ABSTRACT

CARRELL, ANA ANIKA. Implications of Urbanization on Flood Vulnerability in Walnut Creek Watershed: A Land Use/Land Use Change Study. (Under the Direction of Dr. Louie Rivers III, Dr. Stacy Nelson and Dr. Zakiya Leggett).

Geographic information systems (GIS) are an effective tool for the elaboration and deliberation of different types of land systems and the ways that they interact with the public/community (Hale, et al, 2018). A common issue in areas experiencing rapid urbanization includes flooding because of the influx of intense storms and cities that are unprepared to handle them (Eui Hoon and Joong Hoon, 2017). These increases in intense storms can be attributed to the recent climatic changes that are occurring (Suttles, et al, 2018). It is important to study land use changes so that the city's stormwater infrastructure can be adequately maintained. It is also important to be able to help mitigate the different changes that are happening in the stormwater systems. To maintain these systems it is important for the city government to be able to know where the problem areas are within their designated stormwater infrastructure. By using remote sensing and GIS technology we can create a visualization of the areas that are at risk for flooding (Haq, et al., 2012). Additionally, we can also determine which areas have the potential to flood (Orkan and Nebiye, 2010).

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Implications of Urbanization on Flood Vulnerability in Walnut Creek Watershed: A Land Use/Land Use Change Study

by
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DEDICATION

I dedicate this Master’s thesis to my parents, Chanel and Aziz Carrell.

BIOGRAPHY

Ana Carrell is a Durham, NC native who did her undergraduate at The Illustrious North Carolina Agricultural and Technical State University studying Environmental Science. After graduating in 2018 she continued her education at North Carolina State University studying Forestry and Natural Resources. With the completion of her Masters degree she will continue to work on helping others understand the interdisciplinary aspects of the world.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisory team Dr. Louie Rivers III, Dr. Stacy Nelson and Dr. Zakiya Legget for pushing me to complete this thesis. It has been truly a pleasure to work with all of you. This process was not easy and I thank Louie for keeping me on my toes, and keeping me laughing. I am thankful for Dr. Stacy for the conversations that lifted my spirit and kept me motivated. And having someone on my side such as Dr. Zakiya Legget was truly a blessing, to be able to communicate the struggles of going from an HBCU to a PWI and having her help me through the many challenges that come with developing a thesis.

I am forever grateful for my family and friends for their support. My parents Chanel and Aziz Carrell whose love and unconditional support helped me through this process. My dad, Aziz, for instilling my love for the planet and my mom, Chanel, for my sense of discipline. Special acknowledgement to my best friend- Bernadette Vereen- I couldn’t have gotten through graduate school without you.

I am forever thankful for all of the love and support that I received from everyone during this journey to completion.

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INTRODUCTION

In the city of Raleigh, North Carolina there is a serious issue of nuisance flooding due to increased development. Nuisance flooding (NF) is defined as a low-level threat of inundation that can 'disrupt routine day-to-day activities, put added strain on infrastructure systems such as roads and sewers, and cause minor property damage' (Moftakhari et al, 2018). The increased development can be observed using analytic tools such as geographic information systems (GIS) to determine how much land has changed within a certain time period (Hegazy and Kaloop, 2019; Wang and Xie, 2018; Suttles et al, 2018). Increased development upstream of the watershed may be linked to increased flooding downstream of the urbanization (Diaz et al, 2019; Zeinali et al, 2019). These occurrences of nuisance flooding tend to have an outsized impact on minority and low income communities (Sprin, 2005; Cutter, 2018).

Demographic data from the census as well as creating a land classification study was used to show a link between at risk areas that are disproportionately affected by the increased urbanization and therefore have been flooding. Determining where land use change has occurred and its potential for causing increased flooding will be analyzed using geographic information systems. Geographic information systems (GIS) are an effective tool for the elaboration and deliberation of different types of land systems and the ways that they interact with the public/community. Flooding is a common issue in areas experiencing rapid urbanization, as well as the influx of intense storms because of the recent climate changes that are occurring. It is important to study these types of changes so that the city infrastructure can keep up appropriately and maintain beneficial storm water structure. It is also important to be able to help mitigate the different changes that are happening in the stormwater systems. By using remote sensing and

GIS technology we can create a visualization of the areas that have had a land use change. Additionally, we can also determine which areas have the potential to flood (Ozcan and Musaoglu, 2010; Araujo et al, 2019). Using GIS can be a low-cost way to prepare, store, update, analyze and display data relating to urban stormwater systems and urban growth (Meyer et al, 1993; Hegazy and Kaloop, 2015).

This study will make use of GIS to examine satellite imagery to determine the difference of land cover between two time periods (Hegazy and Kaloop, 2019). The time periods looked at will be from 1992 & 2019. The satellite imagery will be obtained looking at USGS Landsat2 imagery taken from the different time periods. A subsequent examination of demographic data from the census will show where people of minority background and low income communities are located. Using a supervised classification process, this research will look at the urban development within the Walnut Creek Watershed. This will determine how much urban infrastructure has occurred between 1992 and 2019. As well as what demographic lives within the watershed and how their placement might correlate with where infrastructure development occurs and the implication of flooding that is associated with location.

Understanding changes in land use development in Raleigh is important because of the flooding implications that can occur. Walnut Creek watershed is a sub water basin (also known as sub-watershed) that is located within the Neuse River watershed. The Walnut Creek watershed is geographically located at the downstream of the Neuse River water basin. When there is more built infrastructure in an area it produces more runoff because the surfaces are not porous (Downer et al, 2011). This runoff flows downstream into the storm water infrastructure and because these structures were built to handle a certain amount of water they can be overwhelmed with the increase that has occurred because of the current urbanization that has happened (Elliot J.R and Pais, J, 2006; Sprin, 2005; Cutter et al, 2018). The lower part of the Walnut Creek watershed has a rich Black history. Biltmore Hills and Rochester Heights were African American communities built during the late 1950s and early 1960s (https://rhdc.org/rochester-heights-historic-district). These neighborhoods still have predominantly black residents. This disproportionately describes the low income community that is located downstream of the watershed, these areas are created historically specifically because of Jim Crow laws and other policies created (Cutter et al, 2018).

The specific objectives of this study are to quantify the land-cover change in the Walnut Creek watershed from 1992 to 2019, determine the rate of change of urbanization as well as the where these changes are occurring and determine their positioning when it comes to demographics in the community. To examine this objective a geospatial analysis was completed to evaluate the urbanization that has occurred in Raleigh. This reveals how much built development has occurred within the city and shows the possibility of it negatively affecting community members.

LITERATURE REVIEW

Flooding events have been known to be related to meteorological, hydrological and anthropogenic factors (Erena and Hailu, 2018). An anthropogenic factor that may be a strong indicator of flood risk is urban growth (Erena and Hailu, 2018; Miller, 2017; Hemmati et al, 2020). There are trends that are well covered in the literature related to flooding and urban development. For example, when there is more urban development there is an increase in flooding that occurs downstream. The rapid population growth and development puts an increased strain on the likelihood of flood related risks (Hemmati et al, 2020). This result was shown through 42 different inundation scenarios that were evaluated, in each one increased flooding happened when the urban, economic and population growth increased (Hemmati et al, 2020). The communities that become the most at risk are those generally located in the floodplain, having low income, and low health (Walker & Burningham, 2011; Elliot and Pais, 2006; Hemmati et al, 2020).

Traditionally, urban development and water management is conceived as an engineer's job and that process often lacks a social dimension (Schirmer, et al. 2018). By using a more comprehensive understanding of water structure and urban water systems (WSUD = water-sensitive urban design) there has been a boost in identifying the need for public support but not identifying it as a way of changing human behavior (Schirmer et al, 2018). Water sensitive urban designs are ways that new construction is developed that are ecologically sensitive. The WSUD implementation by putting in sustainable drainage systems, sustainable urban stormwater drainage systems by using ecological and socio-ecological management systems. Water structure in this context is used as the natural hydrologic flow of river systems, while urban water systems are man-made water systems; ie, pipes, conveyances, storm drains etc. This means that although it has been identified that there is a need for public support in sustaining strategic urban water systems, there has not quite been a successful way to change the behavior of the patrons in the local community. In many cities they are starting to create city development plans that are designed to help the city build up its local community involvement (Molle, 2009).

Recently, rapid urban development has been seen in the Southeast United States (Suttles et al., 2018). This type of urban development as alluded to above can have many impacts on the environment (Johnson, 2001). These trends often exacerbate already existing environmental justice issues since the urban development that occurs can create even larger gaps in areas that are affected by environmental injustices.

These characteristics can generate different environmental impacts that researchers will focus on - these range from increased runoff of stormwater, increased risk of flooding, to reduced regional open space, and greater air pollution (Johnson, 2001; Walker and Burningham 2011). When these impacts are spread over a large area with different stakeholder groups being affected it requires a coherent management decision that is able to appropriately compare city utilities such as storm water drains, roads, buildings, rivers (Johnson, 2001). There needs to be a comprehensive management decision so that the city ecosystem flows appropriately and sustainably without environmental justice issues (Hemmati et al, 2020; Hale et al, 2018; Molle, 2009). The pollution that is created from new development can be described as plastics, chemical, or excess natural substances. Pollution can be used in terms of any excess of a material that is disrupting the flow of a natural cycle. So we can refer to the pollution as an excess of water, sediments, soil, plastic and chemicals.

Furthermore, by using remote sensing with an 'Urban Growth Effect on Surface Runoff Model' researchers were able to show that an area with more urban growth will have higher potential for having more surface runoff (Weng, 2001; Thanapura et al, 2007). Surface runoff occurs more frequently when the land becomes impervious (Thanapura et al 2007; Kelleher and McPhilips, 2019). The amount of impervious surfaces are important to assess since urbanization often results in a loss of areas are urbanized a lot of the penetrable surface. Pervious surfaces are important in the water cycle because they allow precipitation to seep into the ground. When this precipitation cannot seep into the ground, it becomes runoff. So when lots of the area becomes impervious and the precipitation cannot go into the ground, it sits on top of the developed area and can cause more runoff to occur. Urbanization has been known to be a stressor of rivers and streams (Hamel et al, 2013; Kelleher and McPhillips, 2019; Hemmati et al, 2020). When the impervious surface of an area goes up due to urbanization the water quality of an area decreases (Bhandari et al, 2017).

Some of these negative environmental changes can also be categorized as environmental injustices since the location the impacts take place are located in minority communities meaning they suffer disproportionately from urban disinvestment (Johnson, 2001). Environmental justice has been defined many times since its origin (Fielding, 2007; Johnson 2001) and can be defined as the right for communities to have "equal protection of environmental and public health laws and regulations (Bullard, 1996).

The concept of environmental justice was integrated into federal procedures by the Clinton Administration executive order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations was issued in 1994. This executive order was set in place to help identify areas where environmental justice issues were occurring, develop a strategy to help fix the issues and promote nondiscrimination in federal problems to help provide access of information to minority and low income communities (Environmental Protection Agency, Laws and Regulations).

Another important concept to consider is the three pillars of environmental justice formally introduced by David Schlosberg (2003). They include aspects that need to be addressed when coming to a conclusion about how to manage a citation that has an environmental justice background. The first pillar Schlosberg (2003) talks about is distributional justice. Distribution touches on the fact that historical inequities exist and the experience of environmental harms and goods are not equally distributed across the population. Secondly he mentions lack of recognition, meaning there is a devalued identity of those who are at risk for suffering environmental justice issues. Thirdly he talks about participation - saying that it is important for the communities that are deemed at risk to have fair participation in the politics that occur around their health and community (Schlosberg, 2003).

When looking at the areas that are most in need of help when it comes to flood management, they are poor communities within the flood plain of a watershed (Elliot & Pais, 2006). After slavery Jim Crow laws kept poor and minority people from living in certain areas. We can see this still occurring in neighborhoods throughout the South. The current neighborhoods still represent the historical development patterns that disproportionately impact minority communities (Cutter et al, 2018). Flooding can be seen as an issue that is about poor land-use decisions rather than one that is about where the homeowner chooses to live (Cutter et al, 2018). Flooding increases can also be attributed to recent climatic changes as well as socioeconomic development (Hemmati et al, 2020).

METHODS

In this study, a supervised image classification technique was used to determine the different types of land cover throughout Wake County, North Carolina, and more specifically the Walnut Creek Watershed, to analyze the urban land cover for the time period from 1992 to 2019. The land cover data was used to examine the spatial relation to certain demographics that have a high probability of environmental injustice. The demographics used in this study were related to household income and poverty levels. The poverty level that was used was people in 100%-200% poverty. This means that people within this demographic make a certain income with a certain amount of people living at the house- they are likely to need government assistance. Household income is total household income with the total amount of people living in the house. These demographics were looked at in relation to the development that has occurred within Walnut Creek Watershed.

Research Area

Walnut Creek Watershed is located within the Neuse River Watershed portion of Wake County, North Carolina. Wake County (Figure 1) covers 857 square area and has a population of 1,111,761 (US Census). The Neuse River watershed covers approximately 77 municipalities such as the city of Raleigh - the state capital of North Carolina. Walnut Creek watershed is approximately 119.07 square kilometers and located at the lowest point of the Neuse River watershed in Raleigh (USGS WBD). The lowest parts of the watershed flow through South East Raleigh (figure 2). This watershed is considered to be urban which means that most of the area that the Walnut Creek flows through is developed.

Demographics

Demographics can give insight into how cities are made. They can show areas of poverty, low income, and minority communities. With this information we can tie together the link between social and environmental impacts on marginalized people with the help of spatial analysis.

The demographic data used in this study were obtained from the website of the United States Census database that is stored within the governmental data on Tiger/LINE Shapefiles. The U.S. Census demographics data was extracted from the 1992 and 2019 for Wake County. These demographics described the race, income and amount of poverty within the county. This data was then converted from a table format to a GIS database to more readily examine the areas that show the distribution of these groups within the area of study. These demographics were of interest for this study because they showed how different groups of people were affected by the urbanization occurring throughout the study area. These data also showed the different groups of people within the areas that have been developed and the areas that may be experiencing certain by-products of urban development- such as flooding.

Using the difference between the changes in the scenes, we created another image that shows where the most change occurs. This difference scene can be compared to the demographics to help visualize the change that has occurred and where it is occurring demographically. This shows the social disparity of where urbanization occurs and who it is affecting.

Satellite Image Data

Using satellite imagery we were able to look at the different Landsat images for 1992 and 2019. These two different time stamps will be used to determine the difference between land uses during the two time periods. Using these two different images we can analyze how much development has occurred during the time frame. Only one satellite image scene was needed for Walnut Creek though two of them had to be used for the whole of Wake County. The satellite images for Wake County are two images for the same date combined together. Since Wake County is spread over a larger area than the Walnut Creek watershed there was two Landsat images that were obtained from Earth Explorer to cover the whole Wake County area.

Supervised Image Classification

Supervised image classification was used to determine the land use within each satellite image scene. From the 1992 image we were able to detect 5 major land classes - (1) Water, (2) Urban, (3) Barren, (4) Grass Field, and (5) Forest. These same land classes were used for the 2019 data set as well. Both images were digitally rectified to be similar so that we were able to accurately determine how the land has changed over time. Both images were put into true color composite and false color composite and stretched to make the images sharper.

Using a supervised image classification system we developed land use images for 1992 and 2019 respectively. A supervised image classification is a way that users can define land classifications within a satellite image. When it is supervised image classification the user is in charge of picking sample pixels that represent a land classification throughout the image, this shows reference pixels that are used by the software to develop land classifications. This was done by using training samples throughout the satellite image. Training samples are areas within the satellite image that are the same color showing similar land classifications. These training samples are picked throughout the image. The training samples are hand-picked by experienced users to determine which pixel belongs to certain land classification. An accuracy assessment is used to determine how well the supervised classification worked related to the data. Two accuracy assessments were created for both scenes in 1992 and 2019. The accuracy assessment will be used to estimate the classification accuracy and to do that we will create error matrices to show the difference between the scenes and the images.

Data

Walnut Creek is a sub-watershed within Wake County. Its United State Geological Survey (USGS) hydraulic unit code is (HUC) 12 – 030202011101, within the Wake County District in North Carolina (Environmental Protection Agency Communications). The Walnut Creek watershed covers part of the city of Cary and Raleigh. The hydrologic unit codes are a hierarchical standard created by the USGS. Hydrologic units are determined by the amount of source area that contributes surface water to a specific outlet. This watershed is 119.07 square kilometers, and is in the Neuse River Watershed located in Wake County.

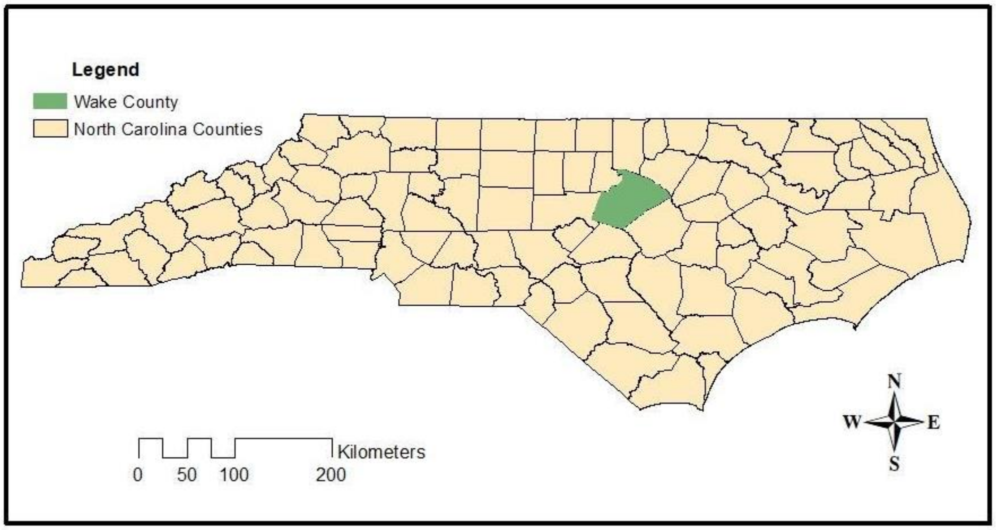

Figure 1: Study Area- North Carolina counties with Wake County highlighted

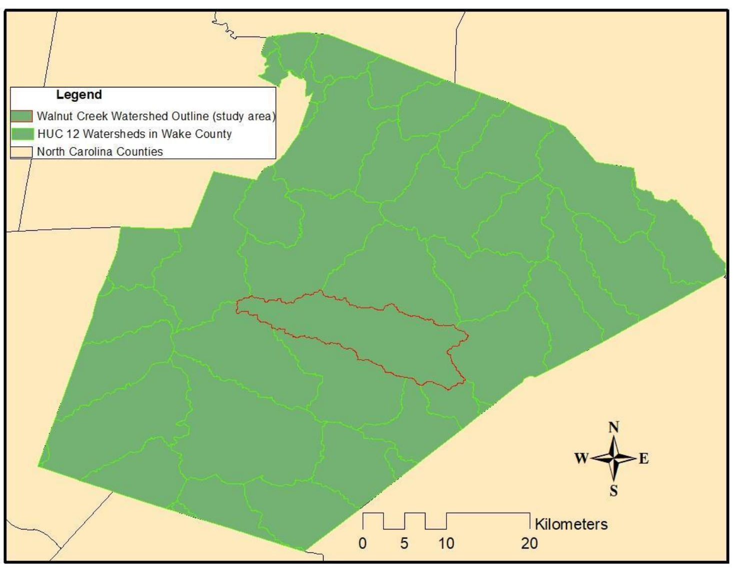

Figure 1.1: Study Area- Wake County with all the subwatersheds; Walnut Creek highlighted in red.

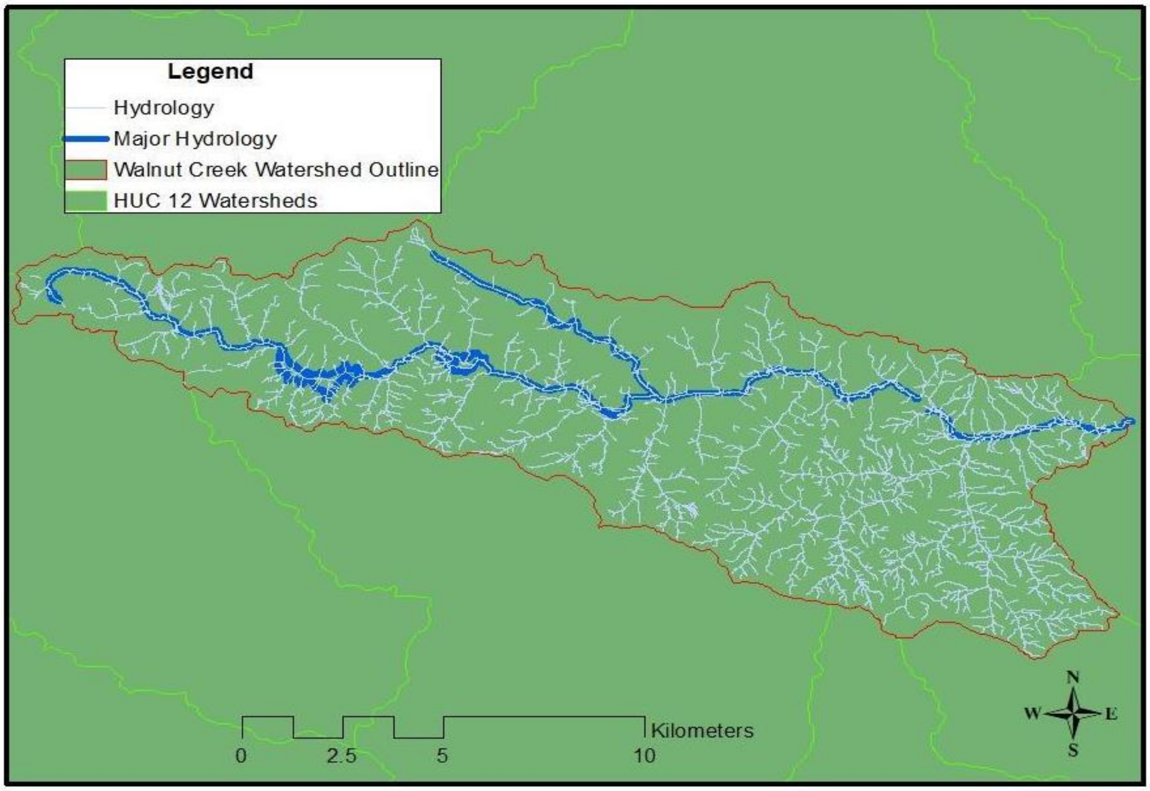

Figure 1.2: Study Area- Walnut Creek Subwatershed with hydrology

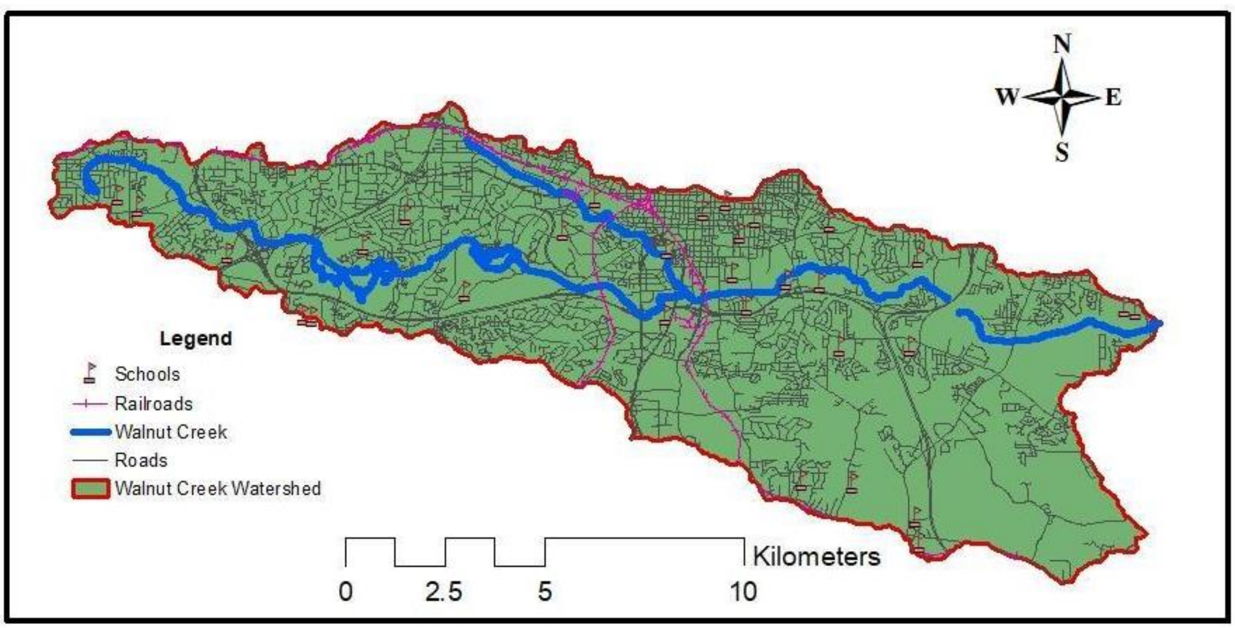

Figure 1.3: Study Area- Walnut Creek Watershed with roads, major hydrology, railroads and schools

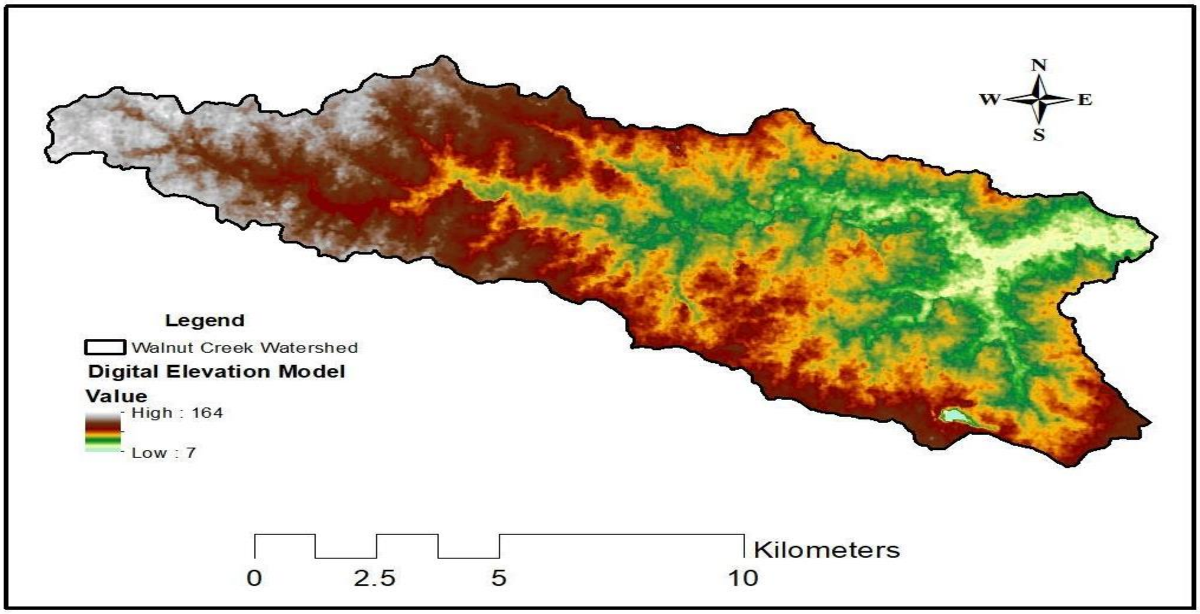

Figure 2: USGS Earth Explorer - Digital Elevation Model of the Walnut Creek Watershed (published September 23. 2014). The resolution of this DEM is 1-ARC with an entity ID of SRTM1N35W079V3.

A digital elevation model (DEM) was acquired from the USGS EarthExplorer. This digital elevation model was created to determine the top and the bottom of the Walnut Creek subwatershed. The bottom of this sub-watershed is the lowest part of the watershed, meaning that it is in pale yellow. While the highest part of the sub-watershed in the west is a white color and located at the top.

In order to evaluate the land classifications a land cover analysis was used by doing a supervised image classification for USGS Earth Explorer 1992 and 2019 data. The data for the map from 1992 was acquired from the National Land Cover Database (NLCD). The satellite imagery was obtained from European Space Agency's Multispectral Instrument Sentinel - 2. Supervised classification is a way of creating a land classification for an area from a satellite image.

Supervised classification involves the process of selecting representative training sample pixels throughout the image that are representative of specific classes. These training sites are picked by an experienced user to determine what pixel colors represent each land cover category, specific or land cover class. The image is enhanced before this process to make certain features (classes) stand out. After adding the USGS Earth Explorer raster data sets on the map they were then clipped to the Wake County shapefile. Image enhancements were utilized to clarify the image for an accurate assessment. Using the image classification tool we created five different classes including ‘Water’, ‘Urban’, ‘Grass Field’, ‘Forest’, and ‘Barren’. After classifying the different areas for 1992, the process was repeated for 2019. The two different rasters covered different areas within the Wake County shapefile meaning that there was a new polygon created that is specific to the two different rasters. To do this operation the Wake County shapefile was clipped to the first raster, and to the second raster creating a new Wake County shapefile that contains the county limits of both of the raster images. This is done to create an equal area polygon within both raster images for the completion of the accuracy assessment. The accuracy assessment needs to have an equal area within both of the raster images or errors associated with the calculations may occur.

Next, an image difference operation was created for both of the classified images to determine the changes in urbanization in the clipped Wake County area. The clipped Wake County area is the new polygon that was created with both of the raster images (from 1992 and 2019). Using an image difference operation can determine the changes that have occurred in both 1992 and 2019 of the classified images that have been created within the Wake County area. The difference operation will show how much urbanization has occurred from 1992 to 2019 by showing the high areas of change during that time frame. The high-value differences will show up in a different color than the ones that have no land classification change. This tool was used to create a map that accurately depicts the Land Cover changes within Wake County limits.

To determine if there has been an increase of runoff from the urbanization process, we examine the stream gauges during heavy rain events. There are stream gauges located at the top of the watershed and some near the bottom. These gauges will help determine the amount of flow that is occurring during heavy rain events.

RESULTS AND ANALYSIS OF DATA

Shown below is a map of Wake County, North Carolina with identified land classes. The two images are from 1992 and 2019 respectively. Below the Wake County images are zoomed in areas of the Walnut Creek Watershed. This watershed is a subbasin of the Neuse River Watershed.

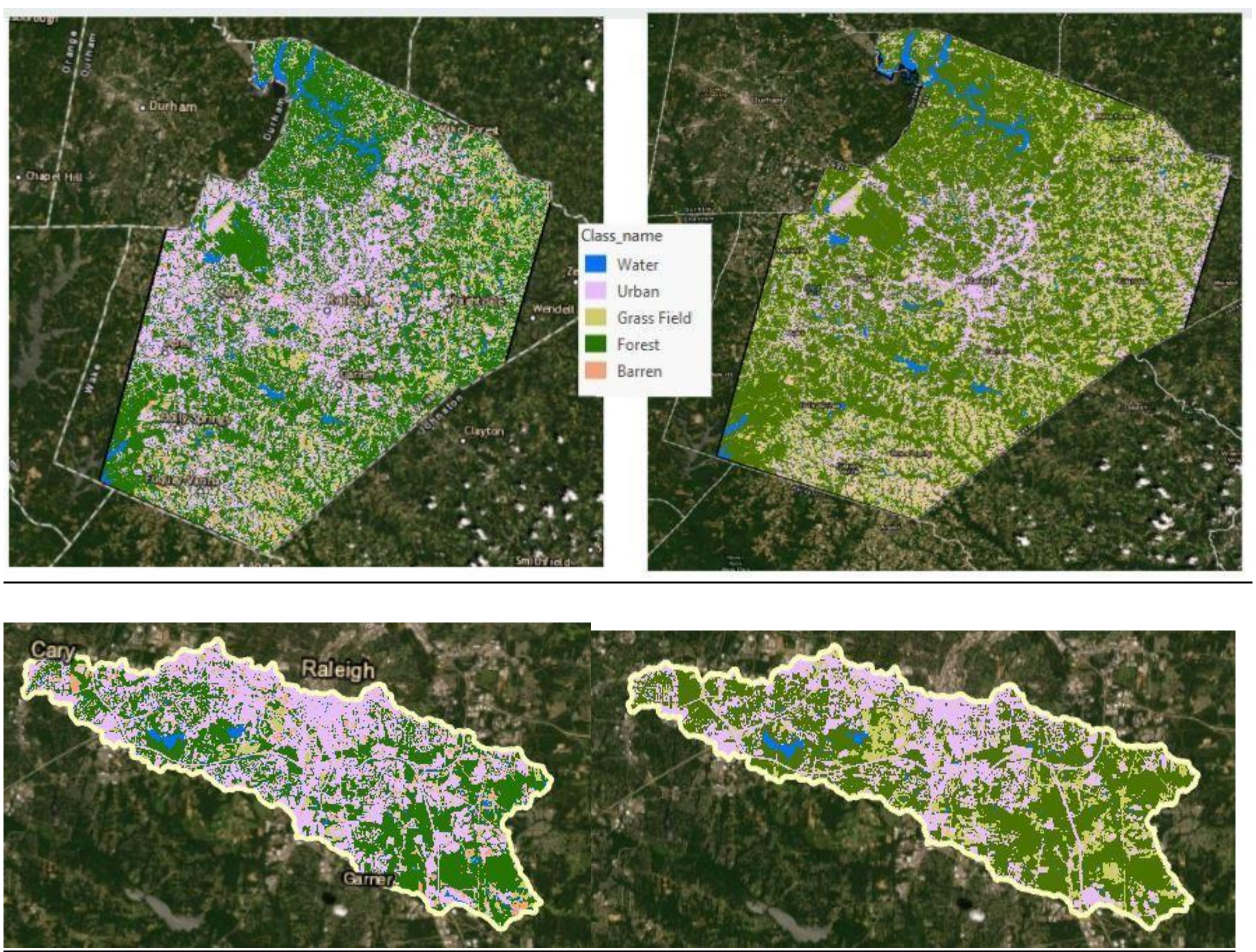

Figure 3: Left Top Wake County Land Use 2019 Right Top Wake County Land Use 1992

Bottom Left Walnut Creek Watershed Land Use 2019 Bottom Right Walnut Creek Watershed Land Use 1992

Within this sub-watershed, there are nine USGS stream gauges. These stream gauges are located along a major highway and in the major urbanized city within the sub-watershed. The major urbanization that is within the watershed is the lower part of downtown Raleigh. In reference to Figure 3 the bottom images of Walnut Creek Watershed the lower part of downtown Raleigh is located in the center middle of the watershed. Stream gauges are used by the USGS to keep track of data within the watershed. These types of data recorded include streamflow, precipitation, groundwater, and a flood event viewer.

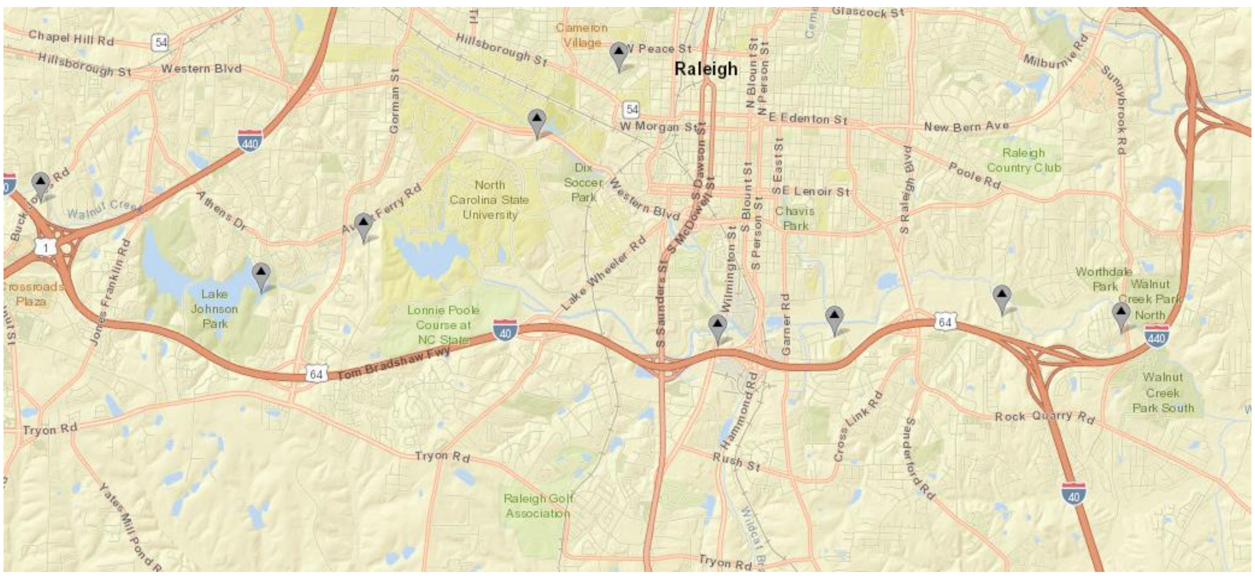

Figure 4- Shows placement of stream gauges within Walnut Creek watershed

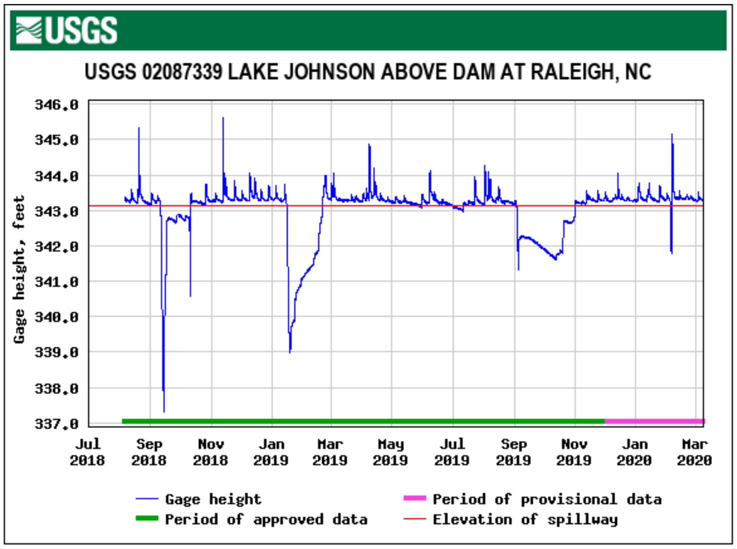

Figure 4.1 - Stream gauge at Lake Johnson Dam (above dam)

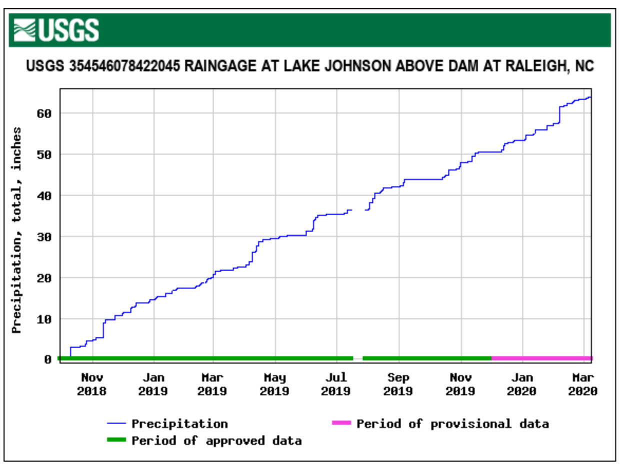

Figure 4.2 - Rain gauge at Lake Johnson (above dam)

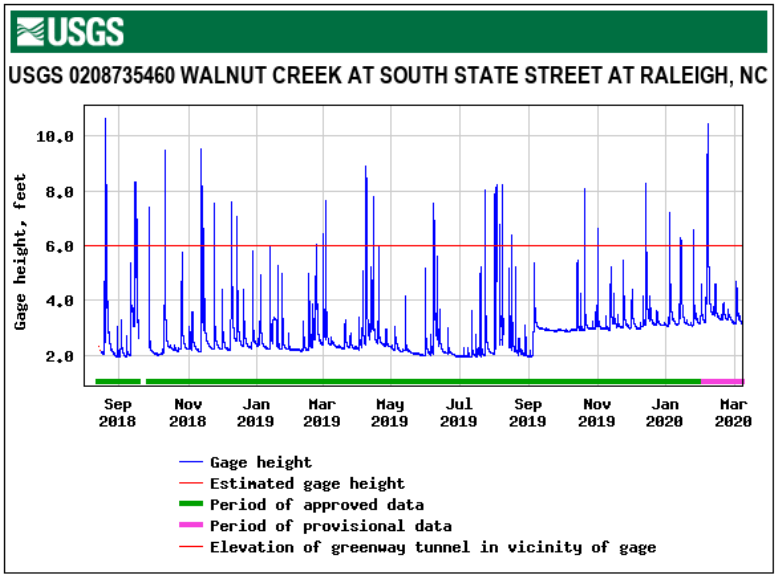

Figure 4.3 - Stream gauge on Walnut Creek at South State Street

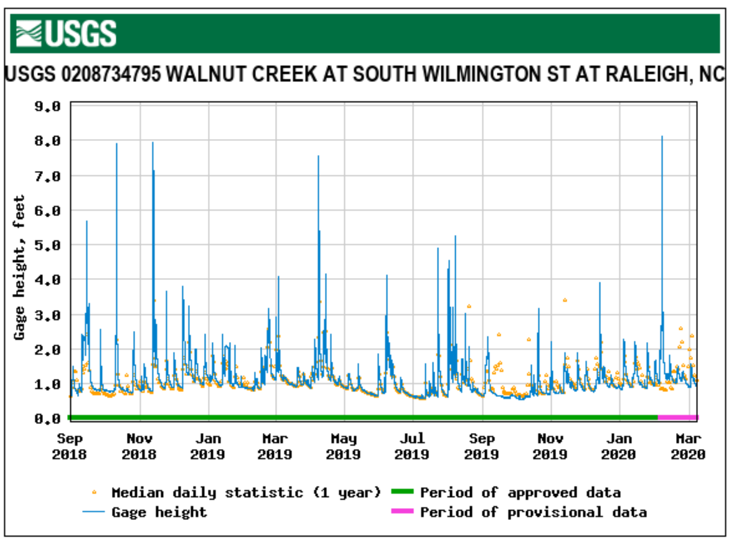

Figure 4.4 - Stream gauge at South Wilmington Street in Walnut Creek Watershed.

These three images are a representation of the stream stats from three different gauge locations. The three different locations are at the top of the sub-watershed in the middle and the end. The two-stream gauges in the middle - South Wilmington Street- and the end - South State Street- are in urbanized areas while the first one located above the Lake Johnson Dam. The Lake Johnson

Dam Stream gauge is at the top of the watershed and is also the most un-urbanized area of the three gauges based on figure 3. The two stream gauges - South Wilmington Street and South State Street- that are in urbanized areas have very high highs and low lows as it relates to a natural stream. Figure 4.4 and 4.3 represents an urbanized stream. Urbanized streams are streams that run through the city and do not maintain their natural flowing state (Konrad, 2016;). Most urbanized streams have been piped up. Whereas more natural streams do not have as extreme fluctuations (Konrad, 2016).

When a stream becomes urbanized, the total maximum daily load (TMDL) of the stream changes from its natural streaming (Konrad, 2016). The TMDL is defined in the U.S. Clean Water Act, that says how much pollutant a body of water can have while still meeting water quality standards. You can tell the difference between a natural stream and an urbanized stream by the amount of stream discharge and how frequently they become polluted and flooded. When there is less pervious surface in a landscape it makes the proportion of floods increased (Downer et al, 2011). The amount of runoff that occurs is more because the water has nowhere to go but flow downstream towards the naturally formed outlet.

Figure 3 images show the amount of urban land (purple) that has been developed since 1992 to 2019. The Walnut Creek watershed is an important area in this County because of the historic placement of the neighborhoods within the watershed. At the bottom of the watershed is a predominantly black neighborhood that was built between 1957 and 1964. When looking at figure 2, the digital elevation model shows that the lower part of the watershed with the least elevation at 7 meters above sea level is South East. While the top of the watershed, the North

West most corner, located in Cary is 164 meters above sea level. The historic and current predominantly black neighborhoods located at the bottom of the watershed are called Rochester Heights and Biltmore Hills.

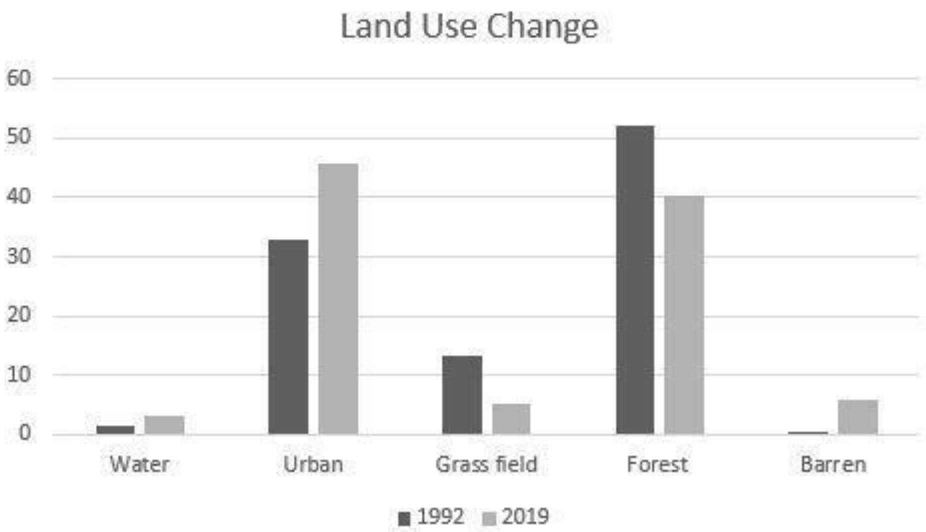

Figure 5- Per Area is the percentage of land that is occupied by the class value; top 2019, bottom 1992

Table 1: Land Use Graph Percentage Per Area of the Walnut Creek Watershed

Class Name	Red	Green	Blue	Count	Per Area
Water	0	112	255	4081	3.07
Urban	232	190	255	60757	45.78
Grass Field	205	205	102	6661	5.02
Forest	38	115	0	53475	40.29
Barren	245	162	122	7745	5.84

Class Name	Red	Green	Blue	Count	Per Area
Water	0	112	255	1667	1.26
Urban	232	190	255	43628	32.92
Grass Field	205	205	102	17359	13.1
Forest	76	115	0	69222	52.22
Barren	255	190	190	671	0.51

In Table 1 there is a clear distinction between the amount of land that has changed between 1992 and 2019. Between 1992 and 2019 there was an increase of urbanized area by 13%. While the barren landscape has increased by 4.5% this could indicate that there are plans to develop. With a

13% increase in urbanized area and a decrease of forest land of 12% over the 18 years evaluated, it can be said that there has been more impact on the natural flooding that occurs downstream making it more of a nuisance flooding issue.

There is a large difference between urban development, the amount of forested lands, and grass fields. These changes can also be seen in Figure 3. The high values of change are shown with a bright yellow/orange color while the areas that have stayed relatively the same are a magenta color. This map corresponds with Figure 3 as well showing the most change in the western area of Wake County.

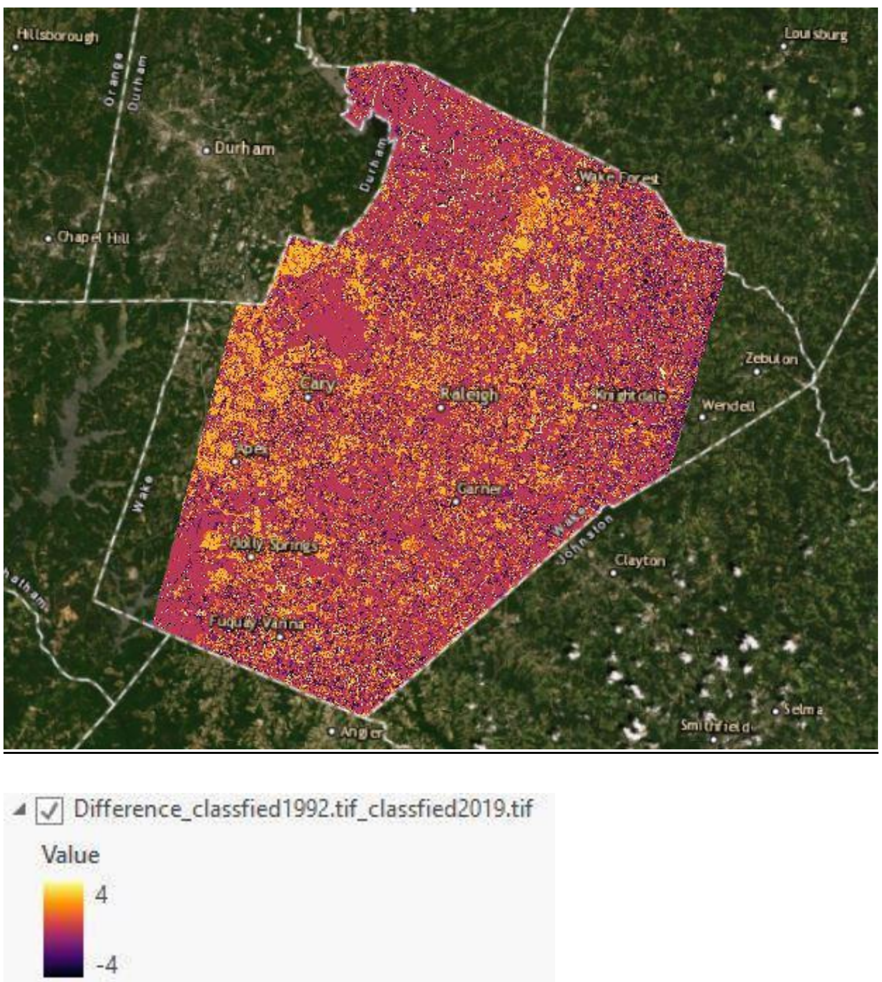

Figure 6: Difference of Land Use within Wake County

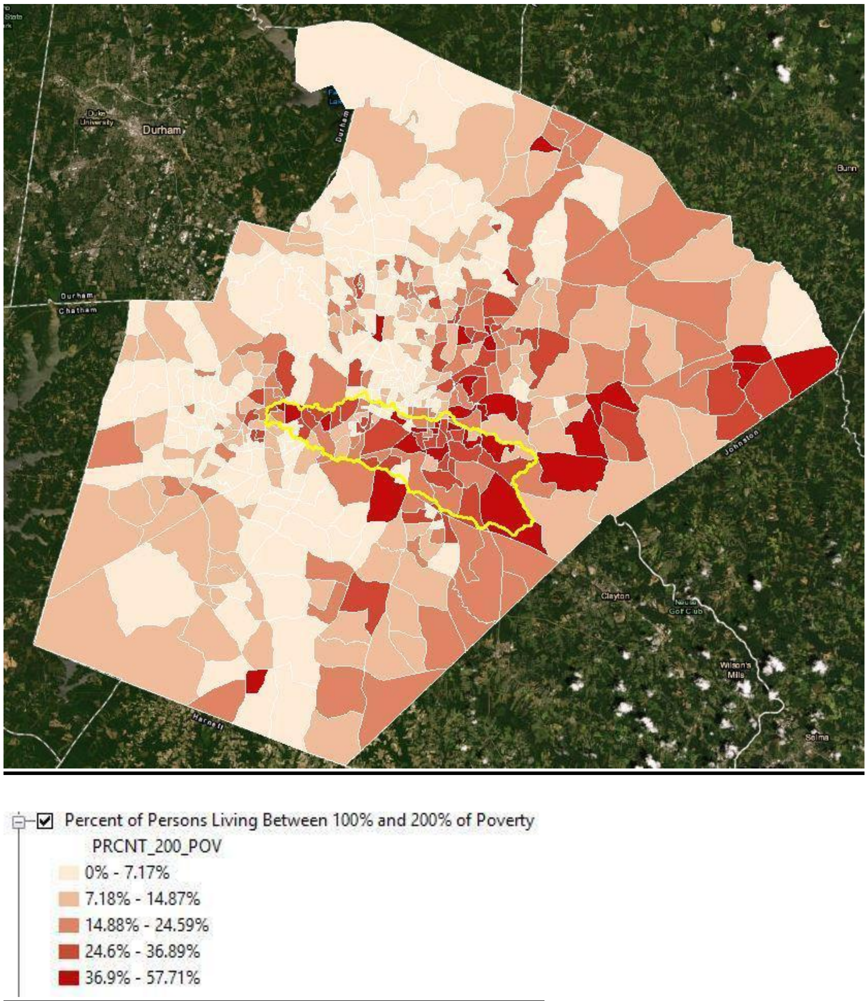

Figure 7: Wake County Poverty Distribution Percent of Persons Living Between 100% and 200% of Poverty in 2017

-Walnut Creek Watershed in yellow

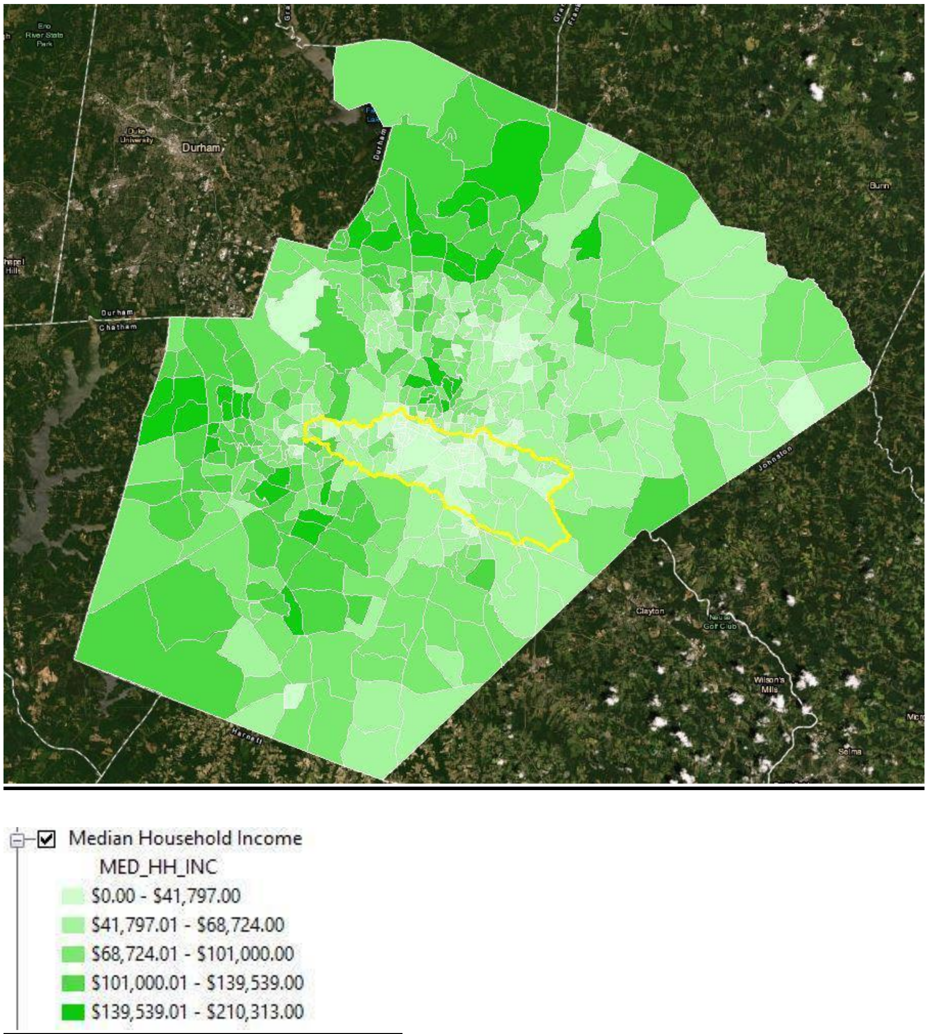

Figure 8: Wake County Median Household Income 2017 - Walnut Creek Watershed in yellow.

Figure 7 and figure 8 suggests differences in the socioeconomic status of people within Wake County. Figure 7 shows the percent of people living between 100% and 200% poverty in 2017. Figure 8 shows the median household income in 2017 with the lighter green being on the lower end of household income and the darker green being higher income. Based on figure 7 and 8 the lower-income groups are located near the Southeast corner of the Walnut Creek Watershed. With the poverty map (Figure 7), those areas experiencing high poverty are located at the central and Southeast corner of the map. This is in direct contrast to the occurrence of urban development.

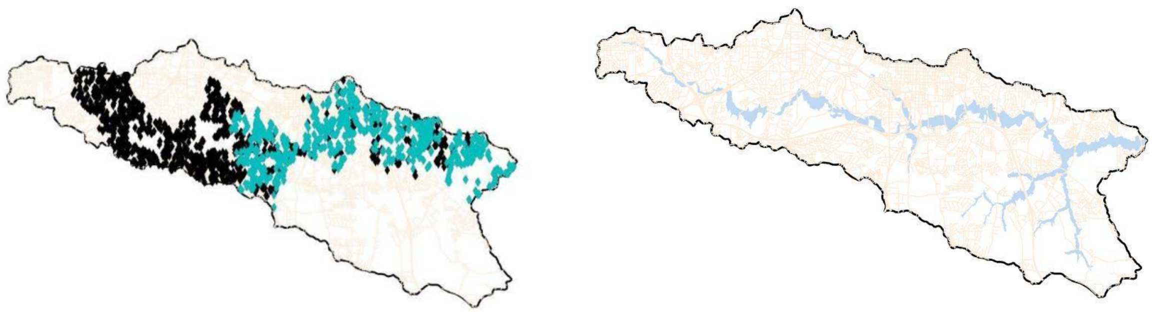

Figure 9: Left- Walnut Creek Watershed with pipe locations (black & blue dots). Blue dots are pipes that were last checked on or before 2003. Right- Walnut Creek Watershed with 2019 flood plains in blue. Both have roads in light yellow.

DISCUSSION

In the supervised maps created we are able to see that there is a change in the amount of urban landscape in Wake County NC. Most of it occurs west and north of central Raleigh; Cary, Apex and North Raleigh respectively. These are also the most highlighted areas in the image created from the difference which have a value of positive 4 (the high value of yellow). The yellow in Figure 3 shows the areas in the landscape that have changed the most between 1992 and 2019. This demonstrates that the upper part of the watershed located in West and North Raleigh have undergone the most urbanization in the past ~30 years.

The differences in values can be attributed to land cover change. When looking at Table 1 you can see that the amount of water areas are still very similar and therefore have not changed much. The little bit of change that has occurred can be attributed to sharper images between 1992 and 2019 that can be seen at a higher resolution therefore a more appropriate representation. Whereas the barren areas and the grass fields have a high difference, as close as the urban and forested areas. The percentage in the grass fields decreases from 1992 to 2019 as well as the forest area also decreases. While the barren area and the urban area increased from 1992 to 2019.

The increase in urban development can be identified as a proxy for having a higher potential of surface runoff (Weng, 2001). Since flooding is an issue that needs a form of integrated management then there should be a way to change the current protocols. Flooding as seen as an environmental problem requires adaptive management responses meaning that the management response needs to be changed from the way they used to be done because of the integrated assessment of the problem. The integrated assessment is when there are several different entities that need to all be on the same page about the types of responses and the reasons for the disparity and problem (Lurie and Hibbard, 2008). These types of environmental problems require adaptive management responses due to the integrated assessment of the problem (Hale et al, 2018). When flooding occurs it is not just set in one area, it transcends political jurisdictions and therefore needs to be dealt with as so. This issue (flooding) needs a group of people working on it that not only are from different parts of the local city government but also the local community because they are there experiencing things first hand on the ground. It is also important to realize that because watersheds transcend governmental boundaries, municipal officials should work together for a broader understanding of how the watershed flows through the development.

In a natural stream it is expected that the stream flow stays relatively consistent throughout the stream during heavy rain events (Konrad, 2016). With a highly urbanized stream there will be areas near the bottom of the watershed that will have very high levels of water flowing through it (Konrad, 2016). This can be attributed to the amount of water that is accumulated from the highest elevation of the watershed that flows to the lower elevation at the bottom of the watershed and changes the stream geomorphology. In Figure 9 the image of the pipe data shows the different locations of pipes in the Walnut Creek Watershed. These blue pipes indicate ones that haven't been looked at since 2003 or before based on the attribute table from the shapefile given from the City of Raleigh. They are all congregated near the bottom of the watershed. This is where we can see areas of the hydrology that have been disrupted from its natural flow state because they are receiving so much water from the urbanized areas upstream. This data can be publicly viewed on the iMaps application but cannot be downloaded, therefore was personally asked for. It was received from Matthew Cherry in the Stormwater Mapping division, our connection was made by Kevin Boyer from Raleigh's Stormwater Division. There are also parts of the flood zones that are not properly managed - this can be seen where pipes haven't been checked on for multiple years. There is an area of the flood zone that does not have any kind of piping according to the data received from the City of Raleigh. This type of negligence may be a contributing factor in the nuisance flooding that is occurring in the lower part of the watershed.

CONCLUSION

The development within the watershed can be linked to the nuisance flooding events that happen in South East Raleigh. Because this area is disproportionately occupied by minority and low income communities, the nuisance flooding that happens in the area at the lower part of the watershed could be classified as an environmental justice issue. The increased amount of development that has occurred within Walnut Creek Watershed has had a disproportionate effect on the at-risk communities within the South East area of the watershed. This research shows how demographics can be related to urban development and how it has the potential to affect at risk communities who live downstream - at the lower elevations in the watershed.

The downstream of the watershed is an area that is known to have a history of flooding (Hasala et al, 2020). As shown in the images above, the amount of urbanization that has occurred mainly happens upstream in the more affluent neighborhoods. As a result, urban runoff increases and puts the communities downstream at risk for increased flooding potential (Zeinali et al, 2019).

The nuisance flooding downstream may increase since the watershed is experiencing a 13% increase in urbanization. These urbanized areas are being developed in the communities that are affluent (with incomes of $100,000+) according to Figure 7 and 8, obtained from the US Census. The communities impacted by the increased runoff due to urbanization will be the at risk communities (incomes of less than 50,000) because they are at the bottom of the watershed. It appears as if there is a connection between the amount of development that is occurring and the socioeconomic status. The at-risk communities that were afore mentioned in this paper are ones that have lower income, are older and largely composed of people of color. The more at risk communities are facing the effects of what is happening upstream. They are not able to handle the amount of runoff that is to be expected because their infrastructure has not been updated in a way that will be able to keep up with the growing urbanization (Figure 9). No error matrix was done therefore there could be some discrepancies in the accuracy of the land cover change.

To be able to better understand how these areas are affected and how to properly mitigate the issue, there needs to be a thorough development plan on how to fix the problem. This can be done by using the three pillars of environmental justice which include recognition, distributive and procedural processes (Schlosberg, 2003). City officials and policy makers need to recognize that there is an environmental justice problem occurring. After the recognition of the problem there must be analytical steps to realize where the issue is occurring. This can be done through governmental surveys or university research which would likely result in a suggestion of improvements in the infrastructure in the neighborhoods that are most adversely affected. This can be done by implementing green infrastructure (Hasala et al, 2020). Green infrastructure is a management style that tries to keep the natural state of the water system. It will be important to involve the community with the development of where to place the green infrastructure as well as determining areas of flooding (Molle, 2009). The procedural process of environmental justice is answered by involving the local community members in decision making.

In closing, future work that needs to be done would be to complete a model to determine the impact of urban development on the stream flow. This can be done by using a modeling tool such as SWMM, SWATT, and rec-hass II (Suttles et al, 2018). There are many different types of models that can be used when determining areas at risk for flooding, drought and precipitation within an urbanized area (Wang and Xie, 2018). The most common models for flood, rainfall runoff simulation, and flood inundation forecast include RCM, LSM, ARX regressor, moga ALGORITHM, gssha MODEl. GPM IMERG (Wang and Xie, 2018). These kinds of models are used to determine the kinds of flooding that will occur in these areas. For this study these models will not be used.

By working with the communities, a city can implement a water-sensitive urban design (WSUD) that would help improve the quality of life, health and water in urban areas (Schirmer and Dyer, 2018; Kelleher and McPhilips, 2019). Using one of these models and engaging the local community in research to know where to implement a WSUD. An example of an WSUD would be implementing green infrastructure (Hasala et al, 2020). Future work should also examine current stormwater infrastructure within the watershed as well as analyze the different parts of the watershed that need the most improvement. Looking at the current ways that the City of Raleigh plans to implement bottom up infrastructure to engage the community may be one of the first steps in attaining environmental justice within these communities. A bottom up infrastructure can be defined as a way that the local community can engage and govern policies, projects, and ideals (Lurie & Hibbard, 2005). Within the city of Raleigh, one way they are trying to engage the local community is by creating a GIS application that will not only teach them about their local watershed but allow them to engage with the city to show problem areas within the watershed. This tool they have created is called a WaterShed Action Plan; and within this tool is another tool called SCITS that stands for Source Conveyance Information Tracking System. This will allow for the local community to alert the city government of areas where pipes and conveyances may not be working properly. Teaching the community how to use the SCITS tool will give them a convenient and effective way to communicate with the regulatory agencies. The new bottom up approach is a new initiative that the U.S. EPA has implemented that they believe may be a better way of environmental management allowing emphasis on local control (Wagenet et. al. 2007). This provides the local community a voice in the decision process related to the implementation of stormwater projects. The SCITS tool will be used to create a dialogue with multiple stakeholders. Well-designed community involvement is imperative for the local government to be able to develop and create regulatory systems that seriously values the concerns of its citizens.

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