Bacteria Sampling in the Niagara River/Lake Erie Watershed

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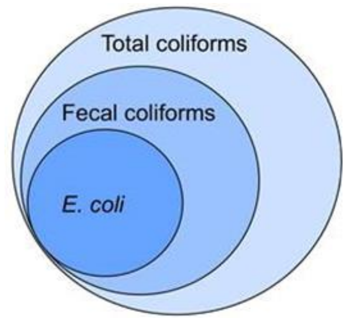
Introduction:

The Niagara River/Lake Erie Watershed drains approximately 2380 square miles in western New York State (NYS). Water quality issues in the basin are associated with land use including agricultural, residential, commercial, and industrial activities; inadequate infrastructure; and private and municipal wastewater discharges. The county health departments in Chautauqua and Erie counties have conducted stream sanitary surveys that have indicated that *E. coli* contamination from tributaries to Lake Erie may be causing beach closures. In some cases, beaches have been closed up to 40% of the time between Memorial Day and Labor Day.



These conditions founded the basis for an interest in a study that generates data about the prevalence of coliform bacteria in the watershed. This ensuing study sampled the waterways of the Niagara River/Lake Erie Watershed at 19 different locations on 15 different occasions. Twelve samples were obtained on a monthly basis, and 3 additional samples were taken during, or shortly after heavy precipitation events. Sampling began in May 2019 and continued until June 2020. A Quality Assurance Project Plan was approved by the NYS Department of Environmental Conservation (NYSDEC) for this project. The project was expanded to include not just *E. coli*, but also fecal coliform and total coliform data, as required by NYSDEC. It is important to note that several samples did not meet the QAPP established quality control duplicate limits and therefore this data is not considered approved by NYSDEC and is only used for survey baseline purposes.

Proportion of Excessive Coliform Occurrence Analysis in the Watershed:

The first and simplest approach to analyzing the data on coliform bacteria within the Lake Erie watershed was to look at which sub-watersheds were producing measurements that exceeded acceptable levels more frequently than others. This was assessed by calculating the proportion of the measurements that exceeded acceptable levels. This was calculated by using equation 1.

Equation 1: Used for calculation of how often a sampling site exceeded acceptable levels over the sampling period.

$$\begin{matrix}\text{Proportion of Occurences} \\ \text{of Excessive Coliform}\end{matrix} = \frac{\text{Number of Measurments Exceeding Acceptable Levels}}{\text{Total Number of Measurements}}$$

Initially, calculating the mean coliform concentration over the time of the study seemed like a valid way to assess which sub-watersheds were experiencing greater concentrations of coliform bacteria. However, due to the limited sample size of 15 measurements, and excessively high concentrations of coliform associated with precipitation events, the mean became inflated and driven by those precipitation events. This made mean coliform an unideal approach for characterizing how frequently a site exceeded acceptable levels relative to other sites. Due to the relative closeness of the sites to one another geographically, it was likely that most of the sites would be subject to precipitation events on the same days as one another. These conditions made using the proportion of occurrences of excessive coliform a better way of assessing which sites were experiencing excessive coliform bacteria more frequently than others. It is possible that sites experiencing excessive coliform more frequently than others may have underlying issues that are either causing higher coliform levels, or making it easier to tip coliform levels past accepted limits. However, it should be noted that due to time constraints with sample holding time and the drive-time needed between sites, the sampling occurred over a 2-day span in order to get all samples to the laboratory within the holding time,

This analysis was done for all three categories of coliform that were surveyed for, including *E. coli*, fecal coliform, and total coliform. The significant results of statistical analysis of the proportion of occurrences of excess coliform can be found in table 1. Big Sister Creek, Cazenovia Creek, Walnut Creek, Buffalo Creek, and the Upper Cattaraugus Creek all produced proportions of occurrences in at least one of the measurement categories that were higher than the mean, but not significantly higher**.** However, Crooked Brook produced a higher proportion of occurrences in all three categories, and with *E. coli* concentrations occurring significantly more than any of the other sub-watersheds. These results illuminate a significant water quality issue in Crooked Brook, along with potential public health concerns due to frequent excessive *E. coli* measurements.

Table 1: Details of the statistically significant or notable results from proportion of occurrences analyses. Results are broken up by coliform measurement class. Only Crooked Brook's E. coli result is statistically significant, but all results one standard deviation above the mean could still be of interest.

Measurement	Acceptable Threshold (cfu/100 mL)	Mean Proportion of Occurrences	Sites One Standard Deviation Above	Sites Two Standard Deviations Above
E. coli	575	0.127	None	Crooked Brook
Fecal Coliform	200	0.385	Crooked Brook Big Sister Creek Cazenovia Creek Upper Cattaraugus Creek	None
Total Coliform	2400	0.185	Crooked Brook Walnut Creek Buffalo Creek	None

Analyses of Correlation and Significance Between Water Data Variables:

R, a program for statistical computing was used to do a large-scale analysis and comparison across all of the data variables obtained during the coliform sampling surveys. This was done to see what variables had relationships with changes in the concentrations of coliform bacteria in the watershed. All of the variables assessed can be found in table 2. A Pearson correlation analysis of these variables returned correlation coefficients between each variable, along with a significance score. However, only relationships that returned a correlation of magnitude 0.3 or greater will be reported due to a correlation of less than 0.3 being considered to be indicative of no correlation or a very weak correlation. It should also be noted that relationships with discharge are difficult to assess due to a limited number of sample sites providing discharge data. Relationships were assessed on two different scales, across the dataset as a whole, and within each individual sample site.

Table 2: Data was collected for 12 different variables during sampling of coliform bacteria.

Variables Assessed During Coliform Bacteria Surveys

• E. coli	• Fecal coliform	• Total coliform
• Temperature of stream	• Specific conductivity	• pH
• Dissolved oxygen	• Nitrate	• Discharge volume
• Atmospheric temperature maximum (3 day forecast)	• Atmospheric temperature minimum (3 day forecast)	• Precipitation (3 day forecast)

Analysis of correlative relationships across the entire dataset and Lake Erie Watershed gives a general idea of what factors could be influencing coliform bacteria abundance in the waterways of WNY. The most prominent result across the entire watershed was a moderate strength correlation (table 3) between higher concentrations of coliform bacteria and higher amounts of precipitation. This suggests that the influx of water into waterways during precipitation events is potentially either carrying coliform bacteria into waterways from external sources, or carrying nutrients into the waterway that allow coliform populations to flourish. In line with this, it was found that higher concentrations of coliform bacteria had a weak but significant correlation with higher concentrations of nitrate. Precipitation events often carry influxes of nutrients such as nitrate and phosphorus into waterways and can lead to increases in microbial populations and algal blooms. This lines up with the result that nitrogen and precipitation were significantly correlated, but very weakly ($r = 0.172$). However, it has previously been found that nitrogen doesn’t necessarily stimulate growth of coliform bacteria, but phosphorus does (Chudoba et al., 2013). With this consideration in mind, it could be inferred that since precipitation events often cause an influx of sediments and phosphorus into waterways, that a partial contributor to coliform bacteria concentrations in the watershed could be this influx of phosphorus associated with precipitation. However, sampling didn’t generate data for phosphorus, and therefore a correlation between phosphorus and coliform bacteria is unable to be investigated. Another potential contributor to exceedingly high coliform concentrations associated with precipitation could be from non-point pollution sources in the area such as sewage, septic systems, or animal waste. Precipitation would lead to an influx of coliform from these contamination sources through runoff into waterways from the surrounding area.

Table 3: Statistically significant results from correlation analysis across the entire watershed and all datapoints. Only relationships between coliform bacteria and precipitation were significant, and with weak to moderate strength of correlation.

Correlation Analysis Across the Entire Watershed			
Correlated Variables	**R Score of Correlation**	**Statistically Significant**	**Relationship**
E. coli : Precipitation	0.29	Yes	Higher precipitation Higher *E. coli*
Fecal coliform : Precipitation	0.57	Yes	Higher precipitation Higher fecal coliform
Total coliform : Precipitation	0.49	Yes	Higher precipitation Higher total coliform

Due to an analysis of the entire dataset being broad and potentially missing fine details, an analysis for correlations by individual sampling sites was also performed. This was done in an effort to assess if any particular areas were exhibiting localized relationships with coliform that weren't captured in the correlations produced by the entire dataset. These correlations were now being derived from smaller sub-datasets, and as a result the 0.7 threshold indicating a strong correlation was used as the criteria for reporting instead of the 0.3 used in the full dataset analysis.

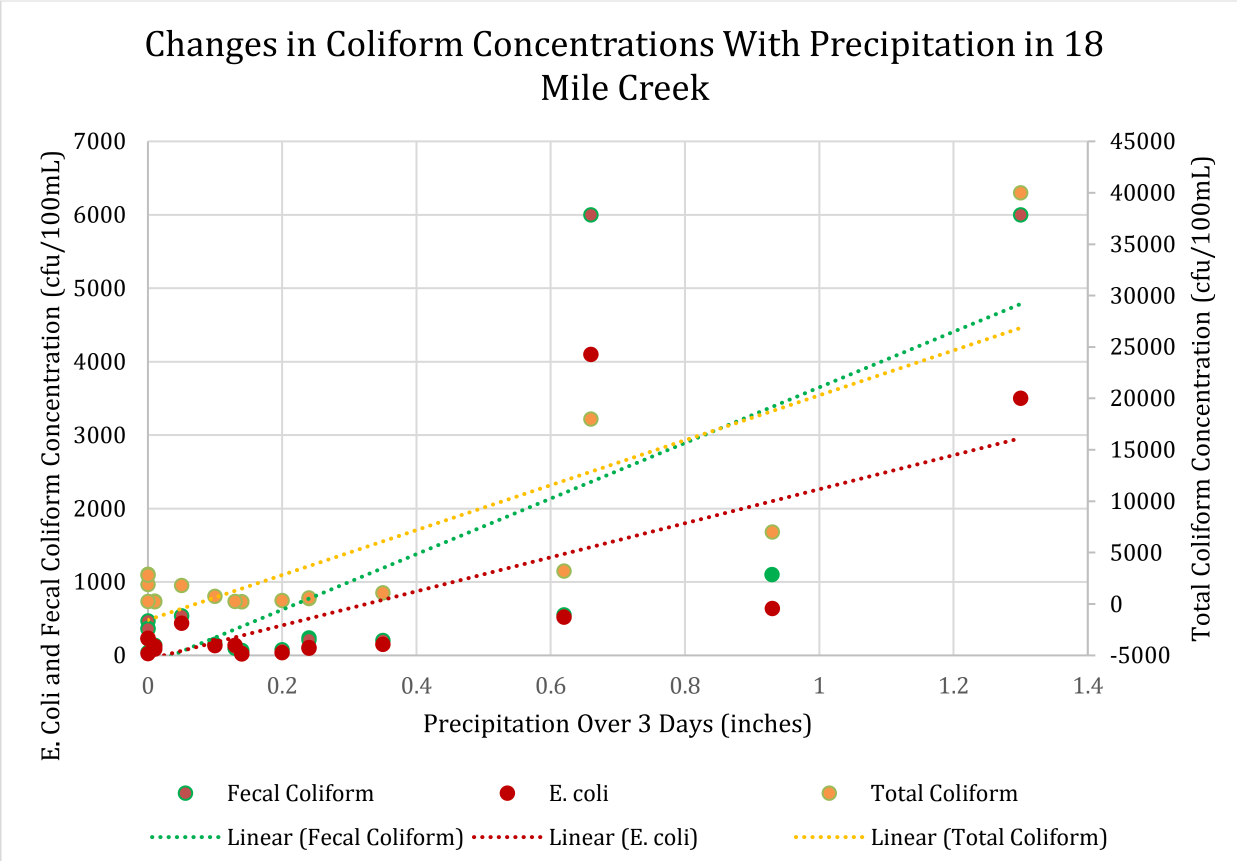


Figure 1: Scatterplot showing all data for E. coli, fecal coliform, and total coliform and how it responds to changes in precipitation across all sampling dates at the 18 Mile Creek sampling site. Total coliform datapoints are plotted in respect to the right y-axis, while E. coli and fecal coliform are in respect to the left y-axis. Each of the 3 coliform data classes is fit with a linear trendline and displays a trend of increasing coliform concentration with increasing precipitation. This relationship was found to have a statistically significant correlation.

Results of the site analysis again found that precipitation is significantly related to coliform concentrations (table 4). This suggests that these areas may be particularly sensitive to coliform increases during precipitation events. The sites located at Chautauqua Creek, Big Sister Creek, 18 Mile Creek, 18 Mile Creek South, Ellicott Creek, Clear Creek, and Upper Cattaraugus Creek produced strong correlations between higher precipitation and higher *E. coli* concentrations. This indicates that given the human health concern surrounding *E. coli*, that these waterbodies may pose a public health risk during and immediately after precipitation events. Significant strong correlations were also found between higher nitrate and higher coliform concentrations (fecal and total) at sites at 18 Mile Creek, 18 Mile Creek South, and Cazenovia Creek. However, these sites all exhibited significant correlations between higher nitrate and higher precipitation (figure). This again supports the idea that the correlation between nitrate and coliform is mainly being driven by the fact that both components simultaneously increase in response to precipitation. Considering that sites at 18 Mile Creek and 18 Mile Creek South produced strong correlations with both coliform and nitrate in their relationships to precipitation, it seems that precipitation events likely pose serious water quality issues to 18 Mile Creek. These water quality issues come in the form of coliform pollution leading to human health risk, and nitrate pollution leading to harmful algal blooms and ecological risk.

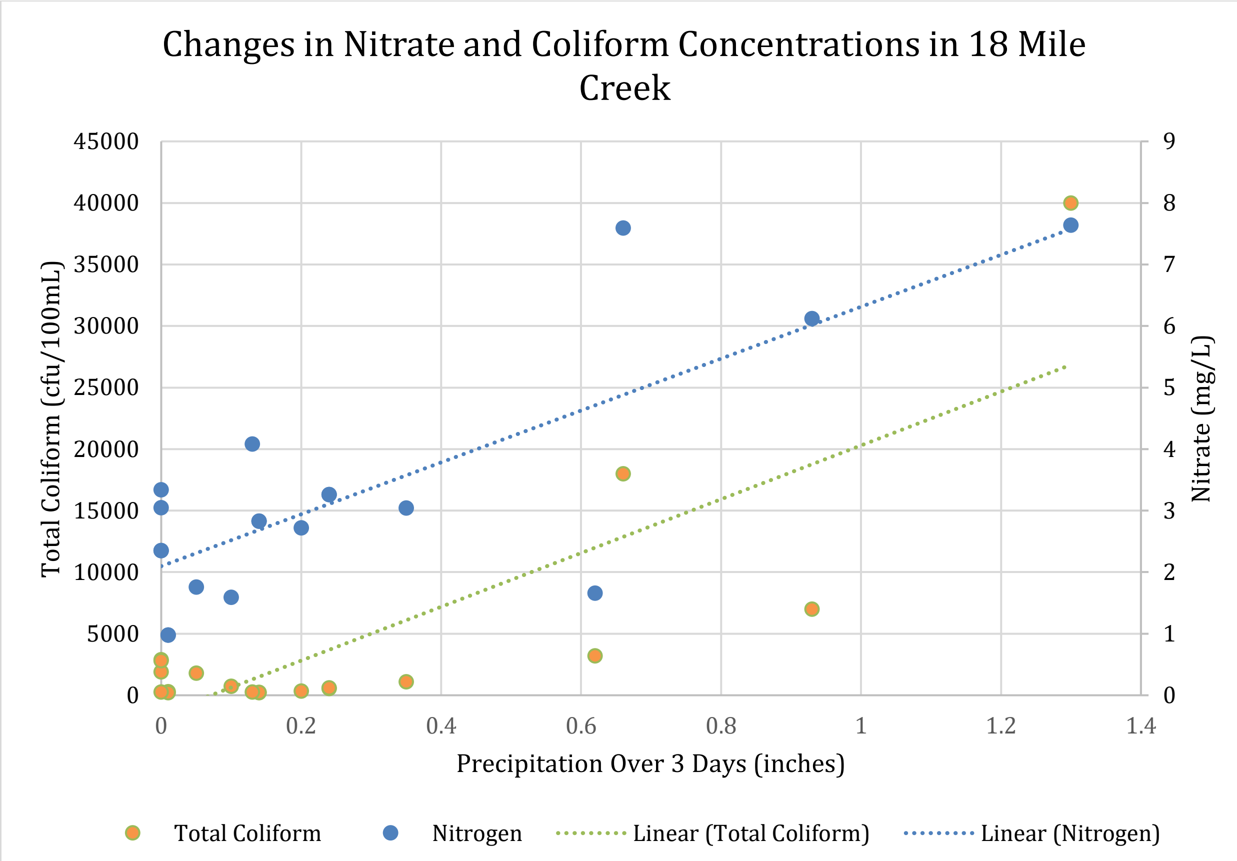


Figure 2: Scatterplot showing all data for total coliform and nitrate and how it responds to changes in precipitation across all sampling dates at the 18 Mile Creek sampling site. Total coliform datapoints are plotted in respect to the left y-axis, while nitrate is plotted in respect to the right y-axis. Both total coliform and nitrate datapoints are fit with linear trendlines that display increases in coliform and nitrate in response to increases in precipitation. The correlations represented by both of these trends are statistically significant. This exemplifies the concept that total coliform and nitrate concurrently increase in response to increasing precipitation, but independently of each other.

Table 4: Table 5: Statistically significant results from correlation analysis at the individual site level at all sampling sites in the watershed. Results in this table reports only significant relationships with coliform measurements, with an additional result for the relationship between precipitation and nitrate. All reported relationships are statistically significant and returned a strong correlation ($R>0.7$ or $R<-0.7$). Crooked Brook is reported despite not meeting the strong correlation threshold due to results returned by the proportion of excessive coliform occurrence analysis making it a special site of interest.

Correlation Analysis Across Individual Sites

Correlated Variables	Sites	R Score of Correlation	Statistically Significant	Relationship
E. coli : Precipitation	Chautauqua Creek	0.84	Yes	Higher precipitation Higher *E. coli*
	Big Sister Creek	0.77		
	18 Mile Creek South	0.70		
	18 Mile Creek	0.72		
	Ellicott Creek	0.80		
	Clear Creek	0.73		
	Upper Cattaraugus Creek	0.74		
	Crooked Brook	0.37		
Fecal coliform : Precipitation	Chautauqua Creek	0.78	Yes	Higher precipitation Higher fecal coliform
	Big Sister Creek	0.78		
	18 Mile Creek South	0.73		
	18 Mile Creek	0.75		
	Clear Creek	0.81		
	Crooked Brook	0.63		
Fecal coliform : Nitrate	18 Mile Creek South	0.93	Yes	Higher nitrate Higher fecal coliform
	18 Mile Creek	0.83		
	Cazenovia Creek	0.70		
Total coliform : Precipitation	Chautauqua Creek	0.83	Yes	Higher precipitation Higher total coliform
	Walnut Creek	0.82		
	Big Sister Creek	0.80		
	18 Mile Creek South	0.75		
	18 Mile Creek	0.82		
	Upper Cattaraugus Creek	0.73		
	Crooked Brook	0.52		
Total coliform : Nitrate	18 Mile Creek South	0.72	Yes	Higher nitrate Higher total coliform
	18 Mile Creek	0.81		
	Cazenovia Creek	0.78		
Nitrate : Precipitation	18 Mile Creek South	0.75	Yes	Higher precipitation Higher nitrate
	18 Mile Creek	0.79		

Conclusions:

There is a clearly a relationship between precipitation and coliform concentration increases within the Lake Erie watershed in Western New York. Precipitation facilitates either the transport of coliform into the waterways, or the transport of nutrients into the waterways that allows coliform populations to flourish. Which vector is the primary contributor still needs to be identified through further study, and coupling coliform data with data on phosphorus concentrations or suspended sediments could perhaps elucidate this.

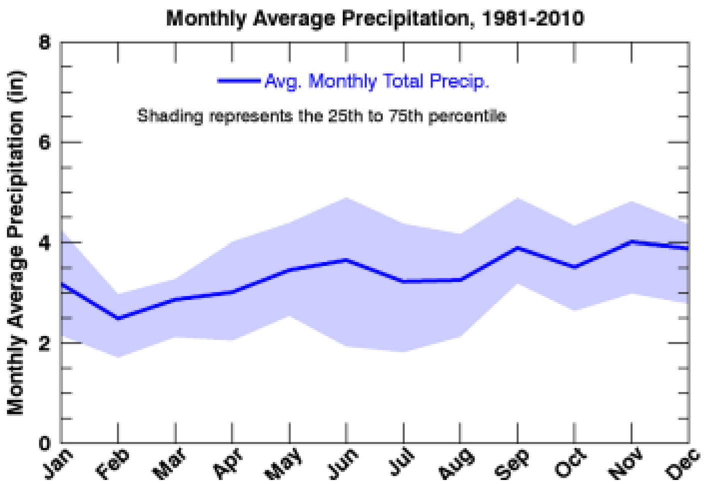


Figure 3: Graph showing the climatic precipitation trends over the year for Buffalo, NY from 1981 to 2010. (Great Lakes Integrated Sciences and Assessments)

Seasonality of coliform increases wasn't able to be determined with confidence from this dataset due to a lack of resolution in the data. Once a month sampling over the span of 13 months combined with several significant precipitation events captured in the dataset makes it difficult to determine how coliform concentrations behave over time in the area without the influence of precipitation. However, given the relationship between precipitation and coliform concentrations, it can be inferred that the seasonality of coliform increases likely follows the seasonality of precipitation in Buffalo. This makes late spring, early summer, early fall times of particular concern for coliform pollution due to a climate history of those being the times of year associated with the highest precipitation in Buffalo (GLISA Buffalo Climatology). This relationship also makes coliform a potential area of concern in regards to climate resiliency for the area. According to the most recent IPCC report, climate change associated with greenhouse gas emissions and global warming could potentially lead to "increases in frequency, intensity, and/or amount of heavy precipitation in several regions" (IPCC 6th Assessment Summary for Lawmakers, 2021). As a region that is already relatively wet, these increases in precipitation could be possible, leading to increased coliform and amount of time with excessive coliform concentrations in the Lake Erie watershed in Western New York. In order to preserve water quality in the region, considerations for management and reduction of coliform should be provided for in climate resiliency plans for the region.

Several specific sites were also identified as displaying significant relationships with coliform concentrations (table 4). These areas seemed to be particularly susceptible to coliform pollution associated with precipitation events, and deserve attention to identify and manage coliform inputs. Crooked Brook may deserve special attention considering the high frequency with which it exceeds acceptable coliform levels, along with the prominence of excess *E. coli* in the waterbody. Interestingly, despite its high frequency of exceeding allowable coliform limits, the correlation between coliform concentrations and precipitation wasn't as strong as other sites. This may indicate other factors involved in the coliform related issues observed in Crooked Brook.

References:

Chudoba, E. A., Mallin, M. A., Cahoon, L. B., & Skrabal, S. A. (2013). Stimulation of fecal bacteria in ambient waters by experimental inputs of organic and inorganic phosphorus. *Water Research*, *47*(10), 3455–3466. https://doi.org/10.1016/j.watres.2013.03.047

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SAMPLING LOCATIONS OF THE NIAGARA RIVER / LAKE ERIE WATERSHED

Sampling Locations

1 - Chautauqua Creek
2 - Canadaway Creek
3 - Crooked Brook
4 - Walnut Creek
5 - Silver Creek
6 - Cattaraugus Creek / Gowanda
7 - Big Sister Creek
8 - Eighteenmile Creek S. Branch
9 - Eighteenmile Creek
10 - Cazenovia Creek
11 - Buffalo Creek
12 - Cayuga Creek
13 - Ellicott Creek
14 - Tonawanda Creek
15 - Cattaraugus Creek / Zoar Valley
16 - Cattaraugus Creek / Rte 12
17 - Cattaraugus Creek / Hake Rd
18 - Clear Creek
19 - Upper Cattaraugus Creek

(orange box) - Sampling site vulnerable to coliform pollution due to precipitation
(red box) - Sampling site of special concern