ENEC 698: ENVIRONMENTAL CAPSTONE

BOLIN CREEK WATERSHED: STORMWATER MANAGEMENT & EQUITY

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Executive Summary

Bolin Creek Watershed is an urban watershed, meaning town development and impervious surfaces within it contribute to biological and biophysical impairment. This development is evident in high levels of pavement in both roads and sidewalks, rooftops, and compacted soil, particularly in the southern part of the watershed in Chapel Hill’s business district, part of the university campus, and the immediate surrounding residential areas. With more development in Chapel Hill, factors contributing to negative impacts in this watershed will only become more prevalent. Bolin Creek is on the EPA’s 303(d) impaired waters list for biological impairment, meaning the town’s stormwater management department and other relevant departments are mandated to address and mitigate this impairment. Most stormwater mitigation efforts are often planned from a purely engineering and biophysical
perspective. Our project aims to understand the biophysical problems within the watershed in regards to nitrogen and sediment pollution as well as flooding, and then frame this within a socioeconomic context. Though acknowledging the intersection of biophysical mitigation and inequality is a relatively new concept, it is our hope that introducing a social factor will help prevent mitigation efforts from contributing to existing structural inequality.

Although we examined equity issues for the entire watershed, our GIS and water quality analysis focused on Tanyard Branch and Mill Race subwatersheds, which are two areas of high impervious surfaces. Although these subwatersheds are similar biophysically, our analysis indicates large differences in the socioeconomic status of these subwatersheds.

We analyzed monthly water quality samples collected by Chapel Hill Stormwater Management from January 1994 to June 2009. There were three sample sites on the main stem of Bolin Creek. We examined total suspended solids (TSS) and nitrate + nitrite concentrations in order to analyze sediment and nitrogen pollution that contributes to Bolin Creek’s impairment. By looking at concentrations between these upstream and downstream sampling points we conclude that TSS is generally increasing downstream in Bolin Creek, which could indicate that sediment pollution is entering the Creek from Tanyard Branch or Mill Race. Similar analysis for nitrogen concentrations also shows that nitrogen is generally increasing as we move downstream in Bolin Creek. This could also indicate that Tanyard Branch and Mill Race are largely responsible for this nitrogen pollution as well. However, discharge data for Bolin Creek during this time period is needed to draw further conclusions from this water quality data. These pollutant concentrations are affected by discharge at each sampling site, so comparing discharge with sediment and nitrogen concentrations would be an important next step for this data analysis.

By combining nitrogen and sediment data, we were able to identify the gaps in current data and also to see that the Bolin Creek Watershed is in need of a more holistic approach to stormwater management. We believe this assistance should include the implementation of green infrastructure throughout the watershed in order to mitigate the effect that impervious surfaces have on stream and river health. However, socio-economic factors should be taken into consideration when implementing green infrastructure throughout the watershed, specifically in the disparity of mitigation between Tanyard Branch and Mill Race. This human, hydrological, and biological approach to stormwater management will create a better Bolin Creek Watershed.
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Introduction and Background

Bolin Creek & Chapel Hill

The Bolin Creek Watershed is a highly urbanized watershed that contains parts of Chapel Hill and a small segment of Carrboro. Bolin Creek is on the EPA’s 303(d) impaired waters list for biological impairment, meaning the town’s stormwater management department and other relevant departments are mandated to address and mitigate this impairment. The complexity of the land use throughout the watershed and socioeconomic breakdown complicate the stormwater management needed to address impairment within the watershed. Stormwater management has evolved significantly throughout the past century. Historically, the main focus of mitigation was to remove and reroute water away from urban areas. The focus has changed to emphasize treating the water where it falls and allowing natural processes to manage water filtration and runoff (Walsh et al. 2005).
In Chapel Hill there have been recent developments relevant to Bolin Creek Watershed. The 2006 Community Survey and subsequent 2008 and 2012 Master plans were done by a consulting firm to create a united vision of stormwater management for the town. These include, but are not limited to, mitigation in the Bolin Creek subwatershed, but did not include funding to implement the plan. In 2012, the town of Chapel Hill received a federal grant specifically for Bolin Creek. Though many of the projects were a success, some projects were stopped because of lack of cooperation from residents.

In the most recent election, residents overwhelmingly voted to approve $8 Million for high-priority projects for Chapel Hill Stormwater. This money will fund projects all around Chapel Hill, including Bolin Creek.

**Flooding, Nitrogen, & Sediment in Urban Watersheds**

Complications in urban watersheds often derive from increased impervious surfaces from development. Figure 1 below illustrates how impervious surfaces affect the hydrology of a stream in storm events. Runoff volumes will increase and enter a stream more rapidly than in areas without impervious surfaces. This happens because overland flow is increased and the water cannot infiltrate the land given the imperviousness of surfaces.

![Flow rate vs. time graph to display impervious surface and development’s effects on streamflow](image)

This impervious surface can play into a variety of harmful effects on the stream within a watershed. For flooding, because the runoff reaches a higher peak discharge more quickly, water will often collect downstream and flood at the bottom of watersheds (Konrad 2003). Sometimes, in efforts to move the high volumes of runoff from areas of
impervious surfaces, stormwater mitigation systems will also funnel this water downstream.

Increased runoff from development also contributes to erosion in streams, which will degrade the geomorphic stability of the streambed (Tillinghast 2012). This happens not only due to more volumes of runoff but because it can also happen rapidly. This erosion will contribute to total suspended solids pollution, and runoff will also be able to pick up and carry sediment more easily into the stream.

Nitrogen plays a more complicated role; impervious surfaces make the nutrient transport easier, and stormwater best management practices attempt to address nitrogen pollution. However, nitrogen originates from a variety of landscapes, from it is from agriculture runoff or septic leakage, and current stormwater BMPs may not always address nitrogen effectively (Koch et al. 2015). This nitrogen can lead to eutrophication, which degrades the biological integrity of a stream by increasing nutrients. This is in part what the EPA uses to determine impaired waters, and a total maximum daily load may be set to give guidance to the amount of pollutants allowed in a stream (EPA 2015).

It is important to emphasize that different areas in a watershed contribute to stream impairment in different ways and thus mitigation efforts are put in different areas to address these problems. Finding out at which points in a watershed these problems persist the most can help with determining where mitigation efforts are most effective. Thus, we are examining these three biophysical problems in order to help frame mitigation.

**Environmental Justice & Equity**

In order to understand equity problems that contribute to the community in the Bolin Creek Watershed and problems could be exacerbated by stormwater mitigation, we outlined environmental justice within Chapel Hill. The most public environmental justice issues in this watershed originate from the Rogers Road Community in Chapel Hill, which is a historically African American community. The root of this issue dates back to the early 1970s, when Chapel Hill made the decision to build a new landfill within the Rogers Road Community (RENA 2014). There was strong opposition to this decision by residents in the area, but, nevertheless, the landfill was constructed. The landfill was unlined and built on 80 acres of land on Eubanks Road, where it still remains today. Residents have had to face many negative impacts that come with living in close proximity such as increased traffic, illegal dumping, and contaminated water (RENA 2014). The reason why this is an important environmental justice issue ties back to a
study found that in the state of North Carolina, a landfill is three times more likely to be put into a minority community than into a predominantly white area (RENA 2014). This is a fact that the Rogers Road Community has dealt with on a daily basis for the past forty years.

The Rogers Road community is continually dealing with the repercussions of living near an unlined landfill. In a survey carried out by the town in 2014, 79% of homes in the Historic Rogers Road Community would like to be hooked up to sewer lines (Jackson Center 2014). But over half of respondents replied that the costs associated with installation would make this extremely difficult or impossible for them to do on their own. But this issue appears to be getting resolved, as the Orange County Board of Commissioners passed a solution to help households to get hooked up to sewer, and residents are hopeful for this new development (Jackson Center 2014). The engineering and permitting phase was scheduled to be completed by November 2015, which is one of the first steps in a long road of getting residents connected to sewer lines. Orange County, Chapel Hill, and Carrboro are sharing the duties of paying for the sewer line extension into Rogers Road, which is expected to cost anywhere between $5.5 – 6 million by the time it is completed (Rogers Road Task Force 2007). New developments within Rogers Road are instilling hope in the citizens that before long they may be connected to county sewer lines.

Another issue of environmental equity within the Bolin Creek Watershed is the Camelot Village Apartment Complex. These are inexpensive housing options for residents in the Chapel Hill area, with average rents about $200 cheaper than the Chapel Hill average. This makes these apartments a great option for many people who are looking for affordable housing in Chapel Hill. However, these inexpensive apartments have received bad flood damage in recent years, most recently in the summer of 2013. These apartments are a part of the Bolin Creek floodway and its fringes, which makes it especially vulnerable to flooding events (Ball 2013). The apartments were constructed years before the town stopped allowing construction in flood-prone areas. Three of the apartment buildings are located on elevations that are several feet under the 100-year floodplain. Flooding in the apartment complex has happened at least five times in the past twenty years, so this is an issue that residents deal with every few years (Ball 2013). Yet, the apartment does not mention these dangers when people are looking to buy or rent in the complex. Flooding inexpensive housing is a problem because low-income households often lack the capital to be able to get back on their feet after a storm event. A UK study showed that deprived households feel the impacts of flooding more severely than others. This has to deal with their lack of extra savings to be able to replace items they might have lost in the flood damage.
In 2005 FEMA granted Chapel Hill the money to condemn these apartments, but no progress was ever made because of the various different apartment and landowners involved in the transaction (Town of Chapel Hill 2013). It seems that the future of Camelot Village remains precarious when dealing with heavy rainfall events that disproportionately impact its low-income residents. The issue at hand here is the fact that the low-income housing units are located in the floodplain, when it is largely this population both that is less able to recoup losses following a storm and its renters, who have little influence on decisionmaking for this complex.

Finally, we took a look at the Historic Northside Community in Chapel Hill. This historically African American community is situated adjacent to downtown Chapel Hill and the University. The Tanyard Branch section of Bolin Creek extends into the Northside neighborhood. It is primarily an area with low home values and household incomes with a mix of renter and owner occupied lots that are facing an increasing student population. This area receives stormwater runoff from the neighboring Business District of Chapel Hill, which is a highly impervious area. The central part of Chapel Hill needs to work on implementing green infrastructure, so that this problem can be dealt with where the rain is falling. In terms of equity, the Northside neighborhood should not have to deal with the impacts of the runoff coming from blocks away, when they are not responsible for generating the large amounts of runoff.

**Green Infrastructure & Stormwater Mitigation**

Green stormwater infrastructure (GSI) is an approach to managing hydrological features in a way that provides community and environmental benefits (Odefey et al. 2002). This encompasses things such as bioswales, detention and retention ponds, permeable pavement, infiltration strips, and green roofs. Traditionally best management practices (BMPs) have focused solely on diverting water away from where it fell, and to get it into a stream or water body. BMPs aim to deal with issues of water quality and quantity on site. Over time, traditional best management practice have come to include natural hydrology in the process, which leads to the implementation of green stormwater infrastructure. Green infrastructure is a unique type of BMP that integrates stormwater management into a holistic ecosystem perspective. Using green infrastructure allows planners to go into a site and work with nature, and then using low-impact stormwater management practices where applicable (Odefey et al. 2002). The advantages of implementing green stormwater infrastructure into a watershed are immense, and these benefits should be felt in the Bolin Creek Watershed.
Currently the town of Chapel Hill is facing impervious surface cover that endangers watershed health, which can occur at impervious levels at 10%, as demonstrated in part by Figure 2 above (UNC-CH Department of City & Regional Planning 2011). Because of the issues that come with increasing amounts of impervious cover, such as higher runoff quantities and higher stormwater pollution levels, Chapel Hill should work to take action to ensure that this degradation does not intensify. Green infrastructure is a smart way to assist the town in limiting its imperviousness, while not completely limiting development within the watershed.

**Methods**

**Water Quality Data**

Chapel Hill Stormwater Management measured several water quality parameters at thirteen different locations in Chapel Hill from January 1994 to June 2009 on a monthly basis. We extracted sites 4, 5, and 11, called Bolin Creek at Pritchard Avenue, Bolin Creek at Franklin Street, and Bolin Creek at Pathway Drive, respectively, since they were the only three sites located in the Bolin Creek watershed. The criteria used to determine when to take these water quality measurements was that there must have been no precipitation on the chosen day. We decided to use Total Suspended Solids or TSS, represented as “Suspended Solids” in ChapelHillWQData.xls, to examine
To examine nitrogen pollution, we chose to use Nitrate plus Nitrite concentrations, denoted as “Nitrate+Nitrite” in ChapelHillWQData.xls.

Sediment and nitrogen levels were used to compare upstream to downstream concentrations to help determine where these pollutants may be entering Bolin Creek. We calculated ratios of Pathway TSS to Pritchard TSS, Pritchard TSS to Franklin TSS, Pathway Nitrate+Nitrite to Pritchard Nitrate+Nitrite, and Pritchard Nitrate+Nitrite to Franklin Nitrate+Nitrite. These ratios were then area weighted to account for increasing watershed size at each site, which allows for increasing volumes of water entering the creek at each site to be taken into account. This was necessary since we did not have discharge data for this time period. Weighted areas for each site were determined using GIS data from the subwatershed delineation. Pathway upstream accumulation was determined to be 73% the area of Pritchard’s, and Pritchard’s upstream accumulation was determined to be 81% the area of Franklin’s upstream accumulation. We used these percentages to estimate the relative volumes of water entering Bolin Creek at each of our sampling locations which would affect the concentrations of both sediment...
and nitrate+nitrite. These percentages were multiplied by the upstream site’s concentration.

\[ Area\ Weighted PathwayTSS = 0.73 \times PathwayTSS \]

\[ Area\ WeightedRatioTSS = Area\ WeightedPathwayTSS / PritchardTSS \]

Figure 4. The upstream accumulation for each sampling site increases in area for each downstream site. Pathway’s watershed is 73% the area of Pritchard’s watershed. Pritchard’s watershed is 81% the area of Franklin’s watershed.

**Precipitation Data**

Precipitation data was ordered from NOAA’s website for two locations in Chapel Hill: CH 2 W and Horace Williams Airport. CH 2 W sampling site is located in Carrboro, NC, right outside of the Bolin Creek watershed, but it had the most extensive history of precipitation records for the area. The airport sampling site did not contain data for the first four and half years of our water quality data.

The daily precipitation data was added for the current day and previous two days, so that it could better be used with our monthly water quality data. This was done in the Excel sheet NOAA data 2.xlsx. The water quality sample dates were then used to extract the daily precipitation data so that we had precipitation and water quality measurements for the same days.

**GIS Data**

For this project, GIS was used to delineate watersheds for data collection points and for various tributaries, to describe subject areas in terms of parcel values, impervious surfaces, and land cover, and as a way to visualize and present the data. This section will describe methods, data sources, and organization of data for GIS analyses in Bolin Creek.
**POI Folder:**
The previous capstone provided shapefiles with data collection points. In order to delineate the watersheds for the sites of interest each point was exported to its own shape file by the description of the point. For example, the sample point with the name “Bolin Creek at Village Drive at Chapel Hill, NC" is in the POI folder as VillagePt.shp. In addition points were created manually for Mill Race tributary (MillRacept.shp), Tanyard Branch Tributary (TotTanyardPt.shp), and Tanyard Branch through Northside Tributary (Tanyardpt.shp). RentionPt.shp is a manually created point estimating the location of the proposed retention pond. These points were created by clicking the location of the tributary closest to Bolin Creek without being on Bolin Creek as shown in Chapel Hill’s stream shapefile (streams.shp).

**Watersheds folder:**
The watershed delineations was done using ArcGIS Spatial Analyst tools and adapting steps from a PLAN591 lab taught by Chaosu Li at University of North Carolina - Chapel Hill. Digital Elevation Model data was acquired from Orange County Tax Administration Land Records. There is also DEM data available from NC Department of Transportation (NCDOT) and NC State University GIS Library. The DEM data from NC State has a “user-defined” projected coordinate system and NCDOT’s DEM data is rounded to the nearest foot, making Orange County’s Tax data the most promising choice.

Inconsistencies in the DEM data were filled using ArcGIS “fill” tool, then the filled DEM was put into tool “Flow Direction” and the option to “Force all edge cells to flow outward” was checked. These intermediate raster datasets are in a subfolder called “Intermediates”. The resulting raster dataset was used to delineate watersheds for the points described in “POI folder” using the tool “Watershed” in Spatial Analysts Hydrology Toolbox. These watersheds are named by the location followed by ws, so the upstream accumulating area for villagept.shp is VillageWS. Many of these raster datasets were converted to shapefile for analyses; these are named with an ‘ft’ at the beginning (villagews becomes ftvillagews.shp).

**Land Cover folder:**
This folder contains National Land Cover Database 2011 data clipped to fit some of the watersheds described in the points folder. Naming conventions are the point’s name followed by cvr, so ftvillagews.shp becomes villagecvr.
Impervious folder:
This folder includes impervious surface data from the previous capstone clipped to fit some of the watersheds described in the points folder. Naming conventions are the point’s name followed by imp, so ftvillagews.shp becomes villageimp.shp

Parcels folder:
This folder includes parcel data from The Orange County Tax Administration website. Included in the attribute table is parcel values. These values were used to show differing home values in Bolin Creek Watershed. A way to distinguish between commercial and residential parcels would be ideal and even more ideal a way to distinguish between owner inhabited and rental properties, but no way to filter between the zoning of these parcels was found. Instead property was filtered out by owner (e.g. excluding university owned property.

Census Data:
Census Data was collected from the American Community Survey 2005 – 2010 estimates. Census tracts for Orange County, North Carolina were selected, with information regarding population and median household income. We then focused in on the Bolin Creek Watershed by clipping the polygon of the Bolin Creek Watershed on top of the Census Data. Symbology was then selected in order to show median household income differences between each one of the census tracts, with darker blue colors symbolizing lower median household incomes, and yellow showing higher incomes.

PCSWMM Modeling
Permission for the PCSWMM modeling software was requested from Computational Hydraulics International (CHI). Because we are university affiliated, we were able to obtain a free license for the PCSWMM software for one year’s use. This software was chosen given its use in previous modeling of Tanyard Branch, completed by Erica Tillinghast from NC State in her master’s thesis report (2012). Our intentions with working with the PCSWMM model that Tillinghast created were to call into question the amount and placement of green infrastructure implementation as well as to try to lift the model's parts and apply them to the Mill Race subwatershed within the Bolin Creek Watershed. However, the model data, which is located in this project’s files, has incomplete time series for discharge and precipitation. One attempt to input the time
series with the updated file directory name resulted in the model taking 14 hours to run to completion. We were unable to use the Tanyard Branch part of the model for Mill Race or another subwatershed because we needed information about the pipe system and conduits in each area. The green infrastructure parts of the model (rain gardens, cisterns, green roofs, and wet pond) can be transferred once this base system is established for a subwatershed.

**Results**

**Water Quality Data**

We constructed plots of sediment and nitrogen levels to compare the upstream to downstream concentrations. The red lines represent a one-to-one line, which would indicate the upstream and downstream locations have the same pollutant concentrations if the point lands on this line. If a point lands above this line, this would indicate that the pollutant concentration is higher downstream, and if a point lands below this line, this would indicate that the pollutant concentration is larger upstream. We also plotted a linear regression that is an average of our data to represent the average relationship shown as a blue line in our plots. This line can be looked at in the same way as the individual data points; if the line is above the red line, the downstream concentrations are higher relative to the upstream concentrations and if the line is below the red line, then the upstream concentrations are higher relative to the downstream locations.

Looking at Pritchard TSS compared to Pathway TSS (Figure 5), we can see that Pritchard TSS is generally higher when Pathway TSS is at lower concentrations, specifically below about 5 mg/L. When Pathway TSS is larger than about 5 mg/L, Pritchard TSS is relatively lower. There are several outliers in this plot that should be accounted for. It also appears that there is a pattern of very low Pritchard TSS, at or below 5 mg/L, when Pathway TSS if relatively high, from 0 mg/L to 45 mg/L.
Figure 5. Ratios of Pritchard TSS to Pathway TSS were plotted in order to look at patterns in downstream to upstream TSS concentrations. The blue line represents a linear regression of the data points, and the red line represents a one-to-one line. The linear regression indicates that Pritchard TSS is relatively higher than Pathway TSS when it is at or below 5 mg/L, and Pathway TSS is relatively higher than Pritchard TSS when Pathway TSS is larger than 5 mg/L.

The same pattern can be seen for the linear regression of Franklin TSS vs Pritchard TSS (Figure 6) as the one seen in Pritchard TSS vs Pathway TSS (Figure 5). However, these data points seem to be clustered overall in lower concentrations, about less than 10 mg/L, for each location. There is also a pattern seen for relatively higher Franklin TSS when Pritchard TSS is relatively low. This is opposite from what was seen when we compared Pathway TSS and Pritchard TSS.
Figure 6. Ratios of Franklin TSS to Pritchard TSS were plotted in order to look at patterns in downstream to upstream TSS concentrations. The blue line represents a linear regression of the data points, and the red line represents a one-to-one line. The linear regression indicates that Franklin TSS is relatively higher than Pritchard TSS when it is at or below 10 mg/L, and Pritchard TSS is relatively higher than Franklin TSS when Pritchard TSS is larger than 10 mg/L.

We also plotted Pritchard nitrogen vs Pathway nitrogen to compare nitrogen concentrations along Bolin Creek (Figure 7). The linear regression indicates that Pritchard N is relatively larger than Pathway N among all concentrations, but there are several points that fall below this line. The linear regression falls very close to the one-to-one line, showing that Pritchard and Pathway are usually similar in N concentrations, but Pritchard N concentrations are often slightly higher than Pathway’s.
Figure 7. Ratios of Pritchard N to Pathway N were plotted in order to look at patterns in downstream to upstream N (taken from Nitrate+Nitrite measurements) concentrations. The blue line represents a linear regression of the data points, and the red line represents a one-to-one line. Pritchard N is relatively higher than Pathway N among all N concentrations, and the linear regression is close to the one-to-one line.

Franklin N concentrations were plotted against Pritchard N concentrations (Figure 8). We can see that Franklin N concentrations are relatively higher than Pritchard N concentrations when Pritchard N is less than 0.5 mg/L, and most of the data points are clustered in this area of the plot. The linear regression also indicates that, on average, Pritchard N is higher than Franklin N at or above 0.5 mg/L, but there is only one data points (1.5309, 0.44) that is skewing this data in this direction. There are several data points at relatively large N concentrations (larger than 1.0 mg/L) for Franklin when Pritchard N is relatively low (less than 0.6 mg/L).
Figure 8. Ratios of Franklin N to Pritchard N were plotted in order to look at patterns in downstream to upstream N (taken from Nitrate+Nitrite measurements) concentrations. The blue line represents a linear regression of the data points, and the red line represents a one-to-one line. Franklin N is relatively higher than Pritchard N when Pritchard N is less than 0.5 mg/L.
GIS Data

Figure 9. Parcel Values in Mill Race and Tanyard Branch Subwatersheds. The median household value of Chapel Hill is $332,100. Parcels that are valued at or below this are shown in light blue to green. Properties owned by the university were excluded from this analysis.

Figure 9 shows the disparity between home values in Mill Race and Tanyard Branch subwatersheds; this map in part helps synthesize socioeconomic data with geographical and hydrological data. It highlights the lower values of properties in the Tanyard Branch subwatershed in comparison to the higher property values in Mill Race.
Figure 10 is able to offer a clear perspective of the development in Bolin Creek Watershed: the northern half is relatively rural, with development concentrated in the southern half. In particular, the downtown area is very clearly impervious, which when put into the context of information regarding stormwater management and impervious surfaces, supports the need for mitigation to address this concentrated imperviousness. The yellow segments, which indicate pasture/hay, also show that despite the imperviousness of the southern half, there is agriculture in the northern half of the watershed, which may contribute to increased nitrogen loads.
Figure 11. Impervious Surfaces in Bolin Creek Watershed. Overall the watershed is 16.9% impervious.

Figure 11 shows the impervious surface make-up of Bolin Creek Watershed. The Town of Chapel Hill has a stormwater fee that is proportional to the amount of impervious surface on the homeowner’s land. This map shows large amounts of impervious surface in the southern and downtown parts of the watershed.
Figure 12. Data collection points used in analysis and their upstream accumulating area. From top left, clockwise: Pathway Drive, Pritchard, and East Franklin Street.

Table 1. Summary of area, impervious surface, and land cover data for Bolin Creek Watershed and relevant subwatersheds/upstream accumulating areas.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Bolin Creek Watershed</th>
<th>Pathway</th>
<th>Pritchard</th>
<th>Franklin</th>
<th>Mill Race</th>
<th>Tanyard Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area (US Acres)</td>
<td>7748.45</td>
<td>4040.84</td>
<td>5518.81</td>
<td>6818.11</td>
<td>207.56</td>
<td>356.24</td>
</tr>
<tr>
<td>Percent Impervious</td>
<td>16.40%</td>
<td>9.23%</td>
<td>14.23%</td>
<td>15.58%</td>
<td>89.37%</td>
<td>58.56%</td>
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<tr>
<td>Developed</td>
<td>18.55%</td>
<td>10.69%</td>
<td>16.10%</td>
<td>17.87%</td>
<td>48.76%</td>
<td>65.14%</td>
</tr>
<tr>
<td>Wooded</td>
<td>44.30%</td>
<td>60.07%</td>
<td>51.33%</td>
<td>46.74%</td>
<td>3.33%</td>
<td>2.55%</td>
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<tr>
<td>Water</td>
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<td>0.75%</td>
<td>0.55%</td>
<td>0.45%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other</td>
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<td>11.92%</td>
<td>9.24%</td>
<td>7.67%</td>
<td>0.21%</td>
<td>0.54%</td>
</tr>
<tr>
<td>Open Space</td>
<td>29.74%</td>
<td>16.58%</td>
<td>22.79%</td>
<td>27.28%</td>
<td>47.69%</td>
<td>31.77%</td>
</tr>
</tbody>
</table>
Census Data

Data obtained from the Census Bureau showed interesting statistics from our watershed that helped us to better understand the area we were dealing with. We were able to see that the median household income of the Census Tract 113, which the Northside neighborhood takes up a large area of, was $21,719. The US government sets the poverty level for a family of four at $24,250, so that would put many of these households under the poverty line, depending on family size (2015 Poverty Guidelines 2015). This Census data concludes our assumptions made about Northside being a low-income community. Looking into the future, the socio-economic status of areas of the watershed should be taken into account before recommendations are made. An example of how this would work is by making sure that there is a proportionate allocation of green infrastructure within this area of Northside. This is to ensure that all residents have a chance to feel the positive impacts that green infrastructure can have on stormwater in their area, not just those who have extra money to put towards the problem. Figure 13 below shows the median household incomes for the Census Tracts located within the Bolin Creek Watershed. Maps like these should be used for informing officials on making stormwater management decisions in the future.

By working with Census data we learned that the data we obtained was very hard to work with because of the level of detail it gave. We got it down to the most detailed information they offered, but it was still lacking when we looked at neighborhoods within the Bolin Creek Watershed. We would have liked to look at a more focused data, which was in part accomplished by using parcel data to look at home values for the Tanyard Branch and Mill Race areas.
Discussion

Green Infrastructure & Stormwater Mitigation

Green infrastructure should be looked at as a viable option for the Bolin Creek Watershed. The benefits of adding this into the watershed’s stormwater management framework will provide numerous stormwater as well as financial benefits. GI techniques reduce stormwater runoff rates by infiltrating more water into the ground, lessening peak runoff rates and removing pollutants from stormwater (Hjerpe and Adams 2015). One financial advantage to implementing green infrastructure is reducing the impacts of floods on the economy. Flood events are a strain on the economy of a city as well as its residents, but green infrastructure is able to reduce these costs by reducing peak runoff rates (Odefey et al. 2002). A study conducted in Boise, Idaho aimed to looked at the economics behind green infrastructure, which should be an important consideration when weighing whether or not to implement these techniques in our own watershed. Green infrastructure has been found to have higher initial costs, but longer lifespans, which can be money saving in the long run (Hjerpe and Adams 2015). And while green and gray infrastructure have similar costs associated with capturing stormwater, GI techniques are more effective at reducing pollutants from stormwater (Hjerpe and Adams 2015).
The figure above is from a study conducted by the US EPA comparing the costs of green infrastructure to gray infrastructure (Odefey et al. 2002). Gray infrastructure includes the engineered solutions that have previously been implemented in order to divert stormwater, including storm sewers and culverts. For any point on this graph that is below the line, it means that the cost for green infrastructure is less than it would be for gray infrastructure. It shows how out of 10 stormwater management projects, only one green infrastructure technique was more expensive than putting in traditional gray infrastructure. The other nine green infrastructure projects were all less expensive than implementing gray infrastructure (Odefey et al. 2002). While this study is not definitive proof for all circumstances, it does show that green infrastructure can be made to be less expensive than traditional stormwater management techniques.

Conventional stormwater management is implemented in watersheds at the cost of the stream and ecosystem health, which is why there is a need for green infrastructure. Currently there is a detention pond that has been proposed to go into the Tanyard Branch area in order to store stormwater in times of excess (D’Arconte 2012). Detention ponds can be seen as visually displeasing or as a safety hazard, but we believe that the town can make this an asset to the Northside neighborhood through one specific approach. This would include designing it to be a multi-use detention basin. Multi-use detention basins are an attempt to manage hydrological functions within a framework that residents can enjoy. This includes putting a detention pond within a golf course, park, or sports fields. If this is carried out properly, these facilities can be a positive addition to the community. One benefit of a multi-use detention pond is that when implemented in a way that is advantageous for the community, it actually increases
property values in the area (Shinde 2002). A big determinant on whether or not the community accepts the detention pond is how well it blends in with the landscape and how aesthetically pleasing the pond is (Shinde 2002). In order for the pond in Tanyard Branch to become an accepted part of the community, careful design consideration should be put into it, so that the community can be involved with its recreational use for years to come.

**Water Quality Data**

Both the sediment and the nitrogen data need to be compared with respective discharge in order to further analyze what these results mean and to look for patterns in these concentrations. However, some assumptions may be drawn with this preliminary data that has relative size of each sampling site’s watershed taken into account. Since TSS and Nitrogen is relatively larger at the downstream locations when it is relatively small in the upstream location in both comparisons, sediment and nitrogen pollution must be entering after the Pathway sampling site and the Pritchard sampling site respectively. Tanyard Branch and Mill Race, as already discussed, are prime suspects for this pollution, as their large areas of impervious surfaces has larger volumes of and faster runoff. These larger volumes of water are able to wash larger volumes of pollutants into the creek, and the faster the runoff is, the less chance the pollutants have of being absorbed into permeable surfaces before entering the creek.

**PCSWMM**

As outlined in methods, results from the PCSWMM model were unable to be obtained for this project. It is recommended that should the next group want to use models and to get results, one of the first steps early in the semester should be obtaining the licensing for this software, beginning to familiarize oneself with the software, and determining what GIS data and collected data will be necessary to run this model effectively. Suggestions for results that may be useful include the implementation of a greater area of green roofs, alternate location for the modeled wet pond within Tanyard Branch, and the application of both of these suggestions in other subwatersheds within Bolin Creek Watershed. Further, the Tillinghast model does not include pollution; it is possible that the PCSWMM software could incorporate pollution loading in stormwater in order to address the TMDL. These suggestions are provided given the disparity between the two sizes of wet ponds that the Tillinghast paper suggested (the size of the pond required to address the NCDENR Requirements and the largest size that can fit currently in this watershed), and given that the area of green roofs suggested is relatively small in comparison to the area of roofs in the Business District (Tillinghast 2012). It is our hope
to consider the socioeconomic repercussions of stormwater mitigation through results of modeling implementation in different areas than have been modeled.

Conclusion

The Bolin Creek Watershed is facing issues of biological impairment because of impervious surfaces, from development within watershed boundaries, and leaking sanitary sewer lines (D'Arconte 2012). These stormwater issues are ones that have been dealt with in the past, but looking into the future we would like to see an integration of socioeconomic data along with the hydrological aspect of the watershed. This means looking at the people who live in the watershed to see what impacts they are facing and if these impacts are fair for the amount they are contributing to the watershed. By combining nitrogen and sediment data we were able to see that the Bolin Creek Watershed is in need of a more holistic approach to stormwater management. We believe this assistance should include the implementation of green infrastructure throughout the watershed, in order to mitigate the effect that impervious surfaces have on stream and river health. Socio-economic factors should be taken into consideration when implementing green infrastructure throughout the watershed. This human, hydrological, and biological approach to stormwater management will create a better Bolin Creek Watershed.
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