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Analysis of Stream Runoff Trends in the Blue Ridge and Piedmont of Southeastern United States

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ANALYSIS OF STREAM RUNOFF TRENDS IN THE BLUE RIDGE AND PIEDMONT OF SOUTHEASTERN UNITED STATES

by

USHA KHAREL

Under the Direction of Seth Rose

ABSTRACT

The purpose of the study was to examine the temporal trends of three monthly variables: stream runoff, rainfall and air temperature and to find out if any correlation exists between rainfall and stream runoff in the Blue Ridge and Piedmont provinces of the southeast United States. Trend significance was determined using the non-parametric Mann-Kendall test on a monthly and annual basis. GIS analysis was used to find and integrate the urban and non-urban stream gauging, rainfall and temperature stations in the study area. The Mann-Kendall test showed a statistically insignificant temporal trend for all three variables. The correlation of 0.4 was observed for runoff and rainfall, which showed that these two parameters are moderately correlated.

INDEX WORDS: Mann-Kendall test, Correlation , Spatial distribution, Linear trends, Stream runoff, South-eastern United States, Climate and land cover change, Hydrology

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1. INTRODUCTION

1.1 Purpose of the Study

In recent years, climatic observations have shown that global mean temperature has increased approximately by 0.4 to 0.8^{o}C over the last century (IPCC, 2001). The greenhouse gas effect is expected to cause temperature increase globally. This process could lead to climatic abnormalities that will cause alteration in precipitation amount and storm patterns (Yue et al., 2002). Vinnikov et al. (1990), Gan (1991), Groisman and Easterling (1994), and Karl and Knight (1998), Zhang et al. (2000) have found increases in the precipitation amount and intensity across US and Canada in recent years. The understanding of stream runoff to changes in precipitation and other climate parameters is well known, and it is thus important that researchers continue to look for evidence of trend in stream runoff that could be caused by climatic change (Yue et al., 2002).

Detail trend analyses of stream runoff conducted in the United States (e.g., Lettenamier et al., 1994) and Canada (Burn and Hag Elnur, 2002) have shown complex behavior of precipitation and stream runoff in which the significance of the trend depends on flow magnitude and season. Changes in climate and landcover variation cause most of the observed variability in stream runoff (Hu et al., 2005). Anthropogenic changes resulted from urbanization such as clearing the forest in a watershed, alter the surface hydrology, and stream runoff. The change in climate such as change in temperature and precipitation will alter evaporation and transpiration of hydrologic cycle and ultimately change the stream runoff. The popular nonparametric Mann-Kendall test (Mann, 1945; Kendall, 1975, Hirsch et al., 1982) has been used to identify if trends exist in stream runoff data. Similarly, Geographic Information Systems (GIS) have been

identified as a useful tool for analyzing and modeling spatiotemporal trends in hydrology (Johnson, 1990).

The purpose of this thesis is to analyze the historical trend of stream runoff in different watersheds, including both urban and non-urban, located in the Blue Ridge and Piedmont in North Carolina and Georgia since the runoff changes in highly urbanized basins are more vulnerable to changes in climate. This study also describes the historical trend of rainfall and temperature of the study area. The study also examines the relationship between runoff and rainfall in the Blue Ridge and Piedmont provinces of the study area. It has been hypothesized that there is a negative temporal trend in the historical dataset of runoff, rainfall, and temperature of the study area. In order to test this hypothesis, stream runoff, rainfall and temperature data were collected and analyzed for trend. The nonparametric Mann-Kendall test was applied to determine if there is a significant trend in the three-hydroclimatological parameters of the study area. Spatial autocorrelation technique, Moran's I, was used to identify the spatial dependency in temperature, rainfall, and runoff data among the total stations in the study area. Finally, inverse distance weighting (IDW) method was used to display the spatial distribution of the rainfall and temperature data of the study area. The correlation test was also used to test the relationship between rainfall and runoff in the study area.

1.2 Research Questions

Globally, many researchers have found significant increase or, decrease in trends of stream runoff in relation to temperature and rainfall; however, it is difficult to predict with certainty. Only a few studies have been done which examine the trends and relationship of stream runoff, rainfall and air temperature in the Blue Ridge and the Piedmont provinces of the Southeast United States.

The southeastern United States is clearly affected by rapid population growth as well as alteration of land uses (U.S. Census Bureau, 2000). Georgia is one of the fastest growing states in the United States in terms of both population and economy and its water demand has been increasing with increasing population. The rapidly growing Piedmont province of Georgia and Blue Ridge province of Georgia and North Carolina offered an excellent opportunity to explore hydrology and the effects of land use and climate change on hydrology. Land use and /or land cover plays a vital role in driving hydrolological processes within the watersheds (Schoonover et. Al, 2006). The study area covers both urban and non-urban area since urban areas are more likely affected by changes in temperature, rainfall, and stream runoff.

In addition, most of the large rivers that flow in Georgia originate in the Blue Ridge Mountains of North Carolina and north Georgia. Moreover, surface water is the primary source of water in the northern half of Georgia including big cities like metropolitan Atlanta and Athens where limited groundwater resources are difficult to obtain (USGS, 2007). Surface water provides 78% of the total fresh water supply in Georgia (Fanning, 2003) and 82% of the public supply in North Carolina (Wrri, 2006). The study of stream runoff in both urban and non-urban area is expected to be helpful in the future water resource management for the growing population within the study area.

The other factor that influenced the choice of study area was that, there are limited numbers of studies that are specifically concentrated on the southeastern United States which examine the temporal trend of stream runoff. The rapidly growing metropolitan Atlanta, Georgia offered an excellent opportunity to explore the effects of land development on hydrology. The urban (such as Peachtree Creek basin) and non-urban river basins located in the study area makes it an ideal study area for assessing the effect of climate and land cover changes on runoff.

1.3 Aims and Objectives

The main aim of the study is to provide another practical example of the application of statistical analysis technique Mann-Kendall test and IDW method to access the historical trend and spatial distribution of runoff, rainfall, and temperature in the Blue Ridge and Piedmont provinces of North Carolina and Georgia.

The other purpose of this research was to identify and document the effects of urbanization and land-use changes on stream runoff in the study area. The focus is to analyze urban and non-urban stream runoff data, considering climate, and topography. Based on information in the literature, it was hypothesized that the stream runoff in urban area would exhibit an increasing trend (seasonal trend, high peak flow) with urban development and would decrease with non-urban area.

The main objectives of this study are to:

- Analyze the temporal trend and spatial distribution of stream runoff, rainfall, temperature, rainfall-runoff ratio using Mann-Kendall test and Inverse Distance Weighting method using GIS in order to observe whether there is evidence of long-term temporal trends of climate (temperature), rainfall and stream runoff in different land-cover scenarios (urban vs. non urban) of the Blue Ridge and Piedmont Province watersheds of Georgia and North Carolina (Figure 2-1); and,
- Test the correlation between runoff and rainfall and analyze if there is any significance exists in their positive relationship since rainfall influences runoff.

1.4 Structure

Chapter 2 describes the geography and geology of the study area. This chapter provides information on the streams that have shaped the Blue Ridge and Piedmont and provides the

information on the stream runoff. Chapter 3 reviews the literature related to trend and spatial distribution of stream runoff, precipitation using different statistical and GIS analysis. This chapter also discusses the current research related to stream runoff, precipitation and temperature and their relationship in southeastern United States as well as in different parts of the world.

Chapter 4 describes the methodology employed to access the temporal trend, spatial distribution, and relationship of hydroclimatological parameters in the study area. Data collection, processing procedures, and methods of analysis are also discussed here. The analysis procedure begins with the collection of spatial and hydroclimatological data. Finally, the statistical and GIS techniques that are employed to assess the trend, spatial distribution, and correlation are discussed.

Chapter 5 presents the results of the trend analysis of the stream runoff, precipitation, and temperature in the Blue Ridge and Piedmont provinces of North Carolina and Georgia. In the first section, temporal trend analyses, using the Mann-Kendall test are summarized. The second section expands the spatial analysis that explores the type and location of change that occur within the study area. A synopsis of the relation between stream runoff with precipitation and temperature concludes the chapter. Finally, Chapter 6 presents the discussions and conclusions of the study. This chapter also provides implications of the research.

2. GEOGRAPHY AND GEOLOGY OF THE STUDY AREA

2.1 Geography of Georgia and North Carolina

Georgia is one of the southeastern states of the United States located at 30.356-34.985^{o}N latitude and 80.840-85.605^{o}W longitude (USGS, 2008). Georgia is divided into three physiographic regions: the Blue Ridge, Piedmont, and the Coastal Plain. The Blue Ridge

province is a hilly to mountainous area in the northern part of the state, which consist largely of the southern tip of Blue Ridge Mountain (Geography of Georgia, 2008). Elevations are highest in the Blue Ridge. Georgia's highest point Brasstown Bald is 4,784 feet (1,458m) (USGS, 2008). The study area, the Piedmont, lies between the Blue Ridge to the north and the Coastal Plain to the south. It is upland with rolling terrain and deep, narrow-valleys cut by rivers and streams. The Piedmont ends at the fall line. The Coastal plain is the largest physiographic region of Georgia, which occupies about half of the state (Geography of Georgia, 2008).

Georgia is drained by rivers flowing southward to either the Atlantic Ocean or to the Gulf of Mexico. The major lakes in Georgia are Hartwell Lake, Russell Lake, and J.Strom Thurmond Lake, on the Savannah River; Lakes Oconee and Sinclair, on the Oconee; Lake Sydney Lanier, west Point Lake, and Walter F. George Reservoir, on the Chattahoochee; and Lake Seminole, on the Chattahoochee and Flint rivers (Geography of Georgia, 2008). The climate of Georgia is characterized as humid and subtropical all over the year with hot summers in the south and warm and cool summers in the northern mountainous area. July temperatures average about 79^{o}F in the Piedmont and about 81^{o}F in the Coastal Plain. January temperatures average about 55^{o}F in the south and decline northward, averaging about 45^{o}F in the Piedmont and slightly lower in the north (NCDC, 2006).

North Carolina is also one of the southern states of the United States located at 33.50-36.35^{o}N latitude and 75.28-84.19^{o}W longitude (USGS, 2008). It borders South Carolina and Georgia to the south, Virginia to the north, and Tennessee to the west. The area is 53,821 square miles. The physiographic division of North Carolina contains Blue Ridge to the west, Piedmont in the middle, and the Atlantic Coastal Plain to the east. The Atlantic Coastal Plain, which occupies almost half of the state, is a low, sandy, and relatively flat land (USGS, 2008). The

Piedmont, which covers almost other rest of the state begins at fall line and extends westward to the Blue Ridge. There are numerous rapids waterfalls where rivers cross the fall line. Bulk of the population of North Carolina resides in the Piedmont. The Blue Ridge is a mountainous region with high peaks, deep valleys, and heavily forested slopes (Geography of North Carolina, 2008).

The major rivers of North Carolina begin either in the Blue Ridge or in the Piedmont and flow southeasterly to the Atlantic Ocean. The major natural lakes of this state are Mattamuskeet, Phelps, and Waccamaw. North Carolina has a subtropical climate that is partly affected by cold, continental type found to the north and west. Average summer temperature varies from about 80^{o}F in the south coast to75^{o}F in the Piedmont and 67^{o}F at some mountains in the western area. Average January temperature varies from 50^{o}F in the southeast to 35^{o}F in some northwest mountains (NC Climate and Geography, 2008)

2.2 Blue Ridge and Piedmont

The Blue Ridge is a physiographic province of the larger Appalachian division. It is separated to the north by the Valley and Ridge province and to the south by the Piedmont province (Appalachian Highlands, 2008). The Blue Ridge contains the highest mountains in the eastern North America. Most of the rocks that form the Blue Ridge Mountains are ancient granitic charnockites, metamorphosed volcanic formations, and sedimentary limestones.

The Georgia Piedmont lies between the Blue Ridge Mountains and the Upper Coastal Plain. It runs in a northeast-to-southwest direction, following the main axis of the mountains, faults, and coastline of the southeastern United States. The Piedmont comprises nearly one-third of the area of the state. The boundary of the Piedmont on the southeastern side is the fall line, which generally separates the crystalline rocks of the Piedmont from the sedimentary rocks of the Atlantic Coastal Plain (Appalachian Highlands, 2008). Elevations range from near 1,200 feet

in the north to 500 feet in the south (Georgia State Climate Office, 1998). Major streams located within this province include the Chattahoochee, Flint, Ocmulgee, Oconee, and Savannah Rivers (Georgia State Climate Office, 1998). The study area encompasses the north central part of Georgia, the Blue Ridge and Piedmont provinces and western part of North Carolina, the Blue Ridge province (Figure 2-1). The study area also covers the Atlanta metropolitan area, which is the ninth-largest metropolitan area in the United States, and the mountainous region of North Carolina.

2.3 River Basins of the Blue Ridge and Piedmont

A river basin is the land that water flows across or, under on its way to a river. The river basins in the study area are given in Table 2-1. A river basin drains all the land around a major river. Basins can be divided into watersheds, or areas of land around a smaller river, stream, or lake (www.garivers.org).The drainage patterns in these areas are dendritic (USGS, 2007). The rivers and streams in the Blue Ridge Mountains of the study area are generally steep, fast flowing, cold and clear, whereas in the Piedmont, rivers have more gradual gradients and a high proportion of suspended sediment load because of the flatter, rolling topography (Brown and Jones, 1996).

The study area (Figure 2-1) covers the following ten river basins; Chattahoochee, Flint, Coosa, and Savannah in Georgia and Kanawha, and Little Tennessee in North Carolina (Figure 2-2). Among them, the Chattahoochee River is a major water resource in Georgia. The Chattahoochee River originates from the northern Georgia Mountains, and flows towards southwest Georgia until it joins the Flint River and flows into the Gulf of Mexico at Apalachicola Bay near Apalachicola Florida (USGS, 2007). The river basins are given below in the Table 2-1.

Table 2-1: Stream gauging stations grouped by river basins in the study area.

Basins	County	Name of the River	Lat.	Lon.	Area
Altamaha	Baldwin	Oconee R.at Milledgeville	33.09	83.22	2950
	Clarke	Middle Oconee River, Athens	33.95	83.42	398
	Jones	Falling Creek near Juliette	33.10	83.72	72.2
Chattahoochee	white	Chattahoochee R.at Helen	33.70	83.73	447
	Habersham	Chattahoochee R.near Cornella	34.54	83.62	315
	Carroll	Chattahoochee R.near Whitesburg	33.48	84.90	2430
	Lumpkin	Chestatee R.near Dahlonega	34.53	83.94	153
	Gwinett-F	Chattahoochee R.at Buford dam	34.16	84.08	
	Gwinett	Chattahoochee R.near Norcross	34.00	84.20	1170
	Fulton	Chattahoochee R.at Atlanta	33.87	84.45	1450
	Douglas	Sweetwater creek near Austell	33.77	84.62	246
	Carroll	Snake creek near Whitesburg	33.53	84.93	35.5
	Troup	Chattahoochee R. at Westpoint	32.89	85.18	3550
	Fulton	Big Creek Alpharetta	34.05	84.27	72
	Fulton	Chattahoochee R.near Fairburn	33.66	84.67	2060
	Fulton	Peachtree Creek	33.81	84.40	86.6
Coosa	Cherokee	Etowah R.at Canton	34.24	84.50	613
Flint	Upson	Flint River near Culloden	32.72	84.23	
	Spalding	Flint River near Griffin	33.24	84.43	272
	Coweta	Line creek near Senola	33.32	84.52	101
Kanawha	Ashe	South fork new River near Jefferso	36.39	81.41	205
Savanna	Oconee	Chattooga R. near Clayton	34.81	83.31	207
	Rabun	Tallulah R.near Clayton	34.89	83.53	56.5
	Madison	Broad river above Carlton	34.07	83.00	760
	Wikes	Little R.near washington	33.61	82.74	292
Tennessee	Cherokee	Valley River at Tomotla	35.14	83.98	104
	Macon	Nantahala River near Rainbow Spr	35.13	83.62	51.9
	Swain	Little Tennessee River at Needmor	35.34	83.53	436
	Macon	Little Tennessee River near Pren	35.15	83.38	140
	Madison	French Broad River at Marshall	35.79	82.66	1332
	Madison	Ivy River near Marshall	35.77	82.62	158
	Buncombe	French Broad River atAsheville	35.61	82.58	945.59
	Buncombe	Swannanoa River at Biltmore	35.57	82.55	130
	Buncombe	Bee Tree Creek near Swannanoa	35.65	82.41	5.46
	Henderson	Mills River near mills river	35.40	82.60	66.7
	Transylva	French Broad River at Blantyre	35.30	82.62	296
	Transylva	Davidson River near Brevard	35.27	82.71	40.4
	Transylva	French Broad River at Rosman	35.14	82.83	67.9
	Watauga	Watauga River near Sugargrove	36.24	81.82	92.1

The Flint River, which is about 350 miles long, drains an area of 8460 sq. miles (Brown, 2001), and begins in the Piedmont province near Atlanta's Hartsfield Jackson International Airport. The Savannah River, which is also one of the major rivers in the southeastern United States, runs along the border of South Carolina and Georgia, and drains an area of 5,821 sq. miles in eastern Georgia (USGS, 2005). It is also a major source of drinking water in eastern Georgia. The Oconee and Ocmulgee River Basins are located in the central part of the study area and drain an area of 2,929, and 6,180 sq. miles respectively. Most of the rivers in the Piedmont of the study area originate in the Blue Ridge mountain and the rivers drain either eastward to the Atlantic Ocean or, southward to the Gulf of Mexico. The characteristics of rivers basins are given in Table 2-2.

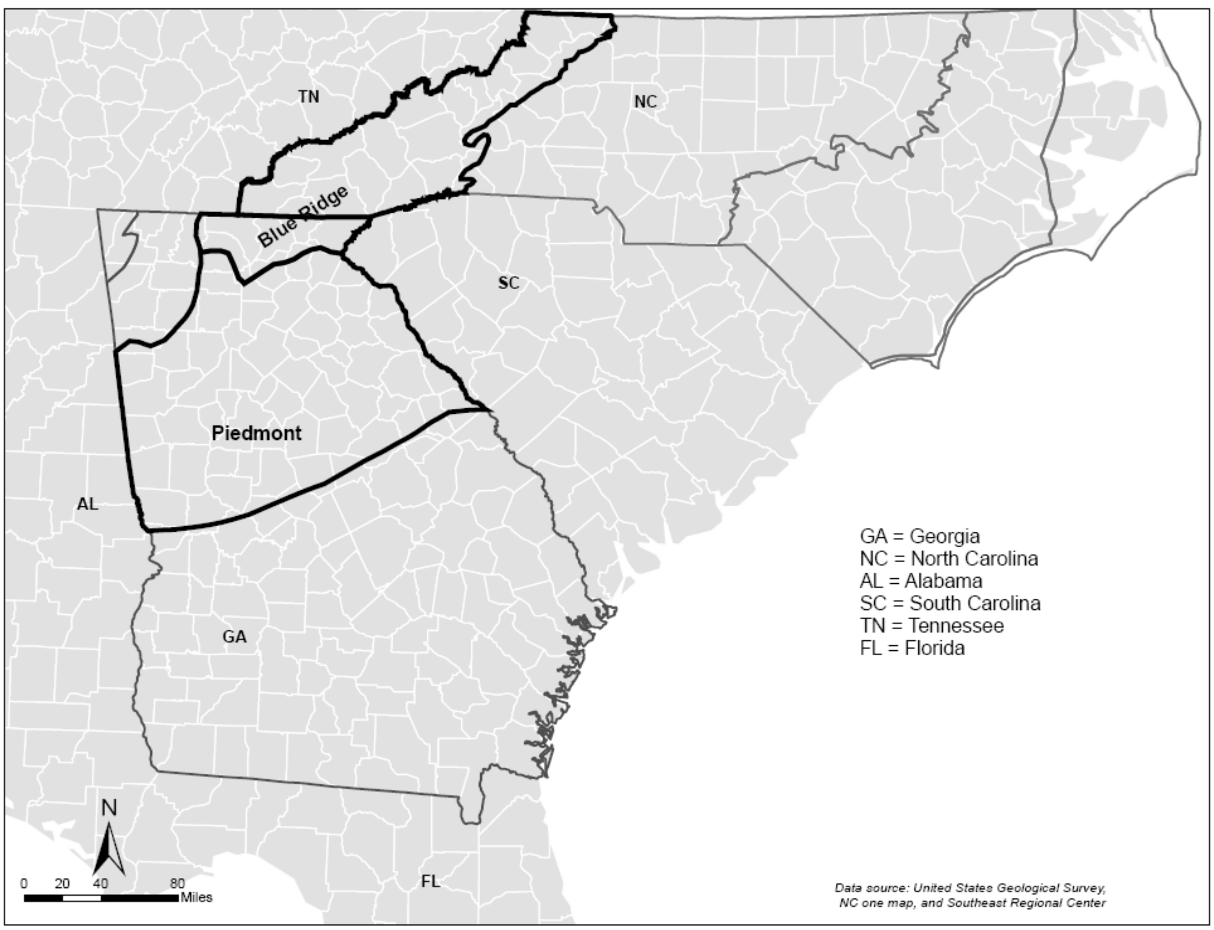

Figure 2-1: Blue Ridge and Piedmont provinces of the study area.

The headwater of the Hiawassee River originates in North Carolina and northern Georgia and flows towards the Tennessee River and drains an area of 644 sq. miles The French Broad River drains an area of 2,830 sq. miles. Similarly, the Little Tennessee drains an area of 1,797 sq. miles, and the New drains an area of 753 sq. miles. The size of the Savannah basin is 10,577 square miles; 5,821 in eastern Georgia, 4,581 in western South Carolina and 175 in southwestern North Carolina. The river supplies drinking water to Augusta, Savannah, Hilton Head, and Beaufort, SC, and many other smaller municipalities in the area (Georgia River Network, 2008). Similarly, the Watagua River drains an area of 205 sq. miles and the Savannah River, drains an area of 172 sq. miles in North Carolina. All of these river basins in North Carolina are a part of Mississippi river basin, which finally drains to the Gulf of Mexico. The length and drainage area of the river basins is given in Table 2-2.

Table 2-2: The length and drainage area of the river basins.

River Basin	Length (miles)	Drainage Area (sq. miles)
Chattahoochee	430	8700
Flint	350	8460
Savannah	350	5821
Oconee	170	2929
Ocmulgee	255	6180
Hiawassee	23	644
French Broad	210	2830
Little Tennessee	135	1797
New	50	753
Watauga	60	205

Source: USGS, 2007.

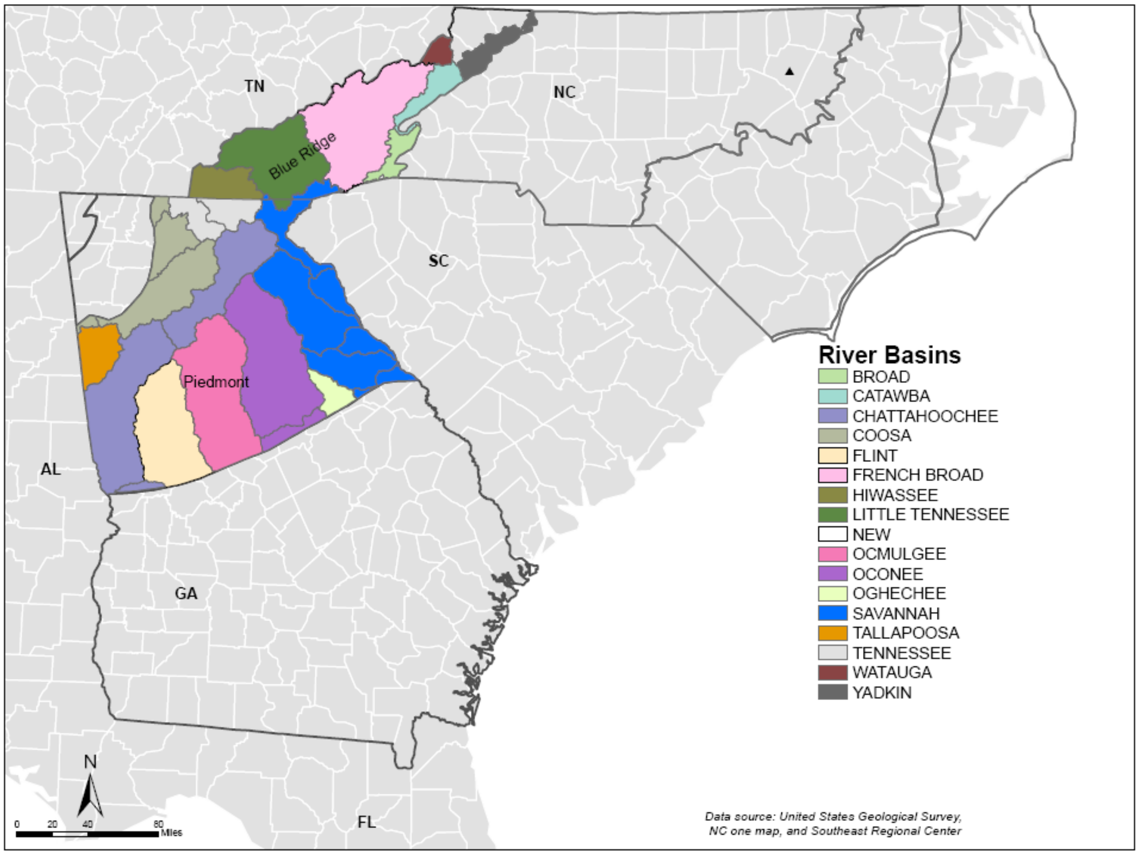

Figure 2-2: River basins in the study area.

2.4 Stream Runoff

Stream runoff is a large percentage of surface runoff that reaches streams when surface storage is filled and precipitation continues to exceed infiltration and water begins to move downslope as overland flow or in defined channels (Ward and Trimble, 2004). The main influence on stream runoff is precipitation runoff in the watershed (USGS, 2008). The flow of a river is primarily a function of the rainfall upon its drainage area, and is therefore subject to fluctuations (Breed and Hosmer, 2007).

In urban streams, runoffs enter the river very quickly than in non-urban streams. Figure 2-3 shows an influence of precipitation on stream runoff. The brown line in the figure shows that the base flow was about 50 ft^3/s before the river started to rise, but after few hours, at 9:00 AM

Stream runoff was over 6, 000 ft^3/s - that is about 150 times the amount of water flowing by as during base flow conditions (USGS, 2008).

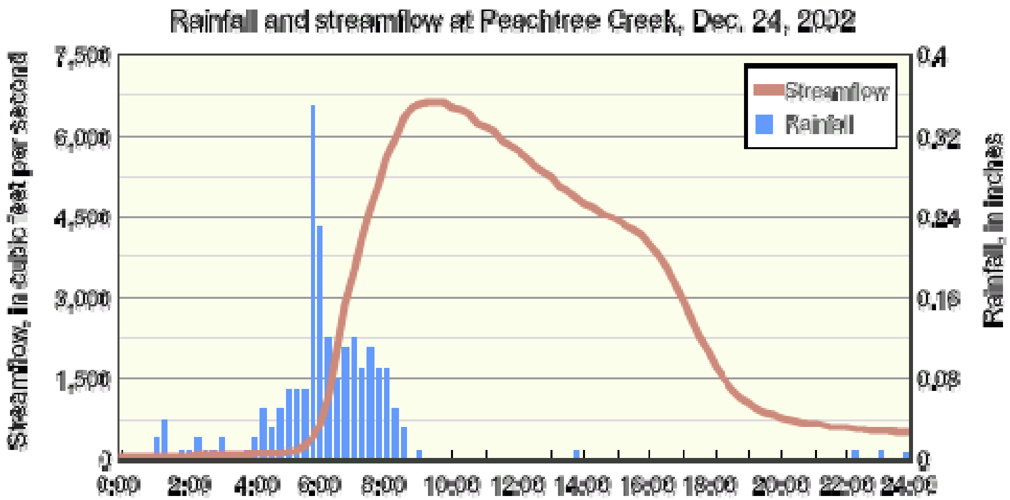

Figure 2-3: Precipitation influences on stream runoff. *Source: USGS, 2008*.

There are many factors, both natural and human-induced, that cause changes in stream runoff. Natural causes are runoff from rainfall and snowmelt, groundwater discharge from aquifers etc, and examples of manmade causes are stream channelization and levee construction, land-use changes such as urbanization, which eventually change the rate of erosion, infiltration, overland flow, or evapotranspiration etc (USGS, 2008).

2.5 Urban and Non-urban Stream Runoff

Urbanization is a pervasive and rapidly growing form of land use change (Paul and Meyer, 2001). According to the U.S. Census Bureau, urbanized areas are defined as places with at least 50,000 people and a suburban fringe with at least 600 people square mile. A dominant feature of urbanization is a decrease in the perviousness of the catchments to precipitation, leading to a decrease or and an increase in surface runoff (Dunne and Leopold, 1978). As the percent of catchments impervious surface cover increases, runoff increases (Figure 2-4) (Arnold and Gibbons, 1996).

Increased surface runoff during heavy precipitation could reduce groundwater recharge and results in a reduction of base flow discharge in urban streams (Kelin 1979, Barringer et al, 1994). Stream runoff are mainly determined by a watershed geology, climate and topography but may also be affected by many factors (Evett, 1994). Many researchers have found that urbanization decreases low flows, while some have reported that it increases low stream runoffs, and others have concluded that it has no or, little effect on stream runoff (Kelin 1979). The urban and non-urban of the study area is given below (Figure 2-5).

2.6 Regional Climate

The regional climate of the study area is characterized as humid and subtropical all over the year with hot summers in the south and the warm and cool summers in the northern mountainous area, since elevation strongly influences the climate of individual location.

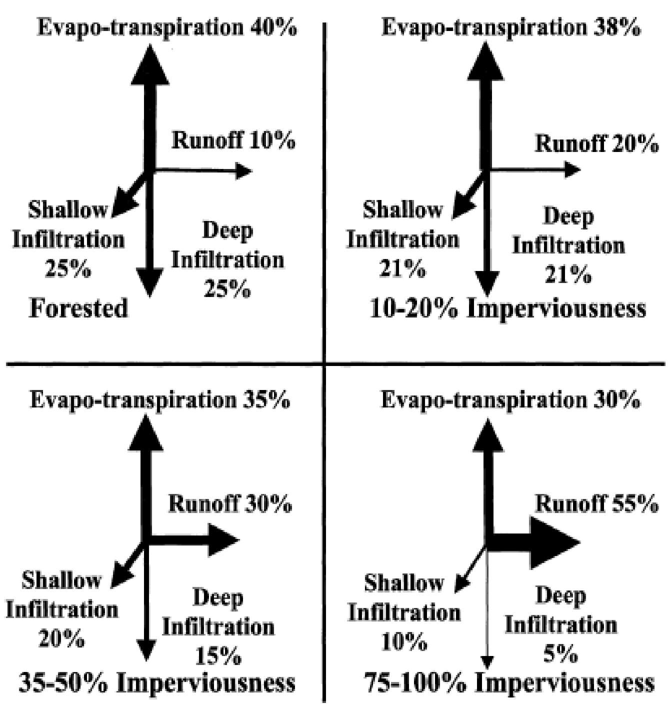

Figure 2-4: Changes in hydrologic flows with increasing impervious surface cover in urbanizing catchments (After Arnold and Gibbons, 1996).

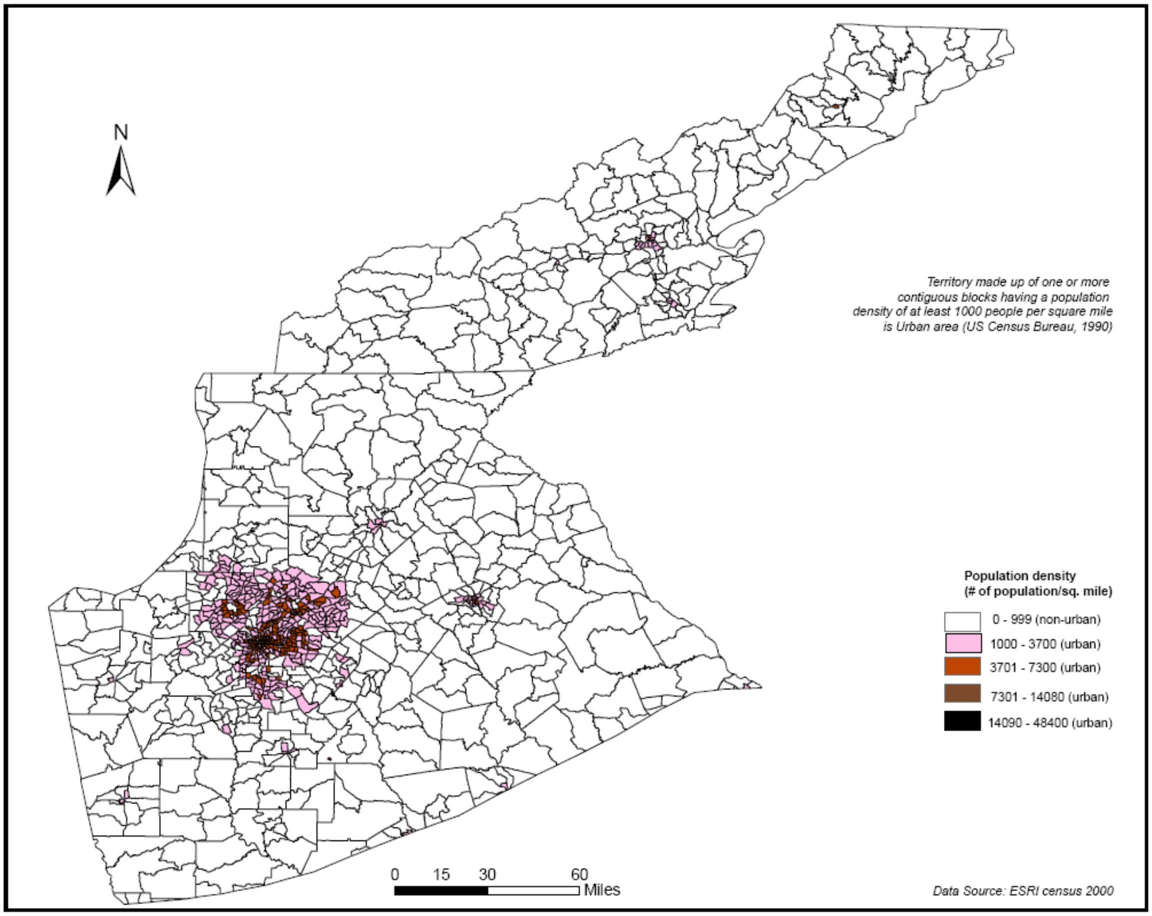

Figure 2-5: Urban and non-urban area within the study area.

The study area has a humid subtropical climate (Koppen climate classification *Cfa*), except in the higher elevations of the mountains, which have a subtropical highland climate (Koppen climate classification *Cfb*). Summers are usually hot and humid in the study area generally experiences widespread precipitation. Winters are usually mild, with some snow in parts, particularly in the mountains.

The Intergovernmental Panel on Climate Change (IPCC), 2007 report finds that the average temperature in Albany, Georgia has been decreased by 0.8^{o} F. Similarly, the report suggests that precipitation has been increased by 10% in the different parts of the state over the last century. The average annual rainfall in Georgia ranges from 43 to 55 inches and annual

runoff ranges from 12 to 28 inches, which is much less than in the Blue Ridge Province, North Carolina (Karl et al 1996). Rainfall varies throughout the Piedmont province. Rainfall averages in excess of 40 inches and tends to be greatest in the north (Georgia State Climate Office, 1998). Dry years occur frequently affecting different locations at different times and extreme wet events are not uncommon, which can lead to flooding (Georgia State Climate Office, 1998).

The annual average rainfall of North Carolina is 45 to 50 inches in a year. July storms account for much of this precipitation. There is some snowfall in the mountain in the fall and winter. Moist winds from the southwest drop an average of 80 inches (2,000mm) of precipitation on the western side of the mountains, while the northeast facing slopes average less than half that amount (North Carolina Climate, 2008). The French Broad River valley, surrounded by mountain ranges is the driest point in the North Carolina. Here the average annual precipitation is only 37 inches (North Carolina Climate, 2008).

As much as 15% of the rainfall during the warm season in the state can be attributed to tropical cyclones (Knight and Davis, 2008). 75 tropical cyclones affected the state between 1900-1949 (50-year period). Similarly, 79 tropical cyclones affected the state between 1950 to 1979 (30-year period) and 107 tropical or subtropical cyclones that affected the state from 1980 to 2006 (28 years period) (North Carolina, 2006). The change in temperature and precipitation could influence the stream runoff, soil moisture and groundwater storage in the whole system. The high temperature leads to an increase in evaporation of water from the streams and can reduce the discharge of the stream. Precipitation, on the other hand, is of course the primary factor accounting for higher flow. Unlike the other regions, studies show a slight downward trend of temperature in the southeastern part of the United States (Lettenmaier et al, 1994, Soule, 2005, IPCC, 2007).

3. LITERATURE REVIEW

3.1 Trend of Stream Runoff and Statistical Test

Many studies show that the global temperature is increasing gradually (Shi et al., 2007; Kamga 2000; Huntington 2003). The impact of temperature change is likely to affect water demand, planning, precipitation and runoff patterns (Kenneth and Major, 1997). Many authors have studied the effect of temperature change on stream runoff using numerical, statistical, and GIS models (Novotny and Stefan 2007; Kamga 2000; Knight et al. 2000; Klaus et al. 1998). One of the major effects of rising temperature on stream runoff is a decreasing trend of stream runoff, due to potential increase in evapotranspiration (Christensen et al. 2004).

Lettenmaier et al. (1994) examined trends of average temperature, precipitation, stream runoff from 1948-1988, and average daily temperature range for the continental United States using Seasonal Kendall test and found annual temperature increase mostly in the north and west and observed downtrends in the south and east. The observed that trends in stream runoff were not entirely consistent with the changes in the temperature and precipitation. Similarly, Lins and Slack (1999) examined the trends in stream runoff in the conterminous United States using the non-parametric Mann-Kendall test and found that stream runoff has increased in broad sections of the United States and decreased only in parts of the Pacific Northwest and in the southeast.

Lins and Slack (2005) found similar result when they examined the stream runoff trend in all water resources in the conterminous United States between the period from 1940 to 1999 using the same Mann-Kendall test, and observed that the increase was most pronounced in the central two-thirds of the nation and, to a lesser extent in the eastern coastal regions and in the Great Basin. They noticed a decrease in the annual minimum flows in Georgia and the Pacific Northwest.

Rose and Peters (2001) observed significant difference in stream runoff between urban and less developed watershed near Atlanta and other watersheds in the Blue Ridge and the Piedmont provinces. The most noticeable feature was the difference in peak flow. Peak flows were 30% to more than 100% greater in the urbanized Peachtree Creek than any other basins. The storm flow was also more frequent and higher in the urbanized Peachtree Creek.

On the limited studies done in the stream runoff of southeastern region of the United States, an inverse trend of temperature with stream runoff was noticed (Lettenmaier et al., 1994, Lins and Slack, 1999). In contrast, Rose (2008) found that no consistent statistically significant temporal trends for rainfall and runoff in the southeast region of the United States. The study also found that the average runoff/rainfall ratio during the study period varied between 0.24 in the southernmost Coastal Plain to 0.64 in the Blue Ridge Province.

3.2 Stream Runoff and Impact of Climate Change

Earth surface has experienced a climate warming since late 19th century (IPCC, 2001). Many researchers have predicted more likelihood of temperature warming and its impact on water resources. Nohara et al. (2006) investigated the impact of climate change on the river discharge for 24 major rivers in the world. Their results suggested that by the end of the 21st century, the annual mean precipitation, evaporation, and runoff would increase in high latitudes of the Northern Hemisphere, Southern to Eastern Asia, and Central Africa. In contrast, they would decrease in the Mediterranean region, Southern Africa, Southern North America and Central America.

Payne et al. (2004) simulated climate for next 105 years within the Columbia River basin by using parallel climate models (PCM). The PCM model for three periods (2010-2039, 2040-2069, and 2070-2098) predicted temperature and precipitation would increase in the future. The

2007 report published by IPCC showed that the effects of climate change on rainfall and Stream runoff in this area is subjected to considerable uncertainty since, some of the models they used for the study showed little to no change in precipitation unlike the northeast and southwest United States (IPCC, 2007).

Among the very few studies on the southeastern part of the United States, Soule (2005) studied 30-year climatic normal temperature from 1961-1990, and 1971-2000 for the southeastern United States and found that the thermal climate of this region is stable with some exceptions of slightly warming towards coastal areas. Soule (2005) observed some degree of spatial continuity in the warming patterns on all of the stations of coastal plain of Georgia and Florida, except on Miami Beach where, there was a cooling trend. However, the study showed no spatial continuity (either cooling or warming) throughout much of the Blue Ridge Mountains and Piedmont Provinces, where adjacent stations often show opposite trends. On the other study Diem (2006), found increased summer precipitation over the 50 years period (1953-2002) was significantly correlated with increased occurrences of midtropospheric troughs in the southeastern United States. 37

These changes are predicted to lead to an increase in precipitation and atmospheric moisture (Novotny and Stefan, 2006). In fact, an increase in atmospheric moisture at a rate of about 5% per decade has been observed over the United States favoring stronger rainfall or, snowfall events (Trenberth, 1998).

4. RESEARCH METHODOLOGY

4.1 Data Collection

Stream runoff is the volume of water passing through a river channel during a certain period which can be expressed as Q = W*D*V, where Q is stream runoff, W is channel width, D is channel depth and V is velocity of flowing water (Ward and Trimble, 2004). Stream runoff is a flow of water in a river channel and is calculated by discharge per unit area as shown in equation (1) below;

Runoff = Q/A, -------------- (1)

Where, Q= discharge and,

A= Area

Stream runoff, rainfall, and temperature data were collected from the United States Geological Survey (USGS) and Southeast Regional Climate Center (SERCC) website from the year 1948 to 2006 for the study area. The USGS Stream runoff data, measured in cubic feet per second (CFS), was converted into stream runoff (millimeter/year) for the study.

Stream gauging stations, rainfall, and temperature monitoring stations were selected based on the length and continuity of their records from the United States Geological Survey (USGS) as shown in Figure 4-1, (http://waterdata.usgs.gov/ga/nwis/rt) and Southeast Regional Climate Center (SERCC) Figure 4-2) (http://www.sercc.com/). The monthly and annual stream runoff data and temperature records were collected during the period from 1948 to 2006 to make the data as current as possible, for more than 30 USGS stream gauging stations and SERCC rainfall and temperature monitoring stations. For the study, urban and non-urban stations were selected based on the population density and landuse/ landcover data using the GIS analysis such as extraction and overlay.

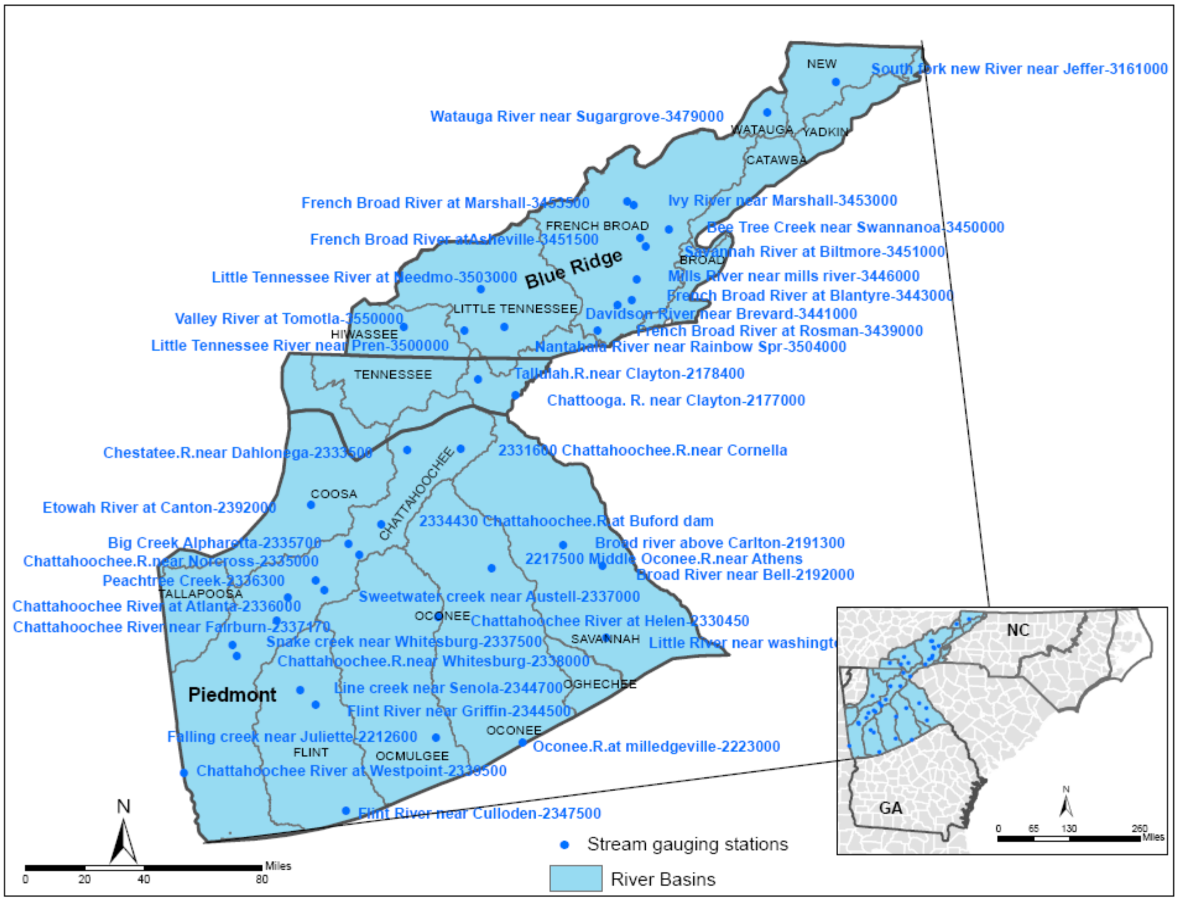

Figure 4-1: Runoff monitoring stations in the river basins of the study area.

The spatial data of the seven river basins for the study area were collected and downloaded from the USGS. The metro Atlanta region has experienced explosive growth over 50 years (USGS, 2008), and, along with it, large amounts of impervious surfaces have replaced the natural landscape. The landuse/land cover data and the physiographic data created by the USGS were obtained from the Georgia GIS clearing house (https://gis1.state.us) and the USGS Land Cover Institute (LCI) (http://landcover.usgs.gov) respectively. The census 2000 data, produced by the Environmental System Research Institute (ESRI) was downloaded from the Geospatial data bank from Georgia State University, Department of Geosciences and from the North Carolina GIS clearinghouse. The spatial data were tried to maintain as current as possible for the research.

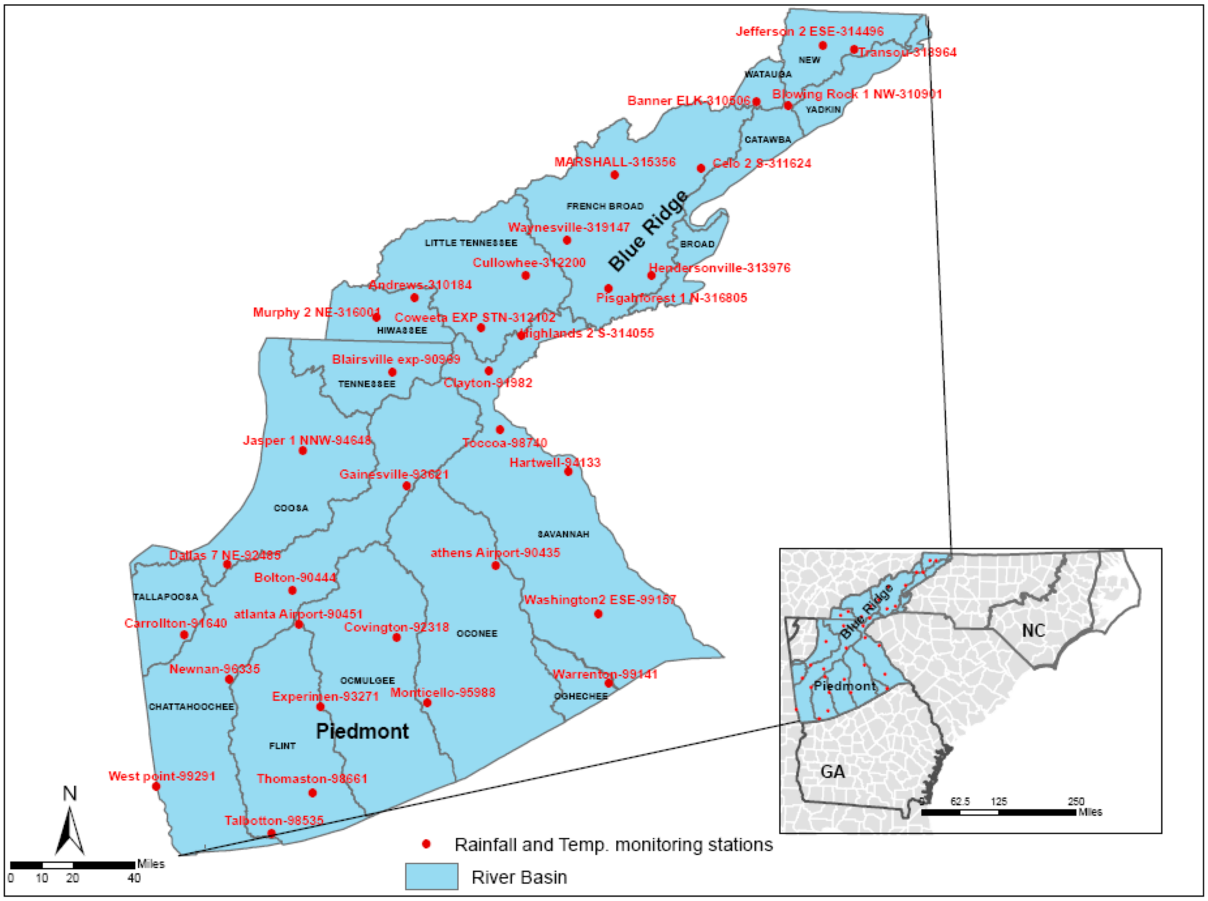

Figure 4-2: Rainfall and temperature monitoring stations in the study area.

4.2 GIS Analysis

Extraction, overlay, and spatial analysis are the three main GIS functions that were used for the study. Extraction and overlay analysis were used to create subset maps of the study area from a large spatial database. Similarly, spatial analysis function, known as spatial interpolation was used to calculate the spatial distribution of hydrological parameters such as rainfall and temperature. The spatial interpolation technique uses points with known values to estimate the values at other unknown points by converting the discrete point data into a continuous surface. The main purpose of the GIS analysis was to find and integrate the urban and non-urban river basins in the Blue Ridge and the Piedmont provinces using landuse/landcover and population density data. The flow chart of GIS analysis is given in Figure 4-3.

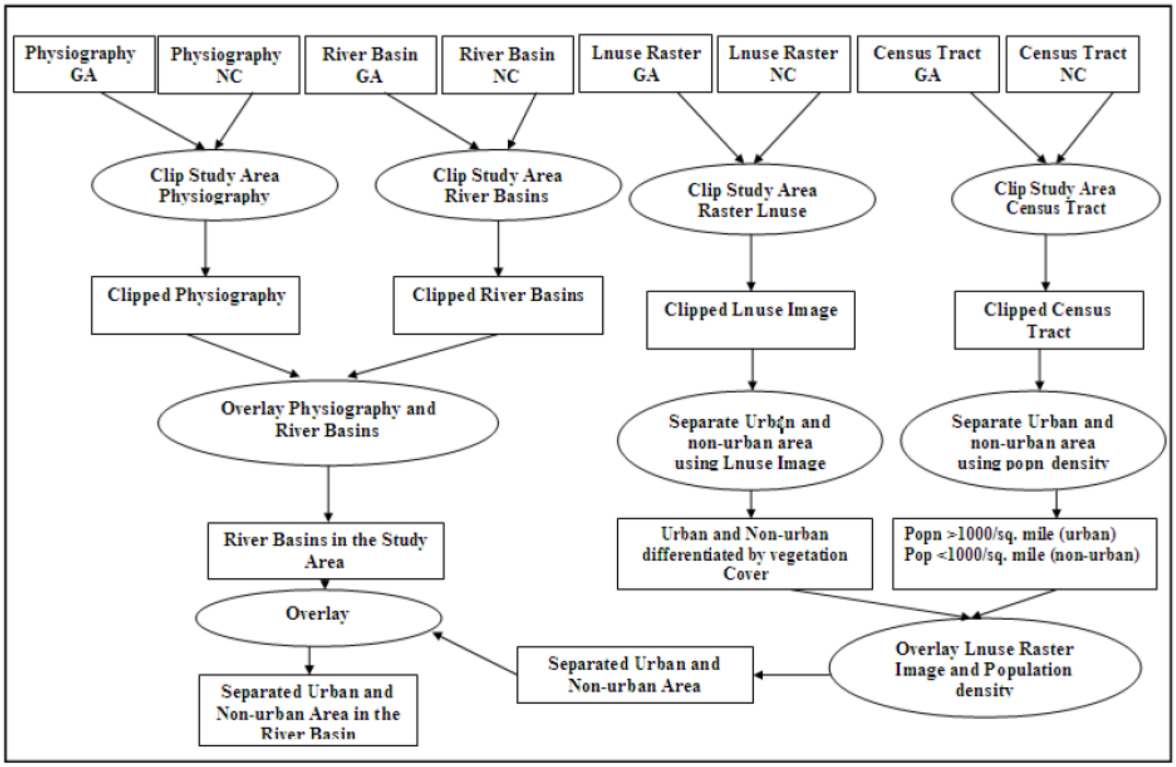

Figure 4-3: Flow chart of GIS analysis.

Extraction function was used to extract the boundary of the study area from the physiographic provinces of the Blue Ridge and Piedmont of North Carolina and Georgia. The boundary was then used to extract river basin, landuse/land cover and the census tract layers of the study area. Once the study area was selected, the urban and non-urban river basins in the study area were separated based on the landuse/land cover distribution map and the population density map using the overlay technique. According to population density and land use/landcover area, more than 80% of the study area came out to be non-urban area and less than 20% came out to be urban area. Once the river basins were separated, statistical analyses such as Mann-Kendall test, correlation test, and Inverse Distance Weighting methods were performed to analyze the trend and correlation between the surface temperature, rainfall and the stream runoff of the study area.

Urban and non-urban area using population density

According to the United States Census Bureau, an urban area is defined as blocks or block groups with at least 1,000 persons per square mile (386 per square kilometer) and surrounding blocks or block groups with 500 persons per square mile (US Census Bureau, 2000). In this study, census 2000 data was obtained from the online database of Environmental Systems Research Institute (ESRI). Extraction technique in GIS was used to obtain the data for North Carolina and Georgia. The urban area was determined by calculating the density populations map using 1,000 persons per square mile (Figure 4-4 and 4-5). Non-urban area covers the most part of the study area. The total urban area was calculated as 1626.38 sq. miles, which is 5.96 % of the total study area of 27,246 sq. miles. The urban area in the study area is given below in the Figure 4-4.

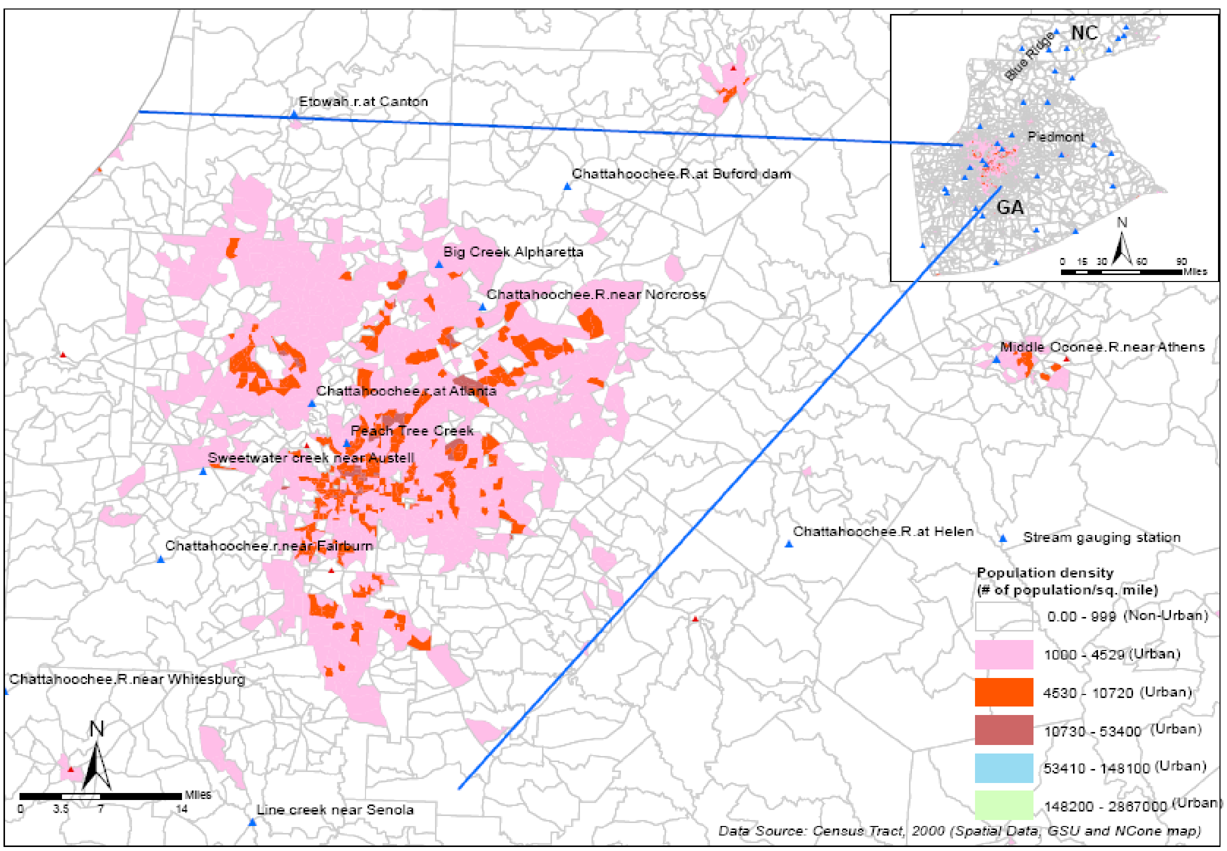

Figure 4-4: Urban and non-urban area using population density in the Piedmont province.

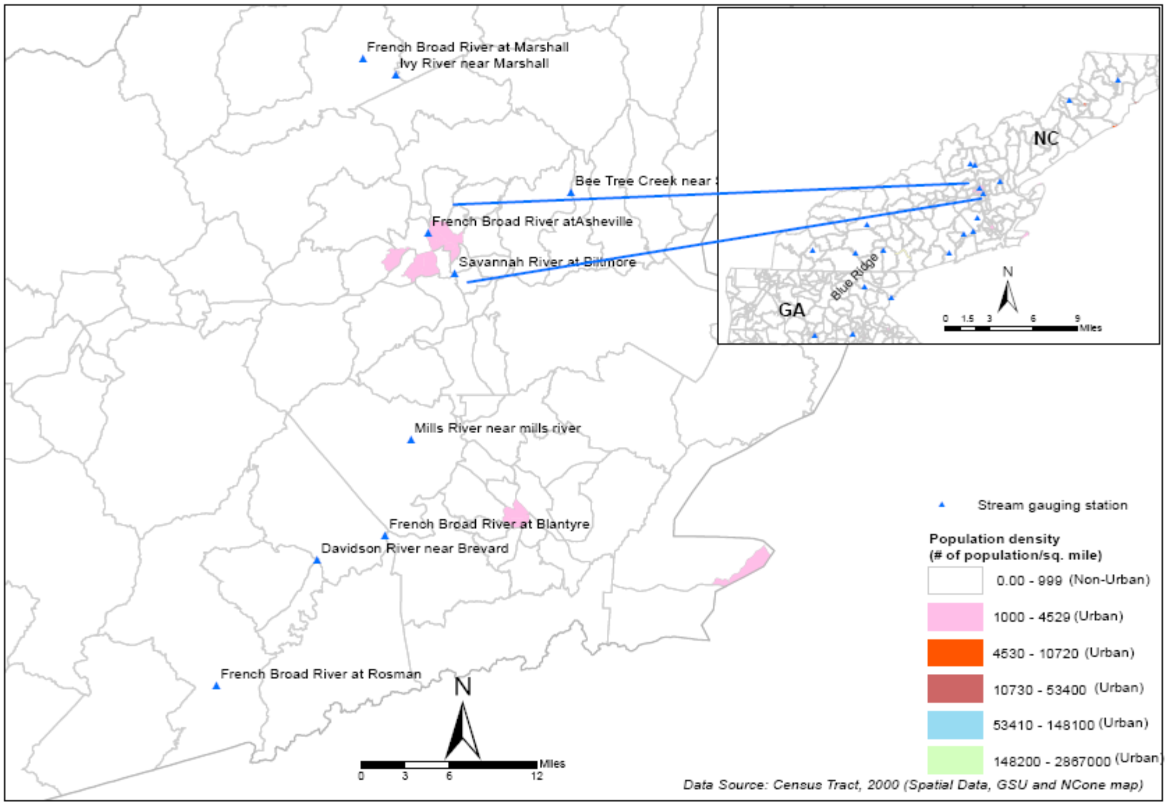

Figure 4-5: Urban and non-urban area using population density in the Blue Ridge province.

Urban and non-urban area using landuse/land cover

The landuse/land cover data of 2000 was obtained from the USGS. The population data were normalized by study area using GIS in order to calculate the population density map of the study area. The population density map was then used to classify urban and non-urban areas. The determined urban and non-urban area for the Piedmont and Blue Ridge are shown in Figure 4-6 and Figure 4.7 respectively. Based on the metadata that was documented with the landuse/ land cover data, four classes in urban areas were determined from the percent imperviousness mapping product as described below. The threshold values for the four landuse/land cover classes are listed in Table 4-1. The most of the urban part in the Piedmont province is located in the metropolitan Atlanta and the urban part in the Blue Ridge province is located in the Asheville area.

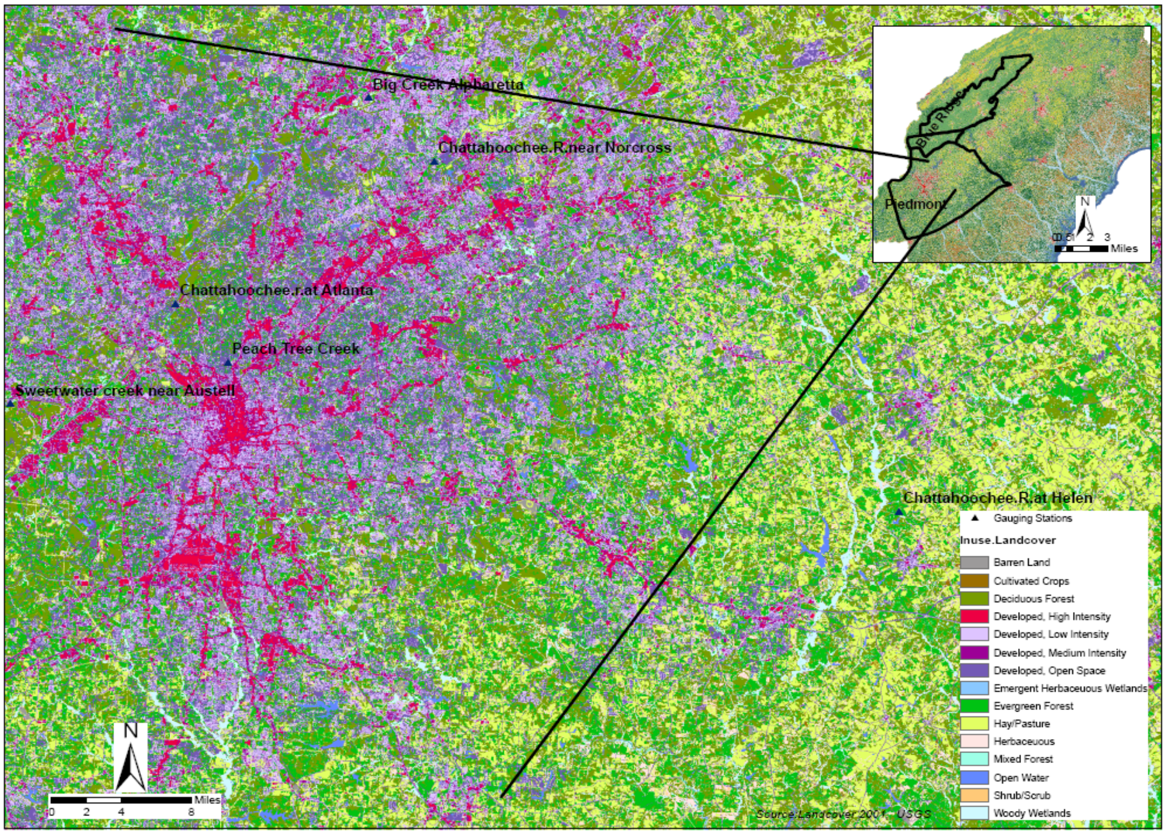

Figure 4-6: Urban and non-urban area in the Piedmont province using landuse/land cover product.

Table 4-1: Classification of urban area according to percent imperviousness.

Category	Imperviousness (%)
Developed open space	<20
Low intensity developed	20-49
Medium intensity developed	50-79
High intensity developed	>79

Developed open space includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. Similarly, developed low intensity includes areas with a mixture of constructed materials and vegetation. Developed medium

intensity includes areas with a mixture of constructed materials and vegetation. Developed high intensity includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Barren lands are the areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines and gravel pits. The urban and non urban area in the Blue Ridge province is given in the figure 4-7 below.

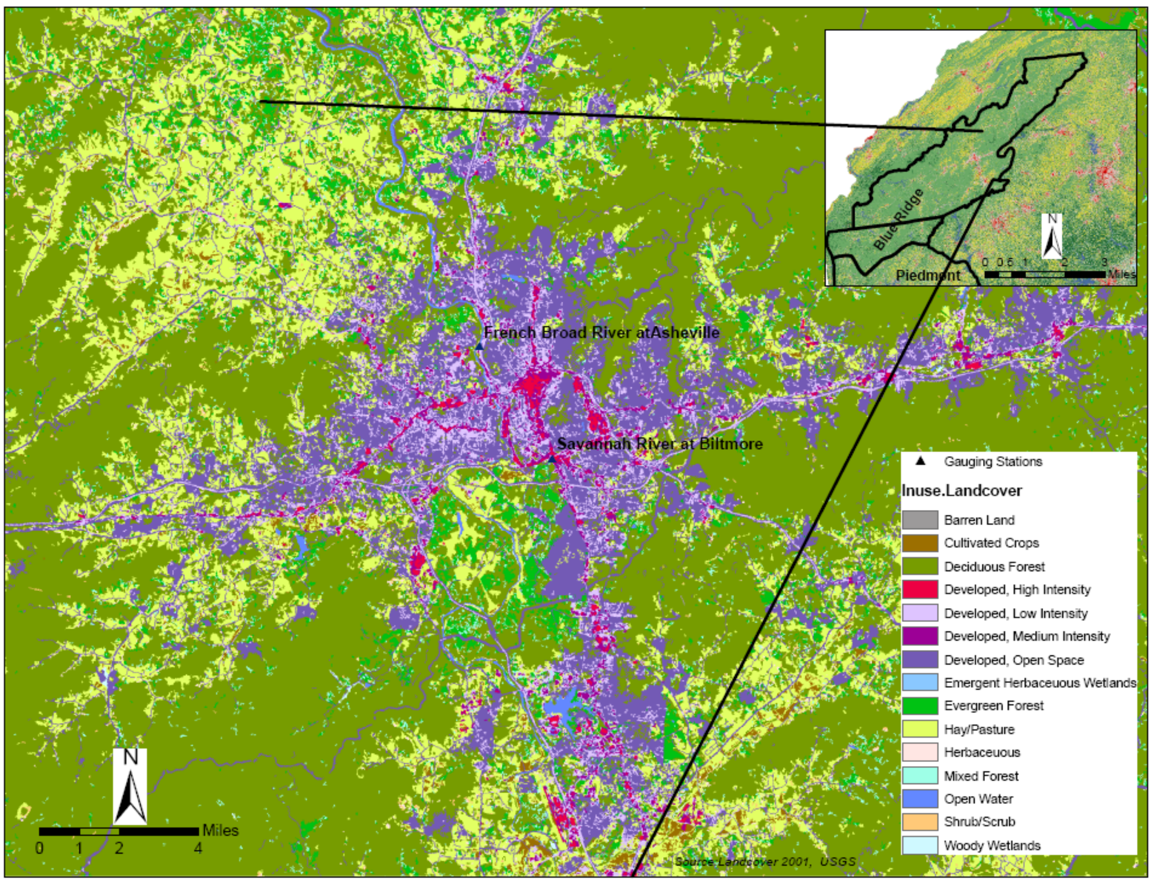

Figure 4-7: Urban and non-urban area in the Blue Ridge province using landuse/land cover product.

Deciduous, evergreen, and mixed forests are the areas that are dominated by trees generally greater than 5 meters tall (USGS, 2003). Both of the maps (Figures 4-4, 4-5, 4-6, and 4-7) showed the same determination for urban and non-urban area. The urban stations are those

found within metropolitan areas with population more than 1000 per square mile and non-urban stations are those found in non-metropolitan areas with population less than 1000 per square mile (US Census Bureau, 2000). There are six watershed located in the urban area (Table 4-3) and 33 in non-urban area (Table 4-2). Among six watersheds, five watersheds were from Piedmont and one from Blue Ridge province.

4.3 Mann-Kendall Analysis

In order to determine if stream runoff, rainfall, and air temperature characteristics are changing in urban and non-urban area of the Blue Ridge and Piedmont, long-term (56 years) stream runoff records were analyzed for more than 30 USGS stream gauging stations (Figure 4-1) and SERCC rainfall and temperature monitoring stations (Figure 4-2). The time trends of stream runoff, rainfall, and air temperature at all stations were investigated by computing the statistical test called Mann-Kendall test. It is a nonparametric or, distribution free test for trends. This method has not any assumptions. It is appropriate since there is no assumption of a normal distribution in the data. Most of the stream runoff data are not distributed normally due to different reasons.

A parametric test like linear regression is not considered appropriate since stream runoff characteristics generally are not normally distributed (Gebert and Krug, 1996). However, in this study linear regression is also used to see the disparity between the two analyses. Many authors have successfully used Mann-Kendall test to identify the trends in the stream runoff and rainfall data (Gebert and Krug, 1996, Yue and Wang, 2002, Kahya and Kalayci, 2004, Rose, 2008). The null hypothesis, H_o, is that there is no (X_1……X_n) significant temporal trend in the data set. The Mann-Kendall analysis tests H_o against the alternative hypothesis H_1, that the dataset show significant temporal trends.

Table 4-2: Non urban rivers of the study area.

Stations	Name of the River	County	Province	(Sq mile)
2212600	Falling creek near Juliette	Jones	Piedmont	72.2
2223000	Oconee River at Milledgeville	Baldwin	Piedmont	2950
2330450	Chattahoochee River at Helen	white	Piedmont	447
2331600	Chattahoochee River near Cornella	Habersham	Piedmont	315
2338000	Chattahoochee R. near Whitesburg	Carroll	Piedmont	2430
2333500	Chestatee River near Dahlonega	Lumpkin	Piedmont	153
2337000	Sweetwater creek near Austell	Douglas	Piedmont	246
2337500	Snake creek near Whitesburg	Carroll	Piedmont	35.5
2339500	Chattahoochee River at Westpoint	Troup	Piedmont	3550
2337170	Chattahoochee River near Fairburn	Fulton	Piedmont	2060
2392000	Etowah River at Canton	Cherokee	Piedmont	613
2347500	Flint River at US19, Carsonville	Upson	Piedmont	1850
2344500	Flint River near Griffin	Spalding	Piedmont	272
2192000	Broad River near Bell	Elbert	Piedmont	1430
2344700	Line creek near Senola	Coweta	Piedmont	101
3161000	South fork new River near Jefferson	Ashe	Piedmont	205
2177000	Chattooga River near Clayton	Oconee	Piedmont	207
2178400	Tallulah River near Clayton	Rabun	Piedmont	56.5
2191300	Broad river above Carlton	Madison	Piedmont	760
2193500	Little River near washington	Wikes	Piedmont	292
3550000	Valley River at Tomotla	Cherokee	Blue Ridge	104
3504000	Nantahala River near Rainbow Spr	Macon	Blue Ridge	51.9
3503000	Little Tennessee River at Needmore	Swain	Blue Ridge	436
3500000	Little Tennessee River near Pren	Macon	Blue Ridge	140
3453500	French Broad River at Marshall	Madison	Blue Ridge	1332
3453000	Ivy River near Marshall	Madison	Blue Ridge	158
3451000	Swannanoa River at Biltmore	Buncombe	Blue Ridge	130
3450000	Bee Tree Creek near Swannanoa	Buncombe	Blue Ridge	5.46
3446000	Mills River near mills river	Henderson	Blue Ridge	66.7
3443000	French Broad River at Blantyre	Transylva	Blue Ridge	296
3441000	Davidson River near Brevard	Transylva	Blue Ridge	40.4
3439000	French Broad River at Rosman	Transylva	Blue Ridge	67.9
3479000	Watauga River near Sugargrove	Watauga	Blue Ridge	92.1

Table 4-3: Urban rivers of the study area.

No	Stations	Name of the River	County	Province	A.(Sq mile)
1	2217500	Middle Oconee River near Athens	Clarke	Piedmont	398
2	2335000	Chattahoochee River near Norcross	Gwinnett	Piedmont	1,170
3	2336000	Chattahoochee River at Atlanta	Fulton	Piedmont	1450
4	2335700	Big Creek Alpharetta	Fulton	Piedmont	72
5	2336300	Peachtree Creek	Fulton	Piedmont	86.6
6	3451500	French Broad River at Asheville	Buncombe	Blue Ridge	945.59

In this study, 95% confidence level is used. The confidence level is a measure of confidence in rejecting the null hypothesis. The corresponding (Z-critical) standard deviate for 95% confidence level is 1.96. The test statistics S is calculated by using the equations (2) and (3) below (Kahya and Kalayci, 2004);

$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\ (X_j - X_k)$ ………..(2) where n is the number of values in the data set

$$sgn\ (X_j - X_k) = \begin{cases} +1 & \text{if } (X_j - X_k) > 0 \\ 0 & \text{if } (X_j - X_k) = 0 \\ -1 & \text{if } (X_j - X_k) < 0 \end{cases} \quad \text{……… (3)}$$

A positive value of S indicates an upward trend and a negative value indicates a downward trend (Kahya and Kalayci, 2004). A Z-critical value is calculated from the S given in the equation (2) to evaluate the level of significance of the trend. If Z-critical value is greater than 1.96, then the data has significant positive trend and if it is less than -1.96, the data has significant negative trend. A Mann-Kendall analysis spreadsheet program in this study was designed and used with method reference from “Trend analysis of streamflow in Turkey” (Kahya and Kalayci, 2004).

4.4 Linear Trend and Slope Analysis

Slope of the lines fit to the time series of climatic data provide a picture of changes that have occurred at any location over an extended period. Monthly mean (average of maximum and minimum) temperature records were summed up to provide seasonal and annual totals for each year. Seasonal averages were calculated for each monitoring station based on the following seasonal breakdown; winter as December, January, February (DJF), spring as March, April, May (MAM), summer as June, July, August (JJA) and fall as September, October, November (SON).

Seasonal and annual averages were calculated for each station and a linear trend was fitted to each time series for all calculated average seasonal and annual data for temperature, and precipitation (see Appendix A, B, and C). With linear trends, the slopes were calculated at each station and were spatially analyzed for the regional changes in the Piedmont and Blue Ridge. Positive slopes stand for a linear increase in the variable over time, while negative slopes represent a linear decrease in the parameter over time. Linear slopes from all observed stations were analyzed for each season using inverse distance weighting (IDW) with the help of ArcGIS 9.2 software.

4.5 Spatial Autocorrelation

A spatial autocorrelation technique called Moran's I was used to identify the spatial dependency among temperature, rainfall, and runoff trends at all 73 stations in the study area. Moran's I is a measure of spatial autocorrelation which is produced by standardizing the spatial autocovariance by the variance of the data using a measure of the connectivity of the data (Cliff and Ord, 1973, Boots and Getis, 1988, Chang et al., 2008). Formula for the he Moran's I test is given below:

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (X_i - \overline{X})(X_j - \overline{X})}{\sum_{i=1}^{n} (X_i - \overline{X})^2}$$

Where, n is the number of spatial units indexed by i and j, X is the variable of interest; $\overline{X}$ is the mean of X; and W_{ij} is a matrix of spatial weights (Chang et al., 2008). In this study, 0.05 significance level was used. The corresponding (Z-critical) standard deviate for 0.05 significance is 1.645. The null hypothesis, H_o, states that there is no significant spatial autocorrelation in the data set and the alternative hypothesis H_1, states that the dataset show significant spatial autocorrelation. The study showed that there is significant spatial autocorrelation for the rainfall and temperature data in the study area.

4.6 Inverse Distance Weighting (IDW) Interpolation

After the calculation of seasonal and annual averages and spatial autocorrelation test, spatial interpolation technique called, IDW was performed using GIS to observe the changes in hydrological and climatic patterns. IDW is one of the most commonly used techniques for interpolation of scatter points and it is good for those data which have no spatial dependency or has no spatial autorrelation. Inverse distance weighted methods are based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points.

IDW is a weighted average interpolator, which can be either exact or smoothing (Watson et al., 1985). With inverse distance, data are weighted during interpolation, so that the influence of one point, relative to another, declines with distance from the grid node. Weighting is assigned to data through the use of a weighting power, which controls how the weighting factors drop off as distance from the grid node increases (Bakkali and Amrani, 2008). As the power increases, the

grid node value approaches the value of the nearest point. For a smaller power, the weights are more evenly distributed among the neighboring data points (EL Abbas et al, 1990).

For precipitation, and temperature analyses, an IDW was used since this technique provides better interpolation than other methods and has been successfully used by other authors (Boyles and Raman, 2003). Finally, a continuous surface of precipitation, and temperature were calculated for all the stations using the IDW interpolation technique. The simplest weighting function is inverse power: $w(d) = 1/d^p$, with $p>0$ (Maguire et al. 2005). For the IDW analysis, inverse power of 2 and maximum neighbors of 15 and minimum neighbors to include 10 has been used for the study. The example of different inverse power is given in the Figure 4-8.

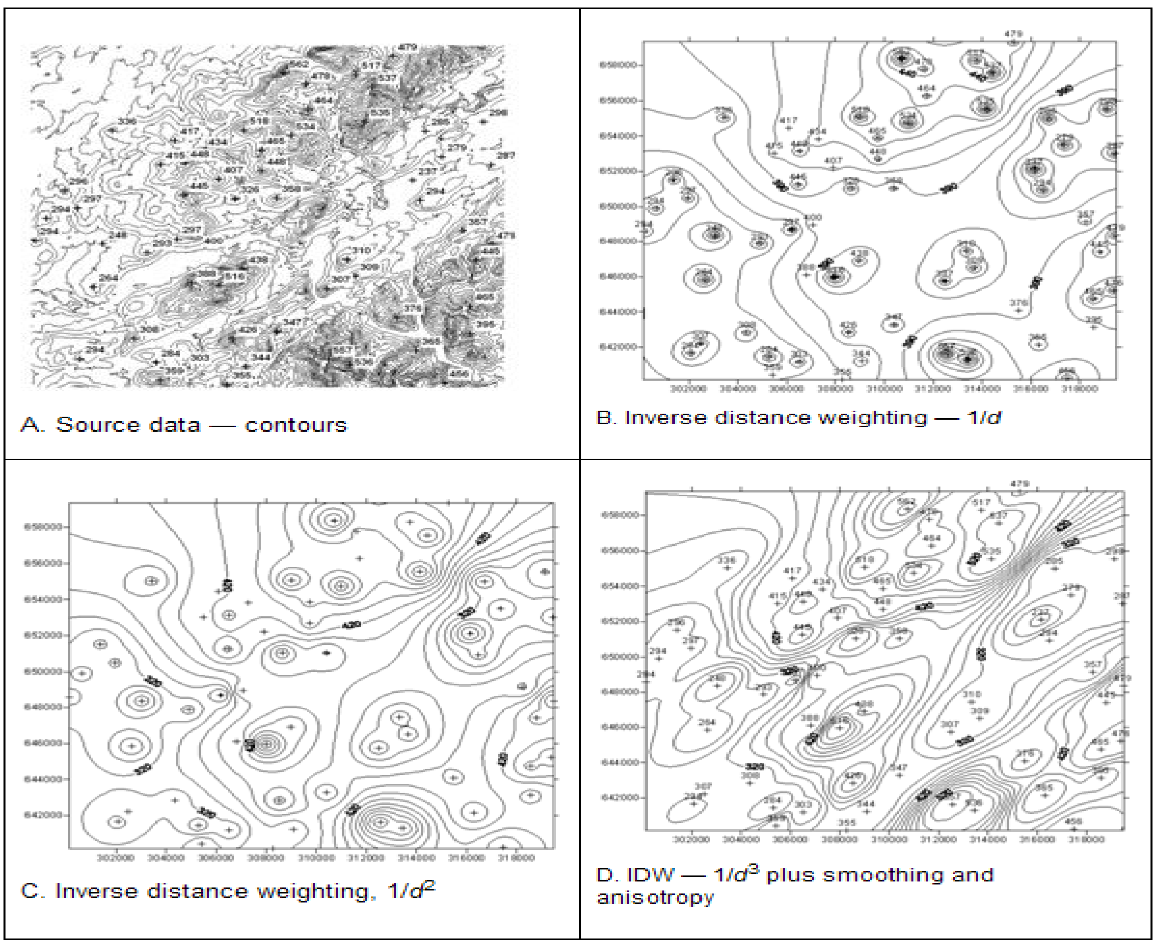

Figure 4-8: Contour plots (with different inverse power) for alternative IDW methods (After de smith, Goodchild, and Longley, 2006-2008).

The neighborhood size determines how many points are included in the inverse distance weighting. The neighborhood size can be specified in terms of its radius (in km), the number of points, or a combination of the two (Watson and Philip, 1985). In many instances, the observation points are not uniformly spaced about the interpolation points, with several in a particular direction and fewer in others. This situation produces a spatial bias of the estimate, as the clustered points carry an artificially large weight. The anisotropy corrector permits the weighted average to down weight-clustered points that are providing redundant information. The user selects this option by setting the anisotropy factor to a positive value. A value of 1 produces its full effects, while a value of 0 produces no correction (Maguire et al. 2005). In this study, value of 0 is used, which produces no correction.

4.7 Correlation Test

Correlation indicates the strength and direction of a linear relationship between two random variables (Rogerson, 2004). The correlation values of 0 and +1 stand for no correlation and perfect positive correlation respectively. Similarly, the value -1 stands for perfect negative correlation. A correlation between stream runoff and precipitation can be expected. To quantify the relationship, a correlation analysis was performed between the mean annual stream runoff rates at individual stream gauging stations and total annual precipitation using a spreadsheet correlation program. Apart from rainfall characteristics such as intensity, duration, and distribution, there are a numbers of other factors such as evapotranspiration, soil type, vegetation, slope etc, which affect the runoff.

5. RESULTS AND DISCUSSIONS

5.1 Temperature in the Study Area

The MK analysis for long-term annual and seasonal temperature over the Blue Ridge and Piedmont show no significant trend except a very few at Piedmont and Blue Ridge (Table 5-1). Table 5-1 shows the significant trend in bold texts. However, very few stations in the southern Piedmont and the northern Blue Ridge show significant positive trend in temperature during spring and summer months (Table 5-2).

Table 5-1: Annual temperature trend over the Blue Ridge and the Piedmont in the study area.

Station#	Province	Range of years	n(years)	Zstatistic
310506	Blue Ridge	1948-2006	59	1.341
310814	Blue Ridge	1948-2006	59	1.184
310901	Blue Ridge	1961-2006	42	0.639
311624	Blue Ridge	1948-2006	59	0.059
312200	Blue Ridge	1948-2006	59	1.641
313228	Blue Ridge	1950-2006	57	0.193
314055	Blue Ridge	1948-2006	59	0.334
314496	Blue Ridge	1967-2006	40	1.934
316001	Blue Ridge	1969-2006	37	1.779
312102	Blue Ridge	1949-2006	58	**2.478**
90435	Piedmont	1948-2006	59	0.163
90451	Piedmont	1944-2006	63	0.884
91982	Piedmont	1944-2006	63	0.332
92006	Piedmont	1944-2006	63	0.380
92318	Piedmont	1948-2006	59	0.987
93271	Piedmont	1944-2006	61	0.803
94133	Piedmont	1941-2006	66	1.799
98535	Piedmont	1944-2006	63	1.779
99157	Piedmont	1948-2006	59	0.857
99291	Piedmont	1944-2006	63	0.528
92485	Piedmont	1958-2006	49	**3.551**
95988	Piedmont	1948-2006	59	**2.668**

Note: z-critical = 1.96.

Usually, summer months in the study area experience warmer temperatures than the mild winter months. Significant positive trends found in temperature at some of the stations (Table 5-1 and 5-2) contradict the results of long-term trend analyses (50-100 yr trends) of temperature in the southeast where a clear cooling trend was observed (Karl et al, 1996, Saxena and Yu 1998). Nevertheless, the result from this study is somewhat similar to the recent analyses done by Soule (2005), which suggest either slight movement toward warming or, no change in temperature in the southeastern states.

Table 5-2: Significant positive trends in seasonal temperature in the study area.

Station Number	Season	Province	zstatistic
314496	spring	Blue Ridge	3.639
314496	summer	BlueRidge	2.336
310506	spring	BlueRidge	2.992
310506	summer	Blue Ridge	2.079
311624	spring	BlueRidge	2.401
310814	summer	BlueRidge	2.257
316001	winter	Blue Ridge	1.986
316001	spring	BlueRidge	4.953
90435	spring	Piedmont	2.694
90969	summer	Piedmont	3.529
91982	spring	Piedmont	2.995
92485	fall	Piedmont	3.862
92485	summer	Piedmont	2.017
93271	spring	Piedmont	2.086
93271	summer	Piedmont	2.43
98535	summer	Piedmont	2.07
99517	summer	Piedmont	2.522

Note: z- critical = 1.96.

5.2 Rainfall in the Study Area

The results of MK analyses (using 95% confidence level) indicate significant increase in the long-term annual rainfall at some of the stations over the Blue Ridge province whereas; the analyses show no significant trend in annual rainfall data in the Piedmont province (Table 5-3).

The annual precipitation trends is increased in the five stations located in the Blue Ridge province show the significant increase (using 95% confidence level) in the annual rainfall (Table 5-3). Some of the stations show significant positive trend in seasonal rainfall in the Blue Ridge province (Table 5-4). Significant increases in summer and spring rainfall were observed at some of the stations in the Blue Ridge and the Piedmont provinces. This may be associated with the increase in temperature during the spring and summer seasons as suggested by the MK temperature analysis (Table 5-1 and Table 5-2). The other possible cause may be middle troposphere troughing as Diem (2006), found strong correlation of increased summer precipitation with increased occurrences of midtropospheric troughs in the southeastern United States.

The increased in annual precipitation over the Blue Ridge may be also associated with combination of increase in tropical cyclones during the warm season (Knight and Davis, 2008) and orographic uplift. As much as 15% of the rainfall during the warm season in the North Carolina can be attributed to tropical cyclones .This result is consistent with the study done by Karl and Knight (1998), which suggests that precipitation amount is increasing across the United States and precipitation derived from heavy precipitation events is increasing (Karl and Knight, 1998). In North Carolina, heavy precipitation events are generally associated with local thunderstorms during the spring and summer months (Boyles and Raman, 2003).he increase in frequency of tropical storms correlates strongly with the rise in North Atlantic sea surface

temperature (Andre et al, 2008). However, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4) reported no clear global trend in the frequency of tropical cyclones. The summary result of seasonal (significant positive) and annual trend found in the study area using the MK analysis for rainfall data are given in Tables 5-3 (significant trend in bold texts), and Table 5-4.

Table 5-3: Annual rainfall trend found in the study area.

Station#	Parameter	Province	Range of Years	n (years)	Zstatistic
318694	Rainfall	Blue Ridge	1949-2006	58	**2.737**
316001	Rainfall		1949-2006	58	**4.454**
319147	Rainfall		1949-2006	58	**2.713**
318744	Rainfall		1949-2006	58	**3.756**
91982	Rainfall		1944-2006	63	**2.367**
310184	Rainfall		1948-2006	59	1.838
310506	Rainfall		1948-2006	59	0.072
310901	Rainfall		1948-2006	59	1.785
311624	Rainfall		1948-2006	59	0.046
312200	Rainfall		1948-2006	59	0.608
313976	Rainfall		1949-2006	58	1.436
314055	Rainfall		1948-2006	59	1.916
314496	Rainfall		1949-2006	58	0.443
315356	Rainfall		1949-2006	58	1.006
316805	Rainfall		1949-2006	58	1.818
99157	Rainfall	Piedmont	1948-2006	59	1.001
95988	Rainfall		1948-2006	59	0.719
92318	Rainfall		1948-2006	59	0.896
92006	Rainfall		1948-2006	59	0.386
96407	Rainfall		1948-2006	59	1.210
90444	Rainfall		1956-2006	50	1.263
90451	Rainfall		1944-2006	63	0.101
99291	Rainfall		1944-2006	63	0.231
93271	Rainfall		1944-2006	63	1.441
98535	Rainfall		1944-2006	63	1.216

Note: z- critical = 1.96.

Table 5-4: Significant positive trend found in seasonal rainfall in the study area.

Station Number	Season	Province	zstatistic
319147	summer	BlueRidge	2.965
314055	winter	BlueRidge	2.287
312200	summer	BlueRidge	2.047
312102	winter	BlueRidge	1.972
310506	spring	BlueRidge	2.455
98535	spring	Piedmont	2.478
96407	spring	Piedmont	2.027
93271	winter	Piedmont	2.091
92485	fall	Piedmont	2.962
92485	spring	Piedmont	3.034
90435	summer	Piedmont	3.211
90435	summer	Piedmont	3.211

5.3 Stream Runoff in the Study Area

The MK analyses (using 95% confidence level) show no significant trend for a long-term annual runoff at the river basins of the Blue Ridge and Piedmont provinces (Table 5-5) except at a very few stations located in the Chattahoochee and Ocmulgee River Basins of the Piedmont province (Table 5-5). Trends in seasonal patterns of runoff in the Blue Ridge and Piedmont 30exhibited variations in the data. No significant trend was observed for most of the stations in the study area. A very few stations showing significant trend for seasonal (summer and fall) runoff are given in Table 5-6. The increase in runoff during summer and fall may be associated with increase in temperature and rainfall during that season. In winter months, there seem to be

an increased runoff in the northern part of the Piedmont province; however, there was not much change in temperature and rainfall in that season.

The Peachtree creek, one of the urban stations located in the Chattahoochee River Basin (Figure 5-1) showed significant positive trend in runoff data for all seasons except for the fall. The reason for significant positive trend in seasonal runoffs in the Peachtree Creek may be high urbanization; since it has been urbanized for a long time than the other urban basins such as Big Creek, Chattahoochee River near Norcross and Atlanta. These stations showed no significant trend on annual and seasonal runoff value. The other reason may be due to non-uniform land use change across the different urban watershed. Peter and Rose (2001) analyzed the runoff in urbanized and less urbanized basin and found that non-uniform change in population and associated land use results lead to the increase in annual runoff in more urbanized basin than in the less urbanized basin.

Stream runoff are mainly determined by a watershed geology, climate and topography but may also be affected by many factors (Evett, 1994) and urbanization is one of them. The metro Atlanta region has experienced explosive growth over last 50 years (USGS, 2008). Urbanization is a pervasive and rapidly growing form of land use change (Paul and Meyer, 2001). Urbanization leads to a net increase in total runoff from the land surface due to the areas with impermeable surfaces (e.g., concrete, asphalt etc).

In addition, water might have moved away efficiently from the urban areas through storm-water drainages and sewers. A study done by Peter and Rose (2001) found that the higher population density increase in the Peachtree Creek watershed results in high annual runoff whereas less annual runoff was recorded in the less urbanized Big Creek and the Sweetwater Creek watersheds.

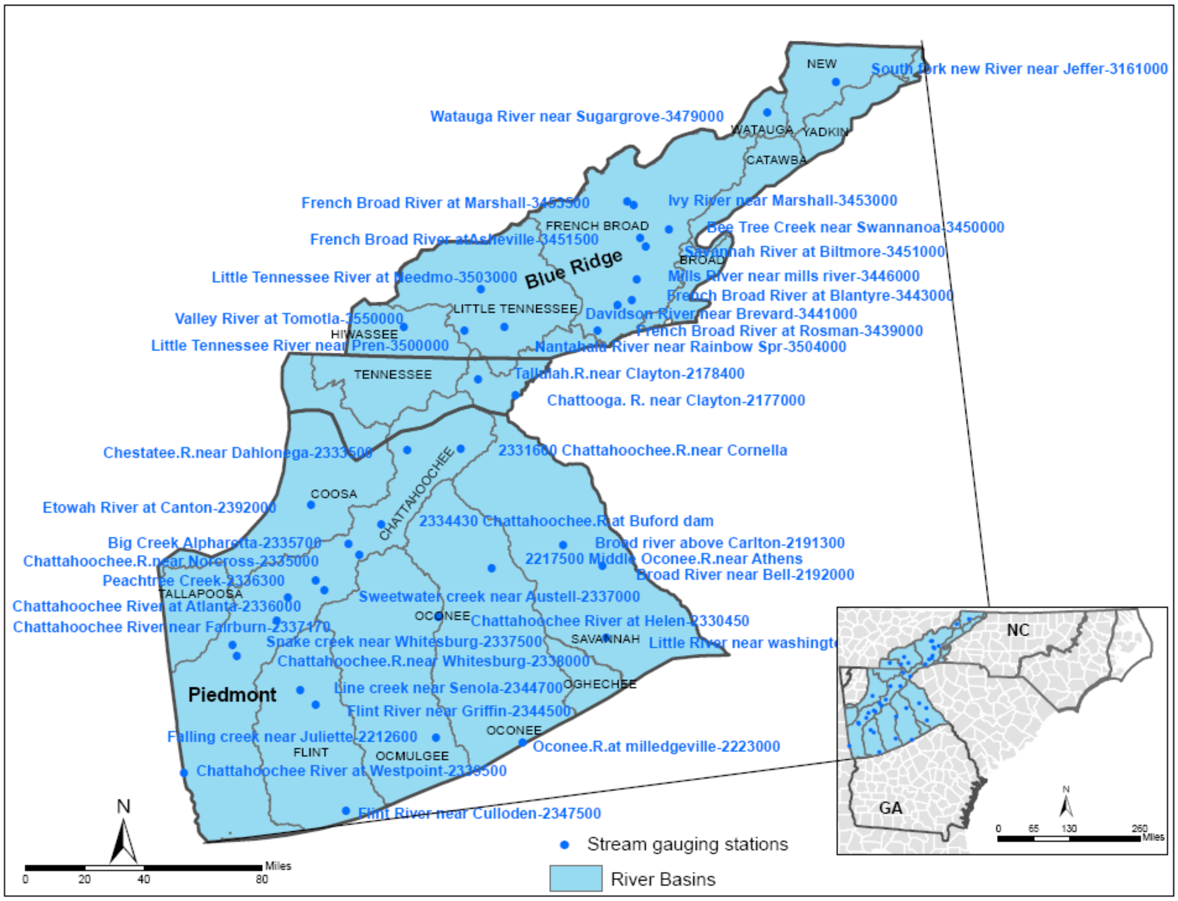

Figure 5-1: River basins and runoff monitoring stations in the study area.

The summary results of annual runoff trend and seasonal runoff trend (significant positive) in the study area using Mann Kendal analysis are given in Table 5-5, and Table 5-6 respectively. None of the stations in the Blue Ridge (urban and non-urban) shows a significant trend in annual runoff. However, most of the stations in the Blue Ridge show significant increase in runoff in the summer months. One of reasons may be due to increase in rainfall in the Blue Ridge during summer months. The other reason could be due to loss of small amount of water to evapotranspiration in low temperatures at relatively high elevations (Rose, 2008). Generally, the long-term trends for annual runoff indicate no consistent statistically significant trends from the year 1948 to 2006 in the study area, which also concurs the study of rainfall-runoff trends in the southeastern USA, done by Rose (2008).

Table 5-5: Annual runoff trend found in the study area.

Watershed	Station#	Region	Year Range	n (years)	Zstatistic
Savannah	2193500	Piedmont	1950-2006	57	1.115
Flint	2192000		1944-2006	63	0.172
Attamaha	2217500		1944-2006	63	0.658
Altamaha	2223000		1953-2006	54	0.343
Chattahoochee	2333500		1944-2006	63	0.130
Chattahoochee	2334430		1956-2006	51	0.902
Chattahoochee	2335000		1957-2006	50	0.427
Chattahoochee	2335700		1961-2006	42	0.124
Chattahoochee	2336000		1956-2006	51	0.560
Chattahoochee	2336300		1959-2006	48	1.431
Chattahoochee	2337000		1944-2006	63	0.255
Chattahoochee	2337500		1955-2006	52	1.065
Chattahoochee	2331600		1958-2006	49	1
Chattahoochee	2337170		1965-2006	42	**2.991**
Chattahoochee	2338000		1966-2006	41	**3.055**
Flint	2344700		1961-2006	42	0.282
Flint	2347500		1944-2006	67	0.157
Coosa	2392000		1944-2006	63	0.148
Flint	2344500		1944-2006	63	0.119
Ocmulgee	2212600		1965-2006	42	**3.078**
Kanawha	3161000	Blue Ridge	1944-2006	63	0.650
Tennessee	3439000		1944-2006	63	1.821
Tennessee	3441000		1947-2006	60	0.663
Tennessee	3443000		1944-2006	63	1.168
Tennessee	3446000		1944-2006	63	0.338
Tennessee	3450000		1944-2006	60	0.950
Tennessee	3451000		1944-2006	63	0.012
Tennessee	3451500		1944-2006	63	0.575
Tennessee	3453500		1944-2006	63	0.943
Tennessee	3479000		1944-2006	63	1.062
Tennessee	3500000		1945-2006	62	0.431
Tennessee	3503000		1941-2006	66	0.244
Tennessee	3504000		1944-2006	63	1.287
Tennessee	3550000		1944-2006	63	0.386

Note: z- critical = 1.96.

Table 5-6: Trends of seasonal runoff at different stations in the study area.

Watershed	Station #	Season	Parameter	Province	zstatistics
Savannah	2193500	summer	Runoff	Piedmont	2.308
Chattahoochee	2212600	winter	Runoff	Piedmont	2.187
Chattahoochee	2212600	summer	Runoff	Piedmont	4.071
Chattahoochee	2331600	summer	Runoff	Piedmont	2.491
Chattahoochee	2333500	summer	Runoff	Piedmont	2.414
Chattahoochee	2333500	fall	Runoff	Piedmont	2.568
Chattahoochee	2334430	fall	Runoff	Piedmont	2.391
Chattahoochee	2336000	winter	Runoff	Piedmont	2.391
Chattahoochee	2336300	winter	Runoff	Piedmont	3.084
Chattahoochee	2336300	spring	Runoff	Piedmont	2.302
Chattahoochee	2336300	summer	Runoff	Piedmont	2.373
Chattahoochee	2337500	winter	Runoff	Piedmont	2.117
Chattahoochee	2337500	fall	Runoff	Piedmont	2.209
Tennessee	3439000	summer	Runoff	Blue Ridge	2.583
Tennessee	3441000	summer	Runoff	Blue Ridge	2.208
Tennessee	3443000	summer	Runoff	Blue Ridge	2.125
Tennessee	3451000	summer	Runoff	Blue Ridge	2.094
Tennessee	3451500	summer	Runoff	Blue Ridge	2.975
Tennessee	3453500	summer	Runoff	Blue Ridge	2.622
Tennessee	3550000	summer	Runoff	Blue Ridge	2.688

Note: z- critical = 1.96.

5.4 Runoff-rainfall Ratio

The runoff-rainfall ratio is defined as the ratio of runoff to precipitation (Chang, 2007). It was assumed that annual runoff-rainfall ratio is closely associated with the percentage of impervious land cover and the ratio is lowest within the least urbanized watershed than it is in urbanized watershed (Chang, 2007). However, this seems to be just reversed in this study. Stream runoff data for 10 stream gauging stations from the USGS were calculated to obtain the runoff value (see equation 1) for the study area. The rainfall stations that fall within the 10 miles of the gauging stations were used to calculate the rainfall-runoff ratio. Since the rainfall and runoff stations were not in the same location, 10 mile buffer zone was created using GIS for the calculation (Figure 5-2) considering rainfall values vary from place to place and more than 10 miles might not reflect the true result.

The streams in the Blue Ridge province showed the higher ratio than the streams in the Piedmont province. The MK analyses show no significant annual trend for the Piedmont province. However, the analysis show significant trend some stations located in the Blue Ridge province (Table 5-7) where an increasing trend in runoff-rainfall ratio were observed. This result is similar to the recent analysis done by Rose (2008), which suggests that the trend of rainfall-runoff ratio is high in the Blue Ridge than in Piedmont and Coastal Plain provinces, indicating that over 80% of the total rainfall was converted to runoff. The observed high runoff-rainfall ratios in the Blue Ridge province indicate that only a relatively small percentage of water is lost to evapotranspiration in the high-relief catchments due to low temperatures (Rose, 2008). The average annual temperature of the Blue Ridge is lower than the Piedmont province (Appendix-A). The annual runoff-rainfall ratios show significant positive trends for the two stations in the Blue Ridge are given below in the Table 5-7.

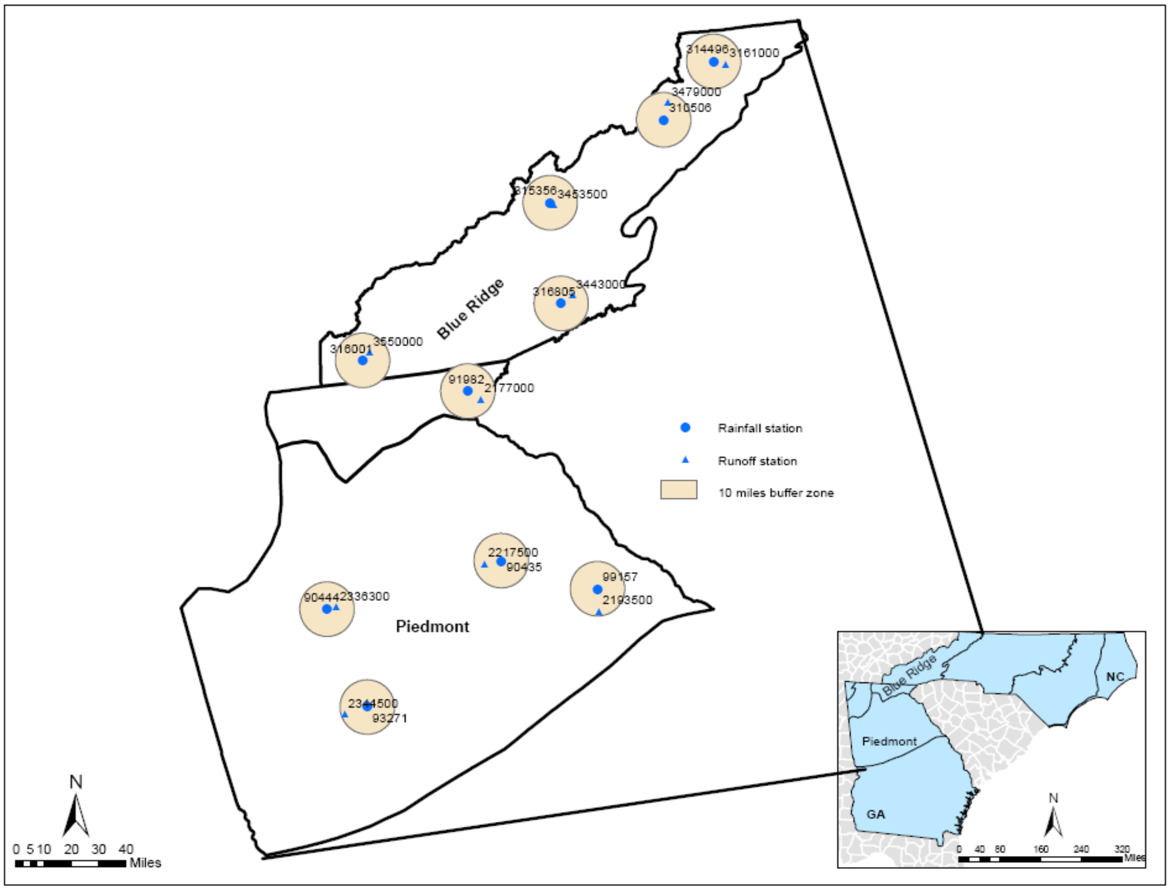

Figure 5-2: Runoff-rainfall ratio at different stations in the study area.

Table 5-7: Annual trend of runoff-rainfall ratio found in the study area.

No	Station Number		Range of years	n(years)	Province	zstatistics
1	3479000/310506	Runoff-rainfall ratio	1949-2006	57	BlueRidge	**2.039**
2	3550000/316001		1949-2006	57	BlueRidge	**2.041**
3	3453500/315356		1949-2006	57	BlueRidge	0.939
4	3443000/316805		1948-2006	58	BlueRidge	0.765
5	3161000/314496		1949-2006	57	BlueRidge	0.711
6	2336300/90444		1959-2006	47	Piedmont	0.391
7	2344500/93271		1944-2006	62	Piedmont	0.320
8	2193500/99157		1950-2005	55	Piedmont	1.140
9	2217500-90435		1948-2006	58	Piedmont	0.137
10	2177000/91982		1944-2006	62	Piedmont	0.340

Note: z- critical = 1.96.

5.5 Linear Trend and Spatial Analysis

The Moran's I analysis for spatial autocorrelation for temperature and rainfall showed significant spatial autocorrelation in the data whereas the runoff data showed no significant spatial autocorrelation. Therefore, using linear trends, the slopes of temperature and rainfall were calculated (Appendix A-1, A-2 and B-1, Appendix B-2) at each station. The calculated slopes were spatially analyzed for the regional changes in the Piedmont and Blue Ridge provinces (Figure 5-3, 5-4, 5-6 and Figure 5-7). Positive and negative slope numbers signify a linear increase and linear decrease in the parameter over time respectively.

5.5.1 Temperature

Annual and seasonal mean averages of temperature trends were analyzed. Average annual temperature shows some spots of increasing temperature in the Blue Ridge and Piedmont as well (Figure 5-3). These slope values are not significant enough to make decisions whether the trend is increasing or decreasing in both the Blue Ridge and Piedmont regions. Average seasonal temperatures for the winter season are given in Figure 5-4.

Small positive slope values are evident in the eastern Piedmont and some parts of the Blue Ridge in the study area. Similar to winter season, fall season shows a positive slope values throughout the study area (Appendix-D).Similarly, spring season shows a negative slope values throughout the study area (Figure 5.4, station number 91982 and 316001). Winter temperatures seem to be more positive in the Blue Ridge, which also concurs with the result obtained from the Mann-Kendall test (Table 5-3, station number 91982 and 316001). However, the slopes are not significantly greater than zero. The positive slopes throughout the study area during the fall season suggest that seasonal temperatures are slightly increasing (Figure 5-4, Appendix-D), which is somewhat similar to the recent analysis done by Soule, 2005.

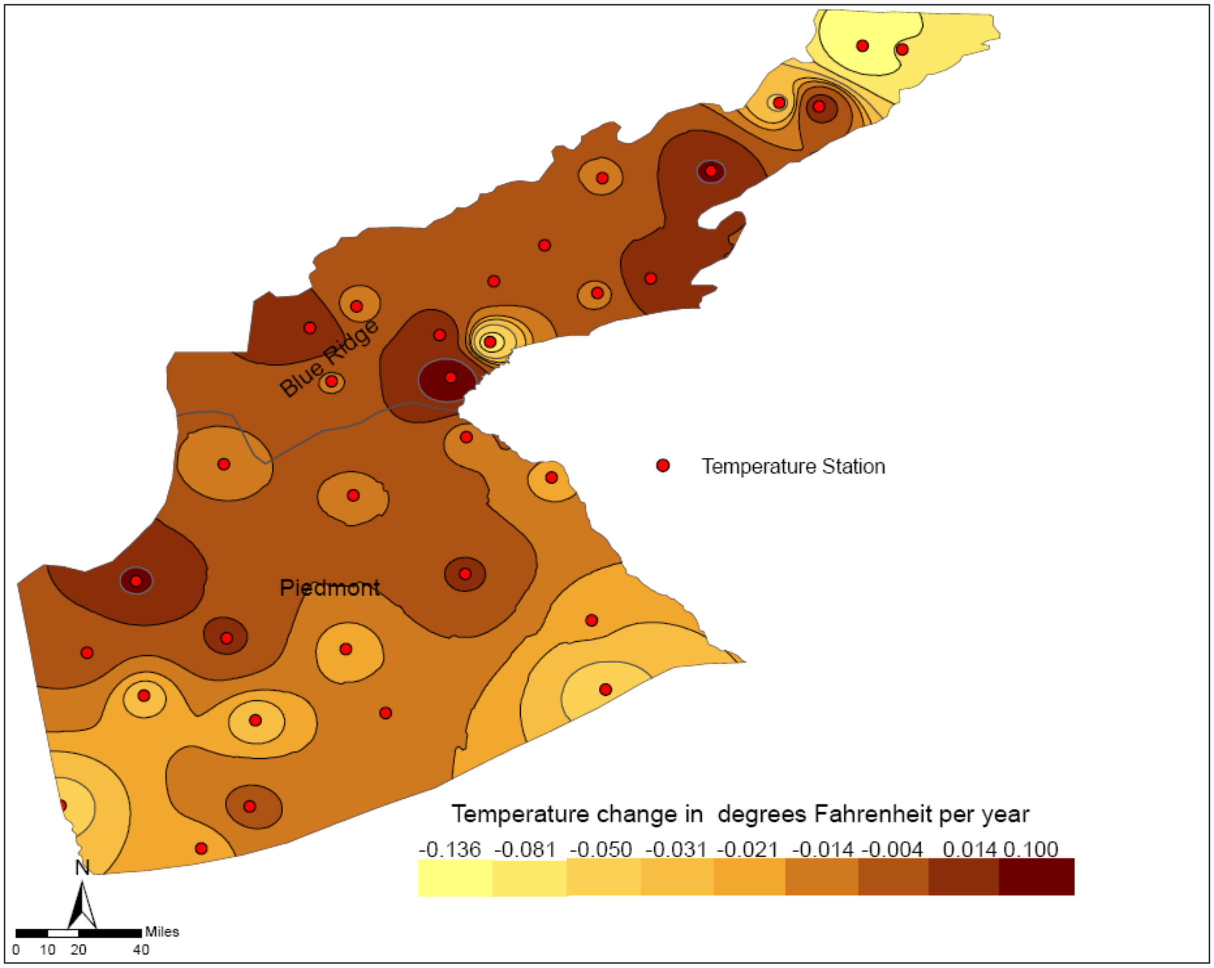

Figure 5-3: Average annual temperature based on the period 1948-2006.

In this study, it is found that average seasonal temperature pattern for the summer months are similar to that for the fall season (Figure 5-4). During these seasons, more widespread positive slopes are observed in the most part of the southern Blue Ridge whereas, more negative slopes are observed towards southern part of the Piedmont in the study area. The less than zero of slope values of average annual temperature (Figure 5-3, Appendix-D) suggest that there is no significant change in annual temperature in the study area from the period between 1948 and 2006. These very small values of positive and negative slopes for all the seasons are not statistically significant to conclude whether the temperature trend is increasing or decreasing in the study area.

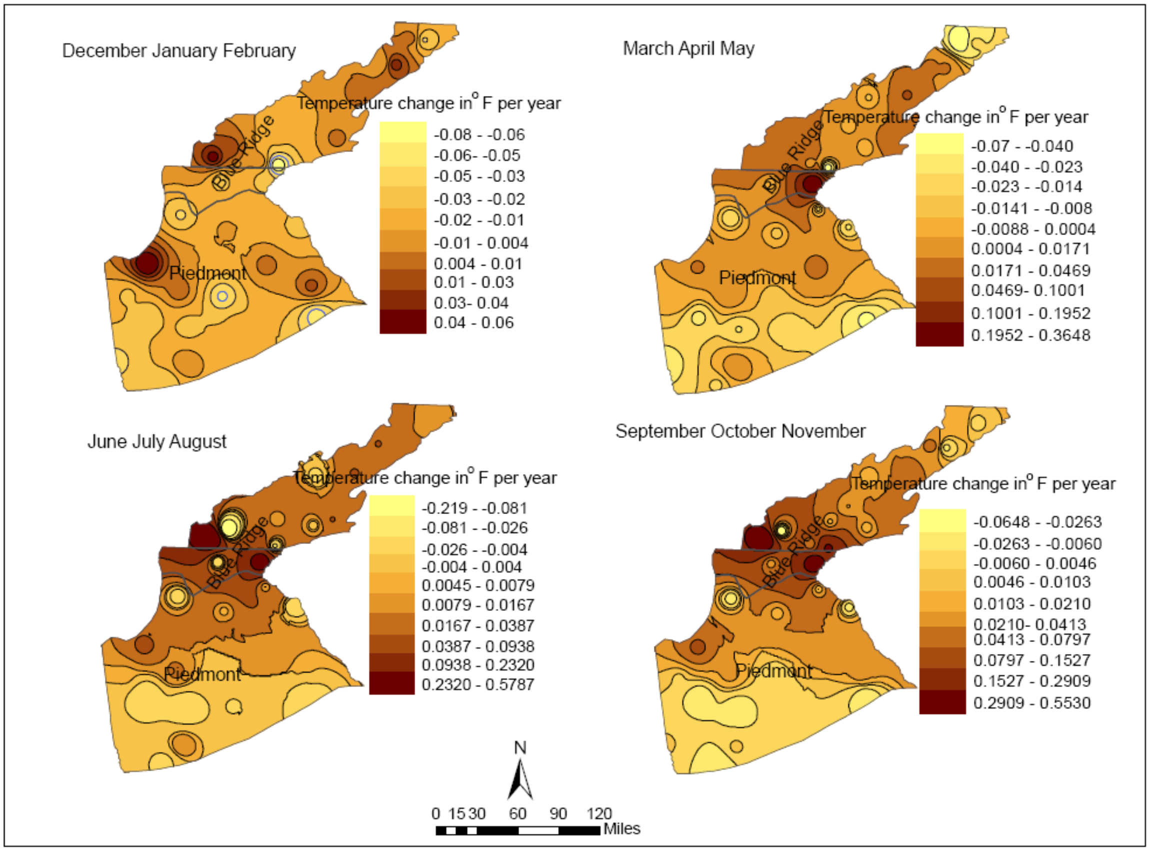

Figure 5-4: Mean seasonal temperature based on the period 1948-2006.

The 10-year average temperature from period of 1944 to 2004 for the study area also shows decrease in temperature throughout the study area except at some stations. The data shows that the temperature values in 2006 are not significantly different, (i.e., not warmer) than they are in 1950's (Appendix G-1, G-2) at most of the stations of the study area and only the seasonal temperatures are fluctuating, (i.e., going towards slight warming).

More positive slopes can be seen in the Blue Ridge province. However, the slopes are very close to zero. The reason could be associated with land use/land cover change that occurs during different seasons which changes how much solar radiation the land reflects and absorbs (IPCC, 2007). Urbanization often contributes to changes in temperature. Again, these very small values of positive and negative slopes for all the seasons are not statistically significant to conclude whether the temperature trend is increasing or decreasing.

5.5.2 Rainfall

The annual rainfall trend in both Blue Ridge and Piedmont shows no linear increase or decrease of rainfall in the Blue Ridge and Piedmont of the study area (Figure 5-6). The positive and negative slopes are also given in Figure 5-5 and Appendix-B.

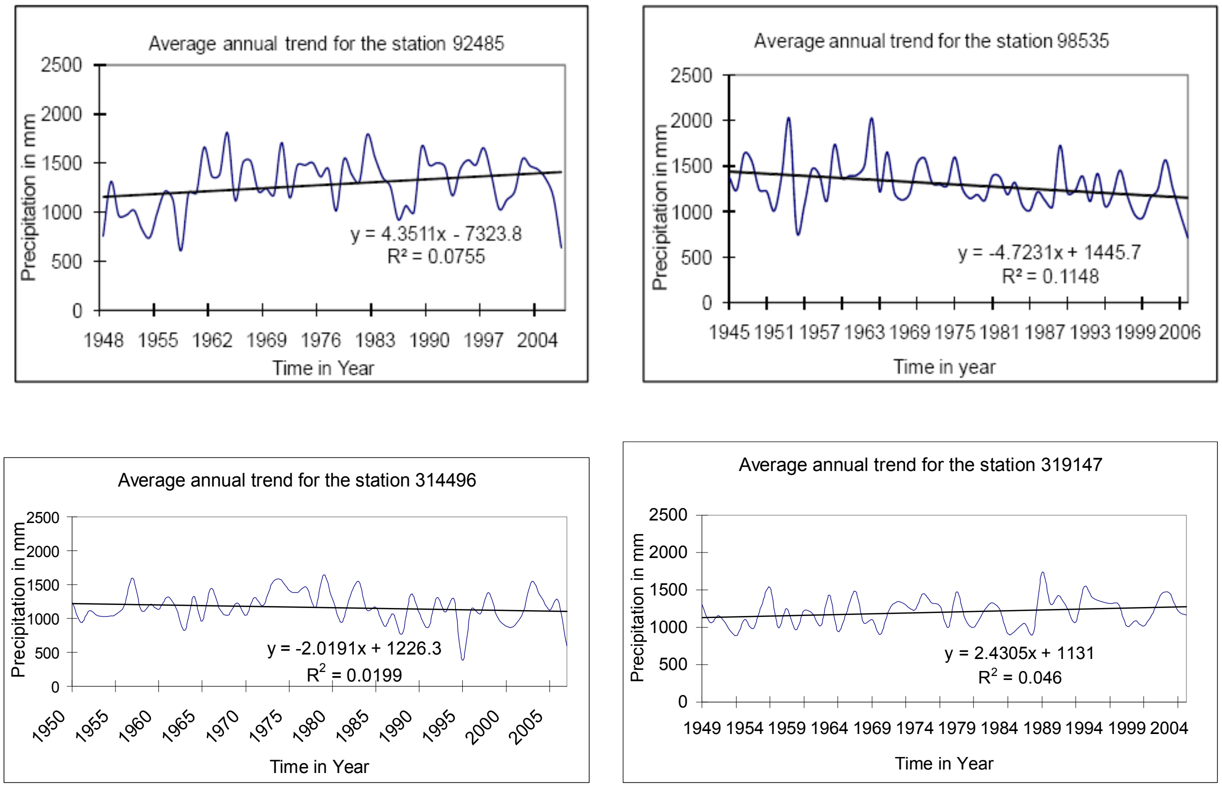

Figure 5-5: Linear slopes of positive and negative trend for annual rainfall in the Piedmont.

The interpolated linear slopes for the winter season (Figure 5-7) shows positive slope for some parts of Blue Ridge (stations no 314055, 312102), which is similar to the result obtained from the Mann-Kendall test (Table 5-4). The annual slopes of Blue Ridge region are not significantly greater than zero. The winter slopes are negative toward Piedmont region. This relates to an decrease in winter precipitation over the 56-year period for the month of December, January, and February in the Piedmont. However, this result is not statistically significant to draw the conclusion that winter precipitation is decreasing in the Piedmont when tested with Mann-Kendall analysis.

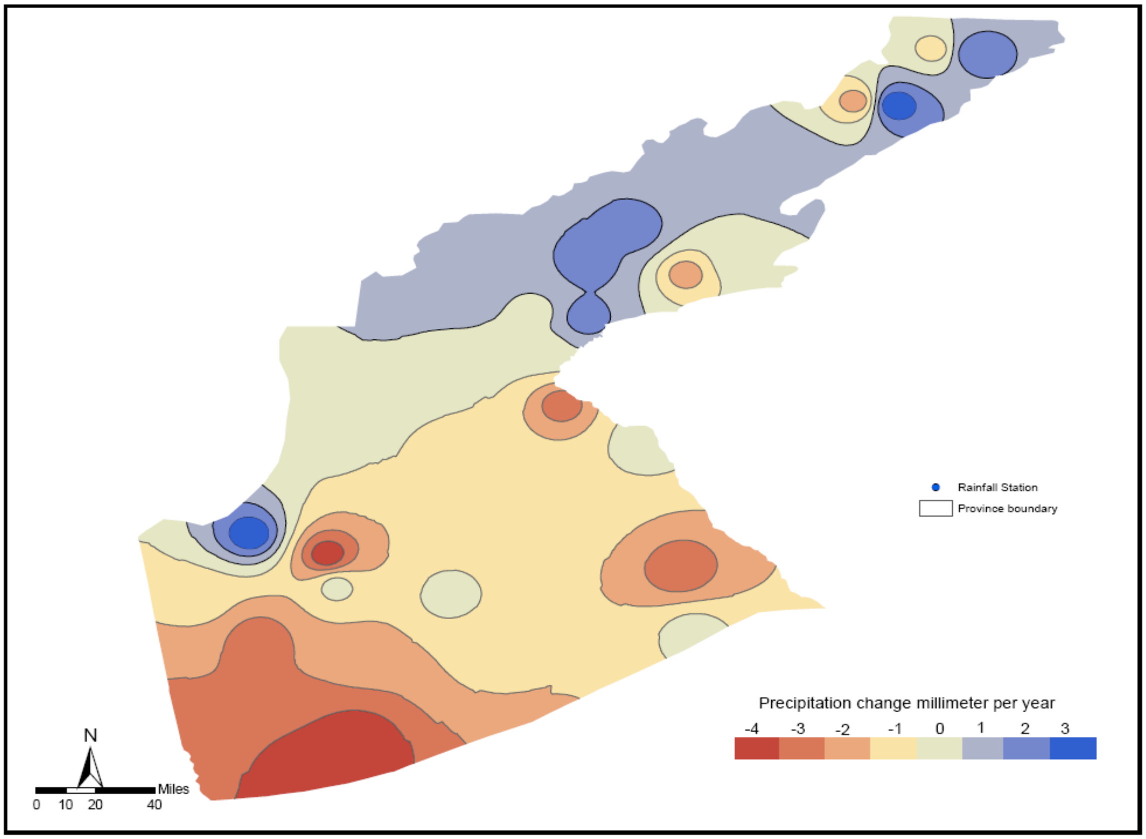

Figure 5-6: Average annual rainfall based on the period 1948-2006.

The interpolated surface slope for spring season shows negative values for the most of the Blue Ridge and Piedmont (Figure 5-7). However, comparatively prominent negative slopes can be seen for Piedmont province than for the Blue Ridge province (Figure 5-7). The summer slope for the study area shows widespread positive slopes covering most of the study area.

However, the overall magnitude of slope is not great since the slope values are nearly zero. Some of the positive slopes for the stations (e.g., station no; 90435, 312200 and 319147) are statistically significant and others are not according to the result from the Mann-Kendall test (Table 5-4). At the same time, negative slopes can be seen in parts of the southwestern Piedmont. The winter slopes widespread negative values for Piedmont than the Blue Ridge. However, the slopes values are nearly zero. The slopes for the fall season (Figure 5-7), also show widespread positive values.

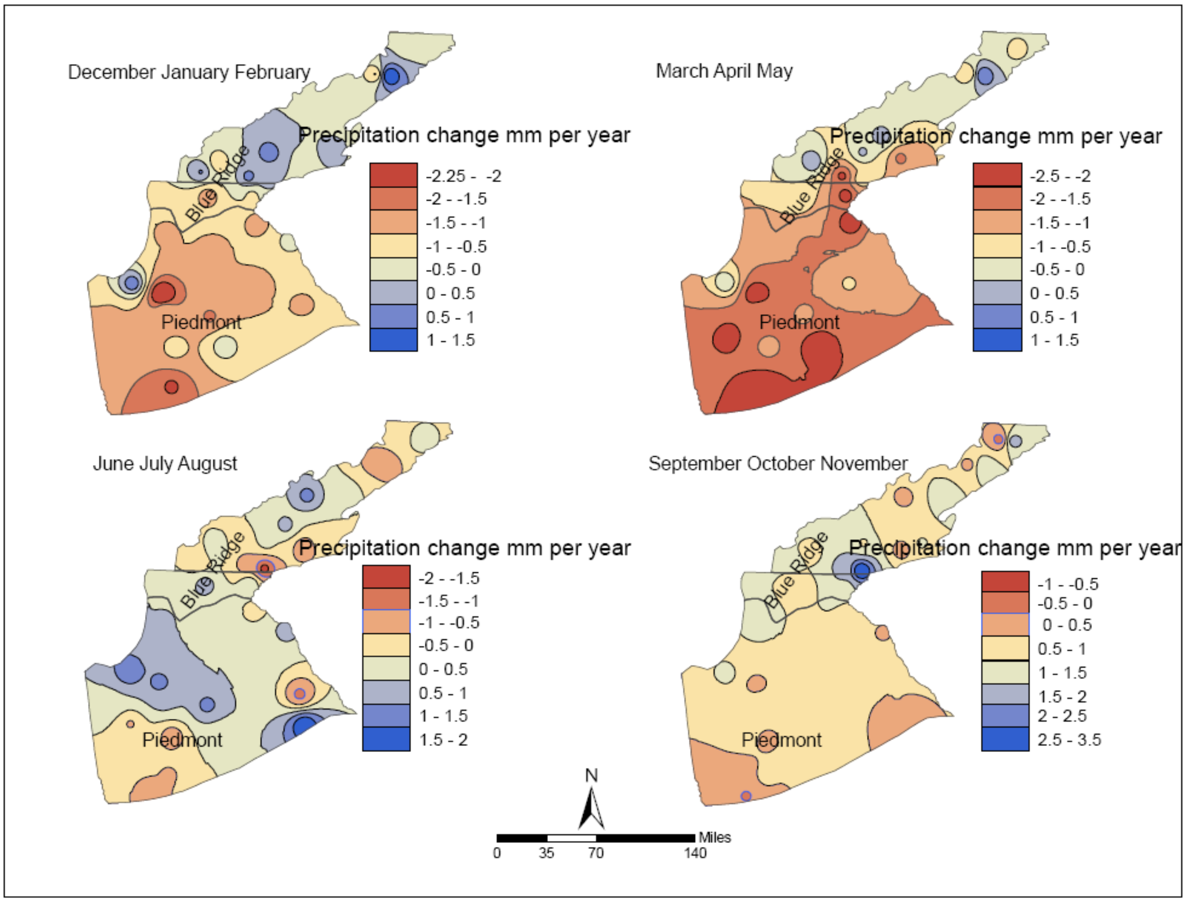

Figure 5-7: Mean seasonal rainfall based on the period 1948-2006.

Similar to temperature slope, rainfall has slightly increased in summer and fall seasons (Figure 5-5b, Appendix-E). These seasons show relatively increasing trends when compared to other seasons. The possible reason may be middle troposphere troughing, which is significantly correlated with summer precipitation in the southeastern United States (Diem, 2006). The other reasons could be due to increase in temperature and coastal storm activities, which are greatest during the summer and fall seasons from where the study area can get affected. There could be other physical mechanisms responsible for this slight increase in rainfall.

The 10-year average (1948-2006) of annual rainfall in both Piedmont and Blue Ridge show highest increased precipitation during 1980's (Appendix H-1, H-2). The small increase in annual rainfall was observed in most of the stations in the Blue Ridge in 2006 compare to 1954,

which is not consistent with the temperature recorded in the same period, where very slight cooling was observed for most of the stations.

5.5.3 Stream Runoff

Figure 5-8 compares the temporal variation in runoff for the urban streams in the Piedmont province. Different runoff slopes for Piedmont province is given in Appendix C-1,C-2. High degree of synchronicity was observed for runoff with respect to time in the study area as noted earlier by Rose (2008). The annual runoff trends for the urban streams in the Piedmont are given Figure 5-8.

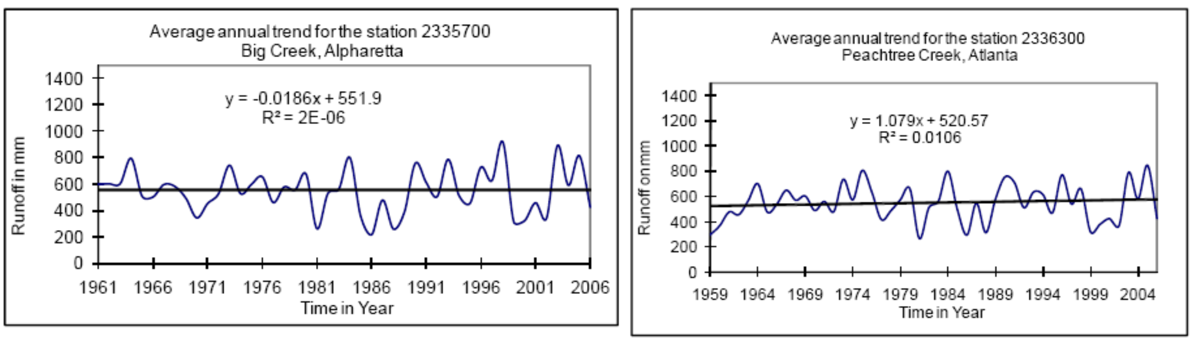

Figure 5-8: Annual runoff trend for the urban streams in the Piedmont province.

Similar to the Mann-Kendall analyses, the slope data for summer and fall seasons show widespread positive values for the northern Blue Ridge and southern Piedmont regions (Appendix-F). The reason may be associated with the slight increase in temperature, which could eventually lead to increase in evapotranspiration and precipitation during those seasons (Appendix-F). Widespread negative slopes are observed in the study area during winter and spring seasons, however the slope values are not statistically significant when tested with the Mann-Kendall test. This may be associated with slightly negative slopes in temperature and precipitation during those seasons (Appendix-D, Appendix-E). Reversed to rainfall data, the 10-year runoff average in the study area show decrease in runoff in 2006 than in 1954 (Appendix I-1, I-2).

5.6 Stream Runoff- rainfall Relationships

The same stations and selection criterion for the runoff-rainfall ratio was used for the correlation test. The runoff-rainfall relationship developed with Spreadsheet Analyst indicates that stream runoff of the Blue Ridge and Piedmont moderately correlated to rainfall (Table 5-8). Correlation coefficients between annual precipitation and annual stream runoff ranged from 0.04 to 0.55 (Table 5-8) with an average value of 0.4. Correlation of rainfall-runoff in the urban, non-urban area shows the similar result of medium correlation. The correlation analysis for runoff and rainfall show an average correlation value of 0.4, which signifies that the rainfall and runoff in the study area are moderately correlated

Table 5-8: Correlation value for annual runoff- rainfall in the study area.

No	Station Number	R-value	Name of the River
1	2177000/91982	0.4697	Chattooga River near Clayton
2	2193500/99157	0.3354	Little River near washington
3	2217500/90435	0.5009	Middle Oconee River near Athens
4	2336300/90444	0.4021	Chattahoochee River at Atlanta
5	2344500/93271	0.2883	Flint River near Griffin
6	316100/314496	0.4454	South fork new River near Jeffer
7	3443000/316805	0.4738	Davidson River near Brevard
8	3453500/315356	0.2970	French Broad River at Marshall
9	3479000/310506	0.0454	Watauga River near Sugargrove
10	03550000/316001	0.5534	Valley River at Tomotla

6. SUMMARY AND CONCLUSIONS

6.1 Summary and Conclusions

Temperature, rainfall, and runoff trends were analyzed for a 58-year period between 1948 and 2006 in the Piedmont and Blue Ridge Provinces of Georgia and North Carolina of southeastern United States. Average annual precipitation of some of the stations in the Blue Ridge show significant increase in rainfall over the study period. The data also show slight

increase in summer and winter rainfall over the study period. Increase in annual rainfall in the Blue Ridge and increase in summer and winter rainfall at some of the stations in the entire study area over the study period indicate that mountain basins are environmentally vulnerable in terms of climate change since watershed properties of such basins promote fast runoff and their vulnerability to temperature changes effects rainfall, snowfall and, snow and ice melt (Birsan et al, 2005).

The observed trends in stream runoff are not entirely consistent with the changes in climate. Unlike the other areas noted by different authors (e.g. IPCC, 2007) which suggest upward trend in temperature for northern hemisphere, this results show that there are strong spatial variations in such trends, and there are more stations with positive annual trends than negative annual trends in the Blue Ridge of the study area. More than half of the stations in the Blue Ridge and Piedmont show negative trend of temperature during winter months (December, January, February), and positive trend for the fall season which are not statistically significant when tested using the MK analysis.

All of the streams in the urban area exhibited no significant trend except the Peachtree Creek in Atlanta. The Peachtree Creek located in the highly urbanized area showed significant positive trend for winter, spring, and summer months except the annual runoff and no negative trend was observed at all for the Peachtree Creek. This could be the result of non-uniform land cover and population change in the urban basins. It was concluded from the study that there is some support for the hypothesis that urbanization causes an increase in stream runoff over time (Peachtree Creek station) and shows that land cover change might be more important than climate change in affecting the stream flow in the highly urbanized basin. It appears more likely that most streams in both urban and non-urban area are experiencing increasing trends over time

in summer and fall seasons could be the effect of rainfall since medium correlation of 0.4 was observed for runoff and rainfall in the study area.

There is a strong spatial and seasonal structure in the trend analysis done by both the Mann-Kendall test and linear trend method. Based on the Mann-Kendall analysis of Stream runoff, rainfall, and temperature over the 58-year period (1949-2006), a few general but important, conclusions can be made as listed below;

1. The Mann-Kendall analyses shows that trends in air temperature point towards a slight increase in seasonal temperatures, summer, fall, and spring, for both Blue Ridge and Piedmont of the study area (Table 5-1, 5-2, Appendix-D). However, almost all of the stations in the study area show slight decrease in temperature during winter months (Figure 5-3, 5-4) (Appendix A-1, A-2).
2. Annual precipitation trend were significant in the Blue Ridge region for some of the stations. However, seasonal precipitation in the same study periods came out not as significant as the annual precipitation in the Blue Ridge (Table 5-3, 5-6). Positive slopes are widespread throughout the summer and fall season, this could be the reason of slight increase in temperature during the same season, which are not significant when tested with Mann-Kendall test,
3. The Mann-Kendall analyses indicate no consistent significant temporal trend for the long-term annual runoff in the study area (Table 5-5). Seasonal positive slopes were spread across the region for summer and fall season (Appendix C-1, C-2); however, the trends are not statistically significant. The most dominant changes have occurred in the summer season in the Blue Ridge region (Table 5-6). I am not able to explain stream runoff changes on the basis of changes in precipitation alone,

4. The average annual rainfall-runoff ratio trend in the Blue Ridge show higher ratio than it did in the Piedmont province (Table 5-7).
5. The rainfall-runoff relationship of average annual stream runoff with average annual precipitation show that these two parameters are moderately correlated since medium correlation of average 0.4 has been observed (Table 5-8) for the Blue Ridge and Piedmont provinces.

In general, the findings from this study, based on the Mann-Kendall analysis, suggest that there is no consistent statistically significant (using 95% confidence level) temporal trend in the runoff, rainfall, and temperature in the Blue Ridge and Piedmont provinces of the study area. In addition, the results from linear regression are also not different from Mann-Kendall analysis, which shows no consistent significant increase or decrease in rainfall and runoff with time series in the study area with some exceptions.

6.2 Implications

It is hoped that the trend analysis of hydrological parameters, rainfall, temperature, and runoff, and correlation analysis between such hydrological parameters in the Blue Ridge and Piedmont provinces will help improve our understanding of the hydrology of the southeastern United States.

The temporal trend analysis of hydrological parameter in the study will help understand the effect of climate change on rainfall runoff of southeastern United States. The findings of trend analysis of rainfall-runoff will help to understand the rainfall-runoff in different physiographic regions. The MK test on runoff trend will help understand the effect of landcover change caused by urbanization on runoff, since urban runoff showed no significant trend except at the highly urbanized Peachtree Creek station. Future research in this area can also be

benefitted from the different GIS methods that were used in this research for spatial analysis of atmospheric data.

In general, the findings of this study will have significant implication for the water resource management by implementing adaptive water resource guidelines to future changes resulting from climate and urbanization since surface water is the main source of water in the study area.

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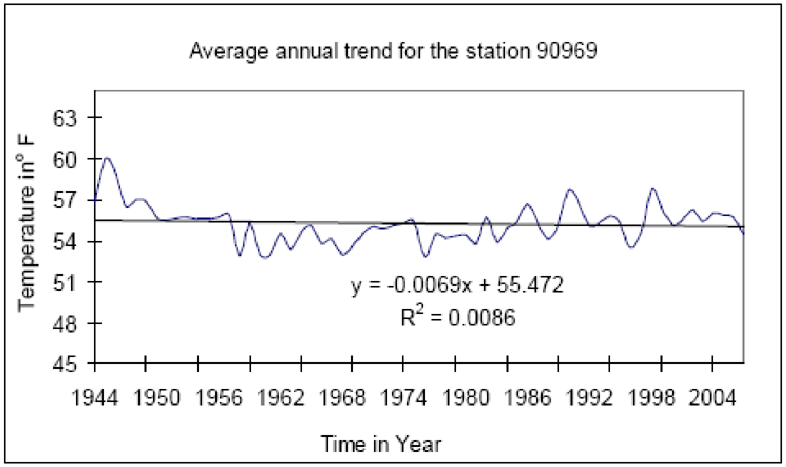
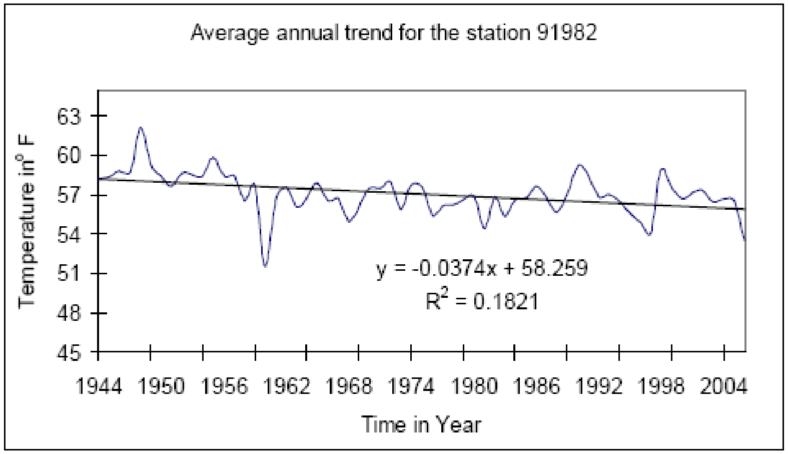
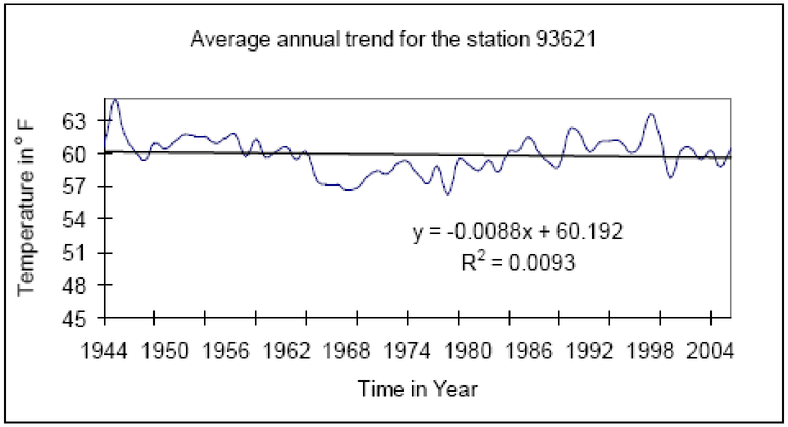
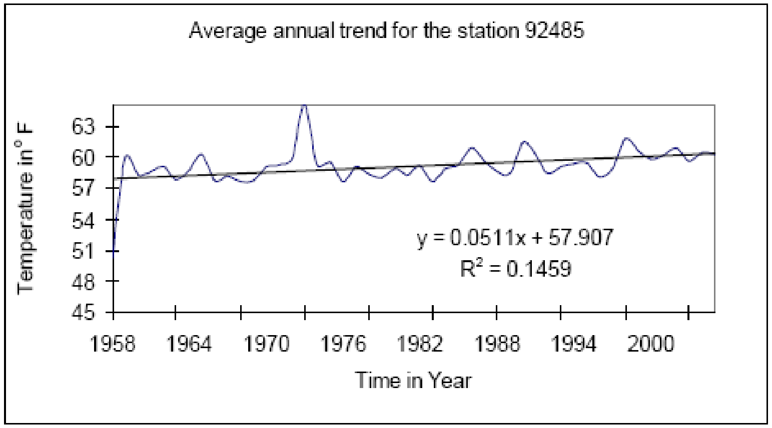
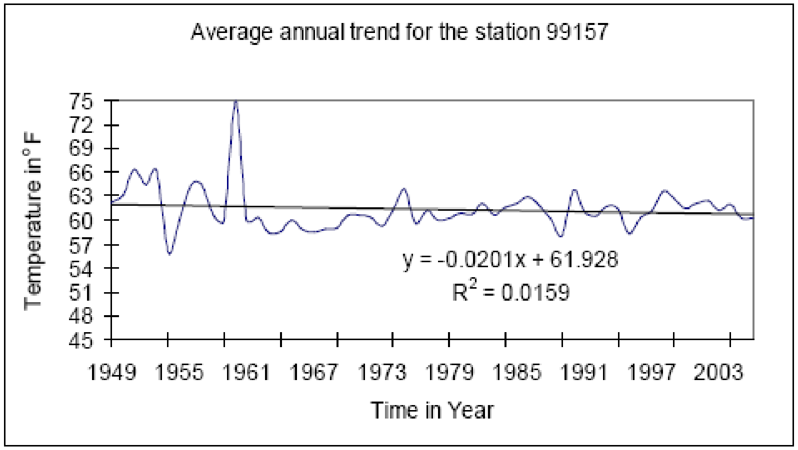
Appendix A-1: Average annual temperature trend in the Piedmont province (1948-2006).



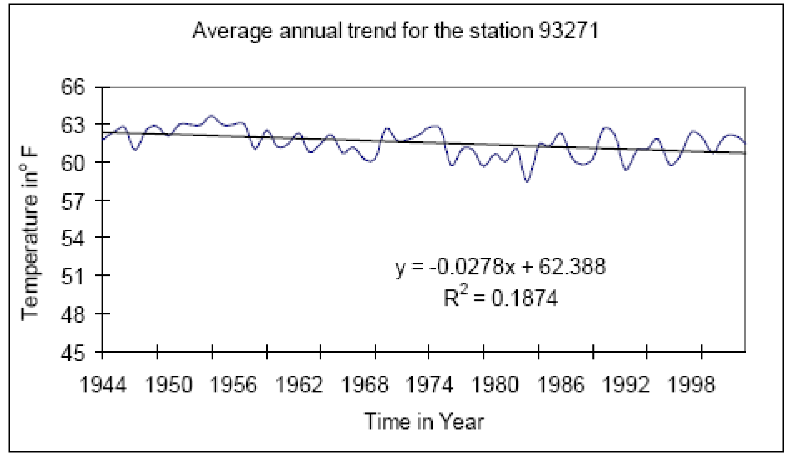




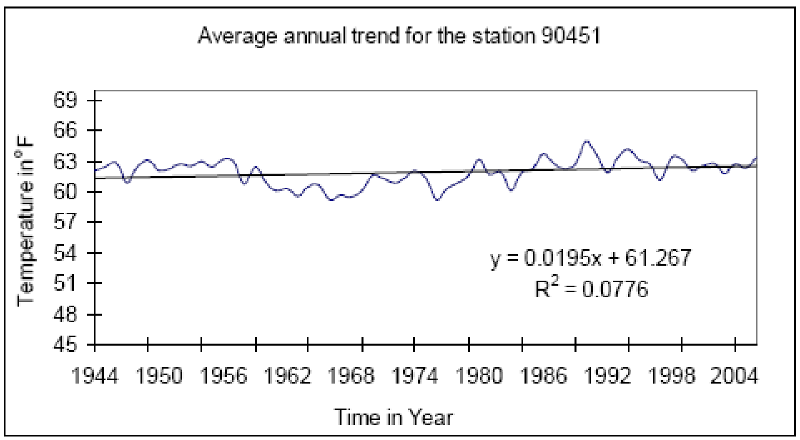




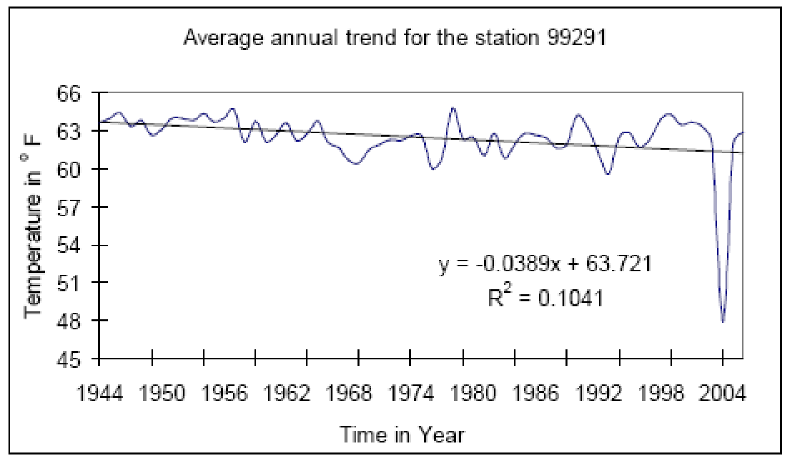
Average annual trend for the station 99157
Temperature in° F
75
72
69
66
63
60
57
54
51
48
45
1949 1955 1961 1967 1973 1979 1985 1991 1997 2003
Time in Year
y = -0.0201x + 61.928
R2 = 0.0159



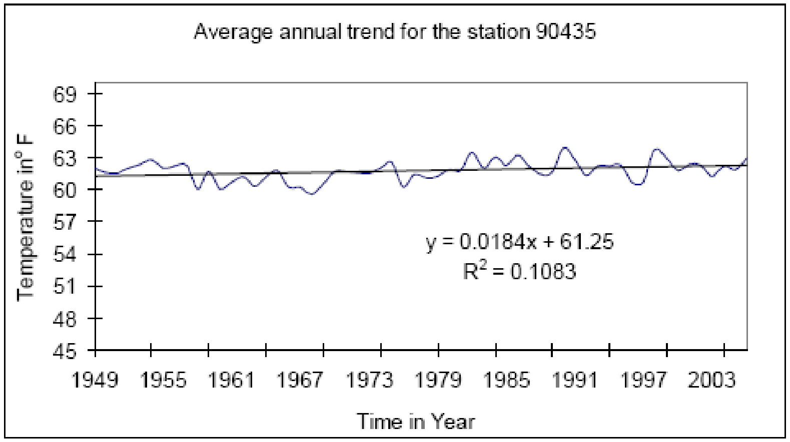
Average annual trend for the station 93271
Temperature in° F
66
63
60
57
54
51
48
45
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998
Time in Year
y = -0.0278x + 62.388
R2 = 0.1874

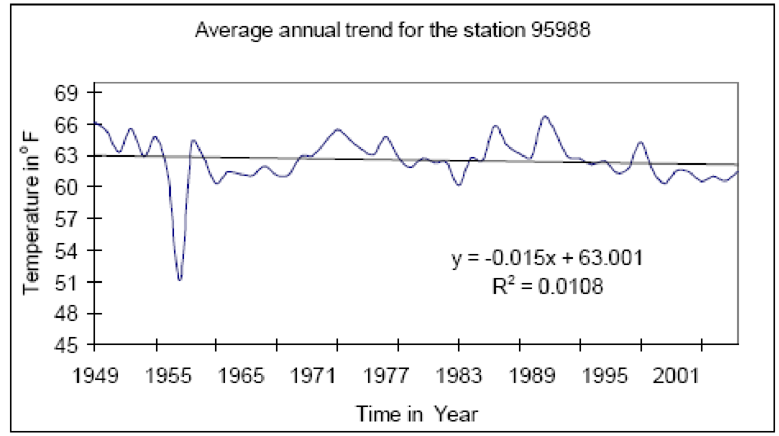


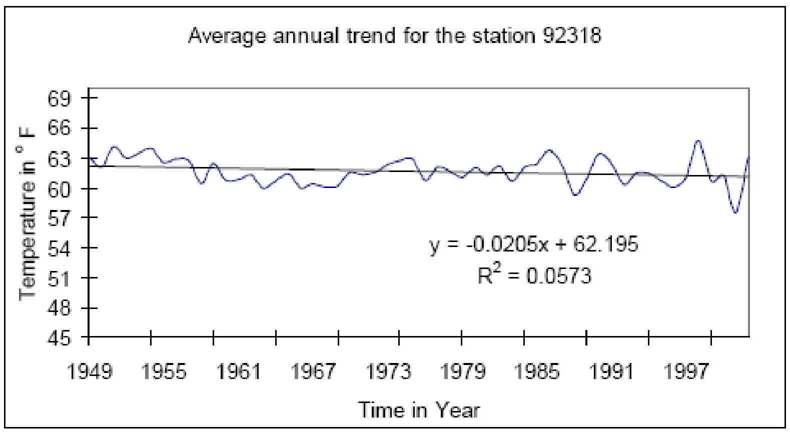
Average annual trend for the station 90451
Temperature in° F
69
66
63
60
57
54
51
48
45
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year
y = 0.0195x + 61.267
R2 = 0.0776

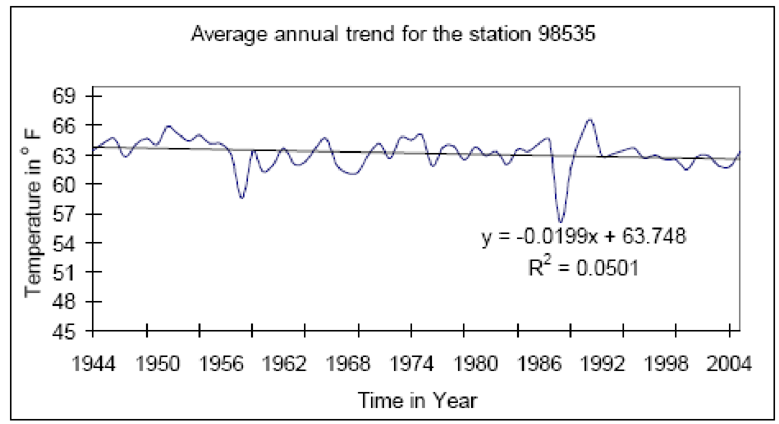


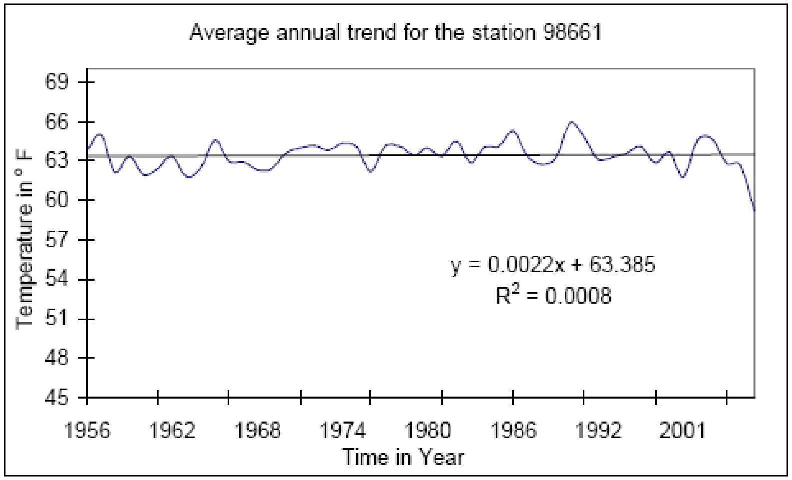
Average annual trend for the station 99291
Temperature in ° F
66
63
60
57
54
51
48
45
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year
y = -0.0389x + 63.721
R2 = 0.1041

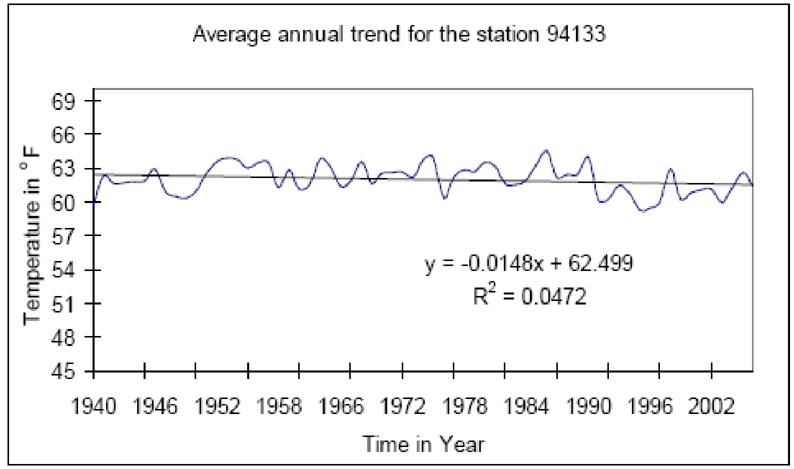

Average annual trend for the station 90435
Temperature in° F
69
66
63
60
57
54
51
48
45
y = 0.0184x + 61.25
R^2 = 0.1083
1949 1955 1961 1967 1973 1979 1985 1991 1997 2003
Time in Year

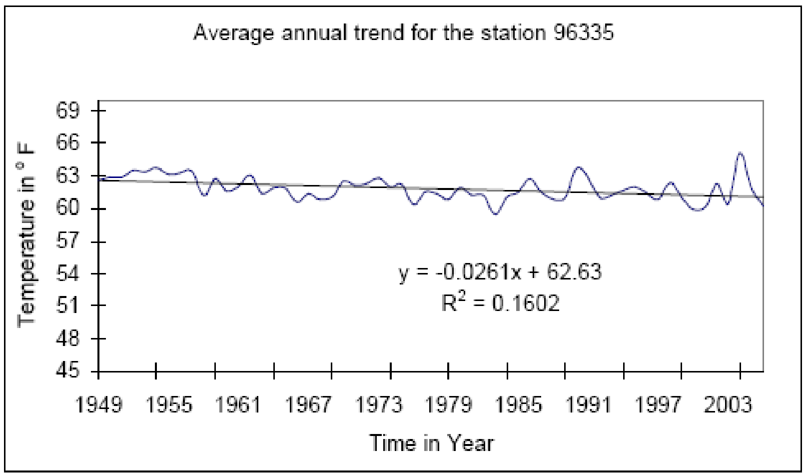

Average annual trend for the station 95988
Temperature in° F
69
66
63
60
57
54
51
48
45
y = -0.015x + 63.001
R^2 = 0.0108
1949 1955 1965 1971 1977 1983 1989 1995 2001
Time in Year

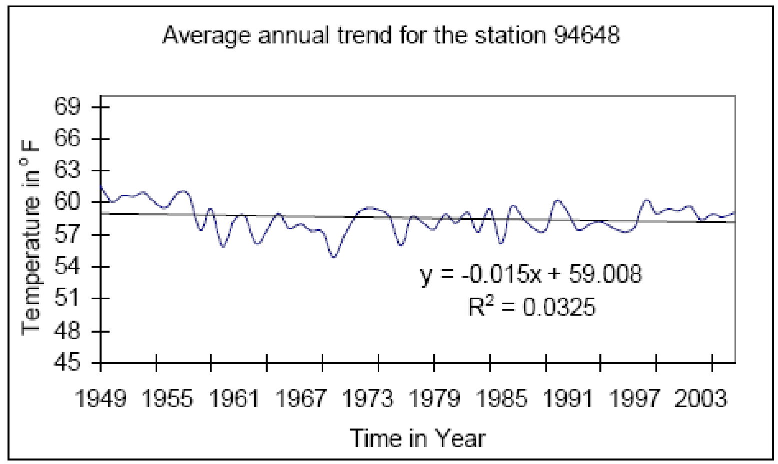

Average annual trend for the station 92318
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = -0.0205x + 62.195
R^2 = 0.0573
1949 1955 1961 1967 1973 1979 1985 1991 1997
Time in Year

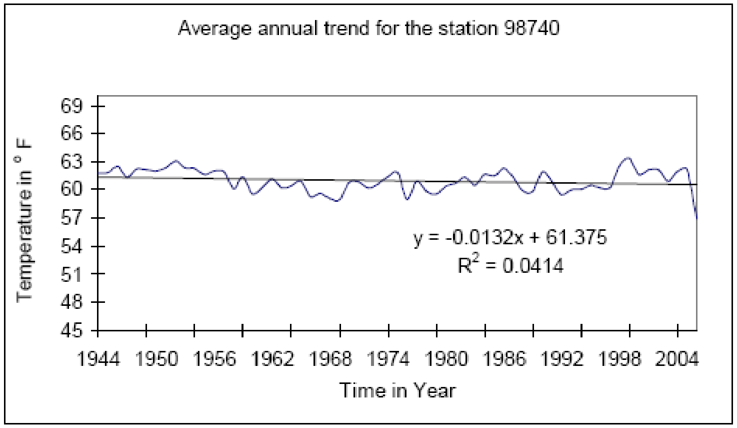

Average annual trend for the station 98535
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = -0.0199x + 63.748
R^2 = 0.0501
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year

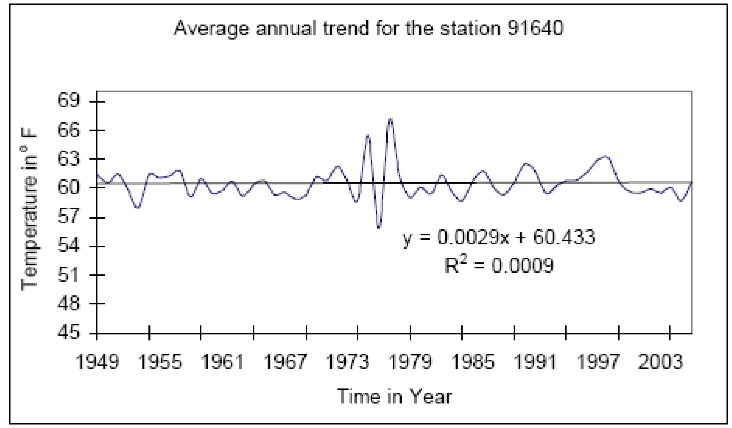

Average annual trend for the station 98661
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = 0.0022x + 63.385
R^2 = 0.0008
1956
1962
1968
1974
1980
1986
1992
2001
Time in Year


Average annual trend for the station 94133
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = -0.0148x + 62.499
R^2 = 0.0472
1940
1946
1952
1958
1966
1972
1978
1984
1990
1996
2002
Time in Year

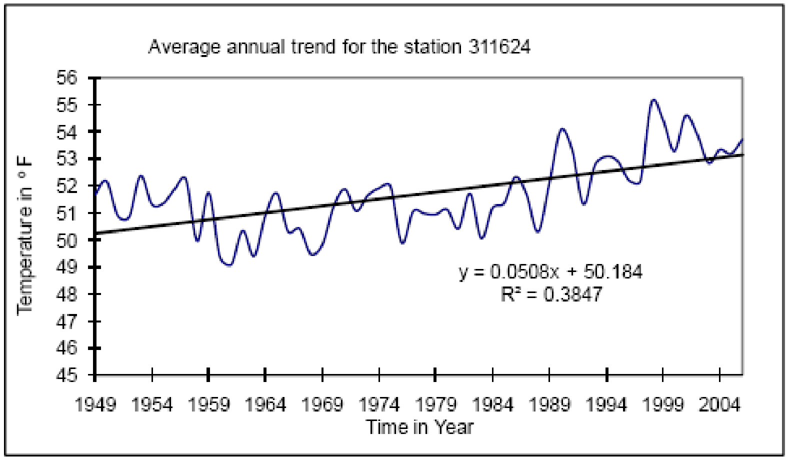

Average annual trend for the station 96335
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = -0.0261x + 62.63
R^2 = 0.1602
1949
1955
1961
1967
1973
1979
1985
1991
1997
2003
Time in Year

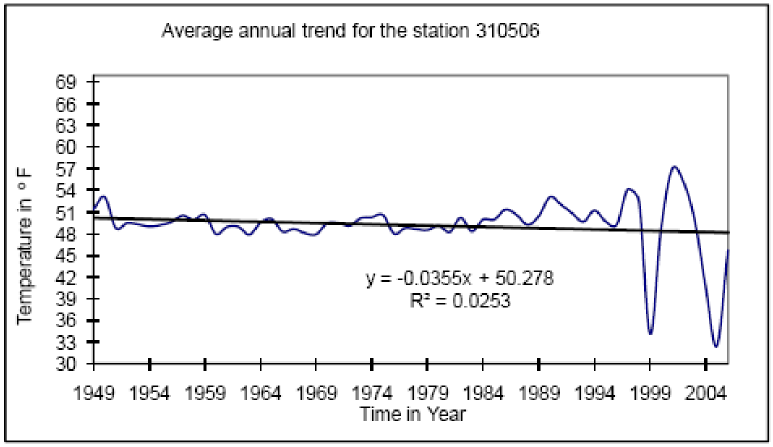

Average annual trend for the station 94648
Temperature in ° F
69
66
63
60
57
54
51
48
45
y = -0.015x + 59.008
R^2 = 0.0325
1949
1955
1961
1967
1973
1979
1985
1991
1997
2003
Time in Year

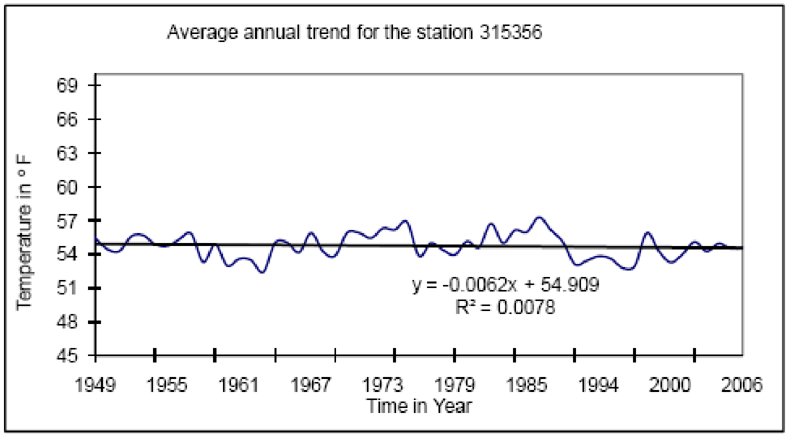

Average annual trend for the station 98740
Temperature in ° F
69
66
63
60
57
54
51
48
45
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year
y = -0.0132x + 61.375
R2 = 0.0414

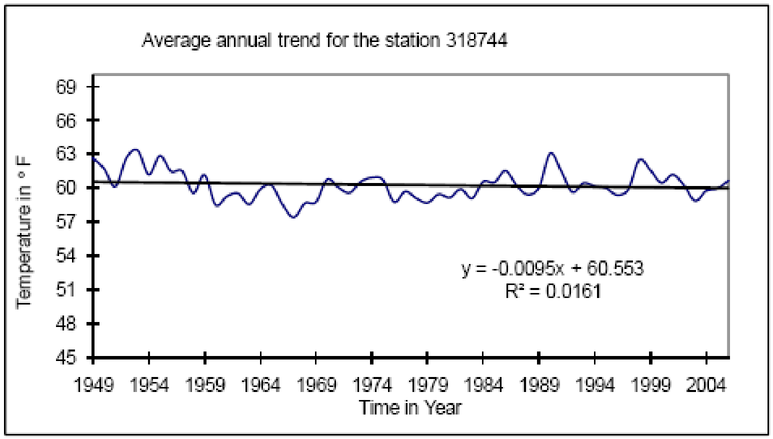

Average annual trend for the station 91640
Temperature in° F
69
66
63
60
57
54
51
48
45
1949 1955 1961 1967 1973 1979 1985 1991 1997 2003
Time in Year
y = 0.0029x + 60.433
R2 = 0.0009

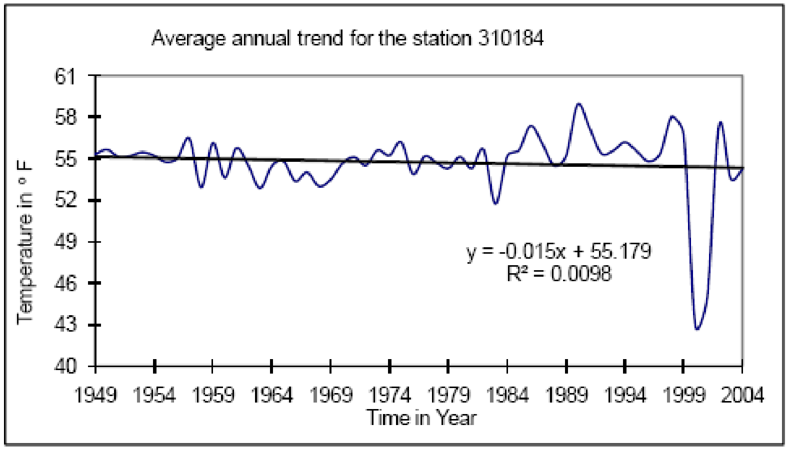
Appendix A-2: Average annual temperature trend in the Blue Ridge province (1948-2006).

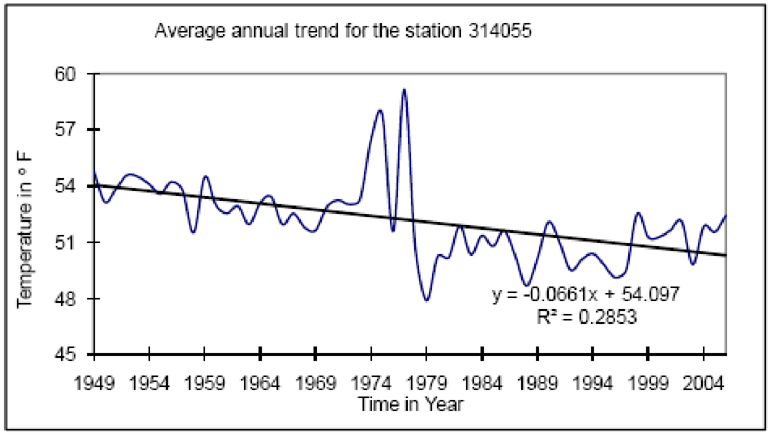


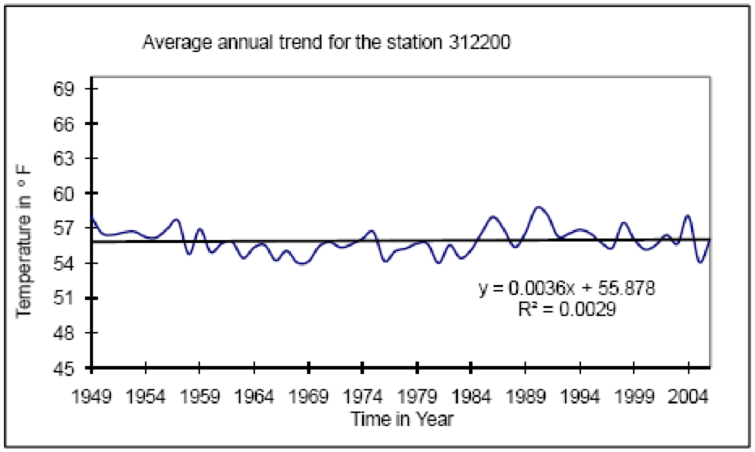


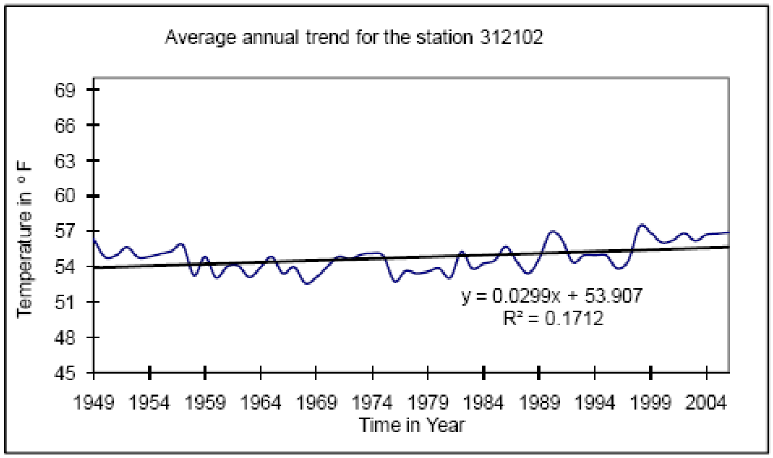


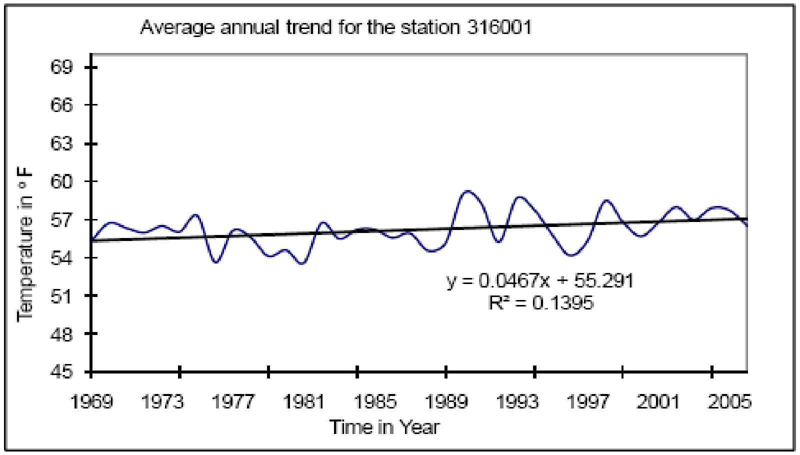


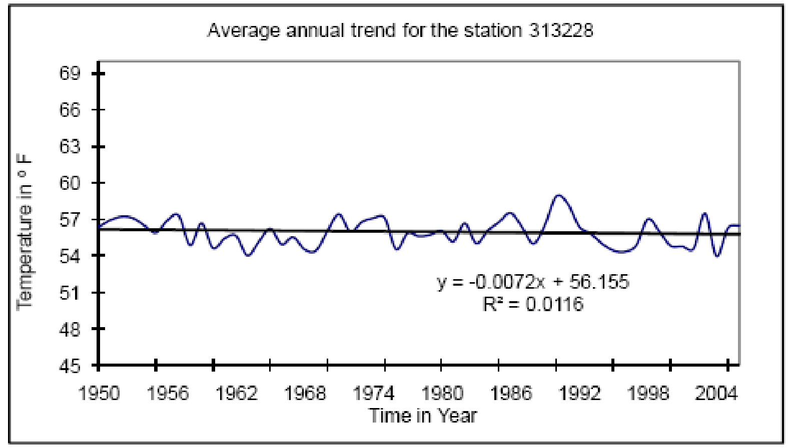

Average annual trend for the station 310184
61
58
55
52
49
46
43
40
Temperature in ° F
y = -0.015x + 55.179
R² = 0.0098
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

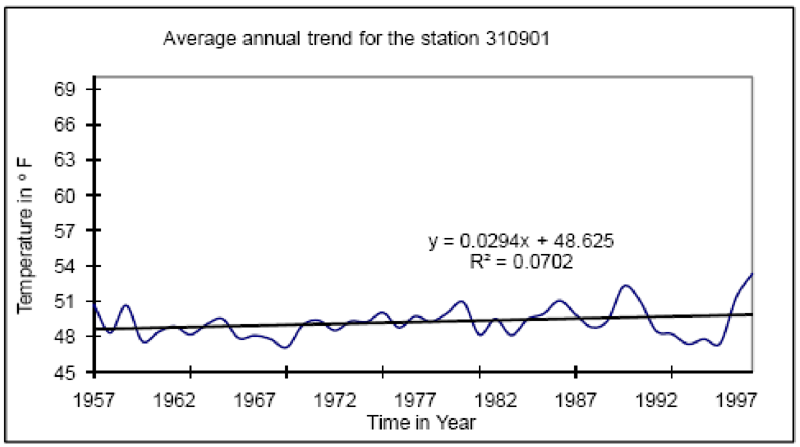

Average annual trend for the station 314055
60
57
54
51
48
45
Temperature in ° F
y = -0.0661x + 54.097
R² = 0.2853
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

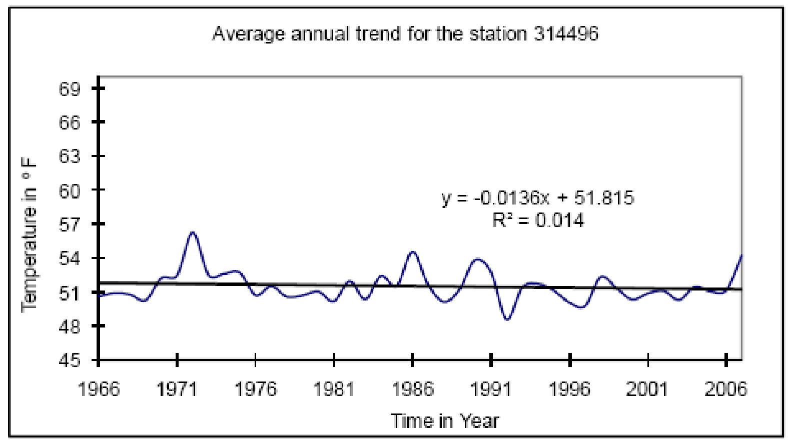

Average annual trend for the station 312200
69
66
63
60
57
54
51
48
45
Temperature in ° F
y = 0.0036x + 55.878
R² = 0.0029
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

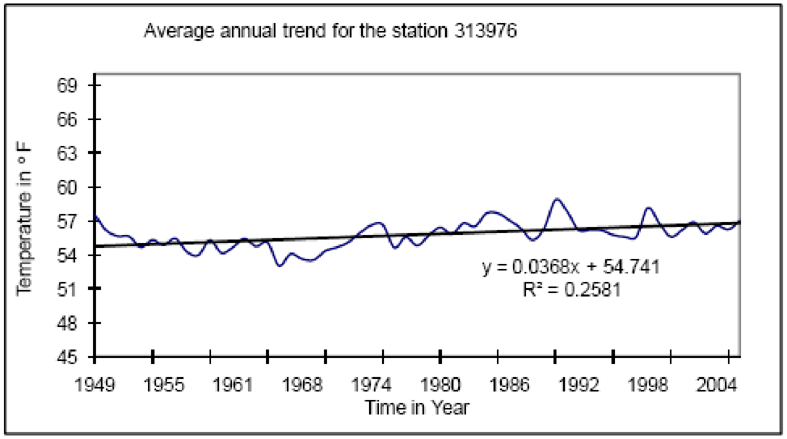

Average annual trend for the station 312102
69
66
63
60
57
54
51
48
45
Temperature in ° F
y = 0.0299x + 53.907
R² = 0.1712
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year


Average annual trend for the station 316001
y = 0.0467x + 55.291
R² = 0.1395
Temperature in ° F
69
66
63
60
57
54
51
48
45
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
Time in Year

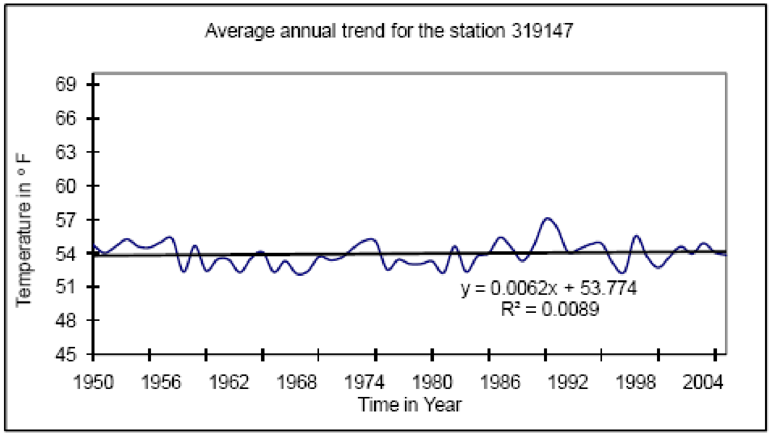

Average annual trend for the station 313228
y = -0.0072x + 56.155
R² = 0.0116
Temperature in ° F
69
66
63
60
57
54
51
48
45
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
Time in Year


Average annual trend for the station 310901
y = 0.0294x + 48.625
R² = 0.0702
Temperature in ° F
69
66
63
60
57
54
51
48
45
1957
1962
1967
1972
1977
1982
1987
1992
1997
Time in Year

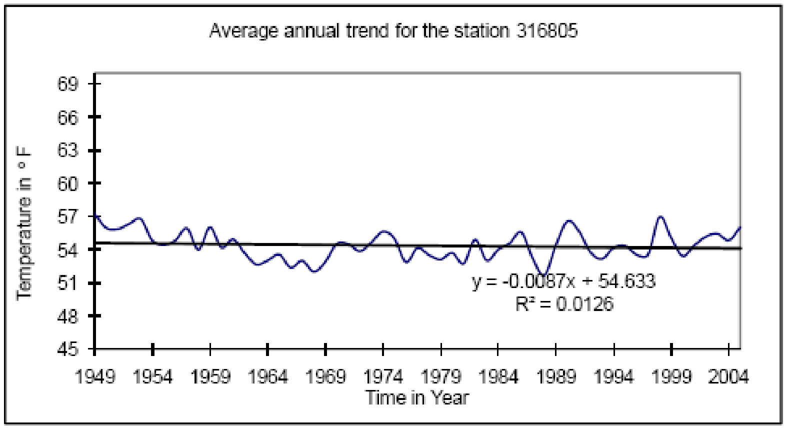

Average annual trend for the station 314496
y = -0.0136x + 51.815
R² = 0.014
Temperature in ° F
69
66
63
60
57
54
51
48
45
1966
1971
1976
1981
1986
1991
1996
2001
2006
Time in Year



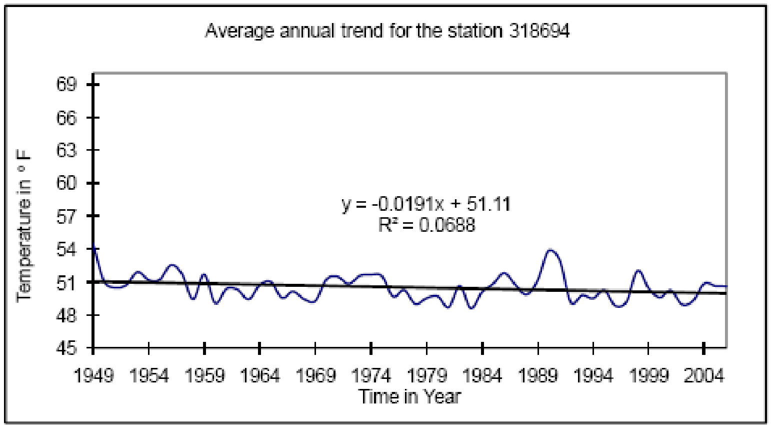
Average annual trend for the station 313976
Temperature in ° F
69
66
63
60
57
54
51
48
45
1949
1955
1961
1968
1974
1980
1986
1992
1998
2004
Time in Year
y = 0.0368x + 54.741
R² = 0.2581



Average annual trend for the station 319147
Temperature in ° F
69
66
63
60
57
54
51
48
45
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
Time in Year
y = 0.0062x + 53.774
R² = 0.0089

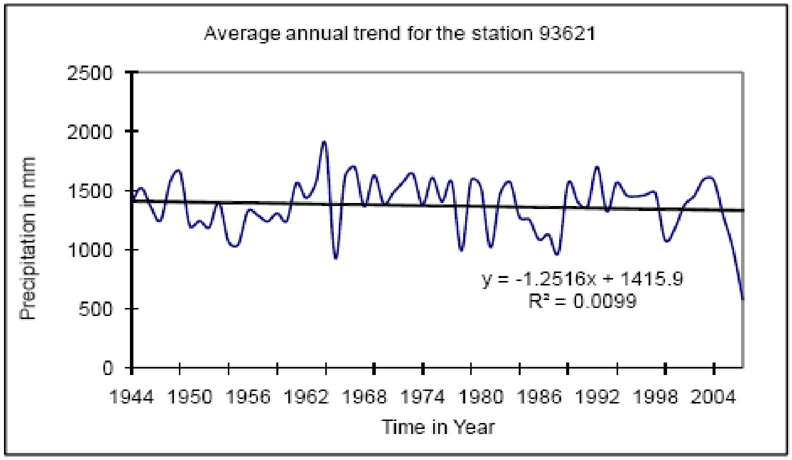


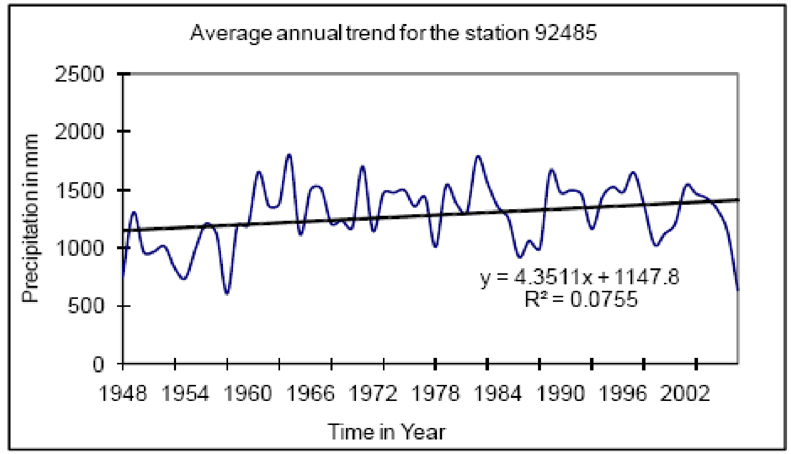
Average annual trend for the station 316805
Temperature in ° F
69
66
63
60
57
54
51
48
45
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
Time in Year
y = -0.0087x + 54.633
R² = 0.0126

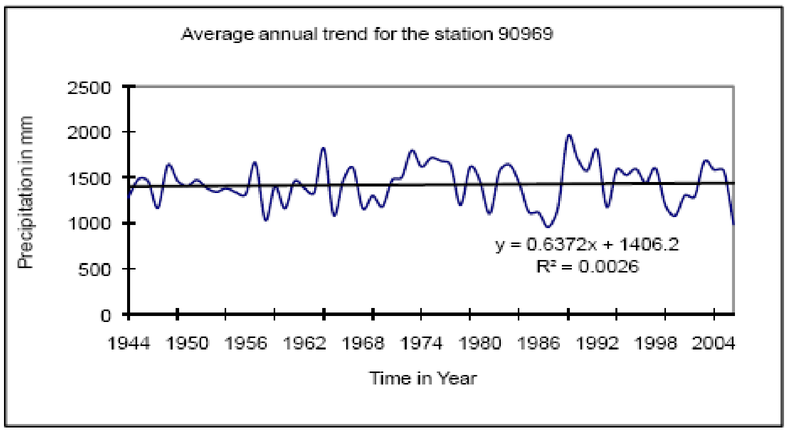


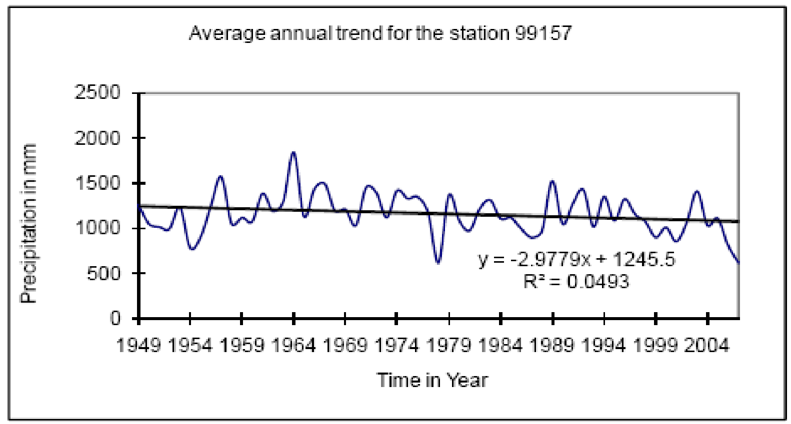
Average annual trend for the station 318694
Temperature in ° F
69
66
63
60
57
54
51
48
45
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
Time in Year
y = -0.0191x + 51.11
R² = 0.0688

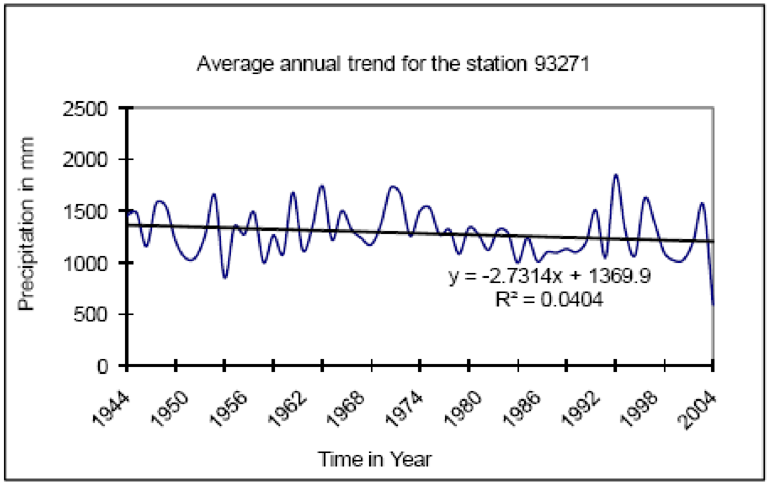
Appendix B-1: Average annual rainfall in the Piedmont province (1948-2006).

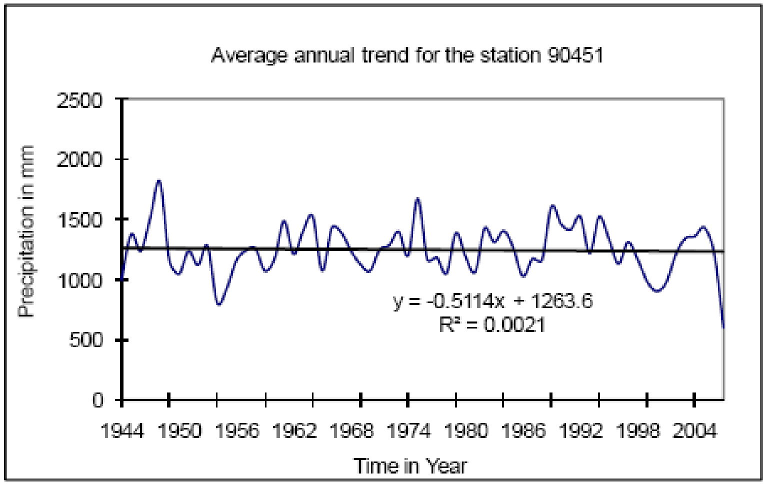


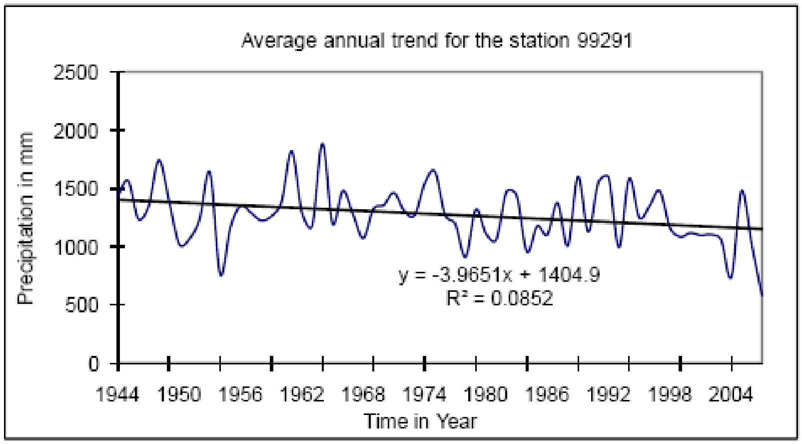


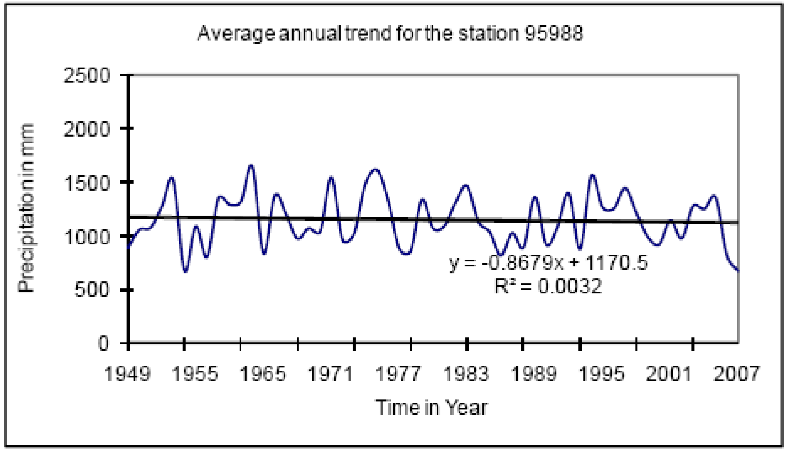


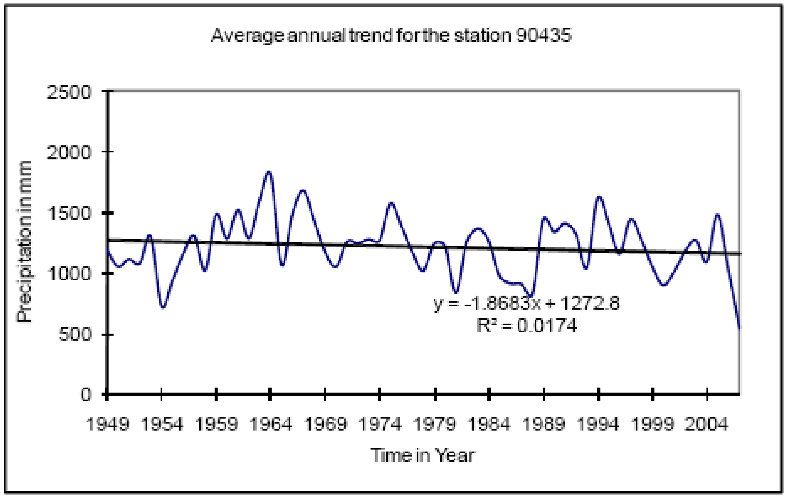


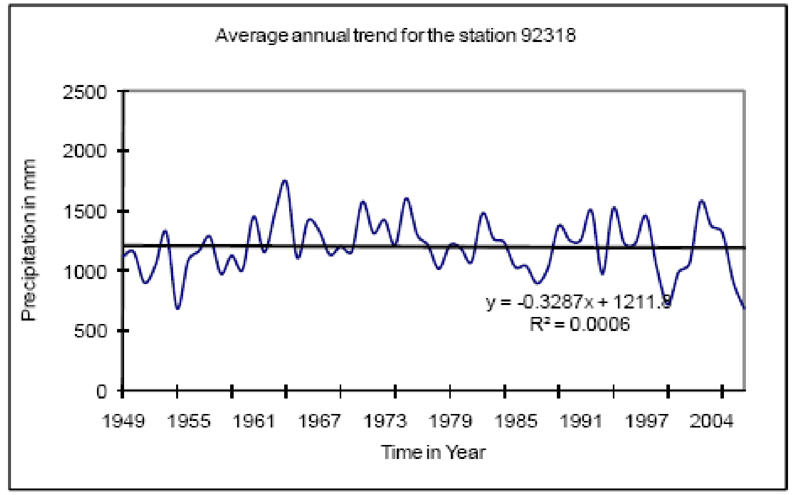

Average annual trend for the station 93271
Precipitation in mm
2500
2000
1500
1000
500
0
y = -2.7314x + 1369.9
R² = 0.0404
1944
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
Time in Year

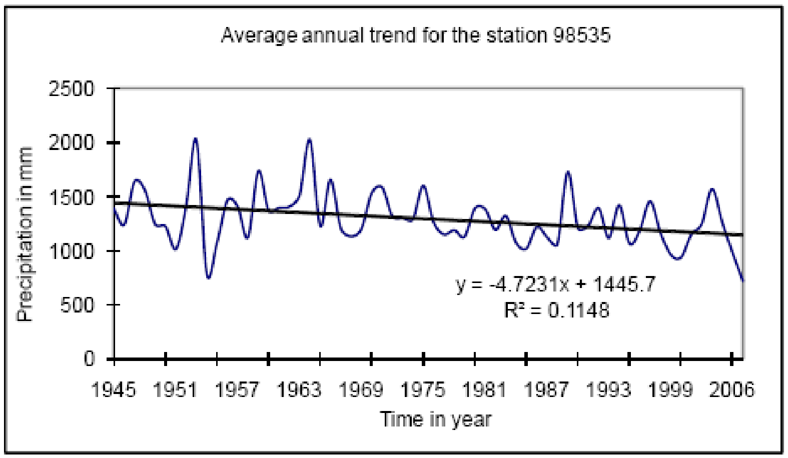

Average annual trend for the station 90451
Precipitation in mm
2500
2000
1500
1000
500
0
y = -0.5114x + 1263.6
R² = 0.0021
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year

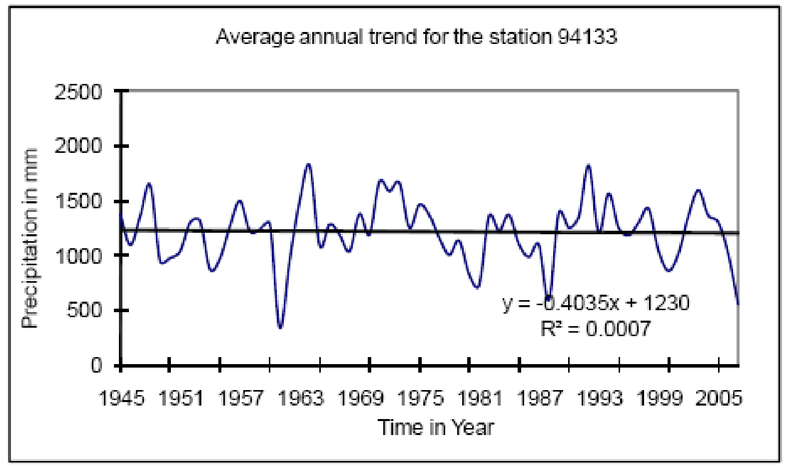

Average annual trend for the station 99291
Precipitation in mm
2500
2000
1500
1000
500
0
y = -3.9651x + 1404.9
R² = 0.0852
1944 1950 1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year

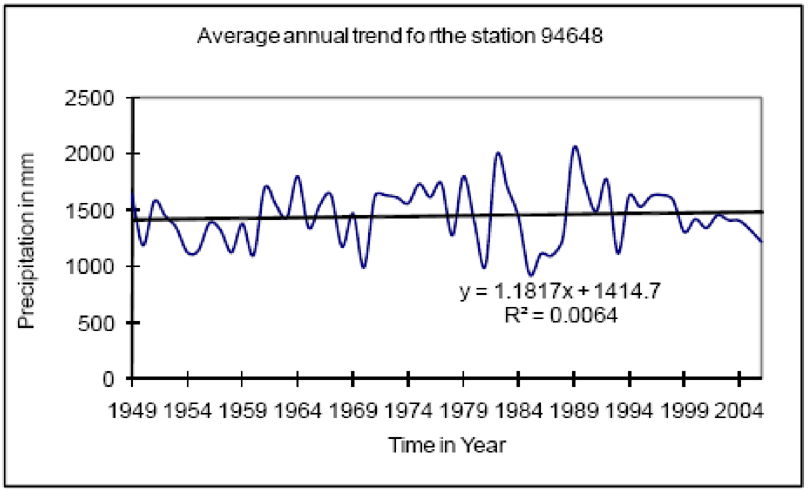

Average annual trend for the station 95988
Precipitation in mm
2500
2000
1500
1000
500
0
y = -0.8679x + 1170.5
R² = 0.0032
1949 1955 1965 1971 1977 1983 1989 1995 2001 2007
Time in Year

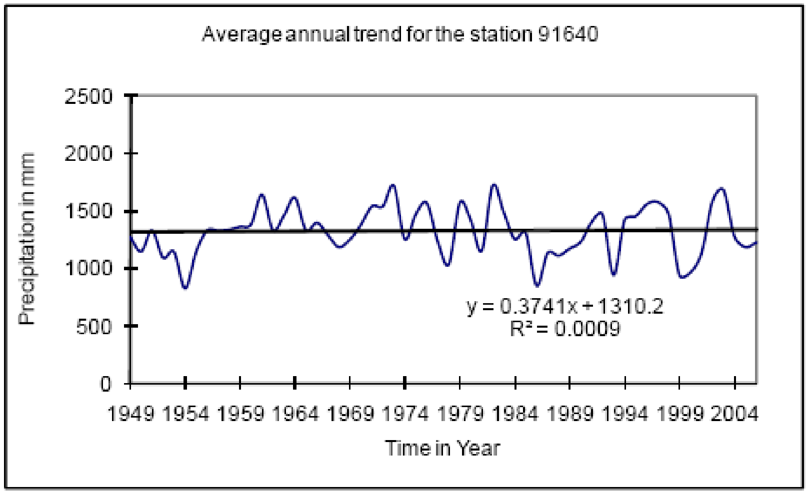

Average annual trend for the station 90435
2500
2000
1500
1000
500
0
Precipitation in mm
y = -1.8683x + 1272.8
R² = 0.0174
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

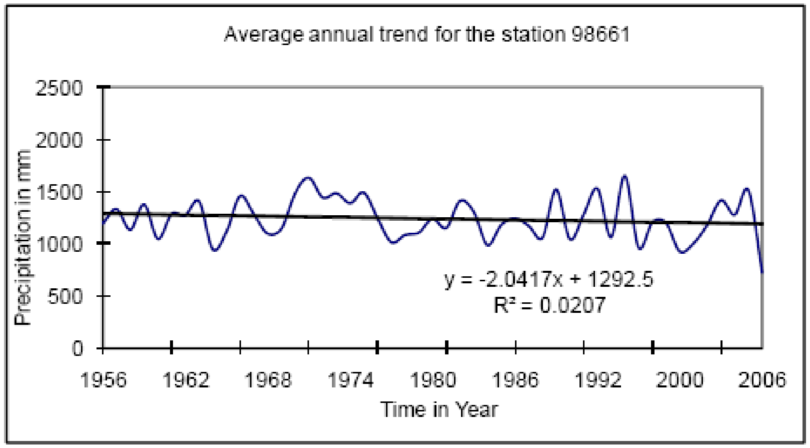

Average annual trend for the station 92318
2500
2000
1500
1000
500
0
Precipitation in mm
y = -0.3287x + 1211.9
R² = 0.0006
1949 1955 1961 1967 1973 1979 1985 1991 1997 2004
Time in Year

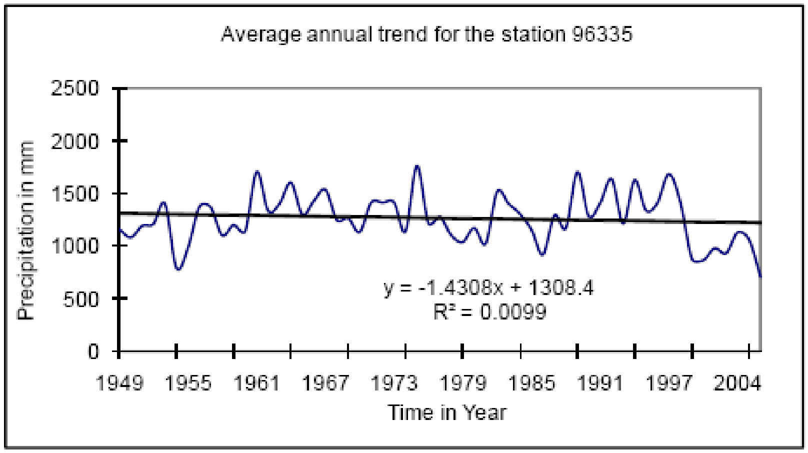

Average annual trend for the station 98535
2500
2000
1500
1000
500
0
Precipitation in mm
y = -4.7231x + 1445.7
R² = 0.1148
1945 1951 1957 1963 1969 1975 1981 1987 1993 1999 2006
Time in year

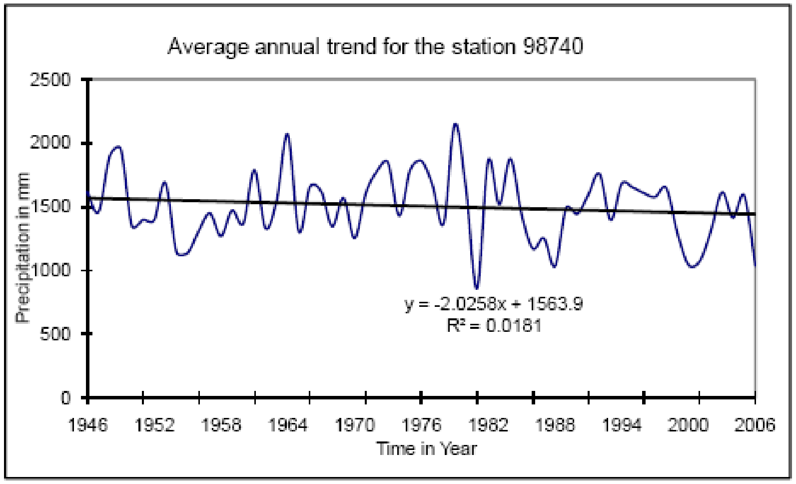

Average annual trend for the station 94133
2500
2000
1500
1000
500
0
Precipitation in mm
y = -0.4035x + 1230
R² = 0.0007
1945 1951 1957 1963 1969 1975 1981 1987 1993 1999 2005
Time in Year

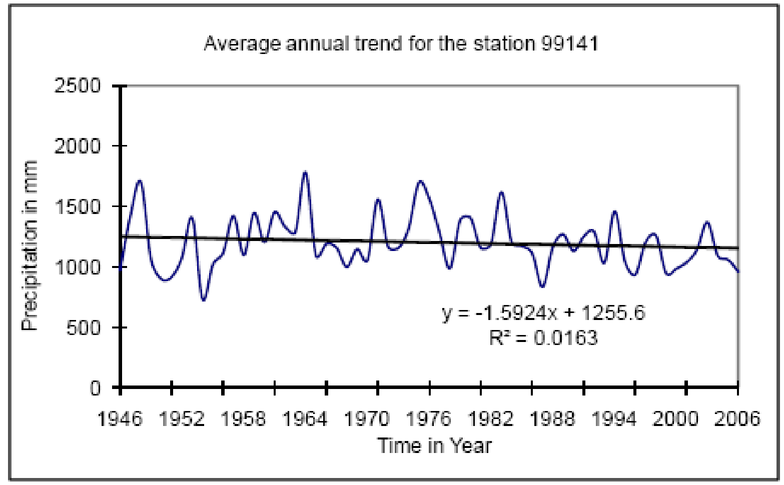

Average annual trend fo rthe station 94648
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year
y = 1.1817x + 1414.7
R² = 0.0064

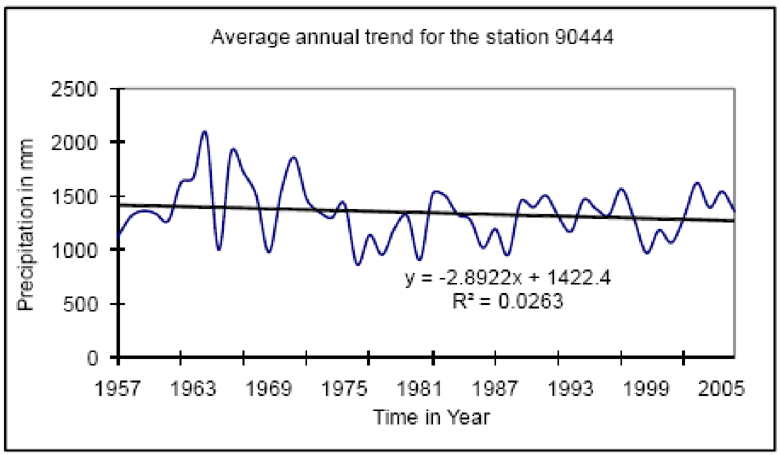

Average annual trend for the station 91640
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year
y = 0.3741x + 1310.2
R² = 0.0009


Average annual trend for the station 98661
Precipitation in mm
2500
2000
1500
1000
500
0
1956 1962 1968 1974 1980 1986 1992 2000 2006
Time in Year
y = -2.0417x + 1292.5
R² = 0.0207

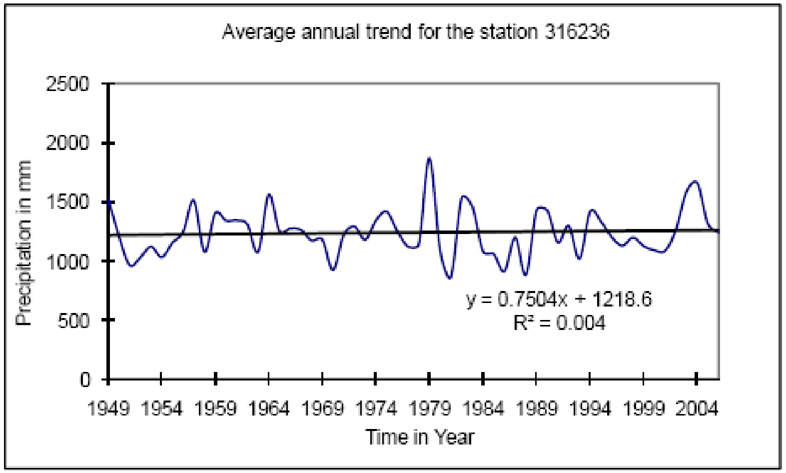

Average annual trend for the station 96335
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1955 1961 1967 1973 1979 1985 1991 1997 2004
Time in Year
y = -1.4308x + 1308.4
R² = 0.0099

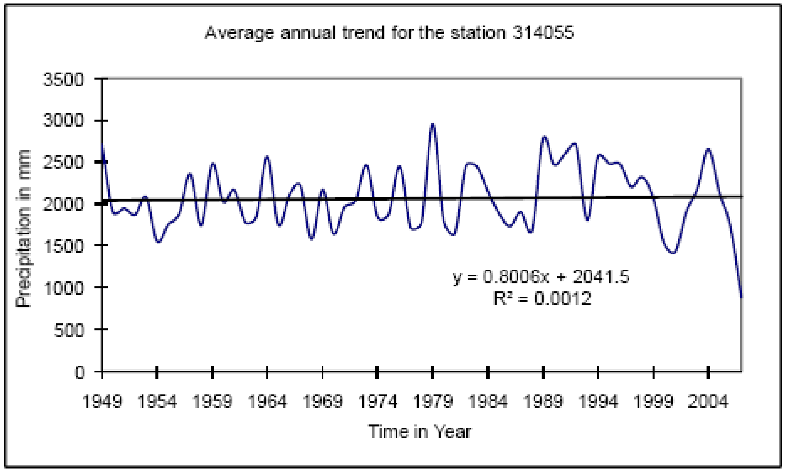

Average annual trend for the station 98740
2500
2000
1500
1000
500
0
Precipitation in mm
y = -2.0258x + 1563.9
R² = 0.0181
1946 1952 1958 1964 1970 1976 1982 1988 1994 2000 2006
Time in Year

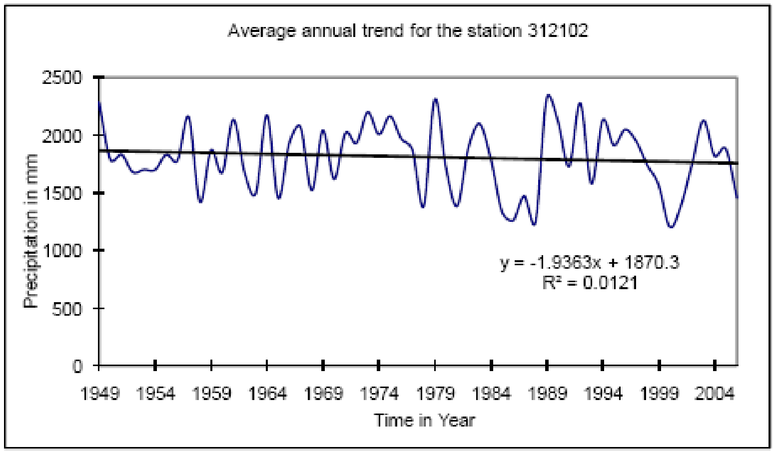

Average annual trend for the station 99141
2500
2000
1500
1000
500
0
Precipitation in mm
y = -1.5924x + 1255.6
R² = 0.0163
1946 1952 1958 1964 1970 1976 1982 1988 1994 2000 2006
Time in Year

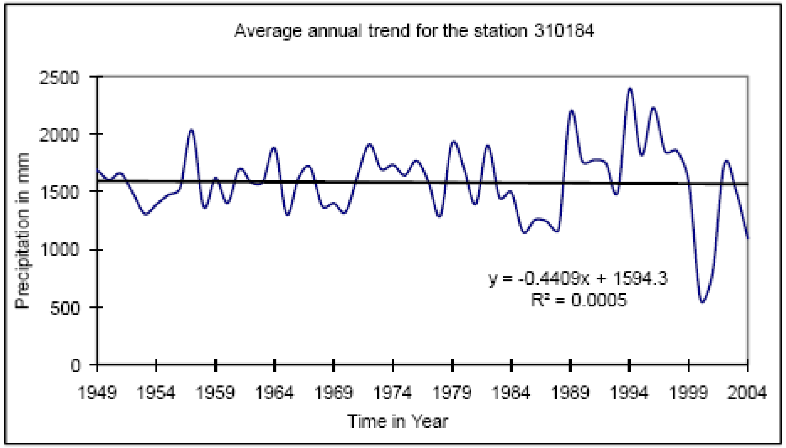

Average annual trend for the station 90444
2500
2000
1500
1000
500
0
Precipitation in mm
y = -2.8922x + 1422.4
R² = 0.0263
1957 1963 1969 1975 1981 1987 1993 1999 2005
Time in Year

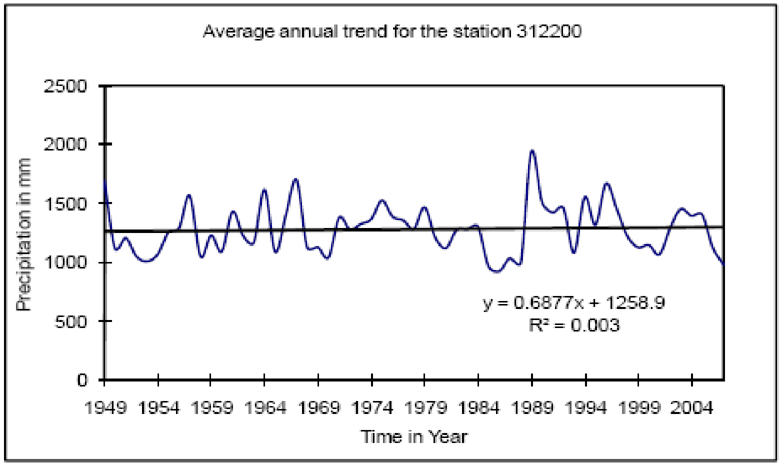
Appendix B-2: Average annual rainfall in the Blue Ridge province (1948-2006).

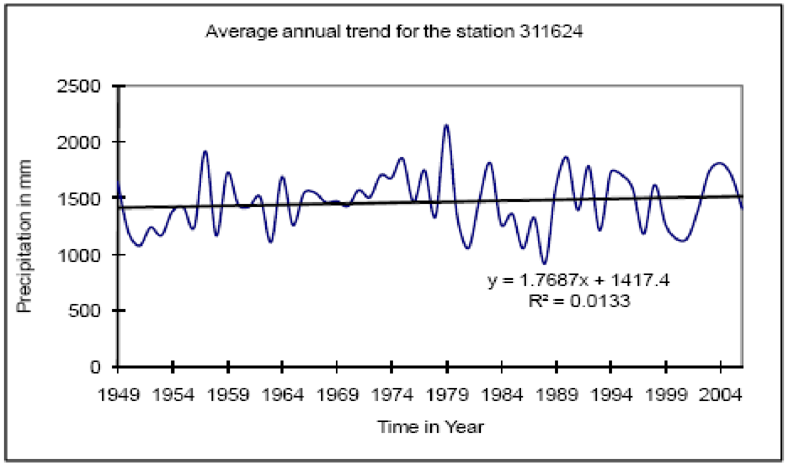


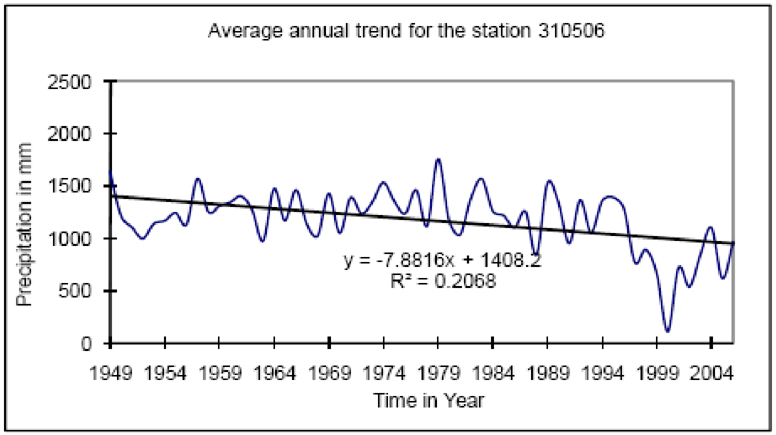


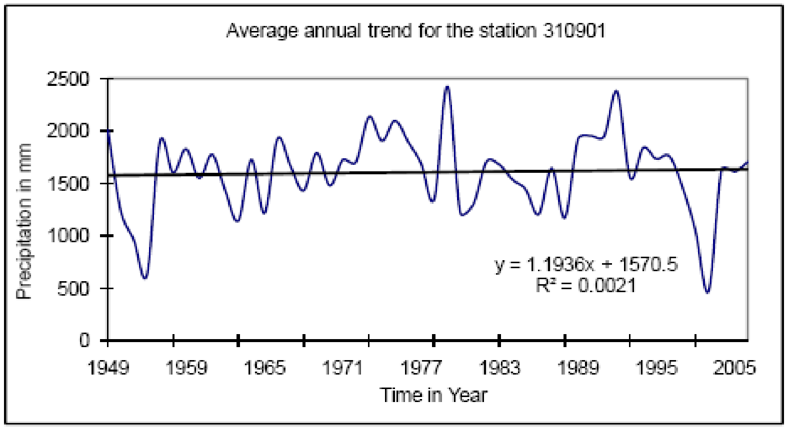


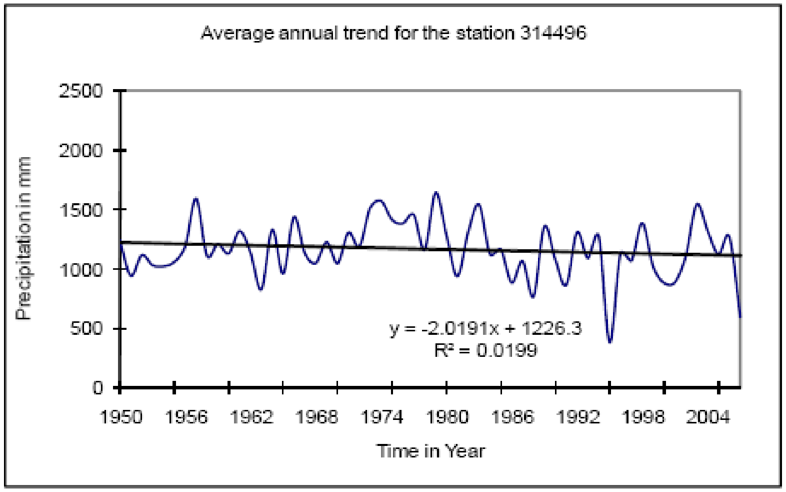


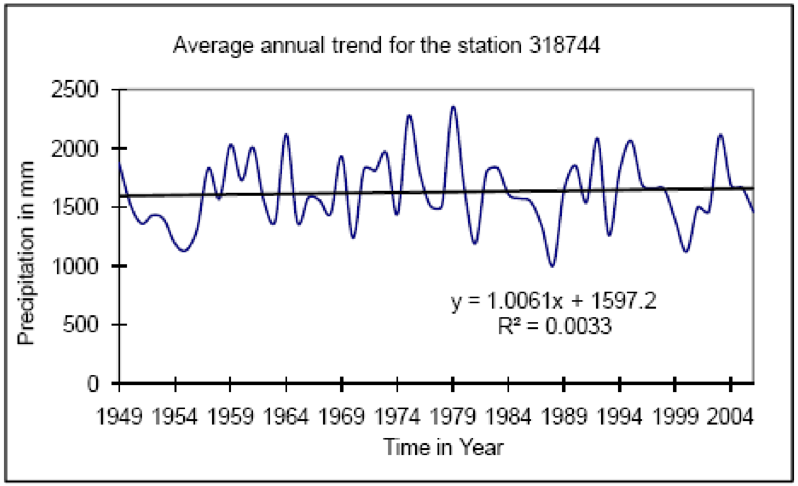

Average annual trend for the station 312200
Precipitation in mm
2500
2000
1500
1000
500
0
y = 0.6877x + 1258.9
R^2 = 0.003
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

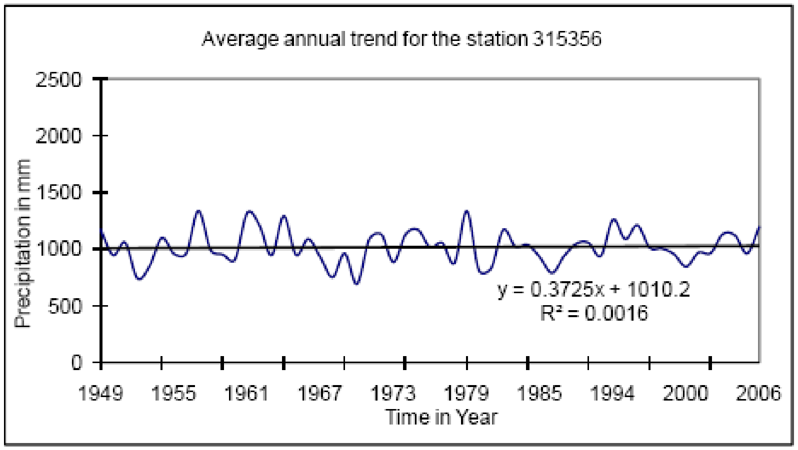

Average annual trend for the station 311624
Precipitation in mm
2500
2000
1500
1000
500
0
y = 1.7687x + 1417.4
R^2 = 0.0133
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

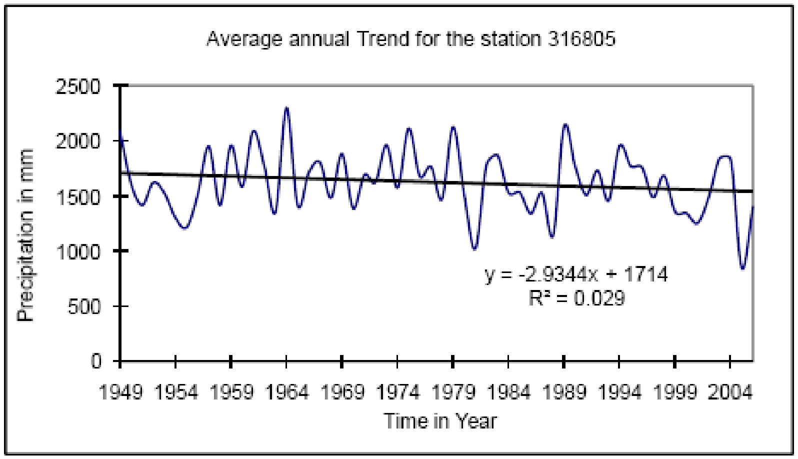

Average annual trend for the station 310506
Precipitation in mm
2500
2000
1500
1000
500
0
y = -7.8816x + 1408.2
R^2 = 0.2068
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

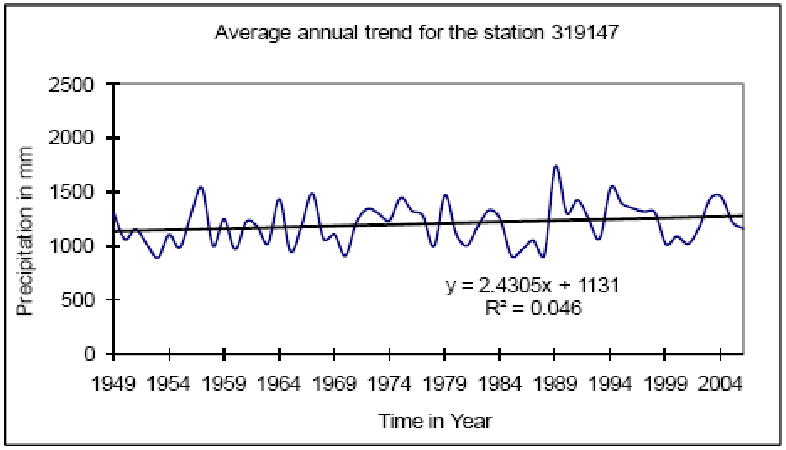

Average annual trend for the station 310901
Precipitation in mm
2500
2000
1500
1000
500
0
y = 1.1936x + 1570.5
R^2 = 0.0021
1949 1959 1965 1971 1977 1983 1989 1995 2005
Time in Year


Average annual trend for the station 314496
2500
2000
1500
1000
500
0
Precipitation in mm
y = -2.0191x + 1226.3
R² = 0.0199
1950
1956
1962
1968
1974
1980
1986
1992
1998
2004
Time in Year

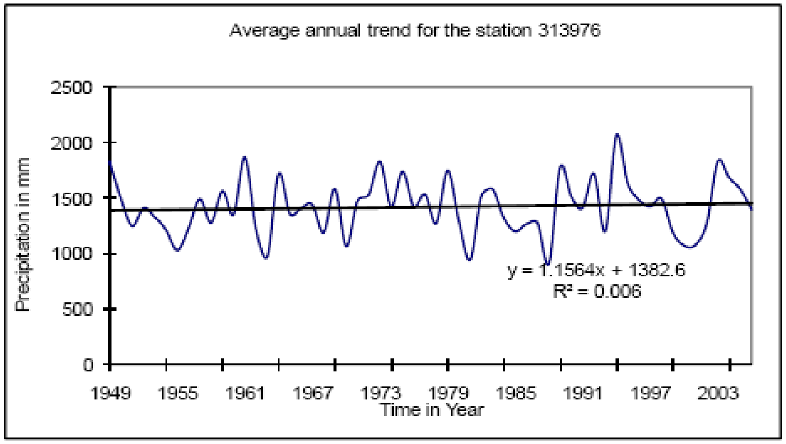

Average annual trend for the station 318744
2500
2000
1500
1000
500
0
Precipitation in mm
y = 1.0061x + 1597.2
R² = 0.0033
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
Time in Year


Average annual trend for the station 315356
2500
2000
1500
1000
500
0
Precipitation in mm
y = 0.3725x + 1010.2
R² = 0.0016
1949
1955
1961
1967
1973
1979
1985
1994
2000
2006
Time in Year

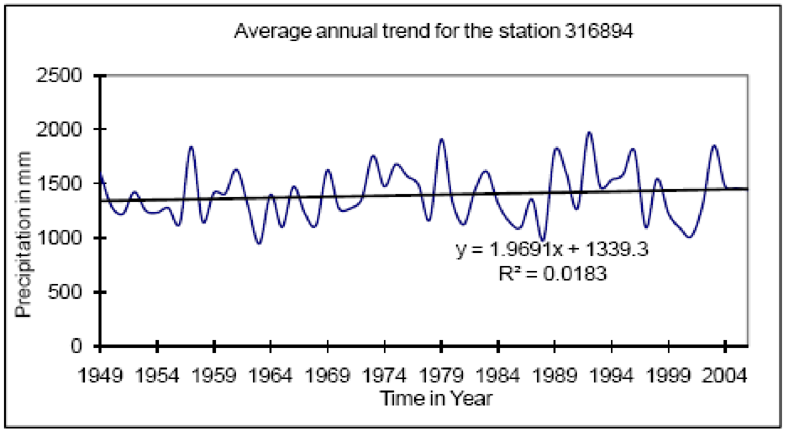

Average annual Trend for the station 316805
2500
2000
1500
1000
500
0
Precipitation in mm
y = -2.9344x + 1714
R² = 0.029
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
Time in Year



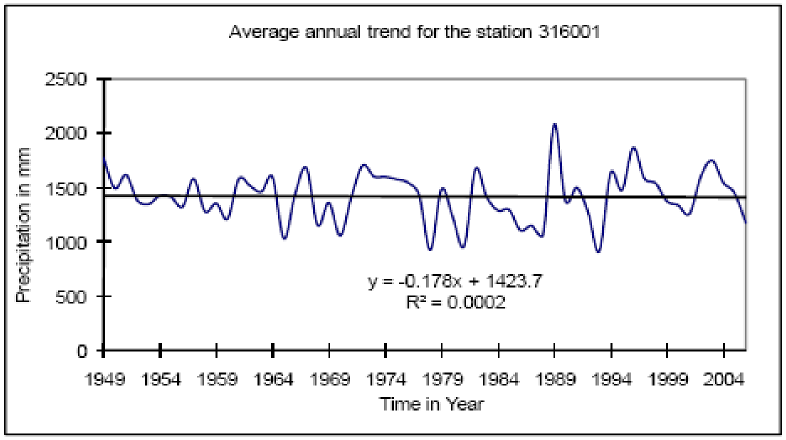
Average annual trend for the station 319147
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year
y = 2.4305x + 1131
R² = 0.046



Average annual trend for the station 313976
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1955 1961 1967 1973 1979 1985 1991 1997 2003
Time in Year
y = 1.1564x + 1382.6
R² = 0.006

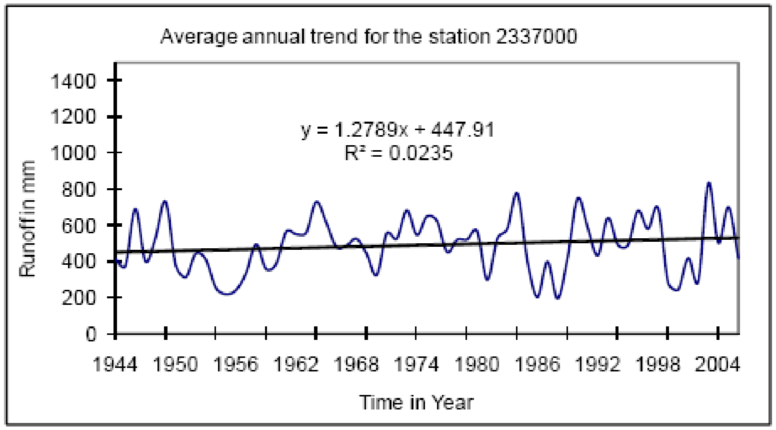


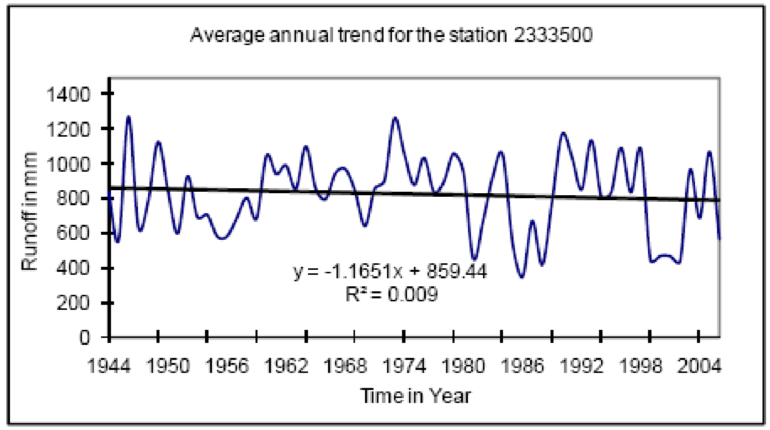
Average annual trend for the station 316894
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year
y = 1.9691x + 1339.3
R² = 0.0183

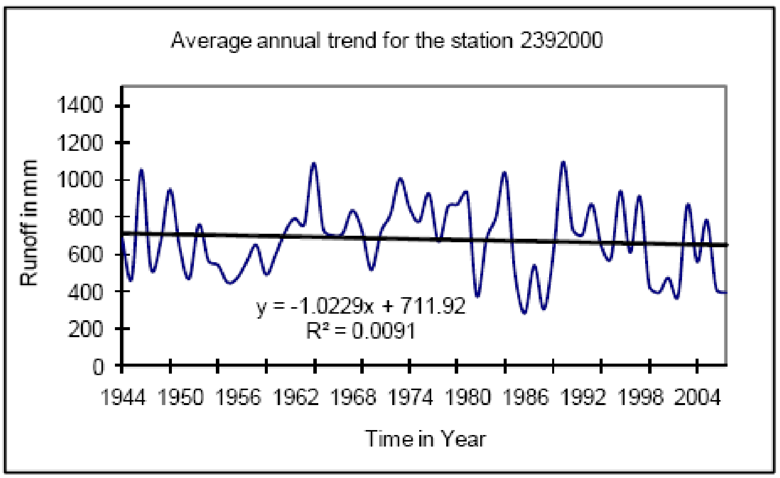


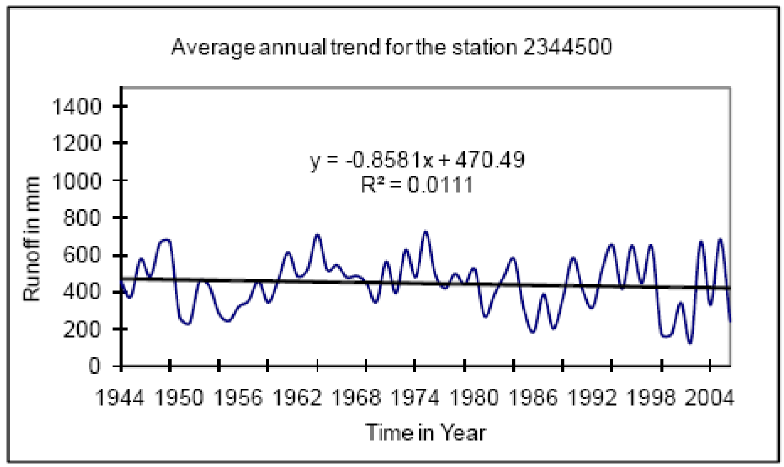
Average annual trend for the station 316001
Precipitation in mm
2500
2000
1500
1000
500
0
1949 1954 1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year
y = -0.178x + 1423.7
R² = 0.0002

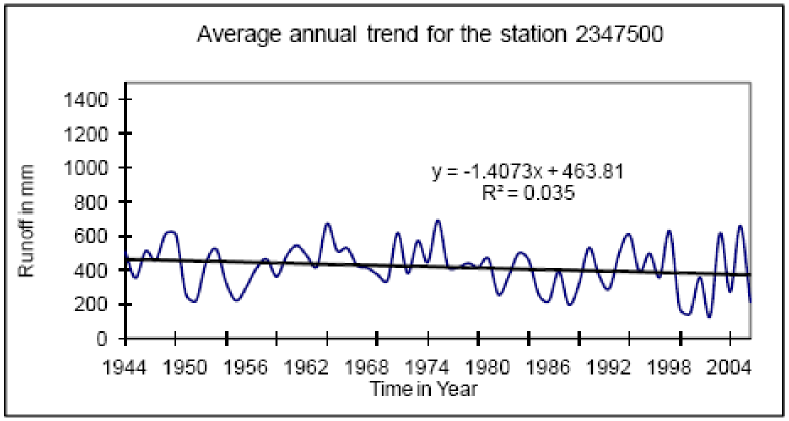
Appendix C-1: Average annual stream runoff in the Piedmont province (1948-2006).

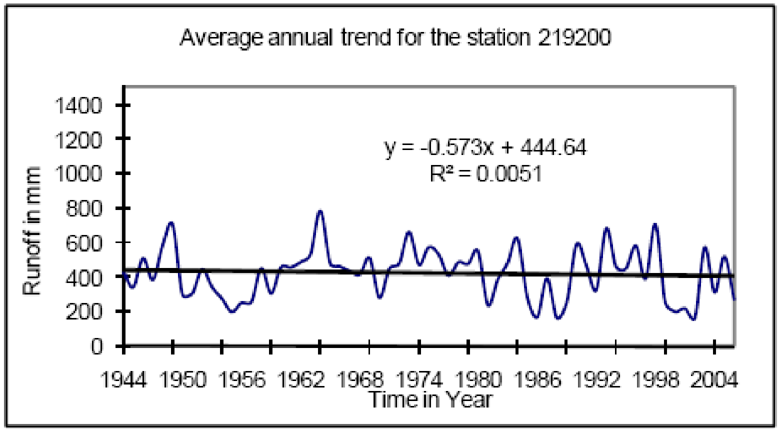


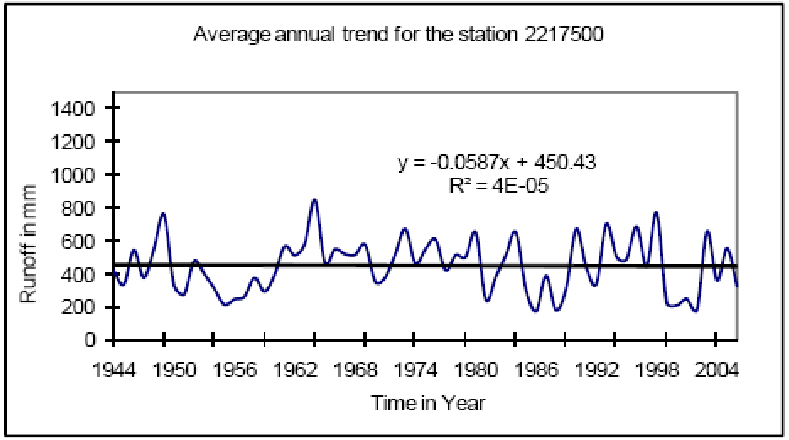


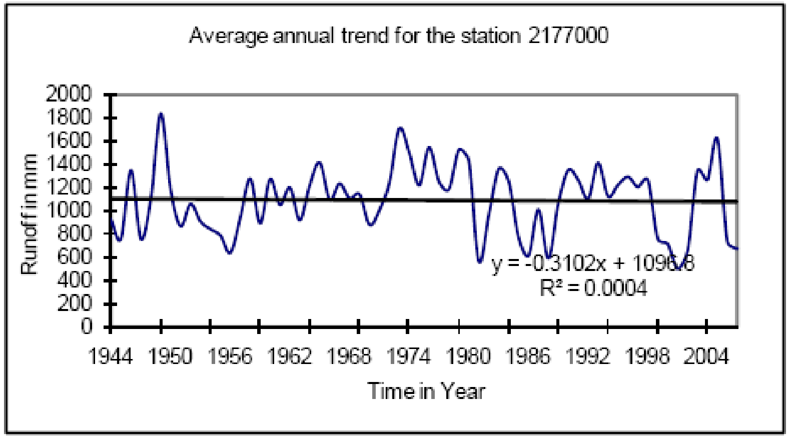


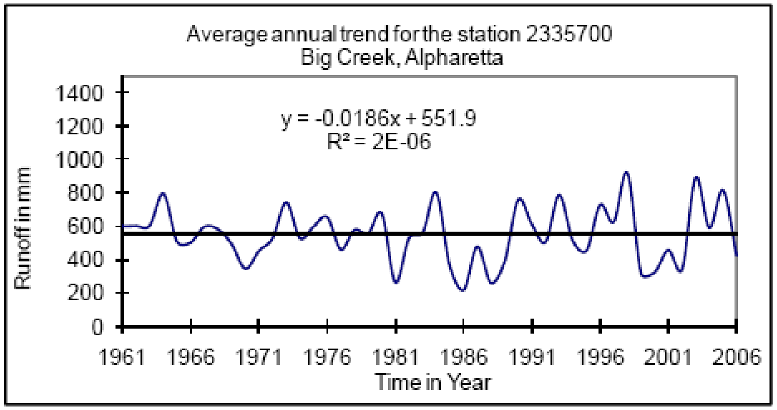


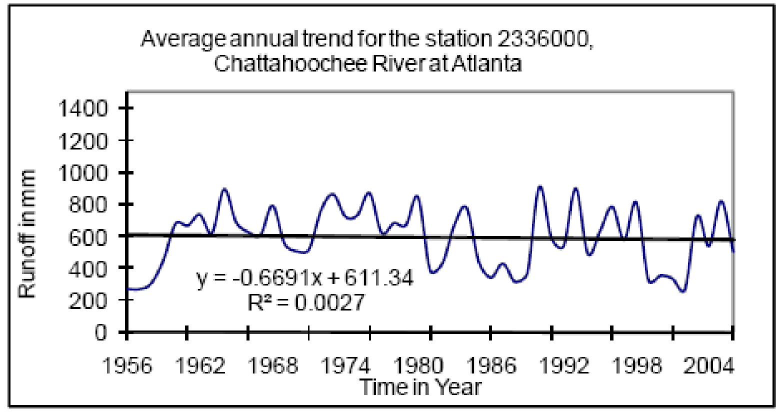

Average annual trend for the station 2347500
y = -1.4073x + 463.81
R² = 0.035
Runoff in mm
Time in Year

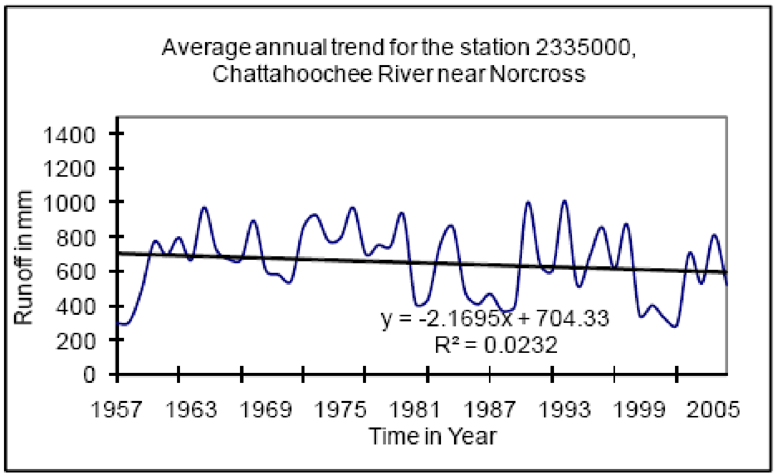

Average annual trend for the station 219200
y = -0.573x + 444.64
R² = 0.0051
Runoff in mm
Time in Year

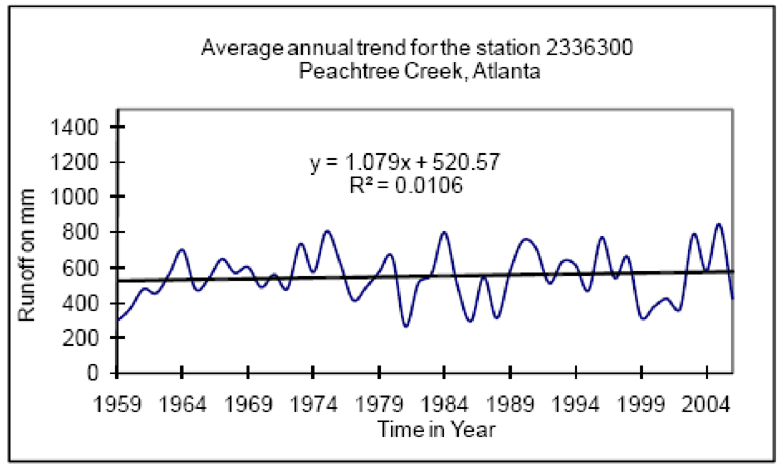

Average annual trend for the station 2217500
y = -0.0587x + 450.43
R² = 4E-05
Runoff in mm
Time in Year

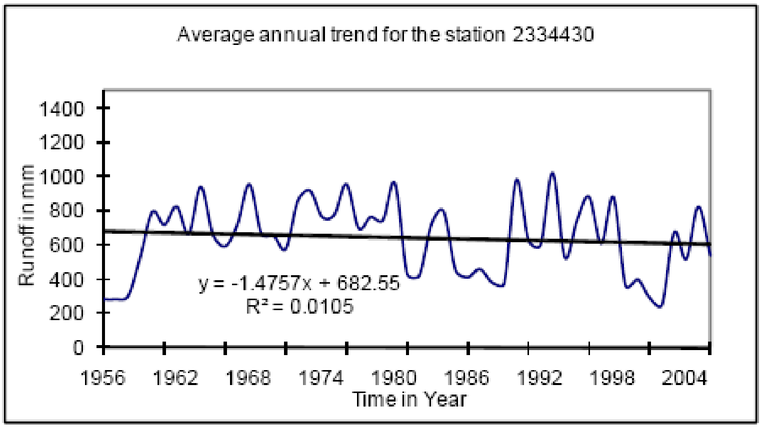

Average annual trend for the station 2177000
y = -0.3102x + 1096.8
R² = 0.0004
Runoff in mm
Time in Year

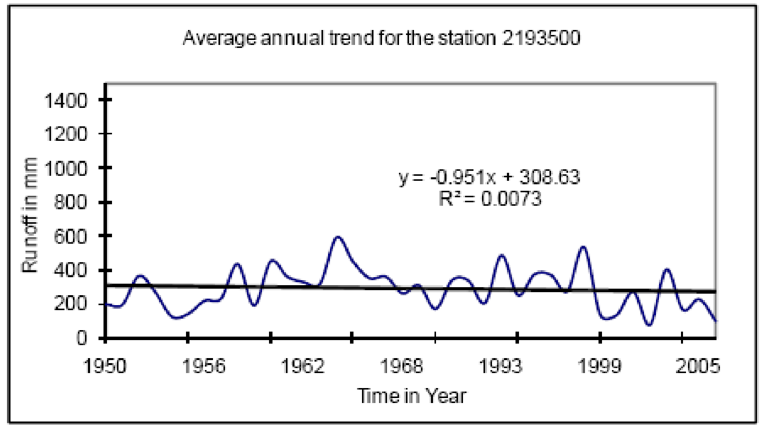

Average annual trend for the station 2335700
Big Creek, Alpharetta
y = -0.0186x + 551.9
R² = 2E-06
Runoff in mm
1400
1200
1000
800
600
400
200
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
Time in Year

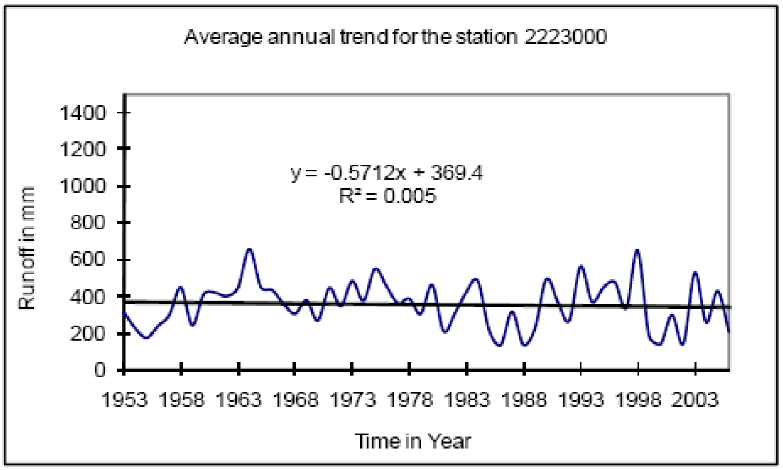

Average annual trend for the station 2336000,
Chattahoochee River at Atlanta
y = -0.6691x + 611.34
R² = 0.0027
Runoff in mm
1400
1200
1000
800
600
400
200
0
1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year

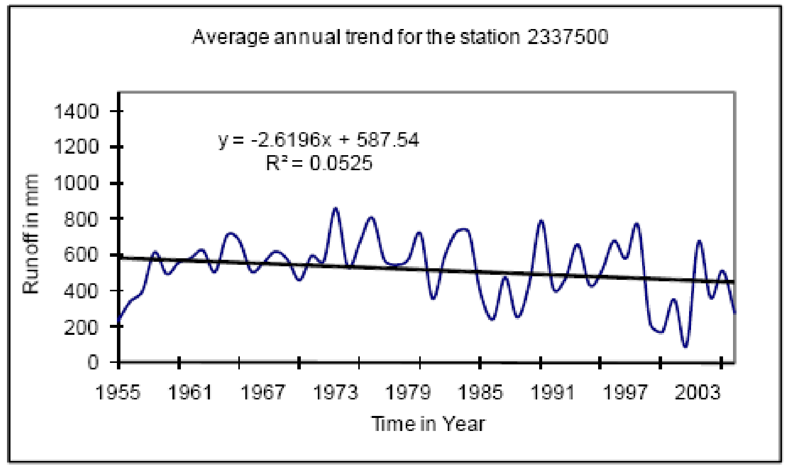

Average annual trend for the station 2335000,
Chattahoochee River near Norcross
y = -2.1695x + 704.33
R² = 0.0232
Runoff in mm
1400
1200
1000
800
600
400
200
0
1957 1963 1969 1975 1981 1987 1993 1999 2005
Time in Year

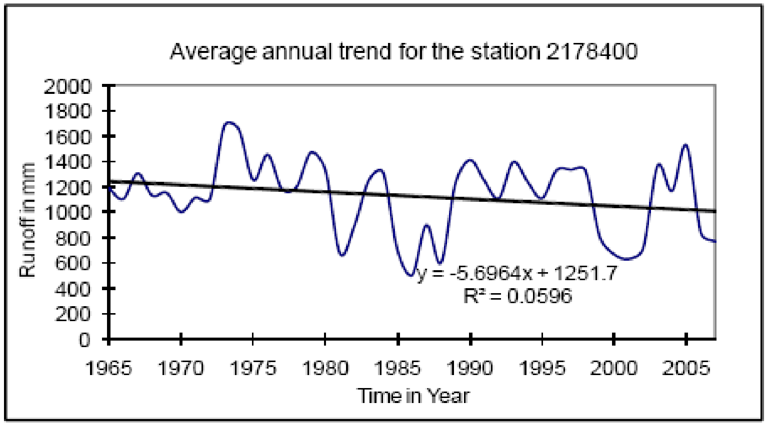

Average annual trend for the station 2336300
Peachtree Creek, Atlanta
y = 1.079x + 520.57
R² = 0.0106
Runoff on mm
1400
1200
1000
800
600
400
200
0
1959 1964 1969 1974 1979 1984 1989 1994 1999 2004
Time in Year

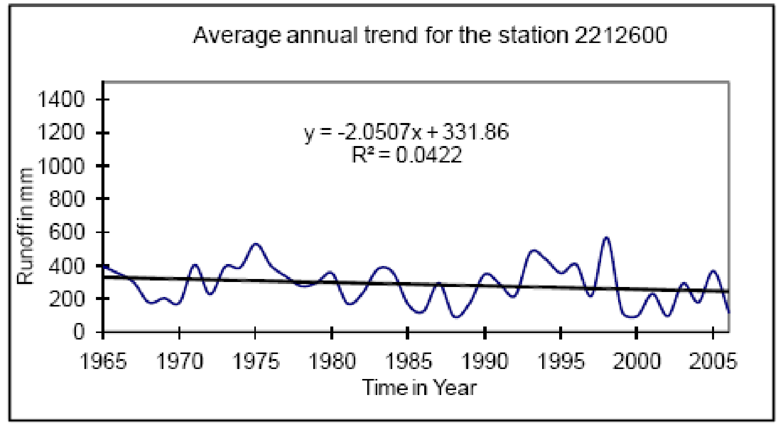

Average annual trend for the station 2334430
1400
1200
1000
800
600
400
200
0
Runoff in mm
y = -1.4757x + 682.55
R² = 0.0105
1956 1962 1968 1974 1980 1986 1992 1998 2004
Time in Year

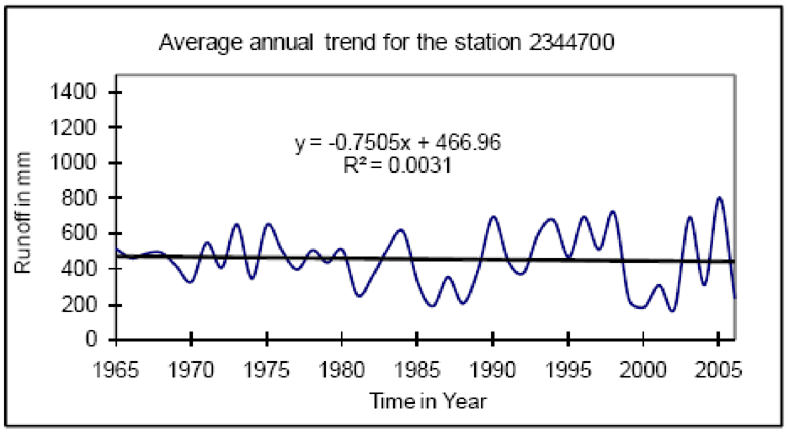

Average annual trend for the station 2193500
1400
1200
1000
800
600
400
200
0
Runoff in mm
y = -0.951x + 308.63
R² = 0.0073
1950 1956 1962 1968 1993 1999 2005
Time in Year

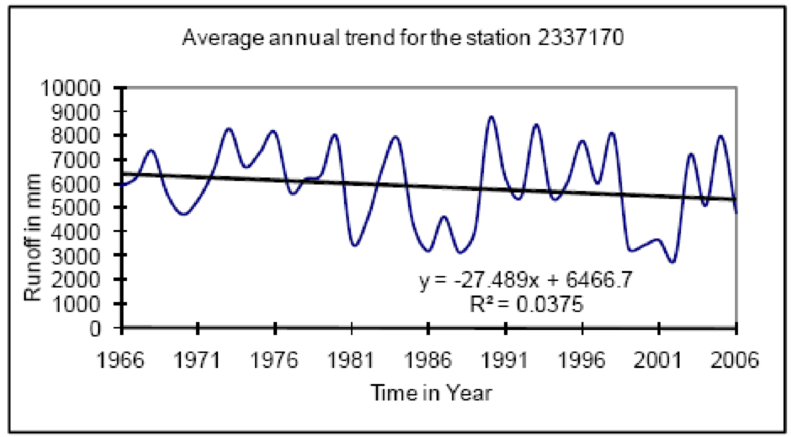

Average annual trend for the station 2223000
1400
1200
1000
800
600
400
200
0
Runoff in mm
y = -0.5712x + 369.4
R² = 0.005
1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year

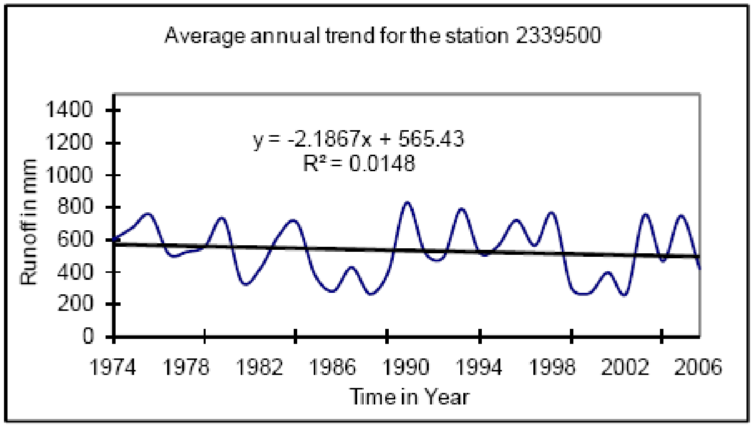

Average annual trend for the station 2337500
1400
1200
1000
800
600
400
200
0
Runoff in mm
y = -2.6196x + 587.54
R² = 0.0525
1955 1961 1967 1973 1979 1985 1991 1997 2003
Time in Year

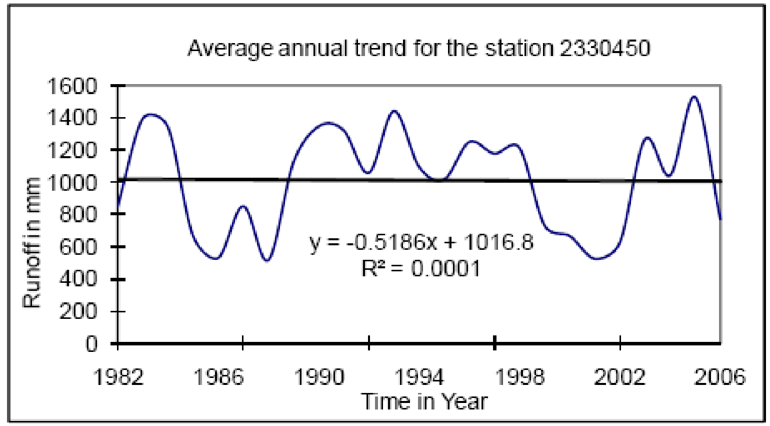

Average annual trend for the station 2178400
Runoff in mm
2000
1800
1600
1400
1200
1000
800
600
400
200
0
y = -5.6964x + 1251.7
R² = 0.0596
1965
1970
1975
1980
1985
1990
1995
2000
2005
Time in Year

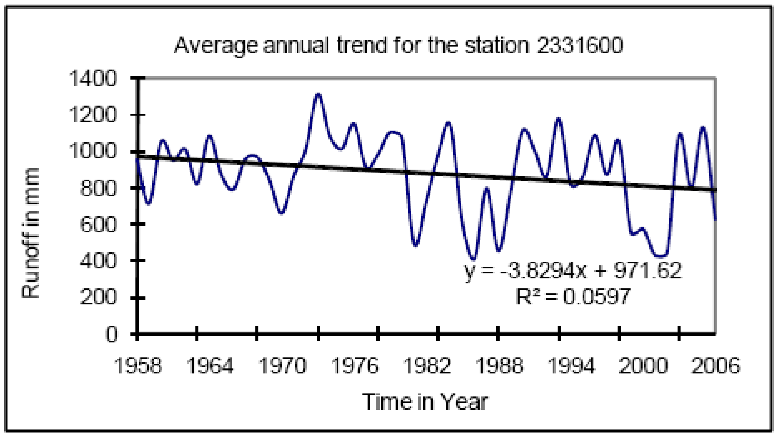

Average annual trend for the station 2212600
Runoff in mm
1400
1200
1000
800
600
400
200
0
y = -2.0507x + 331.86
R² = 0.0422
1965
1970
1975
1980
1985
1990
1995
2000
2005
Time in Year

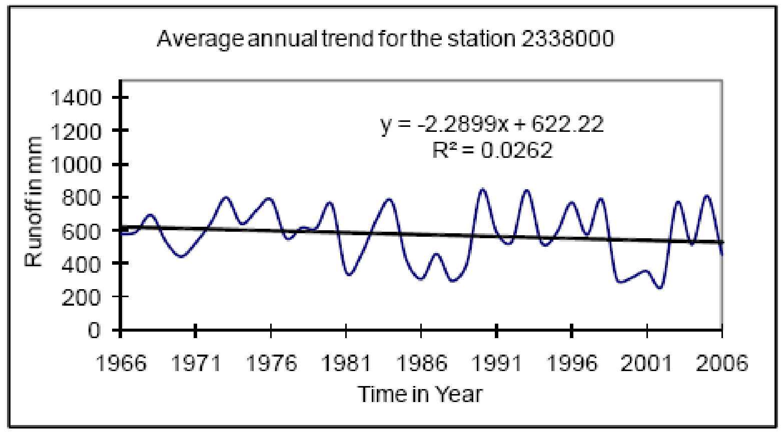

Average annual trend for the station 2344700
Runoff in mm
1400
1200
1000
800
600
400
200
0
y = -0.7505x + 466.96
R² = 0.0031
1965
1970
1975
1980
1985
1990
1995
2000
2005
Time in Year


Average annual trend for the station 2337170
Runoff in mm
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
y = -27.489x + 6466.7
R² = 0.0375
1966
1971
1976
1981
1986
1991
1996
2001
2006
Time in Year

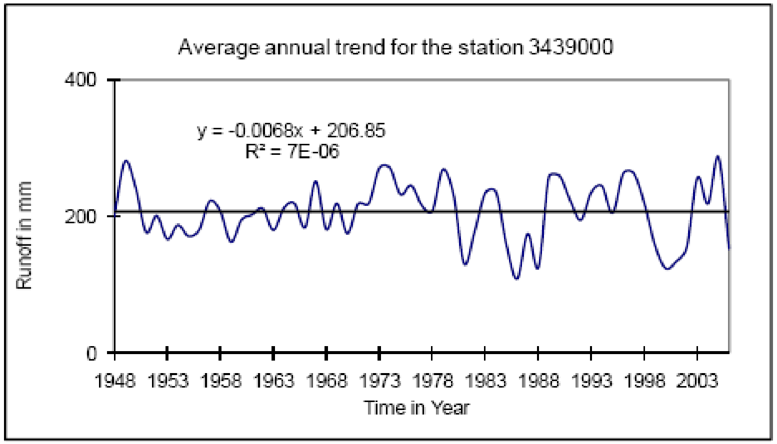

Average annual trend for the station 2339500
y = -2.1867x + 565.43
R² = 0.0148
Runoff in mm
Time in Year
1400
1200
1000
800
600
400
200
0
1974 1978 1982 1986 1990 1994 1998 2002 2006

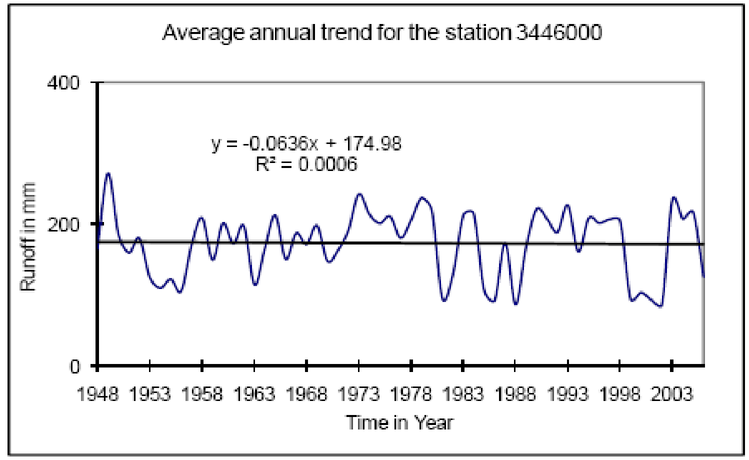

Average annual trend for the station 2330450
y = -0.5186x + 1016.8
R² = 0.0001
Runoff in mm
Time in Year
1600
1400
1200
1000
800
600
400
200
0
1982 1986 1990 1994 1998 2002 2006

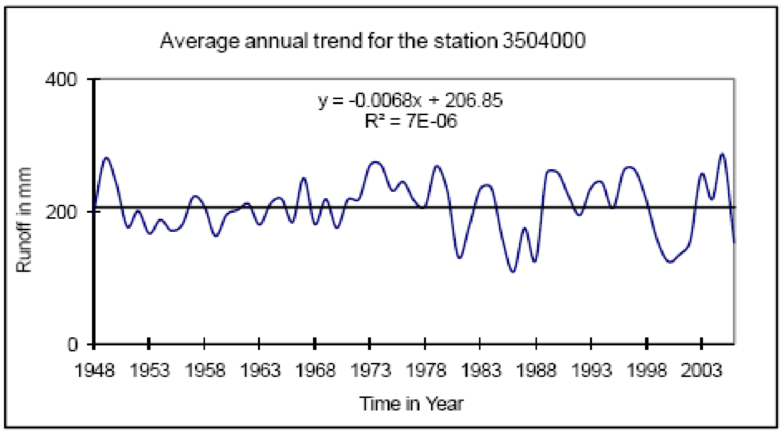

Average annual trend for the station 2331600
y = -3.8294x + 971.62
R² = 0.0597
Runoff in mm
Time in Year
1400
1200
1000
800
600
400
200
0
1958 1964 1970 1976 1982 1988 1994 2000 2006

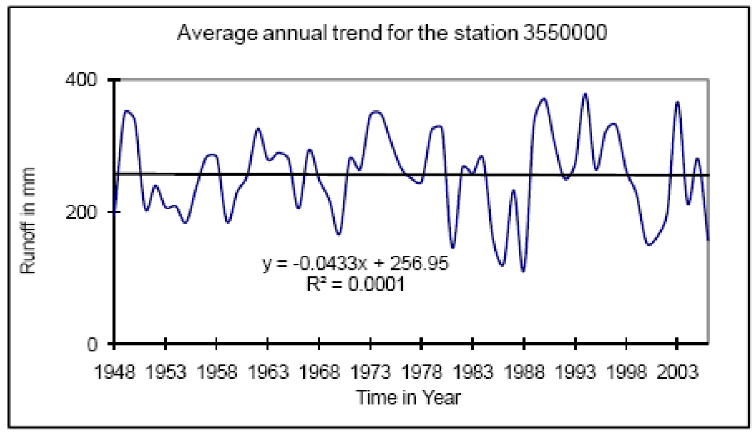

Average annual trend for the station 2338000
y = -2.2899x + 622.22
R² = 0.0262
Runoff in mm
Time in Year
1400
1200
1000
800
600
400
200
0
1966 1971 1976 1981 1986 1991 1996 2001 2006

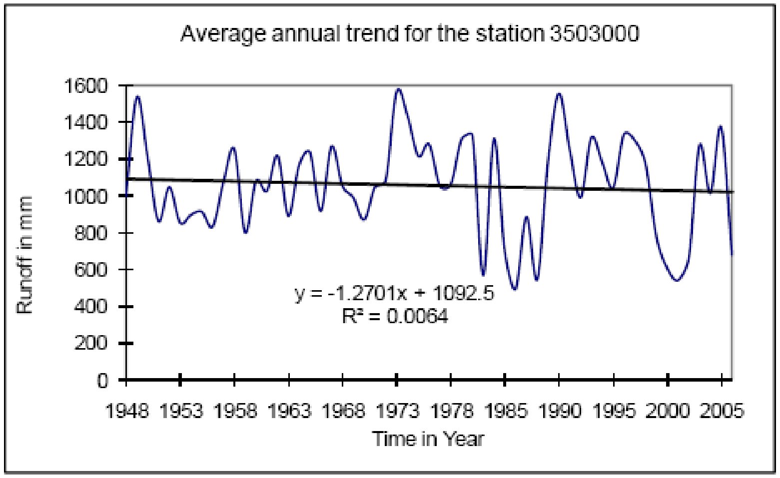
Appendix C-2: Average annual stream runoff in the Blue Ridge province (1948-2006).

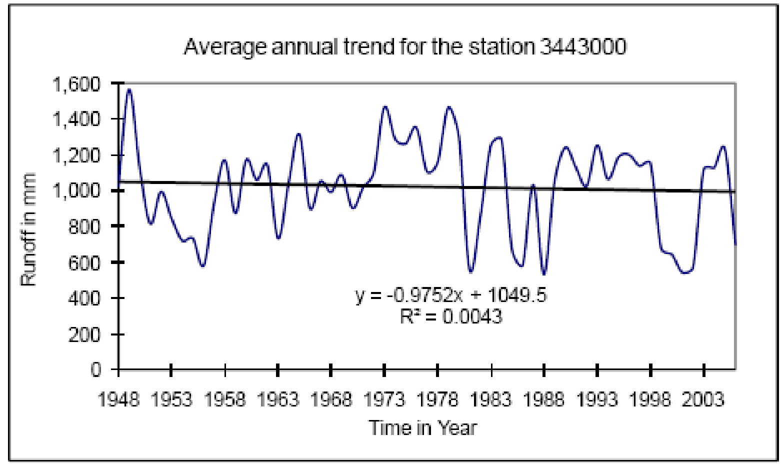


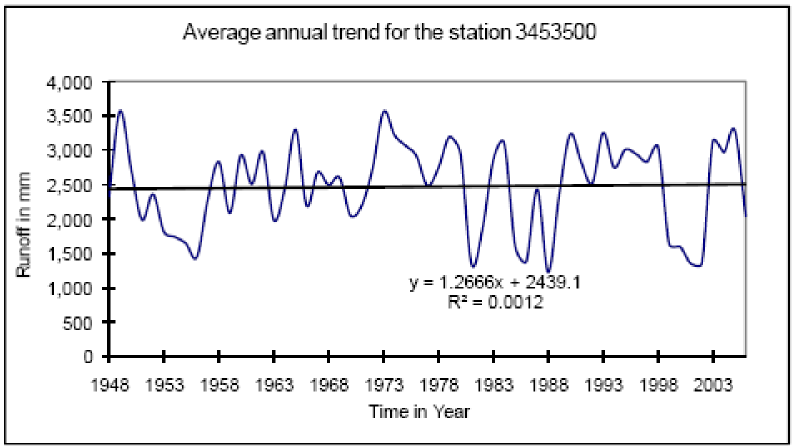


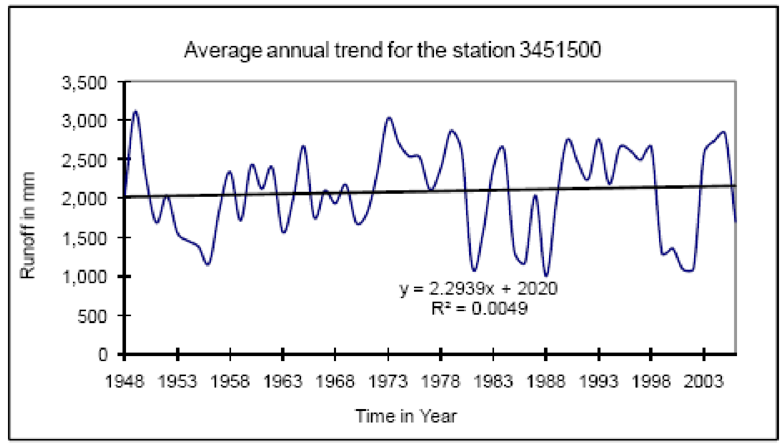


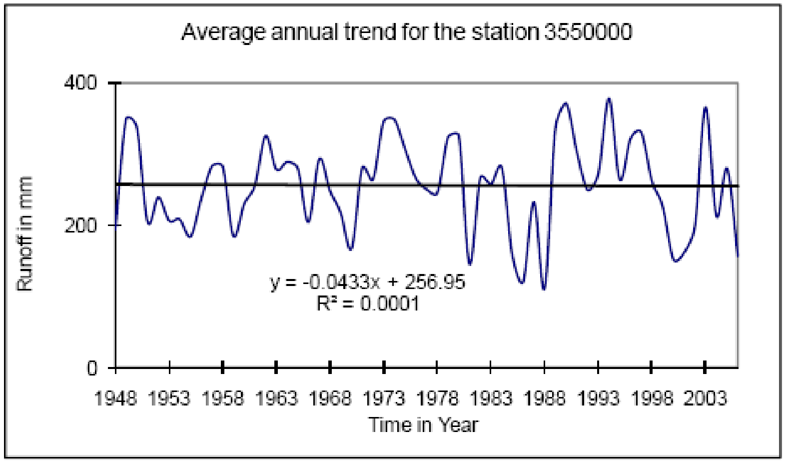


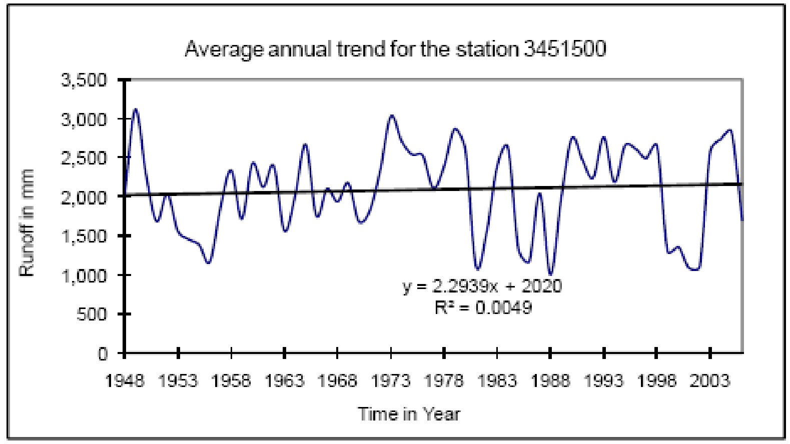

Average annual trend for the station 3503000
Runoff in mm
1600
1400
1200
1000
800
600
400
200
0
y = -1.2701x + 1092.5
R² = 0.0064
1948 1953 1958 1963 1968 1973 1978 1985 1990 1995 2000 2005
Time in Year

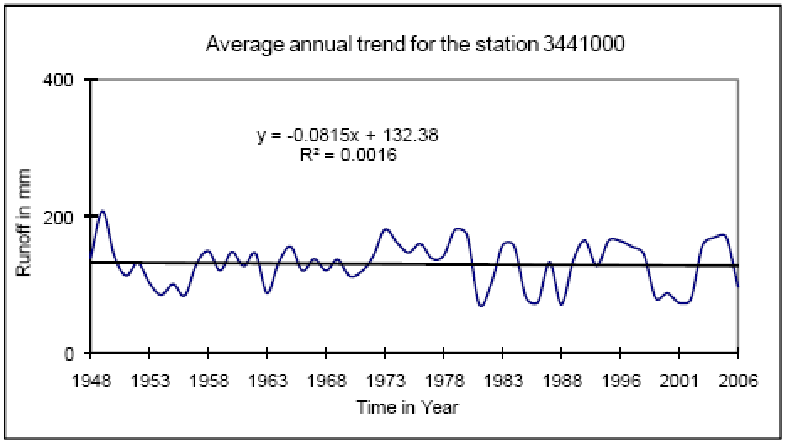

Average annual trend for the station 3443000
Runoff in mm
1,600
1,400
1,200
1,000
800
600
400
200
0
y = -0.9752x + 1049.5
R² = 0.0043
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year

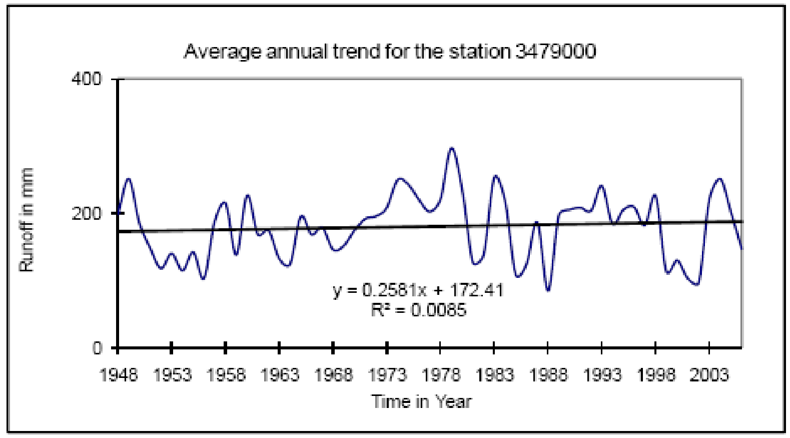

Average annual trend for the station 3453500
Runoff in mm
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
y = 1.2666x + 2439.1
R² = 0.0012
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year

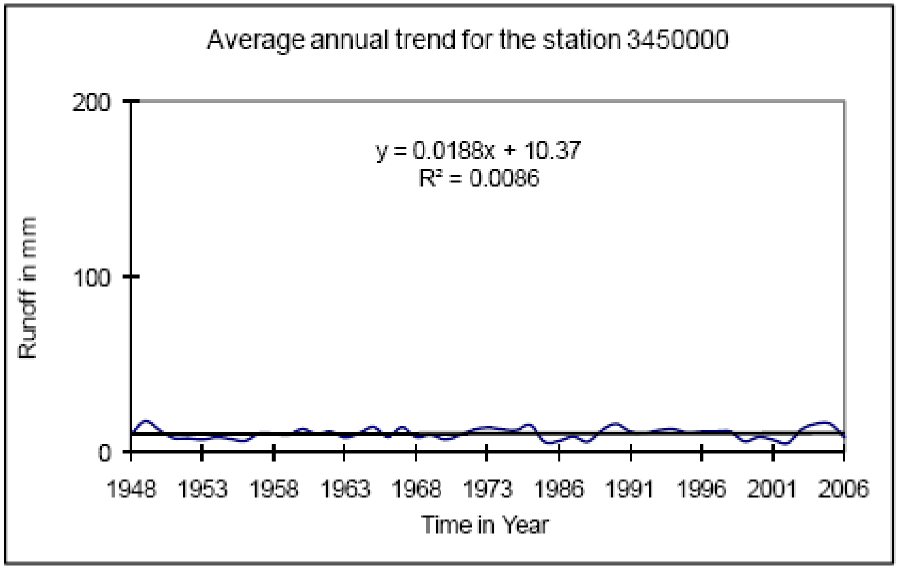

Average annual trend for the station 3451500
Runoff in mm
3,500
3,000
2,500
2,000
1,500
1,000
500
0
y = 2.2939x + 2020
R² = 0.0049
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year


Average annual trend for the station 3550000
Runoff in mm
400
200
0
y = -0.0433x + 256.95
R² = 0.0001
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year


Average annual trend for the station 3451500
Runoff in mm
3,500
3,000
2,500
2,000
1,500
1,000
500
0
y = 2.2939x + 2020
R² = 0.0049
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year


Average annual trend for the station 3441000
Runoff in mm
400
200
0
y = -0.0815x + 132.38
R² = 0.0016
1948 1953 1958 1963 1968 1973 1978 1983 1988 1996 2001 2006
Time in Year


Average annual trend for the station 3479000
Runoff in mm
400
200
0
y = 0.2581x + 172.41
R² = 0.0085
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003
Time in Year


Average annual trend for the station 3450000
y = 0.0188x + 10.37
R² = 0.0086
Runoff in mm
200
100
0
1948
1953
1958
1963
1968
1973
1986
1991
1996
2001
2006
Time in Year

Appendix D: Average annual and seasonal slope for temperature (1948-2006).

Station_No	County	State	DJF	MAM	JJA	SON	Annual
91982	Clayton	GA	-0.03	0.36	0.40	0.45	0.30
98535	Talbotton	GA	-0.03	-0.02	-0.01	-0.02	-0.02
93271	Experiment	GA	-0.03	-0.02	-0.02	-0.02	-0.02
310184	Andrews	NC	0.03	0.04	-0.22	-0.06	-0.05
93621	Gainesville	GA	-0.01	-0.01	0.01	0.01	0.00
90435	athens Airport	GA	0.01	0.02	0.01	0.02	0.02
92318	Covington	GA	-0.06	-0.01	0.00	0.00	-0.02
99157	Washington2 ESE	GA	0.02	0.00	0.00	0.03	0.01
95988	Monticello	GA	-0.02	-0.02	-0.01	0.00	-0.01
94133	Hartwell	GA	-0.03	-0.03	-0.02	-0.01	-0.02
92485	Dallas 7 NE	GA	0.07	0.02	0.05	0.09	0.06
90969	Blairsville exp	GA	-0.04	-0.01	-0.03	0.03	-0.01
316001	Murphy 2 NE	NC	0.05	0.05	0.58	0.55	0.31
312200	Cullowhee	NC	-0.02	0.01	0.01	0.02	0.00
314055	Highlands 2 S	NC	-0.09	-0.06	-0.03	0.32	0.03
311624	Celo 2 S	NC	0.01	0.05	0.04	0.06	0.04
310901	Blowing Rock 1 NW	NC	0.04	0.02	0.02	-0.01	0.02
314496	Jefferson 2 ESE	NC	0.01	-0.07	0.02	0.02	-0.01
310506	Banner ELK	NC	-0.01	0.02	0.04	0.05	0.03
315356	MARSHALL	NC	-0.01	-0.01	-0.01	0.01	-0.01
313976	Hendersonville	NC	0.01	0.03	0.04	0.06	0.03
319147	Waynesville	NC	-0.02	-0.01	0.02	0.02	0.00
316805	Pisgahforest 1 N	NC	-0.01	-0.01	0.00	0.01	0.00
318964	Transou	NC	-0.04	-0.02	0.01	0.00	-0.01
94648	Jasper 1 NNW	GA	-0.04	-0.02	-0.01	-0.01	-0.02
91640	Carrollton	GA	-0.03	0.00	0.01	0.00	0.00

98661	Thomaston	GA	0.00	0.01	0.01	0.01	0.01
96335	Newnan	GA	-0.04	-0.03	-0.02	-0.02	-0.03
98740	Toccoa	GA	-0.02	-0.02	0.01	0.01	0.00
99141	Warrenton	GA	-0.06	-0.04	-0.01	-0.02	-0.03
90444	Bolton	GA	0.00	0.00	0.00	0.00	0.00
312102	Coweeta EXP STN	NC	0.00	0.00	0.04	0.04	0.02
90451	atlanta Airport	GA	0.01	0.02	0.02	0.03	0.02
99291	West point	GA	-0.04	-0.03	0.00	0.01	-0.02

DJF= December, January, February
MAM= March, April, May
JJA= June, July, August
SON= September, October, November
Annual= Average annual temperature

Appendix E: Average annual and seasonal slope for rainfall (1948-2006).

Station_No	County	State	DJF	MAM	JJA	SON	Annual
91982	Clayton	GA	-1	-2	0	2	0
98535	Talbotton	GA	-2	-2	-1	0	-1
93271	Experimen	GA	-1	-1	-1	1	-1
93621	Gainesville	GA	-1	-2	0	1	0
90435	athens Airport	GA	-1	-1	0	1	0
92318	Covington	GA	-1	-1	1	1	0
99157	Washington2 ESE	GA	-1	-1	-1	1	-1
95988	Monticello	GA	0	-2	0	1	0
94133	Hartwell	GA	0	-1	1	1	0
92485	Dallas 7 NE	GA	1	0	1	1	1
90969	Blairsville exp	GA	-1	-1	1	1	0
94648	Jasper 1 NNW	GA	-1	-1	1	2	0
91640	Carrollton	GA	-1	-1	0	1	0
98661	Thomaston	GA	-2	-2	-1	1	-1
96335	Newnan	GA	-1	-2	-1	1	-1
98740	Toccoa	GA	-1	-2	0	1	-1
99141	Warrenton	GA	-1	-2	2	0	0
90444	Bolton	GA	-3	-2	1	0	-1
90451	atlanta Airport	GA	-1	-2	1	1	0
99291	West point	GA	-1	-2	0	0	-1
316001	Murphy 2 NE	NC	1	0	0	1	0
312200	Cullowhee	NC	1	0	0	1	1
314055	Highlands 2 S	NC	0	-1	-2	4	0
311624	Celo 2 S	NC	0	0	0	2	0
310901	Blowing Rock 1 NW	NC	2	1	-1	2	1
314496	Jefferson 2 ESE	NC	0	0	0	0	0

310506	Banner ELK	NC	-1	-1	-1	1	0
315356	Marshall	NC	0	0	1	0	0
313976	Hendersonville	NC	0	-1	0	1	0
319147	Waynesville	NC	0	0	1	1	1
316805	Pisgahforest 1 N	NC	0	-2	-1	0	-1
318964	Transou	NC	0	-1	0	2	0
312102	Coweeta EXP STN	NC	1	-2	-1	2	0
310184	Andrews	NC	-1	0	0	1	0

DJF= December, January, February
MAM= March, April, May
JJA= June, July, August
SON= September, October, November
Annual= Average annual rainfall

Appendix F: Average annual and seasonal slope for stream runoff (1948-2006).

SON	Station #	Area (Sq. mile)	County	River Name	DJF	MAM	JJA	SON	Annual
348.00	2330450	45	white	Chattahoochee River at Helen	-6	-5	4	7	0
608.00	2331600	315	Habersham	Chattahoochee River near Cornella	-3	-10	-3	0	-4
446.00	2338000	2430	Carroll	Chattahoochee River near Whitesburg	-2	-6	0	-1	-2
199.00	2347500	1850	Upson	Flint River near Culloden	-3	-4	0	0	-2
240.00	2344500	272	Spalding	Flint River near Griffin	-3	-4	0	1	-1
259.00	2192000	1430	Elbert	Broad River near Bell	-1	-2	0	0	-1
77.00	2217500	398	Clarke	Middle Oconee River near Athens	0	0	0	0	0
110.00	2212600	72	Jones	Falling creek near Juliette	-4	-3	0	1	-2
801.00	2177000	270	Oconee	Chattooga River near Clayton	-1	-5	1	3	0
776.00	2178400	57	Rabun	Tallulah River near Clayton	-8	-12	-4	0	-6
134.00	2193500	292	Wikes	Little River near washington	0	-4	1	1	-1
189.00	2223000	295	Baldwin	Oconee River at milledgeville	-2	-3	0	1	-1
511.00	2333500	153	Lumpkin	Chestatee River near Dahlonega	-2	-5	0	1	-2
611.00	2334430	1040	gwinett-F	Chattahoochee River at Buford dam	1	-5	-1	-3	-2
600.00	2335000	1170	Gwinett	Chattahoochee River near Norcross	1	-6	-2	-3	-2
518.00	2336000	1450	Fulton	Chattahoochee River at Atlanta	1	-4	0	-1	-1
263.00	2337000	246	Douglas	Sweetwater creek near Austell	1	0	2	3	1
290.00	2337500	36	Carroll	Snake creek near Whitesburg	-4	-6	-1	0	-3
398.00	2339500	3550	Troup	Chattahoochee River at Westpoint	-5	-7	2	-1	-2
404.00	2392000	613	Cherokee	Etowah River at Canton	-2	-4	-1	2	-1
337.00	2335700	72	Fulton	Big Creek Alpharetta	-3	-5	1	5	0
4821.00	2337170	206	Fulton	Chattahoochee River near Fairburn	-2	-5	-1	-2	-3

272.00	2336300	86.6	Fulton	Peachtree Creek	1	-3	3	2	1
192.00	2344700	101	Coweta	Line creek near Senola	-5	-3	3	1	-1
307.27	3550000	104	Cherokee	Valley River at Tomotla	-3	0	0	1	0
625.05	3504000	52	Macon	Nantahala River near Rainbow Spr	-3	-1	0	2	0
387.25	3503000	436	Swain	Little Tennessee River at Needmo	-2	-2	0	0	-1
462.03	3500000	140	Macon	Little Tennessee River near Pren	-2	-3	0	1	-1
3335.10	3453500	1332	Madison	French Broad River at Marshall	4	-4	1	-1	0
411.43	3451500	945	Buncombe	French Broad River atAsheville	1	-1	0	0	0
195.84	3451000	130	Buncombe	Savannah River at Biltmore	-1	-1	0	0	0
284.16	3450000	5	Buncombe	Bee Tree Creek near Swannanoa	0	0	0	1	0
489.06	3446000	67	Henderson	Mills River near mills river	-1	-2	0	0	-1
659.32	3443000	296	Transylva	French Broad River at Blantyre	0	-3	-1	0	-1
603.82	3441000	40	Transylva	Davidson River near Brevard	1	-3	-1	0	-1
672.14	3439000	68	Transylva	French Broad River at Rosman	0	-3	-1	0	-1
341.53	3479000	92	Watauga	Watauga River near Sugargrove	0	0	0	1	1
425.91	3161000	205	Ashe	South fork new River near Jeffer	-1	-1	0	0	0

Appendix G-1: 10-year temperature (^{o} F) average in the Blue Ridge province, NC.

Year	**318694**	**316805**	**319147**	**313976**	**315356**	**318744**	**314496**	**310901**	**310506**	**311624**	**314055**	**312102**
1954	51.65	56.15	55.06	55.87	55.03	61.94			50.20	51.60	54.16	55.30
1964	50.67	54.36	53.72	54.84	54.14	60.24		48.99	49.34	50.62	53.11	54.25
1974	50.63	53.69	53.48	54.80	55.27	59.56	52.08	48.60	49.17	50.93	53.02	54.15
1984	49.79	53.69	53.36	56.21	55.15	59.53	51.23	49.42	49.06	50.92	52.11	53.86
1994	50.98	54.27	54.88	56.64	54.40	60.65	51.75	49.67	50.87	52.22	50.45	55.03
2004	49.99	54.66	53.96	56.39	54.36	60.38	50.89		49.15	53.46	50.89	55.97
2005		54.83		56.54								
2006	50.20		53.96			60.51	51.44		47.07	53.64	51.39	56.46

310184	**312200**	**313228**	**316001**
55.37	56.88	56.82	
54.69	55.92	55.65	
54.42	55.18	55.89	56.11
54.66	55.20	55.78	55.30
56.24	57.05	56.66	56.62
53.39	56.24	55.22	56.56
	56.03	55.63	56.99

Appendix G-2: 10-year temperature (^{o} F) average in the Piedmont province, GA.

Year	90969	91982	93621	92485	99157	93271	90451	99291	95988	90435		92318	98535	94133
1954	56.75	58.85	61.38		63.38	62.64	62.39	63.78	64.97	62.48	63.38	63.28	64.44	62.14
1964	54.37	56.98	60.52	57.58	62.15	61.99	61.55	63.18	61.78	61.20	60.26	61.44	62.41	62.85
1974	54.45	56.85	57.82	59.46	59.73	61.57	60.45	61.94	62.70	61.12	59.73	61.13	63.13	62.55
1984	54.40	56.21	58.52	58.58	61.10	60.57	61.20	62.00	62.66	61.90	61.10	61.66	63.22	62.40
1994	55.72	57.20	60.64	59.58	61.34	61.04	63.16	62.24	63.81	62.37	61.34	61.74	63.03	62.17
2004	55.6	56.51	60.55	60.01	61.53	61.38	62.67	61.60	61.66	62.06		61.39	62.46	60.61
2006		56.48	60.35		61.71			61.63	61.48	62.26	61.71	61.18		61.14

Year	98661	96335	98740	99141	94648	91640
1954		63.56	62.19	63.90	61.14	60.43
1964	62.59	62.40	60.84	63.41	58.47	60.35
1974	63.53	61.77	60.14	62.51	57.89	60.14
1984	63.70	61.13	60.54	61.90	58.17	60.81
1994	63.98	61.81	60.69	61.42	58.22	60.71
2004	63.02	61.56	61.53	61.93	58.76	60.81
2006		61.42	61.37	62.28	59.04	60.49

Appendix H-1: 10-year rainfall (millimeter) average in the Blue Ridge province, NC.

Year	**310184**	**312102**	**314055**	**312200**	**316236**	**311624**	**310506**	**310901**	**314496**
1953	1438.4	1718.1	1942.6	1114.1	1061.2	712.5	1217.4		1141.2
1963	1548.0	1771.9	1971.1	1214.1	1239.6	1414.0	1253.1	1458.9	1150.7
1973	1589.6	1863.9	2032.3	1293.5	1219.5	1486.4	1243.2	1628.9	1185.7
1983	1646.8	1913.1	2129.4	1324.6	1298.3	1605.3	1358.2	1761.7	1385.7
1993	1525.4	1753.5	2197.6	1262.3	1176.4	1422.1	1224.3	1673.2	1116.3
2003	1623.7	1768.3	2088.2	1304.6	1224.9	1434.6	875.4	1409.6	1073.2
2006		1726.3			1265.1	1459.4	774.4		1160.9

Year	**318744**	**315356**	**313976**	**319147**	**316805**	**318694**	**316001**
1953	1517.8	954.2	1116.7	1086.4	1307.6	1358.1	1521.9
1963	1741.1	1049.3	1318.7	1132.1	1609.1	1327.2	1408.1
1973	1754.9	974.6	1412.3	1183.6	1694.2	1323.7	1408.9
1983	1770.3	1028.3	1478.5	1244.8	1718.0	1507.4	1403.6
1993	1681.0	1030.0	1375.7	1201.6	1595.6	1423.2	1314.4
2003	1517.6	1034.7	1426.5	1246.5	1583.6	1412.1	1484.8
2006			1405.1	1231.9	1483.3	1392.4	

Appendix H-2: 10-year rainfall (millimeter) average in the Piedmont province, GA.

Year	**90969**	**91982**	**92006**	**93621**	**91585**	**92485**	**96407**	**99157**	**93271**	**90451**	**99291**	**95988**	**90435**
1944													
1954	1411.1	1768.8	1514.4	1353.3	1349.4	939.4	1147.1	1006.1	1298.8	1236.5	1314.5	1035.3	1050.3
1964	1393.2	1740.1	1646.1	1363.8	1378.6	1207.4	1232.2	1219.0	1293.3	1206.5	1329.6	1139.6	1286.0
1974	1459.9	1853.6	1735.5	1510.9	1479.2	1398.1	1382.5	1334.1	1430.7	1273.1	1381.0	1160.1	1340.7
1984	1520.2	1961.9	1645.6	1403.4	1539.4	1428.3	1483.9	1172.8	1277.3	1279.4	1266.5	1093.1	1237.3
1994	1421.8	1724.5	1599.2	1332.4	1304.2	1299.7	1363.4	1152.7	1208.5	1345.5	1280.3	1203.9	1187.5
2004	1446.3	1869.6	1573.5	1429.1	1388.9	1389.3	1384.6	1109.9		1205.6	1184.7		1218.8
2006	1396.1	1733.7	1526.6	1362.4	1391.2	1345.1		1062.7		1187.4	1154.1		1170.9

Year	**91640**	**98661**	**96335**	**98740**	**99141**	**90444**	**92318**	**98535**	**94133**	**94648**
1944				1460.0	1169.5			1241.3		
1954	983.4		968.0	1549.5	1131.0		999.1	1358.4	1182.6	1312.9
1964	1341.4	1120.4	1277.3	1441.3	1265.8	1410.3	1198.7	1390.8	1180.0	1370.9
1974	1409.4	1319.2	1358.7	1585.7	1241.3	1522.0	1331.6	1407.1	1378.8	1492.8
1984	1379.0	1222.7	1272.6	1635.1	1348.7	1225.8	1257.0	1271.0	1173.0	1568.9
1994	1207.9	1250.4	1342.1	1464.4	1176.9	1281.2	1192.6	1236.2	1249.2	1420.4
2004	1369.6	1189.5	1214.9	1443.0	1136.6	1327.0	1228.5	1220.8	1270.0	1487.7
2006	1327.3			1378.6	1092.8	1332.2			1224.6	1431.9

Appendix I-1: 10-year runoff (millimeter) average in the Blue Ridge province, NC.

Year	**3161000**	**3439000**	**3446000**	**3453000**	**3504000**	**3450000**	**3550000**	**3503000**	**3500000**
1954	427.41	242.90	171.14	143.21	207.70	10.48	248.76	1058.21	398.19
1964	404.93	223.68	160.89	157.81	194.33	10.19	255.22	1026.14	368.52
1974	464.71	257.15	188.00	157.20	220.47	11.44	265.12	1147.41	420.59
1984	497.26	260.52	190.72		217.83	10.88	267.05	1212.54	419.96
1994	426.85	232.51	163.20		198.03	10.62	253.40	1011.58	357.03
2004	402.47	226.00	164.23	150.47	199.28	10.46	249.75	973.48	358.02
2005	481.90	296.90	216.80	180.10	286.40	16.30	280.00	1373.00	534.30
2006	368.30	156.70	126.20	129.50	152.60	8.85	156.70	679.20	276.90

Year	**3453500**	**3451500**	**3451000**	**3443000**	**3441000**	**3479000**
1954	2365.57	2025.14	162.14	1014.87	131.64	165.40
1964	2317.90	1900.70	154.18	945.52	122.53	161.53
1974	2704.10	2223.80	173.32	1113.42	138.61	186.20
1984	2654.80	2274.10	178.80	1159.45	142.43	215.82
1994	2359.80	1994.00	139.64	959.64	119.89	174.69
2004	2389.40	2060.40	152.06	937.68	127.37	173.94
2005	3288.00	2834.00	217.20	1234.00	169.60	202.50
2006	2041.00	1702.00	127.60	700.70	96.60	147.30

Appendix I-2: 10-year runoff (millimeter) average in the Piedmont province, GA.

Year	2333500	2334430	2335000	2336000	2337000	2337500	2339500	2392000	2337170	2344700	2336300
1954	815.69				450.88			665.42			
1964	826.30	594.10	623.38	544.95	444.58	504.27		658.20			476.93
1974	912.90	737.78	725.12	665.73	519.16	592.55	598.38	760.92	6321.88	464.00	566.96
1984	875.56	728.70	736.61	670.41	551.96	627.32	579.95	790.07	6437.51	472.94	571.29
1994	774.90	585.05	589.15	533.45	453.51	452.99	485.26	628.29	5376.53	425.05	544.67
2004	729.67	562.29	562.27	536.30	502.41	438.60	502.19	614.60	5361.47	427.54	529.50
2005	1069.75	826.83	811.58	822.50	701.07	508.93	744.26	416.28	8007.14	802.92	846.08
2006	560.45	541.39	520.43	505.06	419.63	275.83	415.88	396.82	4808.64	236.57	424.63

Year	2330450	2331600	2338000	2347500	2344500	2192000	2217500	2212600	2177000
1954				438.82	444.17	424.53	434.21		1045.75
1964		938.01		437.34	446.97	421.24	429.02		1014.03
1974		932.77	607.66	461.59	459.35	468.29	500.33	303.34	1225.82
1984	1191.46	954.33	630.99	443.36	486.88	479.34	502.63	335.10	1222.52
1994	991.17	799.21	523.00	368.59	448.81	382.07	401.66	263.32	1024.62
2004	947.59	773.59	526.44	357.35	410.67	388.20	426.74	258.02	1016.43
2005	1523.40	1129.60	810.18	660.69	684.13	522.25	553.83	368.67	729.39
2006	766.71	623.69	456.03	213.02	240.21	273.66	324.69	119.86	669.26

Year	2178400	2192000	2193500	2217500	2223000
1954		424.53	231.03	434.21	267.53
1964		421.24	327.28	429.02	370.95
1974	1244.90	468.29		500.33	374.14
1984	1203.04	479.34		502.63	391.77
1994	1034.61	382.07	307.42	401.66	306.13
2004	1047.06	388.20	274.45	426.74	343.27
2005	837.87	522.25	228.72	553.83	425.79
2006	771.96	273.66	99.07	324.69	203.02