Relationships among *Escherichia coli* (*E. coli*), Total Suspended Solids and Flow for Three Northern Virginia Subwatersheds: Rabbit Branch, Upper Accotink Creek, and Daniels Run

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Summary

This project was designed and completed to satisfy the requirements for the M.S. Program in Environmental Science and Policy at George Mason University. Three sites located in Fairfax, Virginia residential areas were chosen to monitor *Escherichia coli* concentrations between May 18th and July 19th, 2013 and to examine the relationship of *E. coli* to stream flow, total suspended solids (TSS) and impervious cover. Each site was visited a total of 9 times during the study period.

Analysis of data from these sites indicated that they are not meeting the Virginia Department of Environmental Quality (VDEQ) standard of 235 CFU/100 mL for *E. coli* in recreation streams. The range for *E. coli* over all three sites was 78 - 19,100 CFU/100 mL. There were also nine samples in which the levels were above the range of the test procedure (>20,000 CFU). This study also suggested that *E. coli* may respond to increased impervious cover, TSS and rainfall; however, due to a high degree of variability most of the relationships were not significant. Visual examination of the watersheds indicate that there are multiple potential upstream non-point sources including human and animal activity that could contribute to elevated *E. coli* levels.

Because these sites are in violation of state water quality standards, it is imperative that the County and City Storm Water Planning Divisions further investigate and devise plans to fulfill the purpose of the Clean Water Act. Two of the three sites, Daniels Run and Rabbit Branch, could benefit from projects that have been proposed.

Introduction

Under the Clean Water Act (CWA) of 1972, water quality monitoring in Fairfax, VA is conducted by the state and local governments to ensure that the integrity of navigable waters is maintained. Under this regulation, protection of recreation in and on the water, as a designated use, is very important to support human health. Furthermore, the Virginia Department of Environmental Quality (VDEQ) water quality standards expect VA waters to be suitable for all designated uses specified by the CWA, which are "recreation, fishing, agricultural, public water supply, and the propagation of fish and shellfish" (Annual Report, 2012). Over several years, there has been concern for the presence of *Escherichia coli (E. coli*) in Virginia's waterways at levels that constitute a danger for contact recreation. *E. coli*, an indicator of human and animal waste, can arise from a variety of point sources and non-point sources in residential, urban, and forested areas. Due to the difficulty in managing *E. coli* to levels that remain below the VDEQ geometric mean standard of 126 CFU/ 100 mL or the instantaneous standard of 235 CFU/100 mL for freshwater, hundreds of Virginia surface waters are on the "impaired list" in DEQ's section 303 (d) report as required by the Clean Water Act (Annual Report, 2012). This poses a great risk to the public that may come in contact with these impaired waters directly and indirectly. As the water from these streams flows to larger bodies of water, such as the Chesapeake Bay, the risk to public health becomes more of a concern. But, it is imperative that *E. coli* monitoring of recreational streams be conducted to determine if streams are meeting the VDEQ standard. Preliminary research on *E. coli* in streams has found that storm run-off, total suspended solids (TSS) and impervious cover can have significant effects on its behavior.

According to multiple studies, TSS and *E. coli* have a positive relationship, similar to the relationship of *E. coli* with rainfall. Malin *et al.* (2008) compared water quality results from both wet and dry sampling periods and found that all three of their sites (urban, suburban and rural) had higher TSS and fecal coliform concentrations during wet periods. These correlations are commonly found in other studies as well as a significant relationship between TSS and fecal coliform. Sediment often serves as a method of transport for *E. coli* (Malin *et al*. 2000), but Desai and Rifai (2010) argue that land use plays a role in defining that relationship. The results from their study showed two of the four sites of interest had a significant relationship between TSS and *E. coli* due to their urban location. Oregon streams showed similar relationships between TSS and *E. coli* and rainfall and TSS (Anderson and Rounds, 2003).

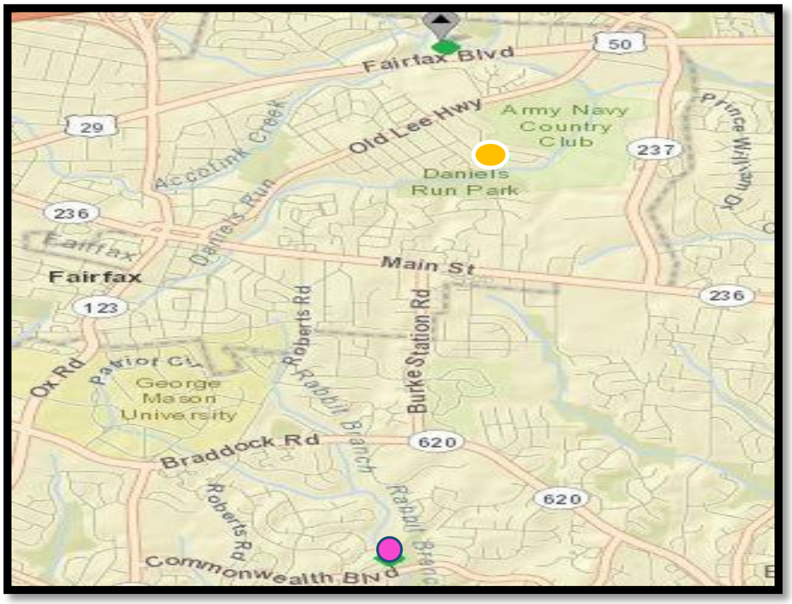
Several studies show linkages between levels of *E. coli* in water sources and the percentage of imperviousness which is manifest in surrounding roads, sidewalks, driveways, and bridges (Hat *et al*., 2004). Malin *et al.* (2000) provides evidence of a linear relationship between the geometric mean concentration and percent impervious cover of estuarine creeks draining residential areas (p=.005). When rain hits impervious surfaces, it may carry animal waste, nutrients and other pollutants with it until it reaches its destination. Several studies take storm events or storm run-off into consideration when looking at *E. coli* concentrations in streams because of these nonpoint source contributions. The findings from these seminal studies laid the foundation for this Master’s Research project.

Purpose and scope

In this report, the findings from a three month long *E. coli* monitoring project of three streams, Accotink Creek (Ranger Road Park), Rabbit Branch, and Daniels Run, are discussed. The data will be examined to understand any correlations between total suspended solids, imperviousness and *E. coli* as well as potential threats to public health. Over the past years, the state took action to improve the water quality of Fairfax streams. Watershed management plans were created in compliance with Fairfax County's MS4 permit for all 30 watersheds after a baseline study of the streams were conducted in 1999 (Accotink WMP, 2011). All plans have three common goals, which include improving the water quality and protecting human health (Accotink WMP, 2011).The plans for these watersheds were created between 2010 -2011 and include recommendations for hundreds of projects that extend over a 10-25 year period.

The objectives of this research were 1) to understand the relationship between *E. coli* and TSS at each site, 2) determine if there is a significant relationship between *E. coli* and rainfall at Site B, and 3) determine the impact of imperviousness on *E. coli* concentrations in three Fairfax County/City, VA streams.

Description of Site Areas



Graphic 1: Map of three study sites, pink circle (Rabbit Branch), yellow circle (Daniels Run), green circle (Accotink Creek-Ranger Road)

All three sites, Rabbit Branch, Accotink Creek-Ranger Rd. and Daniels Run are located in parkland surrounded by residential areas in Fairfax, Virginia with similar characteristics and comparable drainage areas.

Site A. Rabbit Branch

Rabbit Branch, is a tributary of Pohick Creek in the Pohick Creek watershed. The stream drains 3.95 square miles, including most of the George Mason University main campus. The stream was sampled in a forested residential area at Crooked Creek Park located just upstream of Commonwealth Drive. The area was accessible from the street and access to the site was regularly mowed, but there was no sign active public use near the stream. From observations of the site, the stream banks were eroded and incised. Located in the south central part of the county, the watershed drains into the Potomac River similar to sites B and C. Currently, there are not any existing or pending *E. coli* TMDLs for Rabbit Branch.

Site B. Accotink Creek-Ranger Road Park

The second site in this study was located in the upper reaches of the main stem of Accotink Creek located in Fairfax City. The sample site was sited in Ranger Road Park, which is located in a forested residential area. The watershed for this site has a drainage area of 3.99 square miles. This stream flows into Lake Accotink, Accotink Bay, Potomac River and then the Chesapeake Bay. This is the only site in this study that is continuously monitored by USGS for pH, temperature, flow, dissolved oxygen and turbidity.

Accotink Creek, one of the largest watersheds in Fairfax County, has been scrutinized closely since it was listed as an impaired water in 1998. The EPA attempted to restore the quality of Accotink Creek by establishing a TMDL for storm-flow (Kobell, 2013). The rationale was that change in storm-flow dynamics induced by increased impervious cover was causing excess sedimentation. However, the TMDL was ruled to be invalid by U.S District Court in Alexandria on the rationale that the CWA does not allow for water to be treated as a pollutant. Under the CWA, a pollutant is specifically defined as “dredged soil, solid waste, incinerator residue, sewage…industrial, municipal and agricultural waste”, which led to a successful lawsuit against EPA blocking the TMDL (USEPA, 2012). Although this case did not involve discussion about *E. coli* pollution, it provided understanding of some of the water quality issues Accotink Creek is suffering from. As of 2002, the TMDL for Crook Branch, another Accotink Creek subwatershed above Lake Accotink was determined to be1730 BCFU (Bacterial colony forming units) /yr, Another TMDL is scheduled for development for a third Accotink Creek subwatershed, Long Branch, in 2020 (VDEQ, 2012). As of now, there is not a TMDL that covers the location of the Accotink Creek – Ranger Rd. study site.

Site C. Daniels Run

Daniels Run, a subwatershed of Accotink Creek, is a shallow stream that flows from the Fairfax City Hall area through Daniels Run Park. Daniels Run drains 1.9 square miles and is one of the main Accotink Creek tributaries within the City of Fairfax, VA. The site for sampling was located between the Army Navy Country Club and single family homes at the end of St. Andrews Drive. A few years ago, the stream underwent a restoration project that focused on limiting sediment inputs and erosion. This project came after the 2002 stream assessment ranked 50% of Daniels Run “very poor” or “fair” (Stream Assessment, 2005). Water quality is of high importance in this stream as well because it flows to the Potomac River and ultimately the Chesapeake Bay.

Methods of Study

Three independent sites in proximity to George Mason University were selected. A total of 9 water samples were collected at each respective site, (A) Rabbit Branch, (B) Accotink-Ranger Road, and (C) Daniels Run, on a fixed sampling schedule. Because it was a wet year, some samples were collected at base flow and some at elevated flows. Water samples were collected weekly, generally on Fridays (except June 8th) beginning May 18th 2013 and ending July 19th 2013 using sterile 3.84 L polypropylene Nalgene collection bottles for each site. The bottle was lowered just beneath the surface of the stream (facing upstream) until the bottle was filled and was placed in the ice chest and returned back to the lab for analysis. The time of sampling and the weather the day prior and the day of was recorded/noted in a lab notebook. Three glass fiber filters (Whatman 984AH) were prepared for the total suspended solids (TSS) EPA filtration method 160.2 in the lab before sample collection.

All glassware, twenty-seven 100mL polypropylene dilution bottles, three 3.84 L sample bottles and MI agar media was autoclaved prior to use. A total of 30-35 *E. coli* plates were made no more than two weeks in advance and three dilutions in triplicate were made for each site as described in MI Agar EPA method 1604. Plates were kept in sealed plastic bags in the refrigerator prior to use. All samples were filtered through a 47 mm round 0.45 µm pore size gridded filter in the lab and incubated at 35^{o}C for 22-24hr (Oshiro, 2002). The following day, each blue colony on the plate was counted and recorded. The average concentration for each dilution at each site was computed, converted to CFU/mL using the formula *E. coli*/100mL= (#blue colonies/vol. H_20 filtered in mL) x 100 and the lowest rounded averages were used for SPSS analysis.

After *E. coli* filtration, EPA method 160.2 for TSS filtration was completed by filtering 200-500mL of water from each site through the filter prepared before going into the field. After 24 hrs of drying in the oven, the filter was weighed and the filterable residue (mg/L) was calculated using the formula [dried filter/foil (g) - before drying filter/foil (g)] / volume filtered (L) x 1000.

Results

Watershed imperviousness and average values of water quality parameters for each of the sites are given in Table 1. This table serves as a summary of the data obtained during this research project and reflects the similarities and differences amongst the three sites.

Site attributes	Site A Rabbit Branch	Site B Accotink Creek Ranger Road	Site C Daniels Run
Drainage Area	3.99 sq. miles	3.95 sq. miles	1.9 sq. miles
Latitude/longitude	38°49'7.68" 77°17'42.00"	38°51'58.47", 77°17'10.98"	38°51'10.00" 77°16'46.00"
% imperviousness	27.8%	35.2%	25%
Average *E. coli* (CFU)	165.1 2.2 (log)	2275.1 2.4 (log)	487.6 2.3 (log)
Average TSS (mg/L)	6.2	5.3	38.4
Average Flow (CFS)	n/a	1.94 (8hr) 4.14(12hr)	n/a

Table 1: Characteristics of each site including percent imperviousness, average *E. coli*, average TSS, lat/long, and average flow for specified periods prior to sample collection at Site B. In addition to arithmetic mean, the geometric mean (log base 10) was computed for *E. coli*. The latitude and longitude information was obtained from Google Earth and waterdata.usgs.gov.

During the sample period of May 17^{th} - July 19^{th}, it rained more than 50% of the days prior to the sample day. However, averages discharges for the 8 and 12 hr periods prior to sample collection were not indicative of high flow conditions (Table 2).

Date	After 12hr discharge (cfs)	After 8hr discharge (cfs)	Rainfall previous day/sample day (in)
May 17th	1.5	1.4	T/0
May 25th	1.6	1.5	0.01/0
May 31st	1.4	1.4	0/0
June 14th	3.5	2.5	0.02/0.02
June 22nd	1.5	1.6	0/0
June 28th	1.4	1.4	0.23/2.86
July 4th	5.2	4.6	0.15/0
July 11th	2.9	1.9	0.57/0
July 19th	1.3	1.0	1.04/0

Table 2: 8 and 12 hour discharge measurements (preceding sample day) of Site B-Ranger Road (USGS) stream from May 17th-July 19th and rainfall measurements from the previous day and day of sampling from the National Airport website.

Table 3 lists the *E. coli* and TSS values for each date per site. There were two sample days at Site A (July 11th and July 4th) on which *E. coli* could not be recorded due to an excessive number of colonies even at the highest dilution. Both dates corresponded to higher flows (Table 2). Excluding these dates entirely from analysis, the average at Site A was lower than Site B and C.

	Site A			Site B			Site C		
Sample Date	***E.Coli* (CFU/100mL)**	**TSS (mg/L)**	**Log *E.coli***	***E.coli* (CFU/100mL)**	**TSS (mg/L)**	**Log *E. coli***	***E.coli* (CFU/100mL)**	**TSS (mg/L)**	**Log *E. coli***
May 17th	78	3	1.90	84	2.5	1.90	41	6	1.60
May 25th	183	11.5	2.25	149	4.5	2.17	1890	79.5	3.27
May 30th	142	6.5	2.14	166	6.5	2.23	144	6.5	2.14
June 14th	238	13.5	2.38	19100	10	4.28	191	238	2.27
June 22nd	143	4	2.14	106	8.5	2.02	84	7	1.90
June 28th	242	1.8	2.38	196	2.8	2.29	141	1.6	2.14
July 4th*	tmtc	4	-	470	7	2.67	1137	2.6	3.05
July 11th	tmtc	7.62	-	105	3	2.02	730	2	2.86
July 19th	130	3.8	2.11	100	3.2	2.0	30	2.2	1.47
averages	170	6.19	2.20	2280	5.33	2.39	490	38.37	2.30
α	r=.391	w/out 2 dates:			r=.639	r =.712		r=.083	
	r^2=.153	r=.430			r^2=.408	r^2=.508		r^2=.007	
	ρ=.336	r^2=.185			ρ=.064	ρ=.037		ρ=.832	

Table 3: *E. coli* (rounded), TSS, and Log *E. coli* at each site on each date. Pearson correlation coefficient (r), ρ value (alpha=.05) and r^2 are shown for TSS-*E. coli* correlation based on 9 samples days (except for Site A) by site. tmtc = too many to count, corresponds to >20,000 *E.coli* CFU/100mL.

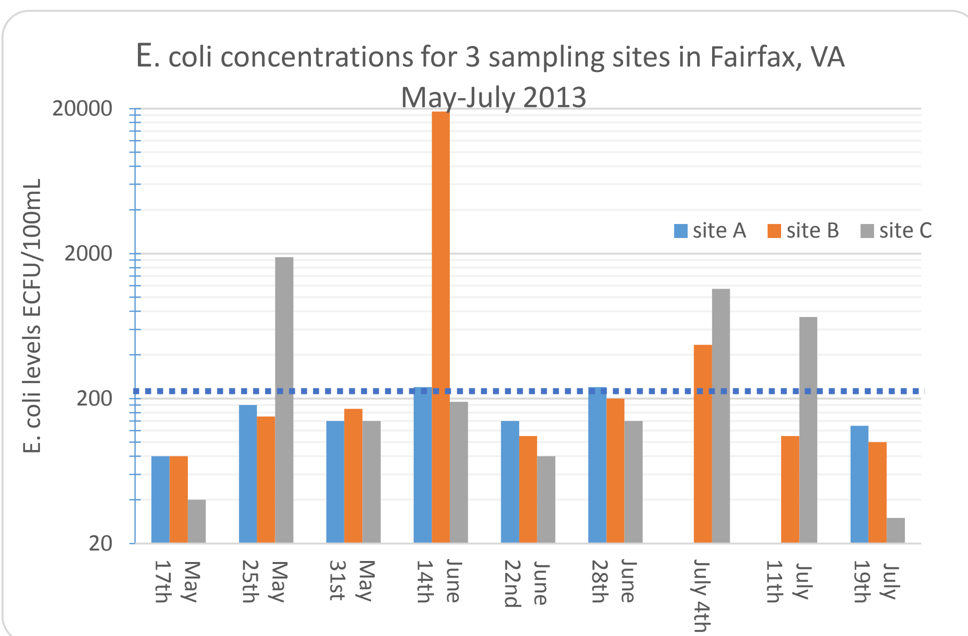


Figure 1: Bar graph of the three sampling sites by date to show the differences in *E. coli* concentrations. The sites are color coded and the blue horizontal line represents the 235 CFU/100mL standard for recreational waters.

From May 10th to July 19th, 27 samples were collected but only 25 were used for excel and SPSS analysis. The first analysis looked at the *E. coli* samples of each site to determine if there were any significant differences among sites. Using the ANOVA test (site vs. avg. *E. coli*), it was determined that the sites were not significantly different (ρ =.435), which is consistent with the results in Table 1.

As shown in Figure 1, majority of the samples were below the instantaneous standard of 235 CFU/100mL. The instantaneous standard was used instead of the geometric mean 126 CFU/100mL standard because there were only three samples per month. There were four sample days (May 25th, June 14th, July 4th and July 11th) where some sites exceeded the water quality standard for *E. coli*—however, all three sites never exceeded the standard on the same day. On June 14th, Site B greatly exceeded the standard and was the highest concentration (19,100 CFU/100mL) out of all 25 samples that could be quantitatively evaluated. There were two samples from Site A that exceeded the standard but were "tmtc", indicating that they were above 20,000 CFU/100mL. The average *E. coli* concentration for each site was 165 (Site A, n=7), 2275 (Site B, n=9), and 487 (Site C, n=9) CFU/100mL.

The *E. coli* and TSS concentrations for each site (Figures 2-4) underwent a correlation and regression test which determined that there was a low correlation between the two variables and no significance. Figure 2 represents all seven samples for Site A and produced non-significant results. However, after one apparent outlier in the data set was removed, the correlation was improved ($r = .920$) and the relationship was significant at $\alpha = .05$ ρ=.019. Site B (Figure 3) had a relatively strong correlation ($r = .630$) driven mostly by one high value (19100

CFU/100mL), but there was no significance at α= .05. There was essentially no relationship between *E. coli* and TSS at Site C (Figure 4).

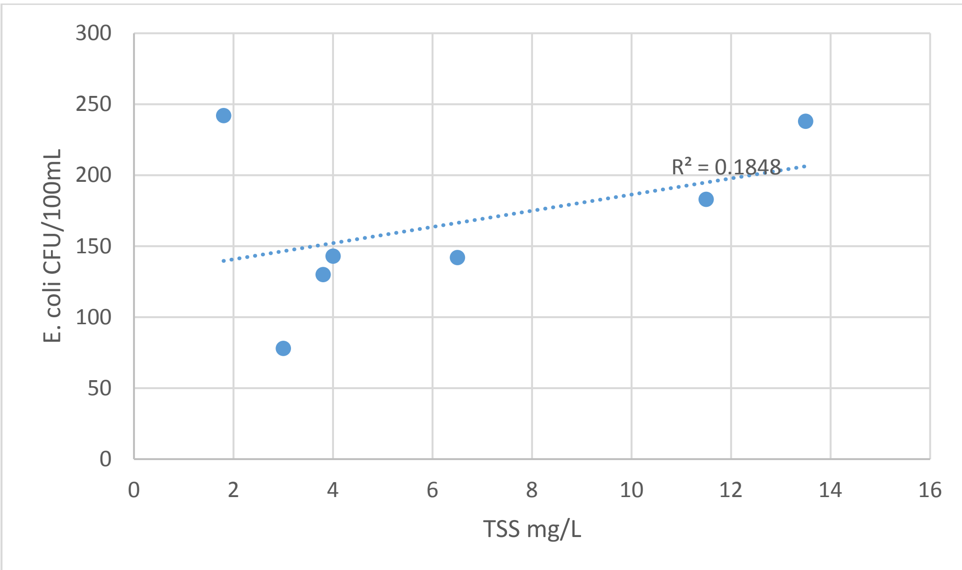


Figure 2: Site A- *E.coli* (CFU/100mL) vs TSS (mg/L), n=7 (two samples were noted as tmtc and excluded from the analysis)

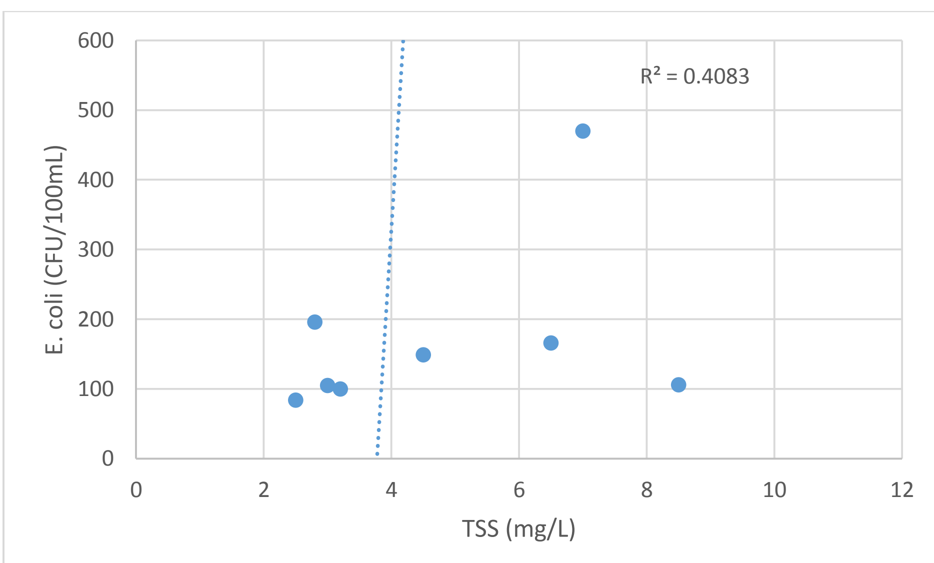


Figure 3: Site B-*E. coli* (CFU/100mL) vs TSS (mg/L), n=9 (data point *E. coli*=19100, TSS=10 not shown)

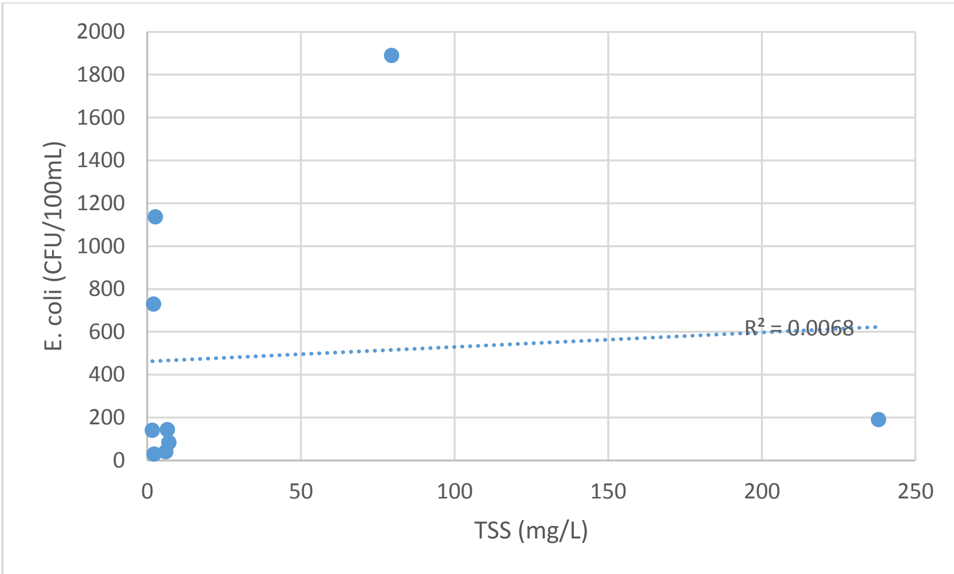


Figure 4: Site C-Relationship between *E. coli* (CFU/100mL) vs TSS (mg/L), n=9

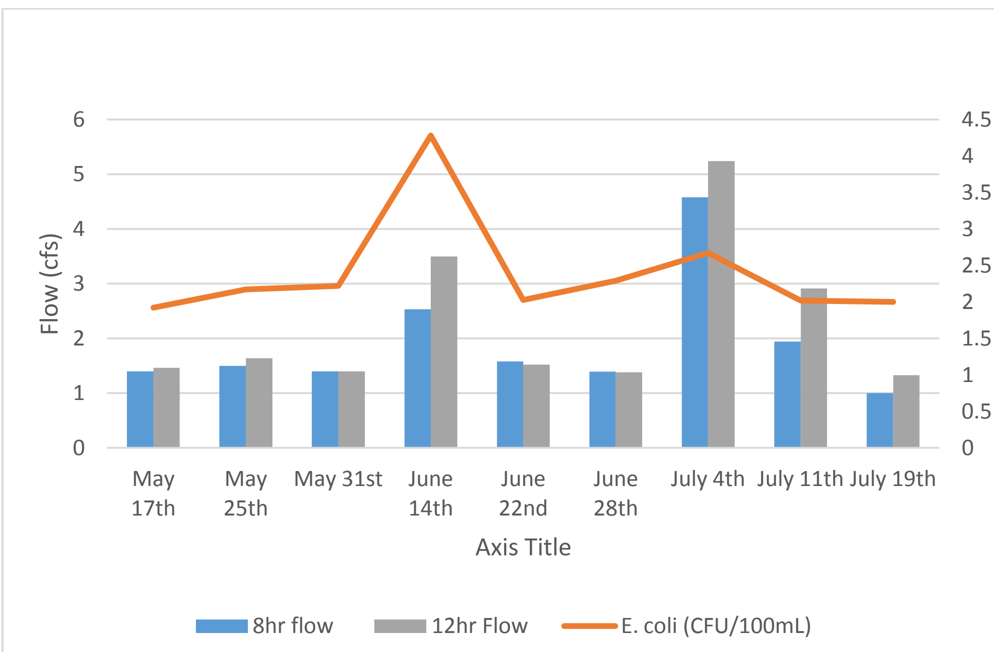


Figure 5: Relationship between flow and *E. coli* log10 concentrations at Site B on the 9 sample days. Blue bars represent the 8 hr average flow (ft^3/s), the grey bars represent 12 hr average flow, and the orange line represents the *E. coli* levels (CFU/100mL).

The flow (discharge) data from site B was obtained from the USGS website that manages that site. Since this was the only site with this data available, it was used to show the effects of rain events on *E. coli* concentrations throughout this project. Each sampling day, the weather on the day prior to and the weather on the day of sampling was recorded, along with the time. Based the day and time of sampling, 8 hour and 12 hour flow averages were calculated using the data available. These averages were paired with the *E. coli* log10 concentration averages for that day. The *E. coli* concentrations were converted to log10 to improve the readability and analysis. The flow vs. log *E. coli* graph in Figure 5 indicates a positive correlation (8hr r =.444, 12hr r =.536) but no significance (α =.05, p =.231 and .136). Although the correlation was not significant, the graph shows some apparent response of *E. coli* to increased flow such as the peaks on June 14th and July 4th (Flow = 4.1 cfs and log *E. coli* = 2.67 log CFU/100mL). Also Table 3 shows the TSS (7 mg/L) was slightly above average for that day as well. On that same day, the other sites had similar responses. The *E. coli* concentration for site A was “tmtc” and site C was 1137 CFU/100mL, both of which were substantially above the average and the standard.

A multiple regression analysis was performed on the flow data (8hr) and TSS data (independent variables) and *E. coli* (dependent variables) for site B to determine which variable was more closely related. Both independent variables were not significant. However when the dependent variable was converted to log 10 *E. coli*, the TSS and *E. coli* had a significant relationship (p= .037, r = .697α= .05).

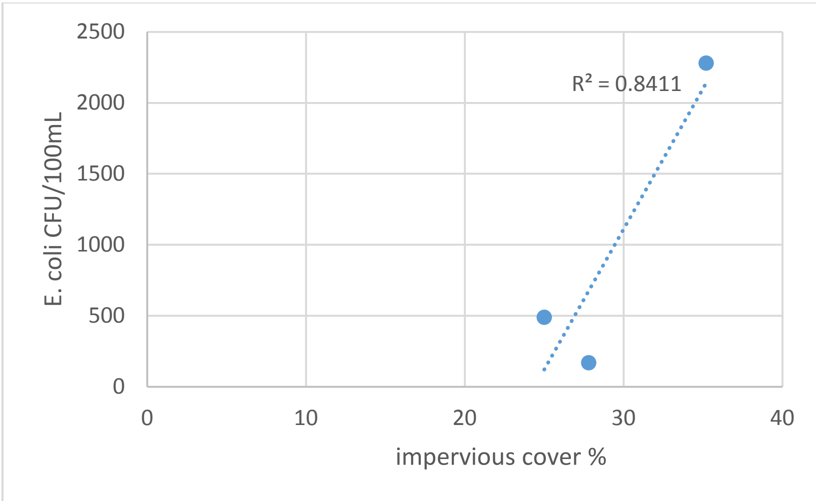


Figure 6: Relationship between average *E. coli* (CFU/100mL) and percentage of impervious cover (%) for each site (r2= .8411). Site A average *E. coli* does not include "tmtc" readings.

In addition, the impervious cover percentage for each watershed was correlated against the average log *E. coli* concentration (Figure 7). Since this study only looked at three sites, there was not sufficient data to conduct ANOVA or multiple regression analysis for all the variables (TSS, flow, and *E. coli)*. However, the graph reflects a positive correlation between impervious cover percentage and average *E. coli* concentrations; as impervious cover increases the *E. coli* concentration increases ($r = .679$, $r^2 = .463$).

Discussion

The results from this study indicate that these sites are not meeting the VDEQ *E. coli* water quality instantaneous standard of 235 CFU/100mL. The future projects and watershed plans designed by the county make it evident that Fairfax is vulnerable to stream water quality issues including sediment, runoff and *E. coli*. Although the results from this study do not provide definitive results linking high *E. coli* concentrations, rainfall, and TSS, there are suggestions of these relationships and the results clearly indicate impairments of water quality that constitute a threat to public health.

The first objective of this study was to understand the relationship between *E. coli* and TSS at each of the three sites. A positive relationship between *E. coli* and TSS was observed for all three sites, but only site A was significant and then only after removing one apparent outlier. Although there was not a clear positive trend for site C, there was a direct relationship for site A and B and it was reflected in the higher Pearson coefficients. This relationship which was observed at all three sites supports the concept that TSS can have an effect on *E. coli* and draws our attention to the importance of reducing erosion and run-off which can contribute to TSS and pollutants in streams.

Site A (Rabbit Branch) was the only site with samples that had unreadable *E. coli* plates and these two samples were subsequently excluded from the analysis. Because this site had higher *E. coli* levels compared to the others it became important to investigate the reasons. Based on the averages, it appeared that Site A had lower *E. coli* levels when actually it would have been higher if "tmtc" was quantifiable. There are several possible reasons of why this site had higher concentrations. First, the summer season was very rainy. Although it may not have rained the day of sampling, it could have rained a few days before and contributed to this result. But aside from these possibilities, the site is in a forested area with a lot of vegetation and space for animals to inhabit. Other nonpoint sources such as wild animals and dogs and run-off from George Mason University could have contributed to those results. Since the stream is in a residential area—surrounded by roads, buildings, sidewalks and other impenetrable surfaces—impervious cover could be a primary nonpoint source of *E. coli* found at this site. The impervious cover percentage determined by the County was 27.8% and is around the same figure as the other two sites (Pohick Creek Workbook, 2008).

Although there isn't a current TMDL project for this specific site, the county has proposed a "best management practices/ low impact development" project for a nearby site to address some of the storm run-off issues nearby (Pohick Creek WMP, 2012). The project location site is west of the Laurel Ridge elementary school (located on Commonwealth Blvd.) and will begin this year. According to the management plan, the project includes "bioretention landscaping" and the "installation of bioswale" that will help control and filter storm run-off (p.5-63). This will help to protect the stream from pollution and *E. coli* over time. In the meantime, there are biorentention facilities in the Pohick watershed that were designed to reduce stream erosion and improve water quality. These types of facilities are designed to slow down storm flow into water bodies and reduce pollution (Pohick Creek WMP, 2012). It is difficult to know if the facilities are efficient because there is not a flow monitoring station at this site to analyze the effects of flow on *E. coli*. This study was limited to the flow data obtained from USGS for Site B.

Although there isn't a TMDL developed for Rabbit Branch there are two being developed for Pohick Creek in 2018 and 2024 (VDEQ, 2012) . This stream reach is located downstream from Site A and actually begins at the confluence of Sideburn and Rabbit Branch. It is probable that Pohick Creek is impaired at least partially due to pollution from Rabbit Branch.

The two outliers in the data for Site B caused the *E. coli* average at Site B to be the highest compared to the other sites. The positive relationship between log *E. coli* and TSS at this site was strong and significant ($p= .037$ $\alpha=.05$). Converting the concentrations to log10 *E. coli* improved the correlation and made the data significant. The average for TSS (5.3 mg/L) was lower than the other averages. Looking at each respective date, seven of the nine samples were below the *E. coli* standard for Virginia. However, since the sample size was nine, it only took one sample above 235 CFU/100mL to make it non-compliant. In the Accotink watershed management plan, there are several impaired water-bodies. Although, there isn't an existing *E. coli* TMDL for this part of the watershed, there are several forthcoming TMDL's including the Long Branch, Bear Branch and Crook Branch sub-watersheds which are all downstream from Site B (Accotink Creek WMP, 2012). The TMDL was developed after the county did a bacteria source tracking (BST) study that identified the sources of fecal contamination. Although it is difficult to track non-point sources, it is probable that impairments of downstream waters such as Crook Branch could be from upstream contamination. With the help of the county's bacterial monitoring program through organizations and universities, this stream should be under investigation for an *E. coli* TMDL. The city currently has a water quality monitoring contract with George Mason University's Potomac Environmental Research and Education Center under the Director, Dr. Chris Jones, for four sites in the upper Accotink Creek watershed. This type of partnership could help increase sampling and monitoring over the year, allow for a more in-depth study, and possibly help with future decision making.

In 2005 a stream physical assessment was done and found that 26% of Accotink Creek was in a "poor" condition (Stream Assessment, 2005). This assessment was a supplement to the stream protection study in 2001 which looked at the health condition of each stream in all of Fairfax watersheds (Stream Protection Study, 2003). The study assessed the health conditions of each stream based on a set of 16 different metrics including sediment deposition and channel flow status. According to the plan, the reach in which Site B is located has been listed for impairment due to the general standard for benthic macroinvertebrates since 2008 and is scheduled for a TMDL in 2020 (Accotink Creek WMP, 2012). Although this is not directly related to *E. coli*, it sheds light on the other water quality issues which Accotink is facing.

The results of Site C were somewhat consistent with the results of the other sites except that the average TSS was abnormally high (38mg/L). The average was elevated due to two dates (May 25th and June 14th) that had a TSS value of 79 and 238 mg/L, respectively. The second value was the highest TSS value throughout the study. In the past, several studies and restoration projects were created for Daniels Run. The most recent study is a three part project with one objective to address stream erosion near Daniels Run Elementary School (Feasibility Report, 2013). The project site will be upstream from Site C and could improve the stream's water quality if the proposed plan is executed. Although Site C looked stable, there is always a possibility of sediment and pollutants flowing downstream and impacting water quality. The large stormwater pond located upstream could be another source of sediment and pollutants if not properly controlled. When factors such as runoff and impervious cover are considered, it helps to understand the cause of stream erosion and the overall integrity of the streams.

From the results of this study, we know that discharge and *E. coli* are closely related. This relationship not only helps to clarify the behavior of *E. coli* and TSS due to rainfall (either the day before or day of), but it can help with storm water management in these watersheds. Site B was the only site with USGS flow monitoring and therefore it was the only site used for analysis of flow and *E. coli*. As shown in Figure 5, the *E. coli* levels responded to the 8hr and 12hr flow for each day. Although the correlations ($r = .536$ (12hr), $r = .444$(8hr)) were not significant ($p = .136$, $p = .231$ α=.05), the trend helped to show the effect of rainfall on *E. coli*. The peaks on June 14th and July 4th reflect the flow that occurred 8 and 12 hours before sampling. Interestingly, the TSS data for those days were also higher, which supports previous studies (i.e Malin 2008) findings on the behavior of TSS, *E. coli* and discharge. The other two sites also had higher *E. coli* and TSS levels for those two days. However, there were some sample days that did not have a clear response even though it rained 8-12 hr before-hand. One example of this is the data for Site B on May 25th. Compared to the other two *E. coli* levels, 149 CFU/100mL is very low. But, after looking at the 8hr and 12hr flow data for that day and comparing it to the other rain dates mentioned above, it is evident that it rained more on June 14th and July 4th. This shows the dependency which *E. coli* can have on rainfall. However, Site C responded differently. Both the *E. coli* and TSS concentrations on May 25th were very high, which was consistent with the higher flow concentrations. At Site A, however, some of the days of higher flow had lower *E. coli* levels and vice versa. The differences in results show that watersheds are unique in how they respond to rainfall and there are a number of explanations. One possible reason for lower concentrations is due to dilution from the heavy flow in the stream (USGS, 2003). But also each watershed has different characteristics including vegetation buffers, imperviousness, and morphology which can often be a good measure how much pollution or run-off the stream may receive. These characteristics, whether big or small, can make a big difference in how a stream is impacted.

Identifying the relationship of imperviousness and average *E. coli* concentrations for each watershed was the final objective of this study. As stated earlier in this report, impervious cover can be detrimental to a stream's water quality. The Pohick Creek and Accotink Creek Workbooks (Pohick Creek Workbook, 2008; Accotink Creek Workbook, 2008) discussed the implications of imperviousness in their management plans and are aware of the relationship between storm run-off and *E. coli*. The feasibility study for Daniels Run recognized that the stream's degradation was due to the land development of the watershed overtime and illustrated how impervious cover can change the hydrologic cycle (Feasibility Report, 2013). From this study, the results supported that *E. coli* concentrations are dependent upon impervious cover (r^2= .841, r = .917).

The impervious cover percentages (range: 25-35.2%) for each site were obtained from the Accotink and Pohick watershed plans and used in the analysis. The percentages represent the entire sub-watershed and were used because they appeared to be valid approximations. The calculations were done during the stream protection strategy baseline study using GIS (Accotink Workbook, 2008).

With population growth on the rise, it will be challenging to control the construction of new homes, offices, and roads. Therefore, storm run-off will reach these streams faster. To address these challenges, three organizations are collaborating on a multi-year project to investigate the effects of development, impervious cover and run-off, amongst other issues. (Annual Report, 2012).

The county and city are aware of the conditions of these streams and they are taking action to mitigate the ongoing contamination problems. Ultimately, the goal is for these streams to meet the *E. coli* standard and all of the designated uses for VA waterbodies. Even though the new assessment will not address *E. coli* or fecal contamination directly, the findings and future plans could still help reduce levels in the future since storm-flow is a non-point source.

Conclusions

The findings from this study show that the three sites (Rabbit Branch, Accotink Creek, and Daniels Run) are exceeding the Virginia water quality standard for *E. coli* in recreation streams. This study suggested that *E. coli* responds to increased impervious cover, TSS and rainfall. However, most of the relationships were not significant. These results are not as conclusive as previous studies; however, this study was only 9 weeks long. A longer study with possibly more sites could yield more definitive results. There were other limitations in this study. There was flow data only for Site B, which didn't allow for direct comparisons between flow and *E. coli* at the other sites. Based on the area of the subwatersheds it was assumed that flow at each site would respond similarly to Site B. In coming years, it would be beneficial for the county to invest in flow monitoring for Site A and C since they have high *E. coli* levels.

Unlike other studies, this study didn't fully support the theory that TSS is a transporter of *E. coli*. The correlations showed that there was some dependency, but the non-significant findings for Site A and C suggest that these streams may receive direct inputs of *E. coli* most likely from wildlife animals and dogs. If this is the case, then several projects that the county has underway to restore the streams and address stream erosion, may not be as beneficial in lowering *E. coli* at these study sites.

It may be difficult to control wildlife waste in forested areas, but the county may want to consider some possibilities since this is most likely the primary source of *E. coli*. But in the meantime, the storm water management approach will be the best option for these streams. If assumptions about flow vs. *E. coli* are true for Site A and C the upcoming projects for Daniels Run and Rabbit Branch might help in curtailing the *E. coli* levels.

Another area that will be difficult to control is land development and imperviousness. This study and several others confirm the relationship between impervious surfaces and pollutant delivery to streams, but realistically population growth and development will continue. But vegetation along the stream banks serve as great buffers against pollutants like *E. coli* (Feasibility Report, 2013).

These sites should continue to be monitored as projects are proposed and completed. It will be important to know the effects on *E. coli* levels in the stream and if the changes can improve current conditions.

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