An Evaluation of Fecal Coliform Bacteria Concentrations Up- and Downstream of the Irwin Creek and Sugar Creek Wastewater Treatment Plants in Mecklenburg County, North Carolina, 1998-2001

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Fecal coliform bacteria cause water quality problems for many urban areas across the United States. The objective of this study is to determine if the Irwin Creek and Sugar Creek wastewater treatment plants, located near Charlotte in Mecklenburg County, North Carolina, contribute significantly to the fecal coliform concentrations in the creeks. Fecal coliform densities in the wastewater effluent discharged from wastewater treatment plants were compared to the concentrations downstream of the facilities, and downstream bacterial levels were compared to the bacterial levels upstream of the facilities. Mann Whitney Sum Rank test suggests that the Sugar Creek and the Irwin Creek wastewater treatment plants are not contributing to elevated fecal coliform bacteria levels. Furthermore, linear regression analysis reveals that the stream flow does not have an effect on the fecal coliform concentrations at the sampling sites.

Introduction

Urban development can affect surface waters by increasing the amount of microorganisms from wastewater treatment plants (Fisher et al., 2000). According to the United States Geological Survey (2001), the main point source for bacterial pollutants is wastewater treatment plant outfall, the location where water is released into the receiving stream. States report that the effluent released from the wastewater treatment plants is the second major source of water quality impairment (Copeland, 1999).

The North Carolina water quality standard for fecal coliform states that fecal coliform concentrations should not exceed an average of 200 colonies/100mL from at least five consecutive samples analyzed within a 30 day period, nor surpass 400 colonies/100mL in more than 20 percent of the samples tested during certain a time period (North Carolina Department of Environment and Natural Resources, 2003). Little Sugar Creek and Irwin Creek were listed on the 2000 North Carolina 303(d) report for exceeding the fecal coliform bacteria standards (NCDENR, 2000). Pollution in these streams is primarily fecal coliform bacteria released with wastewater discharge (NCDENR, 1999)

The threat of bacterial contamination increases in areas where there is under-treated or untreated wastewater. High levels of fecal coliform bacteria and possibly other pathogenic microorganisms are present in untreated wastewater. The presence of these bacteria in streams indicates that the water has been contaminated with human or other warm-blooded animals. Elevated amounts of fecal coliform bacteria have been correlated with the presence of disease causing agents in the water, which could endanger the health of those individuals who are exposed to it (USGS, 2001).

Mecklenburg County's source of drinking water came from Sugar Creek during the late 1800s. The drinking water source was changed to Irwin Creek in 1904, because the water quality conditions in Sugar Creek were decreasing due to improper collection and disposal of waste. As a result of an extreme drought, Irwin Creek was unsuccessful in providing drinking water for the city of Charlotte. Although some Charlotte residents were on septic tanks in the early 1900s, the majority lacked adequate sewage disposal. Therefore, the residents dumped the raw sewage directly into the streams. Two wastewater treatment plants were built in 1927; one next to Little Sugar Creek and the other along the Irwin Creek.

In addition to the dumping of raw sewage from the local residents and businesses, Little Sugar Creek and Irwin Creek were receiving improperly treated wastewater from the wastewater treatment plants. The bacteria amounts measured in the streams were considerably high thus making them unsuitable for human contact. The fecal coliform concentrations in Mecklenburg County's urban streams are much lower today than in the past, but these streams continue to have bacteria counts that exceed the North Carolina standard (Mecklenburg County Department of Environmental Protection, 2000).

Charlotte wastewater treatment plants are the largest dischargers in the city (North Carolina Department of Environment and Natural Resources, 1999). The effectiveness of any wastewater treatment plant in removing the fecal coliform bacteria is highly dependent on the quality of treatment that it provides (George et al., 2002). It is common for some tributaries in the Sugar Creek sub-basin to experience increased bacteria concentrations during non-storm periods, which suggests that point sources, such as wastewater treatment plants, are major contributors to the high fecal coliform bacteria concentrations (North Carolina Department of Environment and Natural Resources, 1999). Wastewater treatment plants are expected to prevent streams from receiving fecal contaminates, however, there continues to be increased concentrations of these bacteria.

There have been several studies conducted that compared the fecal coliform concentrations upstream and downstream of wastewater treatment plants to determine if wastewater treatment plants influence the fecal coliform concentrations entering surface waters. A study conducted by Vilanova et al. (2002) in Barcelona, Spain revealed that there was a 2-log reduction in the fecal coliform concentrations between the raw sewage and the upstream and downstream sites. Beck (1995) indicated that wastewater effluent not properly treated can influence the fecal coliform concentrations downstream of the treatment plant. Hoch et al. (1996) suggested that wastewater influx influenced the downstream levels close to the outfall, and decreased with distance from the influx of the sewage treatment plant, which indicated rapid dilution of the discharged effluent.

The purpose of this study is to determine if the Irwin Creek Wastewater Treatment Plant and Sugar Creek Wastewater Treatment Plant contribute significantly to the fecal coliform bacteria concentrations in the receiving streams. This study provides an understanding of the association between wastewater treatment plants and fecal coliform levels by answering the following questions: (1) Is there a significant statistical difference in bacteria levels upstream and downstream of the wastewater treatment plants? (2) Is there a significant statistical difference between the downstream site and the effluent released into the streams? (3) Is there a significant correlation between the fecal coliform concentrations at the three sites and stream discharge?

Study Area

Mecklenburg County is located in the South Central Piedmont region of North Carolina. The county is separated by two river basins, the Catawba and the Yadkin (See Figure 1). Streams located in the western two-thirds of the county normally flow in a southwest direction towards the Catawba River. Irwin Creek (IC) and Little Sugar Creek (LSC) drain into Sugar Creek, which empties into the Catawba River five miles south of Fort Mill, South Carolina.

The study includes two sampling sites on each of the two streams and the Sugar Creek and Irwin Creek wastewater treatment plants (See Figure 2). Site MC32A is located along Little Sugar Creek at Archdale Drive, which is approximately 1.05 kilometers (0.65 miles) downstream from the Sugar Creek wastewater treatment plant. Site MC29 is positioned near Park Road about 1.05 kilometers (0.65 miles) upstream of the Sugar Creek wastewater treatment plant. The MC22A sampling site is located on Irwin Creek roughly 0.19 kilometers (0.12 miles) upstream from the Irwin Creek Wastewater Treatment Plant. Site MC23A is located near Arrowood Road nearly 10.73 kilometers (6.67 miles) downstream from the Irwin Creek wastewater treatment plant. This site is located on Sugar Creek. Irwin Creek

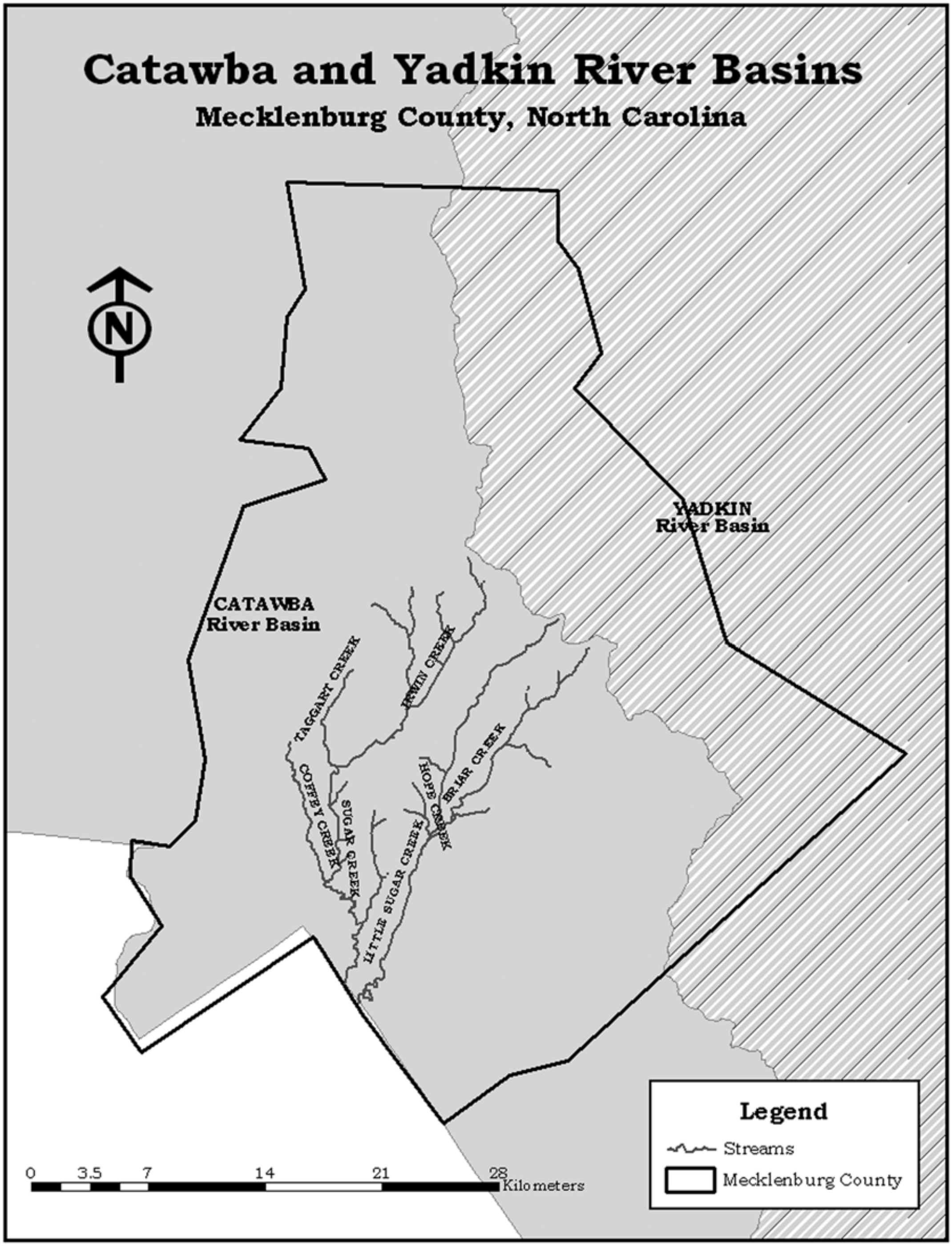

Figure 1. Mecklenburg County's River Basins

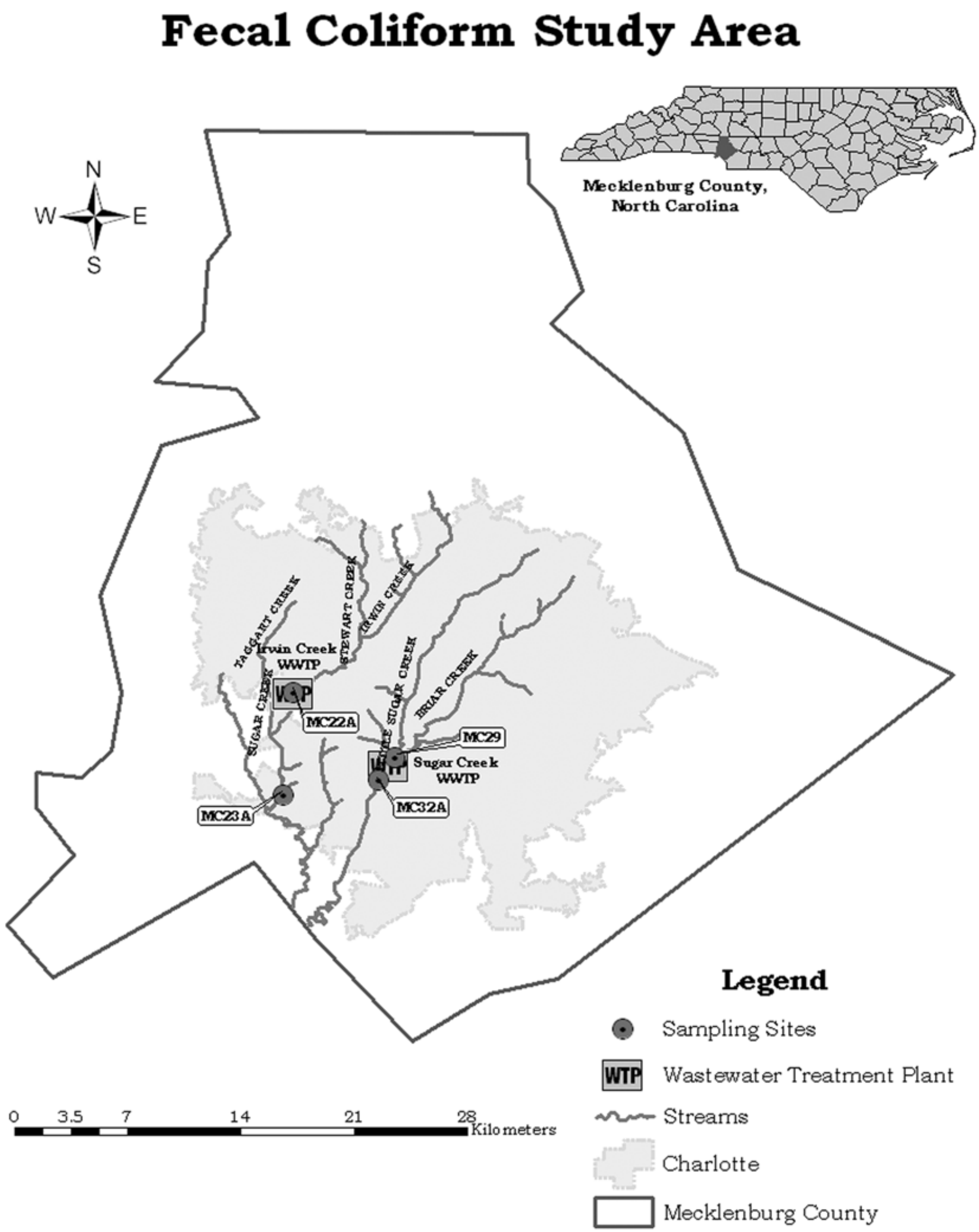

Figure 2. The locations of the stream sampling sites and the wastewater treatment plants

empties into Sugar Creek approximately 1.37 kilometers (0.85 miles) downstream from the Irwin Creek Wastewater Treatment Plant (See Table 1).

These streams drain most of the urbanized areas and are reported to have the worst water quality in Mecklenburg County (Ferrell, 2001). Little Sugar Creek is surrounded predominately by residential neighborhoods with a small amount of wood/brush and commercialized areas. Irwin Creek is surrounded mainly by wood/brush and commercialized areas with a small portion of residential neighborhoods (See Figures 3 and 4).

Methodology

The samples used in this study were collected and processed by the Mecklenburg County Department of Environmental Protection Environmental Laboratory (Mecklenburg County Department of Environmental Protection, 2000). Stream samples were collected randomly four to six times a year after at least 72 consecutive hours of dry weather as part of the phase one requirements for the city of Charlotte National Pollutant Discharge Elimination System Permit. Mecklenburg County Department of Environmental Protection assigned the site names and numbers and the prefix MC signifies that the sites drain into the Catawba River basin.

The daily average stream flow rates were obtained from the United States Geological Survey gauges located at or near the sampling sites (See Figure 5). There are stream flow gauges at the Little Sugar Creek downstream site (Little Sugar Creek at Archdale Drive 02146507) and Irwin Creek upstream site (Irwin Creek near Charlotte, NC 02146300). There were no USGS stream flow gauges positioned at the LSC upstream site or the IC downstream site, therefore the closed gauges were used to obtain the stream flow. The LSC upstream flow rates were obtained from the gauge located along Little Sugar Creek at Medical Center Drive at Charlotte, NC (02146409), and the IC downstream rates were obtained from the gauge positioned on Sugar Creek at NC51 near Pineville, NC (02146381).

A unique Fecal Coliform Membrane Filtration Technique, which is a combination of several methods, was used to analyze the grab effluent samples for fecal coliform. The calculation method for the fecal coliform densities was the same as in the 9222B.6 Total Coliform Membrane Filtration Procedure from USEPA Standard Methods (Eaton and Greenberg, 1999).

Table 1. Sampling Site Locations and Distance from WWTP

Site Number	Site Name	Latitude	Longitude	Distance From WWTP
MC32A	Little Sugar Creek at Archdale Drive	35.1478N	80.8579W	1.049 km 0.6524mi
MC29	Little Sugar Creek at Park Road	35.1599N	80.849W	1.049 km 0.6524 mi
MC23A	Irwin Creek at Arrowood Drive	35.1391N	80.911W	10.725 km 6.6642mi
MC22A	Irwin Creek at WTTP	35.1964N	80.9056W	0.199 km 0.1242 mi

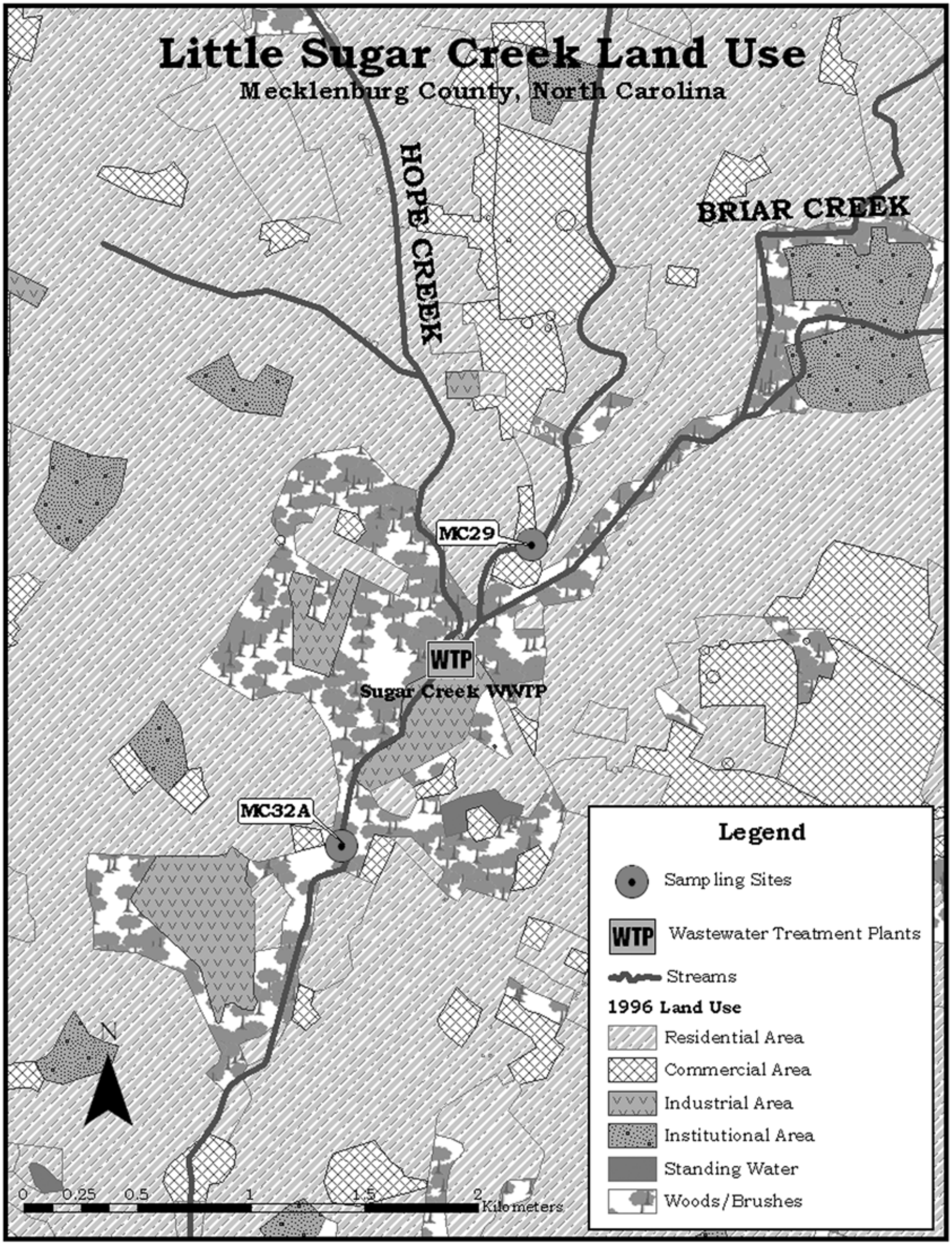

Figure 3. The land use surrounding Little Sugar Creek

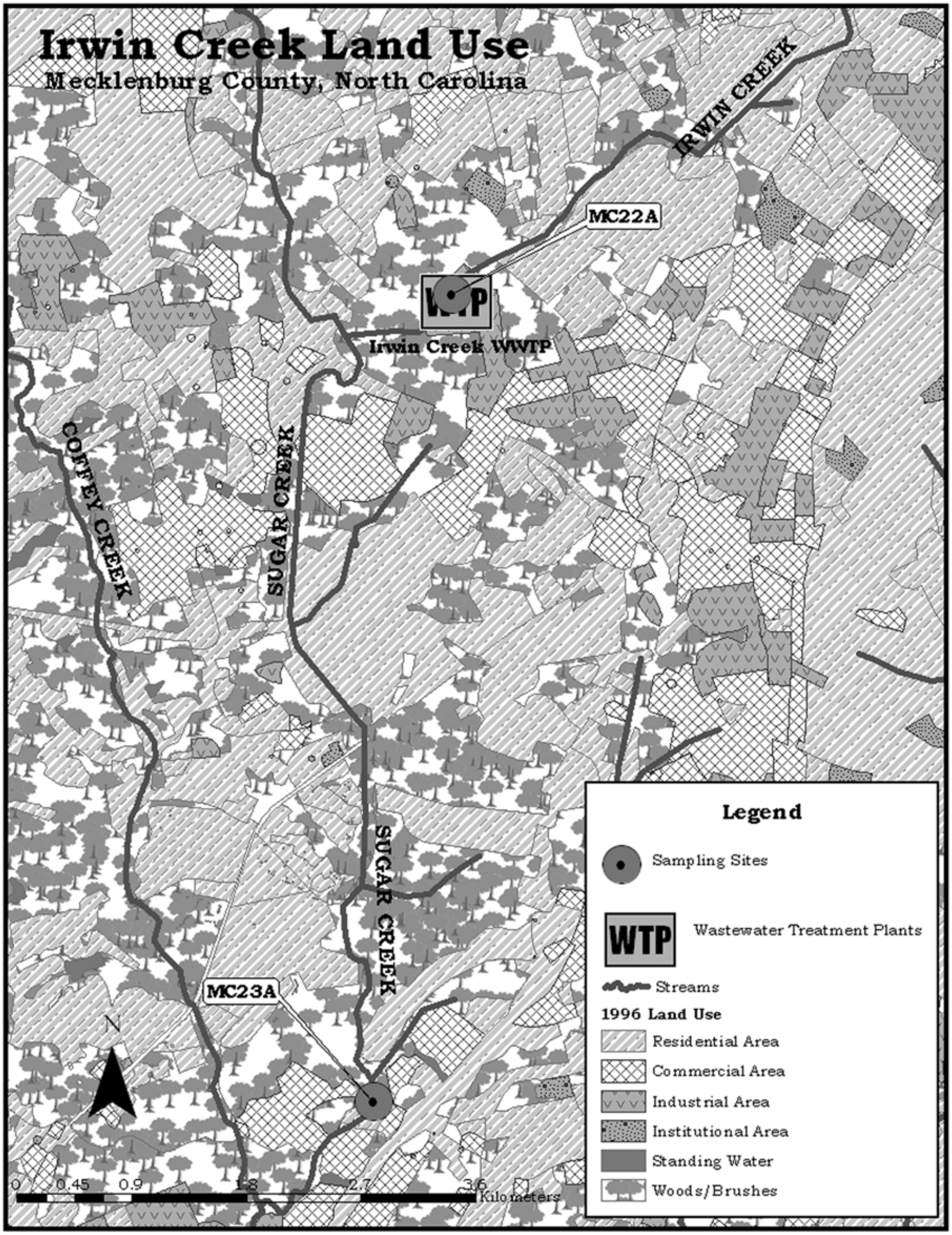

Figure 4. The land use surrounding Irwin Creek

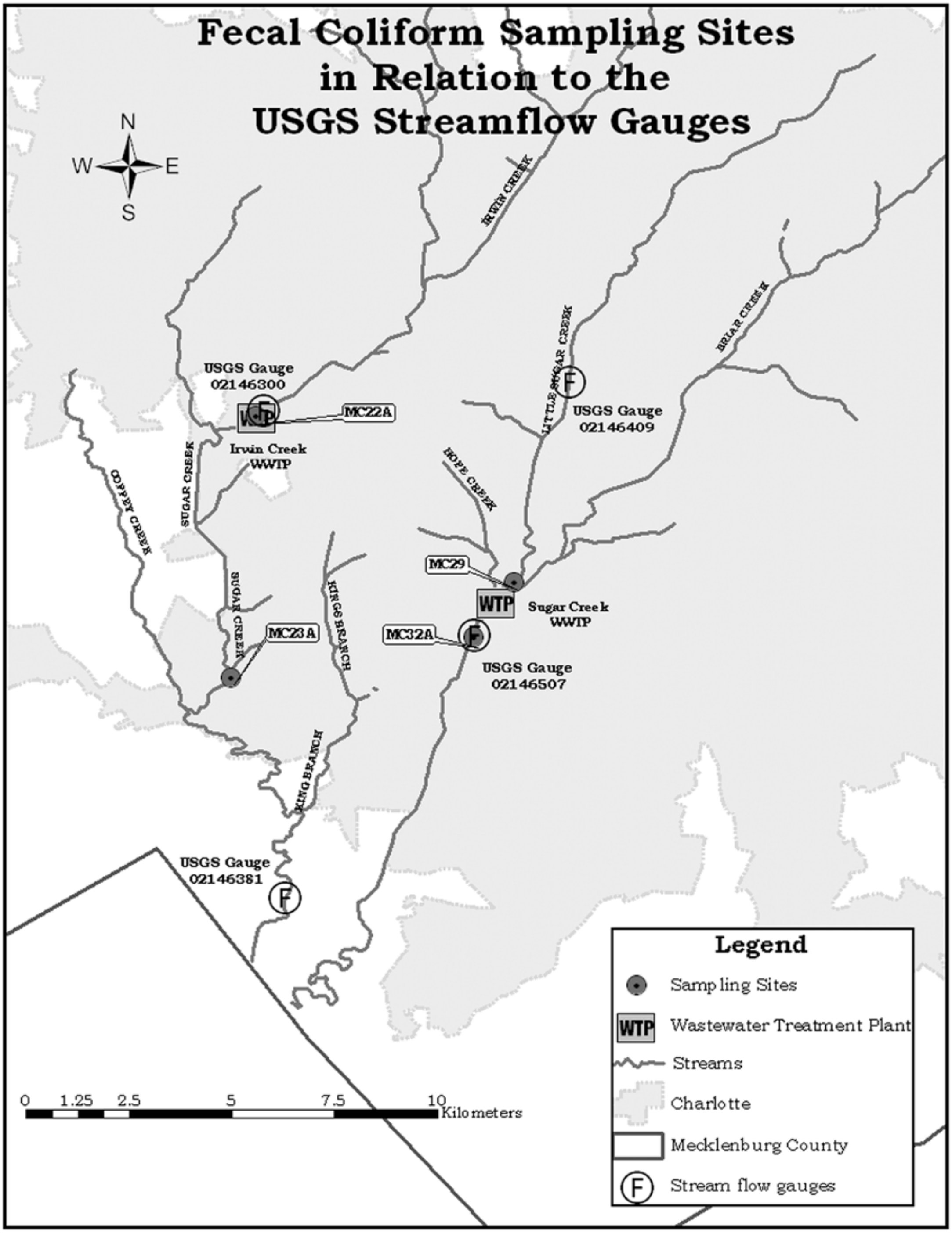

Figure 5. The Irwin Creek and Little Sugar Creek sampling sites in relation to the USGS stream flow gauges

A simple linear regression analysis was performed on the fecal coliform and stream flow data to determine the nature of the relationship between the stream flow and fecal coliform. The data were also analyzed using the Mann Whitney Sum Ranks test. This nonparametric statistical procedure was used to compare the medians of the sample groups. The median was used as the measure of central tendency because outliers do not affect the median. This test was used to evaluate the statistical difference between fecal coliform concentrations in the wastewater effluent at the upstream site and the downstream site.

The fecal coliform data from the sample sites were combined into one group and ordered from smallest to largest, then assigned a rank. If some of the observations were identical, an average rank was assigned. The ranked observations were then divided into the original groups. Next, the sum of the ranks corresponding to each of the samples was calculated. The "W" represented the smaller of the two sums. The "ns" signified the smaller number of samples and the "nL" indicated the larger number of samples. The mean sum of the ranks and the standard deviation of the test statistic were calculated before the test statistic. Once the test statistic was calculated, it was used to determine the probability of the test. Below are the statistical equations for the Mann Whitney Sum Ranks Test:

Test Statistic

$$Zw = \frac{W-\mu w}{\delta w}$$

Mean Sum of the Ranks

$$\mu w = \frac{ns(ns+nL+1)}{2}$$

Standard Deviation of W

$$\delta w = \sqrt{\frac{nsnL(ns+nL+1)}{12}}$$

Zw: the test statistic
W: the small sum of the two sums
μw: mean sum of the ranks
δw: standard deviation of the test statistic
ns: smaller number of samples
nL: larger number of samples

The upstream samples were compared to the downstream samples collected over a four-year period from 1998 to 2001. The downstream ambient samples were also compared to the wastewater effluent fecal coliform bacteria samples over the same four-year collection period. The downstream samples were compared to the weekly effluent average because the travel time for the bacteria from the plant to the downstream site remains unknown. The weekly effluent average, which consisted of the fecal coliform discharged for the week, was calculated for the same week the downstream sample was collected. The level of significance was placed at 0.05 for a two-tailed test.

There were a few limitations with this investigation. Since some sites were sampled on a quarterly basis, there were four to six samples collected each year. There is only one Irwin Creek upstream ambient sample available for 1998 because the site did not exist before October of 1998. Also, there is no 2001 effluent data for the IC upstream site. Therefore, the upstream site for 1998 and the effluent data for 2001 were not completely represented during the four-year sample period. The total number of samples ranges between 14 and 22 samples per site. With a small number of samples, it could be difficult to be 95% confident. However, a small amount of data can verify if there is a statistical difference between the sample sites.

Results

There are 21 upstream (MC29) ambient samples and 22 downstream (MC32A) samples for Little Sugar Creek. There are 13 upstream (MC22A) ambient samples and 19 downstream (MC23A) samples for Irwin Creek. A total of 21 weekly mean effluent samples for the Sugar Creek Wastewater treatment plant and 14 weekly mean effluent samples were collected from the Irwin Creek Wastewater treatment plant (See Figures 6a and 6b). A summary of the descriptive statistics for Little Sugar Creek and Irwin Creek is provided in Tables 2 and 3.

The Little Sugar Creek fecal coliform concentrations varies between 50 colonies /100mL and 3000 colonies/100mL upstream and between 3

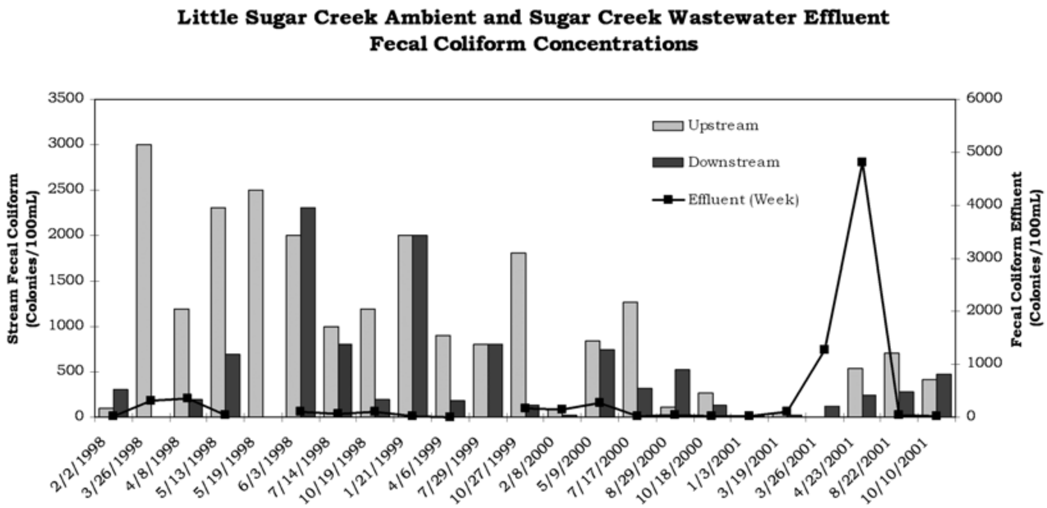

Figure 6a. Bar graph showing the data distribution for the upstream site, downstream site, and wastewater effluent for Little Sugar Creek

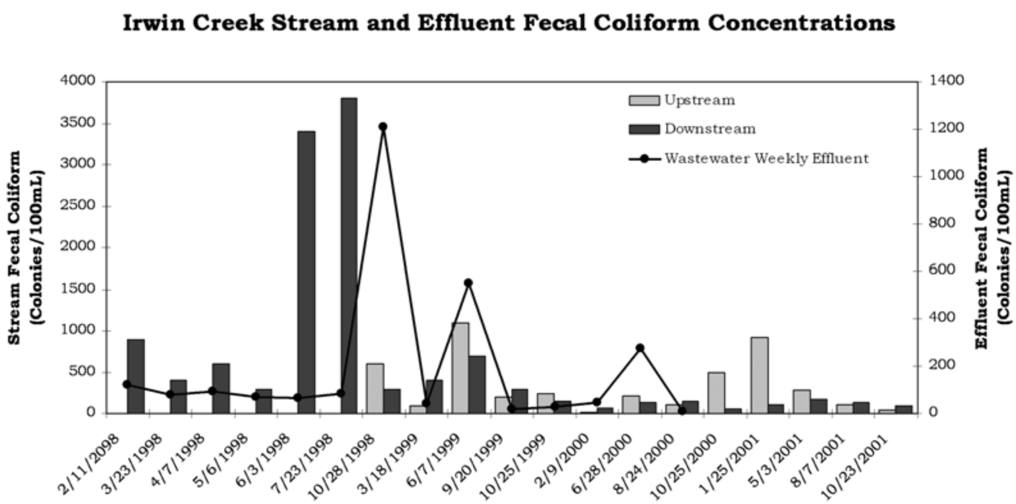

Figure 6b. Bar graph showing the data distribution for the upstream site, downstream site, and wastewater effluent for Irwin Creek

colonies/100mL and 2300 colonies/100mL downstream of the wastewater treatment facility. The Irwin Creek fecal coliform densities vary between 10 colonies/100mL and 1100 colonies/100mL upstream and 50 colonies/100mL and 3800 colonies/100mL downstream. The maximum concentration of fecal coliform (3000 colonies/100mL) measured from the Little Sugar Creek is observed upstream from the wastewater treatment plant. However, Irwin Creek's downstream site has the single greatest incident of fecal coliform bacteria (3800 colonies/100mL). Likewise, the median fecal coliform bacteria are higher upstream (900 colonies/100 mL) than downstream (260 colonies/100mL) of Little Sugar Creek while the Irwin Creek median fecal coliform bacteria concentration is higher downstream (300 colonies/100mL) than upstream (210 colonies/100mL).

The 200 colonies/100mL standard only applies to the effluent samples in this study because the stream samples were not collected consecutively within a 30-day period. Little Sugar Creek has samples that exceeded the North Carolina 400 colonies/100 mL standard for the study period in 76% of the samples collected at the upstream site and 36% at the downstream site. The stream samples analyzed from Irwin Creek exceeded the limitation in 31% upstream and 36% downstream. The wastewater effluent surpassed the North Carolina limitation 24% at the Sugar Creek Wastewater Plant and 21% at the Irwin Creek Wastewater Treatment Plant.

The simple linear regression was performed to determine the strength of the correlation between the stream flow and coliform densities. The results from the test show that both upstream sites have higher correlations than the downstream sites, but the relationship between the two constituents is very weak (See Table 4). However, the graphs display that as the stream flow increases the fecal coliform concentrations decreases (See Figures 7a. and 7b. and 8a. and 8b.).

Table 2. Summary Statistics for Little Sugar Creek (colonies/100mL)

SiteLocations	Number of Samples	Minimum	Median	Mean	Maximum	Standard Deviation
Upstream (MC 29)	21	50	900	1099.05	3000	869.78
Downstream(MC 32A)	22	3	260	478.78	2300	599.98
Effluent (Week)	21	10.20	68.4	379.85	4813.8	1053.42

Table 3. Summary Statistics for Irwin Creek (colonies/100mL)

SiteLocations	Number of Samples	Minimum	Median	Mean	Maximum	Standard Deviation
Upstream(MC 22A)	13	10	210	339.23	1100	343.57
Downstream(MC 23A)	19	50	300	640.53	3800	1069.65
Effluent (Week)	14	9.20	73.8	191.95	1210.2	325.41

Table 4. Correlation Coefficients Between Fecal Coliform and Stream flow

Site Location	Correlation Coefficients
Upstream LSC (MC29)	0.113
Downstream LSC (MC32A)	0.035
Upstream IC (MC22A)	0.197
Downstream IC (MC23A)	0.091

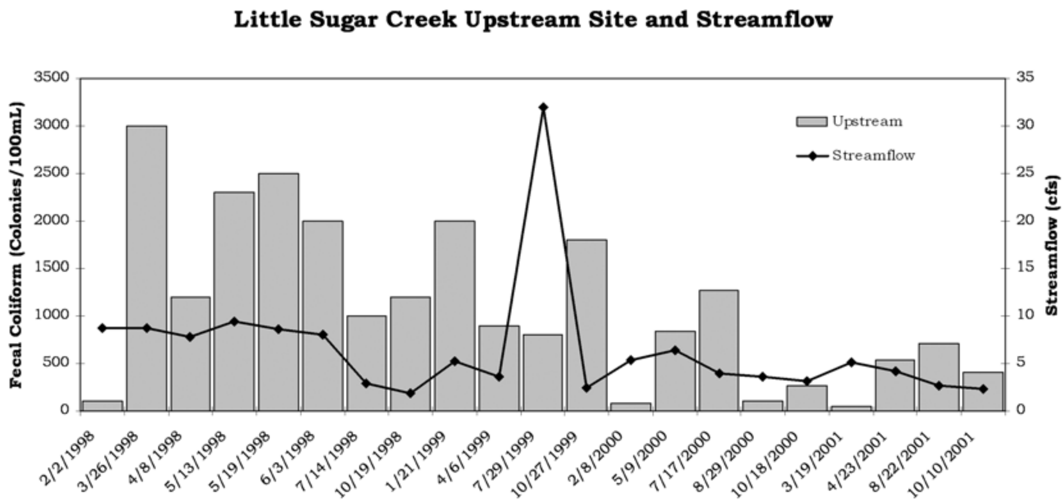

Figure 7a. The relationship between the stream flow rates at the Little Sugar Creek site

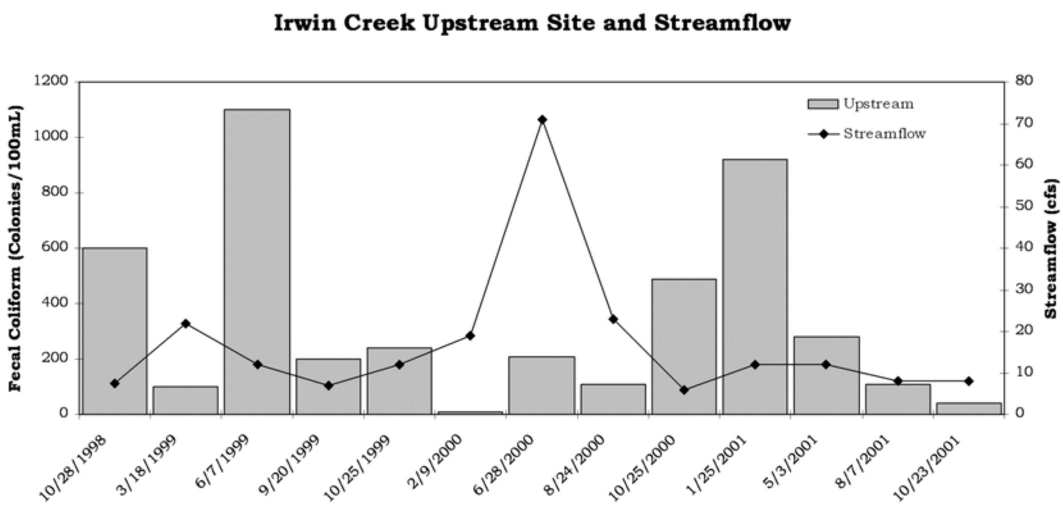

Figure 7b. The relationship between the stream flow rate and the Irwin Creek upstream site

The Mann Whitney Sum Ranks procedure was employed to determine if the fecal coliform bacteria concentration medians of the two locations are statistically equivalent. The results from the Mann Whitney Sum Ranks test revealed a significant statistical difference between median concentrations at the Little Sugar Creek upstream and downstream sites. Concentrations at the upstream site are significantly higher than the downstream site. The sum of the ranks is associated 570.50 upstream and 375.50 downstream of LSC. The Wilcoxon "W" is 375.50 and the associated "z" score is –2.637. The "p" value for the statistical test is 0.008 for the two-tailed test. There is not a statistical difference between upstream and downstream sites located along Irwin Creek. The sum of the ranks is 199.00 upstream IC

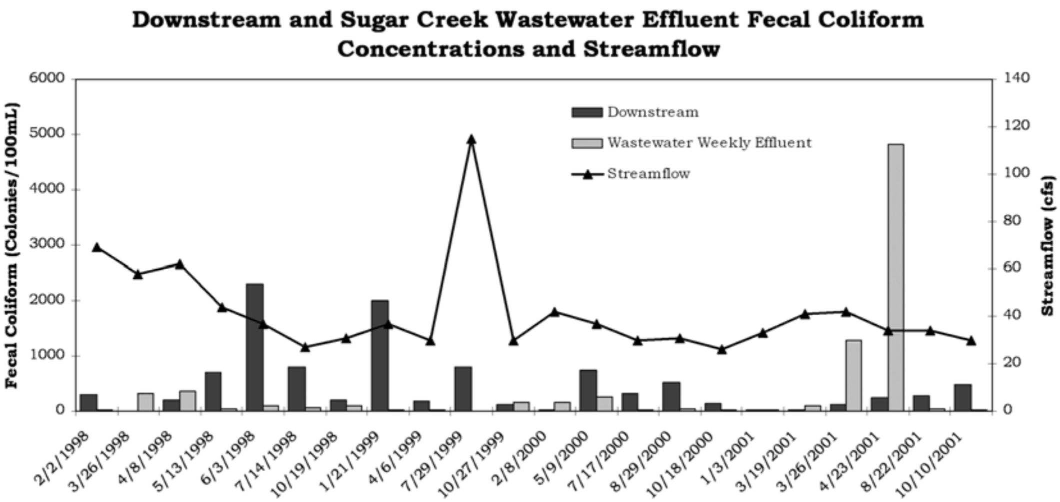

Figure 8a. The relationship between the discharge rate at the Little Sugar Creek downstream site and wastewater effluent

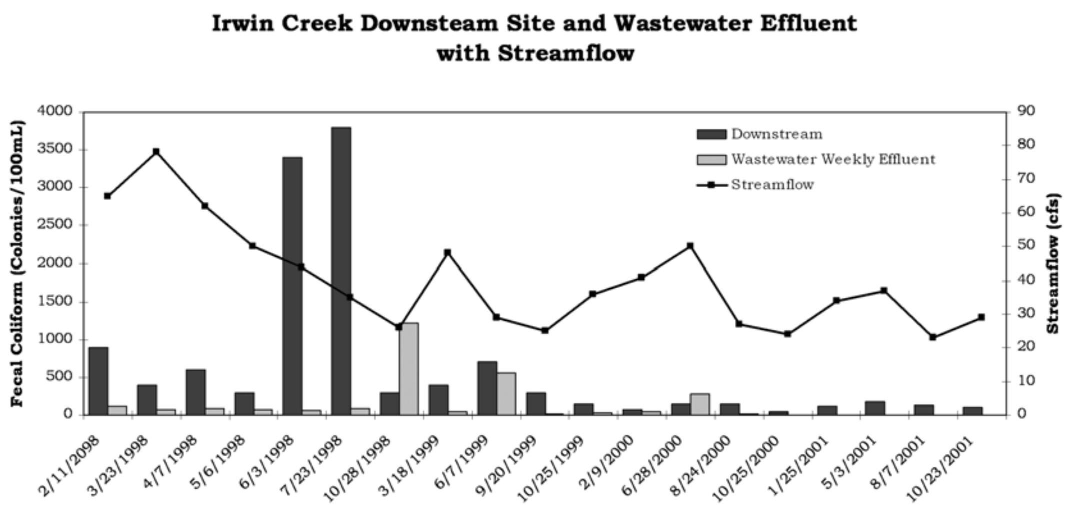

Figure 8b. The relationship between the discharge rate at Irwin Creek downstream site and wastewater effluent

and 329.00 downstream IC. The Wilcoxon "W" is 199.00 and the associated "z" score is –0.595. The "p" value for the statistical test is 0.552.

The Sugar Creek wastewater effluent fecal coliform concentration ranges from 10.20 colonies/100mL to 4813.8 colonies/100mL. The Irwin Creek wastewater effluent levels vary between 9.20 colonies/100mL and 1210 colonies/100mL. The median coliform concentration for the effluent is 68.4 colonies/100mL for Sugar Creek Wastewater treatment plant and 73.8 colonies/100mL for Irwin Creek.

The Mann Whitney Sum Ranks test indicated that there is a significant statistical difference between both downstream sites (MC32A and MC23A) and the effluent discharged into Little Sugar Creek and Irwin Creek. The sum of the ranks is 584.00 downstream of LSC and 362.00 for the Sugar Creek effluent. The Wilcoxon "W" is 362.00 and the "z" score is -2.430. The "p" value for the statistical test is 0.015. The sum of the ranks is 403.50 downstream of IC and 157.50 for the Irwin Creek Wastewater Treatment Plant effluent. The Wilcoxon "W" is 157.5 and the "z" score is -2.934. The "p" value for the statistical test is 0.003. The sum of the ranks is 584.00 for site MC23A and 362.00 for the Irwin Creek effluent. The Wilcoxon "W" is 362.00 and the "z" score is -2.430. The "p" value for the statistical test is 0.015.

Discussion

There were differences in the fecal coliform concentrations measured from the two creeks. Little Sugar Creek had a higher median and experienced more fluctuation than Irwin Creek. Interestingly, the highest concentrations were observed at the upstream site on Little Sugar Creek, whereas Irwin Creek maximum concentrations were found downstream.

Stream discharge rates are known to have an effect on fecal coliform concentrations in streams. The stream flow and fecal coliform data reveal that the fecal coliform concentrations are high when the stream flow is low and suggest that the fecal coliform concentrations at downstream sites of both streams are effected by the increased stream flow rates. These results are very similar to those from the study conducted by Hoch et. al (1996). However, the regression analysis shows that there is no significant correlation between the two constituents, suggesting that the stream flow does not have a statistical effect the fecal coliform concentrations.

When testing to determine if the fecal coliform bacteria medians were equivalent, the outcomes of the Mann Whitney Sum Ranks test were different between the upstream and downstream sites at Little Sugar Creek and Irwin Creek. The significant difference between Little Sugar Creek upstream and downstream sites are similar to that found in a study conducted by Hoch et al. (1996) on the Danube River in Vienna, Austria. However, in their study, the downstream site had higher concentrations. They revealed there is a significant difference between the fecal coliform concentrations at the upstream and downstream sites with the downstream site having higher concentrations close to the outfall, but decreased further downstream. While conducting a similar study in Canada, Beck (1995) concluded that the upstream site met the required standard for fecal coliform bacteria, but the downstream site did not, indicating the wastewater treatment plant effluents increased the fecal coliform concentrations. The Little Sugar Creek upstream site had higher levels of fecal coliform than the downstream site, which suggests that either the wastewater treatment plants are not increasing the amount of fecal coliform bacteria flowing downstream or is being diluted downstream. Unlike Little Sugar Creek, the insignificant difference between the Irwin Creek sites suggested that the wastewater treatment plant may have had a nominal effect on the water quality downstream from the plant. However the significant difference between the IC downstream site and wastewater effluent indicate that the other streams draining into the Sugar Creek may be influencing the fecal coliform concentrations at the IC downstream site.

Little Sugar Creek sampling sites are located around areas dominated with residential neighborhoods, whereas industrial and commercial areas influence the water quality of the Irwin Creek sites. The dissimilarity in land uses apparently impacted the fecal coliform bacteria concentrations measured at the different sampling sites. In a study conducted by Bales et al. (1999), fecal coliform bacteria densities in Mecklenburg County streams are higher at the sampling sites located near residential areas during low flow storm events. The storm water travels directly into the streams without receiving any treatment from the wastewater treatment plant. The authors did not explore the possible sources for the elevated concentrations in residential areas. Based on the descriptive statistics, their conclusion suggests that increased levels of fecal coliform bacteria are related to residential land use. Even though the ambient samples used in this study were collected at least 72 hours after the last rain event, there could have been some fecal coliform bacteria lingering in the streams.

These streams are located in areas with high population densities and impervious surfaces. Young et al. (1999) analyzed fecal coliform samples from different classes of land use and revealed that high population density and impervious surface cover increases the concentrations of fecal coliform entering streams located in urban areas. Also, those watersheds containing municipal sewage systems tend to have elevated fecal coliform bacteria levels over those watersheds with septic systems. According to an article appearing in the Charlotte Observer newspaper on November 7, 1996, the area surrounding Little Sugar Creek and Irwin Creek contains sewage pipes that tend to overflow or leak when the passageways are blocked, which increases the possibility of fecal coliform entering the streams.

Beck (1995) found that fecal coliform bacteria levels were directly influenced by the discharges from the wastewater treatment plant, because the treated effluent and downstream samples exceeded the set standards for recreational activities. The authors noted that the treatment plant in their study did not properly treat the effluent to minimal standards of <200 colonies/100mL set by Manitoba Environment. In this study, the downstream fecal coliform concentrations along both streams were higher than the levels discharged from the wastewater treatment plants. The Sugar Creek and Irwin Creek wastewater treatment plants had a small quantity of the effluent that surpassed the 200 colonies/100mL average with a 30 day standard set by the state of North Carolina. Those few discharges were insignificant in contributing to the streams' elevated fecal coliform concentrations. The results suggest that wastewater treatment plants were not contributing to the elevated fecal coliform bacteria concentrations.

This study does not address other possible sources of the contamination. However, according to the Charlotte Observer (July 19, 2000), misdirected pipelines and illegally connected sewer lines tied to storm drains are found several times a year in the Charlotte area and could be the point sources contributing to the increased fecal coliform bacteria levels. In 1999, a Mecklenburg County owned building located upstream from the upstream sampling site (site MC29) had been illegally discharging raw sewage into Little Sugar Creek. These findings suggest that there may be other unknown illegal sewer lines connected to storm drains discharging raw sewage into Little Sugar Creek. Non-point sources such as fecal coliform bacteria in the feces of domestic and wild animals excreted in and near the streams, and illegal dumping of raw sewage are other are also possible contributors (Mecklenburg County Department of Environmental Protection 2000).

Conclusions

It is important to be knowledgeable of the factors that contribute to the degradation of our surface waters and how effective wastewater treatment plants are in preventing fecal coliform bacteria from entering into our waterways. According to prior studies conducted by the Mecklenburg Department of Environmental Protection (2000), fecal coliform bacteria have degraded the quality of water in Little Sugar Creek and Irwin Creek for decades. The purpose of this study is to determine if the Irwin Creek and Sugar Creek wastewater treatment plants contribute significantly to the fecal coliform bacteria concentrations in Irwin Creek and Little Sugar Creek. The fecal coliform samples used in this study are collected and processed by the Mecklenburg County Department of Environmental Protection between 1998 and 2001.

The findings from the Mann Whitney Sum Ranks test reveal that there is a significant statistical difference between median concentrations upstream and downstream from the Sugar Creek wastewater treatment plant, but not a statistical difference between upstream and downstream sites located along Irwin Creek. There is not a statistical difference between both downstream sites and the effluent from the wastewater treatment plants. Simple correlation coefficients revealed that there is not a significant relationship between stream flow and the fecal coliform concentrations. Therefore, it is concluded that the Sugar Creek and the Irwin Creek wastewater treatment plants do not contribute to elevated fecal coliform bacteria levels measured in the streams.

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