Citizen Science on the Bronx River: An Analysis of Water Quality Data

BRONX river alliance

FUSS & O'NEILL

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Bronx River Alliance

Executive Summary

The Bronx River Alliance has been organizing and assisting volunteer groups to conduct weekly water quality monitoring for the past several years. Water quality monitoring data for the Bronx River is also available dating back to the early 1990s, collected under the direction of the Alliance's predecessors, Bronx River Restoration. Combined, over 1,000 water quality samples have been collected on the Bronx River since 1990. Analysis of this large data set was undertaken to summarize the data, identify water quality trends and data gaps, and make recommendations for the water quality monitoring program to improve the quality, usefulness, and educational value of future monitoring data for the Bronx River.

Water Quality

The statistical summary considered over 3,800 individual measurements of water quality collected by the Bronx River Alliance volunteers, Bronx River Restoration, the New York City Water Trail Association, and the NYC DEP New York Harbor Watch Program and included comparison with water quality standards and examination of spatial and temporal trends.

The analysis showed that water temperatures show typical seasonal variation and are generally within the range of 5-30°C, which is acceptable for aquatic life. Although no statistically significant spatial trend was found, temperatures in the northern part of the river tend to have lower median and mean water temperatures, an observation consistent with the greater impervious cover and stormwater and combined sewer overflow (CSO) discharges downstream that introduce warmer runoff into the river.

pH measurements in the Bronx River generally meet established water quality standards to protect aquatic health and are similar to other rivers in the region. A decreasing temporal trend was detected at a few stations over the past several years, but generally pH values are close to neutral and are higher and less variable downstream along the Bronx River, consistent with the influence of higher pH marine water south of Interstate 95.

Average dissolved oxygen (DO) concentrations in the Bronx River are typically above surface water quality criteria, which is a positive indicator of water quality. However, several stations have low DO values, a cause for concern, especially in the lower portions of the river. A statistically significant downstream decreasing trend in DO was observed in the 2011 data. Because of the identified DO impairments in the Bronx River and recent delisting of the lower Bronx River, monitoring DO will continue to be important to assess the water quality and overall health of the river.

The fecal coliform and enterococcus data show that there is a statistically significant decrease in fecal coliform bacteria from upstream to downstream, and mean and median fecal coliform and enterococcus concentrations are routinely the highest at the upstream station (233rd Street and Bronx Boulevard) of the three stations where bacteria data were collected. In addition, examination of correlations between precipitation and fecal indicator bacteria concentrations shows that there is a strong correlation with wet weather sources. The Bronx River Intermunicipal Watershed Management Plan identified several management strategies for the portions of the Bronx River watershed in Westchester County, including investigation and reduction of illicit discharges and stormwater source controls. The fecal indicator bacteria data concurs with these recommendations, and the magnitude of the observed upstream concentrations, especially compared to concentrations at the downstream stations, provides evidence of illicit discharges in the upper watershed.

Observations of dinoflagellate and algal blooms have been noted in the Bronx River by volunteers over the past decade. Because of the growing concern about the acute and chronic human health effects and the water quality and aquatic impacts of harmful algal blooms (HABs), continued and standardized methods for observation of blooms is an important component for ongoing water quality monitoring.

Citizen Scientist Monitoring Recommendations

The review and analysis of the water quality data resulted in several recommendations for ongoing and future citizen scientist monitoring efforts related to identification of bacteria sources and causes of low DO conditions, refinements to nutrient and HABs monitoring, and the establishment of "sentinel stations," in addition to encouraging targeted monitoring projects.

The elevated concentrations of fecal indicator bacteria in the upstream portions of the Bronx River require further investigation to identify and eliminate sources. The Bronx River Intermunicipal Watershed Management Plan recommended investigation and reduction of illicit discharges and stormwater source controls. Monitoring for indicators of sanitary sewer discharge such as optical brighteners (found in some laundry detergents), caffeine, methylene blue active substances (surfactants found in detergents and soaps), or other bacteria source tracking methods could help confirm or deny the presence of human sources of the fecal indicator bacteria. Similarly, because analysis of DO and fecal indicator bacteria data suggest that sources other than fecal material are consuming oxygen and depressing dissolved oxygen concentrations, measurement of biochemical oxygen demand, along with bacteria concentrations, in areas of low DO could help to identify locations where discharge of non-sewage organic matter may be impacting DO levels.

Lower detection limits for nitrogen data and measurement of phosphorus could be useful to characterize nutrient conditions, track the relationship between nutrients and HABs, and determine if there is any relationship between nutrients and low DO in all or portions of the Bronx River. Blooms of dinoflagellates, algae, and cyanobacteria may continue to be a water quality issue in the Bronx River. The volunteer monitoring program could be expanded to include formal HAB data collection. Training in the identification of algal blooms could be useful since pollen, aquatic weeds, and green algae can sometimes be mistaken for HABs.

Analysis of long-term changes in the health of the river requires consistent records of water quality at several locations. Consequently, the designation of specific "sentinel stations" that could be used to benchmark water quality in the Bronx River could be a useful addition to the volunteer monitoring program. These stations would be the focus of consistent, routine monitoring for an established suite of water quality parameters. In addition to the sentinel stations, the use of targeted investigations, over a short period of time such as a season or a few weeks or over a limited number of locations, could help to address specific water quality questions in the Bronx River.

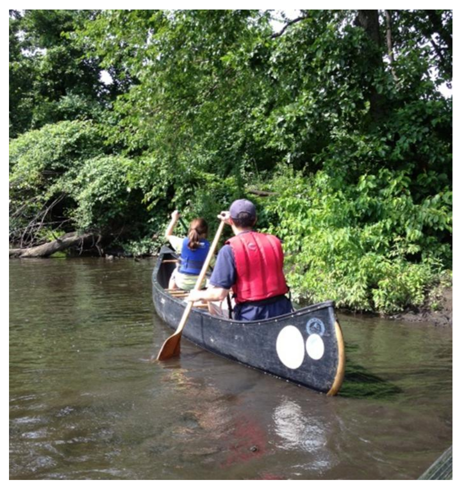
1 Introduction

The Bronx River flows 23 miles from its headwaters in Valhalla, New York and discharges to the East River in the South Bronx, between the Southview and Hunts Point neighborhoods. The north-south oriented, approximately 56 square mile, watershed flows through fifteen municipalities in New York and a small area of Fairfield County, Connecticut. Although a freshwater river for 20.7 miles, the lower 2.5 miles of the river, south of the182nd street dam, is a tidally-influenced estuary (Bronx River Intermunicipal Watershed Plan, 2010).

The Bronx River has been significantly altered by human activity over the past 200 years. Urban land uses dominate the watershed and have led to physical, chemical and biological changes in the river and its watershed. The river is identified as impaired by the New York State Department of Environmental Conservation (NYSDEC), which means it does not meet clean water and other resource goals. Despite that, the river still supports recreational and wildlife uses. Those who live and work in the watershed have recognized the need for restoration of the Bronx River, and central to that effort is the collection and understanding of relevant data about the River's water quality.

The Bronx River Alliance organizes a volunteer water quality monitoring program for the Bronx River. Volunteer stewards, including school groups, community groups, and individual residents, monitor the chemical, physical and biological conditions at fifteen locations along the Bronx River. The Alliance provides equipment and hosts volunteer monitoring workshops to train volunteers in how to collect, submit, analyze and share monitoring data, using standardized protocols and equipment. The volunteer monitoring program is helping to create a water quality database to evaluate the health of the river and identify water quality issues as they arise, as well as provide educational opportunities for students and local residents of the watershed.

The Bronx River Alliance has been organizing and assisting volunteer groups to conduct weekly monitoring for the past 5 or 6 years. Collected data is maintained locally using Excel spreadsheets and uploaded to the Global Learning and Observations to Benefit the Environment (GLOBE) program, a web-based primary and secondary school science and education program. Water quality monitoring data for the Bronx River is also available dating back to the early 1990s, collected under the direction of the Alliance's predecessors, Bronx River Restoration. The consistency and overall quality of this data is uncertain.



Bronx River near Bronx Zoo

The Bronx River Alliance has asked Fuss and O'Neill to evaluate the large amount of water quality data that has been collected to date to: (1) better understand and utilize the data, (2) identify water quality trends and data gaps, and (3) recommend modifications or additions to the water quality monitoring program to improve the quality, usefulness, and educational value of future monitoring data for the Bronx River. This report is the result.

1.1 Goals and Outcomes

The data analysis and conclusions described in this report support the large scale goals of the Bronx River Alliance water quality monitoring efforts:

- Strengthen the core partnerships with volunteer monitors in the community by helping them to understand the relevance of the data they have/are collecting and how it helps to establish baseline water quality conditions and track changes in water quality.
- Develop annotated mapping to illustrate spatial and temporal changes in water quality along the Bronx River.
- Provide for greater efficiency and more effective use of limited resources by helping to refine the water quality monitoring program based on the results of prior monitoring.

By analyzing the existing water quality data, this work will support the following outcomes:

- While there have been several years of water quality data collected, the analysis of this data to understand its implications for water quality and, in turn, human health, has been missing. This project addresses this need by providing knowledge and awareness of baseline conditions, which will help identify areas of concern that can be used to educate decision makers, residents, and state and local government.
- Educating volunteer monitors and other stakeholders about the link between water quality and environmental health by relating the data they collect to water quality standards.
- Raising environmental awareness and environmental education of water quality issues in the Bronx River by having a concise, readable document with illustrative graphics to explain the status of water quality as tracked by the volunteers.
- Providing a platform for identifying specific water quality issues based on statistical data analysis and developing plans to address them.

Students Sampling on the Bronx River

This work also supports the long term progress of the Bronx River Alliance monitoring efforts by helping to refine the current volunteer water quality monitoring program to more efficiently and effectively use limited resources. Identification of indicators that show little variation and that could be sampled less frequently or would benefit from only seasonal monitoring allows for re-allocation of resources to expand the monitoring program to other water quality parameters, locations, or methods that would improve the understanding of environmental and human health conditions in the Bronx River.

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1.2 Approach to Data Analysis

Data analysis began with a review of the existing data sources. The purpose of this screening-level evaluation is to determine the appropriate period of record for use in the overall water quality data analysis and provide a proposed outline for the data analysis. Data sources used in the screening analysis and the recommended period of record are described in Section 2.

The data analysis presented in Section 3 consists of three main components:

- Graphical and tabular statistical summary
- Correlation analysis
- Trend analysis

The graphical and tabular statistical summary characterizes the mean, median, and variability of the data. Both data table and graphics are used. Correlation of water quality parameters with other environmental parameters such as precipitation, streamflow and tidal conditions are calculated. This analysis is both helpful in understanding potential pollution sources and a necessary step for trend analysis. Trend analysis is useful to determine both spatial and temporal changes in water quality. Trend analysis in Section 3.3 follows the methods outlined in Statistical Methods in Water Resources.[1]

2 Data Sources

Table 1 and *Figure 1* illustrate the location of surface water quality monitoring locations along the Bronx River. Available data at some of these locations dates back to the 1990s. The data are from three general sources: (1) data provided by the Bronx River Alliance to the Global Learning and Observations to Benefit the Environment (GLOBE) program website[2], (2) other local monitoring by Bronx River Restoration , and (3) recent fecal indicator bacteria data collected by the New York City Department of Environmental Protection (NYCDEP) Harbor Watch[3], and the NYC Water Trail Association Citizens Water Quality Testing Program.[4]

Table 1. Bronx River Monitoring Locations (1990-2013)

Site ID	Site Name/Location	Data Source(s)	Latitude	Longitude
SWS-21	Bronx Muskrat Cove 2	• Bronx River Alliance	40.9031	-73.8585
SWS-02	Muskrat Cove North	• Bronx River Alliance	40.9000	-73.8606
BR1	233rd Street & Bronx Blvd	• DEP New York Harbor Watch	40.8950	-73.8622
SWS-03	219th Street	• Bronx River Alliance • Bronx River Restoration	40.8844	-73.8673
SWS-05	East Gun Hill Road	• Bronx River Alliance	40.8763	-73.8702

[1] Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 pages. (http://pubs.usgs.gov/twri/twri4a3/)

[2] http://www.globe.gov/

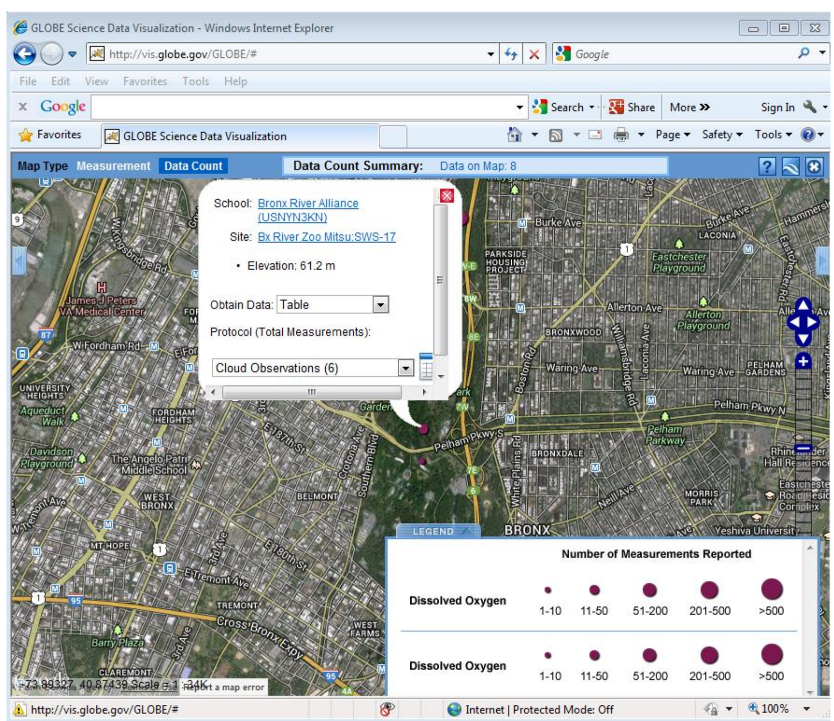
[3] http://www.nyc.gov/html/dep/html/harborwater/ harbor_water_sampling_results.shtml

[4] http://www.nycwatertrail.org/water_quality.org

Site ID	Site Name/Location	Data Source(s)	Latitude	Longitude
		• Bronx River Restoration		
SWS-06	Burke Avenue Bridge	• Bronx River Alliance • Bronx River Restoration	40.8717	-73.8728
SWS-07	Kazimiroff Blvd Bridge	• Bronx River Alliance • Bronx River Restoration	40.8670	-73.8742
SWS-09	Fordham Bridge "A" (Bronx Park Road)	• Bronx River Restoration	40.8589	-73.8765
SWS-17	Bronx Zoo (Fordham Bridge "B")	• Bronx River Alliance • Bronx River Restoration	40.8570	-73.8763
SWS-10	Mitsubishi River Walk: Bronx Zoo	• Bronx River Alliance	40.8548	-73.8764
SWS-11	180th Street	• Bronx River Alliance • Bronx River Restoration	40.8431	-73.8769
SWS-13	Tremont Avenue	• Bronx River Alliance • Bronx River Restoration	40.8390	-73.8789
SWS-14	Starlight Park	• Bronx River Alliance • NYC Water Trail Association	40.8326	-73.8829
BR3	Westchester Avenue	• DEP New York Harbor Watch	40.8283	-73.8839
SWS-15	Concrete Plant Park	• Bronx River Alliance	40.8251	-73.8850
SWS-16	Hunts Point Riverside Park	• Bronx River Alliance • NYC Water Trail Association	40.8179	-73.8814
BR5	Soundview Park North	• DEP New York Harbor Watch	40.8140	-73.8714
SWS-01	Soundview Park South	• Bronx River Alliance	40.8082	-73.8594
SWS-18	East River Barretto Point Park	• Bronx River Alliance	40.8048	-73.8879

2.1 GLOBE Data

The Global Learning and Observations to Benefit the Environment (GLOBE) program website (http://www.globe.gov/) has historically been the most consolidated source of volunteer water quality monitoring data for the Bronx River. Over several years, water quality data collected by the Bronx River Alliance and its monitoring partners was contributed to the GLOBE database, which was designed to provide a repository for worldwide data collection. Data available from the GLOBE site for the period 2003-2010 was provided directly to Fuss & O'Neill by the Bronx River Alliance. In addition, data for some stations for 2011 and 2012 became available on the GLOBE site



GLOBE Website

during the report preparation and was downloaded by Fuss & O'Neill directly from the GLOBE site. Data from GLOBE typically consists of water temperature, dissolved oxygen (DO), and pH. Nitrate and transparency is also frequently available for many sites for several years. Data was typically collected throughout the calendar year on an intermittent basis. A total of 16 stations were included in the available data.

Figures 2 and 3 summarize the data available from the GLOBE website.

2.2 Other Local Data Sources

The Bronx River Alliance provided several additional data files. Review of these files and correlation with existing monitoring locations identified on the GLOBE site revealed that water quality data collected as early as the 1990s was available for the following stations: SWS-03 (219th Street), SWS-05 (East Gun Hill Road), SWS-06 (Burke Avenue Bridge), Kazimiroff Blvd Bridge (SWS-07), SWS-09 (Fordham Bridge "A"), SWS-11 (180th Street), SWS-13 (Tremont Avenue), and SWS-17 (Bronx Zoo (Fordham Bridge "B")). The Bronx River Restoration data was collected throughout the calendar year from 1990 to 1998 and consistently included water temperature, DO and pH. The Bronx River Alliance River Stewards data was collected at SWS-01 (Soundview Park South), SWS-02 (Muskrat Cove North), SWS-06 (Burke Avenue Bridge), and SWS-16 (Hunts Point Riverside Park) during 2010-2012 and at Kazimiroff Blvd Bridge (SWS-07) and SWS-21 (Bronx Muskrat Cove 2) in 2011 and typically included water temperature, dissolved oxygen (DO), pH, salinity, nitrates, and phosphate.

2.3 Fecal Indicator Bacteria (FIB) Data

Collection of fecal indicator bacteria data on the Bronx River began in 2011 by the NYC DEP Harbor Watch and in 2013 by the NYC Water Trail Association. Both fecal coliform and enterococcus data have been collected by Harbor Watch, and only enterococcus data has been collected to date by the Bronx River Alliance and analyzed by the NYC Water Trail Association. Sampling has been performed by the NYC Water Trail Association approximately weekly since May 2013 and includes only enterococcus data. DEP Harbor Watch data collection has been approximately weekly throughout the calendar year since 2011 and consistently included DO, fecal coliform, and enterococcus data. Fecal Indicator Bacteria (FIB) data was also collected by both groups in 2014, but was not available in time for inclusion in this project. (Data from this study has not been analyzed within this report.)

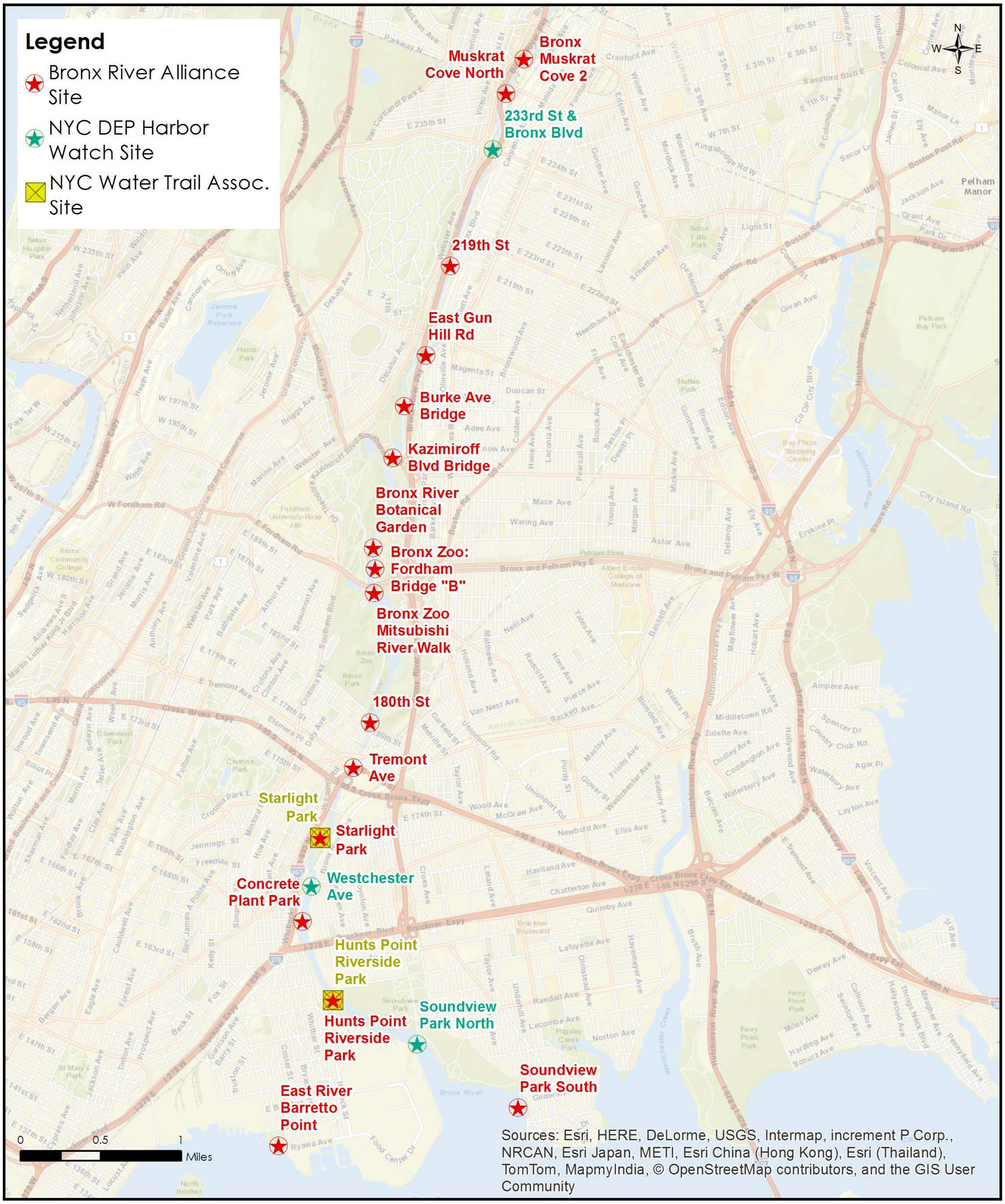


Figure 1. Bronx River Water Quality Monitoring Station Locations

3 Statistical Analysis of Data

3.1 Graphical and Tabular Summary

Since 1990, over 1,012 water quality samples have been collected along the Bronx River. *Figure 2* shows that the majority of the data has been collected at SWS-06 (Burke Avenue Bridge), about one-third of the way down the river, and SWS-16 (Hunts Point Riverside Park), and SWS-01 (Soundview Park South), located in the lower, tidal portions of the river. The greatest number of samples has been collected since 2008, with the greatest annual number of samples to date (*Figure 3*) collected in 2011[5].

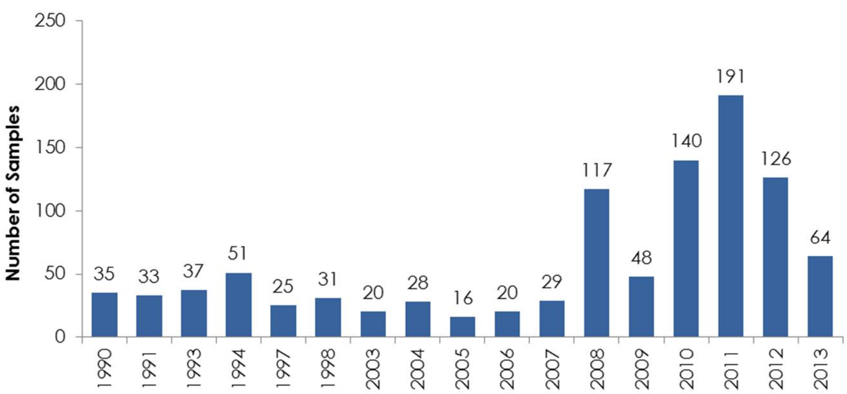


Figure 3. Number of Samples Collected by Year

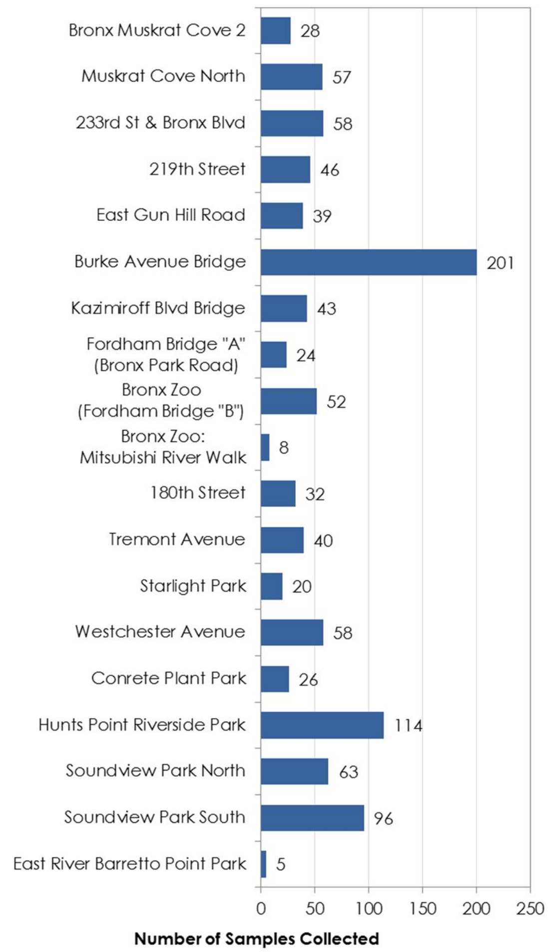


Figure 2. Number of Samples Collected at Each Monitoring Location over the Period of Record (1990-2013)

Table A-1 in *Appendix A* summarizes the data collected by monitoring location, year, and water quality parameter. Review of this table shows that the following parameters have been consistently collected at many locations:

- Water temperature (C)
- pH (standard units)
- Dissolved Oxygen (mg/L)

These parameters, along with the FIB data collected more recently, are the best candidates for comprehensive analysis because they have a relatively long period of record at multiple stations and allow for more in-depth analysis of spatial and temporal differences in water quality along the river. Other parameters have been collected less frequently – total nitrogen, nitrate, nitrite, conductivity, transparency, and salinity – but still provide some ability to evaluate spatial differences along the river.

Table A-2 in *Appendix A* provides a statistical summary of the data over the period 1990-2013. In reviewing the data in *Table A-2*, it is important to remember that some stations may have had only a few

[5] Data for 2013 represents only a partial year, spanning approximately January to August 2013.

samples collected or samples collected only during a single season of the year. Summary statistics for these stations and water quality parameters provide a less representative picture of conditions than stations with multiple samples taken over a longer period of time.

Several of these parameters provide insight into the water quality conditions in the river both over time and in space. In Is the Bronx River Healthy?[6] (Bronx River Alliance, 2007), the importance of temperature, pH, and DO as indicators of a healthy waterbody's capability to support biodiversity is highlighted. These three parameters are the focus of a graphical analysis of the data to provide a more comprehensive understanding of water quality conditions. Other water quality parameters addressed in this section include: salinity, conductivity, and total dissolved solids; nutrients; transparency; and cyanobacteria and harmful algal blooms.

Throughout this report, box and whisker plots, also referred to as boxplots, are used as a tool to summarize water quality data. *Figure 4* shows the elements of a boxplot.

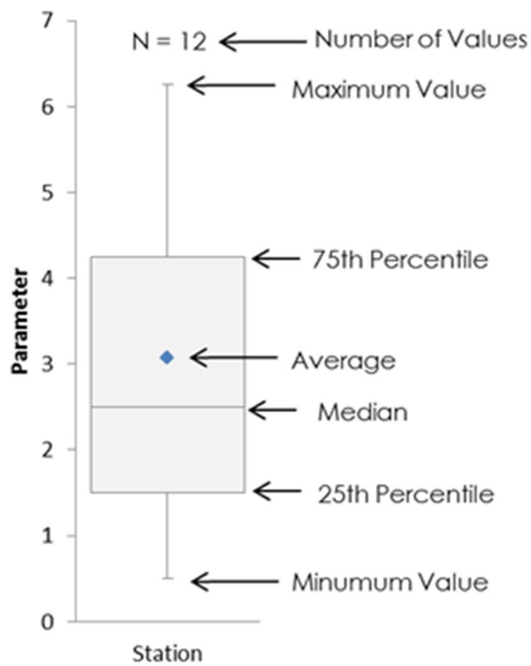


Figure 4. Elements of a Boxplot

3.1.1 Water Temperature

Ambient water temperature is important for the survival of aquatic organisms. Most aquatic animals have adapted to living within a specific temperature range and do not tolerate extremes of heat or cold. In addition, temperature affects the amount of DO present in the water column, with cooler water being able to hold more oxygen. *Figure 5* illustrates the relationship between temperature and habitat conditions for aquatic organisms. Elevated temperatures may reflect the influence of thermal pollution,

[6] http://www.bronxriver.org/puma/images/usersubmitted/file/007_IstheBxRHealthy.pdf

i.e., warm runoff or industrial discharges into the river, or the presence of low flows that allow more sunlight penetration and subsequent warming of the water column, especially in the summer season.

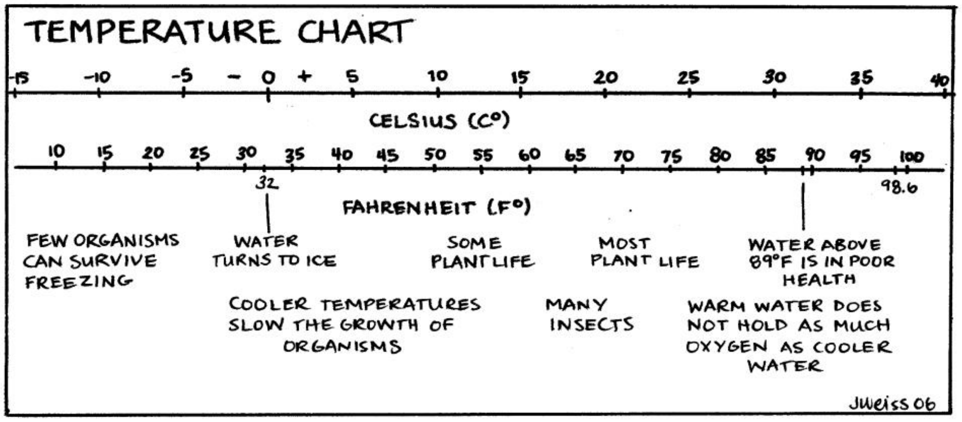


Figure 5. Temperature and Aquatic Health
(Bronx River Alliance, 2007)

Generally, temperatures above the freezing point of water and below approximately 30 degrees Celsius (ºC) are best suited for aquatic organisms. *Figures 6 and 7* provide two ways of looking at water temperature along the Bronx River and over time. The line plot in *Figure 6* shows changes in temperature at stations upstream (SWS-02 (Muskrat Cove North)), near the midpoint (SWS-06 (Burke Avenue Bridge)), and near the mouth (SWS-16 (Hunts Point Riverside Park)) of the river. As expected, temperatures show relatively consistent seasonal variation at all three locations. Temperatures throughout the period 2003-2013 are generally within the 5-30 ºC range, indicating acceptable temperature conditions for aquatic organisms.

Figure 7 provides a comparison of water temperature in 2011 at seven stations along the Bronx River. Most of the sampling locations in *Figure 7* have approximately 20 samples collected through the year, with the exception being SWS-07 (Kazimiroff Blvd Bridge) with only four samples. A few key observations about spatial differences in temperature illustrated in *Figure* 7 are:

- Mean (indicated by dot) and median (indicated by horizontal line within the box) values are of similar magnitude, indicating a fairly normal distribution of high and low temperature data.
- All the stations except for BR5 (Soundview Park North) have similar variability, with the majority of the temperature values within a 10 degree range. BR5 (Soundview Park North) shows both less variability and higher overall temperatures.
- Minimum temperatures were above 5 ºC and below 30 ºC at all seven locations, indicating a suitable temperature range for aquatic organisms.
- Temperatures at Burke Avenue Bridge (SWS-06) and upstream tend to have lower mean, median, and maximum temperature values than downstream locations.
- Temperatures at SWS-07 (Kazimiroff Blvd Bridge) and downstream tend to have higher mean, median, and maximum temperature values; however, the apparent "jump" in temperature between SWS-06 (Burke Avenue Bridge) and SWS-07 (Kazimiroff Blvd Bridge) is likely the result of the small number of temperature observations at SWS-07 (Kazimiroff Blvd Bridge).

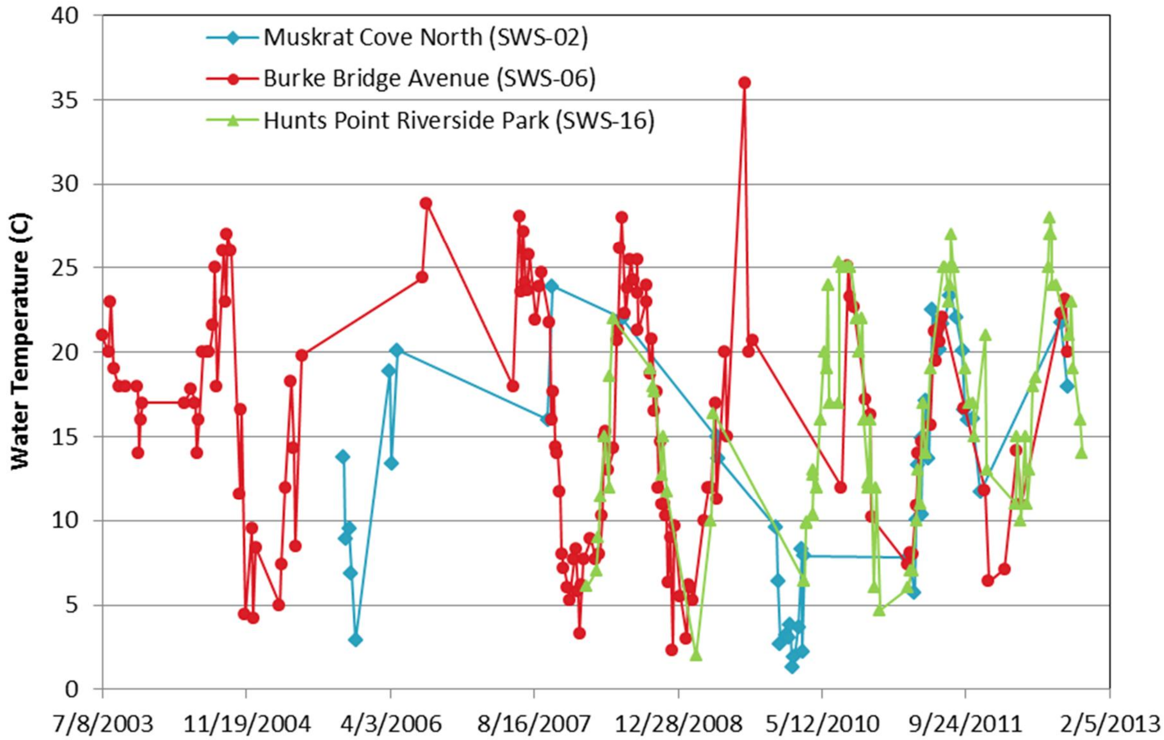


Figure 6. Temporal Variation of Water Temperature along the Bronx River

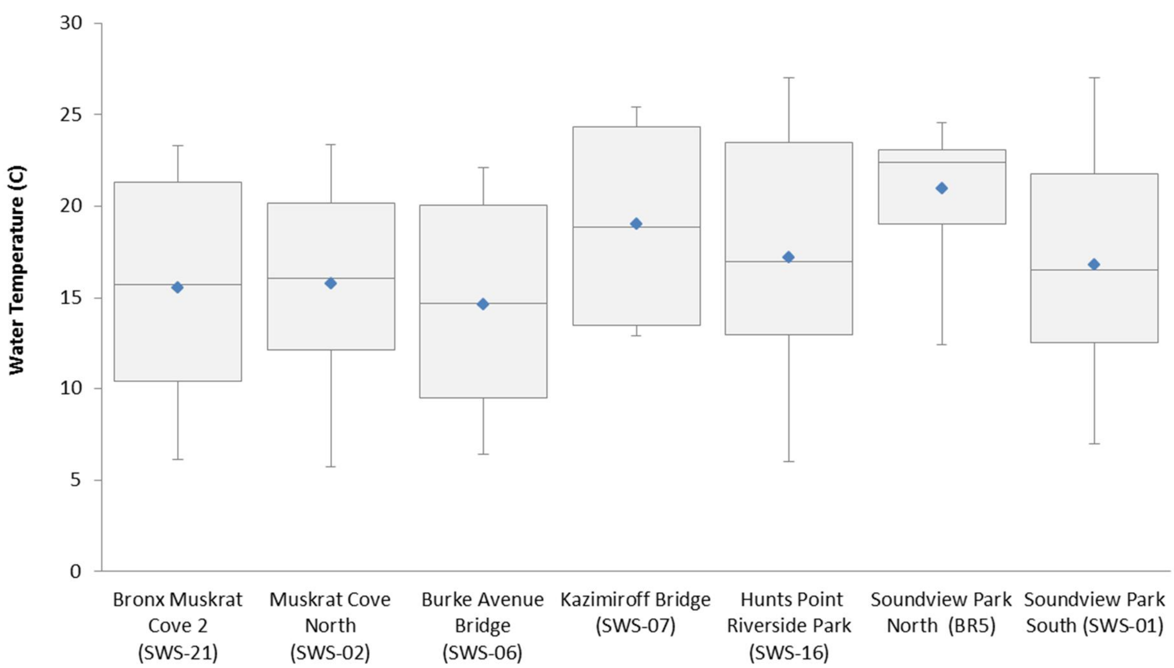


Figure 7. Boxplots of Water Temperature along the Bronx River in 2011

3.1.2 pH

pH is a measurement of the hydrogen concentration in water and indicates the acidity or alkalinity of a substance. pH ranges from 0 (highly acidic) to 14 (highly alkaline), with 7 being a neutral pH (*Figure 8*). The pH of precipitation is slightly acidic (usually near 6), influencing the pH of receiving waters. A pH range of 6.5-8.5 is best for most organisms, and aquatic life is impacted at pH values outside of this range. Both acute (pH = 3) and chronic (pH = 4.8) standards for pH have been established by NYSDEC. Examination of *Table A-2* and *Figure 9* shows that these standards are achieved at most locations along the river the majority of the time over the period of record,[7] although greater variability in pH is typically observed upstream.

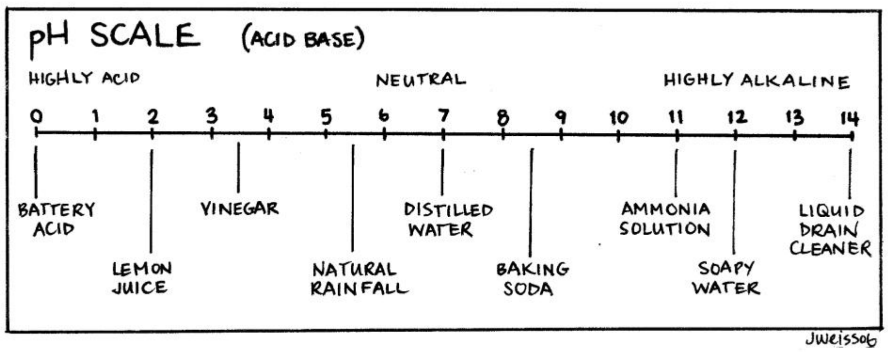


Figure 8. pH and Household Equivalents
(Source: Bronx River Alliance, 2007)

[7] It should be noted that in the review of the data, pH values that were less than 4 were removed from the analysis, since they were most likely due to instrument calibration issues, given the unlikeliness of encountering values that low in ambient waters. The pH measurements removed included 5 taken in June and August 2011 that ranged from 1 to 3.03.

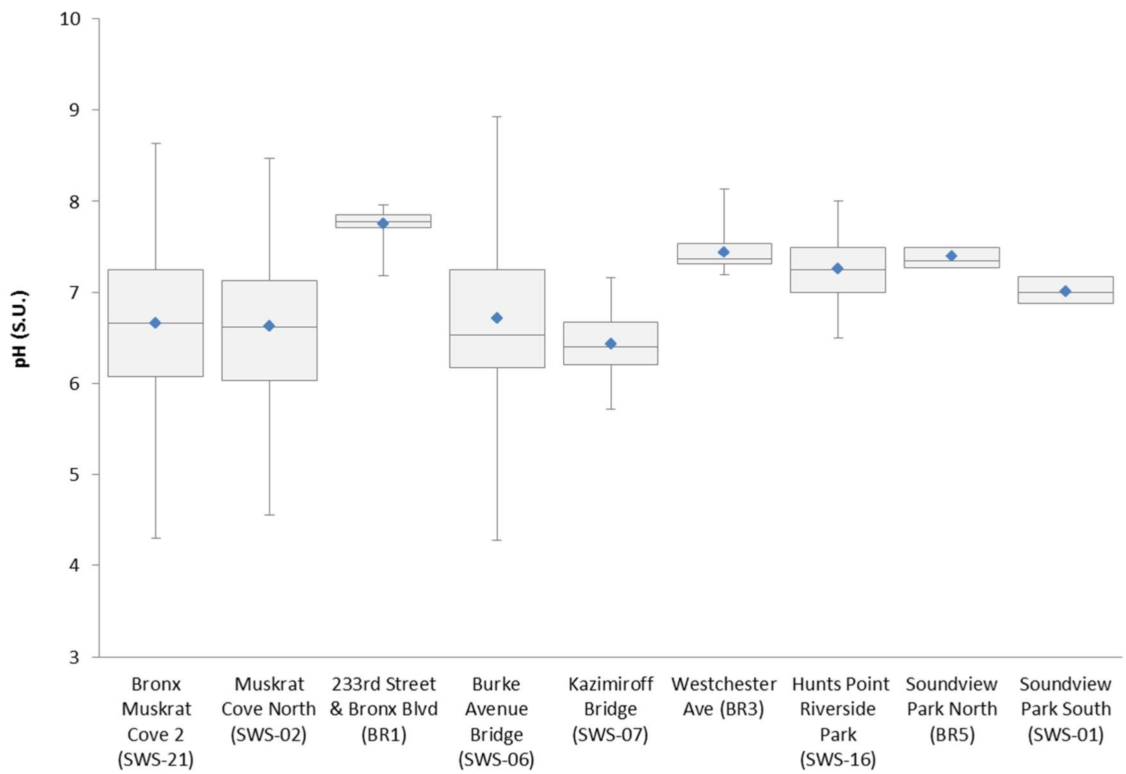


Figure 9. Boxplots of pH along the Bronx River

3.1.3 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen (O_2) dissolved in water. DO is a key indicator of aquatic water quality and sufficient concentrations of DO are needed for aquatic organisms to survive. Oxygen is both generated and consumed in a river. It enters a river from the atmosphere and from aquatic plants during photosynthesis. Running water, because of its churning movement, dissolves more oxygen from the atmosphere than still water. Oxygen is consumed in a water body through respiration by aquatic animals and as a result of decomposition of organic material. Stormwater runoff and wastewater discharges typically contain organic material. As it is decomposed by microorganisms, oxygen is consumed. This consumption is measured by another water quality parameter, biochemical oxygen demand or BOD.

DO is also influenced by temperature and fluctuates both seasonally and diurnally. Cooler water is capable of holding more DO than warmer water, so conditions which lead to higher water temperatures also typically result in lower DO. DO concentrations of 6 mg/L and above are best for aquatic organisms. Values between 2.5 and 6 mg/L represent stressed conditions and values below 2.5 mg/L are extremely poor, with values less than 1 mg/L representing anoxic (absence of oxygen) conditions (*Figure 10*).

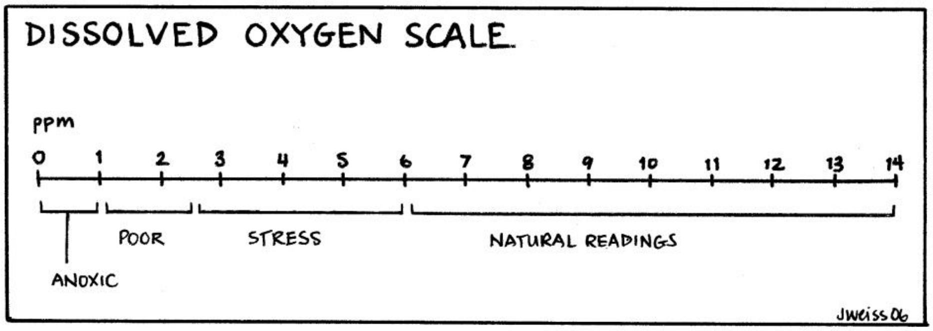


Figure 10. Dissolved Oxygen and Aquatic Health
(Source: Bronx River Alliance, 2007)

The NYSDEC has a classification system for water quality and its anthropogenic use. The Bronx River is classified in three segments due to its change from freshwater in its headwaters to brackish water . Within Westchester Country, the Bronx River is classified by the NYS DEC as a Class C freshwater, which recommends that the water is suitable for fish, shellfish, and wildlife propagation and survival and the water quality is suitable for primary and secondary contact recreation. From the Bronx border of Westchester County to the 180th Street Dam, the River is classified as a Class B freshwater. A Class B freshwater is suitable for fish, shellfish, and wildlife propagation and survival and the best usage of the water is for primary and secondary contact recreation and fishing. The estuary and tidal portion of the river are considered Class I waters, which are best used for secondary contact recreation and fishing and are suitable for fish, shellfish, and wildlife propagation and survival.

Applicable water quality standards for DO are presented in *Table 2*. Because of the importance of DO as a water quality indicator, the data was examined in several ways. The information in *Table A-2* provides a broad summary of all the stations over the entire period of record. Average and median concentrations over the period of record for each station are above the water quality standards for DO in *Table 2*.

Table 2. New York State Numeric Surface Water Quality Criteria for Dissolved Oxygen

Class	Dissolved Oxygen
B,C (Freshwater)	>5.0 mg/L daily average >4.0 mg/L
I (Saline)	≥ 4.0 mg/L

Examining the marine water (Class I) stations, five of the seven stations have minimum values less than 4 mg/L, and of those, two stations (BR3 (Westchester Avenue) and SWS-18 (East River Barretto Point Park)) have first quartile values (i.e., lowest 25% of the values) less than 4 mg/L, indicating that 25% of the data is less than the water quality standard. An examination of the raw data shows that SWS-18 has only 5 dissolved oxygen data points in 2008, so BR3 (Westchester Avenue) is more representative of current conditions. For the freshwater locations, while five of the 15 stations have minimum values less than 4 mg/L, none has a 25th percentile, i.e., first quartile, value less than 4 mg/L. This suggests that while there are episodes of low DO, they are not as frequent as the downstream, marine water, stations.

To more closely examine current conditions, DO data over the period 2010-2013 was plotted as averages along the river (*Figure 11*) and as boxplots for stations at several locations (*Figure 12*). *Figure 11* shows that average DO concentrations for the past 3 years have been both above the water quality standard for the respective portions of the river (freshwater and tidal) and also within a range suitable for aquatic organisms. The larger circles in the upper portion of the watershed indicate higher average DO values in these areas compared to downstream areas of the river. The boxplots for the same stations and time period provide additional insight into DO conditions. SWS-06 (Burke Avenue Bridge) shows the greatest variability, with DO values ranging from nearly 18 mg/L to less than 2 mg/L. The wide range for this station may be indicative of its location between dams, which can result in changes in flow conditions. Summer conditions at that location can be characterized by shallow, calm waters, which generate low DO conditions.

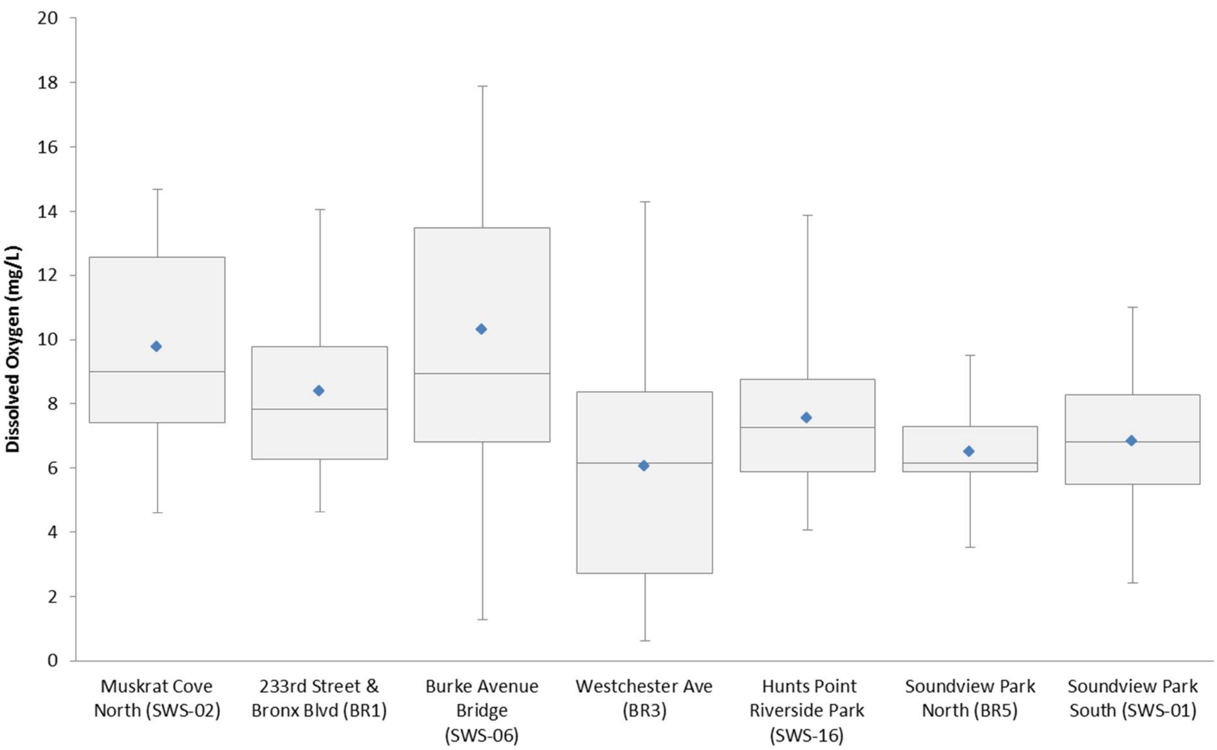


Figure 11. Boxplots of Dissolved Oxygen (2010-2013)

Despite the variability at SWS-06 (Burke Avenue Bridge), the 25th percentile value (6.8 mg/L) is higher than the median value at BR3 (Westchester Avenue) or BR5 (Soundview Park North). Although there is less variability in DO concentration at stations downstream of I-95, the mean, median, and 75th percentile (highest 25% of the data) of the data is not noticeably lower than the upstream stations examined. This comparison of upstream and downstream stations is illustrated well by a comparison of BR1 (233rd Street & Bronx Blvd) and BR3 (Westchester Avenue). Both sampled as part of the DEP's Harbor Watch program, they provide a matched set of DO values. *Figure 12* shows that DO values at BR3 (Westchester Avenue) are usually lower than BR1 (233rd Street & Bronx Blvd) on the same day, sometimes by as much as 2 mg/L or more.

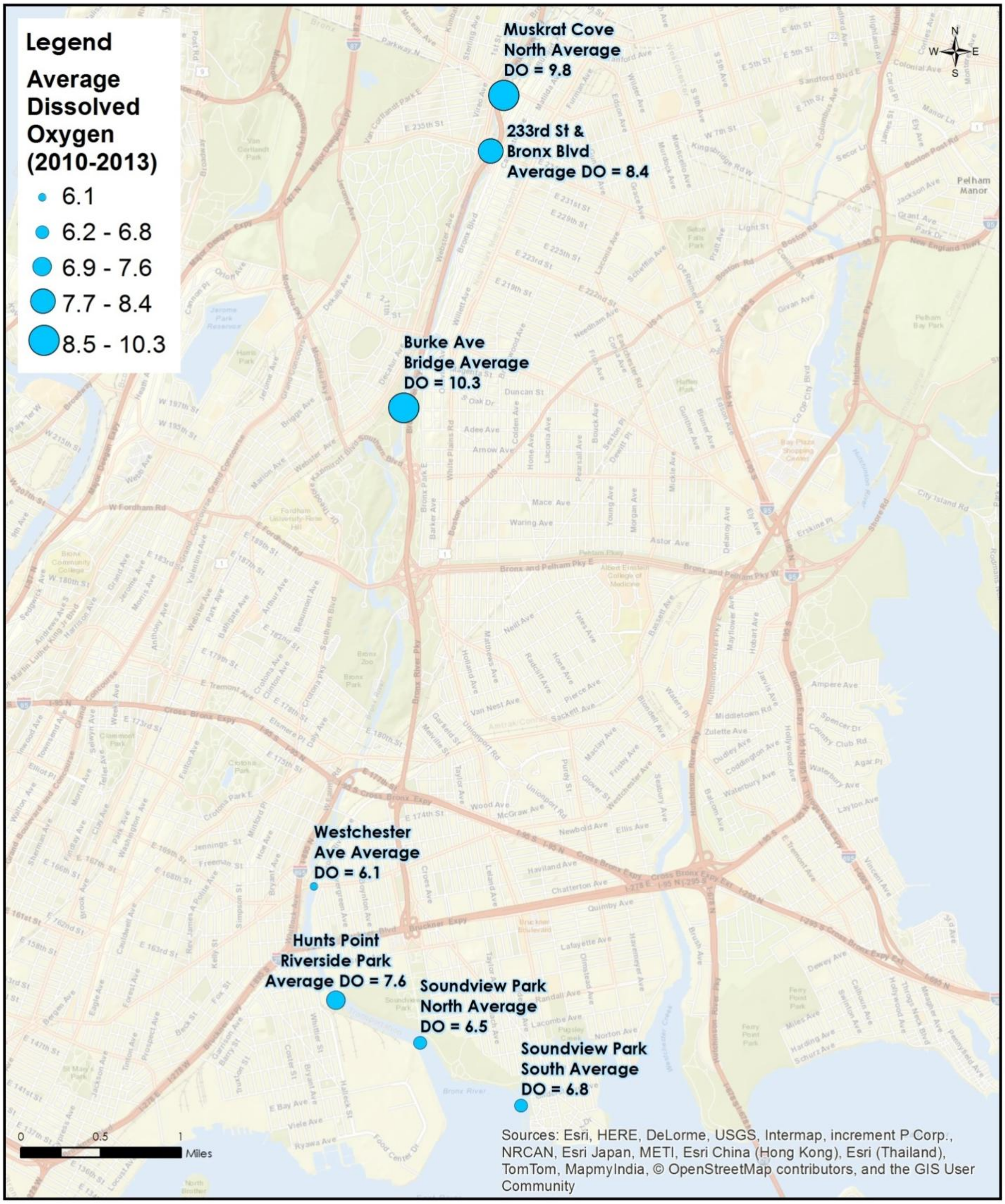


Figure 12. Map of Average Dissolved Oxygen in the Bronx River (2010-2013)

(Note: Data Compiled from Sources Listed in Table 1)

Data from 1994, one of the early years of the period of record, was also examined (*Figure 13*). Too few observations were available in the tidal portion of the river to create boxplots, so the comparison between upstream and downstream locations cannot be made. Although there were only 6-8 values at the stations in 1994, the median of all values is approximately 13 mg/L, with the lowest values near 7 mg/L. This raises the question if there has been a decline in DO concentrations over the past decade. Further assessment of that issue is important because the lower Bronx River and its tributaries were recently delisted for DO based on planned improvements (NYSDEC, 2013b).

As *Table A-1* in *Appendix A* shows, few sampling locations have had a sufficient number of samples collected from the 1990s through present to answer that question. 2008 marks the start of more consistent and frequent sampling at a number of stations. To look more closely at DO over the period 2008-2012, SWS-06 (Burke Avenue Bridge) and SWS-16 (Hunts Point Riverside Park) were compared. *Figure 14* shows that the mean values of DO have varied over the time period but do not show a consistent pattern based on visual inspection alone, other than the apparent spatial differences between stations. Possible trends in DO and other water quality parameters will be examined in more detail in later sections.

As discussed above, changes in DO along the stream can be the result of changes in flow and water depth that can influence oxygen exchange with the atmosphere, temperature, and inputs from stormwater runoff and wastewater discharges. In this comparison it should be noted that SWS-06 (Burke Avenue Bridge) is located upstream of the Combined Sewer Overflow (CSO) outfalls along the Bronx. These outfalls are a source of organic material (and subsequent oxygen demand) that are not present at SWS-06 (Burke Avenue Bridge) and points upstream.

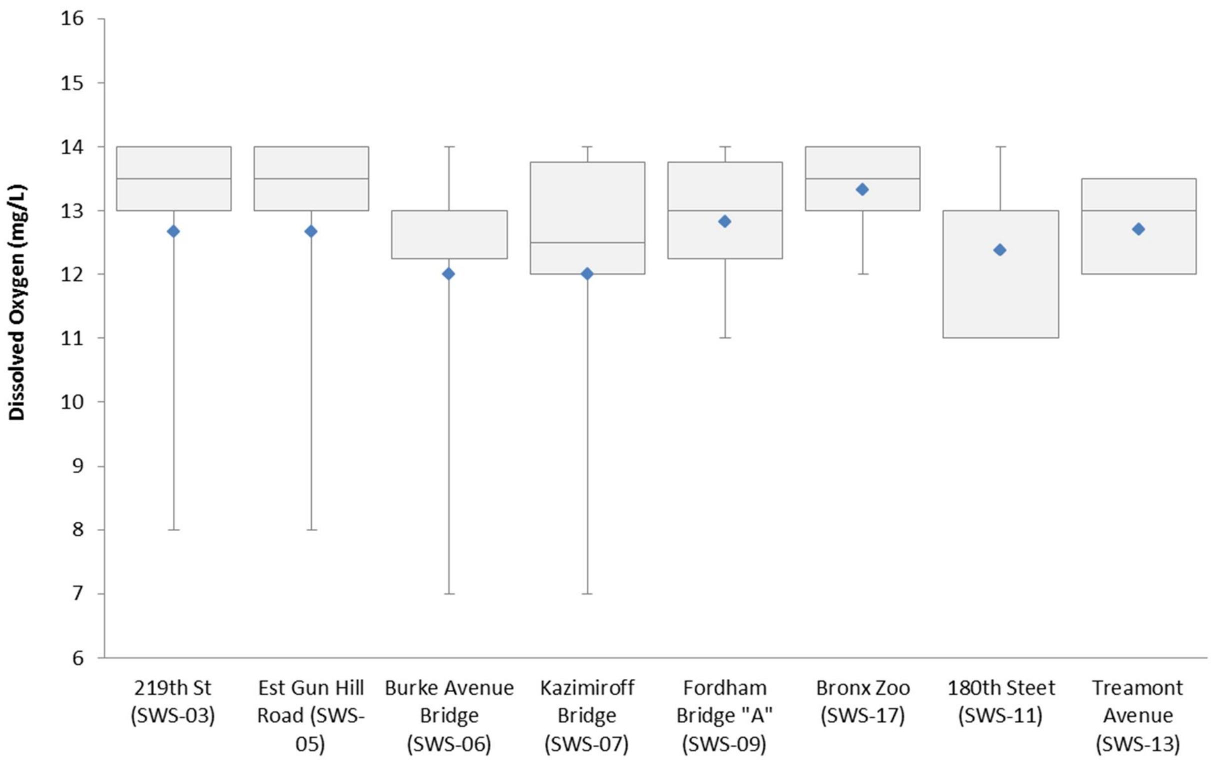


Figure 13. Boxplots of Dissolved Oxygen along the Bronx River in 1994

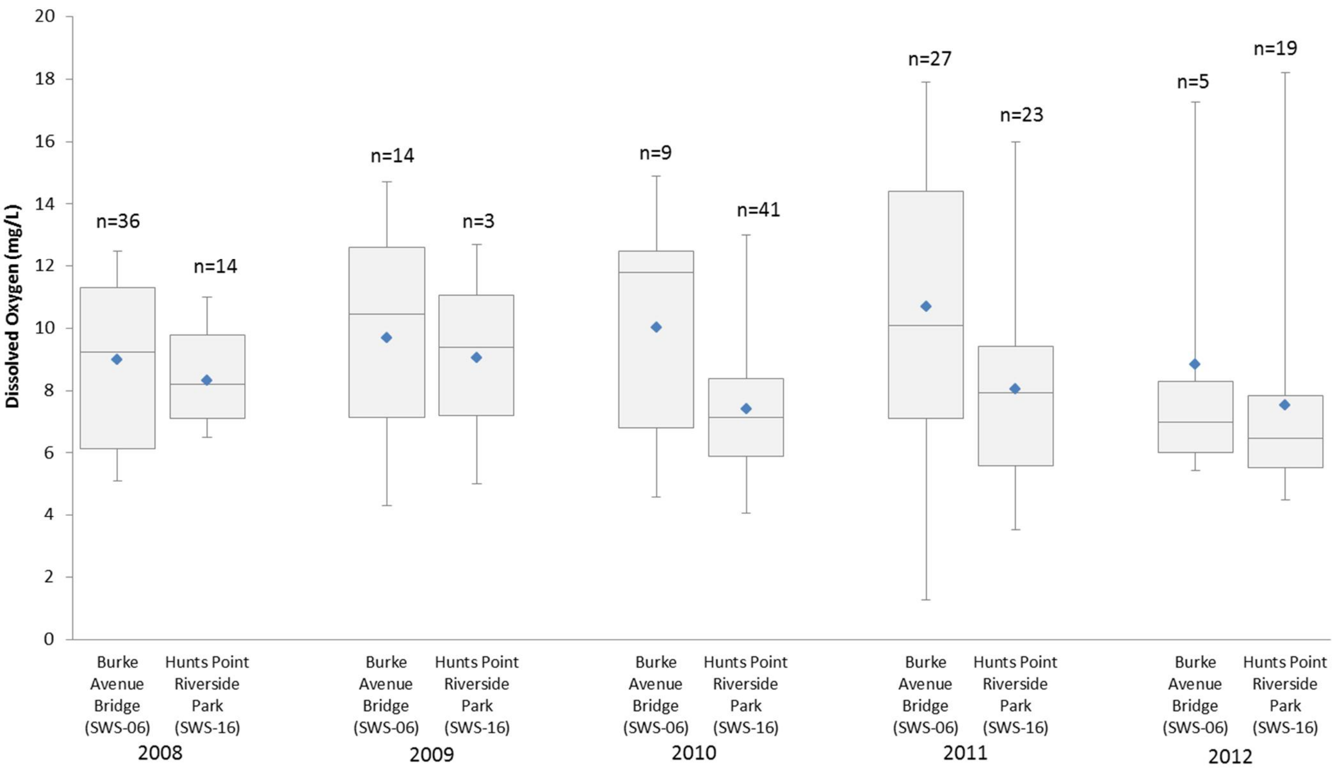


Figure 14. Boxplots of Dissolved Oxygen at SWS-06 (Burke Avenue Bridge) and SWS-16 (Hunts Point Riverside Park) (2008-2012)

3.1.4 Fecal Indicator Bacteria

While other parameters are indicators of water quality important for aquatic habitat, concentrations of fecal indicator bacteria (FIB) are the basis for the standards for primary and secondary contact recreation. Primary contact recreation includes swimming and bathing; secondary contact recreation includes boating, paddling, and fishing. As shown in *Table 3*, the freshwater standards for FIB use total and fecal coliform concentrations. For saline waters, enterococci standards are also in place, but not for Class I waters. For reference, the enterococci standard for SB/SC, which would be the next most stringent water quality classification for the tidal portion of the Bronx River, is ≤ 35/100 mL.

As mentioned in *Section 2.3*, consistent collection of FIB data has begun only recently (2011). However, examination of data from 2011-2013 highlights some of the spatial differences in the river. (Note that data was collected in 2014, but was not available in time for inclusion in this report.) *Figure 15* shows the geometric mean (i.e., geomean) for all FIB data collected at BR1 (233rd Street & Bronx Blvd), BR3 (Westchester Avenue), and BR5 (Soundview Park North) over the period 2011-2013. Geomean values for both enterococci and fecal coliform are the highest at BR1 (233rd Street & Bronx Blvd), the most upstream location, and exceed the monthly geomean fecal coliform standard of 200/100 mL by an order of magnitude.

Table 3. New York State Numeric Surface Water Quality Criteria for Fecal Indicator Bacteria

Class	Fecal Indicator Bacteria		
	Total Coliform (per 100 mL)	Fecal Coliform (per 100 mL)	Enterococci (per 100 mL)
B,C (Freshwater)	Monthly median <2,400 80%<5,000	Monthly geometric mean <200	NA
I (Saline)	≤10,000	≤2,000	NA

Looking at the same data using boxplots (*Figures 16 and 17*) shows the changes moving down the river. Although sometimes difficult to perceive on a logarithmic scale, which is often used to display bacteria data that varies several orders of magnitude, the variability in fecal coliform (as indicated by the height of the boxes) is similar at BR1 (233rd Street & Bronx Blvd) and BR3 (Westchester Avenue), but an order of magnitude less at BR5 (Soundview Park North). For enterococcus, variability decreases moving down the river. Geomean values for both fecal coliform and enterococcus are below the water quality standard for Class I waters at BR5 (Soundview Park North), but geomean fecal coliform concentrations at BR1 (233rd Street & Bronx Blvd) are an order of magnitude above the water quality standard. Even the lowest 10% of the data is above the Class B,C water quality standard.

To determine compliance with the monthly geomean standard, the appropriate FIB values were calculated and plotted as a time series for BR1 (233rd Street & Bronx Blvd), BR3 (Westchester Avenue), and BR5 (Soundview Park North). Comparison of the monthly geomean with the applicable water quality standard illustrates the greater frequency of violation of the applicable standard for BR1 (233rd Street & Bronx Blvd) (Class B,C) compared to BR3 (Westchester Avenue) and BR5 (Soundview Park North) (Class I). Although the Class SB,SC enterococcus standard does not apply to BR3 (Westchester Avenue) and BR5 (Soundview Park North), *Figure 18* shows that BR5 (Soundview Park North) would comply with the standard for the majority of the period of record. For reference, the EPA recommended enterococcus standard of 61 cfu/100 mL for contact recreation in freshwaters is also shown in *Figure 18*. Comparison with BR1 (233rd Street & Bronx Blvd) monthly geomean values shows that the only compliant month was April 2012.

Comparison of the data in *Figure 12* and *Figure 15* shows that although DO concentrations are typically lower downstream, FIB do not increase with decreasing DO, indicating that other drivers of oxygen depletion, not necessarily associated with FIB, are influencing DO concentrations.

Figures 15-17 provide visualization of the spatial and temporal differences in FIB. Comparison of mean, median, maximum, and minimum values shows that while values at an individual station remained relatively consistent from year to year, upstream stations consistently show higher values of each of these statistics.

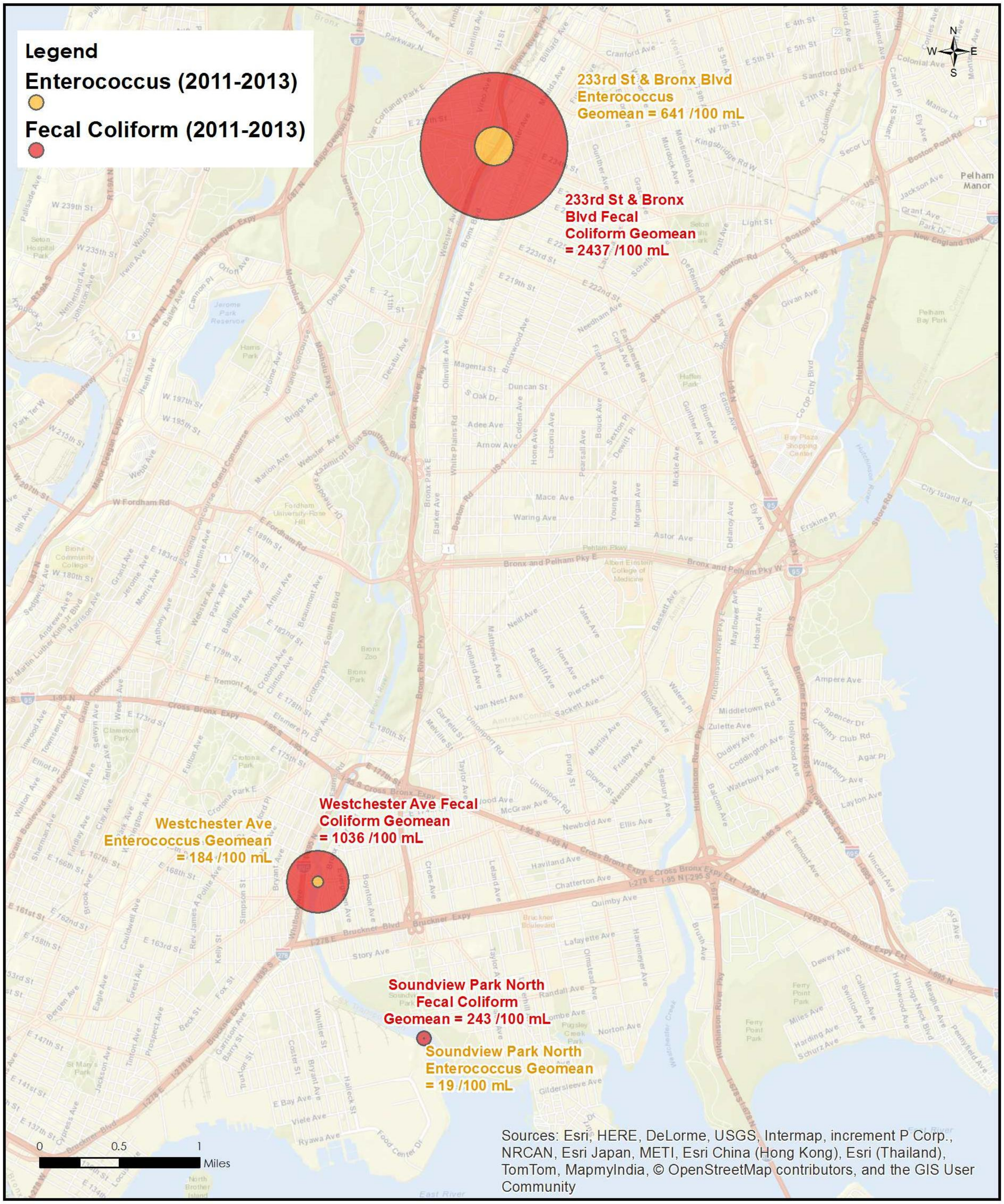


Figure 15. Map of Geomean of Bacteria Data (2011-2013)

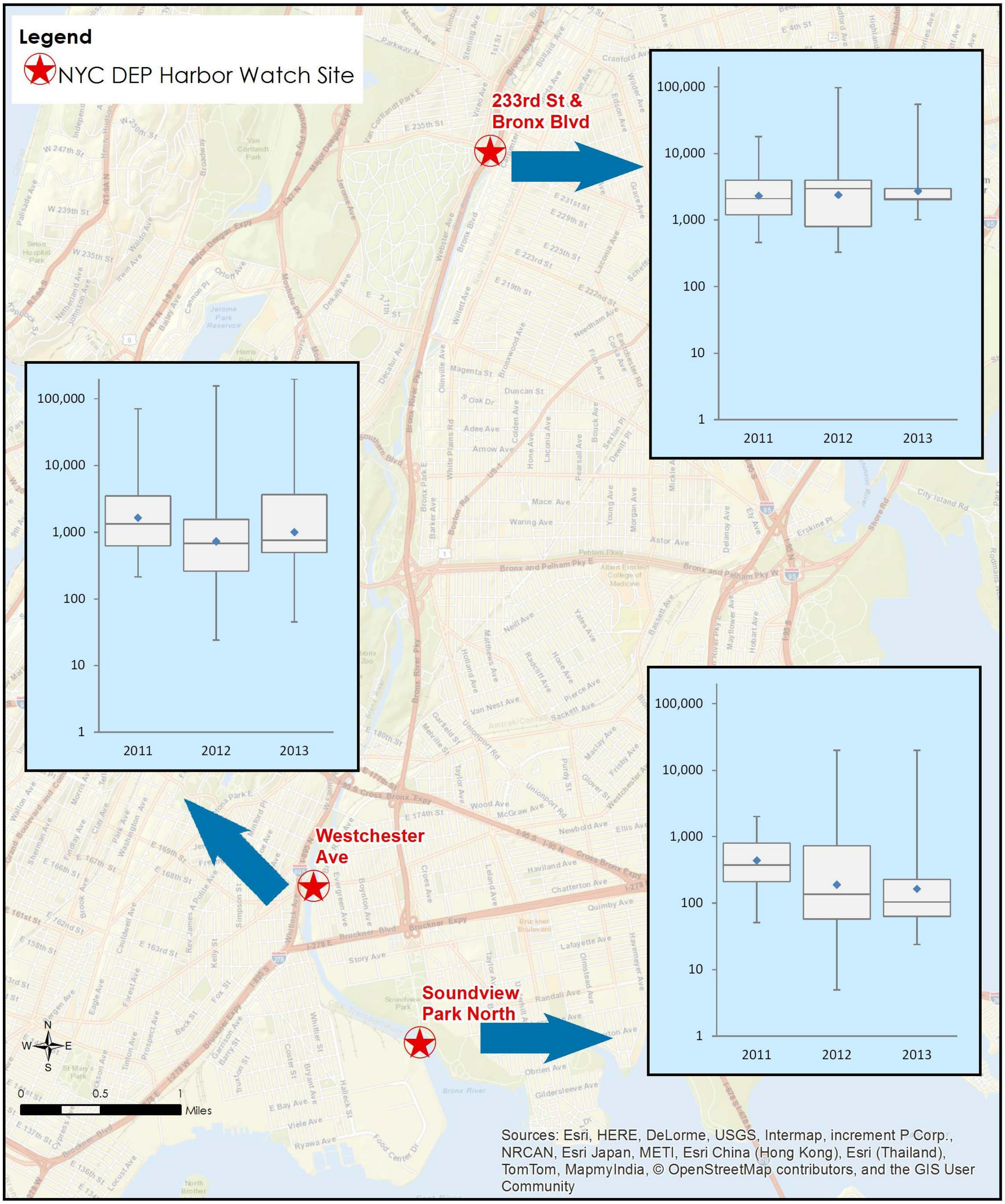


Figure 16. Spatial and Temporal Differences in Fecal Coliform (2011-2013)

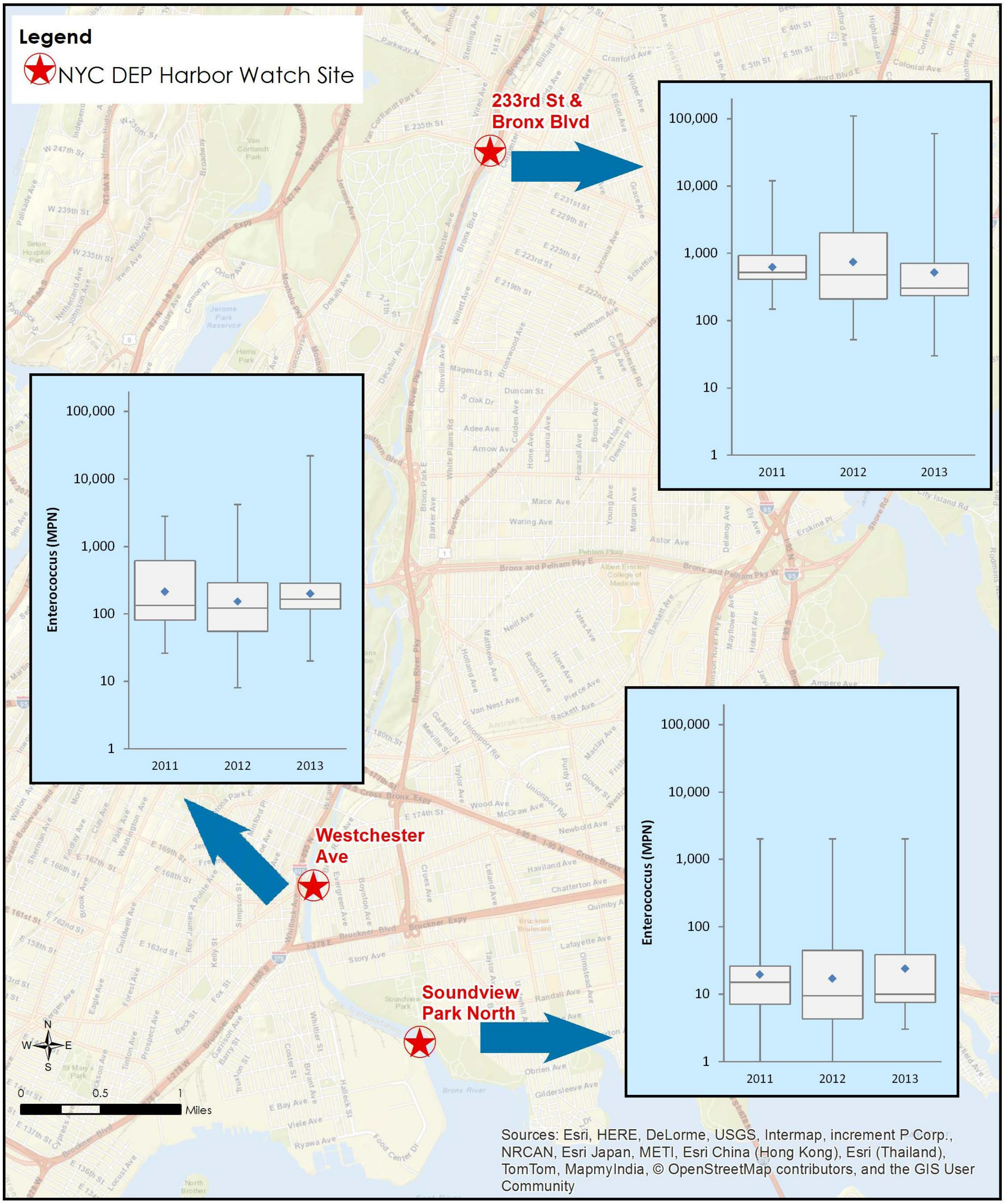


Figure 17. Spatial and Temporal Differences in Enterococcus (2011-2013)

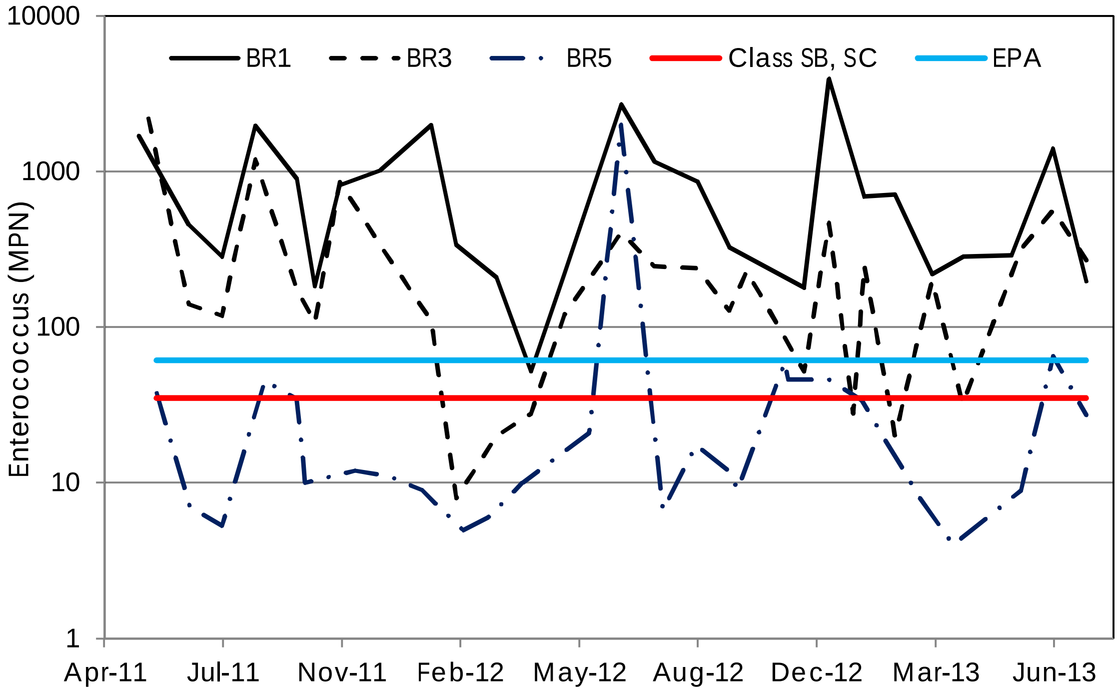


Figure 18. Time Series of Enterococcus and Reference Water Quality Criteria at 233rd Street & Bronx Blvd (BR1), Westchester Ave (BR3), and Southview Park North (BR5)

It should be noted that, at the time of writing of this report, only one year of data from the New York Water Trail monitoring (Starlight Park and Hunts Point Riverside Park) was available. Additional years of data will provide more information about the magnitude and distribution of FIB at those locations. Data from these FIB studies conducted from 2011-present day are available on the EPA STORET webpage (www.epa.gov/storet/) and the Bronx River Alliance Water Quality webpage (www.bronxriverwater.org).

3.1.5 Salinity, Conductivity, and Total Dissolved Solids

Salinity is a measure of the dissolved salts in water. The salinity of seawater is typically near 35 psu. Freshwater should have salinity near 0 psu. Not surprisingly, the stations in the tidally-influenced sections of the Bronx River show higher salinity values. Although there are relatively few measurements in the upstream portions of the river (e.g., SWS-02 (Muskrat Cove North), SWS-05 (East Gun Hill Road), they have higher than expected salinity values (*Figure 19*). These elevated concentrations in the upstream areas of the Bronx River may reflect the input from stormwater and (illicit) sanitary sewer discharges. *Figure 20* shows that the variation in salinity is relatively consistent at upstream and downstream locations from year to year.

Conductivity can provide additional insight into potential pollution sources. While the conductivity of freshwater can vary depending on watershed characteristics, variability in conductivity and total dissolved solids (TDS) measurements can indicate the influence of wet weather sources including stormwater runoff. *Figure 21* and *Figure 22* show the data for non-tidally-influenced stations with greater than 10 conductivity and TDS measurements; 2011 is the only year of record to meet the requirement for a minimum of 10 measurements. They are listed by location upstream to downstream along the river and show that variability in conductivity and TDS is relatively consistent, but slightly greater at the downstream station (SWS-06 (Burke Avenue Bridge)), likely indicating the influence of stormwater and other discharges into the river.

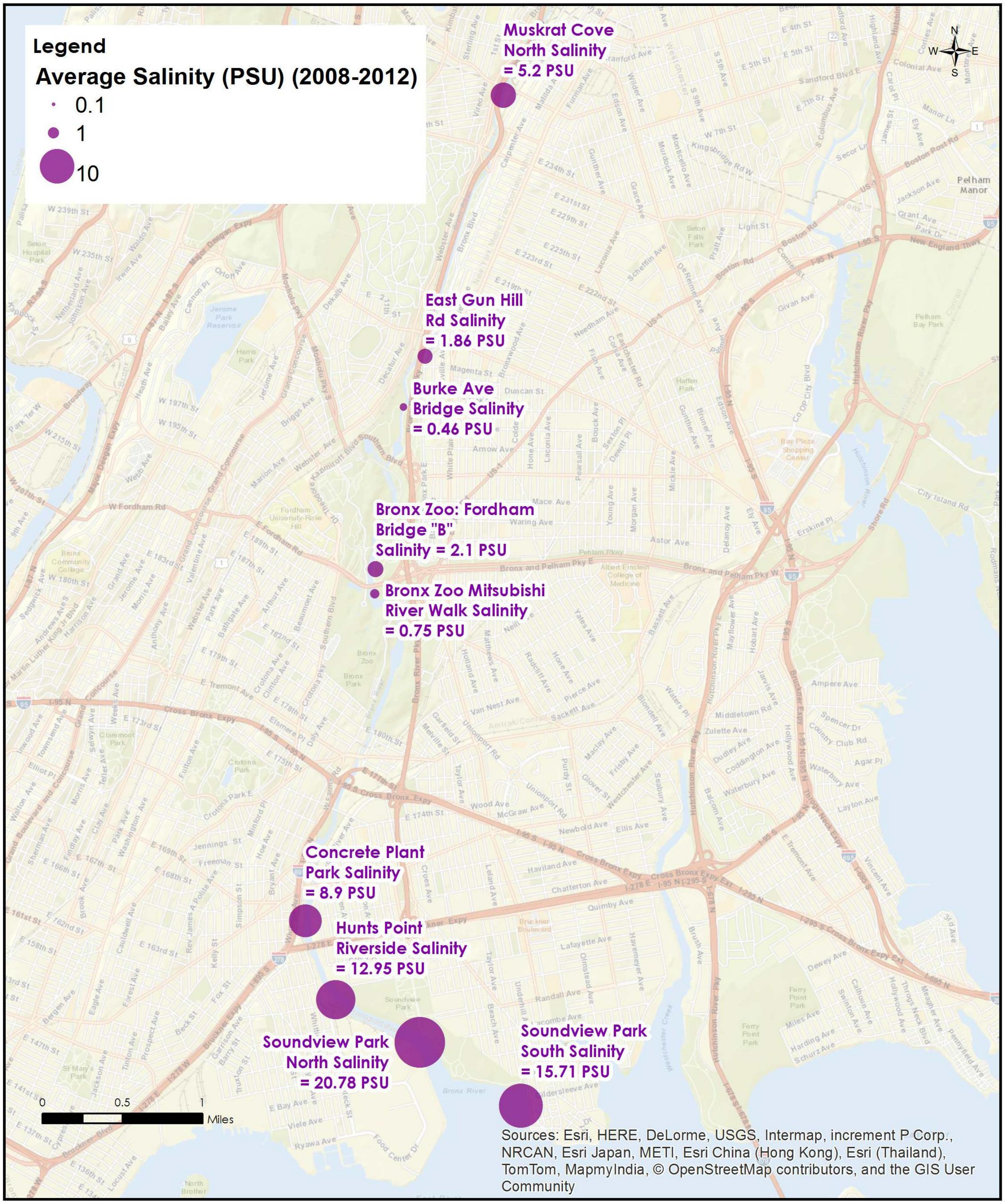


Figure 19. Map of Average Salinity (2008-2012)

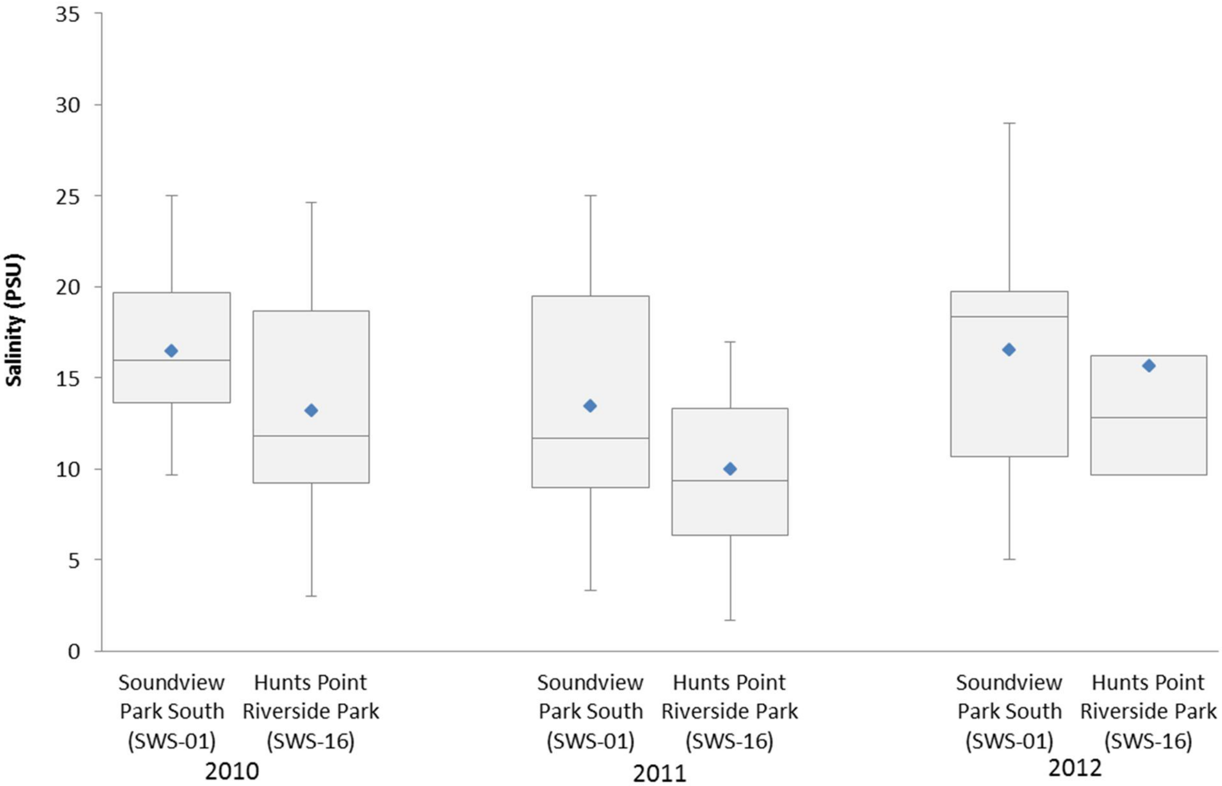


Figure 20. Boxplots of Salinity at Sites SWS-01 (Soundview Park South) and SWS-16 (Hunts Point Riverside Park) (2010 – 2012)

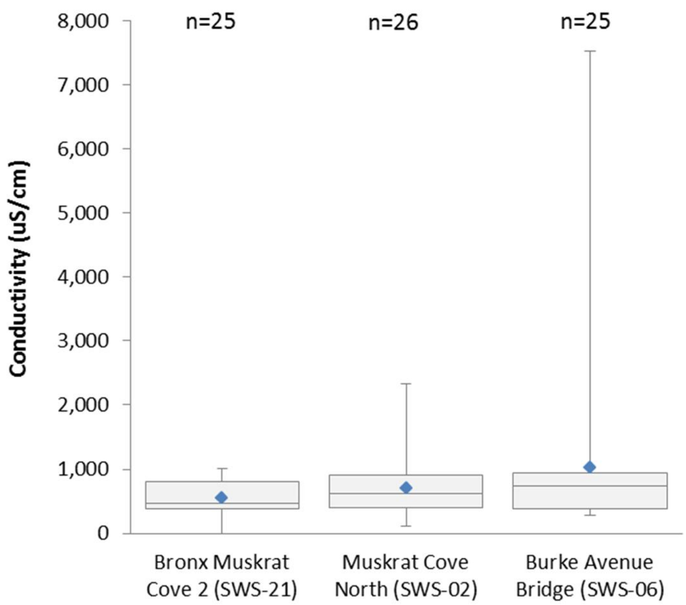


Figure 21. Boxplots of Conductivity at Upstream and Downstream Non-Tidal Locations (2011)

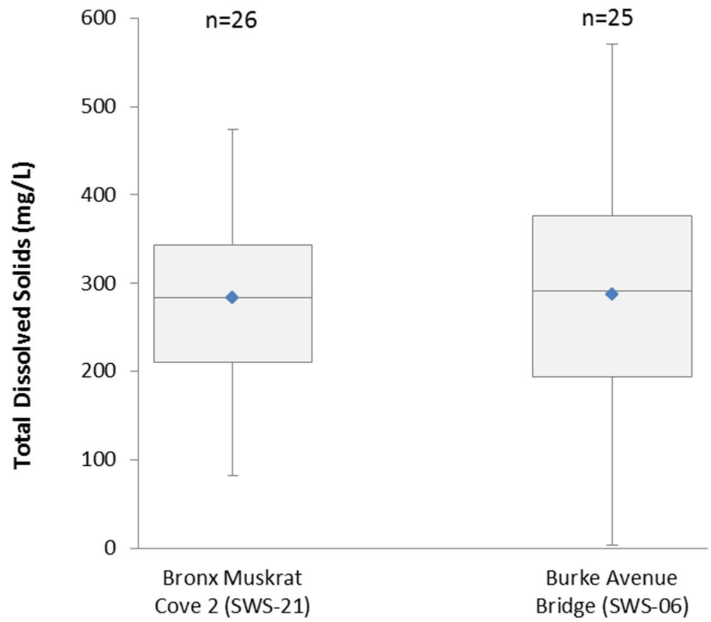


Figure 22. Boxplots of Total Dissolved Solids at Upstream and Downstream Non-Tidal Locations (2011)

3.1.6 Transparency

Transparency is a measure of water clarity. It can be used as a surrogate for turbidity and is a function of both the color and suspended particles in the water. Dissolved materials can also affect transparency by changing the color of water. For example, dissolved organic material can give a brownish, tea-like color to water. Suspended material, like sediment or algae, in the water column also reduces transparency.

There is less light penetration in low transparency waters, impacting the growth of beneficial (and sometimes nuisance) aquatic plants. High sediment loads impact water quality and aquatic health because they can interfere with the ability for fish to see and capture prey, and sediment settled on a stream bottom can smother fish eggs. In addition, pollutants such as phosphorus or hydrocarbons (petroleum products) can attach to sediment and be introduced to the water column through erosion into the stream or stormwater runoff. Finally, algae in the water column (discussed in more detail below), can also reduce the transparency.

Transparency data has been collected at several stations since 2008 (*Table A-1*). *Figure 23* shows boxplots for the year 2010 at three locations along the river with several measurements during the year. There is greater transparency at SWS-02 (Muskrat Cove North) in the upper portion of the river. Transparency near the mouth of the river is both lower on average and more variable. The decreased transparency and increased variability in transparency likely indicate the influence of runoff or other wet weather discharges along the river. The presence of algae, which has been reported in the downstream area of the river, also contributes to decreased and more variable transparency. Few stations have several years of consecutive data, making meaningful temporal comparisons impossible.

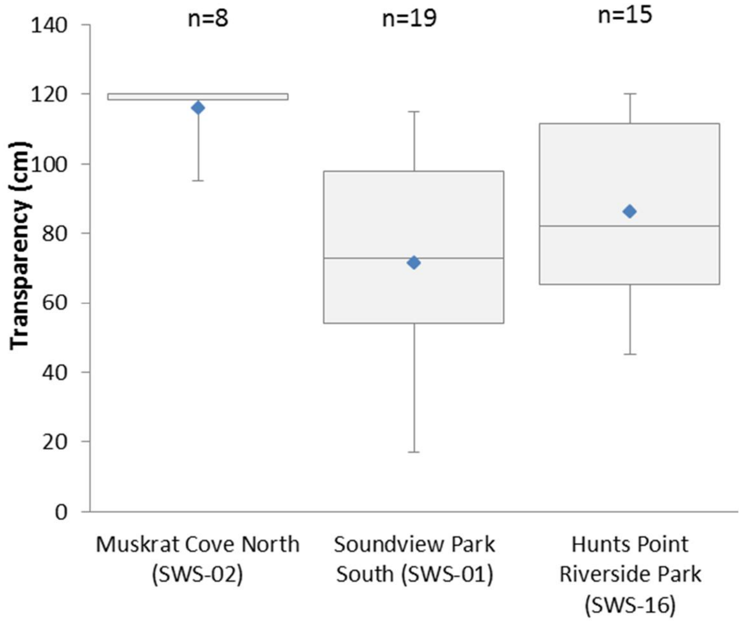


Figure 23. Boxplots of Transparency (2010)

3.1.7 Nutrients

Although nitrogen and phosphorus are natural and important parts of an aquatic ecosystem, excess nutrients can negatively impact water quality. Too much nitrogen and phosphorus can fuel a rapid growth, or bloom, of algae, which can impact water quality by depleting oxygen from the water column. As discussed in Section 3.1.3, DO is critical for aquatic life. In addition, certain species of algae are toxin-producing and can result in short-term negative health effects, as well as potential chronic health concerns from extended exposure.

While nitrate, nitrite, and total nitrogen data was collected, the detection limit (i.e., the lowest quantity of a substance that can be distinguished from the absence of that substance) appears to be too high to accurately differentiate between stations. Use of a lower detection limit (i.e., 0.1 mg/L) would provide more useful characterization of nutrient conditions and could be used to determine if there is any relationship between nutrients and low DO in all or portions of the Bronx River.

3.1.8 Harmful Algal Blooms

Harmful algal blooms, including cyanobacteria (often called blue-green algae), “red tide,” and “brown tide” are of concern for marine, estuarine, and freshwater habitats.

Harmful algal blooms (HABs) present both public health and water quality concerns for recreational waters and drinking water supplies due to the fact that certain species are toxin producing. Although algae are normally present in aquatic systems, prolific growth of algae blooms. The decay of this organic matter can deplete oxygen in the water column, leading to hypoxia and subsequent fish mortality and release of substances that were bound to oxidized sediments. In addition, blooms can block sunlight penetration, are often aesthetically unpleasant and can generate disagreeable odors.

HABs tend to form under conditions of warm, calm, nutrient-rich waters. While the rise of cultural eutrophication by polluted runoff and nutrients has been identified as a contributing factor to the increase in HABs over past several decades, blooms have also been reported in near-pristine watersheds and oligotrophic lakes (WHO, 1999).

An apparent algal blooms on the Bronx River near Starlight Park were reported in August and September 2013 (*Figure 24*). The blooms observed were later identified to be the species dinoflagellate *Gymnodium sp*. Blooms of *Gymnodium sp* have been reported in the Bronx River over the past decade. In order to assess the potential relationship between the blooms and other environmental factors, the dates of bloom observation are highlighted on the graph of streamflow at the U.S. Geological Survey (USGS) Gage 01302020 at the New York Botanical Garden and precipitation recorded at New Rochelle, NY in *Figure 25*. It appears that the bloom first formed during relative quiet conditions on the river. Increased streamflow on August 14 may have dissipated the bloom. Following another period of lower flows, a bloom was again observed in late August. A rain event on September 2 did not dissipate the blooms, but may have added additional nutrients to the water column from runoff to fuel the bloom after a nearly 2 week dry period. The 1.36-inch rain event on September 12 and corresponding rapid increase in streamflow likely dissipated the bloom.

Figure 24. *Gymnodium sp* Bloom at Starlight Park (Station SWS-14) on August 6, 2013

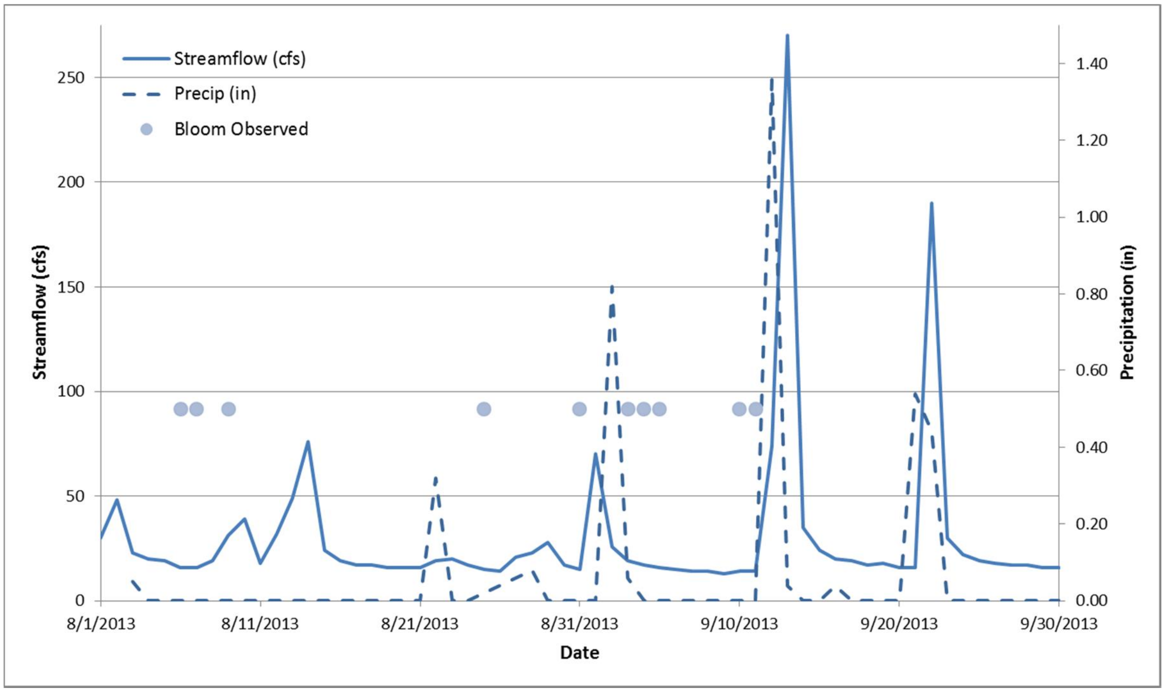


Figure 25. Precipitation, Rainfall and Bloom Observations at Starlight Park

4 Correlation and Trend Analysis

The purpose of correlation analysis is to investigate possible relationships among and between water quality parameters and environmental conditions, like precipitation and streamflow. While the presence of a statistically significant correlation does not prove causation, i.e., that the behavior of one variable causes the response of another, it does demonstrate that the variables co-vary or change in ways that relate to each other. The relationships between variables can often be inferred from an understanding of the physical, chemical, and biological processes that influence water quality.

Correlation is also an important first step in trend analysis. The results of the correlation analysis are used to determine if precipitation or streamflow conditions are acting as exogenous variables, i.e., variables that have considerable influence on the water quality parameter of interest. In the case of dissolved oxygen, temperature is also evaluated as an exogenous variable. By identifying and removing the influence of exogenous variables, the background variability or “noise” is reduced so that any trend “signal” can be more readily observed.

The correlation analysis was designed with its ultimate use (trend analysis) in mind. As described in more detail in the following sections, the trend analysis focuses on (a) temporal trends – how do water quality conditions change over time? and (b) spatial trends – how does water quality change along the length of the river? In order to explore the first question, it is necessary to identify monitoring locations that have multiple years of monitoring data for the same water quality parameter. To investigate the second question, it is necessary to identify monitoring locations that have concurrent data for the same water quality parameters.

Water quality data from the following stations were examined for correlation: SWS-01 (Soundview Park South), SWS-02 (Muskrat Cove North), SWS-03 (219th Street), SWS-5 (East Gun Hill Road), SWS-06 (Burke Avenue Bridge), SWS-07 (Kazimiroff Blvd Bridge), SWS-09 (Fordham Bridge “A”), SWS-13 (Tremont Avenue), SWS-16 (Hunts Point Riverside Park), SWS-17 (Bronx River Zoo), SWS-21 (Bronx Muskrat Cove 2), BR1 (233rd Street & Bronx Blvd), BR3 (Westchester Avenue), and BR5 (Soundview Park North). The analysis used daily total precipitation data available from the National Climatic Data Center station 30001494 located in the Bronx. Daily mean discharge data for streamflow was used from the USGS gage 01302020 on the Bronx River at New York Botanical Garden in Bronx, New York.

4.1 Correlation

Correlation analysis was first examined by combining data from all stations and all years to see if large-scale correlations were observed. Both untransformed and natural log-transformed data were considered. The Pearson’s r or correlation coefficient was calculated for each pair of variables shown in *Table 4*. Both untransformed and natural log-transformed values were evaluated for correlation. If there was a statistically significant correlation (p-value <0.05), the sign of the correlation is shown in the table. Some of the correlations are expected. Dissolved oxygen is inversely correlated to water temperature; cooler waters can hold more dissolved oxygen. The fecal indicator bacteria, fecal coliform and enterococcus, are positively correlated with each other. Other correlations between water quality parameters are of interest. DO shows a positive correlation with pH and transparency, indicating that the higher DO waters are less acidic and have greater clarity. Although no apparent relationship with enterococcus was observed, fecal coliform is negatively correlated with DO, indicating that conditions that lead to higher fecal coliform are associated with conditions where oxygen demand is greater, removing DO from the water column. Transparency is negatively correlated with water temperature, and is positively correlated with DO. Deeper waters, which may have higher transparency depths, tend to be cooler, holding more DO, and cooler waters may indicate the absence of point and non-point discharges that introduce thermal pollution and reduce DO.

Of particular interest for the trend analysis is the relationship between streamflow and precipitation (“precip” in *Table 4*) and water quality. Streamflow is positively correlated with DO, fecal coliform and enterococcus, as well as precipitation. More flow tends to increase aeration, increasing DO, but higher flows are also likely to occur during and after a rainfall event when point and non-point source runoff, potentially containing fecal indicator bacteria, is discharged to the river. Precipitation showed a negative, but fairly weak, correlation with DO, possibly indicating the influence of precipitation-driven runoff into the river. Similarly, a weak positive correlation between precipitation and water temperature was observed, again possibly indicating the influence of precipitation-driven, warmer, urban runoff into the river. Precipitation and enterococcus were positively correlated, suggesting that precipitation events introduce sources of bacteria into the river.

In general, correlation coefficients ranged from r = 0.01 to r = 0.5. The strongest correlation observed, other than those between temperature and DO (r = 0.555), precipitation and streamflow (r = 0.361), and fecal coliform and enterococcus (r = 0.821), was between enterococcus and streamflow. The correlation coefficient of 0.378 indicates that approximately one-third of the variation in enterococcus can be explained by the variation in streamflow. The presence of these overall correlations in the dataset indicates that the effect of exogenous variables needs to be accounted for in the trend analysis.

Table 4. Correlation Summary

Parameter	Water Temperature	pH	Dissolved Oxygen	Transparency	Fecal Coliform	Enterococcus	Precip	Streamflow
Water Temperature			-	-			+	-
pH			+			+		-
Dissolved Oxygen	-	+		+	-		-	+
Transparency	-		+					
Fecal Coliform			-			+		+
Enterococcus		+			+		+	+
Precip	+		-			+		+
Streamflow	-	-	+		+	+	+	

\+ indicates positive correlation - indicates negative correlation

4.2 Spatial Trend Analysis

Table 5 summarizes the monitoring locations and parameters that were used for spatial trend analysis. Four years were selected during which five or more samples of the indicated water quality parameter were collected at the sampling locations listed. Before trend testing, the data for individual stations were checked to confirm that the correlations with streamflow and precipitation observed for the entire data set for the period of record were valid for the more limited data set associated with each time period and station. For 1994, streamflow and precipitation data was not readily available so parameters were not adjusted for any exogenous variables; also, relatively few data points were available at each location. Parametric methods for trend analysis described by Helsel and Hirsch (2002) were used for the spatial trend analysis. A statistically significant trend was only identified if the p-value associated with the slope of the coefficient indicating location was less than 0.05. While the focus of this work has been a holistic examination of water quality over time in the Bronx River, the spatial trend analysis for 2011 and 2012 was also considered for the meteorological summer (June, July, August) and winter (December, January, February) seasons to identify any seasonal differences that may exist and remove the possible influence of differing numbers of measurements taken during different times of the year at different locations.

Table 5. Locations[8] and Parameters Used for Spatial Trend Analysis

Water Quality Parameter	Time Period			
	1994	2010	2011	2012
Water Temperature			SWS-21, SWS-02, BR1, SWS-06, BR3, SWS-16, BR5, SWS-01	
pH	SWS-03, SWS-05, SWS-06, SWS-07, SWS-09, SWS-17, SWS-13		SWS-21, SWS-02, BR1, SWS-06, BR3, SWS-16, BR5, SWS-01	
Dissolved Oxygen	SWS-03, SWS-05, SWS-06, SWS-07, SWS-09, SWS-17, SWS-13		SWS-21, SWS-02, BR1, SWS-06, BR3, SWS-16, BR5, SWS-01	
Transparency		SWS-02, SWS-06, SWS-01		
Fecal Coliform				BR1, BR3, BR5
Enterococcus				BR1, BR3, BR5

[8] Refer to *Table 1* for names of locations.

Table 6. Results of Spatial Trend (Upstream to Downstream) Analysis

<table>
<tr><th rowspan="2">Water Quality Parameter</th><th colspan="6">Time Period</th></tr>
<tr><th>1994</th><th>2010</th><th colspan="2">2011</th><th colspan="2">2012</th></tr>
<tr><td rowspan="2">Water Temperature</td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2">●</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>n/a
Winter</td><td>●
Summer</td></tr>
<tr><td rowspan="2">pH</td><td rowspan="2">▲</td><td rowspan="2"></td><td colspan="2">▲</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>●
Winter</td><td>▲
Summer</td></tr>
<tr><td rowspan="2">Dissolved Oxygen</td><td rowspan="2">●</td><td rowspan="2"></td><td colspan="2">▼</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>n/a
Winter</td><td>●
Summer</td></tr>
<tr><td>Transparency</td><td></td><td>▼</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Fecal Coliform</td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2" rowspan="2"></td><td colspan="2">▼</td></tr>
<tr><td>▼
Winter</td><td>▼
Summer</td></tr>
<tr><td rowspan="2">Enterococcus</td><td rowspan="2"></td><td rowspan="2"></td><td colspan="2" rowspan="2"></td><td colspan="2">▼</td></tr>
<tr><td>▼
Winter</td><td>▼
Summer</td></tr>
</table>

● = no trend observed, ▲= increasing downstream, ▼ = decreasing downstream
n/a indicates insufficient data for trend analysis

Table 6 summarizes the results of the spatial trend analysis. No statistically significant trends in temperature were observed in the 2011 data, although insufficient data was available to examine just winter conditions. A downstream increase in pH was observed in the 1994 data, as well as 2011 year-round and summer season data. This observed trend from upstream to downstream is consistent with the influence of higher pH marine water influence at downstream stations. As shown in *Figure 9*, pH tends to be higher and show less variability at monitoring locations south of Interstate 95.

Dissolved oxygen showed no statistically significant trend based on the 1994 or Summer 2011 data. However, a downstream decreasing trend was observed for 2011 overall. These results are consistent with the visual analysis of DO data presented in *Figures 10-14*.

Although sufficient data measurements of transparency were limited to a few stations, 2010 data showed a decreasing trend in transparency from upstream to downstream. This may be due to the presence of more suspended sediment and floatable material with increasing discharges to the river in the downstream direction. Further analysis of a trend in transparency would benefit from measurements in the middle portion of the watershed, in the area of the Bronx Zoo.

Spatial trend analysis of fecal indicator bacteria in 2012 showed a statistically significant decreasing downstream trend in both fecal coliform and enterococcus for the entire year, as well as the winter and summer seasons. This is consistent with the observations in *Figures 15-17* and is also confirmed by the recent work of Enecio and Krakauer (2014). They sampled nine locations along the Bronx River in the summer of 2014 under both wet weather and dry weather conditions and found that enterococcus concentrations decreased downstream under both wet weather and dry weather conditions.

4.3 Temporal Trend Analysis

Temporal trend analysis requires relatively consistent measurements of a water quality parameter over several years of record. Fecal coliform and enterococcus measurements over the three-year period 2011-2013 are one set of data that can be used for a short-term trend analysis. Temporal trend analysis for other parameters is more challenging because of less frequent sampling in the 1990s, followed by increased yet still irregular sampling in the early and mid-2000s, and then more regular and frequent sampling during and after 2008 (*Figure 3*). Consequently, only a few station/parameter combinations were suitable for a meaningful temporal trend analysis. In some cases, the analysis is split into two periods due to a gap in the data. *Table 7* summarizes the monitoring locations and time periods used for temporal trend analysis.

Table 7. Locations, Time Periods, and Parameters Used for Temporal Trend Analysis

Water Quality Parameter	Monitoring Location					
	SWS-02 Muskrat Cove North	SWS-06 Burke Avenue Bridge	SWS-16 Hunts Point Riverside Park	BR1 233rd Street & Bronx Blvd	BR3 Westchester Avenue	BR5 Soundview Park North
Water Temperature	2005-2011	2003-2012	2010-2012			
pH	2005-2011	1990-1994 2003-2012	2010-2012			
Dissolved Oxygen		1990-1994 2003-2012	2010-2012	2011-2013	2011-2013	2011-2013
Fecal Coliform				2011-2013	2011-2013	2011-2013
Enterococcus				2011-2013	2011-2013	2011-2013

Results of the temporal trend analysis showed no statistically significant change in water temperature measurements at the Muskrat Cove North (SWS-02) or Burke Avenue Bridge (SWS-06) stations, but an increase in water temperature at the Hunts Point Riverside Park (SWS-16) station over the period 2010-2012. This increase at Hunts Point is also apparent by visual examination of *Figure 6*. It should be noted that the maximum temperature at Hunts Point Riverside Park for the period of record was 28 C, which is still within the range considered acceptable for aquatic life. However, given the shorter period of record at this station, continued monitoring would be helpful to confirm if a consistent trend in present.

pH showed a decreasing trend in the post-2000 periods examined. However, overall pH has remained close to neutral and within acceptable ranges for aquatic life. At the Burke Avenue Bridge (SWS-06) station, mean and median pH for 1990-1994 were 7.56 and 7.5, respectively. Mean and median values for the 2003-2012 period were 7.43 and 7.5, respectively. Although pH values should continue to be monitored, there does not appear to be a dramatic decline in pH over the periods examined.

Table 8. Results of Temporal Trend Analysis

Water Quality Parameter	Monitoring Location[9]					
	SWS-02	SWS-06	SWS-16	BR1	BR3	BR5
Water Temperature	●	●	▲			
pH	▼	● 1990-1994 ▼ 2003-2012	▼			
Dissolved Oxygen		● 1990-1994 ● 2003-2012	●	●	●	●
Fecal Coliform				●	●	●
Enterococcus				●	●	●

● = no trend observed, ▲= increasing downstream, ▼ = decreasing downstream

Dissolved oxygen concentrations showed no statistically significant temporal trend for the time periods and monitoring locations studied. The upper Bronx River and its tributaries remain impaired for DO (NYSDEC, 2013a)[10] and the lower Bronx River and its tributaries were recently delisted for DO based on planned improvements (NYSDEC, 2013b).[11] Continued monitoring of DO at stations with a multi-year record will be important to assess actual improvements in water quality compared with the anticipated benefits to water quality that are the basis of delisting.

Due to the short period of record, the lack of a temporal trend for fecal indicator bacteria is not surprising. Given the high concentrations in the upper portions of the watershed and the identified water quality impairments in the Bronx River due to bacteria, continued monitoring for trends in fecal indicator bacteria will be an important measure of water quality and the success of ongoing and future management measures. As with DO, although the upper segment of the Bronx River and its tributaries remain listed as impaired for pathogens (NYSDEC, 2013a), the middle and lower portions were delisted due to planned improvements (NYSDEC, 2013b).

[9] Refer to *Table 7* for names of locations.
[10] http://www.dec.ny.gov/docs/water_pdf/303dlistfinal12.pdf
[11] http://www.dec.ny.gov/docs/water_pdf/303ddelisted12.pdf

5 Conclusions and Recommendations

This report provides a review and assessment of water quality data collected in the Bronx River since the 1990s to summarize water quality conditions, identify trends in water quality, and make recommendations regarding ongoing and future volunteer monitoring efforts. Based on the analysis described in prior sections of the report, the following conclusions and recommendations are presented.

5.1 Water Quality Conditions

The analysis consisted of a statistical summary of water quality data, identification of correlations between water quality parameters, and screening for spatial and temporal trends in water quality. The statistical summary considered over 3,800 individual measurements of water quality collected by the Bronx River Alliance volunteers, Bronx River Restoration, the New York City Water Trail Association, and the DEP New York Harbor Watch Program. Many different parameters were sampled in the Bronx River, although only a limited number were routinely sampled at the same location for several years. While the experience of water quality monitoring and data collection has value for the citizen scientist, and all data can provide a snapshot of conditions relative to water quality standards and benchmarks, consistent sampling of the same parameters, at the same locations, over several years is the most useful for summarizing water quality conditions and tracking if and how conditions have changed.

Review of the data showed that water temperature (561 data measurements), pH (810 data measurements), and dissolved oxygen (DO) (865 data measurements) were the water quality parameters most often collected. To a lesser extent salinity (201 data measurements), transparency (179 data measurements), and total dissolved solids (87 data measurements) were collected. Nutrients were measured either infrequently or at a high detection limit, limiting their usefulness. Recently, routine collection of fecal coliform (177 data measurements) and enterococcus (200 data measurements) was begun, and observations of algalblooms have been reported over the past decade. As a result, the parameters that best describe the past and current state of the Bronx River are water temperature, pH, and DO. DO is perhaps the most important of these due to the recognized DO impairment in the upper and lower Bronx River. The following are highlights of the water quality analysis:

- Water temperatures show typical seasonal variation and are generally within the range of 5-30°C, which is acceptable for aquatic life. Temperatures upstream of the Burke Avenue Bridge (SWS-06), in the northern part of the river, tend to have lower median and mean water temperatures (*Figure 7*). This observation is consistent with the greater impervious cover and stormwater and combined sewer overflow (CSO) discharges downstream that introduce warmer runoff into the river. However, trend analysis did not find any statistically significant spatial trend based on 2011 data from 8 stations along the river (*Table 6*). Lack of a trend does not eliminate the possibility that individual stations located near outfalls experience higher water temperatures as a result of stormwater and CSO discharges. The analysis of water temperature at the Hunts Point Riverside Park (SWS-16) station over the period 2010-2012 indicates an increasing trend, although the maximum temperature measured at that location (28°C) was still within the acceptable range.

- pH measurements in the Bronx River are generally above the acute (pH = 3.0) and chronic (pH = 4.8) water quality standards established by NYSDEC, which represent pH values below which aquatic life is negatively impacted. pH values in the Bronx River have remained close to neutral, although a decreasing temporal trend was detected at Muskrat Cove North (SWS-02), Burke Avenue Bridge (SWS-06), and Hunts Point Riverside Park (SWS-16) over the past several years (*Table 8*). The increasing and less variable pH values downstream along the Bronx River (*Table 6* and *Figure 9*) are consistent with the influence of higher pH marine water south of Interstate 95. Mean pH values in the Bronx River are similar to other rivers in the region. For example, mean pH at the Burke Avenue Bridge (SWS-06) for the period 2003-2012 was 7.43. For comparison, average pH for the Hudson River at West Point, NY (USGS Station 01374019) was 7.69 in water year 2013, and average annual pH for the Hohokus River at Paramus, NJ (USGS Station 01391100) ranged from 7.35 to 7.63 over the 2000-2009 water years.

- Average dissolved oxygen (DO) concentrations in the Bronx River are typically above the surface water quality criteria established by NYSDEC, which is a positive indicator of water quality. However, review of the data revealed several stations with low DO values, a cause for concern, especially in the lower portions of the river. Examining the marine water (Class I) stations, five of the seven stations have minimum values less than 4 mg/L, and of those, two stations (BR3 (Westchester Avenue) and SWS-18 (East River Barretto Point Park), which is located on the East River) have first quartile values (i.e., lowest 25% of the values) less than 4 mg/L, indicating that 25% of the data points are less than the water quality standard. An examination of the raw data shows that SWS-18 has only 5 data points in 2008, so BR3 (Westchester Avenue) is more representative of current conditions. For the freshwater locations, while five of the 15 stations have minimum values less than 4 mg/L, none has a 25th percentile, i.e., first quartile, value less than 4 mg/L. This suggests that while there are episodes of low DO at upstream locations, they are not as frequent as the downstream, marine water, stations. Simple visual inspection of the data (*Figure 14*) also indicates a notable difference between upstream and downstream monitoring locations, which is confirmed by a statistically significant decreasing trend in the 2011 DO data (*Table 6*). Because of the identified DO impairments in the Bronx River (NYSDEC, 2013a; 2013b) and recent delisting of the lower Bronx River, monitoring DO will continue to be important to assess the water quality and overall health of the river.

- The fecal coliform and enterococcus data indicate that there is a source of fecal indicator bacteria in the upper portions of the watershed. Review of data from the New York Harbor Watch Program shows that (1) there is a statistically significant decrease in fecal coliform bacteria from upstream to downstream, and (2) mean and median fecal coliform and enterococcus concentrations are routinely the highest at the upstream station (233rd Street and Bronx Boulevard) of the three stations where bacteria data were collected. The high concentrations of fecal indicator bacteria at 233rd Street and Bronx Boulevard (BR1) are surprising because this station is upstream of any CSO outfalls, but could point to the presence of illicit discharges. The Westchester Avenue station (BR3), located near the CSO outfalls HP-007 and HP-004, has lower mean and median fecal indicator bacteria values, despite a larger range of observed values, which is consistent with "spikes" in fecal indicator bacteria from CSO discharge events. In addition, examination of correlations between precipitation and fecal indicator bacteria concentrations shows that there is a strong correlation with wet weather sources. The Bronx River Intermunicipal Watershed Management Plan (Bronx River Intermunicipal Watershed Plan, 2010) identified several management strategies for the portions of the Bronx River watershed in Westchester County, including investigation and reduction of illicit discharges and stormwater source controls. The fecal indicator bacteria data concurs with these recommendations, and the magnitude of the observed upstream concentrations, especially compared to concentrations at the downstream stations, provides evidence of illicit discharges in the upper watershed.

- Observations of dinoflagellate and algal blooms have been noted in the Bronx River by volunteers over the past decade. Because of the growing concern about the acute and chronic human health effects and the water quality and aquatic impacts of harmful algal blooms, continued and standardized methods for observation of blooms is an important component to ongoing water quality monitoring. Specific recommendations regarding monitoring are discussed below.

5.2 Recommendations

One of the goals of the data analysis was to facilitate greater efficiency and more effective use of limited resources by helping to refine the water quality monitoring program based on the results of prior monitoring. A retrospective look at the water quality data collected since the 1990's, along with consideration of ongoing watershed management activities and emerging water quality issues, form the basis of the following recommendations for the citizen scientist monitoring efforts guided by the Bronx River Alliance.

5.2.1 Dissolved Oxygen and Fecal Indicator Bacteria

Although fecal indicator bacteria concentrations generally decrease downstream, dissolved oxygen concentrations are typically also lower in the downstream reach of the Bronx River. Because one would expect that DO would increase as sources of fecal indicator bacteria decrease, this counterintuitive result suggests that sources other than fecal material are consuming oxygen and depressing dissolved oxygen concentrations. Measurement of biochemical oxygen demand (BOD[12]), along with bacteria concentrations, in areas of low DO could help to identify locations where discharge of non-sewage organic matter may be impacting DO levels.

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[12] BOD measurement requires taking two samples at each site. One is tested immediately for dissolved oxygen, and the second is incubated in the dark at 20 C for 5 days and then tested for the amount of dissolved oxygen remaining. The difference in oxygen levels between the first test and the second test, in milligrams per liter (mg/L), is the amount of BOD. This represents the amount of oxygen consumed by microorganisms to break down the organic matter present in the sample bottle during the incubation period. Because of the 5-day incubation, the tests should be conducted in a laboratory (USEPA, 2015).

5.2.2 Bacteria Source Identification

The elevated concentrations of fecal indicator bacteria in the upstream portions of the Bronx River require further investigation to identify and eliminate sources. As mentioned above, the Bronx River Intermunicipal Watershed Management Plan (River Intermunicipal Watershed Plan, 2010) identified several management strategies for the portions of the Bronx River watershed in Westchester County, including investigation and reduction of illicit discharges and stormwater source controls. Monitoring for indicators of sanitary sewer discharge such as optical brighteners (found in some laundry detergents), caffeine, methylene blue active substances (surfactants found in detergents and soaps), or other bacteria source tracking methods could help confirm or deny the presence of human sources of the fecal indicator bacteria. Of the limited number mentioned above, monitoring for optical brighteners is one of the most easily implemented by volunteer monitors.[13]

5.2.3 Nutrients

Although various forms of nitrogen (nitrate, nitrite, and total nitrogen) were collected in the Bronx River, the detection limit of the existing data is too high to accurately differentiate between stations. Use of a lower detection limit (i.e., 0.1 mg/L) would provide more useful characterization of nutrient conditions. While concerns about the impacts of nitrogen to water quality have traditionally dominated the monitoring of waters draining to Long Island Sound, the presence of algal and dinoflagellate blooms also suggest that measurement of total phosphorus could provide a more complete picture of nutrient conditions in the Bronx River, since cyanobacteria blooms are often an indication of excess phosphorus in surface waters. Collection of both nitrogen and phosphorus data at suitable detection limits could also be used to determine if there is any relationship between nutrients and low DO in all or portions of the Bronx River.

5.2.4 Harmful Algal Blooms (HABs)

Blooms of dinoflagellates, algae, and cyanobacteria may continue to be a water quality issue in the Bronx River. The volunteer monitoring program could be expanded to include HAB data collection. Training in the identification of algal blooms could be useful since pollen, aquatic weeds, and green algae can sometimes be mistaken for cyanobacteria blooms. Information on bloom identification, including photos to aid identification, is available from NYSDEC (http://www.dec.ny.gov/chemical/77118.html), as well as USEPA (http://www2.epa.gov/nutrient-policy-data/cyanohabs) and neighboring states, such as Vermont (http://healthvermont.gov/enviro/bg_algae/photos.aspx). In addition to visual observations, testing for the algal toxins is possible. Microcystin is currently the algal toxin most readily measured and the one for which exposure guidelines are available for recreational and drinking waters. If cyanobacteria blooms are confirmed on the Bronx River, test kits for microcystin requiring limited

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[13] http://www.epa.gov/owow/monitoring/volunteer/newsletter/volmon11no2.pdf
http://nature.thecompass.com/8tb/sampling/

laboratory resources are available from several vendors[14] and could be incorporated into a volunteering monitoring program that involves a secondary school or university partner.

Because of the potential human health implications from acute exposure, volunteers should be trained in proper handling of water quality samples from bloom areas. Information on potential health effects and proper handling of water samples containing cyanobacteria is available from several sources including the Centers for Disease Control (http://www.cdc.gov/nceh/hsb/hab/), USEPA (http://www2.epa.gov/nutrient-policy-data/health-and-ecological-effects), and USGS (http://pubs.usgs.gov/sir/2008/5038/pdf/SIR2008-5038.pdf).

5.2.5 Sentinel Stations

As discussed in *Section 5.1*, many different parameters were sampled in the Bronx River, although only a limited number were routinely sampled at the same location for several years. Analysis of long-term changes in the health of the river requires consistent records of water quality at several locations. Consequently, the designation of specific "sentinel stations" that could be used to benchmark water quality in the Bronx River could be a useful addition to the volunteer monitoring program. These stations would be the focus of consistent, routine monitoring for an established suite of water quality parameters. Stations identified for trend analysis in *Section 4.3*, Muskrat Cove North (SWS-02), Burke Avenue Bridge (SWS-06), Hunts Point Riverside Park (SWS-16), as well as the New York Harbor Watch Stations monitoring FIB, would be logical choices for long term monitoring locations. The selected stations should provide the ability to assess spatial difference along the length of the river and/or monitoring changes in water quality at a single location over time.

5.2.6 Targeted Sampling Projects

The recent study of enterococcus concentrations by Enecio and Krakauer (2014) is a good example of how a short-term, targeted sampling effort can address specific water quality questions for the Bronx River. The use of targeted investigations, over a short period of time such as a season or a few weeks or over a limited number of locations, could help to address specific water quality questions. Possible targeted sampling projects could include:

- "wet" weather and "dry" weather monitoring to assess the influence of stormwater runoff on water quality at specific locations,
- Benthic macroinvertebrate monitoring by volunteers to provide comparison with the baseline assessment by the U.S. Army Corps of Engineers (2006).
- Monitoring upstream and downstream of stormwater and/or CSO outfalls to assess impacts associated with outfall discharges and to assess anticipated improvements in the recently delisted middle and lower Bronx River due to CSO management activities.

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[14] Abraxis (www.abraxiskits.com), Envirologix (www. envirologix.com/), Beacon Analytical Systems (http://www.beaconkits.com/)

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Appendix A

Statistic Tables of Bronx River Water Quality Data

Table A-1. Summary of Monitoring Data for the Bronx River (1990-2013)

	Water Temperature (C)	pH (S.U.)	Total Nitrogen (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Transparency Tube (cm)	Salinity	Salinity (specific gravity)	Fecal Coliform (MPN)	Entero-coccus (MPN)
	WTEMP	WPH	NOX	NO2	NO3	WOXYG	WCON	TUBE	WSALT	WSALH	FC	ENT
Soundview Park South (SWS-01)	2008 (4) 2009 (4) 2010 (45) 2011 (18) 2012 (24)	2008 (4) 2009 (4) 2010 (45) 2011 (14) 2011 (22)	2009 (1) 2010 (6)	2008 (3) 2010 (1)	2009 (1) 2010 (27) 2011 (19) 2012 (20)	2008 (3) 2010 (25) 2011 (19) 2012 (20)		2008 (3) 2009 (4) 2010 (19)	2008 (4) 2010 (19) 2011 (19) 2012 (20)			
Muskrat Cove North (SWS-02)	2005 (5) 2006 (3) 2007 (2) 2008 (1) 2009 (5) 2010 (9) 2011 (18) 2012 (2)	2005 (5) 2006 (4) 2007 (2) 2008 (1) 2009 (3) 2010 (9) 2011 (26) 2012 (2)	2005 (5) 2007 (2) 2009 (1) 2010 (8)	2005 (1)	2005 (5) 2007 (2) 2009 (1) 2010 (8) 2011 (11)	2005 (3) 2006 (1) 2007 (2) 2008 (1) 2009 (5) 2010 (10) 2011 (26) 2012 (2)	2009 (4) 2010 (10) 2011 (25)	2009 (4) 2010 (9) 2011 (26)				
219th Street (SWS-03)	1990 (3) 1991 (1) 1993 (4) 1994 (6) 1997 (5) 1998 (6) 2006 (13) 2007 (5) 2009 (1) 2010 (1)	1990 (2) 1991 (2) 1993 (4) 1994 (6) 1997 (5) 1998 (6) 2006 (10) 2007 (5) 2009 (1) 2010 (1)	2006 (1) 2007 (1)		2006 (1) 2007 (1)	1990 (3) 1991 (2) 1993 (4) 1994 (6) 1997 (5) 1998 (6) 2006 (10) 2007 (4) 2009 (1)	2010 (1)	2009 (1) 2010 (1)				
East Gun Hill Road (SWS-05)	1990 () 1991 () 1993 (7) 1994 (6) 1997 (1) 1998 (7) 2004 (1) 2008 (8) 2009 (7)	1990 () 1991 () 1993 (7) 1994 (6) 1997 (2) 1998 (7) 2004 (1) 2008 (7) 2009 (6)	2008 (6) 2009 (4)	2009 (1)	2008 (6) 2009 (4)	1990 () 1991 () 1993 (7) 1994 (6) 1997 (2) 1998 (7) 2004 (1) 2008 (8) 2009 (6)		2008 (5) 2009 (6)	2008 (7) 2009 (6)			
Burke Avenue Bridge (SWS-06)	1990 (8) 1991 (3) 1993 (8) 1994 (6) 1997 () 1998 (4) 2003 (10) 2004 (21) 2005 (7) 2006 (2) 2007 (20) 2008 (41) 2009 (15) 2010 (7) 2011 (15) 2012 (6)	1990 (8) 1991 (3) 1993 (8) 1994 (6) 1997 () 1998 (4) 2004 (23) 2005 (9) 2006 (2) 2007 (21) 2008 (41) 2009 (14) 2010 (11) 2011 (28) 2012 (6)	2004 (19) 2005 (6) 2007 (1)		2004 (19) 2005 (6) 2007 (1) 2011 (7)	1990 (7) 1991 (3) 1993 (8) 1994 (6) 1997 () 1998 (4) 2004 (27) 2005 (10) 2006 (2) 2007 (19) 2008 (36) 2009 (14) 2010 (9) 2011 (27) 2012 (5)	2009 (2) 2010 (8) 2011 (25) 2012 (3)	2007 (7) 2008 (34) 2009 (12) 2010 (3)	2009 (1) 2010 (9) 2011 (27) 2012 (3)	2008 (26) 2009 (3)		
Kazimiroff Blvd Bridge (SWS-07)	1990 (10) 1991 (4) 1993 (5) 1994 (6) 1997 (3) 1998 () 2003 (10) 2011 (4)	1990 (7) 1991 (5) 1993 (5) 1994 (6) 1997 (4) 1998 () 2011 (6)				1990 (7) 1991 (5) 1993 (5) 1994 (6) 1997 (4) 1998 () 2011 (2)	2011 (6)		2011 (3)			

Table A-1. Summary of Monitoring Data for the Bronx River (1990-2013)

	Water Temperature (C)	pH (S.U.)	Total Nitrogen (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Transparency Tube (cm)	Salinity	Salinity (specific gravity)	Fecal Coliform (MPN)	Entero-coccus (MPN)
	WTEMP	WPH	NOX	NO2	NO3	WOXYG	WCON	TUBE	WSALT	WSALH	FC	ENT
Fordham Bridge "A" (Bronx Park Road) (SWS-09)	1990 (1) 1991 (5) 1993 (3) 1994 (6) 1997 (3) 1998 (6)	1990 (2) 1991 (5) 1993 (3) 1994 (6) 1997 (3) 1998 (4)				1990 (2) 1991 (5) 1993 (3) 1994 (6) 1997 (3) 1998 (4)						
Mitsubishi River Walk: Bronx Zoo (SWS-10)	2008 (3) 2009 (4)	2008 (3) 2009 (4)	2008 (1) 2009 (2)		2008 (1) 2009 (2)	2008 (3) 2009 (4)		2008 (3) 2009 (5)	2009 (2)			
180th Street (SWS-11)	1990 (7) 1991 (5) 1993 (4) 1994 (8) 1997 (4) 1998 (2) 2010 (1)	1990 (7) 1991 (6) 1993 (4) 1994 (8) 1997 (4) 1998 (2) 2010 (1)				1990 (5) 1991 (6) 1993 (4) 1994 (8) 1997 (4) 1998 (2) 2010 (1)	2010 (1)	2010 (1)				
Tremont Avenue (SWS-13)	1990 (10) 1991 (6) 1993 (4) 1994 (7) 1997 (3) 1998 (2) 2008 (8) 2010 (1)	1990 (7) 1991 (8) 1993 (4) 1994 (7) 1997 (3) 1998 (2) 2008 (7) 2010 (1)				1990 (7) 1991 (8) 1993 (4) 1994 (7) 1997 (3) 1998 (2) 2008 (6) 2010 (1)		2008 (7) 2010 (1)		2008 (1)		
Starlight Park (SWS-14)	2008 (7) 2009 (2)	2008 (7) 2009 (2)				2008 (5) 2009 (2)		2008 (2)		2008 (7) 2009 (2)		2013 (12)*
Concrete Plant Park (SWS-15)	2010 (22)	2010 (23)				2010 (21)	2010 (19)		2010 (15)			
Hunts Point Riverside Park (SWS-16)	2008 (14) 2009 (3) 2010 (43) 2011 (23) 2012 (19)	2008 (14) 2009 (4) 2010 (43) 2011 (20) 2012 (18)	2008 (7) 2009 (2) 2010 (5)	2008 (2) 2010 (1)	2008 (7) 2009 (2) 2010 (28) 2011 (22) 2012 (15)	2008 (14) 2009 (3) 2010 (41) 2011 (23) 2012 (19)		2008 (6) 2009 (4) 2010 (15)	2008 (6) 2010 (2) 2010 (20) 2011 (23) 2012 (18)			2013 (12)*
Bronx Zoo (Fordham Bridge "B") (SWS-17)	1990 (1) 1991 (4) 1993 (2) 1994 (6) 1997 (4) 1998 (5) 2007 (1) 2008 (17) 2009 (4) 2010 (1)	1990 (1) 1991 (4) 1993 (2) 1994 (6) 1997 (4) 1998 (5) 2007 (1) 2008 (19) 2009 (4) 2010 (1)	2007 (1) 2008 (2)	2008 (1)	2007 (1) 2008 (2)	1990 (1) 1991 (4) 1993 (2) 1994 (6) 1997 (3) 1998 (4) 2007 (1) 2008 (17) 2009 (3) 2010 (1)	2008 (1)	2008 (18) 2009 (4)	2008 (1) 2010 (1)	2008 (1)		
East Rover Barretto Point Park (SWS-18)	2008 (4)	2008 (4)	2008 (1)		2008 (1)	2008 (5)		2008 (3)		2008 (1)		
Bronx Muskrat Cove 2 (SWS-21)	2009 (1) 2011 (21)	2009 (1) 2011 (27)			2011 (12)	2009 (1) 2011 (27)	2009 (1) 2011 (26)		2011 (26)			
233rd Street & Bronx Blvd (BR1)	2011 (20)	2011 (20)				2011 (20) 2012 (25) 2013 (14)*					2011 (20) 2012 (25) 2013 (14)*	2011 (20) 2012 (25) 2013 (14)*
Westchester Avenue (BR3)	2011 (20)	2011 (20)				2011 (20) 2012 (24) 2013 (14)*					2011 (20) 2012 (24) 2013 (14)*	2011 (20) 2012 (24) 2013 (14)*
Soundview Park South (BR5)	2011 (22)	2011 (22)				2011 (20) 2012 (29) 2013 (16)*					2011 (20) 2012 (29) 2013 (16)*	2011 (20) 2012 (29) 2013 (16)*

Table A-2. Statistics of Bronx River Data (1990-2013)

Parameter	Site ID	No. of Samples	Average	Standard Deviation	Variance	Minimum	First Quartile (Q1)	Median	Third Quartile (Q3)	Maximum	Range
Water Temperature (C)	BR5	22	20.4	4.1	17.0	9.6	18.0	22.4	23.1	24.6	14.9
	SWS-01	95	17.0	5.8	33.8	7.0	13.0	17.0	23.0	28.0	21.0
	SWS-02	45	12.5	6.9	48.2	1.3	6.7	13.4	18.5	23.9	22.6
	SWS-03	20	14.1	7.5	55.6	1.2	7.3	15.4	19.9	25.8	24.6
	SWS-05	16	13.6	6.7	45.4	2.7	8.5	13.8	19.1	25.4	22.7
	SWS-06	144	16.1	7.0	48.8	2.3	10.2	16.7	21.8	36.0	33.7
	SWS-07	14	19.2	4.5	20.6	12.9	14.8	18.5	23.3	27.0	14.1
	SWS-10	7	19.5	4.5	20.1	11.0	17.0	22.0	23.0	23.0	12.0
	SWS-11	1	9.4	*	*	9.4	*	9.4	*	9.4	0.0
	SWS-13	9	22.0	2.5	6.5	17.0	20.3	23.0	23.9	25.0	8.0
	SWS-14	9	14.6	9.2	84.0	2.0	6.9	11.0	24.0	28.0	26.0
	SWS-15	22	3.8	2.5	6.3	0.6	2.0	3.3	5.9	9.9	9.3
	SWS-16	102	16.8	6.3	39.4	2.0	12.0	17.0	22.3	28.0	26.0
	SWS-17	28	18.1	6.0	35.5	1.7	13.5	20.0	22.0	28.0	26.3
	SWS-18	4	23.1	0.9	0.9	22.0	22.3	23.0	24.0	24.3	2.3
	SWS-20	1	2.0	*	*	2.0	*	2.0	*	2.0	0.0
	SWS-21	22	15.4	5.6	31.2	6.1	10.4	15.2	21.3	23.3	17.2
pH (S.U.)	BR1	20	7.76	0.17	0.03	7.18	7.70	7.78	7.88	7.96	0.78
	BR3	20	7.45	0.23	0.05	7.19	7.30	7.37	7.54	8.14	0.95
	BR5	22	7.40	0.23	0.05	7.10	7.26	7.35	7.52	8.08	0.98
	SWS-01	89	7.40	0.46	0.21	6.50	7.00	7.50	7.70	8.60	2.10
	SWS-02	52	6.79	1.21	1.47	2.74	6.33	7.00	7.50	9.80	7.06
	SWS-03	42	7.49	0.36	0.13	6.80	7.20	7.50	7.53	8.20	1.40
	SWS-05	36	7.78	0.57	0.33	7.00	7.50	7.50	7.95	9.40	2.40
	SWS-06	184	7.45	0.96	0.93	1.00	7.10	7.50	7.90	10.50	9.50
	SWS-07	33	7.34	0.52	0.27	5.72	7.33	7.50	7.50	8.00	2.28
	SWS-09	23	7.80	0.29	0.09	7.50	7.50	8.00	8.00	8.50	1.00
	SWS-10	7	7.66	0.51	0.26	7.00	7.20	7.70	8.00	8.50	1.50
	SWS-11	32	7.88	0.28	0.08	7.50	7.50	8.00	8.00	8.50	1.00
	SWS-13	39	7.88	0.39	0.15	6.80	7.50	8.00	8.00	8.90	2.10
	SWS-14	9	8.04	0.33	0.11	7.40	7.85	8.00	8.30	8.50	1.10
	SWS-15	23	6.94	0.54	0.30	6.30	6.60	6.90	7.10	8.90	2.60
	SWS-16	99	7.47	0.48	0.23	6.50	7.20	7.50	7.80	8.60	2.10
	SWS-17	47	7.69	0.51	0.26	6.50	7.50	7.80	8.00	9.00	2.50
	SWS-18	4	7.35	0.13	0.02	7.20	7.23	7.35	7.48	7.50	0.30
	SWS-20	1	7.30	*	*	7.30	*	7.30	*	7.30	0.00
	SWS-21	28	6.56	1.28	1.65	2.50	6.00	6.66	7.38	8.63	6.13
Total Nitrogen (mg/L)	SWS-01	7	1	0	0	1	1	1	1	1	0
	SWS-02	16	1.4	0.4	0.2	1	1	1.5	2	2	1
	SWS-03	2	1	0	0	1	*	1	*	1	0
	SWS-05	10	1.1	0.2	0.0	1	1	1	1	1.5	0.5
	SWS-06	26	1.4	1.0	1.0	1	1	1	2	6	5
	SWS-10	3	1.3	0.6	0.3	1	1	1	2	2	1
	SWS-16	14	1.1	0.3	0.1	1	1	1	1.1	2	1
	SWS-17	3	1.2	0.3	0.1	1	1	1	1.5	1.5	0.5
	SWS-18	1	1	*	*	1	*	1	*	1	0
Nitrite (mg/L)	SWS-01	4	1.85	1.7	2.89	1	1	1	3.55	4.4	3.4
	SWS-02	1	1	*	*	1	*	1	*	1	0
	SWS-05	1	1	*	*	1	*	1	*	1	0
	SWS-16	3	2.13	1.96	3.85	1	1	1	4.4	4.4	3.4
	SWS-17	1	1	*	*	1	*	1	*	1	0

Table A-2. Statistics of Bronx River Data (1990-2013)

Parameter	Site ID	No. of Samples	Average	Standard Deviation	Variance	Minimum	First Quartile (Q1)	Median	Third Quartile (Q3)	Maximum	Range
Nitrate (mg/L)	BR1	20	1.04	0.17	0.03	0.58	0.95	1.03	1.09	1.31	0.73
	BR3	20	0.68	0.26	0.07	0.20	0.52	0.72	0.86	1.15	0.95
	BR5	22	0.33	0.19	0.04	0.06	0.18	0.28	0.55	0.71	0.64
	SWS-01	67	0.76	1.13	1.28	0	0	1	1	6	6
	SWS-02	27	1.79	4.74	22.50	0	0	1	1.5	25.2	25.2
	SWS-03	2	1	0	0	1	*	1	*	1	0
	SWS-05	10	1.05	0.16	0.03	1	1	1	1	1.5	0.5
	SWS-06	33	1.14	1.08	1.18	0	1	1	1.25	6	6
	SWS-10	3	1.33	0.58	0.33	1	1	1	2	2	1
	SWS-16	74	0.56	0.83	0.69	0	0	0.15	1	4.4	4.4
	SWS-17	3	1.17	0.29	0.08	1	1	1	1.5	1.5	0.5
	SWS-18	1	1	*	*	1	*	1	*	1	0
	SWS-21	12	5	11.75	138	0	0	0	0	33	33
Dissolved Oxygen (mg/L)	BR1	38	8.4	2.5	6.3	4.6	6.2	7.8	9.9	14.1	9.4
	BR3	38	6.1	3.6	13.1	0.6	2.7	6.2	8.6	14.3	13.7
	BR5	63	7.0	2.6	6.9	3.2	5.0	6.2	8.8	14.1	11.0
	SWS-01	89	6.9	2.3	5.3	2.0	5.5	7.1	8.5	12.7	10.7
	SWS-02	50	10.7	4.5	20.6	2.5	7.6	10.1	14.2	26.7	24.2
	SWS-03	41	9.8	2.8	7.6	4.9	7.7	10.0	13.0	14.0	9.1
	SWS-05	37	10.0	2.5	6.1	6.0	8.0	9.6	12.2	14.0	8.0
	SWS-06	177	9.8	10.1	102.9	1.3	6.7	8.4	11.7	137.0	135.7
	SWS-07	29	9.8	4.6	21.4	2.0	7.0	8.0	13.0	25.0	23.0
	SWS-09	23	12.3	1.9	3.5	8.0	11.0	13.0	14.0	15.0	7.0
	SWS-10	7	6.7	2.5	6.0	2.0	6.0	7.0	8.0	10.0	8.0
	SWS-11	30	11.8	2.1	4.6	8.0	10.0	12.0	14.0	15.0	7.0
	SWS-13	38	10.3	2.7	7.2	5.0	8.0	10.0	13.0	15.0	10.0
	SWS-14	7	8.4	1.4	2.0	6.4	7.1	9.1	9.2	10.3	3.9
	SWS-15	21	11.2	1.7	2.8	8.4	10.0	11.3	12.3	14.9	6.5
	SWS-16	100	7.7	2.6	7.0	3.5	5.9	7.2	9.1	18.2	14.7
	SWS-17	42	9.9	3.3	11.1	4.1	7.2	9.2	13.0	17.0	12.9
	SWS-18	5	5.0	1.3	1.6	3.8	3.9	5.0	6.0	7.0	3.2
	SWS-20	1	9.0	*	*	9.0	*	9.0	*	9.0	0.0
	SWS-21	28	14.9	22.0	485.0	4.1	6.9	9.0	14.3	124.1	120.0
Conductivity (µS/cm)	BR5	22	3.023	0.431	0.185	1.940	2.660	3.095	3.435	3.650	1.710
	SWS-02	39	384	352	123736	1	1	379	746	977	976
	SWS-03	1	688	*	*	688	*	688	*	688	0
	SWS-06	38	721	1186	1406781	1	346	442	896	7531	7530
	SWS-07	6	274	304	92175	1	15	189	598	674	673
	SWS-11	1	867	*	*	867	*	867	*	867	0
	SWS-15	19	56	184	33723	3	7	11	16	813	810
	SWS-17	1	22	*	*	22	*	22	*	22	0
	SWS-20	1	7	*	*	7	*	7	*	7	0
	SWS-21	27	497	292	85384	-90	371	433	768	933	1023
Transparency Tube (cm)	SWS-01	26	75	29	847	17	56	83	99	120	103
	SWS-02	12	112	18	324	60	115	120	120	120	60
	SWS-03	2	89	45	1985	57	*	89	*	120	63
	SWS-05	14	59	3	12	47	60	60	60	60	13
	SWS-06	56	72	26	698	15	60	60	83	120	105
	SWS-10	8	54	17	276	13	60	60	60	60	47
	SWS-11	1	120	*	*	120	*	120	*	120	0
	SWS-13	8	82	28	807	55	60	68	116	120	65
	SWS-14	2	90	42	1800	60	*	90	*	120	60
	SWS-16	25	91	25	633	45	71	90	119	120	75
	SWS-17	22	60	0	0	58	60	60	60	60	2
	SWS-18	3	52	8	64	44	44	52	60	60	16

Table A-2. Statistics of Bronx River Data (1990-2013)

Parameter	Site ID	No. of Samples	Average	Standard Deviation	Variance	Minimum	First Quartile (Q1)	Median	Third Quartile (Q3)	Maximum	Range
Salinity (PSU)	BR5	22	20.8	2.6	6.8	13.2	19.7	21.8	22.4	23.5	10.3
	SWS-01	60	15.7	5.9	35.2	3.3	10.7	15.3	20.0	29.0	25.7
	SWS-02	2	5.2	2.3	5.1	3.6	*	5.2	*	6.8	3.2
	SWS-05	14	1.8	1.3	1.6	0.5	1.0	1.0	2.3	4.3	3.8
	SWS-06	8	0.5	0.2	0.0	0.4	0.4	0.5	0.5	1.0	0.6
	SWS-10	2	0.8	0.4	0.1	0.5	*	0.8	*	1.0	0.5
	SWS-15	21	8.9	7.1	50.4	0.4	4.2	5.9	13.1	24.1	23.7
	SWS-16	69	13.0	8.2	67.3	1.7	8.9	11.7	15.5	63.3	61.6
	SWS-17	2	2.1	1.3	1.6	1.2	*	2.1	*	3.0	1.8
	SWS-20	1	0.1	*	*	0.1	*	0.1	*	0.1	0.0
Salinity (specific gravity)	SWS-06	29	2.79	1.927	3.712	1	1	2.9	3.35	9	8
	SWS-13	1	2.8	*	*	2.8	*	2.8	*	2.8	0
	SWS-14	9	4.2	2.337	5.463	1.5	2.9	2.9	6.6	8.3	6.8
	SWS-17	1	0.1	*	*	0.1	*	0.1	*	0.1	0
	SWS-18	1	26.5	*	*	26.5	*	26.5	*	26.5	0
Fecal Coliform (MPN)	BR1	57	6803	17473	305309503	328	1130	2100	4000	98000	97672
	BR3	57	9227	34191	1168998651	24	363	920	3150	200000	199976
	BR5	63	1157	3523	12408492	5	80	220	800	20000	19995
Enterococcus (MPN)	BR1	58	4534	16775	281386389	30	220	470	1100	110000	109970
	BR3	58	860	2957	8745899	8	60	132	448	22000	21992
	BR5	62	222.2	590.5	348711.5	1	5.8	11	43.5	2000	1999
	SWS-14	11	2856	7164	51327807	73	187	241	784	24196	24123
	SWS-16	11	3154	7106	50501610	52	109	247	3130	24196	24144
Turbidity (NTU)	SWS-01	54	70.31	28.05	786.9	12	50	73	95	120	108
	SWS-02	10	119.6	1.26	1.6	116	120	120	120	120	4
	SWS-06	7	117.03	7.51	56.47	100	119.2	120	120	120	20
	SWS-16	54	75.71	27.53	758.1	25.7	52.6	74.55	99.85	120	94.3
	SWS-21	12	112.67	22.94	526.24	40	117.75	120	120	120	80
TDS (mg/L)	SWS-02	26	278.3	100.3	10065.4	77.8	210.1	278	354.5	458	380.3
	SWS-06	31	262.9	128.5	16517.3	2.9	176.4	248.5	352.4	570.1	567.2
	SWS-07	4	10.74	11.7	136.8	0.02	0.32	10.86	21.03	21.21	21.19
	SWS-21	26	282.3	95	9023.6	82.4	209.7	283.9	344.3	473.9	391.5
NaCL (mg/L)	SWS-02	27	576	906	821148	1	371	463	505	5043	5042
	SWS-06	33	385	195.1	38051.4	1.2	338.7	445.6	477.9	872.7	871.5
	SWS-07	3	21.09	17.14	293.66	1.3	1.3	30.93	31.04	31.04	29.74
	SWS-21	26	496.6	434.8	189068.3	1.5	383.5	460.4	485.8	2516.6	2515.1

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