Evaluation of Sweeping and UV Light Treatment of Street and Sidewalk Surfaces for the Reduction of Enterococci in Stormwater Runoff

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EXECUTIVE SUMMARY

This study is a follow-up to the University of Miami (UM) studies during 2022 and 2024 aimed at identifying the source of the fecal indicator bacteria, enterococci, to the Parkview Canal (PVC) located in Miami Beach, Florida. This canal has experienced elevated levels of enterococci since monitoring began in 2019. The prior UM studies 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. Sources of waste identified through microbial source tracking included bird fecal waste and on occasion dog and human waste. This study aimed to evaluate potential methods to reduce enterococci levels in runoff through cleaning of street and sidewalk surfaces given the widespread distribution of fecal waste sources observed in stormwater that drains towards the PVC and the lack of first flush treatment required of modern stormwater conveyance systems. Two methods of cleaning were the focus of this study: sweeping and ultraviolet (UV) light treatment. Street sweeping was conducted using industrial street sweepers, and sidewalk sweeping was conducted manually with dust pans and brooms. UV light treatment was conducted using a retrofitted UV disinfection system (Sterilaser^{TM}) designed for inactivating microbes from wrestling and yoga mats for the purpose of reducing the transmission of disease between one mat user and another.

The study was conducted along 73rd Street between Dickens and Harding Avenues in Miami Beach, one of the hotspot areas for degraded stormwater quality. The south side of the street (eastbound) and corresponding sidewalk were separated into three segments: segment A (between Dickens and Carlyle), segment B (between Carlyle and Byron), and segment C (between Byron and Harding). Experiments were conducted over a period of three days (September 19, September 26, and October 17, 2025). On each day, each segment was assigned a treatment condition consisting of either "no treatment" as a control, "swept", or "swept plus UV". Over the course of the three days, each segment received each of the three treatments. On the third day, regardless of treatment, the sidewalks for all three segments received an "extra UV" treatment to evaluate specifically the effectiveness of UV treatment on "no treatment", "swept", and "swept plus UV" to reduce levels of enterococci in runoff from the sidewalks.

During each experiment, rainfall was simulated by attaching three lawn sprinklers to de-chlorinated hydrant water. Initial wetting times were 10 minutes for the streets and 5 minutes for the sidewalks. After the initial wetting, five water samples were collected in 5-minute intervals from the street gutter downstream. These samples were analyzed for enterococci by chromogenic substrate (IDEXX) and enumerated as most probable number (MPN) per 100 mL. Results confirm elevated levels of enterococci in runoff from the streets and sidewalks with levels from untreated surfaces averaging 24,800 MPN/100 mL for streets and 12,600 MPN/100 mL for sidewalks, with sidewalks showing higher variability with maximum values exceeding the upper detection limit of 241,900 MPN/100 mL. In general, results also showed that treatment of the surfaces resulted in an average enterococci concentration of 15,800 MPN/100 mL for the streets and 10,700 MPN/100 mL for sidewalks. The treatment of sweeping plus UV further decreased average runoff concentrations (11,000 MPN/100 mL for streets and 6,600 MPN/100 mL for sidewalks), with average reductions by about a factor of two between no cleaning and sweeping plus UV. However, due to the variability of the runoff concentration data, the observation of statistically significant differences was limited. When evaluating the runoff enterococci concentration by experimental day, the effects of repeated treatment provided more robust statistical differences with a 4-fold reduction in the street runoff concentrations and a 7-fold reduction in the sidewalk runoff concentrations, from 40,700 MPN/100 mL on Day 1 to 9,300 MPN/100 mL on Day 3 for streets and from 19,000 MPN/100 mL on Day 1 to 2,700 MPN/100 mL on Day 3 for sidewalks. Overall, results support that repeated treatment of the street and sidewalk surfaces reduces enterococci levels significantly.

Analysis of sediments obtained from the industrial street sweepers and from manual sidewalk cleaning allowed for direct quantification of the number of enterococci removed through sweeping activities. We estimate that sweeping removes 63,000 MPN per square foot for streets and 44,000 MPN per square foot for sidewalks.

The amount currently removed through industrial street sweepers, given street sweeping information provided by the City, is estimated at 3.6×10^{14} MPN per year, which we roughly estimate to represent an equivalent reduction in the enterococci to the PVC by about 4,300 MPN/100 mL.

Given the significance of sweeping in removing enterococci, the practice of sweeping should continue. We recommend that the City of Miami Beach add cleaning of the sidewalks given the very high levels of enterococci in sidewalk runoff, especially in areas with dense tree cover and areas with visible debris accumulations. Sidewalk cleaning should provide minimal disturbance to the community since it does not require the removal of cars. We also recommend that the City explore improvements to current industrial street sweeping practices (e.g., manual pick up of street debris not captured by the sweepers and removal of parted cars). It is recognized that due to high density and limited parking options for residents that removal of parked cars to faciliate industrial street sweeper access will be a challenge. In addition, we also recommend further work with UV light disinfection of surfaces. The results from the current study point towards reductions in enterococci levels, but given the variability in the stormwater runoff, enterococci reductions were not consistently statistically significant. We recommend continued research to explore UV light disinfection and to consider engineering the technology for its practical use at the larger city scale.

Overall, we recommend that the City of Miami Beach add sidewalk cleaning to their sweeping efforts and as part of its current aggressive street sweeping program, consider adding elements of manual sweeping of the streets to remove incidental debris. We also recommend that the City explore further development of UV technology for its potential widespread implementation at the city scale.

LIST OF ACRONYMS

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
KL: Kayak Launch
KLW: Kayak Launch Waterway (used interchangeably with PVC)
MPN: Most Probable Number
PVW: Parkview Canal Watershed
PVC: Park View Canal
PVI: Park View Island
PVP: Park View Park
UM: University of Miami
US EPA: United States Environmental Protection Agency

CHAPTER I

MOTIVATION AND OBJECTIVES

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MOTIVATION AND OBJECTIVES

The Parkview Canal Watershed (PCW, Figure I.1) is part of the City of Miami Beach (CMB) North Beach Watershed, which is undergoing major planning for improvements and restoration. As part of these efforts, considerable attention is given to the Parkview Canal (PVC), which consistently exceeds levels considered acceptable for swimming (US EPA 2012, FDOH 2024), for kayaking (US EPA 2024), and other recreational uses (FDEP 2016). As a result of the excessive enterococci levels, the PVC and the kayak launch (Figure I.2) from the Parkview Canal park have been closed to the public since 2019, prompting studies to evaluate the causes of elevated enterococci levels.

Our prior research through the University of Miami (UM) and supported by the CMB (Montas et al. 2023, Amirali et al. 2025), showed that a major source of enterococci to the PCW is storm water. This storm water is contaminated with high levels of enterococci which then flows into the PVC or is discharged to groundwater. After testing PVC water, groundwater, and stormwater, the highest bacteria levels were consistently found in stormwater runoff. Microbial source tracking (MST) of stormwater collected from the streets identified the primary source of enterococci as birds, followed by dogs and humans. The contamination from birds was greatest within the canal but also observed in the street runoff within the stormwater catchment area (light blue line in Figure I.1). Most modern stormwater conveyance systems require the retention of the first flush of water, usually the first half to one inch of rainfall, prior to discharge to a receiving water body. The stormwater conveyance system in the study area was constructed between the 1930s through the 1950s and is not fitted with first-flush stormwater treatment. Therefore, stormwater is contaminated by fecal bacteria deposited on surfaces (e.g., streets, sidewalks, roof tops, parking lots, and grassy areas) and is conveyed to the PVC with little or no treatment contributing towards the elevated levels of enterococci in the PVC.

Mitigation strategies previously recommended for the reduction of enterococci in the PVC include both long-term (i.e., retrofitting the drainage system to include first flush treatment) and short-term solutions. One of the primary short-term solutions listed within the 2025 report was to focus on “cleaning” street surfaces, as best as possible, to reduce levels of enterococci entering the stormwater system. Additional recommendations included increased frequency of street sweeping, augmenting street sweeping by removing visible debris and fecal deposits manually, and the possible use of ultraviolet (UV) light to disinfect street surfaces.

Due to the continued excessive levels of enterococci in the PVC, in Spring of 2025, the CMB enacted “Operation Clean Water” to address street level pollutants in the North Beach watershed entering the stormwater system and impacting the PVC. This current study addresses the following two items in “Operation Clean Water.”

- Item 6. Explore additional street and sidewalk cleaning mechanisms to include smaller-scale equipment, including pooper scoopers to remove visible animal waste, increase hand crew collection, and potentially a restricted parking program to ensure street sweeping measures are effective.
- Item 7. Investigate the feasibility and cost of implementing a UV disinfection of street level hotspots in a heavily urbanized environment, perhaps utilizing similar technologies to yoga studios.

In response to these items that are part of “Operation Clean Water”, we established the following objectives for the current study.

- **To evaluate the improvements of sweeping on stormwater enterococci levels from streets and sidewalks.** Streets were swept using the City's large industrial street sweepers. Sidewalks were swept manually with dust pans and brooms. Improvements were assessed by documenting changes in water quality before and after sweeping, plus measuring the number of enterococci in sediments removed through sweeping.

- **To evaluate the improvements of UV light disinfection of streets and sidewalks.** UV light is a known disinfection technology which is environmentally friendly in that it does not impart a chemical residual. UV light disinfection was evaluated through a retrofitted UV sterilizer that was originally designed for disinfecting wrestling and yoga mats (Sterilaser^{TM}). Such mats retain microbes from human skin during their use, and the Sterilaser^{TM} is used to inactivate the microbes from the mats to minimize transmission of skin illnesses from one mat user to another. The Sterilaser^{TM} was applied to both street and sidewalk surfaces in the field with documentation of the changes in storm water quality.

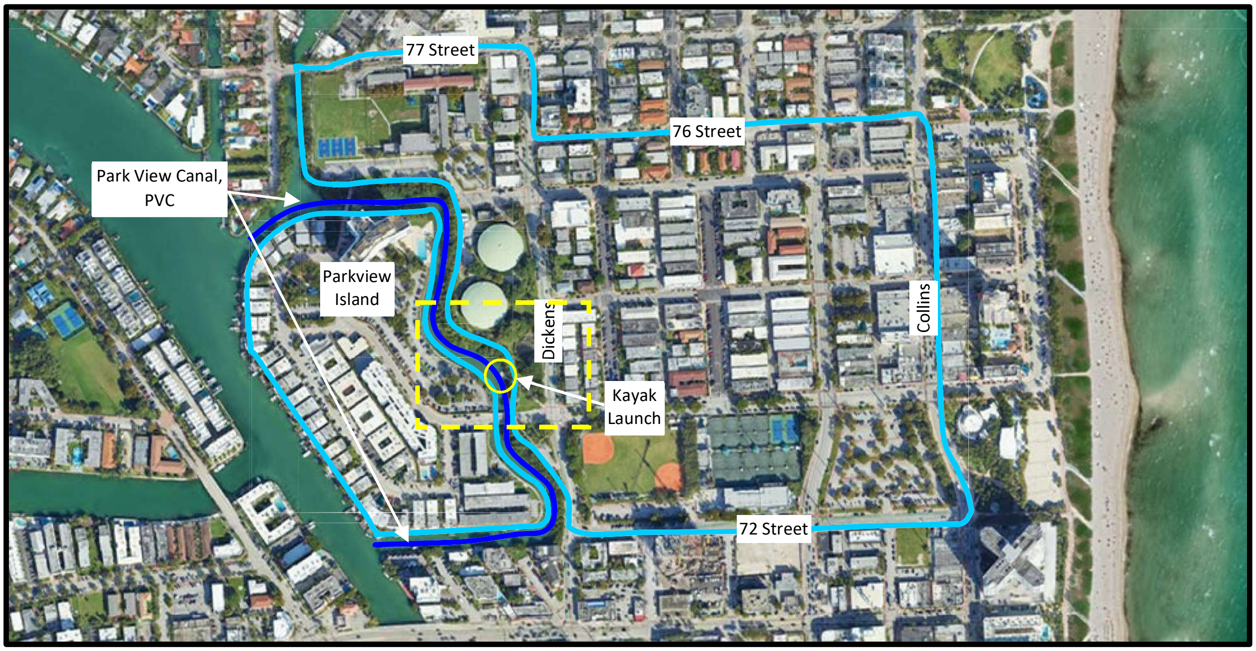

Figure I.1: Park View Canal (dark blue) and Park View Watershed (cyan blue). The areas outlined in cyan blue contribute stormwater towards the PVC. Close-up of kayak launch area (yellow square) shown in Figure I.2. Base image from Google Earth (January 2023).

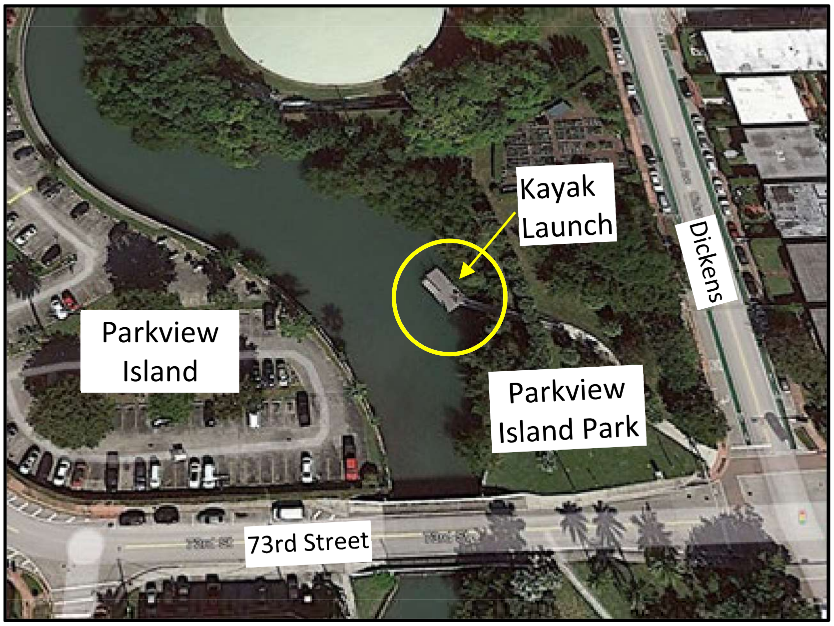

Figure I.2: Kayak launch location. Located within the Parkview Island Park northwest of the intersection of Dickens and 73rd Street, Miami Beach, FL. (GPS: 25˚ 51’ 31.20” N. 80˚ 07’ 33.00” W for the Launch)

CHAPTER II

EXPERIMENTAL DESIGN AND LABORATORY METHODS

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EXPERIMENTAL DESIGN AND LABORATORY METHODS

This chapter covers the methods used to complete this study. The sections are separated into field sample collection (II.1), laboratory methods (II.2), and statistical analyses (II.3).

II.1 FIELD SAMPLE COLLECTION

To evaluate the effectiveness of sweeping and ultraviolet (UV) disinfection in reducing enterococci in runoff from streets and sidewalks, stormwater runoff was collected after undergoing the following conditions:

For streets

a) No cleaning
b) Sweeping by industrial-scale sweepers
c) Sweeping plus UV disinfection

For sidewalks

a) No cleaning (paired with "a" above)
b) Sweeping manually with manual pick up of visible waste (paired with "b" above)
c) Sweeping plus UV disinfection (paired with "c" above).

II.1.a Location of Experimentation

Tests were conducted along three street segments (A, B, C) and three sidewalk segments (A, B, C). These segments corresponded to the south, east-bound lanes of 73rd Street in Miami Beach between Dickens and Harding, located just east of the PVC. This street was chosen because of:

1) **Uniformity.** All street segments consisted of two lanes of traffic and one lane of parallel parking. All segments were bound by a central median to the north and a street curb/gutter to the south. All sidewalk segments were bound by the street curb to the north and a park to the south.

2) **Traffic Logistics.** The median in the middle of the street facilitated experimental and traffic logistics.

3) **High Enterococci in Runoff.** It is in an area where the University of Miami 2024 study showed elevated levels of enterococci (See Figure II.1).

4) **Availability of Water to Generate Runoff.** Two hydrants are located along 73rd Street, which facilitated the generation of runoff needed for experimentation purposes.

The CMB facilitated the street closures and parking restrictions to allow for experimentation during the three experiment dates.

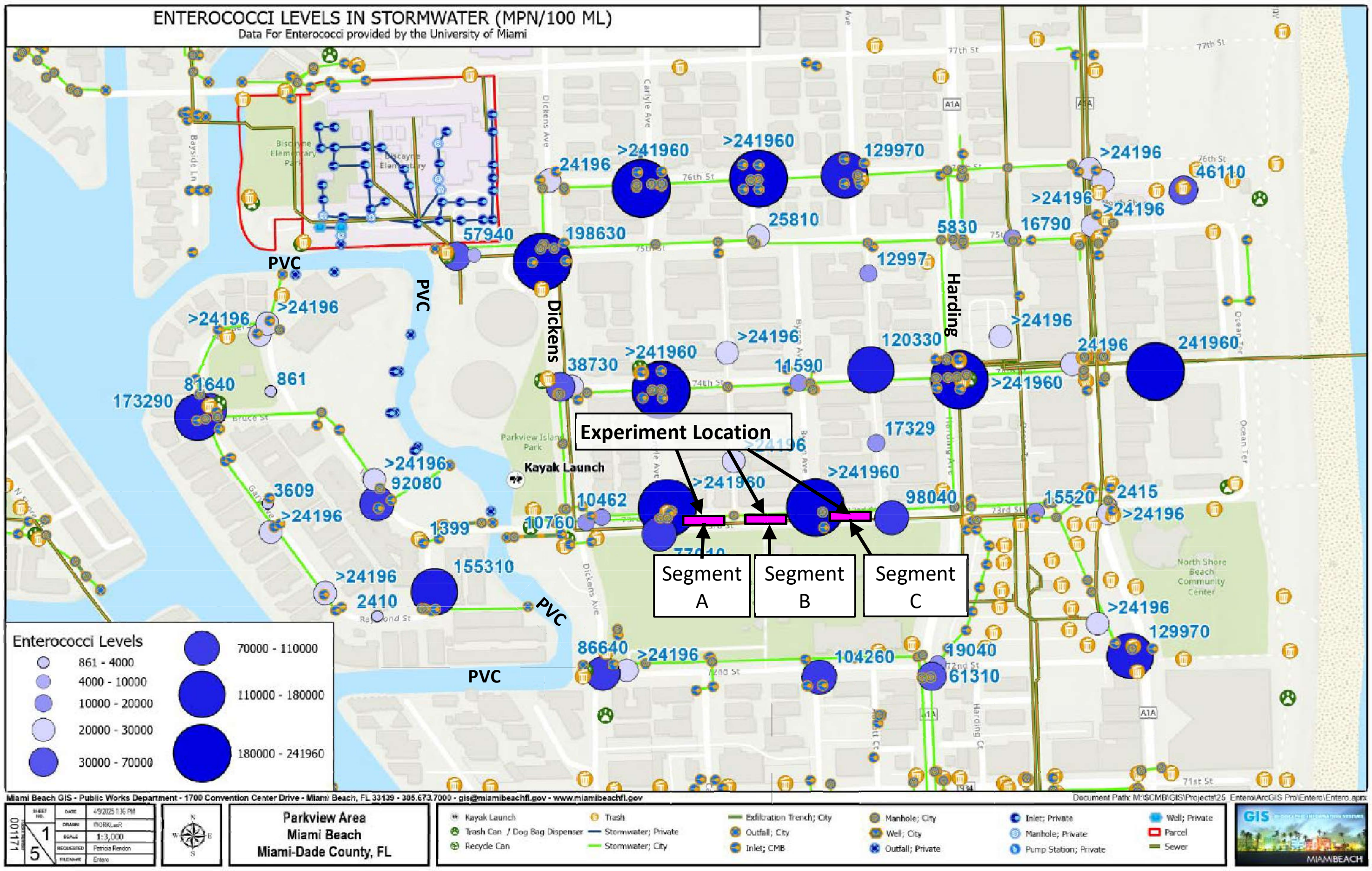


Figure II.1. Spatial distribution of enterococci levels in stormwater samples. The sizes of blue circles are proportional to the enterococci levels. Image by Roberto Lasaga of CMB with overlay of enterococci data collected by University of Miami during 2024. Pink boxes show locations of stormwater quality experiment. A close-up of the potential experimental segments is given in Figure II.2.

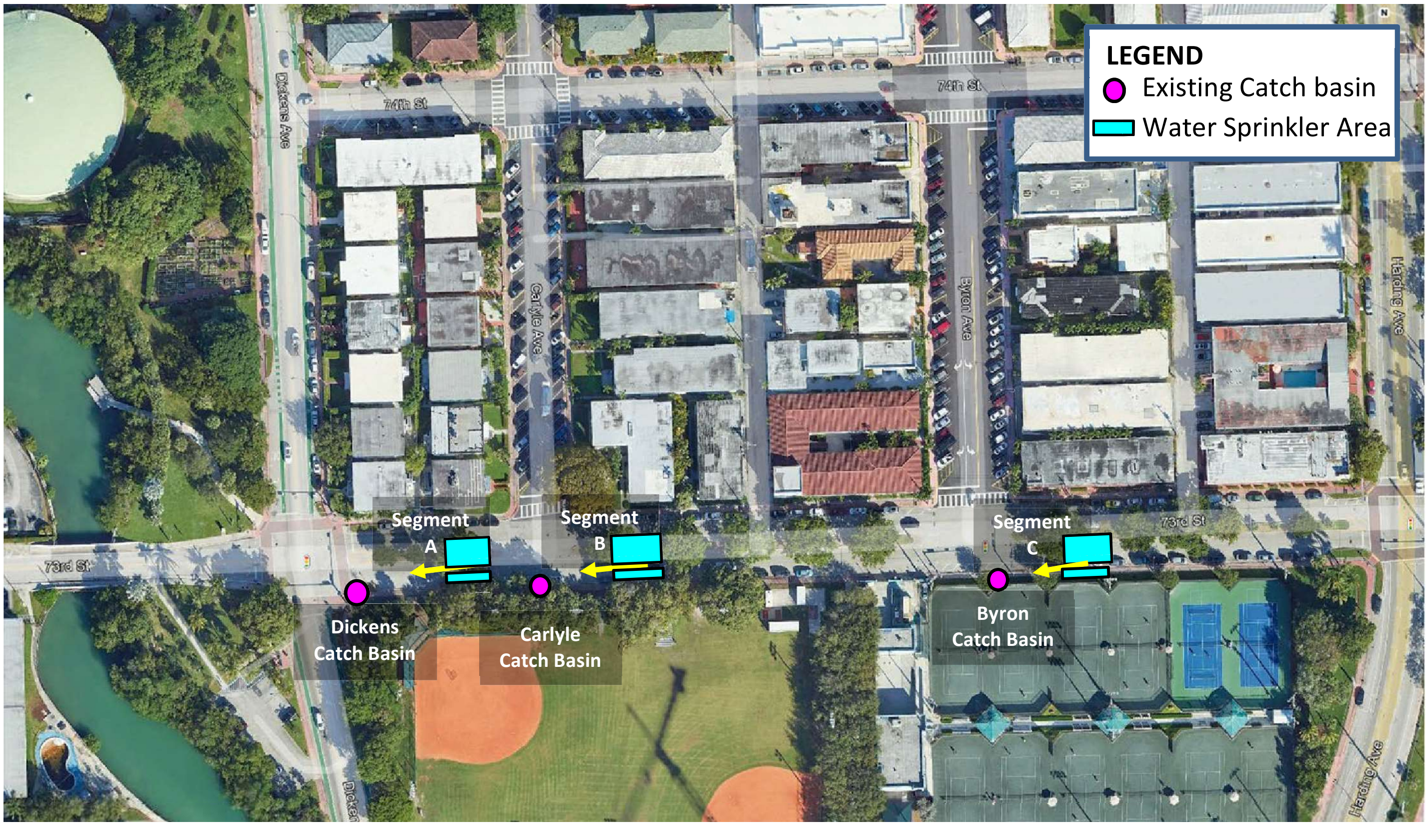


Figure II.2. Street layout for street cleaning experimentation, including segments to test. he conditions tested for streets and sidewalks were: a) no cleaning, b) sweeping (industrial for streets and manual for sidewalks), and c) sweeping plus UV. These conditions were tested three times, once in each segment.

II.1.b Water Supply to Generate Runoff

The water supply used to generate runoff came from two fire hydrants. One hydrant, used as the source water for segments A and B, was on the sidewalk on the south side of 73rd Street and Carlyle (Figure II.3, panel A) . The second hydrant was in the median at Byron and 73rd Street (Figure II.3, panel B) and was used as the source water for segment C. Preliminary testing of water from both hydrants indicated that they had a chlorine residual (HDX 5-Way Kit), and that the residual showed evidence of inactivating the enterococci from the street runoff. This inactivation of enterococci would not be observed during natural rainfall conditions. Therefore, the chlorine residual was to be removed.

After preliminary testing of different chlorine removal systems at the University of Miami, a home dechlorination unit (Culligan Portable Exchange Deionizer, 12-inch diameter by 44-inch high activated carbon filter) was used to remove the chlorine from the source water. The filter was placed downstream from the hydrant. A flow meter (Gryvoze ¾ inch digital turbine fuel flow meter) was placed in line to monitor the total amount of water that was used for street and sidewalk experimentation to provide estimates of the equivalent rainfall depth used to generate the samples (Table II.1).

Prior to experimentation, each hydrant was flushed for 5 minutes with water flowing directly into the catch basin or grassy areas not impacting the experimental segments. After the 5-minute flushing period, samples of hydrant water were collected prior to filtration and after filtration to document the reduction of the chlorine residual. No chlorine was detected after the filtration unit, confirming that the residual was removed.

To simulate runoff production during rain, three sprinklers (Eden 96212 Turbo Oscillating Sprinkler) were connected via hoses to sprinkle water on the experimental segments for both the street and sidewalks (example photos shown in Figures II.4 and II.5).

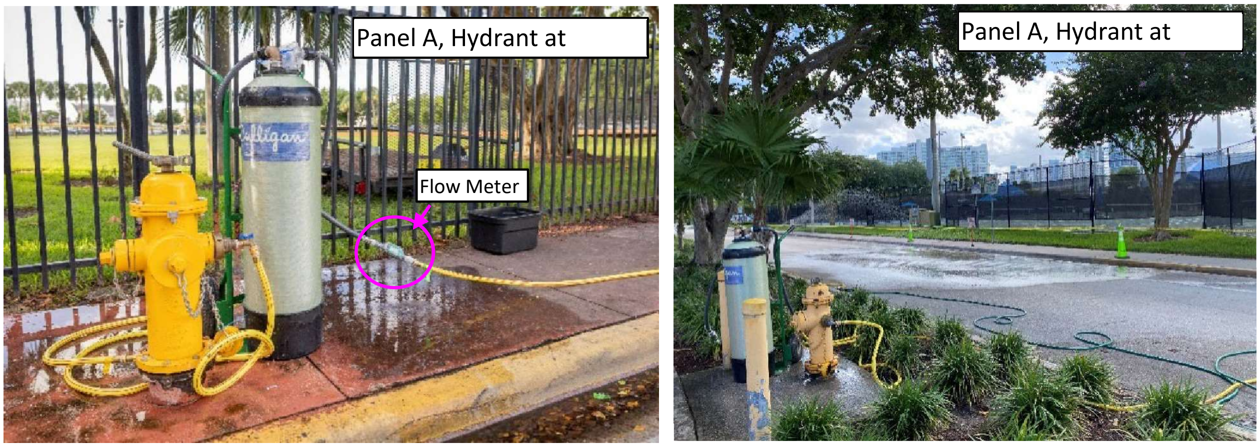


Figure II.3. Hydrant set up for experimentation showing the chlorine filter downstream of the hydrant at Carlyle (Panel A) and at Byron (Panel B). Panel A also shows the flow meter used to measure flow from the filter system.

Figure II.4. Examples of street sprinkler set up for Segment A (Panel A) and for Segment C (Panel B). Three lawn sprinklers were used at each segment with sample collection in the stormwater gutter downstream.

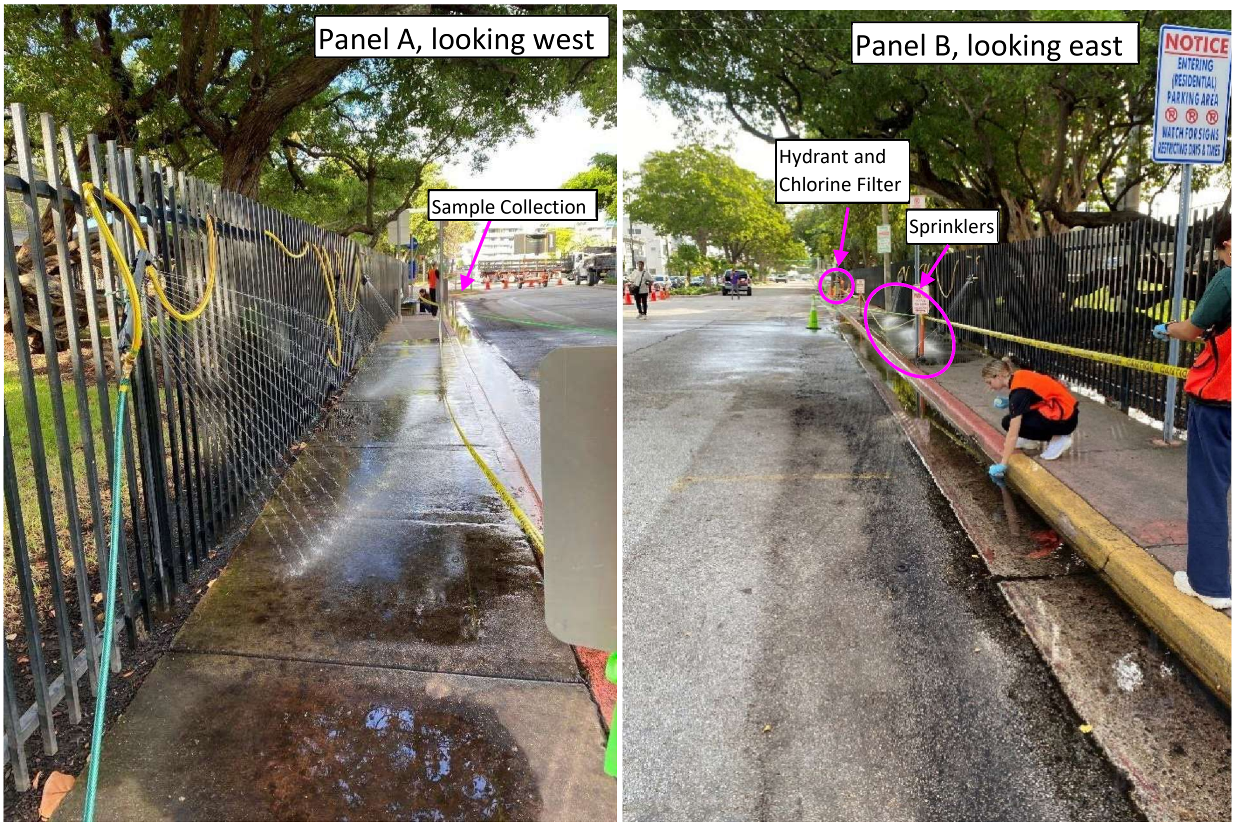


Figure II.5. Example of sidewalk sprinkler set up for Segment A with view looking west (Panel A) and east (Panel B). Three lawn sprinklers were used at each segment with sample collection in the stormwater gutter downstream.

Table II.1. Amount of water applied to each segment during experimentation.

Experimental Day	Sample ID	Segment	Area Sprinkled with Water (ft^2)	Duration of Water Sprinkling[a] (minutes)	Average Flow Rate During Water Sprinkling (gallons per min)	Volume of Water Applied to the Test Surface[a] (gallons)	Equivalent Rain Depth (inches)
1	Street 250919	A	756	30	8	240	0.51
1	Sidewalk 250919	A	143.64	25	7.95	199	2.22
1	Street 250919	B	760.76	30	7.8	234	0.49
1	Sidewalk 250919	B	NA[b]	25	7.85	196	NA
1	Street 250919	C	1011.44	30	7.7	231	0.37
1	Sidewalk 250919	C	143.52	25	7.55	189	2.11
2	Street 250926	A	1000	30	7.65	230	0.37
2	Sidewalk 250926	A	217.5	25	7.3	182.5	1.35
2	Street 250926	B	1586	30	7.6	228	0.23
2	Sidewalk 250926	B	269.5	25	7.2	180	1.07
2	Street 250926	C	1438.4	30	8.1	243	0.27
2	Sidewalk 250926	C	227.9	25	7.85	196	1.38
2	Street 251017	A	1046.74	30	8	240	0.37
3	Sidewalk 251017	A	216	25	8.05	201	1.50
3	Sidewalk 251017	A	216	25	8.05	201	1.50
3	Street 251017	B	1407.15	30	8.65	260	0.30
3	Sidewalk 251017	B	183.6	25	8.7	218	1.90
3	Sidewalk 251017	B	183.6	25	8.7	218	1.90
3	Street 251017	C	1286.42	30	8.15	245	0.31
3	Sidewalk 251017	C	178.74	25	7.65	191	1.72
3	Sidewalk 251017	C	178.74	25	7.65	191	1.72

[a] Included pre-wetting time of 10 minutes for streets and 5 minutes for sidewalks.

[b] NA=Not Available

*For experimental day 1 the area sprinkled with water is the area that was disinfected.

II.1.c UV Disinfection

Ultraviolet (UV) disinfection was conducted with two Sterilasers™ (Figure II.6). Both deliver UVC at a wavelength of 254 nanometers. The first unit, the main one, was a retrofitted floor model that delivers UVC at an intensity of 54,000 mJ/cm^2 per second (dimensions of 22 inches by 48 inches by 6 inch). e retrofit involved placing swivel wheels on the unit to help absorb vibrations from uneven street surfaces. The second Sterilaser^{TM} was a handheld unit (dimensions of 25 inches by 4.75 inches by 5.5 inches) used for disinfecting street segment C on day 1, all sidewalk segments, and for disinfecting the curb and gutter. The handheld unit delivers UVC at an intensity of 33,000 mJ/cm^2 per second at 3 inches from surfaces. Both units were battery-powered.

The areas to be disinfected were measured and marked off. The start and end times for disinfecting the street and sidewalk segment were noted to determine the duration of disinfection. Prior to disinfection, the Sterilaser^{TM} wheels were alcohol sprayed to minimize microbe carry over through the wheels. Additionally, the bottom of the shoes of the person applying the Sterilaser^{TM} was also sprayed with alcohol. The person applying the Sterilaser^{TM} would walk slowly backwards pulling the Sterilaser^{TM} towards them to avoid stepping through the disinfected surface. The UV dose, *D*, applied through disinfection was determined from:

$$D = I * \left(\frac{a}{A}\right) * t$$

Where *I* is the intensity of UVC delivered by the Sterilaser^{TM} unit, *a* is the area of the UV light provided by the bottom of the unit, *A* is the area of the street or sidewalk disinfected, and *t* is the time for disinfection. The value of *I* for the floor unit, as mentioned above, was 54,000 $mJ\ /cm^2/sec$ which represents the nominal floor-level output of the large sterilaser unit. The value of *I* for the handheld unit was assumed at 33,000 $mJ\ /cm^2/sec$. The value of a for the small handheld Sterilaser^{TM} was set to 766 square centimeters (119 square inches), and for the large floor Sterilaser^{TM} it was set to 6,813 square centimeters (1,056 square inches). The area of the sidewalk and street disinfected is listed in Table II.2 and converted from square feet to square centimeters. The time it took to disinfect the sidewalk or street was converted to units of seconds. The final UV dose was reported in units of mJ/cm^2 (Table II.2).

A list of microbes and disinfection times for each of these units is provided in Appendix C. Comparing the computed dose in the field (Table II.2) to the dose needed to inactivate the microbes (Tables C.1 and C.2 in Appendix C), the dose from the Sterilasers^{TM} were larger than the dose needed to inactivate bacteria and viruses by at least an order of magnitude. Specifically for enterococci, the UV dose was sufficient to for its inactivation. Enterococci are closely related to *Streptococcus* species, including *Streptococcus faecalis* (now classified as *Enterococcus faecalis*), and are both gram-positive cocci. The manufacturer reported that UV doses of approximately 10,000 mJ/cm² are required to inactivate *Streptococcus faecalis*. The delivered UV doses during street and sidewalk disinfection were approximately 22,000–242,000 mJ/cm², which exceeded the threshold. Results thus suggest that the dose administered should be sufficient to inactivate enterococci on the surfaces. The actual biological effectiveness of the dose, however, may be lower due to lamp angle, surface roughness (which is substantial on the street and sidewalks), and non-uniform exposure during operation. Therefore, the calculated doses may represent an upper-bound estimate of the expected UV energy.

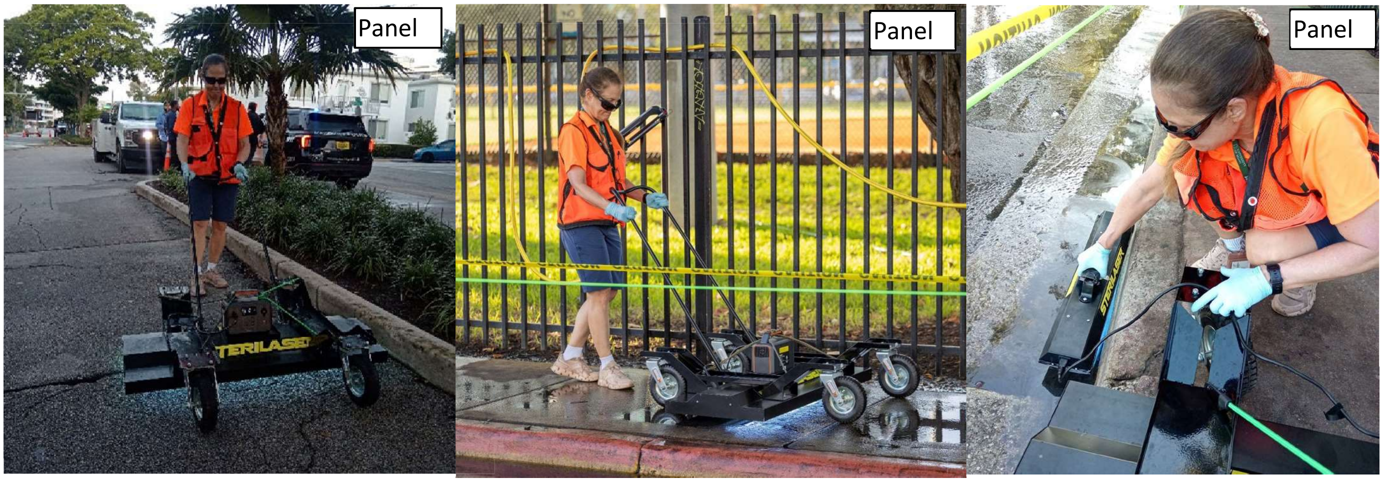


Figure II.6. Disinfection of street (Panel A) and sidewalk (Panel B) using a retrofitted large floor model Sterilaser^{TM}. Plus disinfection of curb and gutter area using the handheld model of the Sterilaser^{TM} (Panel C).

Table II.2. UV doses applied to each street and sidewalk segment.

Experimental Day	Sample ID	Segment	Disinfection Method	Area of Disinfection (ft^2)	Duration (sec)	UV Dose (mJ/cm^2)
1	Street 250919	C	Handheld Sterilaser	-	1,200	-
1	Sidewalk 250919	C	Handheld Sterilaser	459	600	35,573
2	Sidewalk 250926	B	Handheld Sterilaser	220	300	37,109
2	Street 250926	B	Large Sterilaser	1,586	3,360	838,941
2	Sidewalk 250926	B	Large Sterilaser	265	2,580	3,849,297
3	Sidewalk 251017	A	Handheld Sterilaser	220	180	22,266
3	Street 251017	A	Large Sterilaser	1,041	1,020	387,919
3	Sidewalk 251017	A	Large Sterilaser	220	1,200	2,160,001
3	Sidewalk 251017	A	Large Sterilaser	220	600	1,080,000
3	Sidewalk 251017	B	Large Sterilaser	220	600	1,080,000
3	Sidewalk 251017	C	Large Sterilaser	220	600	1,080,000

II.1.d Experimentation Schedule

Each segment received the three designated treatments each on different days (Table II.3). For example, on Day 1, the street and sidewalk for segment A received no treatment. The street and sidewalk for segment B was swept. The street and sidewalk for segment C was swept and treated with UV light. These treatments were rotated the following two experimental days. On the last day, an additional UV treatment (called "extra UV") was performed on the sidewalks regardless of the treatment that the segment received.

Table II.3. Experimental schedule emphasizing the rotation of sample collection among the three segments

Day during 2025	No Cleaning		Sweeping		Sweeping Plus UV		Extra UV
	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Sidewalk
Day 1, September 19	A	A	B	B	C	C	
Day 2, September 26	C	C	A	A	B	B	
Day 3, October 17	B	B	C	C	A	A	A B C

Prior to each sampling day, the CMB informed the residential community of the parking restrictions by placing signage and through email via Constant Contact. The morning of each sampling day, the UM research team and the CMB support staff arrived at 73rd street at 5:45 am. The street was blocked off by the CMB. The area to be swept would be marked with caution tape, and the CMB staff worked towards calling residents to move their cars to avoid towing in the specific areas where the experiments were to take place. Between 6:15 am and 6:45 am, the sidewalks designated for sweeping on a given day would be swept manually using new and alcohol sprayed brooms and dust pans. These manual sweepings would be placed into a pre-weighed sterile aluminum container and then processed in the laboratory later that day after all field work had been completed.

At about 6:45 am, the industrial street sweeper would sweep the street only for the designated segments as marked by caution tape. Once the street sweeping was completed (15 minutes), samples were collected from the industrial sweepers. This included two sediment samples and two liquid samples. Once the street sweeping was completed, then the experimentation would begin with segment A, street first and then sidewalk (7:00 am to 8:30 am time frame), followed by segment B, street first and then sidewalk (9:00 am to 10:30 am time frame), and then followed by segment C, street and then sidewalk (11:00 am to 12:30 pm time frame).

Prior to starting experimentation on segment A, the hydrant at Carlyle would be opened by CMB staff and the dechlorination filter and flow meter would be attached, and the valve would be opened and allowed to flush for five minutes without impacting the areas designated for experimentation. After those 5 minutes, hydrant samples would be collected before and after the filter. The sprinkler system would be laid out on the street and the sprinkler was turned on and allowed to flow for 10 minutes, to allow time for wetting of the street and for the flow of water within the storm-water curb. After the 10-minute initial sprinkler period, 5 samples were collected in 5-minute intervals using presterilized prelabeled 500 mL polypropylene bottles. Upon collection, the sample collection time and water temperature (MT Raytek® laser thermometer) were recorded followed by placing the sample immediately within a cooler with frozen ice packs. Upon the completion of the sample collection period of 20 minutes (samples at times 0, 5, 10, 15, and 20), the sprinkler system was then moved to the sidewalk. Like the street, the sprinkler was allowed to flush for 5 minutes, to allow time for wetting of the sidewalk and for the flow of sidewalk water to flow downstream along the curb. After the 5-minute initial sprinkler period for the sidewalks, 5 samples were then collected in 5-minute intervals. This process was repeated for segment B. After completion of the experiment at segment B, the hydrant at Carlyle would be turned off and the filter and flow meter would be transferred to the hydrant at Byron. Once reconnected, the Byron hydrant would be flushed for 5 minutes with hydrant samples collected before and after the filters as described above. The sprinkler system would be laid out on the street and the sprinkler would be turned on and allowed to flow for 10 minutes as described above. A set of 5 storm-water samples would then be collected in 5-minute intervals for the street and another set of 5 storm-water samples would be collected in 5-minute intervals for the sidewalks as described above.

The “extra UV” samples collected from the sidewalks on Day 3 were collected in a similar fashion as those described above, with 5 samples collected from the stormwater gutter after an additional UV treatment of the sidewalk. For example, on Day 3, the street and sidewalk for Segment A were swept plus treated with UV light. This first part of the experiment for this segment involved initiating the sprinklers, followed by sample collection (n=5 for the street and n=5 for the sidewalk). After the collection of the 5th sidewalk sample, the sidewalk was treated again with UV light (extra UV), and the sidewalk was flushed for 5 minutes. Samples (n=5 for the sidewalk after the extra UV) were again collected in 5-minute intervals.

II.1.e Details About Sediment Sample Collection

To directly measure the removal of enterococci provided by sweeping, the following samples were collected (Table II.4).

Table II.4. Summary of samples collected to measure enterococci removed by sweeping. Number of samples listed in the column.

	Sample Collection Date				
	July 7 (practice)	**September 5 (practice)**	**September 19 (full experiment, segments B,C)**	**September 26 (full experiment, segments A,B)**	**October 17 (full experiment, segments A,C)**
Curb scraping, Solids only	2	0	0	0	0
Manual Sweepings from Sidewalks, Solids only	0	0	2	2	2
Small Sweeper Solids	1	1	0	0	0
Small Sweeper Liquids	1	1	0	0	0
Large Sweeper Solids	1	1	2	2	2
Large Sweeper Liquid	0	1	2	2	2

Prior to full scale experimentation, “practice” samples were collected to determine dilutions during our two field scouting days (on July 7, 2025, and September 5, 2025). These samples were processed by multiple dilutions to identify the levels of enterococci so that they could be determined within the detectable range of the analysis method. Once these dilutions were determined, they were used for the full-scale experimentation during which only the large industrial sweeper was used to sweep the street segments.

Curb scrapings were collected during the July 7 practice day from the curbs at Byron and Dickens. Manual sweepings were collected from the sidewalks with a new dustpan and new broom during each of the experimental days (Figure II.7). Street sweepings were collected from a “small” industrial street sweeper (Multihog), in addition to the “large” industrial street sweeper (Global R4Air) (Figure II.8). Samples were collected from the small street sweeper only on practice days. Samples were collected from the large street sweepers on all days.

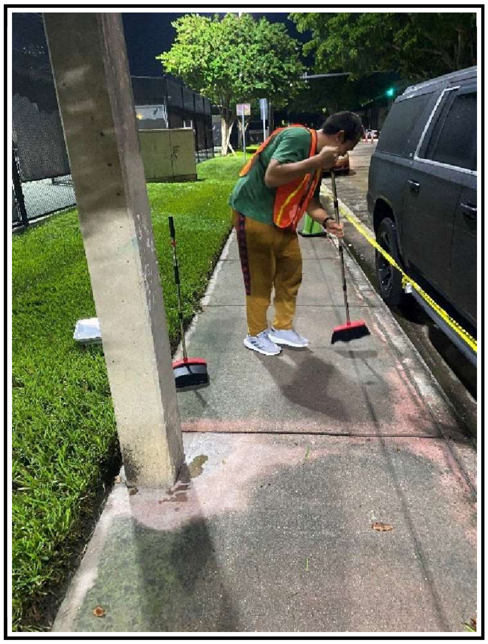


Figure II.7. Photo from manual sweeping of sidewalk.

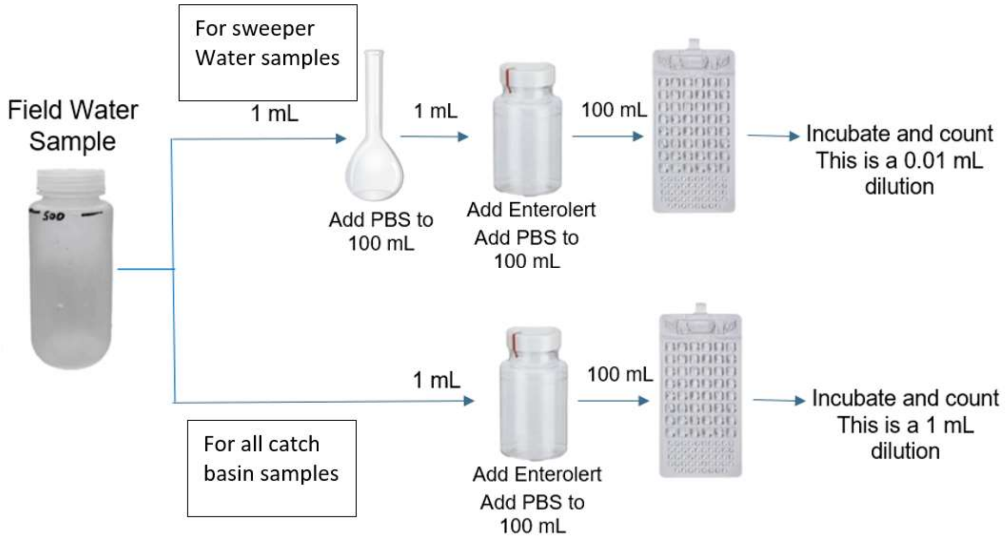
Figure II.8. Photos from street sweeper and sediment sample collection. Large industrial street sweeper (panel A), small industrial street sweeper (panel B), sample collection from large street sweeper (panel C), sample collection from small street sweeper (panel D), Sample collection from curb at Dickens (panel E).

II.2 LABORATORY METHODS

Laboratory methods focused on measuring enterococci in water and sediment samples. 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 ºC for 24 hours ± 2 hours). Trays were checked for fluorescence at two time points (24 hours and 26 hours for confirmation of lightly fluorescing wells). Results from these analyses are provided in units of Most Probable Number (MPN) per 100 mL of processing volume. 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.

II.2.a Analysis of liquid samples

Testing with "practice" samples collected on July 7 and September 5, 2025, established the dilutions to be used for the liquid samples. he dilutions were: "none" for hydrant samples (used 100 mL for 1:1), 1 ml or 100:1 for storm water samples collected near the catch basins, and 0.01 mL or 10,000:1 for liquids obtained from within the street sweepers. These dilutions are illustrated in Figure II.9.



For hydrant waters, use same procedure as catch basins BUT take 100 mL from the field water sample.

Figure II.9. Summary of laboratory method used to process liquid samples.

II.2.b Analysis of sediment samples

The analysis of sediment samples is like the analysis of liquid samples. Pre-processing of sediment samples required mixing to homogenize and taking two aliquots of the sediment sample (Boehm et al. 2009). The first aliquot was used to measure moisture content (drying at 110 °C for 24 hours). The second aliquot was used to measure enterococci. The measurement of enterococci required the elution of the bacteria from the sediment to the liquid phase. To accomplish this, 5 g of sediment were placed into a sterile elution bottle. Sterile phosphate buffered saline (PBS) was added to obtain a 100 mL volume. The sediment and PBS solution were shaken for 2 minutes and allowed to settle for 2 minutes. This solution was then diluted by a factor of 10,000 to 1 due to the very high levels of enterococci in the sweeper sediments. This was accomplished through two 100:1 sequential dilutions using sterile PBS solution. The 10,000:1 dilution was then analyzed like a liquid sample using Enterolert^{TM} reagents and IDEXX Quantitrays for enumeration by MPN. The MPN per 100 mL of solution processed were then converted mathematically to MPN per dry gram of sediment based upon the initial mass of sediment that was eluted (about 5 grams), the moisture content of the sediment sample, and the 10,000:1 dilution factor. The process is illustrated in Figure II.10.

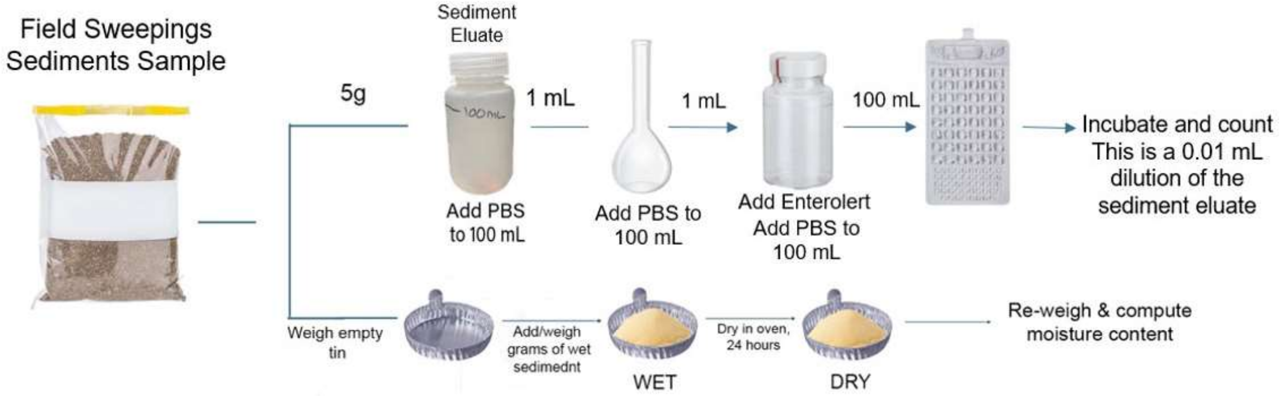


Figure II.10. Summary of laboratory method used to process sediment samples.

II.2.c Computation method to estimate enterococci removed per surface area swept

For manual sweeping of sidewalks, enterococci removal was calculated based on the mass of sediment collected from a measured surface area of sidewalk. Sediment samples were transferred from the dust pans to pre-weighed sterile aluminum pans. Upon return to the laboratory, the pans were re-weighed to obtain a measure of the wet sediment mass collected from the sidewalk. After weighing, sediments in the pans were mixed to homogenize, and two aliquots were removed for analysis as described above, with one aliquot for moisture content, *MC*, and another used for enterococci analysis.

The dry weight of sediment collected from the sidewalk area was calculated from the moisture content (*wet weight of sediment* × *(1-MC)*). Enterococci concentrations were measured from the second aliquot using the elution method described in the prior section, and converted to units of MPN/g. The total number of enterococci removed per pan in units of MPN was calculated as:

$$Number\ of\ Enterococci\ Removed\ in\ Pan, MPN = (MPN/g) \times (Dry\ Weight\ of\ Sediment\ (g))$$

To compare across sampling areas, the number of enterococci removed was normalized by the surface area swept as follows:

$$MPN\ Removed\ per\ Unit\ Area = \frac{Number\ of\ Enterococci\ Removed\ in\ Pan}{Area\ Swept}$$

This equation produced enterococci removal values expressed in MPN per square foot, as listed in the column *MPN Removed in Pan per Sq. ft* in Table III.7 in the results section.

For the large industrial street sweepers, enterococci removal was estimated by considering both the liquid and solid fractions collected by the sweeper. Enterococci concentrations measured in the sweeper liquid and sediment were combined and divided by the surface area swept.

To obtain a representative concentration of enterococci in the street sweepings, which consist of both a solid and liquid portion, mass balance equations were applied such that:

$$C_T = \frac{M_S C_S \times M_L C_L}{M_T}$$

Where M_S and M_L are the mass of solids and liquid collected by the street sweeper, respectively. M_T is the total mass from the street sweeper (solids plus liquids). C_S and C_L represent the geometric mean of the enterococci concentration in the solids and liquid portions, respectively. The geometric mean concentration was chosen because statistical analyses indicated that the data were log-normally distributed (see next section).

The value of M_T was provided by Alvaro Rueda of CMB, who indicated that the estimated mass of material collected by the CMB street sweepers was 137.55 tons for the month of October 2025. From the values reported, the mass of street sweepings per year, M_T, was estimated at 1.498×10^9 grams per year (=137.55×12×2,000×1000/2.204). The geometric mean of the moisture content of street sweepings was 0.37. Therefore, M_S corresponds to 0.944×10^9 grams of dry solids per year (=M_T×(1-0.37)) and M_L corresponds to 0.55×10^9 grams per year (=M_T×0.37). Values of C_S and C_L were obtained from measurements described in section III.3.

To compute the number of enterococci removed per year by the street sweepers, N_R, in units of MPN/year, the following equation was used:

$$N_R = C_T \times M_T$$

Finally, enterococci removal per unit surface area, in units of MPN/ft^2, was calculated as:

$$Enterococci\ per\ Surface\ Area = \frac{N_R}{Surface\ Area\ Swept\ per\ Year}$$

To obtain the surface area swept per year, the miles of street swept per week were also reported by Alvaro Rueda as 952.18 miles. Using this value, the surface area swept was estimated at 6.815×10^9 square feet per year (=952.18×5,280×26×52.14) based upon the assumption that the average width of the street is 26 feet. Given these values, we were able to compute enterococci removal in units of MPN/ft^2, as seen in the column labeled *Total MPN/ft²* as listed in Table III.7 in the results section.

II.3 STATISTICAL ANALYSIS

Data were analyzed to determine which statistical tests were appropriate. The analysis first focused on determining the distribution of the data. Results from the Shapiro-Wilks test (conducted using R Studio, version of R) indicated that the data were log-normally distributed. Therefore, data sets were analyzed in Excel for statistical differences using two-sample t-tests for the log-transformed data. For small data sets ($n<3$), the Welch's t-test and the Dixon's Q-Test outlier test were utilized to analyze whether individual data points could be classified as outliers. Statistical tests were used to evaluate differences in enterococci levels between: a) treatment conditions (including the extra UV treatment on Day 3), b) sampling days, and c) sidewalk versus street. Additionally, sweeper enterococci data were compared between the small and large street sweeper and between manual versus industrial street sweeping. Data sets were considered different for p-values less than 0.05.

The data were visualized using Excel through 2D clustered column charts and box-and-whisker plots. The plots were created to illustrate the variability in bacterial levels, differences by day and condition, and distribution and outliers across segments. The box-and-whisker plots have five parts: the minimum, first quartile (Q1), median (Q2), third quartile (Q3), and maximum. The minimum and maximum are represented by the whiskers. Data points beyond the whiskers are considered outliers. The “×” symbols within the boxes represent the geometric means.

Enterococci results are reported in both basic number format and as $\log_{10}$ concentrations, due to the wide range of enterococci levels observed. Plots are typically presented for the $\log_{10}$-transformed data to facilitate observation of the wide range of concentrations. Also, when discussing reductions in enterococci, reductions are expressed in basic number format and as $\log_{10}$ removals. Log_{10} removals are a common unit used when describing the reductions of microbes when treating drinking water with disinfectants. In the drinking water literature, several $\log_{10}$ removals are the target of disinfection treatment in controlled systems at water treatment plants that utilize powerful disinfectants such as chlorine. For this study, the water was not treated. Instead the surfaces upon which water flows was treated. Since the water was not treated directly, a one $\log_{10}$ removal of microbes in water is considered to be a significant improvement due to the “indirect” treatment of the water.

CHAPTER III

RESULTS AND DISCUSSION

CHAPTER III
RESULTS AND DISCUSSION

This chapter describes the results. The sections are separated into results from: hydrant water sample collection (section III.1), storm water sample collection (section III.2), and sediment sample collection (section III.3).

III.1 RESULTS FROM HYDRANT SAMPLE COLLECTION

Results from hydrant sample collection (Table III.1) confirm that the chlorine filter successfully removed the chlorine residual from the hydrant water. All chlorine residuals measured at zero mg/L. Additionally , enterococci measurements of the hydrant water indicated that the enterococci levels were primarily below the 1 MPN/100 mL detection limit with only one sample measuring at the detection limit of 1 MPN/100 mL. Results therefore indicate that the source water was characterized by very low nearly non-detectable enterococci levels and did not contribute enterococci significantly to the storm water runoff.

Table III.1. Results from hydrant sample collection including results from chlorine residual and enterococci measurements

Date	Sample ID	Chlorine Residual Before Filter (mg/L)	Chlorine Residual After Filter (mg/L)	Enterococci (MPN/100 mL)
250919	Carlyle-HYD	2	0	<1
250919	Byron-HYD	2	0	1
250926	Carlyle-HYD	1	0	<1
250926	Byron-HYD	1	0	<1
251017	Carlyle-HYD	0	0	<1
251017	Byron-HYD	2	0	<1

III.2 RESULTS FROM STORM WATER SAMPLE COLLECTION

The experimental design allowed for the comparison of treatments as follows:

- A three-way comparison between no cleaning, swept, and swept + UV for a given segment. This was accomplished by comparing the results for one segment among the three different experiment days. In addition to this, a comparison was necessary among the different experimental days because of the effects of repeated cleaning on enterococci concentrations.
- The extra UV treatment on Day 3 compared to the prior treatment received by the sidewalk on that day. One segment on Day 3 received no cleaning, one received sweeping treatment only, and one received both sweeping + UV treatment.

Additionally, comparisons were made between:

- Street versus sidewalk for a segment on each day.
- Between segments on a given day.

III.2.a Comparison between treatment conditions and between experimental days

Below is a summary table (Table III.2) and plots of the data sets (Figure III.1) showing comparisons between the different treatment conditions of no cleaning, sweeping, and sweeping + UV during the three sampling days. The overall trend was that the combination of surface treatment and experimental day, resulted in a decline in enterococci levels. Surfaces receiving multiple treatments over the course of the three experimental days tended to have reduced levels of enterococci.

Table III.2. Geometric mean values of enterococci runoff concentrations in MPN/100 mL and in log$_{10}$ concentration values for stormwater runoff for all segments from streets and sidewalk surfaces

	Street Runoff Enterococci Concentration		Sidewalk Runoff Enterococci Concentration			
	Segments A, B, C		Segments A, B, C		Extra UV	
	(MPN/100 mL)	(Log$_{10}$ MPN/100 mL)	(MPN/100 mL)	(Log$_{10}$ MPN/100 mL)	(MPN/100 mL)	(Log$_{10}$ MPN/100 mL)
Treatment Condition						
No cleaning	24,800	4.39	12,600	4.10	2,100	3.33
Swept	15,800	4.20	10,700	4.03		
Swept + UV	11,000	4.04	6,600	3.82		
Experimental Day						
Day 1	40,700	4.61	19,000	4.28	2,100	3.33
Day 2	11,500	4.06	17,800	4.25		
Day 3	9,300	3.97	2,700	3.43		

When evaluating treatment conditions specifically, the geometric mean levels for all treatment conditions and experimental days showed that enterococci levels decreased consistently with added treatment. The highest enterococci levels were observed in runoff from untreated streets (24,800 MPN/100 mL) and untreated sidewalks (12,600 MPN/100 mL). Intermediate levels were observed in runoff from swept streets (15,800 MPN/100 mL) and swept sidewalks (10,700 MPN/100 mL for sidewalks). The lowest levels were observed from streets treated with sweeping + UV (11,000 MPN/100 mL) and from sidewalks treated with sweeping + UV (6,600 MPN/100 mL). The extra UV treatment on Day 3 resulted in an even lower geometric mean concentration of 2,100 MPN/100 mL for the sidewalks.

Evaluating the treatment effects **statistically,** considering all segments together (Figure III.2, Table III.3), the only statistically significant reductions in enterococci were observed for street runoff between no cleaning versus sweeping + UV ($p=0.012$). The treatment of sweeping + UV resulted in a 0.35 log$_{10}$ reduction from 24,800 MPN/100 mL for no cleaning to 11,000 MPN/100 mL for swept + UV. No statistically significant differences were observed for any other combination, although the reduction in enterococci between swept and swept + UV was marginally significant ($p=0.087$) for the sidewalks.

When splitting the data sets by segment, results showed that additional treatment through sweeping or through sweeping + UV generally improved water quality for segments A and C. Of the six conditions evaluated at segments A and C, four showed a statistically significant decrease in enterococci storm water concentrations. Results for Segment B, on the other hand, were mixed with treatment showing a reduction and an increase in enterococci (as shown by the blue p values in Table III.3).

Segment B was characterized by very high levels of enterococci and sediment accumulation on the streets. This segment was swept on Day 1 and then again on Day 2 (as part of the sweeping + UV condition). By Day 3, segment B had been cleaned multiple times resulting in the vast removal of the accumulated sediment, thereby masking the effect of the treatment condition which on Day 3 was "no cleaning."

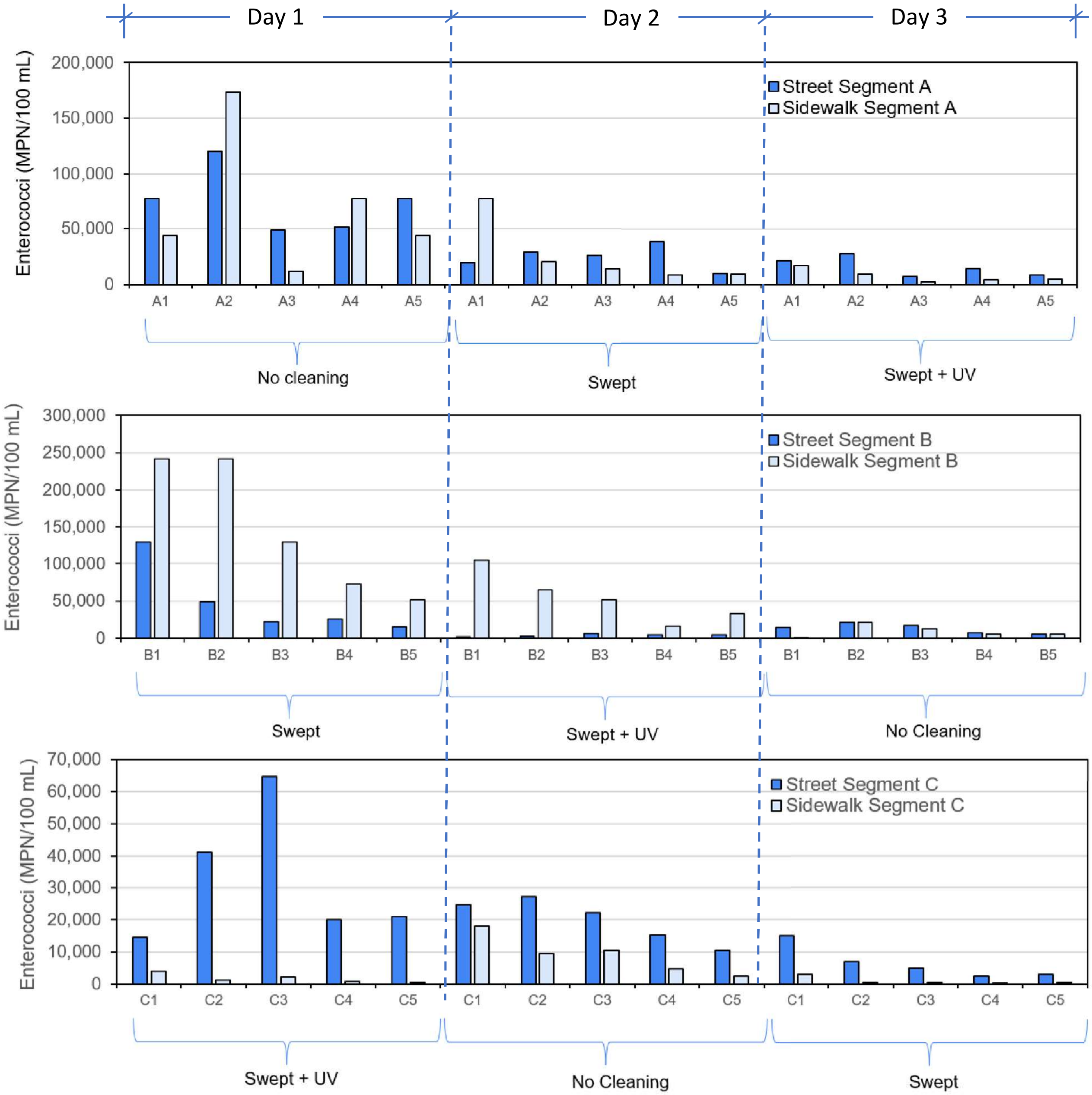


Figure III.1. Enterococci in run-off samples from streets and sidewalks for all 3 days for segments A, B, and C.

Table III.3. Enterococci comparison by treatment conditions across all segments and across individual segments A, B, and C. First and second conditions reported as the $\log_{10}$ transformed enterococci concentrations of MPN/100 mL. Conditions with statistically different $\log_{10}$ enterococci values are highlighted in red, if the condition with additional treatment resulted in lower levels. If the additional treatment resulted in statistically significant higher levels (which is counter to the hypothesis) then the p value is highlighted in blue.

Conditions	Street			Sidewalk		
	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value
All Segments						
No Cleaning vs Swept	4.39	4.20	0.207	4.10	4.03	0.821
No Cleaning vs Swept+UV	4.39	4.04	0.012	4.10	3.82	0.279
Swept vs Swept+UV	4.20	4.04	0.467	4.03	3.82	0.087
Segment A:						
No Cleaning vs Swept	4.85	4.35	0.021	4.70	4.24	0.149
No Cleaning vs Swept+UV	4.85	4.14	0.001	4.70	3.77	0.005
Swept vs Swept+UV	4.35	4.14	0.145	4.24	3.77	0.010
Segment B:						
No Cleaning vs Swept	4.06	4.55	0.024	3.75	5.09	0.007
No Cleaning vs Swept+UV	4.06	3.54	0.041	3.75	4.65	0.036
Swept vs Swept+UV	4.55	3.54	0.017	5.09	4.65	0.005
Segment C:						
No Cleaning vs Swept	4.28	3.71	0.004	3.86	2.76	0.002
No Cleaning vs Swept+UV	4.28	4.44	0.226	3.86	3.05	0.000
Swept vs Swept+UV	3.71	4.44	0.020	2.76	3.05	0.135

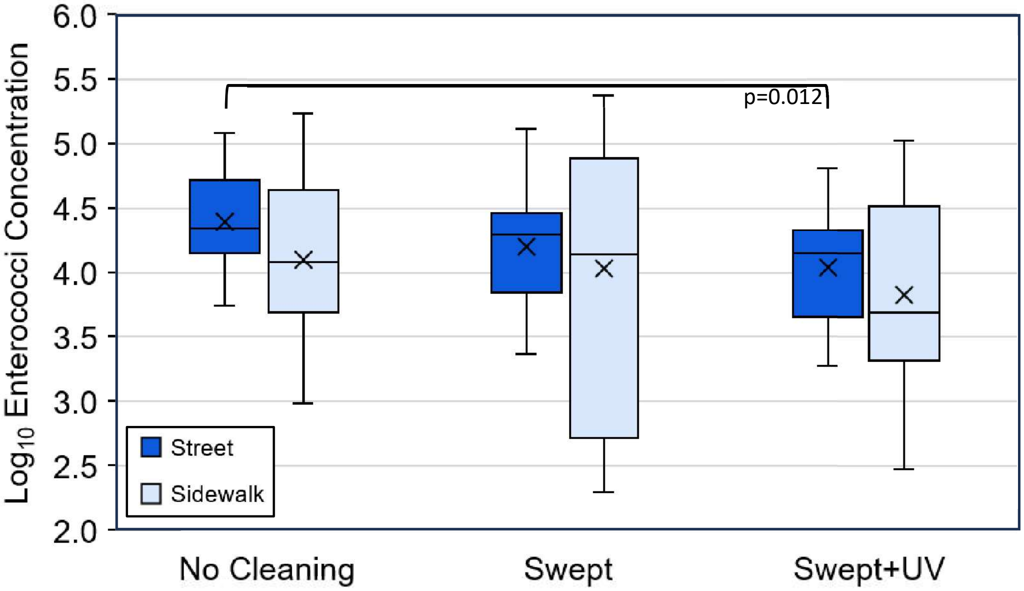


Figure III.2. Evaluation of treatment conditions for all segments together for streets and sidewalks. Results show that for streets, the treatments of sweeping and sweeping + UV resulted in statistically significant improvements over no cleaning in storm water quality.

When evaluating the influence of experimental day, again like treatment condition, as the days progressed the average enterococci levels in the runoff tended to decrease (Table III.2). We attribute this decrease due to the repeated cleaning that segments received over the course of the experimental days. By Day 3, all segments had been swept at least twice and received UV treatment at least once. We believe the cumulative effects of cleaning through sweeping and UV treatment resulted in the net decline. Specifically for the streets, the geometric mean declined from 40,700 MPN/100 mL on Day 1, to 11,500 MPN/100 mL on Day 2, and 9,300 MPN/100 mL on Day 3. **For the sidewalks, the geometric mean declined from 19,000 MPN/100 mL on Day 1, to 17,800 MPN/100 mL on Day 2, to 2,700 MPN/100 mL on Day 3. After the sidewalk surfaces were retreated with UV on Day 3, the geometric mean declined further to 2,100 MPN/100 mL**.

Evaluating the day effects **statistically**, results showed that, when evaluating day effects for all segments together (top rows of Table III.4), four out of the six comparisons resulted in statistically significant enterococci reductions as the days progressed. For the street, the enterococci reductions from 40,700 MPN/100 mL from Day 1 to 11,500 MPN/100 mL on Day 2 were statistically significant ($p=0.001$) and corresponded to a 0.55 $\log_{10}$ reduction. Also, for the street, the reductions from 40,700 MPN/100 mL on Day 1 to 9,300 MPN/100 mL on Day 3 were also statistically significant ($p<0.001$), corresponding to a 0.64 $\log_{10}$ reduction. For the sidewalks, the reduction from 17,800 MPN/100 mL on Day 2 to 2,700 MPN/100 mL on Day 3 (0.82 $\log_{10}$ reduction) and from 19,000 MPN/100 mL on Day 1 to 2,700 MPN/100 mL on Day 3 (0.85 $\log_{10}$ reduction) were also statistically significant ($p<0.001$).

When splitting the data sets by segment results showed that the progression of day generally resulted in improved water quality. Two exceptions were noted. One exception was for Segment B between Days 2 and 3 which showed an increase in enterococci concentrations, likely because Day 3 corresponded to a “no cleaning” day for segment B. Similarly, the second exception was for Segment C between Days 1 and 2, which showed an increase as well. This increase is also consistent with the treatment as Segment C was swept + UV treated on Day 1 and not cleaned on Day 2. Therefore, the variations observed in the data are a combination of the effects of treatment conditions and experimental day. **In combination, results suggest that treatments improve the quality of stormwater runoff with repeated treatments contributing towards an improvement.**

Table III.4. Enterococci comparison by day for all segments combined and across individual segments A, B, and C. First and second conditions reported as the $\log_{10}$ transformed enterococci concentrations of MPN/100 mL. Conditions with statistically different $\log_{10}$ enterococci values are highlighted in red, if the condition with additional treatment resulted in lower levels. If the additional treatment resulted in statistically significant higher levels (which is counter to the hypothesis) then the p value is highlighted in blue.

Conditions	Street			Sidewalk		
	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value
All Segments						
Day 1 vs Day 2	4.61	4.06	0.001	4.28	4.25	0.877
Day 2 vs Day 3	4.06	3.97	0.543	4.25	3.43	<0.001
Day 1 vs Day 3	4.37	3.97	<0.001	4.28	3.43	<0.001
Segment A:						
Day 1 vs Day 2	4.85	4.35	0.021	4.70	4.24	0.149
Day 2 vs Day 3	4.35	4.14	0.145	4.24	3.77	0.010
Day 1 vs Day 3	4.85	4.14	0.001	4.70	3.77	0.005
Segment B:						
Day 1 vs Day 2	4.55	3.54	0.017	5.09	4.65	0.005
Day 2 vs Day 3	3.54	4.06	0.041	4.65	3.75	0.036
Day 1 vs Day 3	4.55	4.06	0.024	5.09	3.75	0.007
Segment C:						
Day 1 vs Day 2	4.44	4.28	0.226	3.05	3.86	<0.001
Day 2 vs Day 3	4.28	3.71	0.004	3.86	2.76	0.002
Day 1 vs Day 3	4.44	3.71	0.020	3.05	2.76	0.135

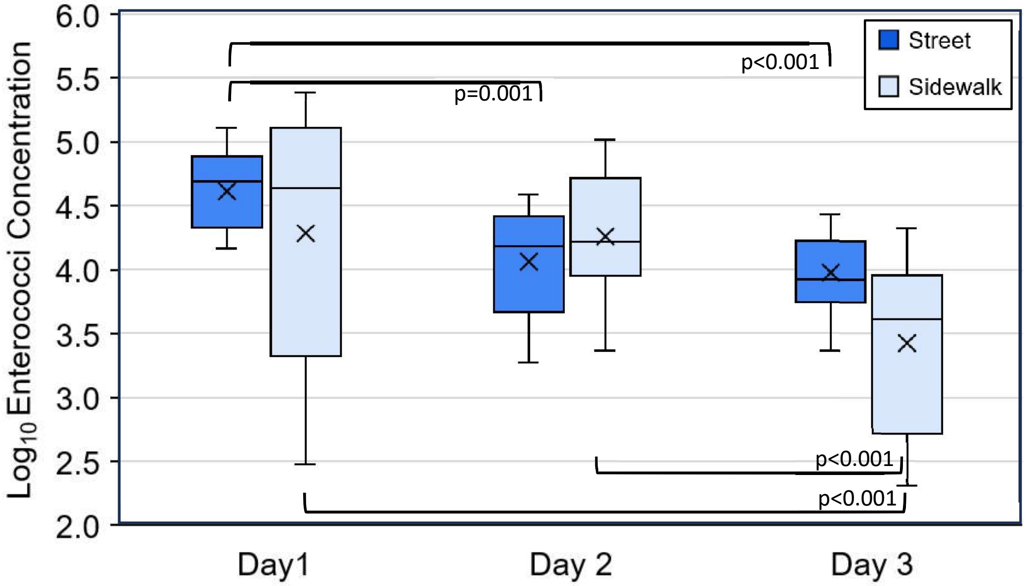


Figure III.3. Evaluation of experimental day for all segments together for streets and sidewalks. Results show that for streets, the progression of day (Day 1 to Day 3, and Day 1 to Day 2) resulted in statistically significant improvements in stormwater quality. Similarly, for sidewalks, the progression of day (Day 1 to Day 3, and Day 2 to Day 3) also resulted in statistically significant improvements in stormwater quality.

III.2.b Evaluation of extra UV on Day 3 (sidewalks only)

The results from the "extra UV" treatment were variable (Figure III.4). The mean values for all five samples of extra UV treatments across all three segments were lower (geometric mean of 2,100 MPN/100 mL) compared to those for the initial Day 3 sidewalk condition (2,700 MPN/100 mL) (Figure III.5); however, the difference was not statistically significant (Table III.5, $p = 0.40$). Similarly, no statistical differences were observed when the data were split by segment, although, on average, a consistent drop in the geometric mean of the enterococci levels was observed (Table III.5). These results point to "extra UV" as a potentially viable method of decreasing enterococci levels in runoff; however, due to the variability of the runoff data these decreases were not statistically robust suggesting that future studies should integrate more controlled conditions and larger sample sizes in efforts to obtain reductions that are statistically significant.

As mentioned in section II.1.c, the estimated doses from the Sterilasers^{TM} were larger than the doses needed to inactivate bacteria and viruses by at least an order of magnitude. Street surfaces have a rough texture and may not allow the light to penetrate all exposed crevices. Sidewalk surfaces tend to be smoother but generally have more obstructions such as sign posts, light posts, and benches which make it difficult to reach all areas uniformly. As a result, the effectiveness of the dose may be lower, and thus the calculated doses may represent an upper-bound estimate of the expected UV energy.

In summary, results do support that UV light reduces enterococci levels in stormwater. However, the practical larger-scale application of the technology would require additional research and development so that it can overcome limitations associated with street and sidewalk surfaces (rough texture and obstructions), and it would need to be engineered so it can be applied in a practical fashion on a larger city scale.

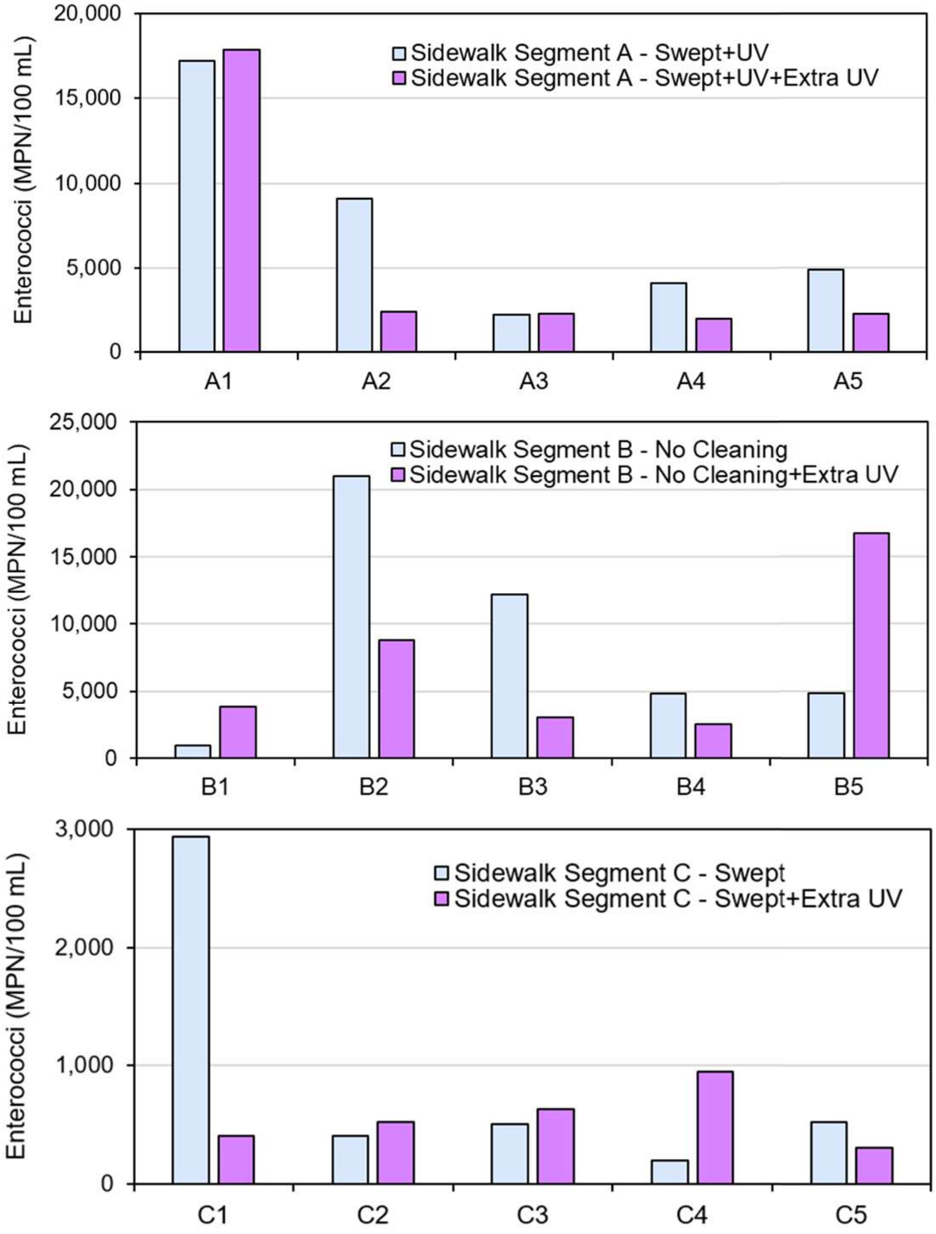


Figure III.4. Effects of extra UV treatment for Day 3 sidewalk treatments for Segments A, B, and C. No statistical differences were observed between the initial condition and the initial condition + UV treatment.

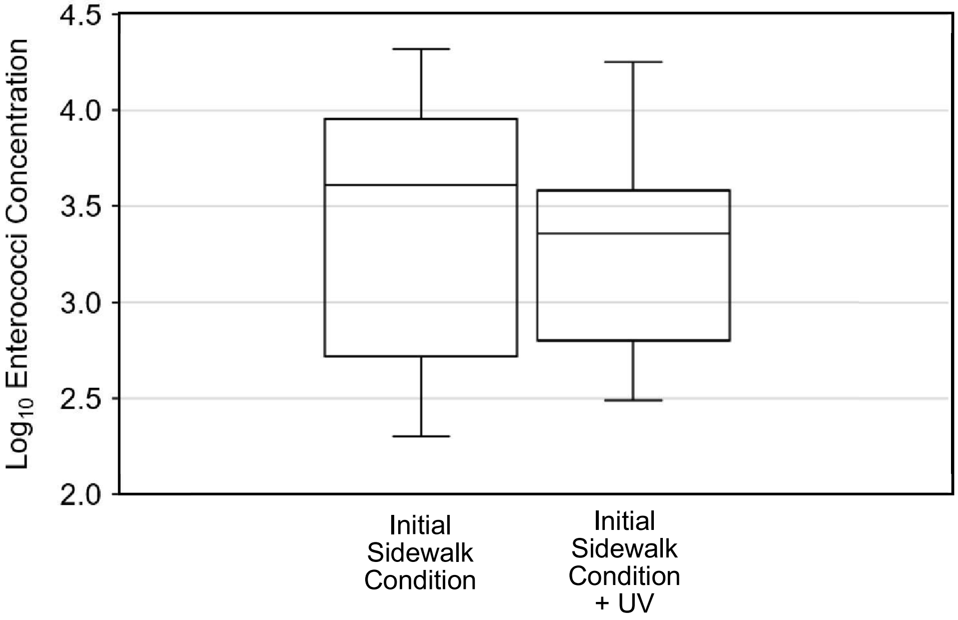


Figure III.5. Comparison of enterococci concentrations for the Day 3 initial sidewalk condition followed by the initial condition plus UV disinfection. The results show that although the geometric mean decreased between the initial condition to the initial condition plus UV, the decrease was not statistically significant.

Table III.5. Enterococci comparison for sidewalks treated on Day 3 with an extra UV treatment.

	First Condition	Sidewalk				
		First Condition (MPN/100 mL)	First Condition ($\log_{10}$ ENT)	First Condition + UV (MPN/100 mL)	First Condition + UV ($\log_{10}$ ENT)	p Value
All Segments	Not applicable	2,700	3.43	2,100	3.33	0.398
Segment A	Swept + UV	5,900	3.77	3,400	3.53	0.101
Segment B	No Cleaning	5,600	3.75	5,400	3.73	0.926
Segment C	Swept	580	2.76	520	2.72	0.876

III.2.c Comparison between street versus sidewalk

When comparing the enterococci concentrations between the street (12,900 MPN/100 mL) and sidewalk (8,900 MPN/100 mL), the geometric means were not statistically different (p=0.13) (Figure III.6). The sidewalk enterococci concentrations, however, were more variable (coefficient of variation of 22%) in comparison to the street (coefficient of variation of 11%). In fact, the highest level of enterococci observed was from runoff of sidewalks (>241,900 MPN/100 mL). These results emphasize the importance of cleaning the sidewalks in addition to cleaning the streets.

Figure III.6. Comparison of enterococci concentrations from the street and sidewalk, emphasizing that the geometric means of the two data sets were not statistically different. However, the sidewalk enterococci levels showed more variability than the street enterococci levels.

III.2.d Comparison between segments on a given day

When comparing segments, results emphasize that enterococci concentrations from the sidewalk Segment C was statistically different (1,700 MPN/100 mL) than the enterococci concentrations from the sidewalks at Segments A (17,400 MPN/100 mL, p<0.001) and B (31,600 MPN/100 mL, p<0.001). The sidewalk at Segment C is characterized by significantly less tree cover compared to the sidewalks at Segments A and B (Figure III.7). The type of trees is also different. Segments A and B, the trees are dominated by seagrapes which cover the sidewalks (especially along Segment B). Birds could be commonly heard chirping in the early mornings at Segments A and B, flocks were observed from the roofs of buildings that drain towards the site. Additionally, bird feces were commonly observed below the seagrape trees within these two segments (See Figure B.1 in Appendix B). Dog feces were more commonly observed in the grassy area that separates the sidewalk from the tennis courts at Segment C. The lower levels of enterococci from the sidewalk at Segment C could be due to less bird feces and the possible treatment provided by the grassy area that would minimize contamination from dog feces found within the grassy area adjacent to the sidewalk. In addition to this, the lack of tree cover would result in more direct sunlight on the sidewalk, resulting in some added level of natural disinfection through solar light and heating.

Table III.6. Enterococci comparison by segment for streets and sidewalks

Conditions	Street			Sidewalk		
	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value	First Condition ($\log_{10}$ ENT)	Second Condition ($\log_{10}$ ENT)	p Value
All Segments						
Segment A to Segment B	4.45	4.05	0.002	4.24	4.50	0.073
Segment B to Segment C	4.05	4.14	0.546	4.50	3.22	<0.001
Segment A to Segment C	4.45	4.14	0.001	4.24	3.22	<0.001

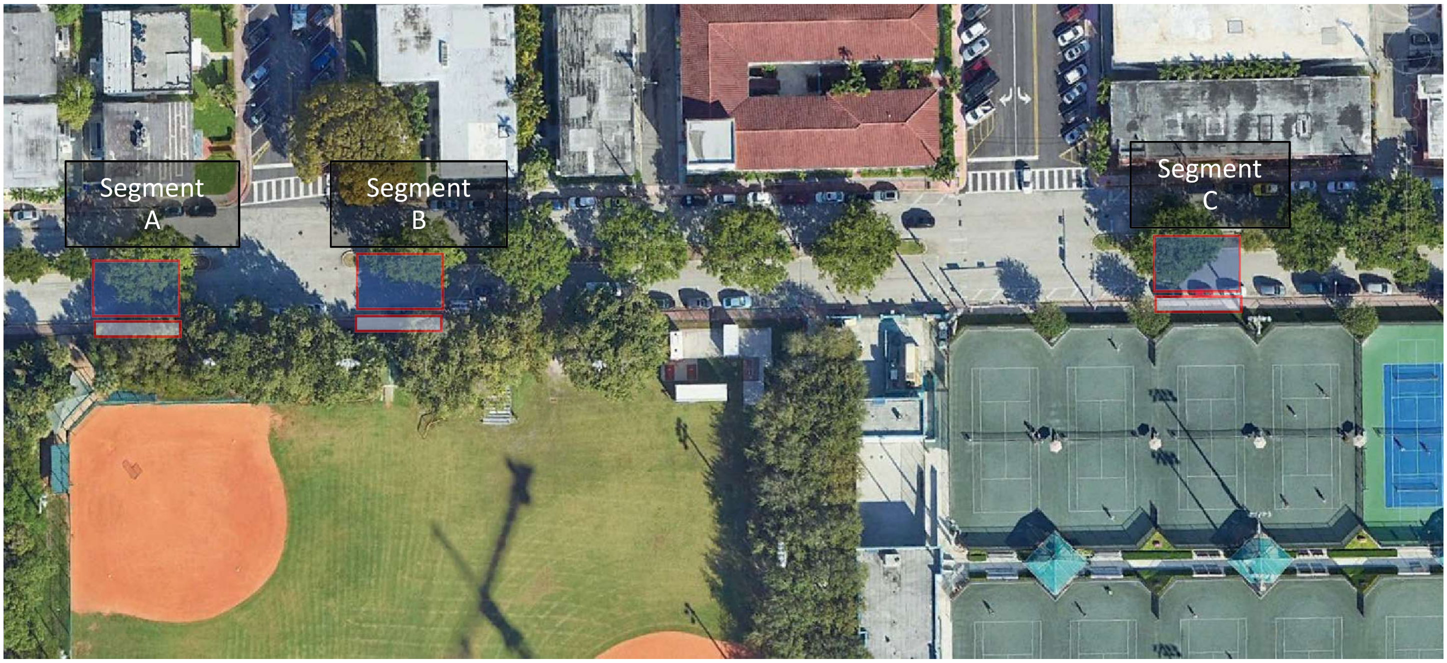


Figure III.7. Close-up of segments emphasizing tree cover. Street segments shown by dark blue boxes and sidewalk segments shown by light blue boxes. The difference in tree cover is particularly noticeable along the sidewalks between segments C (minimal tree cover on the sidewalk) versus segments A and B.

III.3 RESULTS FROM SEDIMENT SAMPLE COLLECTION

This section provides the results from the analysis of street sweeping solids. Street sweepings were collected from the streets using industrial street sweepers (from both a small and large unit) and from sidewalks through manual sweeping. The industrial street sweepers function by adding water to the streets as they sweep, and this water is collected by the sweeper. Thus, the industrial sweepers sediment samples consist of both a dry solids portion (63%) plus a liquid portion (37%). The following sections report on the concentrations of the sweepings (section III.3.a) and on the number of enterococci removed per unit area by sweeping (section III.3.b).

III.3.a Concentrations of street sweeping solids and liquids

For sweeping solids (Figure III.8, Table A.2 in Appendix A), results showed very high enterococci concentrations, ranging from 1,700 MPN/g ($\log_{10}$ 3.2) to 4,300,000 MPN/g ($\log_{10}$ 6.2). The geometric mean of all sweeping solids collected was 160,000 MPN/g. When splitting out the sweeping solids by manual versus industrial, the geometric mean concentration of the manually-collected sidewalk sediment was 27,000 MPN/g, whereas the geometric mean concentration of the industrial street sweeper sediments was 370,000 MPN/g (=C_S as explained in section II.2.c). Between the industrial and manual sweepings, no statistically significant difference was observed in the mean concentration ($p = 0.124$). Of note is the very large level of enterococci in the segment B (northwest side of Youth Center) sidewalk samples (geometric mean of 670,000 MPN/g with a maximum of 4,300,000 MPN/g). The level of enterococci at segment B was analyzed by Dixon's Q-Test outlier test and was found to be an outlier compared to levels observed at segments A and C (using arithmetic numbers). This segment had considerable tree cover. The trees serve as habitat for birds, which are a source of fecal contamination. The trees also release considerable debris (leaves and seagrapes), which can serve as a substrate for the enterococci to grow. The shade afforded by trees also limits the amount of heat and sunlight disinfection that may be found in areas with less tree cover. Fecal waste deposited in shaded areas with considerable debris is more likely to support the survival and growth of enterococci. Cleaning sidewalk areas, especially those with heavy tree cover, is therefore highly recommended.

Similarly, the liquids from sweepings (Figure III.9, Table A.3 in Appendix A) were also high, with levels ranging from 31,000 MPN/100 mL ($\log_{10}$ 4.5) to values exceeding 24,000,000 MPN/100 mL ($\log_{10}$ 7.4). The geometric mean of all sweeping liquids was 3,600,000 MPN/100 mL. No statistical difference (Welch's t-test $p = 0.887$) was observed in the geometric mean enterococci concentration between small (4,400,000 MPN/100 mL, $\log_{10}$ 6.6, geometric mean) and large industrial sweeper liquids (3,400,000 MPN/100 mL, $\log_{10}$ 6.5 geometric mean) (=$C_L \times 100$ as explained in section II.2.c).

Taking into consideration that the large industrial street sweeper solids consist of both a liquid (37%, C_L=34,000 MPN/g) and a dry solids portion (63%, C_S=370,000 MPN/g), the overall weighted average concentration of street sweeper wet solids is estimated at 240,000 MPN/g (=C_T as explained in section II.2.c).

Given the extraordinarily high levels of enterococci in street sweeping liquids (maximums exceeding 24,000,000 MPN/100 mL) and solids (with maximum levels exceeding 4,200,000 MPN/g), care must be taken to minimize leakage during the cleaning of street sweeping equipment and during the disposal of street sweeping and sidewalk solids. All fluids (and solids) from cleaning surface sweeping equipment must be diverted from the stormwater conveyance system.

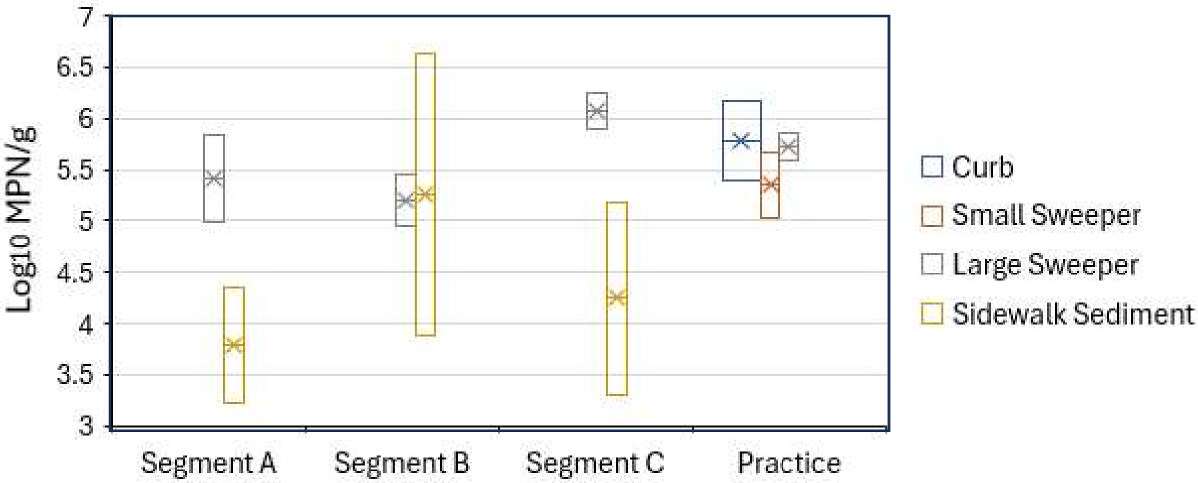


Figure III.8. Enterococci concentrations for sweeping solids.

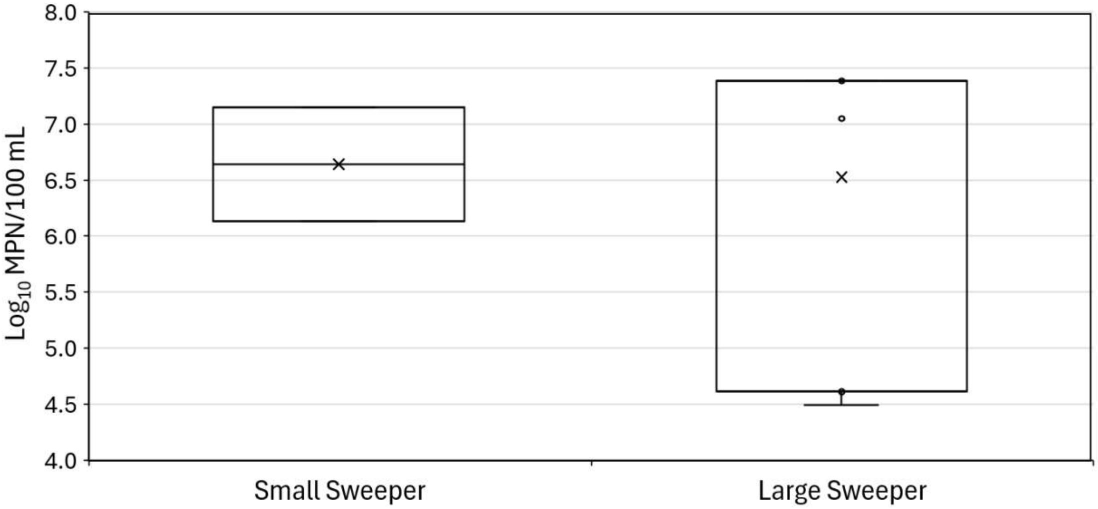


Figure III.9. Enterococci concentrations in sweeping liquids, comparison of levels between small and large industrial street sweepers.

III.3.b Number of enterococci removed per surface area through sweeping

To further assess the data, the enterococci concentration for the sweeping sediments were used to compute the number of enterococci removed per surface area (Table III.7). As mentioned earlier in section II.2.c, the area swept by the large industrial street sweeper was provided by Alvaro Rueda of the City of Miami Beach as, "952 miles of roadway swept per week; during the month of October 2025, 137.55 tons of sweepings were collected." Using this information and assuming the width of the street at 26 feet (more details in section II.2.c), we computed that,

Industrial Street Sweepers Remove→ 63,000 MPN per square foot swept.

The sweepings collected during October 2025 alone, therefore, correspond to 3.0×10^{13} MPN of enterococci. The amount collected per year corresponds to 3.6×10^{14} MPN of enterococci. The volume of water within the PVC is estimated at 819,000 ft^3 (assuming 2600 ft length, with a triangular cross-section of 90 ft wide and 7 ft deep in the middle). There are two tidal exchanges per day, and assuming that half of the water in the PVC is exchanged per tidal cycle, **the 3.6×10^{14} MPN removed per year is roughly estimated to represent a reduction in the PVC enterococci by 4,300 MPN/100 mL.**

The amount of enterococci removed through industrial street sweeping is significant and therefore, street sweeping should continue. In addition, we recommend that the CMB consider improvements to industrial street sweeping. When speaking with the staff, in many cases, cars are not removed to avoid towing charges to residents. However, such a practice impedes the ability of street sweepers to access critical areas of the street where debris accumulates, reducing the effectiveness of industrial street sweeping. Additionally, during the field visits, we had the opportunity to pull back curb grates that are found along many street corners in the area (See Figure B.2, panel A in Appendix B). These curbs covered by grates are not accessible to industrial street sweepers. When these grates were pulled, a considerable amount of debris was accumulated within them. Given the very high levels of enterococci found in curb sediments (1,500,000 MPN/g at the Dickens curb grate), these grates should be cleaned manually. Finally, at the end of each industrial street sweeper run, a pile of debris remains at the end of the run (See Figure B.2, panel B in Appendix B). These piles should also be manually collected and disposed given the very high levels of enterococci found in sediments collected from the streets (maximum of 4,300,000 MPN/g, 160,000 MPN/g geometric mean).

As computed for the streets, we also computed the amount removed by manually sweeping the sidewalks based on the mass of sediment collected and the surface area manually swept. Using this information, we computed that,

Manual Sidewalk Sweeping Removes → 44,000 MPN per square foot swept.

Please note the significant decrease in enterococci removed using manual sweeping, when the segment was swept for a second time (Table III.7). This significant decrease suggests that repeated sweeping of sidewalks within a one-month time interval will result in less enterococci removal per square foot than listed above. Given the very high levels of enterococci removed upon first sweeping, all sidewalks contributing towards the PVC should be cleaned. The cleaning frequency is not entirely clear, but perhaps the CMB can consider sidewalk cleaning at the same frequency as street sweeping, plus more frequently if there is visible buildup on a sidewalk. Priority should be given to sidewalks covered by trees due to the greater debris accumulation and impacts from bird feces. Sidewalks should be visually inspected frequently and disinfected when bird or dog fecal matter is visibly present (see example photos in Appendix B, Figure B.1).

Table III.7. Removal of enterococci by sweeping per square foot swept.

Original Name	**Sample Date**	**Sample Type**	**MPN/ft^2 removed by sweeping**
Large Industrial Sweeper			
BE-SED	September 19, 2025	Large Sweeper	739,064
CE-SED	September 19, 2025	Large Sweeper	542,930
AE-SED	September 26, 2025	Large Sweeper	13,233
BE-SED	September 26, 2025	Large Sweeper	12,912
AE-SED	October 17, 2025	Large Sweeper	25,077
CE-SED	October 17, 2025	Large Sweeper	36,752
		Geometric Mean	63,112
Manual Sweeping			
AM-SED, Segment A	September 26, 2025	Manual Sweeping	89,975
AM-SED, Segment A	October 17, 2025	Manual Sweeping	1,598
BM-SED, Segment B	September 19, 2025	Manual Sweeping	9,373,018
BM-SED, Segment B	September 26, 2025	Manual Sweeping	48,135
CM-SED, Segment C	September 19, 2025	Manual Sweeping	43,400
CM-SED, Segment C	October 17, 2025	Manual Sweeping	2,530
		Geometric Mean	43,866

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

CHAPTER IV

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Results from this study confirm that stormwater from the street and sidewalk surfaces have excessive levels of enterococci with maximum values exceeding the upper detection limit of 241,900 MPN/100 mL. The geometric means measured at 24,800 MPN/100 mL for runoff from streets and 12,600 MPN/100 mL for runoff from sidewalks. On average, results from this study demonstrate that the progression of treatment condition from no cleaning, to sweeping, to sweeping plus UV reduced enterococci levels in runoff from streets and sidewalks, down to average levels of 11,000 MPN/100 mL for streets and 6,600 MPN/100 mL for sidewalks. When evaluating the data by experimental day, which reflects the impacts of two treatments over a period of about a month, the reductions were even higher. For Day 1, the geometric mean enterococci level in the street runoff was 40,700 MPN/100 mL. This was reduced to 9,300 MPN/100 mL for street runoff by Day 3. Similarly, for sidewalks on Day 1, the geometric mean enterococci level in the sidewalk runoff was 19,000 MPN/100 mL, whereas on Day 3, the geometric mean dropped to 2,700 MPN/100 mL. On Day 3, all segments received an "extra UV" treatment and this resulted in a further drop in the mean enterococci concentration in sidewalk runoff to 2,100 MPN/100 mL. The reductions in the geometric mean concentrations were consistent when evaluating treatment condition and experimental day. However, given the variability of the enterococci runoff concentrations, statistically significant reductions were not always demonstrated. A larger number of samples would need to be collected in future studies to increase statistical power. Overall, results support that street sweeping and street sweeping combined with UV reduce enterococci levels in storm water runoff.

Based upon direct analysis of sediments from industrial street sweepers, we estimate that industrial street sweepers remove an average of 63,000 MPN per square foot swept. Given the street sweeping data provided by the CMB and assumptions about the tidal flushing of the PVC, we estimate that currently, industrial street sweeping results in about a 4,300 MPN/100 mL reduction in PVC enterococci levels. As a result, results support the continuation of sweeping with industrial sweepers. To improve the efficacy of industrial street sweeping we recommend manually picking up incidental debris at end of a sweeper run, manually removing curb grates found at the corners of most streets and removing accumulating debris, and the removal of cars prior to sweeping. It is recognized that street sweeping is a challenge given the limited amount of residential parking in the area and that removal of cars may not be always practical.

The results from this study also emphasize that sidewalks contribute enterococci to runoff. Results from manual sweeping of the sidewalks indicate that 44,000 MPN/square foot of enterococci can be removed with a broom and dust pan. We therefore recommend that the CMB consider and implement practical approaches for sidewalk cleaning. The advantage of sidewalk sweeping is that it does not require the removal of cars, avoiding the need to remove cars associated with sweeping the streets. Sidewalks should be cleaned on a set schedule (perhaps at a similar schedule as street cleaning) plus given the ease of sidewalk access (no need to move cars) we recommend that they be inspected and cleaned more frequently when debris is visible. Priority should be given to sidewalk areas that are covered by trees given that they attract birds and limit the natural solar heating and disinfection from sunlight. In addition, we recommend more frequent visual inspections and disinfection of the sidewalks (perhaps with a combination of chemical disinfectant and UV light) when signs of bird and dog feces are visible.

Results from this study support that UV contributes towards the reduction in enterococci from street and sidewalk surfaces. Most of the statistically significant reductions were observed upon repeated sweeping and

UV application. Although the UV system utilized for this study was retrofitted to better accommodate street surfaces, the technology should be further engineered to increase its practical use for city-scale disinfection of street and sidewalk surfaces. Overall, results support that industrial street sweeping should continue. The CMB should consider adding sidewalk sweeping to their sweeping schedule. The integration of UV light disinfection is also recommended but will require additional development before it can be used on the city scale.

To implement these recommendations it is recognized that CMB resources will be needed (e.g., staff and equipment) and ordinances will need to be in place to facilitate implementation. In order to facilitate implementation based upon available resources we rank the recommendations as follows.

1. Manually remove incidental debris at the end of each street sweeping run.
2. Manually remove debris from under the curb grates found at many street corners.
3. Sweep sidewalks with prioritization of sidewalks covered by trees and where visible debris is found to accumulate.
4. Disinfection of sidewalks with UV or a combination of UV and chemicals with minimal residual.
5. Disinfection of streets as above, requiring the removal of parked cars.

ACKNOWLEDGMENTS

This project would not have been possible without the incredible support received from the City of Miami Beach and from Sterilaser^{TM}. The City of Miami Beach provided logistical support for diverting the traffic, clearing the streets of parked cars, for access to the water hydrants, and for managing the storage and connection of the dechlorination filter. The City also facilitated industrial street sweeping including sample collection from both the small and large industrial sweepers. Sterilaser^{TM} provided the handheld and retrofitted floor unit to the project free of charge. We are very grateful to Steve Kowalski for facilitating the retrofit and for his advice during this project. We also thank the many interested parties who have shared their insights with us during our time out in the field and during meetings within the City to better understand the cause of the elevated enterococci levels.

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APPENDICES

APPENDIX A

DATA

Table A.1. Raw enterococci data for liquid samples collected during experimental days.

Sample ID	Date (YYMMDD)	Enterococci (MPN/100 mL)
Carlyle-HYD-FilterTS	250919	<1
Byron-HYD-FilterTS	250919	1
AT1	250919	77,010
AT2	250919	120,330
AT3	250919	48,840
AT4	250919	51,720
AT5	250919	77,010
AW1	250919	43,520
AW2	250919	173,290
AW3	250919	11,990
AW4	250919	77,010
AW5	250919	43,520
BT1	250919	129,970
BT2	250919	48,840
BT3	250919	21,870
BT4	250919	26,130
BT5	250919	14,670
BW1	250919	241,960
BW2	250919	241,960
BW3	250919	129,970
BW4	250919	72,700
BW5	250919	51,720
CT1	250919	14,390
CT2	250919	41,060
CT3	250919	64,880
CT4	250919	20,140
CT5	250919	20,980
CW1	250919	3,930
CW2	250919	1,210
CW3	250919	2,090
CW4	250919	600
CW5	250919	300
BE-LIQ	250919	>24,196,000
CE-LIQ	250919	>24,196,000

Table A.1. (continued)

Sample ID	**Date (YYMMDD)**	**Enterococci (MPN/100 mL)**
Carlyle-HYD-FilterTS	250926	<1
Byron-HYD-FilterTS	250926	<1
AT1	250926	19,560
AT2	250926	29,090
AT3	250926	26,030
AT4	250926	38,730
AT5	250926	10,120
AW1	250926	77,010
AW2	250926	20,640
AW3	250926	13,740
AW4	250926	8,600
AW5	250926	8,890
BT1	250926	1,870
BT2	250926	2,230
BT3	250926	6,400
BT4	250926	4,570
BT5	250926	3,990
BW1	250926	104,620
BW2	250926	64,880
BW3	250926	51,720
BW4	250926	16,240
BW5	250926	32,550
CT1	250926	24,810
CT2	250926	27,230
CT3	250926	22,240
CT4	250926	15,150
CT5	250926	10,460
CW1	250926	17,890
CW2	250926	9,330
CW3	250926	10,430
CW4	250926	4,730
CW5	250926	2,310
AE-LIQ	250926	41,000
BE-LIQ	250926	31,000

Table A.1. (continued)

Sample ID	Date (YYMMDD)	Enterococci (MPN/100 mL)
Carlyle-HYD-FilterTS	251017	<1
Byron-HYD-FilterTS	251017	<1
AT1	251017	21,430
AT2	251017	27,230
AT3	251017	7,230
AT4	251017	14,210
AT5	251017	8,260
AW1	251017	17,230
AW2	251017	9,090
AW3	251017	2,230
AW4	251017	4,100
AW5	251017	4,880
AU1	251017	17,850
AU2	251017	2,410
AU3	251017	2,280
AU4	251017	1,990
AU5	251017	2,260
BT1	251017	14,210
BT2	251017	20,980
BT3	251017	16,580
BT4	251017	6,970
BT5	251017	5,520
BW1	251017	960
BW2	251017	20,980
BW3	251017	12,230
BW4	251017	4,880
BW5	251017	4,880
BU1	251017	3,830
BU2	251017	8,840
BU3	251017	3,050
BU4	251017	2,560
BU5	251017	16,740
CT1	251017	15,000
CT2	251017	6,970
CT3	251017	5,040
CT4	251017	2,310
CT5	251017	2,850
CW1	251017	2,940
CW2	251017	410
CW3	251017	510
CW4	251017	200
CW5	251017	520
CU1	251017	410
CU2	251017	520
CU3	251017	630
CU4	251017	950
CU5	251017	310
AE-LIQ	251017	>24,196,000
CE-LIQ	251017	>24,196,000

Table A.2. Enterococci data for street sweeping solids.

Original Name	Sample Date	Sample Type	Segment	Water Content	Enterococci (MPN/g)	Enterococci (Log$_{10}$ MPN/g)
Byron/CB 250707	July 7, 2025	Curb	Practice	0.780	252,576	5.40
Dickens/CB 250707	July 7, 2025	Curb	Practice	0.962	1,470,347	6.17
BE-Sweeper/S 250707	July 7, 2025	Small Sweeper	Practice	0.552	108,656	5.04
BE-SED 250905	September 9, 2025	Small Sweeper	Practice	0.271	463,187	5.67
BE-Sweeper/L 250707	July 7, 2025	Large Sweeper	Practice	0.342	380,832	5.58
BE-SE-LARGE 250905	September 5, 2025	Large Sweeper	Practice	0.358	732,573	5.86
BE-SED 250919	September 19, 2025	Large Sweeper	Segment B	0.464	286,724	5.46
CE-SED 250919	September 19, 2025	Large Sweeper	Segment C	0.341	783,388	5.89
AE-SED 250926	September 26, 2025	Large Sweeper	Segment A	0.319	97,349	4.99
BE-SED 250926	September 26, 2025	Large Sweeper	Segment B	0.356	90,077	4.95
AE-SED 251017	October 17, 2025	Large Sweeper	Segment A	0.433	689,845	5.84
CE-SED 251017	October 17, 2025	Large Sweeper	Segment C	0.387	1,790,305	6.25
BM-SED 250919	September 19, 2025	Sidewalk Sediment	Segment B	0.450	4,269,950	6.63
CM-SED 250919	September 19, 2025	Sidewalk Sediment	Segment C	0.239	154,349	5.19
AM-SED 250926	September 26, 2025	Sidewalk Sediment	Segment A	0.186	22,735	4.36
BM-SED 250926	September 26, 2025	Sidewalk Sediment	Segment B	0.251	7,800	3.89
AM-SED 251017	October 17, 2025	Sidewalk Sediment	Segment A	0.051	1,712	3.23
CM-SED 251017	October 17, 2025	Sidewalk Sediment	Segment C	0.023	2,010	3.30

Table A.3. Sweeping enterococci concentration data for liquid samples.

Original Name	**Sample Date**	**Sample Type**	**Segment**	**Enterococci (MPN/100 mL)**	**Enterococci (Log_{10} MPN/100 mL)**
Sweeper/S	July 7, 2025	Small Sweeper	Practice	1,354,000	6.13
BE-LIQ	September 5, 2025	Small Sweeper	Practice	14,136,000	7.15
BE-LIQ-LARGE	September 5, 2025	Large Sweeper	Practice	11,199,000	7.05
BE-LIQ	September 19, 2025	Large Sweeper	B/C	>24,196,000	7.38
CE-LIQ	September 19, 2025	Large Sweeper	B/C	>24,196,000	7.38
AE-LIQ	September 26, 2025	Large Sweeper	A/B	41,000	4.61
BE-LIQ 26 hr	September 26, 2025	Large Sweeper	A/B	31,000	4.49
AE-LIQ	October 17, 2025	Large Sweeper	A/C	>24,196,000	7.38
CE-LIQ	October 17, 2025	Large Sweeper	A/C	>24,196,000	7.38

APPENDIX B

IMAGES OF SURFACES EMPHASIZING SOURCES OF ENTEROCOCCI

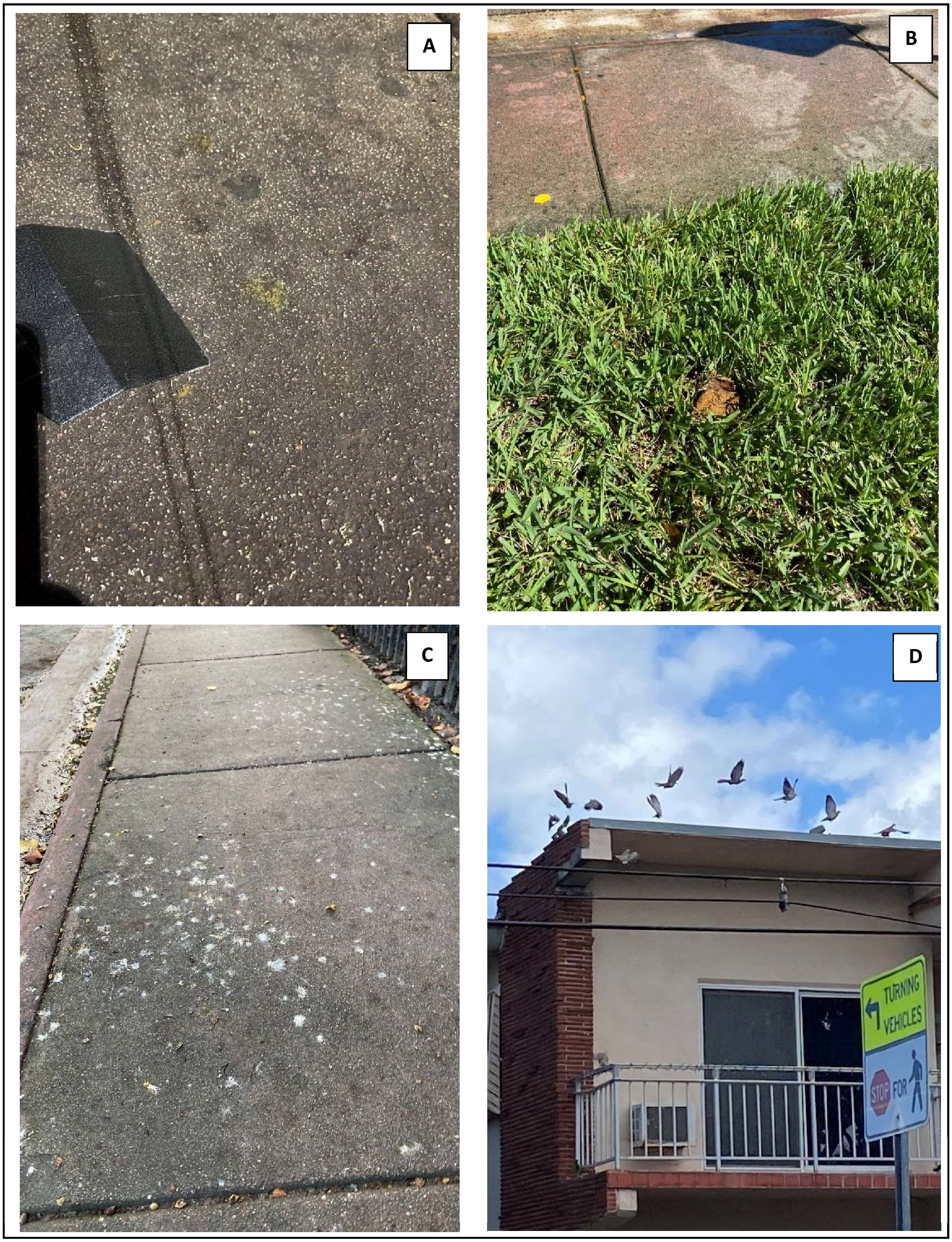


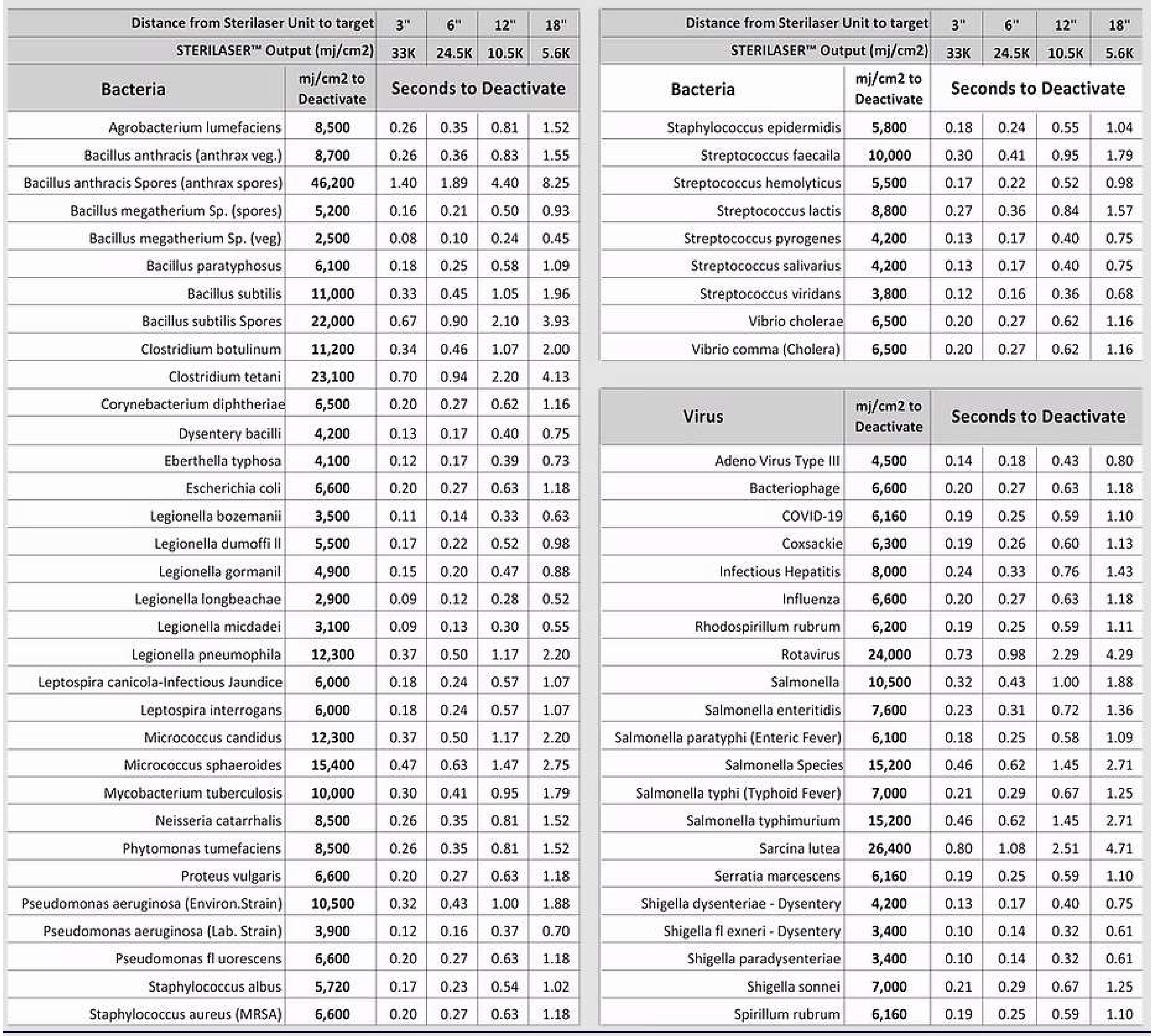
Figure B.1. Dog feces visible on sidewalks (Panel A) and in grassy area adjacent to sidewalk at segment C (Panel B). Bird feces visible on sidewalk at segment B (Panel C). Birds observed throughout sampling period including roofs which drain directly to the street (Panel D).

Figure B.2. The storm drain grates at most corners (Panel A) should be lifted and debris removed as part of regular street sweeping. Debris left behind by street sweepers at the end of the run should be picked up manually (Panel B).

APPENDIX C

STERILASER MICROBE DISINFECTION DATA

Table C.1. Disinfection of microbes using the handheld Sterilaser^{TM} unit. Data from Sterilaser web site (https://www.thesterilaser.com/copy-of-chamber-unit, accessed on December 26, 2025).

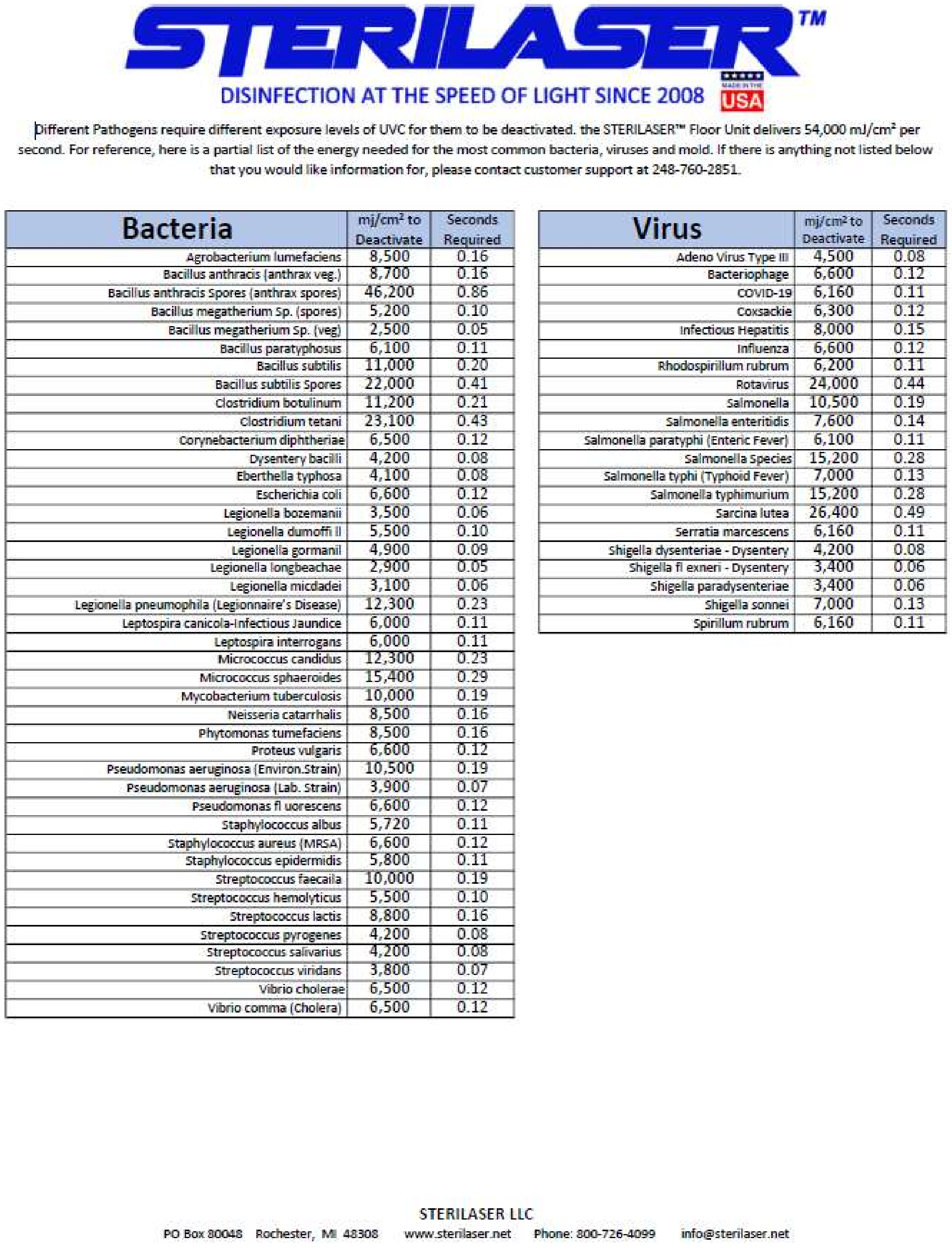


Distance from Sterilaser Unit to target		3"	6"	12"	18"
STERILASER™ Output (mj/cm2)		33K	24.5K	10.5K	5.6K
Bacteria	mj/cm2 to Deactivate	**Seconds to Deactivate**			
Agrobacterium lumefaciens	**8,500**	0.26	0.35	0.81	1.52
Bacillus anthracis (anthrax veg.)	**8,700**	0.26	0.36	0.83	1.55
Bacillus anthracis Spores (anthrax spores)	**46,200**	1.40	1.89	4.40	8.25
Bacillus megatherium Sp. (spores)	**5,200**	0.16	0.21	0.50	0.93
Bacillus megatherium Sp. (veg)	**2,500**	0.08	0.10	0.24	0.45
Bacillus paratyphosus	**6,100**	0.18	0.25	0.58	1.09
Bacillus subtilis	**11,000**	0.33	0.45	1.05	1.96
Bacillus subtilis Spores	**22,000**	0.67	0.90	2.10	3.93
Clostridium botulinum	**11,200**	0.34	0.46	1.07	2.00
Clostridium tetani	**23,100**	0.70	0.94	2.20	4.13
Corynebacterium diphtheriae	**6,500**	0.20	0.27	0.62	1.16
Dysentery bacilli	**4,200**	0.13	0.17	0.40	0.75
Eberthella typhosa	**4,100**	0.12	0.17	0.39	0.73
Escherichia coli	**6,600**	0.20	0.27	0.63	1.18
Legionella bozemanii	**3,500**	0.11	0.14	0.33	0.63
Legionella dumoffi II	**5,500**	0.17	0.22	0.52	0.98
Legionella gormanil	**4,900**	0.15	0.20	0.47	0.88
Legionella longbeachae	**2,900**	0.09	0.12	0.28	0.52
Legionella micdadei	**3,100**	0.09	0.13	0.30	0.55
Legionella pneumophila	**12,300**	0.37	0.50	1.17	2.20
Leptospira canicola-Infectious Jaundice	**6,000**	0.18	0.24	0.57	1.07
Leptospira interrogans	**6,000**	0.18	0.24	0.57	1.07
Micrococcus candidus	**12,300**	0.37	0.50	1.17	2.20
Micrococcus sphaeroides	**15,400**	0.47	0.63	1.47	2.75
Mycobacterium tuberculosis	**10,000**	0.30	0.41	0.95	1.79
Neisseria catarrhalis	**8,500**	0.26	0.35	0.81	1.52
Phytomonas tumefaciens	**8,500**	0.26	0.35	0.81	1.52
Proteus vulgaris	**6,600**	0.20	0.27	0.63	1.18
Pseudomonas aeruginosa (Environ.Strain)	**10,500**	0.32	0.43	1.00	1.88
Pseudomonas aeruginosa (Lab. Strain)	**3,900**	0.12	0.16	0.37	0.70
Pseudomonas fluorescens	**6,600**	0.20	0.27	0.63	1.18
Staphylococcus albus	**5,720**	0.17	0.23	0.54	1.02
Staphylococcus aureus (MRSA)	**6,600**	0.20	0.27	0.63	1.18

Distance from Sterilaser Unit to target		3"	6"	12"	18"
STERILASER™ Output (mj/cm2)		33K	24.5K	10.5K	5.6K
Bacteria	mj/cm2 to Deactivate	**Seconds to Deactivate**			
Staphylococcus epidermidis	**5,800**	0.18	0.24	0.55	1.04
Streptococcus faecaila	**10,000**	0.30	0.41	0.95	1.79
Streptococcus hemolyticus	**5,500**	0.17	0.22	0.52	0.98
Streptococcus lactis	**8,800**	0.27	0.36	0.84	1.57
Streptococcus pyrogenes	**4,200**	0.13	0.17	0.40	0.75
Streptococcus salivarius	**4,200**	0.13	0.17	0.40	0.75
Streptococcus viridans	**3,800**	0.12	0.16	0.36	0.68
Vibrio cholerae	**6,500**	0.20	0.27	0.62	1.16
Vibrio comma (Cholera)	**6,500**	0.20	0.27	0.62	1.16

Virus	mj/cm2 to Deactivate	**Seconds to Deactivate**			
Adeno Virus Type III	**4,500**	0.14	0.18	0.43	0.80
Bacteriophage	**6,600**	0.20	0.27	0.63	1.18
COVID-19	**6,160**	0.19	0.25	0.59	1.10
Coxsackie	**6,300**	0.19	0.26	0.60	1.13
Infectious Hepatitis	**8,000**	0.24	0.33	0.76	1.43
Influenza	**6,600**	0.20	0.27	0.63	1.18
Rhodospirillum rubrum	**6,200**	0.19	0.25	0.59	1.11
Rotavirus	**24,000**	0.73	0.98	2.29	4.29
Salmonella	**10,500**	0.32	0.43	1.00	1.88
Salmonella enteritidis	**7,600**	0.23	0.31	0.72	1.36
Salmonella paratyphi (Enteric Fever)	**6,100**	0.18	0.25	0.58	1.09
Salmonella Species	**15,200**	0.46	0.62	1.45	2.71
Salmonella typhi (Typhoid Fever)	**7,000**	0.21	0.29	0.67	1.25
Salmonella typhimurium	**15,200**	0.46	0.62	1.45	2.71
Sarcina lutea	**26,400**	0.80	1.08	2.51	4.71
Serratia marcescens	**6,160**	0.19	0.25	0.59	1.10
Shigella dysenteriae - Dysentery	**4,200**	0.13	0.17	0.40	0.75
Shigella flexneri - Dysentery	**3,400**	0.10	0.14	0.32	0.61
Shigella paradysenteriae	**3,400**	0.10	0.14	0.32	0.61
Shigella sonnei	**7,000**	0.21	0.29	0.67	1.25
Spirillum rubrum	**6,160**	0.19	0.25	0.59	1.10

Table C.2. Disinfection of microbes using the large floor model Sterilaser^{TM} unit. Information provided by Steve Kowalski, Vice President of Operations for Sterilaser LLC.



STERILASER™

DISINFECTION AT THE SPEED OF LIGHT SINCE 2008

MADE IN THE USA

Different Pathogens require different exposure levels of UVC for them to be deactivated. the STERILASER™ Floor Unit delivers 54,000 mJ/cm² per second. For reference, here is a partial list of the energy needed for the most common bacteria, viruses and mold. If there is anything not listed below that you would like information for, please contact customer support at 248-760-2851.

Bacteria	mj/cm² to Deactivate	Seconds Required
Agrobacterium lumefaciens	8,500	0.16
Bacillus anthracis (anthrax veg.)	8,700	0.16
Bacillus anthracis Spores (anthrax spores)	46,200	0.86
Bacillus megatherium Sp. (spores)	5,200	0.10
Bacillus megatherium Sp. (veg)	2,500	0.05
Bacillus paratyphosus	6,100	0.11
Bacillus subtilis	11,000	0.20
Bacillus subtilis Spores	22,000	0.41
Clostridium botulinum	11,200	0.21
Clostridium tetani	23,100	0.43
Corynebacterium diphtheriae	6,500	0.12
Dysentery bacilli	4,200	0.08
Eberthella typhosa	4,100	0.08
Escherichia coli	6,600	0.12
Legionella bozemanii	3,500	0.06
Legionella dumoffi II	5,500	0.10
Legionella gormanil	4,900	0.09
Legionella longbeachae	2,900	0.05
Legionella micdadei	3,100	0.06
Legionella pneumophila (Legionnaire's Disease)	12,300	0.23
Leptospira canicola-Infectious Jaundice	6,000	0.11
Leptospira interrogans	6,000	0.11
Micrococcus candidus	12,300	0.23
Micrococcus sphaeroides	15,400	0.29
Mycobacterium tuberculosis	10,000	0.19
Neisseria catarrhalis	8,500	0.16
Phytomonas tumefaciens	8,500	0.16
Proteus vulgaris	6,600	0.12
Pseudomonas aeruginosa (Environ.Strain)	10,500	0.19
Pseudomonas aeruginosa (Lab. Strain)	3,900	0.07
Pseudomonas fl uorescens	6,600	0.12
Staphylococcus albus	5,720	0.11
Staphylococcus aureus (MRSA)	6,600	0.12
Staphylococcus epidermidis	5,800	0.11
Streptococcus faecaila	10,000	0.19
Streptococcus hemolyticus	5,500	0.10
Streptococcus lactis	8,800	0.16
Streptococcus pyrogenes	4,200	0.08
Streptococcus salivarius	4,200	0.08
Streptococcus viridans	3,800	0.07
Vibrio cholerae	6,500	0.12
Vibrio comma (Cholera)	6,500	0.12

Virus	mj/cm² to Deactivate	Seconds Required
Adeno Virus Type III	4,500	0.08
Bacteriophage	6,600	0.12
COVID-19	6,160	0.11
Coxsackie	6,300	0.12
Infectious Hepatitis	8,000	0.15
Influenza	6,600	0.12
Rhodospirillum rubrum	6,200	0.11
Rotavirus	24,000	0.44
Salmonella	10,500	0.19
Salmonella enteritidis	7,600	0.14
Salmonella paratyphi (Enteric Fever)	6,100	0.11
Salmonella Species	15,200	0.28
Salmonella typhi (Typhoid Fever)	7,000	0.13
Salmonella typhimurium	15,200	0.28
Sarcina lutea	26,400	0.49
Serratia marcescens	6,160	0.11
Shigella dysenteriae - Dysentery	4,200	0.08
Shigella fl exneri - Dysentery	3,400	0.06
Shigella paradysenteriae	3,400	0.06
Shigella sonnei	7,000	0.13
Spirillum rubrum	6,160	0.11

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