The Effect of Land Use and Stormwater Control Measures in the Jordan Lake Watershed
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I. Abstract

Since the 1983 creation of Jordan Lake, a reservoir in North Carolina, it’s watershed has experienced rapid development. The reservoir has become periodically eutrophic, characterized by excess algal growth and oxygen-poor waters. A major cause of eutrophication is nitrogen and phosphorus pollution from urban development (Brett et al., 2005; Duan, Kaushal, Groffman, Band, & Belt, 2012; Shields et al., 2008). Further research is needed in order to understand the impact that development has had on Jordan Lake and the effectiveness of different stormwater control measures on mediating these effects.

This project aims to analyze effects of urbanization on nutrient loading by conducting research on five subwatersheds within the Jordan Lake watershed that vary by land use and stormwater control measure (SCM) implementation. Field sampling was conducted to determine total dissolved nitrogen concentrations, ion concentrations, nitrogen load, flow rates and water level for each site. Comparing these variables with different land use metrics including, but not limited to, % impervious surface cover (ISC), % canopy cover and SCMs allowed for an analysis of how land use and SCMs and development intensity can influence nutrient loading. Measured nutrient loading was also compared to modeled predictions from the SNAP 4.0 model. Our results indicate that SCMs, canopy cover and ISC are important drivers of nutrient concentration and that low ISC development and implementation of SCM retrofits may reduce the impacts of development on nutrient loading. The study sampling period was not sufficient to make conclusions regarding the accuracy of the SNAP 4.0 model.

II. Introduction

Located in the Upper Cape Fear River Basin of central North Carolina, Jordan Lake is a reservoir that provides drinking water for approximately half of a million people. The lake is also used for recreational activities and flood control, and serves as habitat for fish and other wildlife (Development of the Jordan Lake Nutrient Strategy, Jordan Lake Water Supply Allocation). Since it was impounded in 1983, Jordan Lake has experienced eutrophication and excessive algal growth, in part due to excess nitrogen and phosphorus in its water. In addition to creating a harmful anoxic environment for fish, this pollution also leads to odd tastes and odors in the
drinking water, resulting in higher water treatment costs. Eutrophication also poses the threat of decreasing the recreational value of lake. There has been one documented fish kill due to this eutrophication and the town of Cary has implemented chemical treatment in its drinking water process in response to decreased water quality (Development of the Jordan Lake Nutrient Strategy). Despite the nutrient limits that have been in place since the lake’s impoundment and legislative efforts to minimize nutrient loading, Jordan Lake continues to experience eutrophication (Development of the Jordan Lake Nutrient Strategy).

Jordan Lake’s waters have been declared as “nutrient-sensitive” since 1983 and have been consistently considered eutrophic or hypereutrophic, yet legislation to address the issue has not had a meaningful impact on the waterbody (Background). The Environmental Management Commission (EMC) placed “phosphorus limits on wastewater dischargers” in 1983, but the entire lake exceeded this standard in 2006, with the Haw River arm also exceeding the pH standard, another indicator of excessive nutrients used at the time (Development of the Jordan Lake Nutrient Strategy). Several pieces of legislation, including the Clean Water Responsibility Act of 1997, S.L 2005-190, and the federal Clean Water Act, required the EMC to implement “load reduction limits for point and nonpoint sources” (total maximum daily load) and management strategies for the sake of maintaining drinking water potability (Development of the Jordan Lake Nutrient Strategy). Local legislation includes House Bill 239 and its amendment, Senate Bill 838, passed in 2009. These pieces of legislation enacted a new Stormwater Management for Existing Development rule, called for local governments to create management programs to reduce nutrient loading from existing development, and set nutrient thresholds for new development. There was also language intended to protect existing riparian buffers as stormwater control measures (SCMs). However, this rule has not been actively implemented, which has stalled efforts to mitigate nutrient loading (Development of the Jordan Lake Nutrient Strategy).

Strategies to decrease eutrophication in Jordan Lake thus far have not been successful. Most strategies are expensive, with the cost of implementing the environmental rules estimated at one to two billion dollars (Kenney, 2013). One less expensive approach involving the installation of large underwater propellers known as SolarBees was implemented in 2013 in an effort to aerate the lake; however, this proved to be an ineffective bandage with no impact on incoming nutrients. The 36 SolarBees deployed in Jordan Lake were intended to use mechanical in-lake circulation to decrease algae levels, but the strategy was abandoned before
the full lease period ended due to the lack of results (Specht, 2016). Abundant resources have been devoted to developing strategies on remediation of the affected lake, but the apparent lack of results from this approach convey the need to focus more on the pollution sources and nutrient loading issues from the surrounding watershed. The SNAP (Stormwater Nitrogen and Phosphorous) v.4.0 model developed by the Nonpoint Source Division of the North Carolina Department of Environmental Quality (NCDEQ) hopes to achieve this by providing developers a tool to estimate nutrient levels and runoff for different urban land covers and stormwater control measures (NCDEQ, 2017). The model quantifies levels of nitrogen and phosphorus loading from the landscape before and after stormwater control measure implementation based on land cover and control measure metrics, but has not been extensively tested for accuracy. Increased research on nutrient loading from streams throughout the watershed and the effectiveness of different stormwater control measures is needed to understand the effect development is having on the water’s quality and inform potential mitigation strategies.

Nutrients come from a variety of sources, including sanitary sewer leaks, agricultural runoff, and stormwater runoff from nearby developed areas (Development of the Jordan Lake Nutrient Strategy; Urban Stormwater Management in the United States, 2009). Sewer leaks and agricultural runoff are easier to track and regulate while it is more difficult to gauge the impact urban runoff has on nutrient loads (Urban Stormwater Management in the United States, 2009). This gap in research makes it critical to gain more information on nutrient levels in urban streams that feed into Jordan Lake. Several researchers have found connections between development and nutrient loading to nearby watersheds (Brett et al., 2005; Schoonover, Lockaby, & Pan, 2005; Duan et al., 2012; Shields et al., 2008). As the Jordan Lake watershed has experienced development over the last three and a half decades, it is possible that this increase in urban land use, and thus impervious surface cover is contributing to the lake’s eutrophication.

Development increases the percentage of impervious surface cover in the Jordan Lake watershed, which may increase flow rates and the routing of nutrients to streams. Replacing the nitrogen sinks of soil and vegetation with impervious surfaces of roads and parking lots more effectively routes nutrients to bodies of water (Shields et al., 2008; Groffman, Law, Belt, Band, & Fisher, 2004; Duan et al., 2012). In comparing three Baltimore watersheds that varied in levels of impervious surface cover, Shields and a team of researchers found that areas with higher impervious surface cover exported the majority of their nitrogen during high-flow conditions.
They argued this was likely because roads are more effective than vegetation in routing urban sources of nitrogen to storm sewers that flow to waterways (Shields et al., 2008). Other researchers share similar findings on storm nutrient fluxes (Groffman et al., 2004; Duan et al., 2012). Areas with low impervious surface cover tend to export the majority of their nitrogen during low to moderate flow periods, experiencing fewer fluxes (Shields et al., 2008; Duan et al., 2012; Groffman et al., 2004). Urbanization changes the natural hydrology of a watershed, increasing nutrient exports by eliminating natural processes that would have absorbed the nutrients before they could reach the stream (Duan et al., 2012). Higher levels of runoff in areas with greater impervious surface cover create large and sudden pulses of nutrients during peak flows. These rapid peak flow pulses are more difficult to capture and treat than baseflow loading or moderate stormflow loading (Urban Stormwater Management in the United States, 2009).

The Jordan Lake watershed is experiencing a loss of vegetation from development, which is likely contributing to nutrient loading. Development removes a great deal of a landscape’s soil and vegetation, replacing it with impervious surface cover (Urban Stormwater Management in the United States, 2009). This causes watersheds to lose much of their naturally occurring water retention and evapotranspiration functions that prevent nutrients from flowing immediately into streams (Urban Stormwater Management in the United States, 2009). Development reduces subsurface water flow, which is typically over 90 percent in natural ecosystems and helps process nitrogen and phosphorus and prevent those nutrients from entering streams (Kaye, Groffman, Grimm, Baker, & Pouyat, 2006). Higher levels of forest cover in a watershed are also correlated with lower nitrogen and phosphorus exports (Beaulac & Reckhow, 1982; Basnyat, Teeter, Flynn, & Lockaby, 1999; Groffman et al., 2004). Groffman and a team of researchers found that in Baltimore, Maryland, nitrate concentrations in completely forested areas were ten times less than those in urban and suburban landscapes. This could be because there are both more sources of nutrient pollution and fewer nutrient sinks in urban and suburban areas. The team of researchers also found that the forested watershed retained 95 percent of nitrogen compared with the suburban watershed that retained 75 percent of nitrogen, highlighting the importance of soil and vegetation to absorb nutrients (Groffman et al., 2004).

The positive impact of vegetation is seen in the success of riparian buffers as a stormwater control measure. Natural riparian areas are a location for biogeochemical transformation for nutrients as they slow down flow and encourage infiltration. Eliminating these buffers alters the hydrology of the landscape in a way that prevents important biogeochemical
processes from taking place (Urban Stormwater Management in the United States, 2009). Maintaining riparian buffer systems around streams or establishing new ones is considered effective for controlling “nitrate in shallow groundwater moving toward streams,” removing potentially 90 percent of the nitrate inputs in the Inner Coastal Plain, but not as effective in areas where “water moves to regional groundwater” (Lowrance et al., 1997, p. 709). Jones and a team of researchers studied the correlation between types of landscapes and water quality, finding that nutrient yield scored lowest in areas where forest surrounded streams (Jones et al., 2001). Several other researchers have experienced similar findings, conveying the importance of vegetation as a nutrient sink (Karr & Schlosser, 1978; Yates & Sheridan, 1983; Lowrance et al., 1984; Cooper, Gilliam, Daniels, & Robarge, 1987). A loss of these buffers may be contributing to Jordan Lake’s eutrophication, and adding buffers could be an effective approach in the future.

Certain attributes of development are correlated with an increase in total available nutrients in a watershed. Development is associated with increased fertilizer use, which adds nitrogen to the watershed, as well as construction, which increases erosion that transports sediment-bound phosphorus (Law et al., 2004; Kaye et al., 2006). Law and a team of researchers found that in Baltimore, Maryland, 53 percent of total nitrogen inputs came from fertilizers. 62 percent of these residents applied fertilizer, but many did not know their lawn’s initial nitrogen content in order to make informed decisions on the amount to apply (Law et al., 2004). Kaye and a team of researchers found anthropogenic sources of nitrogen, including atmospheric deposition and fertilizer, account for over 90 percent of nitrogen inputs in Phoenix, Arizona (Kaye et al., 2006). While the conversion period from forested to urban land use has not been extensively covered, several researchers have found that this stage is positively correlated with very high nitrogen levels, possibly because recently developed urban areas undergo erosion that transports nutrients and because newer homes have higher nitrogen applications to compensate for less developed soil (Kaye et al., 2006; Schoonover et al., 2005; Law et al., 2004). As the Jordan Lake watershed has experienced new development over the last four decades, the reservoir’s eutrophication may be due in part to continually high nitrogen levels from erosion and fertilizer application.

To gain insight on nutrient loading for Jordan Lake and test the SNAP 4.0 model, we studied five sites in the Jordan Lake watershed that span a range of impervious surface cover and stormwater control measures. Metrics concerning land cover and stormwater control measures were calculated in ArcGIS for both our own data analysis and inputs into the SNAP
To determine the potential impact urban streams can have on nutrient loading to Jordan Lake, we analyzed water chemistry for major anions and specific conductivity and measured water level and flow at several sites with different aspects of urban development. We developed the following hypotheses:

**H1**: Nutrients (i.e. phosphorus and nitrogen) will be lower in urban streams with SCMs integrated into their watersheds than those without SCMs for similar levels of impervious surface cover, canopy cover, road density, and sanitary sewer density.

**H2a**: When looking at geologically similar urban watersheds, there is a positive correlation between metrics of urban development and nutrient loading.

**H2b**: When looking at geologically similar urban watersheds, there is a negative correlation between metrics of vegetation density and nutrient loading.

### III. Methods

**Site Selection Methods**

To test each hypothesis, four urban streams in Chapel Hill, NC that lie within the Jordan Lake watershed were chosen for hydrologic sampling. The four stream sites are Tanyard (TY), Tanbark (TB), Martin Luther King (MLK), and Burlage (BG). Burlage and MLK represent a nested sampling site since the MLK watershed falls inside of the boundaries of the Burlage watershed. Subtracting the MLK load measurements from the Burlage measurements allows us to estimate the loading for a third watershed which we refer to as Cole Springs (CS). The streams were chosen for their similarities and differences in urban densities and applications of stormwater control methods (SCMs) that allow for comparisons of nutrient loading and flow metrics (flow rate, number of peak flows above the 75th percentile) under different circumstances.

The sites all varied in the number and type of SCMs that are in use as well as the percentage of impervious surface cover (ISC), total area, parcel density, and percentage canopy cover present in the sub-watersheds where the streams are found (Table 1). A synoptic sampling method was carried out once a week for six weeks during the months of October and
November in 2017. These weekly data collections were typically performed on Fridays, but some collection dates vary for the Burlage site due to incorporation of data collected by the North Carolina Jordan Lake Nutrient Study (NCJLNS). The synoptic method was used to create paired data that can be easily compared and tested for significance.

Table 1: Urban Metrics for Each Stream Site

<table>
<thead>
<tr>
<th>Watershed ID</th>
<th>Watershed Area (ft²)</th>
<th>% ISC</th>
<th>Parcel Density</th>
<th>% Area Paved Road</th>
<th>SCMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>TY</td>
<td>9154499</td>
<td>47.26%</td>
<td>2.729</td>
<td>10.20%</td>
<td>0</td>
</tr>
<tr>
<td>TB</td>
<td>5342414</td>
<td>42.68%</td>
<td>2.313</td>
<td>6.99%</td>
<td>15</td>
</tr>
<tr>
<td>BG</td>
<td>16256360</td>
<td>14.58%</td>
<td>0.910</td>
<td>4.38%</td>
<td>11</td>
</tr>
<tr>
<td>MLK</td>
<td>1714763</td>
<td>24.45%</td>
<td>0.967</td>
<td>3.62%</td>
<td>11</td>
</tr>
<tr>
<td>CS</td>
<td>14541597</td>
<td>13.38%</td>
<td>0.903</td>
<td>4.47%</td>
<td>0</td>
</tr>
</tbody>
</table>

Field Sampling Methods

Flow velocity (m/s) was collected using the Marsh McBirney flow sensor over even intervals across the width of the stream. Parts of the stream where flow was visually observed and the water lacked leaf litter and other debris were sought out for that measurement. Stream depth at each flow interval was also recorded during velocity measurements. Two grab samples were taken per data collection and syringe filtered in the field through a 0.45 mixed cellulose filter. With each grab samples water temperature and specific conductivity was measured using a YSI Scientific 556 handheld multisensor. As to not disturb grab sampling and YSI, streamflow measurements were taken downstream from the grab site. Specific conductivity was used as a metric for contaminant loading which allows for easier comparison of total ions in the water. All grab samples were labeled by stream location and stored in a freezer to ensure sample preservation until data analysis could be run. At TY, BG, and MLK a HOBO U20 water level sensor was employed by the North Carolina Jordan Lake Nutrient Study as well as a HOBO U24 conductivity sensor at BG and TY and a s::can spectro::lyser at BG to measure nitrate concentrations. These devices set up by the NC JLNS take continuous measurements and were set up before the start of this experiment. Previous data obtained from these sensors was used when needed as well as current water level data and some conductivity measurements.
Data Analysis Methods

During field sampling, timestamped measurements for temperature and specific conductivity were collected using a YSI probe. Channel width was measured with a tape measure, and at 10 cm intervals depth and velocity were collected using the Marsh McBirney Flo-Mate 2000 Flow Meter. Cross-sectional area was calculated by multiplying the channel width by the channel depth. To calculate the flow rate of the stream, the average velocity in meters/second was multiplied by the cross-sectional area in square meters. After receiving the nutrient analysis from our grab samples, the load was calculated for each nutrient by multiplying the concentration of the nutrient by the flow rate on that particular day.

For each site, the median, average, standard deviation, and variation was collected for temperature, specific conductivity, channel width, average depth, cross-sectional area, mean velocity, flow rate, and the load of each nutrient. Correlations between each of the observational variables were also calculated.

Grab samples were run through a Shimadzu total carbo/total nitrogen analyzer to determine concentrations of total nitrogen (TN). A Dionex IC-2000 was used to measure nitrate ($\text{NO}_3^-$) and phosphate ($\text{PO}_4^{3-}$). Other ion concentrations found in grab samples such as $\text{Cl}^-$, $\text{Br}^-$, $\text{F}^-$, $\text{Mg}^{2+}$, and $\text{Ca}^{2+}$, were recorded if present in significant quantities and are used as a measure of urban impact because they are most often a byproduct of human activity.

Flow rate, stream depth, and stream width intervals from Marsh McBirney measurements were used to calculate streamflow (Q) for each data collection. Subsequently those values were used to calculate total load (TL) for each stream as well as total load per area (TL/A) of the watershed once the area was calculated using GIS.

Generalized linear models with regression values were performed to analyze the statistical significance behind various hydrologic and geographic factors such as nitrate concentrations, nitrate load, mean specific conductivity, % ISC, % canopy cover, and other variables that are given in the results.
Significant findings allowed for analyses on the impact of urbanization on nutrient export. The 75th percentile from water level data was calculated for each of the three stream sites with water level sensors, Tanyard, MLK, and Burlage. These percentiles were used to count the number of water level peaks above that point in order to gain insight into frequency of extreme peak flow events as a function of % ISC. This is a metric of the flashiness of flow for the given sites with a larger number representing greater sensitivity to rainfall events. A hydrograph of water level over time was made to analyze how amount of rainfall relates to flow and nitrogen presence over a range of % ISC. A box plot of nitrate concentration as a function of % ISC and a box plot of total dissolved nitrogen for all four sites with additional plot points for SNAP v.4.0 model predictions for comparison were added. This provided insight into how the predictions determined using SNAP v.4.0 compares to the nutrient measurements taken during field research. Boxplots showing all nutrients and other dissolved constituents obtained during grab sampling were also created for each site in order to supply an added visual comparison of nutrient loads as a result of varying urban metrics.

GIS and SNAP v.4.0 Methods

Using ArcMap 10.5, individual watersheds were delineated for the Tanyard, Tanbark, Burlage and MLK (at UNC Facility Services) study sites with the TauDEM tool set as part of the NC JLNS. The percentage and area of forested land in each watershed was calculated two ways using NLCD mapping and aerial orthographic imagery. Using a 30 meter resolution 2011 NLCD map, canopy cover within each watershed was calculated by summing the area of the classes for Evergreen Forest, Deciduous Forest, Mixed Forest and Woody Wetland. Using 2016 aerial orthographic imagery obtained from NC One Map, canopy cover was also calculated through classifying images based on raster pixel color representing tree cover. Canopy cover percentage calculated from orthographic imagery was used in calculations because of the low resolution of the NLCD map made for a significantly less accurate representation of canopy cover. Parcel density and average parcel size were calculated within each of the watersheds by counting the number of county land parcels with any part in each watershed; however, only the area completely within the study site boundaries was used for analysis. Parcel density is a metric of development intensity where more parcels per area represent a greater density of housing in the residential areas that make up most of our study watersheds. Parcel data was provided by Orange County, NC. SCM data for the Tanbark site was provided by the city of Carrboro, NC and SCM data for the MLK site was provided by Sally Hoyt, P.E. of UNC Facility
SNAP v.4.0 requires a number of land cover and stormwater control metrics to run. These include the area of rooftops, roads, sidewalks, parking lots, driveways and area forested for land cover metrics. It also requires inputs for SCM size, area of drainage to each SCM and the area of each of the aforementioned land cover metrics within each SCM drainage area. All areas were converted to square feet for each site. Using planimetric impervious surface cover (ISC) files provided by the towns of Chapel Hill and Carrboro, the total area of land as well as the total area occupied by roofs, paved roads, and an amalgamation of parking lots, driveways and sidewalks were calculated individually for each watershed to be input into the Land Cover Characteristics section of the SNAP model. Other pervious surface cover such as cemeteries, airstrips and unpaved driveways were delineated manually and collected for input into Land Cover Characteristics of SNAP. Only the area of these features directly within the boundary of each subwatershed was used for measurements. Dominant hydrologic soil type, as well as specific SCM effluent retention values, were determined through information provided by the NCDEQ Nonpoint Source Planning division in the SNAP 4.0 manual. Annual precipitation for the SNAP model was determined using the closest 1981–2010 US Climate Normals Station as provided by the National Center for Environmental Information. The Nutrient Management Strategy Watershed Map provided by the Nonpoint Source Planning division was used to determine the Nutrient Management Watershed and subwatershed as well as nitrogen and phosphorous delivery zones of Jordan Lake as classified in the SNAP v.4.0 model. A North Carolina geologic survey map provided by the NCDEQ was used to determine the physiographic regions of the four sites as a model input including geological parameters controlling flow and loading.

IV. Results

Land-cover

Land-cover statistics represent a wide range characteristic of urban areas (Table 1). Among the study watersheds, ISC ranged from 13% ISC to 47% ISC. Parcel density was positively linearly correlated to %ISC ($R^2=0.93$). The percent road area ranged from 3.62% to 10.20% and accounted for 14.8 – 33.4 % of the total ISC with the largest portion of ISC being roads at the least densely developed watershed, Cole Springs. The number of SCM’s ranged
from 0 at Tanyard Branch to 15 at Tanbark Branch. There was no correlation between the number of SCMs and watershed development metrics among study sites. Canopy Cover ranged from high levels of 68% at Cole Springs and 63% at Burlage (Cole Springs + MLK) to as low as 22% at Tanyard, revealing a negative linear correlation between parcel density and canopy cover ($R^2=0.50$).

**Table 2: Calculated Land Cover Metrics**

<table>
<thead>
<tr>
<th>Watershed ID</th>
<th>Canopy Cover</th>
<th>Area Draining to SCMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>TY</td>
<td>21.75%</td>
<td>0%</td>
</tr>
<tr>
<td>TB</td>
<td>27.95%</td>
<td>49.98%</td>
</tr>
<tr>
<td>BG</td>
<td>63.22%</td>
<td>6.96%</td>
</tr>
<tr>
<td>MLK</td>
<td>26.00%</td>
<td>84.56%</td>
</tr>
<tr>
<td>CS</td>
<td>67.61%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

**Nutrient Concentration**

The Tanyard watershed, which had high ISC and no SCMs, had the highest average TN concentration and the greatest range in values (Figure 1). The MLK watershed, which had moderate ISC and high implementation of best management practices (11 SCMs) had intermediate TN concentrations with little variability. The Tanbark watershed, which is located right next to Tanyard and had nearly as much ISC by percent, but also had high SCM implementation (15 SCMs) had the second lowest TN concentrations with little variability. Burlage, being the least developed with SCMs in the MLK portion of the watershed, had the lowest TN concentration on average as well as a much smaller range than Tanyard.
Very little data was collected on phosphate concentration due to its low concentration relative to nitrate and the analytical method used; however, existing phosphate data was available from the JLNS for Tanyard and Burlage. Tanyard had mean phosphate concentration 7 times greater than Burlage. The variability at Tanyard was also greater (Figure 2).

**Figure 1:** Boxplot of total dissolved nitrogen in ascending order of % ISC for all four sampled watersheds.

**Figure 2:** Boxplot of phosphate concentration as a function of % ISC for Burlage and Tanbark. No phosphate data was retrieved for Tanyard or MLK.
Hydrology

Hydrographs of water level over the study period for Tanyard, Burlage, and MLK show that Tanyard and MLK had a greater response in event flows than Burlage (Figure 3,4,5). The Burlage stream also tended to have higher base-flow water levels. Burlage and MLK had seven peak flow events exceeding the 75th percentile of water level, a metric of hydrologic flashiness, and Tanyard had eight (Figure 3,4,5).

Figure 3: Hydrograph for Tanyard showing water level as a function of time during the six week collection period.
Figure 4: Hydrograph for MLK showing water level as a function of time during the six week collection period.
Figure 5: Hydrograph for Burlage showing water level as a function of time during the six week collection period.

Water levels were low during the period of study, with Tanbark’s flow being often too low to measure reliably. Flow measured at base-flow during weekly sampling ranged from 0 to 0.0093 cu m/s. Burlage had the highest mean flow (0.0082 cu m/s) followed by MLK and Tanyard (both 0.0021 cu m/s) with Tanbark having the least flow (0.0003 cu m/s).

**Nutrient Loading**

The MLK watershed had the highest mean nitrate load (Figure 6, Table 1) followed by Tanyard, then Burlage and finally Tanbark. Patterns in nitrate loading differ from nutrient concentration significantly due to the relatively low flow at Tanbark and relatively high flow at Burlage.

![Nitrate Load](image)

**Figure 6:** Boxplot of nitrate load in order of ascending %ISC for four sampled watersheds.

**Chemistry**

Specific conductivity was used as another metric of stream contamination. A boxplot compares this to % ISC (Figure 7). Mean specific conductance was similar across all streams, however Tanyard and Tanbark had higher mean specific conductance than MLK and Burlage.
Burlage had a very large range that encompassed MLK and went far lower than the other sites.

![Specific Conductivity of Site Locations](image.png)

**Figure 7:** Boxplot of specific conductivity as a function of % ISC for all four sites.

**SNAP model predictions**

In order to compare the SNAP v4.0 predictions to measured nitrate, the mean concentration prediction was compared to measured values in boxplots (Figure 8). The predicted nitrogen values for Tanyard, Tanbark, MLK and Burlage were respectively 8.86, 2.55, 3.5 and 5.6 lb/ac/yr.
**Figure 8:** Boxplot of total nitrate concentration as a function of % ISC for all four sites. Additional plot points are for SNAP v.4.0 model predictions.

An additional boxplot with total nitrogen concentration as a function of % ISC with SNAP v.4.0 predictions was created to compare each of the four sites (Figure 9). Tanyard again had the highest mean TN concentration as well as the largest range in data points. The trend from the previous graph is almost identical to this one, with Burlage having the lowest mean concentration. SNAP v.4.0 predictions are slightly more accurate for TN than nitrate. The SNAP v4.0 model successfully predicts that Tanyard will have the highest NO3 and TN concentration, however it does not match the pattern observed by the other three sites.
Linear models

Linear regression models for single variables and multiple variables were run in order to determine which land cover metrics were significant predictors of nutrient concentration, nutrient loading and hydrologic metrics (R Core Team, 2017). Since only four stream sites were tested (as well as one which was extrapolated for; Cole Springs) during the experiment a p-value of 0.1 or less was used to determine significance. Adjusted R² values and slope estimates were also noted. The % area entering SCMs was a highly significant predictor of total nitrogen concentration (slope= -0.282, adjusted R²=0.95, p=0.003). Watershed area was a significant predictor for total nitrogen concentration (slope=1.48e-08, adjusted R²=0.54, p=0.097). Stormwater control measures per unit area of the watershed also served as a highly significant predictor for total nitrogen concentration amongst the sub-watersheds (slope= -3.92e-04, adjusted R²=0.86, p=0.014). When doing multiple linear regressions % canopy cover and watershed area together were the only significant predictors of total nitrogen concentration (slope_canopy= -5.08e-1, slope_area=3.06e-08, adjusted R²=0.87, p=0.067). Parcel density was significant in predicting specific conductivity (slope=35.16, adjusted R²=0.75, p=0.038) as well as the % paved road (slope=1209.35, adjusted R²=0.85, p=0.016). The only multiple linear regression that showed significance for predicting mean specific conductivity was a combination of parcel density and the % canopy cover (slope_canopy= -94.29, slope_parcel=51.80, adjusted R²=0.98, p=0.008). The only significant finding was a multiple variable model including % ISC, % canopy cover, and SCMs per unit area predicting nitrate concentration (slope_ISC= 1.19e+01, slope_canopy= -1.18e+01, slope_SCMs= -4.78e+05, adjusted R²=0.10, p=0.040).

Figure 9: Boxplot of total dissolved nitrogen concentration as a function of % ISC for all four sites. Additional plot points for SNAP v.4.0 model predictions.
V. Discussion

The results indicate that SCMs, canopy cover and ISC are important drivers of nutrient concentration, supporting our hypotheses. The Tanyard watershed, which was covered 47% by impervious surfaces, and the Tanbark watershed, which had a 42% impervious surface cover, had similar land use characteristics and levels of development due to their geographic proximity, but differed in application of stormwater control measures and nutrient concentrations. Tanbark had 15 individual stormwater control measures, while Tanyard had zero. While these SCMs are small, this study indicates that the retrofitting high density urban areas with SCMs may be able to significantly reduce in stream nutrient concentration. A conclusion for phosphate cannot be made because there was not enough data collected to perform statistical analyses.

The results suggest that canopy cover reduces nutrient concentration and ISC increases concentration. Tanyard had the highest percentage of impervious surface cover at 47% and the highest nitrate concentration, while Burlage had the lowest percentage of impervious surface cover at 14% and the lowest nitrate concentration. Neither of these sites had stormwater control measures, allowing us to infer that a relationship between impervious surface cover and nitrate concentrations is related more to the anthropogenic land use over other factors. The curtailed hydraulic conductivity of the impervious land cover promotes runoff and nutrient loading rather than soil leaching that would ordinarily occur under conditions untouched by human activity and development. As the infiltration capacity of the land within the watershed falls, the volume of stormwater runoff increases. This finding upholds hypothesis H2, suggesting that there is a positive correlation between metrics of urban development and nutrient loading, along with a negative correlation between metrics of vegetation density and nutrient loading.

Urban development mitigates the amount of vegetation that buffers nutrient loading in runoff. Thus, as urban development increases, filtration from vegetation decreases; the effects of which may be compounded by the fact that increased ISC also results in quicker more efficient deposition of nutrients from landscapes into bodies of water. As a side effect to the pervasiveness of impervious surface cover, less water is capable of infiltrating into groundwater reservoirs, exacerbating the effects we incur from increasingly strengthening droughts due to climate change. While we looked at nitrate loading as a metric for water quality that is
particularly relevant to Jordan Lake’s eutrophication issues, direct stormwater runoff has to potential to deliver many contaminants that may be harbored on the surface of the runoff flow path. Vegetative buffers may also help to reduce the loading of metals, pesticides and even garbage that effect aquatic life and water quality as well.

Values for predicted nitrogen concentration obtained using the SNAP model were higher at each of the four study sites not including Cole Springs, as depicted in figure 9. However, the model did project Tanyard significantly higher than the other three study sites, a projection to be expected from the site with the highest impervious surface cover and no SCMs. The SCMs played a large role in SNAPs projections, as predictions for Tanbark and MLK were the closest to actual nitrogen and phosphorous levels. The high percentage of canopy cover at Burlage also played an important role in nutrient predictions. The SNAP model predicted higher nutrient concentrations for the Burlage watershed than the MLK watershed. Although the Burlage watershed contains the MLK watershed, it has higher canopy cover and lower %ISC and so it is not surprising that we measured lower nutrient concentrations. This may highlight the effects of instream nutrient removal processes that are not accounted for in the model or the model’s difficulty accounting for pervious flow paths.

Errors and Limitations

Our findings were impacted by unusually low precipitation during our sampling period, resulting in reduced runoff from the landscape with generally low flows in the streams throughout the sampling period. Our results did not provide confident estimations of total nitrogen loading due to the low flow during the period of study. We found that nutrient concentrations were lowest at the Tanbark site which also had the lowest flows. The long residence time of stream flow during this period likely contributed to these low concentrations and may have confounded the investigation of SCMs. Since the stream sites all had fairly low flow velocity, it is possible that the Marsh McBirney measurements were also somewhat inaccurate because the stream velocity were often near the sensors detection limit. A comparison of these results with measurements taken over a longer period of time, under more normal precipitation and streamflow conditions would provide a more comprehensive composite of the watershed.

The few number of sites in this study limited our ability to do statistical analyses or graphical evaluations of much of the data. Since there was no suitable location for a water level
sensor at the Tanbark site, a hydrograph could not be created and water level and peak flow could not be compared with the other sites.

There were a number of assumptions in the SNAP inputs that could have potentially skewed the results of the model. The model is designed to predict the future impact of implementing new SCMs during development of a site, making backtracking calculations for already installed SCMs difficult. It is a valuable tool for future designing, but difficult to parameterize from existing landscapes. The model also produces annual outputs base on annual precipitation values. Abnormally low precipitation during our 6 week sample period leads us to believe that annual values of nitrogen in our sampled streams would be higher than those values we extrapolated out of our 6 weeks of data. This is because the model deals with annual storm fluxes, which we were not able to capture in our data in our short sampling period. Furthermore, the SNAP model is designed for development in small sites, making values significantly less reliable with less impervious surface cover, as it becomes harder to predict nutrient loading from pervious and vegetated surfaces.

Finally, it was a very difficult and an error prone process to delineate drainage areas from Digital Elevation Models for individual SCMs. The MLK and Tanbark sites have high levels of development, and as a result, the landscape is highly anthropogenically modified. Through the construction of sewers, drains, retaining walls and more, flow paths in these landscapes are no longer strictly dictated by the elevation of the landscape, and we did not have the resources in this study to sufficiently conduct onsite appraisals.

**Recommendations**

Our results lead us to recommend that urban planners strive for low ISC development and that SCM retrofits be more widely considered in high density urban areas. However, the short period of study and lack of replication requires us to recommend that future research look at the impact of stormwater control measures on nutrient loading for a full year so that data can be interpreted for an annual range. Since the data that was collected was during a time period with low flow, it would be valuable to see whether the observations that were found in our research would hold during times of higher flows or through the growing season. It would also be helpful to replicate the experiment for a full year in another geographical location similar to the Jordan Lake Watershed so that both sites can be compared and contrasted. More stream sites within the watershed should be chosen so that there are enough data points available for
linear regression modeling and other data analysis methods. Further testing of the SNAP v.4.0 model is also needed in order to determine the efficacy of its predictions with a wide variety of urban land use characteristics.

VI. Conclusion

Over the course of three months, our study gathered data on nutrient loading in Tanyard, Tanbark, MLK, Burlage, and Cole Springs watersheds in order to study the effect of urbanization on the Jordan Lake watershed. It was particularly important to study the loads of nitrogen and phosphorus because they are leading contributors to eutrophication, which is causing uninhabitable environments for fish and aquatic vegetation and endangers drinking water sources. Comparing these nutrient levels with different land use metrics including % ISC, % canopy cover and stormwater control measures allowed for analysis of how land use and SCMs can influence nutrient concentration which should correlate to nutrient loading.

Our findings from these sites suggest that there is a positive correlation between metrics of urban land development (namesly %ISC) and nutrient loading and predict that with increasing urban development in watersheds, nutrient loading will continue to increase. We can also conclude that use of stormwater control measures may reduce nitrogen concentrations, but due to the lack of robust data, it would be important to look more closely at the stormwater control measures that were used and their effectiveness over a longer course of time. Looking at these details would also allow for greater optimization of the SNAP v.4.0 model, which consistently overestimated nitrogen loading at each of our sample sites. We hope that further research is conducted in the Jordan Lake watershed to gather more robust analyses to not only help solve Jordan Lake's eutrophication issue but provide management solutions that can help protect waterbodies from rapid urbanization worldwide.
Sources


