huang, and J. S. Tsai. "Winbasin: Using Improved algorithms and the Gis Technique for Automated Watershed Modelling Analysis from Digital Elevation Models." *International Journal of Geographical Information Science* 22, no. 1 (2008): 47-69.

Lorenzo-Rigney, B. & J. M. Sharp, Jr. (1999) Urban recharge in the Edwards Aquifer. *Abstracts with Programs - Geological Society of America,* 31**,** 12-12.

Martin, D., and S. K. Saha. "Integrated Approach of Using Remote Sensing and Gis to Study Watershed Prioritization and Productivity." *Photonirvachak-Journal of the Indian Society of Remote Sensing* 35, no. 1 (2007): 21-30.

________. "Land Evaluation by Integrating Remote Sensing and Gis for Cropping System Analysis in a Watershed." *Current Science* 96, no. 4 (2009): 569-575.

McBride, M. & D. B. Booth (2005) Urban impacts on physical stream condition: Effects of spatial scale, connectivity, and longitudinal trends. *Journal of the American Water Resources Association,* 41**,** 565-580.

McCuen, R. H. 1998. *Hydrologic Analysis and Design*. Upper Saddle River New Jersey: Prentice Hall.

Mendoza, M. E., E. L. Granados, D. Geneletti, D. R. Perez-Salicrup, and V. Salinas. "Analysing Land Cover and Land Use Change Processes at Watershed Level a Multitemporal Study in the Lake Cuitzeo Watershed, Mexico (1975-2003)." *Applied Geography* 31, no. 1 (2011): 237-250.

Meyer, S. C. (2005) Analysis of baseflow trends in urban streams, northeastern Illinois, USA. *Hydrogeology Journal,* 13**,** 871-885.

Milhous, R. T. & P. C. Klingeman (1973) Sediment transport system in a gravel-bottomed stream. *Am. Soc. Civ. Eng., Hydraul. Div., Annu. Spec. Conf., Proc.***,** 293-303.

Moglen, G. E. & R. E. Beighley (2002) Spatially explicit hydrologic modeling of land use change. *Journal of the American Water Resources Association,* 38**,** 241-253.

Moglen, G. E., K. C. Nelson, M. A. Palmer, J. E. Pizzuto, C. E. Rogers & M. I. Hejazi (2004) Hydro-ecologic responses to land use in small urbanizing watersheds within the Chesapeake Bay watershed. *Geophysical Monograph,* 153**,** 41-60.

Niezgoda, S. L. & P. A. Johnson (2005) Improving the urban stream restoration effort: Identifying critical form and processes relationships. *Environmental Management,* 35**,** 579-592.

O'Driscoll, M., S. Clinton, A. Jefferson, A. Manda & S. McMillan (2010) Urbanization Effects on Watershed Hydrology and In-Stream Processes in the Southern United States. *Water,* 2**,** 605-648.

Pandey, V. P., S. K. Chapagain & F. Kazama (2010) Evaluation of groundwater environment of Kathmandu Valley. *Environmental Earth Sciences,* 60**,** 1329-1342.

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

Paynter, S., M. Nachabe & G. Yanev (2011a) Statistical Changes of Lake Stages in Two Rapidly Urbanizing Watersheds. *Water Resources Management,* 25**,** 21-39.

Perlman, H. February 8, 2011. The effects of urbanization on water quality: Population growth. . http://ga.water.usgs.gov/edu/urbanpop.html: U.S. Geological Survey.

Petchprayoon, P., P. D. Blanken, C. Ekkawatpanit & K. Hussein (2010) Hydrological impacts of land use/land cover change in a large river basin in central-northern Thailand. *International Journal of Climatology,* 30**,** 1917-1930.

Peterson, H. M., J. L. Nieber, and R. Kanivetsky. "Hydrologic Regionalization to Assess Anthropogenic Changes." *Journal of Hydrology* 408, no. 3-4 (2011): 212-225.

Pickup, G. & R. F. Warner (1976) Effects of hydrologic regime on magnitude and frequency of dominant discharge. *Journal of Hydrology,* 29**,** 51-75.

Pitt, R., S. E. Chen, S. E. Clark, J. Swenson & C. K. Ong (2008) Compaction's impacts on urban storm-water infiltration. *Journal of Irrigation and Drainage Engineering-Asce,* 134**,** 652-658.

Poelmans, L., A. Van Rompaey, V. Ntegeka & P. Willems (2011) The relative impact of climate change and urban expansion on peak flows: a case study in central Belgium. *Hydrological Processes,* 25**,** 2846-2858.

Price, K. (2011) Effects of watershed topography, soils, land use, and climate on baseflow hydrology in humid regions: A review. *Progress in Physical Geography,* 35**,** 465-492.

Psychoyou, M., T. Mimides, S. Rizos & A. Sgouboopoulou (2007) Groundwater hydrochemistry at Balkan coastal plains - the case of Marathon of Attica, Greece. *Desalination,* 213**,** 230-237.

Randhir, T. O. & O. Tsvetkova (2011) Spatiotemporal dynamics of landscape pattern and hydrologic process in watershed systems. *Journal of Hydrology,* 404**,** 1-12.

Ribeiro, Caas, V. P. Soares, R. M. dos Santos, and C. P. B. Soares. "Topologically-Structured Large Datasets for Watersheds." *Revista Arvore* 32, no. 4 (2008): 687-696.

Richardson, M. C., M. J. Fortin, and B. A. Branfireun. "Hydrogeomorphic Edge Detection and Delineation of Landscape Functional Units from Lidar Digital Elevation Models." *Water Resources Research* 45, (2009): 18.

Rivett, M. O., P. A. Ellis & R. Mackay (2011) Urban groundwater baseflow influence upon inorganic river-water quality: The River Tame headwaters catchment in the City of Birmingham, UK. *Journal of Hydrology,* 400**,** 206-222.

Robins, N., B. Adams, S. Foster & R. Palmer Groundwater vulnerability mapping: the British perspective.

Rose, S. & N. E. Peters (2001a) Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. *Hydrological Processes,* 15**,** 1441-1457.

Santra, P., B. S. Das, and D. Chakravarty. "Delineation of Hydrologically Similar Units in a Watershed Based on Fuzzy Classification of Soil Hydraulic Properties." *Hydrological Processes* 25, no. 1 (2011): 64-79.

Sauer, V. B. & J. M. Fulford. 1983. Floods of December 1982 and January 1983 in central and southern Mississippi River basin. United States: U. S. Geological Survey : Reston, VA, United States.

Sawyer, R. M. 1963. Effect of urbanization on storm discharge and ground-water recharge in Nassau County, New York; Article 106. C185-c187. United States: U. S. Geological Survey : Reston, VA, United States.

Schoonover, J. E. 2005. Hydrology, water quality, and channel morphology across an urban-rural land use gradient in western Georgia, USA. United States.

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

Seaburn, G. E. 1969. Effects of urban development on direct runoff to East Meadow Brook, Nassau County, Long Island, New York. B1-b14. United States: U. S. Geological Survey : Reston, VA, United States.

Service, N. W. NOWData. http://www.nws.noaa.gov/ (accessed 08-01-2014).

Sharp, J. M., Jr., L. N. Christian, B. Garcia-Fresca, S. A. Pierce & T. J. Wiles (2006) Changing recharge and hydrogeology in an urbanizing area; example of Austin, Texas, USA. *Abstracts with Programs - Geological Society of America,* 38**,** 289-289.

Sharp, J. M., Jr., T. Halihan, M. M. Uliana, G. P. Tsoflias, M. T. Landrum & R. Marrett (2000) Predicting fractured rock hydrogeological parameters from field and laboratory data. *Proceedings of the ... IAH Congress on Groundwater...* 30**,** 319-324.

Sharp, J. M., Jr., J. N. Krothe, J. D. Mather, B. Garcia-Fresca & C. A. Stewart. 2003. Effects of urbanization on groundwater system. 257-278. United States: American Geophysical Union : Washington, DC, United States.

Sharp, J. M., Jr. & M. M. Uliana (1998) Regional groundwater flow in a semi-arid region; controls of fracture systems in carbonate units. *Abstracts with Programs - Geological Society of America,* 30**,** 203-204.

Sharp, J. M., L. E. Llado, T. J. Wiles, T. J. Budge & B. Garcia-Fresca (2008) alterations to recharge to the Edwards Aquifer, Barton Springs segment, caused by urbanization. *Abstracts with Programs - Geological Society of America,* 40**,** 30-31.

Shaw, E. 1994. *Hydrology in Practice*. London: Chapman & Hall.

Sidle, R. C. (1988) Bed load transport regime of a small forest stream. *Water Resources Research,* 24**,** 207-218.

Smucygz, B., J. A. Clayton & Z. Comarova (2010) "Comparison of Changes in Runoff and Channel Cross-sectional Area as a Consequence of Urbanization for Three Chattahoochee River Subbasins, Georgia, USA.". *Southeastern Geographer,* 50**,** 468-483.

Sulam, D. 1979a. Streamflow augmentation. 225-225. United States: U. S. Geological Survey : Reston, VA, United States.

Sulam, D. J. (1979b) Analysis of changes in ground-water levels in a sewered and an unsewered area of Nassau County, Long Island, New York. *Ground Water,* 17**,** 446-455.

Sun, F., H. B. Shao, T. Kalbacher, W. Q. Wang, Z. S. Yang, Z. F. Huang & O. Kolditz (2011) Groundwater drawdown at Nankou site of Beijing Plain: model development and calibration. *Environmental Earth Sciences,* 64**,** 1323-1333.

Sun, G., S. G. McNulty, D. M. Amatya, R. W. Skaggs, L. W. Swift, J. P. Shepard & H. Riekerk (2002) A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. *Journal of Hydrology,* 263**,** 92-104.

Sun, G., S. G. McNulty, J. Lu, D. M. Amatya, Y. Liang & R. K. Kolka (2005) Regional annual water yield from forest lands and its response to potential deforestation across the Southeastern United States. *Journal of Hydrology,* 308**,** 258-268.

Survey, U. S. G. 11-23-2011. Groundwater for USA: Water Levels. usgs.gov: U.S. Department of the Interior
U.S. Geological Survey.

Survey, U.S. Geological, "Water Data for the Nation", U.S. Department of the Interior
U.S. Geological Survey waterdata.usgs.gov (first accessed 2-20-2012).

(UNFPA), U. N. P. F., The state of world population 1999-6 billion-A time for choices. UNFPA: New York, NY, 1999.

Viger, R. J., L. E. Hay, S. L. Markstrom, J. W. Jones & G. R. Buell (2011) Hydrologic Effects of Urbanization and Climate Change on the Flint River Basin, Georgia. *Earth Interactions,* 15.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman & R. P. Morgan (2005) The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society,* 24**,** 706-723.

Wang, D. B. & X. M. Cai (2009) Detecting human interferences to low flows through baseflow recession analysis. *Water Resources Research,* 45.

Yang, X. & C. P. Lo (2002) Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. *International Journal of Remote Sensing,* 23**,** 1775-1798.

APPENDICES

APPENDIX A Data

Appendix A.1 Stream Data

Suwanee Creek									
Year	5th Per-centile (mm/yr)	10th Per-centile (mm/yr)	25th Per-centile (mm/yr)	50th Per-centile (mm/yr)	Avgd Annual Rainfall (mm/yr)	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile
1987	25.20	34.50	60.90	183.00	989.40	0.03	0.03	0.06	0.19
1988	20.70	36.30	103.00	183.00	1054.60	0.02	0.03	0.10	0.17
1989	178.00	194.00	249.00	345.00	1611.30	0.11	0.12	0.15	0.21
1990	126.00	147.00	191.00	315.00	1473.80	0.09	0.10	0.13	0.21
1991	147.00	154.00	220.00	337.00	1422.40	0.10	0.11	0.15	0.24
1992	169.00	198.00	249.00	352.00	1472.90	0.11	0.13	0.17	0.24
1993	73.40	95.40	176.00	345.00	1184.30	0.06	0.08	0.15	0.29
1994	242.00	264.00	315.00	403.00	1451.40	0.17	0.18	0.22	0.28
1995	103.00	128.00	205.00	352.00	1437.30	0.07	0.09	0.14	0.24
1996	161.00	176.00	220.00	345.00	1406.00	0.11	0.13	0.16	0.25
1997	110.00	176.00	257.00	389.00	1646.00	0.07	0.11	0.16	0.24
1998	125.00	139.00	198.00	396.00	1578.20	0.08	0.09	0.13	0.25
1999	38.40	58.70	139.00	242.00	1031.20	0.04	0.06	0.14	0.23
2000	88.00	95.40	139.00	216.00	1058.80	0.08	0.09	0.13	0.20
2001	103.00	117.00	139.00	242.00	1315.70	0.08	0.09	0.11	0.18
2002	45.80	72.00	169.00	308.00	1434.20	0.03	0.05	0.12	0.21
2003	213.00	230.00	345.00	470.00	1533.10	0.14	0.15	0.22	0.31
2004	176.00	198.00	257.00	348.00	1210.30	0.15	0.16	0.21	0.29

2005	191.00	205.00	308.00	418.00	1754.70	0.11	0.12	0.18	0.24
2006	88.00	110.00	147.00	249.00	1034.10	0.09	0.11	0.14	0.24
2007	25.70	31.80	63.10	132.00	887.10	0.03	0.04	0.07	0.15
2008	36.50	56.50	95.40	198.00	881.00	0.04	0.06	0.11	0.22
2009	68.50	95.40	198.00	381.00	1986.00	0.03	0.05	0.10	0.19
2010	95.40	128.00	205.00	352.00	979.00	0.10	0.13	0.21	0.36
2011	39.90	56.80	132.00	257.00	1250.30	0.03	0.05	0.11	0.21
2012	38.90	62.00	110.00	154.00	1305.10	0.03	0.05	0.08	0.12
2013	205.00	220.00	279.00	411.00	1935.70	0.11	0.11	0.14	0.21
SOPE CREEK									
Year	5th Per-centile (mm/yr)	10th Per-centile (mm/yr)	25th Per-centile (mm/yr)	50th Per-centile (mm/yr)	avgd annual rainfall (mm)	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile
1987	57.28	64.02	123.54	247.08	1195.30	0.05	0.05	0.10	0.21
1988	37.34	48.85	110.34	168.46	958.50	0.04	0.05	0.12	0.18
1989	179.69	213.39	269.54	325.70	1452.00	0.12	0.15	0.19	0.22
1990	110.06	123.54	168.46	314.47	1397.50	0.08	0.09	0.12	0.23
1991	168.46	190.93	258.31	348.16	1507.00	0.11	0.13	0.17	0.23
1992	168.46	190.93	247.08	353.77	1330.40	0.13	0.14	0.19	0.27
1993	104.22	123.54	190.93	348.16	1280.00	0.08	0.10	0.15	0.27
1994	213.39	235.85	269.54	359.39	1466.90	0.15	0.16	0.18	0.24
1995	92.32	157.23	179.69	280.77	1386.20	0.07	0.11	0.13	0.20
1996	123.54	134.77	179.69	292.00	1320.30	0.09	0.10	0.14	0.22
1997	88.95	128.03	235.85	325.70	1569.00	0.06	0.08	0.15	0.21
1998	94.56	111.19	157.23	325.70	1294.90	0.07	0.09	0.12	0.25
1999	41.55	59.52	123.54	168.46	974.60	0.04	0.06	0.13	0.17
2000	27.23	42.12	77.49	168.46	1184.10	0.02	0.04	0.07	0.14

2001	90.97	95.46	134.77	247.08	1071.00	0.08	0.09	0.13	0.23
2002	25.16	57.73	123.54	235.85	1258.50	0.02	0.05	0.10	0.19
2003	224.62	235.85	303.23	426.77	1624.20	0.14	0.15	0.19	0.26
2004	224.62	235.85	269.54	336.93	1395.10	0.16	0.17	0.19	0.24
2005	123.54	139.26	213.39	336.93	1543.80	0.08	0.09	0.14	0.22
2006	65.59	79.07	104.45	202.16	1361.80	0.05	0.06	0.08	0.15
2007	39.31	49.42	69.63	146.00	890.90	0.04	0.06	0.08	0.16
2008	30.60	42.68	66.54	146.00	998.10	0.03	0.04	0.07	0.15
2009	80.86	111.64	157.23	303.23	1850.90	0.04	0.06	0.08	0.16
2010	70.98	80.19	146.00	303.23	1119.90	0.06	0.07	0.13	0.27
2011	29.20	41.55	93.22	168.46	1141.80	0.03	0.04	0.08	0.15
2012	26.95	43.24	60.65	99.39	904.50	0.03	0.05	0.07	0.11
2013	146.00	157.23	224.62	325.70	1906.70	0.08	0.08	0.12	0.17
PEACHTREE CREEK									
Year	5th Percentile (mm/yr)	10th Percentile (mm/yr)	25th Percentile (mm/yr)	50th Percentile (mm/yr)	avgd annual rainfall (mm)	5th Percentile	10th Percentile	25th Percentile	50th Percentile
1987	47.67	55.61	83.42	182.72	1195.30	0.04	0.05	0.07	0.15
1988	47.67	51.64	67.53	127.11	958.50	0.05	0.05	0.07	0.13
1989	91.36	103.28	119.17	186.69	1452.00	0.06	0.07	0.08	0.13
1990	83.42	95.33	131.08	242.31	1397.50	0.06	0.07	0.09	0.17
1991	111.22	127.11	186.69	270.11	1507.00	0.07	0.08	0.12	0.18
1992	124.13	143.00	170.81	258.19	1330.40	0.09	0.11	0.13	0.19
1993	59.58	67.53	107.25	226.42	1280.00	0.05	0.05	0.08	0.18
1994	146.97	158.89	182.72	246.28	1466.90	0.10	0.11	0.12	0.17
1995	68.32	88.98	146.97	218.47	1386.20	0.05	0.06	0.11	0.16
1996	99.31	107.25	146.97	250.25	1320.30	0.08	0.08	0.11	0.19

1997	64.35	95.33	139.03	246.28	1569.00	0.04	0.06	0.09	0.16
1998	59.58	71.50	107.25	242.31	1294.90	0.05	0.06	0.08	0.19
1999	47.67	59.58	91.36	143.00	974.60	0.05	0.06	0.09	0.15
2000	39.72	51.64	75.47	131.08	1184.10	0.03	0.04	0.06	0.11
2001	55.61	59.58	83.42	146.97	1071.00	0.05	0.06	0.08	0.14
2002	31.06	63.56	107.25	190.67	1258.50	0.02	0.05	0.09	0.15
2003	115.99	139.03	210.53	286.00	1624.20	0.07	0.09	0.13	0.18
2004	166.83	178.75	214.50	270.11	1395.10	0.12	0.13	0.15	0.19
2005	123.14	135.06	186.69	301.89	1543.80	0.08	0.09	0.12	0.20
2006	76.27	87.39	115.19	198.61	1361.80	0.06	0.06	0.08	0.15
2007	26.38	33.92	51.64	139.03	890.90	0.03	0.04	0.06	0.16
2008	21.05	29.39	47.67	115.19	998.10	0.02	0.03	0.05	0.12
2009	55.61	69.12	103.28	206.56	1850.90	0.03	0.04	0.06	0.11
2010	43.69	55.61	111.22	242.31	1119.90	0.04	0.05	0.10	0.22
2011	23.04	31.94	71.50	150.94	1141.80	0.02	0.03	0.06	0.13
2012	33.37	39.72	55.61	123.14	904.50	0.04	0.04	0.06	0.14
2013	107.25	119.17	170.81	238.33	1906.70	0.06	0.06	0.09	0.12
SOUTH RIVER									
Year	5th Per-centile (mm/yr)	10th Per-centile (mm/yr)	25th Per-centile (mm/yr)	50th Per-centile (mm/yr)	Avgd Annual Rainfall (mm)	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile
1987	107.98	117.46	159.13	265.22	1175.10	0.09	0.10	0.14	0.23
1988	111.77	128.82	161.03	223.54	1165.00	0.10	0.11	0.14	0.19
1989	208.39	222.41	248.17	318.27	1608.50	0.13	0.14	0.15	0.20
1990	198.92	214.07	255.75	390.26	1462.40	0.14	0.15	0.17	0.27
1991	221.65	231.88	284.17	386.47	1419.50	0.16	0.16	0.20	0.27
1992	212.65	234.91	280.38	376.05	1527.30	0.14	0.15	0.18	0.25

1993	159.13	179.97	250.07	378.89	1221.20	0.13	0.15	0.20	0.31
1994	284.17	311.45	365.63	433.83	1525.40	0.19	0.20	0.24	0.28
1995	187.93	214.83	322.06	416.78	1341.10	0.14	0.16	0.24	0.31
1996	217.86	229.23	284.17	409.20	1133.30	0.19	0.20	0.25	0.36
1997	181.87	214.83	293.64	378.89	1313.50	0.14	0.16	0.22	0.29
1998	181.87	187.55	219.76	401.62	1172.90	0.16	0.16	0.19	0.34
1999	130.72	148.52	202.71	253.86	987.70	0.13	0.15	0.21	0.26
2000	141.14	155.34	189.44	260.49	904.00	0.16	0.17	0.21	0.29
2001	162.92	166.71	200.81	274.69	976.00	0.17	0.17	0.21	0.28
2002	121.62	152.31	217.86	286.06	1215.30	0.10	0.13	0.18	0.24
2003	250.45	273.56	371.31	454.67	1344.30	0.19	0.20	0.28	0.34
2004	253.86	276.59	328.21	421.51	1361.90	0.19	0.20	0.24	0.31
2005	306.90	318.27	378.89	483.08	1434.40	0.21	0.22	0.26	0.34
2006	219.76	234.91	267.12	363.73	1232.00	0.18	0.19	0.22	0.30
2007	136.40	142.08	157.24	231.12	809.20	0.17	0.18	0.19	0.29
2008	119.82	136.40	157.71	209.34	1052.80	0.11	0.13	0.15	0.20
2009	170.88	195.13	231.12	388.36	1764.00	0.10	0.11	0.13	0.22
2010	151.56	161.79	225.44	352.37	1223.60	0.12	0.13	0.18	0.29
2011	115.94	126.93	162.92	255.75	996.90	0.12	0.13	0.16	0.26
2012	115.56	125.03	147.77	186.60	941.20	0.12	0.13	0.16	0.20
2013	199.30	208.39	255.75	361.84	1678.00	0.12	0.12	0.15	0.22
BIG CREEK									
Year	5th Percentile (mm/yr)	10th Percentile (mm/yr)	25th Percentile (mm/yr)	50th Percentile (mm/yr)	Avgd ANNUAL PRECIP (MM)	5th Percentile	10th Percentile	25th Percentile	50th Percentile
1987	52.68	57.46	86.20	244.23	989.40	0.05	0.06	0.09	0.25
1988	22.63	32.32	90.99	177.18	1054.60	0.02	0.03	0.09	0.17

1989	138.87	158.03	239.44	335.21	1611.30	0.09	0.10	0.15	0.21
1990	124.51	138.87	215.49	363.94	1526.60	0.08	0.09	0.14	0.24
1991	205.92	210.70	311.27	450.14	1422.40	0.14	0.15	0.22	0.32
1992	144.86	186.76	272.96	402.25	1472.90	0.10	0.13	0.19	0.27
1993	71.83	86.20	167.61	378.31	1184.30	0.06	0.07	0.14	0.32
1994	215.49	234.65	272.96	373.52	1451.40	0.15	0.16	0.19	0.26
1995	67.04	86.20	181.97	325.63	1437.30	0.05	0.06	0.13	0.23
1996	134.08	143.66	196.34	347.18	1406.00	0.10	0.10	0.14	0.25
1997	120.68	179.10	272.96	407.04	1646.00	0.07	0.11	0.17	0.25
1998	105.35	126.42	205.92	392.68	1578.20	0.07	0.08	0.13	0.25
1999	47.89	57.46	143.66	220.28	1031.20	0.05	0.06	0.14	0.21
2000	49.08	62.25	105.35	210.70	1058.80	0.05	0.06	0.10	0.20
2001	105.35	110.14	138.87	249.01	1315.70	0.08	0.08	0.11	0.19
2002	34.96	49.80	119.72	263.38	1434.20	0.02	0.03	0.08	0.18
2003	205.92	234.65	363.94	488.45	1533.10	0.13	0.15	0.24	0.32
2004	181.97	210.70	258.59	359.16	1210.30	0.15	0.17	0.21	0.30
2005	191.55	207.83	316.06	426.20	1754.70	0.11	0.12	0.18	0.24
2006	81.41	90.99	129.30	244.23	1034.10	0.08	0.09	0.13	0.24
2007	48.85	52.68	81.41	158.03	887.10	0.06	0.06	0.09	0.18
2008	42.26	55.07	81.41	179.58	881.00	0.05	0.06	0.09	0.20
2009	71.83	88.11	205.92	335.21	1986.00	0.04	0.04	0.10	0.17
2010	124.51	138.87	205.92	354.37	979.00	0.13	0.14	0.21	0.36
2011	41.66	47.89	86.20	225.07	1250.30	0.03	0.04	0.07	0.18
2012	81.41	95.77	114.93	172.39	1305.10	0.06	0.07	0.09	0.13
2013	205.92	234.65	277.75	402.25	1935.70	0.11	0.12	0.14	0.21
SNAKE CREEK									
Year	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile	Annual Avgd	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile

	(mm/yr)	(mm/yr)	(mm/yr)	(mm/yr)	Rainfall (mm)				
1987	14.60	16.54	20.43	30.16	1145.10	0.01	0.01	0.02	0.03
1988	6.35	7.98	11.68	18.49	1111.00	0.01	0.01	0.01	0.02
1989	22.38	23.35	32.11	39.89	1214.50	0.02	0.02	0.03	0.03
1990	11.68	13.62	17.51	33.08	1230.60	0.01	0.01	0.01	0.03
1991	21.41	21.41	28.22	36.97	1440.60	0.01	0.01	0.02	0.03
1992	21.41	23.35	29.43	43.79	1521.70	0.01	0.02	0.02	0.03
1993	11.68	13.62	19.46	38.92	939.90	0.01	0.01	0.02	0.04
1994	24.33	26.66	35.03	42.81	1421.00	0.02	0.02	0.02	0.03
1995	12.65	14.60	23.35	40.87	1452.50	0.01	0.01	0.02	0.03
1996	18.49	19.46	24.33	37.95	1557.40	0.01	0.01	0.02	0.02
1997	19.46	20.82	34.06	47.68	1579.40	0.01	0.01	0.02	0.03
1998	13.82	15.57	18.49	43.79	1477.40	0.01	0.01	0.01	0.03
1999	3.31	4.38	8.37	19.46	911.30	0.00	0.00	0.01	0.02
2000	2.26	3.21	4.57	14.60	964.00	0.00	0.00	0.00	0.02
2001	7.84	9.54	11.68	22.38	1133.60	0.01	0.01	0.01	0.02
2002	4.87	5.06	5.45	6.13	1584.10	0.00	0.00	0.00	0.00
2003	24.33	28.61	37.95	53.52	1684.40	0.01	0.02	0.02	0.03
2004	7.30	8.12	16.78	32.11	1278.00	0.01	0.01	0.01	0.03
2005	9.05	10.70	23.35	36.00	1309.70	0.01	0.01	0.02	0.03
2006	8.56	8.99	9.73	10.70	1224.70	0.01	0.01	0.01	0.01
2007	3.31	3.41	4.87	8.56	774.70	0.00	0.00	0.01	0.01
2008	2.72	4.18	4.87	6.91	1214.70	0.00	0.00	0.00	0.01
2009	9.05	9.05	11.68	32.11	1750.90	0.01	0.01	0.01	0.02
2010	10.70	11.68	12.65	27.24	1176.50	0.01	0.01	0.01	0.02
2011	9.26	9.54	9.73	10.70	1222.50	0.01	0.01	0.01	0.01
2012	8.49	9.73	10.70	11.68	1067.60	0.01	0.01	0.01	0.01

2013	9.55	10.70	16.54	34.06	1620.70	0.01	0.01	0.01	0.02
KETTLE CREEK									
Year	5th Per-centile (mm/yr)	10th Per-centile (mm/yr)	25th Per-centile (mm/yr)	50th Per-centile (mm/yr)	Annual Avgd Rainfall (mm)	5th Per-centile	10th Per-centile	25th Per-centile	50th Per-centile
1987	21.36	28.48	36.61	71.20	945.30	0.02	0.03	0.04	0.08
1988	4.68	7.63	14.24	39.67	963.70	0.00	0.01	0.01	0.04
1989	31.73	45.77	63.06	90.52	1523.90	0.02	0.03	0.04	0.06
1990	7.45	13.63	38.65	83.40	1045.20	0.01	0.01	0.04	0.08
1991	73.23	82.38	92.55	152.56	1271.60	0.06	0.06	0.07	0.12
1992	62.30	74.76	97.64	142.39	1423.60	0.04	0.05	0.07	0.10
1993	16.27	23.39	44.75	111.88	1011.80	0.02	0.02	0.04	0.11
1994	48.82	79.74	122.05	172.90	1347.20	0.04	0.06	0.09	0.13
1995	47.19	57.97	100.69	183.07	1163.80	0.04	0.05	0.09	0.16
1996	56.96	69.16	86.71	142.39	1321.70	0.04	0.05	0.07	0.11
1997	49.84	64.48	98.66	152.56	1151.20	0.04	0.06	0.09	0.13
1998	39.67	43.73	55.94	101.71	1070.30	0.04	0.04	0.05	0.10
1999	20.34	23.39	31.53	62.04	894.00	0.02	0.03	0.04	0.07
2000	11.19	11.19	17.29	41.19	1004.40	0.01	0.01	0.02	0.04
2001	10.17	13.63	19.32	41.70	849.40	0.01	0.02	0.02	0.05
2002	0.92	4.33	18.31	51.87	1060.20	0.00	0.00	0.02	0.05
2003	45.77	60.41	76.28	142.39	1407.00	0.03	0.04	0.05	0.10
2004	25.43	28.48	54.16	84.42	1029.00	0.02	0.03	0.05	0.08
2005	14.24	17.29	38.65	122.05	1105.70	0.01	0.02	0.03	0.11
2006	2.34	4.48	9.76	28.48	1052.50	0.00	0.00	0.01	0.03
2007	0.00	0.31	3.25	14.24	839.40	0.00	0.00	0.00	0.02

2008	0.41	1.63	7.20	30.51	1018.90	0.00	0.00	0.01	0.03
2009	1.12	2.44	31.53	80.35	1321.30	0.00	0.00	0.02	0.06
2010	6.18	12.20	27.46	67.13	951.30	0.01	0.01	0.03	0.07
2011	0.00	0.00	4.68	24.41	939.70	0.00	0.00	0.00	0.03
2012	0.00	0.00	0.00	3.46	853.40	0.00	0.00	0.00	0.00
2013	4.50	16.27	27.46	62.04	1478.30	0.00	0.01	0.02	0.04
LINE CREEK									
Year	5th Per-centile mm/yr	10th Per-centile (mm/yr)	25th Per-centile (mm/yr)	50th per-centile (mm/yr)	AVGD Annual Rainfall (mm/yr)	5th Per-centile	10th Per-centile	25th Per-centile	50th per-centile
1987	15.02	18.23	51.21	143.38	1175.10	0.01	0.02	0.04	0.12
1988	9.22	10.58	32.86	119.48	1165.00	0.01	0.01	0.03	0.10
1989	106.51	122.90	167.27	269.69	1608.50	0.07	0.08	0.10	0.17
1990	23.76	34.14	85.34	238.96	1462.40	0.02	0.02	0.06	0.16
1991	64.86	78.52	163.86	273.10	1419.50	0.05	0.06	0.12	0.19
1992	58.03	85.34	133.14	307.24	1527.30	0.04	0.06	0.09	0.20
1993	26.01	33.25	81.93	238.96	1221.20	0.02	0.03	0.07	0.20
1994	96.27	134.50	238.96	344.79	1525.40	0.06	0.09	0.16	0.23
1995	44.38	51.21	119.48	256.03	1341.10	0.03	0.04	0.09	0.19
1996	51.21	61.45	85.34	196.29	1133.30	0.05	0.05	0.08	0.17
1997	58.03	88.76	153.62	307.24	1313.50	0.04	0.07	0.12	0.23
1998	62.13	75.10	116.07	225.31	1172.90	0.05	0.06	0.10	0.19
1999	51.21	59.40	88.76	150.21	987.70	0.05	0.06	0.09	0.15
2000	25.01	29.02	40.97	85.34	904.00	0.03	0.03	0.05	0.09
2001	44.38	51.21	68.28	126.31	976.00	0.05	0.05	0.07	0.13
2002	28.06	35.50	71.69	136.55	1215.30	0.02	0.03	0.06	0.11
2003	81.93	95.59	194.58	365.27	1344.30	0.06	0.07	0.14	0.27

2004	48.65	64.86	119.48	211.65	1361.90	0.04	0.05	0.09	0.16
2005	81.93	102.41	198.00	355.03	1434.40	0.06	0.07	0.14	0.25
2006	24.58	30.31	51.21	119.48	1232.00	0.02	0.02	0.04	0.10
2007	14.00	15.36	18.09	34.14	809.20	0.02	0.02	0.02	0.04
2008	15.02	18.43	27.82	81.93	1052.80	0.01	0.02	0.03	0.08
2009	24.99	38.92	122.90	256.03	1764.00	0.01	0.02	0.07	0.15
2010	27.31	31.88	105.83	245.79	1223.60	0.02	0.03	0.09	0.20
2011	11.95	18.23	31.07	88.76	996.90	0.01	0.02	0.03	0.09
2012	16.73	17.75	23.55	44.38	941.20	0.02	0.02	0.03	0.05
2013	47.79	71.69	122.90	232.14	1678.00	0.03	0.04	0.07	0.14

Appendix A.2 Parameter Data

SUWANEE				
YEAR	Population by Census Tract	TOTAL URBAN	High Intensity Urban	Low Intensity Urban
1974	N/A	**9.112428654**	**1.252156984**	**7.860271669**
1975	N/A	9.686819972	1.301631866	8.385188105
1976	N/A	10.26121129	1.351106748	8.910104541
1977	N/A	10.83560261	1.40058163	9.435020977
1978	N/A	11.40999393	1.450056512	9.959937413
1979	N/A	11.98438524	1.499531394	10.48485385
1980	**57262**	12.55877656	1.549006276	11.00977029
1981	58423.3	13.13316788	1.598481158	11.53468672

1982	59584.6	13.7075592	1.64795604	12.05960316
1983	60745.9	14.28195052	1.697430922	12.58451959
1984	61907.2	14.85634184	1.746905804	13.10943603
1985	63068.5	**15.43073315**	**1.796380691**	**13.63435246**
1986	64229.8	16.42986579	1.995209143	14.43465665
1987	65391.1	17.42899843	2.194037595	15.23496083
1988	66552.4	18.42813106	2.392866047	16.03526501
1989	67713.7	19.4272637	2.591694499	16.8355692
1990	**68875**	20.42639634	2.790522951	17.63587338
1991	82683.7	**21.42552897**	**2.989351404**	**18.43617757**
1992	96492.4	23.50258609	3.46026829	20.0423178
1993	110301.1	25.5796432	3.931185176	21.64845803
1994	124109.8	27.65670032	4.402102062	23.25459826
1995	137918.5	29.73375743	4.873018948	24.86073849
1996	151727.2	31.81081455	5.343935834	26.46687872
1997	165535.9	33.88787166	5.81485272	28.07301895
1998	179344.6	35.96492878	6.285769606	29.67915918
1999	193153.3	38.04198589	6.756686492	31.28529941
2000	**206962**	40.11904301	7.227603378	32.89143964
2001	207814.5	**42.19610012**	**7.69852026**	**34.49757986**
2002	208667	43.88424838	8.940672106	34.94357627

2003	209519.5	45.57239663	10.18282395	35.38957267
2004	210372	47.26054488	11.4249758	35.83556908
2005	211224.5	**48.94869313**	**12.66712764**	**36.28156548**
2006	212077	51.72746969	15.27810815	36.44936154
2007	212929.5	54.50624625	17.88908865	36.61715761
2008	213782	**57.28502282**	**20.50006915**	**36.78495367**
2009	214634.5	N/A	N/A	N/A
2010	**215487**	N/A	N/A	N/A
	SOPE			
YEAR	CenTractPopulation	TOTAL URBAN	HIGH INTENSITY URBAN	LOW INTENSITY URBAN
1974	N/A	**29.96205612**	**4.155110514**	**25.8069456**
1975	N/A	31.80325485	4.337173096	27.46608176
1976	N/A	33.64445359	4.519235677	29.12521791
1977	N/A	35.48565232	4.701298259	30.78435406
1978	N/A	37.32685106	4.883360841	32.44349022
1979	N/A	39.1680498	5.065423423	34.10262637
1980	**210471**	41.00924853	5.247486005	35.76176253
1981	218672.8	42.85044727	5.429548587	37.42089868
1982	226874.6	44.691646	5.611611169	39.08003483

1983	235076.4	46.53284474	5.793673751	40.73917099
1984	243278.2	48.37404348	5.975736333	42.39830714
1985	251480	**50.21524221**	**6.157798914**	**44.0574433**
1986	259681.8	49.99321256	6.2500659	43.74314666
1987	267883.6	49.7711829	6.342332886	43.42885001
1988	276085.4	49.54915324	6.434599872	43.11455337
1989	284287.2	49.32712359	6.526866857	42.80025673
1990	**292489**	49.10509393	6.619133843	42.48596009
1991	297145.6	**48.88306428**	**6.711400829**	**42.17166345**
1992	301802.2	50.48966462	6.988783838	43.50088078
1993	306458.8	52.09626497	7.266166847	44.83009812
1994	311115.4	53.70286531	7.543549856	46.15931546
1995	315772	55.30946566	7.820932865	47.48853279
1996	320428.6	56.916066	8.098315874	48.81775013
1997	325085.2	58.52266635	8.375698883	50.14696747
1998	329741.8	60.12926669	8.653081892	51.4761848
1999	334398.4	61.73586704	8.930464901	52.80540214
2000	**339055**	63.34246739	9.20784791	54.13461948
2001	337521.6	**64.94906773**	**9.485230918**	**55.46383681**
2002	335988.2	65.41147912	10.06699487	55.34448425
2003	334454.8	65.87389051	10.64875882	55.22513169

2004	332921.4	66.3363019	11.23052277	55.10577913
2005	331388	**66.79871329**	**11.81228672**	**54.98642657**
2006	329854.6	67.58276671	12.70555163	54.87721508
2007	328321.2	68.36682013	13.59881654	54.76800359
2008	326787.8	**69.15087355**	**14.49208146**	**54.65879209**
2009	325254.4	N/A	N/A	N/A
2010	**323721**	N/A	N/A	N/A
	SOUTH RIVER			
YEAR	CenTractPopulation	Total Urban	High Intensity	Low Intensity
1974	N/A	**19.99157977**	**4.635339076**	**15.35624069**
1975	N/A	20.47697979	4.680619918	15.79635987
1976	N/A	20.96237981	4.725900759	16.23647905
1977	N/A	21.44777983	4.7711816	16.67659823
1978	N/A	21.93317985	4.816462442	17.1167174
1979	N/A	22.41857987	4.861743283	17.55683658
1980	**628890**	22.90397989	4.907024124	17.99695576
1981	628067.2	23.38937991	4.952304966	18.43707494
1982	627244.4	23.87477993	4.997585807	18.87719412
1983	626421.6	24.36017995	5.042866648	19.3173133

1984	625598.8	24.84557997	5.08814749	19.75743248
1985	624776	**25.33097999**	**5.133428331**	**20.19755165**
1986	623953.2	25.49200072	5.242121886	20.24987884
1987	623130.4	25.65302146	5.350815442	20.30220602
1988	622307.6	25.8140422	5.459508997	20.3545332
1989	621484.8	25.97506294	5.568202552	20.40686038
1990	**620662**	26.13608367	5.676896108	20.45918757
1991	633537.8	**26.29710441**	**5.785589663**	**20.51151475**
1992	646413.6	27.1550858	5.931814226	21.22327157
1993	659289.4	28.01306719	6.078038789	21.9350284
1994	672165.2	28.87104857	6.224263352	22.64678522
1995	685041	29.72902996	6.370487914	23.35854205
1996	697916.8	30.58701135	6.516712477	24.07029887
1997	710792.6	31.44499273	6.66293704	24.78205569
1998	723668.4	32.30297412	6.809161603	25.49381252
1999	736544.2	33.16095551	6.955386166	26.20556934
2000	**749420**	34.01893689	7.101610729	26.91732617
2001	756019.9	**34.87691828**	**7.247835292**	**27.62908299**
2002	762619.8	35.94814011	7.810133141	28.13800697
2003	769219.7	37.01936194	8.37243099	28.64693095
2004	775819.6	38.09058377	8.93472884	29.15585493

2005	782419.5	**39.1618056**	**9.497026689**	**29.66477891**
2006	789019.4	40.09488688	10.11211818	29.98276869
2007	795619.3	41.02796815	10.72720968	30.30075847
2008	802219.2	**41.96104942**	**11.34230117**	**30.61874825**
2009	808819.1	N/A	N/A	N/A
2010	**815419**	N/A	N/A	N/A
	PEACHTREE			
YEAR	CenTractPopulation	TOTAL URBAN	High Intensity Urban	Low Intensity Urban
1974	N/A	**51.27021279**	**15.82074877**	**35.44946402**
1975	N/A	53.20106059	16.0252692	37.17579139
1976	N/A	55.13190839	16.22978964	38.90211875
1977	N/A	57.0627562	16.43431008	40.62844612
1978	N/A	58.993604	16.63883051	42.35477349
1979	N/A	60.9244518	16.84335095	44.08110085
1980	**491084**	62.85529961	17.04787138	45.80742822
1981	491750.1	64.78614741	17.25239182	47.53375559
1982	492416.2	66.71699521	17.45691226	49.26008295
1983	493082.3	68.64784301	17.66143269	50.98641032
1984	493748.4	70.57869082	17.86595313	52.71273769

1985	494414.5	**72.50953862**	**18.07047356**	**54.43906505**
1986	495080.6	71.34326499	18.39450196	52.94876303
1987	495746.7	70.17699137	18.71853036	51.45846101
1988	496412.8	69.01071775	19.04255876	49.96815899
1989	497078.9	67.84444412	19.36658715	48.47785697
1990	**497745**	66.6781705	19.69061555	46.98755495
1991	507314.8	**65.51189687**	**20.01464395**	**45.49725292**
1992	516884.6	66.6778545	20.37358103	46.30427347
1993	526454.4	67.84381213	20.73251812	47.11129401
1994	536024.2	69.00976976	21.0914552	47.91831456
1995	545594	70.17572739	21.45039229	48.7253351
1996	555163.8	71.34168502	21.80932937	49.53235564
1997	564733.6	72.50764264	22.16826646	50.33937619
1998	574303.4	73.67360027	22.52720354	51.14639673
1999	583873.2	74.8395579	22.88614062	51.95341728
2000	**593443**	76.00551553	23.24507771	52.76043782
2001	596889.3	**77.17147316**	**23.60401479**	**53.56745837**
2002	600335.6	77.40749995	24.57898647	52.82851348
2003	603781.9	77.64352673	25.55395814	52.08956859
2004	607228.2	77.87955352	26.52892982	51.3506237
2005	610674.5	**78.11558031**	**27.50390149**	**50.61167882**

2006	614120.8	78.43910113	28.73705739	49.70204374
2007	617567.1	78.76262194	29.97021328	48.79240866
2008	621013.4	**79.08614276**	**31.20336918**	**47.88277359**
2009	624459.7	N/A	N/A	N/A
2010	**627906**	N/A	N/A	N/A
	BIG CREEK			
YEAR	CenTractPopulation	TOTAL URBAN	HIGH INTENSITY URBAN	LOW INTENSITY URBAN
1974	N/A	8.934707904	1.497299951	7.437407953
1975	N/A	9.858240504	1.627510111	8.230730392
1976	N/A	10.7817731	1.757720271	9.024052831
1977	N/A	11.7053057	1.887930432	9.817375269
1978	N/A	12.6288383	2.018140592	10.61069771
1979	N/A	13.5523709	2.148350752	11.40402015
1980	72781	14.4759035	2.278560912	12.19734259
1981	76298.5	15.3994361	2.408771072	12.99066502
1982	79816	16.3229687	2.538981232	13.78398746
1983	83333.5	17.2465013	2.669191393	14.5773099
1984	86851	18.1700339	2.799401553	15.37063234
1985	90368.5	19.0935665	2.929611713	16.16395478

1986	93886	20.34661105	3.174406468	17.17220458
1987	97403.5	21.5996556	3.419201223	18.18045437
1988	100921	22.85270015	3.663995978	19.18870417
1989	104438.5	24.1057447	3.908790732	20.19695397
1990	107956	25.35878925	4.153585487	21.20520376
1991	124327.7	26.61183381	4.398380242	22.21345356
1992	140699.4	28.73084483	4.95411994	23.77672488
1993	157071.1	30.84985585	5.509859639	25.3399962
1994	173442.8	32.96886687	6.065599337	26.90326752
1995	189814.5	35.08787789	6.621339036	28.46653884
1996	206186.2	37.20688891	7.177078734	30.02981017
1997	222557.9	39.32589993	7.732818432	31.59308149
1998	238929.6	41.44491095	8.288558131	33.15635281
1999	255301.3	43.56392197	8.844297829	34.71962413
2000	271673	45.68293299	9.400037528	36.28289545
2001	274742.8	47.80194399	9.955777226	37.84616677
2002	277812.6	48.74016886	10.78971126	37.95045761
2003	280882.4	49.67839374	11.6236453	38.05474844
2004	283952.2	50.61661861	12.45757933	38.15903928
2005	287022	51.55484348	13.29151337	38.26333011
2006	290091.8	53.4496521	15.12871025	38.32094185

2007	293161.6	55.34446073	16.96590714	38.37855359
2008	296231.4	57.23926935	18.80310402	38.43616533
2009	299301.2	N/A	N/A	N/A
2010	302371	N/A	N/A	N/A
	KETTLE			
YEAR	CenTractPopulation	TOTAL URBAN	HIGH INTENSITY URBAN	LOW INTENSITY URBAN
1974	N/A	**0.604245344**	**0**	**0.604245344**
1975	N/A	0.605665984	0	0.605665984
1976	N/A	0.607086623	0	0.607086623
1977	N/A	0.608507263	0	0.608507263
1978	N/A	0.609927903	0	0.609927903
1979	N/A	0.611348542	0	0.611348542
1980	**11177**	0.612769182	0	0.612769182
1981	11237.5	0.614189821	0	0.614189821
1982	11298	0.615610461	0	0.615610461
1983	11358.5	0.6170311	0	0.6170311
1984	11419	0.61845174	0	0.61845174
1985	11479.5	**0.619872379**	**0**	**0.619872379**
1986	11540	0.733825166	0.000325572	0.733499595

1987	11600.5	0.847777954	0.000651143	0.84712681
1988	11661	0.961730741	0.000976715	0.960754026
1989	11721.5	1.075683528	0.001302287	1.074381241
1990	**11782**	1.189636315	0.001627859	1.188008457
1991	12051.7	**1.303589102**	**0.00195343**	**1.301635672**
1992	12321.4	1.460254206	0.004688233	1.455565974
1993	12591.1	1.61691931	0.007423035	1.609496275
1994	12860.8	1.773584414	0.010157837	1.763426577
1995	13130.5	1.930249518	0.012892639	1.917356879
1996	13400.2	2.086914622	0.015627442	2.07128718
1997	13669.9	2.243579726	0.018362244	2.225217482
1998	13939.6	2.40024483	0.021097046	2.379147784
1999	14209.3	2.556909934	0.023831849	2.533078085
2000	**14479**	2.713575038	0.026566651	2.687008387
2001	14055.7	**2.870240142**	**0.029301453**	**2.840938688**
2002	13632.4	2.870240142	0.033533886	2.836706256
2003	13209.1	2.870240142	0.037766318	2.832473824
2004	12785.8	2.870240142	0.04199875	2.828241392
2005	12362.5	**2.870240142**	**0.046231182**	**2.82400896**
2006	11939.2	2.973337848	0.056432429	2.916905419
2007	11515.9	3.076435554	0.066633675	3.009801879

2008	11092.6	**3.17953326**	**0.076834922**	**3.102698338**
2009	10669.3	N/A	N/A	N/A
2010	**10246**	N/A	N/A	N/A
	LINE			
YEAR	CenTractPopulation	TOTAL URBAN	High Intensity Urban	Low Intensity Urban
1974	N/A	**5.856761068**	**0.779658442**	**5.077102626**
1975	N/A	6.065314522	0.799622319	5.265692203
1976	N/A	6.273867976	0.819586196	5.45428178
1977	N/A	6.48242143	0.839550073	5.642871357
1978	N/A	6.690974884	0.85951395	5.831460934
1979	N/A	6.899528338	0.879477827	6.020050511
1980	**71398**	7.108081792	0.899441704	6.208640088
1981	70485.9	7.316635246	0.919405581	6.397229665
1982	69573.8	7.5251887	0.939369458	6.585819242
1983	68661.7	7.733742154	0.959333335	6.774408819
1984	67749.6	7.942295608	0.979297212	6.962998396
1985	66837.5	**8.150849061**	**0.999261085**	**7.151587976**
1986	65925.4	8.633715811	1.02676565	7.606950161
1987	65013.3	9.116582561	1.054270215	8.062312346

1988	64101.2	9.599449311	1.08177478	8.517674531
1989	63189.1	10.08231606	1.109279345	8.973036716
1990	**62277**	10.56518281	1.13678391	9.428398901
1991	69379.5	**11.04804956**	**1.164288477**	**9.883761085**
1992	76482	11.61990289	1.249447468	10.37045542
1993	83584.5	12.19175622	1.334606459	10.85714976
1994	90687	12.76360955	1.41976545	11.3438441
1995	97789.5	13.33546288	1.504924441	11.83053844
1996	104892	13.90731621	1.590083432	12.31723278
1997	111994.5	14.47916954	1.675242423	12.80392712
1998	119097	15.05102287	1.760401414	13.29062146
1999	126199.5	15.6228762	1.845560405	13.7773158
2000	**133302**	16.19472953	1.930719396	14.26401014
2001	137850.1	**16.76658287**	**2.015878388**	**14.75070448**
2002	142398.2	17.48509027	2.302159019	15.18293125
2003	146946.3	18.20359767	2.58843965	15.61515802
2004	151494.4	18.92210508	2.874720281	16.0473848
2005	156042.5	**19.64061248**	**3.161000912**	**16.47961157**
2006	160590.6	20.45456115	3.566881694	16.88767946
2007	165138.7	21.26850982	3.972762476	17.29574735
2008	169686.8	**22.08245849**	**4.378643258**	**17.70381523**

2009	174234.9	N/A	N/A	N/A
2010	**178783**	N/A	N/A	N/A
	SNAKE			
YEAR	CenTractPopulation	TOTAL URBAN	HIGH INTENSITY URBAN	LOW INTENSITY URBAN
1974	N/A	**1.478377009**	**0.046055359**	**1.432321651**
1975	N/A	1.507684965	0.047730099	1.459954866
1976	N/A	1.53699292	0.049404839	1.487588081
1977	N/A	1.566300875	0.051079579	1.515221296
1978	N/A	1.595608831	0.05275432	1.542854511
1979	N/A	1.624916786	0.05442906	1.570487726
1980	**27633**	1.654224742	0.0561038	1.598120941
1981	28872	1.683532697	0.057778541	1.625754156
1982	30111	1.712840653	0.059453281	1.653387372
1983	31350	1.742148608	0.061128021	1.681020587
1984	32589	1.771456564	0.062802762	1.708653802
1985	33828	**1.800764519**	**0.064477502**	**1.736287017**
1986	35067	2.055843891	0.063810213	1.992033678
1987	36306	2.310923262	0.063142924	2.247780338
1988	37545	2.566002634	0.062475635	2.503526999

1989	38784	2.821082006	0.061808347	2.759273659
1990	**40023**	3.076161377	0.061141058	3.01502032
1991	40801.3	**3.331240749**	**0.060473769**	**3.27076698**
1992	41579.6	3.58200531	0.070898295	3.511107016
1993	42357.9	3.832769871	0.08132282	3.751447051
1994	43136.2	4.083534433	0.091747346	3.991787086
1995	43914.5	4.334298994	0.102171872	4.232127122
1996	44692.8	4.585063555	0.112596398	4.472467157
1997	45471.1	4.835828116	0.123020924	4.712807192
1998	46249.4	5.086592677	0.13344545	4.953147228
1999	47027.7	5.337357239	0.143869976	5.193487263
2000	**47806**	5.5881218	0.154294501	5.433827298
2001	48511.6	**5.838886361**	**0.164719027**	**5.674167334**
2002	49217.2	6.142263101	0.189196505	5.953066596
2003	49922.8	6.445639841	0.213673983	6.231965858
2004	50628.4	6.749016581	0.238151461	6.51086512
2005	51334	**7.052393321**	**0.262628939**	**6.789764383**
2006	52039.6	7.327500974	0.283938743	7.043562231
2007	52745.2	7.602608627	0.305248547	7.29736008
2008	53450.8	**7.87771628**	**0.326558351**	**7.551157929**
2009	54156.4	N/A	N/A	N/A

2010	**54862**	N/A	N/A	N/A