EVALUATING POLLUTANT CONCENTRATIONS IN URBAN STREAMS BASED ON PRECIPITATION, NETWORK OF STORMWATER BMPs, AND IMPERVIOUS COVER

by

Manish Venugopal

A thesis proposal submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Construction and Facilities Management

Charlotte

2019

Approved by:

____
Dr. Nicole Barclay (Chair)

____
Dr. Craig Allan

____
Dr. Don Chen

ABSTRACT

MANISH VENUGOPAL. Evaluating pollutant concentrations in urban streams based on precipitation, network of stormwater BMPs, and impervious cover
(Under the direction of DR. NICOLE BARCLAY)

The increase in impervious surfaces accompanying urban development in the recent decade has caused an increase in the volume of stormwater runoff and pollutant loads flowing downstream to receiving waters. In response to increased volumes of impaired stormwater runoff, there is a growing use of stormwater best management practices (BMPs) in urban areas. As such, there is a need to monitor the concentration of pollutants that enter receiving streams. This monitoring aids in decision-making to improve the efficiency of the BMPs. In addition, monitoring may provide a case for increasing the number of BMPs to reduce the pollutants entering downstream and improving the efficiency of the existing BMPs. The purpose of this study is to evaluate stormwater runoff quality in various creeks in the City of Charlotte and show the associated needs for BMPs. Pollutant concentration data is collected from Charlotte-Mecklenburg Stormwater Services, and rainfall data is gathered from the United States Geological Survey. The water quality data is collected for all the creeks in Mecklenburg County. However, the data and analysis of Mallard Creek, Reedy Creek, and Sugar Creek is used to show the results. Rainfall data is collected from the rain gauge set-up at Fire Station 30 near the Charlotte Douglas Airport. Temporal and spatial relationships are explored with variables including time, precipitation, pollutant loading, and concentration and urbanization-as measured by the rate of increase of impervious surfaces within watersheds. These relationships will help in understanding the variations in the pollutant concentration, and will also aid in recommendations for the allocation of BMPs throughout watersheds. Overall, this work will contribute to the literature about the need for improving efficiencies in location, design and maintenance of stormwater systems.

ACKNOWLEDGMENTS

I would like to dedicate this work to my advisor Dr. Nicole Barclay. Her consistent guidance and motivation has helped me to carve out goals and achieve them. Without her insights and knowledge this thesis would not be possible. I would also like to thank my committee members Dr. Don Chen and Dr. Craig Allan for their pertinent advice, invaluable comments, and time to help with this research.

Finally, I would like to thank my parents for their constant support and encouragement during the toughest of times. This accomplishment would not have been possible without their blessings and love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BMPs- Best Management Practices

TSS- Total Suspended Solids

TP- Total Phosphorous

TKN- Total Kjeldahl Nitrogen

TN- Total Nitrogen

TZn- Total Zinc

SSC- Suspended Sediment Concentration

E. coli- Escherichia Coli

Cu- Copper

Ni- Nickel

Cd- Cadmium

Zn- Zinc

Pb- Lead

Mn- Manganese

OP- Ortho Phosphate

TOC- Total Organic Carbon

DOC- Dissolved Organic Carbon

BOD- Biological Oxygen Demand

COD- Chemical Oxygen Demand

NPA- Neighborhood Profile Area

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Population growth has increased the demand for urban land use. According to reports from the U.S. Census Bureau (2010), eighty percent of the population live in urban areas. The result of this continuous development in urban areas is a major source of environmental change in the country (Coles et al., 2012). In general, urbanization takes place near streams, and rivers considering the need for water are being fulfilled, the result of which is an increase in the impervious surface near these water sources.

The volume of stormwater runoff and amount of pollution flowing downstream to receiving waters has increased due to the increase in impervious surface accompanying urban development over recent decades (Dietz, 2007; Lucke & Beecham, 2011; Lucke & Nichols, 2015). Measures are needed to alleviate the resulting flood risk and nuisance caused by excess stormwater runoff. Therefore, in planning and construction of new developments and maintenance of existing stormwater infrastructure, the management of stormwater runoff in urban areas has become a priority issue for those responsible (Lucke & Nichols, 2015).

Pollutants such as heavy metals, nitrogen, phosphorous and suspended solids come from construction, industrial, and municipal wastes (Carpenter et al., 1998; Pappu, Saxena, & Asolekar, 2007). To mitigate the negative environmental and ecological impacts in terms of stormwater runoff quantity and quality, various stormwater best management practices are implemented in urban areas. Examples of these include wet ponds, bio-retention basins, ecology ditches, and green roofs.

The US Census Bureau (2010) states that the population of North Carolina was 9,535,483 and is estimated to be 10,383,620 as of 2018. Out of this Mecklenburg County had a population of 919,628 and was stated as the most urbanized county in North Carolina. Ninety nine percent of the Mecklenburg's population live in urban areas with 86% of land being classified as urbanized as of 2010.

Rural regions such as agricultural land, wildlife habitat, and open spaces are converted into urban areas due to the increase in population growth. The United States Department of Agriculture- National Resources Conservation Service (2003) stated that the annual rate of land conversion has nearly doubled and shown it across two measured periods of 1982-1992; 1992-2001 by National Resource Inventory (McColl & Aggett, 2007). Increased volumes of surface water runoff, greater incidence of flooding, altered downstream river channel geometry through erosion, and the degradation of aquatic habitat of fish and other biota have occurred as a result of alteration in a watershed's response to precipitation events (McColl & Aggett, 2007).

Since urbanization is on the rise in this Mecklenburg County area, impervious cover has also been on an increase. This has resulted in bank erosion and stream instability. In addition, the pollutants can be both of point and non-point sources. These impacts cannot be tackled by stream restoration alone. Therefore, in order to mitigate the menace, Charlotte Mecklenburg Stormwater Services use stormwater BMPs, also known as green infrastructure to supplement traditional stormwater infrastructure. According to Charlotte Mecklenburg Stormwater Services, there are nine types of BMPs approved to be used in Charlotte, Mecklenburg County. They are: Bio-retention, Wet Ponds, Wetlands, Enhanced

Grassed Swales, Grass Channels, Infiltration Trenches, Filter Strips, Sand Filters, and Extended Dry Detention BMPs.

1.2 Objectives and Scope

The goal of this project is to investigate how seasonal variation in precipitation and the network of existing BMPs in watersheds affect the concentration of pollutants that enter receiving streams in Mecklenburg County, NC watersheds. Additionally, this study gives a basis for predictive stormwater modeling to forecast the needs for BMPs in the studied watersheds. To perform this goal, we use pollutant concentration data obtained from Charlotte-Mecklenburg Stormwater Services. Also, we obtained rainfall data from the United States Geological Survey. In addition, data for the existing network of stormwater BMPs and the percentage impervious cover of Mecklenburg County was obtained from Open Mapping Charlotte Mecklenburg Stormwater Services.

The main goal is achieved through the completion of the following objectives. The first objective is to evaluate the pollutant concentration from stormwater runoff that enters streams during storm events. These results will be compared with that of base flow in these streams. Direct runoff resulting from storm events is known as storm flow while flow which occurs during normal weather conditions is known as base flow. The scope of this objective is to identify the variations in the pollutant concentration during varying seasons. The second objective is to establish and evaluate the relationships between existing BMPs, urbanization in terms of impervious cover, and pollutant concentration in the streams. The results will aid in identifying the effects of urbanization on the pollutant concentration that the BMPs must treat.

This document will help in providing recommendations for the allocation of stormwater BMPs throughout watersheds in the state of North Carolina based on the precipitation, existing network of BMPs and impervious cover percentage. Results can be used by engineers and contractors as a guiding factor to plan for design, operation, and maintenance of BMPs. This will aid in treating various pollutants before they enter streams due to the increase in stormwater runoff from development due to construction.

1.3 Research Questions

1. What is the seasonal variation of pollutant concentrations in streams over a 10-year period from 2010 to 2019?
2. What is the relationship among existing stormwater BMPs, urbanization in terms of impervious cover and water quality in streams?
3. How can the modelled data be used to predict the need for BMPs and serve as a guiding factor in the design and implementation of stormwater systems?

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the health of urban streams and impacts of various factors that affects them. The various factors such as precipitation, existing BMPs and urbanization in terms of impervious cover and their effects are explained from the existing literature available. It also provides details on how the BMPs are used to address problems related to stormwater.

2.2 Urbanization and Land Use

Human population is on the rise across the globe. A large proportion of the earth's land surface is been transformed due to the conversion of natural landscapes by humans (Foley et al., 2005). Fifty percent of the population resides in the urban areas across the globe (O'Driscoll et al., 2010). This trend will be on the rise in the future. People living in cities globally and in Europe and United States will be 60% and 83% respectively at the end of 2025 (Morley & Karr, 2002). On May 16, 2018 a United Nations report stated that 55% of the world population live in cities. Most of the growth takes place downstream where streams and other water bodies like rivers and coastal waters are connected (Coles et al., 2012). The result of which there is an increase in urbanization and usage of land near the watersheds.

Increase in urbanization has also increased the demand for water. Therefore, urbanization usually happens where there is a potential source of water. This will provide water for drinking and transportation. Land use and hydrological functions of the watershed are affected due to this process. There is also a snowballing in impervious surface areas in the region which contributes to floods during storm events (Cheng, Lee, & Lee, 2010).

Impervious surfaces such as roads, rooftops, and less permeable surfaces like lawns and parks are taking over the pervious-forest cover due to urbanization (Finkenbine, Atwater, & Mavinic, 2000).

2.3 Urban Stream Health

Streams are affected hydrologically, and morphologically. The ecological health of the watersheds is affected by urbanization near streams and rivers (Morley & Karr, 2002). Watershed paving is responsible for most of the physical damage in urban streams (Finkenbine et al., 2000). Growth of impervious surface areas is always directly proportional to the surface runoff (Cheng et al., 2010), resulting in potential floods. Severe erosion, habitat destruction and degradation of stream ecosystem take place because of these floods (Coles et al., 2012). Intense floods also result in infrastructure damage (Bell et al., 2016).

During storm events, there is an upsurge in the volume of surface runoff, and the amount of pollution flowing downstream with decreased flow time. There is a change in the pattern of flow, channel morphology, frequency and magnitude of peak flows, and the decrease in base-flow (Line, 2013). The stream ecosystems nutrient cycling and temperature is affected by the changes in base-flow (Bhaskar et al., 2016). As impervious surfaces prevent infiltration, the amount of ground-water recharge is reduced (Finkenbine et al., 2000).

Construction activities in watersheds affect the fine sediment, while stream enlargement through the bed and bank erosion are caused by high peak flows (Finkenbine et al., 2000). There is an increase in nitrogen, sediment and phosphorous content due to the growth of residential areas (Line, 2013).

2.4 Stormwater Impacts on the Environment

Worldwide, there is a well-documented decline in habitat and water quality of urban streams (Elliott & Trowsdale, 2007). Untreated stormwater runoff possesses significant threats to our environment. An important cause of surface water quality degradation in the United States is urban nonpoint pollution. In the US, urban stormwater is thought to be the fifth leading cause of impairments of streams and rivers and the tenth leading cause of impairments of estuaries (Schwartz, Sample, & Grizzard, 2017). Runoff from developed areas continues to be a leading cause of impairments in the nation's waterways (US EPA, 2002). Development continues at a rapid pace throughout the country, with some cities increasing in spatial size by up to 50% in the past 30 years (US EPA, 2001).

The polluted runoff consists of total suspended solids, nitrogen, phosphorous and other heavy metals which causes various impacts on human health and the environment. Decreased infiltration is the cause of more runoff and the reduced time during which the runoff occurs. Land-use changes coinciding with urbanization is caused by detrimental water quality effects of stormwater runoff (Brezonik & Stadelmann, 2002). This leads to the identification of goals to manage the stormwater runoff by maintaining the quality and quantity as close to predevelopment levels as possible (Hatt, Fletcher, & Deletic, 2009). Avoiding or abating increased flooding and pollution risks whilst snowballing performance efficiency and augmenting local environmental quality-of-life tends to become the priority objective(Lundy, Ellis, & Revitt, 2012). Therefore, reducing stormwater runoff volume and the various pollutants by using stormwater Best Management Practices is important.

2.5 Hydrologic Effects of Stormwater

Rapid urbanization was experienced by many countries in the mid-20th century, typified by increased areas of medium to low-density housing which resulted in the notable increase of land cover by impervious surfaces (Brown, Keath, & Wong, 2009). Urbanization leads to significant impacts on watershed hydrology and affects both local and regional-scale water resources (Loperfido et al., 2014). Related effects of urbanization on hydrology are changes in peak flow, changes in total runoff, and changes in the water quality (Leopold, 1968).

Changes in the runoff quantity due to urbanization will lead to lower base flows between storms because of higher peak flows. This creates channel enlargement in the urban and suburban streams since they are dominated by surface flows (Hancock, Holley, & Chambers, 2010). Watershed imperviousness shows a positive correlation with total runoff volume (Dietz & Clausen, 2008) and flood frequency (Navratil et al., 2013) and negative correlation with flow duration (Poff, Bledsoe, & Cuhaciyan, 2006). The development also results in the reduction of permeability of remaining soil by compaction (Schwartz et al., 2017). Urbanization increases flow volume, but the effect diminishes as flood size increases for less frequent floods. Overall, urbanization tends to increase flow variability relative to undeveloped watersheds (Poff et al., 2006). Due to the effects of increased runoff, we require the implementation of Stormwater BMP's in order to minimize impacts on the receiving water (Hancock et al., 2010).

2.6 Water Quality Effects of Stormwater

Common urban stormwater runoff pollutants include Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorous (TP), Zinc (Zn), Lead (Pb), Copper (Cu), BOD and COD. Lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) are also almost always present in elevated concentrations (Schwartz et al., 2017). High retention of sediment, heavy metals, nitrogen and phosphorus was reported from past studies (Hatt et al., 2009). Major sources of nitrogen and phosphorous in stormwater runoff comprise of vegetative detritus, septic leachate, soil erosion, fertilizers, line and fuel combustion(Schwartz et al., 2017). Stormwater runoff from urban construction contains sediments. They are naturally occurring material which is broken down into smaller particles by weathering and erosion.

In addition, pathogen pollution contributes to the reduction in water quality. In the U.S EPA's National Water Quality Inventory in 2000 (U.S. EPA, 2002), 13% of the river and stream miles that were surveyed were impaired by indicator bacteria. Water quality degradation is assessed using indicator bacteria such as Total Coliform, Fecal Coliform, Escherichia Coli and Enterococci. From the various bacteria's used to assess water quality degradation Escherichia Coli (E.coli) and Enterococci were recommended as indicator bacteria in the aquatic environment(Hathaway, Hunt, & Jadlocki, 2009).

2.7 Water Quality Monitoring in Streams

In urban areas pollution sources are complex including: surface runoff from urban areas, and superimposed impact of waste discharges, which makes it difficult to assess the water quality (Duda, Lenat, & Penrose, 1982). Understanding and developing solutions to complex urban problems can be approached using system analysis (Cheng et al., 2010). Degradation of surface water quality in ponds, streams, wetlands, and lakes happens as a result of augmented stormwater runoff (Weiss, Hondzo, & Semmens, 2006). The growth of construction leads to development of impervious areas which results in the upsurge in stormwater runoff volume and pollutant concentration. This affects both the quality and quantity of runoff that enters receiving waters.

Nonpoint-source pollutants can be a menace to the receiving water. Stormwater runoff consists of: Total Suspended Solids (TSS), Suspended Sediment Concentration (SSC), Total Phosphorous (TP), Total Kjeldahl Nitrogen (TKN) and heavy metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc(Zn) which affect the quality of runoff (Hossain, Alam, Yonge, & Dutta, 2005). Minimizing the construction taking place near the streams will reduce the pollutant loading entering the streams, which is one of the proposed solutions (Line, 2013). However, monitoring and modeling for the effects in the streams involves factors such as: urbanization rate, rainfall charactersitics, and seasonal variations. Urbanization accounts for both spatial and temporal variations. But there is scarce data on temporal, and spatial variations caused by the construction (Peters, 2009).

Duda et al. (1982) studied how urban runoff affects the aquatic life in streams. The study was conducted at Asheville, North Carolina. The city had a population of approximately 60,000. The purpose of the study was to monitor whether the water quality in the streams are sufficient for aquatic life growth. Two urban streams, Nasty Branch and Sweeten Creek, were selected for the study. Biological monitoring was performed by taking benthic macroinvertebrates as the appropriate group of aquatic life. Intensive grab sampling was done to find out whether the water quality standards are within the prescribed limit. The results indicated that three urban reaches were of poor water quality. Nearly 70% and 80% reduction in the average number of types of animals found in each square meter bottom sample were found in Sweeten Creek and Nasty Branch respectively. Only 7 to 10 different types of animals were found in urban reaches compared to 35 varieties in rural reaches in both Nasty Branch and Sweeten Creek. Intensive grab sampling by taking low-flow samples weekly for 4 weeks and storm-flow samples for two separate storm events indicated metals, dissolved oxygen, and other constituents were found to be well within the standards whereas chromium was found in higher levels.

Line (2013), performed a study to document the effects of development on stream water quality. The study was conducted by monitoring base flow and storm discharges of seven watersheds with varying development density. In addition, two of the seven watersheds had wastewater treatment facilities. Monitoring of base flow and storm event discharges was done by taking manual grab samples on a monthly basis and flow proportion samples respectively and were analyzed for nitrogen, phosphorous, sediment and bacteria. Results showed that in base flow samples and impervious cover the five watersheds without wastewater treatment facilities had a significant linear relationship between fecal coliform and enterococci levels. This indicated that increase in residential development resulted in increase in bacteria levels. The remaining two watersheds with wastewater treatment plants had a higher bacteria levels. And when the annual export rates of ammonia nitrogen were found out for the two undeveloped watersheds it was more than the compiled annual rates across the United States.

Stream water quality originating in urban landscape was influenced while flowing through the forested area, this impact was evaluated by Clinton & Vose (2006). The study area consisted of an urban stream, national forest, and the main stream for reference. Water quality was monitored from March 2002 to June 2003. Average base flows were 184 l/s, 420 l/s, and 17 l/s for the urban stream, national forest, and main stream respectively.

Weekly water samples were analyzed for ammonia, phosphorous, calcium, magnesium, chloride, and nitrogen. The results indicated that total suspended solids, bacteria count, and solutes were higher in urban site rather than national forest. Higher amount of bacteria population which was reactive to stream temperature in urban site. In general, water quality was better in the national forest as compared to the urban site.

2.8 Rainfall Characteristics

The most important influential factors in relation to urban stormwater quality are rainfall and catchment characteristics. Rainfall characteristics comprise of rainfall intensity, rainfall duration and antecedent dry days (Liu et al., 2013). A short high intense rain can have the same impact as the rainfall with longer duration and low intensity. Intensity and duration are the key factors that determine the volume of stormwater. The effect these factors have on the runoff quality is variable and is difficult to identify as they have ambiguous relationship (Opher & Friedler, 2010). Within total suspended solids, for example, the concentration of fine size fractions was found to be less dependent on rainfall characteristics as compared to coarse fractions (Aryal et al., 2005). Rainfall carries off dissolved, colloidal and solids constituents in a heterogeneous mixture comprising of organic and inorganic compounds, nutrients, oils, greases and heavy metals as it washes dusts away from the atmosphere and the impervious urban surfaces (Gnecco et al., 2005).

There is a phenomenon called first flush which means the early runoff in a storm event is often more contaminated than the later part of runoff. This phenomenon depends upon various factors such as lack of dilution flow and a disproportionate runoff volume from the impervious surfaces, where pollutants may accumulate (Barco, Papiri, & Stenstrom, 2008). The best management practices (BMPs) can be selected by considering the first flush effect as an important phenomenon as it provides reasonable pollutant treatment criteria (Kim et al., 2007).

2.9 Stormwater Best Management Practices

Historically, Best Management Practices (BMP's) were used to reduce soil erosion and sediments (Yu, Yu, & Xu, 2013). Since there has been significant quantities of pollutants to the surrounding surface water bodies recently due to stormwater runoff from impervious or pervious surfaces which causes increasing concerns about the environment have led to development and construction of various kinds of BMP's (Yu et al., 2013). In response to the impacts of stormwater runoff and associated pollutants, a range of stormwater BMP's have been developed namely wet ponds, bio-retention basins, infiltration systems, ecology ditches, green roofs and constructed stormwater wetlands. Such an approach is termed as LID (low impact development), but alternative acronyms are SUDS (sustainable urban drainage systems), WSUD (water sensitive urban design), and LIUDD (low impact urban design and development, a term used in New Zealand) (Elliott & Trowsdale, 2007). LID devices are designed to detain, store, infiltrate, or treat urban runoff, and so reduce the impact of urban development (Elliott & Trowsdale, 2007).

Each BMP has its own way of treating the stormwater runoff. For example, Infiltration Systems operate by filtering diverted runoff through dense vegetation followed by vertical filtration through soil filter media. Treatment is achieved via a number of processes including sedimentation, fine filtration, sorption, and biological uptake (Hatt et al., 2009). Detention ponds release the stormwater runoff slowly into the receiving waters while detaining it for hours or days (Comings, Booth, & Horner, 2000). They are used for both controlling the quantity of water quantity increases as well as to reduce the nonpoint pollution (Whipple 1979). Reduction and mitigation of peak discharges and elimination of pollutants associated with urban stormwater runoff can be done by a modified partial infiltration trench called as ecology ditch (Barber et al., 2003). An infiltration trench stores stormwater temporarily and dewaters through deep infiltration. Green roofs have the potential to delay and attenuate stormwater runoff at the source. Extensive green roofs form a carpet of plants with an overlying drainage layer and are supported by lightweight growing media. There are intensive green roofs which are incorporated by deeply planted vegetation (Stovin, 2010). Vegetative filter strips are used to reduce pollutant transportation in runoffs. They are helpful in refining water quality and have surplus environmental benefits when used with other BMP’s (Rankins and Shaw 2001; Borin et al., 2004; Otto et al., 2008). Hydrodynamic separators have potential to remove pollutants from runoff. They use the centrifugal force inside the device to remove sediments, debris and litter from stormwater runoff (Yu et al., 2013). Bioretention basins are one of the commonly used BMPs in the United States. They utilize filtration as the primary source for the removal of pollutants (Mangangka et al., 2015). The pollutants are removed by filtration with the help of biologically active plants. They also reduce the runoff volume and peak flow (Trowsdale & Simcock, 2011).

The BMP’s should be selected depending upon the environmental and pollutant removal performance required. Currently, various BMP’s both infield and offsite are being used to treat and improve the quality and quantity of the runoff water before entering the receiving water. Better performance related information about the BMP’s will improve their application and development (Yu et al., 2013).

Table 1: Pollutants Treated by Various Best Management Practices (Hathaway et al., 2009) , (Roseen et al., 2009), (Hatt et al., 2009), (Comings et al., 2000), (Moore, Hunt, Burchell, & Hathaway, 2011), (Winston et al., 2013), (Merriman & Hunt III, 2014)

Best Management Practices	**Pollutants Treated**
Wet ponds	Cd, Cu, Zn, Pb, Cr, Ni, TSS, TP, OP, TOC, DOC, COD, TN, OP, OX-N
Wet lands	TP, TN, Organic Nitrogen, Oxidized Nitrogen, TKN, NO_2, NO_3, TKN, Ortho Phosphate, Cd, Cu, Pb, Zn, TSS, TP, BOD, COD, NH_4N
Bio-retention basins	Zn, Pb, TSS, TN, TP, Cu, Mn, DON, PON, NO_X, NH_4^+, E. coli, TZn, TPH-D, DIN
Gravel Wetland	TSS, TP, TPH-D, TZn, DIN
Stone Swale	TSS, TP, TPH-D, TZn, DIN
Vegetated Swale	TSS, TP, TPH-D, TZn, DIN
Aqua filter	TSS, TP, TPH-D, TZn, DIN
Hydrodynamic Separators	TSS, BOD, COD, TN, TP
Infiltration Trenches	TSS, BOD, COD, TN, TP

2.10 Predictive Stormwater Modeling

Greater sustainability in the water sector through holistic management and optimization of drinking water, wastewater, stormwater, and receiving water systems can be achieved through stormwater quality models (Obropta & Kardos, 2007). Predicting and assessing the performance of stormwater treatment measures are important in order to implement them. Predicting general performance of a variety of stormwater treatment measures can be accomplished with the use of predictive models which can be applied to a range of locations and conditions (Wong et al., 2006). There are various urban stormwater pollution modeling programs in use namely: Stormwater Management Model (SWMM), Model for Urban Stormwater Improvement Conceptualization (MUSIC), and XP-AQUALM (networked stormwater quality model).

From the various models, SWMM model is the most commonly used stormwater modeling technique which is an open source model developed by the U.S EPA (Wang, Forman, & Davis, 2017). Urban and sub-urban hydrologic systems can be simulated using the SWMM model. In addition, the quantity and quality of runoff through a BMP can also be tracked using this model (Wang et al., 2017).

2.11 Conclusion

Runoff quantity and amount of pollutants entering the urban streams have increased due to various factors such as precipitation increase and urbanization in terms of impervious cover. From which, the question arises, to what extent do these factors have an impact individually on the quality of pollutants entering the urban streams. This study shows how various trends impact the quality of water entering the streams based on these factors. In addition, this study will also provide us with a guiding factor to plan for design, operation, and maintenance of BMPs.

CHAPTER 3 METHODS AND DATA COLLECTION

3.1 Introduction

This chapter provides an overview on the watersheds selected for the study, data collection, and how the data is being analyzed. In addition, it also provides details on the efficiency standards set for different types of BMPs in use in the study region.

The first objective was to evaluate the pollutant concentration from stormwater runoff that enters streams during storm events. These results were compared with that of base flow in these streams. For this objective the major question to be answered was how the pollutant concentrations in streams vary across different seasons. The data for pollutant concentration entering streams during stormflow and base flow was obtained from Charlotte Mecklenburg Stormwater Services and it was analyzed to show how the pollutant concentration in streams were higher during the stormflow rather than the base flow.

The second objective was to establish and evaluate the relationships between existing BMPs, urbanization in terms of impervious cover and pollutant concentration in the streams. The results will aid in identifying the effects of urbanization on the pollutant concentration that the BMPs must treat. For this objective the major question to be answered was how the pollutant concentrations varied based on impervious cover and the existing network of BMPs in those creeks.

The data for the existing network of BMPs for the year 2016 was obtained from Charlotte Mecklenburg Stormwater Services and it was analyzed to show the exact location, types and number of BMPs in each of the watersheds and Mecklenburg County as a whole. The data for the impervious cover was obtained from Open Mapping Charlotte

Mecklenburg Stormwater Services and it was analyzed to determine the exact impervious cover for residential, commercial and other sites in percentage and acres for the year 2019.

3.2 Research Area Description

The water quality data is collected for 24 watersheds in Mecklenburg County, However, for Catawba basin, Lake Norman, Mountain Island Lake and Lake Wylie watersheds, water quality data was not available. Mecklenburg County contains of 3,000 miles of creeks and drains into two major watersheds namely: Catawba River and the Yadkin-Pee Dee. Two thirds of the county is in the former and the eastern third is in the latter respectively. Turbidity, copper, and the lack of diversity of aquatic insects are the important factors contributing to the watersheds' impairment (Watch, 2015b). There are 24 types of pollutants that are flowing in the streams as per the data from Charlotte Mecklenburg Stormwater Services.

The average annual rainfall in the City of Charlotte is approximately 1,071.75 mm (42.19 inches) and the average annual temperature is about 59.8°F (15.44 degree Celsius). Average annual rainfall for the past 8 years and average temperatures for the past 8 years are shown in Tables 2 and 3 respectively. The precipitation data helps in determining the approximate quantity of expected runoff in the region and frequency of diverse magnitude storm events, on which to base sample collection.

Table 2: Charlotte Temperature Averages by Year (Charlotte Douglas International Station)

Year	High (Degree Celsius)	Low (Degree Celsius)	High (Degree Fahrenheit)	Low (Degree Fahrenheit)
2017	23	11	74	52
2016	23	11	74	52
2015	23	11	73	52
2014	22	9	71	49
2013	21	10	71	50
2012	23	11	74	51
2011	23	10	73	50
2010	22	9	72	49

Table 3: Total Precipitation in Charlotte (Charlotte Douglas International Station)

Year	Days	Inches	Millimeters
2017	113	44.7	1,136
2016	59	33.6	852
2015	81	49.5	1,257
2014	69	45.5	1,155
2013	77	49.7	1,261
2012	63	33.7	856
2011	74	44.6	1,132
2010	62	36.4	925

Figure 1 shows the watersheds in Mecklenberg County. The map was created using ArcGIS. The shape file for the state boundaries, and watersheds was obtained from the Open Mapping Mecklenburg County GIS, North Carolina (GIS, 2019).

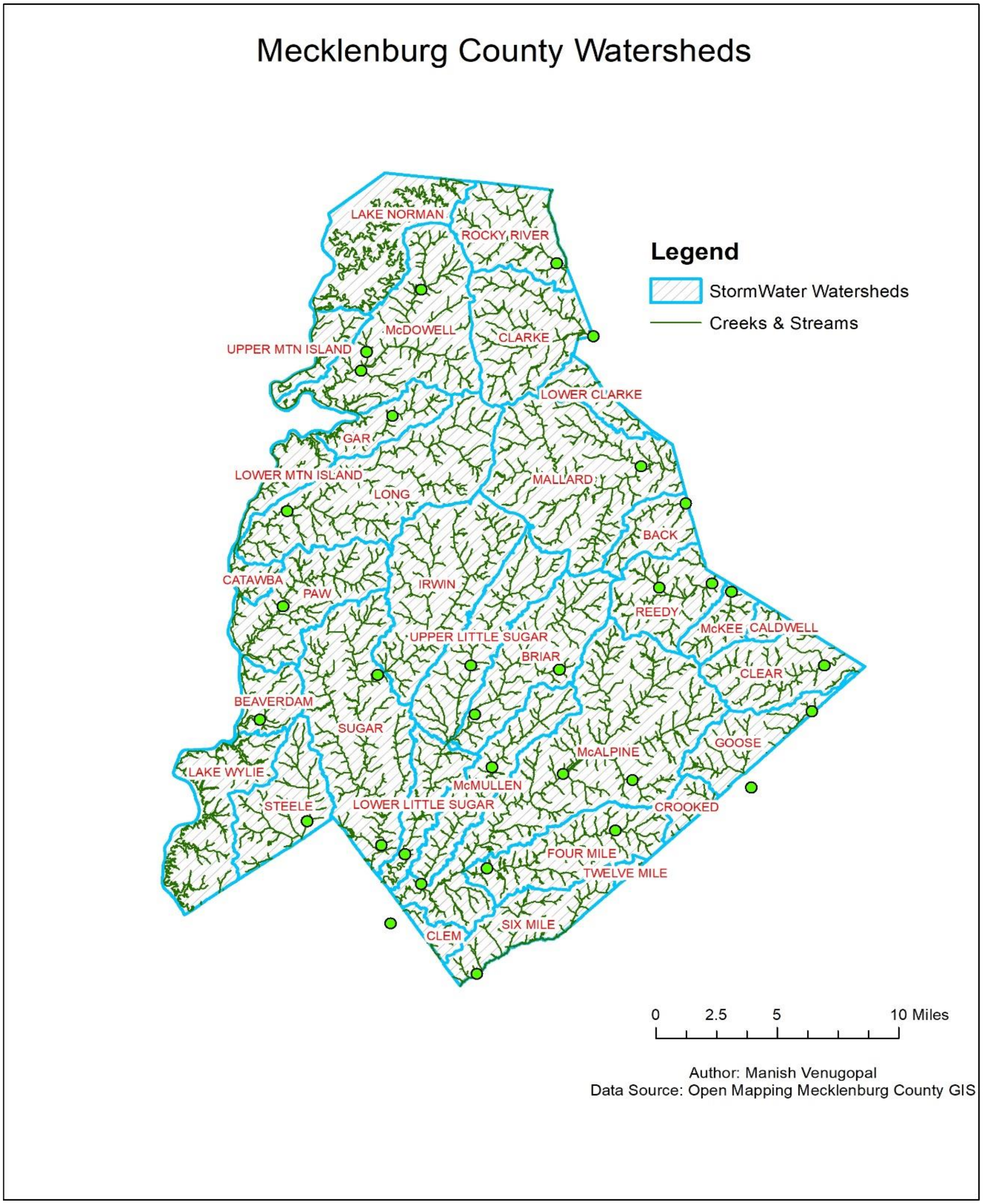


Figure 1: Watersheds in Mecklenburg County

3.3 Data Collection

Pollutant concentration and loading data are gathered from Charlotte-Mecklenburg Stormwater Services. Precipitation data collected by Charlotte-Mecklenburg Stormwater Services and the United States Geological Survey is used.

Water quality monitoring was performed in all the creeks by personal from Charlotte Mecklenburg Stormwater Services. Data from all the creeks were analyzed to show the results. The samples were taken manually during storm events from the free-flowing streams. A solar panel was provided in each of the monitoring sites. The manual samples were analyzed in a Charlotte Mecklenburg Stormwater Services` laboratory.

Rainfall data measured by United States Geological Survey around Charlotte was considered. Rainfall events were divided based on the following assumptions by Charlotte Mecklenburg Stormwater Services:

- Stormflow- Amount of rainfall is greater than 0.1 inches in the 72 hours prior to the sample collection date and time
- Base flow- Amount of rainfall is lesser than 0.1 inches in the 72 hours prior to the sample collection date and time

Table 4: Categorization of Rainfall Events

Amount of Rainfall	**Category**
> 0.1 inches precipitation	Stormflow
< 0.1 inches precipitation	Base flow

Table 4 explains the assumptions on which the stormflow and base flow are classified.

Data on the number of BMPs and their locations were obtained from the Open Mapping Mecklenburg County GIS, North Carolina. The exact location of the BMPs in the watersheds are obtained by adding the shape file in ArcGIS. Then a spatial overlap was performed with the watershed in Mecklenburg County to compute the exact location of BMPs in each of the watershed.

The attribute table for the created overlap was converted into excel. The analyses were then performed to derive the exact number, types and location of BMPs in each of the individual creeks as well as the Mecklenburg County as a whole.

The pollution removal rates for nine types of BMPs were obtained from the Charlotte Mecklenburg Stormwater Services design standards manual as shown in Table 5. The values were compared with the amount of pollutants being treated to check for the efficiency of the BMPs in use.

Table 5: Pollution Removal Rates Charlotte Mecklenburg Stormwater Services (Charlotte, 2013)

Types of BMP	**Optimal Efficiency**	**Standard Efficiency**	**TSS only Efficiency**
Bio-retention	85% TSS 70% TP	85% TSS 60% TP	85% TSS 45% TP
Wet Ponds	85% TSS 70% TP	60% TSS 40% TP	85% TSS
Wetlands	85% TSS 70% TP	60% TSS 40% TP	85% TSS
Enhanced Grass Swale	45% TSS 30% TP		

Table 5: Pollution Removal Rates Charlotte Mecklenburg Stormwater Services (Charlotte, 2013) (Continued)

Types of BMP	Optimal Efficiency	Standard Efficiency	TSS only Efficiency (Continued)
Grass Channel	20% TSS 0% TP		
Infiltration Trench	85% TSS 70% TP		
Filter Strip	20% TSS 0% TP	15% TSS 0% TP	10% TSS (Minimal) 0% TP
Sand Filter	85% TSS 70% TP	70% TSS 35% TP	85% TSS
Extended Dry Detention		30% TSS 30% TP	

The impervious cover data shape files for 2019 were obtained from Open Mapping Charlotte Mecklenburg Stormwater Services. The shape file was added in ArcGIS and a spatial overlap was performed with the watersheds in Mecklenburg County to determine the exact impervious cover of each of the watersheds in terms of percentage and acres.

The attribute table for the created overlap was converted into excel. Then analyses was performed to calculate the impervious cover content of the individual creeks as well as the Mecklenburg County as a whole.

3.4 Methods

3.4.1 Seasonal Variation of Pollutant Concentration

Recall, the first objective is to evaluate the pollutant concentration from stormwater runoff that enters streams during storm events. The results were compared with that of pollutant concentration during base flow in these streams, the results of which were used to determine if pollutant concentration in streams during storm flow is greater than pollutant concentration during base flow.

The variation in the water quality was analyzed based on the measurements taken during storm flow or base flow. Preliminary analyses were performed using Microsoft Excel. Graphs were plotted between varying seasons and pollutant concentration during stormflow and for the base flow across the different watersheds in Mecklenburg County.

The data for all the 24 creeks, Rocky River and, Edward's branch was provided by Charlotte Mecklenburg Stormwater Services. The data set included 24 types of pollutants. Out of the 24, only 8 pollutants had data for all 10 years from 2010 to 2019. Therefore, those 8 pollutants were selected for evaluation. Water quality parameters that were evaluated included: Total Suspended Solids, Suspended Sediment Concentration, Total Phosphorous, Total Kjeldahl Nitrogen, Copper, Turbidity, Escherichia Coli, and Nitrate and Nitrite. Storm events between January 2010 and March 2019 were analyzed for the scope of this study.

The data was analyzed based on whether it was taken during stormflow or base flow. There were around 80-90 entries for stormflow and 35-40 entries for base flow across all creeks for 7 types of pollutants over a period of 10 years. Copper alone had more than 100 entries for stormflow and 60-70 entries for base flow across 10 years. Each year was divided into four seasons and the entries were grouped based on the seasons. For analysis the months were divided into various seasons as follows:

Table 6: Seasons defined by months

Months	**Seasons**
March- May	Spring
June- August	Summer
September- November	Fall
December- February	Winter

Summation of pollutant concentration across each season was determined. Then the average pollutant concentration for each pollutant across all the creeks were determined. Finally, a one tailed t-test with unequal variances was run to determine the statistical significance of the results.

3.4.2 Network of Existing BMPs

The dataset consisted of the shape file indicating the location of different types of BMPs in the creeks. There were in total nine major types of BMPs in use as mentioned in the Table 5 and eight minor types of BMPs in use. The location of each type of BMP in the individual creeks was determined from the spatial overlap between the shape file indicating the location of the BMPs and watershed locations. From the spatial overlap, the various types of the BMPs in the individual creeks and the exact number were determined. There were a total of 2806 BMPs in the Mecklenburg County which were divided into the major and minor types.

3.4.3 Determination of Impervious Cover

The dataset had three different types of data namely:

- Commercial Impervious Cover- industries
- Single Family Impervious Cover- residential
- Other Impervious Cover- roadways, curbs

The commercial impervious cover data consisted of more than 130,000 entries, single family impervious cover data consisted of more than 940,000 entries and the other impervious cover data consisted of more than 35,000 entries. Each of the shape files were added to ArcGIS and a spatial overlap with the watershed area was performed to find the location of them in the individual watersheds for each creek.

The area for the each of the impervious structures were then computed in ArcGIS. From the individual areas of each of the impervious structure located in the watersheds, the sum of impervious cover area was calculated in excel. The sum of the impervious cover area was divided by the total area of the each of the watersheds, to determine the impervious cover content of them. Then the total sum of the impervious cover of the Mecklenburg County was calculated by adding the impervious cover area of each of the watersheds.

The results obtained show the variation in the pollution concentration across the years due to the increase in impervious cover.

3.4.4 Secondary Data on Impervious Cover

The NPA (Neighborhood Profile Area) political boundaries data shape files for Mecklenburg County were obtained from Charlotte/Mecklenburg Quality of Life Explorer an affiliation of Mecklenburg County Open Mapping. The shape file was added in ArcGIS and a spatial overlap was performed with the watersheds in Mecklenburg County to determine the exact NPA boundaries where each of the watersheds are located.

The attribute table for the created overlap was converted into excel. Then analyses were performed to calculate the impervious cover content of the individual creeks as well as the Mecklenburg County as a whole based on the NPA boundaries they were located. The grouping of the NPAs were based on two assumptions namely:

- If a single NPA boundary contacts two watersheds and when inspecting it visually in ArcGIS it is present in one creek more than 90% in area then it was assigned to that individual watershed.
- Similarly, if a single NPA is located in two watersheds and when inspecting it visually in ArcGIS it is present in both the watersheds less than 90% in area then it was assigned to both the creeks and the area was divided into two.

3.4.5 Sorting and Grouping of Creeks

The watersheds can be sorted and grouped based on the following:

- The similarity in size
- The number of BMPs in the watersheds
- The impervious cover in the watershed

The watersheds were then grouped into three categories namely based on the size:

- Small watersheds- less than 7,500 acres
- Medium watersheds- greater than 7,500 acres but less than 15,000 acres
- Large watersheds- greater than 15,000 acres

The watersheds were analyzed in terms of their variation depending upon the precipitation. Then they were grouped based on considering the multiple factors previously listed to show how the pollutant concentration has varied based on multiple factors for a similar geographical location.

CHAPTER 4 RESULTS AND ANALYSIS

4.1 Introduction

This chapter provides results which help answer the research question and fulfil the objectives. It explains the variation of pollutant concentration due to varying seasons across a 10-year period and how the existing network of BMPs and urbanization in terms of impervious cover has an effect on it. This analysis helps with the evaluation of the BMPs in the location in terms of efficiency. It also provides details on determining the type of BMP to be used to address problems related to stormwater based on the conditions mentioned.

4.2 Seasonal Variation of Pollutant Concentration

Recall, the first objective is to evaluate the pollutant concentration from stormwater runoff that enters streams during storm events. The results are compared with that of base flow in these streams to test the hypotheses pollutant concentration in streams during storm flow is greater than pollutant concentration during base flow.

The variation in the water quality was analyzed based on the measurements that were taken during either storm flow or base flow. Microsoft Excel was used to perform the analyses. Graphs were plotted between varying seasons and pollutant concentration during stormflow and base flow across the different watersheds in Mecklenburg County.

As mentioned earlier in the methods, summation of pollutant concentration across each season was determined. Then the average pollutant concentration for each pollutant across all the creeks was determined. Out of the eight pollutants selected for analysis, graphs and tables for common pollutants such as: copper, total suspended solids, and total kjeldahl nitrogen are shown below. Figures 2 to 4 and Tables 7 to 9 represent the variations in TSS mg/l, Figures 5 to 7 and Tables 10 to 12 represent the variations in TKN mg/l, and Figures 8 to 10 and Tables 13 to 15 represent the variations in Copper µg/l respectively. Copper is selected as it is one of the major factors affecting several watersheds. Total Suspended Solids and Total Kjeldahl Nitrogen are highlighted in this document as they are two of the common pollutants from the past studies and literature available.

Varying spikes were seen at the end of preliminary analyses for the different seasons as shown in Figure 2 to Figure 10. The spikes were used in evaluating how the pollutant concentration in the streams was varying according to the seasonal variation in the rainfall. The varying spikes across seasons presented us with results on how the pollutant concentrations has been increasing and varying during storm flow.

From Figures 2 to 10, it was evident that there was a variation and increase in the pollutants during storm flow measurements.

The average pollutant concentration in the selected watersheds during the stormflow and base flow are depicted in the tables below

Table 7: Variation in Total Suspended Solids mg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	34.69	29.00	18.24	15.95	24.47
Beaverdam	80.53	73.12	13.89	42.90	52.61
Back	20.55	16.28	11.06	18.42	16.58
Gar	17.46	10.68	9.80	10.19	12.03
Duck	8.68	6.13	9.22	10.18	8.55
Goose	14.52	10.80	11.25	8.48	11.26

Table 7: Variation in Total Suspended Solids mg/l across seasons in Small Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	7.91	19.60	5.21	6.25	9.74
Beaverdam	8.72	13.47	11.00	17.25	12.61
Back	5.44	6.50	6.89	5.49	6.08
Gar	5.05	5.03	6.56	5.42	5.51
Duck	4.94	5.29	5.70	5.45	5.35
Goose	2.33	1.85	4.64	5.91	3.68

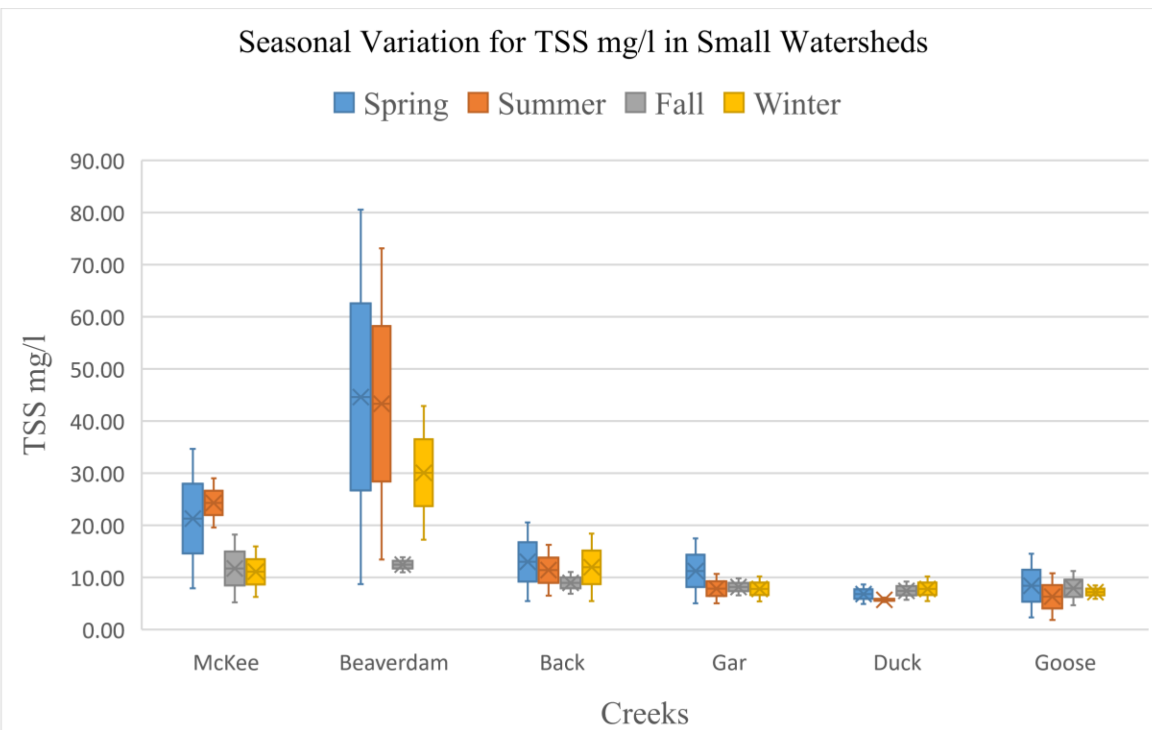


Figure 2: Variation in Total Suspended Solids mg/l across seasons during stormflow & base flow for Small Watersheds

Table 8: Variation in Total Suspended Solids mg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	13.40	8.14	10.13	12.31	11.00
Reedy 1	260.90	344.17	101.50	102.20	202.19
Reedy 2	134.91	238.88	30.35	51.85	114.00
McMullen	16.55	6.96	7.91	16.68	12.02
Clear	12.15	12.09	23.92	12.46	15.15
Rocky	78.66	19.80	73.67	52.76	56.22
Steele	8.48	9.39	9.56	16.38	10.95
Fourmile 1	17.50	12.31	20.30	14.21	16.08
Fourmile 2	18.17	15.62	14.07	11.48	14.83
Paw	27.94	17.64	16.84	25.16	21.90
Briar	21.96	10.76	16.49	15.86	16.26
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	6.76	8.90	8.69	5.33	7.42
Reedy 1	6.80	5.50	5.00	5.89	5.80
Reedy 2	10.80	6.33	4.89	7.58	7.40
McMullen	4.72	5.00	4.74	5.45	4.98
Clear	5.22	5.87	5.31	5.00	5.35
Rocky	20.54	5.83	4.71	12.45	10.88

Table 8: Variation in Total Suspended Solids mg/l across seasons in Medium Watersheds (Continued)

Base flow (Continued)					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Steele	5.09	5.00	4.64	5.92	5.16
Fourmile 1	6.16	7.12	8.43	6.41	7.03
Fourmile 2	5.60	16.86	6.58	8.47	9.38
Paw	4.93	5.00	5.71	5.45	5.27
Briar	5.00	5.83	4.72	5.91	5.37

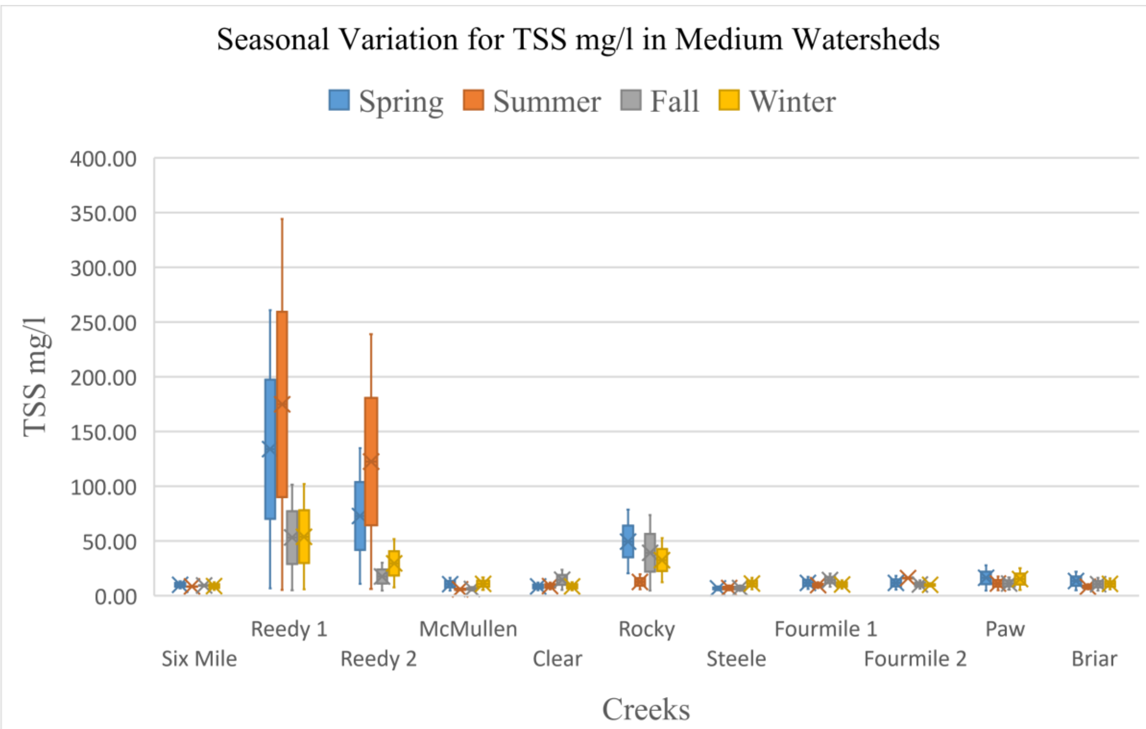


Figure 3: Variation in Total Suspended Solids mg/l across seasons during stormflow & base flow for Medium Watersheds

Table 9: Variation in Total Suspended Solids mg/l across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	63.64	32.75	68.31	38.78	50.87
Little sugar 1	25.58	14.49	13.34	15.84	17.31
Little sugar 2	34.70	18.81	30.02	19.11	25.66
Irwin	24.19	8.87	12.28	27.87	18.30
McDowell	39.23	12.55	31.72	11.16	23.67
MC 4 McDowell	38.66	40.38	38.09	25.36	35.62
Long	49.12	36.95	31.54	24.57	35.55
Sugar	53.21	22.42	32.95	27.41	34.00
Coffey	31.63	9.16	23.21	22.87	21.72
Mallard	70.08	16.33	23.30	30.18	34.97
Edward's	100.18	60.06	76.31	29.73	66.57
Irvins	27.91	24.54	9.10	8.28	17.46
McAlpine 1	21.05	10.77	15.00	23.52	17.58
McAlpine 2	29.62	23.79	32.88	25.42	27.93
McAlpine 3	21.74	14.32	13.90	12.96	15.73
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	23.14	17.97	10.00	7.18	14.57
Little sugar 1	4.87	6.11	7.43	6.80	6.30

Table 9: Variation in Total Suspended Solids mg/l across seasons in Large Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Little sugar 2	5.96	5.40	4.64	5.25	5.31
Irwin	5.48	5.00	4.93	5.78	5.30
McDowell	6.60	5.43	4.85	5.59	5.62
MC 4 McDowell	13.39	5.47	3.29	12.40	8.64
Long	7.02	8.33	7.58	7.44	7.59
Sugar	6.20	5.00	4.75	6.11	5.52
Coffey	6.44	7.62	6.01	5.38	6.36
Mallard	10.08	5.13	4.99	8.62	7.20
Edward's	12.99	5.63	5.11	6.18	7.48
Irvins	6.00	22.71	4.83	6.27	9.95
McAlpine 1	6.60	5.04	4.86	5.48	5.49
McAlpine 2	9.87	7.24	6.33	6.84	7.57
McAlpine 3	6.53	8.57	5.42	5.11	6.41

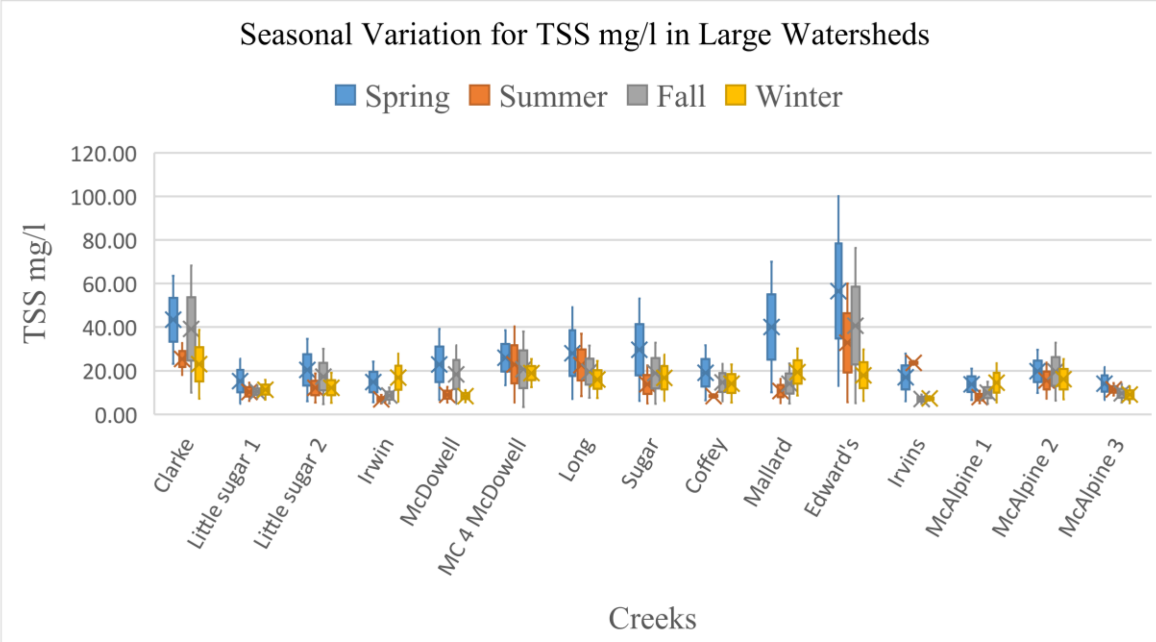


Figure 4: Variation in Total Suspended Solids mg/l across seasons during stormflow & base flow for Large Watersheds

Table 10: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.50	0.41	0.35	0.39	0.42
Beaverdam	0.58	0.56	0.36	0.51	0.50
Back	0.61	0.47	0.35	0.43	0.46
Gar	0.56	0.43	0.37	0.37	0.43
Duck	0.53	0.52	0.50	0.47	0.50
Goose	0.51	0.36	0.44	0.39	0.43

Table 10: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Small Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.29	0.33	0.28	0.25	0.29
Beaverdam	0.28	0.38	0.29	0.26	0.30
Back	0.34	0.44	0.29	0.29	0.34
Gar	0.32	0.26	0.25	0.25	0.27
Duck	0.41	0.64	0.44	0.44	0.48
Goose	0.32	0.32	0.32	0.25	0.30

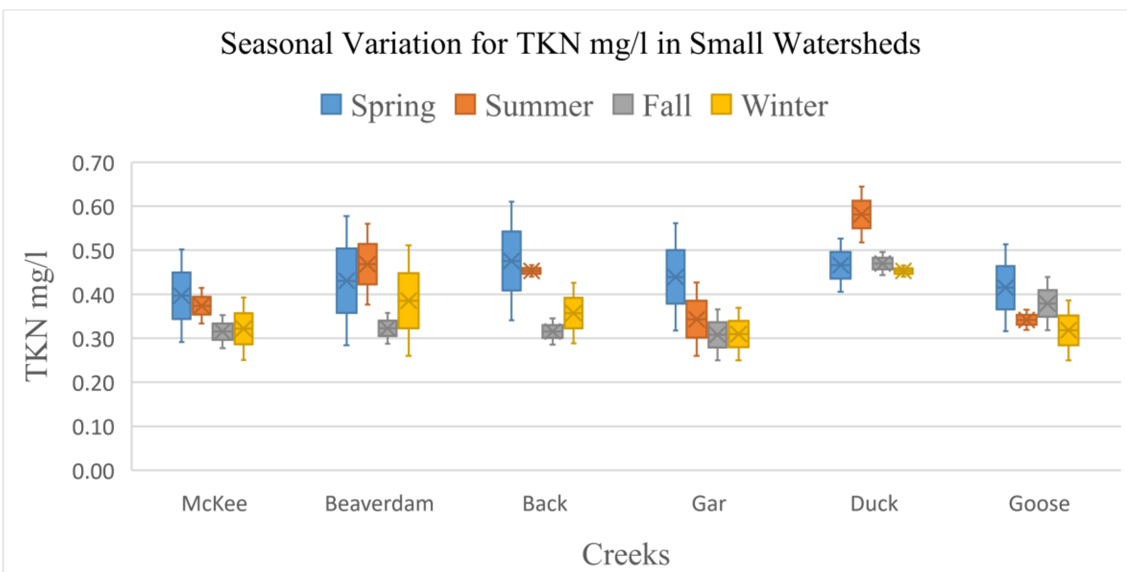


Figure 5: Variation in Total Kjeldahl Nitrogen mg/l across seasons during stormflow & base flow for Small Watersheds

Table 11: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.55	0.48	0.42	0.45	0.47
Reedy 1	0.85	0.86	0.47	0.43	0.65
Reedy 2	0.63	0.58	0.34	0.41	0.49
McMullen	0.73	0.57	0.50	0.56	0.59
Clear	0.35	0.32	0.36	0.31	0.33
Rocky	0.48	0.34	0.46	0.41	0.42
Steele	0.68	0.47	0.48	0.45	0.52
Fourmile 1	0.63	0.56	0.43	0.43	0.51
Fourmile 2	0.56	0.48	0.39	0.43	0.46
Paw	0.45	0.40	0.34	0.44	0.41
Briar	0.61	0.46	0.36	0.40	0.46
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.40	0.43	0.40	0.30	0.38
Reedy 1	0.25	0.25	0.25	0.25	0.25
Reedy 2	0.27	0.25	0.29	0.27	0.27
McMullen	0.44	0.49	0.67	0.51	0.53
Clear	0.25	0.39	0.28	0.25	0.29

Table 6: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Medium Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Rocky	0.25	0.25	0.27	0.25	0.25
Steele	0.38	0.31	0.29	0.28	0.31
Fourmile 1	0.29	0.49	0.41	0.31	0.38
Fourmile 2	0.35	0.43	0.29	0.27	0.34
Paw	0.27	0.27	0.27	1.45	0.57
Briar	0.29	0.33	0.28	0.31	0.30

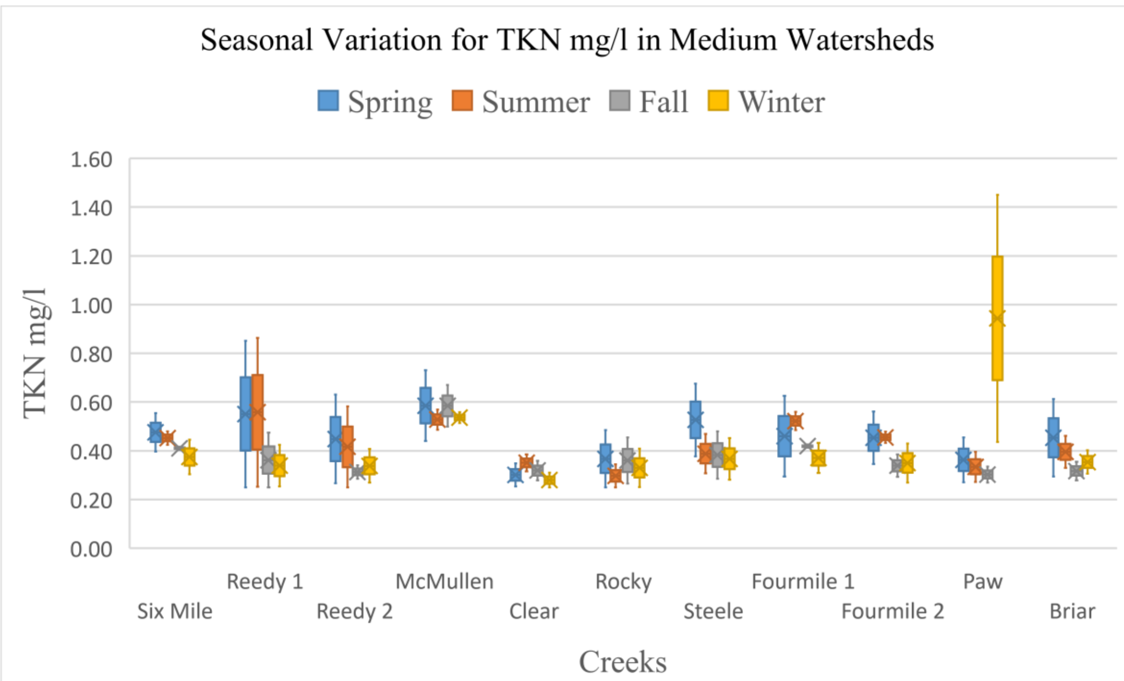


Figure 6: Variation in Total Kjeldahl Nitrogen mg/l across seasons during stormflow & base flow for Medium Watersheds

Table 7: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.52	0.50	0.58	0.40	0.50
Little sugar 1	0.62	0.51	0.41	0.53	0.52
Little sugar 2	0.86	0.71	1.02	0.81	0.85
Irwin	0.44	0.34	0.34	0.65	0.44
McDowell	0.44	0.41	0.47	0.34	0.41
MC 4 McDowell	0.45	0.43	0.42	0.32	0.40
Long	0.47	0.41	0.44	0.37	0.42
Sugar	0.82	0.58	0.48	1.00	0.72
Coffey	1.32	0.44	0.39	3.18	1.33
Mallard	0.53	0.39	0.36	0.35	0.41
Edward's	1.21	0.66	0.69	0.55	0.78
Irvins	0.58	0.42	0.38	0.41	0.45
McAlpine 1	0.62	0.52	0.40	0.48	0.50
McAlpine 2	0.76	0.63	0.72	0.85	0.74

Table 12: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Large Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McAlpine 3	0.57	0.47	0.41	0.39	0.46
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.35	0.50	0.63	0.28	0.44
Little sugar 1	0.27	0.41	0.51	0.53	0.43
Little sugar 2	0.50	0.53	0.58	0.91	0.63
Irwin	0.31	0.27	0.30	0.26	0.28
McDowell	0.28	0.28	0.26	0.25	0.26
MC 4 McDowell	0.27	0.25	0.25	0.28	0.26
Long	0.27	0.28	0.30	0.27	0.28
Sugar	0.52	0.48	0.45	0.39	0.46
Coffey	0.49	0.49	0.35	0.47	0.45
Mallard	0.28	0.29	0.29	0.25	0.28
Edward's	0.30	0.32	0.27	0.27	0.29

Table 12: Variation in Total Kjeldahl Nitrogen mg/l across seasons in Large Watersheds (Continued)

Base flow (Continued)					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Irvins	0.38	0.38	0.25	0.27	0.32
McAlpine 1	0.37	0.41	0.39	0.28	0.36
McAlpine 2	0.74	0.50	0.88	0.66	0.70
McAlpine 3	0.31	0.37	0.30	0.27	0.31

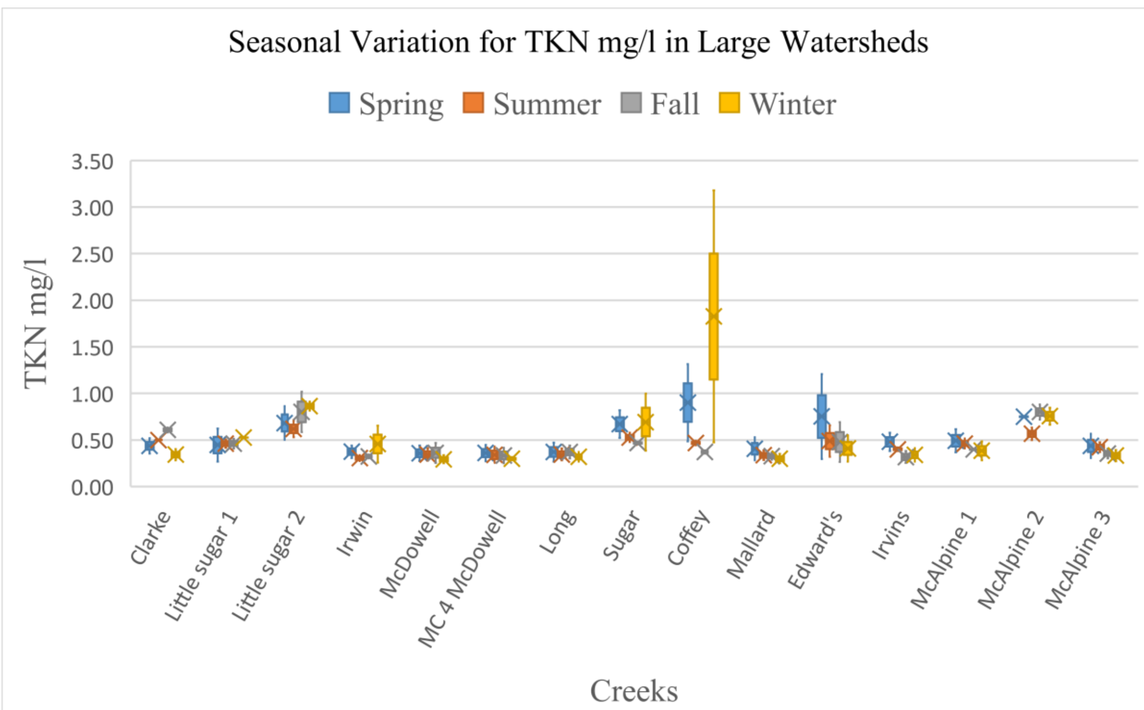


Figure 7: Variation in Total Kjeldahl Nitrogen mg/l across seasons during stormflow & base flow for Large Watersheds

Table 13: Variation in Copper µg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	2.69	2.48	2.72	2.97	2.71
Beaverdam	5.13	3.78	2.21	4.04	3.79
Back	2.96	3.05	2.63	3.09	2.93
Gar	2.65	2.74	2.37	2.76	2.63
Duck	2.39	3.85	4.00	2.98	3.30
Goose	2.63	2.74	2.95	3.14	2.86
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	2.01	2.00	1.95	2.04	2.00
Beaverdam	2.10	2.00	1.80	2.08	2.00
Back	1.90	2.21	1.96	2.16	2.06
Gar	2.06	2.00	1.89	2.06	2.00
Duck	2.30	3.73	5.13	2.40	3.39
Goose	2.11	2.30	2.49	2.04	2.23

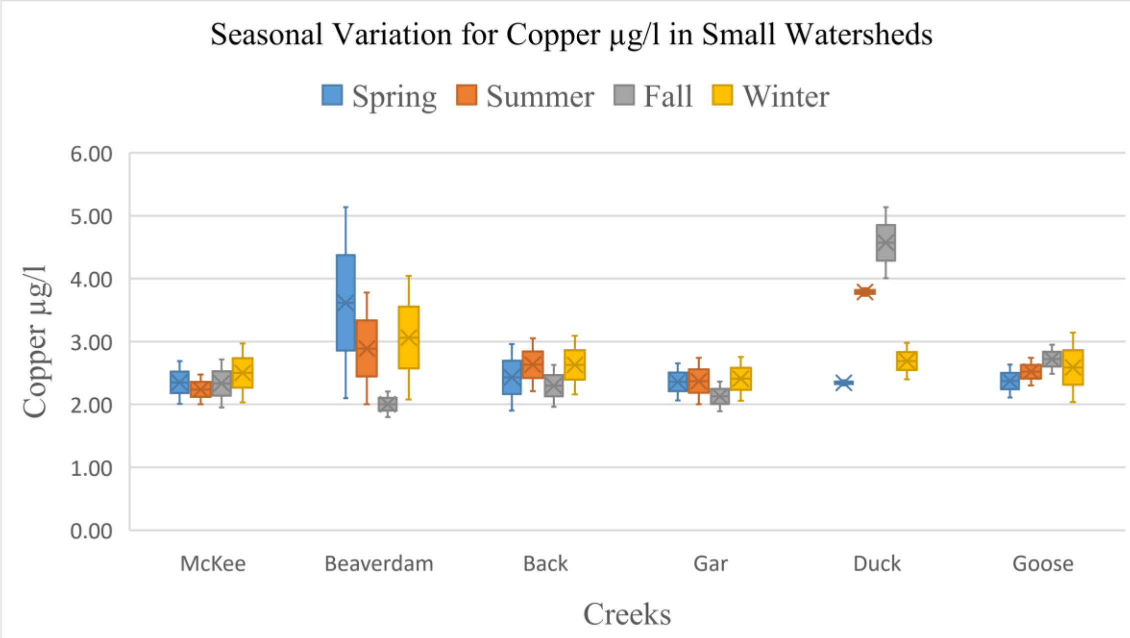


Figure 8: Variation in Copper µg/l across seasons during stormflow & base flow for Small Watersheds

Table 14: Variation in Copper µg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	2.64	2.23	2.54	2.75	2.54
Reedy 1	7.80	8.94	3.99	3.93	6.16
Reedy 2	7.63	9.28	3.90	4.13	6.23
McMullen	5.52	4.49	13.18	6.09	7.32
Clear	2.40	2.96	2.72	3.31	2.85
Rocky	4.23	3.00	5.77	4.82	4.45
Steele	2.69	3.00	3.22	3.50	3.10
Fourmile 1	2.78	2.31	4.12	2.83	3.01
Fourmile 2	3.18	4.26	3.84	3.78	3.76

Table 14: Variation in Copper µg/l across seasons in Medium Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Paw	4.39	2.57	2.66	3.70	3.33
Briar	3.94	2.85	3.67	4.18	3.66
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	2.09	2.01	1.88	2.03	2.00
Reedy 1	2.05	2.00	2.23	2.16	2.11
Reedy 2	2.19	2.00	1.88	2.07	2.03
McMullen	2.45	3.09	5.75	2.50	3.45
Clear	2.08	2.03	1.75	2.00	1.97
Rocky	3.19	2.00	1.87	2.36	2.35
Steele	2.01	2.17	2.29	2.07	2.13
Fourmile 1	2.12	2.00	2.11	2.79	2.25
Fourmile 2	2.30	2.06	2.00	2.73	2.27
Paw	2.25	2.00	1.85	2.05	2.04
Briar	2.01	2.14	2.27	2.18	2.15

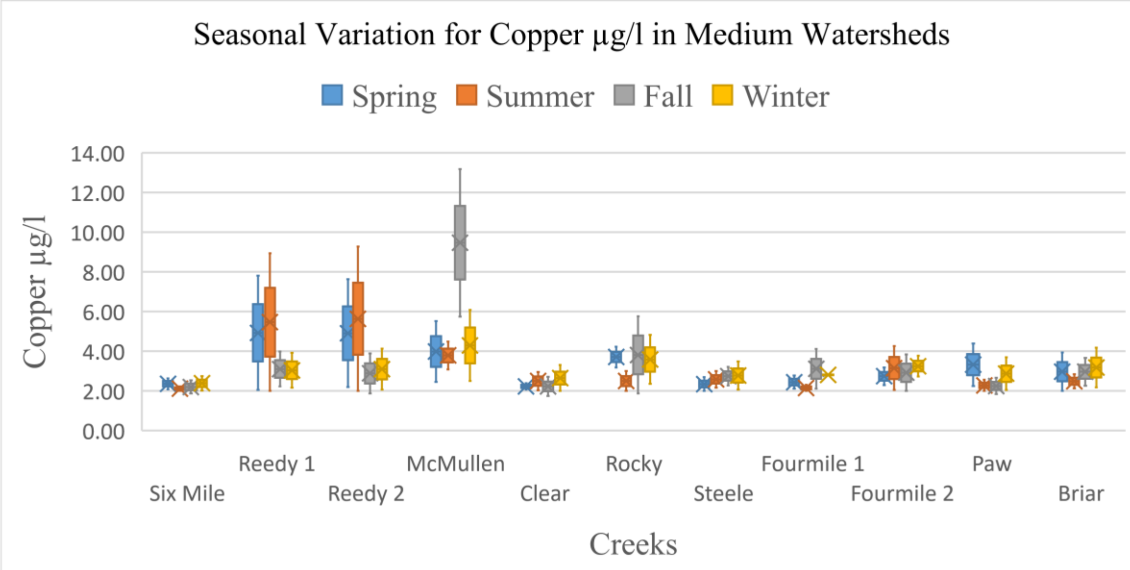


Figure 9: Variation in Copper µg/l across seasons during stormflow & base flow for Medium Watersheds

Table 15: Variation in Copper µg/l across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	6.91	9.26	16.24	7.82	10.06
Little sugar 1	5.70	4.34	5.25	5.89	5.29
Little sugar 2	5.32	4.39	4.48	5.27	4.87
Irwin	3.65	2.53	3.29	5.01	3.62
McDowell	2.75	2.97	3.78	3.04	3.14
MC 4 McDowell	3.70	4.09	3.75	3.09	3.66
Long	4.21	2.85	2.88	3.77	3.43
Sugar	5.47	4.10	4.38	5.03	4.75
Coffey	4.49	3.04	3.74	4.88	4.04
Mallard	4.48	2.80	2.99	4.30	3.64

Table 15: Variation in Copper µg/l across seasons in Large Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Edward's	8.35	5.75	6.77	5.74	6.65
Irvins	5.27	4.16	4.03	4.40	4.47
McAlpine 1	3.69	2.71	3.18	4.29	3.47
McAlpine 2	4.07	3.41	3.73	4.36	3.89
McAlpine 3	3.28	2.56	3.29	3.41	3.14
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	3.52	4.90	4.03	7.31	4.94
Little sugar 1	2.39	3.96	5.76	2.80	3.73
Little sugar 2	3.51	4.62	4.56	3.03	3.93
Irwin	2.06	2.02	2.28	2.19	2.13
McDowell	2.33	2.00	1.91	2.14	2.09
MC 4 McDowell	2.31	2.00	1.87	2.05	2.06
Long	2.09	2.00	1.97	2.09	2.04
Sugar	3.28	4.48	3.86	2.69	3.58
Coffey	2.06	2.32	3.86	2.01	2.56
Mallard	2.12	3.13	2.01	2.11	2.34
Edward's	2.04	2.00	2.24	2.13	2.10
Irvins	3.24	5.59	2.81	2.56	3.55
McAlpine 1	2.21	2.00	1.91	2.34	2.12

Table 15: Variation in Copper µg/l across seasons in Large Watersheds (Continued)

Base flow (Continued)					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McAlpine 2	3.37	3.60	3.76	3.66	3.60
McAlpine 3	2.01	2.24	1.76	1.95	1.99

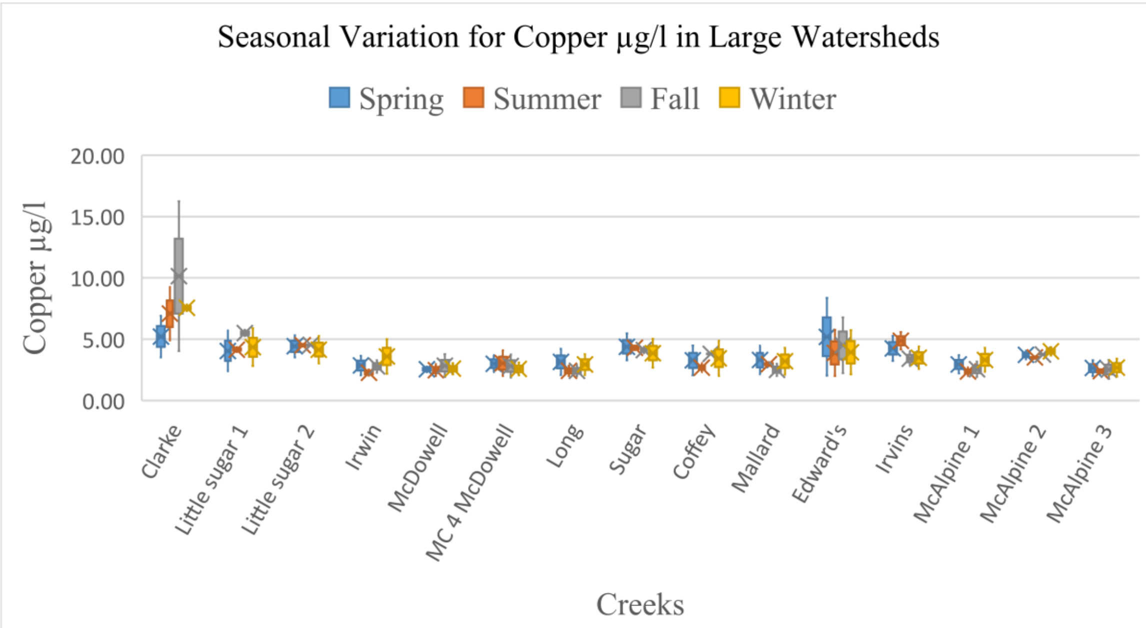


Figure 10: Variation in Copper µg/l across seasons during stormflow & base flow for Medium Watersheds

From the Tables 7 to 15 and Figures 2 to 10, the pollutant concentration in the stream was varying with an increase in precipitation. During base flow it remained a constant, except when there was some rainfall on days prior to the measurement being taken. The value of pollutant concentration in the stream stormflow was greater than in the base flow for most of the pollutants except Nitrate/ Nitrite and Total Phosphorous. One of the possible reasons for this might be the presence of Total Phosphorous in dissolved (soluble) form rather than particulate (solid) form. The source of Nitrate/Nitrite is from leaking septic tanks, fertilizers, and pet wastes. The result of which might lead to them washed off by the stormflow.

Therefore, it was evident that the pollutant concentration entering the stream during the storm flow was greater than base flow.

The average pollutant concentration across various seasons in the stream during stormflow was in general high during the spring, but the greater spikes were observed during either the summer or fall season respectively. During base flow they were all nearly the same with little variation for TSS, TKN, and Copper respectively.

Table 16: Predominant Pollutants in different creeks

Predominant Pollutants	**Creeks**
Total Suspended Solids	Reedy
Total Phosphorous	Little Sugar, McAlpine, Sugar
Total Kjeldahl Nitrogen	McAlpine
Turbidity	Reedy
Suspended Sediment Concentration	Reedy
Copper	Across all the creeks
Nitrate/Nitrite	Little Sugar, McAlpine, Sugar
Escherichia Coli	Steele

Table 16 gives the creeks in which the different types of pollutants were higher compared to the other creeks. From table 10, for 3 out of the 8 pollutants analyzed namely: Total Suspended Solids, Turbidity, and Suspended Sediment Concentration the average pollutant concentration across various seasons in the stream was higher for the Reedy Creek watershed.

Copper was one of the predominant pollutants in Mecklenburg County. It was found to be higher than the threshold value of 2µg/l for most of the creeks. However, on an average it was determined to be 37.4% higher for Clarke Creek watershed (10.05µg/l) compared to McMullen creek watershed (7.32µg/l).

For Total Kjeldahl Nitrogen, all the watersheds had a similar value of pollutant concentration except a spike was noticed in Coffey Creek, Edward's Branch (situated in McAlpine Creek) during the winter season alone. Similarly for Escherichia Coli all the watersheds had a similar value of pollutant concentration except a spike was noticed in Steele Creek during the fall season alone.

For Total Phosphorous and Nitrate/Nitrite, as mentioned the trends were opposite-the value of pollutant concentration in the stream was higher during the base flow rather than the stormflow. The value of pollutant concentration was similar to most of the creeks except a group of 4 creeks namely: Duck Creek, Little Sugar Creek, McAlpine Creek, and Sugar Creek. There were huge spikes in pollutant concentration noticed only in these four creeks mentioned above compared to the other creeks.

In addition, one-tailed t-test was also run to determine the statistical significance of the results. From average values across seasons the mean values standard deviation was determined. Table 17 shows the p-value determined by running the one tailed t-test for unequal variances. Out of the eight pollutants again six of them had a p-value of less than 0.05 except for total phosphorous and nitrate/nitrite. This indicates the pollutant concentration during stormflow was greater than base flow. For total phosphorous and nitrate/nitrite for which the p-value was greater than 0.05 indicating pollutant concentrations were higher during base flow (BF) rather than stormflow (SF).

Table 17: One Tailed t-test with unequal variances

Pollutants	Stormflow		Base flow		P-value	Significance	Result
	Mean	SD	Mean	SD			
TSS	33.10	37.55	7.07	2.39	0.000230525	<0.05	SF>BF
TKN	0.53	0.19	0.36	0.12	3.81022E-05	<0.05	SF>BF
Copper	4.15	1.63	2.54	0.77	3.83546E-06	<0.05	SF>BF
SSC	30.11	29.56	6.37	2.39	4.04782E-05	<0.05	SF>BF
Turbidity	37.77	29.20	8.58	4.56	1.70774E-06	<0.05	SF>BF
E.coli	1967	1054	481	222	2.32526E-09	<0.05	SF>BF
TP	0.16	0.21	0.16	0.32	0.485580174	>0.05	BF>SF
Nitrate/Nitrite	1.55	3.03	1.78	4.13	0.397600356	>0.05	BF>SF

4.3 Network of Existing BMPs

Recall the objective is to establish and evaluate the relationships between existing BMPs, urbanization in terms of impervious cover and pollutant concentration in the streams. The results will aid in identifying the effects of urbanization on the pollutant concentration that the BMPs must treat.

The 17 different types of BMPs were divided into nine major types and eight minor types of BMPs. This was based on the established standard on the pollution removal rates as stated by Charlotte Mecklenburg Stormwater Services in Table 5. From the spatial overlap between the watershed boundaries and different types of BMPs in the creeks present in the Mecklenburg County, Table 19 and 20 were created by analyzing the exact number of BMPs in each of the creeks and the Mecklenburg County as a whole. There were a total of 2841 BMPs in the Mecklenburg County which were divided into the major and minor types. There were a total of 2429 major types of BMPs and 412 minor types of BMPs. Based on the pollution removal rates as stated by Charlotte Mecklenburg Stormwater Services in Table 5, the major and minor types are divided. The types of BMPs mentioned in Table 5 are considered to be major and the remaining are considered to be minor.

Table 18: Total Number of BMPs in Mecklenburg County

County	Major Types	Minor Types	Total
Mecklenburg	2429	412	2841

The major and minor types of BMPs are listed in the Table 12 and 13 with their individual sum in different creeks and also cumulative sum in the Mecklenburg County. The terms indicated in Table 19 are: bio-retention basins (BR), wet ponds (WP), wetlands (WL), enhanced grass swale (EGS), grassed channel (GC), infiltration trenches (IT), filter strips (FS), sand filters (SF), and dry ponds (DP).

Table 19: Major Types of BMPs in Mecklenburg County

Watersheds	BR	WP	WL	EGS	GC	IT	FS	SF	DP	Sum
Back	6	6	2	-	-	-	-	-	10	24
Beaverdam	-	7	-	-	-	-	-	3	1	11
Briar	3	10	2	-	-	2	-	3	64	84
Caldwell	-	-	-	-	-	-	-	-	3	3

Table 19: Major Types of BMPs in Mecklenburg County (Continued)

Watersheds	BR	WP	WL	EGS	GC	IT	FS	SF	DP	Sum
Catawba	1	4	-	-	3	-	1	-	4	13
Clarke	45	3	1	13	-	2	-	5	21	90
Clear	3	1	-	1	-	-	-	-	6	11
Clem	3	8	1	-	-	-	-	1	8	21
Crooked	-	1	-	-	-	-	-	1	1	3
Four Mile	4	9	-	-	-	-	-	7	37	57
Gar	2	-	-	-	4	-	-	1	3	10
Goose	16	-	-	1	-	-	-	-	9	26
Irwin	10	3	2	-	-	1	-	3	117	136
Lake Norman	32	10	3	-	1	-	1	1	6	54
Lake Wylie	30	22	6	-	2	4	1	1	13	79
Long	24	35	4	3	9	-	6	15	74	170
Lower Clarke	7	4	-	-	-	-	-	-	11	22
Lower Little Sugar	11	7	2	-	-	-	-	5	31	56
Lower Mountain Island	1	15	-	-	-	-	-	-	6	22
Mallard	21	41	3	-	-	-	-	11	156	232
McAlpine	16	39	3	-	-	1	-	22	163	244
McDowell	240	59	12	15	11	3	-	24	72	436
McKee	-	1	-	-	-	-	-	1	1	3
McMullen	1	6	-	-	-	-	-	3	41	51

Table 19: Major Types of BMPs in Mecklenburg County (Continued)

Watersheds	BR	WP	WL	EGS	GC	IT	FS	SF	DP	Sum
Paw	1	17	-	-	-	-	-	2	30	50
Reedy	-	6	-	-	-	-	-	-	14	20
Rocky River	16	2	-	-	-	-	-	-	1	19
Six Mile	1	10	1	-	-	-	-	2	27	41
Steele	7	18	3	-	-	-	-	10	74	112
Sugar	14	41	-	-	-	-	-	14	177	246
Twelve Mile	-	1	-	-	-	-	-	3	1	5
Upper Little Sugar	13	3	12	-	-	-	1	2	43	74
Upper Mountain Island	1	1	-	-	1	-	-	-	1	4
Sum	529	390	57	33	31	13	10	140	1226	2429

The terms indicated in Table 20 are: buffer (B), cistern (C), level spreader (LS), open spaces (OS), rain garden (RG), stream restoration (SR), underground detention (UD), and underground sand filter (USF).

Table 20: Minor Types of BMPs in Mecklenburg County

Watersheds	B	C	LS	OS	RG	SR	UD	USF	Sum
Back	-	-	-	6	-	-	5	-	11
Beaverdam	-	-	-	2	-	-	-	-	2
Briar	-	-	-	10	-	-	25	2	37

Table 20: Minor Types of BMPs in Mecklenburg County (Continued)

Watersheds	B	C	LS	OS	RG	SR	UD	USF	Sum
Caldwell	-	-	-	-	-	-	-	-	0
Catawba	-	-	-	-	-	-	-	-	0
Clarke	-	-	-	-	-	-	-	-	0
Clear	-	-	-	-	-	-	-	-	0
Clem	-	-	-	4	-	-	1	-	5
Crooked	-	-	-	-	-	-	-	-	0
Four Mile	-	-	-	1	-	-	7	-	8
Gar	-	-	-	-	-	-	-	-	0
Goose	-	-	-	-	-	-	-	-	0
Irwin	-	-	-	13	-	-	38	-	51
Lake Norman	-	-	-	-	-	-	-	-	0
Lake Wylie	3	-	-	-	-	-	-	-	3
Long	-	-	-	7	-	1	1	-	9
Lower Clarke	-	-	-	-	-	-	1	-	1
Lower Little Sugar	-	-	-	1	-	-	7	-	8
Lower Mountain Island	-	-	-	1	-	-	-	-	1
Mallard	2	-	-	9	-	-	18	-	29
McAlpine	-	-	-	21	-	2	26	-	49
McDowell	-	-	1	-	1	7	7	-	16
McKee	-	-	-	1	-	-	-	-	1

Table 20: Minor Types of BMPs in Mecklenburg County (Continued)

Watersheds	**B**	**C**	**LS**	**OS**	**RG**	**SR**	**UD**	**USF**	**Sum**
McMullen	-	-	-	12	-	-	22	-	34
Paw	-	-	-	4	-	-	2	-	6
Reedy	-	-	-	4	-	-	1	-	5
Rocky River	-	-	-	-	-	-	-	-	0
Six Mile	-	-	-	3	-	-	2	1	6
Steele	-	-	-	12	-	-	4	1	17
Sugar	-	-	-	15	-	-	28	-	43
Twelve Mile	-	-	-	6	-	-	-	-	6
Upper Little Sugar	-	1	-	13	-	8	42	-	64
Upper Mountain Island	-	-	-	-	-	-	-	-	0
Sum	**5**	**1**	**1**	**145**	**1**	**18**	**237**	**4**	412

From Tables 19 and 20, it is clear that the most and least common major type of BMP used in Mecklenburg County are the dry pond (sum of 1,226) and filter strips (sum of 10) respectively. Similarly, the most common minor type of BMP used in Mecklenburg County are the underground detention and with a cumulative sum of 237. Whereas there was only 1 recorded cistern, level spreader, and rain garden in use in Mecklenburg County.

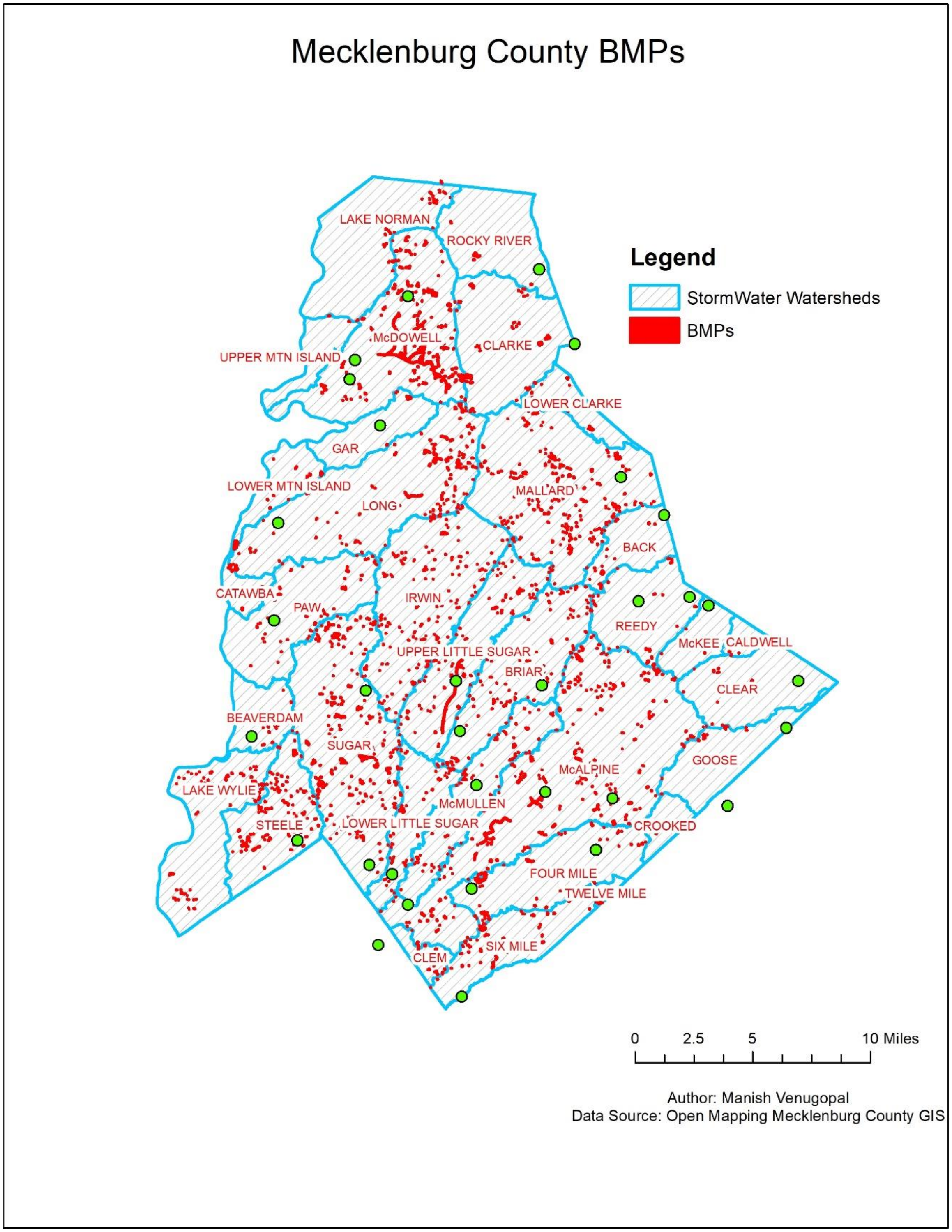


Figure 11: Location of major and minor BMPs in the Mecklenburg County

From the Table 19 and 20, it is also clear that the McDowell Creek has the maximum number of BMPs with a total of 452, followed by McAlpine Creek with 293, Sugar Creek with 289, and Mallard Creek with 261. Caldwell and Crooked Creek have the least number with 3 recorded BMPs each. In addition, Figure 11 shows the exact location of all the major and minor types of BMPs in the Mecklenburg County for each of the watersheds. The map was developed using ArcGIS. The shape file for the state boundaries, watersheds, and exact location of BMPs was obtained from the Open Mapping Mecklenburg County GIS, North Carolina (GIS, 2019).

4.4 Determination of Impervious Cover

The impervious cover dataset for 2019 was obtained from Open Mapping Charlotte Mecklenburg Stormwater Services. There were three different types of impervious cover namely: commercial, single family, and other. From the spatial overlap between the watershed boundaries and different types of impervious cover in the creeks present in the Mecklenburg County, Table 21, 22 and 23 were created by analyzing the exact number of BMPs in each of the creeks and the Mecklenburg County as a whole.

Table 21: Commercial Impervious Cover in Mecklenburg County

Watersheds	**Commercial Impervious %**	**Commercial Impervious Area Acres**
Back	4.21%	212.93
Beaverdam	2.30%	107.76
Briar	12.68%	1,753.03
Caldwell	1.29%	17.52
Catawba	5.61%	108.51

Table 21: Commercial Impervious Cover in Mecklenburg County (Continued)

Watersheds	**Commercial Impervious %**	**Commercial Impervious Area Acres**
Clarke	3.15%	433.60
Clear	0.88%	86.58
Clem	10.31%	179.29
Crooked	2.00%	43.81
Four Mile	5.38%	641.98
Gar	0.36%	19.01
Goose	0.84%	61.37
Irwin	15.55%	2,983.68
Lake Norman	3.56%	489.47
Lake Wylie	2.32%	294.04
Long	7.32%	1,702.24
Lower Clarke	4.41%	161.34
Lower Little Sugar	16.29%	1,043.31
Lower Mtn Island	2.58%	108.87
Mallard	10.64%	2,646.07
McAlpine	9.35%	3,541.84
McDowell	6.71%	1,394.49
McKee	0.99%	37.33
McMullen	9.51%	925.71

Table 21: Commercial Impervious Cover in Mecklenburg County (Continued)

Watersheds	**Commercial Impervious %**	**Commercial Impervious Area Acres**
Paw	6.25%	799.81
Reedy	1.30%	118.41
Rocky River	1.73%	171.74
Six Mile	6.89%	566.91
Steele	14.51%	1,443.06
Sugar	17.89%	4281.42
Twelve Mile	1.48%	7.88
Upper Little Sugar	20.86%	2,577.22
Upper Mtn Island	0.18%	6.18
Total	8.29%	28,966.40

Table 22: Single Family Impervious Cover in Mecklenburg County

Watersheds	**Single Family Impervious %**	**Single Family Impervious Area Acres**
Back	7.19%	363.66
Beaverdam	2.49%	116.66
Briar	10.26%	1418.46
Caldwell	1.23%	16.71

Table 22: Single Family Impervious Cover in Mecklenburg County (Continued)

Watersheds	Single Family Impervious %	Single Family Impervious Area Acres
Catawba	1.39%	26.89
Clarke	3.36%	462.51
Clear	3.26%	320.76
Clem	10.20%	177.38
Crooked	5.15%	112.81
Four Mile	9.21%	1,099.00
Gar	1.56%	82.39
Goose	3.90%	284.93
Irwin	4.73%	907.58
Lake Norman	4.25%	584.34
Lake Wylie	4.45%	564.00
Long	4.22%	981.34
Lower Clarke	7.46%	272.93
Lower Little Sugar	7.41%	474.58

Table 22: Single Family Impervious Cover in Mecklenburg County (Continued)

Watersheds	**Single Family Impervious %**	**Single Family Impervious Area Acres**
Lower Mtn Island	5.01%	211.41
Mallard	5.07%	1,260.86
McAlpine	8.66%	3,280.46
McDowell	5.14%	1,068.21
McKee	5.72%	215.69
McMullen	10.86%	1,057.11
Paw	3.82%	488.84
Reedy	5.07%	461.79
Rocky River	4.13%	409.99
Six Mile	9.40%	773.43
Steele	5.30%	527.10
Sugar	1.74%	416.42
Twelve Mile	13.38%	71.24
Upper Little Sugar	7.65%	945.15

Table 22: Single Family Impervious Cover in Mecklenburg County (Continued)

Watersheds	**Single Family Impervious %**	**Single Family Impervious Area Acres**
Upper Mtn Island	1.70%	58.39
Total	5.59%	19512.99

Table 8: Other Impervious Cover in Mecklenburg County

Watersheds	**Other Impervious %**	**Other Impervious Area Acres**
Back	4.06%	205.35
Beaverdam	1.91%	89.49
Briar	6.88%	951.17
Caldwell	0.64%	8.69
Catawba	0.80%	15.47
Clarke	1.96%	269.80
Clear	1.82%	179.07
Clem	5.25%	91.30
Crooked	2.70%	59.15
Four Mile	4.26%	508.33
Gar	0.49%	25.88
Goose	2.02%	147.58
Irwin	6.43%	1233.77
Lake Norman	1.99%	273.61

Table 23: Single Family Impervious Cover in Mecklenburg County (Continued)

Watersheds	Other Impervious %	Other Impervious Area Acres
Lake Wylie	2.80%	354.87
Long	3.13%	727.87
Lower Clarke	5.11%	186.95
Lower Little Sugar	4.31%	276.04
Lower Mtn Island	3.12%	131.65
Mallard	4.49%	1116.62
McAlpine	4.97%	1882.67
McDowell	4.32%	897.79
McKee	3.43%	129.34
McMullen	4.88%	475.02
Paw	3.00%	383.91
Reedy	2.84%	258.68
Rocky River	2.35%	233.29
Six Mile	5.63%	463.24
Steele	3.70%	367.98
Sugar	3.67%	878.30
Twelve Mile	3.81%	20.29
Upper Little Sugar	8.16%	1008.16
Upper Mtn Island	0.70%	24.04
Total	3.97%	13875.34

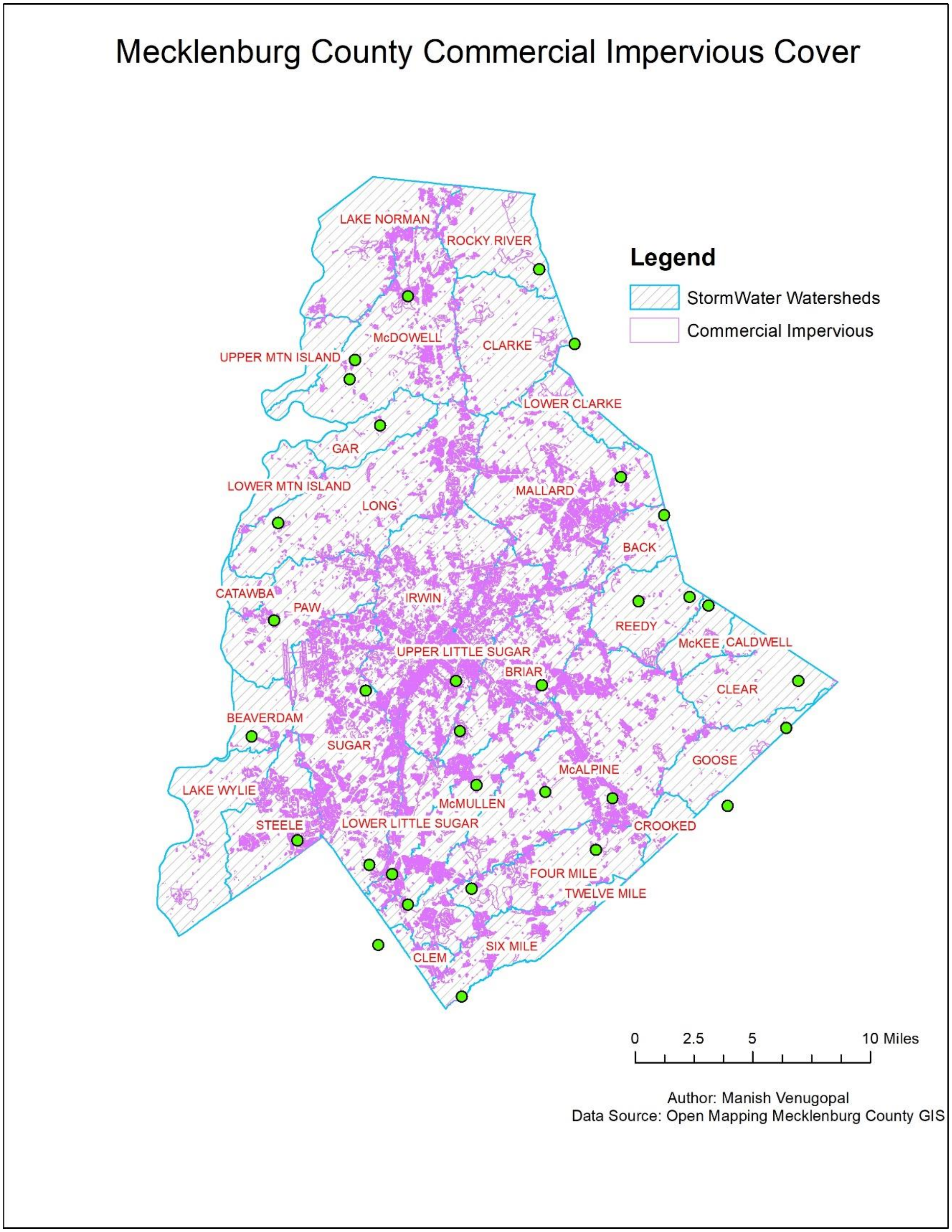


Figure 12: Commercial impervious cover in the Mecklenburg County

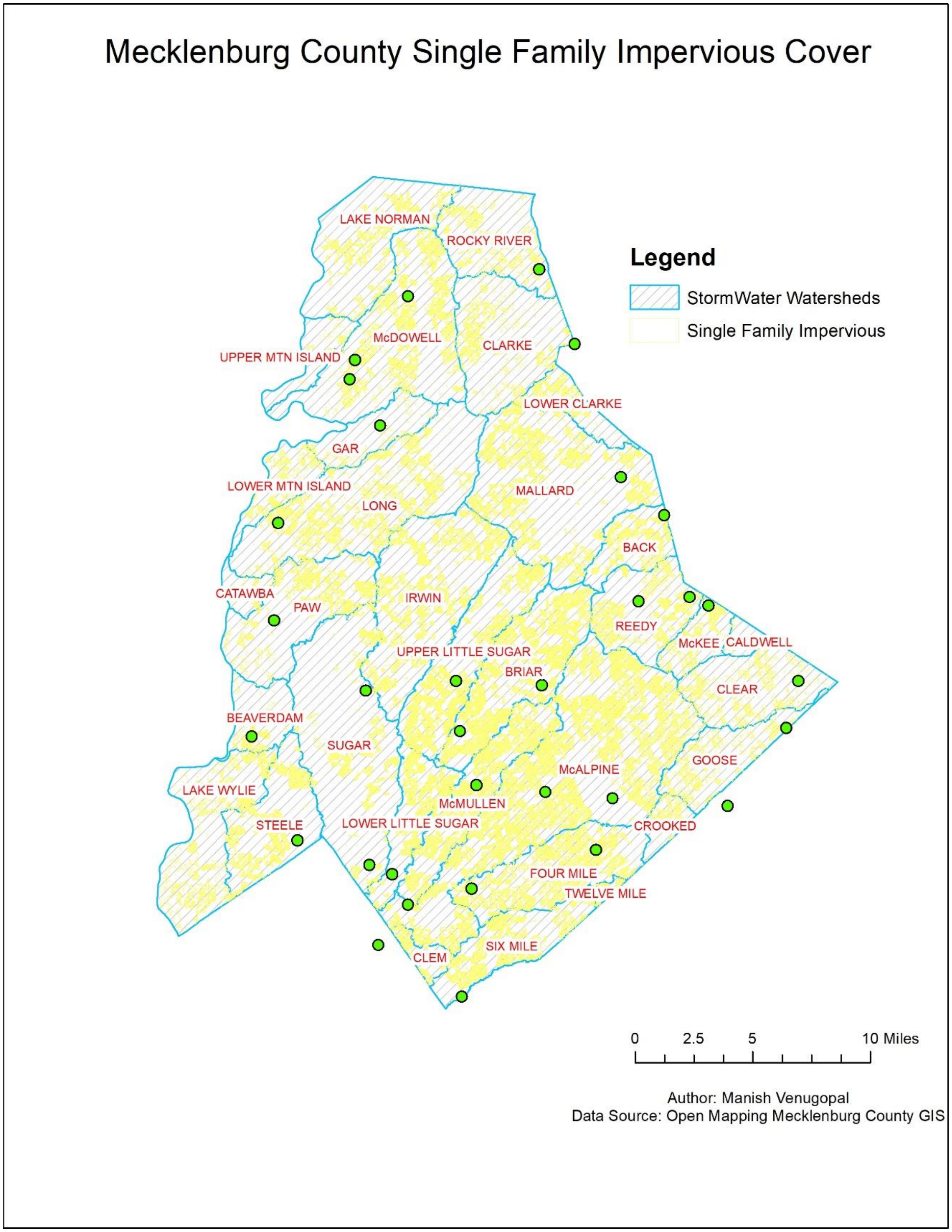


Figure 13: Single family impervious cover in the Mecklenburg County

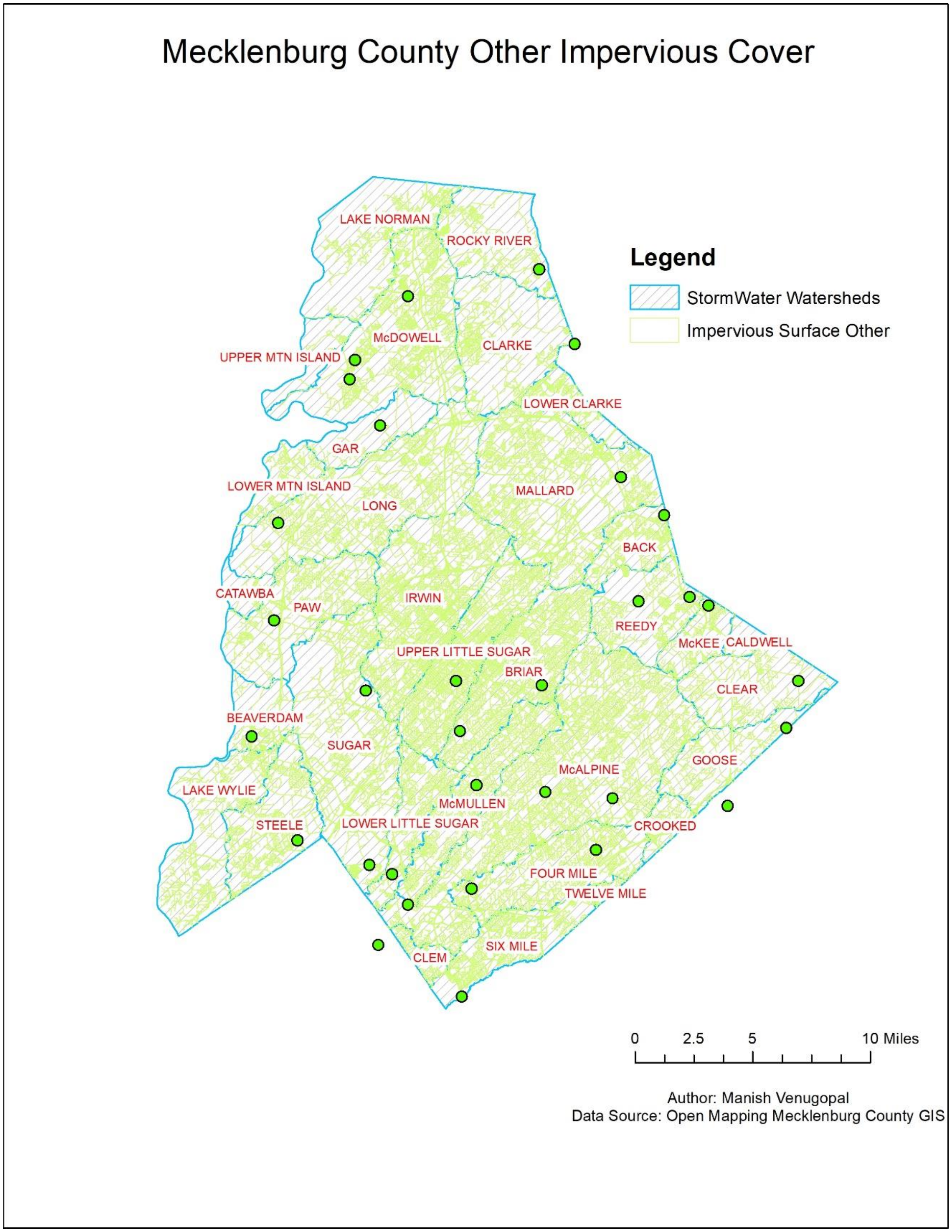


Figure 14: Other impervious cover in the Mecklenburg County

Figures 12, 13, and 14 indicate the commercial, residential, and other impervious cover present in the Mecklenburg County in each of the creeks. Tables 21, 22, and 23 was created using the data from the Figures 12, 13, and 14. The maps were developed using ArcGIS. The shape files for the state boundaries, watersheds, and commercial, residential, and other impervious cover were obtained from the Open Mapping Mecklenburg County GIS, North Carolina (GIS, 2019).

From Table 21, 22 and 23, it was clear that the commercial, single family and other impervious cover were 8.29%, 5.59%, and 3.97% respectively in Mecklenburg County as a whole. The total impervious cover of Mecklenburg County was 17.85% or 62354 acres. It was evident that, the commercial impervious cover because of the industries, commercial buildings, and parking lots was the major source and accounted for 28966 acres of impervious surface. Whereas, the single family and other impervious cover due to residential construction and sidewalks, edge of streets, common area accounted for 19512 and 13875 acres respectively.

From Table 21, it was also evident that Sugar and Little Sugar Creek had the highest impervious cover content in terms of commercial construction with 17.89% and 19.30% respectively. However, in terms of acres Sugar Creek was the highest with 4281.42 acres followed by McAlpine Creek with 3581.84 acres or 9.35% impervious cover.

From Table 22, it was also evident that McMullen, Twelve Mile, Clem and Briar Creek had high impervious cover content in terms of residential construction with more than 10% each. Twelve Mile had the highest with 13.38%. In terms of impervious acres McAlpine Creek was the highest with 3280.46 acres with an 8.66% impervious cover.

From Table 23, it was also evident that Little Sugar and Briar Creek had the highest impervious cover content in terms of other construction with 6.85% and 6.88% respectively. However, in terms of acres Little Sugar Creek was the highest with 1284.19 acres.

4.5 Secondary Data on Impervious Cover

The impervious cover data for 2013, 2015, 2016, 2017, and 2018 were obtained from Charlotte Mecklenburg Quality of Life Explorer. Figure 15 indicates the NPA defined boundaries present in the Mecklenburg County in each of the creeks. From the spatial overlap between the watershed boundaries and NPA boundaries in the creeks present in the Mecklenburg County, Table 24 was created. The exact number of NPA defined areas were marked using ArcGIS in each of the creeks and the Mecklenburg County as a whole. This was used to determine the impervious cover percentage for the years stated in the Table 23.

Table 24: Secondary (NPA) data on impervious cover

Mecklenburg County	**Impervious Cover**	
Years	**Percentage**	**Acres**
2013	14.10%	47340
2015	14.50%	48489
2016	14.70%	49354
2017	15.00%	50169
2018	15.20%	50878
2019	17.85%	62354

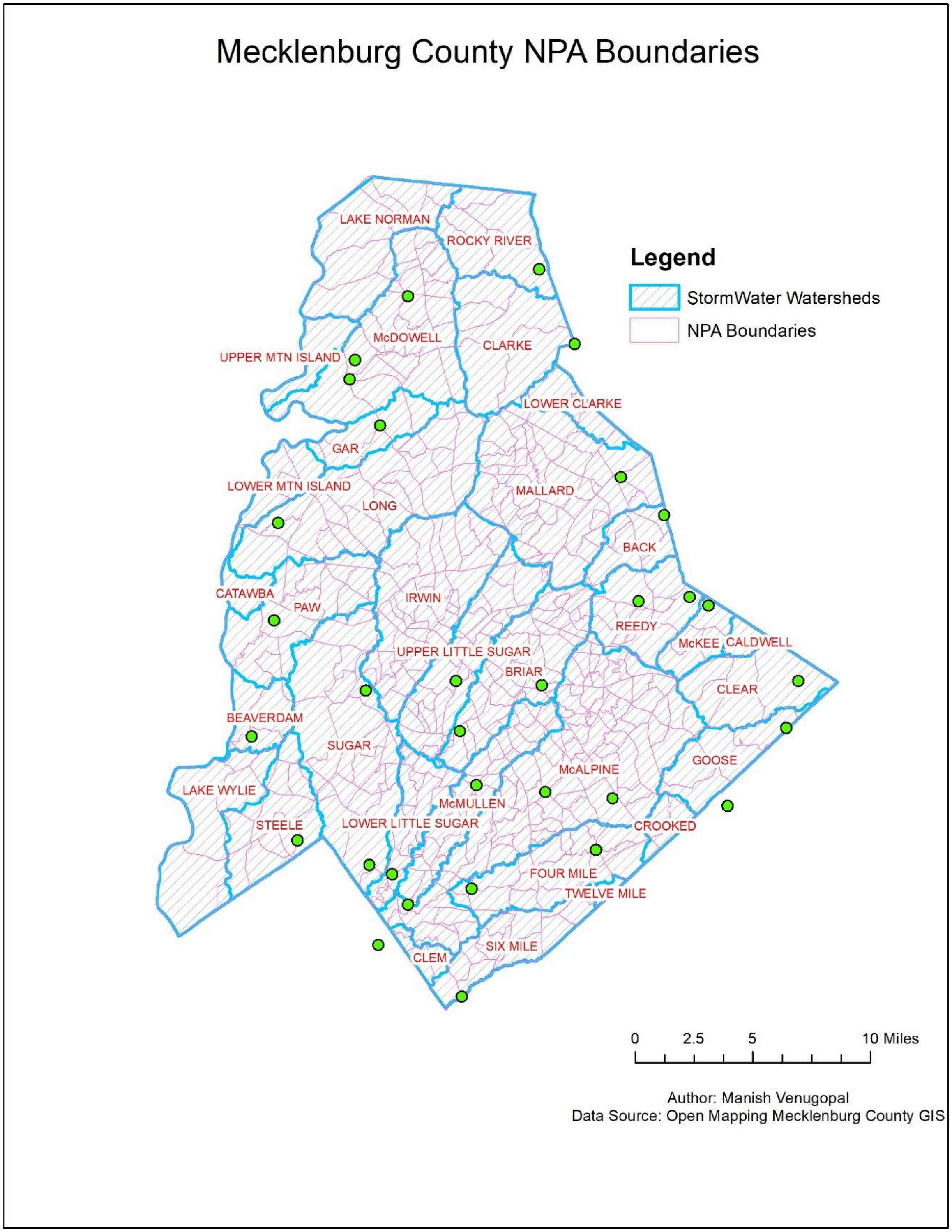


Figure 15: NPA boundaries in the Mecklenburg County

The overall impervious cover percentage for Mecklenburg County had increased from 2.65% (11476 acres) from 2018 to 2019. The impervious cover data calculated using ArcGIS had an error of 4% for the impervious cover area calculated using the assumptions as defined for the NPA boundaries compared to the impervious cover area calculated by the Charlotte Mecklenburg Quality of Life Explorer.

4.6 Sorting and Grouping of Creeks:

As stated earlier, the watersheds can be sorted and grouped based on the similarities of the following factors:

- The size of the waterhsed
- The number of BMPs in the watershed
- The percentage of impervious cover in the watershed

The watersheds in here are sorted and grouped based on the similar size criterion. This is done to show how the similar watersheds with varying number of BMPs and impervious cover percentage had different types and amount of pollutant concentrations.

Table 25: Comparison table between the creeks in terms of area, number of BMPs and impervious cover percentage

Watersheds	**Watershed Area Acres**	**Number of BMPs**	**Total Impervious Cover %**	**Total Impervious Area**	**BMPs:IC Ratio**
McKee	3,770.80	4.00	10.14%	382.36	96
Beaverdam	4,685.10	13.00	6.70%	313.90	24

Table 25: Comparison table between the creeks in terms of area, number of BMPs and impervious cover percentage (Continued)

Watersheds	Watershed Area Acres	Number of BMPs	Total Impervious Cover %	Total Impervious Area	BMPs:IC Ratio
Back	5,057.83	35.00	15.46%	781.94	22
Gar	5,281.19	10.00	2.41%	127.28	13
Goose	7,306.01	26.00	6.76%	493.89	19
Six Mile	8,228.00	47.00	21.92%	1,803.58	38
Reedy	9,108.29	25.00	9.21%	838.87	34
McMullen	9,734.02	85.00	25.25%	2,457.84	29
Clear	9,839.16	11.00	5.96%	586.41	53
Rocky River	9,927.21	19.00	8.21%	815.02	43
Steele	9,945.29	129.00	23.51%	2,338.14	18
Fourmile	11,932.70	65.00	18.85%	2,249.31	35
Paw	12,796.99	56.00	13.07%	1,672.57	30
Briar	13,825.14	121.00	29.82%	4,122.66	34
Clarke	17,423.64	113.00	10.26%	1,787.12	16

Table 25: Comparison table between the creeks in terms of area, number of BMPs and impervious cover percentage (Continued)

Watersheds (Continued)	**Watershed Area Acres**	**Number of BMPs**	**Total Impervious Cover %**	**Total Impervious Area**	**BMPs:IC Ratio**
Little sugar	18,759.44	202.00	33.71%	6324.45	31
Irwin	19,187.65	187.00	26.71%	5125.02	27
McDowell	20,782.27	452.00	16.17%	3360.49	7
Long	23,254.60	179.00	14.67%	3411.45	19
Sugar	23,931.90	289.00	23.30%	5576.13	19
Mallard	24,869.07	261.00	20.20%	5023.55	19
McAlpine	37,880.60	293.00	22.98%	8704.96	30

Table 25 gives the watershed creek names with their respective areas, number of BMPs located in them, and the impervious cover in terms of percentage and area in each of the watersheds. The BMPs:IC is the ratio of number of BMPs present in terms of impervious cover area in each of the creeks. For example, BMPs:IC ratio of 1:7.43 for McDowell Creek means the creek had 1 BMP for an impervious cover area of 7.43 acres. From Table 17, it indicates that the Mecklenburg County had increased the number of BMPs based on the area of the watershed in most of the locations irrespective of the impervious cover. In addition, the watersheds were grouped based on their similar size criterion into:

- Small Watersheds
- Medium Watersheds
- Large Watersheds

Figures 16 to 21, indicates the grouping of watersheds based on the similar size criterion. They show the watershed area in acres, total impervious area in acres, number of BMPs, and BMPs: IC ratio for each individual watersheds present in the Mecklenburg County.

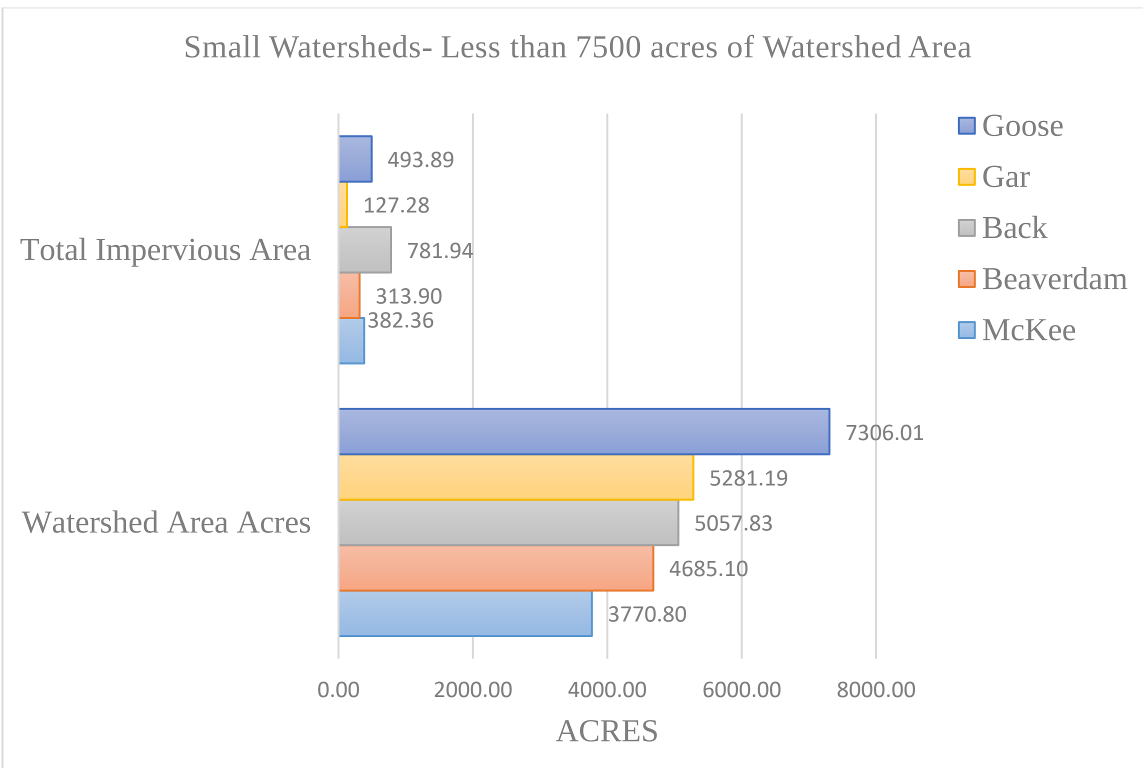


Figure 16: Small Watersheds Grouping based on Watershed Area

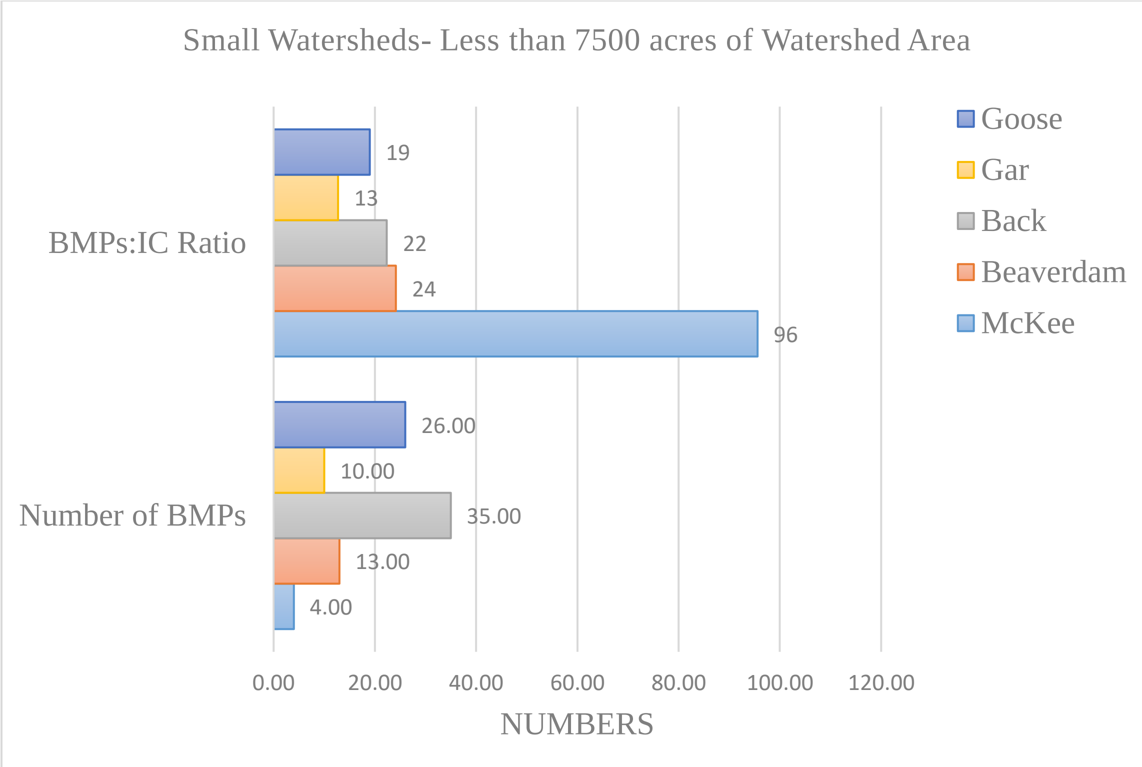


Figure 17: Comparison of BMPs and BMPs: IC Ratio in the small watersheds

For example, looking at the Figure 16 and 17, Mckee Creek which had an watershed area of 3,770.80 acres with an impervious cover of 10.14% (382.36 acres) but had only 4 reported BMPs in the region. Beaverdam Creek had an watershed area of 4,685.10 acres with an impervious cover of 6.70% (313.90 acres) and has 13 BMPs in the region. However, Gar Creek which had an watershed area of 5,281.19 acres with an impervious cover of 2.41% (127.28 acres) but had 10 reported BMPs in the region. Back Creek had an watershed area of 5,057.83 acres with an impervious cover of 15.46% (781.94 acres) and had 35 BMPs in the region. All the watersheds were similar in area, but had different numbers of BMPs compared to the impervious cover in the range 1:96, 1:24, 1:13, and 1:22 respectively.

As stated above Mckee Creek with a ratio of BMPs:Impervious cover of 1:96 was the least among the small watersheds, whereas Gar Creek with a ratio of 1:13 had the highest. Back Creek had 35 BMPs which the highest in this region.

However, Gar Creek which was had the least amount of impervious cover and Back Creek which was had the highest amount of impervious cover had the least amount of pollutant concentrations for majority of the pollutants such as TSS, copper, TKN, turbidity,SSC compared to McKee and Beaverdam Creek watersheds. As stated earlier, both Gar and Back Creek watersheds had better BMPs:IC ratio compared to the other two watersheds. This indicates the pollutant concentrations in this region have been treated better with more number of BMPs in that region based on the impervious cover rather than the watershed area.

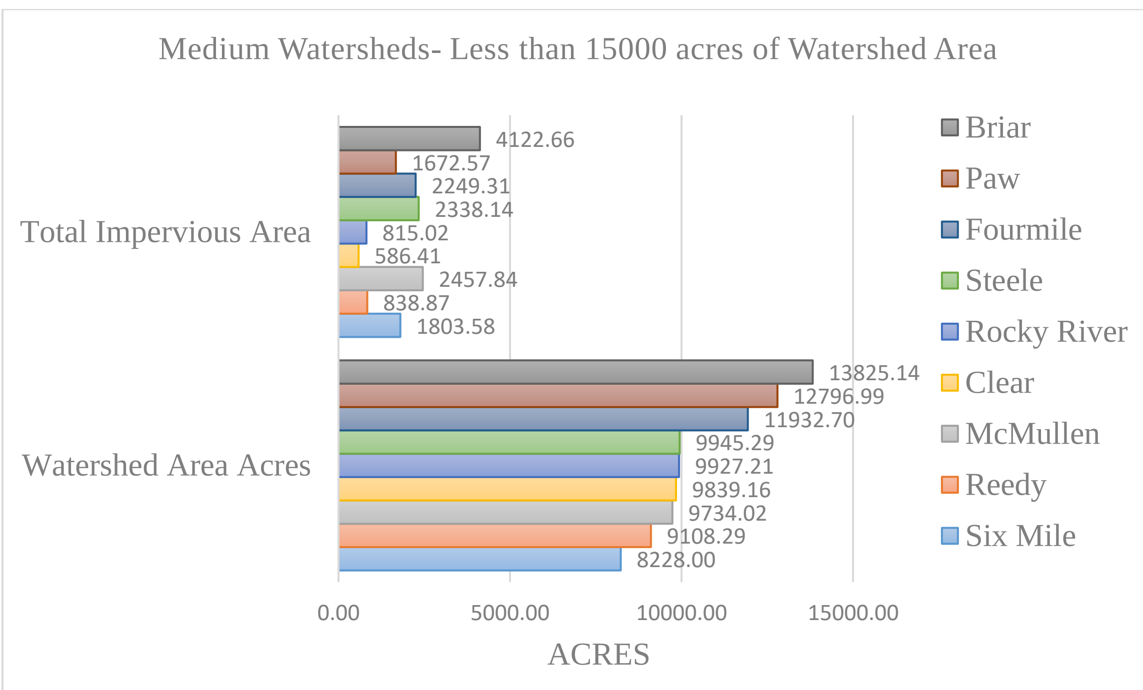


Figure 18: Medium Watersheds Grouping based on Watershed Area

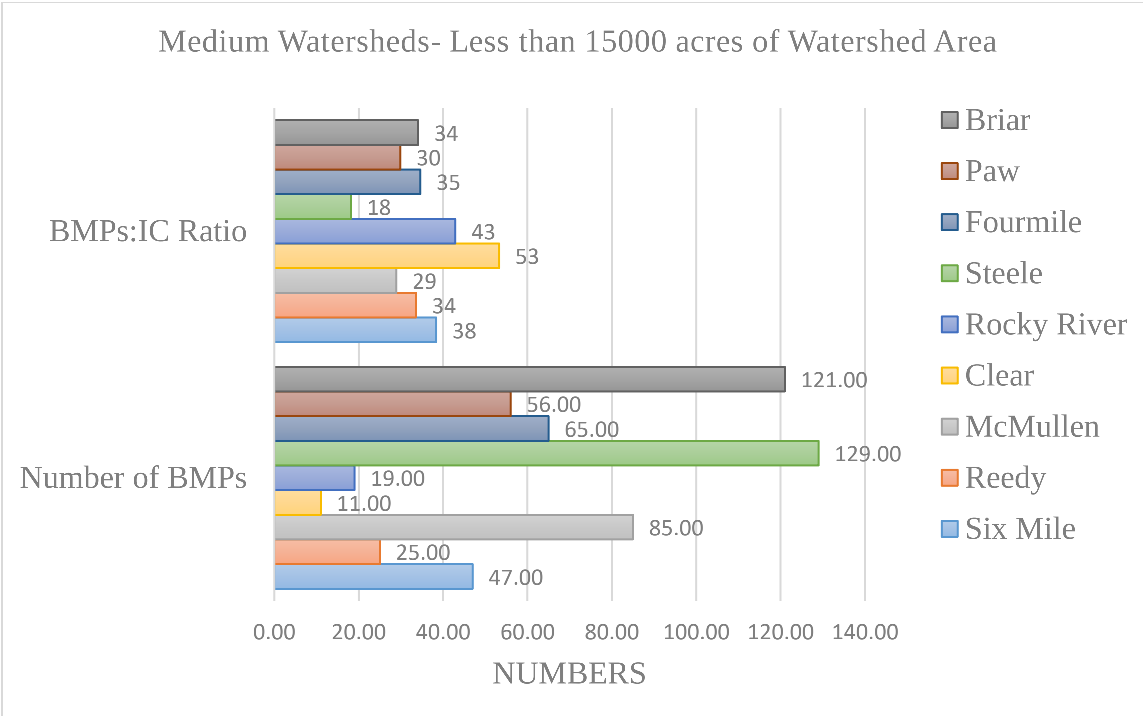


Figure 19: Comparison of BMPs and BMPs:IC Ratio in the medium watersheds

For example, looking at the Figure 18 and 19, Clear Creek which had an watershed area of 9,839.16 acres with an impervious cover of 5.96% (586.41 acres) had only 11 BMPs. Similarly, Reedy Creek which had an watershed area of 9,108.29 acres with an impervious cover of 9.21% (838.87 acres) but had only 25 reported BMPs in the region. Rocky River had an watershed area of 9,927.21 acres with an impervious cover of 8.21% (815.02 acres) and has 19 BMPs in the region. However, Steele Creek which had an watershed area of 9,945.29 acres with an impervious cover of 23.51% (2338.14 acres) but had 129 reported BMPs in the region. Briar Creek had an watershed area of 13,825.14 acres with an impervious cover of 29.82% (4122.66 acres) and had 121 BMPs in the region. All the watersheds were similar in area, but had different numbers of BMPs compared to the impervious cover in the range 1:53, 1:34, 1:43, 1:18, and 1:34 respectively.

As stated above Clear Creek watershed with a ratio of BMPs:Impervious cover of 1:53 with 11 BMPs which was the least among the medium watersheds, whereas Steele Creek watershed with a ratio of 1:18 with 129 BMPs which the highest.

Rocky River and Reedy Creek watersheds which had only 19 and 25 BMPs respectively had the highest amount of pollutant concentrations for majority of the pollutants such as TSS, copper, TKN, turbidity,SSC, Escherichia Coli compared to other watersheds. As stated earlier, Steele Creek watershed had better BMPs:IC ratio compared to the other watersheds and lesser amount of pollutant concentration for a majority of pollutants such as TSS, turbidity, SSC, and nitrate/ nitrite. In terms of the other pollutants too it had the second lowest pollutant concentrations. This also indicates the pollutant concentrations in this region have been treated better with more number of BMPs in that region based on the impervious cover rather than the watershed area.

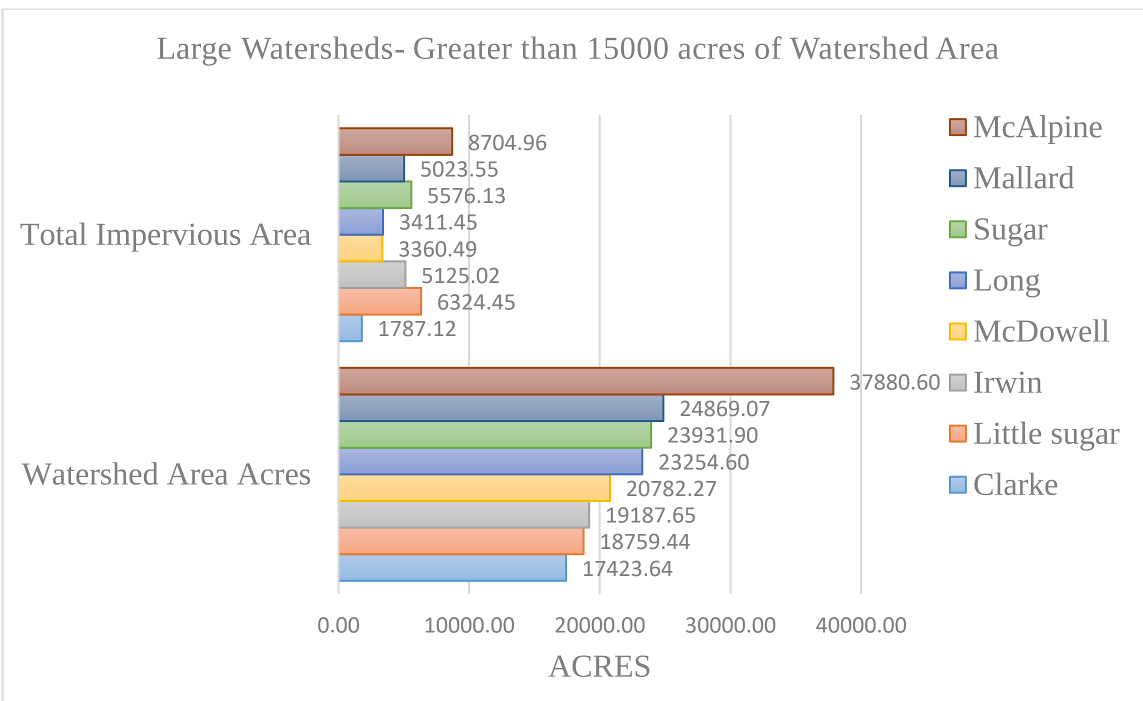


Figure 20: Large Watersheds Grouping based on Watershed Area

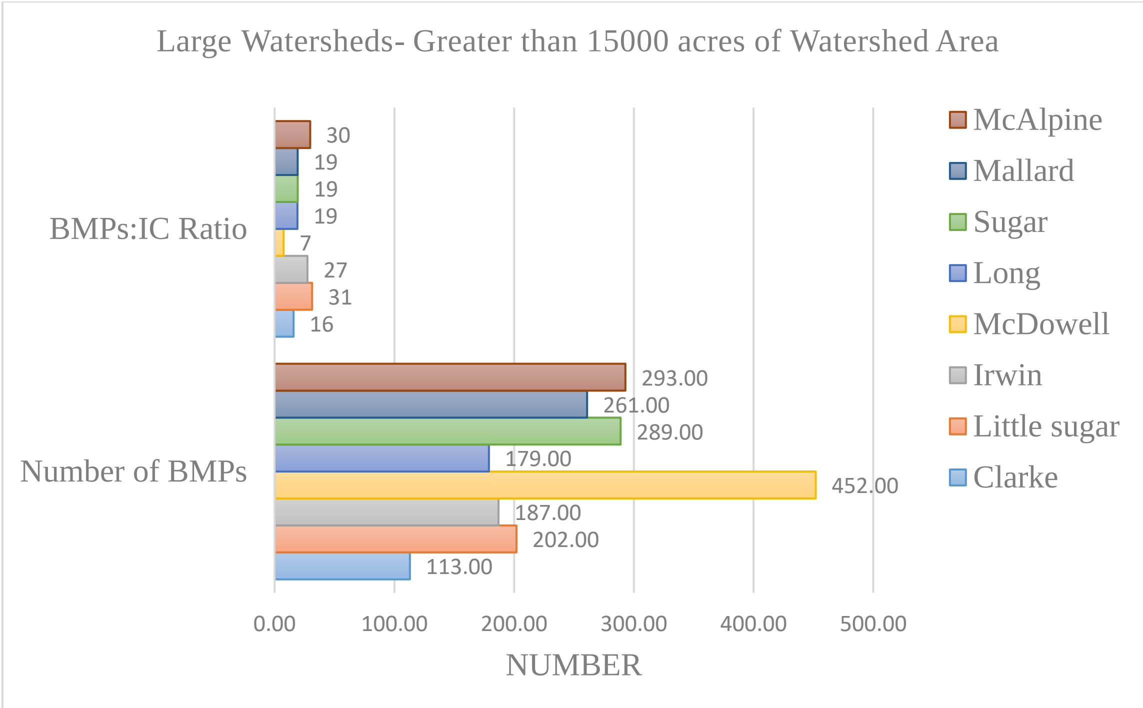


Figure 21: Comparison of BMPs and BMPs IC ratio in large watersheds

For example, looking at the Figure 20 and 21, Little Sugar Creek which had an watershed area of 18,759.44 acres with an impervious cover of 33.71% (6,324.45 acres) had 202 BMPs. Similarly, Sugar Creek and McAlpine Creek which had an watershed area of 23,931.90 and 37,880.60 acres with an impervious cover of 23.30% (5576.13 acres) and 22.98% (8,704.96 acres) had 289 and 293 reported BMPs in the region respectively. Clarke Creek with an watershed area of 17,432.64 acres and an impervious cover of 10.26% (1,787.12 acres) had the least amount of BMPs in the region with 113 BMPs. However, McDowell Creek which had an watershed area of 20782.27 acres with an impervious cover of 16.17% (3,360.49 acres) but had 452 reported BMPs in the region. All the watersheds were similar in area, but had different numbers of BMPs compared to the impervious cover in the range 1:31, 1:19, 1:30, 1:16 and 1:7 respectively.

As stated above Little Sugar Creek watershed with a ratio of BMPs:Impervious cover of 1:31 with 202 BMPs which was the least among the large watersheds, whereas McDowell Creek watershed with a ratio of 1:7 with 452 BMPs which the highest.

Clarke Creek watershed which had the least number of BMPs among the large watershed had the highest amount of pollutant concentrations for majority of the pollutants such as TSS, copper, turbidity,SSC compared to other watersheds. TP, TKN, and nitrate/nitrite were higher in McAlpine, Sugar and Little Sugar Creek watersheds compared to the other watersheds. As stated earlier, McDowell Creek watershed had better BMPs:IC ratio compared to the other watersheds and lesser amount of pollutant concentration for a majority of pollutants such as TP, TKN copper, escherichia coli and nitrate/ nitrite. In terms of the other pollutants too it had the second lowest pollutant concentrations. This also indicates the pollutant concentrations in this region have been treated better with more number of BMPs in that region based on the impervious cover rather than the watershed area.

As stated above Mckee Creek watershed with a ratio of BMPs: Impervious cover of 1:96 was the least among the creeks, where as Mcdowell Creek with a ratio of 1:7 had the highest number of BMPs. McDowell Creek watershed had 452 BMPs in the region with an watershed area of 20,782.27 acres and a impervious cover of 16.17% (3,360.49 acres). However, the creek had the least amount of pollutant concentrations for all types of pollutants.

4.7 Recommendations and Discussions

It was evident from the results that the pollutant concentration did vary across different seasons based on precipitation. However, the amount of pollutant concentration does not depend upon precipitation alone. For example from Table 10, out of the watersheds selected, Reedy Creek had higher pollutant concentrations for three out of the eight pollutants. In general, Little Sugar, McAlpine, and Sugar Creek had more pollutant concentration compared to the other creeks. The higher pollutant concentration amounts in the streams may also result from the increase in percentage impervious cover and the efficiency of stormwater structures already in use in the region.

As shown in Table 16, Reedy Creek was the most impacted by three different types of pollutants namely: total suspended solids, turbidity, and suspeneded sediment concentration. The three pollutants are interrelated to each other; whenver one of them is going to be more it is going to affect the other. Total Suspended Solids are particles larger than 2 microns in size which includes: sediment, silt, plankton, and algae (Fondriest Environmental, 2014);(Agency, 2008) stated, particles suspended or dissolved in water makes it to appear cloudy or murky which can result in turbidity. This indicates that when Total Suspended solids is high, generally turbidity is also going to increase.

The major source of suspended solids as stated is domestic wastes (Edwards & Withers, 2008). Watch (2015d) stated, the population of Reedy Creek between 1990 and 2010 had increased three times over time from 1990 to 2010. There were 8,274 people in 1990 compared to 27,023 people in 2010 (Watch, 2015d). In comparison, McAlpine Creek had 168,000 people in 2010.

Reedy creek had only 25 BMPs with an impervious cover of 9.21% (838.87 acres) compared to its watershed area of 9,108.29 acres. Out of the 9.21% of impervious cover in Table 22, the residential impervious cover was alone 5.07% which included a lot of suspended solids. In contrast, McAlpine Creek had the most residential impervious cover of 3,280.46 acres (8.66%). However, it had more number of BMPs based on the watershed area and lesser amount of the similar types of pollutants. From Table 5, these three pollutants are treated well using a bio-retention, sand filters, wet pond, and wetland compared to a dry pond. However, out of the 25 BMPs Reedy Creek had only 6 wet ponds and no bio-retentions, sand filters, or wetlands. In comparison, McAlpine had 16 bio-retentions, 22 sand filters, 39 wet ponds and 3 wetlands.

McAlpine, Little Sugar, and Sugar Creek had the highest pollutant concentration for Total Phosphorous and Nitrate/Nitrite from Table 10. From Table 14, the commercial impervious cover as been higher for all of them. The impervious cover for Little Sugar and Sugar Creek was 19.30% and 173.89% respectively. However McAlpine Creek had an commercial impervious cover area of 3,581.84 acres (9.35%) only behind the two mentioned above.

The major source of Total Phosphorous and Nitrate/Nitrite is from agricultural land (Edwards & Withers, 2008). Little Sugar, McAlpine, Sugar Creek eventually flow into southwest South Carolina. The sub-basin they belong to consist of 31% agricultural land and 14% forested lands respectively (DWQ, 2010). As stated in Watch (2015a), Little Sugar Creek had been used as business settlement over two decades for now. The creek was used as a sewer for years by the people. In addition, McAlpine and Sugar Creek have wastewater treatment plants located in the downstream side which are a source of phosphorous and nitrate. This indicates the higher concentrations of these pollutants in this region. In addition, they were the only pollutants that were higher during the base flow rather than the stormflow. One reason for this is nitrates/nitrites aren’t exported during the storm events to a greater extent. And they are mostly present in subsurface runoff (Almeida, Butler, & Friedler, 1999).

As shown in Table 16, Total Kjeldahl Nitrogen concentration were higher in McAlpine Creek compared to the other creeks. Total Kjeldahl Nitrogen is formed by the combination of organic nitrogen and ammonia. The major source of nitrogen is agriculture, urban waste and untreated sewage from pets, mammals and wildlife (Ghaly & Ramakrishnan, 2015). Another indicator of the higher concentration of Total Kjeldahl Nitrogen is the presence of fecal coliform and lack of aquatic insects (Watch, 2015c). As shown above, McAlpine Creek is one of the creeks with more nitrate/nitrite compared to the other creeks. It consisted of 168,000 people (Watch, 2015c), with a residential and commercial impervious cover of 9.35% (3,541.84 acres) and 8.66% (3,280.46 acres) respectively. This shows the presence of Total Kjeldahl Nitorgen in the creek.

From Table 1 and 5, Total Phosphorous, Total Kjeldahl Nitrogen and Nitrate/Nitrite are well treated by a bio-retentions, wet ponds, and wetlands. Little Sugar, McAlpine, and Sugar Creek had 202, 289 ,and 293 BMPs respectively. However, out of that only 48 ,58, and 55 the combined total of bio-retentions, wet ponds, and wetlands respectively for each of the creeks. Whereas, McDowell creek had a combined total of 311 bio-retentions, wet ponds, and wetlands out of 452 BMPs. McDowell Creek had one of the lowest pollutant concentrations in terms of Total Phosphorous, Total Kjeldahl Nitrogen and Nitrate/Nitrite.

Therefore, the results indicate that appropriate types of BMPs should be used in each of the watersheds depending upon the type of the pollutant rather than increasing the number of BMPs based on the watershed area alone.

CHAPTER 5 CONCLUSION

Urbanization has resulted in increase in the runoff quantity and surface water quality degradation. The impact of urban stormwater on receiving waters has increased due to advances in wastewater infrastructure (Obropta & Kardos, 2007). Reductions in both macro-invertebrate diversity and quality fish habitat have been caused due to greater flow variability combined with increased downstream sediment loads (McColl & Aggett, 2007).

The study aids in determining how the factors such as precipitation, existing BMPs in use, and impervious cover affect the water quality in streams. It shows how the pollutant concentrations had varied across different creeks based on the precipitation over a 10-year period. In addition, this work shows how these existing network of BMPs and impervious cover plays a major role in the amount of pollutant concentrations present in the creeks.

As stated earlier, it was evident from the results that the pollutant concentration did vary across different seasons based on precipitation. However, the amount of pollutant concentration does not depend upon precipitation alone. It was also based on the efficiency of the existing network of BMPs, which type of pollutants that these BMPs predominantly treat, and also the percentage of impervious cover in the creeks.

In conclusion, it was evident from the analysis that the pollutant concentrations in the creeks were dependent on all the three factors mentioned: precipitation, efficiency of existing BMPs, and percentage of impervious cover in the creeks. It was also palpable, that if the appropriate types and number of BMPs are used in each of the watersheds the pollutant concentrations in streams can be reduced. The suitable types of BMPs should be decided depending upon the type of the pollutant in abundance in that region and the percentage impervious cover.

5.1 Future work

The study can be used in order to perform predictive modeling to determine how the pollutant concentrations will vary based on the factors such as: network of existing BMPs and urbanization in terms of impervious cover. In terms of modeling, pollutant concentrations data will be the dependent variable. The network of existing BMPs and urbanization in terms of impervious cover are the independent variables.

Water quantity variables namely: pH, dissolved oxygen content can also be analyzed to evaluate the water quality in a particular region. This will also aid in the modeling process in terms of both water quality and quantity.

5.2 Limitations

There were several limitations within the study performed. Manual samples were used for analysis in the laboratory by Charlotte Mecklenburg Stormwater services. In terms of using manual samples, human and experimental error are sometimes present. Therefore, the evaluation of the pollutant concentrations performed is subjected to limitations relevant to the data provided.

The quality of water is not affected by the aforementioned factors alone. For example, other factors such as temperature, pH, and dissolved oxygen content can also indicate how the water quality is in a particular region. They were not considered for the water quality analysis due to the scope of this work. Additionally, drainage connections can be included in future studies. Moving forward, these additional factors can be considered for evaluation to provide a more comprehensive understanding.

Precipitation cannot be considered as a factor for a predictive model in the case of the data for Mecklenburg County. This is because the data had a major limitation based on an assumption in the data by the Charlotte Mecklenburg Stormwater Services. In terms of data collection, it was a considered a stormflow, whenever the precipitation was more than 0.10 inches in any of the 70 rain gages in the county as opposed to checking for the individual rain gages in the watersheds.

Additionally, the flow data for each stream from USGS was also investigated for each of the data points when the Charlotte Mecklenburg Stormwater Services measured the precipitation and the pollutant concentration values for each one of the pollutants. This was done to supplement the short comings with the precipitation data, but further work should be done identify relationships to supplement the precipitation data.

REFERENCES

Agency, M. P. C. (2008). Turbidity: Description, Impact on Water Quality, Sources, Measures Retrieved from https://www.pca.state.mn.us/sites/default/files/wq-iw3-21.pdf

Almeida, M., Butler, D., & Friedler, E. (1999). At-source domestic wastewater quality. *Urban water, 1*(1), 49-55.

Aryal, R., Furumai, H., Nakajima, F., & Boller, M. (2005). Dynamic behavior of fractional suspended solids and particle-bound polycyclic aromatic hydrocarbons in highway runoff. *Water Research, 39*(20), 5126-5134.

Barber, M. E., King, S. G., Yonge, D. R., & Hathhorn, W. E. (2003). Ecology ditch: A best management practice for storm water runoff mitigation. *Journal of Hydrologic Engineering, 8*(3), 111-122.

Barco, J., Papiri, S., & Stenstrom, M. K. (2008). First flush in a combined sewer system. *Chemosphere, 71*(5), 827-833.

Bell, C. D., McMillan, S. K., Clinton, S. M., & Jefferson, A. J. (2016). Hydrologic response to stormwater control measures in urban watersheds. *Journal of Hydrology, 541*, 1488-1500.

Bhaskar, A., Beesley, L., Burns, M. J., Fletcher, T., Hamel, P., Oldham, C., & Roy, A. H. (2016). Will it rise or will it fall? Managing the complex effects of urbanization on base flow. *Freshwater Science, 35*(1), 293-310.

Brezonik, P. L., & Stadelmann, T. H. (2002). Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. *Water Research, 36*(7), 1743-1757.

Brown, R. R., Keath, N., & Wong, T. H. (2009). Urban water management in cities: historical, current and future regimes. *Water science and technology, 59*(5), 847-855.

Bureau, U. S. C. (2010). Population Mecklenburg County. Retrieved from https://www.census.gov/quickfacts/fact/table/mecklenburgcountynorthcarolina,charlottecitynorthcarolina/PST045218

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological applications, 8*(3), 559-568.

Charlotte, C. o. (2013). BMP Design Standards. Retrieved from https://charlottenc.gov/StormWater/Regulations/Pages/BMPDesignStandardsManual.aspx

Cheng, S.-j., Lee, C.-f., & Lee, J.-h. (2010). Effects of urbanization factors on model parameters. *Water resources management, 24*(4), 775-794.

Clinton, B. D., & Vose, J. M. (2006). Variation in stream water quality in an urban headwater stream in the southern Appalachians. *Water, air, and soil pollution, 169*(1-4), 331-353.

Coles, J. F., McMahon, G., Bell, A. H., Brown, L. R., Fitzpatrick, F. A., Eikenberry, B. S., . . . Cappiella, K. (2012). Effects of urban development on stream ecosystems in nine metropolitan study areas across the United States. *US Geological Survey Circular, 1373*, 152.

Comings, K. J., Booth, D. B., & Horner, R. R. (2000). Storm water pollutant removal by two wet ponds in Bellevue, Washington. *Journal of Environmental Engineering, 126*(4), 321-330.

Dietz, M. E. (2007). Low impact development practices: A review of current research and recommendations for future directions. *Water, air, and soil pollution, 186*(1-4), 351-363.

Dietz, M. E., & Clausen, J. C. (2008). Stormwater runoff and export changes with development in a traditional and low impact subdivision. *Journal of environmental management, 87*(4), 560-566.

Duda, A. M., Lenat, D. R., & Penrose, D. L. (1982). Water quality in urban streams: what we can expect. *Journal (Water Pollution Control Federation)*, 1139-1147.

DWQ, N. (2010). *CATAWBA RIVER BASIN PLAN*. Retrieved from https://files.nc.gov/ncdeq/Water%20Quality/Planning/BPU/BPU/Catawba/Catawba%20Plans/2010%20Plan/Chapter%203%20-%2003050103.pdf.

Edwards, A., & Withers, P. (2008). Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwaters in the UK. *Journal of Hydrology, 350*(3-4), 144-153.

Elliott, A., & Trowsdale, S. A. (2007). A review of models for low impact urban stormwater drainage. *Environmental modelling & software, 22*(3), 394-405.

Finkenbine, J. K., Atwater, J., & Mavinic, D. (2000). STREAM HEALTH AFTER URBANIZATION 1. *JAWRA Journal of the American Water Resources Association, 36*(5), 1149-1160.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., . . . Gibbs, H. K. (2005). Global consequences of land use. *science, 309*(5734), 570-574.

Fondriest Environmental, I. (2014). Turbidity, Total Suspended Solids & Water Clarity. Retrieved from https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/#cite

Ghaly, A., & Ramakrishnan, V. (2015). Nitrogen sources and cycling in the ecosystem and its role in air, water and soil pollution: A critical review. *Journal of Pollution Effects & Control*, 1-26.

GIS, O. M. M. C. (2019). GIS Shape Files. Retrieved from http://maps.co.mecklenburg.nc.us/openmapping/data.html

Gnecco, I., Berretta, C., Lanza, L., & La Barbera, P. (2005). Storm water pollution in the urban environment of Genoa, Italy. *Atmospheric research, 77*(1-4), 60-73.

Hancock, G. S., Holley, J. W., & Chambers, R. M. (2010). A Field‐Based Evaluation of Wet Retention Ponds: How Effective Are Ponds at Water Quantity Control? 1. *JAWRA Journal of the American Water Resources Association, 46*(6), 1145-1158.

Hathaway, J., Hunt, W., & Jadlocki, S. (2009). Indicator bacteria removal in storm-water best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering, 135*(12), 1275-1285.

Hatt, B. E., Fletcher, T. D., & Deletic, A. (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology, 365*(3-4), 310-321.

Hossain, M. A., Alam, M., Yonge, D. R., & Dutta, P. (2005). Efficiency and flow regime of a highway stormwater detention pond in Washington, USA. *Water, Air, and Soil Pollution, 164*(1-4), 79-89.

Kim, L.-H., Ko, S.-O., Jeong, S., & Yoon, J. (2007). Characteristics of washed-off pollutants and dynamic EMCs in parking lots and bridges during a storm. *Science of the Total Environment, 376*(1-3), 178-184.

Leopold, L. B. (1968). *Hydrology for urban land planning: A guidebook on the hydrologic effects of urban land use* (Vol. 554): US Department of the Interior, Geological Survey.

Line, D. (2013). Effect of development on water quality for seven streams in North Carolina. *Environmental monitoring and assessment, 185*(8), 6277-6289.

Liu, A., Egodawatta, P., Guan, Y., & Goonetilleke, A. (2013). Influence of rainfall and catchment characteristics on urban stormwater quality. *Science of the Total Environment, 444*, 255-262.

Loperfido, J. V., Noe, G. B., Jarnagin, S. T., & Hogan, D. M. (2014). Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale. *Journal of Hydrology, 519*, 2584-2595.

Lucke, T., & Beecham, S. (2011). Field investigation of clogging in a permeable pavement system. *Building Research & Information, 39*(6), 603-615.

Lucke, T., & Nichols, P. W. (2015). The pollution removal and stormwater reduction performance of street-side bioretention basins after ten years in operation. *Science of the Total Environment, 536*, 784-792.

Lundy, L., Ellis, J. B., & Revitt, D. M. (2012). Risk prioritisation of stormwater pollutant sources. *Water Research, 46*(20), 6589-6600.

Mangangka, I. R., Liu, A., Egodawatta, P., & Goonetilleke, A. (2015). Performance characterisation of a stormwater treatment bioretention basin. *Journal of environmental management, 150*, 173-178.

McColl, C., & Aggett, G. (2007). Land-use forecasting and hydrologic model integration for improved land-use decision support. *Journal of environmental management, 84*(4), 494-512.

Merriman, L. S., & Hunt III, W. F. (2014). Maintenance versus maturation: Constructed storm-water wetland's fifth-year water quality and hydrologic assessment. *Journal of Environmental Engineering, 140*(10), 05014003.

Moore, T. L., Hunt, W. F., Burchell, M. R., & Hathaway, J. M. (2011). Organic nitrogen exports from urban stormwater wetlands in North Carolina. *Ecological Engineering, 37*(4), 589-594.

Morley, S. A., & Karr, J. R. (2002). Assessing and restoring the health of urban streams in the Puget Sound basin. *Conservation Biology, 16*(6), 1498-1509.

Navratil, O., Breil, P., Schmitt, L., Grosprêtre, L., & Albert, M. (2013). Hydrogeomorphic adjustments of stream channels disturbed by urban runoff (Yzeron River basin, France). *Journal of Hydrology, 485*, 24-36.

O'Driscoll, M., Clinton, S., Jefferson, A., Manda, A., & McMillan, S. (2010). Urbanization effects on watershed hydrology and in-stream processes in the southern United States. *Water, 2*(3), 605-648.

Obropta, C. C., & Kardos, J. S. (2007). Review of Urban Stormwater Quality Models: Deterministic, Stochastic, and Hybrid Approaches 1. *JAWRA Journal of the American Water Resources Association, 43*(6), 1508-1523.

Opher, T., & Friedler, E. (2010). Factors affecting highway runoff quality. *Urban Water Journal, 7*(3), 155-172.

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. *Building and environment, 42*(6), 2311-2320.

Peters, N. E. (2009). Effects of urbanization on stream water quality in the city of Atlanta, Georgia, USA. *Hydrological Processes: An International Journal, 23*(20), 2860-2878.

Poff, N. L., Bledsoe, B. P., & Cuhaciyan, C. O. (2006). Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. *Geomorphology, 79*(3-4), 264-285.

Roseen, R. M., Ballestero, T. P., Houle, J. J., Avellaneda, P., Briggs, J., Fowler, G., & Wildey, R. (2009). Seasonal performance variations for storm-water management systems in cold climate conditions. *Journal of Environmental Engineering, 135*(3), 128-137.

Schwartz, D., Sample, D. J., & Grizzard, T. J. (2017). Evaluating the performance of a retrofitted stormwater wet pond for treatment of urban runoff. *Environmental monitoring and assessment, 189*(6), 256.

Stovin, V. (2010). The potential of green roofs to manage urban stormwater. *Water and Environment Journal, 24*(3), 192-199.

Trowsdale, S. A., & Simcock, R. (2011). Urban stormwater treatment using bioretention. *Journal of Hydrology, 397*(3-4), 167-174.

Wang, J., Forman, B. A., & Davis, A. P. (2017). Probabilistic stormwater runoff and water quality modeling of a highway in suburban Maryland. *Journal of Hydrologic Engineering, 23*(2), 05017034.

Watch, K. (2015a). Little Sugar Creek. Retrieved from https://keepingwatch.org/wp-content/uploads/creeks-brochures/Brochure-Individual-Little-Sugar.pdf

Watch, K. (2015b). Mallard Creek. Retrieved from https://keepingwatch.org/wp-content/uploads/creeks-brochures/Brochure-Individual-Mallard.pdf

Watch, K. (2015c). McAlpine Creek. Retrieved from https://keepingwatch.org/wp-content/uploads/creeks-brochures/Brochure-Individual-McAlpine.pdf

Watch, K. (2015d). Reedy Creek. Retrieved from https://keepingwatch.org/wp-content/uploads/creeks-brochures/Brochure-Individual-Reedy.pdf

Weiss, J. D., Hondzo, M., & Semmens, M. (2006). Storm water detention ponds: modeling heavy metal removal by plant species and sediments. *Journal of Environmental Engineering, 132*(9), 1034-1042.

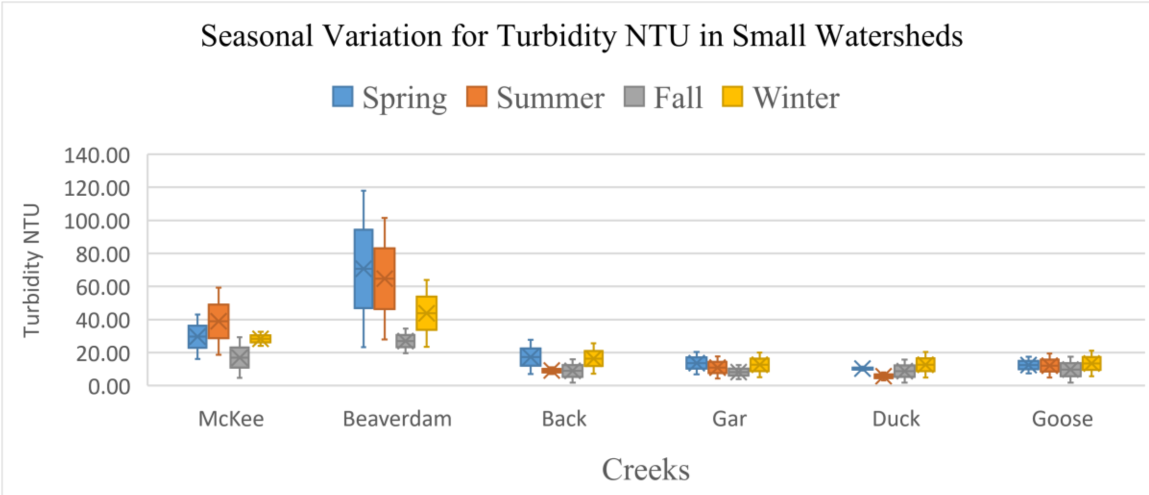
Winston, R. J., Hunt, W. F., Kennedy, S. G., Merriman, L. S., Chandler, J., & Brown, D. (2013). Evaluation of floating treatment wetlands as retrofits to existing stormwater retention ponds. *Ecological Engineering, 54*, 254-265.

Yu, J., Yu, H., & Xu, L. (2013). Performance evaluation of various stormwater best management practices. *Environmental Science and Pollution Research, 20*(9), 6160-6171.

APPENDIX A: VARIATION IN TURBIDITY NTU ACROSS SEASONS

Variation in Turbidity NTU across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	43.09	59.21	29.33	32.66	41.07
Beaverdam	117.91	101.45	34.45	63.85	79.41
Back	27.65	11.12	15.98	25.65	20.10
Gar	20.48	17.65	12.40	20.06	17.65
Duck	11.56	7.96	15.76	20.43	13.93
Goose	17.45	19.33	17.51	21.09	18.84
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	16.08	18.58	4.68	24.07	15.85
Beaverdam	23.36	28.00	19.60	23.58	23.64
Back	6.95	7.03	1.84	7.18	5.75
Gar	6.93	4.33	3.98	5.08	5.08
Duck	9.13	3.26	1.85	4.91	4.79
Goose	7.38	4.96	1.82	5.67	4.96



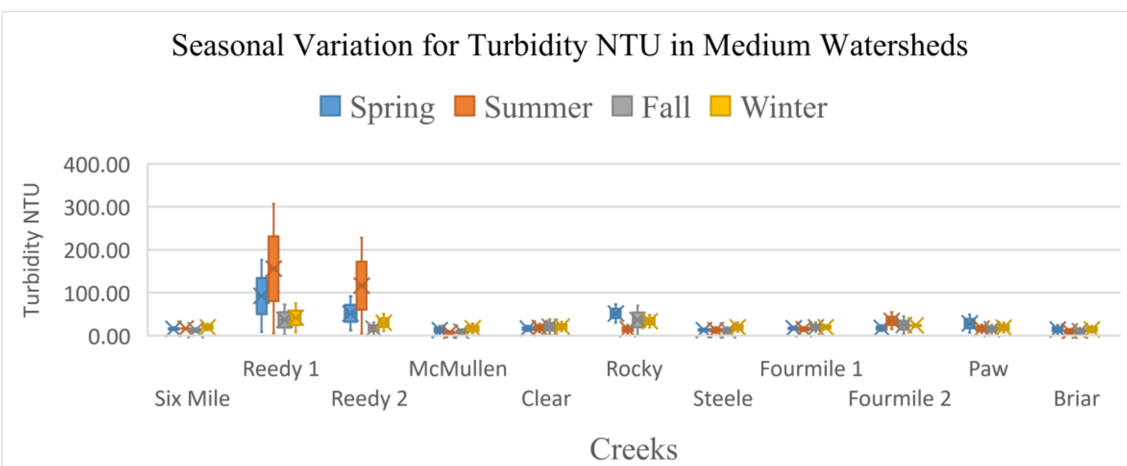
Variation in Turbidity NTU across seasons during stormflow & base flow for Small Watersheds

Variation in Turbidity NTU across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	19.11	16.84	17.29	27.84	20.27
Reedy 1	176.35	306.56	72.36	75.21	157.62
Reedy 2	91.77	227.96	30.68	50.39	100.20
McMullen	22.48	10.48	14.92	28.28	19.04
Clear	22.86	27.98	38.30	31.79	30.23
Rocky	73.26	24.57	70.35	48.61	54.19
Steele	16.38	19.45	19.66	30.45	21.48
Fourmile 1	20.97	20.36	30.40	24.60	24.08
Fourmile 2	24.71	54.12	44.70	26.11	37.41
Paw	49.36	25.45	25.57	30.30	32.67
Briar	24.43	15.68	18.35	22.60	20.27

Variation in Turbidity NTU across seasons in Medium Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	12.60	15.93	8.06	11.85	12.11
Reedy 1	8.30	5.18	1.29	7.90	5.67
Reedy 2	11.87	4.63	2.40	9.98	7.22
McMullen	3.54	3.63	2.89	6.03	4.02
Clear	10.28	7.62	3.63	9.91	7.86
Rocky	30.00	5.67	2.66	18.40	14.18
Steele	9.47	6.16	3.79	8.89	7.08
Fourmile 1	13.29	10.35	8.90	14.73	11.82
Fourmile 2	10.89	14.70	4.42	21.26	12.82
Paw	6.86	6.99	5.06	7.56	6.62
Briar	4.80	3.92	2.37	6.48	4.39



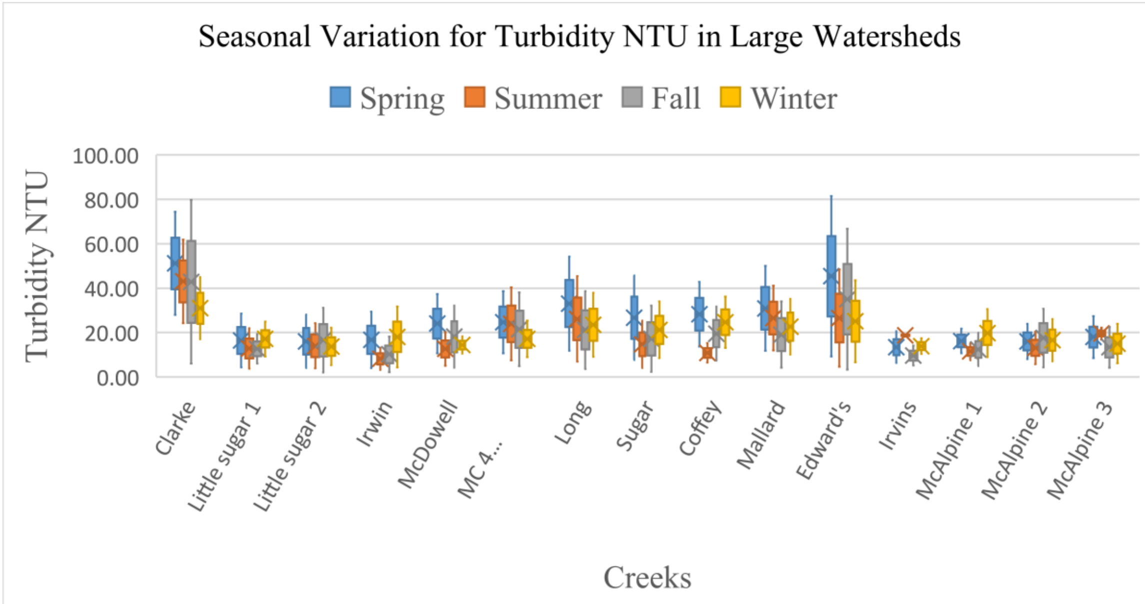
Variation in Turbidity NTU across seasons during stormflow & base flow for Medium Watersheds

Variation in Turbidity NTU across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	74.31	61.81	79.69	44.91	65.18
Little sugar 1	28.54	21.88	19.31	25.00	23.68
Little sugar 2	28.12	24.25	31.12	22.16	26.41
Irwin	29.42	13.20	18.17	31.76	23.14
McDowell	37.39	20.23	32.18	18.29	27.02
MC 4 McDowell	38.66	40.38	38.09	25.36	35.62
Long	54.25	45.37	38.71	37.93	44.06
Sugar	45.75	25.46	32.15	33.98	34.34
Coffey	42.84	15.25	31.75	36.21	31.51
Mallard	50.01	41.10	34.00	35.22	40.08
Edward's	81.45	48.45	66.68	43.58	60.04
Irvins	20.57	18.22	14.13	17.53	17.61
McAlpine 1	21.78	15.50	19.98	30.59	21.96
McAlpine 2	23.99	20.31	30.78	26.18	25.31
McAlpine 3	27.40	22.24	22.58	23.95	24.04
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	27.94	24.28	6.03	17.00	18.81
Little sugar 1	4.43	3.86	6.06	9.32	5.92

Variation in Turbidity NTU across seasons in Large Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Little sugar 2	4.07	3.90	2.00	5.43	3.85
Irwin	4.09	3.22	2.26	4.40	3.49
McDowell	10.70	5.13	4.16	10.56	7.64
MC 4 McDowell	10.70	7.52	4.89	9.04	8.04
Long	11.85	6.95	3.63	9.18	7.90
Sugar	7.71	4.04	2.29	8.51	5.64
Coffey	13.67	6.52	7.37	13.22	10.20
Mallard	11.85	11.98	4.26	10.07	9.54
Edward's	9.28	4.64	3.30	6.68	5.97
Irvins	6.36	19.26	5.16	10.35	10.28
McAlpine 1	10.70	7.52	4.89	9.04	8.04
McAlpine 2	8.06	5.88	4.40	7.17	6.38
McAlpine 3	8.57	16.97	4.18	6.18	8.97

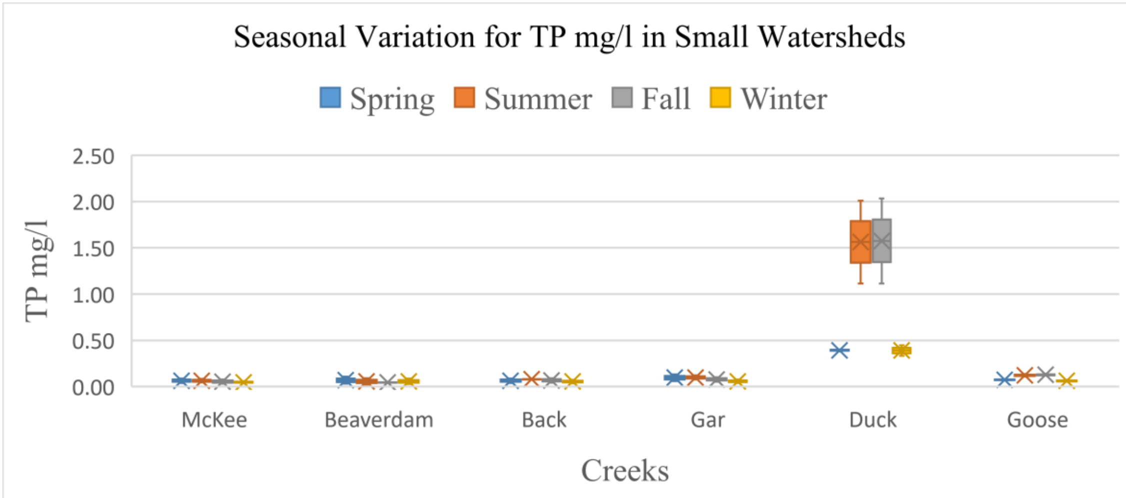


Variation in Turbidity NTU across seasons during stormflow & base flow for Medium Watersheds

APPENDIX B: VARIATION IN TOTAL PHOSPHOROUS ACROSS SEASONS

Variation in Total Phosphorous mg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.09	0.08	0.08	0.06	0.08
Beaverdam	0.11	0.09	0.05	0.09	0.08
Back	0.09	0.08	0.09	0.07	0.08
Gar	0.13	0.12	0.10	0.08	0.11
Duck	0.40	1.12	1.12	0.33	0.74
Goose	0.08	0.11	0.14	0.07	0.10
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.04	0.05	0.03	0.04	0.04
Beaverdam	0.03	0.02	0.04	0.03	0.03
Back	0.04	0.08	0.04	0.04	0.05
Gar	0.06	0.08	0.05	0.04	0.06
Duck	0.38	2.01	2.03	0.45	1.22
Goose	0.07	0.14	0.12	0.05	0.09



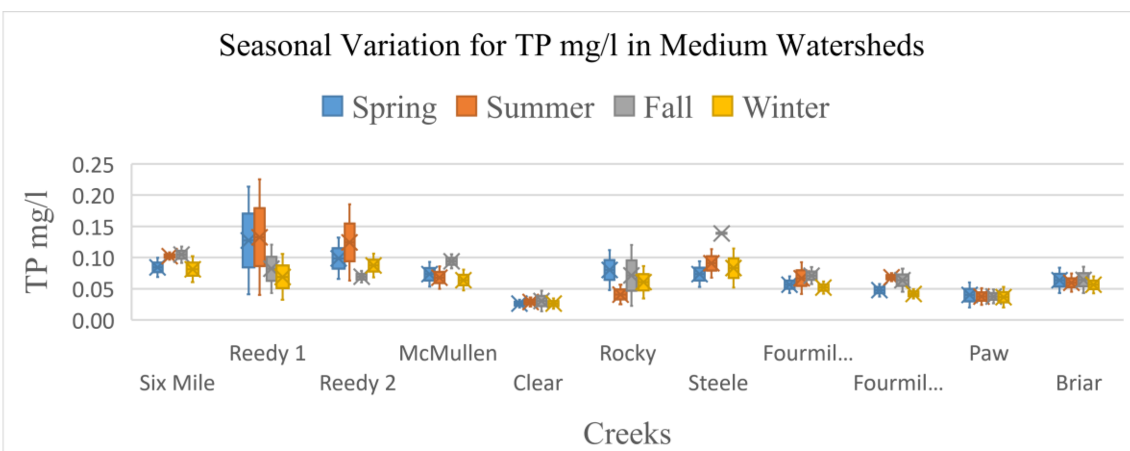
Variation in Total Phosphorous mg/l across seasons during stormflow & base flow for Small Watersheds

Variation in Total Phosphorous mg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.10	0.11	0.12	0.10	0.11
Reedy 1	0.21	0.23	0.12	0.11	0.17
Reedy 2	0.13	0.19	0.08	0.11	0.13
McMullen	0.09	0.09	0.11	0.08	0.09
Clear	0.03	0.04	0.05	0.03	0.04
Rocky	0.11	0.06	0.12	0.09	0.09
Steele	0.09	0.11	0.14	0.11	0.12
Fourmile 1	0.07	0.09	0.08	0.06	0.08
Fourmile 2	0.06	0.08	0.08	0.05	0.07
Paw	0.06	0.05	0.05	0.05	0.05
Briar	0.08	0.07	0.09	0.07	0.08

Variation in Total Phosphorous mg/l across seasons in Medium Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.07	0.10	0.09	0.06	0.08
Reedy 1	0.04	0.04	0.04	0.03	0.04
Reedy 2	0.07	0.06	0.06	0.07	0.06
McMullen	0.05	0.05	0.08	0.05	0.06
Clear	0.02	0.02	0.01	0.02	0.02
Rocky	0.05	0.03	0.02	0.03	0.03
Steele	0.05	0.07	0.14	0.05	0.08
Fourmile 1	0.04	0.04	0.06	0.04	0.05
Fourmile 2	0.04	0.06	0.05	0.03	0.04
Paw	0.02	0.02	0.03	0.02	0.02
Briar	0.04	0.05	0.04	0.04	0.04



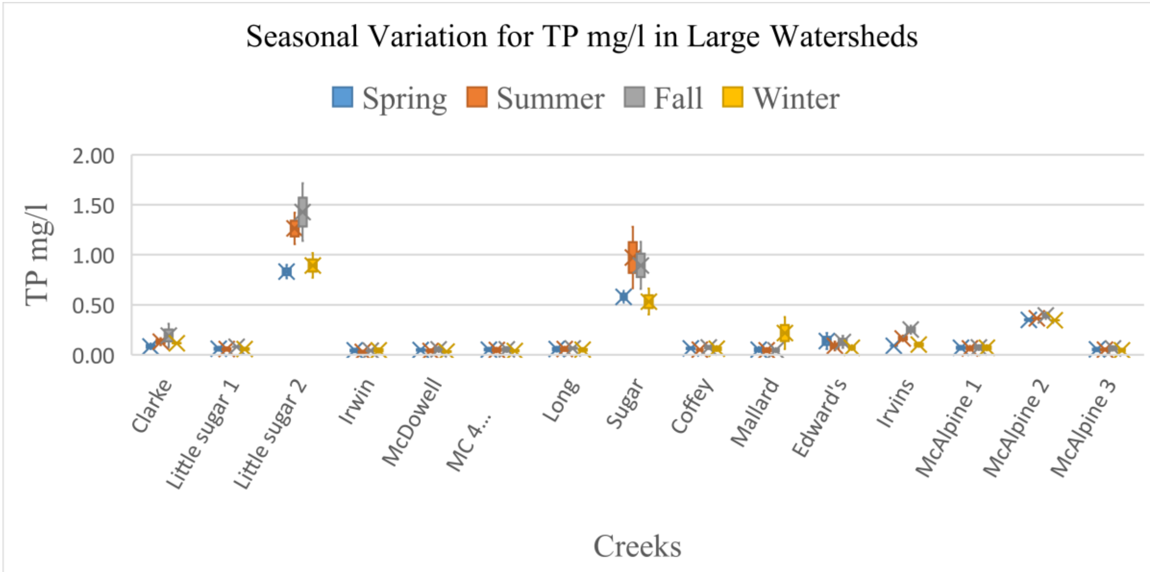
Variation in Total Phosphorous mg/l across seasons during stormflow & base flow for Medium Watersheds

Variation in Total Phosphorous mg/l across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.11	0.17	0.31	0.12	0.18
Little sugar 1	0.08	0.07	0.08	0.07	0.08
Little sugar 2	0.76	1.11	1.14	0.77	0.94
Irwin	0.06	0.04	0.05	0.07	0.05
McDowell	0.06	0.05	0.08	0.04	0.06
MC 4 McDowell	0.07	0.07	0.08	0.05	0.07
Long	0.08	0.08	0.07	0.07	0.07
Sugar	0.64	0.67	0.66	0.40	0.59
Coffey	0.08	0.06	0.09	0.09	0.08
Mallard	0.08	0.07	0.07	0.06	0.07
Edward's	0.22	0.13	0.19	0.10	0.16
Irvins	0.09	0.14	0.21	0.08	0.13
McAlpine 1	0.09	0.09	0.10	0.10	0.09
McAlpine 2	0.36	0.36	0.36	0.35	0.36
McAlpine 3	0.07	0.06	0.09	0.06	0.07
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.06	0.10	0.08	0.11	0.09
Little sugar 1	0.04	0.04	0.08	0.05	0.05

Variation in Total Phosphorous mg/l across seasons in Large Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Little sugar 2	0.90	1.42	1.71	1.02	1.26
Irwin	0.03	0.01	0.03	0.02	0.02
McDowell	0.04	0.03	0.03	0.03	0.03
MC 4 McDowell	0.04	0.03	0.03	0.03	0.03
Long	0.03	0.04	0.06	0.03	0.04
Sugar	0.52	1.28	1.13	0.66	0.90
Coffey	0.05	0.04	0.06	0.04	0.05
Mallard	0.03	0.03	0.03	0.38	0.11
Edward's	0.06	0.05	0.07	0.05	0.06
Irvins	0.09	0.19	0.29	0.12	0.17
McAlpine 1	0.05	0.04	0.05	0.04	0.05
McAlpine 2	0.34	0.37	0.43	0.35	0.37
McAlpine 3	0.03	0.04	0.04	0.03	0.04

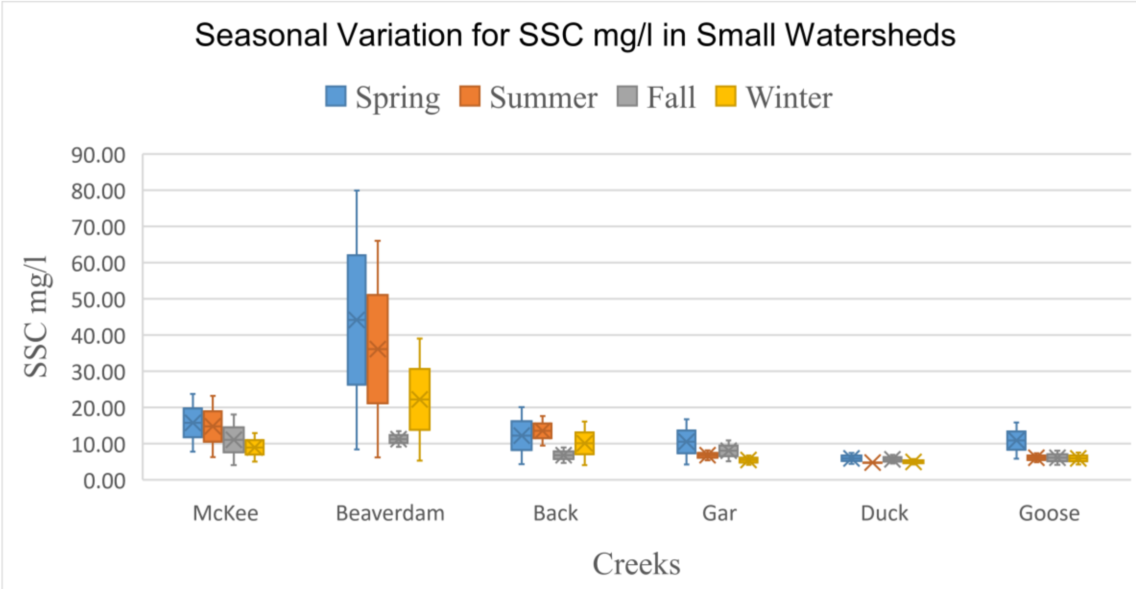


Variation in Total Phosphorous mg/l across seasons during stormflow & base flow for Large Watersheds

APPENDIX C: VARIATION IN SUSPENDED SEDIMENT CONCENTRATION MG/L ACROSS SEASONS

Variation in Suspended Sediment Concentration mg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	23.70	23.21	18.04	12.93	19.47
Beaverdam	79.87	66.04	13.45	39.07	49.61
Back	20.13	17.58	8.91	16.13	15.69
Gar	16.78	8.15	10.94	6.76	10.65
Duck	7.45	4.89	6.90	5.77	6.25
Goose	15.85	7.40	8.10	7.54	9.72
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	7.82	6.33	4.12	5.04	5.83
Beaverdam	8.42	6.23	9.13	5.35	7.28
Back	4.33	9.45	4.69	4.06	5.63
Gar	4.23	5.43	5.14	4.16	4.74
Duck	4.44	4.64	4.50	4.22	4.45
Goose	5.88	4.86	4.17	4.29	4.80



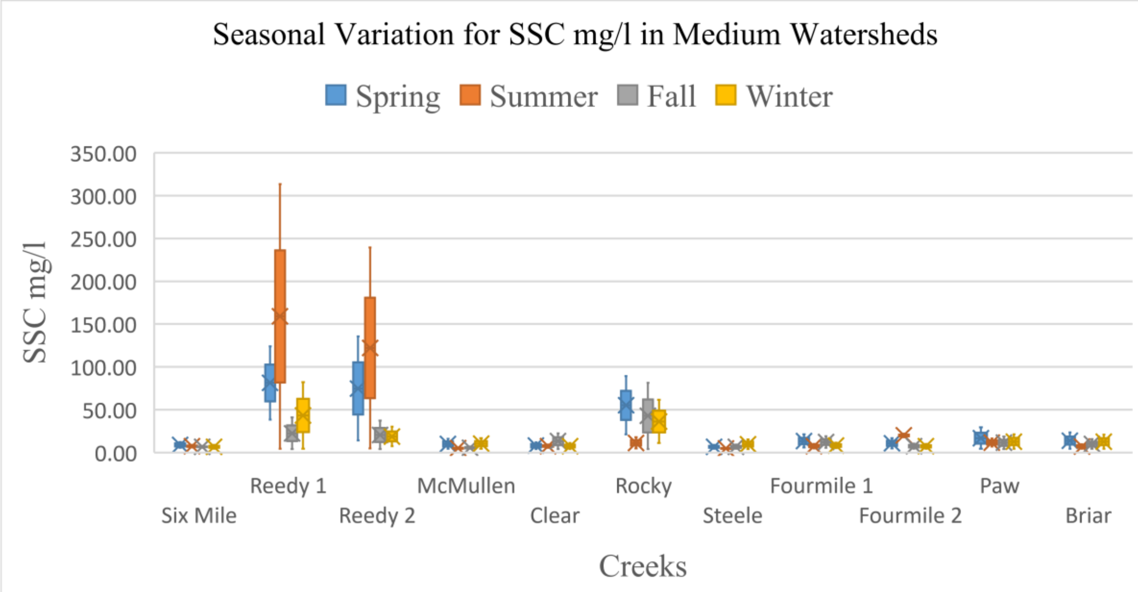
Variation in Suspended Sediment Concentration mg/l across seasons during stormflow & base flow for Small Watersheds

Variation in Suspended Sediment Concentration mg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	12.56	6.20	7.76	9.05	8.89
Reedy 1	124.15	313.40	41.06	82.15	140.19
Reedy 2	135.52	239.46	37.25	30.40	110.66
McMullen	16.04	5.92	7.05	16.69	11.42
Clear	12.02	9.37	22.44	11.11	13.74
Rocky	89.12	18.01	81.59	61.62	62.59
Steele	9.05	5.71	9.26	15.51	9.88
Fourmile 1	21.20	10.32	19.29	11.45	15.57
Fourmile 2	16.87	18.04	10.35	10.17	13.86

Variation in Suspended Sediment Concentration mg/l across seasons in Medium Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Paw	29.42	16.51	18.76	21.25	21.48
Briar	23.59	9.88	15.63	21.13	17.56
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	5.53	9.12	5.73	4.56	6.24
Reedy 1	38.41	4.63	4.13	4.71	12.97
Reedy 2	14.28	4.85	4.09	7.38	7.65
McMullen	4.36	4.32	4.36	4.45	4.37
Clear	4.28	5.75	4.20	4.23	4.61
Rocky	21.31	4.85	4.11	11.14	10.35
Steele	4.58	4.18	4.47	4.24	4.37
Fourmile 1	6.03	4.90	5.73	5.45	5.53
Fourmile 2	4.78	22.08	4.43	4.53	8.95
Paw	4.37	7.03	4.35	4.62	5.09
Briar	4.43	4.62	4.48	4.39	4.48



Variation in Suspended Sediment Concentration mg/l across seasons during stormflow & base flow for Medium Watersheds

Variation in Suspended Sediment Concentration mg/l across seasons in Large Watersheds

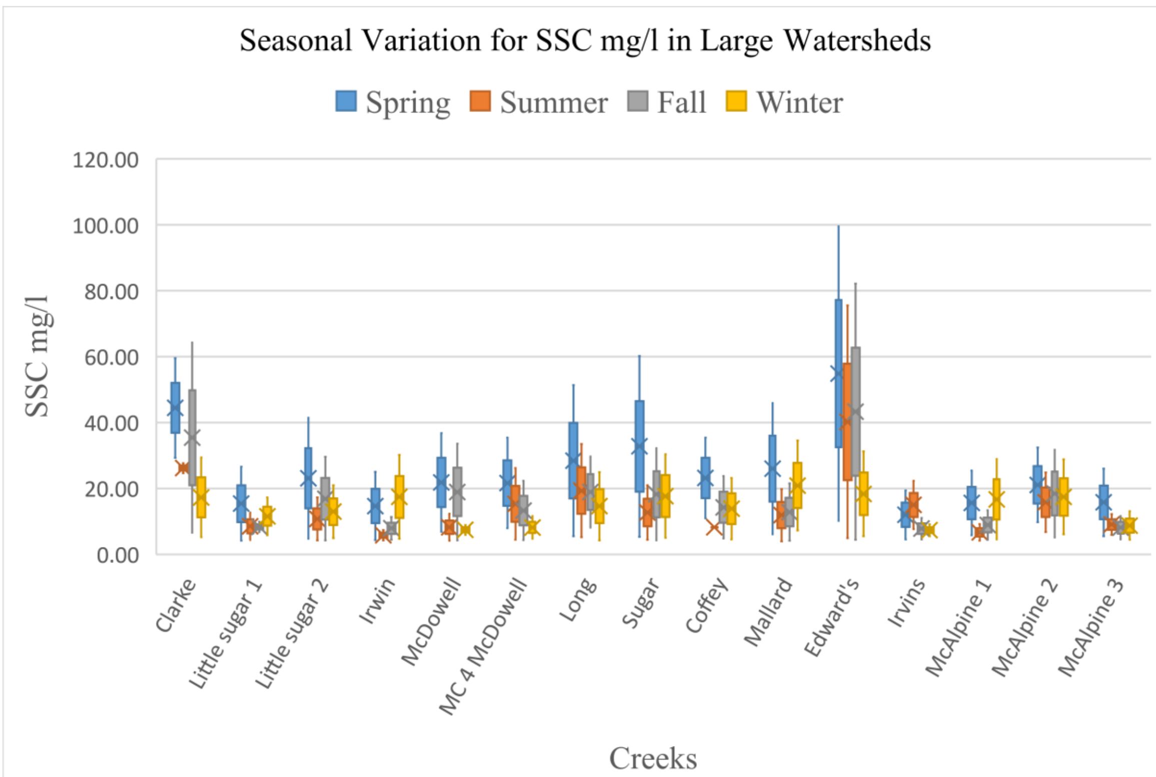
Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	59.53	27.66	64.22	29.36	45.19
Little sugar 1	26.54	12.72	9.89	17.28	16.61
Little sugar 2	41.40	17.20	29.53	20.97	27.28
Irwin	24.98	7.34	11.33	30.17	18.45
McDowell	36.80	12.33	33.60	8.93	22.91
MC 4 McDowell	35.38	26.21	22.25	11.56	23.85
Long	51.37	33.42	29.72	24.96	34.87
Sugar	60.16	20.94	32.24	30.35	35.92
Coffey	35.36	8.09	23.75	23.21	22.60

Variation in Suspended Sediment Concentration mg/l across seasons in Large Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Mallard	45.90	19.80	21.47	34.52	30.42
Edward's	99.46	75.52	82.16	31.20	72.08
Irvins	19.43	7.65	11.07	9.10	11.81
McAlpine 1	25.38	9.21	13.33	28.88	19.20
McAlpine 2	32.42	24.81	31.75	28.78	29.44
McAlpine 3	25.96	12.18	11.63	13.03	15.70
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	29.29	24.65	6.54	5.19	16.42
Little sugar 1	4.18	4.29	6.73	5.82	5.25
Little sugar 2	4.73	4.26	4.24	4.93	4.54
Irwin	4.34	4.26	4.44	4.68	4.43
McDowell	6.87	4.18	4.23	5.91	5.30
MC 4 McDowell	7.89	4.46	4.30	4.75	5.35
Long	5.52	5.18	8.09	4.28	5.77
Sugar	5.31	4.42	4.26	5.00	4.75
Coffey	10.96	8.30	4.79	4.48	7.13
Mallard	6.07	3.95	4.12	7.21	5.34
Edward's	10.19	4.86	4.41	5.49	6.24

Variation in Suspended Sediment Concentration mg/l across seasons in Large Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Irvins	4.56	22.31	4.50	5.54	9.23
McAlpine 1	5.76	4.18	4.46	4.48	4.72
McAlpine 2	9.72	6.76	5.15	6.06	6.92
McAlpine 3	5.53	5.90	4.52	4.43	5.10

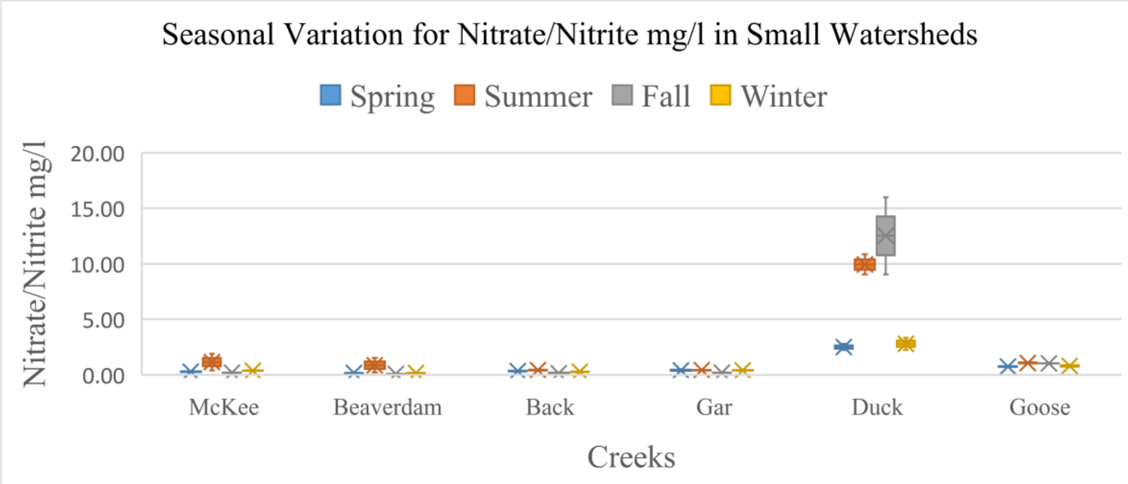


Variation in Suspended Sediment Concentration mg/l across seasons during stormflow & base flow for Large Watersheds

APPENDIX D: VARIATION IN NITRATE/NITRITE MG/L ACROSS SEASONS

Variation in Nitrate/Nitrite mg/l across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.33	0.38	0.21	0.41	0.33
Beaverdam	0.16	0.21	0.09	0.16	0.16
Back	0.40	0.49	0.22	0.30	0.35
Gar	0.50	0.45	0.20	0.45	0.40
Duck	2.79	9.04	9.04	2.25	5.78
Goose	0.68	1.01	1.02	0.67	0.84
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	0.23	1.89	0.18	0.34	0.66
Beaverdam	0.14	1.52	0.06	0.17	0.47
Back	0.29	0.36	0.07	0.25	0.24
Gar	0.31	0.38	0.19	0.37	0.31
Duck	2.23	10.85	16.00	3.34	8.10
Goose	0.81	1.14	1.05	0.91	0.98



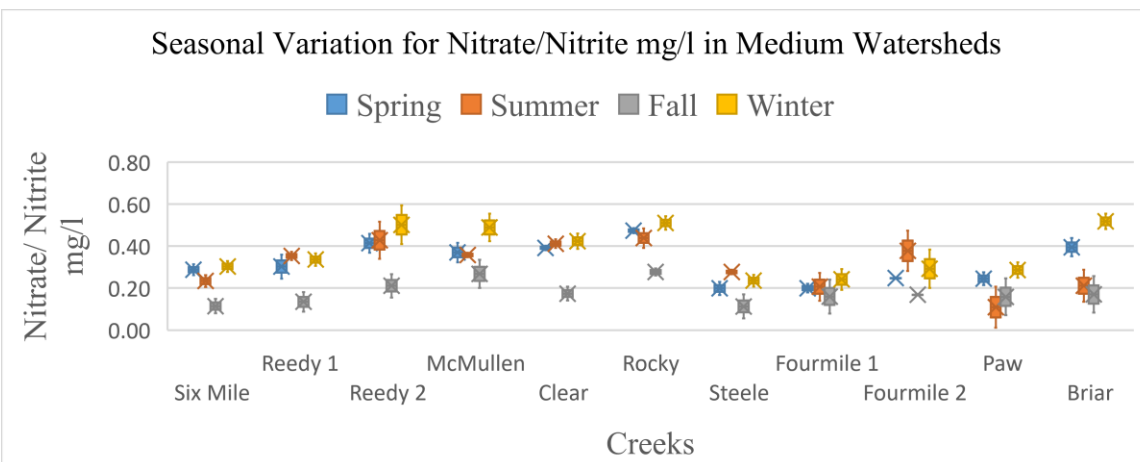
Variation in Nitrate/Nitrite mg/l across seasons during stormflow & base flow for Small Watersheds

Variation in Nitrate/Nitrite mg/l across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.31	0.26	0.15	0.33	0.26
Reedy 1	0.25	0.33	0.18	0.31	0.27
Reedy 2	0.46	0.34	0.27	0.41	0.37
McMullen	0.42	0.37	0.34	0.55	0.42
Clear	0.40	0.43	0.21	0.39	0.36
Rocky	0.46	0.39	0.29	0.48	0.41
Steele	0.23	0.27	0.17	0.26	0.23
Fourmile 1	0.22	0.27	0.24	0.29	0.26
Fourmile 2	0.24	0.28	0.17	0.38	0.27
Paw	0.27	0.01	0.25	0.32	0.21
Briar	0.44	0.29	0.26	0.55	0.38

Variation in Nitrate/Nitrite mg/l across seasons in Medium Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	0.26	0.21	0.08	0.28	0.21
Reedy 1	0.36	0.37	0.09	0.37	0.30
Reedy 2	0.37	0.52	0.16	0.59	0.41
McMullen	0.32	0.35	0.20	0.42	0.32
Clear	0.38	0.39	0.14	0.46	0.34
Rocky	0.49	0.49	0.26	0.54	0.44
Steele	0.17	0.29	0.06	0.21	0.18
Fourmile 1	0.18	0.14	0.08	0.19	0.15
Fourmile 2	0.25	0.47	0.17	0.20	0.27
Paw	0.21	0.21	0.07	0.25	0.19
Briar	0.35	0.14	0.08	0.48	0.26



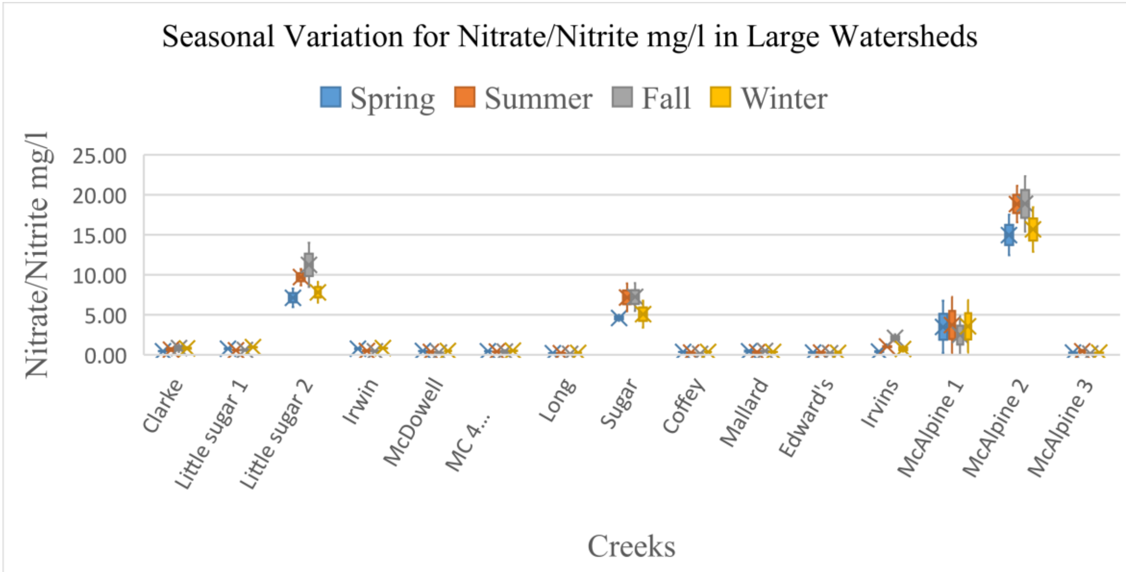
Variation in Nitrate/Nitrite mg/l across seasons during stormflow & base flow for Medium Watersheds

Variation in Nitrate/Nitrite mg/l across seasons in Large Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.50	0.83	1.29	0.66	0.82
Little sugar 1	0.68	0.63	0.66	0.88	0.71
Little sugar 2	5.98	8.69	8.47	6.51	7.41
Irwin	0.69	0.60	0.51	0.78	0.64
McDowell	0.44	0.32	0.28	0.48	0.38
MC 4 McDowell	0.44	0.42	0.57	0.54	0.49
Long	0.22	0.25	0.14	0.27	0.22
Sugar	4.24	5.46	5.47	3.40	4.64
Coffey	0.37	0.31	0.22	0.35	0.31
Mallard	0.33	0.42	0.53	0.34	0.40
Edward's	0.31	0.36	0.26	0.39	0.33
Irvins	0.31	0.92	1.65	0.42	0.82
McAlpine 1	6.76	7.25	4.84	6.82	6.42
McAlpine 2	12.45	16.56	15.40	12.88	14.32
McAlpine 3	0.29	0.31	0.26	0.32	0.29
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	0.40	0.49	0.36	0.97	0.56
Little sugar 1	0.86	0.51	0.52	1.00	0.72
Little sugar 2	8.28	10.72	14.00	9.13	10.53

Variation in Nitrate/Nitrite mg/l across seasons in Large Watersheds (Continued)

Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Irwin	0.83	0.38	0.40	0.87	0.62
McDowell	0.50	0.38	0.25	0.51	0.41
MC 4 McDowell	0.46	0.35	0.24	0.47	0.38
Long	0.18	0.15	0.09	0.24	0.17
Sugar	4.99	8.90	8.98	6.74	7.40
Coffey	0.36	0.24	0.04	0.35	0.25
Mallard	0.58	0.24	0.40	0.36	0.39
Edward's	0.28	0.23	0.11	0.10	0.18
Irvins	0.50	1.13	2.56	1.06	1.31
McAlpine 1	0.23	0.19	0.08	0.28	0.20
McAlpine 2	17.50	21.12	22.33	18.45	19.85
McAlpine 3	0.24	0.58	0.09	0.23	0.29

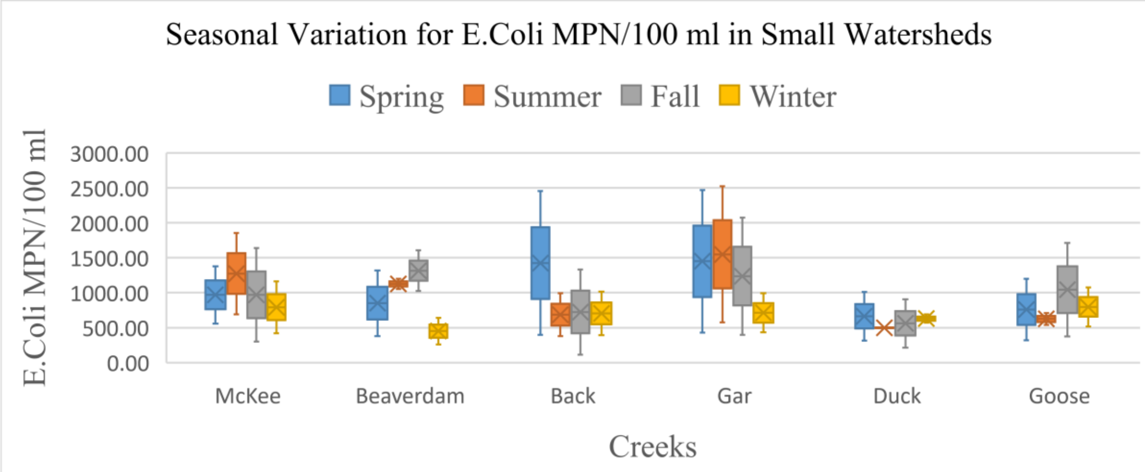


Variation in Nitrate/Nitrite mg/l across seasons during stormflow & base flow for Large Watersheds

APPENDIX E: VARIATION IN ESCHERICHIA COLI MPN/100ML ACROSS SEASONS

Variation in Escherichia Coli MPN/100 ml across seasons in Small Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	1378.86	1854.39	1639.14	1162.00	1508.60
Beaverdam	1317.00	1196.91	1605.55	640.96	1190.10
Back	2452.10	994.14	1333.45	1015.30	1448.75
Gar	2467.14	2524.68	2075.96	991.39	2014.79
Duck	1009.80	504.04	907.30	688.06	777.30
Goose	1199.86	710.25	1709.68	1075.06	1173.71
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McKee	558.60	692.25	298.92	420.42	492.55
Beaverdam	380.60	1050.33	1025.00	259.67	678.90
Back	396.73	377.57	114.56	391.18	320.01
Gar	430.20	573.86	398.33	433.92	459.08
Duck	315.18	492.50	214.64	571.09	398.35
Goose	320.55	538.30	375.10	517.45	437.85



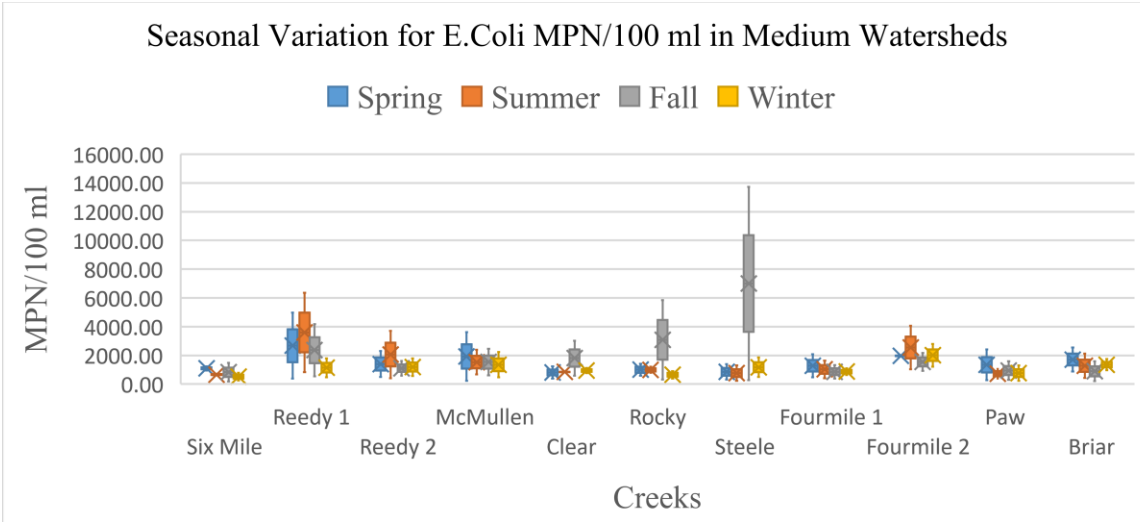
Variation in Escherichia Coli MPN/100ml across seasons during stormflow & base flow for Small Watersheds

Variation in Escherichia Coli MPN/100 ml across seasons in Medium Watersheds

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	1243.81	718.86	1476.43	782.36	1055.36
Reedy 1	4964.25	6354.00	4181.05	1800.29	4324.90
Reedy 2	2300.09	3695.50	1618.74	1800.42	2353.69
McMullen	3620.09	2393.38	2455.89	2243.79	2678.29
Clear	1230.05	833.18	3016.50	1116.28	1549.00
Rocky	1412.88	1204.04	5833.85	910.32	2340.27
Steele	1381.58	1295.13	13724.05	1857.17	4564.48
Fourmile 1	2084.24	1629.38	1326.35	1107.78	1536.94
Fourmile 2	1928.89	4052.80	2167.64	2800.63	2737.49

Variation in Escherichia Coli MPN/100 ml across seasons in Medium Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Paw	2421.10	1064.25	1583.62	1295.78	1591.19
Briar	2538.83	2124.26	1585.54	1751.61	2000.06
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Six Mile	952.80	606.00	183.00	244.00	496.45
Reedy 1	383.44	834.20	540.00	475.89	558.38
Reedy 2	501.50	402.38	589.67	564.82	514.59
McMullen	225.82	670.25	615.67	466.45	494.55
Clear	395.00	864.86	596.45	761.54	654.46
Rocky	590.09	778.14	319.67	391.08	519.74
Steele	329.71	224.86	284.11	488.50	331.80
Fourmile 1	466.70	420.43	389.78	634.33	477.81
Fourmile 2	2009.40	1032.29	918.63	1212.57	1293.22
Paw	286.60	381.88	308.08	224.91	300.37
Briar	875.73	426.25	199.18	958.18	614.84



Variation in Escherichia Coli MPN/100ml across seasons during stormflow & base flow for Medium Watersheds

Variation in Escherichia Coli MPN/100 ml across seasons in Large Watersheds

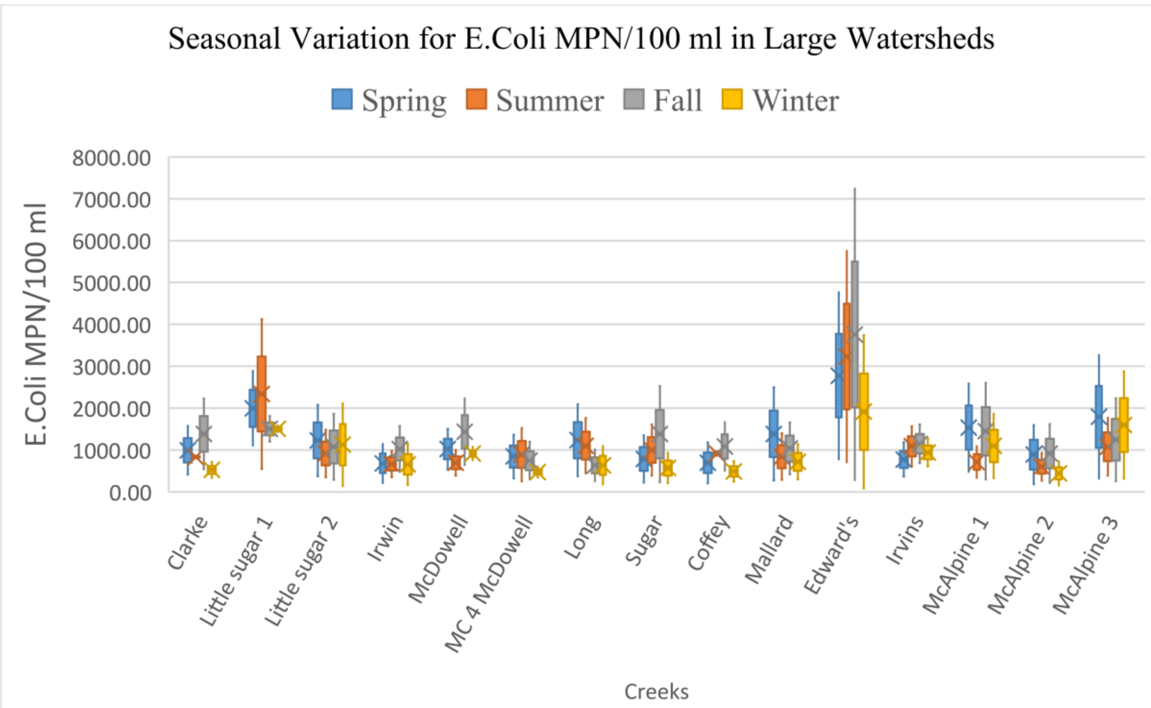
Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	1570.56	799.14	2231.25	714.25	1328.80
Little sugar 1	2884.71	4123.52	1810.90	1577.61	2599.19
Little sugar 2	2080.29	1478.41	1860.83	2116.05	1883.89
Irwin	1147.60	976.83	1568.80	1146.10	1209.83
McDowell	1506.89	995.33	2226.36	1071.75	1450.08
MC 4 McDowell	1364.27	1528.38	1196.28	604.28	1173.30
Long	2091.22	1763.00	1016.38	1096.61	1491.80
Sugar	1351.21	1612.68	2529.95	929.39	1605.81
Coffey	1186.19	858.77	1664.40	731.67	1110.26
Mallard	2498.05	1394.33	1654.65	1139.45	1671.62

Variation in Escherichia Coli MPN/100 ml across seasons in Large Watersheds (Continued)

Stormflow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Edward's	4767.25	5753.09	7245.35	3742.05	5376.94
Irvins	1181.28	1566.64	1610.48	1273.31	1407.93
McAlpine 1	2589.56	1088.41	2602.45	1863.33	2035.94
McAlpine 2	1595.32	932.68	1618.18	727.85	1218.51
McAlpine 3	3267.19	1759.48	2239.40	2877.74	2535.95
Base flow					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
Clarke	410.09	863.43	536.89	330.82	535.31
Little sugar 1	1103.36	550.33	1195.40	1428.45	1069.39
Little sugar 2	371.30	348.14	285.78	136.68	285.48
Irwin	211.36	351.57	478.40	167.38	302.18
McDowell	532.11	389.78	643.09	755.83	580.20
MC 4 McDowell	322.00	251.88	296.11	345.27	303.81
Long	374.55	437.57	253.60	170.92	309.16
Sugar	220.70	387.00	225.30	207.00	260.00
Coffey	206.36	969.33	498.56	245.38	479.91
Mallard	270.70	285.63	418.33	292.69	316.84
Edward's	779.42	705.00	277.14	85.75	461.83
Irvins	363.70	609.78	685.00	608.55	566.76

Variation in Escherichia Coli MPN/100 ml across seasons in Large Watersheds (Continued)

Base flow (Continued)					
Creeks	**Spring**	**Summer**	**Fall**	**Winter**	**Average**
McAlpine 1	479.92	335.88	292.78	326.00	358.64
McAlpine 2	183.08	263.60	213.33	153.31	203.33
McAlpine 3	314.70	389.67	253.83	309.09	316.82



Variation in Escherichia Coli MPN/100ml across seasons during stormflow & base flow for Large Watersheds