Enterococci levels in the Bronx River during dry and wet weather conditions

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Abstract

The purpose of this project was to understand fecal microorganism contamination in the Bronx River within New York City and how it is affected by combined sewer overflow (CSO) events. Nine sites along the Bronx River were sampled throughout the summer of 2014 during wet and dry weather conditions. The samples were analyzed for enterococcus fecal indicator bacteria (FIB) concentration. The data revealed that wet weather enterococci concentrations are as 3 to 28 times greater than dry weather concentrations. The highest enterococci concentrations were found where the river enters Bronx County from Westchester County and near a storm water outfall. The positive correlation shown between the amount of rainfall and the FIB concentrations verifies that CSO and storm water discharges are a major source of FIB contamination in the river.

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Introduction

Many urban areas are drained by combined sewer systems which transport sanitary wastewater and storm water through a single pipe to a wastewater treatment facility. During high precipitation events, the collection capacity of these combined sewer systems may be exceeded. These events lead to combined sewer overflow (CSO) where untreated wastewater and surface runoff are directly discharged into surface waters. In the United States, combined sewer systems are found in 32 states and the District of Columbia. It is estimated that about 850 billion gallons of untreated wastewater and storm water are released as CSO each year. (US EPA, 2004)

Some of the impacts of CSO in surface water bodies include decrease of dissolved oxygen concentration due to biodegradation of the increased amount of organic matter, increased levels of metallic and organic pollutants, and high concentration of fecal microorganisms. (Even et al., 2007; Weyrauch et al., 2010; Gasperi et al., 2008) The amount of fecal microorganisms in surface waters is a public health concern because of the possible presence of human pathogens. This is especially a problem for waters that are designated for recreational uses.

Several studies have shown that CSO during high rainfall events are responsible for the increase of fecal indicator bacteria (FIB) concentration in various urban streams. (Outtara et al., 2014; Passerat et al., 2011; Cho et al., 2010; Garcia-Armisen & Servais, 2007) FIB are used to identify the potential for illness resulting from contact with surface waters contaminated by fecal pollution during recreational activities. Although most strains of FIB are not pathogenic, they serve as good indicators of the potential presence of fecal pathogens that can cause illness for people who come into contact with the polluted water.

The Bronx River is a tributary of the East River and flows for more than 20 miles through Westchester and Bronx Counties of New York. About 8 miles of the river flows through the Bronx, which is a borough of New York City. The northern portion of the river, from its headwaters at Kensico Dam until East Tremont Avenue in the Bronx, is freshwater. South of this point, the river is tidally influenced and brackish. The New York State Department of Environmental Conservation (DEC) designates the freshwater part of the Bronx River to be used for primary and secondary contact recreation and fishing. The designated use for the tidal part of the Bronx River is secondary or limited-contact recreation and fishing.

Total and fecal coliform concentrations are the current FIB used in New York State Water Quality Standards for waters designated for recreational use. Sampling initiatives were conducted in the Bronx River in 1988, 1993 and 2000. The results, as reported by the NYC Department of Environmental Protection in 2010, show that the Bronx River waters do not meet the standards for its designated recreational use. Because of the presence of pathogens (as well as oxygen demand exceeding the water quality standards), the Bronx River is currently listed as impaired. The New York State list of Impaired/Total Maximum Daily Load Waters identifies water bodies that do not support appropriate uses. Currently, the only allowed uses of the Bronx River are power boating (limited to tidal sections), canoeing, kayaking and fishing. Although unauthorized, wading and swimming still occur, which has led to “No Swimming” signs being posted at the locations where swimming has been observed.

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The Bronx River flows through an urban watershed. Combined sewers serve 2,657 acres out of the 4,163 acres that drain into the Bronx River. (HydroQual Inc., 2001) Several studies have been published on the presence of nutrient pollutants such as nitrogen and phosphorus in the Bronx River. (Wang & Pant, 2011; Hoellein et. al., 2011) Total and fecal coliform concentrations were also reported by the DEP in their Waterbody/Watershed Facility Plan published in 2010. In 1986, The United States Environmental Protection Agency (EPA) recommended new water quality criteria that replaced the previously recommended FIB, fecal coliform, with enterococci. Enterococci was shown to be a good predictor of gastrointestinal illness in freshwater and saltwater recreational waters, while *Escherichia Coli* was shown to be a good predictor for freshwater only. (EPA, 1986; EPA, 2012)

This project studied the 2014 summer fecal microorganism contamination in various parts of the Bronx River as it flows through New York City using enterococci as FIB. It also aimed to identify the impact of CSO events on the FIB concentration. The sampling sites that were selected are parts of the river near CSO outfalls as well as areas where the surrounding community regularly accesses the river. The goal was to understand the risks to the community who regularly use the river for recreational activities and determine which areas need to be monitored closely.

II. Methodology

Project site description

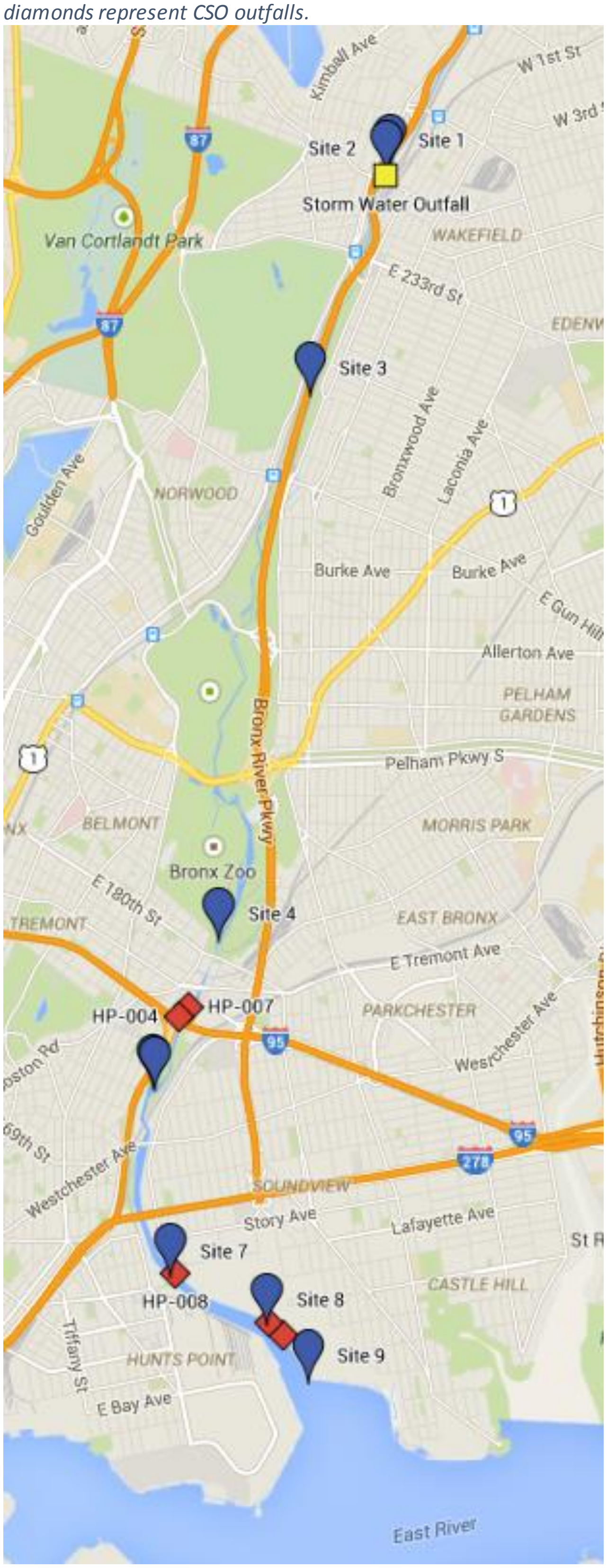
The New York City portion of the Bronx River drains approximately 6.5 square miles or 17% of the total Bronx River drainage area. The U.S. Geological Survey stream gauge located at the New York Botanical Garden recorded an annual mean discharge for the year 2010 of 81.3 cubic feet per second (cfs). The highest daily mean flow recorded for the same year was 1,120 cfs and the lowest daily mean was 12 cfs. (U.S. Geological Survey, 2014) This wide range of discharge values show a flashy hydrology typical of urban streams because of the increased amount of impermeable surfaces that lead to less rainwater absorbed by the ground. Out of the drainage area of the river within the Bronx, 44% of the land area is classified as residential, 27% as parkland, 13% as manufacturing and the rest are classified as commercial or other. (Bronx River Alliance, 2006)

There are five CSO outfalls along the Bronx River within New York City. The locations of the CSO outfalls are shown in the following figure. It is estimated that these 5 permitted CSO outfalls discharge 1 billion gallons of combined sewage per year. (NYC DEP, 2010) Additionally, there is also a storm water outfall carrying a constant flow from Westchester County near the Westchester/Bronx county border.

Sampling Sites

Figure 1 shows the nine sampling sites that were chosen for their accessibility and proximity to possible sources of pollution and places with public access to the river. Sampling **Site 1** is located in the channel where the river enters the Bronx from Westchester County. **Site 2** is located near a storm water outfall carrying a constant flow from McClean Avenue in Yonkers in Westchester. **Site 3** is a publicly accessible canoe/boat launch in Shoelace Park downstream of a Metro North rail station. **Site 4** is downstream of the Bronx Zoo complex. **Site 5** is located at a dock north of a 3 meter high tidal weir and is downstream of two CSO outfalls, HP-007 and HP-004. **Site 6** is 20 yards from Site 5 and downstream from the tidal weir. Sites 5 and 6 are also areas of public access. **Site 7** is at a dock across from the CSO outfall HP-008. **Site 8** is directly in front of storm water outfall HP-009 and near CSO outfall HP-010. **Site 9** is at the river's mouth where it empties into the East River.

Figure 1. Bronx River Map. Blue balloons represent sampling sites, Yellow boxes represent a storm water outfall and red diamonds represent CSO outfalls.



Sampling and Analysis

Nine sites were sampled on a weekly basis over the summer of 2014. An additional three sampling days after rain events were added to increase data for wet weather conditions (Arbitrarily set at more than 0.01 total inches of rainfall for two days prior to sampling day). There were a total of 15 sampling days, 6 after or during wet weather events and 9 in dry weather. Water samples were collected approximately 1 foot under the surface of the water. The samples were immediately placed in a cooler. Within 4 hours of sampling, the water samples were analyzed for enterococci concentration using IDEXX Laboratories' Enterolert substrate and the Quanti-tray 2000. Dissolved oxygen, temperature, pH, salinity, and conductivity were also measured using a handheld multi-parameter meter (YSI 556 MPS).

III. Results and Discussion

Enterococci Concentration during Dry Weather Conditions

Figure 2 shows the geometric mean (GM) enterococci concentration at each sampling site. The triangular data points show the concentrations observed during dry weather conditions. The highest GM for dry weather conditions, at 706.71 MPN/100 ml, was found at Site 1. Site 1 is close to the Bronx border with Westchester, hence the water entering the Bronx from Westchester already contains a high concentration of FIB. High concentrations of total coliform and fecal coliform concentrations from upstream of the Bronx border were also reported in the 2006 Bronx River Cooperative Sampling Initiative. (NYCDEP, 2010) The GM concentration then decreases downstream. The lowest FIB concentration was at the mouth of the river at 24.42 MPN/100 ml. This decrease in concentration of FIB as it flows downstream has been attributed to mortality of the FIB and sedimentation in other urban rivers. (Outtara et. al., 2014)

Figure 3 shows a boxplot of the enterococci concentration at each sampling site during dry weather conditions. The figure shows that Site 2 has a wider range of concentration compared to the other sampling sites. The wider range in values appears to be caused by input from the storm water outfall in the site. The higher FIB concentrations for Site 2 were recorded during 2 out of the 3 times that the outfall was observed to be discharging into the river during dry weather conditions. These findings suggest that this outfall may be discharging sewage during dry weather conditions.

Enterococci Concentration during Wet Weather Conditions

In Figure 1, the square data points show the GM of the FIB concentrations recorded for wet weather conditions. Depending on the sampling site, wet weather GM concentrations were observed to be from 3 to 28 times greater than the dry weather GM. The site with the highest GM concentration was at the Westchester storm water outfall pipe (Site 2) at 4067.39 MPN/100 ml. The second highest GM concentration (2134.92 MPN/100 ml) was at Site 1 where the water enters the Bronx from Westchester. The GM concentration decreases to 1250.97 MPN/100 ml downstream at Site 3. Further downstream from site 3, the GM varies only slightly until it reaches site 8, where the GM drops to 325.10 MPN/100 ml. The GM concentration further drops to 226.06 MPN/100 ml at the mouth of the river. The boxplot in Figure 4 shows that the range of values for Sites 2 and 8 extends to higher values than the rest of sampling sites which was expected because of the proximity of these sites to storm water and CSO outfalls.

Multiple regression analysis was conducted on Microsoft Excel (Output shown in tables 2 and 3) to determine the correlation of the enterococci concentration with the amount of rainfall. Daily rainfall measurements were taken from the monthly weather summary for La Guardia airport, NY reported by the National Oceanic and Atmospheric Administration (NOAA, 2014). The La Guardia airport weather station is approximately 2.2 miles from the mouth of the Bronx River. The rainfall measurements for 2 days prior to sampling day, 1 day prior to sampling day and on the sampling day were used. The enterococci concentration was found to be positively correlated (Adjusted $r^2 = 0.59$, $p<0.001$) with the amount of rainfall for the sampling day and the day before. This correlation suggests that the enterococci concentrations in the Bronx River are affected by CSO discharged into the river for at least 1 day after a rain event.

Figure 2. Enterococci Geometric Mean Concentration

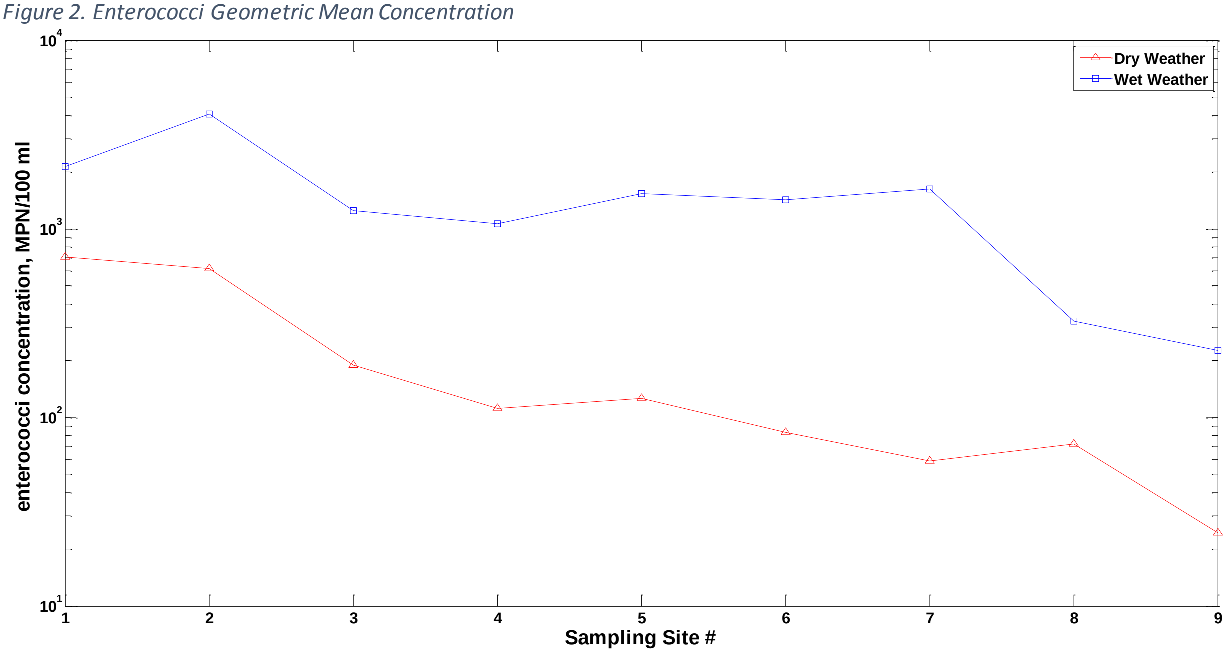


Figure 3. Dry Weather Enterococci Concentration Boxplot (9 sampling days at each site)

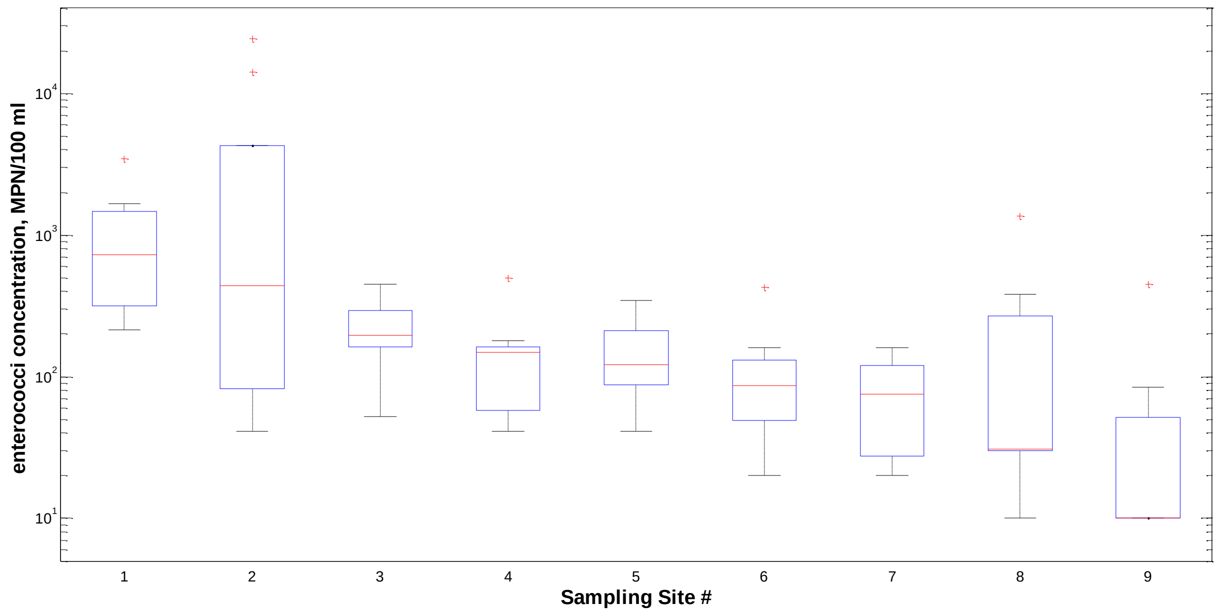
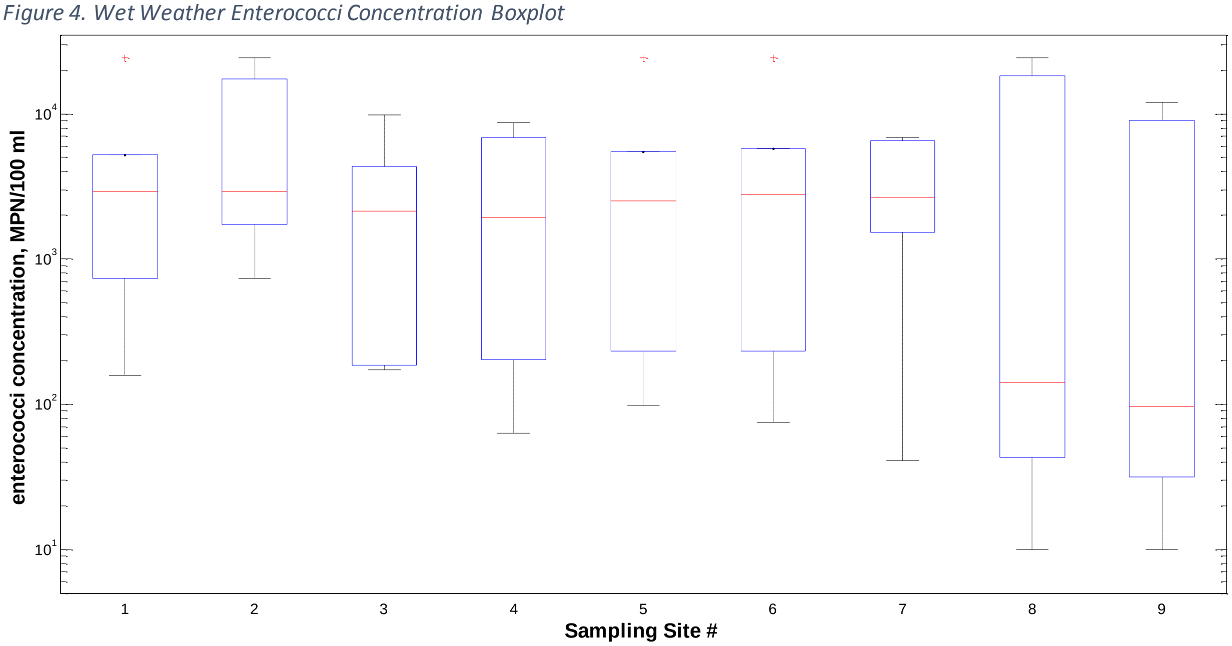


Figure 4. Wet Weather Enterococci Concentration Boxplot



Note: Because of lack of access to a boat on some wet weather days, there were only 3 wet weather water samples taken for site 8 and 9. Other sites were sampled on 6 wet weather days.

Table 1. The MS Excel Regression Analysis for precipitation measurements up to 2 days prior sampling day and the logarithm of the measured enterococci concentration. P-values below shows that the rainfall measured for 2 days prior to sampling day is not significant to the measured enterococci concentration (P-value for 2 days prior precipitation > 0.01).

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.790059005							
R Square	0.624193231							
Adjusted R Square	0.598570042							
Standard Error	0.574850379							
Observations	48							
ANOVA								
	df	***SS***	***MS***	***F***	***Significance F***			
Regression	3	24.14998007	8.049993	24.36048	1.92052E-09			
Residual	44	14.53993017	0.330453					
Total	47	38.68991024						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	2.030299811	0.157714464	12.87326	1.61E-16	1.712447193	2.348152428	1.712447193	2.348152428
2 days prior precipitation (inches)	0.66036227	0.548873178	1.203124	0.235362	-0.445818935	1.766543475	-0.445818935	1.766543475
1 day precipitation (inches)	1.117714941	0.373402607	2.993324	0.004514	0.365171435	1.870258447	0.365171435	1.870258447
sampling day precipitation (inches)	1.657264963	0.199162438	8.321172	1.4E-10	1.255879443	2.058650482	1.255879443	2.058650482

Table 2. The MS Excel Regression Analysis for precipitation measurements up to 1 day prior sampling day and the logarithm of the measured enterococci concentration. The MS Excel Regression Analysis P-values below shows that the rainfall measured 1 day prior to sampling day and on sampling day is significant to the measured enterococci concentration (P-value < 0.01).

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.78219562							
R Square	0.611829988							
Adjusted R Square	0.594577987							
Standard Error	0.577701633							
Observations	48							
ANOVA								
	df	***SS***	***MS***	***F***	***Significance F***			
Regression	2	23.6716473	11.83582	35.46429	5.66232E-10			
Residual	45	15.01826294	0.333739					
Total	47	38.68991024						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	2.043618419	0.158105814	12.92564	9.41E-17	1.725176963	2.362059874	1.725176963	2.362059874
1 day prior precipitation (inches)	1.446684442	0.255556025	5.660929	9.92E-07	0.931968186	1.961400697	0.931968186	1.961400697
sampling day precipitation (inches)	1.616339686	0.197209408	8.196058	1.79E-10	1.21913955	2.013539823	1.21913955	2.013539823

Recreational Use of the Bronx River

In 2012, the U.S. Environmental Protection Agency recommended a new set of Recreational Water Quality Criteria (RWQC) for adoption by the states. New York State is currently in the process of adopting these new criteria. (NYCDEC, 2014a) The criteria require that the waterbody FIB GM should not be greater than the selected GM magnitude in any 30-day interval. Also, there should not be greater than a 10% excursion frequency of the selected Statistical Threshold Value (STV) magnitude in the same 30-day interval. The possible thresholds, which depend on the estimated illness rates, are shown in the table 3 below. The states are allowed to adopt either one for their criteria. The calculated 30-day GM during the summer of 2014 (shown in Figure 5) shows that most the Bronx River waters exceeded the recommended RWQC criteria for enterococci for both illness rates. Primary contact recreation, which is the designated use for some parts of this river and the ultimate goal of the federal Clean Water Act, is still not supported according to these standards.

Table 3. EPA 2012 Recreational Water Quality Criteria

Criteria Elements	**Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreators**		OR	**Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreators**	
	Magnitude			**Magnitude**	
Indicator	GM (cfu/100 mL)[a]	STV (cfu/100 mL)[a]		GM (cfu/100 mL)[a]	STV (cfu/100 mL)[a]
Enterococci – marine and fresh	35	130		30	110
OR					
E. coli – fresh	126	410		100	320
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval.					

[a] EPA recommends using EPA Method 1600 (U.S. EPA, 2002a) to measure culturable enterococci, or another equivalent method that measures culturable enterococci and using EPA Method 1603 (U.S. EPA, 2002b) to measure culturable *E. coli*, or any other equivalent method that measures culturable *E. coli*.

The RWQC are derived from epidemiological studies that evaluate how FIB levels are associated with health effects for primary-contact recreation such as swimming and bathing. Although swimming is prohibited in all parts of the Bronx River, unauthorized swimming still occurs, especially in parts where there is public access. Swimming was not observed during any of the water sampling events, but several instances of children swimming in the river were observed by Bronx River Alliance staff during the summer.

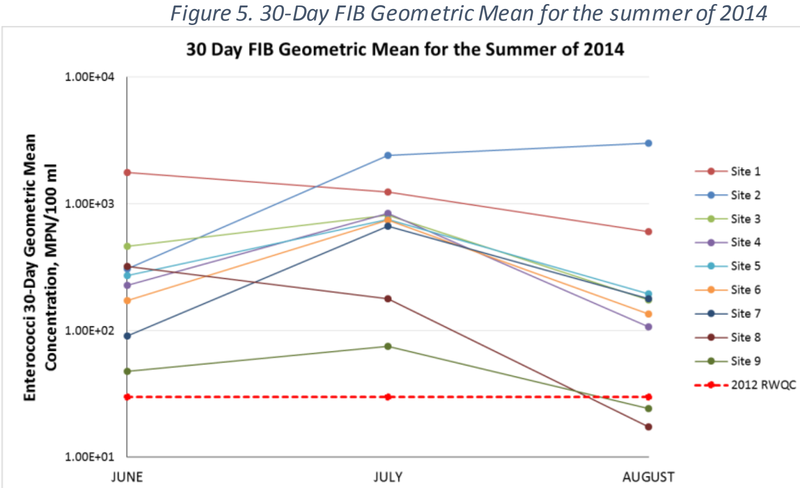
The most common recreational use observed during the water sampling events were boating and rowing which are classified as limited or secondary-contact water recreation. These activities were mostly observed near the estuary (Sites 7 – 9). There is a dock located at Site 7 that is frequently used by a youth organization called Rocking the Boat for maritime skills training. The Bronx River Alliance and Rocking the Boat also held frequent rowing and canoeing events in both the freshwater and estuary portions of the river throughout the season.

Fishing was also observed at Sites 7 and 9 during water sampling. The New York City Department of Parks & Recreation permits fishing but requires fish caught in freshwater areas to be immediately released. (DPR, 2000) The New York State Department of Environmental Conservation lists Hunts Point Riverside Park (Site 7) and Soundview Park (Site 9) as allowed saltwater fishing spots within New York City. There are health advisories against the consumption of any fish from this waterbody for women under 50 and children under 15 years of age. The advisory for men over 15 and women over 50 varies from none to 4 meals per month depending on the species of fish that is caught. (DOH, 2014) However, these advisories are given to limit exposure to chemicals of concern in the fish tissue such as Polychlorinated Biphenyls, Dioxins and Cadmium. There were no fish consumption advisories related to the FIB levels in the water.

Even though boaters and fishermen are advised to refrain from direct contact with the water during these activities, the high FIB concentrations in the river may present a health risk to recreationists from unintended contact (ie. ingestion of water from hand-to-mouth transfer). An increased risk of gastrointestinal illness has been associated with limited-contact water recreation.

(Donovan et al, 2007; Dorevitch et al, 2012) The study by Dorevitch et al (2012) also reported that an increased risk of eye symptoms such as redness, crusting, itching, or draining was attributed to limited-contact water recreation in waters with increased pathogen concentrations.

Figure 5. 30-Day FIB Geometric Mean for the summer of 2014



Relationship with Other Measured Water Parameters

Regression analysis was conducted to determine the correlation of enterococci concentration with conductivity measurements. Table 4 shows that there was a negative correlation found between conductivity and enterococci concentration (Adjusted $r^2 = 0.21$, $p<0.01$). Passerat et al (2010) and Weyrauch et al (2010) notes that the conductivity of river water decreases because of the dilution with storm water during rain events. This weak correlation suggests that the CSO is only one of the sources of increased Enterococci concentration in the river during wet weather conditions. Another possible source of the increase in concentration could be the resuspension of FIB from sediments to the water column due to the increased flow rate during and after rainfall. This factor has been shown to significantly affect FIB concentration in Gwanju Creek in Korea (Cho et al, 2010).

There was no significant correlation found between the FIB concentration and the dissolved oxygen (DO) content of the water. This suggests that CSO contributions to the waterway are washed away fast enough that they do not affect the oxygen concentration. However, low DO concentrations (DO < 3 mg/L) were recorded at Sites 5 and 6 (both found in Starlight Park) four times during the summer. Algal blooms were observed in this area during 2 out of the 4 times that low DO concentrations were recorded. The effect of other factors that are unique to this site, such as the presence of the tidal weir, tidal influences, and the shape of the river (the river bends at this point and floating debris usually collect at this site), should be studied to better understand how to prevent DO depletion.

Table 4. The MS Excel Regression Analysis for conductivity and the logarithm of the measured enterococci concentration shows that the negative correlation is significant (P-value < 0.01)

Regression Statistics								
Multiple R	0.467511849							
R Square	0.218567329							
Adjusted R Square	0.212414316							
Standard Error	0.806186074							
Observations	129							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	23.08702559	23.08702559	35.52199922	2.32646E-08			
Residual	127	82.54187023	0.649935986					
Total	128	105.6288958						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.854021325	0.093629477	30.48208125	2.89277E-60	2.668745487	3.039297163	2.668745487	3.039297163
Conductivity, mS/cm	-0.028371668	0.00476032	-5.960033491	2.32646E-08	-0.037791483	-0.018951853	-0.037791483	-0.018951853

IV. Conclusions

This study has shown that the Bronx River still does not meet the recommended recreational water quality standards for its designated use of primary contact recreation. The data shows that FIB concentrations are already very high once the water enters New York City, so the problem must also be addressed further upstream in order to be able to achieve the “swimmable waters” goal of the Clean Water Act. The data also suggests that storm water outfalls, such as the one in Site 2, are possibly releasing sewage to the river even in dry weather conditions. Further study on other storm water outfalls discharging into the river is recommended.

The study has shown a positive correlation between the amount of rainfall and the FIB concentration which proves that CSO is a major source of water quality impairment in the river. It is recommended to conduct further study on how FIB concentrations respond to the amount of rainfall by taking hourly water samples and rainfall measurements during and after rain events. Learning how quickly FIB concentrations rise and fall in response to the amount of rainfall could help the organizations that use the river to better plan their recreation programs and enable them to issue proper warnings regarding the risk of illness when using the river after rain events.

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