

Assessment of Enterococci in Groundwater and Stormwater at the Miami Beach Park View Canal

DRAFT REPORT

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EXECUTIVE SUMMARY

This study is a follow up to the University of Miami (UM) initial study conducted during 2022 aimed at identifying the source of enterococci to the Parkview Canal (PVC) located in Miami Beach, Florida. This canal has experienced elevated levels of fecal indicator bacteria including enterococci since monitoring began in 2019. The 2022 study concluded that the primary source of enterococci to the PVC was stormwater runoff which was contaminated by waste deposited on surfaces that drain towards the PVC. In addition, the study concluded that between storm events contaminated groundwater was also contributing enterococci to the PVC. The prior study did not determine the source of groundwater contamination, whether it was contaminated from stormwater runoff or by sanitary sewage, as samples were collected from the underground stormwater conveyance system which receives both sources of water.

As a first step of the current 2024 study, available historical data collected by the City of Miami Beach (CMB) and by Miami Surfrider were analyzed to determine whether remediation efforts initiated by the CMB since 2022 have resulted in a reduction in PVC enterococci levels. Remediation efforts included community outreach to pet owners and homeless populations, increased intensity of street sweeping, enforcement of appropriate solid waste handling and disposal, assessment and rehabilitation of sanitary collection and transmission system to include lining of gravity pipe and manholes plus the replacement of air release valves within the sanitary sewer system. Assessment and rehabilitation of sanitary system was prioritized in North Beach because of the PVC water quality issues. Results showed that enterococci levels, although still high, did drop after remediation efforts. This drop was observed from the CMB and the UM historical records. Of significance was that the pattern observed earlier between storm events was not observed in 2024, indicating that groundwater was not a primary source of enterococci to the PVC during 2024. Although improvements were observed between 2022 and 2024, they were not sufficient to bring the PVC to levels that are considered safe for recreational use.

Given that enterococci levels continue to be elevated, this current project aimed to identify the source of enterococci contamination to the PVC by collecting and analyzing samples of groundwater and stormwater separately, outside of the underground stormwater conveyance system. Groundwater was collected by drilling temporary wells and stormwater was collected from the street surface during storm events. Samples were also collected hourly over a 12-hour period within the PVC canal. All samples were analyzed for physical-chemical parameters (temperature, pH, salinity, dissolved oxygen, and turbidity) and for enterococci by culture using the most probable number (MPN) method. To determine the source of the enterococci for each of these waters, a subset of samples (number of samples, $n=78$) was analyzed for five genetic markers. Four are microbial source tracking markers (MST) targeting human, dog, bird, and gull fecal waste sources. The last genetic marker was an *Enterococcus* species marker for comparing MST results (which do not test for viability) against the traditional culture-based method of enterococci analysis used for regulatory purposes.

Results showed that enterococci by culture were extremely high. Most samples were above the 24,196 MPN/100 mL quantification limit. When sample dilutions were adjusted, samples also exceeded the 241,960 MPN/100 mL quantification limit. For groundwater, levels of enterococci were variable with values ranging from below detection limits (<10 MPN/100 mL) to above the limit of detection ($>24,196$ MPN/100 mL). The groundwater hot spot measuring above the detection limit led to investigations of the outfall from Biscayne Beach Elementary School (BBE), which showed enterococci at levels (198,000 MPN/100 mL maximum) significantly above levels observed at the Kayak Launch (9,800 MPN/100 mL maximum). The CMB is currently working with Miami-Dade County Public Schools to mitigate the cause of the elevated levels of enterococci at the BBE outfall. For samples collected hourly from the PVC, enterococci levels dropped throughout the course of the day presumably because of solar radiation. The highest level (9,800 MPN/100 mL) from the PVC was collected from the water's surface during the late afternoon and shortly after a small rain event.

Results from MST showed that groundwater had no quantifiable levels of dog nor human marker. The bird marker was found in most samples (in groundwater, stormwater, and PVC water) with the highest levels observed for samples collected from within the PVC. The general bird GFD MST marker was statistically higher in the PVC (88,000 genomic copies (gc) per 100 mL) compared to the groundwater (400 gc/100 mL) and stormwater (430 gc/100 mL). We therefore hypothesize that birds are a significant source of fecal waste “interior” to the PVC. It is possible that birds along the banks of the PVC deposit fecal matter directly into the PVC and along the shore which is then washed in during high tide. It is also possible that water from the PVC backflows through the storm conveyance system into the groundwater resulting in detectable levels of bird marker in the groundwater samples. In general seagull specific Gull2 MST marker was not found in most of the samples, except for four stormwater samples, suggesting that the bird fecal input observed was predominantly from other bird species during the period immediately preceding sample collection.

The distribution of the MST bird marker is contrary to what was observed for enterococci measurements, with enterococci showing high and sustained levels in stormwater. Of significance was the intermittent quantification of dog (11 out of 37 samples) and human marker (18 out of 37 samples) in stormwater collected at the street surface. Given the intermittency of the observed dog and human markers, we believe that the sustained elevated levels in stormwater came from “aged” fecal waste which may have lost the original fecal source signal (due to die off of a different bacteria used for MST).

The consistently high enterococci levels observed in stormwater collected at the street surface (which may come from sustained aged dog and human sources, intermittent fresh dog and human sources, plus bird sources), emphasize that efforts should focus on reducing enterococci in street-level stormwater runoff. To augment ongoing efforts of the CMB, we recommend “deep cleaning” of grassy areas, gutters and anywhere animal waste is seen. In addition to industrial scale street sweeping, smaller scale street sweepers are recommended that can be walked through gutters and curbs where sediments accumulate to provide more frequent and detailed cleaning. In addition to encouraging pet owners to pick up after their pets, we recommend designated pooper scoopers followed by possible disinfection to further clean up areas with visible feces. The area is also impacted by populations (inclusive of homeless and others) who lack access to sanitary facilities. Consideration should include augmenting access to sanitation facilities, especially during hours when public facilities are closed. Until significant engineering stormwater treatment systems can be implemented, we believe that “deep cleaning” and enhanced access to sanitation will be necessary to further improve the quality of the PVC.

Quick turn-around actions taken by the CMB to limit enterococci contamination have included its aggressive program of education and outreach. The CMB has expanded its community outreach efforts through its Constant Contact system through which updates are provided to the community and from which the City solicits input from its residents. The CMB continues with the provision of extensive outreach services to the homeless in the area, with education programs to minimize dog fecal waste throughout the stormwater catchment, and with the management of non-native feral animals. Trash on streets continues to be minimized through street sweeping, code enforcement, educational outreach, and clean up. The CMB is committed to minimizing the leakage from trash bins through education campaigns aimed at commercial business owners by emphasizing the importance of covers on trash bins and frequent trash pickup.

For the long term, we recommend that the flushing capacity of the PVC be improved through the removal of trash and debris that inhibits water flow and tidal flushing. We also recommend upgrading the stormwater conveyance system to include trash removal and the treatment of the first flush of stormwater, which is currently standard among stormwater conveyance systems. The CMB has already taken immediate action on these long-term items including plans for dredging the PVC to improve water circulation and have contracted a consulting firm for the design of the stormwater treatment system. To date the work toward dredging has included the completion of the bathymetric analysis of the PVC in preparation for soliciting bids from canal dredging companies. The timeline includes the release of bid documents and technical specifications by January

2026 with project mobilization by June 2026 and completion by January 2027. In terms of stormwater treatment, the CMB, through \$200K requested and funded by the city commission, has contracted the design and permitting for the addition of hydrodynamic separators to the stormwater conveyance system as a means of reducing trash and sediments discharged to the PVC. The permit will be submitted by March 2025. Additionally, the CMB has been awarded a \$10M Florida Resilient Grant for the design and permitting of the North Shore D Neighborhood Improvement project) which includes a proposed stormwater conveyance system that will replace the existing stormwater pipe network between 69th and 73rd Streets. The stormwater conveyance system is to include injection wells (to treat the first flush) and two stormwater pump stations fitted with bar racks, vortex water quality structures, and upflow stormwater cartridge filters. The completion target date for this larger project is 2028.

Specifically, to address sanitary sewage, as part of Phase 2 North Beach and Park View Extended Area, more than \$2.5 million of upgrades have been invested to line 90% of the sewer lines from 73 to 76 Street, rehabilitate manholes, rehabilitate a pump station, and plan for a force main replacement. As of mid-January 2025, all the Phase 2 infrastructure upgrades have been completed. Additionally, the CMB has conducted city wide force main leak detection. The leak detection tests concluded no leaks in the force main transmission system. As part of the planned \$70M 72nd Street Community Complex the intense wastewater infrastructure (within a secondary groundwater hotspot area) will be bypassed by a new force main system. The old lines will be abandoned eliminating the existing sanitary sewer force mains in the area as a potential source in the future. This project will be submitted to the Design Review Board of the CMB during early 2025.

Additionally, as evidenced by the exceedances detected in the Biscayne Beach Elementary outfall and groundwater, private property should continue to be investigated as sources of pollution to the Park View Canal. However, this poses a challenge for the City of Miami Beach which does not have the authority for enforcement of private stormwater systems maintenance. Private property owners should have Class II stormwater permits with Miami-Dade County and properly maintain the system as to not contribute to the PVC water quality degradation.

Overall, the mitigation plan for the stormwater conveyance and sanitary sewer systems should provide improvements to water quality in the PVC. Some short-term improvements have been observed; however, the levels are still considered excessive. To make more substantive improvements, major investments in the stormwater infrastructure are needed which the CMB has initiated by procuring funds for design and permitting, which is the necessary first step to implementation.

LIST OF ACRONYMS

AOML: Atlantic Oceanographic and Meteorological Laboratory
BAV: Beach Action Value
CFU: Colony Forming Units
CMB: City of Miami Beach
COV: Coefficient of Variation
EPA: Environmental Protection Agency
FDEP: Florida Department of Environmental Protection
FDOH: Florida Department of Health
FIB: Fecal Indicator Bacteria
gc: Target Gene Copies
GIS: Geographic Information System
KL: Kayak Launch
KLW: Kayak Launch Waterway (used interchangeably with PVC)
MF: Membrane Filtration
MPN: Most Probable Number
MST: Microbial Source Tracking
NOAA: National Oceanic and Atmospheric Administration
PCR: Polymerase Chain Reaction
POR: Period of Record
PVW: Parkview Canal Watershed
PVC: Park View Canal
PVI: Park View Island
PVP: Park View Park
QMRA: Quantitative Microbial Risk Assessment
RBT: Risk Based Threshold
SFWMD: South Florida Water Management District
STV: Statistical Threshold Value
TKN: Total Kjeldahl Nitrogen
TPTV: Ten Percent Threshold Value
UM: University of Miami
US EPA: United States Environmental Protection Agency

CHAPTER I

MOTIVATION, OBJECTIVES, AND BACKGROUND

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MOTIVATION, OBJECTIVES, AND BACKGROUND

This chapter focuses on describing the motivation, objectives (Section I.1) and the project background for this study, including target levels for enterococci and fecal coliform, background information for MST (Section I.2), and general conditions of the Park View Canal (Section I.3)

I.1 MOTIVATION AND OBJECTIVES

Stormwater from the Parkview Canal Watershed (PCW, Figure I.1) within the City of Miami Beach (CMB) contributes large pulses of fecal bacteria, known as enterococci, at levels thousands of times higher than regulatory guidelines for recreational use of waterways to its receiving water body (Parkview Canal, PVC). As a result of the stormwater contamination, and the excessive bacteria levels, the adjacent PVC and the kayak launch (Figure I.2) from its park has been closed to the public since 2019. This closure represents a lost resource for the community.

Our prior research through the University of Miami (UM) and supported by the CMB (Montas et al. 2023), showed that stormwater from the PCW is contaminated with high levels of enterococci and flows into the PVC, or is discharged to groundwater, with little to no treatment. The most extreme contamination was observed during storm events, with impacts also observed between storm events, presumably due to stormwater contamination of groundwater. Therefore, a strong need exists to document stormwater quality and groundwater quality.



Figure I.1: Park View Canal (dark blue) and Park View Watershed (cyan blue). The areas outlined in cyan blue contribute stormwater towards the PVC. Close up of kayak launch area (yellow square) shown in Figure I.2. Base image from Google Earth (January 2023).

To assess stormwater and groundwater quality, the objectives of this study were:

- **Update the Analysis of Regular Enterococci Monitoring Data.** The CMB and Surfrider collect data on a regular basis from the PVC at the Kayak Launch. Our objective was to statistically analyze this data through the end of September 2024 to document whether enterococci levels have declined over time as the CMB has enhanced mitigation measures.
- **Evaluate PVC Surface Water Elevations Relative to Groundwater Elevations.** The prior UM study conducted in 2022 suggested that contaminated groundwater contributed to the PVC when hydraulic gradients were in favor of this occurrence (when the elevation of water in the PVC was lower than the groundwater elevation). This occurrence could not be evaluated quantitatively because the elevation of the PVC water was unknown. In this current 2024 study, a benchmark was installed from which the PVC surface water elevations could be determined allowing for the comparison of PVC water elevations relative to groundwater. This information was then used to analyze the historical enterococci data to determine if enterococci levels were correlated with the hydraulic gradients.
- **Evaluate Elevations of the Stormwater Conveyance System.** The PVC surface water elevations and the groundwater elevations were also used to evaluate the extent and periods of inundation of the stormwater conveyance system. Such an evaluation provided information about whether the stormwater conveyance system skims the upper surface of the groundwater, providing for a direct connection between the PVC and, potentially, contaminated groundwater.
- **Collect and Analyze Shallow Groundwater Samples.** Shallow groundwater was implicated as a source of enterococci between storm events during the 2022 UM study. Samples of groundwater were collected from the catchment area using direct push technology and analyzed for enterococci and for physical-chemical parameters (water temperature, pH, salinity, dissolved oxygen, and turbidity). Sample splits were archived for Microbial Source Tracking (MST) Analysis.
- **Collect and Analyze Stormwater Samples.** Stormwater runoff was implicated as the primary source of enterococci during the 2022 UM study. The stormwater was believed to contribute directly during storms and indirectly by contaminating shallow groundwater. To confirm stormwater as a source of enterococci, samples were collected from storm water before or as it enters the catch basins. Similar to the groundwater samples, sample splits of stormwater were archived for MST Analysis.
- **Collect and Analyze Water from the PVC.** The study focused on evaluating the sources of enterococci to the PVC. Samples from the PVC were collected to assess trends over time and depth. Similar to the above, sample splits of PVC water were archived for MST Analysis.
- **Measure Source Tracking Markers.** A subset of the samples collected were analyzed for four MST markers. MST markers are specialized molecular analyses that further identify which species (humans, dogs, birds and/or gulls) are contributing fecal waste to a sample. MST was used to assess potential contributions of enterococci from humans, dogs, birds and gulls to groundwater, stormwater, and to the PVC. A fifth genetic marker analysis was included in this study to measure *Enterococcus* (molecular based representation of enterococci) to provide a comparison between the culture-based method (provides data in units of MPN) versus the molecular-based method (provides data in units of gc).



Figure I.2: Kayak launch location. Located within the Parkview Island Park northwest of the intersection of Dickens and 73rd Street, Miami Beach, FL. (GPS: 25° 51' 31.20" N. 80° 07' 33.00" W for the Launch)

I.2 TARGET LEVELS FOR ENTEROCOCCI AND MICROBIAL SOURCE TRACKING MARKERS

I.2.a Target Levels for Enterococci

Enterococci is a group of bacteria species recommended by the U.S. Environmental Protection Agency (US EPA) as the fecal indicator bacteria (FIB) to assess the microbiological safety of marine recreational waters. It is used to assess the potential relative risk of gastrointestinal illness from incidental ingestion. The largest amount of incidental ingestion generally occurs during primary contact which is full body contact activities (such as swimming, surfing, and water skiing) (US EPA 2022). Incidental ingestion also occurs during secondary contact recreation such as kayaking and fishing. Secondary contact is presumed to be associated with smaller amounts of incidental ingestion so standards for secondary contact are less stringent than for primary contact. Regulatory levels for FIB are set based upon type of contact (primary or secondary) and levels of estimated gastrointestinal illness (generally from 19 to 36 illnesses per 1000 people exposed) as determined from epidemiologic studies.

In Florida, regulatory limits for FIB in recreational waters are based upon the guidelines established by the US EPA, with two State agencies setting regulatory limits: the Florida Department of Health (FDOH) and the Florida Department of Environmental Protection (FDEP). Both agencies base their regulations on the distributions focused on estimated illness rates of 36 per 1000 persons exposed. The FDOH, through the Florida Healthy Beaches Program, assumes primary contact or full body contact (swimming) and establishes beach advisories for recreational bathing beaches through a centralized reporting website that lists a recreational water as good, moderate, or poor quality (See: floridahealth.gov/environmental-health/beach-water-quality/index.html). Good quality beach water is defined as enterococci levels less than 36 enterococci per 100 mL, moderate quality as levels between 36 and 70 enterococci per 100 mL, and poor quality as levels exceeding 70 per 100 mL. Beach “advisories” are issued when two consecutive samples exceed 70 per 100 mL. The value of 70 per 100 mL corresponds to the US EPA recommended beach action value (BAV) which is a more

conservative estimate for beach management decisions. The BAV of 70 enterococci per 100 mL corresponds to the 75th percentile of the enterococci distribution (US EPA 2012) for waters to meet an acceptable illness rate.

Similarly, the FDEP also has guidelines established for enterococci. The FDEP regulates surface waters of the state according to their designated uses. The surface waters of the state are separated into one of six classes. The classes that most closely align to the current uses of the PVC are Class III and Class III – Limited (See, floridadep.gov/dear/water-quality-standards/content/surface-water-quality-standards-classes-uses-criteria). These are defined as:

- Class III: Fish Consumption, Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife
- Class III – Limited: Fish Consumption, Recreation or Limited Recreation, and/or Propagation and Maintenance of a limited population of fish and wildlife.

The bacteriological criteria are the same for both classes listed above (FAC 2016). The criterion is listed in the Florida Administrative Code as, “Most Probable Number (MPN) or Membrane Filtration (MF) counts shall not exceed a monthly geometric mean of 35 nor exceed the Ten Percent Threshold Value (TPTV) of 130 in 10% or more of the samples during any 30-day period. Monthly geometric means shall be based on a minimum of 10 samples taken over a 30-day period.” The 130 corresponds to 90% percentile of the US EPA statistical threshold value (STV) of the enterococci distribution, which is less conservative than the BAVs.

A summary of the threshold values as established by the FDOH, FDEP, and US EPA is given by Table I.1. When evaluating enterococci levels based upon single sample analyses, the general practice has been to use a threshold value of 70 per 100 mL to designate the quality of a beach site (FDOH 2024). For subsequent discussion purposes, the value of 70 will be used as the target threshold for assessing the microbial quality of the PVC. However, the CMB may consider other acceptable levels consistent with secondary contact uses, such as kayaking (calm versus turbulent waters) and fishing, which can potentially raise the threshold levels to 371 and 391, respectively. Given the intended use of the kayak launch and the calm waters within the PVC, a target value of 370 MPN/100 mL may be considered as a future health-based guideline level once the levels within the PVC fall consistently below this level.

Table: I.1: Target Guideline Levels for Enterococci as Listed by the FDOH, FDEP, and U.S. EPA

Agency	
FDOH Beach Recreational Standards (Primary Contact, Swimming)	<ul style="list-style-type: none"> • Good quality < 36 per 100 mL • Moderate quality between 36 and 70 per 100 mL • Poor quality > 70 per 100 mL (Beach Action Value)
FDEP Class III standards (Recreation)	<ul style="list-style-type: none"> • Geometric mean < 36 per 100 mL, • 10% of samples within a 30-day period < 130 per 100 mL
U.S. EPA (Primary Contact, Swimming)	<ul style="list-style-type: none"> • Geometric mean < 36 per 100 mL • 10% of samples < 130 per 100 mL
U.S. EPA (Kayaking in turbulent waters, with capsizing)	<ul style="list-style-type: none"> • Geometric mean < 45 per 100 mL • 10% of samples < 164 per 100 mL
U.S. EPA (Kayaking in calm waters, no capsizing)	<ul style="list-style-type: none"> • Geometric mean < 100 per 100 mL • 10% of samples < 371 per 100 mL
U.S. EPA (Fishing)	<ul style="list-style-type: none"> • Geometric mean < 106 per 100 mL • 10% of samples < 391 per 100 mL

I.2.b Differences in Viability of Enterococci Measurements by Culture and the Measurements by qPCR

Accepted methods by the regulatory community for measuring enterococci require the counting of viable (live) cells within a known volume of water sample. The live culture method used in the current study and by the CMB and Surfrider, is based upon a Most Probable Number (MPN) enumeration using a chromogenic substrate. The chromogenic substrate used by all groups is the commercially available “IDEXX Enterolert” assay. The chromogenic substrate method is based upon adding an enzyme or nutrient indicator to the water sample. After incubation of the water sample the live enterococci in the water sample will consume the enzyme releasing a fluorescent dye into the water that can be seen under ultra-violet light. Enumeration is accomplished by separating the sample into individual wells which can then be counted for positive fluorescence. Statistical methods are then used to estimate the Most Probable Number based upon the probability of a viable cell being caught in the number of positive (or fluorescing) wells. Because the method requires the growth of the enterococci, these measurements provide confirmation that the target bacteria are still viable (capable of metabolism, growth, and reproduction).

The measurements of microbial source tracking (MST) genetic markers and the general enterococci marker differ from those for live culture enterococci measurements. First, the measurements of the genetic markers are based upon extracting DNA from the total population of microbial organisms in an environmental sample. This multi-organism environmental DNA extract is abbreviated here as “eDNA”. The eDNA contains all types of DNA from all sources. For this study we targeted a suite of fecal bacteria genetic markers that are found exclusively in humans (called “HF183”), in dogs (called “DG3”), in birds (called “GFD”), and in gulls (called “Gull2”), which are specific to each type of animal, plus the general enterococci genetic marker called “EnterolA” for all enterococci sources. Each type of MST assay DNA target marker has a specific and unique sequence of the basic building blocks of DNA called nucleotides (i.e., DNA target sequences) that are specific to particular species and/or strains of fecal bacteria that are only found in the gut microbiome of that particular animal host. The DNA target sequences are then replicated from the eDNA extracted from the environmental samples by a process called amplification through Polymerase Chain Reaction, PCR. Amplification through PCR proceeds through repetitive cycles of heating and cooling until there is enough target sequence (specific to fecal bacterial DNA from dog, human, bird, gull, or to general enterococci species DNA) to detect by the instrumentation. In the case of MST, this is done in a quantitative fashion on specific instruments in a process called “real-time PCR” or “quantitative PCR” (qPCR) that can measure and calculate the original concentration of the specific DNA target sequence in the environmental sample that is being measured.

During the analysis process, total microbial cells from a water sample are collected onto a membrane filter, then the cells on the filter are broken open (lysed) which releases the entire eDNA content of all the bacteria on the filter, which is then purified and analyzed by qPCR for the concentration of the specific diagnostic gene that is chosen to be measured. This, of course, kills the microbial cells in the analysis process since the cells are being broken open to release their DNA. Therefore, the qPCR process, used in MST, measures a fundamentally different population of cells than the ones measured by the live culture growth methods used for regulatory purposes. The live culture methods measure only cells that are alive and capable of reproduction. The qPCR-based methods measure the specific DNA signal from each of the targeted specific types of cells being measured, regardless of whether those cells were alive or dead at the time of collection. Therefore, amplification of any **genetic marker by qPCR does not indicate whether the bacteria that hosted the DNA is still viable**. This is a fundamental difference between the live culture assays that are used for regulatory purposes versus assays based upon qPCR.

I.2.c Differences in Persistence of Enterococci Measurements versus MST Markers

The gut of warm-blooded animals consists of a wide array of microbes. Enterococci, one of the groups of bacteria found in high abundance in the gut of many animals including humans, is the target group

recommended by the state and federal agencies (as listed in the prior section) for routine monitoring of recreational waters to evaluate safety from fecal waste contamination. It consists of several species of bacteria including the species of *Enterococcus faecalis*, *E. faecium*, *E. avium*, *E. gallinarum*, *E. casseliflavus*, and *E. durans*. One of the drawbacks of using enterococci is that there are sources of enterococci in the environment, in addition to fecal sources. Enterococci are known to survive outside of the gastro-intestinal tract (Wright et al. 2009). They can inoculate an environment (including soils, sediments, plant surfaces, biofilms on debris, and biofilms on hardened urban infrastructure such as concrete gutters, storm drains and conduits, etc.). Depending upon the environmental conditions, enterococci can persist for long periods of time and even multiply (Desmarais et al. 2000). Enterococci can thus also be present in the environment without any recent fecal contamination events, and its detection in the environment by either live culture or qPCR might also be due (at least in part) to persistence from a historic contamination event in the past (e.g., a prior sewage leak). It is generally accepted that enterococci from legacy contamination may not represent the same level of risk from fecal pathogens as from a more recent contamination event.

Total enterococci measured by qPCR assays target unique gene sequences (encoded in the 23S ribosomal RNA) found in most species of fecal enterococci. Since it is measuring enterococci which persists in the environment, the qPCR measurements of the EnterolA marker are subject to the same persistence and possible environmental regrowth issues as enterococci measured by live culture. Since the qPCR is based upon DNA measurements of enterococci, both live and DNA from non-viable bacterial cells will be detected using this method. Differences in the trends between enterococci by chromogenic substrate versus by qPCR are likely due to differences in the relative levels of non-viable enterococci which are measured only by qPCR.

In this study, microbial source tracking (MST) markers specific to human and dog sources of fecal waste were based upon the measurement of a specific gene (same as DNA target sequence but specifically references a short sequence of DNA) within the bacteria genus *Bacteroides*. The unique gene marker for strains of *Bacteroides* fecal bacteria that are found exclusively in humans is called “HF183”, and the unique gene marker for strains of *Bacteroides* found exclusively in dogs is called “DG3”. Both are encoded within a specific part of the bacterial genome called 16S ribosomal RNA. *Bacteroides* are bacteria that are obligate anaerobes: they can survive exposure to oxygen for a limited time but cannot grow in the presence of oxygen. They do not survive under prolonged aerobic conditions and cannot reproduce under aerobic conditions. *Bacteroides* will die relatively quickly upon release into aerobic environments such as the water column (typically within a period of a few days to a few weeks, depending upon environmental circumstances).

For birds, the “GFD” gene marker was measured (also encoded in the 16S ribosomal RNA) within specific strains of fecal bacteria from the genus *Helicobacter* that are found exclusively in birds. These bird-specific *Helicobacter* strains are common gut bacteria in a wide variety of many different types of birds. *Helicobacter* can survive under both aerobic and anaerobic conditions, and so it tends to survive in the environment longer than the *Bacteroides*. In this study we also measured specifically for a subset of the bird population, seagulls. The seagull host specific fecal marker called “Gull2” targets the 16S ribosomal RNA gene of the bacteria *Catellibacterium marimammalium*. This *C. marimammalium* species was first identified as an opportunistic pathogen of marine mammals but is actually a common normal gut bacteria specific to seagulls and terns (but may also sometimes be found in certain other seabirds and waterfowl such as pelicans, Canadian snow geese, or even some coastal pigeons depending upon their feeding, scavenging, or co-nesting behavior with seagulls). The *Catellibacterium marimammalium* Gull2 marker typically has a longer environmental persistence than the human HF183 or dog DG3 but may be shorter than that typical of the *Helicobacter* GFD marker in the water column. *Catellibacterium* grows best under increased carbon dioxide and reduced oxygen, which is consistent with the intestinal environment of birds, but it does not grow as well under full outdoor aerobic conditions.

In terms of relative persistence, the bird MST host bacteria are believed to persist longer than the human and dog MST host bacteria, with the human and dog MST markers being lost quickly due to the inability of the host

bacteria, *Bacteroides*, to survive in an aerobic environment. Therefore, the host bacteria that survive and persist the longest (and can possibly multiply in the environment) are enterococci which can be measured by live culture or by qPCR EnterolA marker. The next most persistent bacteria are the *Helicobacter* which carry the markers (GFD) for the general bird marker. Next are the *Catelliboccus* bacteria which carry the gull marker (Gull2), followed by the *Bacteroides* which are the weakest and carry the human (HF183) and dog (DG3) markers.

I.2.d Target Levels for Enterococci and MST

The differences between viability and in the persistence of the gene carried by the host bacteria used for measurements, makes it difficult to compare target levels between viable enterococci (used for regulatory purposes) and the qPCR-based enterococci and MST markers. Regardless of these differences, attempts have been made to establish equivalent Risk Based Thresholds (RBT) among the different methods (Tables I.2 and I.3). As a reminder from Section I.2.a, the regulatory threshold for enterococci for full-body contact (swimming) is 70 MPN/100 mL which corresponds to a 75% probability of less than 36 gastrointestinal illnesses among individuals exposed.

The US EPA has established a BAV for the qPCR EnterolA assay of 1000 gc/100 mL (US EPA, 2012b, page 44) which corresponds to full-body contact and considering an RBT of 36 illnesses per 1000 exposures. The State of Florida has accepted this recommended BAV for enterococci qPCR of 1000 gc/100mL for those counties and managers that may wish to use it to supplement swim advisories in addition to the culture-based enterococci BAV of 70 MPN/100mL for live enterococci. However, the qPCR specific BAV for enterococci is not currently promulgated as a required regulatory criterion in Florida. It currently serves as an optional guidance for beach management advisories. To the best of our knowledge, no beach managers in Florida are currently using the enterococci qPCR option for beach advisories.

The RBT recommended for human marker (HF183) in water is 525 gc/100 mL from single-grab samples (when no other fecal source risks are present). This RBT is based upon an assumption of 32 illnesses per 1000 exposures. This RBT has been proposed by researchers and has not been adopted by the State. We are not aware of any RBT based upon the dog marker (DG3). Since humans share the most diseases amongst other humans, the threshold for the MST human HF183 marker can be considered an upper bound in comparison to the threshold level for the dog DG3 marker.

There are no current RBTs determined yet for public health impacts from specific concentrations of general bird (GFD *Helicobacter*) marker in water, but there are already such RBT determinations for specific concentrations of a seagull marker (*Catelliboccus*) in water as computed by researchers (Boehm and Soller 2020). In this study, we have used these RBT values based upon seagulls to suggest potential levels of risk from exposure to the more general bird GFD *Helicobacter* marker exposure in water for possible human health impacts. In the absence of a human source, the RBT for the gull marker is computed as 200,000 gc/100 mL. Researchers have also determined combinations of fecal contamination from gulls and humans together cumulatively. Lower levels of human fecal waste have much greater risk when there is also fecal waste from other sources, such as bird, present simultaneously in the same water body. The combination for human and gull markers that are associated with excess risk (Boehm and Soller 2020) are given in Table I.2 below. As per our understanding, the bird-related RBTs have not been adopted by the State.

Table I.2: Simplified comparison between recommended threshold levels and enterococci and MST markers analyzed in this study. Thresholds are calculated to equate to a projected illness rate of either 32 or 36 illnesses per 1000 exposures for full body contact with water. See following table (Table I.3) for a more thorough and detailed explanation of the meaning of each target and their basis of comparison.

Target	Purpose	Measurement	Persistence in Environment	Recommended Risk Based Threshold Level for Swimming	Reference
Live Enterococci	Identify waters impaired by fecal waste	By culture so must be viable	Long and may regrow	70 MPN/100mL for 36 illness/1000 exposures (60 MPN/100 mL for 32 illness/1000 exposures)	- FDOH regulatory - EPA 2012 recreational water quality criteria recommendations
EnterolA marker of general Enterococci	Identify waters impaired by fecal waste	By PCR so viability unknown	Long	1000 gc/100mL for 36 illness/1000 exposures (640 gc/100mL for 32 illness/1000 exposure)	- EPA 2012 recreational water quality criteria recommendations
HF183 marker of <i>Bacteroides</i> (human)	Identify human waste	By PCR so viability unknown	Short	525 gc/100 mL (for 32 illness/1000 exposure)	Research paper
DG3 marker of <i>Bacteroides</i> (dog)	Identify dog waste		Short	Not Determined	Research paper
GFD marker of <i>Helicobacter</i> (general birds)	Identify bird waste		Medium	Not Determined	Research paper based upon <i>Catelliboccus</i> seagull marker
Gull2 marker of <i>Catelliboccus</i> (gull)	Identify gull waste		Medium	200,000 gc/100 mL (for 32 illness/1000 exposure)	Research paper
Combinations of human and gull marker genes equating to 32 illnesses/1000 exposures					
1 HF183	Human and gull combinations	By PCR so viability unknown	Short (persistence of combination is driven by the HF183)	22,500 gc/100 mL (gull)	Research paper
7 HF183				10,000 gc/100 mL (gull)	
30 HF183				3,000/100 mL (gull)	
70 HF183				1,000/100 mL (gull)	
120 HF183				300/100 mL (gull)	
370 HF183				1/100 mL (gull)	

Table I.2: Detailed comparison between recommended threshold levels of enterococci and MST markers analyzed in this study.

Target	Purpose	Measurement	Persistence in Environment	Recommended Risk Based Threshold Level for Human Swimming ^{1,2}	References
Live enterococci (official regulatory method)	Identify waters potentially impaired by fecal waste, issue exposure warnings	By culture. Cells must be viable (can metabolize, grow, and reproduce)	Long (multi-year) and may even regrow. Testing takes more than 24 hours for results.	BAV of 70 MPN or CFU/100 mL for viable cells from single-grab samples. Risk = 36 illnesses/1000 exposures. Adopted by the State of Florida.	Method: "IDEXX Enterolert" or EPA Method 1600" (US EPA, 2009). BAV: (US EPA, 2012b).
"EnterolA" Total general enterococci (live and dead) (alternate official regulatory method)	Identify waters potentially impaired by fecal waste, issue exposure warnings.	By qPCR of eDNA, so viability is unknown. (Measures both live and dead cells)	Long (multi-year) and may even regrow. May be tested more rapidly than by culture methods, may be combined with other genetic tests.	BAV of 1000 gc/100 mL from single-grab samples. Risk = 36 illnesses/1000 exposures. Not adopted by State. May optionally be used to supplement advisories.	Method: "EPA Method 1611" (US EPA, 2012a). BAV: (US EPA, 2012b).
"HF183" gene marker in human-host-specific <i>Bacteroides</i>	Identify human fecal waste – track fecal contamination to human sources such as sewage, seepage, illicit dumping, etc.		Short (typically days to only a few weeks)	525 gc/100 mL from single-grab samples (when no other fecal source risks are present). Risk = 32 illnesses/1000 exposures. Not adopted by State.	Method: "EPA Method 1696" (US EPA, 2019). RBT: (Boehm & Soller, 2020).
"DG3" gene marker in dog-host-specific <i>Bacteroides</i>	Identify dog fecal waste – track fecal pollution to potential terrestrial runoff sources such as stormwater, tidal flooding, etc.		Short (typically days to only a few weeks)	Risk Based Thresholds for DG3 marker have not yet been determined, and we are not aware of any studies yet that suggest what level of human exposure risk to DG3 might be. Humans and dogs share a wide range of pathogens, so risk is possible. Not adopted by State.	Method: (Green et al., 2014). RBT: No consensus for DG3 thresholds. For this study we arbitrarily suggest that > 10,000 copies/100 mL might be considered a risk.
"Gull2" gene marker in seagull-host-specific <i>Catellibacter marimammali</i>	Identify seagull/seabird fecal waste – track fecal pollution to seabird inputs, including direct deposition, runoff, stormwater, etc.		Medium (a few weeks)	200,000 gc/100mL from single-grab samples when no other fecal sources are present. 22,500 gc/100 mL if 1 gc/100mL human HF183 is present. Risk = 32 illnesses/1000 exposures. Not adopted by State. See prior table for RBTs of combinations of gull+human markers.	Method: (Sinigalliano et al. 2013). RBT: (Boehm & Soller, 2020).
"GFD" gene marker in <i>Helicobacter</i> fecal bacteria found in most birds. (Note: general composite for total birds – but some birds may represent more risk than others)	Identify bird fecal waste – track fecal pollution to bird inputs, including direct deposit to water bodies, as well as runoff, stormwater, etc.		Medium (a few weeks, usually less than a month)	RBTs for GFD general bird marker have not yet been determined. We suggest for this study, to consider an arbitrary use of the Gull risk thresholds for GFD as well, in consideration of the RBT for seagull <i>Catellibacter</i> fecal bacteria. Not adopted by State.	Method: (Green et al., 2011) RBT: Boehm & Soller, 2020 for Gulls.

¹ The recommended "Beach Action Values" (BAV) are regulatory recommendations for triggering public health warnings from single-grab sample results. The BAVs are guideline values recommended by the US EPA to the states. The BAVs become enforceable when the States adopt them through statutes.

² Risk Based Thresholds (RBT) are based upon either actual epidemiological studies of human exposure or upon Quantitative Microbial Risk Assessment (QMRA) predictive computer modeling of human illness risk from exposure. Measurements of the targets greater than these RBTs are estimated to have significant illness risk for human health outcomes. Note that these are not the regulatory criteria for declaring impaired waters legal status, but rather guidelines for issuing public warnings as estimated within the research literature.

I.3 GENERAL CONDITIONS OF THE PVC

The PVC resides within the degraded northern Biscayne Bay (BBTF 2020). Degradation of Biscayne Bay has been attributed to concentrated freshwater inputs at canal inlets to the bay which erode sediments, carry pulses of nutrients that encourage algal blooms, and contribute towards seagrass die offs. In addition to lying within a degraded Bay area, it suffers from restrictions to natural water flows. Tidal flushing from the Atlantic Ocean to northern Biscayne Bay is provided through Baker's Haulover Inlet located 3 miles to the north and Government Cut located 6.6 miles to the south (Figure I.3). Flushing is further restricted through its lack of direct connection to the bay. The PVC is connected to a network of waterways that run north to south (Tatum, Biscayne Point, and Normandy N-S Waterways) and east to west (Normandy E-W Waterway) (Figure I.4). Most of the waterways in this network have direct access to Biscayne Bay, however the PVC does not. The PVC is unique in that it is a waterway embedded within a waterway which allows for the accumulation of the FIB and is known to be a common symptom for waterways with limited flushing (Donahue et al. 2017, Kelly et al. 2018). Other waterway characteristics include its relatively shallow depth, its numerous bends, and the mangroves and shallow banks along its edge which have been shown to allow for FIB persistence and growth (Desmarais et al. 2002).

In addition to the lack of limited flushing of the PVC, the area receives a considerable amount of stormwater runoff. It receives the entirety of the stormwater runoff from Parkview Island to the west (18.7 acres or 75,700 m²) as all stormwater outlets on the island flow towards the east. It also receives stormwater runoff from a considerable area to the west (62.6 acres or 253,400 m²) extending from the canal to Collins Avenue between 72 and 77 Streets. The size of the PVW catchment area is estimated at 81.3 acres (329,000 m²). Overall, Parkview Island represents 23% of the area, and the area to the east on the main Miami Beach barrier island represents the remaining 77% of the area.

Additionally, the entire watershed area is highly urbanized with a considerable underground infrastructure designed to carry stormwater and sanitary sewage. The stormwater conveyance system is old (portions are over 80 years old) and designed prior to modern requirements for treatment of the first flush of stormwater. The sanitary sewer system consists of two primary systems (gravity and force mains). The sanitary sewer systems are of variable age and, although inspected, lined, and monitored, continue to be considered as a possible source of enterococci. More details about the stormwater conveyance and sanitary sewer systems are provided in Chapter III of this report.

Monitoring of the PVC by the CMB began in April 2019 as part of a stormwater management program designed to inform decision-making. At the time during 2019, CMB was in the process of identifying priority areas within Miami Beach for possible installation of stormwater pump and treatment stations. At other locations, the CMB has installed stormwater pump stations fitted with treatment systems designed to remove trash and grit (via vortexer). However, such systems have not yet been installed to treat the stormwater within this catchment.

Since April 2019 the area has experienced sewage spills including a major spill (665,000 gallons) in March 2020 located at Harding and 72 Street (located 1500 feet east of the PVC). When the FIB at the PVC did not decrease to below regulatory levels (following the March 2020 sewage spill) the CMB contracted to have samples analyzed for Microbial Source Tracking (MST) markers between October 2020 and September 2021. Results from these analyses indicated a dominance by dog markers with some evidence of human and bird markers. As a result of these MST sampling efforts, the CMB developed an educational campaign to encourage dog owners to properly dispose of dog waste. The CMB constructed facilities with doggie bags and garbage bins with signage at the park area that leads to the PVC (Parkview Island Park) to encourage proper disposal of dog waste and thus reduce contamination of runoff by dog fecal matter.

Additionally, the CMB has conducted a comprehensive set of studies of the area in attempts to isolate potential sources of FIB. In addition to the efforts at reducing the impacts from dog waste, CMB has conducted extensive studies evaluating the sanitary sewer system, inclusive of smoke testing, camera inspections, and acoustic testing to identify potential leaks. For details see Montas et al. 2023. For cases where leaks have been identified, the City has taken corrective action. A repair was made to the sanitary sewer infrastructure during the first weeks of February 2023 when twelve force main air release valves (from 77th Street just north of the PVC to 73rd Street and Harding Court) were inspected and a subset of which (3) were found to be leaking. These air release valves (at 75th and Dickens, 74th and Dickens, and at 73rd and Harding Court) were immediately replaced at the time (between February 4 and February 12, 2023). Regular inspections made since the replacements, as of the writing of this report, indicate that the air release valves remain intact.

Concurrently, Miami Surfrider, a non-governmental organization which coordinates citizen's groups to engage in water quality monitoring programs, initiated two sets of monitoring efforts. The first of which was initiated October 2021 and consisted of weekly monitoring of PVC surface water at the Kayak Launch, at the same location that the CMB conducts its monthly monitoring efforts. A comparison and analysis of the CMB and Surfrider regular monitoring efforts are provided in Section II.1 of this report. In addition to regular weekly monitoring, Miami Surfrider organized two MST studies (JV 2022a,b) during July and August 2022 which included PVC samples collected at the Kayak Launch location. Results from the Surfrider MST studies indicated the presence of human marker within five of the six samples collected.

In addition to the work through CMB and Miami Surfrider, the University of Miami (UM) conducted an intense targeted study during 2022. The 2022 study evaluated historical records of enterococci measurements and found strong correlations with 24-hour antecedent rainfall and low canal-water salinity. Through measurements, the study documented a large pulse of enterococci at the canal immediately after a storm event with the highest levels found at the surface within a floating freshwater layer. The study also found highly elevated levels of enterococci in the stormwater conveyance system with the highest levels towards the top of the water surface, suggesting enterococci contamination of the shallow groundwater. These results collectively suggest that the primary source of enterococci to the PVC was stormwater runoff which was contaminated by waste deposited on surfaces that drain towards the PVC. Results from the 2022 study also found that between storm events, enterococci levels were lower in the PVC but still elevated above the recreational guideline levels of 70 Most Probable Number (MPN) per 100 mL. The enterococci levels between storm events coincided with tidal cycles with higher levels observed during low tide. This pattern suggested that contaminated groundwater was also a source of enterococci to the PVC. The source of contamination to the shallow groundwater was believed to be either storm water runoff (from rainwater runoff from the streets) or leaking sanitary sewage.

The goal of this current study was to evaluate the ultimate source of shallow groundwater contamination. The chapters and sections of the report that follow are intended to build upon the results from the UM 2022 study by: 1) analyzing regular monitoring data to include new data gathered between October 2022 and September 2024 (Chapter II), 2) evaluating of the existing stormwater conveyance infrastructure to understand when it hydraulically connects shallow groundwater to the PVC (Chapter III), and 3) analysis of enterococci in groundwater, stormwater, and surface water from the PVC (Chapter IV). Sample collection of these different waters was augmented by MST (Chapter V) in efforts to determine the extent to which dog, humans, and gulls/birds contribute towards these different water types. An overall assessment and recommendations are provided in Chapter VI.

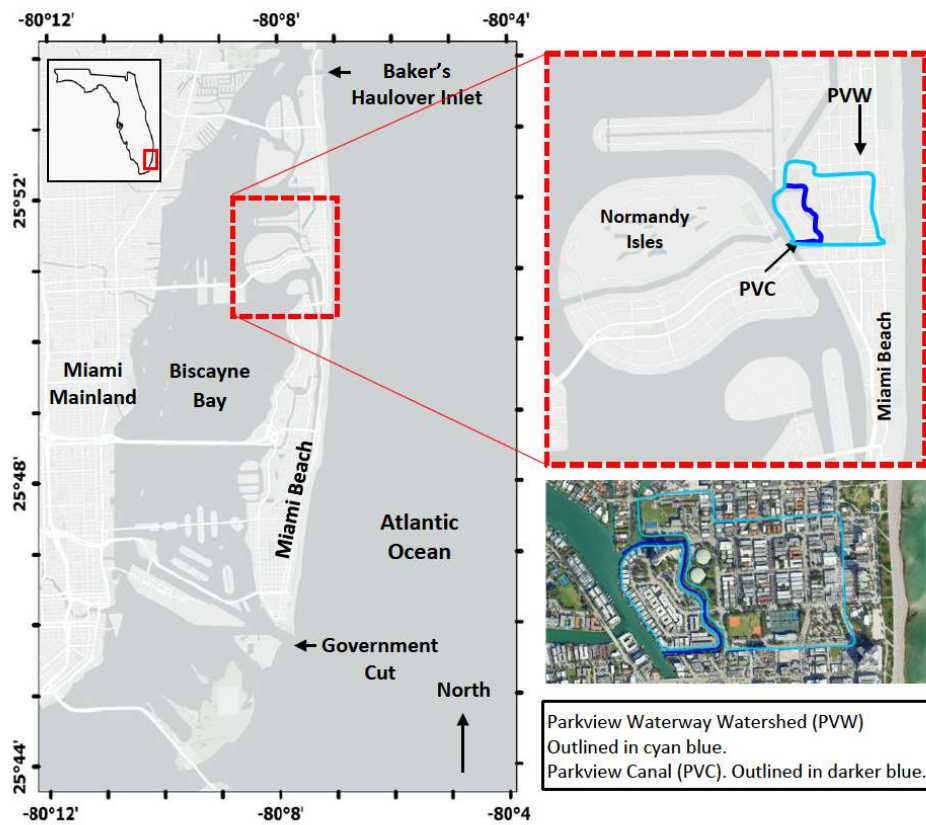


Figure I.3: Location of Park View Canal within North Biscayne Bay and its interconnections through secondary waterways to the bay.

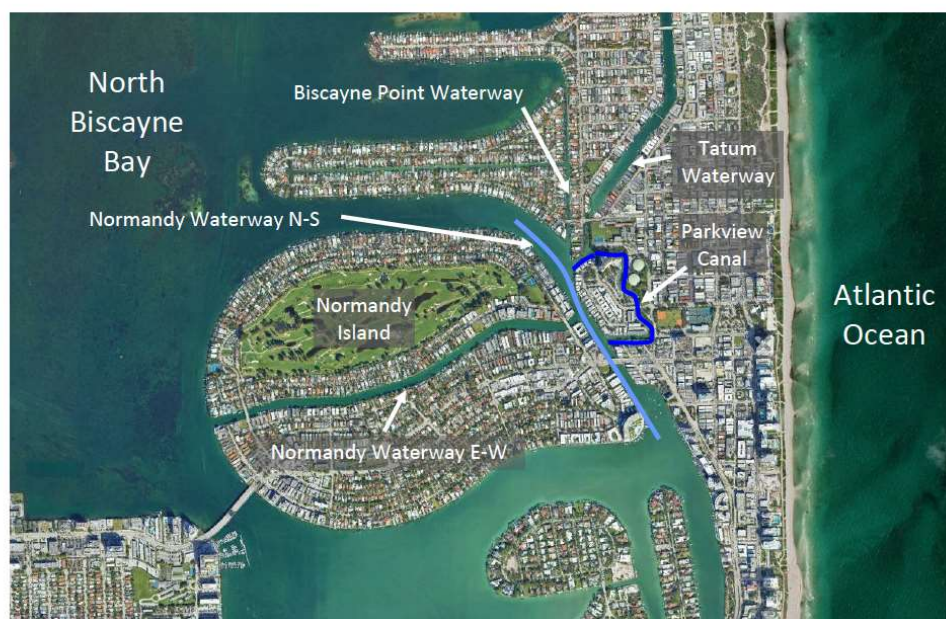


Figure I.4: Map showing locations of 1) Park View Canal, 2) Biscayne Point Waterway, 3) Tatum Waterways, 4) Normandy Waterway N-S, and 5) Normandy Waterway E-W.

CHAPTER II

ANALYSIS OF HISTORICAL DATA

CHAPTER II

ANALYSIS OF HISTORICAL DATA

The analysis described in this chapter is based upon the large amount of data collected and shared through the CMB and through Miami Surfrider. The focus of this historical data analysis was to evaluate enterococci data to document long term trends (Section II.1), identify the sources of ambient data (Section II.2), and evaluate correlations between enterococci and environmental factors (ambient plus water quality) (Section II.3).

II.1 ANALYSIS OF HISTORICAL ENTEROCOCCI RECORDS OVER TIME

Two groups (CMB and Surfrider) have been regularly monitoring enterococci levels at the PVC. The CMB has been monitored monthly for FIB since April 17, 2019. Monitoring consists of collecting a water sample at the Kayak Launch Pad within the PVC, followed by laboratory analysis to measure the Most probable Number of enterococci per 100 mL (MPN/100 mL). In addition to monthly enterococci measurements, the CMB also collects samples for another fecal bacteria, fecal coliform, plus for the analysis of nitrogen (nitrate + nitrite, ammonia, and total Kjeldahl) and phosphorus (total). The results from sample analysis are augmented by field measurements of basic physical-chemical parameters (water temperature, pH, salinity, specific conductance, dissolved oxygen, and turbidity).

Miami Surfrider has been monitoring water quality at the same location as the CMB. Monitoring by Miami Surfrider has been conducted weekly since October 14, 2021. Their laboratory measurements are solely focused on enterococci and are reported, like CMB, as MPN per 100 mL. The results from enterococci sample analysis are augmented by field measurements of water temperature and with information about ambient conditions [air temperature, wind speed and direction, and estimates of weather conditions (specifically qualitative descriptions of recent rainfall and tidal height)]. The Miami Surfrider data is available online at: <https://bwtf.surfrider.org/explore/57/1183>.

The first comparison between the data sets was to plot the two data sets in time series (Figure II.1). Results of this comparison emphasize the differences in the periods of record for each data set and the influence of the different time frequencies of sample collection, with more samples collected by Surfrider during recent times. Regardless of the differences associated with sample collection timing, both data sets emphasize that the enterococci levels are chronically elevated exceeding the 70 MPN/100 mL threshold (red and yellow bars) most of the time. When focusing on the green bars (below the 70 MPN/100 mL threshold), there appear to be fewer green bars during the first half of the record (prior to 2022) compared to the second half of the record (2022 and beyond), especially for the CMB data set. The color coding also includes a yellow bar for informational purposes which corresponds to samples between 70 MPN/100 mL and the upper US EPA recommended limit for kayaking in calm waters (370 MPN/100 mL).

Statistics were computed to further assess the historical records of enterococci over the period of record and yearly (Section II.1.a), separated by antecedent rainfall (Section II.1.b) and separated by timing of mitigation measures (Section II.1.c). Statistical analysis of this data was conducted by first evaluating the distribution of the data. The Shapiro-Wilk Test which is used to test for normality showed that the data was not normally distributed so non-parametric statistical tests were chosen to further analyze the data. These non-parametric tests include the Kruskal Test to evaluate multiple comparisons across data sets and the Mann Whitney U test to evaluate individual pairs of data. Additionally, Chi-Square Tests were run to analyze categorical data (e.g., number of data points above or below the water quality threshold). This test was used to evaluate whether

frequencies (of above versus below a water quality threshold) were different among the different sets of enterococci data evaluated.

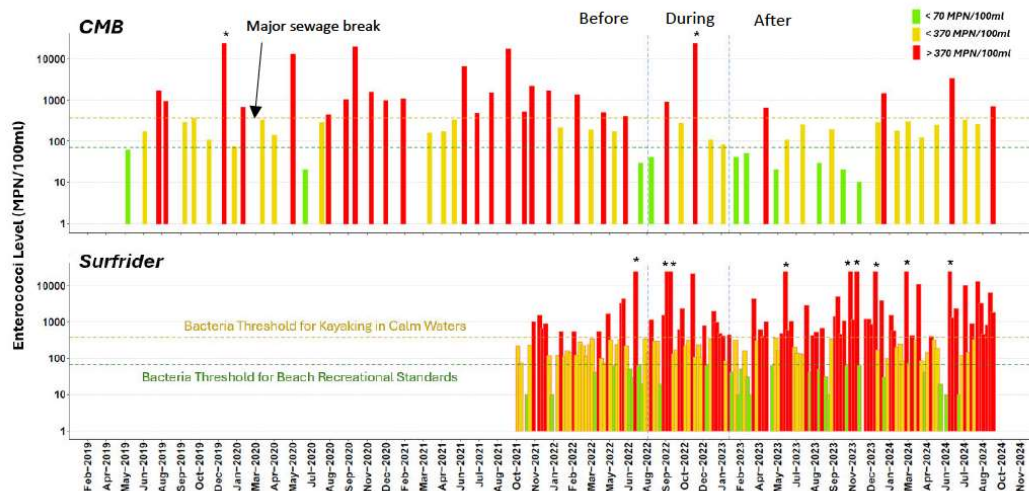


Figure II.1: Enterococci measurements at the PVC corresponding to the CMB dataset (top panel) and to the Surfrider dataset (bottom panel). Green bars correspond to data points below the 70 MPN/100 mL recommended recreational level for full body immersion, whereas yellow bars correspond to data points between 70 and 370 MPN/100 mL, corresponding to the recommended level for kayaking in calm waters. Red bars correspond to data points which exceed the 370 MPN/100 mL level. The “*” over the red bars indicates that the samples exceeded the 24,196 MPN/100 mL detection limit. The vertical lines separating the time series corresponds to the 6-month period between August 3, 2022, to February 3, 2023, which is when the CMB enhanced mitigation measures. Note the data are plotted on a logarithmic scale due to the wide range of measurements.

II.1.a Period of Record and Yearly Evaluation of CMB and Surfrider Data Sets

We compiled sampling data corresponding to the period of record (POR) from April 2019 to September 2024 and found that enterococci levels for samples collected in the vicinity of the Kayak Launch pad continue to regularly exceed the 70 MPN/100 mL threshold. The majority, especially for the CMB data set in more recent years, fall within the 70 to 370 MPN/100 mL threshold for kayaking in calm waters. Samples that exceeded the detection limit of 24,196 MPN/100 mL were observed only in the Surfrider data set in the last two years (Figure II.1). As emphasized from the earlier UM study of 2022 and in the current 2024 study (described later), water quality is much more variable with higher enterococci levels closer to the PVC water surface due to a freshwater layer that floats atop of saltier water. Given this observation we expect higher and more variable enterococci levels the shallower the water samples, which is reflected in the comparison of the CMB (sample at a 1-foot depth) and Surfrider (sample at 6-inch depth) data sets.

To further describe the exceedances at the PVC, enterococci levels for each year from the CMB and Surfrider data sets were converted to exceedances above the 70 MPN/100 mL beach advisory threshold, between the 70 and 370 MPN/100 mL kayaking recommended threshold, and to exceedances above the limit of detection of 24,196 MPN/100 mL. For the CMB period of record, the 70 MPN/100 mL threshold was exceeded 85% of the

time, the 370 MPN/100 mL was exceeded 43% of the time, and the 24,196 MPN/100 mL threshold was exceeded 3% of the time. For the Surfrider period of record, the 70 MPN/100 mL threshold was exceeded 82% of the time, the 370 MPN/100 mL was exceeded 44% of the time, and the 24,196 MPN/100 mL threshold was exceeded 5% of the time.

Evaluating the historical data on a year-by-year basis showed that for the CMB data set (Table II.1, left hand side), 2019 was a year of particularly poor water quality with 11% of the samples exceeding the 24,196 MPN/100 mL threshold and 89% of the samples exceeding the 70 MPN/100 mL threshold. For 2020 and 2021, no exceedances of the 24,196 MPN/100 mL threshold were observed, although the lower threshold of 70 MPN/100 mL was exceeded 92% and 100% of the time during these years, respectively. In addition, the more lenient threshold of 370 MPN/100 mL was also exceeded most of the time during 2020 and 2021. During 2022, samples again exceeded the 24,196 MPN/100 mL threshold, and for this year it was measured for 8% of the samples collected. The year 2023 appears to be a particularly good year (in comparison to other years) for water quality. Samples collected during 2023 showed an improvement in water quality with none of the samples exceeding the 24,196 MPN/100 mL threshold, 9% exceeding the 370 MPN/100 mL threshold, and 45% of the samples exceeding the 70 MPN/100 mL threshold. During 2024, all samples collected exceeded the 70 MPN/100 mL threshold, 30% exceeded the 370 MPN/100 mL threshold, and none exceeded the 24,196 MPN/100 mL threshold. No apparent trend was observed with yearly total rainfall (note that 2019 and 2024 are partial years), as 2020 was a particularly wet year (94 inches of rain measured at S27_R) with a median enterococci level of 558 MPN/100 mL and 2021 was drier (60 inches) with a median of 1090 MPN/100 mL. Evaluation of yearly rainfall totals in 2022 and 2023 against median enterococci levels further enforces the lack of correlation with yearly rainfall totals, suggesting that long term rainfall trends are not a strong factor impacting enterococci levels. Rather shorter term (e.g., 24-hour antecedent rainfall) plays a more significant role in influencing the levels of enterococci in the PVC.

Evaluating the historical data yearly for the Surfrider data set (Table II.1, right hand side) shows a relatively consistent exceedance of the 70 MPN/100 mL threshold between 72% and 87%, and relatively consistent exceedances of the 370 MPN/100 mL threshold between 31% and 54%. Exceedances of the 24,196 MPN/100 mL threshold varied between 0% and 8% per year with no distinct yearly trend. Associations with yearly rainfall totals are limited for this data set due to the availability of only two full calendar years of rainfall data at this time. Of note, for the two years of data available, the year (2023) with the higher rainfall total coincided with a higher enterococci median value, in comparison to the year (2022) with the lower rainfall total and lower enterococci median value.

When evaluating the means and medians of the CMB and Surfrider data sets the values were similar. No statistical differences were observed between the median of the CMB data set and the median of the Surfrider data set ($p=0.89$). On a year-by-year basis, the means and medians usually align within the same order of magnitude suggesting a consistency between the data sets. These consistencies exist although two separate groups collected samples using different sample collection methods. The CMB uses a certified laboratory for sample analysis who collect samples using a pole sampler at a one-foot depth, whereas Surfrider enrolls citizen scientists to collect samples using either a glass jar or a Whirlpak bag at a sample collection depth of 6 inches below the water surface. Although Surfrider is not currently certified, the Surfrider sample collection process includes documented protocols and training resources for citizen scientists to maintain consistency (<https://bwtf.surfrider.org/resources>).

II.1.b Separation of CMB and Surfrider Datasets Based Upon Antecedent Rainfall

To further evaluate the data, each set (CMB and Surfrider) were further split into two sets. The sets included times with and without 24-hour antecedent rainfall (Table II.2). The split based upon antecedent rainfall was chosen given that earlier analysis indicated that antecedent rainfall was the most significant environmental

factor influencing enterococci levels. For the CMB data set (Table II.2, top half of table), results from this analysis show that percent exceedances were not sensitive to antecedent rainfall conditions. However, the mean and median of the enterococci levels were sensitive. The median of the entire CMB data set was lower during dry conditions (no 24-hour antecedent rainfall) compared to wet conditions (with 24-hour antecedent rainfall ($p=0.009$)). This statistical difference in the median was not observed when splitting the data by sample collection year ($p=0.48$). Similarly, for the Surfrider data set (Table II.2, bottom half of table), the medians of the enterococci levels were lower during dry conditions compared to wet conditions ($p<0.001$). Again, these statistical differences were not observed when splitting the data by sample collection year ($p=0.55$). The interpretation of this trend is that the baseline enterococci levels conditions, which are better represented by the mean and median, are lower during dry conditions compared to wet conditions. The lack of statistical significance when evaluating the data year-by-year may be due to the limited number of data points when splitting the data into shorter one-year data sets.

Table II.1: Means (arithmetic, geometric), median, and percent of exceedances of 70, 370, and 24,196 MPN/100 mL thresholds per year for the entirety of the CMB and Surfrider data sets. The 70 is the guideline for recreational bathing waters. The 370 is the recommended guideline for kayaking in calm waters. The 24,196 corresponds to the upper detection limit of the analysis method. Rainfall corresponds to station S27_R

<i>CMB Data Set</i>									<i>Surfrider Data Set</i>						
<i>Year</i>	<i>Total Rain (inches)</i>	<i>N</i>	<i>Arith. Mean</i>	<i>Median</i>	<i>Geo. Mean</i>	<i>% Exceed 70</i>	<i>% Exceed 370</i>	<i>% Exceed 24,196</i>	<i>N</i>	<i>Arith. Mean</i>	<i>Median</i>	<i>Geo. Mean</i>	<i>% Exceed 70</i>	<i>% Exceed 370</i>	<i>% Exceed 24,196</i>
2024^a	49.74	10	727	295	408	100%	30%	0%	38	3,175	373	504	87%	50%	3%
2023	77.49	11	137	52	65	45%	9%	0%	50	2,548	427	372	72%	54%	8%
2022	70.00	12	2,362	245	327	83%	42%	8%	52	2,301	243	335	81%	31%	4%
2021	60.23	11	2,905	1,090	1,039	100%	73%	0%	10 ^c	484	227	184	80%	40%	0%
2020	93.71	12	3,200	558	602	92%	58%	0%	NA ^d	NA	NA	NA	NA	NA	NA
2019^b	54.17	9	3,472	322	508	89%	44%	11%	NA	NA	NA	NA	NA	NA	NA
Entire Period of Record	405.34	65	2,113	297	370	85%	43%	3%	150	2,484	324	370	82%	44%	5%

^aData through September 30, 2024

^bData for CMB set starts April 17, 2019

^cData for Surfrider set starts October 14, 2021

^dNot applicable. Prior to Surfrider monitoring period.

Table II.2: Means (arithmetic, geometric), median, and percent of exceedances of 70, 370, and 24,196 MPN/100 ml thresholds per year including and excluding time periods with 24-hour antecedent rainfall. The rainfall uses the WS3 weather station with S_27R as the backup.

Times with 24-hr. Antecedent Rainfall (wet)								Times w/out 24-hr. Antecedent Rainfall (dry)						
Year	N	Arith. Mean	Median	Geo. Mean	% Exceed 70	% Exceed 370	% Exceed 24,196	N	Arith. Mean	Median	Geo. Mean	% Exceed 70	% Exceed 370	% Exceed 24,196
CMB Data Set														
2024 ^a	3	1,480	683	914	100%	67%	0%	7	404	259	289	100%	14%	0%
2023	6	218	152	122	67%	17%	0%	5	39	30	30	20%	0%	0%
2022	2	654	654	602	100%	100%	0%	10	2,704	199	289	80%	30%	10%
2021	5	5,509	1,660	2,684	100%	100%	0%	6	735	422	471	100%	50%	0%
2020	5	6,873	1,010	1,180	80%	80%	0%	7	575	331	372	100%	43%	0%
2019 ^b	2	12,565	12,565	4,754	100%	100%	50%	7	441	227	241	86%	29%	0%
Entire Period of Record	23	4,091	683	804	86%	70%	5%	42	2,136	292	367	84%	29%	2%
Surfrider Data Set														
2024 ^a	15	6,081	2,359	1,906	93%	80%	7%	23	1,280	185	212	83%	30%	0%
2023	23	5,120	677	1,035	91%	70%	17%	27	356	160	156	63%	41%	0%
2022	22	3,973	538	751	95%	55%	5%	30	1,075	194	185	77%	13%	3%
2021 ^c	1	1,019	1,019	1,019	100%	100%	0%	9	425	218	152	78%	33%	0%
Entire Period of Record	61	4,876	905	1,071	93%	67%	10%	89	844	185	178	74%	28%	1%

^aData through September 30, 2024

^bData for CMB set starts April 17, 2019

^cData for Surfrider set starts October 14, 2021

II.1.c Separation of CMB and Surfrider Datasets Based Upon Timing of Mitigation Measures

Data were separated into batches to evaluate whether improvements to water quality were observable during key periods of mitigation. These batches were called “before”, “during”, and “after” and corresponded to the following time periods:

- Before: the time before August 3, 2022
- During: the time between August 3, 2022, and February 3, 2023, and
- After: The time after February 3, 2023, through September 30, 2024

The time between August 3 and February 3 (6 months) corresponded to the period when the CMB transitioned towards increased intensity of efforts to mitigate contamination to the PVC inclusive of increased frequency of street sweeping, increased frequency of waste litter removal, additional community education and outreach to encourage pet waste cleanup, outreach to homeless populations, reductions in feral animal feeding, enforcement of trash bin covers, and replacement of the sanitary sewer air release valves.

For the CMB data set (Table II.3, top third), comparing the enterococci measurements between each of these periods shows an improvement in water quality between before and after periods. “Before” had an arithmetic average (2,700 MPN/100 mL), geometric mean (580 MPN/100 mL), and median (460 MPN/100 mL) higher than “after” (430 MPN/100 mL, 160 MPN/100 mL, and 220 MPN/100 mL for arithmetic mean, geometric mean, and median, respectively). Percent exceedances of the 70 MPN/100 mL threshold dropped from 92% to 70% between before and after. Additionally, the percent exceedances of the 24,196 MPN/100 mL threshold were reduced from 3% to 0%. Statistical analysis of the enterococci data separated between “before”, “during”, and “after” (using the Chi-Squared test), showed that statistical differences in the medians were observed only between before and after ($p=0.01$), and no statistical differences were observed between before and during ($p=0.30$) and between during and after ($p=0.67$). When evaluating the frequency of exceedances above the 70 MPN/100 mL threshold, the frequencies were not statistically different at 95% confidence limits but were statistically different at 90% confidence limits ($p=0.08$). The most pronounced improvements were for the frequency of exceedances above the 370 MPN/100 mL threshold. The frequency of exceedances above 370 MPN/100 mL threshold dropped significantly ($p=0.02$) from 56% during the “before” period to 20% during the “after” period.

For the Surfrider data set (Table II.3), enterococci levels appear to be very similar or increasing from the “before” to “after” period. The “before” arithmetic average (1,100 MPN/100 mL) was lower than the “after” arithmetic average (3,000 MPN/100 mL). Similarly, the “before” geometric mean (220 MPN/100 mL) was lower than the “after” geometric mean (430 MPN/100 mL). The same was observed for the median which was lower “before” (220 MPN/100 mL) than “after” (400 MPN/100 mL). Statistical analysis of the enterococci from the Surfrider data set showed no significant difference among the “before”, “during”, or “after” groups ($p=0.128$). When evaluating the frequency of exceedances above the 70 MPN/100 mL threshold, the frequencies were not statistically different ($p=0.29$). For the frequency of exceedances above 370 MPN/100 mL, the frequencies were again statistically different between before and after ($p=0.05$), but the results were reversed with “after” showing a higher frequency of exceedance (51%) compared to “before” (28%).

The results indicate that the CMB data sets show an improvement between “before” and “after” whereas the Surfrider data are not as clear. The differences observed between the CMB and Surfrider data sets may be due to the fact the CMB data set goes back further in time and therefore represents water quality when it appears to have been poorer, whereas the Surfrider data set emphasizes more recent times. Also, when comparing the coefficient of variation (CoVs) between the CMB and Surfrider datasets, the CMB dataset has lower CoVs (less variability) which may also have influenced the ability to observe statistically significant differences within the CMB and Surfrider data sets. The higher COV for the Surfrider set may be because samples are collected at a

shallower depth (6 inches) whereas the CMB samples are collected at a depth of one foot. As the next chapter shows, the shallower the depth the higher the variability of the enterococci readings. This difference in sample collection depth may also contribute towards the differences in documenting statistical differences between “before” and “after”.

When aggregating both data sets together (Table II.3), no statistical differences were observed in the medians between “before”, “during”, and “after” ($p=0.84$). When evaluating the frequency of exceedances above the 70 MPN/100 mL threshold, the frequencies were not statistically different ($p=0.13$) for the different time periods evaluated.

Table II.3: Statistics of CMB, Surfrider and Aggregated Data Sets Separated by Before, During and After Enhanced CMB Mitigation Measures. Units for the average, geometric mean, median and standard deviation correspond to MPN/100 mL.

	<i>N</i>	% Exceed 70	% Exceed 370	% Exceed 24,196	Arith. Average	Geo. Mean	Median	Std. Dev.	Coeff. Var (%)
CMB Data Set									
Before	39	92%	56%	3%	2,656	577	462	5,807	2.2
During	6	83%	33%	17%	4,270	363	194	9,767	2.3
After	20	70%	20%	0%	434	161	219	780	1.8
Surfrider Data Set									
Before	40	80%	28%	3%	1,094	221	222	3,846	3.5
During	27	93%	48%	4%	3,081	505	350	7,307	2.4
After	83	80%	51%	6%	2,959	427	404	6,485	2.2
Aggregated CMB and Surfrider Data Sets									
Before	79	86%	42%	3%	1,839	356	323	4,901	2.7
During	33	91%	45%	6%	3,297	476	324	7,649	2.3
After	103	78%	45%	6%	2,469	353	323	5,911	2.4

II.2 SOURCE OF AMBIENT DATA

Environmental factors, including ambient and water quality data, were compared to the historical enterococci levels as measured by the CMB and Surfrider. Ambient data for comparison with the CMB and Surfrider data sets included rainfall, tidal elevations, and groundwater elevations. Additionally, the 12-hour sampling effort (described in Chapter IV) also required compilation of solar radiance. This section focuses on describing the sources of ambient data.

The 2022 UM study (Montas et al. 2023) provides a comprehensive assessment of local ambient environmental monitoring stations. In the current 2024 study, a subset of the stations was utilized. Stations chosen were those that were in closest proximity that provided reliable data with minimal data gaps.

Rainfall was compiled from two stations (Figure II.2, Table II.4). These stations included one operated by the CMB, station WS3, which was in operation during the time of this study and located within the catchment of the study site (located at the North Shore Park & Youth Center). The other two CMB rainfall stations (WS1 and WS2) were not in operation at the time of this study due to construction activities on CMB properties. Data from the closest station operated by the South Florida Water Management District (SFWMD) (S_27R), located 4 miles west of the catchment, was used to fill in the data gaps in the WS3 data set.

Tidal data were compiled from the National Oceanographic and Atmospheric Administration's (NOAA) Tides and Currents repository (Virginia Key, Key Biscayne at Bear Cut). This site includes tidal predictions plus confirmed tidal elevations every six minutes providing high resolution and reliability. The NOAA station at Bear Cut in Virginia Key is the closest NOAA station with this level of resolution. The NOAA tidal data was used to estimate the time of high and low tide at the PVC. The 2022 UM study established that the PVC elevations (inclusive of high and low tides) were at a 17-minute time delay from the NOAA tidal station.

Groundwater monitoring data is available through the CMB. The closest station (Parkview Park, PVP) is located within 100 feet of the southeastern bend of the PVC, located at the northeast corner of 72nd Street and Dickens Avenue within the parking lot of the North Shore Park and Youth Center (Figure II.2, Table II.4). The PVP groundwater monitoring station consists of three groundwater wells that are capped and protected from surface contamination. These wells are screened at different elevations and include a shallow (screened at 25 to 35 feet), an intermediate (85 to 95 feet) and a deep well (200 to 210 feet).

Solar radiance data was available through Miami-Dade Weather Stem station located at Sunny Isles Beach located 2.7 miles north of Haulover Cut. This station records wind speed and direction, air temperature and solar data.

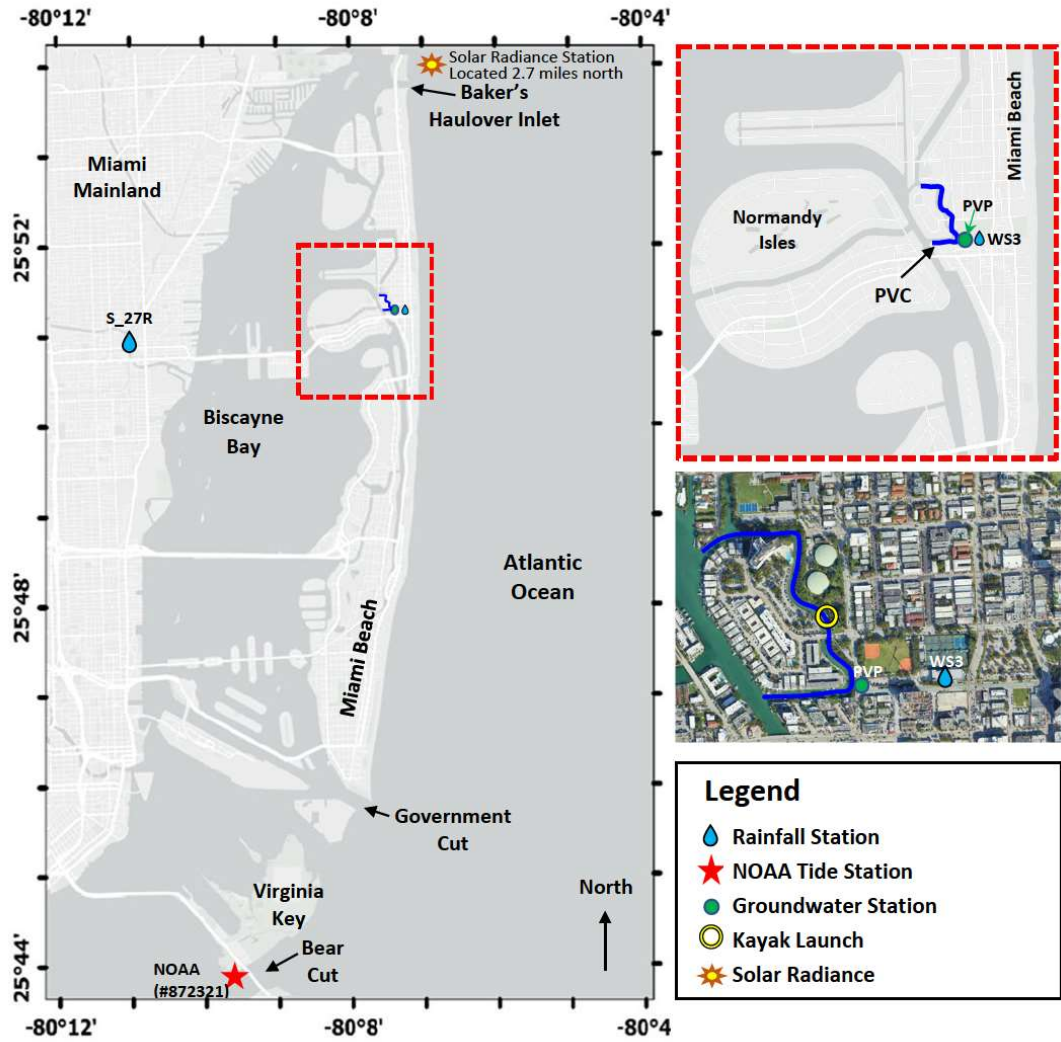


Figure II.2: Map showing locations of the rainfall, tidal, and groundwater stations relative to the Park View Canal (blue line) and Kayak Launch.

Table II.4: Ambient Environmental Gauging Stations Providing Data Used for the Analysis of Enterococci Data

Ambient Parameter Measured	Station Name	Agency Responsible for Station	Period of Record	Measurement Frequency	GPS Coordinates		URL for Station and/or Stations Description
					N	W	
Rainfall Depth	WS3	CMB	12/13/13-present	30 minutes	25.85753	-80.12296	City of Miami Beach Station 3, located at the North Shore Park & Youth Center (501 72nd St, Miami Beach, FL 33141). Data available through Weatherlink. https://www.weatherlink.com/
Rainfall Depth (back up)	S27_R	SFWMD	1/8/91-present	15 minutes	25.85123	-80.18837	SFWMD Rainfall Station S27. Located at spillway on canal C-7. Located northwest of Biscayne Boulevard and NE 83rd Street. https://apps.sfwmd.gov/WAB/EnvironmentalMonitoring/index.html https://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.show_dbkeys_matched?v_station=S27_R&v_js_flag=N
Tidal Elevation	Virginia Key, Biscayne Bay	NOAA	1/28/94-present	6 minutes	25.7314	-80.1618	NOAA station 8723214 located at Bear Cut on pier at UM Marine Campus. https://tidesandcurrents.noaa.gov/stationhome.html?id=8723214
Groundwater Elevation	Parkview Park (PVP)	CMB	9/2/19-present	hourly	25.85724	-80.12490	Three values provided at this station. Elevations are provided for a shallow well screened at 25 to 35 feet, intermediate well at 85 to 95 feet, and deep well at 200 to 210 feet. Data available through HydroVu. https://www.hydrovu.com/#/download/graph-export/5954062857404416
Solar Radiance	FSWN Sunny Isles Beach	Miami-Dade Weather STEM	3/29/22-present	minute	25.93743	-80.12036	FSWN Sunny Isles Beach station. Includes wind, temperature, and solar data. https://miamidade.weatherstem.com/fswnsunnyisles

II.3 RELATIONSHIPS BETWEEN HISTORIC ENTEROCOCCI LEVELS AND ENVIRONMENTAL FACTORS

The available enterococci data were compared with environmental factors (consisting of both ambient and water quality data) to evaluate potential associations that can be used to explain the enterococci levels. As mentioned in Section II.1, two sources of historic enterococci data were available, those from the CMB and those from Miami Surfrider. A summary of the available environmental factors available for each set of data are provided in Table II.5. The comparison shows that the CMB data set is much more comprehensive in terms of the water quality parameters measured. Although the period of record is longer for the CMB data set (5.5 years starting April 2019), the frequency of sampling is monthly providing for a total of 65 sampling days, which is fewer sampling dates than the Surfrider data set. As a result of the weekly sample collection frequency, the Surfrider data set consists of more sampling days (150 days), even though sampling by Surfrider started later (3 years starting October 2024). Water temperatures were available for both the CMB and Surfrider datasets.

Additionally, because sample collection day and time were available for both data sets, we were able to associate the enterococci data with ambient data including antecedent rainfall (6-hour, 24-hour, and 48-hours as measured at WS3), groundwater elevations at Parkview Park (for the shallow, intermediate, and deep wells), tidal elevations (measured at the NOAA station and estimated for the PVC), and differences between elevations to evaluate direction of flow between the PVC and groundwater.

For the CMB data set, the more comprehensive measurements included nutrients including three forms of nitrogen (nitrate+nitrite, ammonia, and total Kjeldahl nitrogen) plus phosphorus (total). During sample collection, field measurements for the CMB data set also included additional physicochemical parameters (salinity, specific conductance, pH, water temperature, dissolved oxygen, and turbidity). Since salinity and specific conductance are linearly correlated, additional analysis focused on using salinity only. Details about the rainfall and tidal stations are available in Section II.2. The enterococci and ambient and water quality data utilized for analysis are provided in Appendix A.

The following subsections provide summary statistics for the ambient and water quality data for the CMB data set (Section II.3.a) and evaluate correlations between enterococci and environmental conditions for the CMB data set (Section II.3.b).

Table II.5: Comparison of data available through the CMB and Miami Surfrider data sets.

	CMB	Miami Surfrider
Period of Record	Apr. 17, 2019, to Sept. 30, 2024	Oct. 14, 2021, to Sept. 30, 2024
Sampling Frequency	Monthly	Weekly
Number of Sampling Days	65	150
Water Quality Data	Enterococci	Enterococci
	Water Temperature	Water Temperature
	Fecal Coliform	
	Nitrate+Nitrite	
	Ammonia	
	Total Kjeldahl Nitrogen	
	Total Phosphorus	
	pH	
	Salinity	
	Specific Conductance	
	Dissolve Oxygen	
	Turbidity	
Ambient Data. Used for the analysis of both data sets.	6-hour Antecedent Rainfall	
	12-hour Antecedent Rainfall	
	24-hour Antecedent Rainfall	
	48-hour Antecedent Rainfall	
	Groundwater Elevation, Shallow Well at PVP	
	Groundwater Elevation, Intermediate Well at PVP	
	Groundwater Elevation, Deep Well at PVP	
	Tide Elevation at NOAA Station	
	Estimated Water Surface Elevation at the PVC	
	Difference between PVC Water Surface Elevation and Groundwater Elevation	

II.3.a Average Environmental Conditions During Sampling for the CMB Data Set

Average environmental conditions of the PVC during CMB sampling are within expected levels for predominantly marine waters. The arithmetic averages of the measurements included: water temperature (26.8 °C), salinity (29.4 psu), pH (7.93), turbidity (5.0 ntu), dissolved oxygen (5.2 mg/L), nitrogen (0.055 mg/L as ammonia, 0.049 as nitrate + nitrite, 0.32 mg/L as TKN), and total phosphorus (0.023 mg/L) (Table II.6). A few of these environmental conditions are listed within the FDEP Florida Surface Quality Criteria (FAC 62-304.530, 2016 and FAC 62-302.400, 2013 for dissolved oxygen (see floridadep.gov/dear/water-quality-standards/content/surface-water-quality-standards-classes-uses-criteria). The parameters that are within the criteria (for a Class III and Class III-Limited water in predominantly marine environments) included pH (between 5 and 9.5), dissolved oxygen (4.0 mg/L for 56% of saturation), turbidity (≤ 29 ntu), and ammonia (≤ 0.49 mg/L as computed using the average temperature and pH). General FDEP water quality criteria include references to nutrient levels (FAC 62-302.300), suggesting that good quality waters are characterized by total nitrogen (e.g., TKN) of less than 0.3 mg/L and total phosphorus of less than 0.04 mg/L. However, specifically for Class III marine waters, the criterion for total phosphorus is listed as ≤ 0.001 mg/L (FAC 62-304.530). Since the PVC is influenced by freshwater inputs, we interpret that the nutrient levels (nitrogen and phosphorus) are within or near acceptable levels. The only criterion that is clearly not met by the FDEP Class III criteria are the enterococci with a measured geometric mean of 370 MPN/100 mL in the PVC for the CMB data set. This value is higher than the Class III regulatory guideline geometric mean of ≤ 35 MPN/100 mL.

To assess environmental conditions when the enterococci levels were within regulatory limits, the CMB data set was split into a set corresponding to values when enterococci was below the 70 MPN/100 mL threshold and another set corresponding to values when enterococci was above. Results from Mann Whitney U Tests show that samples with enterococci levels below 70 MPN/100 mL, had:

- Higher salinity (p=0.30)
- Higher pH (p=0.07)
- Higher turbidity (p=0.46)
- Higher dissolved oxygen (p=0.29)
- Lower antecedent rainfall (p=0.35)
- Higher tides (p=0.29)
- Lower groundwater elevations (p=0.37)

These characteristics suggest that low enterococci levels were dominated by oxygenated and turbid marine waters of higher pH during times with minimal antecedent rain, during periods of high tide (further enhancing tidal influence), and lower groundwater elevations (with lower contributions from groundwater). Times with enterococci above 70 MPN/100 mL were characterized by fresher waters of lower pH, lower turbidity, and lower dissolved oxygen. These fresher waters were observed after rainfall conditions, when the tides were lower, and when the groundwater elevations were higher. Statistically, the parameter that was significantly associated with the 70 MPN/100 mL exceedance was pH; however, the dominance of antecedent rainfall (and secondarily salinity) in their associations with levels of enterococci should also be considered heavily (See next section).

Table II.6: Average of water quality measurements for the available period of record from CMB. Each data set was further split into samples with enterococci levels below the 70 MPN/100ml threshold (green) and levels above the 70 MPN/100ml threshold (red)

Parameter	Entire Data Set		For samples where enterococci were less than 70 MPN/100 ml		For samples where enterococci were greater than 70 MPN/100ml	
	Number of Data Points	Arithmetic mean	Number of Data Points	Arithmetic Mean	Number of Data Points	Arithmetic Mean
Enterococci (MPN/100 mL)	65	2,113 ^a	10	33	55	2,498
Fecal Coliform (MPN/100 mL)	62	266 ^{b,c}	10	79	52	303
Water Temperature (°C)	64	26.8	10	26.9	54	26.9
Salinity (psu)	64	29.4	9	31.6	55	29.0
pH	65	7.93	10	8.20	55	7.88
Turbidity (ntu)	64	4.96	9	7.25	55	4.68
Dissolved Oxygen (mg/L)	65	5.22	10	5.85	55	5.11
Nitrogen, Ammonia (mg/L)	51	0.055	6	0.056	45	0.059
Nitrogen, Nitrate + Nitrite (mg/L)	54	0.049	7	0.033	47	0.047
Nitrogen, Kjeldahl (mg/L)	58	0.32	10	0.32	48	0.32
Total Phosphorus (mg/L)	61	0.023	10	0.015	51	0.024
6-hr Rainfall (inches)	65	0.02	10	0.00	55	0.02
12-hr Rainfall (inches)	65	0.11	10	0.00	55	0.13
24-hr Rainfall (inches)	65	0.26	10	0.01	55	0.31
48-hr Rainfall (inches)	65	0.48	10	0.03	55	0.56
Tide at PVC (ft; NAVD88)	65	-0.72	10	-0.52	55	-0.75
Tide at NOAA Station (ft; NAVD88)	65	-0.35	10	-0.13	55	-0.39
Shallow Groundwater Elevation (ft; NAVD88)	24	0.09	2	-0.37	22	0.14
Intermediate Groundwater Elevation (ft; NAVD88)	37	-0.09	4	-0.16	33	-0.08
Deep Groundwater Elevation (ft; NAVD88)	35	2.67	4	2.38	31	2.7

^aEnterococci geometric mean and median for the entire CMB data set was 370 MPN/100 mL and 297 MPN/100 mL, respectively.

^bFecal coliform geometric mean and median for the entire CMB data set was 140 MPN/100 mL and 142 MPN/100 mL, respectively.

^cFecal coliform standard not currently applicable to Class III and Class III-Limited waters. Applicable currently to shellfish harvesting waters (Class II) with median values not to exceed 14 MPN/100 mL for shellfish harvesting. Fecal coliform standard applied to Class III waters prior to the end of 2016. At this prior time, the monthly average was to be ≤ 200 per 100 mL for Class III.

II.3.b Evaluation of the CMB Data Set for Correlations with Environmental Conditions

To evaluate changes between enterococci concentrations and the environmental factors, exploratory data analysis was conducted by computing Pearson's correlations and Spearman's ranked correlations for the CMB data set. Details of the correlations analysis can be observed in Figures II.3 through II.6, where all correlations, both Pearson and Spearman are plotted and shown. A summary of the correlations for enterococci is given in Table II.7. Correlations were considered significant at 95% confidence limits for p-values less than 0.05. Statistically significant Spearman correlations ($|r_s| > 0.28$, $p < 0.05$) were found between enterococci levels and salinity, fecal coliform, pH, and total phosphorus, plus 12-hour, 24-hour, and 48-hour antecedent rainfall. The

strongest relationships were observed with fecal coliform ($r_s=0.55$) and for 24-hour antecedent rainfall ($r_s=0.41$). Results for Pearson's correlation showed that statistically significant correlations ($|R|>0.26$, $p<0.05$) were found between enterococci levels and salinity, fecal coliforms, and 6-hour, 12-hour, 24-hour, and 48-hour antecedent rainfall. The strongest relationship was observed for 24-hour antecedent rainfall ($R=0.64$). It is interesting to note that a negative relationship was observed between enterococci and salinity. That is the higher the salinity, the lower the concentration of enterococci. Conversely, the lower the salinity (or higher freshwater content), the higher the concentration of enterococci.

Results from multiple linear regression further confirmed that rainfall, in particular 24-hour antecedent rainfall, was the primary parameter correlated with enterococci. Although the model was set up to evaluate multiple parameters, 24-hour rainfall was by far the parameter that contributed the most towards explaining the variability of the enterococci levels. The model developed (Equation II.1) relates P (24-hour antecedent rainfall) to enterococci levels in units of MPN/100 mL as follows:

$$\text{Enterococci (MPN/100 mL)} = 1102 + 3732 \times P \quad (\text{Equation II.1})$$

Table II.7: Correlation between the enterococci in samples collected monthly from Miami Beach (4/17/2019 – 09/30/2024) with other physical chemical parameters (water level, tide cycle, total nitrogen, total phosphorus, salinity, fecal coliforms, field specific conductance, field temperature, pH, dissolved oxygen, turbidity and cumulative precipitation [6-hour, 12-hour, 24-hour, 48-hour]) based on both Pearson's and Spearman's analysis. Yellow indicates significant correlation ("*", "**") indicates a p-value < 0.05, "***" indicates a p-value < 0.01).

		Total Nitrogen, Kjeldahl (mg/L)	Total Phosphorus (mg/L)	Salinity (ppt)	Fecal Coliforms (CFU/100 mL)	Field Specific Conductance (umhos/cm)	Field Temp. (°C)	Field pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	6-hour Rainfall (in)	12-hour Rainfall (in)	24-hour Rainfall (in)	48-hour Rainfall (in)	Water Level (NOAA, ft)
Pearson Correlation: Enterococci (MPN/100 mL)	Correlation Coefficient (R)	0.0440	0.2213	-0.3985*	0.2597*	-0.0519	-0.0652	-0.0955	-0.0104	0.0621	0.3661*	0.5770**	0.6371**	0.4788**	0.0377
	p-value	0.7405	0.0813	0.0011	0.0415	0.6815	0.6086	0.4492	0.9345	0.6259	0.0027	< 0.001	< 0.001	< 0.001	0.7655
Spearman correlation: Enterococci (MPN/100 mL)	Correlation Coefficient (Rs)	0.0178	0.3173*	-0.3760*	0.5496**	-0.0890	0.0312	-0.2915*	-0.0886	-0.0089	0.2218	0.3360*	0.4084**	0.3744*	-0.0595
	p-value	0.8931	0.0113	0.0022	< 0.001	0.4806	0.8064	0.0185	0.4828	0.9445	0.0758	0.0062	< 0.001	0.0021	0.6377
Sample size		58	61	64	62	65	64	65	65	64	65	65	65	65	65

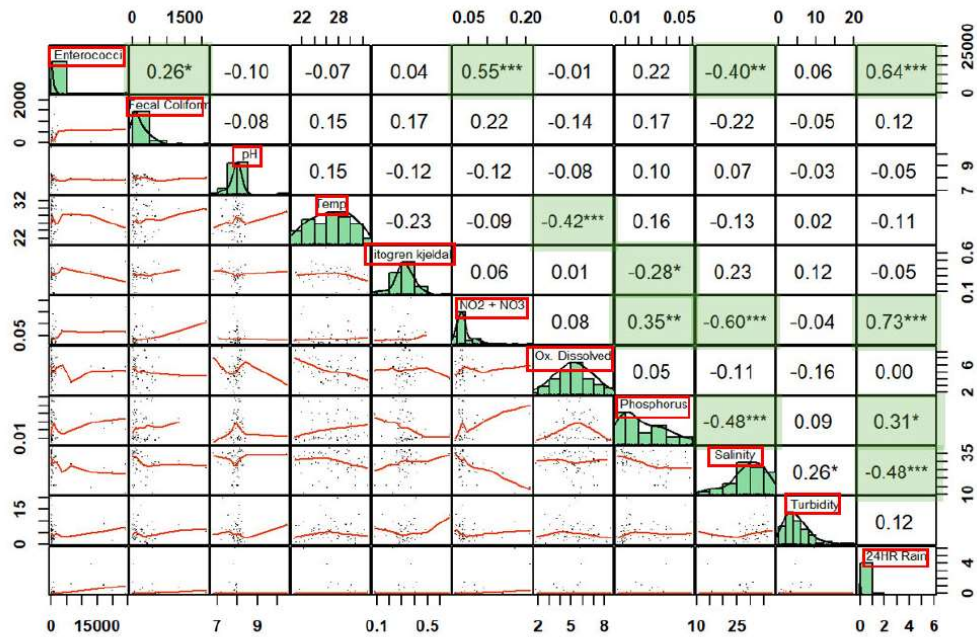


Figure II.3: Correlation plot (Pearson) between enterococci and environmental factors for the CMB data set. Green shading indicates correlations that were statistically significant.

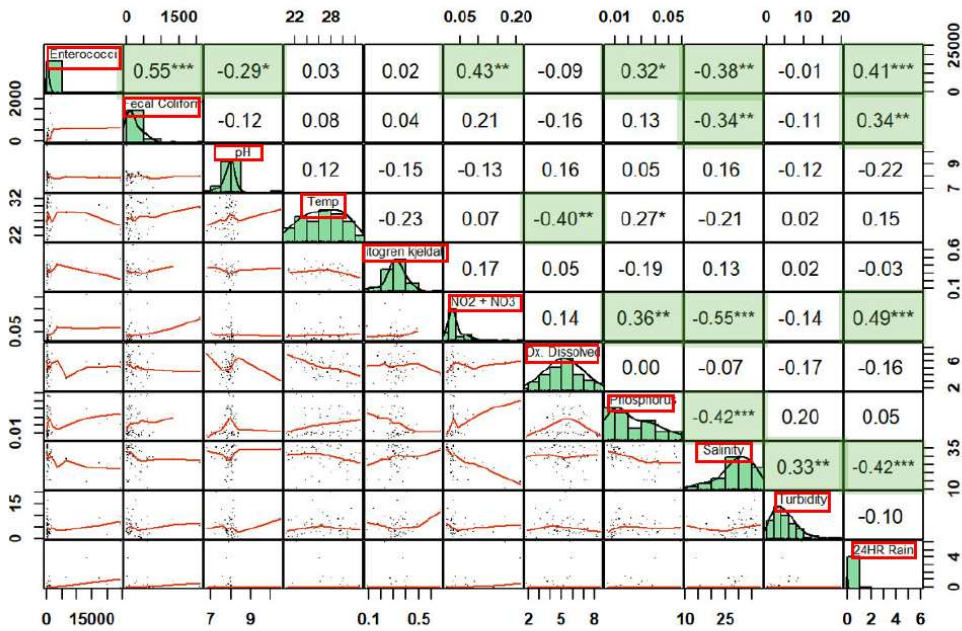


Figure II.4: Correlation plot (Spearman) between enterococci and environmental factors for the CMB data set. Green shading indicates correlations that were statistically significant.

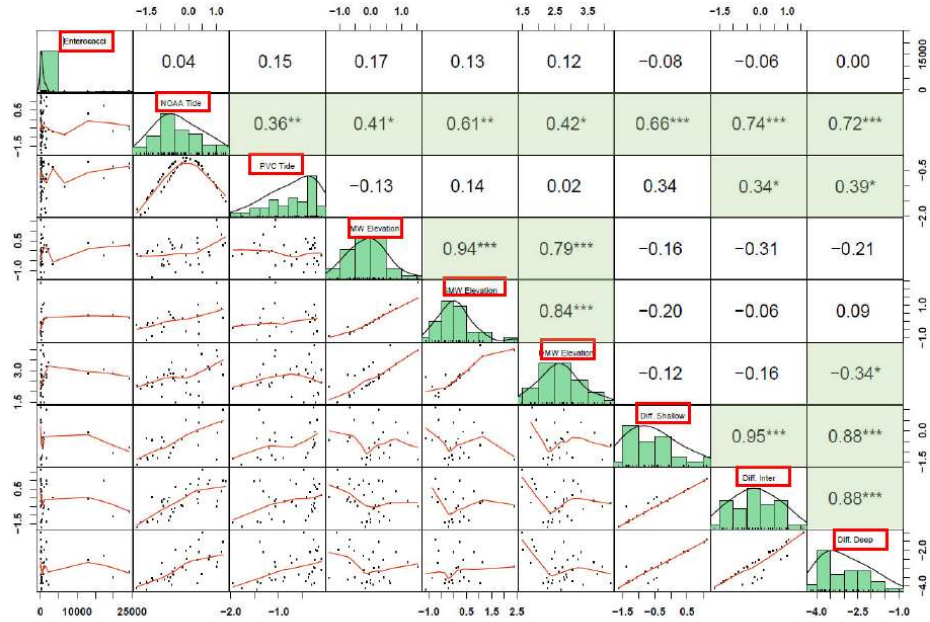


Figure II.5: Correlation plot (Pearson) between enterococci and water elevation data for the CMB data set. Green shading indicates correlations that were statistically significant.

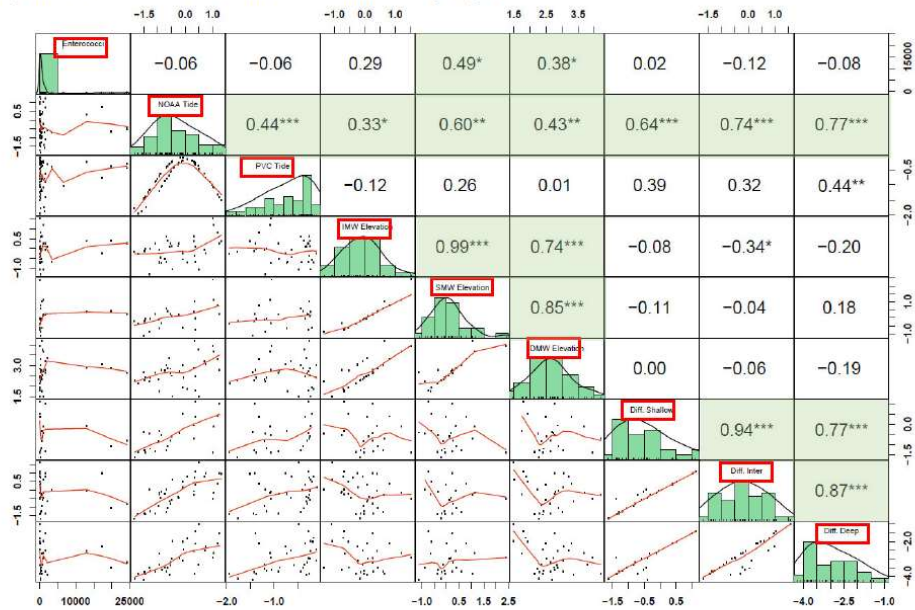


Figure II.6: Correlation plot (Spearman) between enterococci and water elevation data for the CMB data set. Green shading indicates correlations that were statistically significant.

CHAPTER III

**ANALYSIS OF THE
STORMWATER CONVEYANCE SYSTEM**

CHAPTER III

ANALYSIS OF THE STORMWATER CONVEYANCE SYSTEM

The analysis of the stormwater conveyance infrastructure focused on analyzing the conditions during which it would be inundated with water. These conditions included being inundated by water from the PVC, specifically during high tide, and being inundated by groundwater. Direct measurements of groundwater were available through the CMB as described in prior Section II.2 with summary data in Table II.6. However, there were no direct measurements of water level in the PVC. Due to the lack of measurements, a relationship was developed between the tidal height at the PVC and the tidal height as documented by the NOAA tidal station located at Virginia Key at Bear Cut (Section III.1). Once the water elevations were estimated, they were superimposed on an image of the stormwater conveyance system showing the extent to which it is inundated during different tidal and groundwater conditions (Section III.2).

III.1 ESTIMATES OF PVC WATER SURFACE ELEVATIONS

To establish a relationship between water surface elevation at the NOAA tidal station and the PVC, a benchmark was needed. This benchmark was installed by M.G. Vera and Associates (Mark Sowers) in collaboration with TYLin (Jeffrey Marcus) during the week of August 5, 2024. The benchmark is located on a piling (southwest corner) of the Kayak Launch (Figure III.1). The elevation of the benchmark is 3.00 feet referenced to the National American Vertical Datum of 1988 (NAVD88). This benchmark has since been used to measure the elevation of the PVC water surface by measuring the vertical distance from the benchmark to the water's surface. Measurements of PVC water surface elevation were taken hourly from 6:00 am to 5:00 pm on August 15, 2024. Additional spot checks were made on August 6, 2024, at 11:00 am, 1:00 pm and 3:15 pm and on September 19, 2024, at 2:45 pm and at 4:07 pm.



Figure III.1: Benchmark established at the Kayak Launch of the PVC showing the elevation as 3.00 feet NAVD88. Benchmark and photos courtesy of M.G. Vera and Associates and TYLin.

During the hourly surface elevation measurements on August 15, 2024, low tide at the PVC occurred between the 12:00 noon and 1:00 pm measurement period. To interpolate for the exact timing of low tide, a fifth order polynomial was fit to the tidal curve. The extreme low tide at the PVC was estimated to be at 12:20 pm. This was compared to the time of extreme low tide at the NOAA station (12:06 pm). Results of this comparison showed that the timing of the PVC low tide was offset from the NOAA station by 14 minutes (low tide at the PVC is 14 minutes after low tide at the NOAA station). The analysis conducted during the 2022 study found that the offset was 17 minutes. For consistency with the 2022 study the offset of 17 minutes was used again.

Once the data were adjusted for the timing offset, the elevation of the PVC was plotted in time series against the elevation of the NOAA tidal station (Figure III.2). From this plot, an offset in elevation was observed where the measured elevation at the PVC during low tide was lower than the measured elevation at NOAA during low tide (Figure III.2). After testing a few models, the data were fit using four relationships as follows (Table III.1):

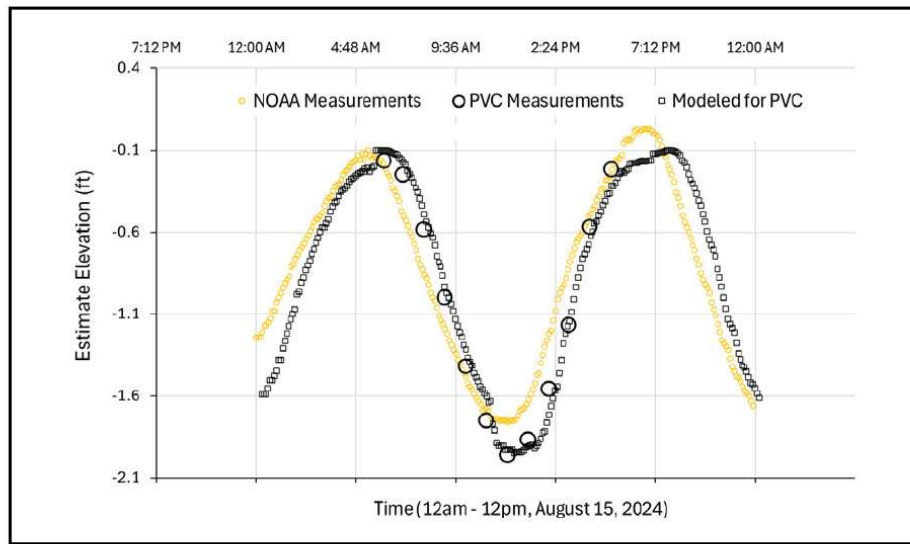
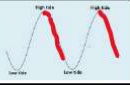
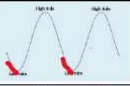
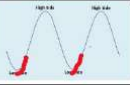
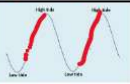


Figure III.2. Elevation at the NOAA Station at Bear Cut on Virginia Key versus Measured and Modeled Elevation at the PVC.

Table III.1: Model developed to estimate PVC water elevation from measured elevations at the NOAA station on Bear Cut at Virginia Key.

Tide Condition	Illustration	Type of Curve	Equation ^a
high tide to one hour before low tide		Sine	$y=0.9 \sin(-1.5x + 1.4) - 1$
one hour before low tide to low tide		Polynomial	$y = -0.5561x^2 + 0.0635x - 0.112$
low tide to one hour after low tide		Polynomial	$y=0.439x^2 + 2.0209x + 0.2483$
one hour after low tide to high tide		Sine	$y=0.9 \sin(-1.67x+1.7) - 1.06$

^aIn these equations, x is the tidal elevation at NOAA at time t minus 17 minutes and y is the modeled elevation at the PVC at time t .

To check the accuracy of the elevation model for PVC water surface elevation, the results of the model were checked against water elevations measured on August 6 and September 19. Results show the model has variable performance against the independent data points. The accuracy of the PVC elevation estimate varies between 0.08 and 0.60 feet. Future work is recommended to develop a better model, one based upon minute-by-minute water level elevations at the PVC using an automated water level data logger over the course of several months. The availability of a larger data set for calibration and verification would allow for the development of a more robust model.

Using the model described in Table III.1, PVC water surface elevations were estimated for the CMB data set and for the Surfrider data set (Table III.3). Data analysis indicates that the mean elevation of the PVC was -0.73 feet NGVD88 with a maximum of -0.10 feet and a minimum of -1.95 feet.

To complete the analysis, mean groundwater elevations were also computed. The mean groundwater elevation for the shallow well was -0.05 feet with a maximum of 2.40 feet and a minimum of -1.23 feet. These elevations were used in the next section to assess the inundation of the stormwater system.

Table III.2: Results from applying the model to estimate PVC water surface elevations using an independent set of water level measurements

Date	Time	Elevation Measured at the PVC (ft NAVD88)	EBB or FLOOD at NOAA	Modeled Elevation (ft NAVD88)	Difference (ft)
Aug. 6, 2024	11:00 AM	0.33	FLOOD	-0.19	0.53
	1:00 PM	0.00	EBB	-0.10	0.10
	3:15 PM	-1.00	EBB	-1.08	0.08
Sep. 19, 2024	2:45 PM	0.33	EBB	-0.27	0.60
	4:07 PM	-0.38	EBB	-0.32	-0.05

Table III.3: Descriptive statistics of PVC water surface, NOAA station water surface, and groundwater elevations at the Parkview Park monitoring stations. All elevations in feet, NGVD88

Station	Arithmetic Mean	Min.	10%	25%	75%	90%	Max.
PVC	-0.73	-1.95	-1.51	-1.09	-0.27	-0.16	-0.10
NOAA Tidal Station	-0.29	-1.85	-1.33	-0.96	0.35	0.79	1.79
Groundwater, Shallow Well	-0.05	-1.23	-0.99	-0.61	0.25	0.79	2.40
Groundwater, Intermediate Well	-0.30	-1.61	-1.08	-0.75	0.09	0.43	1.53
Groundwater, Deep Well	2.76	1.49	1.92	2.40	3.14	3.47	4.20

III.2 INUNDATION OF THE STORMWATER CONVEYANCE SYSTEM

Inundation corresponds to areas of the stormwater conveyance system where the inverts of the stormwater pipes are below the groundwater or PVC tidal elevations. If the stormwater pipe invert elevation is below the groundwater, it can potentially skim the upper layers of the groundwater towards the PVC when the hydraulic gradients are in favor of flow towards the PVC. Similarly, if the stormwater pipe invert elevation is below the PVC water level, it can carry water from the PVC back into the groundwater system when hydraulic gradients favor flow towards the landside or interior of the stormwater conveyance system. In other words, depending upon the elevation of the stormwater conveyance system, inverts relative to groundwater and PVC tidal levels, water will move back and forth through the stormwater conveyance system resulting in an exchange between PVC water and groundwater.

The area contributing stormwater to the PVC (81.3 acres or 329,000 m²) extends from 76th Street including most of the Biscayne Beach Elementary School property on the north, 72nd Street to the south, the entirety of Parkview Island to the west, and Collins Avenue to the east (Figure III.3). The analysis of the pipe inverts of the stormwater conveyance system began with an analysis of information available from the City of Miami Beach Geographic Information System (GIS). The GIS data was then augmented with elevations available through construction drawings of the stormwater conveyance system (Details in Appendix B). For sites with no elevation data by GIS nor construction drawings, the CMB surveyed the invert elevations of the pipe outlets that lead to the PVC. A summary of the pipe invert elevations (Figure III.4) shows that the inverts of pipes contributing directly to the PVC vary from +1.0 to -4.6 feet NGVD88.

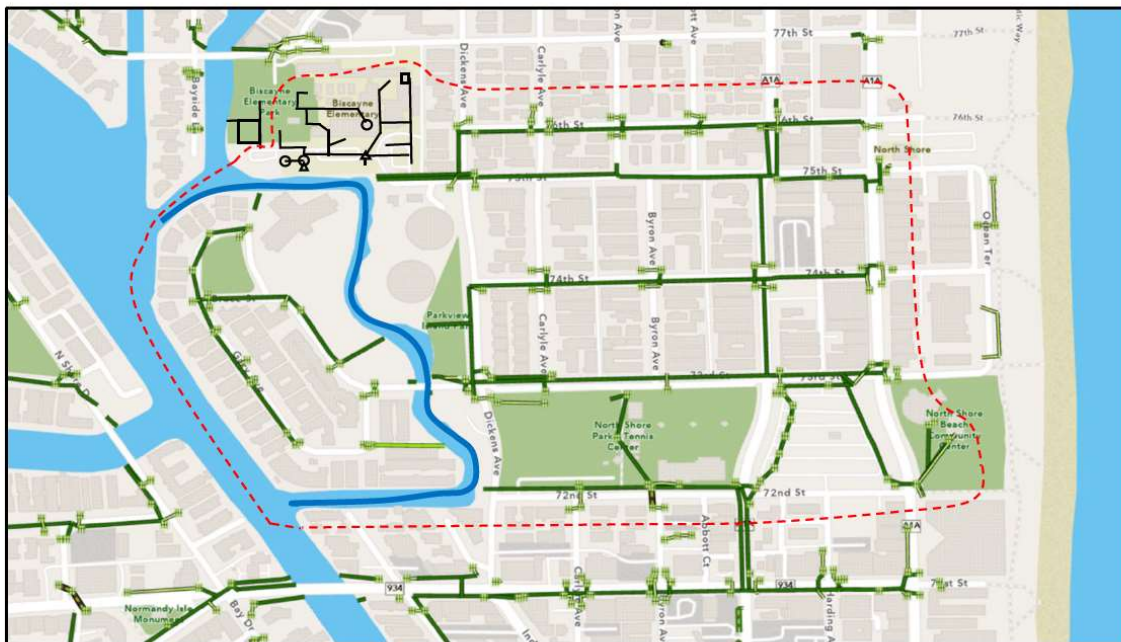


Figure III.3: Stormwater conveyance system contributing to the PVC. The PVC is shown with a dark blue line. The stormwater catchment area is shown in dashed red line. Stormwater conveyance system in green from Miami Beach Geographic Information System along with hand drawing of stormwater infrastructure at the Biscayne Beach Elementary School in black.

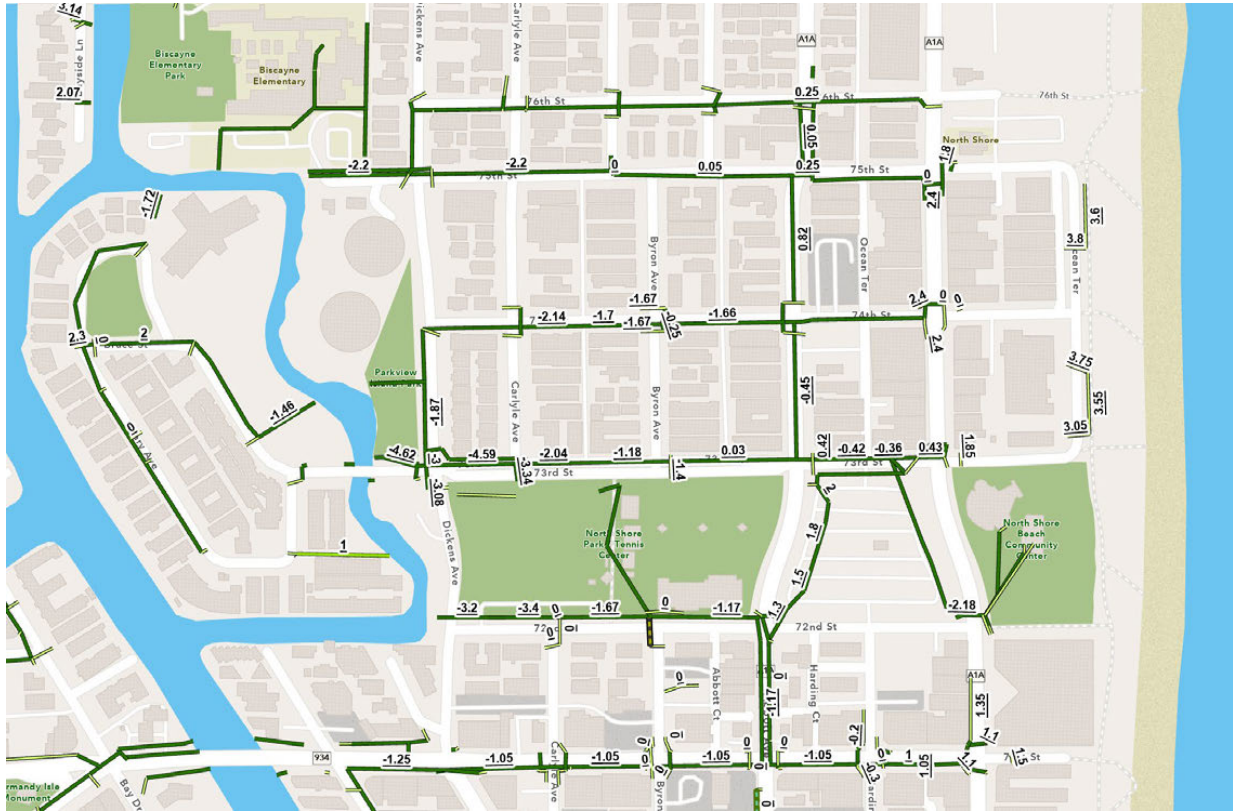


Figure III.4: Storm conveyance system emphasizing elevations (feet NGVD88) of pipe inverts.

The information documenting pipe inverts of the stormwater conveyance system was combined with average elevations of the groundwater (shallow well) at the PVP station and the tide at the NOAA station. This was done to determine areas of stormwater conveyance system inundated during periods of varying from 10% to 90% of the groundwater elevations (Figure III.5) and of the tidal elevations (Figure III.6). The elevation of the tide at the NOAA station was chosen over the modeled tide at the PVC due to the need to establish a more robust model for the tide at the PVC. The result of this analysis shows that most of the stormwater conveyance system is inundated by groundwater and from the tides. The eastern limits of the conveyance system impacted by inundations extends farther east during periods of high groundwater and during periods of high tide.

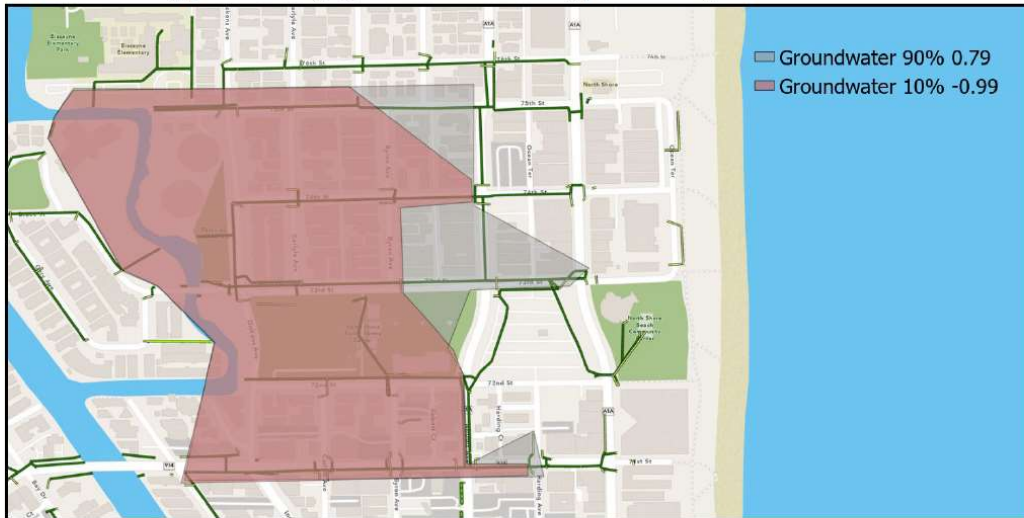


Figure III.5: Stormwater conveyance system with areas of groundwater inundation shown during the lowest 10% elevation (-0.99 ft NGVD) and the highest 90% elevation (0.79 ft NGVD).

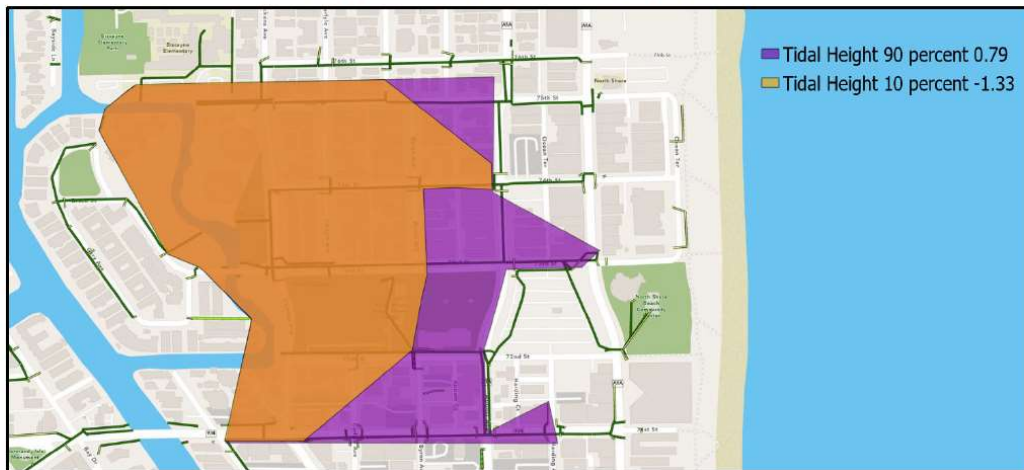


Figure III.6: Stormwater conveyance system with areas of tidal inundation shown during the lowest 10% elevation (-1.33 ft NGVD) and the highest 90% elevation (0.79 ft NGVD). The reference for the tidal data is the NOAA station located on Virginia Key at Bear Cut.

III.3 SANITARY SEWER SYSTEM

In addition to the stormwater conveyance system, another source of fresh water within the watershed is sanitary sewage. The eastern portion of the watershed, the portion corresponding to the main island of Miami Beach, serves as a transmission pathway of sanitary sewerage from northern areas of Miami Beach and Miami Dade County. The area includes a 16-inch force main that runs along the northern leg of the PVC, and a pump station at the end of 75th Street near Dickens Avenue. From the pump station, the force main continues (24 inch) along Dickens Avenue, and heads east along 73rd Street. Another 36-inch force main runs between Harding and Collins Avenue with an intricate series of cross connections below the parking lot located between 72nd and 73rd Street and Harding and Collins Avenues. This intricate network is near the historic ocean outfall (36 inch) that is no longer in service that runs east along 74th Street towards the ocean.

In addition to the force mains along the eastern side of the watershed, all the residential and commercial buildings are serviced by gravity sewer mains. The sanitary sewage from all buildings within Parkview Island flow by gravity (6-to-8-inch lines) towards the northeast side of the island with a siphon crossing below the depths of the PVC toward 75th Street. On the east side of the watershed on the Miami Beach main island, the gravity sewer lines (6-to-8-inch lines) predominantly run north south except for a gravity main (12-to-18-inch lines) which run east west along 75th Street.

Citywide assessment and rehabilitation of sanitary sewer was prioritized in the Parkview Island area and North Beach because of the water quality issues. The public portion of the gravity systems have been inspected and both gravity pipes and manholes have been lined to stop exfiltration to groundwater starting 2023 and completed by late 2024. Laterals in the public portion have been inspected and were found in good condition while the laterals on private property upstream of the public system have not been inspected due to the City's lack of authority on private property. Aged and outdated lateral materials on private property can present a source of leakage to groundwater. Sewer Pump Station no. 23 wet well located at 75th Street and Dickens was rehabilitated to stop exfiltration November 2024. It is recognized that the force mains are aged with susceptibility to leakage. The potential for leakage is continuously monitored by the City of Miami Beach through an existing system (Supervisory Control and Data Acquisition, SCADA) that documents for pressure differentials. Also, the CMB (through a consultant, Utilities Services Associates) recently completed (as of September 20, 2024) a more sensitive analysis based upon acoustics and sonar. This study showed no leaks in the sanitary sewer force main system. An image of the sanitary sewer system super-imposed on the stormwater conveyance system shows many overlaps (Figure III.7). However, no leaks have been detected so far within CMB property.

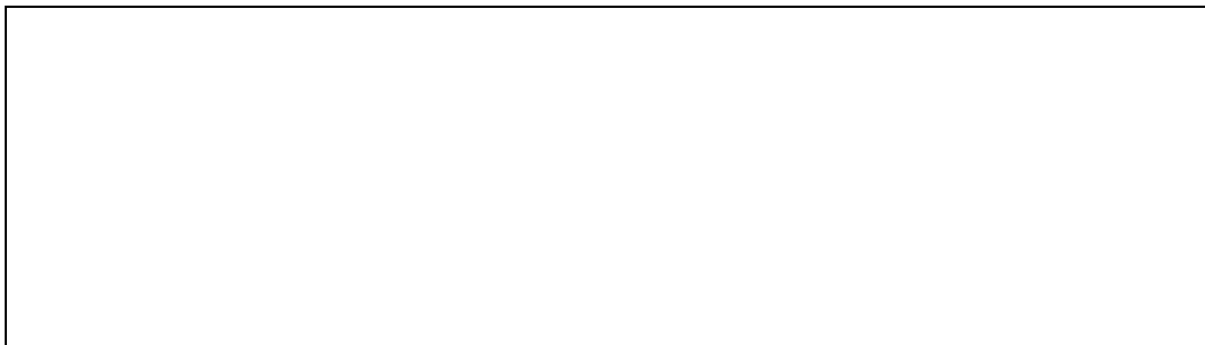


Figure III.7: Stormwater conveyance and sanitary sewer system overlay showing crossings between the stormwater and sanitary sewer. **This image was retracted due to the inclusion of sewer system details which is restricted for distribution.**

CHAPTER IV

ANALYSIS OF ENTEROCOCCI IN GROUNDWATER, STORMWATER, AND WITHIN THE PVC CANAL

CHAPTER IV

ANALYSIS OF ENTEROCOCCI IN GROUNDWATER, STORMWATER, AND WITHIN THE PVC CANAL

Sampling efforts included: 1) groundwater sampling (Section IV.1), 2) stormwater sampling (Section IV.2), and 3) sampling within the PVC Canal (Section IV.3). Combined results are provided in Section IV.4. Sampling within the PVC included intense temporal and depth sampling at the Kayak Launch and sample collection at the stormwater outlet of the BBE. Section IV.5 puts the results from the stormwater and PVC samples in the context of the literature.

The timeline for sample collection efforts superimposed on the rainfall record is illustrated below (Figure IV.1). Groundwater sampling and first day of runoff sampling (last half of July) corresponded to a relatively dry period. Day 2 through Day 7 stormwater sampling efforts corresponded to variable size storms. The hourly sampling at the Kayak launch was preceded by a six-day dry period with rainfall occurring at the very end of the sampling event. BBE canal samples were collected interspersed throughout the sampling period.

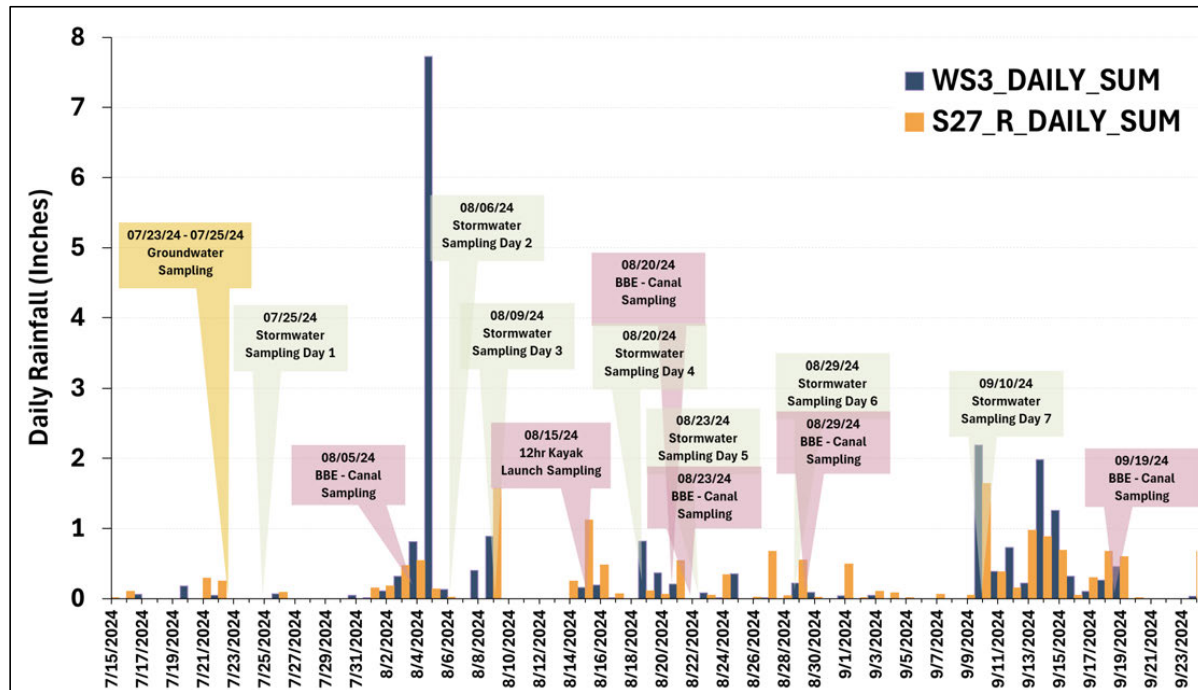


Figure IV.1: Sample collection timeline superimposed on daily rainfall record. Bars correspond to daily rainfall totals with the dark blue bar corresponding to the City of Miami Beach rain gauging station (WS3) and the orange bar corresponding to the South Florida Water Management District rain gauging station (S27_R).

For this study, all samples were collected in either sterilized polypropylene bottles or pre-sterilized Whirlpak bags. One liter of water was collected per site. Upon collection, water temperature was taken using a hand-held laser thermometer (MT Raytek®). Samples were returned immediately to the laboratory for processing the same day. A detailed listing of which samples were collected which day is provided in Table C.1 in Appendix C. Upon receipt at the laboratory samples were split three ways (Figure IV.2).

- **One split (either 10 mL or 1 mL) was used for enterococci analysis.** All enterococci analyses were performed using chromogenic substrates (Enterolert, IDEXX Industries), a standardized well system (Quantitray-2000), and incubation temperatures consistent with enterococci measurements (41.5 °C for 24 hours \pm 2 hours). Trays were checked for fluorescence at two time points (24 hours and at 26 hours for confirmation of lightly fluorescing wells). Results from these analyses are provided in units of Most Probable Number (MPN). The chromogenic substrate and Quantitray approach were chosen because it provides the broadest range of detection (from 1 to 2419.6 counts) for a single analysis, thereby increasing the chances of direct measurements of enterococci concentrations. In addition, it is the same approach used for the CMB and Surfrider data sets. In this study, dilutions of 10:1 were preferentially used early during the study thereby providing analytical ranges between 10 and 24,196 MPN per 100 mL. However, starting on August 20, 2024, the dilutions were changed to 100:1 given that the stormwater samples consistently showed values above 24,196 MPN per 100 mL. At a dilution of 100:1, the range of quantification corresponded to <100 to 241,960 MPN/100 mL.
- **The second split was utilized to prepare an “MST” filter** (Pall GN-6, 47 mm diameter, 0.45 μ m pore size). A subset of these filters (n=78) was then chosen for MST analyses. These filters were processed aseptically by vacuum filtration using sterilized re-usable magnetic filter holders. Sample filtration volumes varied from clogging (80 mL minimum) up to a maximum of 500 mL. Once the samples were filtered, the filters were folded 4 times and placed into pre-labeled presterilized 5 mL centrifuge tubes (Eppendorf) containing 1.5 mL of lysis buffer to preserve the sample (DNA/RNA Shield, Zymo Research Corp.). The filters were then placed in a -80 °C freezer until delivery to the laboratory that processed the samples for MST (National Oceanic and Atmospheric Association Atlantic Oceanographic and Meteorological Laboratory, NOAA-AOML, led by Drs. Christopher Sinigalliano and Maribeth Gidley).
- **The third split was processed for basic physical-chemical analyses.** Sample pH, salinity, and dissolved oxygen were measured using a pre-calibrated water quality sonde (YSI ProDSS). Turbidity was measured using a nephelometer (Turner Designs) calibrated with 2 and 20 nephelometric turbidity units (NTU) formazin standards.

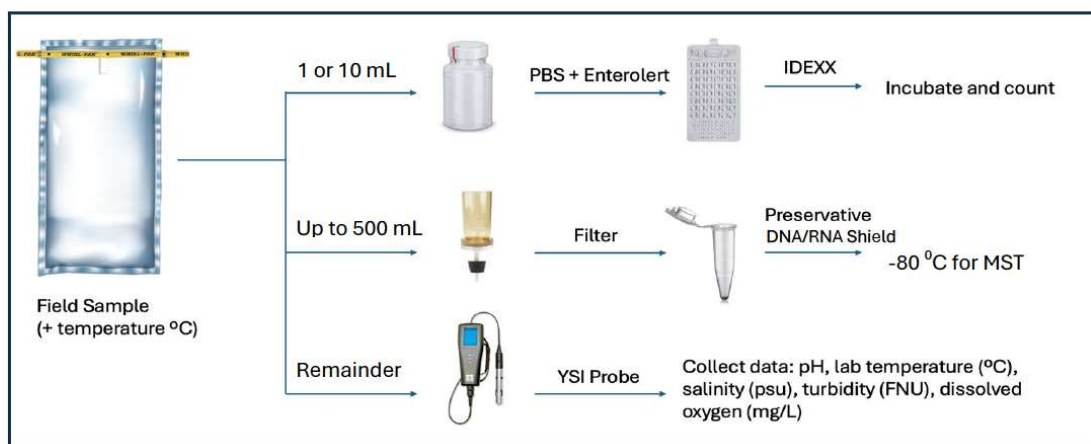


Figure IV.2: Sample splitting protocol to accommodate enterococci analysis, filters for MST, and physical-chemical analysis of water samples.

Statistical analysis of the data was based upon two tests, the Kruskal Wallis Test which compares the medians between two or more groups of samples (e.g., in-person runoff, field-staged bottle, versus puddles) and the Mann Whitney U Test which compares medians between two groups only. Groups of data were considered statistically different for p values less than 0.05.

IV.1 GROUNDWATER

Groundwater sample collection was facilitated through the drilling of shallow groundwater wells using direct push technology. The company contracted for the well drilling (JAEE Environmental Service Inc) uses a retractable groundwater sampler mounted on the back of pickup truck. The groundwater sampler is decontaminated between each use by flushing with clean tap water. To collect samples, the groundwater sampler (diameter of 1 and $\frac{3}{4}$ inches) is drilled to a depth 1 foot below the groundwater's surface. Upon reaching the 1-foot groundwater depth the sampler and drive rods are pulled back to expose the screen (0.007 slot size) allowing for groundwater collection from the upper 1 foot. The upper 1 foot was chosen as prior studies showed that the upper layers of the water in the stormwater conveyance system had the highest levels of enterococci. A new 3/8-inch diameter tubing was placed inside the sampler and groundwater was then pumped using a peristaltic pump for 5 minutes to allow for clearing of the well. After the purge cycle, 1 L of groundwater sample was collected into pre-sterilized and pre-labeled polypropylene bottles. Samples were placed immediately within a cooler on ice and transported to the laboratory at the end of each collection day for immediate processing.

The original goal was to collect 8 to 12 groundwater samples. However, the UM research team decided to extend the sample collection program to select 31 sites (Figure IV.3). Sites were selected to obtain a uniform distribution of groundwater throughout the contributing watershed. Some sites were located near gravity sewer systems (site names start with the letter G), some were located near force mains (site names start with the letter F), and some sites were located near stormwater conveyance systems (site names start with the letter R). Upon the selection of the sites, efforts focused on identifying the underground utilities. This required "white lining" a 15 by 15-foot area of the site where drilling was to take place. Upon white lining the areas, the County 811 underground utilities hotline was contacted and given the site locations so that all utility contractors in the area could visit the site and mark the location of the underground utilities. After the marking of the utilities through 811, a contractor through the well drilling company performed ground penetrating radar of the sites using both handheld and roller units to confirm the location of the underground utilities and identify specific areas (within a 1-foot diameter) that were clear for drilling. Among the 31 sites evaluated, only 26 were deemed to have enough clearance from utilities to allow for safe drilling. Details about each sample location including photos are provided in Appendix C.

In addition to utilities identification, a right-of-way permit was requested and granted (RWP0724-12376) to temporarily block traffic during the well drilling process. The local community was informed of planned activities through the CMB's Constant Contact notification system. Ground penetrating radar was conducted on July 22, 2024. Groundwater sample collection occurred over a period of 3 days, on July 23, 24, and 25. During these days samples were collected from all 26 viable groundwater drilling sites.

Enterococci levels for the 26 groundwater samples ranged from below the lower detection limit (<10 MPN/100 mL) to above the upper detection limit ($>24,196$ MPN/100 mL). The arithmetic and geometric means were 1,100 and 61 MPN/100 mL, respectively. The median was 68 MPN/100 mL (Table IV.1). Given the large range of enterococci in the groundwater samples, outlier statistical tests were conducted including the Rosner test and the Q-test. The Rosner test evaluates outliers by comparing the data point in question relative to the mean. The Q-test evaluates outliers by comparing the data point in question relative to the maximum and minimum value. For both statistical tests, four outliers were identified. The outliers were F7 ($>24,196$ MPN/100 mL), F9 (1,337 MPN/100 mL), F1 (794 MPN/100 mL), and G17 (761 MPN/100 mL).

The spatial distribution of the data indicates a groundwater outlier (hotspot) at the end of 75th Street near the drop off area of the BBE (site F7). The three additional outliers extend from east to west along 73rd Street. The easternmost outlier is located under the parking lot between 72nd and 73rd Street and between Harding and Collins Avenue (site F1), a location with considerable underground sanitary sewer infrastructure. Additional hotspots were found at 73rd Street and Dickens (site F9), and at 73rd Street and Wayne Avenue (site G17) (Figure IV.3). Visual inspection of the distribution of enterococci in groundwater suggest both low and high levels of

Table IV.1: Enterococci levels for the UM samples (MPN/100ml) including groundwater, stormwater, and PVC canal samples. Since two dilutions were used resulting in different levels of detection, data were analyzed two different ways called “All” and “Within Detection Limits (DL)”. For “All”, which considers all samples, samples analyzed using a 1 mL dilution and measuring at values greater than 24,196 MPN/100 mL were set to >24,196 MPN/100 mL so that all samples have the same frame of reference in terms of the upper detection limit. For “Within DL”, only samples were considered that were within upper detection limits. All samples that were <10 MPN/100 mL were set to 10 MPN/100 mL for computation purposes.

	<i>N</i>	Min	Max	Median	Avg.	Geo Mean.	Std. Dev	Coeff Var.
Groundwater	26	< 10	>24,196	68	1,101	61	4,721	4.3
PVC at BBE Outfall	7	740	198,630	2,720	33,096	5,508	73,232	2.2
Runoff								
<i>In-Person (All)</i>	67	740	>24,196	>24,196	18,644	14,996	8,025	0.4
<i>In-Person (within DL)</i>	46	740	241,960	22,030	66,968	27,426	77,048	1.2
<i>Puddles (All)</i>	29	861	>24,196	>24,196	18,922	15,259	7,704	0.4
<i>Puddles (within DL)</i>	20	861	173,290	24,196	30,650	18,131	35,858	1.2
<i>Field-Staged Bottles (All)</i>	11	443	>24,196	>24,196	17,221	12,502	8,742	0.5
<i>Field-Staged Bottles (within DL)</i>	7	443	24,196	19,863	16,188	11,337	8,922	0.6
<i>Overall (All)</i>	113	443	>24,196	>24,196	18,982	15,236	7,902	0.4
<i>Overall (within DL)</i>	79	443	241,960	19,863	55,633	22,365	68,666	1.2

IV.2 STORMWATER

Stormwater samples were collected throughout the catchment using one of three methods. All three methods of sample collection focused on collecting samples at street level prior to entering the stormwater conveyance system. By collecting the samples at street level, we were able to eliminate potential groundwater contributions from samples collected underground from catch basins and stormwater conveyance pipes. The three methods of stormwater sample collection are referred to as:

- **In-person runoff samples.** These are samples collected at the inlet to stormwater catch basins during active rainfall events. During any rain event, up to 8 consecutive samples were collected. Sample collection during active rainfall required the removal of the manhole cover or grate to allow for access to the stormwater as it was falling from the street into the catch basin. This sample type required that the sampling team remain on-site prior to and during a rain event. A total of 67 in-person rain samples were collected.
- **Field-staged bottle samples.** These are samples collected by placing a bottle, tied to a chain, immediately under the grate of the storm drain. Not all storm systems were fitted with grates. This type of sampling allowed the research team to place bottles under grates during the morning prior to a rain event, and then collection of the field-staged bottle sample after the rain event later that same day. A total of 11 field-staged bottle samples were collected.
- **Puddle samples.** Puddle samples are samples of standing water that are collected immediately after a rain event. They represent water that can be potentially carried to the stormwater catch basins. A total of 29 puddle samples were collected.

Stormwater samples were collected during 7 different sampling days. Sampling dates were determined based upon weather forecasts. Days with high probability of forecasted rainfall were chosen for sample collection. Details about the location, sampling date, and sample collection method for each stormwater sample collected is provided in Appendix C.

Results show that all stormwater samples, regardless of sample collection method, were characterized by elevated levels of enterococci (Table IV.1, Figure IV.4). The medians and geometric means of in-person runoff samples, field-staged bottle samples, and puddle samples were all in the tens of thousands of MPN/100 mL. The enterococci levels between these different methods of sample collection were not statistically different ($p = 0.95$). Discussions that follow, therefore describe the stormwater enterococci results for all three sampling methods combined. Overall, the minimum enterococci concentration observed was 443 MPN/100 mL, with a maximum of >241,960 MPN/100 mL. The arithmetic and geometric mean for all samples collectively was 55,600 and 22,400 MPN/100 mL. The median was 19,900 MPN/100 mL. The levels of enterococci observed in the stormwater were statistically higher than the levels observed in groundwater ($p < 0.001$). The distribution of elevated enterococci in stormwater was uniform throughout the catchment. The levels observed on Parkview Island were not statistically different than the levels observed to the east on the main island of Miami Beach ($p = 0.86$).

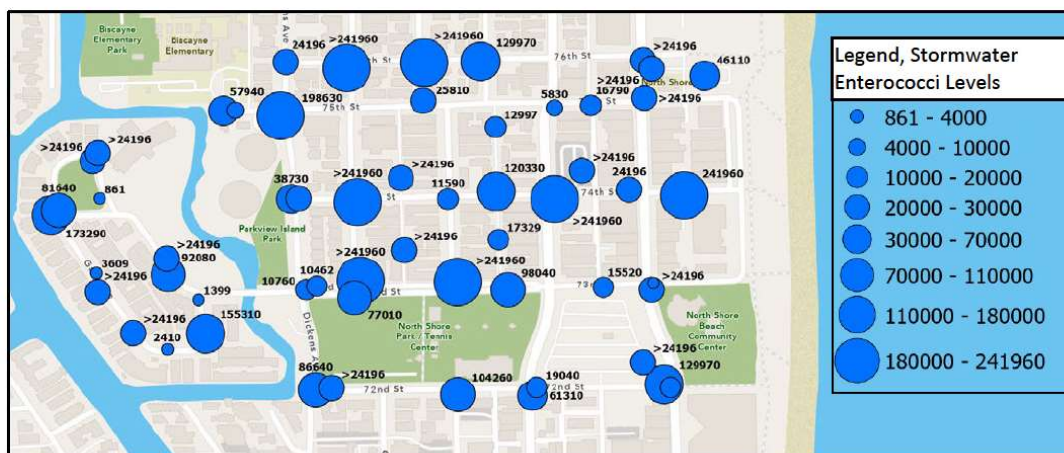


Figure IV.4: Spatial distribution of enterococci levels in stormwater samples. The sizes of blue circles are proportional to the enterococci levels.

IV.3 WATER FROM THE PVC

Two sets of samples were collected from the PVC. The first set of samples collected from the PVC corresponded to hourly samples collected at the Kayak Launch on August 15, 2024 (Section IV.3.a). Hourly sampling was conducted from 6:00 am to 5:00 pm at three depths, at the surface, at 1-foot depth, and at 5-foot depth. Samples at 1- and 5-foot depths were collected using a peristaltic pump with new dedicated tubing fitted with a weighted nozzle which drew water at the designated depth. Samples collected at the Kayak Launch were labeled with a “KS”, “KO”, and “KF”, representing surface, 1-foot, and 5-foot depths, respectively, followed by a number representing the hour during which the sample was collected. A total of 35 samples were collected at the Kayak Launch. One sample at the 5-foot depth could not be collected. Results from this (2024) hourly sampling effort were compared to the hourly sampling effort conducted during the 2022 study to evaluate differences in water quality.

The second set of samples from the PVC were collected from a large (24 inch) outfall which corresponded to the stormwater system that drains the BBE property (Section IV.3.b). The attention drawn to this outfall was due to high levels of enterococci in groundwater from site F7 (BBE school drop off area). Samples collected from the PVC near the BBE outfall were labeled “CS” followed by a number corresponding to different dates of sample collection (e.g., C1 to C7 collected from August 5 to September 19, 2024). A total of 7 samples were collected at the water’s surface from the PVC at the BBE outfall.

IV.3.a Results from sampling at the Kayak Launch

For the UM data set, results show similar median values (216 to 388 MPN/100 mL) regardless of sampling depth (Table IV.2) ($p=0.17$). However, the arithmetic average is highest for the samples collected at the surface (1,381 MPN/100 mL) compared to those collected at 1 foot (249 MPN/100 mL) and at 5 feet (690 MPN/100 mL). Similarly, the geometric means were highest at the surface (423 MPN/100 mL) compared to those at 1 foot (180 MPN/100 mL) and at 5 feet (393 MPN/100 mL). Overall, the enterococci levels at the surface of the PVC were characterized by high variability (standard deviation of 2,620 MPN/100 mL) compared to the variability at lower depths (<180 MPN/100 mL). The variability was statistically higher at the surface compared to the variability at depth ($p<0.001$) based upon the Levene’s test which was used to compare the standard deviation values.

The values observed for the UM data set were consistent with those observed within the CMB and Surfrider data sets (Table IV.2). The medians of all three data sets were in the 200 to 400 MPN/100 mL range ($p=0.35$). Similarly, the geometric means were in the 300 to 370 MPN/100 mL range. The arithmetic averages observed in the UM data set were lower than the arithmetic averages observed for the CMB and Surfrider data sets (690 MPN/100 mL compared to 2,100 and 2,500 MPN/100 mL). This may be because of the dry conditions (six prior days with no rain) preceding the UM sampling date, reducing the influence of stormwater within the PVC.

The hourly time series (Figure IV.5) emphasizes the variability of the enterococci levels at the water’s surface. Enterococci levels were highest at the surface during the early morning and late afternoon hours, and the lowest in the early afternoon. We attribute this trend to solar radiance effects where the heat and UV light from the sun inactivated the enterococci at the water’s surface, whereas water at greater depth was not as impacted by sunlight allowing the enterococci to remain at constant levels. Pearson correlations were evaluated between enterococci levels and sample elevation separated by surface, 1-foot, and 5-foot depths. Results show statistically significant correlations for the surface and 1-foot samples. When evaluating correlations with solar radiance, significant correlations were observed for the 5-foot samples only.

The reason for the very elevated levels at the surface is possibly due to buoyancy effects with freshwater (from stormwater runoff) floating over the saltier water (as documented during the prior study conducted during 2022,

Montas et al. 2023). As reported in Section IV.2, stormwater runoff has elevated levels of enterococci. Towards the end of the hourly sampling period, from 3:45 pm to 4:30 pm, 0.18 inches of rainfall were measured from a rain gauge brought to the Kayak Launch site. The increase in enterococci during the 4 pm and 5 pm periods may be associated with some stormwater entering the PVC from this small rainfall event. However, it is uncertain whether this small amount of rainfall was sufficient to induce flow from the streets towards the catch basins. Alternatively, the increase in enterococci bacteria can be possibly due to “rebounding” at the surface due to less intense solar radiation towards the later hours of the afternoon. When considering both sample elevation and solar radiance, correlations were significant for the 1-foot and 5-foot depth samples. Overall, this analysis suggests that water surface elevation and solar irradiance are environmental factors associated with enterococci levels. In general, high enterococci levels during the 12-hour sampling event were associated with high water elevations and low solar radiance.

The plot of enterococci versus sample elevation (Figure IV.6) illustrates the same data as in Figure IV.5. In this plot, it is emphasized that as the water elevation is higher in the PVC, the enterococci levels are higher. These high-water elevations coincided with early morning and later afternoon hours when solar radiance was not intense. Also, the levels of enterococci appear to converge at an elevation of -6 to -7 ft NGVD88, with levels in the 500 to 700 MPN/100 mL range. Overall, results emphasize that very different enterococci values would be obtained depending upon the depth of the water samples collected and the hydrologic conditions. Although the CMB and Surfrider data sets are consistent, as mentioned earlier, the difference in sample collection depths corresponding to the CMB data set (1 foot) and the Surfrider data set (6 inches) could explain the more nuanced differences observed in the two enterococci data sets (e.g., the larger variability observed for Surfrider relative to CMB).

The high levels of enterococci with high tide contrasted with what was observed during hourly sampling during 2022 (Montas et al. 2023). Comparison of hourly sampling between the current 2024 study and the 2022 study shows that the levels for both studies during non-storm conditions were elevated (Figure IV.7). During 2022, the enterococci concentrations increased during low tide, while during 2024 the enterococci concentrations decreased. This is the opposite trend and represents a potential underlying change in the source of enterococci to the PVC. From a conceptual perspective, elevated levels of enterococci would be expected from sanitary sewers during low tide as this is the time when groundwater predominantly contributes towards the PVC. Low tide is when the hydraulic gradient (elevation between the groundwater and the PVC) is strongest favoring the movement of groundwater “downhill” towards the PVC. **The shift in pattern between enterococci concentrations and tidal heights suggests a potential decrease in groundwater sources of enterococci to the PVC between the 2022 and 2024 study periods.**

Additionally, an important observation is that the enterococci concentrations during 2024, although elevated, were lower than those observed during 2022. During 2024, the levels during low tide between storm events was in the 100’s to 10’s of MPN/100 mL. This contrasts with the levels during 2022 which were in the several 100’s to 1,000’s of MPN/100 mL. This decrease during low tide conditions is significant numerically ($p < 0.001$). Although it appears that there may be a significant improvement in water quality in the PVC during low tide, the levels were still elevated in 2024, **efforts are still needed** to identify and remove enterococci sources that contribute at low tide during dry conditions.

Further analysis of the physical-chemical parameters measured at the time of hourly sampling showed no statistically significant differences with water depth for pH, water temperature, nor dissolved oxygen ($p > 0.15$) (Table IV.3). However, statistically significant differences were observed with depth for turbidity ($p < 0.001$) and salinity ($p < 0.001$). Mann Whitney U tests, used to compare sets of data, showed that for turbidity, the statistical differences were observed between the surface samples and the 5-foot depth ($p < 0.001$) and between 1-foot and 5-foot depths ($p < 0.001$). No statistical differences were observed for turbidity between the surface samples and samples collected at the 1-foot depth ($p = 1.0$). Overall, the water closer to the surface in the PVC (at the surface

and 1-foot depths) were characterized by lower turbidities in comparison to samples collected at depth (5-foot). For salinity, the Mann Whitney U tests showed that the salinity of the PVC water was statistically higher at the surface compared to a 1-foot depth ($p=0.003$) and compared to a 5-foot depth ($p<0.001$). Similarly, salinity at the 1-foot depth was high in comparison to the 5-foot depth ($p<0.001$). These results support the observation from the 2022 study which observed a fresher water layer floating atop a saltier water layer within the PVC. In this 2024 study, the variability of enterococci in the fresher water layer at the surface was higher than the variability of enterococci at 1-foot and at 5-feet.

Table IV.2: Enterococci level summary for the PVC Kayak Launch (MPN/100ml) for samples collected hourly on August 15, 2024 (UM data set). The UM data are summarized by water sampling depth (water surface, 1-foot depth, and 5-foot depth) and overall, considering all depths. The UM data are compared against the summary statistics of the CMB data set (monthly sampling between 2019 – 2024) and the Surfrider data set (weekly sampling between 2022 – 2024).

	<i>N</i>	Min	Max	Median	Avg.	Geo Mean	Std. Dev.	Coeff Var.
UM								
<i>Surface</i>	12	30	9,208	309	1,381	423	2,620	1.9
<i>1 foot</i>	12	41	538	216	249	180	176	0.7
<i>5 feet</i>	11	187	651	388	418	393	146	0.3
<i>Overall</i>	35	30	9,208	350	690	308	1,580	2.3
CMB	65	< 10	>24,196	297	2,113	370	5,392	2.6
Surfrider	150	< 10	>24,196	324	2,484	370	6,086	2.5

Table IV.3: Enterococci level summary for the PVC Kayak Launch compared to physical-chemical properties of the water. Data collected hourly on August 15, 2024 (n=12 for surface, n=12 for 1-foot, and n=11 for 5-feet).

	Surface			1-foot			5-feet		
	arith. mean	geo. mean	median	arith. mean	geo. mean	median	arith. mean	geo. mean	median
Enterococci (CFU/100mL)	1381	423	309	249	180	216	418	393	388
Water. Temp (°C)	33.1	33.0	32.6	33.1	33.1	32.8	33.3	33.3	33.2
pH	7.70	7.69	7.52	7.63	7.63	7.55	7.61	7.61	7.58
Dissolved Oxygen (mg/l)	6.50	6.42	6.02	6.54	6.48	6.25	6.55	6.50	6.25
Salinity (ppt)	31.65	22.36	34.73	35.62	35.60	35.90	36.59	36.59	36.60
Turbidity (ntu)	1.29	1.22	1.20	1.26	1.20	1.15	4.80	4.22	4.00

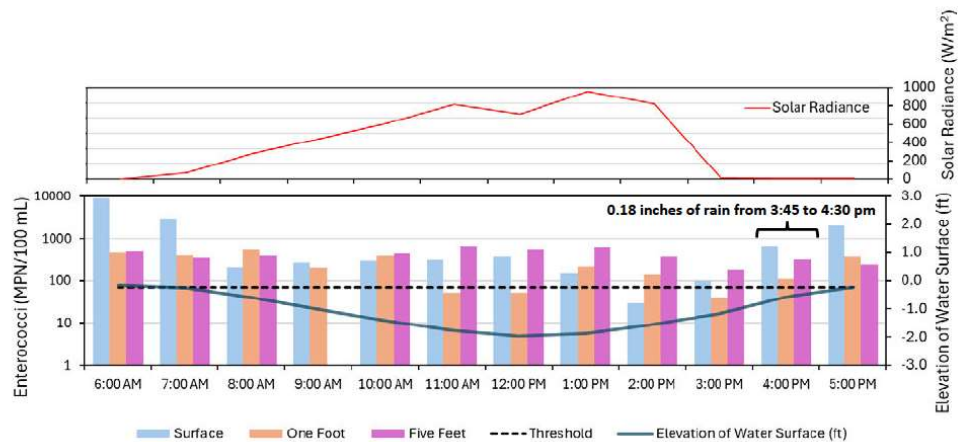


Figure IV.5: Time series of enterococci results from samples collected hourly from the PVC at the Kayak Launch at three different water depths on August 15, 2024. Superimposed as a dashed line is the 70 MPN/100 mL guideline threshold (referenced to the left axis), and as a solid line, water elevation in units of ft NGVD88 (referenced to the right axis). Top panel shows hourly average solar radiation during the time of sampling. Solar radiation data from Miami-Dade Weather Stem Station listed in Table II.2.

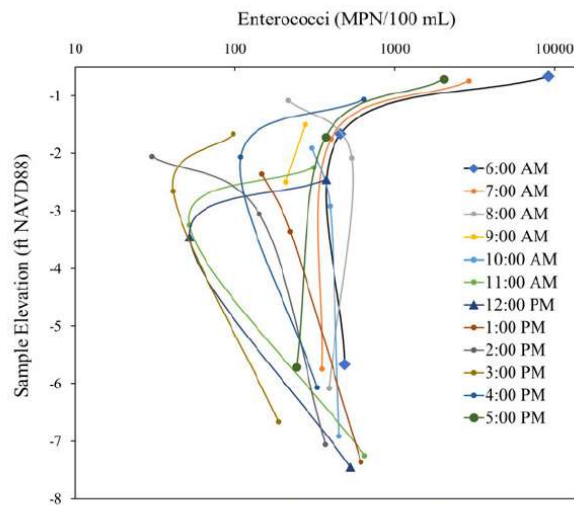


Figure IV.6: Enterococci versus water sample elevation in the PVC at the Kayak Launch. Samples collected hourly on August 15, 2024. Results show that when water elevation is higher the concentration of enterococci at the surface is also higher. The high-water elevations also coincided with very early morning or late afternoon hours when solar radiation was low.

Table IV.4: Pearson correlations (R^2) between enterococci concentrations versus water surface elevation of the PVC, versus solar radiance, and versus elevation of the water sample combined with solar radiance. Solar radiance values corresponded to hourly averages. Analysis was separated by depth of water collected (surface, 1-foot, and 5-foot). Correlations are considered significant for p values less than 0.05 (highlighted in bold font).

Sampling Point Elevation in PVC		Solar Radiance		Elevation and Solar Radiance	
Surface Samples	$R^2 = 0.36$ $p = \mathbf{0.038}$	Solar radiance (surface samples only)	$R^2 = 0.24$ $p = 0.11$	Elevation of surface samples AND solar radiance	$R^2 = 0.37$ $p = 0.12$
One-Foot Depth Samples	$R^2 = 0.41$ $p = \mathbf{0.024}$	Solar radiance (one-foot samples only)	$R^2 = 0.12$ $p = 0.26$	Elevation of one-foot samples AND solar radiance	$R^2 = 0.65$ $p = \mathbf{0.009}$
Five-Foot Depth Samples	$R^2 = 0.32$ $p = 0.068$	Solar radiance (five-foot samples only)	$R^2 = 0.54$ $p = \mathbf{0.010}$	Elevation of five-foot samples AND solar radiance	$R^2 = 0.57$ $p = \mathbf{0.033}$

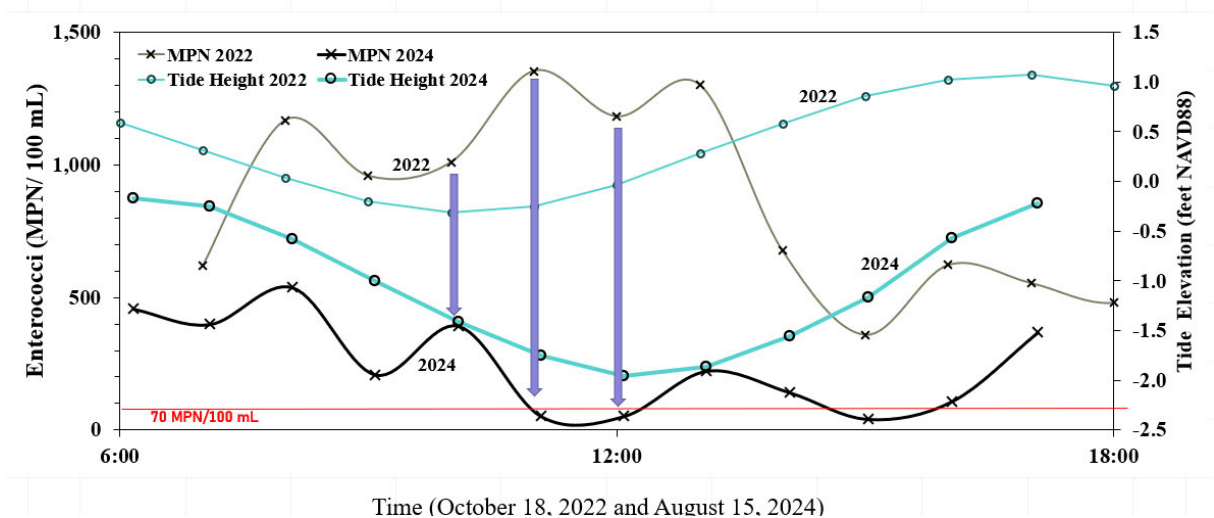


Figure IV.7: Comparison of hourly data during dry conditions and low tide for samples collected at the Kayak Launch during 2022 (October 18) and during 2024 (August 15). Data from the year 2024 is shown by the thick lines and data for the 2022 data set are shown by the thin lines. Data presented for enterococci (left axis and black lines) and water surface elevation of the PVC (right axis and aqua lines). Heavy blue arrows illustrate the difference in enterococci levels between the 2022 and 2024 data sets.

IV.3.b Results from sampling PVC site CS (Outfall at BBE)

Results from sample collection from the PVC at the BBE outfall showed elevated levels of enterococci. The minimum and maximum were 740 MPN/100 mL and 198,630 MPN/100 mL, respectively. The arithmetic and geometric means were 33,100 and 5,510 MPN/100 mL, respectively. The median was 2,720 MPN/100 mL (Table IV.5).

The median concentration at the BBE outfall was between the median observed for stormwater (on the order of tens of thousands of MPN/100 mL, Table IV.1) and the median observed for the PVC at the Kayak Launch (overall median of 350 MPN/100 mL, Table IV.2). The median level of enterococci at the BBE outfall was statistically higher than the levels observed at the Kayak Launch ($p=0.018$). When considering the maximum values (shown in Figure IV.8), the differences in concentration between the BBE outfall and the Kayak Launch are further emphasized. These results support that the BBE outfall is a source of enterococci to the PVC. See Chapter VI for details on how the CMB is addressing this source.

Table IV.5: Data for samples collected from the PVC at the BBE outfall.

Site ID	Sampling Date	Sampling Time	Enterococci Level (MPN/100 mL)
CS1	Aug. 5, 2024	12:35 PM	17,329
CS2	Aug. 20, 2024	4:27 PM	198,630
CS3	Aug. 23, 2024	1:29 PM	980
CS4	Aug. 23, 2024	3:30 PM	740
CS5	Aug. 29, 2024	2:30 PM	2,720
CS6	Sep. 19, 2024	3:36 PM	2,620
CS7	Sep. 19, 2024	4:15 PM	8,650
Median			2,720
Arithmetic Average			33,100
Geometric Average			5,510

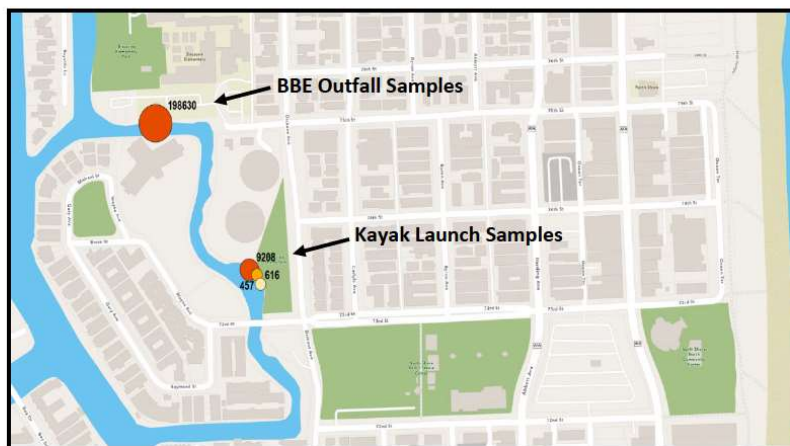


Figure IV.8: Spatial distribution of enterococci concentration for samples collected from within the PVC. The size of the circles corresponds to the maximum concentration of the enterococci observed at the respective sites. The numerical values next to the circles represent the maximum enterococci concentration in MPN/100mL. Samples collected at the PVC water's surface correspond to dark orange. Light orange circles correspond to samples at the Kayak Launch at 1-foot depth. The yellow circle corresponds to samples collected at the Kayak Launch at 5-foot depth.

IV.4 COMBINED RESULTS FROM UM SAMPLES

The combined results from samples collected by the UM are illustrated in Figures IV.9 and IV.10. Results show the relative distribution of enterococci concentrations within the different types of water samples collected. Results show that groundwater enterococci concentrations tend to be the lowest among all sample types. The median levels of enterococci in groundwater were statistically lower than stormwater ($p < 0.001$) and in the PVC including both the Kayak Launch ($p < 0.001$) and the BBE location ($p < 0.001$). Groundwater hotspots were observed at the end of 75th Street at the pickup area for the BBE plus three additional hotspots along 73rd Street.

Stormwater was characterized by elevated enterococci levels consistently throughout the catchment. The median levels of enterococci in the PVC at the Kayak Launch ($p < 0.001$) and, at the BBE ($p = 0.010$), were both statistically lower than stormwater.

Within the PVC, water collected at the surface had higher enterococci levels than water collected at depth. When evaluating the arithmetic averages, levels of enterococci were highest in the surface water. However, when evaluating the medians, no statistical differences were observed within the PVC with water depth ($p=0.17$). Additionally, the BBE outfall was a hotspot for enterococci within the PVC. When comparing the two PVC locations, the enterococci levels collected at the Kayak Launch were statistically lower than the enterococci levels in the samples collected from the BBE outfall ($p=0.018$).

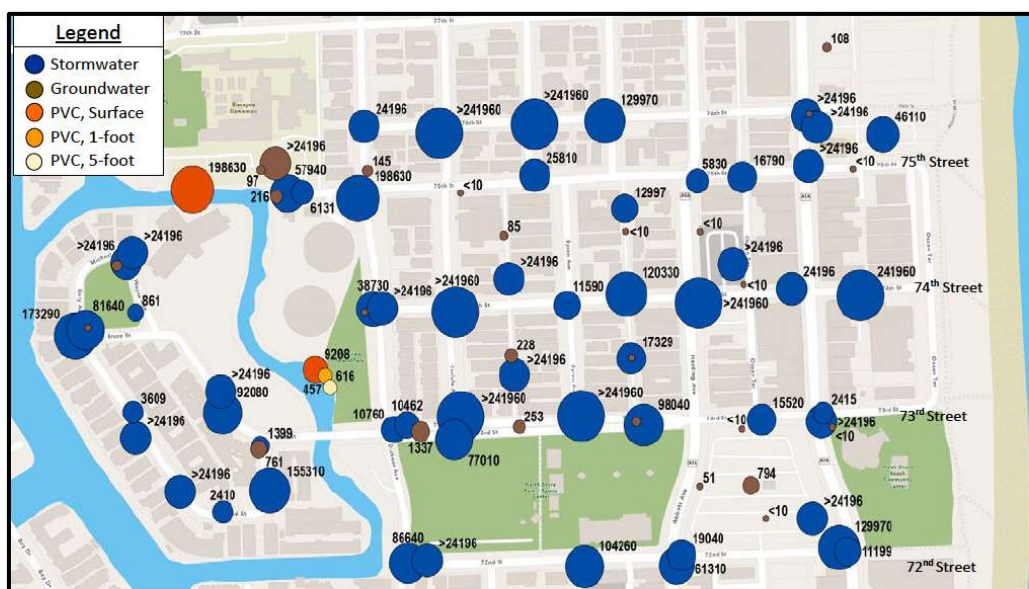


Figure IV.9: Spatial distribution of enterococci concentrations in groundwater, stormwater, and water from the PVC. The size of the circle is proportional to the enterococci concentration. The numerical values represent the maximum values at each site.

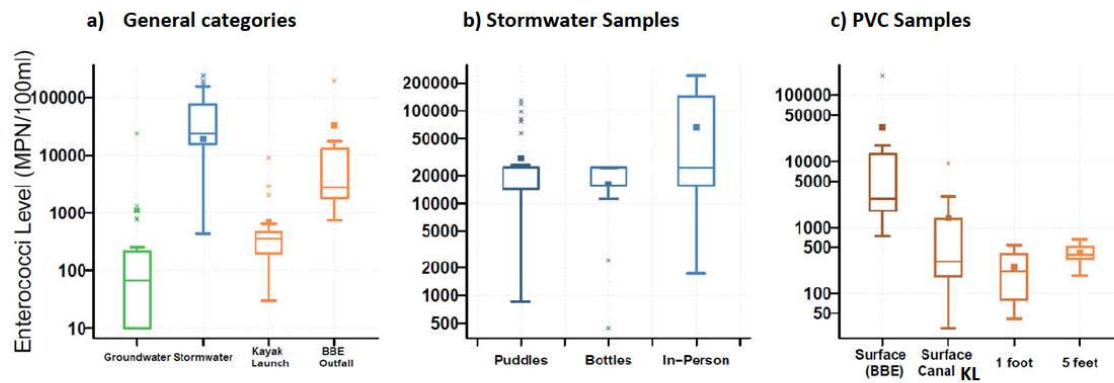


Figure IV.10: Box and whisker plot for the enterococci data collected as part of this current study (UM 2024 samples). Boxes represent the upper and lower quartile, the error bars represent the minimum and maximum values when excluding outliers, and the \times symbols outside the error bars represent outliers. The central line in the box represents the median, and the square represents the mean. Panel a categorizes enterococci data by groundwater, stormwater, PVC water at the Kayak Launch, and PVC water at the BBE outfall. Panel b separates the stormwater samples by method of sample collection (puddles, field-staged bottles, and in person). Panel c corresponds to the enterococci measured within the PVC at the BBE Outfall (surface sample) and at the Kayak Launch by depth of sample collection.

IV.5 STORMWATER AND PVC DATA IN THE CONTEXT OF THE LITERATURE

A literature review was conducted to better assess whether the concentrations of enterococci observed in stormwater within the PVC and the PVC catchment were within the norm of other studies. Studies were separated into three groups: studies that evaluated roof runoff or runoff from experimental plots (Table IV.6), studies that evaluated waterways that were highly impacted by stormwater runoff (Table IV.7), and studies that evaluated stormwater runoff collected from streets prior to entering larger waterways (Table IV.8).

For roof runoff (Table IV.6), levels ranged from single digits to the low thousands of MPN/100 mL. For the study conducted for roofs in Miami, the median concentration was 870 MPN/100 mL, and the arithmetic average was 1,200 MPN/100 mL. These values are on the low end in comparison to the enterococci in the stormwater samples collected from the PVC catchment. Experimental studies conducted to evaluate runoff from a roof, asphalt, permeable pavers, porous concrete and asphalt, again confirmed the relatively low levels observed in roof runoff. Of interest were the relatively higher levels in permeable pavers and the observed lower levels from porous concrete and asphalt suggesting that pavement type may assist in reducing enterococci in stormwater runoff. For all cases listed in Table IV.6, the runoff from the experimental systems (Selvakumar and O'Connor 2022) were all less than the values observed in stormwater runoff within the PVC catchment.

Table IV.6: Enterococci Concentrations in Roof and Pavement Runoff Under Experimental Conditions

Reference	Matrix	Location	Number of Samples	Concentration (MPN or CFU/100 mL)			
				Min	Max	Median	Average
Alja'fari et al. 2022	Roof Runoff	Fort Collins, TX	N=26	5.1	2,420	540	1,040
		Tucson, AZ	N=17	16	2,420	1,690	1,370
		Baltimore, MD, USA	N=19	9.5	2,420	130	523
		Miami, FL	N=17	24	2,420	870	1,200
Selvakumar and O'Connor 2022	Roof runoff	Edison, NJ	N=42	1	1,100	9	73
	Asphalt runoff		N=79	1	48,400	24	1,180
	Permeable Pavers type 1		N=83	1	24,196	177	1,210
	Permeable Pavers type 2		N=47	1	24,196	30	864
	Porous concrete		N=36	<1	563	15	68
	Porous asphalt		N=84	<1	55	1	6

For the environmental waters highly impacted by stormwater runoff (Table IV.7), levels observed were variable with maximums per study ranging from 13,000 MPN/100 mL to values upwards of 480,000 MPN/100 mL. The sites characterized by the lower maximums (New Orleans, LA and Norfolk, VA) were characterized by medians in the 1,000's MPN/100 mL range. The waterway with extreme high levels of enterococci (Southern California) were impacted by runoff from recreational lands that included horse stables. The authors of the Southern California study (Tiefenthaler et al. 2011) imply that the cause of the elevated concentrations for this watershed was due to horse manure. In comparison, the results for the PVC were within range of the low end for these studies. The median for the PVC samples was on the order of 100's of MPN/100 mL which is less than the medians for the New Orleans and Norfolk studies. **Overall water quality within the PVC is within the norm observed for highly impacted waterways within the U.S.**

Table IV.7: Enterococci Concentrations in Environmental Waters Highly Impacted by Stormwater Runoff (representative set). Results for samples from the PVC in bold font.

Reference	Matrix	Location	Number of Samples	Concentration (MPN or CFU/100 mL)			
				Min	Max	Median	Average
Jeng et al. 2005	Stormwater from Jahncke Canal which collects stormwater from urban areas	New Orleans, LA	2 storm events (n=8, n=10) Samples collected from stormwater pumps	440	13,000	4,300	4,900
Macías-Tapia et al. 2021	Floodwaters from Lafayette River in Chesapeake, Bay	Norfolk, VA	N=23	30	>24,000	1,200	6,300
Tiefenthaler, et al. (2011)	Creek from highly urban watershed	Ballona Creek, California Highly Urban	N=10	NA ^a	230,000 ^b	NA	NA
	Runoff from recreational land use (horse stables) watershed	Southern California	N=20	NA	480,000 ^b	NA	NA
UM 2024 study, CMB (top row) and Surfriider data set (bottom row)	PVC canal from Feb'23 to Sep'24	Miami Beach, FL	N=20 N=83	10 10	>24,200 >24,200	160 430	434 2,960

^aNA=Not Available

^bPeak concentration read from graphs

For street-level stormwater samples (Table IV.8), average values were variable. The stormwater collected from the watershed in Sweden had the lowest enterococci levels among all studies evaluated. For watersheds in New Jersey (Selvakumar and Borst 2006), enterococci averages were in the 1,000 to 6,600 MPN/100 mL range. For the study in North Carolina, the maximum level of enterococci observed was 9,700 MPN/100 mL. Studies in Michigan (Gannon and Busse 1989, Hathaway et al. 2010) and Texas (Pan and Jones 2012) show enterococci in street-level stormwater with averages between 6,000 to 25,200 MPN/100 mL. Of note, Hathaway et al. (2010) implicated dogs as the source in their study. The one study conducted from a dog beach in Miami impacted by several local sources found average levels above 15,100 MPN/100 mL (Wright et al. 2011). One study in Blacksburg, VA (Jacobs et al. 2019) found extraordinarily high levels of enterococci in experimental plots where fertilizer was added (14,000,000 MPN/100 mL). **The values observed in these studies suggest that the average enterococci in stormwater from the PVC catchment (55,600 MPN/100 mL) is on the high end but within levels that would be observed from impacted catchments especially those impacted by animal fecal waste (e.g., manure or dog waste).** Also of interest is the possibility that elevated enterococci levels may be exacerbated by fertilizers.

Table IV.8: Enterococci Concentrations in Stormwater Runoff. Results from stormwater samples collected from the PVC catchment are in bold font.

Reference and Location	Matrix	Number of Samples	Concentration (MPN or CFU/100 mL)			
			Min	Max	Median	Average
Galfi, et al. (2016) Ostersund, Sweden	Storm drain from recreational area (21% impervious)	6 to 7 storms per site type with 5 to 15 samples per storm	10	16,000	NA ^a	1,440
	Storm drain from residential area (47% impervious)		10	9,000	NA	730 ^c
	Storm drain from mixed land use (53% impervious)		180	90,000	NA	3,930 ^c
	Storm drain from institutional (hospital) area (85% impervious)		10	30,000	NA	870 ^c
Selvakumar and Borst 2006 Monmouth County, NJ	Storm drain from high density residential (65% impervious)	N=72	NA	NA	NA	3,200-5,000
	Storm drain from low density residential (17% impervious)	N=80	NA	NA	NA	1,000-2,200
	Landscaped commercial	N=73	NA	NA	NA	4,000-6,600
Converse, et al. (2011) Dare County, NC	Catch basins upstream of stormwater outfalls (medium-density residential area)	5 storm events from 5 sites with 3 to 6 samples collected per site per storm	275 (average of 6 samples)	9719 (average of 5 samples)	NA	NA
Gannon and Busse (1989) Ann Arbor, MI	Mouth of storm drain (Allen drain, highest)	N=19	<50	340,000	NA	6,400 ^c
	Mouth of storm drain (North Campus drain, lowest ^d)	N=9	1,700	34,000	NA	91,000 ^c
Pan and Jones (2012) Houston, TX	Stormwater detention basin	N=15	NA	NA	10,100	12,572 ^b
Wright, et al. (2011) Virginia Key, FL	Stormwater runoff from channel on a dog beach impacted by parked cars, open garbage bins, and dogs	N=34	690	>32,600	NA	>15,100
Hathaway et al. (2010) Raleigh, NC	Stormwater from residential watershed (35% impervious). Implicate dogs as a source.	20 storm events (average of 10 samples per storm)	1,300 ^e	182,000 ^e 655,460 ^e	12,300	25,200
Jacobs et al. (2019) Blacksburg, VA	Runoff from experimental land plots with inorganic fertilizer but no manure added	Six storm event samples from 27 plots evaluated with and without dairy manure	NA	14,000,000	NA	NA
UM 2024 study Miami Beach, FL	Stormwater from puddles, field-staged bottles, and in-person sampling	N=79 (within DL)	440	241,960	19,860	55,630

^a NA=Not Available

^b Event Mean Concentration (EMC)

^c Geometric mean. Arithmetic means not provided

^d Mouth of storm drain with lowest level of enterococci was found to have a chlorine residual making this site (Fuller Drain) non-representative of a storm drain not receiving treatment.

^e The study focused on reporting EMC. The absolute maximum value among the estimated 200 storm samples was 655,460 MPN/100 mL (Hathaway et al. 2015).

CHAPTER V

RESULTS FROM MICROBIAL SOURCE TRACKING

CHAPTER V

RESULTS FROM MICROBIAL SOURCE TRACKING

The CMB has used MST to evaluate the potential sources of enterococci to the PVC. Their earlier data showed that dogs and, to a lesser extent, birds, and humans, were sources to the PVC. A similar approach was implemented by Surfrider who found evidence human and, to a lesser extent, dogs, as sources. Our goal was to measure groundwater and stormwater independently for MST, to assist in confirming the source of enterococci to the PVC. Plus, samples from the PVC itself were also measured for MST to reconfirm sources upon entering the PVC. This chapter provides a brief description of the methods (Section V.1) followed by the results from the 2024 UM MST sampling effort, one of the major efforts of this current study (Section V.2). The last section (Section V.3) compares the results from all samples analyzed by qPCR including correlations between the culture-based and qPCR measurements of enterococci and correlations with the individual MST markers.

V.1 SAMPLE PROCESSING FOR MST

The basis of MST analysis is the laboratory qPCR procedure. The markers targeted through qPCR include four that focus on identifying specific animal sources (human, dog, bird, and gull) plus one that focuses on analyzing for enterococci (EnterolA), to be used for comparison against the enterococci measured by culture. The laboratory used to measure markers by qPCR was the microbiology laboratory led by Drs. Chris Sinigalliano and Dr. Maribeth Gidley at NOAA-AOML. Preprocessing of the samples was conducted at UM by preparing filters as described in Chapter IV. These filters were stored at UM at -80 °C in lysis buffer (DNA/RNA Shield by Zymo Research Corp.) to preserve the DNA. The filters chosen for MST analysis were selected based upon the sample type and the enterococci levels that were measured by culture from the sample split. A total of 48 samples were delivered to the NOAA-AOML laboratory on September 6, 2024, and an additional 30 samples were delivered during November 2024. The samples chosen for MST analysis included all the groundwater samples (n=26), 9 PVC samples at the Kayak Launch, 5 PVC samples at the BBE outfall, 37 stormwater samples, and 1 blank. The canal samples corresponded to three depths collected during dry conditions at the early morning high tide (n=3), mid-day low tide (n=3) and shortly after a storm event in the late afternoon (n=3). The five samples chosen from the outfall to the BBE were the first five (of a total of seven) collected. The stormwater samples were chosen from the watershed with a preference of including samples that were collected in-person. Twenty stormwater samples were collected in-person, 11 were field-staged bottle samples, and 6 were puddle samples. A complete list of the samples analyzed for MST is given Table V.1. Locations for each sample collection are detailed in Appendix C.

Sample analysis at the NOAA-AOML laboratory included eDNA extraction and purification with a KingFisher Flex instrument on October 2, 2024 (first batch of 48) and December 16, 2024 (second batch of 30). This was followed by quantitative polymerase chain reaction (qPCR) amplification of five diagnostic target DNA sequence markers, using primers specific for human (HF183 – targets 16S rRNA gene of *Bacteroides* spp.), dog (DG3 – targets 16S rRNA gene of *Bacteriodes* spp.), bird (GFD – targets 16S rRNA gene of *Helicobacter* spp.), gull (Gull2 – targets 16S rRNA gene of *Catelliboccus marimammalium*), and general total enterococci (EnterolA – targets 23S rRNA gene of most species and strains of fecal-associated enterococci) fecal bacteria gene markers. Environmental concentration results for qPCR measurements of each sample were normalized by the sample filtration volume, sample lysate volume, purified eDNA elution volume, and template eDNA volume in the qPCR reaction, thus allowing for the conversion of the results into units of “target gene copies” (gc) per 100 mL of original environmental water sample (gc/100 mL). For the first 48 samples, results were released to UM by October 28, 2024, for human (HF183), dog (DG3), and bird (GFD), and on December 27, 2024, for seagull (Gull2) and general enterococci (EnterolA). For the second batch of 30 samples, results were released on February 18, 2025. Additional details about the laboratory methods for qPCR analyses are given in Appendix D.

V.2 RESULTS FROM MST ANALYSIS

V.2.a Stormwater versus Groundwater as the Enterococci Source

Results from MST (Table V.1 raw data, Table V.2 summarized data, Figure V.1) emphasize that the **source of enterococci to the PVC is from stormwater not groundwater**. The enterococci measurements by qPCR (EnterolA) were all within detection limits (Figure V.2). For groundwater, the highest level of enterococci measured by PCR was at site F7 (10^4 gc/100 L), consistent with the highest enterococci levels measured by culture. All other groundwater samples measured at 10^3 gc/100 L or lower. In contrast, stormwater enterococci levels by qPCR were much higher, from 10^4 to 10^7 gc/100 L, confirming the results observed for enterococci by culture. Like enterococci by culture (Figure IV.9) the enterococci by qPCR were elevated in stormwater collected throughout the watershed (Figure V.3). The contribution of stormwater as the source of enterococci to the PVC is further emphasized by the results from the human and dog MST markers. The human (Figure V.4) and dog (Figure V.5) source tracking markers were found predominantly in stormwater and PVC water, not in groundwater.

V.2.b Dominance of Bird Marker

Among the MST markers, the bird marker dominated (Table V.1, Figure V.6, Figure V.8). Unlike the other MST markers, it was found in all samples with the highest found within the PVC samples at the Kayak Launch (except for one stormwater sample). This spatial distribution of the MST bird marker suggests that the **major source of the bird maker is “internal” to the PVC**, which is consistent with the fact that the trees that border the PVC provide habitat for birds. This distribution of bird MST marker is also consistent with the observation within the PVC with higher levels observed during high tide. It is possible that bird fecal waste is deposited along the banks of the PVC which washes in during high tide. In addition to PVC samples, the bird marker was found in stormwater at elevated levels which suggests that birds are a source of enterococci throughout the catchment. Of interest was the detection of bird marker in groundwater. Since birds were observed in the catchment only above the ground surface, the MST marker measured in the groundwater is likely coming from stormwater impacted by MST bird marker. The gull marker, which represents a subset of the birds, was observed intermittently only in stormwater at a few isolated points in the watershed (Figure V.7). These results indicate that **bird species other than gulls are the dominant contributor to the bird marker** observed.

Although bird waste is considered less infectious than human and dog waste, the levels of the bird marker were elevated above the risk-based threshold (RBT) (22,500 gc/100 mL in the presence of detectable levels of human marker) for acceptable levels of human illness. Thus, **the high concentrations of the bird marker are consistent with the high concentrations of culturable enterococci, suggesting that the PVC should not be used at this time for full body contact recreational activities**.

V.2.c Additional Sources Not Captured by MST Markers

The spatial distribution of the bird marker is not consistent with the spatial distribution of the culturable enterococci. The bird marker is higher in the PVC canal compared to stormwater, whereas the enterococci by culture concentrations are higher in stormwater compared to the PVC. This difference in spatial distribution suggests that there is a source of enterococci to the stormwater and, ultimately to the PVC, that is not consistently detected by MST. **We hypothesize that this additional source of enterococci may be coming from “aged” human and/or dog sources**. This hypothesis is based upon two observations. First, field visits to the catchment show evidence of dog fecal waste on the ground surface. Humans are also believed to be a potential source due to

the homeless populations throughout the catchment and the difficulties in getting access to sanitation facilities. Additionally, historic sanitary sewer overflows could have contaminated sediments which can contribute towards the persistence and growth of enterococci within sediments and possibly within the storm water infrastructure. Second, as mentioned in Chapter I, the bacteria used to measure human and dog sources dies quickly in the environment when exposed to aerobic conditions, whereas enterococci tend to persist. **One explanation for the inconsistency in the spatial distribution is that the MST signal from the stormwater is lost due to die-off of the host bacteria, whereas enterococci remain culturable due to its ability to survive in the environment.**

V.2.d Observations from Human and Dog Markers

For the 26 groundwater samples analyzed, no detections of human nor dog markers were observed except for site R2 (Table V.1). R2 had detectable levels of human marker but below the level of quantification. The lack of human and dog marker was observed for the groundwater site (F7) which showed the highest levels of enterococci. If human and/or dog markers are impacting groundwater, those signals are lost in the groundwater. Therefore, the source of human and dog markers to the PVC is not from groundwater.

Additionally, for the PVC water at the Kayak Launch, no dog marker was detected. Human marker was detected in five of the nine samples, although four of the five were below the levels of quantification. Only one of the nine samples (a surface sample) showed levels of human marker above the limit of quantification, but the level observed (110 gc/100 mL) was below the risk-based threshold for human marker alone (525 gc/100 mL). The comparison of enterococci and human/dog source tracking markers for stormwater showed intermittent impacts from humans and dogs.

For the PVC water at the BBE outfall, human and dog marker were detected in three of the five samples, although all three of the human marker were below the limit of quantification. All three detections for the dog marker were above the limit of quantification.

For the 37 stormwater samples analyzed, 18 showed detectable levels of human marker with seven above the limit of quantification, whereas 11 of the 37 stormwater samples were positive for dog marker, with eight above the limit of quantification. All stormwater samples were positive for general bird marker, and four were positive for seagull marker. **These results suggest that stormwater in the PVC catchment is impacted by intermittent detectable human and dog markers supporting these as contributing sources, in addition to bird sources.**

V.2.e Spatial Distribution of All Markers

To further evaluate the results from MST, the data were plotted spatially in Figure V.8. The results emphasize the dominance of the bird MST marker within the PVC canal with lower levels in groundwater and stormwater throughout the catchment. However, for the time points of the samples collected in this study, seagulls do not appear to be the predominant bird species contributing to the bird fecal contamination. The primary bird species contributing to the observed bird fecal concentrations are not known.

The dog marker was detected above the limit of quantification in the middle and eastern portions of the catchment at 76th Street, along Dickens and 74th Street, and in the parking lots at 75th Street and Ocean Terrace and 74th Street and Harding Avenue. The human MST marker was primarily observed in the same locations as where the dog marker was observed, with the exception that human marker was also observed on Parkview Island. It is interesting to note the vicinity of positive detection of human markers closer to parks. Some parks do have access to sanitation facilities, but these facilities may be closed at night limiting the time frame of public access. Before conclusions can be drawn, **further work is needed to evaluate access and utilization of sanitation facilities within the catchment**, especially at parks.

V.2.f Summary of MST Results

In conclusion, given the spatial distribution of the enterococci in stormwater versus groundwater versus the PVC, and the results from MST, the major sources of enterococci have been identified as:

- 1) Dog fecal waste. Given that dog MST markers were intermittently observed in stormwater, we believe that dog fecal waste is one of the contributors to stormwater enterococci throughout the PVC catchment and it is transported to the PVC through the stormwater infrastructure. It is possible that the reason for the spotty detection of dog MST marker in stormwater (11 out of 37 samples) is due to the die-off of the host bacteria that carries the MST marker gene. Dog marker was also observed in water at the BBE outfall (3 of 5 samples). No detections of dog MST were observed in groundwater nor in the PVC water at the Kayak Launch. Due to the detection of dog MST in stormwater and BBE outfall and the visual observation of dog waste on the ground surfaces within the catchment, **some “fresh” and mostly “aged” dog fecal waste is a likely contributor of enterococci to stormwater and ultimately to the PVC.**
- 2) Human fecal waste. The human MST marker was generally not detected in groundwater except for 1 out of 26 samples. This one sample was observed at low levels, as it was detected but not quantifiable. In stormwater, 18 of the 37 samples showed evidence of human MST marker, with seven of these samples showing levels above the limit of quantification. Three of these samples exceeded the RBT. The detections for human MST were found along the 73rd Street area extending from Park View Island to Byron Avenue with the sample exceeding the RBT collected at Carlyle and 73rd Street. We suspect that stormwater receives intermittent sources of “fresh” and “aged” human fecal waste, especially along the 73rd Street corridor. Stormwater samples appear to have preferentially retained the human MST signal as evidenced by the higher frequency of detection compared to the dog MST signal. Within the PVC at the Kayak Launch, five of the nine samples showed detection of human MST marker, with only one being quantifiable. Given the relative levels of human MST observed in the groundwater, versus stormwater, versus the PVC, **human waste is likely reaching the PVC through stormwater runoff.** Since stormwater originates at the surface, we believe the human signal in stormwater can be from one of two sources. The first source can include humans who defecate on the streets which can include populations without access to sanitation facilities such as homeless, or people who have chosen to not use or have been rejected access to sanitary facilities. The second source may be from surface sediments that have been contaminated by sewage overflows and are washed off during storm events and transported towards the stormwater catch basins.
- 3) Bird fecal waste. The general bird MST marker (GFD) was detected in all samples analyzed, whereas only four stormwater sites had significant detectable seagull-specific MST marker (Gull2). The highest levels for the bird MST were observed in the PVC. The levels of bird MST in the PVC were above the RBT given the detectable levels of human marker. It is likely that birds foraging in the area release their waste directly into the canal or waste can also be released from nesting and wading birds along the shore which can then be washed into the PVC during high tide or during storm events. It is believed that the seagull fecal marker decays more rapidly than the general bird fecal marker, so a mixture of bird fecal inputs of different ages may have had some contribution to the low seagull marker concentrations as compared to general bird fecal marker concentrations. It could also be speculated that other types of birds (e.g., songbirds) might be more predominant in the area immediately prior to the time of sampling, especially near parks or residential areas. The use of bird feeders may attract larger populations of non-gull birds contributing to stormwater and might encourage increased direct deposition of bird feces directly to the shore area and water column of the PVC. The results from this study show that **bird fecal waste is a significant contributor to the PVC and the levels of bird waste are above risk-based thresholds.** This confirms the results from enterococci that the PVC water quality does not meet guideline levels for full body contact recreational activities.
- 4) Potential natural background reservoirs of enterococci. It should be noted that the very high levels of enterococci observed both by live culture and by qPCR are not likely to be fully explained by the levels of

human, dog, or even bird fecal markers observed during this study. Although there are significant elevations of these markers (specifically bird marker) in many samples, in our opinion there are higher observable levels of enterococci in many samples than can reasonably be accounted for by the levels of the specific MST markers that were measured. Therefore, it should be considered that there might be additional non-human-host fecal sources in the region besides the ones measured in this study. There is a **possibility of persistent populations of non-fecal enterococci associated with the environment** contributing to the enterococci loads, such as from sediments/soils, plants, or biofilms of hardened infrastructure in the region. It would be worth following up with studies to evaluate regional soils/sediments and catchment infrastructure to confirm potential background populations of persistent enterococci and conditions under which they regrow. The prior UM study conducted in 2022 did measure enterococci in the surface sediments, sediments along the channel banks, and sediments within the bottom of catch basins and recorded levels on the order of several hundreds of enterococci per gram.

Table V.1: Results from enterococci and MST analysis for the 78 MST samples analyzed in this study inclusive of groundwater, PVC water, and stormwater samples. All samples analyzed for human, dog, bird, and gull markers plus the general enterococci marker (EnterolA). **Bolded** results exceed the estimated risk-based threshold (RBT) of 32 or 36 human illnesses per 1000 exposures for full body contact. See Section I.2.b for an explanation of the sources and assumptions made in the RBT values.

Sample ID ^a	Sample Type	Enterococci by culture MPN/100 mL	General Enterococcus “EnterolA” by qPCR gc/100mL	Human Specific “HF183 Taqman” <i>Bacteroides</i> qPCR gc/100mL	Dog Specific “DG3” <i>Bacteroides</i> gc/100mL	General Bird “GFD” <i>Helicobacter</i> spp. gc/100mL	Seagull Specific “Gull2” <i>Catelliboccus</i> gc/100mL
F11-240723	Groundwater	<10	128	ND ^b	ND	629	ND
F1-240723	Groundwater	794	3,850	ND	ND	93	ND
F3-240723	Groundwater	51	3,107	ND	ND	811	ND
F2-240723	Groundwater	<10	490	ND	ND	139	ND
F10-240723	Groundwater	108	166	ND	ND	412	ND
G8-240723	Groundwater	253	1,343	ND	ND	298	ND
F9-240723	Groundwater	1,337	884	ND	ND	93	ND
G17-240723	Groundwater	761	1,074	ND	ND	74	ND
G10-240723	Groundwater	<10	305	ND	ND	93	ND
G16-240723	Groundwater	137	621	ND	ND	204	ND
F4-240724	Groundwater	<10	171	ND	ND	233	ND
G5-240724	Groundwater	<10	605	ND	ND	878	ND
G4-240724	Groundwater	<10	297	ND	ND	175	ND
G13-240724	Groundwater	108	62	ND	ND	89	ND
G11-240724	Groundwater	<10	151	ND	ND	156	ND
G2-240724	Groundwater	<10	355	ND	ND	323	ND
G1-240724	Groundwater	228	4,853	ND	ND	406	ND
G12-240724	Groundwater	85	4,419	ND	ND	589	ND
F5-240725	Groundwater	<10	1,354	ND	ND	586	ND
R1-240725	Groundwater	10	394	ND	ND	181	ND
R3-240725	Groundwater	97	2,478	ND	ND	526	ND
F7-240725	Groundwater	>24,196	30,387	ND	ND	457	ND
F6-240725	Groundwater	216	1,707	ND	ND	142	ND
G3-240725	Groundwater	145	569	ND	ND	2,184	ND
G7-240725	Groundwater	<10	93	ND	ND	DNQ (35)	ND
R2-240725	Groundwater	10	DNQ (28)	DNQ (9) ^c	ND	206	ND
KS01-240815	PVC Surface	9,208	45,046	DNQ (13)	ND	70,199^d	ND
KO01-240815	PVC 1-ft Depth	457	3,757	DNQ (3)	ND	189,793	ND
KF01-240815	PVC 5-ft Depth	487	4,889	DNQ (18)	ND	131,698	ND
KS07-240815	PVC Surface	373	2,798	ND	ND	39,312	ND
KO07-240815	PVC 1-ft Depth	52	1,645	ND	ND	23,903	ND
KF07-240815	PVC 5-ft Depth	529	11,502	DNQ (10)	ND	108,482	ND
KS12-240815	PVC Surface	2,035	23,356	110	ND	58,014	ND
KO12-240815	PVC 1-ft Depth	369	21,406	ND	ND	110,437	ND
KF12-240815	PVC 5-ft Depth	243	7,685	ND	ND	60,479	ND
CS1-240805	PVC, BBE Outfall	17,329	8,218	ND	ND	120	ND
CS2-240820	PVC, BBE Outfall	198,630	4,830	ND	ND	1533	ND
CS3-240823	PVC, BBE Outfall	980	384,097	DNQ (6)	1,197	52,361	ND
CS4-240823	PVC, BBE Outfall	740	255,555	DNQ (1)	126	7,482	ND
CS5-240829	PVC, BBE Outfall	2,720	1,079,725	DNQ (21)	149	25,886	ND
SRA2-240806	Stormwater	19,863	9,101	ND	ND	93	ND
SRB6-240806	Stormwater	11,199	124,945	ND	ND	853	ND
SRF5-240820	Stormwater	92,080	54,939	DNQ (24)	ND	368	ND
BS14-240820	Stormwater	173,290	108,496	DNQ (26)	ND	150	ND
SRN-240829	Stormwater	241,960	191,868	762	ND	1,026	6,192
SRK-240829	Stormwater	86,640	18,204	DNQ (5)	ND	928	ND
SRL-240829	Stormwater	61,310	13,094	DNQ (11)	ND	149	ND
SRO-240829	Stormwater	>241,960	1,308,273	DNQ (5)	395	312	890
SRE8-240829	Stormwater	19,863	9,312	ND	ND	122	ND
SRJ-240829	Stormwater	38,730	125,193	98	71	529	ND

Table V.1: continued

Sample ID ^a	Sample Type	Enterococci by culture MPN/100 mL	General Enterococcus “EnterolA” by qPCR gc/100mL	Human Specific “HF183 Taqman” <i>Bacteroides</i> qPCR gc/100mL	Dog Specific “DG3” <i>Bacteroides</i> gc/100mL	General Bird “GFD” <i>Helicobacter</i> spp. gc/100mL	Seagull Specific “Gull2” <i>Catelllicoccus</i> gc/100mL
SRI-240829	Stormwater	11,590	14,157	DNQ (8)	ND	163	ND
BS4-240806	Stormwater	>24,196	2,429	ND	ND	2,158	ND
SRC2-240806	Stormwater	>24,196	134,149	DNQ (0.2)	ND	299	ND
BS6-240806	Stormwater	443	95,549	DNQ (17)	121	77	ND
BS7-240809	Stormwater	11,199	552,321	ND	ND	642	ND
SRD2-240809	Stormwater	>24,196	1,633,586	ND	ND	541	ND
BS1-240806	Stormwater	>24,196	207,050	ND	DNQ (1)	934	ND
BS9-240809	Stormwater	19,863	837,129	DNQ (14)	ND	111	ND
BS2-240806	Stormwater	24,196	1,106,920	297	165	2,212	ND
BS10-240809	Stormwater	24,196	62,605	ND	ND	229	ND
RSD-240725	Stormwater	14,136	2,272,419	ND	ND	545	ND
RSF-240725	Stormwater	>24,196	377,307	97	ND	244,327	ND
P1-240805	Stormwater	>24,196	842,109	ND	1137	696	ND
P3-240805	Stormwater	19,863	1,551,216	578	DNQ (46)	745	ND
PS1-240806	Stormwater	>24,196	3,893,670	338	270	1933	ND
PS3-240806	Stormwater	24,196	86,291	ND	ND	950	DNQ (9)
BS11-240809	Stormwater	>24,196	54,733	ND	ND	3,263	ND
BS13-240820	Stormwater	11,780	137,073	ND	DNQ (1)	331	ND
SRY-240910	Stormwater	104,620	1,926,120	ND	ND	2,446	ND
SRH-240829	Stormwater	>241,960	131,751	ND	ND	571	ND
SRV-240910	Stormwater	241,960	669,747	ND	ND	1,010	ND
SRZ-240910	Stormwater	155,310	3,482,500	ND	ND	1,169	1274
BS3-240806	Stormwater	24,196	38,661	106	ND	21,773	ND
SRR-240910	Stormwater	198,630	716,107	ND	ND	507	ND
SRU-240910	Stormwater	46,110	8,884,668	DNQ (16)	5,322	4,114	ND
SRP-240829	Stormwater	77,010	536,051	900	79	533	ND
SRW-240910	Stormwater	>241,960	6,914,729	ND	ND	4,827	ND
Blank-240815	Blank	<10	DNQ (7)	ND	ND	DNQ (8)	ND

^aSample ID corresponds to the location (first 2 to 4 alphanumeric) and sample collection date (in YYMMDD format).

^bND=Not Detected (below limit of detection).

^cDNQ= “Detected but Not Quantified”. These samples were detected at levels less than 50 gc/100 mL but could not be reliably or repeatably quantified because they were below the environmental lower limit of quantification. The value in parenthesis next to DNQ is the estimated value of the qPCR result.

^dBird *Helicobacter* “GFD” values and seagull “gull2” *Catelllicoccus* values which do not meet the RBT just by themselves but are of sufficient level to exceed the risk threshold when also combined with the level of human “HF183” marker in the sample, are also bolded in this table. In addition, those Human “HF183” DNQ values in this table that might contribute synergistically to a combined human+bird fecal risk greater than 32 illnesses per 1000 exposures in a particular sample are also bolded in this table to highlight their potential combined risk contribution. However, these DNQ values should be viewed with some skeptical caution as these low DNQ values might also represent (at least in part) some background “noise” in the analysis since they are below the eLLOQ.

Table V.2: Means (arithmetic and geometric) and medians for the 78 samples submitted for MST analysis. Values provided for enterococci and for the MST markers (human, dog, bird, and gull). For computation purposes, samples measuring at detected but not quantifiable (DNQ) values were set at the 50 gc/100 mL estimated detection limit.

	Enterococci (MPN/100mL)			EnterolA (gc/100mL)			Human (gc/100mL)			Dog (gc/100mL)			Bird (gc/100mL)			Gull (gc/100mL)		
	Arith. Mean	Geo. Mean	Median	Arith. Mean	Geo. Mean	Median	Arith. Mean	Geo. Mean	Median	Arith. Mean	Geo. Mean	Median	Arith. Mean	Geo. Mean	Median	Arith. Mean	Geo. Mean	Median
Overall	38,136	2,318	11,199	532,972	20,046	18,204	137	33	ND	605	78	126	15,472	1,010	571	2,017	453	934
Groundwater	1,101	61	68	2,395	716	605	ND	ND ^b	ND	ND	ND	ND	386	254	220	ND	ND	ND
Stormwater	72,262	37,693	24,196	1,057,418	232,197	191,868	194	59	50	634	57	100	8,152	765	642	2,017	453	934
PVC	16,725	1,262	635	132,465	18,837	9,860	27	11	12	491	282	149	62,836	27,317	55,188	ND	ND	ND
KL + BBE	29,002	3,842	2,378	225,453	43,312	34,201	30	11	13	491	282	149	31,863	11,460	32,599	ND	ND	ND
Surface																		
PVC KL	3,872	1,912	2,035	5,473	1,163	4,889	62	DNQ	62	ND	ND	ND	55,842	54,300	58,014	ND	ND	ND
Surface																		
PVC KL	293	206	369	23,733	14,332	23,356	DNQ	ND	ND	ND	ND	ND	108,044	79,424	110,437	ND	ND	ND
1_foot																		
PVC KL	420	397	487	8,936	5,095	3,757	DNQ	ND	ND	ND	ND	ND	100,220	95,246	108,482	ND	ND	ND
5_feet																		
PVC BBE	44,080	5,839	2,720	346,485	84,099	255,555	9	5	6	491	282	149	17,476	4,506	7,482	ND	ND	ND
Outfall																		

^a DNQ=Detected but Not Quantified. These samples were detected at levels less than 50 gc/100 mL but could not be reliably quantified because they were below the lower limit of quantification.

^b ND=Not Detected (below limit of detection).

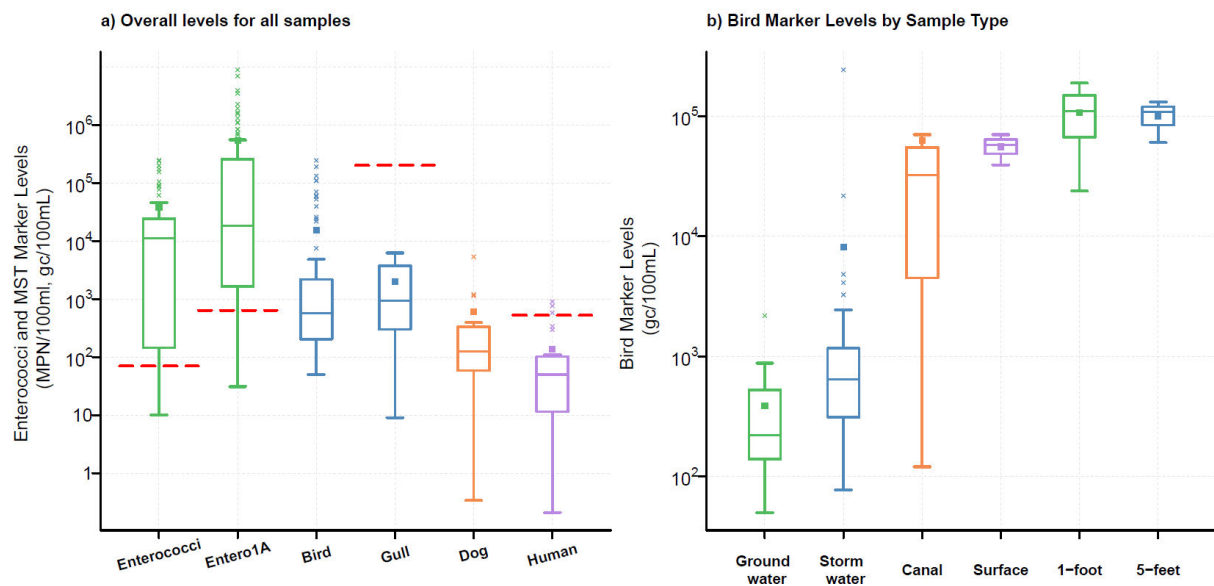


Figure V.1: Box and whisker plot of enterococci (by culture and qPCR) and MST marker levels (bird, gull, dog, and human). Overall levels (panel a) and levels of bird marker by sample type (panel b). For panel b, the canal samples include those from the BBE Outfall. For panel b, the samples labeled, “surface”, “1-foot”, and “5-feet” correspond to the sites from the PVC at the Kayak launch. Red horizontal lines correspond to risk-based thresholds. Two risk-based thresholds are shown for the bird markers, one for samples that show evidence of human marker (22,500 gc/100 L) and another that shows no evidence of human marker (200,000 gc/100 L).

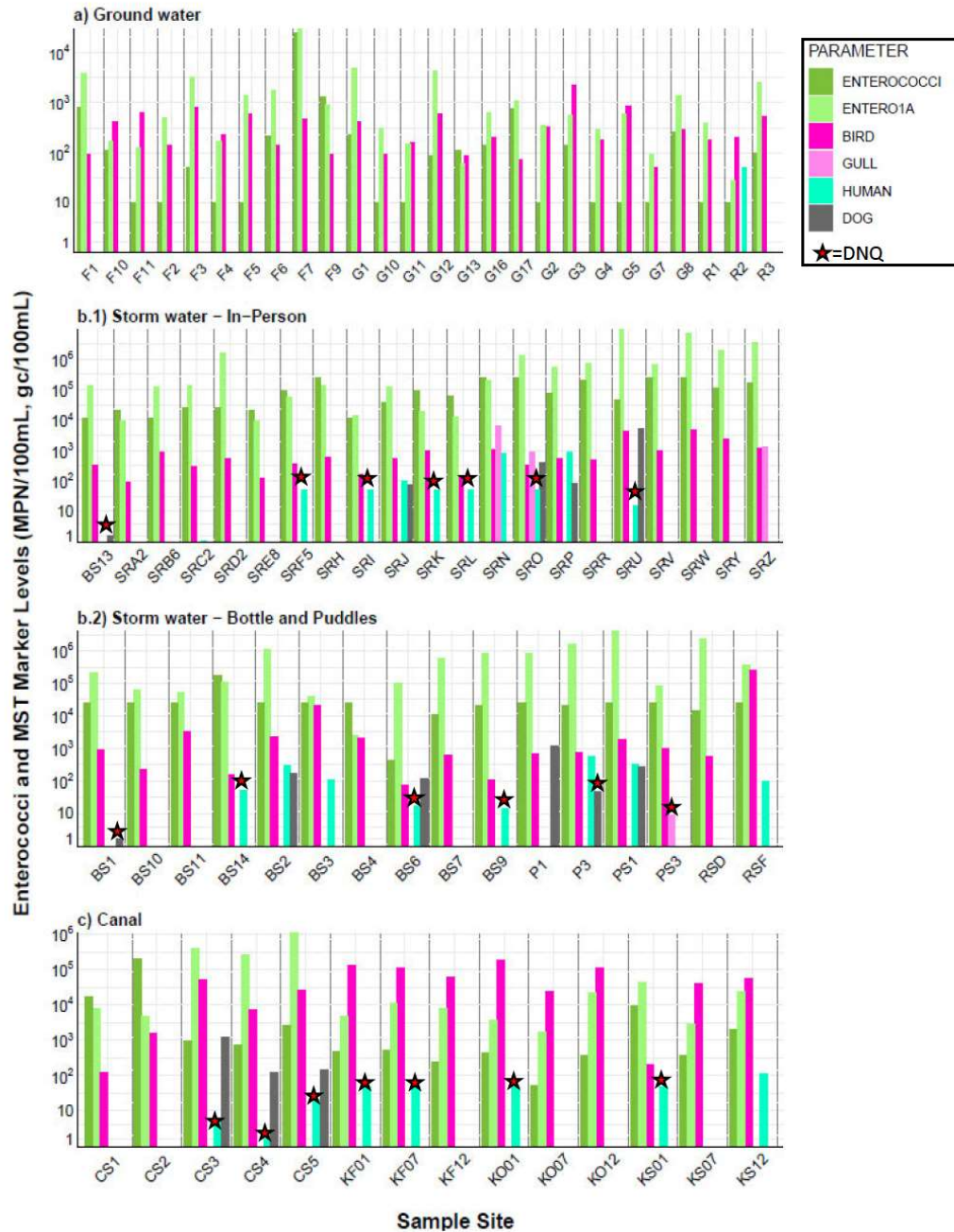


Figure V.2: Results from enterococci (by culture and by Enter1A qPCR) and MST measurements for bird, gull, human, and dog markers by sampling site. Data separated by sample type including groundwater (top panel), stormwater (middle panel), and PVC water collected at BBE and at the Kayak Launch (bottom panel).

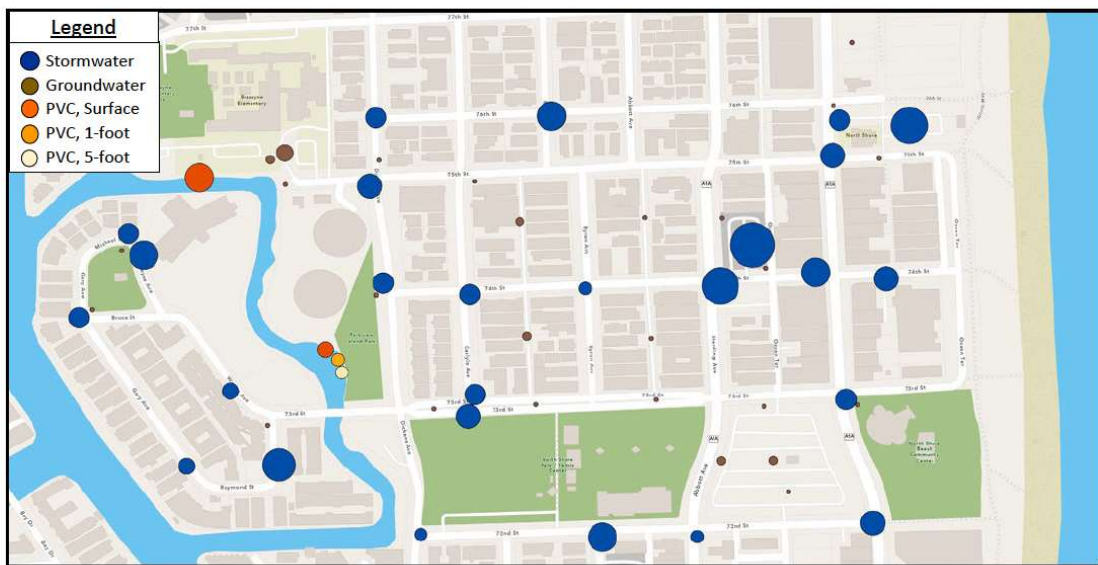


Figure V.3: Spatial distribution of enterococci (Entero-1A) as measured by qPCR.

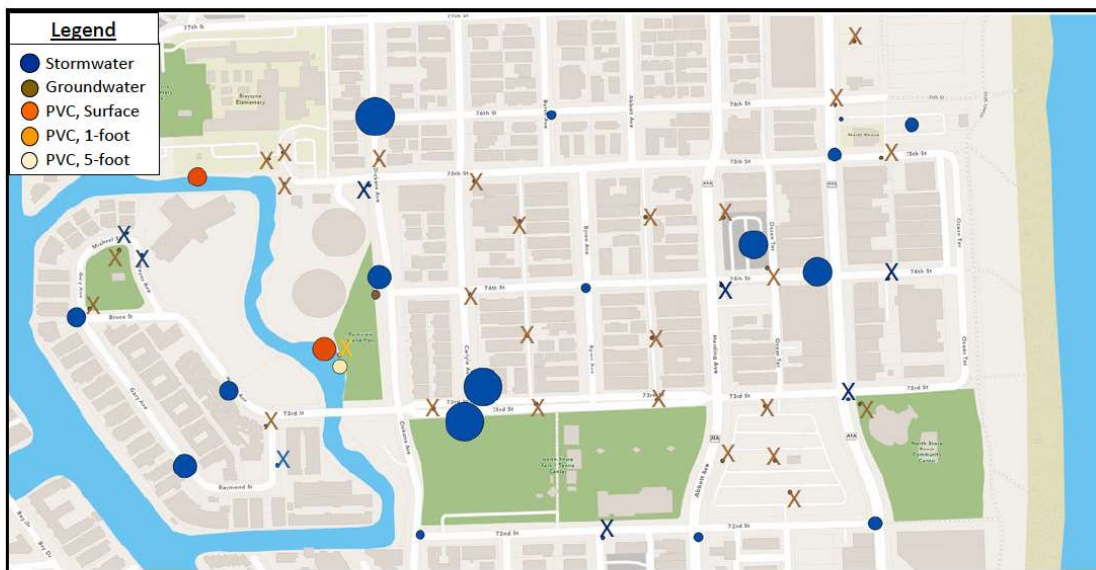


Figure V.4: Spatial distribution of human MST marker. The “X” symbol represents samples below the detection limit.



Figure V.5: Spatial distribution of dog MST marker. The “X” symbol represents samples below the detection limit.

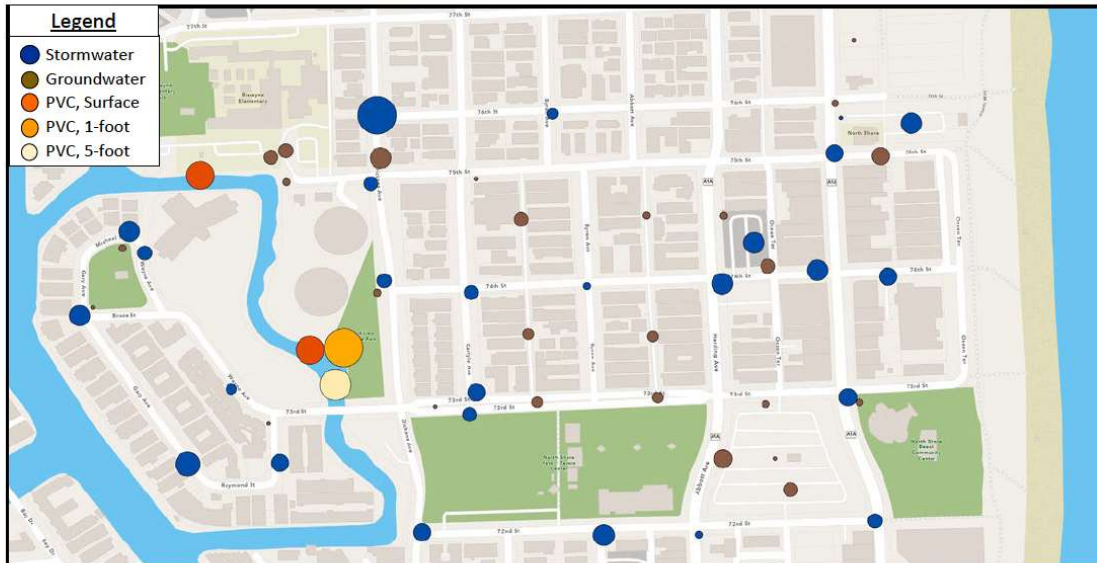


Figure V.6: Spatial distribution of general bird MST marker. The “X” symbol represents samples below the detection limit.

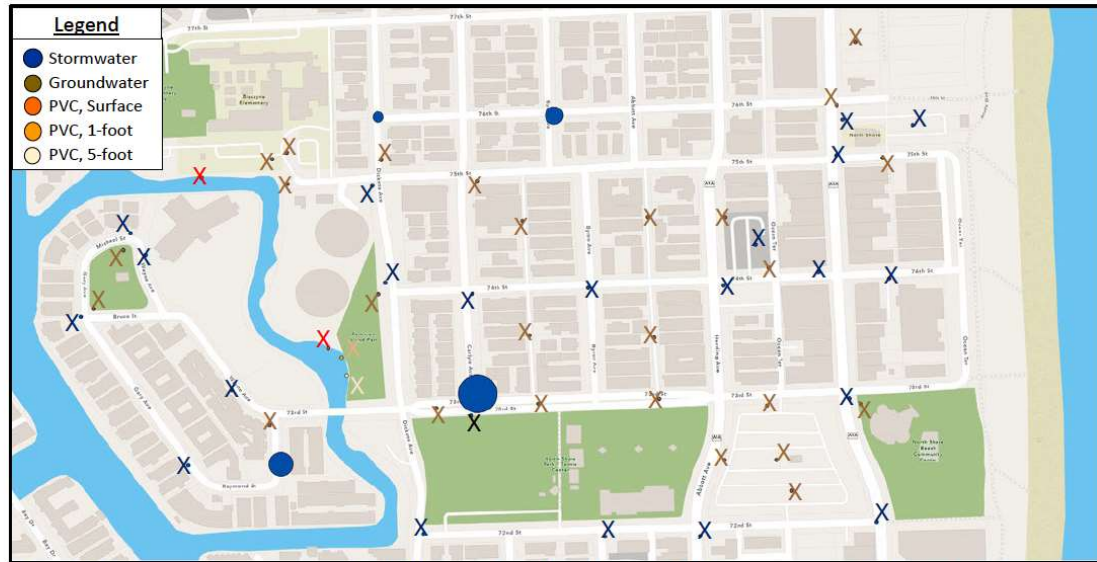


Figure V.7: Spatial distribution of gull MST marker. The “X” symbol represents samples below the detection limit.

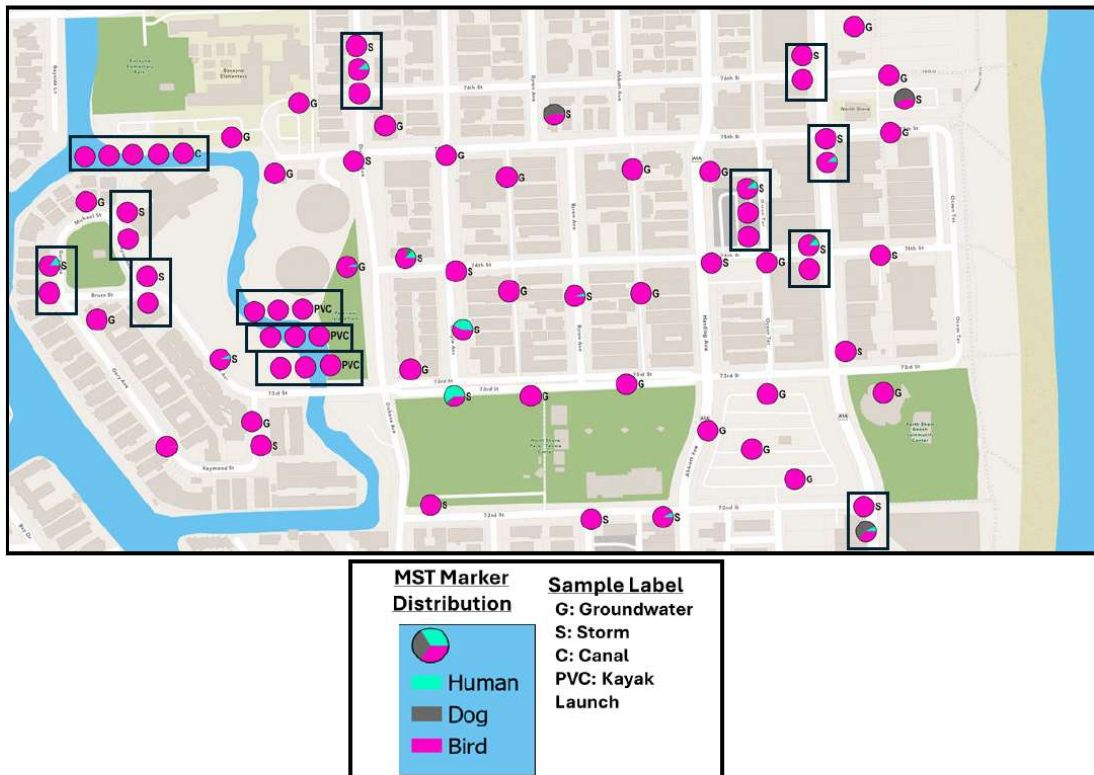


Figure V.8: Spatial distribution of human, dog and bird MST results emphasizing the relative amount of each marker. Spatial distribution of pie charts shown for samples collected from groundwater (shown by G symbol), stormwater (S), PVC at the BBE (C), and PVC at the Kayak Launch (PVC). Pie charts surrounded by a box correspond to samples collected at the same location but during different times.

V.3 CORRELATIONS AMONG ENTEROCOCCI AND MST MEASUREMENTS

To evaluate whether associations exist between the enterococci measurements (by culture and qPCR) and MST measurements, correlations (Pearson's and Spearman's) were evaluated. Details of the correlations analysis can be observed in Figure V.9. Results show that enterococci by culture and by qPCR were significantly correlated with Pearson's correlation coefficient, R , of 0.31 ($p<0.01$) and with a Spearman's correlation coefficient, r_s , of 0.79 ($p<0.0001$). Through the Pearson correlation, enterococci by qPCR was found to be correlated with the dog marker ($R=0.88$, $p<0.0001$). Three additional Spearman correlations were found to be statistically significant and included enterococci by culture and human marker ($r_s=0.53$, $p<0.001$), enterococci by culture and bird marker ($r_s=0.25$, $p<0.01$), enterococci by qPCR and dog marker ($r_s=0.64$, $p<0.01$) and enterococci by qPCR and bird marker ($r_s=0.38$), $p<0.001$).

A correlation among the two methods of measuring enterococci is expected since they are both measuring enterococci. The main difference is that enterococci by culture only measures live bacterial cells whereas enterococci by qPCR measures the target gene copies of both live and inactive bacterial cells. Further focus on the correlation and relationships between enterococci by culture and by qPCR is given in Figure V.10 for an arithmetic plot (panel a) and for a base-10 logarithmic conversion of the enterococci data (panel b). The arithmetic plot is consistent with the Pearson's correlation analysis ($R=0.31$). The logarithmic transformation of the enterococci which is common in the analysis of environmental fecal indicator bacteria data shows an improvement in the correlation with a Pearson's R of 0.81. The high correlation confirms the consistency among the different enterococci measurements.

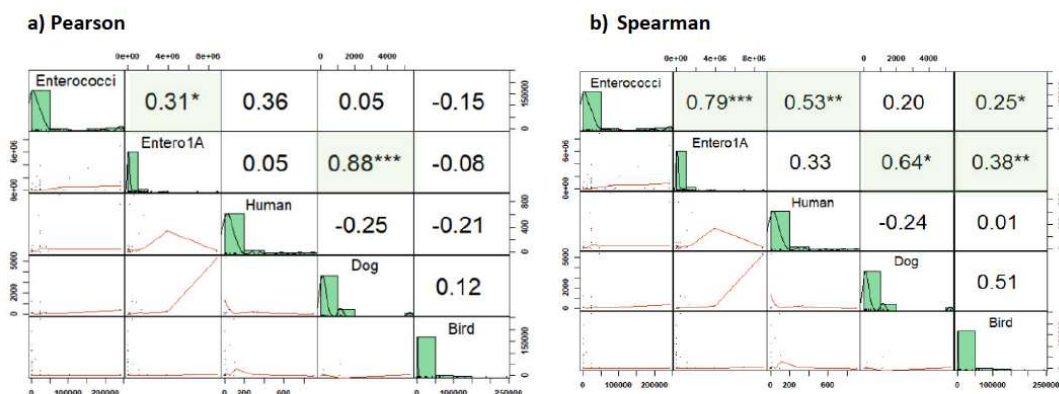


Figure V.9: Correlation plot between enterococci by culture and qPCR plus the MST markers (human, dog, and bird) for the 78 samples analyzed for MST. Gull marker was not included due to insufficient data points with numerical values. Pearson correlation coefficients provided in panel a, and Spearman correlation coefficients provided in panel b. Green shading indicates correlations that were statistically significant. Three stars indicate $p<0.0001$, two stars indicate $p<0.001$, and one star indicates $p<0.01$.

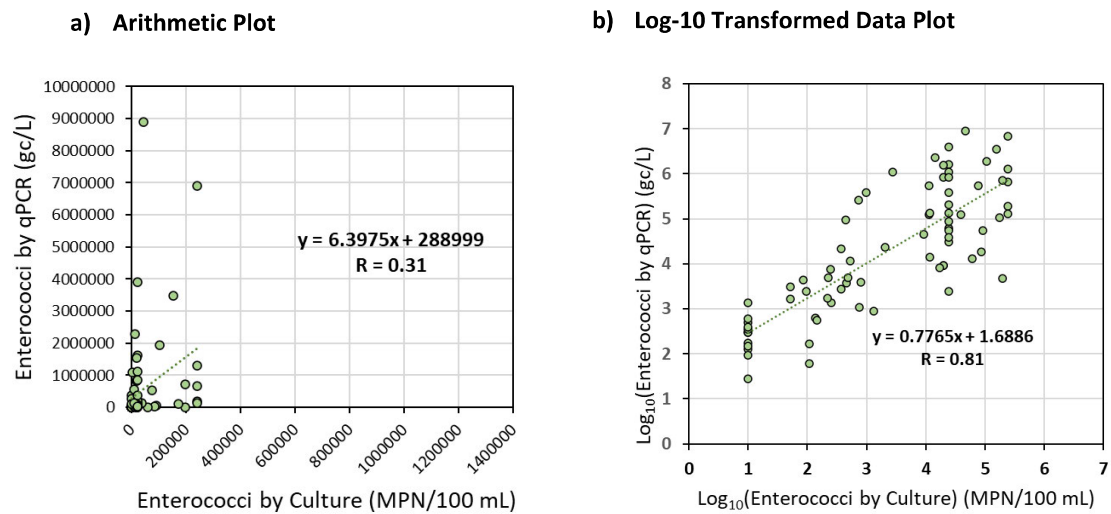


Figure V.10: Enterococci by culture versus enterococci by qPCR for the 78 samples analyzed for Entero1A marker, with an arithmetic plot (panel a) and Log-10 transformed data (panel b).

CHAPTER VI

OVERALL ASSESSMENT AND RECOMMENDATIONS

CHAPTER VI

OVERALL ASSESSMENT AND RECOMMENDATIONS

The recommendations below describe measures to reduce enterococci in stormwater at the street surface (Section VI.1), in the groundwater (Section VI.2), within the stormwater conveyance system (VI.3), within the PVC (Section VI.4) and to integrate treatment for fecal bacteria within long-term comprehensive stormwater planning (Section VI.5).

VI.1 REDUCE ENTEROCOCCI IN STORMWATER AT STREET SURFACE

To reduce enterococci levels in stormwater we recommend the reduction of dog fecal waste (VI.1.a), reduce the human fecal waste impacts to stormwater (VI.1.b), make corrective actions to reduce enterococci from the BBE outfall (VI.1.c), and reduce trash and rainwater in contact with trash (VI.1.d)

VI.1.a Reduce Dog Fecal Waste Impacts to Stormwater

We encourage the following tasks to help minimize dog fecal waste.

- **Community Outreach.** CMB public education efforts are commendable as evidenced by its easy-to-use web site (<https://www.miamibeachfl.gov/engagementtoolbox/>), mobile apps used for communications purposes, and signage to encourage dog owners to pick up pet waste. The CMB communicates the need for dog owners to pick up after their dogs through publications in the CMB Newsletter, signage, doggie bag/bin stations, and public outreach in English and Spanish. Dog friendly events, such as Yappy Hour, held in October each year serve as opportunities for the CMB to encourage dog owners to pick up after their dogs.
- **Actively Enforce Dog Waste Disposal.** CMB Code Compliance continues focusing on proactive patrols while enforcing the cleanup of pet waste. These efforts should continue.
- **Additional Dog Waste Stations.** In addition to the numerous dog waste stations at Parkview Island Park, during August 2024, the CMB added 5 additional dog waste stations throughout the catchment. These new stations were installed at: 74th Street & Carlyle NW Corner, 74th & Harding Ave, 73rd & Byron Park Side, 7141 Dickens Ave, and 73rd & Dickens SW Corner. Given the observation of dog MST marker at 76th Street and Byron, we recommend an additional dog waste station at this location.
- **Completion of the Dog Park.** The CMB has plans for a dog park to include a vegetation buffer to reduce dog waste from entering the canal. Currently, many dog owners walk their dogs through Parkview Island Park along 72nd Street and Dickens but the park is not currently designed to minimize runoff of dog waste into the canal and storm drains. Completion of the dog park will help to properly contain dog fecal waste. We recommend the park be designed to assure a first flush treatment of the stormwater from the park. Upon the completion of the dog park, we recommend making extra efforts at dog waste cleanup through frequent inspections and cleanup for dog waste sanitation.
- **Reduce Other Animal Sources.** Other sources of animal waste should be considered, such as waste from iguanas, racoons, and other animals. The CMB has addressed other potential animal sources through removal of animal feeding stations, signage to the public to not feed wildlife, and staff monitoring of the Parkview Island Park and enforcement of park hours. Despite the signage and enforcement to reduce feeding of wildlife, an animal feeding station (which attracted a flock of birds)

was observed during a January 2025 visit to the PVC (See Figure C.18 in Appendix C). The CMB staff have been aware of attempted continued efforts towards animal feeding stations which they acknowledged have been difficult to police. Regardless, efforts should continue to eliminate animal feeding stations and to reduce fecal waste from non-native wildlife.

- **Continue with Aggressive Street Sweeping Activities.** Through discussions with the superintendent of sanitation for the CMB (Alvaro Rueda), we confirmed that street sweeping activities have increased. There are two forms of street sweeping that involve the removal of solids which are disposed as solid waste: mechanical and manual. Mechanical street sweeping frequency is 3 times per week throughout the catchment. Manual street sweeping occurs 3 times per week on Parkview Island and 1 time per week through the remainder of the catchment. Manual street sweeping is conducted on paved areas curbside using a broom and dust pans (by the CMB litter crew).
- **Consider Expanding Cleanup Activities.** In addition to street sweeping, the CMB should consider adding “poop scoopers” to manual clean-up efforts. The areas cleaned should include grassy areas where visible dog waste is observed. Poop scoopers for grassy areas can include manual devices or devices that can be dragged.
- **Consider Disinfection.** The CMB should also consider the possibility of technologies to disinfect grassy areas and streets after the dog waste is picked up. UV disinfection devices are available for disinfecting yoga mats and studio floors. We recommend applying these same devices to disinfect streets, and grassy areas. The disadvantage of UV light is that it disinfects areas that are accessible to light only. Additional liquid disinfectants should also be considered to penetrate areas not accessible by UV light. The disadvantage of liquid disinfectants are chemical residuals that can impact ecosystems. Studies should be considered to evaluate technologies for disinfection of grassy areas and streets.

VI.1.b Reduce Possibility of Human Fecal Waste Impacts to Stormwater

There is evidence that human fecal waste is contaminating stormwater. The source can come from direct defecation or indirectly through sewer overflows. We therefore recommend the following to address this source.

- **Conduct Study to Learn More About Homeless Populations.** Data showed that human MST was most predominant in the corridor connecting the parks located within Park View Island and the southeast corner of the North Shore Park and Tennis Center. Additional human marker hot spots were observed near parking lots in the center and northeast corner of the catchment. The movement and habits of the homeless in this area should be investigated to better understand the need for sanitation facilities in this area. The homeless in this area should be interviewed to ask about sanitation facility usage during park hours and after hours. Attention should be given to identifying possible locations of encampments, inclusive of the bridge at 73rd Street.
- **Access of Homeless Populations to Sanitation Facilities.** Unlike the prior 2022 study, during the 2024 study the research team did not observe homeless encampments along the PVC. Since 2022, Parks & Recreation continues their roaming patrols, and Environment & Sustainability staff alongside the Public Works Operations team continue to work with Homeless Outreach on their increased routine site visits. Efforts to relocate homeless living along the canal appear to be effective. However, homelessness was observed during 2024 within the broader catchment area. These homeless populations do not have access to sanitation facilities. The waste from these individuals will be carried by stormwater runoff towards the PVC. We recommend that the CMB expand its efforts to provide access to sanitary facilities.
- **Conduct Study to Learn More About Usage of Existing Sanitation Facilities at Parks and at Commercial Establishments.** A study should be conducted about when and by whom the sanitation

facilities are used at the parks. Additionally, workers at commercial establishments should be interviewed about policies allowing non-staff workers usage of available sanitation facilities, especially during non-park hours when public facilities may be closed. The workers at commercial establishments should also be interviewed about the frequency with which non-staff request the use of the sanitation facilities. This information will be helpful to determine whether access to public sanitation facilities should be extended within the catchment.

- **Increase Access of General Populations to Sanitation Facilities.** Access is needed to sanitation facilities. Populations visiting the area may have difficulties in finding facilities. In fact, it was common for members of the research team to be denied access to bathroom facilities at commercial establishments. Access to public facilities (e.g., the Youth Center) is available only during Center hours.
- **Avoid Sewage Backups through Sewage Water Level Monitoring.** We recommend that the CMB invest in technologies that can detect sewage backups. The CMB has evaluated the installation of “smart” manholes fitted with water level recorders which can provide early warnings of sewage backups. The reduction of sewage backups would minimize sewage spillage onto the streets which ultimately enters the stormwater conveyance system. During May 2023, CMB Public Works installed two SmartCover® devices in manholes in Parkview Island to monitor sewer levels to avoid sanitary overflows.
- **Avoid Sewage Backups through Grease Trap Enforcement.** There are a total of 51 grease traps documented in the catchment. Grease trap operations are inspected and monitored through the Building Department the CMB through the FOG (Fats, Oils and Grease) program. Systems out of compliance are notified to Miami-Dade County DERM for code enforcement.
- **Disinfect Streets after Sewage Backups.** When sewage backs up, it flows up through the manhole covers, onto the street, and towards the stormwater system for drainage. In the process, the backed-up sewage will contaminate the sediment on the streets providing for a sustained source of human fecal contamination. The CMB has a Sanitary Sewer Overflow Response Plan (CMB 2022) which includes immediate 24/7 emergency response through on-call staff. Clean up after the spill is to include removal and/or decontamination of soil/plants and application of bleach or hypochlorite to disinfect surface areas except in areas where it might be washed into surface waters. We recommend that the CMB consider how to disinfect surface areas that may wash into surface waters. The disinfection should not result in chemical residuals that may impact the ecosystem that receives the stormwater. The use of hydrogen peroxide (degrades to oxygen and water), use of alcohol disinfectant sprays for small areas, and UV light for surface disinfection should be considered. One advantage of liquids is that they can penetrate areas that are not accessible by light. The advantage of UV light is that it does not cause a chemical residual. Studies should be conducted to evaluate additional methods of disinfecting streets after sewage backups.

VI.1.c Corrective Actions to Reduce Enterococci from the BBE Outfall

Given the distribution of the enterococci within stormwater runoff and groundwater, we have identified the BBE as a priority area for investigation for enterococci levels. Specifically, we recommend that:

- **The CMB works with Miami Dade County Public Schools (MDCPS).** The CMB should work with MDCPS to inspect the BBE stormwater and sanitary systems to address the hotspot observed in groundwater near the BBE and from the stormwater outfall from the MDCPS property. The CMB has been in communication with representatives from the MDCPS Division of Safety and Emergency Management and with the MDCPS Department of Regulatory Compliance. MDCPS have since provided detailed plans about the sanitary and stormwater infrastructure on their site. They are working

with the CMB to inspect areas which are high risk as potential enterococci sources. These high-risk areas include three vertical stormwater wells on-site, a 6-inch cast iron gravity lateral pipe carrying wastewater, a grease trap, and two stormwater conflict structures. One stormwater conflict structure includes the 6-inch cast iron gravity lateral sewer line. The other stormwater conflict structure includes a sanitary force main. Although these structures are designed to keep sanitary sewage separate from storm water, they should be inspected to confirm no leakage. In addition to numerous meetings held virtually, the staff from the CMB met with staff from MDCPS in person at the BBE outfall site on January 31, 2025 to discuss plans for inspection and continued maintenance. MDCPS is required to maintain its stormwater system as per County Class II permit, to avoid PVC water quality degradation.

VI.1.d Reduce Trash and Rainwater in Contact with Trash

Trash and rainwater in contact with trash (leachate) is a source of fecal indicator bacteria. Efforts should focus on minimizing the amount of loose trash within the catchment and within the stormwater conveyance system through the following approaches.

- **Increase Frequency of Trash Pickup from Public Bins.** Currently litter is picked up once a day from public trash bins. No overflowing public trash bins were observed during this study. However, depending upon the events within the area, pick up may need to be adjusted to avoid overflow of trash bins.
- **Assure that all Public Bins have Rain Domes.** To avoid contact with rainwater, all public trash bins in the area should be fitted with rain domes which are designed to eliminate rainfall from contacting the trash. The CMB has since fitted public trash bins in the area with rain domes.
- **Minimize Impacts from Commercial Trash Bins.** Commercial trash bins should remain covered and undischarged washings from such bins should not enter the stormwater conveyance system.
- **Encourage Homeowners to Keep Trash Bins Covered.** The CMB has included messaging about covering trash bins in its public outreach announcements including on the CMB website. (See Community Updates at: <https://www.mbrisingabove.com/climate-adaptation/biscayne-bay/park-view-canal-water-quality/>)
- **Enhance Trash Pickup within Public Areas.** Trash pickup should be included as part of street sweeping and street cleaning initiatives. Although not much trash was observed on the streets, trash should be picked up when seen from all public areas.
- **Avoid Landscaping Trash in Catch Basins.** Leaf blowers should not push gardening debris towards the catch basins as this will clog the catch basins and contribute nutrients that will encourage the persistence of fecal bacteria.
- **Inspection of Catch Basins on a Regular Basis.** Trash that is not picked up will be washed into the stormwater catch basins. Catch basins should be inspected on a regular basis to remove trash for the purpose of eliminating this source of bacterial contamination. Frequent trash removal from catch basins has the added benefit of reducing flooding risks.

Targeted Public Outreach. Targeted public outreach is to continue towards commercial kitchens and restaurants. They are to be informed not to use public streets and alleys to clean dumpsters, mats, and equipment. This is considered littering of streets and illegal dumping into stormwater system as contaminated cleaning water will drain into stormwater inlet. CMB Code Enforcement is to work with business owners to confirm how dumpsters are managed.

VI.2 REDUCE ENTEROCOCCI IN GROUNDWATER

Efforts should continue in inspecting and eliminating any potential leaks from the sanitary sewer system into groundwater. Below are general recommendations (VI.2.a) and recommendations specific to the groundwater hotspots found in this study (VI.2.b).

VI.2.a General Recommendations to Reduce Enterococci in Groundwater

- **Maintenance of Sanitary Force Main Air Release Valves.** During the prior study, between January and February 2023, force main air release valves were replaced or removed by the in-house CMB crews due to observed leaks. Since then, the CMB has developed a Force Main Leak Detection Program led by approved vendors and the CMB Public Works Engineering Division. The latest inspection, during September 2024, included using acoustic/sonar technology to provide an added level of inspection. During the September 2024 inspection, all air release valves, and force mains (21.5 miles inspected) were intact and operating properly with no leaks (Utility Services Associates, 2024).
- **Additional Monitoring of Wastewater Force Mains for Pressure Drops.** The CMB has a pressure gauge system that is integrated into a SCADA (supervisory control and data acquisition) system. Throughout the CMB, all lift stations are fitted with both digital and analog pressure gauges to detect pressure drops which indicate potential leaks in the system. Additionally, field staff perform preventative maintenance on all lift stations seven days a week. Maintenance includes ensuring that both digital and analog pressure gauges are functioning as mandated.
- **Continue with Aggressive Maintenance of Sewer Pump Stations.** The CMB has prioritized North Beach for aggressive sewer pump station maintenance. CMB Public Works has completed the maintenance of sewer Pump Station no. 21 during December 2021, Pump Station no. 23 in February 2023, Pump Station no. 19 in February 2024, and Pump Station no. 22 during mid-2024. Additionally, Pump Station no. 19 force main (discharge line) replacement is currently in the final permit phase with construction to start February 2025. Pump Station no. 22 force main replacement is under design and permitting with construction to start mid-2025.
- **Continue Sanitary Sewer Pipe Lining.** The City completed more than \$640K of Phase 1 Park View Sewer Trenchless Rehabilitation upgrades and sewer force main air release valve replacements. The Public Works Department completed pipelining to 95% of the gravity sanitary sewer pipes and 98% of the manholes in Park View Island during fiscal year 2023. The rehabilitation of Pump Station No. 23 wet well located on 75th Street adjacent to the PVC has been completed during the last quarter of 2024. As part of Phase 2 North Beach and Park View Extended Area, more than \$2.5 million of upgrades have been set aside for improvements to the sanitary sewer system including lining 90% of the sewer lines from 73rd to 76th Street, rehabilitating manholes, rehabilitation of all North Beach the pump station wet wells and planning for a force main replacement. As of mid-November 2025, all tasks associated with the Phase 2 North Beach and Park View Extended Area project were completed except the wet well rehabilitation of the sewer Pump Stations no. 19 and 21. The wet well rehabilitation of Pump Station no. 19 (69th Street and Indian Creek) will be completed mid-December 2024 and Pump Station no. 21 wet well will be coordinated for the early 2025 dry season.
- **Reduce Infiltration and Inflow into the Sanitary Sewer System.** Reduction of infiltration and inflow will help to maintain the capacity of the sewer and result in fewer backups due to limited capacity. The CMB has been conducting work towards reducing infiltration and inflow into the sanitary sewer system (Hazen 2022a). The focus has been on rehabilitating manholes, gravity mains, and laterals. Techniques utilized include night flow isolation, camera inspections (CCTV), manhole inspections, and smoke testing. A study specific to Parkview island (Hazen 2022b) found multiple gravity sewer pipes in need of cleaning and repair. These pipes have been repaired by lining the sewers to reduce leaks. This study

focused on gravity sewers within the public right-of-way and did not evaluate the integrity of sewer laterals on private property.

- **Continue Searching for Sanitary Sewer Leaks.** The CMB has conducted considerable work towards identifying potential sewage leaks. Work should continue in sanitary sewer inspections and stormwater conveyance system inspections, especially those that evaluate the potential cross connections between the sanitary sewer and storm conveyance system. Techniques used by the CMB include evaluation of the proximity of the systems through GIS and evaluation of construction drawings, dye testing, camera inspection (CCTV), acoustical testing, and smoke testing.
- **Continue Water Sampling Efforts.** Sampling and water quality analysis is conducted routinely by the CMB. Additionally, the CMB has contracted special studies to identify sources of contamination. These include a contract with ESciences which sampled the catch basins, and with Source Molecular for the analysis of source tracking markers. They have also contracted two studies through the University of Miami including this current one which includes source tracking.

VI.2.a Location Specific Recommendations to Reduce Enterococci in Groundwater

Groundwater measurements showed the highest hot spot close to the BBE. The next highest spots were along 72nd Street. Recommendations for how to address each hot spot are as follows:

- **Address the hot spot at the BBE** through cooperation with Miami Dade County Public Schools (MDCPS). Additional details in Section VI.1.c above.
- **Address hot spot in the middle of the parking lot between 72nd and 73rd Street between Harding and Collins.** This hot spot is located within an area of intense underground wastewater infrastructure with the capacity of moving wastewater to a historic outfall that extended into the bay at 74th Street. This infrastructure is old and in need of replacement. The new proposed community center for this area (72nd Street Community Complex) includes plans for an Olympic-sized roof-top swimming pool, a warm-up pool, library and media center, community room, fitness gym with running track, greenspace, and multi-level parking. The construction of the complex will result in the removal of the historic wastewater infrastructure within the existing parking lot through the creation of a bypass around the complex along Harding Avenue. If the complex is constructed, the sewage system will be completely replaced. In terms of the timeline, 30% of the design plans, with a cost estimate, were submitted at the end of October 2024. The application to the design review board will likely happen early 2025. The construction budget is estimated at \$70M, and it will likely be funded by a General Obligation Bond.
- **Additional hotspots were observed in groundwater along 73rd Street at Wayne Street and at Dickens Avenue.** These sites are near sites where human MST marker was observed in the stormwater. It is possible that stormwater is contaminating the groundwater at these locations. This specific area should be further studied to evaluate the movement and habits of homeless populations in this area, with frequent inspections of the area under the bridge at 73rd Street for possible homeless encampments. The search for possible sanitary sewage contamination should also continue in this area.

VI.3 REDUCE ENTEROCOCCI WITHIN THE STORMWATER CONVEYANCE SYSTEM

The catchment contributing towards the PVC is highly urbanized with a significant amount of impervious area with disproportionately small areas available for natural treatment or attenuation of contaminants carried by runoff. Due to this situation, the catchment is unable to naturally cleanse itself and will rely on human intervention or actions to reduce levels of enterococci in runoff that is carried towards the PVC. Below are recommendations for actions that can be taken to reduce enterococci through improvements to the stormwater conveyance system.

- **Evaluate Approaches to Increase Pervious Areas.** Common ways to treat the first flush involve letting the first portion of the rainfall-runoff enter a detention area where particulates settle. Other designs are based upon the use of grassy swales to retain the first flush. Given the lack of space for stormwater retention, consideration should be provided towards replacing impervious areas with pervious systems, such as pervious concrete, that allow for runoff treatment.
- **Treat the Stormwater First Flush through a Short-term Solution.** The CMB has plans to add hydrodynamic separators to the stormwater conveyance system as a means of reducing the sediments discharged into the PVC. A notice to proceed has been issued, and a kickoff meeting was held September 2024. The permit will be submitted to DERM during February to March 2025. A two hundred-thousand-dollar budget has been allocated for the design and permitting support. The CMB has allocated \$2M in its capital plan. The scope of services includes retrofits to seven of the major stormwater outfalls that flow directly into the PVC. The completion target date for this work is 2026.
- **Treat the Stormwater First Flush through a Long-term Solution.** The CMB was awarded a \$10M Florida Resilient Grant for the design and permitting of a Neighborhood Improvement Project (North Shore D Neighborhood Improvement Project). This includes a proposed stormwater conveyance system that will replace the existing stormwater pipe network from 69th Street to the south to 73rd Street to the north and from the PVC to the west to Collins Avenue to the east. The stormwater conveyance system is currently projected to include new catch basin structures, manhole structures, conveyance piping, injection wells (to treat the first flush), and up to two stormwater pump stations. The stormwater pump stations will be configured to include upstream water quality filtration and treatment to treat the first flush of contaminants in the form of bar racks, vortex water quality structures, and up flow stormwater quality cartridge filters. Additionally, energy dissipation structures will be constructed downstream of the pump stations prior to discharge into adjacent canals to prevent damage to the existing plant life and canal bottom. The stormwater system will also be fitted with back flow prevention devices to prevent backflow of tidal waters into the stormwater system. The scope of this project also includes the replacement of adjacent potable water and sanitary sewer conveyance, distribution, and transmission systems. The aerial potable water and sanitary sewer pipe crossings at the 71st street bridge immediately south of the PVC will be replaced with subaqueous crossings under the scope of this project. The CMB is applying for additional grants and completing a rate study to secure construction funding. The CMB is working towards a completion target date of 2028. More details about this project is available at: <https://www.miamibeachfl.gov/residents/neighborhood-affairs-division/active-projects/neighborhood-improvements/north-shore-d-phase-one/>
- **Remove Illicit Connections.** Illicit connections are those that are not composed of stormwater or composed of stormwater from private property. Private property is to retain its own rainwater. Illicit can also flow during dry weather due to connections with other sources of water and examples can include water from car washing, clothes washing, and inadvertent cross connections with sanitary sewage. The CMB is currently working with the legal authority (County/DERM) on illicit discharges from outfalls. A list of illicit connections from private storm systems to public sewer systems is provided biannually to DERM and CMB continues to actively notify the environmental regulatory authorities. Connections prior to 1984 (when DERM was established) have been grandfathered. It is our understanding that these grandfathered connections can only be legally addressed when the facility with the connection goes through its 40-year recertification. In the meantime, the CMB will continue to refer these connections to DERM and will press the county for a resolution.
- **Private property stormwater system best management and maintenance practices.** Private property owner shall hold Class II permits with Miami- Dade County and use best management and maintenance practices to avoid further degradation of the PVC.

VI.4 REDUCE ENTEROCOCCI WITHIN THE PVC

In addition to limiting inputs of enterococci through runoff and possible sanitary sewer leaks, efforts should also focus on improving the conditions of the PVC to facilitate the reductions of enterococci once received by the waterway. Efforts to reduce enterococci internal to the PVC are as follows:

- **Dredging of the PVC.** The purpose of dredging is to improve flushing and remove sediment and marine debris. The CMB has committed about \$500,000 in designed fees for canal-based restoration/dredging efforts (contract to TYLin with hydrographic/bathymetric survey by M.G. Vera and Associates). The project is currently in the design phase. The bid documents for this project should be available by January 2026 with project mobilization by June 2026 and completion by January 2027. The cost for design and permitting is \$500K. The dredging is estimated at \$2 million.
- **Improve Shorelines.** To limit the erosion of sediments and transport of trash by runoff along the shoreline, we recommend protecting the shoreline by increasing vegetation cover, inclusive of mangroves and other plant species, which act as deterrents to the public accessing the PVC. To address this issue, the CMB acquired Cummins Cederberg to conduct a Nature Based Shoreline Assessment (CCI 2021) that selected the most viable locations for living shorelines within the sites of CMB-owned seawalls. Ten locations were identified, two of which are directly adjacent to the PVC. The Cummins Cederberg study showed that the 2,460-foot shoreline along the PVC is densely packed with mangroves. The living shoreline project will remove invasive vegetation, repair and rehabilitate damaged seawalls, and mitigate coastline erosion. The CMB had applied for an earlier grant through the NOAA Transformational Habitat Restoration and Coastal Resilience Grants program. This earlier application was not awarded. The CMB, however, has since received a federal appropriation agreement for \$963K which will be used towards the Design of the North Beach Living Shorelines Project which is to include the PVC plus Bayside Lane and 6860 Indian Creek Drive. These funds will be used to acquire engineering and design professional services to complete coastal and civil engineering analysis, preparation of plans and specifications, plan formulations, engineering calculations, and other necessary studies.
- **Conduct Bird Study Focused on the Channel Banks and Fecal Waste Throughout the Catchment.** The MST results support that a major cause of elevated enterococci in the PVC is due to birds. A study is recommended to document the number and type of birds, which nest and forage along its banks, that contribute directly to the waterway. The mitigation measures for the birds will depend upon the type of birds found and through an understanding of what is attracting the birds to the area. In addition to concentrating efforts within the PVC, a study should be conducted throughout the catchment. Of interest would be to inspect roof tops for evidence of bird nests and waste, perhaps using drones. If nesting birds are found on roofs, bird deterrents should be considered in efforts to minimize contamination of roof runoff by bird fecal waste. If migratory birds are found to be the likely contributor, of interest would be to conduct sample analyses over different seasons to determine possible relationships with bird migratory patterns. In addition, efforts are to continue to eliminate illicit bird feeding stations which have been observed to continue (despite enforcement) within the watershed.
- **Continue with Water Quality Monitoring.** The CMB regularly monitors the PVC at the Kayak Launch site for fecal bacteria (enterococci and fecal coliform) monthly, inclusive of measurements of nutrients (Total Phosphorus, Nitrogen as Nitrate+Nitrite, Kjeldahl Nitrogen and Ammonia) and basic physical-chemical parameters (water temperature, pH, dissolved oxygen, salinity, and specific conductivity). Miami Surfrider is also monitoring the PVC for enterococci at the same site on a weekly basis. The CMB has also contracted with consultants and the University of Miami to conduct intense sampling programs aimed at identifying the source of elevated bacteria.

VI.5 LONG-TERM COMPREHENSIVE STORMWATER PLANNING

Long-term comprehensive stormwater planning should include the integration of methods to treat for fecal indicator bacteria. The most recent comprehensive long-term stormwater and sanitary sewer plans that address water quality are listed below.

- **Stormwater Master Plan.** The CMB had initiated through its Stormwater Master Plan Update and Capital Improvement Plan a critical needs analysis to be addressed by the City over 10 years. The plan has taken several criteria into consideration including stormwater flooding, tidal flooding, water quality issues, and resident complaints. The Stormwater Master Plan was presented to City Commission in November of 2023 and approved by the City Commission on March 2024 (<https://www.miamibeachfl.gov/wp-content/uploads/2024/03/Miami-Beach-Prioritizes-95-Million-in-Infrastructure-Improvements.pdf>). The Master Plan prioritizes 20 projects (\$95M) in infrastructure improvements. Within the 20 recommended critical needs projects two projects (North Shore B&C at Dickens Ave ranked 9 and North Shore at Byron Avenue ranked 11) are listed. Among the five on-going water quality projects, one of the major outfalls to the PVC is ranked 3. Among the 14 neighborhood improvement projects, North Shore D & Town Center Improvements is ranked 5. Plan details are available at: https://www.mbrisingabove.com/wp-content/uploads/March_13_2024_CMB_Commission_Presentation_SWMP-1.pdf.

VI.6 SUMMARY AND RECOMMENDATIONS

The PVC is a waterway that is restricted in terms of its flow. It is a canal located within a canal located in north Biscayne Bay which suffers from poor water quality. The PVC receives stormwater from a large area (81.3 acres) and thus, contaminants tend to remain within the waterway and are not flushed readily from the system. Superimposed on the limited dilution capacity is an outdated stormwater infrastructure that was not designed to retain the first flush of contaminants.

In response, the CMB greatly increased the intensity of efforts to control enterococci sources between August 2022 and February 2023. Improvements in water quality were statistically significant when separating the data between before and after these time periods. We also observed a decrease in baseline levels of enterococci between storm events from thousands of MPN/100 mL during 2022 to hundreds of MPN/100 mL during 2024. Of particular significance is the reversal in the trend between storms where during 2024, the highest enterococci levels were observed during high tide, suggesting that groundwater may no longer serve as a primary source of enterococci. Although measurements made during 2024 show improvements in water quality, the levels of enterococci observed in the PVC are still elevated beyond levels considered safe for swimming and for kayaking.

Results from the current study which aimed to identify sources of enterococci within the watershed found very high levels of enterococci within stormwater collected at street level. The highest levels of enterococci in stormwater coincided with quantifiable levels of dog and human fecal waste. Birds were found to be a significant contributor within the PVC. We made several recommendations for the CMB to further work on identifying and eliminating bird, dog, and human waste. Among these three sources, human waste is most concerning given that it was detected in stormwater suggesting the intermittent presence of human waste within the streets. We therefore recommend studies to better understand sanitary facility needs in the area for homeless populations and others who visit the catchment. Once the needs are known, mitigation strategies can be implemented to reduce and/or meet the need.

In the long term, improving the circulation of the PVC (through dredging) and the installation of stormwater treatment processes that include trash racks, sediment vortexers, and beyond would be the most impactful. These improvements, however, require considerable investments and time for design, permitting and construction. In the short term, the CMB should continue its aggressive education and outreach efforts to dog owners, homeless populations, commercial establishments, and the community at large to minimize enterococci contributions on an individual level. Additionally, the CMB should maintain its high frequency of street sweeping and trash collection. We recommend that the CMB go a step further and consider “deep cleaning” which would include dedicated clean-up of visible waste from grassy areas and consideration of disinfection of street surfaces and grassy areas especially after sewage spills. Given that bird fecal waste markers were observed throughout the catchment and especially within the PVC, efforts are needed to better understand the types of birds within the area and what may be attracting them. Once known, mitigation measures can be determined for addressing bird fecal waste. In addition to addressing potential sources of bird, dog, and direct human waste, the CMB should continue its aggressive efforts at monitoring and maintaining the sanitary sewer system to minimize the possibility of impacts from leaks. In addition to continued inspections and lining of the sanitary sewer system, the revamping of the sanitary sewer mains that are part of the proposed 72nd Street Community Complex would also be of benefit by providing a sanitary sewer system that is more robust and less susceptible to leaks. The City should continue to work closely with MDCPS to confirm that the school’s stormwater conveyance and sanitary sewer systems are intact and operating as originally designed.

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APPENDICES

APPENDIX A

HISTORICAL DATA

(CMB AND SURFRIDER)

Table A.1: Concentration of enterococci in samples collected monthly by the CMB from PVC Kayak Launch from 4/17/2019 to 9/30/2024 with fecal coliform and other physical chemical parameters recorded including nitrogen (Nitrate+Nitrite, Ammonia, Kjeldahl), total phosphorus, salinity, water temperature, pH, dissolved oxygen, turbidity, and cumulative precipitation (6-hour, 12-hour, 24-hour, 48-hour) at station WS3 with S27_R as back up. When S27_R is used as the backup, the font color is blue. Data also includes confirmed water elevation at NOAA Virginia Key Station (Bear Cut), estimated water level at the PVC, tide cycle, and groundwater elevations at the PVP within the shallow, intermediate, and deep wells. All elevations are in units of feet NAVD88.

Date	Time	Enterococci (MPN/100 mL)	Fecal Coliforms (CFU/100 mL)	Nitrogen (mg/L)			Total Phosphorus (mg/L)	Salinity (psu)	Water Temp (°C)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				NO ₃ +NO ₂	Ammonia	Kjeldahl							6-hour	12-hour	24-hour	48-hour	Bear Cut	PVC		shallow	inter.	deep
4/17/2019	11:10AM	640	125	<0.025	<0.035	<0.089	0.040	28.2	27.7	7.95	5.20	7.50	0.00	0.00	0.00	0.01	-0.95	-0.72	EBB	-0.63	-0.67	1.75
5/20/2019	11:03AM	63	25	<0.025	0.042	0.21	0.042	27.4	29.9	8.02	5.36	N/A	0.00	0.00	0.00	0.00	0.38	-0.34	EBB	-0.01	0.07	2.49
6/27/2019	10:56AM	169	400	0.029	<0.035	0.34	0.036	20.8	30.8	8.03	6.95	1.28	0.00	0.00	0.00	0.00	-1.45	-1.38	EBB	-0.06	-0.01	2.40
7/29/2019	11:51AM	1660	402	0.044	<0.035	0.27	0.034	15.8	30.9	8.04	7.05	2.66	0.00	0.00	0.00	0.01	-1.09	-0.90	EBB	0.22	0.28	2.64
8/13/2019	11:58AM	934	92	0.072	<0.035	<0.086	0.038	15.8	32.8	7.99	5.21	3.29	0.00	0.00	0.22	1.02	-0.49	-0.24	EBB	0.10	0.11	2.50
9/25/2019	11:10AM	285	157	<0.025	0.04	0.31	0.044	25.2	29.4	7.85	4.63	2.92	0.00	0.00	0.00	0.00	-0.7	-0.43	EBB	0.59	0.61	3.02
10/16/2019	9:26AM	359	430	<0.025	<0.035	0.33	0.058	20.1	28.0	8.10	4.60	3.60	0.00	0.00	0.00	0.00	1.19	-1.32	FLOOD	0.79	0.82	3.29
11/19/2019	11:10AM	108	20	<0.033	<0.035	0.18	0.032	15.8	23.7	7.72	7.32	3.78	0.00	0.00	0.00	0.00	1.02	-1.06	FLOOD	2.40	1.53	3.94
12/23/2019	10:19AM	>24196	600	0.17	<0.035	0.23	0.059	10.8	22.3	7.89	5.79	9.43	0.01	6.01	6.01	6.01	-0.55	-0.29	EBB	0.25	0.27	2.63
1/15/2020	11:15 AM	73	270	<0.033	<0.035	0.290	0.040	17.9	24.9	7.84	5.10	6.24	0.00	0.00	0.00	0.03	-0.080	-0.19	FLOOD	-0.61	-0.55	1.92
2/3/2020	11:22 AM	679	112	0.14	0.12	0.350	0.042	22.6	21.9	7.77	6.19	2.53	0.00	0.00	0.00	0.37	-0.960	-1.20	FLOOD	-0.12	-0.05	2.35
3/17/2020	10:36 AM	331	260	<0.033	<0.0317	0.330	0.055	36.0	25.0	8.11	4.87	16.40	0.00	0.00	0.00	0.00	-1.490	-1.43	EBB	-0.20	-0.12	2.29
4/14/2020	10:06 AM	142	92	<0.033	<0.035	0.290	0.044	36.3	28.0	8.06	6.67	6.44	0.00	0.00	0.00	0.00	-1.720	-1.95	FLOOD	-0.37	-0.29	2.14
5/26/2020	10:23 AM	13000	50	0.21	0.079	0.370	0.040	14.4	26.1	7.78	5.85	4.36	0.03	0.18	3.88	6.30	0.320	-0.23	FLOOD	0.37	0.39	2.87
6/23/2020	10:38 AM	20	50	<0.033	<0.035	0.290	0.027	27.2	30.2	8.25	6.63	1.92	0.00	0.00	0.00	0.00	0.380	-0.27	FLOOD	-0.73	-0.68	1.79
7/29/2020	10:40 AM	283	340	<0.033	<0.035	0.270	0.034	28.0	31.2	8.30	5.26	4.66	0.00	0.00	0.00	0.00	-1.850	-1.77	EBB	-0.22	-0.16	2.28
8/14/2020	11:15 AM	437	570	<0.033	0.054	0.254	0.056	29.3	31.9	7.95	3.88	4.46	0.00	0.01	0.02	0.04	-1.270	-1.15	EBB	-0.08	-0.01	2.42
9/22/2020	10:55 AM	1010	1320	<0.033	0.049	0.390	0.034	30.2	29.9	7.98	4.23	8.14	0.00	0.00	0.00	0.00	1.030	-1.08	FLOOD	1.14	1.21	3.69
10/13/2020	10:47 AM	19900	600	0.066	0.06	0.280	0.028	23.7	29.5	7.88	4.30	1.33	0.00	0.00	0.40	0.44	-0.650	-0.38	EBB	0.41	0.42	2.87
11/18/2020	10:37 AM	1560	142	0.085	<0.035	0.290	0.033	26.0	26.3	8.02	5.74	2.80	0.00	0.00	0.00	0.00	1.250	-1.40	FLOOD	0.23	0.27	2.78
12/21/2020	11:15 AM	959	96	0.036	<0.035	0.310	0.055	31.8	23.1	8.15	5.69	1.60	0.00	0.00	0.00	0.00	-0.220	-0.27	FLOOD	0.18	0.26	2.73
1/28/2021	10:48AM	1090	110	<0.033	0.052	0.370	0.041	32.9	23.6	7.87	5.97	2.07	0.00	0.00	0.00	0.00	-0.460	-0.22	EBB	N/A*	-1.06	1.50
3/29/2021	11:05AM	161	145	<0.033	<0.035	0.360	0.031	36.8	27.4	8.21	4.30	9.58	0.00	0.00	0.00	0.00	0.510	-0.47	EBB	N/A	-1.08	1.49
4/30/2021	11:02AM	173	20	<0.033	<0.035	0.310	0.023	36.2	28.1	8.29	5.72	3.18	0.00	0.00	0.00	0.00	0.080	-0.16	FLOOD	N/A	-0.70	1.87
5/25/2021	10:55AM	323	114	<0.033	<0.035	0.170	0.029	36.3	N/A	8.15	6.81	6.38	0.00	0.00	0.00	0.00	-0.590	-0.32	EBB	N/A	N/A	N/A
6/16/2021	10:41AM	6590	600	N/A	N/A	N/A	N/A	28.5	28.0	7.97	3.45	3.80	0.00	0.07	1.27	1.54	-0.840	-1.03	FLOOD	N/A	N/A	N/A
7/14/2021	11:00AM	487	300	0.088	0.07	0.320	0.030	28.8	26.3	7.97	3.71	6.00	0.00	0.06	0.73	5.46	-0.380	-0.41	FLOOD	N/A	N/A	N/A
8/16/2021	10:47AM	1510	2100	0.11	0.044	N/A	N/A	26.3	29.6	8.02	4.48	5.49	0.00	0.00	0.04	0.41	-1.570	-1.89	FLOOD	N/A	N/A	N/A
9/22/2021	11:50AM	17300	N/A	0.065	<0.035	0.270	0.022	26.2	30.2	7.93	5.55	8.56	0.91	0.91	1.14	1.14	0.750	-0.76	EBB	N/A	-0.25	3.05
10/28/2021	10:29AM	521	670	0.027	<0.035	0.340	0.007	29.6	27.9	7.81	3.80	2.09	0.00	0.00	0.00	0.00	-0.74	-0.88	FLOOD	N/A	-0.53	2.76
11/15/2021	10:45AM	2140	770	0.044	<0.035	0.460	0.011	29.4	24.2	7.05	7.10	4.11	0.00	0.00	0.00	0.00	-0.58	-0.31	EBB	N/A	0.08	3.36
12/22/2021	10:26AM	1660	440	0.018	0.040	0.300	0.011	33.1	21.4	7.72	5.01	7.80	0.00	0.00	0.00	0.13	0.72	-0.63	FLOOD	N/A	-0.05	3.21

*N/A= Not Available

Table A.1 (Continued)

Date	Time	Enterococci (MPN/100 mL)	Fecal Coliforms (CFU/100 mL)	Nitrogen (mg/L)			Total Phosphorus (mg/L)	Salinity (psu)	Water Temp (°C)	pH	Dissolved Oxygen (mg/L)	Turbidity (NTU)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				NO ₃ +NO ₂	Ammonia	Kjeldahl							6-hour	12-hour	24-hour	48-hour	Bear Cut	PVC		shallow	inter.	deep
1/18/2022	11:30AM	211	58	0.024	<0.035	N/A	0.010	32.4	20.5	8.06	6.33	2.07	0.00	0.00	0.00	0.24	-0.09	-0.10	EBB	N/A	-0.23	3.03
2/25/2022	10:28AM	1310	38	<0.015	<0.035	0.250	0.010	34	25.6	7.92	3.25	4.49	0.00	0.00	0.00	0.00	-1.42	-1.74	BOTTOM_UP	N/A	N/A	N/A
3/30/2022	10:48AM	187	82	<0.015M	0.54	0.29	0.011	35.4	24.8	8.03	6.06	8.16	0.00	0.00	0.00	0.00	-0.89	-0.64	EBB	N/A	N/A	N/A
4/25/2022	10:17AM	504	114	<0.015	<0.035	N/A	0.009	38.1	26.5	8.14	6.54	5.76	0.00	0.00	0.00	0.00	-1.07	-0.88	EBB	N/A	N/A	N/A
5/19/2022	10:37AM	173	147	<0.015	<0.035	0.300	0.007	37.2	29.4	8.14	4.59	5.37	0.00	0.00	0.00	0.00	0.26	-0.20	FLOOD	N/A	N/A	N/A
6/14/2022	10:38AM	399	430	N/A	N/A	0.280	0.008	25	30.8	8.05	2.71	0.21	0.01	0.01	0.01	0.01	0.36	-0.32	EBB	N/A	N/A	N/A
7/18/2022	10:53AM	30	20	0.027	<0.035	0.370	0.013	34.6	29.2	10.48	3.13	8.25	0.00	0.00	0.00	0.10	-0.53	-0.58	FLOOD	N/A	N/A	2.84
8/11/2022	10:54AM	41	62	N/A	N/A	0.410	0.011	35.5	27.9	7.26	5.38	19.80	0.00	0.00	0.00	0.00	-0.06	-0.10	EBB	N/A	N/A	2.41
09/15/2022	11:09 AM	909	28	0.038	0.045	0.410	0.018	31.1	26.7	7.59	5.78	6.17	0.00	0.00	0.00	1.67	0.48	-0.36	FLOOD	N/A	N/A	3.79
10/17/2022	10:48 AM	278	184	0.030	N/A	0.420	0.011	29.9	28.5	8.17	7.43	4.19	0.00	0.00	0.01	0.14	-0.14	-0.22	FLOOD	N/A	N/A	N/A
11/17/2022	11:07:00	>24196	640	0.062	0.056	0.49	0.021	28.5	23.6	7.59	5.06	6.14	0	0	0	0	-0.41	-0.44	FLOOD	N/A	N/A	N/A
12/12/2022	10:52:00	109	10	0.046	0.036	0.45	0.010	33	25.5	8.38	4.87	2.71	0	0	0	0	0.98	-1.00	FLOOD	N/A	N/A	N/A
1/20/2023	11:15:00	84	155	N/A	N/A	0.26	0.0080	35.2	23.2	6.78	7.02	3.97	0	0	0	0	-0.95	-0.72	EBB	N/A	-0.76	N/A
2/17/2023	8:13:00	41	24	N/A	N/A	0.33	0.0092	N/A	23.9	7.24	8.53	6.71	0.03	0.03	0.03	0.03	-0.18	-0.10	EBB	N/A	N/A	N/A
3/14/2023	11:07:00	52	70	0.028	N/A	0.32	0.0078	36.1	22.4	8.13	8.17	1.36	0	0	0	0	-0.13	-0.21	FLOOD	N/A	N/A	N/A
4/26/2023	10:33:00	652	240	0.052	<0.035	0.33	0.0094	24.2	26.8	8.02	5.61	1.04	0	0.03	0.03	0.21	-0.68	-0.79	FLOOD	N/A	N/A	N/A
5/16/2023	11:10:00	20	380	N/A	N/A	0.31	0.0062	33.3	22.4	8.36	8.23	0.77	0	0	0.01	0.17	-1.02	-0.81	EBB	N/A	N/A	N/A
6/13/2023	11:11:00	108	240	N/A	N/A	0.28	0.0047	28.9	21.5	7.87	1.87	0.76	0	0	0.46	0.46	-1.35	-1.25	EBB	N/A	N/A	N/A
7/18/2023	10:43:00	292	360	0.032	0.064	0.36	0.0083	27.6	20.9	8.2	8.17	0.63	0	0	0.05	0.16	0.25	-0.20	FLOOD	N/A	N/A	N/A
8/24/2023	11:15:00	30	40	0.017	<0.035	<0.14	0.013	31.6	31.4	8.11	2.62	12.9	0	0	0	0	-0.6	-0.68	FLOOD	N/A	N/A	N/A
9/21/2023	10:40:00	196	N/A	0.031	0.058	0.40	0.011	28.3	29.9	7.19	4.67	1.59	0	0	0.11	0.49	-0.27	-0.31	FLOOD	N/A	0.14	N/A
10/17/2023	11:22:00	20	66	0.038	0.078	0.40	0.011	30.2	26.7	8.06	3.7	11.2	0	0	0	0	1.33	-1.51	FLOOD	N/A	0.39	N/A
11/22/2023	10:13:00	10	50	0.061	0.11	0.38	0.0083	28.9	24.7	8.06	6.74	2.3	0	0	0	0	-0.91	-0.63	BOTTOM_DOWN	N/A	-0.44	N/A
1/4/2024	1:00:00	288	72	0.027	0.13	0.34	0.0078	31.2	20.9	8.02	7.01	7.77	0	0	0	0	-0.5	-0.55	FLOOD	N/A	N/A	N/A
1/17/2024	10:46:00	1440	292	0.024	0.10	0.35	0.0090	32.3	23.6	7.42	4.69	5.36	0	0	0	0	-0.68	-0.79	FLOOD	N/A	N/A	N/A
2/16/2024	10:56:00	175	112	0.018	0.092	N/A	0.012	35.4	23.8	7.67	4.21	5.79	0	0	0	0	-0.87	-1.07	FLOOD	N/A	N/A	N/A
3/12/2024	10:24:00	301	184	N/A	0.05	0.67	0.014	34.8	25.9	7.53	3.95	12.5	0	0	0	0	0.35	-0.25	FLOOD	N/A	-0.38	N/A
4/10/2024	10:55:00	122	29	0.018	N/A	0.34	0.0095	35.2	25.2	7.61	3.51	4.08	0	0	0	0	0.91	-0.90	FLOOD	N/A	N/A	N/A
5/14/2024	10:27:00	241	27	0.015N/	0.035	0.26	0.0040	36.4	29.7	7.8	4.41	3.18	0	0	0	0	-0.86	-1.06	FLOOD	-0.34	-0.75	2.78
6/18/2024	11:01:00	3430	N/A	0.071	N/A	0.42	0.020	23	29.5	7.77	5.47	2.98	0	0	0.09	1.15	-0.68	-0.41	EBB	N/A	-0.69	N/A
7/17/2024	10:55:00	326	142	N/A	N/A	0.32	0.017	32.5	32.3	7.43	2.54	6	0.06	0.06	0.06	0.15	-1.3	-1.19	EBB	-0.86	-1.34	2.24
8/15/2024	10:28:00	259	125	N/A	N/A	0.31	0.014	32	32.9	7.78	2.89	3.71	0	0	0	0	-1.51	-1.45	EBB	-1.12	N/A	2.69
9/19/2024	11:43:00	683	485	0.038	0.039	0.40	0.014	27.4	30.8	7.78	2.18	2.1	0	0.01	0.27	0.31	0.34	-0.25	FLOOD	1.04	0.64	4.20

Table A.2: Concentration of enterococci in samples collected monthly by Surfrider from the PVC Kayak Launch from 10/14/2021 to 9/30/2024 with water temperature and cumulative precipitation (6-hour, 12-hour, 24-hour, 48-hour) at station WS3 with S27_R as back up. When S27_R is used as the backup, the font color is blue. Data also includes confirmed water elevation at NOAA Virginia Key Station (Bear Cut), estimated water level at the PVC, tide cycle, and groundwater elevations at the PVP within the shallow, intermediate, and deep wells. All elevations are in units of feet NAVD88.

Date	Time	Enterococci (MPN/100 mL)	Water Temp (°C)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				6-hour	12-hour	24-hour	48-hour	Bear Cut	PVC		shallow	inter.	deep
10/14/2021	9:00:00	218	29.4	0	0	0	0	-0.59	-0.32	EBB	N/A ^a	-0.71	2.61
10/21/2021	9:00:00	73	28.9	0	0	0	0	0.79	-0.73	FLOOD	N/A	0.26	3.47
11/4/2021	12:40:00	<10	28.3	0	0	0	0	-0.18	-0.10	EBB	N/A	-0.66	2.69
11/11/2021	10:00:00	235	26.1	0	0	0	0	-0.16	-0.23	FLOOD	N/A	-0.11	3.20
11/18/2021	3:25:00	1019	25.0	0.05	0.05	0.05	0.05	-0.86	-1.16	BOTTOM_UP	N/A	-0.63	2.73
12/2/2021	8:30:00	1576	26.1	0	0	0	0	0.83	-0.86	EBB	N/A	0.21	3.46
12/9/2021	3:20:00	684	25.0	0	0	0	0	0.11	-0.15	EBB	N/A	-0.24	3.05
12/16/2021	3:05:00	896	26.1	0	0	0	0.22	-0.83	-1.01	FLOOD	N/A	-0.88	2.45
12/23/2021	10:00:00	120	25.0	0	0	0	0.09	0.26	-0.20	FLOOD	N/A	-0.25	3.00
12/30/2021	12:45:00	<10	25.0	0	0	0	0	-1.3	-1.64	BOTTOM_UP	N/A	-1.06	2.29
1/13/2022	4:10:00	122	25.6	0.01	0.02	0.06	0.82	0.55	-0.43	FLOOD	N/A	-0.08	3.21
1/20/2022	4:15:00	537	25.0	0	0.28	0.28	0.28	-1.32	-1.16	BOTTOM_DOWN	N/A	-1.08	2.24
1/27/2022	3:00:00	110	23.9	0	0	0	0	0.35	-0.25	FLOOD	N/A	-0.22	3.08
2/3/2022	3:05:00	160	23.9	0	0	0	0	-0.96	-0.73	EBB	N/A	-0.58	2.77
2/10/2022	3:16:00	146	23.9	0	0	0	0.1	0.28	-0.21	FLOOD	N/A	-0.33	2.93
2/17/2022	2:00:00	538	22.8	0	0.01	0.08	0.08	-0.95	-0.72	EBB	N/A	-0.71	2.64
2/24/2022	2:15:00	122	24.4	0	0	0	0	0.12	-0.16	FLOOD	N/A	N/A	N/A
3/3/2022	12:30:00	275	24.4	0	0.01	0.04	0.16	-0.35	-0.16	EBB	N/A	N/A	N/A
3/10/2022	2:55:00	226	25.6	0	0	0	0	-0.08	-0.10	EBB	N/A	N/A	N/A
3/17/2022	11:00:00	110	26.1	0.01	0.01	0.01	0.04	0.28	-0.25	EBB	N/A	N/A	N/A
3/24/2022	10:00:00	243	26.1	0	0	0	0	-1.11	-1.42	FLOOD	N/A	N/A	N/A
3/31/2022	11:00:00	345	24.4	0	0	0	0	0.28	-0.25	EBB	N/A	N/A	N/A
4/7/2022	9:00:00	41	23.9	0	0	0	0	-1.04	-1.38	BOTTOM_UP	N/A	N/A	N/A
4/14/2022	12:25:00	548	23.9	0	0	0	0	-1.06	-0.86	EBB	N/A	N/A	N/A
4/21/2022	2:20:00	98	23.9	0	0.01	0.1	0.1	0.68	-0.67	EBB	N/A	N/A	N/A
4/28/2022	12:20:00	75	25.6	0	0	0	0	-1.16	-1.00	EBB	N/A	N/A	N/A
5/5/2022	11:15:00	1679	25.0	0	0	0.04	0.04	-0.25	-0.29	FLOOD	N/A	N/A	N/A
5/12/2022	10:20:00	327	24.4	0	0	0	0	0.21	-0.20	EBB	N/A	N/A	N/A
5/19/2022	11:40:00	63	27.8	0	0	0	0	0.73	-0.64	FLOOD	N/A	N/A	N/A
5/26/2022	9:30:00	243	26.7	0	0	0	0	-0.31	-0.14	EBB	N/A	N/A	N/A
6/2/2022	12:30:00	336	28.3	0.01	0.01	0.14	0.18	0.35	-0.31	EBB	N/A	N/A	N/A
6/5/2022	8:35:00	3282	27.8	0	0.05	0.89	10.21	-0.95	-1.28	BOTTOM_UP	N/A	N/A	N/A
6/9/2022	11:30:00	4352	25.6	0	0	0.45	0.48	-1.33	-1.18	BOTTOM_DOWN	N/A	N/A	N/A
6/16/2022	10:46:00	216	27.2	0	0	0	0	0.7	-0.60	FLOOD	N/A	N/A	N/A
6/23/2022	11:00:00	51	27.2	0	0	0	0.45	-1.09	-0.84	BOTTOM_DOWN	N/A	N/A	2.50
6/30/2022	11:00:00	30	30.0	0	0	0	0	0.17	-0.18	EBB	N/A	N/A	2.69
7/7/2022	11:40:00	>24196	30.0	0	0	0	0.27	-1.26	-1.61	FLOOD	N/A	N/A	2.53
7/14/2022	11:00:00	63	30.0	0	0.07	0.07	0.07	0.48	-0.43	EBB	N/A	N/A	2.59
7/21/2022	1:00:00	20	30.0	0	0	0	0	-0.85	-1.04	FLOOD	N/A	N/A	2.72
7/28/2022	1:00:00	345	30.0	0	0	0	0.67	-0.87	-0.62	EBB	N/A	N/A	2.03

^aN/A=Not Available

Table A.2: (continued)

Date	Time	Enterococci (MPN/100 mL)	Water Temp (°C)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				6-hour	12-hour	24-hour	48- hour	Bear Cut	PVC		shallow	inter.	deep
8/4/2022	1:40:00	142	30.0	0.29	0.29	0.29	0.29	0.43	-0.31	FLOOD	N/A	N/A	3.06
8/11/2022	1:45:00	1169	30.0	0	0	0	0	-1.61	-1.56	EBB	N/A	N/A	1.88
8/18/2022	1:45:00	294	30.0	0	0	0.25	0.25	0.5	-0.38	FLOOD	N/A	N/A	3.30
8/25/2022	12:50:00	288	30.0	0	0	0	0	-1.05	-0.85	EBB	N/A	N/A	2.15
9/1/2022	12:30:00	20	29.4	0	0	0	0	0.4	-0.29	FLOOD	N/A	N/A	3.17
9/8/2022	8:30:00	1576	30.0	0	0.01	0.01	0.01	1.06	-1.17	EBB	N/A	N/A	3.24
9/15/2022	8:45:00	24150	29.4	0.03	0.06	2.09	3.08	-0.61	-0.69	FLOOD	N/A	N/A	3.35
9/22/2022	7:00:00	>24196	30.0	0.12	0.12	0.12	0.96	0.99	-1.02	FLOOD	N/A	N/A	3.79
9/30/2022	1:45:00	134	23.9	0	0	0	0.22	1.33	-1.50	EBB	N/A	N/A	3.64
10/6/2022	2:30:00	173	28.3	0	0	0	0	-0.41	-0.44	FLOOD	N/A	N/A	3.39
10/13/2022	8:30:00	617	26.7	0	0.02	0.02	0.02	0.12	-0.16	FLOOD	N/A	N/A	N/A
10/20/2022	8:00:00	2359	26.7	0	0	0.59	0.63	0.37	-0.33	EBB	N/A	N/A	N/A
10/27/2022	12:15:00	214	26.7	0	0	0	0	1.44	-1.62	EBB	N/A	N/A	N/A
11/3/2022	12:25:00	324	27.2	0	0.05	0.05	0.05	-0.69	-0.94	BOTTOM_UP	N/A	N/A	N/A
11/12/2022	9:30:00	21430	27.8	0	0	0.01	0.05	0.73	-0.64	FLOOD	N/A	N/A	N/A
11/17/2022	12:55:00	106	27.2	0	0	0	0	0.17	-0.17	FLOOD	N/A	N/A	N/A
11/25/2022	11:30:00	243	25.6	0	0	0	0.01	1	-1.09	EBB	N/A	N/A	N/A
12/1/2022	9:30:00	109	25.0	0	0	0.08	0.08	-0.97	-0.70	BOTTOM_DOWN	N/A	N/A	N/A
12/8/2022	9:15:00	823	25.0	0	0	0.1	0.1	0.81	-0.75	FLOOD	N/A	N/A	N/A
12/15/2022	3:05:00	63	23.9	0	0	0	0.34	0.76	-0.77	EBB	N/A	N/A	N/A
12/22/2022	8:50:00	350	22.8	0	0	0	0.2	1.41	-1.59	EBB	N/A	N/A	N/A
12/29/2022	11:45:00	1989	23.9	0	0	0	0.16	0.05	-0.16	FLOOD	N/A	N/A	N/A
1/5/2023	1:30:00	987	23.9	0	0	0	0	-1.44	-1.37	EBB	N/A	-1.13	N/A
1/12/2023	8:30:00	480	23.9	0	0	0	0	-0.74	-0.88	FLOOD	N/A	-1.03	N/A
1/19/2023	2:00:00	414	21.1	0	0	0	0	-1.17	-1.52	BOTTOM_UP	N/A	-1.04	N/A
1/26/2023	2:40:00	85	23.3	0	0	0	0.02	-0.24	-0.12	EBB	N/A	N/A	N/A
2/2/2023	2:00:00	446	23.3	0	0	0	0	-1.14	-1.49	BOTTOM_UP	N/A	N/A	N/A
2/9/2023	11:00:00	41	23.3	0	0	0	0.01	0.54	-0.42	FLOOD	N/A	-0.29	N/A
2/16/2023	1:15:00	323	25.0	0	0	0	0	-1.12	-1.43	FLOOD	N/A	N/A	N/A
2/23/2023	2:30:00	<10	25.0	0	0	0	0	-1.14	-0.97	EBB	N/A	N/A	N/A
3/2/2023	11:00:00	52	23.3	0	0	0	0	-1.06	-0.86	EBB	N/A	N/A	N/A
3/9/2023	9:30:00	160	N/A	0	0	0	0	0.79	-0.73	FLOOD	N/A	-0.26	N/A
3/16/2023	12:00:00	31	21.1	0	0	0.01	0.01	-0.62	-0.84	BOTTOM_UP	N/A	-0.42	N/A
3/23/2023	12:40:00	<10	N/A	0	0	0	0	0.37	-0.33	EBB	N/A	N/A	N/A
3/30/2023	1:00:00	4352	N/A	0.07	0.07	0.36	0.86	-0.9	-1.12	FLOOD	N/A	-0.82	N/A
4/6/2023	8:00:00	295	N/A	0	0	0	0	-0.07	-0.19	FLOOD	N/A	-0.36	N/A
4/13/2023	12:45:00	626	N/A	0.01	0.01	1.16	3.03	0.3	-0.22	FLOOD	N/A	0.43	N/A
4/20/2023	8:40:00	426	N/A	0	0	0	0	0.73	-0.64	FLOOD	N/A	0.07	N/A
4/27/2023	12:30:00	1028	N/A	0	0	2.01	2.04	-0.26	-0.30	FLOOD	N/A	N/A	N/A

Table A.2: (continued)

Date	Time	Enterococci (MPN/100 mL)	Water Temp (°C)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				6-hour	12-hour	24-hour	48- hour	Bear Cut	PVC		shallow	inter.	deep
5/11/2023	10:00:00	63	N/A	0	0	0	0.04	-1.03	-1.31	FLOOD	N/A	N/A	N/A
5/18/2023	11:00:00	359	N/A	0	0	0.14	0.18	-0.15	-0.10	EBB	N/A	N/A	N/A
5/25/2023	12:35:00	166	N/A	0	0	0.11	0.84	0.39	-0.28	FLOOD	N/A	N/A	N/A
6/1/2023	12:00:00	487	N/A	0	0	0.01	1.20	-0.81	-0.55	EBB	N/A	N/A	N/A
6/8/2023	9:00:00	>24196	28.3	0	0	0.22	0.51	-0.47	-0.51	FLOOD	N/A	N/A	N/A
6/15/2023	1:00:00	598	28.9	0	0	0	0	-1.49	-1.43	EBB	N/A	N/A	N/A
6/22/2023	12:40:00	1067	28.3	0.05	0.05	0.05	0.84	0.25	-0.20	FLOOD	N/A	N/A	N/A
6/29/2023	12:30:00	199	29.4	0	0.01	0.01	0.01	-1.38	-1.70	BOTTOM_UP	N/A	N/A	N/A
7/6/2023	9:00:00	140	30.0	0	0	0	0	-0.65	-0.75	FLOOD	N/A	N/A	N/A
7/14/2023	12:28:00	135	30.6	0	0.05	0.05	0.05	-1.32	-1.21	EBB	N/A	N/A	N/A
7/20/2023	1:00:00	122	30.6	0	0	0	0	-0.17	-0.10	EBB	N/A	N/A	N/A
7/27/2023	12:15:00	2924	32.2	0	0.14	0.33	0.45	-1.58	-1.85	BOTTOM_UP	N/A	N/A	N/A
8/3/2023	12:15:00	41	30.6	0	0	0	1.46	0.75	-0.76	EBB	N/A	N/A	N/A
8/10/2023	10:30:00	428	30.0	0	0	0	0	-1.68	-1.79	BOTTOM_DOWN	N/A	N/A	N/A
8/17/2023	12:30:00	520	29.4	0	0.01	0.48	0.52	0.04	-0.12	EBB	N/A	N/A	N/A
8/24/2023	9:00:00	52	27.2	0	0	0	0	-1.02	-0.76	BOTTOM_DOWN	N/A	-0.76	N/A
8/31/2023	12:30:00	677	28.9	0.02	0.09	0.09	0.28	-0.19	-0.11	EBB	N/A	-0.85	N/A
9/7/2023	12:30:00	31	30.0	0	0	0	0	-0.46	-0.50	FLOOD	N/A	N/A	N/A
9/14/2023	12:30:00	<10	31.1	0	0	0	0	-0.13	-0.10	EBB	N/A	N/A	N/A
9/21/2023	12:00:00	345	30.0	0.01	0.01	0.12	0.5	0.22	-0.19	FLOOD	N/A	0.17	N/A
9/28/2023	8:30:00	1421	27.2	0.06	0.09	0.18	2.92	1.79	-1.86	EBB	N/A	0.67	N/A
10/5/2023	8:50:00	4884	26.7	0	0	0.08	0.08	-0.35	-0.41	BOTTOM_UP	N/A	0.09	N/A
10/12/2023	7:00:00	473	27.2	0	0	0.24	0.24	1.18	-1.30	FLOOD	N/A	0.54	N/A
10/19/2023	11:30:00	1082	27.2	0	0	0	0	0.98	-1.00	FLOOD	N/A	0.41	N/A
10/26/2023	11:30:00	63	27.8	0.02	0.03	0.2	0.2	0.13	-0.16	EBB	N/A	-0.20	N/A
11/2/2023	11:50:00	>24196	27.8	0	0.08	0.57	0.57	1.18	-1.30	FLOOD	N/A	0.64	N/A
11/9/2023	2:20:00	1173	26.7	0	0	0	0.01	0.3	-0.22	FLOOD	N/A	-0.02	N/A
11/16/2023	2:00:00	24196	27.2	0	0.3	6.7	8.35	0.7	-0.69	EBB	N/A	1.05	N/A
11/22/2023	1:00:00	63	25.0	0	0	0	0.01	-0.18	-0.24	FLOOD	N/A	-0.31	N/A
12/7/2023	1:00:00	1223	26.1	0	0	0	0	-0.3	-0.33	FLOOD	N/A	-0.56	N/A
12/14/2023	1:00:00	1223	26.1	0.03	0.05	0.13	0.48	0.12	-0.15	EBB	N/A	-0.15	N/A
12/21/2023	2:00:00	865	25.6	0	0	0	0	0.41	-0.30	FLOOD	N/A	-0.13	N/A
12/28/2023	3:00:00	>24196	23.3	0.54	0.56	0.56	0.60	-1.22	-1.02	BOTTOM_DOWN	N/A	-0.73	N/A
1/4/2024	1:00:00	173	23.9	0	0	0	0	0.04	-0.16	FLOOD	N/A	N/A	N/A
1/11/2024	2:15:00	3968	22.8	0.02	0.09	0.19	0.28	-1.5	-1.46	BOTTOM_DOWN	N/A	N/A	N/A
1/18/2024	2:00:00	30	25.0	0.01	0.01	0.01	0.04	0.28	-0.21	FLOOD	N/A	N/A	N/A
1/25/2024	10:00:00	98	21.7	0	0	0	0	0.11	-0.15	EBB	N/A	N/A	N/A
2/1/2024	9:00:00	1565	25.0	0	0	0	0	-0.79	-0.95	FLOOD	N/A	N/A	N/A
2/8/2024	9:00:00	591	21.1	0	0	0.01	0.01	1.04	-1.14	EBB	N/A	N/A	N/A
2/15/2024	10:00:00	199	23.9	0	0	0	0.01	-0.89	-1.10	FLOOD	N/A	N/A	N/A
2/22/2024	1:30:00	246	23.9	0	0	0.01	0.01	-1.14	-0.91	BOTTOM_DOWN	N/A	N/A	N/A
2/29/2024	12:00:00	84	22.8	0	0	0	0	-0.15	-0.22	FLOOD	-0.26	N/A	2.82

Table A.2: (continued)

Date	Time	Enterococci (MPN/100 mL)	Water Temp (°C)	Precipitation (in)				Water Level (ft)		Tide Cycle at PVC	Groundwater elevation (ft)		
				6-hour	12-hour	24-hour	48- hour	Bear Cut	PVC		shallow	inter.	deep
3/7/2024	1:30:00	24196	23.3	0.01	0.27	0.31	0.93	-1.33	-1.66	BOTTOM_UP	N/A	N/A	N/A
3/14/2024	11:00:00	73	22.8	0	0	0	0	-0.21	-0.26	FLOOD	N/A	-0.54	N/A
3/21/2024	12:00:00	441	25.6	0	0	0	0.01	-0.85	-0.60	EBB	N/A	N/A	N/A
3/28/2024	7:00:00	323	25.6	0	0	0	0	-0.74	-0.88	FLOOD	N/A	-0.39	N/A
4/4/2024	12:30:00	11199	25.0	0.03	0.65	0.65	0.65	-1.53	-1.82	BOTTOM_UP	N/A	-1.08	N/A
4/11/2024	1:00:00	86	22.8	0	0	0	0	0.48	-0.43	EBB	N/A	-0.65	N/A
4/18/2024	1:00:00	41	25.6	0	0	0	0	-1.25	-1.59	BOTTOM_UP	N/A	-1.03	N/A
4/25/2024	9:30:00	146	26.1	0	0	0	0	0.25	-0.20	FLOOD	0.03	-0.34	3.14
5/2/2024	8:00:00	404	23.9	0	0	0	0.01	-0.62	-0.35	EBB	N/A	-1.08	N/A
5/9/2024	10:00:00	323	25.6	0	0	0	0	0.69	-0.59	FLOOD	N/A	-0.20	N/A
5/16/2024	8:30:00	185	28.9	0	0	0	0	-0.78	-0.51	EBB	N/A	-1.06	N/A
5/23/2024	12:15:00	20	28.9	0	0	0	0.25	-0.01	-0.11	EBB	-0.20	-0.64	2.91
6/6/2024	1:00:00	<10	26.7	0	0	0	0	-0.71	-0.44	EBB	N/A	-1.04	N/A
6/13/2024	10:00:00	24196	26.7	0.01	0.14	10.68	16.43	-1.22	-1.56	BOTTOM_UP	N/A	N/A	N/A
6/20/2024	1:00:00	1296	28.3	0.01	0.03	0.03	0.05	-1.16	-1.00	EBB	N/A	-1.09	N/A
6/27/2024	12:00:00	2359	28.3	0	0	1.28	1.97	-0.06	-0.18	FLOOD	0.25	N/A	N/A
7/5/2024	2:45:00	10	30.0	0	0	0	0	-1.4	-1.29	BOTTOM_DOWN	-0.77	-1.23	2.31
7/11/2024	10:00:00	122	32.2	0	0	0.06	0.06	-0.61	-0.69	FLOOD	-0.36	N/A	2.73
7/18/2024	12:00:00	10462	32.2	0	0	0	0.06	-1.56	-1.51	EBB	-0.99	-1.45	2.13
7/25/2024	12:00:00	146	28.3	0	0	0	0	0.41	-0.30	FLOOD	0.07	-0.32	3.18
8/1/2024	1:00:00	905	28.3	0.01	0.01	0.01	0.06	-1.76	-1.95	BOTTOM_DOWN	-1.16	-1.61	1.92
8/8/2024	10:00:00	341	27.8	0	0	0	0.13	-0.35	-0.38	FLOOD	-0.37	N/A	2.69
8/15/2024	12:00:00	12997	28.9	0	0	0	0	-1.75	-1.93	BOTTOM_DOWN	-1.23	N/A	1.87
8/22/2024	8:00:00	3300	30.0	0	0	0.21	0.58	-1.11	-1.42	FLOOD	N/A	-1.08	2.44
8/29/2024	12:00:00	473	30.0	0	0	0	0.01	-1.13	-0.96	EBB	-0.63	N/A	2.48
9/5/2024	4:00:00	830	27.8	0	0	0	0.03	0.54	-0.50	EBB	-0.53	-0.98	2.58
9/12/2024	4:30:00	6488	28.3	0.55	0.55	1.08	3.14	-0.87	-1.07	FLOOD	0.67	0.09	3.81
9/19/2024	12:00:00	1850	30.6	0	0.01	0.27	0.31	0.78	-0.71	FLOOD	1.04	0.64	4.20
9/27/2024	1:00:00	10466	30.6	0	0	0.07	0.17	-0.81	-0.55	EBB	0.05	N/A	3.12

APPENDIX B

STORMWATER INFRASTRUCTURE DETAIL

APPENDIX B

STORMWATER INFRASTRUCTURE DETAIL

The stormwater infrastructure was evaluated to document the elevations in reference to groundwater and PVC water levels. The elevations were documented through 1) data available through the CMB GIS system, b) available construction drawings, and 3) for components that did not have elevations measurements, through surveying that was initiated by CMB Public Works Department to measure inverts of outfalls to the PVC. Details of these three approaches are described below.

B.1 GIS MEASUREMENTS

The CMB has a GIS system that documents the stormwater conveyance and sanitary sewer infrastructure. The legend for the stormwater information stored in the CMB GIS system (Figure B.1) documents the locations of catch basins, culverts, trench drains, French drains, etc. In some cases, the dimensions and elevations of the stormwater conveyance system are listed. For the stormwater conveyance lines that have elevation data, that data was recorded and used to document elevations.

B.2 CONSTRUCTION DRAWINGS

The CMB made available construction drawings for both stormwater conveyance and sanitary sewer system. For lines that lacked stormwater conveyance system drawings, the sanitary sewer system drawings were used to obtain elevations as the stormwater conveyance infrastructure was shown on sanitary sewer drawings. A map of the catchment area with the construction drawings available was constructed to confirm coverage. Some details obtained from the construction drawings are provided in Figures B.2 to B.6. Areas that did not have elevation information by either GIS or constructions drawings were then surveyed by the CMB.

B.3 SURVEYING OF OUTFALLS

Visible outfalls discharging to the PVC were surveyed by CMB Public Works on November 4, 2024. All elevations are referenced to NAVD88. The results from this surveying exercise are shown in Figure B.8.

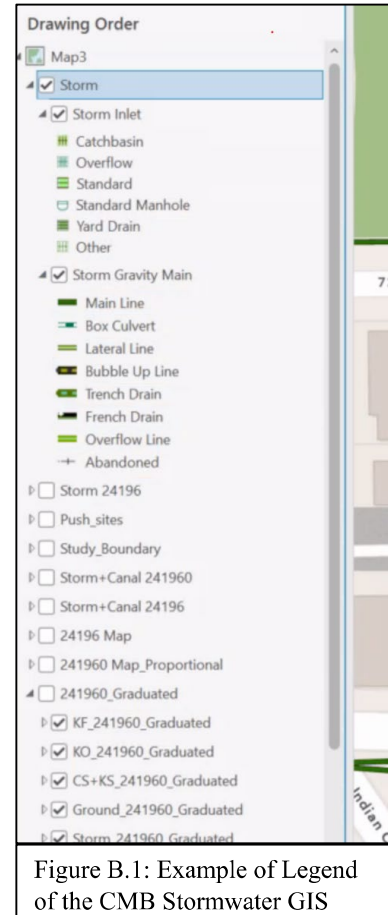


Figure B.1: Example of Legend of the CMB Stormwater GIS

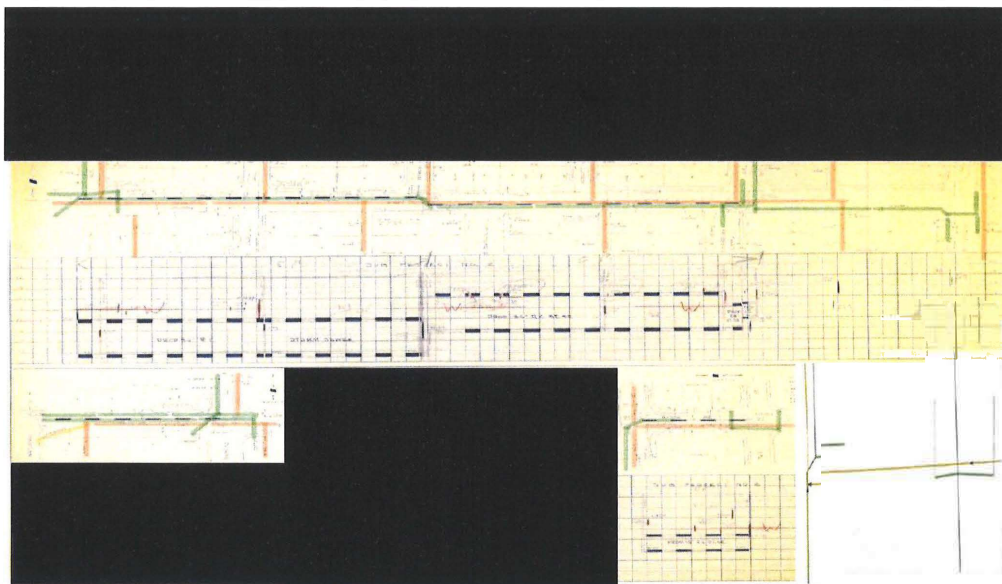


Figure B.2: Storm conveyance construction drawings at 75 Street.

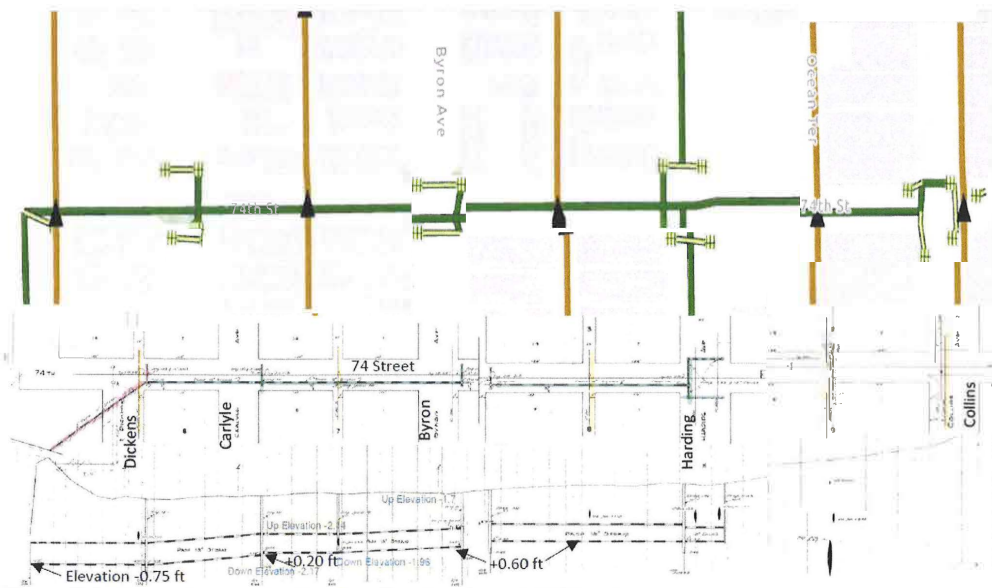


Figure B.3: Storm Conveyance Construction Drawings at 74 Street.

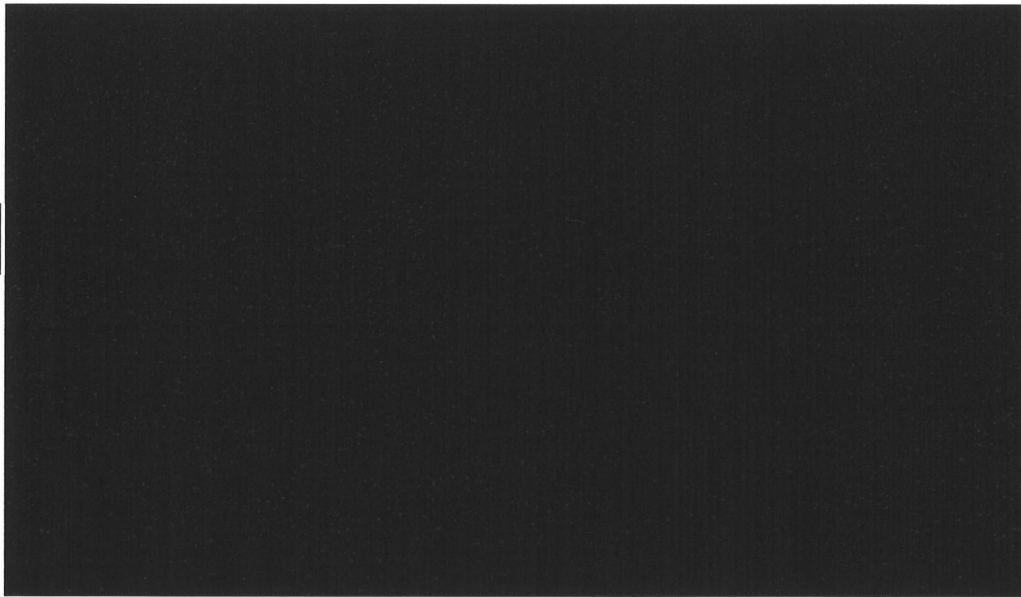


Figure B.4: Sanitary Sewer Construction Drawings at 73 Street.

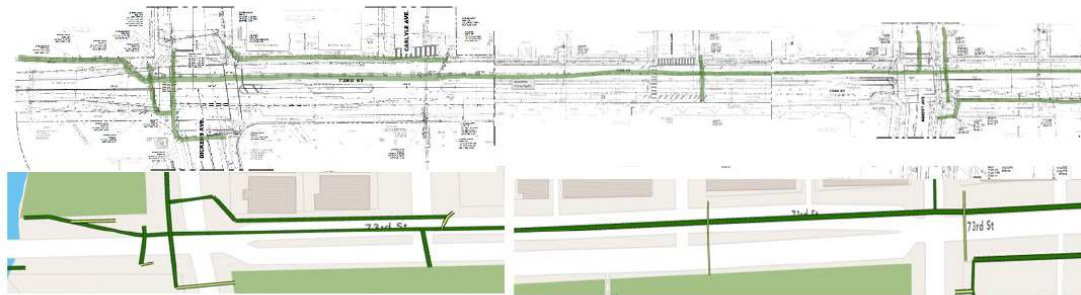


Figure B.5: Surface Elevation Map and GIS Image at 73 Street between Dickens and Abbott Avenue. Surface Elevation Map from CES Consultants Survey February 2024 for the North Shore D – North Beach Town Center Neighborhood Improvement Project.

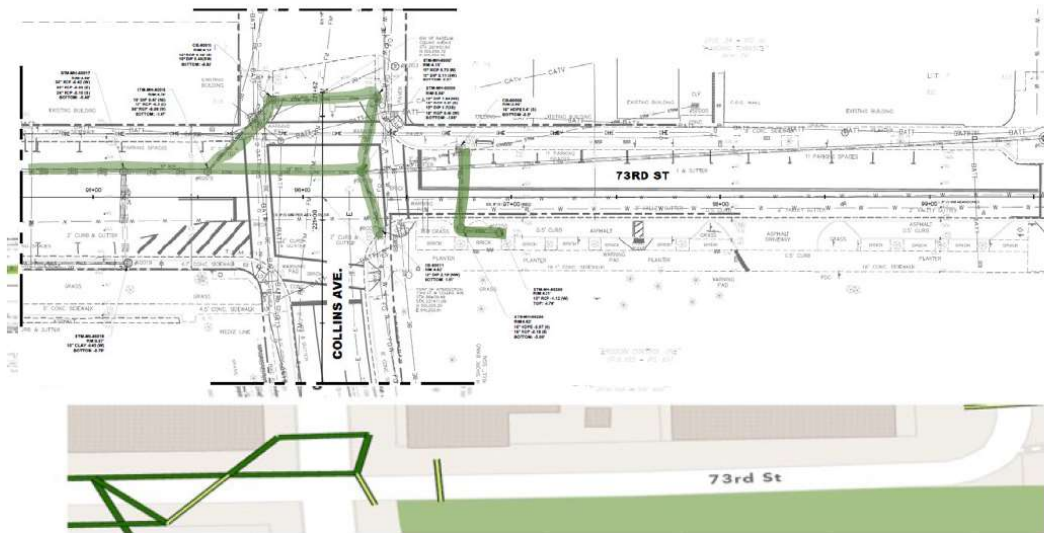


Figure B.6: Surface Elevation Map and GIS Image at 73 Street and Collins Avenue. Surface Elevation Map from CES Consultants Survey February 2024 for the North Shore D – North Beach Town Center Neighborhood Improvement Project.

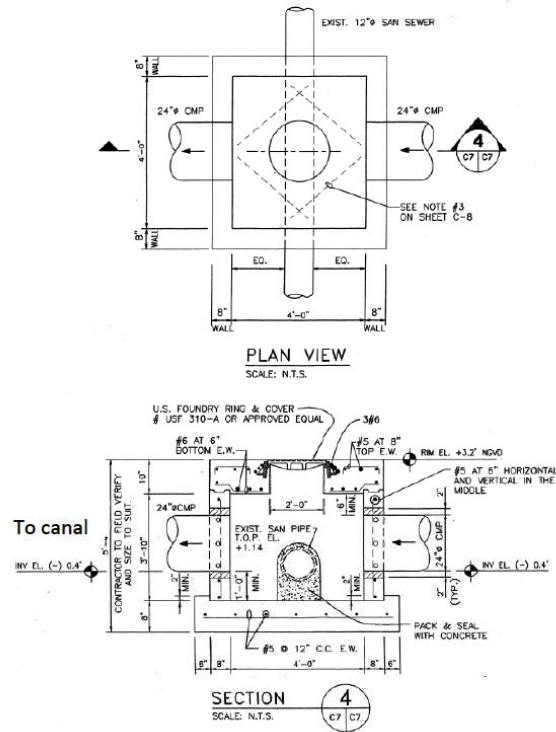


Figure B.7: Detail for BBE Outfall Structure. Floor of vertical well chamber = 0.00 ft. Overflow to second well, invert 0.50 ft. Bypass from wet well to canal, invert at 0.00 ft.

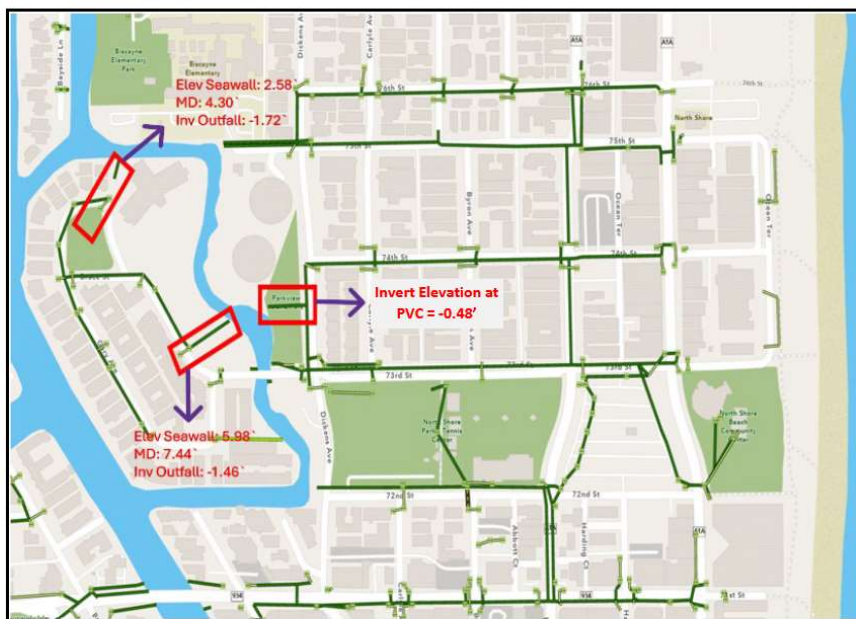


Figure B.8: Results from field survey for outfalls to the PVC.

APPENDIX C
UM SAMPLE COLLECTION TIMELINE
AND DATA DETAILS

APPENDIX C

UM SAMPLE COLLECTION TIMELINE AND DATA DETAILS

Table C.1: Sample Collection Timeline

Date	Location	Activities
6/18/2024	<ul style="list-style-type: none"> Walk through from Parkview Island to Walkway on north end of PVC inclusive of the sanitary sewer pump station Walk through the Parkview Island Park and Kayak Launch Walk through tennis center area inclusive of groundwater well sites Drive through entire watershed up and down streets and avenues 	Scouting visit to identify groundwater drilling sites and possible stormwater collection sites
7/15-19/2024	<ul style="list-style-type: none"> Throughout watershed 	Confirming sites for groundwater sampling including white-lining drill areas and confirming underground utility markings.
7/22/2024	<ul style="list-style-type: none"> Throughout watershed 	Ground penetrating radar of all 31 proposed groundwater sampling sites.
7/23/2024	<ul style="list-style-type: none"> Groundwater on south side of watershed including Parkview Island. Sites F11, F1, F3, F2, F10, G8, F9, G17, G10, G16 	Groundwater sample collection (n=10)
7/24/2024	<ul style="list-style-type: none"> Groundwater on east side and central portion of watershed. Sites F4, G5, G4, G13, G11, G2, G1, G12 	Groundwater sample collection (n=8)
7/25/2024	<ul style="list-style-type: none"> Groundwater on north side of watershed. Sites F5, R1, R3, F7, F6, G3, G7, R2 	Groundwater sample collection (n=8)
July 25, 2024	<ul style="list-style-type: none"> Site RSD. Southeast corner of the private parking lot at the corner of 74th and Harding. Parking lot next to a CVS. Site RSE. Storm drain at the intersection of 74th and Dickens. On the east side of Dickens Ave Site RSF. East side of corner of 76th and Dickens. 	Stormwater sample collection from puddles (n=3)
August 5, 2024 (Day 1 targeted stormwater)	<ul style="list-style-type: none"> Puddle sites P1, P3, P4, P5, P6 Canal site CS1 	Stormwater sample collection from puddles (n=5) Canal sample at outflow by school
August 6, 2024 (Day 2 targeted stormwater)	<ul style="list-style-type: none"> Puddle sites PS1, PS3, PS7, PS8, PS9 Field-staged bottle sites BS1, BS2, BS3, BS4, BS6 In person stormwater sample collection site SRA. Samples collected included SRA-2, SRA-3, and SRA-4. In person stormwater sample collection site SRB. Samples collected included SRB-1, SRB-2, SRB-3, SRB-4, SRB-5, SRB-6, SRB-7, SRB-8 In person stormwater sample collection site SRC. Samples collected included SRC-1, SRC-2, SRC-3 	Stormwater sample collection from puddles (n=5) Stormwater sample collection from field-staged bottles (n=5) In person stormwater sampling at catch basins at three different locations (n = 3 + 3 + 8 = 14 total)

Table C.1 (continued): Sample Collection Timeline

Date	Location	Activities
August 9, 2024 (Day 3 targeted stormwater)	<ul style="list-style-type: none"> • Puddle sites PS10, PS11, PS12, PS13, PS14, PS15 • Field-staged bottle sites BS7, BS8, BS9, BS10, BS11, BS12 • In person stormwater sample collection site SRD. Samples collected included SRD-1, SRD-2, SRD-3, SRD-4, SRD-5, SRD-6, SRD-7, SRD-8 • In person stormwater sample collection site SRE. Samples collected included SRE-1, SRE-2, SRE-3, SRE-4, SRE-5, SRE-6, SRE-7, SED-8 	<p>Stormwater sample collection from puddles (n=6)</p> <p>Stormwater sample collection from field-staged bottles (n=6)</p> <p>In person stormwater sampling at catch basins at two different locations (n = 8 + 8 = 16 total)</p>
August 15, 2024	<ul style="list-style-type: none"> • Sample collection at the PVC Kayak Launch at the water's surface, KS01, KS02, KS03, KS04, KS05, KS06, KS07, KS08, KS09, KS10, KS11, KS12 • Sample collection at the PVC Kayak Launch at one-foot depth, KO01, KO02, KO03, KO04, KO05, KO06, KO07, KO08, KO09, KO10, KO11, KO12 • Sample collection at the PVC Kayak Launch at five-foot depth, KF01, KF02, KF03, KF05, KF06, KF07, KF08, KF09, KF10, KF11, KF12 • Field blank and rainwater collected at the Kayak Launch 	<p>Sample collection at the PVC kayak launch at three different water depths on an hourly basis from 6 am to 5 pm (n=35).</p> <p>Processing of the field blank (n=1)</p> <p>Sample collection of rainwater (n=1)</p>
August 20, 2024 (Day 4 targeted stormwater)	<ul style="list-style-type: none"> • Puddle sites PS15, PS17, PS18, PS19, PS20, PS21, PS22, PS23, PS24 • Field-staged bottle sites BS13, BS14 • In person stormwater sample collection site SRF. Samples collected included SRF-1, SRF-2, SRF-3, SRF-4, SRF-5, SRF-6, SRF-7, SRF-8 • Canal site CS2 	<p>Stormwater sample collection from puddles (n=10)</p> <p>Stormwater sample collection from field-staged bottles (n=2)</p> <p>In person stormwater sampling at catch basin (n=8)</p> <p>Canal sample at outflow by school (n=1)</p>
August 23, 2024 (Day 5 targeted stormwater)	<ul style="list-style-type: none"> • In person stormwater sample collection site SRG. • Canal site CS3 and CS4 	<p>In person stormwater sampling at catch basin (n=1)</p> <p>Canal sample at outflow by school (n=2)</p>
August 29, 2024 (Day 6 targeted stormwater)	<ul style="list-style-type: none"> • In person stormwater sample collection, one per site. Sites included SRH, SRI, SRJ, SRK, SRL, SRM, SRN, SRO, SRP • In person stormwater sample collection site SRQ. Samples collected included SRQ-1, SRQ-2, SRQ-3, SRQ-4, SRQ-5, SRQ-6, SRQ-7, SRQ-8 • Canal site CS5 	<p>In person stormwater sampling at catch basins (n=17)</p> <p>Canal sample at outflow by school (n=1)</p>
September 10, 2024 (Day 7 targeted stormwater)	<ul style="list-style-type: none"> • In person stormwater sample collection, one per site. Sites included SRR, SRS, SRT, SRU, SRV, SRW, SRX, SRY, SRZ. 	<p>In person stormwater sampling at catch basins (n=9)</p>
September 19, 2024	<ul style="list-style-type: none"> • Collected two PVC samples from the outfall at BBE on sample was collected at 3:36 pm and another was collected at 4:15 pm. 	<p>Canal sample at outflow by school (n=2)</p>

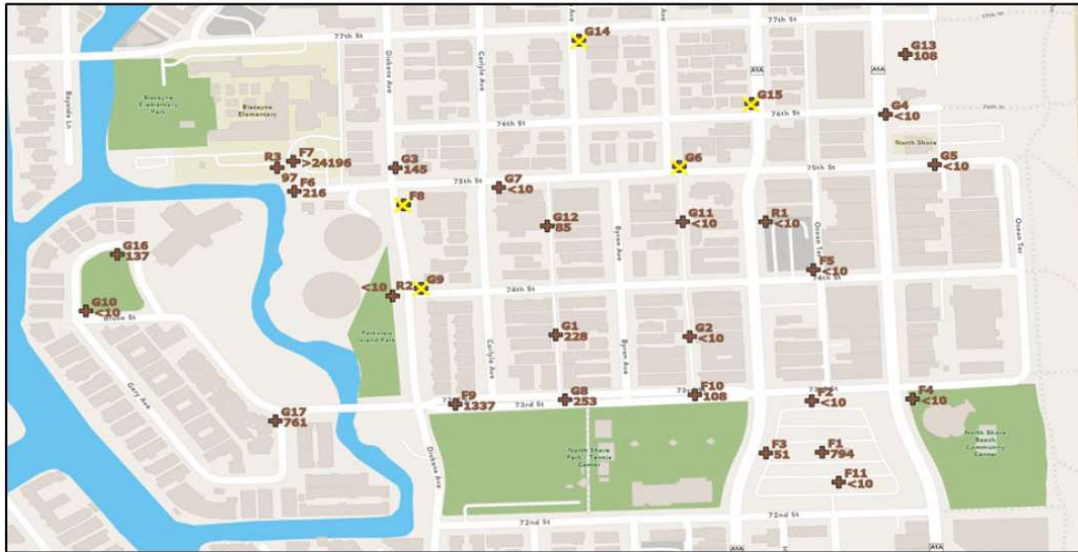


Figure C.1: Groundwater sampling sites. Sites with a yellow “X” were sites that were selected but were found to be non-viable to due excessive underground utilities and were therefore not drilled. The remaining 26 sites without the yellow “X” were sampled. The site ID is given by a “G”, “F”, or “R” (for proximity to gravity sewer, force main, and stormwater conveyance system, respectively) followed by a number. The number below the site ID corresponds to the enterococci concentration in the groundwater in units of MPN/100 mL.

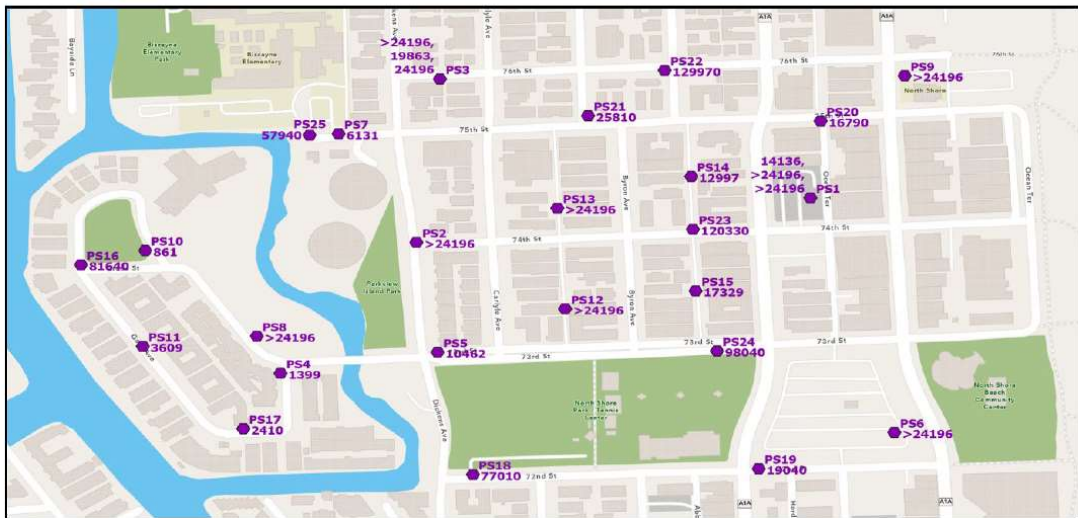


Figure C.2: Puddle sampling sites. The site ID is given by “PS” followed by a number. The number below the site ID corresponds to the enterococci concentration in the puddle water in units of MPN/100 mL.

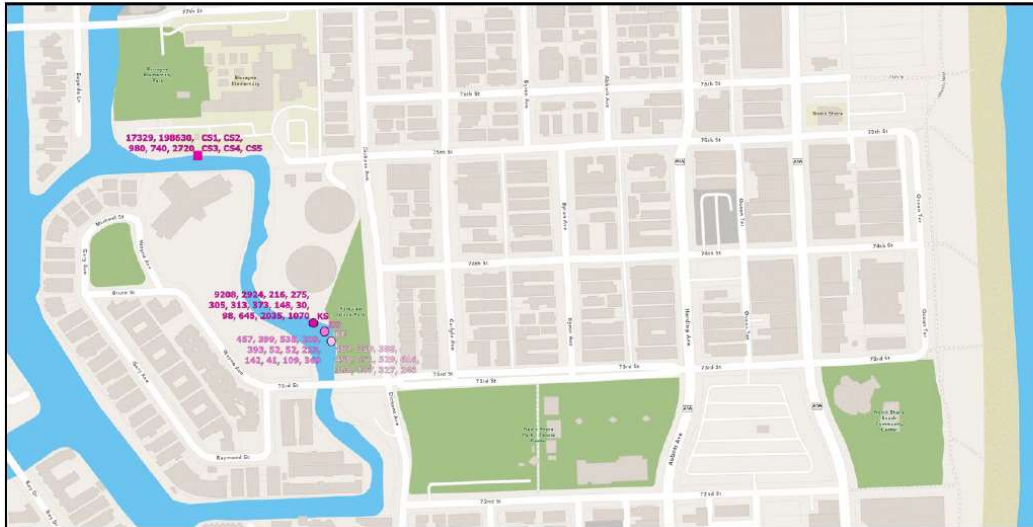


Figure C.5: PVC sampling sites. The site ID is given by “CS” for the outfall at BBE and “KS”, “KO”, and “KF” for the Kayak launch for samples collected at the surface, 1-foot, and 5-foot depths. Each site ID includes a number which corresponds to the sequence of sample collection. The number near the site ID corresponds to the enterococci concentration in the PVC samples in units of MPN/100 mL.



Figure C.6: Spatial distribution of enterococci in water samples collected from the PVC catchment. Brown font corresponds to groundwater, purple corresponds to puddles, rust corresponds to field-staged bottle, black corresponds to in-person runoff, and pink corresponds to samples collected from within the PVC. The number near the site IDs correspond to the enterococci concentration in units of MPN/100 mL.

Table C.2: Data tables for groundwater samples. All times recorded as local time. MST data in main text.

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Collection Depth (ft)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
							pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
F1-A	Grassy stretch W of white structure in middle of parking lot. Corner 73 rd St/Harding Ave	240723	11:25	4 to 5.5	794	32.5/32	6.89	24.1	1.37	20.8	5.42
F2-A	Parking lot located at SE end the intersection between 73 rd St/Harding Ave	240723	10:46	4 to 5.5	<10	32/32	7.46	24.7	0.85	11.3	5.44
F3-A	Grassy stretch along W of parking lot at the corner of 73 rd St and Harding Ave	240723	11:05	4 to 5.5	51	33/33	7.45	24.6	0.31	18.4	5.85
F4-A	Corner of 73rd and Collins Ave, grassy area in front of community center. SE intersection	240723	8:00	7 to 8	<10	30/30	7.10	23.7	0.52	7.5	6.14
F5-A	Parking lot NE of intersection between 74th St/Harding Ave. SE corner	240724	8:01	4 to 5	<10	31/33	7.20	27.9	0.35	2.5	4.83
F6-A	Grassy area next to pump-station, W of 75th St and intersection of Dickens Ave/75th St	240725	11:30	4 to 5	216	32.5/31.5	6.53	26.7	28.61	85.1	3.12
F7-A	W of Dickens Ave/75 th street intersection. Grassy patch W of roundabout, along fence	240725	10:37	4 to 5	>24,196	33.5/32.5	6.61	27.4	1.18	27.0	0.84
F9-A	In the grass of the median along 73 rd between Carlyle Ave and Dickens Ave	240723	9:43	4 to 5.5	1,337	31/31	6.82	23.3	1.51	76.4	4.92
F10-A	In the grass of the median along 73 rd St between Harding Ave and Byron Ave	240723	10:26	4 to 5.5	108	31.5/30.5	6.97	25.3	0.87	39.2	5.27
F11-A	Grassy patch, S end of parking lot E of the corner of 72 nd Street and Harding, middle of lot	240723	11:50	4 to 6	<10	34/34	7.26	23.5	0.38	1.5	5.24
G1-A	Along alley that runs perpendicular to 74 th /73 rd between Carlyle Ave and Byron Ave	240724	11:45	4 to 6	228	35.5/35.5	7.30	27.2	0.33	26.4	3.75
G2-A	Asphalt alley that runs perpendicular to 74 th /73 rd between Harding Ave and Byron Ave	240724	11:17	5 to 6	<10	33.5/33.5	7.81	26.8	0.2	25.5	4.73
G3-A	Asphalt along E sidewalk of Dickens Avenue, NE intersection corner	240725	9:34	4 to 5	145	32.5/32.5	7.51	27.1	0.43	3.5	4.23
G4-A	Grassy stretch SE of intersection between 76 th and Collins	240724	9:05	7.5 to 8	<10	33/32.5	6.95	26.2	0.47	6.8	5.42

Table C.2 (continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Collection Depth (ft)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
							pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
G5-A	Grassy patch east of the intersection between 75 th Street and Collins Avenue	240723	8:35	6.5 to 7.5	<10	33.5/33.5	7.54	24.4	0.36	6.9	5.36
G7-A	Asphalt along S sidewalk of 75 th Street SE intersection corner	240725	10:07	4 to 5	<10	34/34.5	7.30	25.5	0.36	6.9	2.91
G8-A	Grass of median along 73 rd and Carlyle Ave and Byron Avenue	240723	11:17	4 to 5.5	253	33.5/33.5	6.71	24.6	1.03	26.4	4.32
G10-A	SW corner of Parkview Island Park, NE intersection of Bruce Street/Gary Avenue	240723	8:55	4 to 5.5	<10	28.5/29	6.84	24.5	4.94	9.0	2.64
G11-A	Asphalt in alley between 75 th Street and 74 th Street	240724	10:39	4 to 5	<10	35/34.5	7.55	25.6	0.44	10.0	5.32
G12-A	Asphalt in alley between 75 th Street and 74 th Street	240724	12:00	5 to 6	85	34/34	7.20	25.3	0.39	13.6	4.47
G13-A	Grassy area NW corner of Altos Del Mar Park	240724	10:06	8.5 to 9	10	32.5/32	7.01	27.7	0.46	72.2	4.93
G16-A	Parkview Island Park grassy NE corner, SW corner	240723	10:58	5 to 6	97	32.5/32	6.71	23.6	0.96	22.7	5.52
G17-A	Grassy patch at intersection of 73 rd /Wayne Avenue on Parkview Island, SW section	240723	9:15	3.5 to 5	761	31.5/32	7.21	22.7	0.51	82.1	5.34
R1-A	Parking lot NE intersection between 74 th and Harding Avenue, NW corner	240724	8:41	4 to 5	10	32.5/32	7.16	28.6	0.45	96.2	4.42
R2-A	Grassy area N of North Beach Community Garden, W of intersection Dickens Avenue/74 th Street	240725	9:08	4 to 5	10	33.5/32.5	7.11	26.3	0.69	9.9	4.40
R3-A	Roundabout at Biscayne Elementary School drop-off, W of Dickens Avenue/75 th Street intersection	240725	10:58	5 to 6	97	32.5/32	6.41	27.9	26.49	0.43	0.57

Table C.3: Data table for stormwater samples. All times recorded as local time. MST data in main text.

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
BS1	At the grate on the SE corner of the intersection of Collins and 75th. Grate is on the E side of Collins Ave.	240806	14:14	Field-staged bottle	10	>24,196	33.6	7.97	27.0	0.06	25.1	5.95
BS2	Grate on the NW corner of the intersection of Collins Ave and 74th St	240806	11:40	Field-staged bottle	10	24,196	34.2	N/A	N/A	N/A	N/A	N/A
BS3	Grate on S end of Gary Ave. Grate is on the E side of Gary Ave	240806	15:20	Field-staged bottle	10	24,196	33.3	8.05	27.0	0.06	6.3	6.84
BS4	Grate on W side of the intersection Gary Ave and Bruce St, SW corner of the Parkway Park	240806	15:30	Field-staged bottle	10	>24,196	33.5	7.99	26.8	0.06	7.4	6.55
BS5	Storm-drain at the intersection of 76 th Collins Ave, E side of Collins Ave	N/A	N/A	Field-staged bottle	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BS6	Grate on the north side of 72nd St at the NE corner of intersection of 72 nd /Collins	240806	15:00	Field-staged bottle	10	443	33.8	8.74	26.5	0.05	15.8	7.11
BS7	Grate on the N side of 72nd St at the NE corner of the intersection of 72nd and Collins	240809	13:23	Field-staged bottle	10	11,199	28.2	8.6	23.5	0.02	11.5	6.96
BS8	Strom drain at the intersection of Collins Ave and 73rd St E of Collins Ave	240809	13:36	Field-staged bottle	10	2,415	28.5	8.94	23.6	0.03	6.09	7.17
BS9	At the grate on the SE corner of the intersection of Collins and 75th. E of Collins Ave.	240809	12:54	Field-staged bottle	10	19,863	30.5	8.66	24.0	0.05	21.8	7.04
BS10	Grate on the NW corner of the intersection of Collins Ave and 74th St	240809	12:45	Field-staged bottle	10	24,196	34.8	8.76	24.1	0.06	18.5	6.94

Table C.3 (Continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
BS11	Storm-drain at the northeast most point Parkview Island at the intersection of Wayne Ave and Michael St	240809	11:54	Field-staged bottle	10	>24,196	30.4	8.33	23.6	0.06	6.71	7.02
BS12	Storm-drain, W side of Parkview Island E side of Gary Ave, building complex 7311	240809	11:59	Field-staged bottle	10	24,196	34.5	7.79	23.8	0.07	7.50	6.72
BS13	Storm-drain at the northeast most point Parkview Island at the intersection of Wayne Ave and Michael St. Across the street from SRA	240820	14:50	Field-staged bottle	10	14,136	28.6	8.41	23.7	0.06	18.6	7.26
BS14	Grate on west side of the intersection Gary Ave and Bruce St. At the southwest corner of the Parkview Park.	240820	15:03	Field-staged bottle	10	173,290	35.5	8.3	22.7	0.06	9.7	7.02
PS1	Puddle at SE corner of 74th and Harding. Parking lot, CVS	240725	8:10	Puddle	10	14,136	N/A ^a	7.35	26.0	0.09	1.8	5.64
PS2	Storm-drain at the intersection of 74th and Dickens	240725	9:10	Puddle	10	>24,196	N/A	7.97	24.0	0.27	3.5	3.93
PS3	Puddle at the drain opening at the corner of 76th and Dickens	240725	9:40	Puddle	10	>24,196	N/A	7.00	25.9	0.19	9.7	1.72
PS4	Puddle at the intersection of 73rd and Wayne Ave on Parkview Island. On the west side of Wayne Ave.	240806	12:08	Puddle	10	1,399	35.1	8.71	26.1	0.11	3.40	7.08

Table C.3 (Continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
PS5	Puddle on the north side of 73rd St and just east of the intersection of 73rd and Dickens	240806	11:40	Puddle	10	10,462	34.1	7.75	27.3	0.08	2.82	5.40
PS6	Puddle in the southeast corner of the public parking lot at the corner of 73rd and Harding.	240806	11:21	Puddle	10	24,196	31.8	7.25	24.6	0.10	2.10	4.38
PS7	Puddle on the North side of 75th St at the west end of the street by the school.	240806	11:15	Puddle	10	6,131	38.3	7.76	23.0	0.15	6.1	5.82
PS8	Puddle on Parkview Island. 40 yds N of the intersection of 73rd and Wayne Ave	240806	12:57	Puddle	10	>24,196	38	7.51	27.0	0.10	8.5	5.68
PS9	Puddle on the west most side of the parking lot on the north side of the North shore library	240806	14:18	Puddle	10	>24,196	30.5	7.71	24.4	0.07	3.8	5.89
PS10	Puddle at the east entrance to the Parkview Island Park parking lot	240809	12:07	Puddle	10	861	37.4	8.64	26.6	0.04	10.4	7.34
PS11	Puddle on the E side of Gary Ave near BS12	240809	12:11	Puddle	10	3,609	34.4	8.70	25.7	0.05	8.58	6.94
PS12	Puddle in the alley between Carlyle and Byron and 74th and 73rd	240809	12:18	Puddle	10	>24,196	34.8	7.73	25.7	0.05	23.5	5.51
PS13	Puddle in the alley between Carlyle and Byron and 74th and 75th	240809	12:22	Puddle	10	>24,196	35.4	8.06	24.8	0.06	6.81	6.46
PS14	Puddle in the alley between Harding and Byron and 74th and 75th	240809	12:30	Puddle	10	12,997	35.6	8.47	24.8	0.04	19.2	6.71
PS15	Puddle in the alley between Harding and Byron and 74th and 73rd	240809	12:35	Puddle	10	17,329	34.4	8.00	25.2	0.04	3.45	6.54

Table C.3 (Continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
PS16	Southwest corner of Parkview. West side of the street	240820	15:03	Puddle	10	81,640	34.6	8.08	30.1	0.04	5.04	7.82
PS17	Southwest corner of Parkview.	240820	15:08	Puddle	10	2,410	36	8.89	28.6	0.03	8.37	7.78
PS18	Corner of Dickens and 72nd. At the parking lot of the tennis courts	240820	15:19	Puddle	10	77,010	32	8.55	28.7	0.04	150	7.32
PS19	Harding and 72nd. North side of the street	240820	15:27	Puddle	10	19,040	35.2	8.22	29.1	0.05	17.6	7.47
PS20	75th and Ocean Ter. North side of the street	240820	15:35	Puddle	10	16,790	36.2	8.09	26.1	0.07	11.6	6.70
PS21	75th and Abbot. South side of the street	240820	15:44	Puddle	10	25,810	32.3	8.47	28.2	0.05	5.25	7.05
PS22	Abbot and 76th. South side of the street	240820	15:52	Puddle	10	129,970	31.3	8.46	25.8	0.08	7.34	7.20
PS23	74th and Abbot. North side of the street	240820	16:00	Puddle	10	120,330	36.6	8.34	27.3	0.06	21.1	7.14
PS24	Near the intersection of 73rd and Harding on the south side of 73rd	240820	16:08	Puddle	10	98,040	36.8	7.82	26.0	0.07	17.7	6.63
PS25	West most end of 75th at the beginning of the roundabout at the school	240820	16:19	Puddle	10	57,940	38.8	8.38	29.3	0.16	48.1	7.41
SRA	Strom drain at the northeast corner of the Parkview Island Park	240806	13:09	In-person	1.0	>24,196	31.0	8.50	24.2	0.03	12.9	7.10
SRB	Strom drain at intersection Collins Ave/73 rd St, E side of Collins Ave	240806	13:10	In-person	1.0	>24,196	36.9	7.97	26.3	0.11	27.1	6.02
SRC	Storm-drain at the intersection 76 th /Collins Ave, E side of Collins Ave	240806	13:15	In-person	1.0	>24,196	33.0	8.81	26.2	0.04	10.2	6.94

Table C.3 (Continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
SRD	Storm drain at the northeast corner of the Parkview Island Park	240809	11:37	In-person	1.0	>24,196	28.7	8.79	26.2	0.07	24.0	7.26
SRE	Storm-drain at the intersection 76 th /Collins Ave, E side of Collins Ave	240809	13:07	In-person	1.0	24,196	30.7	8.29	26.5	0.07	30.5	7.00
SRF	Parkview Island, W side of Wayne Ave, half-way up street at storm drain	240820	14:30	In-person	1.0	92,080	31.9	8.71	25.8	0.05	16.7	7.38
SRG	Grate at intersection 73 rd /Dickens, N side of 73 rd St	240823	N/A	In-person	1.0	10,760	N/A	N/A	N/A	N/A	N/A	N/A
SRH	Storm-drain SW corner of intersection 74 th /Carlyle Ave	240829	N/A	In-person	1.0	>241,960	N/A	7.57	23.2	0.24	28.4	5.97
SRI	Storm-drain at SW corner of intersection 74 th /Byron Ave	240829	N/A	In-person	1.0	11,590	N/A	7.99	21.9	0.17	6.67	6.74
SRJ	Storm-drain at intersection 74 th /Dickens along W side	240829	N/A	In-person	1.0	38,730	N/A	7.79	21.7	0.16	24.2	6.65
SRK	Storm-drain at NW corner of the intersection Dickens/72 nd	240829	N/A	In-person	1.0	86,640	N/A	8.01	20.4	0.2	58.9	6.17
SRL	Storm-drain at SE corner of intersection of 72 nd /Abbot Ave	240829	N/A	In-person	1.0	61,310	N/A	7.88	21.3	0.42	48.0	6.27
SRM	Storm-drain at SE corner of intersection 73 rd /Ocean Ter. Along S of 73 rd , outside parking lot	240829	N/A	In-person	1.0	15,520	N/A	8.50	22.2	0.08	38.4	6.78
SRN	Storm-drain at NW corner of intersection 73 rd /Carlyle Ave	240829	N/A	In-person	1.0	241,960	N/A	8.36	21.6	0.09	20.8	6.76
SRO	Storm-drain at SE corner of intersection 76 th /Byron Ave	240829	N/A	In-person	1.0	>241,960	N/A	8.39	22.0	0.06	9.34	6.64
SRP	Storm-drain at intersection of 73 rd /Carlyle Ave, S of 73 rd	240829	N/A	In-person	1.0	77,010	N/A	8.91	23.3	0.09	95.0	6.87

Table C.3 (Continued)

Sample ID	Location Description	Sample Collection Date (YYMMDD)	Sample Collection Time	Sample Type	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	Physical Chemical Measurements in Laboratory				
								pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
SRQ	Storm-drain at NW corner of intersection of 73 rd /Byron Ave	240829	N/A	In-person	1.0	173,290	N/A	7.81	23.5	0.08	5.44	6.69
SRR	Storm-drain at the intersection of 75 th /Dickens, SW corner of the intersection	240910	16:16	In-person	1.0	198,630	N/A	7.14	27.5	3.02	9.12	4.81
SRS	Storm-drain at intersection 76 th /Carlyle SW corner	240910	16:20	In-person	1.0	>241,960	N/A	7.16	27.0	0.43	11.3	6.22
SRT	Intersection of 75 th /Harding	240910	16:26	In-person	1.0	6,310	N/A	8.49	26.2	0.31	1.72	7.53
SRU	Storm-drain in SE section of parking lot of library on 75 th /Collins	240910	16:31	In-person	1.0	46,110	N/A	7.68	27.3	0.39	56.5	6.43
SRV	Storm-drain at the end E end of 74 th St past Collins Ave, S side	240910	16:09	In-person	1.0	241,960	N/A	7.35	27.4	0.13	10.3	5.32
SRW	Long storm-drain at corner of Harding/74 th SE corner	240910	16:03	In-person	1.0	>241,960	N/A	7.49	27.0	0.12	8.3	5.88
SRX	Storm-drain at intersection 72 nd /Collins, NW corner (Previous sampling site)	240910	15:51	In-person	1.0	129,970	N/A	7.59	26.5	0.23	35.4	5.53
SRY	Storm-drain along S side of 72 nd on E end of tennis courts	240910	15:45	In-person	1.0	104,620	N/A	7.56	26.7	0.23	573	5.4
SRZ	Storm-drain on SE end of Parkview Island, S side of road	240910	16:41	In-person	1.0	155,310	N/A	7.71	25.5	0.19	10.6	5.73

^a N/A = Not available

Table C.4: Data table for PVC samples collected at the Kayak Launch and at the Biscayne Beach Elementary (BBE) Outfall. All times recorded as local time. MST data in main text.

Sample ID	Location Description	Sample Collection Depth (ft)	Sample Collection Date (YYMMDD)	Sample Collection Time	Water Level Measurement Time	Measured PVC Water Surface Elevation	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
KS01	Kayak Launch	0	240815	6:10	6:05	38	10	9,208	31.5	7.35	N/A ^a	34.53	1.8	5.53
KS02	Kayak Launch	0	240815	7:05	7:00	39	10	2,924	32.1	7.42	N/A	35.48	0.9	5.8
KS03	Kayak Launch	0	240815	8:05	8:00	43	10	216	32.3	7.41	N/A	35.2	0.8	5.5
KS04	Kayak Launch	0	240815	9:05	9:00	48	10	275	32.1	7.54	N/A	35.3	1.3	6.22
KS05	Kayak Launch	0	240815	10:05	10:00	53	10	305	32.4	7.49	N/A	33.87	1.8	6.18
KS06	Kayak Launch	0	240815	11:05	11:00	57	10	313	32.8	7.44	N/A	35.3	1.1	5.67
KS07	Kayak Launch	0	240815	12:05	12:00	59.5	10	373	33.33	7.5	N/A	30.88	2.3	5.51
KS08	Kayak Launch	0	240815	13:05	13:00	58.4	10	148	34.3	7.64	N/A	34.93	0.7	5.85
KS09	Kayak Launch	0	240815	14:05	14:00	54.7	10	30	35.5	8.05	N/A	35.7	1.3	7.73
KS10	Kayak Launch	0	240815	15:02	14:57	50	10	98	35.3	7.96	N/A	34.37	1.1	7.82
KS11	Kayak Launch	0	240815	16:03	15:58	42.8	10	645	33.7	8.83	N/A	34.07	0.9	7.5
KS12	Kayak Launch	0	240815	17:05	17:00	38.6	10	2,035	31.3	7.76	N/A	0.19	1.5	8.73
KO01	Kayak Launch	1	240815	6:15	N/A	N/A	10	457	32.2	7.46	N/A	35.46	0.7	6.22
KO02	Kayak Launch	1	240815	7:07	N/A	N/A	10	399	32.3	7.5	N/A	36.16	0.9	6.23
KO03	Kayak Launch	1	240815	8:04	N/A	N/A	10	538	32.3	7.45	N/A	36.12	1.0	5.52
KO04	Kayak Launch	1	240815	9:45	N/A	N/A	10	209	32.2	7.54	N/A	36.3	1.4	6.22
KO05	Kayak Launch	1	240815	10:50	N/A	N/A	10	393	32.7	7.51	N/A	35.78	2.0	6.27
KO06	Kayak Launch	1	240815	11:34	N/A	N/A	10	52	32.9	7.49	N/A	35.99	1.2	5.66
KO07	Kayak Launch	1	240815	12:16	N/A	N/A	10	52	33.2	7.61	N/A	36.84	1.4	6.33
KO08	Kayak Launch	1	240815	13:05	N/A	N/A	10	223	33.5	7.56	N/A	36.14	1.7	5.29
KO09	Kayak Launch	1	240815	14:11	N/A	N/A	10	142	35	8.05	N/A	35.79	0.9	7.74
KO10	Kayak Launch	1	240815	15:01	N/A	N/A	10	41	35.2	7.86	N/A	35.8	1.1	8.2
KO11	Kayak Launch	1	240815	15:53	N/A	N/A	10	109	33.7	7.83	N/A	34.08	1.0	7.5
KO12	Kayak Launch	1	240815	17:05	N/A	N/A	10	369	32.1	7.73	N/A	32.93	1.8	7.26
KF01	Kayak Launch	5	240815	6:21	N/A	N/A	10	487	32.6	7.49	N/A	36.5	1.4	6.16
KF02	Kayak Launch	5	240815	7:11	N/A	N/A	10	350	32.7	7.51	N/A	36.54	2.4	6.1
KF03	Kayak Launch	5	240815	8:50	N/A	N/A	10	388	32.6	7.48	N/A	36.41	5.7	5.87
KF04	Kayak Launch	5	240815	N/A	N/A	N/A	N/A	N/A	32.6	7.51	N/A	36.39	N/A	5.55
KF05	Kayak Launch	5	240815	10:50	N/A	N/A	10	450	32.8	7.5	N/A	36.71	8.3	5.48
KF06	Kayak Launch	5	240815	11:33	N/A	N/A	10	651	33.2	7.59	N/A	36.95	9.6	6.67
KF07	Kayak Launch	5	240815	12:18	N/A	N/A	10	529	33.2	7.61	N/A	36.84	6.4	6.33
KF08	Kayak Launch	5	240815	13:10	N/A	N/A	10	616	33.2	7.61	N/A	36.66	3.5	6.11

Table C.4 (Continued)

Sample ID	Location Description	Sample Collection Depth (ft)	Sample Collection Date (YYMMDD)	Sample Collection Time	Water Level Measurement Time	Measured PVC Water Surface Elevation	Sample Volume Processed for enterococci (mL)	Enterococci (MPN/100 mL)	Field Water Temperature (°C)	pH	Lab Water Temperature (°C)	Salinity (psu)	Turbidity (ntu)	Dissolved Oxygen (mg/L)
KO09	Kayak Launch	1	240815	14:11	N/A	N/A	10	142	35	8.05	N/A	35.79	0.9	7.74
KO10	Kayak Launch	1	240815	15:01	N/A	N/A	10	41	35.2	7.86	N/A	35.8	1.1	8.2
KO11	Kayak Launch	1	240815	15:53	N/A	N/A	10	109	33.7	7.83	N/A	34.08	1.0	7.5
KO12	Kayak Launch	1	240815	17:05	N/A	N/A	10	369	32.1	7.73	N/A	32.93	1.8	7.26
KF01	Kayak Launch	5	240815	6:21	N/A	N/A	10	487	32.6	7.49	N/A	36.5	1.4	6.16
KF02	Kayak Launch	5	240815	7:11	N/A	N/A	10	350	32.7	7.51	N/A	36.54	2.4	6.1
KF03	Kayak Launch	5	240815	8:50	N/A	N/A	10	388	32.6	7.48	N/A	36.41	5.7	5.87
KF04	Kayak Launch	5	240815	N/A	N/A	N/A	N/A	N/A	32.6	7.51	N/A	36.39	N/A	5.55
KF05	Kayak Launch	5	240815	10:50	N/A	N/A	10	450	32.8	7.5	N/A	36.71	8.3	5.48
KF06	Kayak Launch	5	240815	11:33	N/A	N/A	10	651	33.2	7.59	N/A	36.95	9.6	6.67
KF07	Kayak Launch	5	240815	12:18	N/A	N/A	10	529	33.2	7.61	N/A	36.84	6.4	6.33
KF08	Kayak Launch	5	240815	13:10	N/A	N/A	10	616	33.2	7.61	N/A	36.66	3.5	6.11
KF09	Kayak Launch	5	240815	14:14	N/A	N/A	10	368	33.8	7.79	N/A	36.68	3.2	6.67
KF10	Kayak Launch	5	240815	15:04	N/A	N/A	10	187	34.5	7.86	N/A	36.43	3.9	7.81
KF11	Kayak Launch	5	240815	15:56	N/A	N/A	10	327	34	7.81	N/A	36.72	4.4	8.17
KF12	Kayak Launch	5	240815	17:03	N/A	N/A	10	243	34.1	7.56	N/A	36.3	4.0	7.73
CS1	BBE Outfall	0	240805	12:35	N/A	N/A	10	17,329	N/A	7.29	23.8	20.03	0.76	5.54
CS2	BBE Outfall	0	240820	16:27	N/A	N/A	1.0	198,630	29.5	7.10	26.7	13.74	1.91	5.33
CS3	BBE Outfall, submerged	0	240823	13:29	N/A	N/A	1.0	980	29.2	7.35	21.9	35.64	1.04	5.37
CS4	BBE Outfall, 70% submerged	0	240823	15:30	N/A	N/A	1.0	740	30.8	7.26	23.0	35.76	0.73	4.22
CS5	BBE Outfall	0	240829	N/A	N/A	N/A	1.0	2,720	N/A	6.91	23.5	32.66	1.73	4.76
CS6	BBE Outfall, mostly submerged	0	240919	15:36	N/A	N/A	1.0	2,620	N/A	7.03	23.5	16.66	6.35	4.98
CS7	BBE Outfall, submerged	0	240919	16:15	N/A	N/A	1.0	8,650	N/A	7.1	23.7	14.75	6.67	5.31

^a N/A = Not available or not applicable

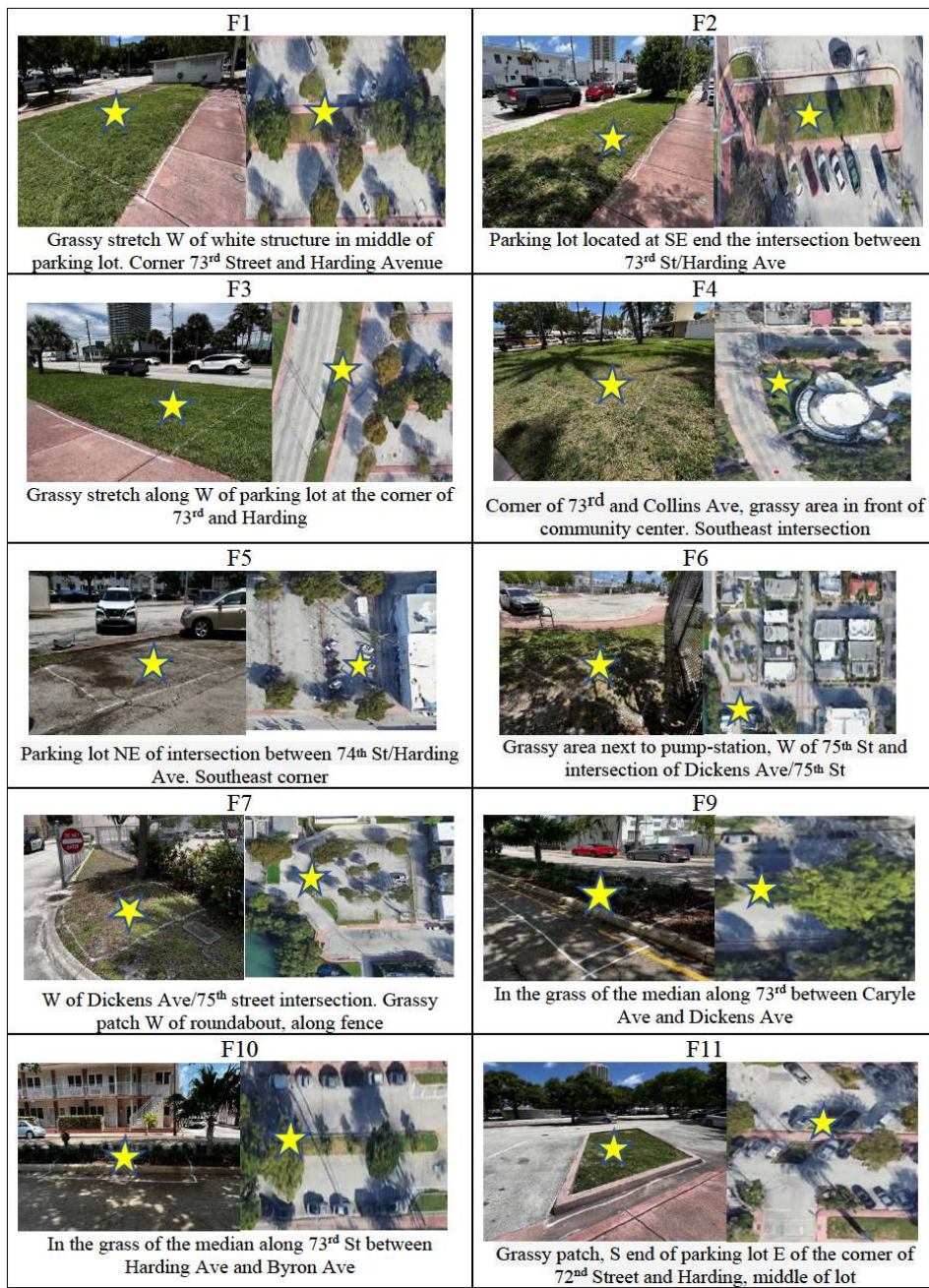


Figure C.7: Photos of groundwater sampling locations.

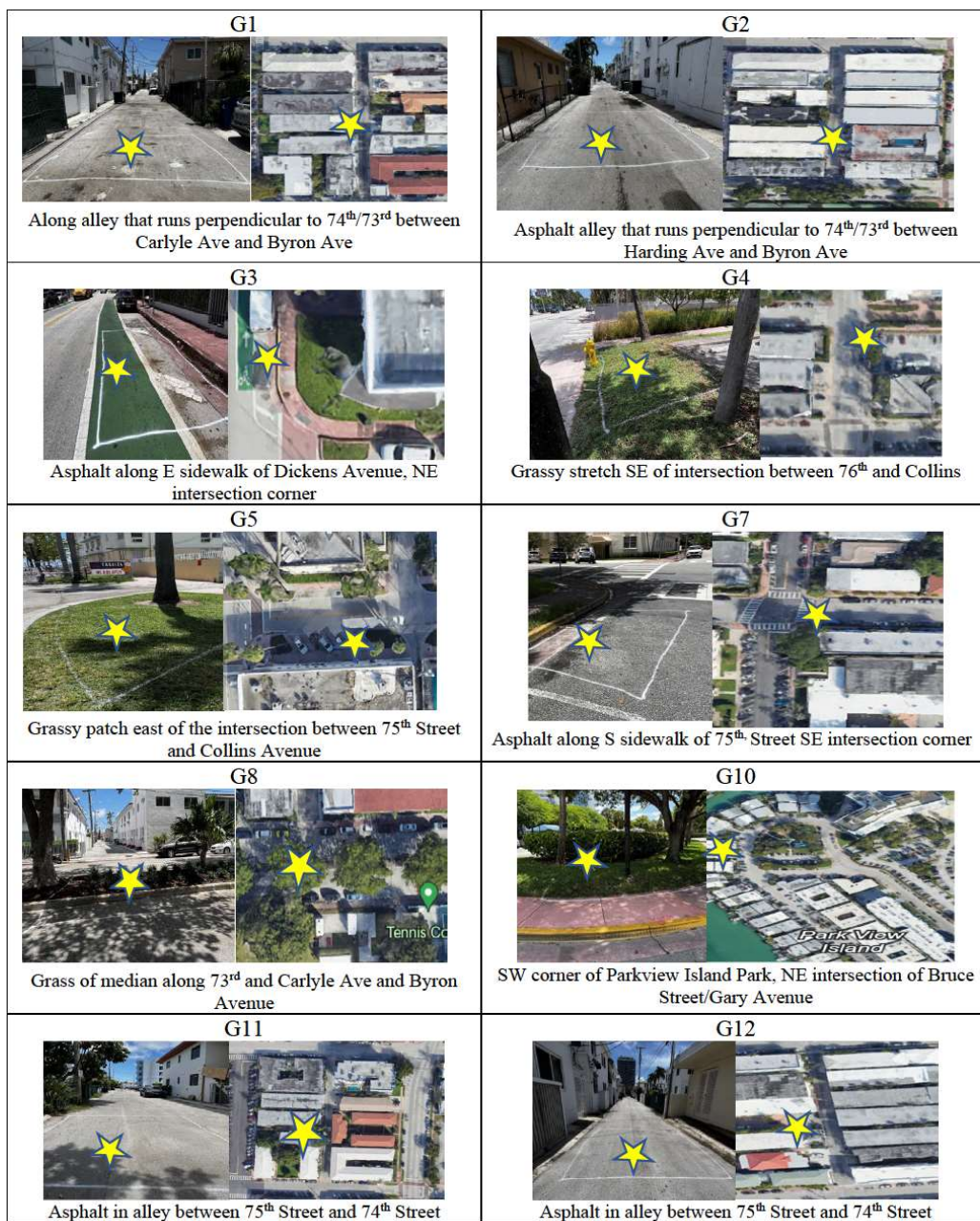


Figure C.7 (continued): Photos of groundwater sampling locations.

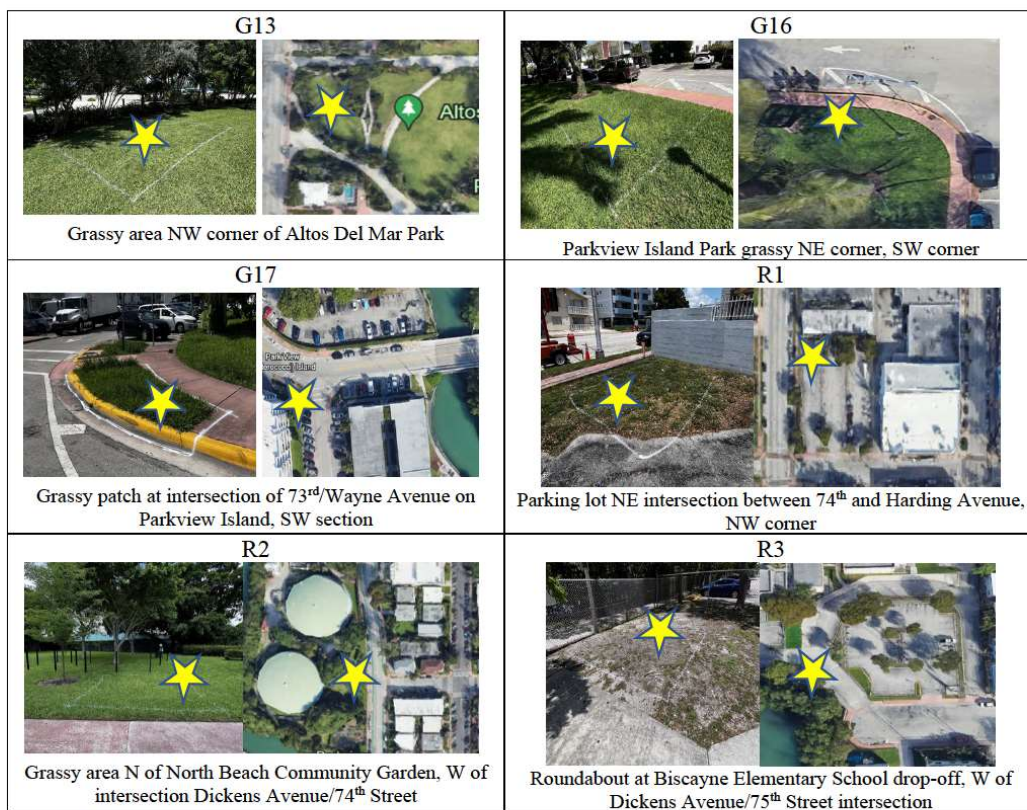


Figure C.7 (continued): Photos of groundwater sampling locations.

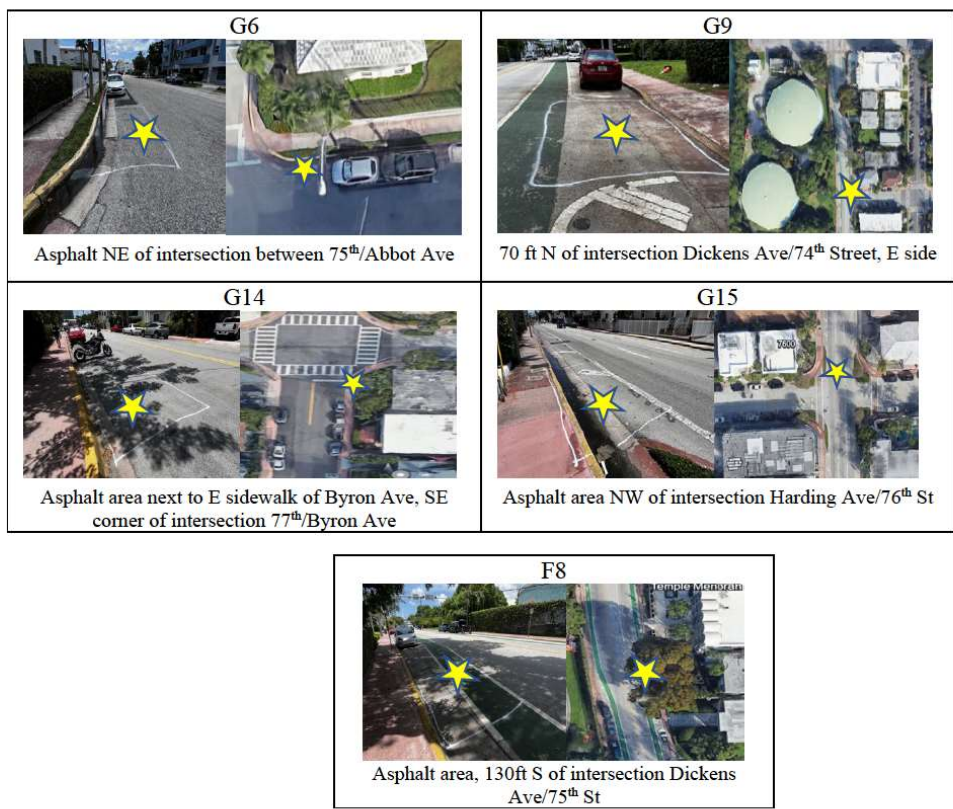


Figure C.8: Photos of sites planned for groundwater sampling but deemed non-viable due to conflicts with underground utilities.

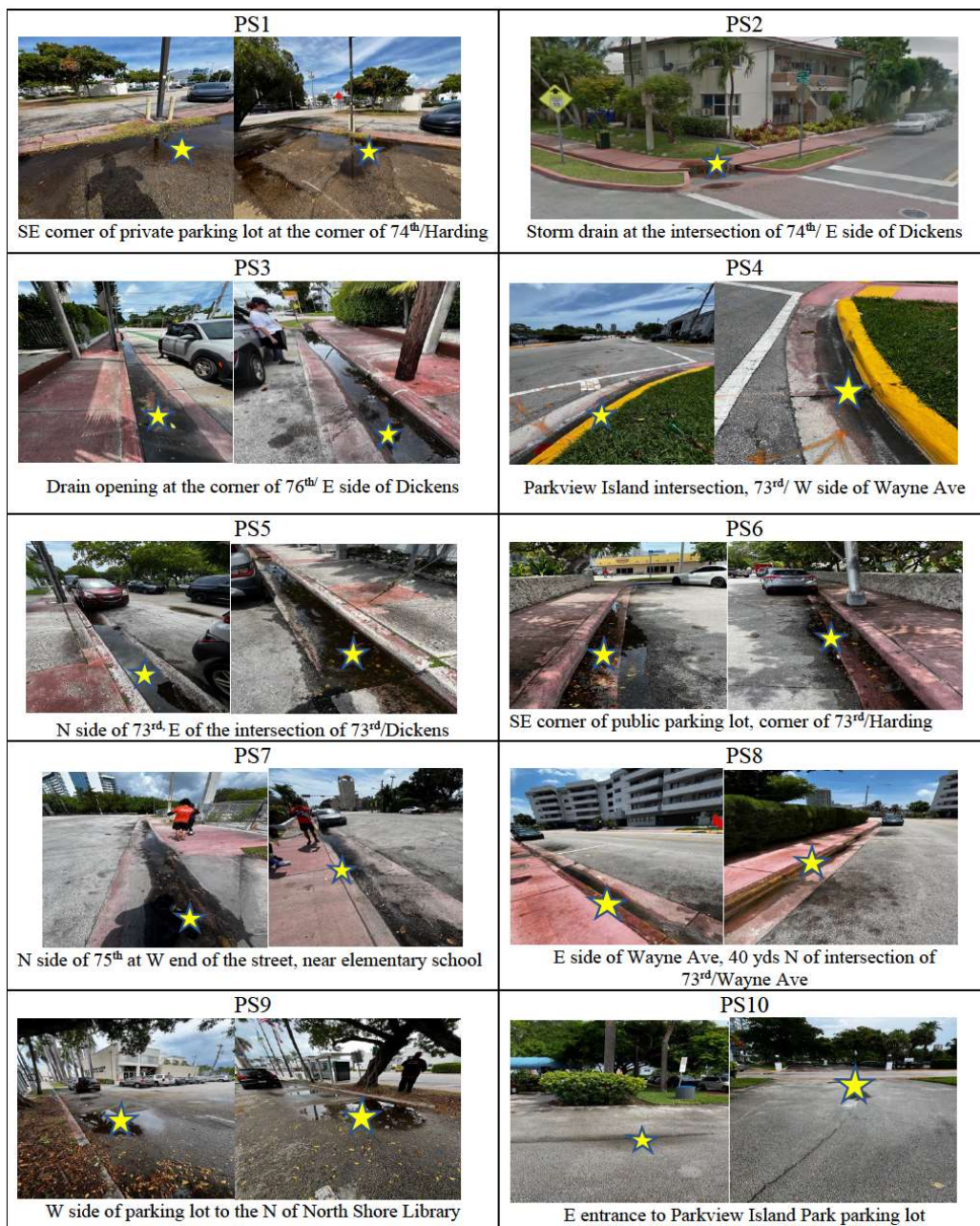


Figure C.9: Photos of puddle sampling sites.

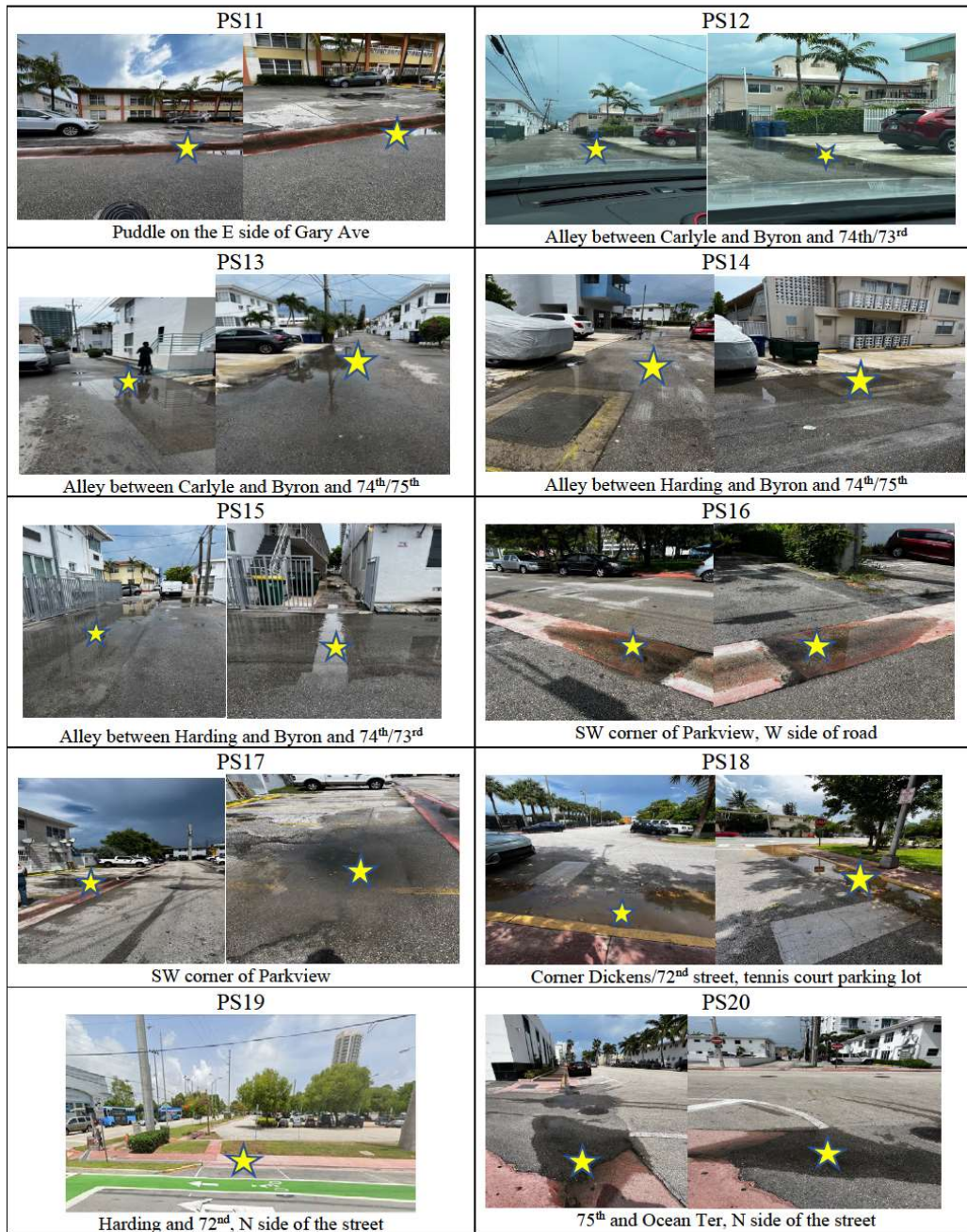


Figure C.9 (continued): Photos of puddle sampling sites.

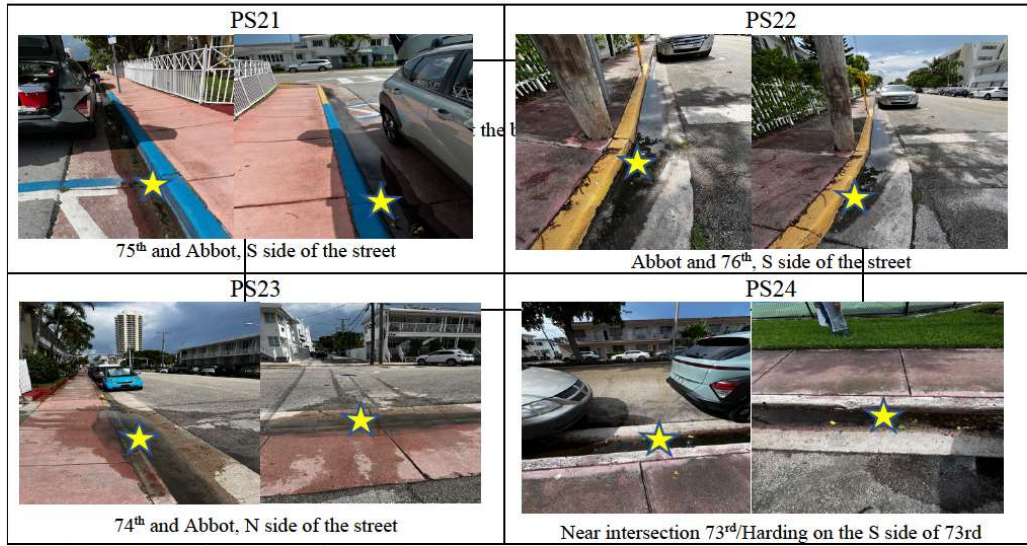


Figure C.9 (continued): Photos of puddle sampling sites.

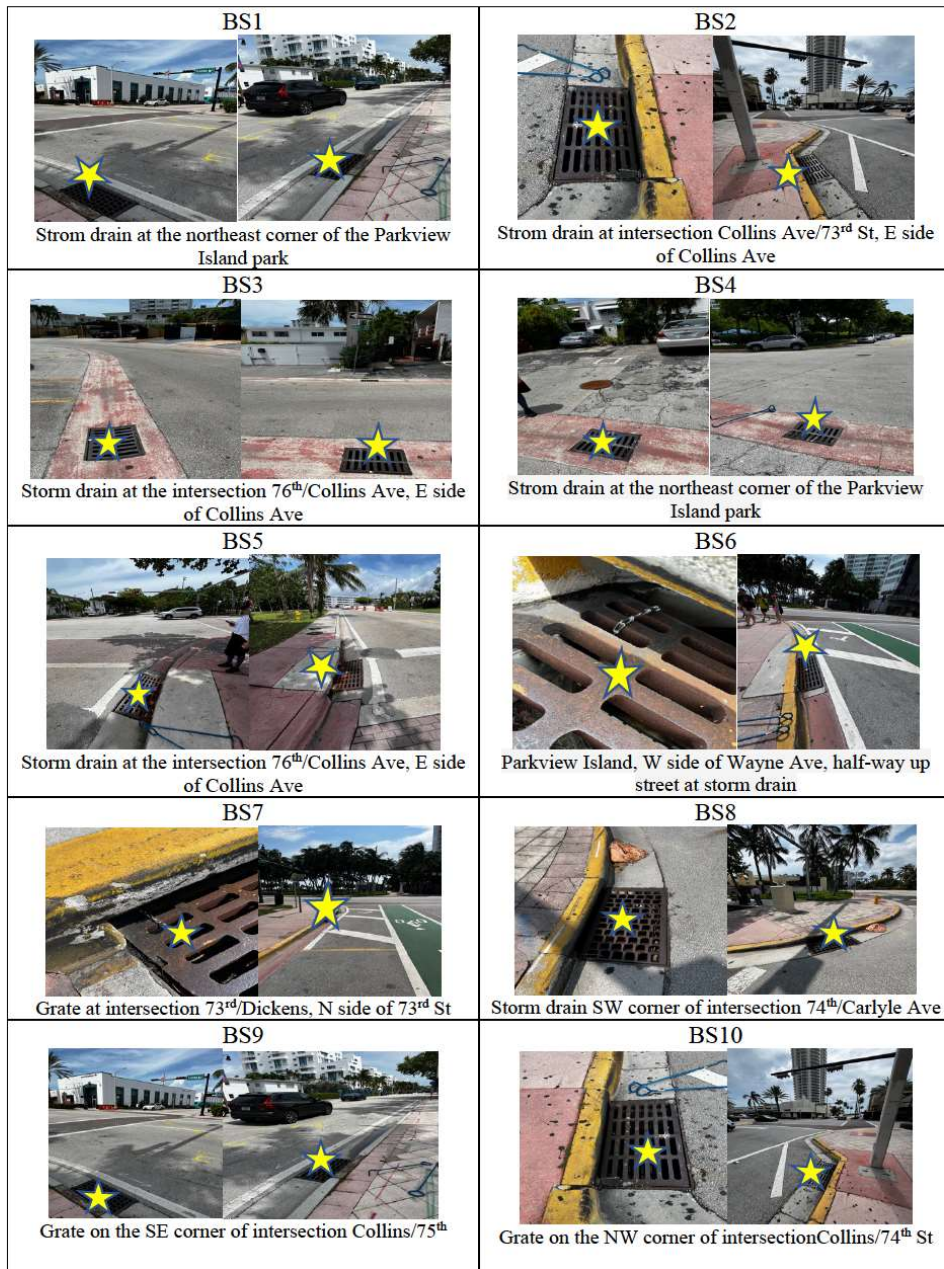


Figure C.10: Photos of “field-staged bottle” sampling locations.

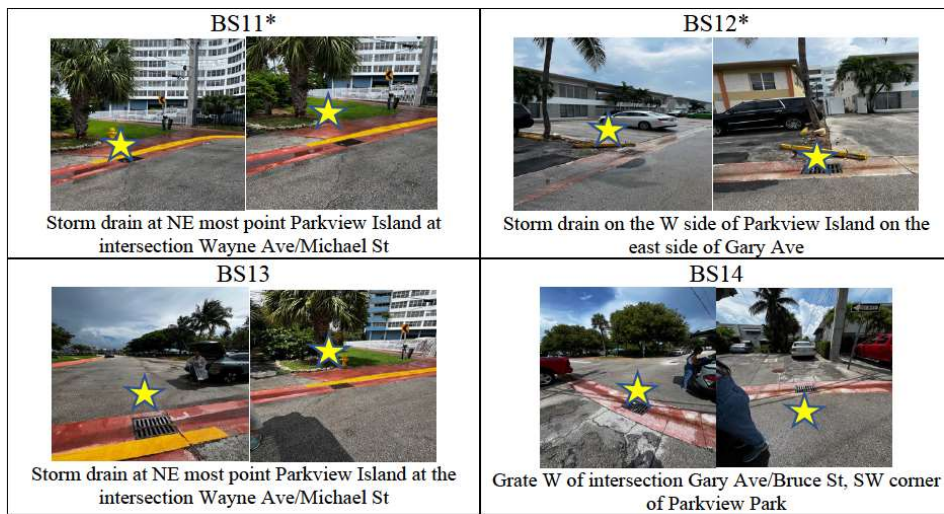


Figure C.10 (continued): Photos of “field-staged bottle” sampling locations. *Samples BS11 and BS12 taken in-person but given a bottle sample (BS) identifier.

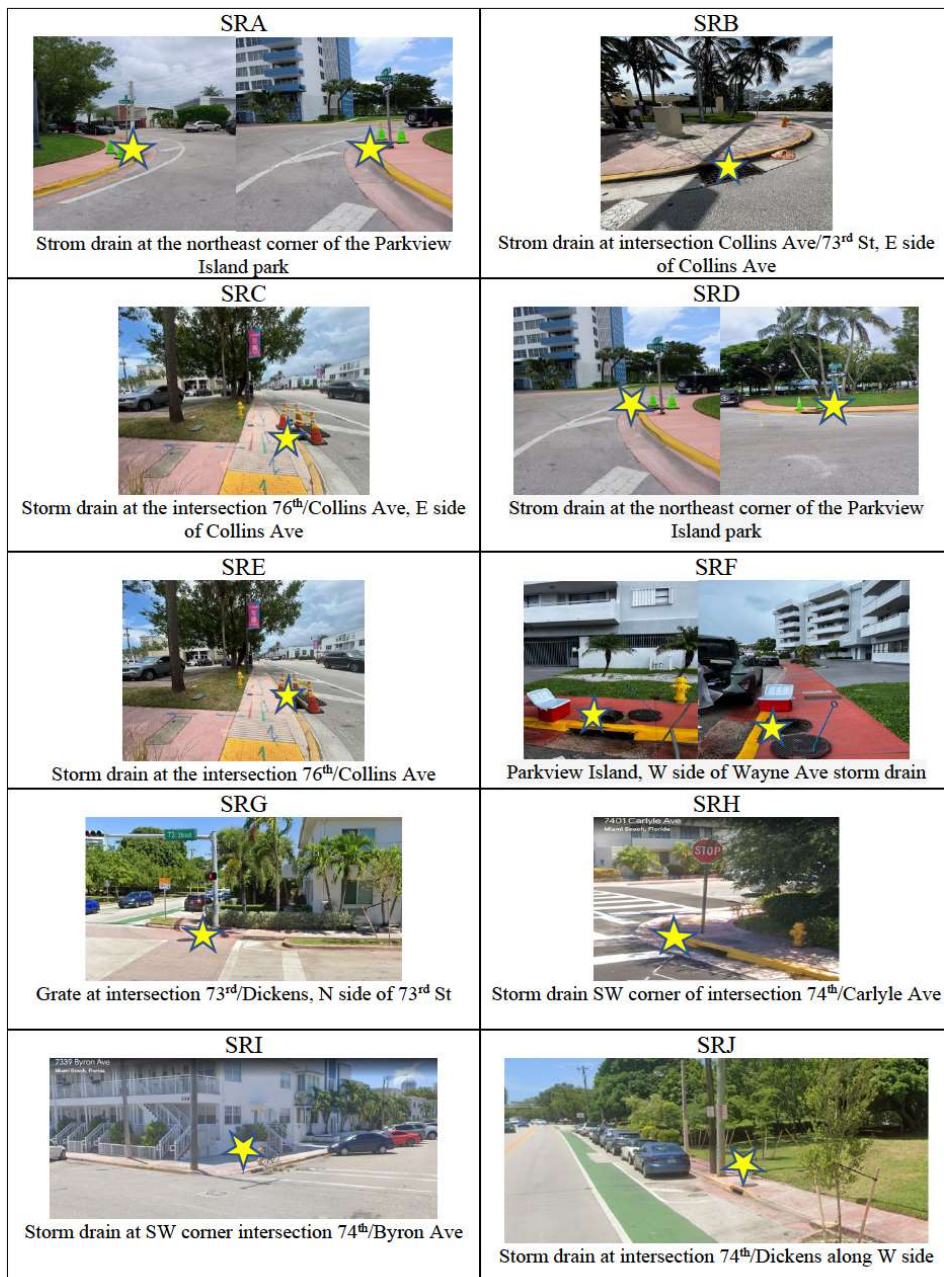


Figure C.11: Photos of “in-person runoff” sampling locations.

<p>SRK</p>  <p>Storm drain at NW corner of intersection Dickens/72nd</p>	<p>SRL</p>  <p>Storm drain at SE corner of intersection of 72nd/Abbot Ave</p>
<p>SRM</p>  <p>Storm drain at SE corner of intersection 73rd/Ocean Ter.</p>	<p>SRN</p>  <p>Storm drain at NW corner of intersection 73rd/Carlyle Ave</p>
<p>SRO</p>  <p>Storm drain at SE corner of intersection 76th/Byron Ave</p>	<p>SRP</p>  <p>Storm drain at intersection of 73rd/Carlyle Ave, S of 73rd</p>
<p>SRQ</p>  <p>Storm drain at NW corner of intersection 73rd/Byron Ave</p>	<p>SRR</p>  <p>Storm drain at the intersection of 75th/Dickens, SW corner</p>
<p>SRS</p>  <p>Storm drain at intersection 76th/Carlyle SW corner</p>	<p>SRT</p>  <p>Intersection of 75th/Harding</p>

Figure C.11 (continued): Photos of “in-person runoff” sampling locations.

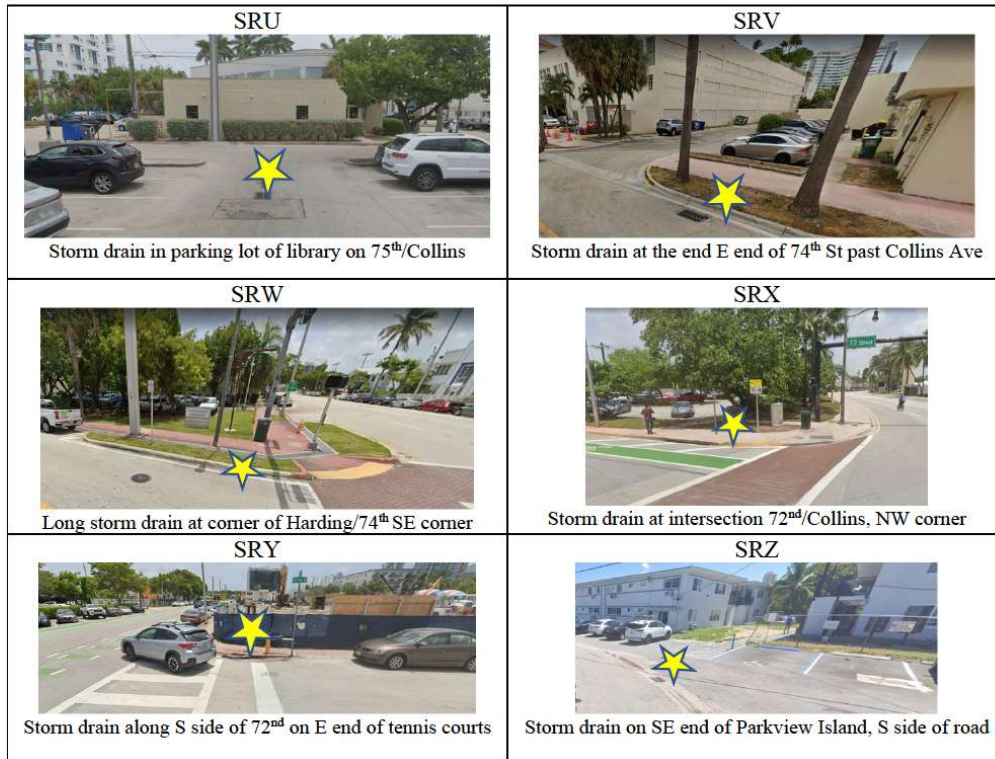


Figure C.11 (continued): Photos of “in-person runoff” sampling locations.

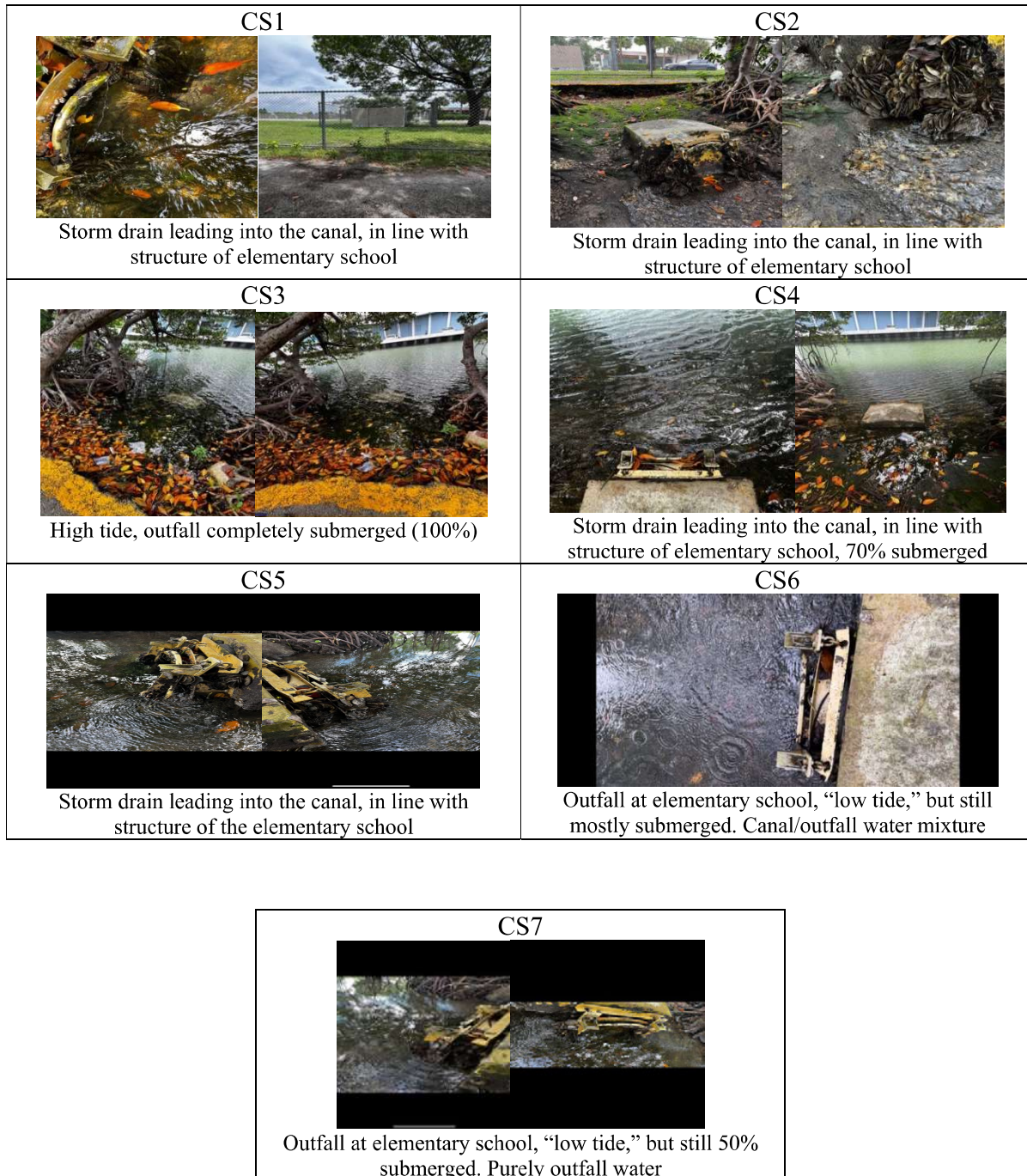


Figure C.12: Photos of "in-person runoff" sampling locations.



Figure C.13: Illustration of process used to identify underground utilities using ground penetrating radar. The roller device is used to obtain an overall mapping of the utilities and the handheld device (in the foreground on the grass) is used to obtain finer resolution of the underground utilities.



Figure C.14: Illustration of groundwater sample collection from behind the pickup truck mounted drill rig.

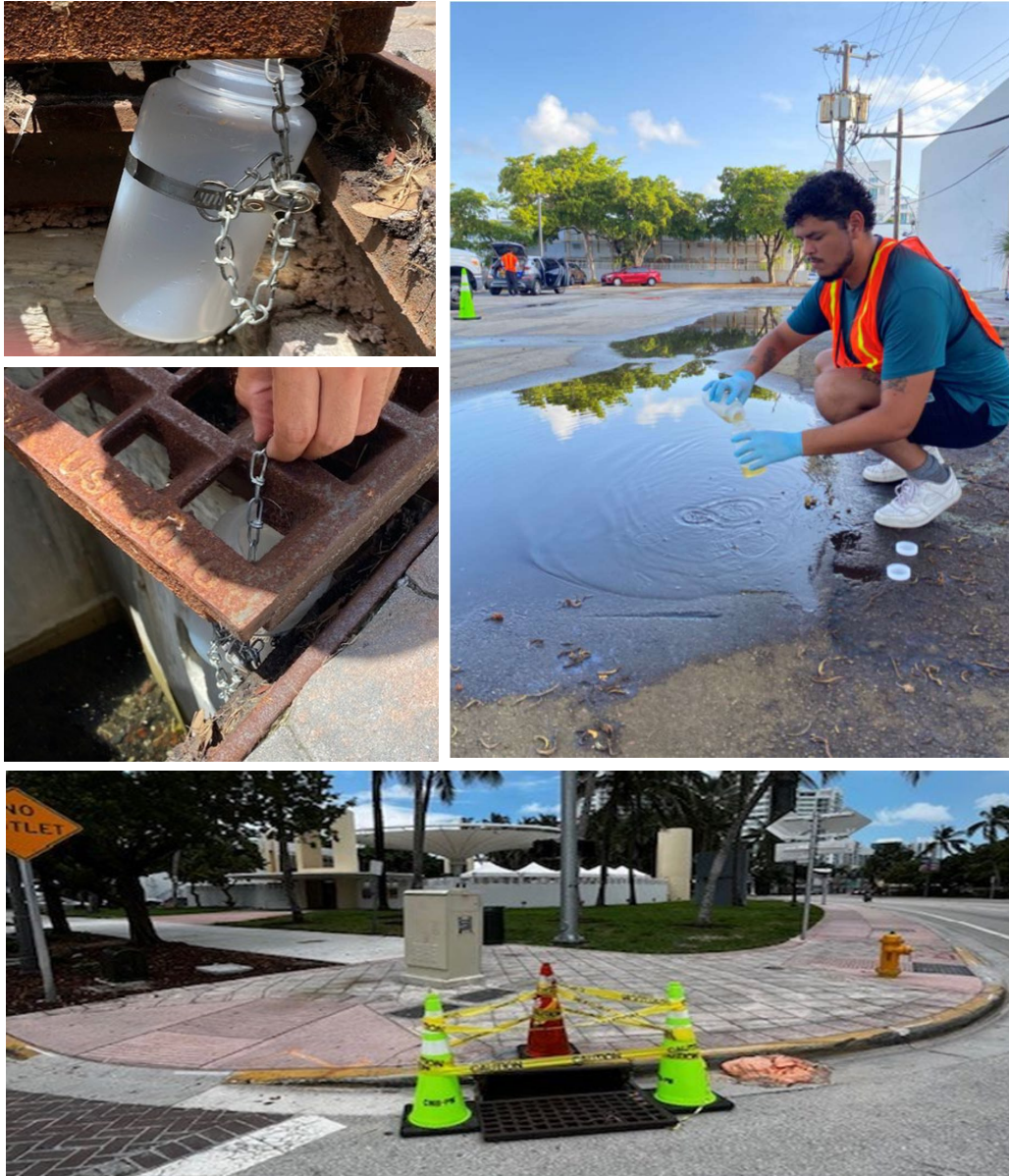


Figure C.15: Illustration of stormwater sampling. Top two square photos illustrate the field-staged bottle sample set up hanging immediately below the catch basin grate. Top right photo illustrates puddle sampling. The bottom photo illustrates the set up for in-person runoff sampling requiring the removal of the top grate or manhole cover for manual placement of a bottle to collect water as it falls into the catch basin.



Figure C.16: Photo of sample collection set up at the Kayak Launch towards the beginning of the 12-hour sampling event.

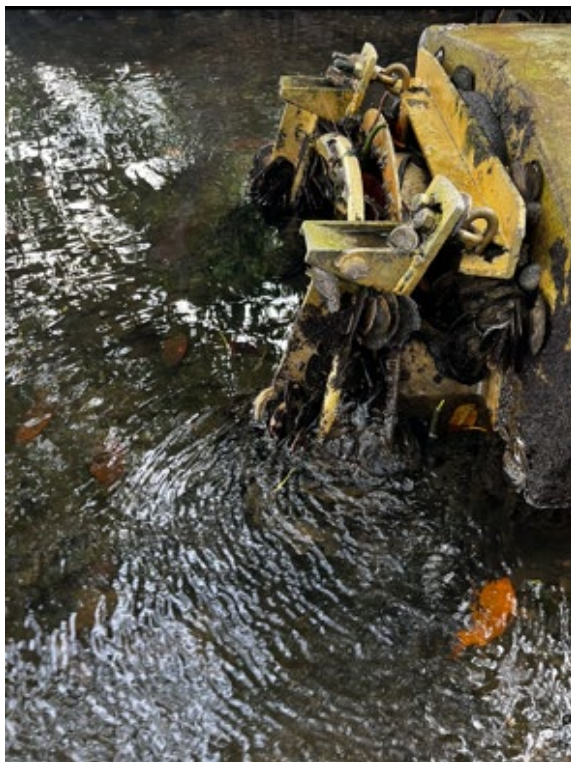


Figure C.17: Photo of outfall at BBE



Figure C.18: Photo of animal feeding station of bread and donuts taken on January 31, 2025, near the entrance to the Kayak Launch. Prior to taking the photo, a flock of birds were seen at the station. These birds flew away once the station was approached to take this photo.

APPENDIX D

**LABORATORY PROCESSING DETAILS FOR MST AND
ENTERO1A MARKERS**

APPENDIX D

LABORATORY PROCESSING DETAILS FOR MST AND ENTERO1A MARKERS

Environmental water samples (from groundwater, stormwater, and the PVC) were aseptically collected into sterile containers and transported back to the laboratory on ice as previously described in the main text. For qPCR analysis of MST and the EnterolA marker analysis, up to 500 mL water samples were aseptically filtered onto sterile mixed cellulose ester (MCE) type membrane filters, 47 mm diameter, 0.45 μ m pore-sized (GN-6, Pall), to collect the bacterial population of the water sample onto the membrane filter. For samples that were too turbid to filter a full 500 mL of water sample, the water sample was passed through the filter until clogging. For each individual filter, the actual volume of water sample that was passed through the filter was recorded, and the filter was assigned a unique filter sample ID tracking number. For tracking purposes, all filter samples were labeled with multiple cross-referenced IDs that included both a unique filter ID number label, and an independent label of a unique combination of sample site ID plus date in YYMMDD format. After filtration, the filters were aseptically folded with sterile forceps and placed into sterile 5 mL microcentrifuge tubes containing 1,500 μ L of 1 \times Zymo DNA/RNA Shield (a nucleic acid preservative by Zymo Research Corporation that keeps both DNA and RNA molecules stable for extended periods at room temperature) and stored frozen at -80°C until later eDNA extraction and purification. The Zymo DNA/RNA Shield can also act directly as a bacterial lysis buffer for nucleic acid purification in combination with bead-beating homogenization (Zymo Research). For extraction of eDNA for this project, the preserved filter tubes with the DNA/RNA Shield were first brought to room temperature, then both the filter and its associated DNA/RNA shield preservative were aseptically transferred to sterile Zymo Bead-Basher tubes (with a mixture of 0.1 mm and 0.5 mm ultra-high-density beads) from the Zymobiomics 96 MagBead DNA Kit (Zymo Research), and all cells on the filter were lysed releasing their DNA content into the lysate by 5 rounds of bead-beating homogenization for 60 sec each at an impact speed of 6.0 m/s in a FastPrep-24 instrument (MP Biomedicals). The resulting lysate was loaded onto KingFisher 96-well deep well plates and the eDNA was purified using a KingFisher Flex automated nucleic acid purification system (ThermoFisher), using the Zymobiomics 96 MagBead DNA Kit (Zymo Research) as per manufacturer directions. Final purified eDNA was eluted into sterile 1 \times TE buffer, and the purified DNA was stored at -20 °C until later qPCR analysis.

The purified eDNA from water samples was analyzed by qPCR in 96-well reaction plates on an Applied Biosystems StepOnePlus real-time qPCR system (ThermoFisher – Applied Biosystems), using the protocols specific for each gene marker target: [1] “HF183 Taqman” human-source *Bacteroides* as per EPA method 1696 (US EPA 2019) with minor modifications noted below; [2] “DG3 Taqman” canine-source *Bacteroides* as per Green et al., 2014 (with minor modifications noted below); and [3] “GFD SybrGreen” general bird *Helicobacter* as per Green et al., 2011 (with minor modifications noted below); [4] “Gull2” seagull/seabird-source as per Sinigalliano et al., 2013 (with minor modifications noted below); [5] “EnterolA” general enterococci as per EPA method 1611 (US EPA, 2012a) with minor modifications noted below. The minor modifications for all these assays were: 25 μ L volume final reactions per well were used; 2 μ L of template eDNA was added per reaction; 12.5 μ L of 2 \times qPCRBIO Probe Master Mix with HI ROX (PCR Biosystems) used per reaction for HF183, DG3, Gull2, and EnterolA, while 12.5 μ L of 2 \times qPCRBIO SyGreen Master Mix with HI ROX (PCR Biosystems) was used per reaction for GFD. In the case of EnterolA, quantitation was not done using the CCE cell calibrators method as per EPA Method 1611, but by quantitation using a standard curve with the newer EPA designed NIST Standard Reference Material plasmid SRM-2917 in the same fashion as EPA Method 1696 but using the EnterolA primers and probes from EPA Method 1611. All standard curves for quantitation of EnterolA, HF183, DG3, and GFD were constructed using NIST-certified quantitative Standard Reference Material # SRM-2917 from the National Institute of Standards and Technologies. (This is a multi-target plasmid positive control developed by the US EPA for these MST assays, at known certified concentrations, and made

commercially available by NIST). The Gull2 seagull target sequence is not on this NIST control plasmid, so for the seagull Gull2 assay, standard curves were generated using known concentrations of synthetic double-stranded DNA gene fragments of the target sequence that had been synthesized by Integrated DNA Technologies (IDT.com). Triplicate standard concentration curves were run on each qPCR plate, and each environmental DNA sample was analyzed in triplicate, along with No-Template negative controls, as well as Inhibition Amplification Controls. The NIST SRM-2917 plasmid can provide certified concentration positive control standard curves for a wide variety of MST targets, including Enterococci EnterolA by EPA Method 1611.1, human *Bacteroides* HF183 by EPA Method 1696, dog *Bacteroides* DG3, bird *Helicobacter* GFD, (as well as many other bacterial and viral MST targets). The quality control and assurance metrics and performance acceptance criteria for the qPCR done in this study was as per EPA Method 1696. The Lower Limit of Quantification (LLOQ) per reaction was determined by the upper 95% prediction interval of the lowest reliably repeatable concentration standard (10 copies), and the r-square of the linear regression of the standard curves and the amplification efficiency of all run plates were well within the acceptance criteria for the standard curves as defined in EPA Method 1696. No Template Controls (NTCs) were negative, and Inhibition Amplification Controls were within acceptable ranges of variation from Method Blank inhibition concentration controls (i.e., the test sample C_q mean within 3 standard deviations of the mean C_q of the triplicate control wells), indicating there was no significant environmental inhibition of the qPCR reactions observed under these circumstances. Taking into consideration the water sample volumes filtered (keeping in mind that the actual water sample volumes varied by sample), the volume of lysate generated and purified, the volume of resulting the resulting pure eDNA elutions, and the volume of purified eDNA eluate used in qPCR reactions, a consensus mean of Environmental Lower Limit of Quantitation (eLLOQ) was estimated to be approximately 50 copies per 100 mL of original water sample. Any qPCR measurements of environmental target concentrations below this value for these samples (as analyzed under these conditions) are hereby designated as “Detected but Not Quantified” or “DNQ”. While we may also report values below this number here in certain tables or on graphs for purposes of graphic visualization, or comparison to combined multi-target RBTs, ANY sample designated as “DNQ” should be recognized as not necessarily reliable, and these low levels of target detection could also possibly be due (at least in part) to “background noise”. Therefore, any values of these environmental MST markers from these sampling and processing conditions that are below a value of 50 copies/100mL of water sample should be viewed with skepticism and be considered as insignificant. Note that this DNQ range is well below the typical Risk Based Threshold for public health decision making (unless one is considering extremely low levels of human marker reducing the RBT of bird markers), so any samples with values below the eLLOQ that are in the DNQ range should not affect any decision-making based on health risk estimates (except for a few instances of combined bird and very low-level human markers).

APPENDIX E
RESPONSE TO WRITTEN COMMENTS FROM THE
COMMUNITY

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