FUSS & O’NEILL

Manhasset Bay Water Quality Analysis

Manhasset Bay Protection Committee

June 2017

Prepared for and funded by

The Manhasset Bay Protection Committee

An intergovernmental group made up of:

The County of Nassau · The Town of North Hempstead
The Villages of: Baxter Estates · Flower Hill · Great Neck · Kensington · Kings Point · Manorhaven · Munsey Park · Plandome
Plandome Heights · Plandome Manor · Port Washington North • Sands Point • Thomaston

Forward & Executive Summary
by
The Manhassett Bay Protection Committee

Who We Are:

The Manhasset Bay Protection Committee is an inter-municipal organization focused on addressing water quality and coastal issues in Manhasset Bay with a coordinated, watershed-level approach. The Committee has 15 member municipalities: Nassau County, the Town of North Hempstead, and 13 Villages who all voluntarily entered into an inter-municipal agreement. The Committee's goals are to protect, restore, and enhance Manhasset Bay so as to insure a healthy and diverse marine ecosystem while balancing and maintaining recreational and commercial uses. Tasks that help toward these goals include the annual water quality monitoring and regular assessment of Manhasset Bay.

Where We Are:

Manhasset Bay is one of the westernmost estuarine embayments of the north shore of Long Island, NY. The Bay is, therefore, influenced by activities in and around New York City and Long Island Sound, but this report only investigates what is happening within the Bay. According to the New York State Department of Environmental Conservation's (the State regulatory agency concerned with environmental issues both on the land and in the water) Priority Waterbodies List, Manhasset Bay is impaired by pathogens (an indicated by the bacteria fecal coliform and enterococcus) from stormwater runoff, which is the focus of this analysis and report.

About This Document:

The Manhasset Bay Protection Committee is pleased to release this report on the water quality data collected from summer 2009 through summer 2015 as summarized and prepared by environmental engineering firm Fuss & O'Neill, Inc. It has been almost a decade (nine years) since a water quality report of this magnitude has been completed for Manhasset Bay. Water quality reports such as this one are important as they set a baseline to compare future progress against, identify sources of water pollution, and set a course of next steps to continue the progress already made.

Focus of This Study:

The Committee requested a study which compiled bacteriological and water quality data available from 2009 – 2015 (inclusive), correlated that data with any weather or environmental variables then present, assessed the water quality relative to applicable standards, and reported on any trends that may be discernible on this time scale. Some of these goals proved beyond the scope of what a seven-year snapshot of data could provide (such as any long-term trends in bacteria over time), but the analysis still provided solid information about the potential impact of weather and land use and where to target future projects.

Method of Data Collection:

From May until September of each year, the Town of North Hempstead Bay Constables collect water samples at six disparate sites in Manhasset Bay (as shown on Figure 1 of the report). The Nassau County Department of Health then analyzes the water samples for fecal coliform and enterococcus, the two different indicator bacteria used to determine swimming safety. The data from these efforts are provided to the Committee in Microsoft Excel. Additionally, the Interstate Environmental Commission (henceforth IEC) collects in situ data every week over the summer at three additional stations within Manhasset Bay and this data was also utilized.

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Results:

The data demonstrated a link between rainfall, sampling location, and bacteria counts consistent with what is expected in this system (see Spatial Summary below). All of the sampling stations are strongly influenced by the input of stormwater runoff and this pattern is consistent with guidance that the Bay is safe to swim in, just not right after (or during!) a storm, as is the case for most of Long Island.

Spatial Summary

Multiple spatial trends were apparent and consistent with expectations in an estuarine ecosystem in a developed area:

- On the eastern shore (Port Washington peninsula), which is more densely populated and has numerous storm drains channeling water into the Bay, elevated bacteria concentrations are more likely to occur on the same day as a rain storm.
- On the western shore (Great Neck peninsula), which is less densely populated, the central Bay sampling stations higher bacteria counts are more likely to occur the day after a rainfall event.
- The eastern shore stations, impacted by higher population densities and multiple outfalls, showed bacteria counts that were higher in general than other stations. However, it is important to note that the majority of samples collected at all stations are below the state standards for safe swimming and over the period of record examined none of the annual median values exceeded the single sample standard for fecal coliform or enterococcus. Additionally, the sources of bacteria may not be human at all, but may be caused by the large populations of different species of waterfowl that inhabit these areas.
- Dissolved oxygen and light penetration (transparency – important for plant species) data, derived from IEC sampling, decrease from the outer Bay (near the inlet to Long Island Sound) to the inner Bay. This is expected as the inner bay is shallow and has less mixing. However, as another important side note, the IEC's measurements in Long Island Sound outside the Bay are actually worse (lower dissolved oxygen and transparency) than those in the Bay, but that data was not included in this report.

Temporal Summary

Over the course of this relatively short sampling period, the range of bacteria concentrations (i.e., the difference between the minimum and maximum count) at most sampling stations decreased, especially since the first few years of the period of record. While no other temporal trends are currently apparent with this small data set, data collection is continuing and even expanding in the hopes that one day, a long data record will be able to demonstrate a positive change in the conditions in the Bay.

Other Spatial Variations and Key Recommendations

The sampling stations in Manhasset Bay near Leeds Pond (MB-1) and Baxter Beach (MB-5) were identified as needing further investigation to determine what factors other than stormwater (such as cesspool drainage or waterfowl congregation) may be impacting the water quality in these locations. An example and a suggestion of a possible test is that of DNA "source tracking." This is a relatively new field of study in which bacterial DNA is used to identify the general source (i.e., human, bird, dog, etc) of the bacteria. This allows for a more targeted program to reduce or even eliminate the source of pollution and will be considered by the Committee as a potential future undertaking.

A key recommendation of the report was that the Committee's and IEC's sampling be aligned to allow for a better data comparison. However, at the time of this writing, the Committee anticipates expanding its own monitoring to include the same parameters that IEC collects on the days that the Bay Constables collect samples. This will allow for a more closely aligned data set and no need to change sampling days.

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Water Quality Conclusion

The water quality of Manhasset Bay has not gotten worse over this sampling time period and, given the many major storms (Super Storm Sandy and Hurricane Irene) and growth of population, no discernable pattern of increased bacteria was evident. Further evidence of this is the abundant wildlife (e.g., whales, porpoises) that have returned to the area. Water quality will certainly continue to recover, especially with the continued diligence of the residents that share the Bay.

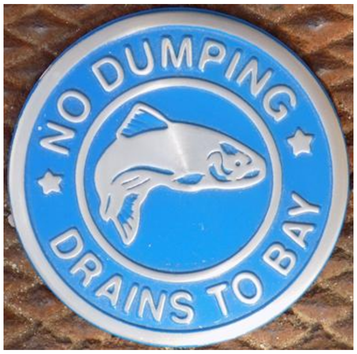
Staying Vigilant:

Manhasset Bay is a vital resource which impacts the local and regional economy and the Manhasset Bay Protection Committee remains committed to implementing projects and activities that facilitate an improvement in water quality toward the swimmable, fishable goals of the Clean Water Act. Many of the key conclusions of this report, such as the improvement in water quality from east (more developed) to west (less developed) and the link between bacteria concentrations and stormwater runoff, are not a surprise and the reason we are already working in this area. Additionally, projects, such as watershed-based planning, a key recommendation of this report, are already being discussed and acted on by the Manhasset Bay and other Protection Committees. Other initiatives aimed at improving water quality include "Get Pumped LI!" and the Long Island Nitrogen Action Plan. However, despite all this great work, water quality cannot improve without the help of everyone.

Recommendations for How Everyone Can Help:

Listed below are some examples of simple changes to everyday activities that will have a positive impact on Manhasset Bay, even in areas seemingly far from the Bay.

- Pick up after pets: dog (and even cat) waste that is left on the ground can be picked up by rain water and transported to Manhasset Bay, increasing bacteria counts.
- Do not put anything down a storm drain, ever. This water is not treated, but instead flows directly to Manhasset Bay.
- Clean up spills of fertilizer and pesticides: like pet waste, these spills can be picked up by rain water and transported to Manhasset Bay, where they can have adverse impacts on water quality.
- If you have a cesspool or septic tank, get pumped out regularly (visit http://www.getpumpedli.org for more information).
- Don't feed ducks, geese, or other birds: there is a bounty of food that nature provides which is better than anything people feed them (and human food can actually be harmful). Also, feeding birds tends to concentrate them in an area, leading to more bacteria entering the water from their droppings.
- Don't flush anything unless it passed through you first, with the exception of toilet paper. Foreign objects, even those that claim to be "flushable," can clog sewer and cesspool systems, causing leaks of untreated or poorly treated sewage.
- Don't fertilize before a rain storm and consider getting your lawn tested to learn how much fertilizer it needs. Also consider leaving grass clippings in place after mowing: they break down quickly and naturally fertilize the soil.
- Do not pour grease and oil down the sink and be sure to report to the Town or Village if you see anyone doing just that. Similar to flushing the unflushables, grease and oil cause clogs and are often the cause of sewage spills.



- Connecting downspouts to the sewer system is illegal. Remove these hook-ups and notify the Town or Village where you live if you see someone else doing this. Consider alternatives, such as rain gardens, for your downspout discharge.
- Volunteer for a beach clean-up! Trash un-intentionally gets blown away and ends up in Manhasset Bay. Help combat this problem at the source by properly disposing of your garbage and on the beach by volunteering.
- Visit http://www.manhassetbayprotectioncommittee.org for more information.

Sarah Deonarine, Executive Director

Manhasset Bay
Protection Committee

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1 Purpose and Objectives

The data collected in Manhasset Bay over the past several years by the Town of North Hempstead (Town) Bay Constables and the Interstate Environmental Commission (IEC) can provide useful insight into historic water quality conditions, including spatial differences and temporal changes in those conditions, and relationships between water quality and environmental variables. Rather than providing a cataloging of water quality conditions, this report is organized to describe targeted analyses of data collected in Manhasset Bay from 2009-2015, to address the following key questions of interest to the Manhasset Bay Protection Committee (MBPC):

- What are potential relationships between bacteria data and rainfall and tidal data?
- Are there temporal and spatial trends in bacteria data that indicate changes in water quality status of the bay relative to applicable standards?
- Can the influence/impact of stormwater runoff on the bay water quality be determined?

To explore these questions, graphical and statistical analysis of the Manhasset Bay and IEC data was performed, along with tide and rainfall data obtained from the National Atmospheric and Oceanic Administration (NOAA) and used for correlation analysis.

2 Data

Four data sets were used in the analysis of water quality. The primary data set consists of seven (7) years of weekly sampling data for fecal coliform and enterococcus as well as limited concurrently-collected environmental data that is both numerical (air and water temperature) and categorical (wave height, wind direction/speed, and weather) at six (6) stations in Manhasset Bay (MB-1 through MB-6 – see Figure 1 and Table 1). Samples are collected once a week from May until September (an average of 13 sampling dates per year) by the Town of North Hempstead Bay Constables. The Nassau County Department of Health then analyzes the water samples for fecal coliform and enterococcus. The data from these efforts are provided to the MBPC Executive Director in Microsoft Excel. PDF versions of this data are available by year (starting in 2009) on the MBPC website at http://www.manhassetbayprotectioncommittee.org/waterquality.htm. The Interstate Environmental Commission (IEC), a tri-state water and air pollution control agency, also collects *in situ* data at three stations within Manhasset Bay every week over the course of the summer (generally 12 weeks) as part of their Long Island Sound ambient water quality monitoring. IEC-collected data at three stations in Manhasset Bay (9-409, 9-412, and 9-413 – see Figure 2) includes temperature, salinity, secchi disk depth, pH, dissolved oxygen, percent cloud cover, and (from 2011-2015) tidal information at New Rochelle and Kings Point, and rainfall in the prior 24- and 48-hour period, as well as categorical variables for weather and sea state. Unfortunately, the dates of data collection for Town-collected and IEC-collected data do not coincide. In addition to the data sources described above, tide data from the gauge at Kings Point, NY[1] and rainfall data from Central Park, New York for the period 2009-2015 was obtained from NOAA and used for correlation analysis (see Figure 1). All data used has been compiled electronically into Microsoft Excel spreadsheets for future use by MBPC.

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[1] https://tidesandcurrents.noaa.gov/waterlevels.html?id=8516945&units=standard&bdate=20150101&edate=20151231&timezone=GMT&datum=MLLW&interval=h&action=data

GIS data layers of known outfall locations and sewer service areas of the watershed (Figure 2) were provided to Fuss & O'Neill by The Bowne Group[2] and the County of Naussau[3] and The Nature Conservancy[4], respectively. The Manhasset Bay watershed was delineated using the Natural Resources Conservation Service (NRCS) Watershed Boundary Dataset (WBD) Hydrologic Unit Code 12-digit (HUC-12) watershed boundary, and verified using 2014 United States Geological Survey (USGS) Coastal and Marine Geology Program (CMGP) Lidar: Post Sandy (Long Island, NY), 1-foot contour topographic data. Subwatersheds within the Manhasset Bay watershed were delineated based on previous delineations by Dvirka and Bartilucci[5] and refined using the 2014 USGS CMGP Lidar data.

Table 1. Manhasset Bay Sampling Stations and Names

Station Identifier	Name
MB-1	Leeds Pond
MB-2	Kennelworth
MB-3	Manorhaven
MB-4	NUN 4
MB-5	Baxter Beach
MB-6	Manorhaven Beach

The sampling locations MB-1 through MB-6 are shown on Figure 2 using field-collected latitude and longitude coordinates. Sampling locations 9-413, 9-412, and 9-409 were placed on Figure 2 in their approximate location using mapping and descriptive site information contained in previous reports[6,7].

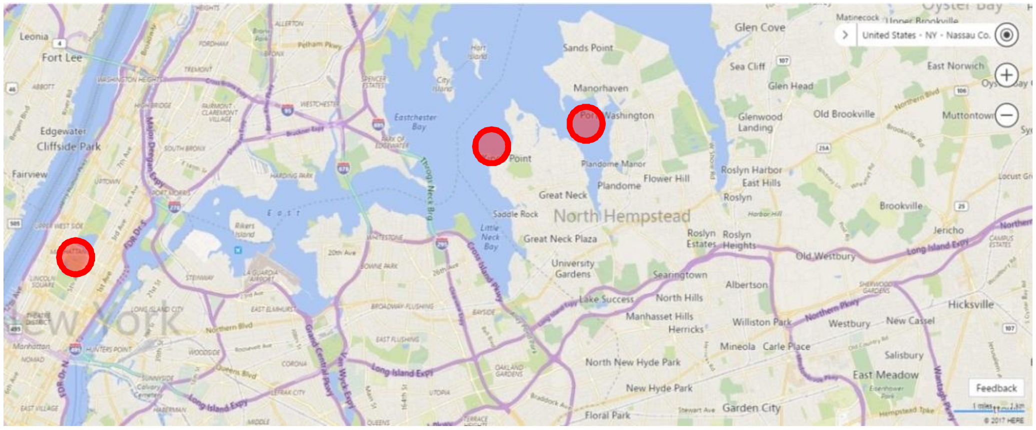

Figure 1. Locations of Tide (King's Point – middle dot) and Rainfall (Central Park – far left dot) Data Relative to Manhasset Bay (far right dot)

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[2] Personal communication from Peter de Sciora, The Bowne A&E Group, December 22, 2016.

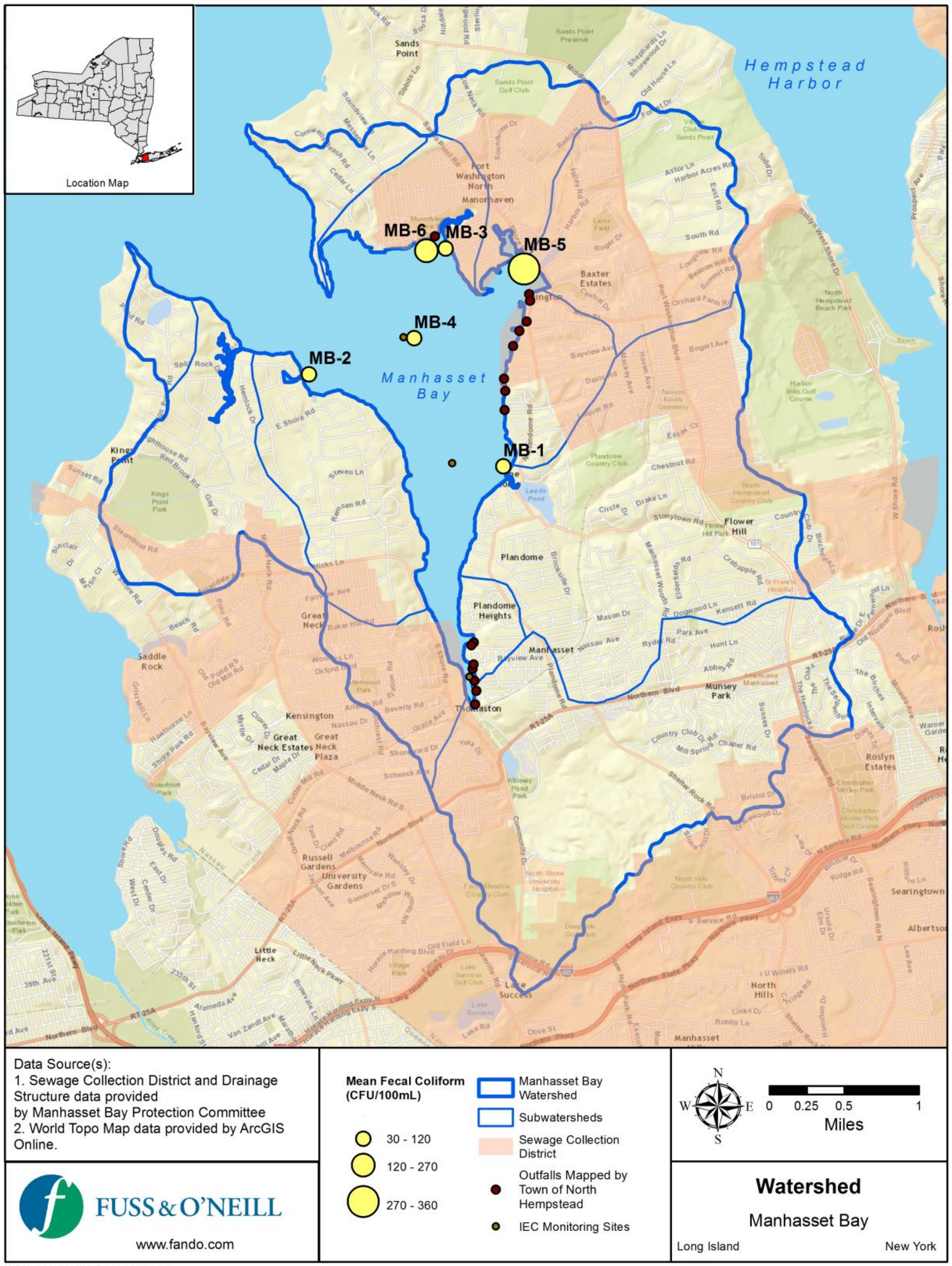
[3] Personal communication from Philip Ciampi, County of Nassau, New York, April 13, 2017.

[4] Personal communication from Stephen Lloyd, the Nature Conservancy, December 12, 2016.

[5] http://www.manhassetbayprotectioncommittee.org/images.htm

[6] LabLite LLC (2008). "Final Report to the Manhasset Bay Protection Committee Concerning Historic and Future Water Quality Monitoring." December, 2008. Accessed at http://www.manhassetbayprotectioncommittee.org/documents/water%20quality/Final%20Report%20to%20MBPC109.pdf

[7] New England Interstate Water Pollution Control Commission Interstate Environmental Commission District (2014). "Hypoxia In Far Western Long Island Sound And Upper East River." Accessed at http://www.iec-nynjct.org/reports/2014.Hypoxia.11.pdf



Data Source(s):
1. Sewage Collection District and Drainage Structure data provided by Manhasset Bay Protection Committee
2. World Topo Map data provided by ArcGIS Online.

K:\P2016\0613\A10\MXD\Watersheds.mxd

Figure 2. Manhasset Bay Watershed and Monitoring Locations (Data at MB Stations collected by Town of North Hempstead Bay Constables; Data at other stations collected by IEC.)

3 Statistical and Graphical Analysis

Graphical and statistical analysis was used to investigate differences in time (i.e., changes over the period of data collection) and space (changes between locations in Manhasset Bay) for water quality data collected at the sampling locations MB-1 through MB-6 and to determine relationships (i.e., correlations) between bacteria indicator organism concentrations and environmental variables consisting of rainfall and tides. Although dates of IEC sampling did not coincide with sampling days at the MB stations, preventing correlation calculations for those variables and bacteria data, an analysis of dissolved oxygen and transparency data at the water surface for stations 9-409, 9-412, and 9-413 was also included. Surface data was used to match with the protocols of the Bay Constables who collect bacteria and temperature data at the surface.

3.1 Statistical Analysis

Statistics provide a way to describe and summarize data and facilitate comparison between different groups of data based on date or location of collection. The summary statistics used in this analysis, and their usefulness in characterizing data, are listed below and described in more detail in Section 3.2:

- Minimum – The lowest observed value in the data set.
- Maximum – Highest observed value in the data set. Together with the minimum value, the maximum determines the range of the data.
- Mean – Measure of the center of a data set, also called the average. It is the sum of all observations in the data set divided by the number of (non-missing) observations.
- Quartiles – First (Q1), Median (50th percentile), Third (Q3) - Each group of data has three quartiles. Sorting the data from smallest to largest values, the first 25% of the data is less than or equal to the first quartile (Q1). The second quartile is the median - 50% of the data is less or equal to the median, and 50% is greater than or equal to the median. The first 75% of the data is less than or equal to the third quartile (Q3), and 25% of the data is greater than or equal to the third quartile.

Tables of summary statistics for the bacteria data collected at MB-1 through MB-6 are provided In Appendix A. Note that MBPC files provided to Fuss & O'Neill used a value of 0.1 CFU/100 ml for zero values of bacteria, presumably to allow log-based calculations. Those values were retained and used for all analyses.

Correlation is another useful statistical tool to describe how two variables, such as bacteria concentrations and rainfall, vary together. In this study, the Pearson product moment correlation coefficient is used to measure the degree of linear relationship between two variables. The statistic computes a value between -1 and +1. If one variable tends to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together, the correlation coefficient is positive. It's important to note that correlation does not always imply causation, i.e., the increase in one variable may not be the cause of the increase (or decrease) in another variable. However, an understanding of underlying processes that affect the variables of interest can be used along with the results of correlation to infer relationships between variables. Tables of correlations between bacteria concentrations, rainfall, and tides are provided in Appendix B.

3.2 Graphical Analysis

The graphical analysis utilizes boxplots (sometimes called box and whisker plots) to concisely summarize the data throughout the period of data collection. The elements of a boxplot are shown in Figure 3.

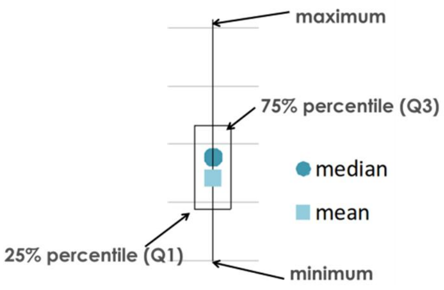


Figure 3. Elements of a Boxplot

When reviewing boxplots, it is important to keep in mind that the height of the box (the difference between the 25th and 75th percentile) is an indication of the variability in the data, with shorter boxes indicating less variability and taller boxes indicating more variability. Boxplots of bacteria data at MB-1 through MB-6 are provided in Appendix C, along with boxplots of dissolved oxygen at the water surface and secchi disk depth (transparency) at IEC stations 9-409, 9-412, and 9-413 provided in Figures 9 and 10.

Scatterplots can also provide a way of visualizing data and the relationships between variables collected at the same time. In this study, we use a scatterplot (along with correlation) to visualize the relationship between the two indicator organism bacteria used.

3.3 Trend Analysis

Trend analysis is a way to detect a pattern, or *trend*, in data and can be useful to determine if measurements exhibit an increasing or decreasing trend which is distinguished from random behavior. Trend analysis can take various forms depending on the data set to be examined. The simplest trend analysis is visual inspection of boxplots of bacteria concentrations at each of the six monitoring locations over the period of record. This provides a simple visual assessment of changes over time and is useful for identifying and discussing obvious changes over time without significant data manipulation. That is the approach used in this study, however, it should be noted that this approach does not account for the influence of other variables that may be impacting the value of the variable of interest (for example, streamflow is influenced by rainfall). A more rigorous approach to trend analysis could be used to perform a statistical test for trend in the bacteria data, which was beyond the scope of this report.

4 Key Questions and Findings

Data analysis for this project was focused on addressing several key questions that the MBPC identified as important to understanding and interpreting the water quality data collected from 2009-2015. The discussion below highlights the findings of the statistical, graphical, and trend analyses relative to those questions.

Although both fecal coliform and enterococcus are fecal indicator bacteria commonly used to assess the presence of fecal pollution and the risk to human health, the two do not always correlate strongly because of differing decay rates and other environmental factors. For the Manhasset Bay data set, there is a relatively strong statistically significant correlation between the two indicator organisms (Figure 4 and Table 2; Note: the correlations were computed for natural log-transformed data). The strong correlation is useful since it gives confidence that one of the fecal indicator bacteria can be used to illustrate spatial and temporal characteristics of the data and also that use of either organism will provide a good surrogate for understanding bacterial water quality conditions.

Table 2. Correlations for Natural Log-Transformed Fecal Coliform and Enterococcus Data at Each Station

Station	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6
Correlation Coefficient	0.600	0.574	0.596	0.565	0.663	0.693
p-value	0.00	0.00	0.00	0.00	0.00	0.00

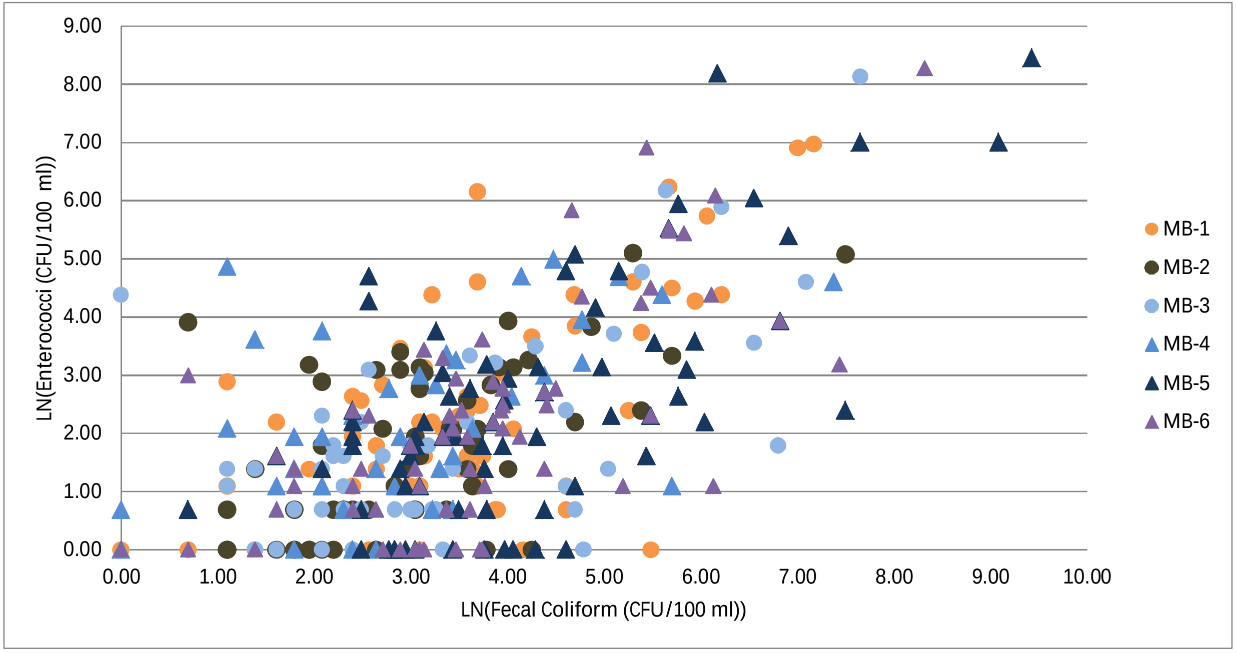


Figure 4. Scatterplot of Fecal Coliform and Enterocci Data at Each Station

4.1 Relationship of Bacteria and Rainfall/Tides

Question: What are potential relationships between bacteria data and rainfall and tidal data?

This question was addressed by extracting four (4) environmental variables from NOAA data sets described in Section 2:

1. tidal elevation at the King's Point tide gauge at 9 AM local time on the day of sampling[8];
2. total rainfall measured at the Central Park station for the day of sampling;
3. total rainfall measured at the Central Park station for the day prior to sampling; and,
4. total rainfall measured at the Central Park station for two days prior to sampling.

The correlation between those four environmental variables and fecal coliform and enterococcus concentrations at stations MB-1 through MB-6 were calculated (see Appendix B). Table 3 provides a summary of the statistically significant ($p<0.05$) computed correlations for rainfall. A range of values is shown because both untransformed and natural log-transformed data were used[9]. Keeping in mind that a value of zero indicates no correlation and a value of one indicates a perfect correlation between two variables, the range of correlations in Table 3 show low to moderate correlations for MB-1, MB-5 and MB-6 with moderate to high correlations for MB-2, MB-3, and MB-4. The results show that there is a statistically significant correlation between rainfall on the day of and the day prior to sampling at all stations. It is worthwhile noting that stations MB-1, MB-3, MB-5, and MB-6, which are located on the eastern side of the bay where many known stormwater outfalls are located[10], generally have higher same-day correlations compared to correlations with rainfall on the day prior to sampling. This is consistent with the idea that the influence of rainfall on bacteria concentrations is going to be more rapid in areas receiving water from stormwater outfalls. In contrast, MB-2 (on the western shore) and MB-4 (in the middle of the bay) show higher correlations with prior day rainfall, consistent with the concept that the influence of rainfall and runoff may take longer to reach these stations. No statistically significant correlation was noted with rainfall two days prior to sampling and, because of their lack of significance, these correlations are not included in Table 3. However, calculated correlation values and associated p-values are provided in Appendix B.

Table 3. Pearson Correlation between Indicator Organism Bacteria and Precipitation

Station	Same Day Precipitation	1 Day Prior Precipitation
MB-1	0.240-0.390	0.242-0.255
MB-2	0.262-0.429	0.356-0.907
MB-3	0.286-0.561	0.361-0.404
MB-4	0.229-0.513	0.383-0.906
MB-5	0.217-0.314	0.327-0.395
MB-6	0.270-0.404	0.238-0.278

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[8] Phase of tide (i.e., ebb, slack, flood) was not considered in the analysis, only the tidal elevation at the approximate time of sampling.

[9] Log transformations are often used to make data consistent with underlying assumptions of procedures including linear correlation.

[10] Only stormwater outfall locations provided by the Town of North Hempstead are included in the mapping in this report. Additional outfalls are located in the bay, but their locations were unavailable

Finding: Yes, there is a moderate to high correlation between rainfall and bacteria concentrations for same day and prior day precipitation. No correlations with tidal elevation were observed.

4.2 Temporal and Spatial Trends

Question: Are there temporal and spatial trends in bacteria data that indicate changes in water quality status of the bay relative to applicable standards?

To understand potential temporal and spatial trends, summary statistics and boxplots of bacteria concentrations at each station for each year of the period of record were generated. Tables 4 and 5 show the summary statistics for both fecal indicator organisms monitored. The New York State marine bathing water quality standards found at NYCRR Title 10 Part 6-2.15[11] are single sample values of 1000 CFU/100 ml for fecal coliform and 104 CFU/100 ml for enterococci[12]. The U.S. Environmental Protection Agency (EPA) has recommended the use of a more-protective Beach Action Value (BAV) of 60 enterococcus bacteria colony forming units (CFU) per 100 ml marine or estuarine water in a single sample. It is worthwhile noting the following key observations:

- While maximum values exceed the standards at all stations for both fecal indicator bacteria, the mean and median values are below the current state standard for fecal coliform for all stations and for enterococcus at all stations except MB-5.
- Only at MB-5 does the mean value for enterococci exceed the state standard of 104 CFU/100 ml[13].
- Both MB-5 and MB-6 have mean values that exceed the recommended BAV of 60 CFU/100 ml.
- Differences between stations are apparent. Comparison of maximum, mean, and median values shows that station MB-3, MB-5, and MB-6 have higher values compared to other stations.

Table 4. Summary Statistics for Fecal Coliform Data (CFU/100 ml)

Summary Statistic	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6
Median	22	11	10	7	35	23
Q1	10	4.5	4	3	17	10
Minimum	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	1300	1800	2100	1600	12400	4100
Q3	40.5	29.5	26	20.25	102.5	51
Mean	76.02	44.47	80.99	39.59	356.24	126.38

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[11] https://www.health.ny.gov/regulations/nycrr/title_10/part_6/subpart_6-2.htm#s6215

[12] New York state regulations also state that the enterococci and fecal coliform geometric means shall not exceed 35 per 100 ml or 200 per 100 ml, respectively, for a series of five or more samples collected during a 30-day period. (More information is available at http://www1.nyc.gov/site/doh/health/health-topics/beach-class.page) Because the data available for this study does not consistently provide the necessary frequency of five samples in a 30-day period, it was not evaluated for this study.

[13] See note 10 above.

Table 5. Summary Statistics for Enterococci Data (CFU/100 ml)

Summary Statistic	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6
Median	3	1	1	0.1	5.5	3
Q1	0.1	0.1	0.1	0.1	1	0.1
Minimum	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	1070	164	3400	147	4700	3900
Q3	11.5	8	4	5.5	16.75	11
Mean	46.71	9.68	51.19	11.29	135.40	74.23

The spatial differences between bacteria concentrations at stations are consistent with the land use in those areas draining to known outfalls proximal to the sampling points. Figure 5 shows the sampling stations with higher bacteria concentrations (left) and land use (right). Higher density development including commercial and industrial development, as indicated by the higher amounts of impervious cover in Figure 5, are located in areas discharging to the eastern shore of Manhasset Bay, where bacteria concentrations are higher.

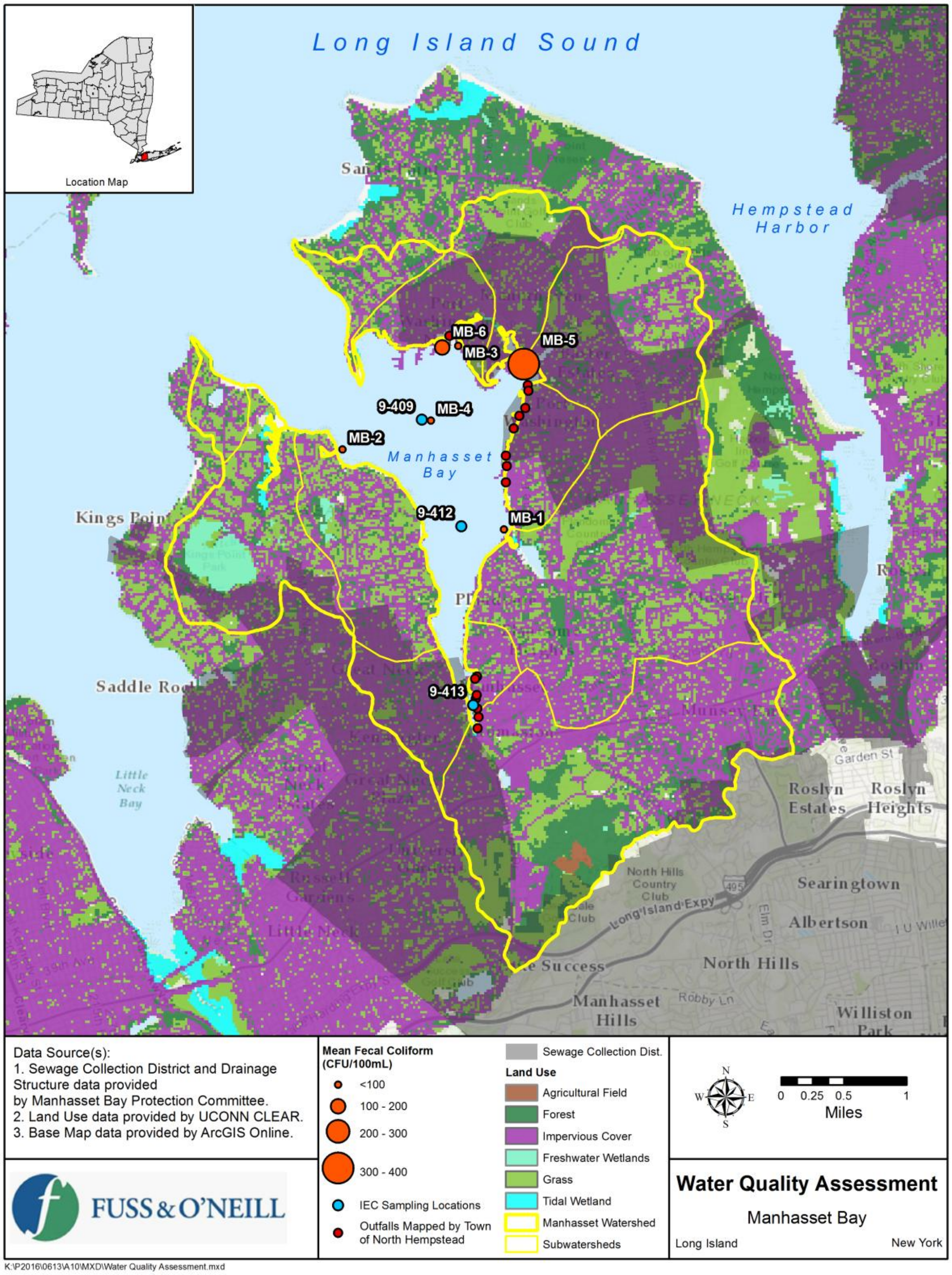

Figure 5. Sampling Locations Relative to Land Cover and Impervious Area

The spatial differences are also apparent when examining boxplots of data comparing stations on the western, central, and eastern parts of the bay. Figure 6 shows fecal coliform concentrations at Stations MB-2, MB-4, and MB-6 with the 1000 CFU/100 ml standard indicated as a red line on the graphs for reference. Comparison of the boxplots shows that all statistical measures are generally higher at MB-5 than either MB-4 or MB-2. The red reference line illustrates that for most years at all three locations, the data collected is less than 1000 CFU/100 ml standard, although the standard is exceeded more often at MB-5. These results all point to spatial differences in water quality consistent with an understanding of how land use impacts stormwater runoff, with more developed areas (such as the commercial and higher density residential land use on the eastern side of Manhasset Bay indicated by the greater area of impervious cover) typically associated with higher bacteria concentrations.

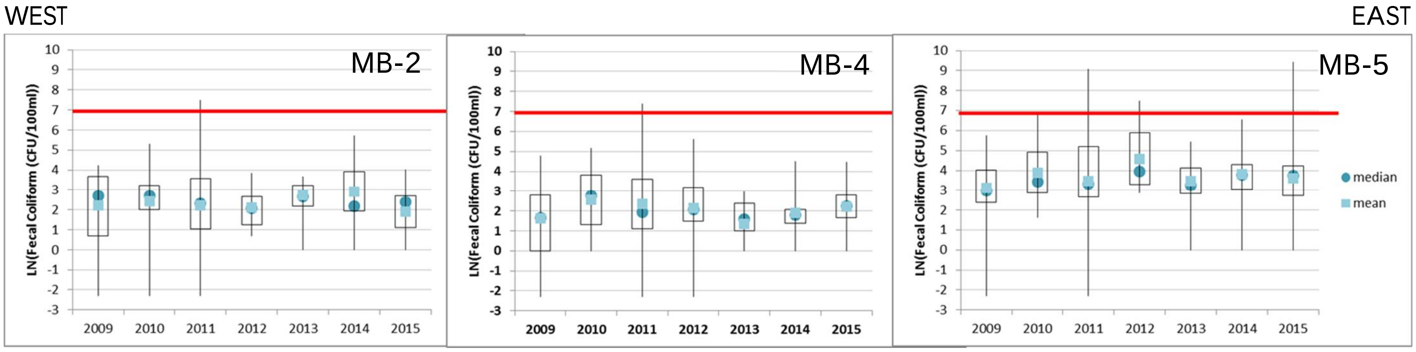

Figure 6. Fecal Coliform Concentrations from West to East Across Manhasset Bay.
(The red line indicates the 1000 CFU/100 ml water quality standard for fecal coliform.)

In addition to the visual analysis, the non-parameteric (i.e., not dependent on data being normally distributed) Kruskal-Wallis test of differences among fecal coliform concentrations by monitoring site showed a significant difference. A similar test performed by sampling year was not significant. A post-hoc Tukey Honest Significant Difference test indicated that this impact stems from monitoring location MB-5, which was significantly greater than MB-2 (p=0.022) and MB4 (p=0.018) and marginally significantly greater than MB-1 (p=0.055) and MB-3 (0.06). Site MB-5 was not significantly greater than MB-6 (p=0.18). This finding is consistent with the discussion above regarding differences in water quality at sampling stations moving west to east across the Bay; with the more densely developed areas and subwatersheds with higher levels of impervious cover coincident with higher bacteria concentrations.

Visual assessment of temporal trends in water quality is most easily assessed with boxplots describing concentrations over time at a single location. Stations MB-2, MB-4, ad MB-5 are also used for that assessment since they are representative of conditions in various locations in the Bay. Fecal coliform is once again used for illustrative purposes since the enterococci and fecal coliform data is fairly highly correlated. In Figure 7, a line connecting median values is used as an aid to detecting patterns. Although there is some variation from year to year, the central tendency of the data does not exhibit a noticeable increase or decrease, suggesting no obvious visual trend. The boxplots do illustrate that 2011 was different from other years because of the wide variability in data, possibly the result of Hurricane Irene in August of that year. Finally, Figure 8 shows data in the middle of the bay at MB-4. No visual trend is apparent there, although there does appear to be a slight decrease in variability as noted by the shorter boxes in 2013-2015.

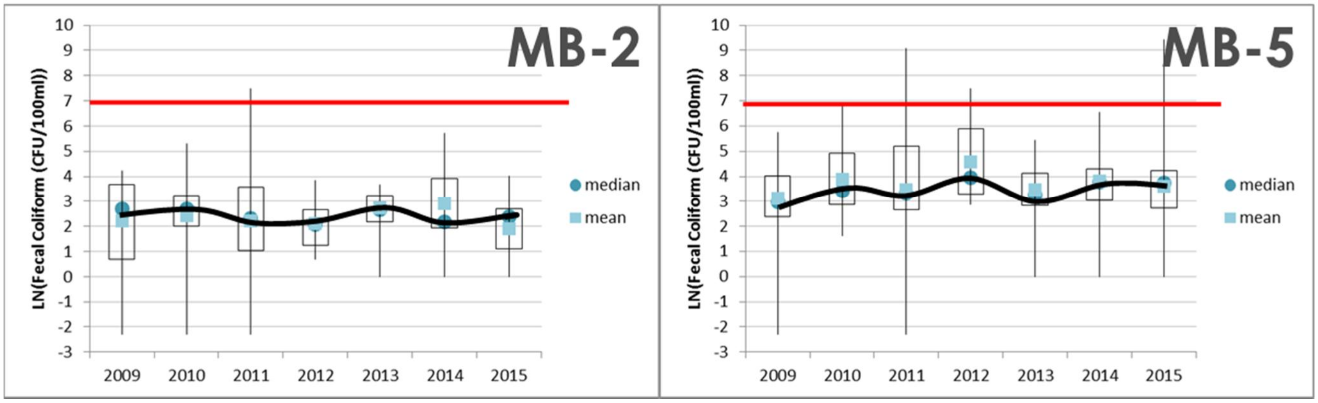

Figure 7. Fecal Coliform Concentrations at MB-2 (West) and MB-5 (East) Across Manhasset Bay.
(The red line indicates the 1000 CFU/100 ml water quality standard for fecal coliform; black line is connected medians.)

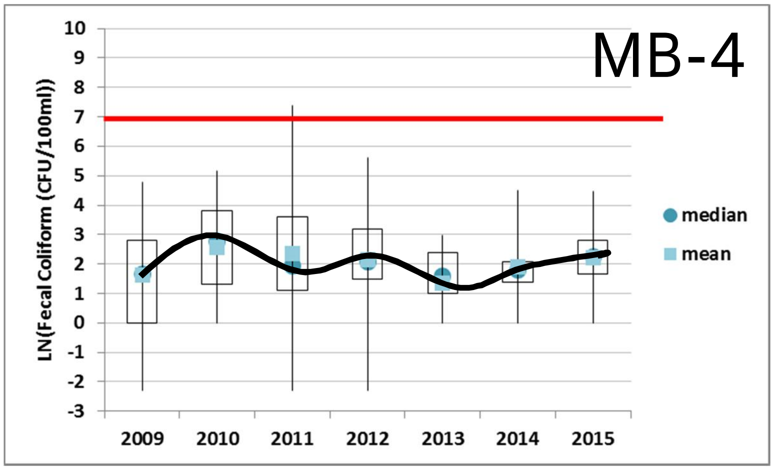

Figure 8. Fecal Coliform Concentrations at MB-4 (Center) of Manhasset Bay
(The red line indicates the 1000 CFU/100 ml water quality standard for fecal coliform;
black line is connected medians.)

Secchi disk depth (transparency) and dissolved oxygen (DO) were plotted for IEC data collected at the water surface at stations 9-409, 9-412, and 9-413. In the boxplots in Figures 9 and 10, median values are shown by a black horizontal line and mean values are shown by a blue dot. Small open circles represent extreme values. Also note that surface data was not available for 9-409 and 9-412 for 2011 and no secchi disk depths were available that year. Figure 9 shows two notable features of the DO values. First, DO concentrations are lower moving from the mouth of the Bay inland. 9-413 has both the lowest mean and median DO concentrations and also has values that are below the New York State acute water quality standard of 3 mg/l found at 6 CRR-NY 703.3. This is consistent with conditions of shallower depth and less mixing with ocean waters at 9-413. Since DO is also influenced by temperature, with cooler water being able to hold more dissolved oxygen, DO values are also influenced by temperature differences between stations which in part reflect differences in depth and tidal influence. Post-2011 values appear to be relatively consistent at all three IEC stations[14].

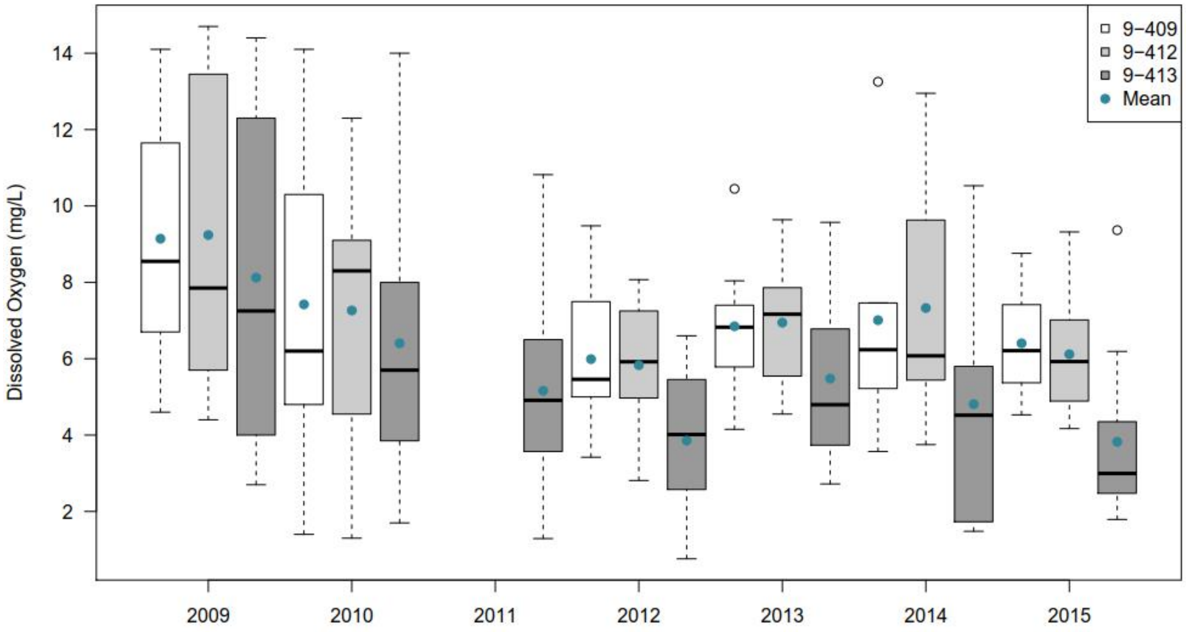

Figure 9. Dissolved Oxygen Concentrations at the Water Surface at IEC Stations 9-409, 9-412, and 9-413

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[14] IEC upgraded to a new probe beginning in 2011, although this likely has no bearing on data consistency.

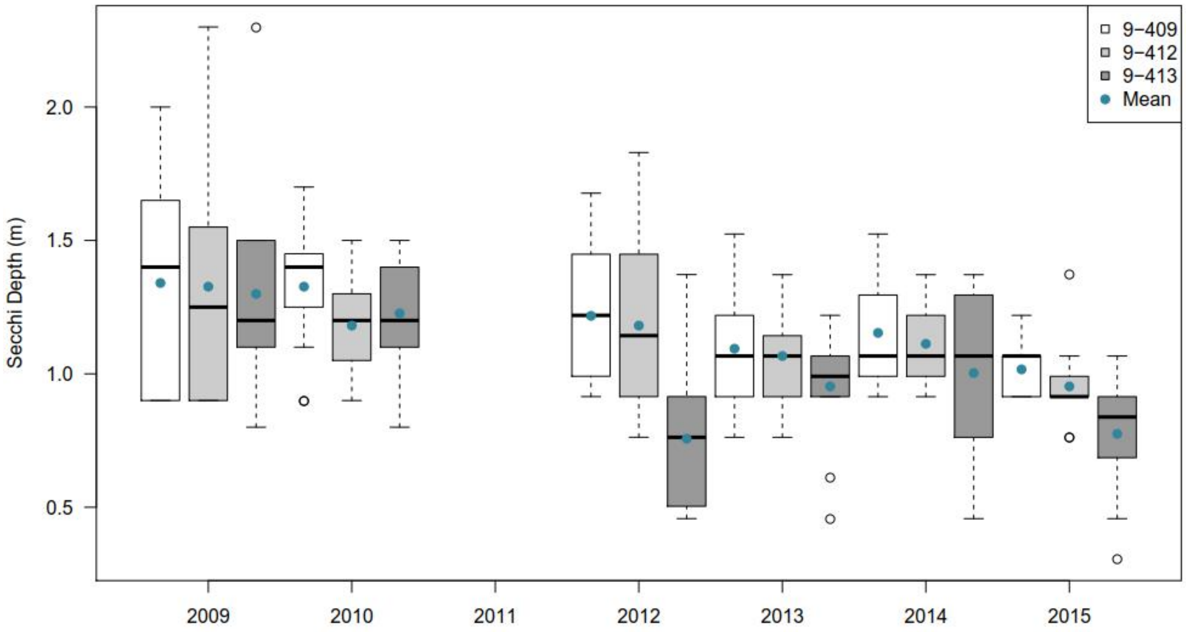

Figure 10. Secchi Disk Depths at IEC Stations 9-409, 9-412, and 9-413

Figure 10 shows that secchi disk depths, which are also indicative of transparency and water clarity, tend to be greater at 9-409 and 9-412, a result which is not surprising given the location of the stations further toward the mouth of the Bay in Long Island Sound. While secchi disk depth was relatively consistent in 2013 and 2014, the 2015 data shows a decline which should be tracked to determine if the decline was a temporary condition or indicative of an underlying change.

Finding: Visual analysis indicates spatial differences in water quality from west to east in the bay and moving from the mouth of the Bay inland, with higher bacteria concentrations observed on the eastern side of the Bay and declines in DO and transparency noted moving landward from the mouth of the Bay. While no strong visual trends in the temporal pattern of bacteria are apparent, continued comparison of data should be done to determine if the reduced variability continues. Recent slight declines in the transparency at the IEC stations should continue to be monitored to determine if 2015 was an anomalous year or indicative of ongoing ambient water quality conditions.

4.3 Influence of Stormwater Runoff

Question: Can the influence/impact of stormwater runoff on the bay water quality be determined?

The results of the correlation analysis showed a positive correlation between rainfall and bacteria concentrations at all sampling locations (Table 3) and the spatial differences in bacteria concentrations across the Bay (Tables 4 and 5 and Figures 6 and 7) coincide with density of known outfalls and land use consistent with higher bacteria loads (Figure 8). Bacteria in stormwater can come from a variety of sources[15] including illicit connections (e.g., sanitary sewer connections to the storm sewer), illicit discharges (e.g., power washing), failing or improperly located onsite wastewater treatment systems (septic systems), urban wildlife, domestic pets, and other sources. In the absence of a targeted sampling program to determine loads from particular drainage areas, the weight of evidence available for this study suggests that stormwater runoff does influence water quality in the Bay as measured by fecal indicator organisms.

In order to further assess the differences between wet weather and dry conditions, two types of additional analysis were performed. The first looked at differences in summary statistics for samples collected under "dry" and "wet" conditions, where dry conditions consisted of no recorded rainfall the day of or up to two days prior to sampling. Table 6 and Table 7 summarize the results for both fecal coliform and enterococcus bacteria at all stations for the period of record. Most locations show substantial differences in wet and dry weather conditions indicating the influence of wet weather runoff. This is especially apparent for enterococcus values at all stations except MB-1. It is also worth noting that the highest wet weather maximum values correspond to stations with high levels of imperviousness as discussed in Section 4.2 (i.e., MB-3, MB-5, and MB-6). What the analysis also shows, however, is that both types of indicator bacteria concentrations are similar in wet and dry weather conditions for MB-1. An unsewered part of the watershed drains to this location and these high values regardless of wet or dry weather conditions suggest the presence of either septic system impacts or illicit discharges introducing wastewater into the stormwater drainage system. It is also worth noting that MB-5 and MB-6 have elevated fecal coliform levels even in dry weather, suggesting a higher "background" of fecal coliform in this sewered area could be due in part to the land uses draining to the sampling locations, but could also be the result of illicit discharges or other non-stormwater sources.

To further explore and compare the differences between MB-1 (suspected of septic system impact) and MB-5 (suspected of being influenced by stormwater in a sewered area), the boxplots in Figures 11 and 12 show the differences between wet and dry weather enterococcus concentrations. While MB-5 (Figure 12) shows a pattern typical of a stormwater impacted system, MB-1 shows less of a distinct difference between wet and dry weather conditions, suggesting another underlying source of bacteria at that station.

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[15] UWRRC Technical Committee (2014). *Pathogens in Urban Stormwater Systems*. Available at: http://stormwater.wef.org/2014/10/ewri-releases-report-pathogens-urban-stormwater-systems/

Table 6. Wet and Dry Weather Summary Statistics for Fecal Coliform Data (CFU/100 ml)

Station	Mean	Minimum	Q1	Median	Q3	Maximum
MB-1						
Dry	78.4	0.1	6.25	22	38.0	1300
Wet	74.3	0.1	11.0	21	51.0	1100
MB-2						
Dry	21.6	0.1	3.00	12	29.25	218
Wet	57.2	0.1	5.50	11	37.0	1800
MB-3						
Dry	63.1	0.1	4.00	11	20.0	900
Wet	90.1	0.1	4.00	10	36.0	2100
MB-4						
Dry	14.43	0.1	1.50	5	15.5	118
Wet	52.8	0.1	3.00	8	26.0	1600
MB-5						
Dry	77.3	0.1	13.0	21	65.5	920
Wet	502	0.1	19.0	44	160.0	12400
MB-6						
Dry	122	0.1	7.50	21.5	48.3	1700
Wet	128	0.1	10.0	28	52.0	4100

Table 7. Wet and Dry Weather Summary Statistics for Enterococcus Data (CFU/100 ml)

Station	Mean	Minimum	Q1	Median	Q3	Maximum
MB-1						
Dry	36.2	0.1	0.1	2.00	8.75	1070
Wet	54.4	0.1	0.1	4.00	21.0	1000
MB-2						
Dry	4.96	0.1	0.1	1.00	5.00	30
Wet	12.31	0.1	0.1	2.00	8.50	164
MB-3						
Dry	2.10	0.1	0.1	0.10	1.75	35
Wet	76.1	0.1	0.1	2.00	6.00	3400
MB-4						
Dry	3.61	0.1	0.1	0.10	2.00	37
Wet	15.32	0.1	0.1	1.00	8.00	147
MB-5						
Dry	10.85	0.1	0.1	0.10	6.50	110
Wet	200.6	0.1	0.1	1.00	24.0	4700
MB-6						
Dry	5.56	0.1	0.1	1.50	8.00	51
Wet	111.3	0.1	0.1	4.00	19.0	3900

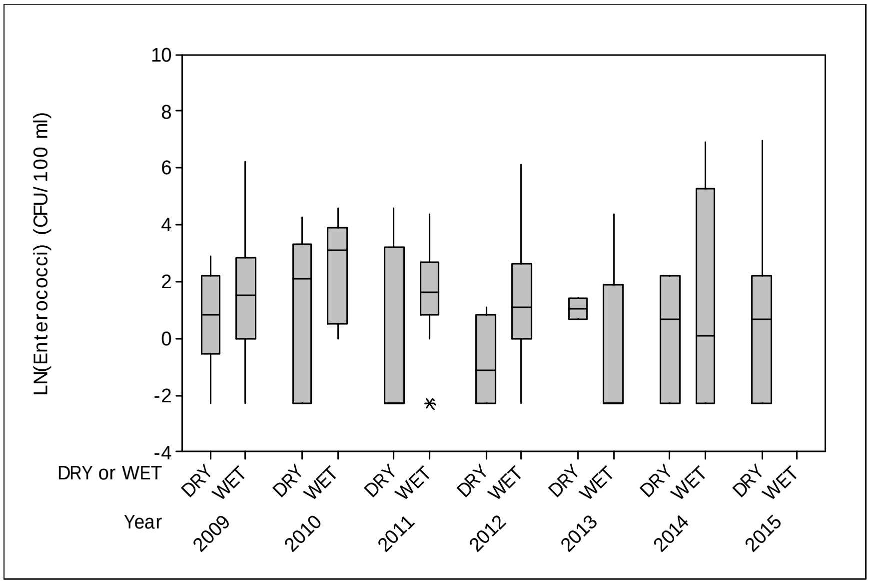

Figure 11. Wet and Dry Weather Enterococcus Concentrations at MB-1

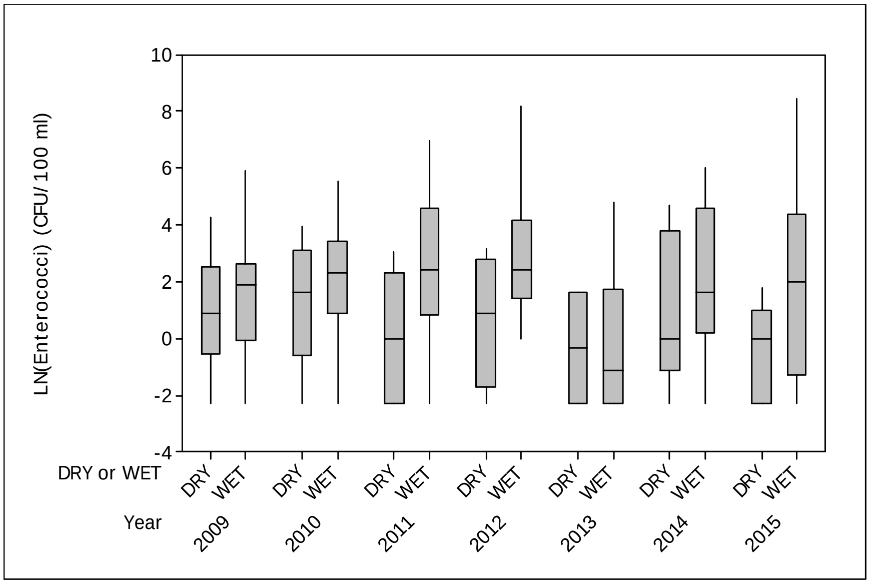

Figure 12. Wet and Dry Weather Enterococcus Concentrations at MB-5

A second analysis of the data looked at the “lag correlation” between rainfall and bacteria concentrations. This statistical analysis examines the link between the individual time series with varying delays or lags between them (e.g. 0 days, ±1 day, ±2 days, etc). All sites showed a strong correlation resulting from a lag of 1 day. In other words, if it rained yesterday, one should expect an increase in fecal coliform. Site MB-5 also showed a strong correlation at 8 days prior to fecal coliform testing. This slight difference is likely the consequence of a series of precipitation events associated with Hurricane Irene that resulted in approximately 9 inches of rain from August 14-21, 2011. Because of this, that value was removed to determine if the relationship would remain in the absence of that large event. Removing the data from that period and reanalyzing in the same manner revealed that a significant correlation remains between previous-day rainfall and fecal coliform concentration at MB-4 and MB-5. A weaker signal remains visible in the data at the other sampling locations, indicating that all locations are impacted by stormwater to some degree.

Finding: Graphical and statistical analysis suggests that concentrations of fecal coliform and enterococcus in the bay are influenced by stormwater runoff. Note that the portion of the watershed draining to Station MB-1 may also be impacted by other discharges into the stormwater system. Station MB-5 bacteria concentrations during dry weather conditions may result from non-compliant MS4[16] *conditions and/or other non-stormwater source issues.*

4.4 Conclusions and Recommendations

The analyses presented in this report resulted in several key conclusions and also suggests several recommendations to further investigate and reduce bacteria sources.

Key Conclusions

- For the Manhasset Bay data set, there is a relatively strong statistically significant correlation between concentrations of fecal coliform and enterococcus. The strong correlation is useful since it gives confidence that one of the fecal indicator bacteria can be used to illustrate spatial and temporal characteristics of the data and also that use of either organism will provide a good surrogate for understanding bacterial water quality conditions.

- There is a statistically significant correlation between rainfall on the day of and the day prior to sampling at all stations. It is worthwhile noting that stations MB-1, MB-3, MB-5, and MB-6, which are located on the eastern side of the bay (Port Washington peninsula) where many known stormwater outfalls are located, generally have higher same-day correlations compared to correlations with rainfall on the day prior to sampling. This is consistent with the idea that the influence of rainfall on bacteria concentrations is going to be more rapid in areas receiving water from stormwater outfalls. In contrast, MB-2 (on the western shore – Great Neck peninsula) and MB-4 (in the middle of the Bay) show higher correlations with prior day rainfall, consistent with the concept that the influence of rainfall and runoff may take longer to reach these stations.

- When compared with state water quality standards for marine bathing beaches, maximum values exceed the standards at all stations for both fecal coliform and enterococcus. The mean and median values for the period of record are below the current state standard for fecal coliform for all stations and for enterococcus at all stations except MB-5. It is important to note that the majority of samples collected at all stations are below the state standards for safe swimming and, over the period of record examined, none of the annual median values exceeded the single sample standard for fecal coliform or enterococcus.

- For both indicator bacteria, differences between stations are apparent. Comparison of maximum, mean, and median values shows that stations MB-3, MB-5, and MB-6 have higher values compared to other stations.

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[16] MS4 refers to municipal separate storm sewer systems (MS4s). Stormwater and certain authorized types of uncontaminated non-stormwater are the only discharges that should enter an MS4. Illegal dumping and connections can result in illicit discharges of non-stormwater wastes like car oil and sanitary waste. (https://www.epa.gov/npdes/stormwater-discharges-municipal-sources#illicitdischarge)

- While no strong visual trends in the temporal pattern of bacteria are apparent, visual analysis of bacteria concentrations by year shows generally decreased variability in the range of values observed, especially for fecal coliform. Continued comparison of data should be done to determine if the reduced variability continues.

- Dissolved oxygen (DO) concentrations are lower moving from the mouth of the Bay inland. Station 9-413 has both the lowest mean and median DO concentrations and also has values that are below the New York State acute water quality standard of 3 mg/l found at 6 CRR-NY 703.3. This is consistent with conditions of shallower depth and less mixing with ocean waters at Station 9-413.

- Most locations show substantial differences in wet and dry weather conditions indicating the influence of wet weather runoff. The highest wet weather maximum values correspond to stations with high levels of imperviousness (i.e., MB-3, MB-5, and MB-6).

- MB-5 and MB-6 have elevated fecal coliform levels even in dry weather, suggesting a higher "background" of fecal coliform in this sewered area could be due in part to the land uses draining to the sampling locations, but could also be the result of non-stormwater discharges or other sources.

- Both fecal coliform and enterococcus concentrations are similar in wet and dry weather conditions for MB-1. An unsewered part of the watershed drains to this location and these high values regardless of wet or dry weather conditions suggest the presence of either septic system impacts or other discharges introducing bacteria into the stormwater drainage system.

Key Recommendations

- The indicator bacteria used tend to vary in similar ways, suggesting that one could be used if constraints on funding or analysis made sampling of both fecal coliform and enterococcus impractical. If only one indicator bacteria were to be used, enterococcus would be recommended due to its use in both state water quality standards and federal guidelines for recreational waters.

- Sampling events should ideally be aligned so that both Manhasset Bay constables and IEC staff are collecting samples on the same day. This would allow for expansion of the data set in the future.

- Coordination with activities required as part of the EPA MS4 program would allow for leveraging discharge investigations to understand (and eliminate) potential bacteria sources to Manhasset Bay.

- Investigation of stormwater outfalls to Manhasset Bay discharging during dry weather would provide information on potential non-compliant MS4 conditions and bacteria sources.

- Targeted sampling of stormwater outfalls during wet weather events for other parameters indicative of sewage (i.e., optical brighteners, ammonia, pharmaceuticals) would help to identify non-stormwater sources of bacteria if they are present.

- Use of DNA-based testing could allow for confirmation or elimination of suspected human sources in areas where dry weather bacteria concentrations remain elevated.

- Electronic mapping the location of all outfalls within the Bay, including information on ownership, size, condition (e.g., percent blocked, etc), would provide a useful resource for future investigations of potential bacteria sources.

- Hydrodynamics within the Bay could be investigated to better understand how tides and discharges interact to influence water quality around the Bay. Tidal phase (i.e., flood, slack, ebb) could also be included as an observation during water quality monitoring to gather additional information about the potential influence of tides.

Appendix A

Tables of Summary Statistics

Period of Record Summary Statistics – Bacteria

Fecal Coliform (CFU/100ml)

	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6
Median	22	11	10	7	35	23
Q1	10	4.5	4	3	17	10
Minimum	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	1300	1800	2100	1600	12400	4100
Q3	40.5	29.5	26	20.25	102.5	51
Mean	76.02	44.47	80.99	39.59	356.24	126.38

Enterococci (CFU/100ml)

	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6
Median	3	1	1	0.1	5.5	3
Q1	0.1	0.1	0.1	0.1	1	0.1
Minimum	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	1070	164	3400	147	4700	3900
Q3	11.5	8	4	5.5	16.75	11
Mean	46.71	9.68	51.19	11.29	135.40	74.23

Q1 = first quartile or 25th percentile
Q3 = third quartile or 75th percentile
Note: MBPC files provided to Fuss & O'Neill used a value of 0.1 CFU/100 ml for zero values, presumably to allow log-based calculations. Those values were retained and used for all analyses.

MB-1 Bacteria Summary Statistics

Fecal Coliform (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	13.00	28.00	15.00	22.00	18.00	31.00	26.00
Q1	4.50	9.5	7.5	10.5	12.25	11	22
Minimum	0.10	0.10	0.10	1.00	3.00	2.00	3.00
Maximum	290.00	380.00	500.00	109.00	48.00	1100.00	1300.00
Q3	22.25	130.5	41	38	26.25	100	100
Mean	42.38	87.55	57.47	29.07	20.17	147.31	163.54

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	4.50	11.00	5.00	3.00	0.55	2.00	2.00
Q1	1.00	1.5	0.55	0.55	0.1	0.1	0.1
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	510.00	100.00	100.00	470.00	80.00	1000.00	1070.00
Q3	8.50	31	11	10.5	4	12	9
Mean	38.58	25.20	16.23	39.89	10.30	106.89	91.42

MB-2 Bacteria Summary Statistics

Fecal Coliform (CFU/100ml)	2009	2010	2011	2012	2013	2014	2015
Median	15.00	15.00	10.00	8.00	14.50	9.00	11.00
Q1	2.00	9	3	3.5	8.75	7	3
Minimum	0.10	0.10	0.10	2.00	7.00	3.00	0.10
Maximum	68.00	200.00	1800.00	46.00	40.00	300.00	55.00
Q3	39.00	25.5	40	15	25	50	15
Mean	22.32	32.37	145.28	12.20	18.42	56.77	14.62

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	1.50	4.00	1.00	2.00	1.00	1.00	0.10
Q1	0.10	0.55	0.1	1	0.1	1	0.1
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	26.00	164.00	160.00	17.00	22.00	28.00	51.00
Q3	4.25	12	23	3	8	18	1
Mean	3.98	20.85	22.37	3.22	5.71	8.87	4.52

MB-3 Bacteria Summary Statistics

Fecal Coliform (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	14.00	9.00	19.00	11.00	9.00	11.00	12.00
Q1	4.00	3	6	2.5	4.25	8	4
Minimum	0.10	0.10	0.10	0.10	1.00	4.00	0.10
Maximum	500.00	700.00	1200.00	73.00	18.00	2100.00	900.00
Q3	53.50	60.5	25	29	10	26	31
Mean	64.19	98.10	101.81	18.94	8.08	200.54	82.48

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	1.00	2.00	2.00	1.00	0.10	1.00	1.00
Q1	0.10	0.1	0.1	0.1	0.1	0.1	0.1
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	360.00	118.00	100.00	33.00	22.00	3400.00	28.00
Q3	2.50	4	5.5	4.5	2.25	6	2
Mean	26.42	15.31	13.98	5.38	2.82	300.20	3.51

MB-4 Bacteria Summary Statistics

Fecal Coliform (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	6.00	16.00	7.00	8.00	5.00	6.00	10.00
Q1	1.00	4.5	3	4.5	2.75	4	5.25
Minimum	0.10	1.00	0.10	0.10	0.10	1.00	1.00
Maximum	118.00	173.00	1600.00	270.00	20.00	90.00	88.00
Q3	16.50	52.5	38	24	11	8	16.5
Mean	16.76	40.91	139.27	29.94	6.76	17.62	16.71

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	0.10	2.00	3.00	0.10	0.10	0.10	0.55
Q1	0.10	0.55	0.1	0.1	0.1	0.1	0.1
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	52.00	109.00	130.00	80.00	10.00	110.00	147.00
Q3	2.50	18	9.5	3.5	1	7	7
Mean	4.81	16.12	18.58	9.25	1.65	14.06	14.98

MB-5 Bacteria Summary Statistics

Fecal Coliform (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	20.00	31.00	28.00	52.00	26.00	44.00	42.50
Q1	11.00	18	15	27	17	21	15.75
Minimum	0.10	5.00	0.10	18.00	3.00	12.00	1.00
Maximum	320.00	920.00	8800.00	1800.00	230.00	700.00	12400.00
Q3	60.50	160	210	365	64.75	73	70
Mean	66.38	153.45	795.75	302.00	62.50	95.85	927.64

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	5.00	9.00	7.00	9.00	0.55	2.00	4.00
Q1	1.75	4	1	3	0.1	1	0.325
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	380.00	250.00	1100.00	3600.00	120.00	420.00	4700.00
Q3	9.25	13	18.5	29.5	4.25	24	7.75
Mean	33.64	32.84	154.69	267.01	12.13	57.94	348.17

MB-6 Bacteria Summary Statistics

Fecal Coliform (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	13.00	31.00	14.00	34.00	26.50	32.00	36.00
Q1	4.50	18	3.5	10	14.5	21	6
Minimum	0.10	5.00	0.10	2.00	6.00	8.00	0.10
Maximum	290.00	920.00	460.00	340.00	180.00	470.00	4100.00
Q3	22.25	160	35	57	38	43	106
Mean	42.38	153.45	76.61	64.93	37.67	80.46	477.79

Enterococci (CFU/100 ml)	2009	2010	2011	2012	2013	2014	2015
Median	1.00	9.00	2.00	7.00	1.00	3.00	8.00
Q1	0.10	4	0.1	0.55	0.1	1	0.1
Minimum	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	240.00	250.00	80.00	230.00	37.00	1000.00	3900.00
Q3	2.50	13	11	19.5	3.25	10	24
Mean	20.23	32.84	10.10	28.16	4.88	114.17	337.42

Appendix B

Tables of Correlations

Pearson Correlation Between Rainfall and Bacteria
Note: p-values are shown in *italics.* Grey-shaded cells indicate statistically significant (p<0.05) correlation.

MB-1	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.133 *0.200*	0.387 *0.000*	0.242 *0.018*	-0.097 *0.351*
LN(Fecal Coliform)	-0.015 *0.885*	0.240 *0.019*	0.255 *0.013*	-0.103 *0.322*
Enterococci	0.065 *0.530*	0.390 *0.000*	0.078 *0.450*	-0.018 *0.865*
LN(Enterococci)	0.004 *0.971*	0.285 *0.005*	0.257 *0.012*	0.042 *0.684*

MB-2	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.033 *0.750*	0.262 *0.010*	0.907 *0.000*	-0.040 *0.700*
LN(Fecal Coliform)	0.089 *0.392*	0.279 *0.006*	0.401 *0.000*	0.113 *0.277*
Enterococci	0.166 *0.107*	0.429 *0.000*	0.748 *0.000*	-0.068 *0.510*
LN(Enterococci)	0.188 *0.068*	0.358 *0.000*	0.356 *0.000*	0.058 *0.576*

MB-3	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.040 0.699	0.503 0.000	0.404 0.000	-0.070 0.500
LN(Fecal Coliform)	-0.100 *0.337*	0.286 *0.005*	0.374 *0.000*	0.050 *0.632*
Enterococci	0.113 *0.275*	0.561 *0.000*	0.032 *0.756*	-0.043 *0.682*
LN(Enterococci)	0.061 *0.554*	0.509 *0.000*	0.361 *0.000*	0.091 *0.380*

MB-4

	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.035	0.200	0.906	-0.012
	0.737	*0.051*	*0.000*	*0.911*
LN(Fecal Coliform)	-0.051	0.229	0.470	0.140
	0.624	*0.025*	*0.000*	*0.172*
Enterococci	0.219	0.513	0.509	-0.011
	0.032	*0.000*	*0.000*	*0.913*
LN(Enterococci)	0.135	0.330	0.383	0.105
	0.189	*0.001*	*0.000*	*0.307*

MB-5

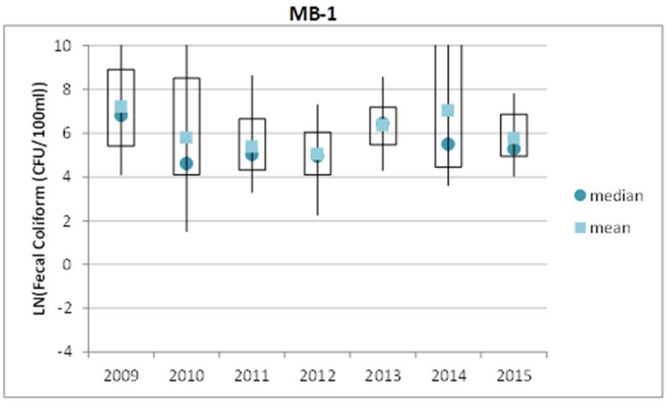
	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.034	0.164	0.327	-0.068
	0.743	*0.111*	*0.001*	*0.513*
LN(Fecal Coliform)	-0.056	0.217	0.345	0.033
	0.589	*0.034*	*0.001*	*0.753*
Enterococci	0.123	0.193	0.354	-0.075
	0.234	*0.060*	*0.000*	*0.465*
LN(Enterococci)	0.052	0.314	0.395	0.015
	0.614	*0.002*	*0.000*	*0.884*

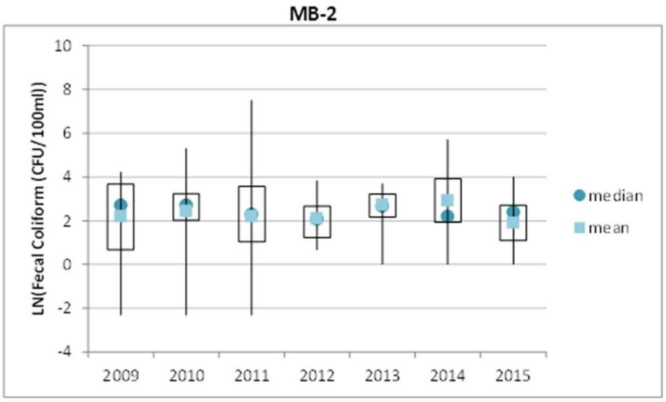
MB-6

	Kings Point Tide Elevation	Same Day Precipitation	Prior Day Precipitation	2-Day Prior Precipitation
Fecal Coliform	0.035	0.185	0.113	-0.080
	0.731	*0.070*	*0.272*	*0.436*
LN(Fecal Coliform)	-0.151	0.270	0.238	-0.089
	0.140	*0.008*	*0.019*	*0.388*
Enterococci	0.136	0.331	0.075	-0.060
	0.183	*0.001*	*0.465*	*0.559*
LN(Enterococci)	-0.183	0.404	0.278	0.067
	0.073	*0.000*	*0.006*	*0.513*

Appendix C

Boxplots of Bacteria


MB-1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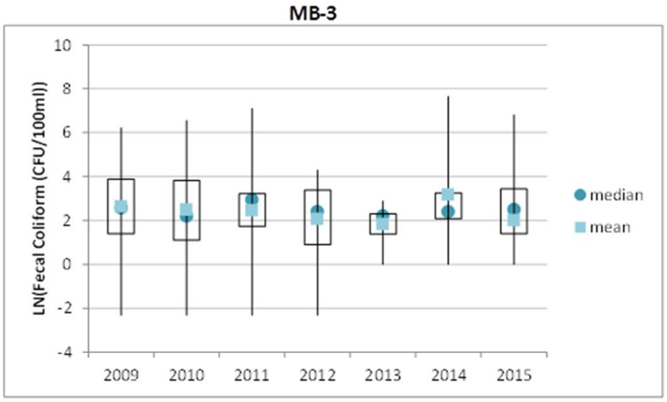
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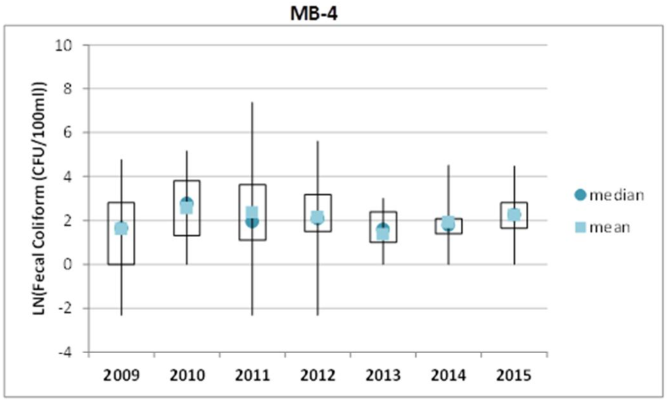
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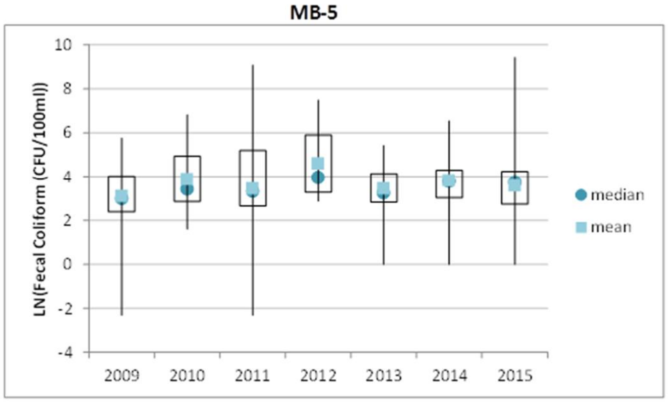
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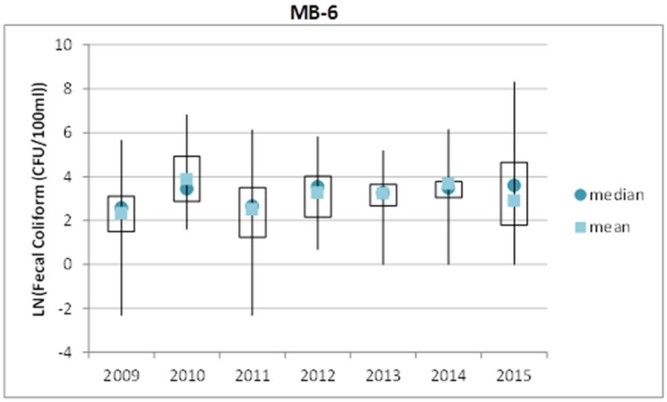
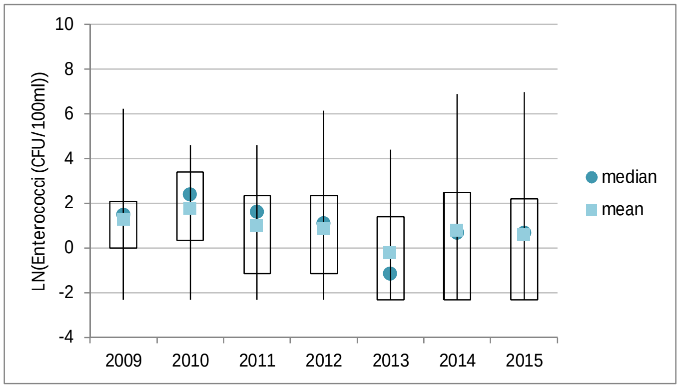
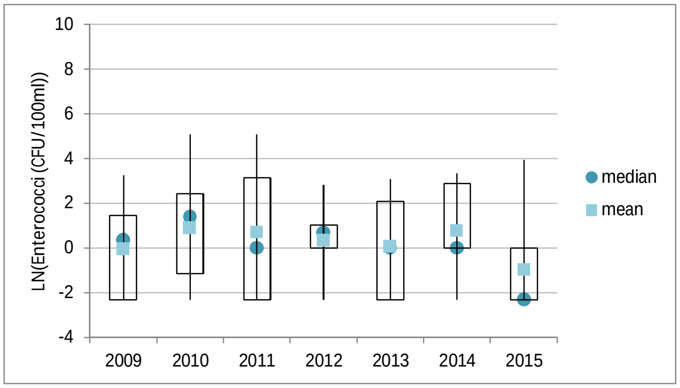

MB-6

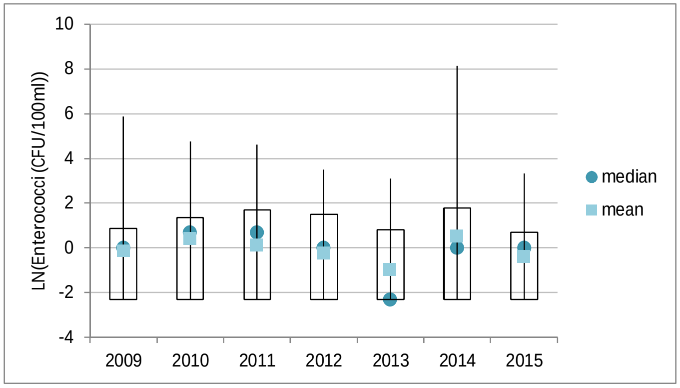
MB-1



MB-2



MB-3



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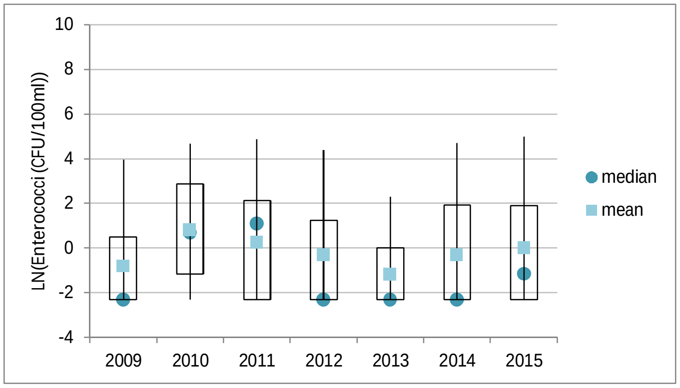

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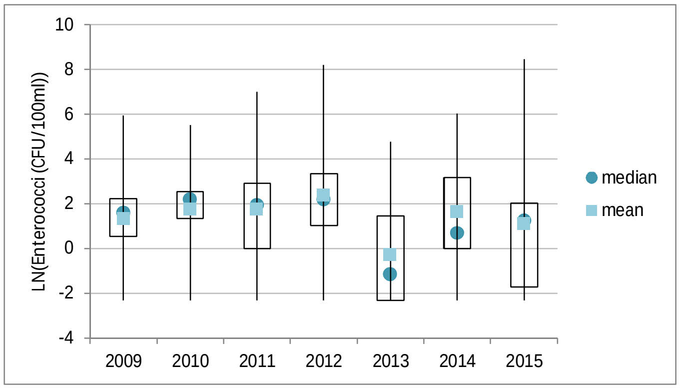

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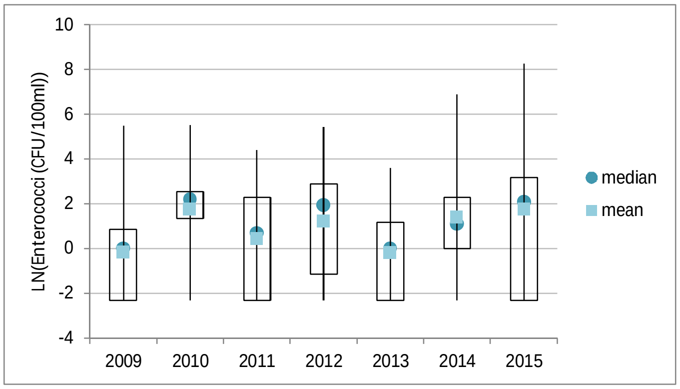

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