The Impact of Storm-water Runoff in the Toms River

The effects of storm drains located in Beachwood Beach in Beachwood Township, N.J., and West Beach in Pine Beach, N.J. on the Toms River

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With Save Barnegat Bay's Barnegat Bay Student Grant Program (BBSGP)

Abstract

The Toms River in New Jersey is a location that has been scrutinized for its high bacteria levels along its bathing beaches. Two such locations have been under fire from the National Resources Defense Council for several years now. Frequently exceeding public safety standards for safe swimming bacteria levels, Beachwood Beach and West beach became a focus for a storm-monitoring project. Utilizing scientific methodology that ensures accuracy and reliability of data in combination with quality assurance methods approved by the New Jersey Department of Environmental Protection, a two month long study was conducted on the bathing beaches. Testing for *E. coli* and *Enterococci*, the Barnegat Bay Student Grant Program focused its attention on making a difference in the two areas. Ultimately, two storm drains displayed frequent bacterial "hot spots" which led to a list of recommendations including more frequent inspections and cleanings of said storm drains. In rain storms over 0.10 inches of rain, there can be significant increases in water-borne bacteria that can exceed public safety standards and pose a risk to human health.

Introduction

Along the Toms River in New Jersey (Figure 10), an interest in public health is steadily rising due to the abnormal bacteriological readings found at several bathing beaches located near the area. One such beach is known as Beachwood Beach located in Beachwood Township, New Jersey. According to the National Resources Defense Council (NRDC), Beachwood Beach's bathing water exceeded safety standards for bacteria in approximately 27 percent of all 2010 samples (National Resources, 2011). The NRDC reports the Department of Environmental Protection's tests of *Enterococcus* bacteria in the water. The national safety limit of *Enterococcus* bacteria is 104 colony forming units (CFUs) per 100 milliliters of water (National Resources, 2011). Since there were only 33 samples taken that year, 9 of those samples were above 104 CFUs/100mL of water. These elevated levels are concerning to the public that wishes to bathe safely in the Toms River. In addition to Beachwood Beach, another location approximately three quarters of a mile away (or 1.05 miles by car) also managed to arouse attention to public health. West Beach located in Pine Beach, New Jersey is a partial bathing beach that is expected to have replenishment work done sometime in the near future. Since beach replenishment is an expensive task, the area must have potential for income; however, West Beach exceeded safety standards in 15% of 26 samples in 2010 (National Resources, 2011). These two locations have alarmed many local citizens and have drawn much attention to the area. The significant link between the two areas and elevated bacteria levels is suspected to be associated with storm-water runoff.

Storm-water sampling is difficult due to several factors of variance. The first factor is the sheer unpredictability of the weather. Certain systems can have unpredictable starts and stops; however, it is usually considered an acceptable sample once the rainfall total exceeds 0.10 inches of rain (Dufour & Ballentine, 1986). It is important to limit the amount of variance as much as possible. By taking samples both during a storm and during dry weather, one can collect a wide variety of data that can be used for comparisons. It is also important for samplers to conduct sampling at several locations because human structures can influence the water quality of an area. One such structure, for example, is a storm drain (Figure 1). During a rainfall event, storm

Figure 1: Storm drain located in the Beachwood Beach parking lot.

drains located throughout a municipality will collect water through drains located on the sides of roads, in parking lots, and other areas that are highly trafficked. These drains lead to larger water bodies and can influence readings during storm events because the rainwater from other locations may be flowing out of the drains. To collect more accurate samples during rainfall events, one must also receive a sample from the first and second flushes of a storm. The first flush of a storm is associated with a period of 30 minutes after a storms initialization (Dufour & Ballentine, 1986). The first flush is the recognized time where most bacteria and other matter will flow out of a storm drain (Dufour & Ballentine, 1986). A second flush sample can also be conducted up to one hour after the storms initialization in order to obtain a sample after the initial discharge. These sampling periods are important because they represent the true storm-water effects on both the water body and the drain itself. Usually if there are high levels of bacteria recorded during the first flush, the assumption can be made that there is a fault with the storm drain. The storm drain may need cleaning; however, the storm drain could also have an infrastructure problem (Figure 2). While it is likely that a rainfall

Figure 2: Storm drain with slight infrastructure problem. Water is leaking out of a crack in the drain.

event will lead to an increase the amount of bacteria in a water body, a dramatic increase could be linked to a problem with the storm drains in the area. If a problem with a storm drain is suspected, sampling should be conducted in the storm drain as well as a distance away from it.

One major threat to bathers during a rainfall event is the potential for increased bacteriological activity. Bacteria and humans coexist and certain bacteria also have a symbiotic relationship with human beings. One such relationship exists with the bacteria *Escherichia coli*. *E. coli* lives in human intestines and aids with the digestion process; however, if *E. coli* is relocated to any other part of the body, the host can become infected and fall ill. For this reason, *E. coli* is studied as a pathogenic fecal coliform (U.S. Environmental, 1999). *E. coli* is part of a fecal coliform group (U.S. Environmental, 1999). These fecal coliforms will not necessarily themselves infect people; however, they are indicators that other infectious pathogens can be present in the water (U.S. Environmental, 1999). The main problem with relying on *E. coli* as an indicator for bacteria in water is its tolerance range. *E. coli* levels are not accurate in marine water settings; therefore, the study of *Enterococcus* bacteria is required (U.S. Environmental, 1992). *Enterococcus* bacteria has been designated by the Environmental Protection Agency as the standard for marine water bacterial monitoring (U.S. Environmental, 1992). Studies have shown that high levels of *Enterococci* in marine waters have had a strong correlation with gastroenteritis, a disease that also has the same correlation with high levels of fecal coliforms (Chen et all., n.d.). In New Jersey, the NRDC cites that the safe swimming limit for *Enterococcus* bacteria is 104 CFUs/100mL of water (National Resources, 2011). Beaches in excess of this standard are subject to retesting and then closing should the level remain above the standard. The main issue between testing for the two types of bacteria is saltwater versus freshwater. Since rainfall and storm-water runoff should be fresh, it might seem appropriate to conduct *E. coli* tests on water; however, the salinity of a bathing beach will usually be above the acceptable mean salinity of a freshwater. This would require testing for *Enterococcus* bacteria. For an accurate storm-water monitoring program, it may be accurate to test both parameters.

Since storm drains are known to elevate bacteria levels in bathing beaches, it is appropriate to question whether the increases are due to natural or unnatural causes. One potential method to determine the source of impact is to look for optical brighteners in water. Optical brighteners (or fluorescent whitening agents) are chemicals commonly found in detergents that will adsorb to fabrics during the cleaning process (Optical brighteners, 2007). These chemicals are acclaimed to fluoresce in ultraviolet light which will make the whites appear "whiter" (Optical brighteners, 2007). Optical brighteners have the potential to reveal human source pollution because only a portion of the chemicals are adsorbed, whereas the rest are emitted as part of a household's wastewater (Optical brighteners, 2007). Optical brighteners also have great potential to reveal human source pollution because they do not biodegrade; rather, they photochemically degrade (Floresguerra, 2003). Should people be dumping detergents down a drain, should people be cleaning boats in excess, or should infrastructure problems lead to links between wastewater and storm-water pipes, there should, theoretically, be an increase in optical brightener levels in the outflow of a storm drain.

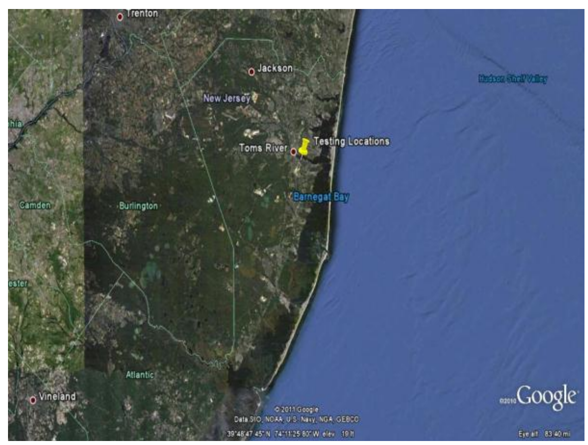

Figure 3: Image of Ocean County and the Barnegat Bay. Testing location along the Toms River is labeled with a yellow peg. Image courtesy of Google Earth.

To obtain a better sample, it is important to include several water quality parameters. As part of New Jersey's Ambient Water Quality Monitoring Program, several parameters are tested as opposed to just one or two (NJDEP Bureau, 2011). As part of the program, the following parameters are tested by field samplers: dissolved oxygen, turbidity, pH, temperature, salinity, and specific conductance (NJDEP Bureau, 2011). These parameters are tested because water flows from several locations into larger bodies of water such as the Barnegat Bay (Figure 3). Such parameters may be of importance to obtain for storm-water sampling as well since storm drains will flush into larger bodies of water too.

Quality assurance is the final component of a proper storm-water monitoring program. The New Jersey Department of Environmental Protection (NJDEP) regulates several actions that must be taken in order to receive recognition for data collected on New Jersey water bodies (NJDEP Office, 2011). Quality assurance officers around the state will review and certify plans according to a tier system (Presenting Data, 2011). Tier A recognized environmental education, Tier B recognizes stewardship, Tier C recognizes a community or watershed assessment, and Tier D recognizes a regulatory response (Presenting Data, 2011). These tiers are designed to give credibility to the data received based on the rigor and accuracy of the sampling methodology. The more rigorous the methodology, the higher the tier indicated. The goal of a solid storm-water monitoring program is to achieve a Tier B or higher recognition in order to have the data recognized and used by decision making officials (Presenting Data, 2011). By introducing quality assurance to a project, it ensures that the data will be recognized and accurate according the approved plan.

Methodology

To plan the experiment, several meetings were held to discuss the most effective methodology. Said methodology must include the most viable field options for quick and accurate storm sampling in order to obtain samples that best represented the Toms River. The methodology also had to incorporate the NJDEP quality assurance guidelines in order to obtain accurate samples that can be recognized at a different level. The proposed plan was approved by the NJDEP at the Tier B level.

To conduct the experiment, several tools had to be prepared in a laboratory setting as well as for a field setting. Thiosulfate treated, sterile, labeled Whirl-Paks were used to obtain water from the sampling locations (Figure 4). A cooler with ice packs was also used to keep samples cool. Waders were required to enter the water to collect samples, and nitrile gloves were used both in the field and in the laboratory. A Turner Designs Aquafluor was used to test for optical brighteners and turbidity in sample water. To properly calibrate the Aquafluor, the NJDEP issued a 5 percent detergent solution to calibrate the optical brightener channel to a 50 on the relative optical brightener scale. The NJDEP also issued 100 NTU turbidity fluid to calibrate the turbidity channel of the Aquafluor. Plastic cuvettes were used to run samples through the Aquafluor. Plastic 1 milliliter pipettes were used to move small amounts of sample water from the Whirl-Paks to other locations. A graduated cylinder was used to measure liquid

Figure 4: Thiosulfate treated sampling Whirl-paks.

volumes. AYSI-85 meter was used to check water quality parameters such as dissolved oxygen, percent saturation, conductivity, salinity, and temperature. An Oakton Handheld pH Meter was used to assess pH of sample water. The YSI-85 was calibrated for dissolved oxygen by comparison to a Winkler Titration. The YSI-85 was also calibrated to NJDEP issued conductivity calibration fluid. To check the calibrations, instruments were also given a blank sample of deionized water. Due to sterilization techniques and calibrations, a large carbuoy of deionized water was utilized. Please note that the carbuoy had to be refilled on several occasions. To conduct the bacteriological assessments, two incubators were used (Figure 5). One incubator was constantly set to 35 degrees Celsius for the incubation of Coliscan plates. The other incubator was constantly set to 41 degrees Celsius for the IDEXX Enterolert Quanti-Trays. Coliscan Easygel media and petri dishes were used to assess *E. coli* in the samples. An IDEXX sealer (Figure 5) as well as IDEXX Enterolert media was used to assess

Figure 5: Incubators and the IDEXX sealer at the lab in Dr. Wnek's garage. From left to right: incubator, incubator, sealer.

Enterococcus sp. in the sample water. In addition to the sealer and media, IDEXX Quanti-Tray/2000 and Quanti-Trays were used to house the sample water and media solutions for incubation. To analyze the results of the Enterolert test, a black light was utilized to count fluorescent wells on the Quanti-Trays (Figure 6). Journals and preformatted data sheets were utilized to record all data and observations made throughout the project.

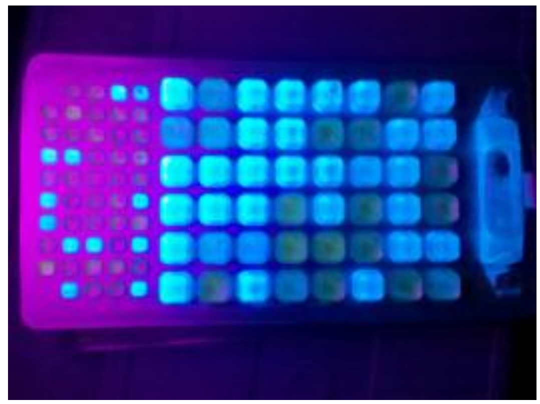

Figure 6: Fluorescent Quanti-Tray/2000 being viewed under a black light.

Throughout the project, NJDEP quality assurance guidelines were met in order to assure accuracy and recognition. No pipettes or Whirl-Paks were ever reused in order to assure sterile equipment. All other equipment was rinsed three times with deionized water before and after use in order to assure sterility. pH samples were tested within 15 minutes of collection time. Bacteria samples were tested within 6 hours of collection time. Samples were also collected at a "thigh-high" level in the water unless sampling within a storm drain. The Aquafluor and pH meters were calibrated at least one time per sampling session. If several sampling sessions existed in a period of 24 hours, equipment was checked to standards in order to ensure accuracy. The Aquafluor was also checked with deionized water before every sampling session. The YSI-85 was calibrated for dissolved oxygen and conductivity at least once a week and checked against deionized water every sampling session. The YSI-85 was also calibrated to NJDEP meters for further accuracy. For each sampling session—or approximately every twenty samples should several sessions exist in one day—a duplicate sample was collected to compare to original results. A blank sample was run on the same basis in order to conduct a handling check. In order to assure sterility, nitrile gloves were worn when collecting or handling samples (Figure 7). Storm sampling generally required a 0.10 inch rainfall before sampling the first and second flush was possible. This plan for quality assurance was submitted to the NJDEP and was approved at the Tier B level.

Two locations were sampled throughout the project; Beachwood Beach and West Beach. These locations were optimal because both have suffered periods of high bacterial activity (National Resources, 2011). These locations are also approximately 0.75 miles apart, so sampling both locations in the event of a storm was possible. Beachwood Beach was broken down into six sampling locations: L1S1, L1S2, L1S2i, L1S3, L1S4, L1S4i (Figure 8). These locations were assigned said codes to convey the location with ease. "L1" was the code for Beachwood Beach. "S*x*" was the code for sampling site at the indicated location. Codes containing a lowercase "i"

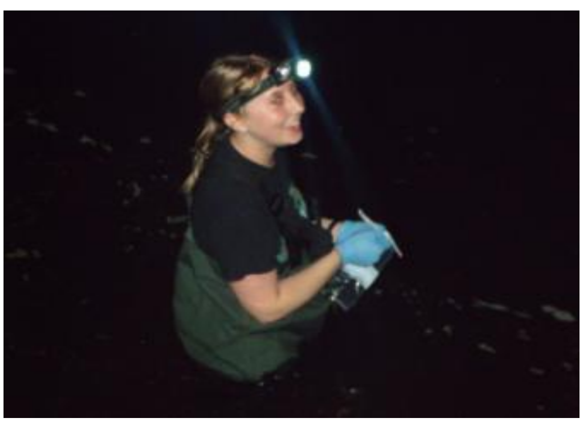

Figure 7: Sampler Danielle Clancy collecting samples wearing gloves according to the quality assurance plan.

were sampling sites inside a given storm drain. All other sampling sites were taken at a thigh-high depth in the water. Sites 1 and 3 at Beachwood Beach were taken for controls, whereas sites 2 and 4 at Beachwood Beach were taken due to their relativity to a storm drain. At West Beach near Avon Road in Pine Beach, New Jersey, there were four sampling locations: L2S1, L2S2, L2S2i, L2S3 (Figure 9). "L2" in the codes indicates the West Beach location. All other characters in the codes follow the same guidelines as the Beachwood Beach codes. Sites 1 and 3 at West Beach were taken for controls, and site 2 was taken due to its relativity to a storm drain.

Two main types of sampling were utilized throughout the project: baseline sampling and storm sampling. Baseline sampling was used as a reference point to determine what would be a typical day on the Toms River. Baseline sampling was only conducted on Mondays so the received data could be compared to the same data collected by the Ocean County Health Department. During baseline sampling, two samplers would go out in waders; one to

Figure 8: Aerial view of Beachwood Beach in Beachwood Township, New Jersey. Sampling locations are labeled next to yellow pegs. Image courtesy of Google Earth.

Beachwood Beach and the other to West Beach. At their locations, they would begin around the same approximate time and start at site one for each respective location. Samplers would move through the sites only collecting sample water (excluding any storm-drain sampling due to a lack of stormwater flow on baseline sampling days). Samplers would also test for pH when in the

Figure 9: Aerial view of West Beach in Pine Beach, New Jersey. Sampling locations are labeled by yellow pegs. Image courtesy of Google Earth.

water, assuming a pH meter was available. Once the samplers obtained all samples, they then placed the samples in coolers for transport to Dr. Wnek's garage which was used as a laboratory. Once at the lab, the samples were tested with the Aquaflor and YSI-85 for any water quality parameters. After these tests were conducted, bacteriological assessments were performed on the sample water. One milliliter of sample water was used for the Easygel plating process. Ten milliliters of sample water was then used for a 10:1 dilution of sample water for the IDEXX Enterolert method. After preparing samples, they were then placed in their respective incubators for a period of 24 hours. After 24 hours, the samples were removed from the incubators and then the bacteria content of each was assessed. The only main difference between storm sampling and baseline sampling was the sample collection process and the type of tray used for the Enterolert method. The laboratory procedures were all the same as per the quality assurance plan that was approved by the NJDEP. During a storm event, samples were collected approximately 30 minutes after the storm's initiation. The purpose of this was to capture the first flush of a storm drain. Approximately one hour after a storms initiation began the second round of sampling. This was to capture the second flush of a storm drain. These samples were all kept in coolers and transported to the laboratory. Furthermore, storm sampling required the use of the Quanti-Tray/2000 for the Enterolert method whereas baseline sampling only required the regular Quanti-Tray. All data was recorded on data sheets, and all observations were recorded in journals.

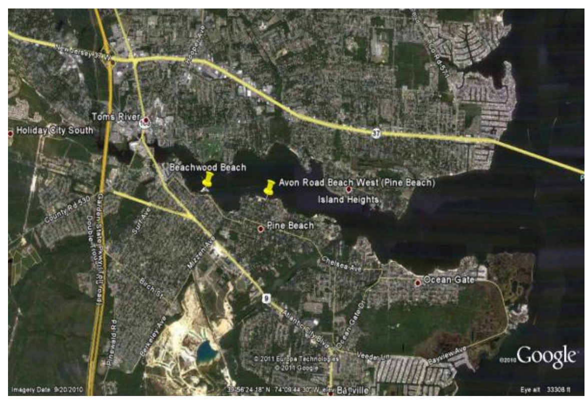

Figure 10: Image of the Toms River. Sampling locations are marked by yellow pins. Image courtesy of Google Earth.

Results

There were several complications with collecting the data. The first issue was a problem with the incubation of the IDEXX Quanti-Trays; therefore, several data points were replaced with the more accurate NRDC *Enterococcus* data. Furthermore, several pH meters broke throughout the project due to

Table 1: Mean values for all baseline parameters at Beachwood Beach and West Beach.

Parameter	L1S1	L1S2	L1S3	L1S4	L2S1	L2S2	L2S3
Percent Saturation (%)	84.8	85.0	91.4	89.4	89.4	95.4	91.8
Dissolved Oxygen (mg/L)	6.57	6.62	6.88	6.79	6.40	6.90	6.80
Conductivity (mS/cm)	17.52	17.65	17.47	19.70	23.83	23.57	24.38
Salinity (‰)	10.3	10.5	10.5	11.5	13.7	13.8	14.0
Temperature (°C)	25.4	25.3	25.6	26.3	28.0	27.9	27.9
pH	6.9	7.0	7.0	7.1	7.7	7.9	7.9
Optical Brighteners	83.56	95.34	90.77	99.23	87.94	395.47	135.85
Turbidity (NTUs)	6.207	4.440	3.351	4.369	5.718	3.633	3.258
***E. coli* (CFUs/100mL)**	650	880	1380	760	260	440	280
***Enterococcus* (mpn)**	18	16	24.2	20	18.2	26.8	16

Table 2: Mean values for all first flush data collected at Beachwood Beach and West Beach.

Parameter	L1S1	L1S2	L1S2i	L1S3	L1S4	L1S4i	L2S1	L2S2	L2S2i	L2S3
Percent Saturation (%)	95.5	94.1	85.2	93.4	96.9	95.2	95.0	92.4	88.9	93.8
Dissolved Oxygen (mg/L)	7.48	7.38	6.55	7.32	7.49	7.19	7.04	7.06	6.49	6.87
Conductivity (mS/cm)	15.27	16.75	15.96	18.35	21.93	21.61	22.61	20.05	24.48	25.42
Salinity (‰)	9.6	9.5	9.0	10.5	12.7	12.6	14.1	14.8	14.5	15.2
Temperature (°C)	26.7	26.6	26.6	26.7	26.7	26.6	26.0	26.4	26.2	25.9
Optical Brighteners	110.80	123.25	158.58	120.90	56.45	100.60	86.42	95.91	103.92	82.88
Turbidity (NTUs)	7.663	9.484	8.889	5.506	14.947	5.203	5.091	5.474	7.317	6.821
***E. Coli* (CFUs/100 mL)**	1000	800	17850	1400	700	2100	900	200	2500	1000
***Enterococcus* (mpn)**	77.5	75	88	85.25	77.5	77.5	72	35	40	60

Table 3: Mean values for second flush parameters at Beachwood Beach and West Beach.

Parameters	L1S1	L1S2	L1S2i	L1S3	L1S4	L1S4i	L2S1	L2S2	L2S2i	L2S3
Percent Saturation (%)	95.3	95.8	84.7	89.8	92.5	90.8	84.3	89.7	85.5	88.5
Dissolved Oxygen (mg/L)	7.36	7.47	6.97	6.75	7.35	6.73	6.75	7.06	6.12	6.59
Conductivity (mS/cm)	16.31	16.09	10.47	17.08	17.82	20.13	23.98	20.16	19.58	24.82
Salinity (‰)	9.1	9.4	5.8	9.7	10.9	12.0	14.5	14.5	11.6	14.8
Temperature (°C)	25.4	25.2	23.6	25.3	25.6	25.3	25.2	25.8	25.9	26.0
pH	7.4	7.3		6.8	6.8					
Optical Brighteners	106.79	104.21	181.13	127.68	97.55	94.50	101.52	86.82	105.11	87.18
Turbidity (NTUs)	4.491	3.583	7.313	4.035	4.398	4.682	5.749	3.839	4.334	5.203
***E. Coli* (CFUs/100mL)**	10740	4825	18725	1440	840	1175	3967	967	8333	933
***Enterococcus* (mpn)**	4899	1435	4938	362	265	246	3416	695	2792	227

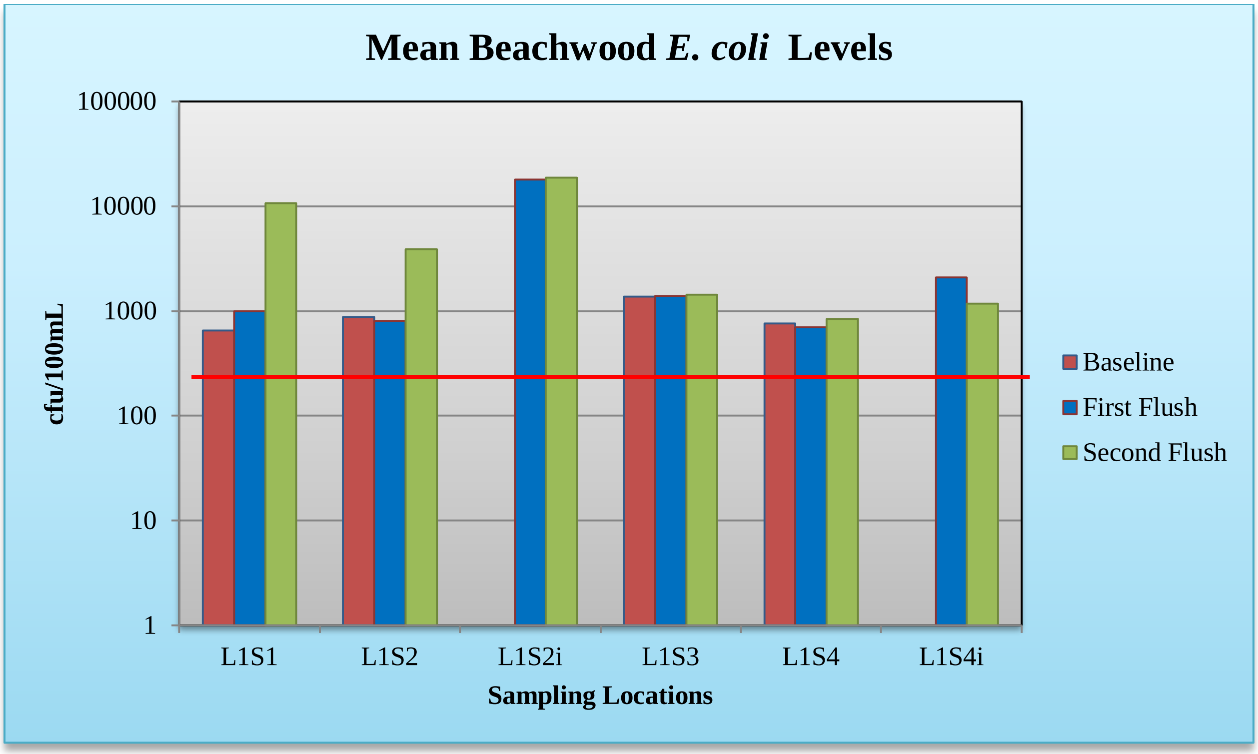

Figure 11: Visual display of mean *E. coli* levels at Beachwood Beach for baseline, first flush, and second flush time periods. The red bar illustrates the recommended safe swimming level for freshwater bathing beaches.

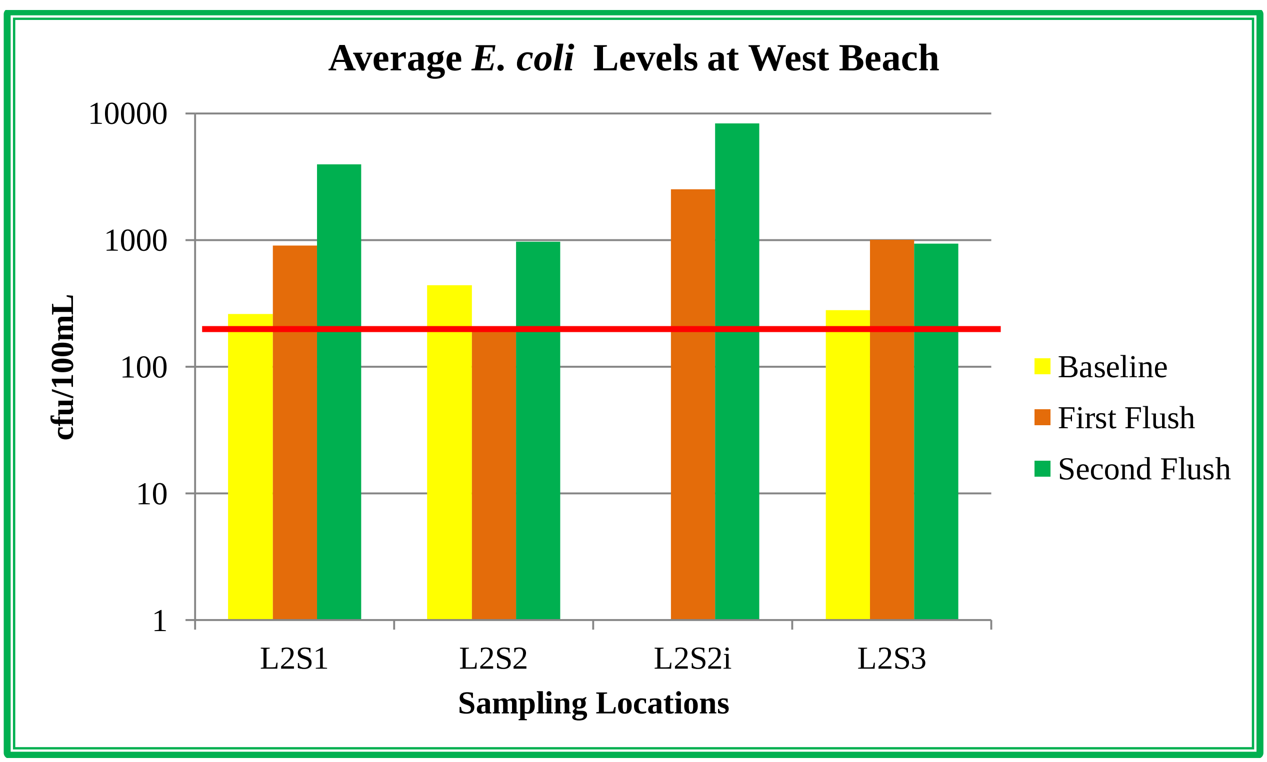

Figure 12: Average *E. coli* levels at West Beach for baseline, first flush, and second flush events. The red bar annotates the recommended freshwater safe swimming level of *E. coli*.

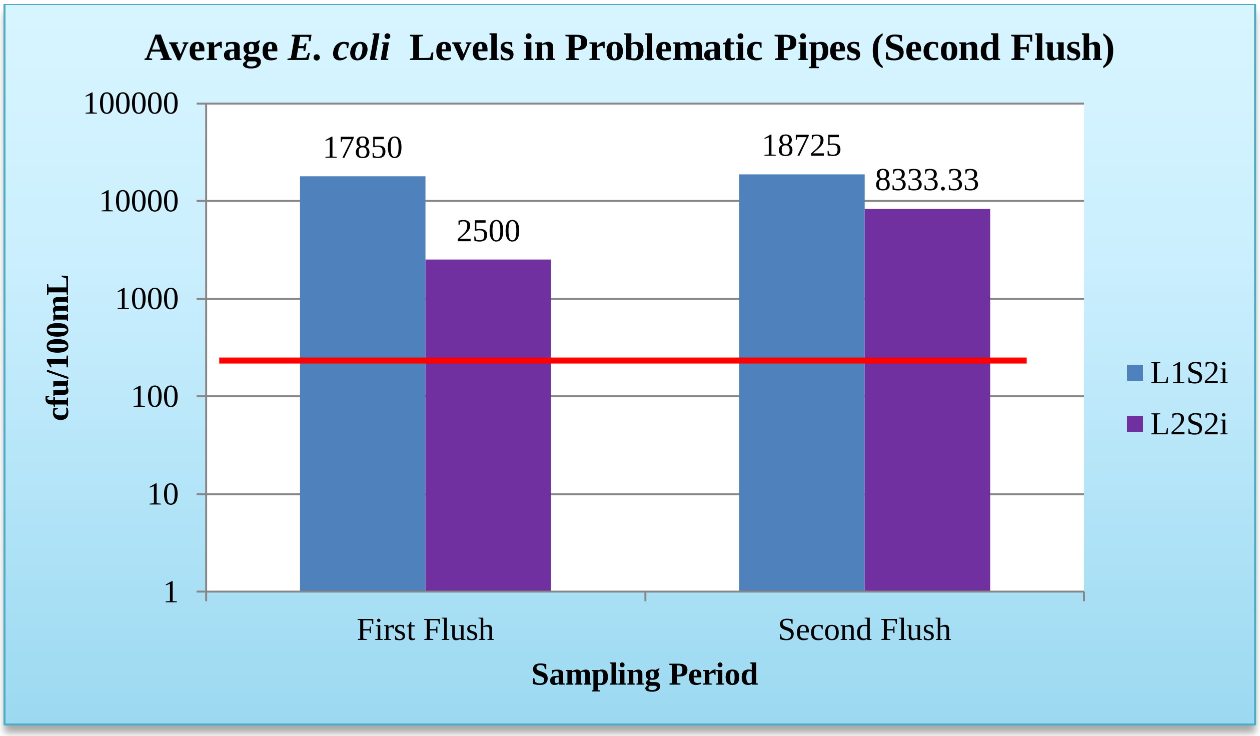

Figure 13: Average *E. coli* levels in suspected problematic pipes during the second flush of a storm. The red bar indicates the 200 CFU/100mL standard of *E. coli* for freshwater bathing beaches.

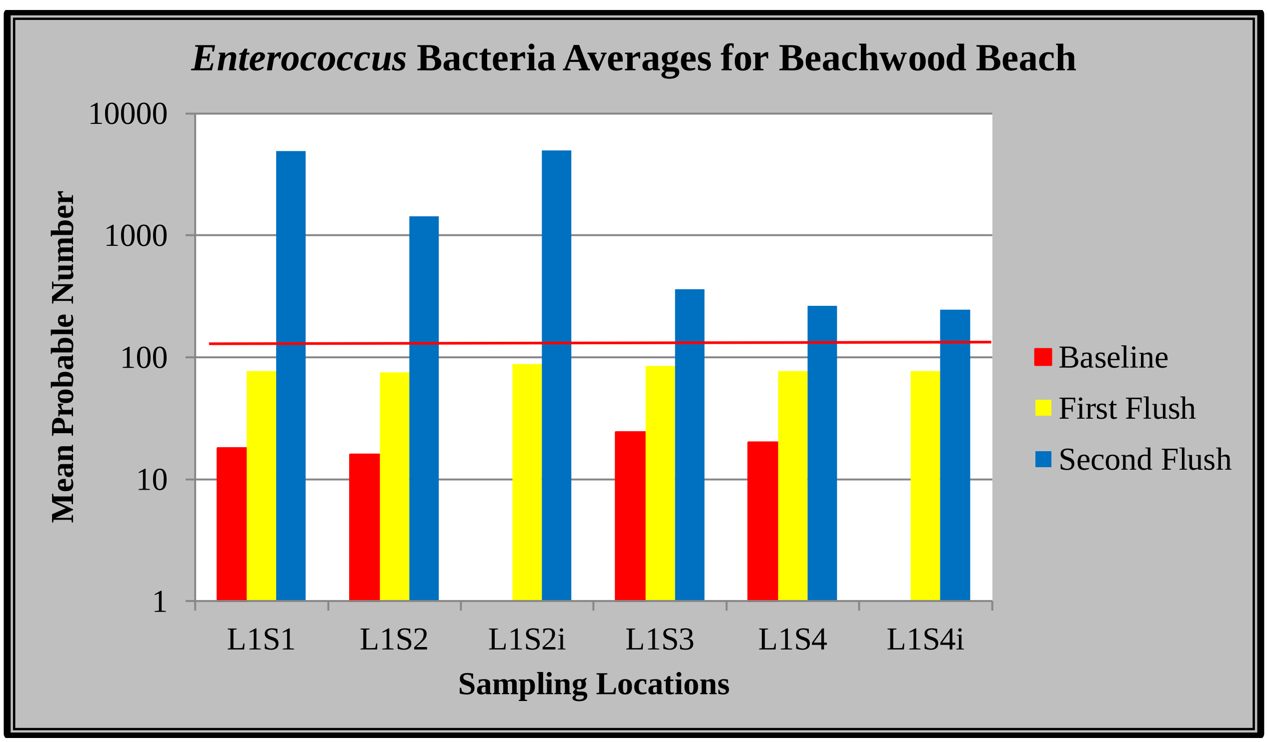

Figure 14: Average *Enterococcus* bacteria levels at Beachwood Beach during baseline, first flush, and second flush sampling. The red bar represents the recommended 104 CFU/100mL standard for marine bathing beaches.

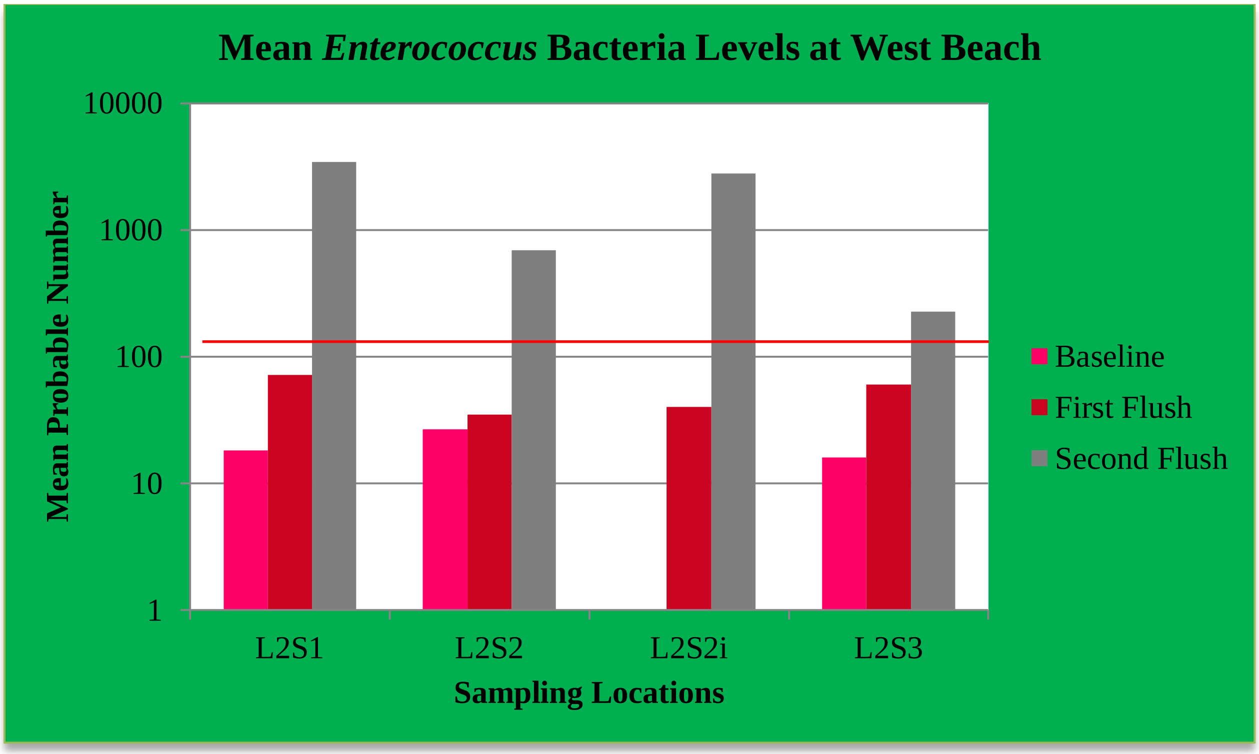

Figure 15: Mean *Enterococcus* bacteria levels at West Beach during baseline, first flush, and second flush sampling. The red bar indicates the NRDC standard for safe marine bathing beaches.

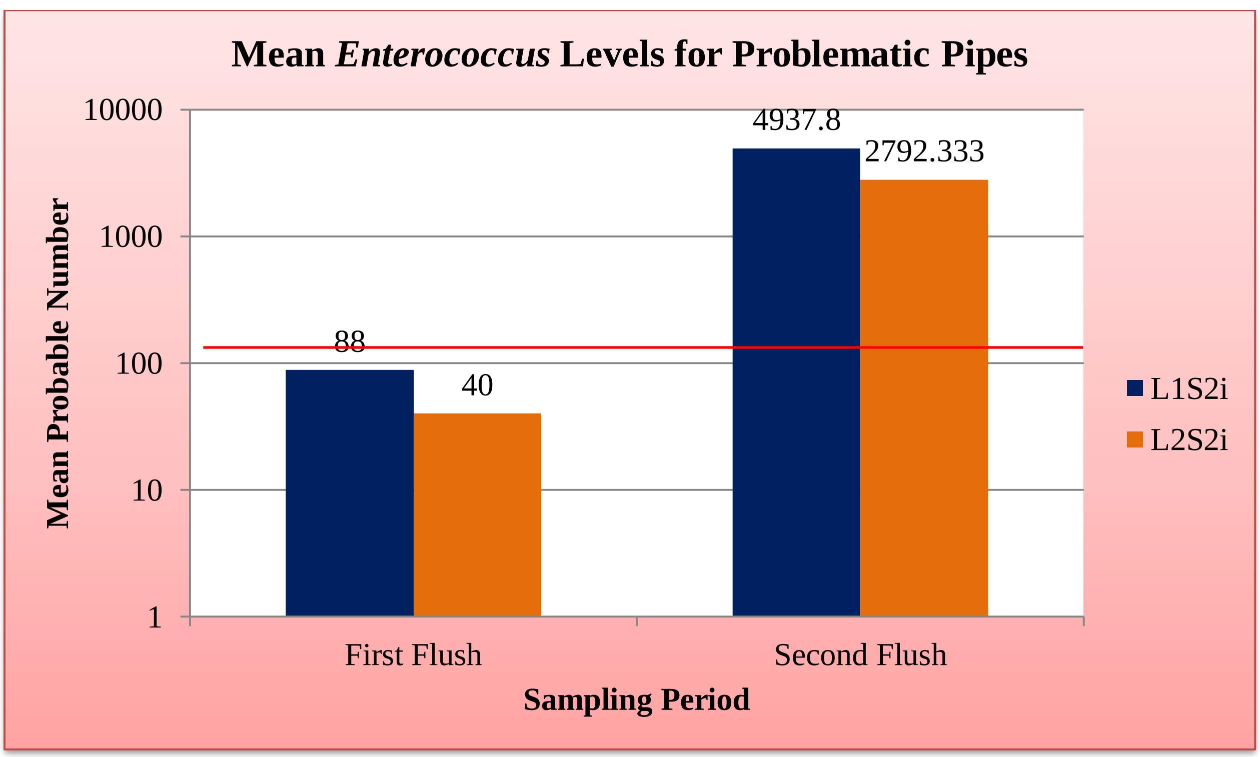

Figure 16: Mean *Enterococcus* levels for suspected problematic pipes at Beachwood Beach and West Beach. The red bar indicates the NRDC safe marine bathing beach standard.

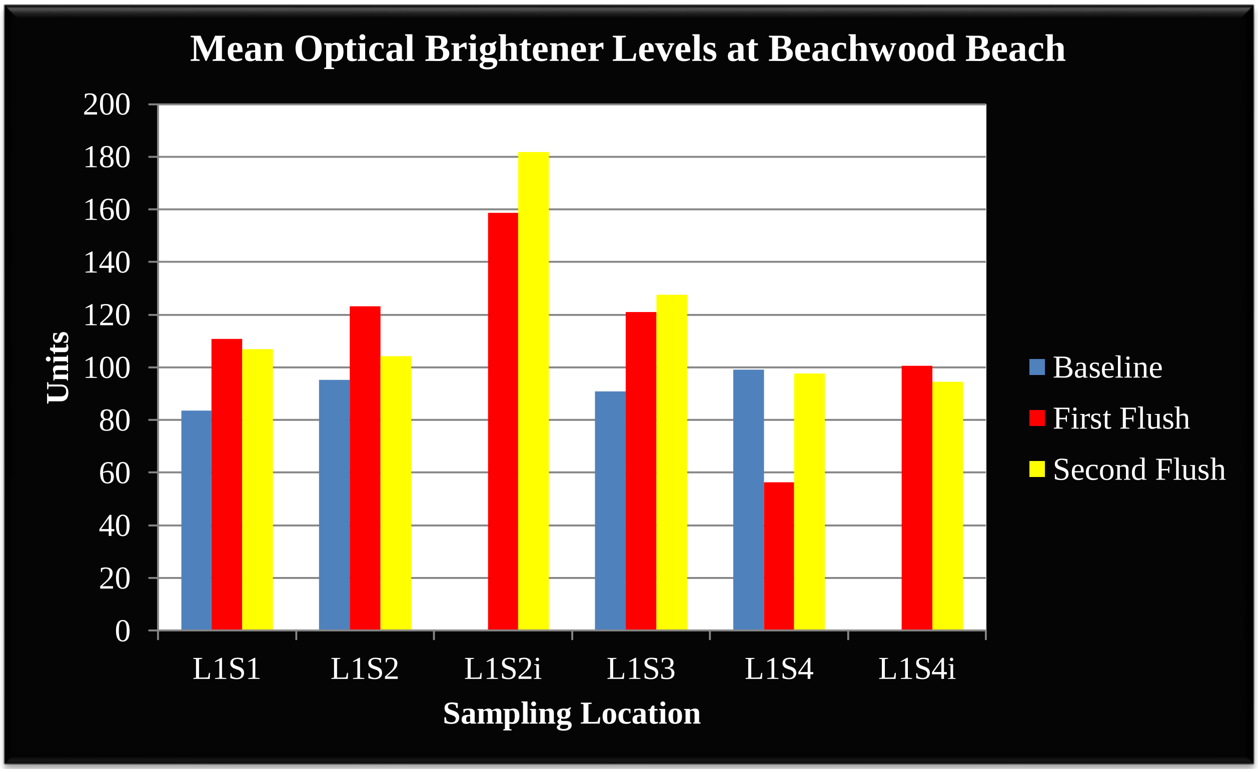

Figure 17: Mean optical brightener levels at Beachwood Beach during baseline, first flush, and second flush sampling events.

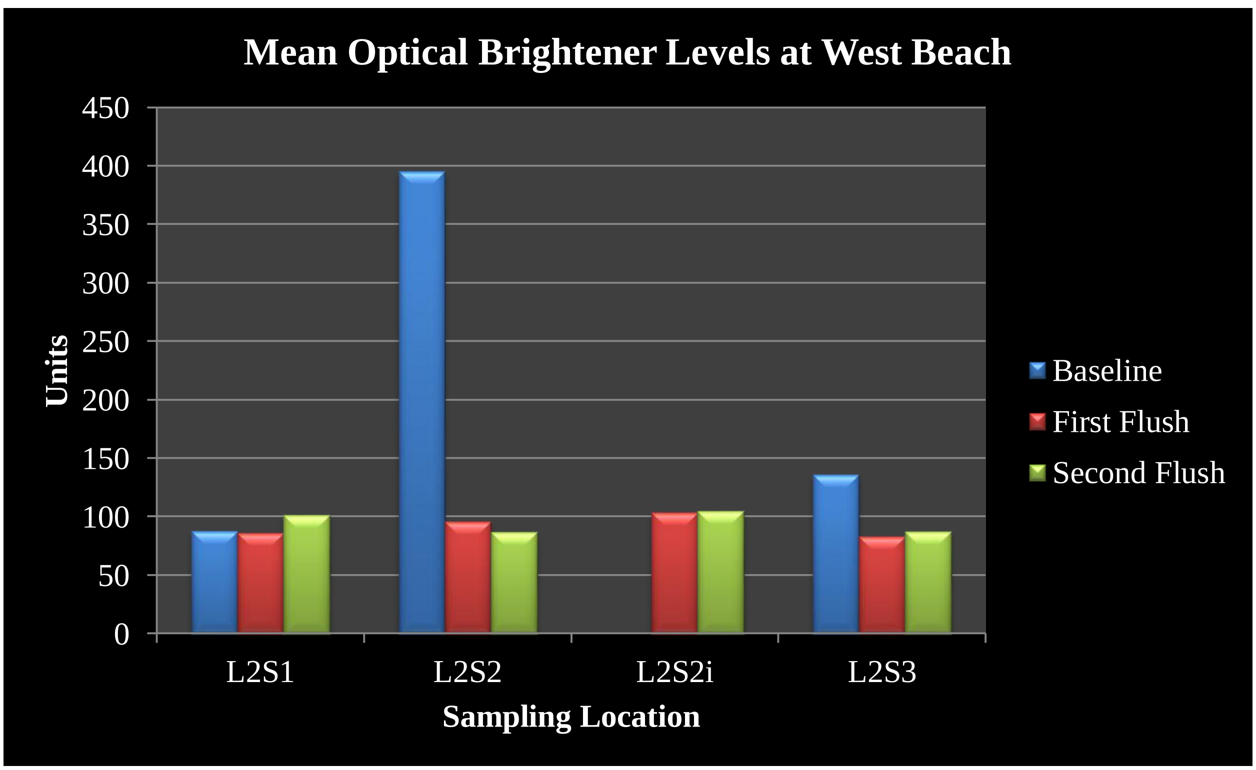

Figure 18: Mean optical brightener levels at West Beach during baseline, first flush, and second flush sampling events.

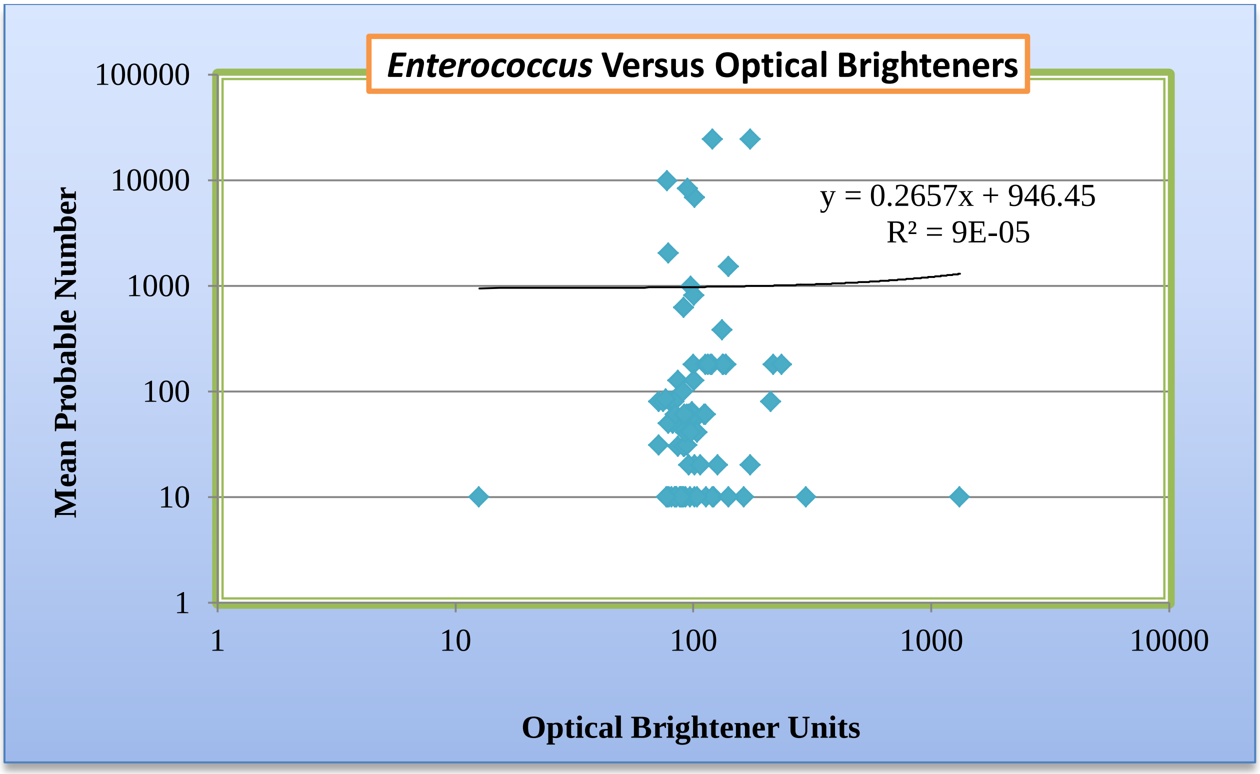

Figure 19: *Enterococcus* values plotted against optical brightener values. The r-squared value is 0.00009.

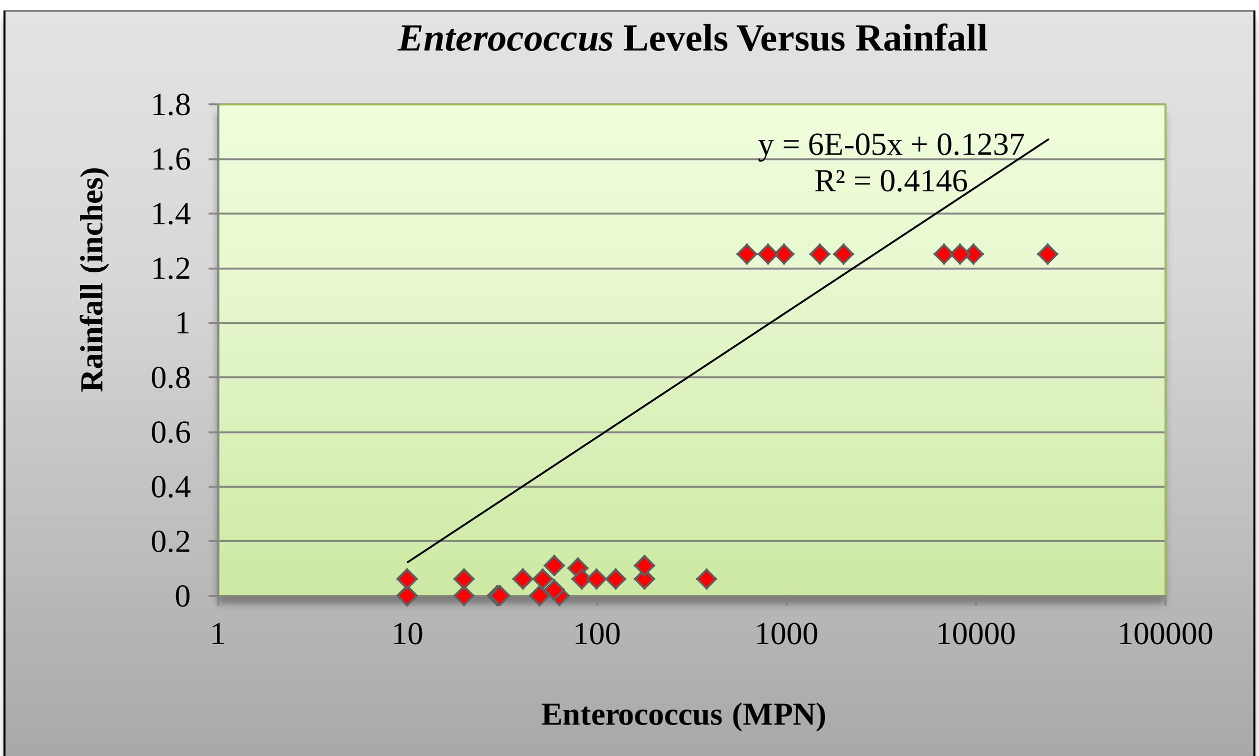

Figure 20: *Enterococcus* bacteria levels plotted against rainfall levels. The r-squared value is 0.4146.

Table 4: Comparison of values received during sampling to values received by the Ocean County Health Department.

Date	Beachwood (CFU/100 mL)		Avon (CFU/100 mL)	
	Health Dept.	Ours (Average)	Health Dept.	Ours (Average)
6/27/2011	10	11.892	34.64	18.371
7/18/2011	10	10	10	10
7/25/2011	40	13.269	10	14.581
8/1/2011	20	11.892	30	18.566

Table 5: Comparison of values received during sampling to values received by the Leed's Point Lab Staff.

Location	Leed's (CFU/ 100 mL)	Ours (CFU/100 mL)
L1S1	30	10
L1S2	20	10
L1S3	37	10
L1S4	3	20

water damage so there is a low number of accurate pH data representing the locations.

Table 1 displays the average of all quantified baseline parameters. No samples were taken inside the pipes during baseline sampling due to a lack of flow from the storm drains. Table 2 displays the averages of first flush data for all sampling locations. Table 3 displays the averages of second flush data for all sampling locations. General trends can be seen in Figures 11 and 12 which illustrate the elevated levels of *E. coli* throughout the first and second flush sampling periods. Figure 13 highlights some of the more dramatic increases in *E. coli* at L1S2i and L2S2i which are both storm drain locations at Beachwood Beach and West Beach respectively. Figures 14 and 15 highlight some of the increases in *Enterococcus* bacteria with the first and second flushes. Figure 16 portrays another dramatic increase in bacteria levels (*Enterococcus*) at the same storm drains that had high increases in *E. coli*. The mean optical brightener levels are portrayed in Figures 17 and 18; however, there appears to be no set pattern to the levels. Figure 19 displays *Enterococcus* bacteria levels plotted against optical brightener levels, and Figure 20 shows *Enterococcus* bacteria levels plotted against rainfall levels. Table 4 displays data received throughout the project as well as data received by the Ocean County Health Department. Table 5 displays data received throughout the project as well as data received by the Leed's Point Lab Staff.

Discussion

Throughout the project, several spikes in both *E. coli* and *Enterococcus* bacteria were seen throughout rainfall events. It can be seen in Figures 11 and 12 that the levels of *E. coli* in the water were abnormally high for baseline, first flush, and second flush sampling sessions. While *E. coli* may not be a great indicator for bacteriological activity in marine water, studying *Enterococcus* bacteria is an acceptable method for both freshwater and marine water (Dufour & Ballentine, 1986); therefore, the elevated levels of *E. coli* are supported by the elevated levels of *Enterococcus* bacteria (Figures 14 & 15). The higher levels of bacteria throughout first and second flush samples are indications that storm-water runoff is the main factor behind such dramatic increases in bacteria. To further this statement, ANOVA was run on baseline *E. coli* values and there was a significant difference between the baseline data and the second flush data ($\alpha = 0.05$, $p = 0.026$, $f = 5.304$, $df = 1$). In addition, an ANOVA test was also run on the *Enterococcus* values received during baseline sampling and second flush sampling. The results of this test showed that there was, yet again, a significant difference between the two sets of data ($\alpha = 0.05$, $p = 0.023$, $f = 5.130$, $df = 1$). Since there is such a significant difference between baseline data and second flush data, it is suggested that the discharge from storm-drains are affecting the bacteria levels on both Beachwood Beach and West Beach. Recorded observations support both the trends as well as the statistical indices. On storm sampling dates over 0.10 inches of rain, a leaf litter discharge was emitted from the storm drain closest to the Beachwood Beach bathing section (L1S2i). On July 8th, a gray discharge was being emitted from the L1S2i storm-drain and a strong odor of septic was found close to the drain as well (Figure 21). Leaf litter seemed to be scattered around the pipe on this date. On July 29th, there was a large amount of rainfall (approximately 1.25 inches of rain) before the second flush. By the time sampling occurred, leaf litter was spotted near L1S1 (due to tides in the Toms River) and near L1S2i (due to the storm-drain). These two locations had the highest bacteria readings of that sampling session.

Rainfall data plotted against *Enterococcus* bacteria data may be indicative of elevated bacteria levels due to

Figure 21: Gray cloud discharge coming from L1S2i on July 8th, 2011.

rainfall. As previously mentioned, there is a significant difference in baseline and second flush bacteria levels; therefore, it can be understood that there is some factor influencing such dramatic changes. When graphed against one another, it appears that there is a possible correlation between *Enterococcus* bacteria and rainfall data. It appears that, on a graph, the higher the amount of rainfall, the higher the amount of *Enterococcus* bacteria. Again, *Enterococci* levels are the best method of determining bacterial influence in systems that may have both marine and freshwater influences. When correlating *Enterococci* values with rainfall in inches, the R^2 value is approximately 0.4146 (Figure 20). This number indicates that there is a statistical correlation between the two factors. By using the previous data that average bacteria levels were highest near storm drains, it can be assumed that the storm drains are the cause of bacterial increases during rainfall since bacteria counts are high near storm drains and there is a correlation between rainfall and *Enterococci* values.

Figure 22: Sludge composition at the bottom of a Pine Beach storm drain.

By utilizing both *E. coli* and *Enterococcus* bacteria as an assessment of the water quality near West Beach and Beachwood Beach, assumptions can be made that the storm drains are either clogged with debris or have an infrastructure problem. By viewing Figure 22, one can see the sludge-like composition within a storm drain on the side of a road in Pine Beach. With unclean storm drains, all sludge, bacteria, and other waste products dumped down roadside or parking lot drains will be disposed of directly into the Toms River through outflow pipes placed at beaches such as Beachwood Beach and West Beach. In the storm drains, it is possible that a biofilm buildup could also be the cause of such high bacteria levels (Ferguson, 2006). A biofilm buildup occurs on just about any surface that has contact with water and can appear in several forms such as a film coating the object's surface, or even a sludgy material as shown in Figure 22 (Ferguson, 2006). Biofilms can house colonies of both *E. coli* and *Enterococcus* bacteria which could explain the dramatic increases in these organisms after a rainfall event (Ferguson, 2006). In order to clean the storm drains, they must be flushed out and the waste product must be contained through a vacuum. In order to remove biofilm, however, ultrasonic cleaning is required in order to separate the bacterial colonies from their adhering surface. Should an infrastructure problem be present, optical brighteners would usually indicate a problem should there not be interference. The other way to identify an infrastructure problem would be to use a camera to investigate the pipes and determine if there are any breaks or separations in the original structures. It is possible that by inspecting the pipes the problem can be identified and corrected. Should the storm drains be free of debris and have no infrastructure problems, theoretically, the bacteria counts from their discharge should be minimal.

The optical brightener averages throughout the study proved to be of little use for the overall assessment of the area. The average optical brightener levels for each sampling site can be viewed in Figures 17 and 18. On these figures, it can be seen that there is no strong trend or pattern in the optical brightener levels. This may be due to interference from salt water conditions or possibly due to tannins in the water which may also affect the optical brighteners. When viewing Figure 19, one can see *Enterococci* values plotted against optical brightener levels on the relative scale. The R^2 value for this comparison is 0.0009. This number represents very little, if any, correlation. As previously stated, optical brightener levels may be a great indicator of human influence in an area; however, with so many variable affecting the experiment, it cannot be definitively stated that they have a correlation with any of our pertinent data. This test may have significance in a freshwater system; however, in a marine water body the fluctuations are too great to truly quantify.

Throughout the project, quality assurance and data comparisons to outside sources seemed to verify the data collected. By running an ANOVA test on the Table 4, one can see that there is no statistical difference between the data collected in this experiment and the data collected by the Ocean County Health Department ($\alpha = 0.05$, $p = 0.151$, $f = 2.308$, $df = 1$). Furthermore, there was no significant difference (Table 5) between the *Enterococci* data collected and the *Enterococci* data evaluated at the Leed's Point Laboratory ($\alpha = 0.05$, $p = 0.247$, $f = 1.648$, $df = 1$). Since these outside sources are more credible than the water quality team, it is suggested that since there is no significant difference between their data and the data received in this experiment, that the data collected is accurate by comparison.

Throughout the project, bacterial increases were seen throughout different storms and different amounts of rainfall. One storm, a rainfall of 0.06 inches was received and was enough to cause a first and second flush in the storm drains. The data received for that storm was slightly higher than the recommended safe bathing level of bacteria. This means that small quantities of rain are enough to cause an increase in bacteria levels. Storms over 0.10 inches of rain seemed to, however, consistently cause hazardous bacteria levels. While storms over 0.10 inches of rain have caused the most consistent increases in bacteria, it should be advised that storms of lesser rainfall can potentially increase bacteria levels as well.

After assessing the storm drains at both Beachwood Beach and West Beach, it can be assumed that there is a potential for both debris and infrastructure problems with the L1S2i and L2S2i pipes. After viewing the drainage spots alongside roads and parking lots, there is a sludge material in the drains which would indicate a biofilm growth. In addition, there is an extreme lag time in flushing materials. On several occasions the team had to wait longer than 30 minutes for the appearance of the first flush. For example, on July 8th the team had to wait one full hour after the storms initialization before any discharge was emitted from the pipes. This lag time in the pipes could represent an infrastructure problem or a blockage in the pipes. Furthermore, the first flush of a storm drain should have the highest bacterial counts of all sampling periods; however, in this experiment, the highest bacterial counts occurred in the second flush. This could be indicative of an infrastructure problem or blockage that is reducing the flow in these storm pipes. This theory is backed by the crushed appearance of the L2S2i pipe, the gurgling noises in the L2S3 pipe, and the blockage of the L2S1 pipe. Due to the blockages of the L2S1 and L2S3 pipes, sampling within the pipes was not even possible. The same potential exists within the other more active storm drains.

One observed storm drain did not experience intense changes in bacterial levels. The storm drain located at L1S4i (Figure 23) appeared to have changes in bacterial levels during storms; however, the significance of the changes is not well understood. L1S4i seemed to have small

Figure 23: Location 1 Site 4 storm drain pictured with researchers Danielle Clancy and Kevin Dillon.

variations in bacteria levels which could mean one of two things. The pipe could either blocked and any flush resulting from the pipe was merely a result of its submersion; or, the pipe could be clean and have little or no infrastructure problems. Throughout the project it was difficult to determine the significance of this pipe's influence on bacteria levels because it was constantly in a state of partial submersion. This leads to the questioning of true flushing or tidal influence from the Toms River. To determine the true influence of this pipe, further inspection would be required.

Conclusions/Recommendations

With the data received, it is suggested that the pipe closest to the Beachwood Beach bathing area (Figure 24) and the submerged pipe at West Beach pose health hazards to bathers. During rainfall events over 0.10 inches, these storm drains will emit a discharge that contains high levels of bacteria that will exceed the Health Department's recommended safe swimming limit for *Enterococci* of 104 CFUs/100 mL. It has also been concluded that there should be an inspection of the pipe located to the east of Beachwood Beach since its significance in this experiment is undetermined. The optical brightener levels received, while a useful tool in other experiments, were too variable to conclude with any significance in this study. Recommendations for the hazardous storm drains include monthly inspections and cleanings of the storm drains. Storm drains can be cleaned by flushing out debris and using a wet-vacuum truck to contain the waste. Ultrasonic cleaning is also recommended for the storm drains to eliminate biofilm residue and completely remove bacteria colonies from the storm drain. Possible ultraviolet treatments could be used inside the storm drains as well in order to sterilize the drains to prevent bacteriological growth and the spread of other diseases including salmonella and MRSA. In order to inspect the storm drains, cameras can be utilized by permission of the Ocean County Health Department to inspect the infrastructure of a storm drain. Should there be a cross connection between storm drains and other networks, the problem can be identified and corrected after a thorough inspection. Township municipalities should also have a diagram of the storm drain networks to get an idea of what the system should look like as opposed to what it may or may not look like in its present state. Until the problem is corrected, a recommended waiting period of 72 hours before bathing in Beachwood Beach and West Beach should be enforced before resuming recreational swimming or beach bathing. This period should allow the bacteria to completely flush out and let the beach return to its prior state. Furthermore, the regulation mandating that a beach should close only after a test and retest of bacteria should be used as a guideline rather than a standard. In the best interest of public health, safety closings should be conducted as a precautionary method whenever rainfall over 0.10 inches is suspected. Several other townships abide by a pre-cautionary closing method (National Resources, 2011) and this could help decrease public exposure to potentially high bacteria levels.

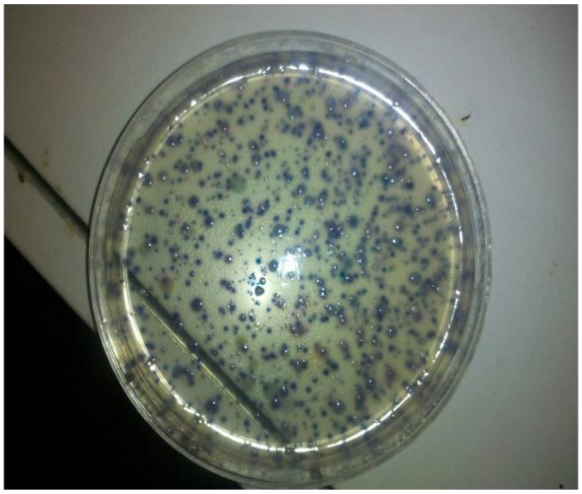

Figure 24: Coliscan petri dish after culturing. The plate represents 41,900 CFUs/100mL from L1S2i.

The potential for error in this study was high due to the unpredictable nature of the weather. By utilizing quality assurance guidelines, the error was reduced; however, there are still potential forms of error in any study. Error could have been possible in the incubation process of the bacteria. Error could have been made when handling samples or storing them for cooling. Error could have been made in the measurements of the fluids and while conducting bacteriological tests. Error could have been made in labeling samples or data as to confuse readings. The human potential for error is limitless; however, by following the proposed methodology, the error potential was decreased.

Recommendations for future studies include studying several locations as to optimize data. A larger team could possibly lead to the utilization of more data; however, it also requires more equipment. Future students should be completely dedicated to the project because it is a huge undertaking and the methodology must be followed in order to receive optimal results. By working well as a team, the project can be much easier and if everyone does their part the experiment becomes that much easier. The biggest recommendation is to continue with quality assurance and *Enterococci* studies. By utilizing quality assurance, the data can be recognized instead of ignored. In addition, by studying *Enterococci*, one can determine bacteria levels in the water without regard to salinity which is the major complication with *E. coli* sampling. By organizing a stringent methodology in advance, creating an efficient system of data collection, and developing an effective way to organize and record data, the project won't be nearly as hard as it would without such organization and planning.

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