Beach Closings Management Actions Project Assessments

Final Report

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Contributing Authors:

Sandra McLellan, Ph.D. (Principal Investigator)

Deborah Dila (Co-Principal Investigator)

Emily Koster (Investigator)

School of Freshwater Sciences, University of Wisconsin-Milwaukee

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EXECUTIVE SUMMARY

Beach closings and recreational restrictions due to high bacterial levels and sewer overflows is a beneficial use impairment (BUI) for Milwaukee's urban beaches (Figure 1). Located in the Milwaukee Estuary Area of Concern (AOC), four public beaches are frequently closed because of high *Escherichia coli (E. coli)* levels in swimming areas. From 2015-2019, AOC beaches were open without advisories 92% (Bradford Beach); 85% (Bay View Beach); 61% (McKinley Beach); and 37% (South Shore Beach) of the swimming season.

To address the concern more accurately for pathogen contamination and facilitate lifting the impairment at the AOC beaches, the Wisconsin DNR (WDNR) developed a revised 2020 target for the Beach Closings (Recreational Restrictions) BUI for the Milwaukee Estuary AOC (WDNR, 2020). Currently two beaches (Bradford and Bayview) meet the EPA's 2012 recreational water quality criteria over a 3-year period for the geomean and the statistical threshold values (STV) considering all values in the season. Thus, best management practices (BMP) and beach management actions are necessary to improve water quality and meet the 2020 BUI removal criteria at all AOC beaches.

To lift the impairment at the beaches, each public swimming beach within the AOC must meet one of the requirements below:

- Be open for at least 90% of the swimming season (between Memorial Day and Labor Day) averaged over a previous 5-year period based on Wisconsin Coastal Beach monitoring protocols for *E. coli* with BMPs in place.

OR

- Public swimming beaches within the AOC are meeting EPA's 2012 recreational water quality criteria over a 3-year period.

Alternatives to the above conditions can be used when sources of bacterial contamination to the beaches are known and controlled through BMPs. These alternatives can be found in the 'Beach Closings' section of the [2020 Removal Target Updates for the Milwaukee AOC].

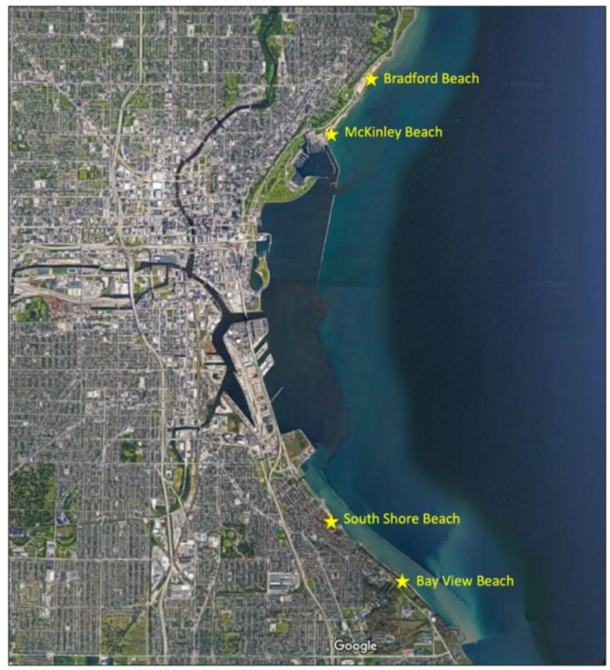

Figure 1. Public swimming beaches in the Milwaukee Estuary Area of Concern (Bradford, McKinley, South Shore, and Bay View).

The McLellan lab at the University of Wisconsin-Milwaukee has been studying the causes of beach closures at these AOC beaches since 2000. In addition, these beaches were included in a large effort to perform sanitary surveys for Milwaukee County beaches between 2010-2012 (Kinzelman et al., 2013). Regional and local sources are both responsible for fecal contamination at the beaches. Gull habitat, stormwater outfalls, *E. coli* reservoirs in sand, extreme weather, and nearshore hydrological conditions have different impacts on the fecal pollution found at Milwaukee's beaches. While each beach has been studied for many years, not all pollution dynamics of individual beaches has been characterized. For **Beach Closings Management Actions Project Assessments,** the lab analyzed new and archived water samples, sand samples, conducted bacterial-pollution flow modeling analysis, and used Milwaukee Health Department beach monitoring records to generate site-specific information about each of Milwaukee's AOC beaches. This information was used in collaboration with WDNR to develop a recommended list of BMPs and management actions for the Beach Closings (Recreational Restrictions) BUI for the AOC (Section 5). Additionally, in collaboration with the City of Milwaukee Health Department and South Milwaukee Health Department, refined beach advisory decision criteria was prepared (Section 6).

Key findings from the analyses:

1. When *E. coli* count are high in swim water, gulls are the primary source of *E. coli* contamination at all of Milwaukee's AOC beaches. In both wet and dry weather conditions the gull genetic marker is present in the highest percentage of samples and at the highest concentration for all beaches. Other genetic markers tested were human and dog.

2. Local outfalls, on or near beaches, are intermittent sources of *E. coli* and sewage contamination during rain events. This occurs when sewage from leaking sanitary sewer infrastructure infiltrate stormwater pipes. All of the accessible (i.e., not submerged) outfalls did not appear to have dry weather flow and thus they would not be an issue on ordinary swimming days. On rain days, the sporadic contamination should not be a primary management concern as it happens when the beaches are closed, however, there should be ongoing investigations by the respective municipalities to track and repair leaking infrastructure. Additionally, many of the outfalls are surrounded by rain gardens that reduce stormwater flow across the beach. Submerged outfalls need further investigation.

3. Regional sources of pollution reach the beaches following large rain events. The impact depends on the pollutant load from urban and agricultural runoff to the Milwaukee River and on the nearshore hydrodynamic conditions. Modeling showed that large rain events with and without CSOs can impact beaches with sewage contamination, which was supported by evidence of human fecal markers during the same time frame. When river discharge is high, ruminant marker is occasionally present at AOC beaches.

4. The proposed South Shore Beach swim area is preferable to the current swim area. The proposed area has significantly lower *E. coli* concentrations in both lowflow and rain conditions. The geomean *E. coli* levels in the proposed swim area are below 126 CFU/100 ml during low flow and rain conditions, whereas the geomean in the existing swim area exceeds this water quality benchmark under both conditions. Both swim areas exceed water quality standards during CSO conditions. Distance from an adjacent marina and a large parking lot, combined with greater water circulation, make the proposed site a better swim area because of the higher water quality.

5. The *E. coli* 235 CFU/100 mL Beach Action Value (BAV) used to evaluate recreational advisories could be increased to 500 CFU/100 mL without increasing the likelihood of human health risk for the AOC beaches that are dominated by gull fecal pollution sources (Bradford, McKinley). Bayview Beach is also impacted by gull fecal pollution but has potential human sources from two outfalls that are under current investigation. Further, there is low but persistent detection of human bacterial markers at South Shore beach that is under current investigation, and the probable source of these markers needs to be considered when applying an increased BAV value to evaluate recreational advisories.

Overall, our findings show that the AOC beaches have problems that are solvable. Days with advisory *E. coli* levels can be reduced by BMPs that deter gulls and geese from gathering at swim areas. Previous remediation efforts at Bradford Beach have made a statistically significant difference in the water quality, which shows that using a combination of BMPs and management actions can move a beach from 'impaired' to 'Blue Wave' status. Moving the swim area at South Shore Beach from the current site to the proposed site will reduce the number of advisory days at a beach the National Resources Defense Council named one of the top 10 offenders in the nation for "persistent contamination problems". A validated hydrodynamic model shows rains of 1-2" do not deliver higher-risk regional pollution to the beaches – only low-risk local runoff (gulls and other wildlife) impacts the beach areas in lighter rain, so the number of preemptory closed days can be reduced. Utilizing an *E. coli* BAV of 500 CFU/100 mL instead of 235 CFU/100 mL does not increase the chances that swimmers will come into contact with high-risk pollution. Using this increased BAV as a metric when assessing the Beach Closings (Recreational Restrictions) target will increase the number of days that the AOC beaches are ranked as open during the swim season. These findings will improve the chances of reaching the revised 2020 targets for lifting the BUI in a timely manner.

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ABBREVIATIONS

AOC	Area Of Concern
BacR	Ruminant *Bacteroides* marker
BAV	Beach Action Value
BB	Bradford Beach
BMP	Best Management Practices
BUI	Beneficial Use Impairment
BV	Bay View Beach
CFU	Colony Forming Unit
CN	Copy Number
CSO	Combined Sewer Overflows
DogBact	Dog *Bacteroides* marker
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
GPS	Global Positioning System
Gull-2	*Catellicoccus marimammalium* marker
HB/HF183	Human *Bacteroides* marker
ISCO	Teledyne automated ISCO sampler
Lachno3	Human *Lachnospiraceae* 3 marker
MCK	McKinley Beach
MPN	Most Probable Number
NOAA	National Oceanic and Atmospheric Administration
QPCR	Quantitative Polymerase Chain Reaction
SS_Curr	Current South Shore Beach
SS_Prop	Proposed South Shore Beach
SSO	Sanitary Sewer Overflows
STV	Statistical Threshold Value
WDNR	Wisconsin Department of Natural Resources

1.0 INTRODUCTION

Background and Approach

One of the eleven beneficial use impairments (BUIs) in the Milwaukee Estuary AOC is the Beach Closings (Recreational Restrictions) BUI. This BUI is listed due to high bacterial concentrations and sewer overflows in the AOC, which cause beach closings and health risks to recreators. Four public swimming beaches within the AOC fall under this BUI: Bradford Beach, Bay View Beach, McKinley Beach, and South Shore Beach. The McLellan lab at the University of Wisconsin-Milwaukee (UWM) has been studying the sources of beach closures at these AOC beaches since 2000 (McLellan and Salmore, 2003; McLellan et al., 2007; Sauer et al., 2011; Newton et al., 2013; Cloutier and McLellan, 2017). Gull habitat, stormwater outfalls, *Escherichia coli* (*E. coli*) reservoirs in sand, and nearshore hydrological conditions have different impacts on the fecal pollution found at Milwaukee's AOC beaches. While each beach has been studied for many years, not all of the pollution dynamics of individual beaches have been characterized. Discerning the sources and beach features that impact nearshore bacterial concentrations is necessary to remove the BUI and lead to the eventual delisting of the Milwaukee Estuary AOC.

Data was evaluated from new and archived water samples, sand samples, outfall samples, bacterial pollution flow modeling, and the Milwaukee Health Department beach monitoring program to generate site-specific information about each of Milwaukee's AOC beaches (sample summary Table 12, Appendix A). Beach samples with high *E. coli* counts were analyzed to determine the distribution of human, gull, and dog, bacterial genetic markers – thus, identifying sources of *E. coli* at the beaches during different weather conditions. At beaches where stormwater outfalls are present, the outfalls were investigated as sources of sewage contamination. Beach samples were analyzed for ruminant marker when Milwaukee River discharge was high and/or ruminant marker was detected in the river. Sand was evaluated as a source of *E. coli* at Bradford Beach and McKinley Beach. Hydrodynamic modeling was used to evaluate regional sources of contamination at Milwaukee beaches. The effectiveness of remediation efforts at Bradford Beach and South Shore Beach was analyzed. This broad assessment of the beaches was used to inform suggestions for 1) recommending management actions, 2) refining the current Beach Action Value (BAV) of 235 CFU/100 mL used in assessing BUI removal targets and 3) refining the decision process used by the Milwaukee Health Department for beach advisories and closures under rainfall conditions.

The samples and data used in these analyses, 2004 through 2020, included years with low and high Lake Michigan water levels (NOAA Great Lakes water level observations, 2021). We would not expect the shift in sand/water interface, due to changes in annual lake level, to have a large effect on *E. coli* concentrations in nearshore water or sand reservoirs of *E. coli*. Issues that could influence *E. coli* concentration due to changes in lake level, such as consistently higher/lower sand moisture or lake distance from a source of runoff, were not evaluated for this project.

Results Summary

Source specific markers showed, overwhelmingly, that gulls were a major source of pollution and the cause of elevated *E. coli* at all beaches in rain and lowflow weather conditions. However, there are also underlying concerns, with potentially higher human health risk, present at each beach. Regional sources impact beaches in the AOC when riverine input carries contaminated stormwater from upstream sewage overflows. Local sources of contaminated stormwater delivered by beach outfalls can also impact specific beaches. Table 1 summarizes the major impairment issues at each AOC beach.

Table 1. Contributing beach features and evidence of fecal pollution sources at AOC beaches in Milwaukee, WI.

Summary Table of AOC Beach Issues

	Gull Marker	Human Marker	Outfalls	Water Circulation	*CSOs*
Bradford Beach	X		X		X
McKinley Beach	X		X	X	X
South Shore-current	X	X		X	X
South Shore-proposed	X	X			X
Bay View Beach	X	X	X		X

(details in section 2.0 Beach Summaries)

2.0 BEACH SUMMARIES

Bradford Beach

Figure 2. Bradford Beach replicate sampling sites. (Google Earth, 2019)

Study Area

Bradford Beach (Figure 2) is currently the most popular swim beach in Milwaukee, Wisconsin. In prior years the beach was classified as an impaired water body until several steps were taken to reduce *E. coli* contamination in the swimming area. The combination of creating rain garden basins at seven beach outfalls, gull abatement with patrol dogs, beach grooming, and regular *Cladophora* removal helped reduce *E. coli* concentrations in nearshore water and resulted in the beach being awarded a Blue Wave certification in 2009. Bradford Beach continues to be an excellent swimming beach with only four days exceeding the advisory limit of ≥ 235 MPN/100 mL over the last three years (2018 through 2020).

Archived and new samples were collected in knee-deep water from three sampling site. GPS coordinates from south to north are listed in Table 2. When Milwaukee Health Department data was used for analysis, data reflects one sampling site which is collected knee-deep near the center of the beach.

Table 2. GPS coordinates of Bradford Beach sampling site.

Site	North	West
BB_1	43° 3'35.40"	87°52'27.96"
BB_2	43° 3'43.56"	87°52'19.92"
BB_3	43° 3'49.60"	87°52'13.75"

Results and Discussion

<u>*Fecal pollution sources when E. coli exceeds standards (does not include CSO or blending events)*</u> – The highest recreational health risk in beach water is associated with high concentrations of human-associated fecal indicator markers because they are proxies for sewage contamination which may contain human viral and bacterial pathogens. To evaluate the human health risk when *E. coli* counts are above the recreational warning limit of 235 CFU/100 mL in beach water samples, the samples were tested for host-associated fecal indicator markers, including human (HF183 and Lachno3), gull (Gull-2), and dog (DogBact) marker. Samples are only considered positive for human contamination if **both** human markers are present in the sample. Gull- and dog-associated fecal markers are less likely to be associated with any human pathogens and, therefore, are less of a risk to swimmers (Soller et al., 2010; Soller et al., 2014; Brown et al., 2017).

The Gull-2 marker was the most frequent and most abundant host-specific genetic marker found in samples collected in lowflow (55%; 5 of 9) and rain (60%; 9 of 15) conditions (Figure 3). Human markers were found occasionally at low concentrations near the limit of quantitation (113 or 225/100 mL depending on sample volume filtered). In lowflow conditions, none of the samples were categorized as human contaminated (positive for both HF183 and Lachno3 markers). In rain conditions, one of the samples was positive for both markers and was therefore categorized as human contaminated. DogBact marker was only found in rain samples (27%; 4 of 15) at Bradford Beach. Dogs are not allowed on Bradford Beach but storm runoff may wash dog feces from walkways to the beach.

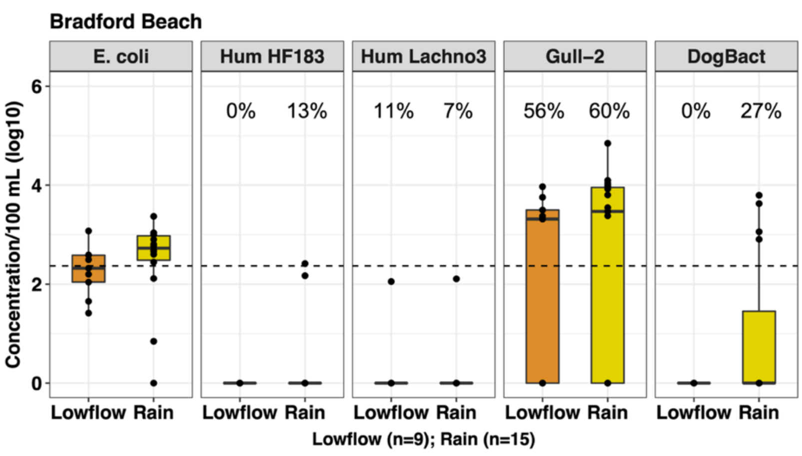

Figure 3. Boxplots of log10 concentrations of E. coli (CFU/100 mL) and host-associated fecal indicators (CN/100 mL) in samples when E. coli is above the advisory limit. Dashed line is 235 (advisory limit) and is also near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) for fecal indicator markers. The percentage of samples positive for each marker is shown.

<u>*Local dynamics of gull marker contamination*</u> – From 2012-2020 Bradford Beach water was tested in a variety of weather conditions for Gull-2 marker. We utilized this dataset to determine if there were specific conditions that produced high levels of gull marker in beach water. For this analysis, all samples were used, regardless of *E. coli* levels since the analysis was intended to understand distribution of gull waste. Of the 31 days tested for Gull-2, 19 days were positive (61%). Analysis of meteorological and lake conditions showed very weak correlations between Gull-2 marker concentration and conditions at Bradford Beach. Spearman rank correlations (rho) were determined for Gull-2 marker concentrations and amount of precipitation (rho = 0.26), wind direction (rho = 0.33), wind speed (rho = -0.15), wave period (rho = -0.30), wave height (rho = -0.23), and wave direction (rho = 0.11). In a multiple linear regression analysis, variables were not significant ($p = 0.0899$, adjusted R squared = 0.066). These results suggest that Gull-2 marker is a dominating factor at Bradford Beach regardless of local weather and wave conditions.

<u>*Ruminant marker (samples include CSO and blending events)*</u> – Human pathogens can be associated with cattle waste (Soller et al., 2010) and approximately 79% of the Milwaukee River watershed is rural land use in the upstream region. Bradford Beach water was tested for ruminant-associated fecal indicator marker (BacR) in

samples (n=25) taken while the Milwaukee River discharge was elevated and/or dates following high concentrations of BacR measured at the Milwaukee River sampling site. While these conditions only encompass a small portion of the beach season, the purpose of the analysis was to determine if there was evidence that agricultural runoff could reach the AOC beaches. Overall, 6 of 25 (24%) of samples tested were positive for BacR marker under this "worst case scenario" and all levels were low and near the limit of detection. The six positive samples were from two dates both of which were during high Milwaukee River discharge. One date was in April with no rainfall 48 hours before collection, but at that time of year snowmelt causes high river discharge and would likely carry cattle feces from northern rural river reaches. The other date with positive BacR samples was during a heavy rain period with CSOs. After heavy rains that extend to rural areas north of Milwaukee, a conservative monitoring approach could monitor for BacR at all AOC beaches. Regional pollution does bring cattle waste down the Milwaukee River and the river plume impacts the beaches in certain weather conditions (McLellan et al., 2020). However, heavy rain conditions are often associated with CSOs or trigger a pre-emptive water quality advisory based on rainfall amounts, and thus the beaches are already closed, so further action may not be necessary.

Outfalls – Sewage pollution at Bradford Beach can result from sewage leaking into local stormwater outfalls (Sauer et al., 2011; Sercu et al., 2011). There are seven stormwater outfall pipes that terminate at rain garden basins on the west side of the swimming beach and five outfalls that terminate near Lake Michigan's edge on the north end of the beach (not a swimming area). There are also four outfalls across a major roadway that feed stormwater to several beach outfalls. It is difficult to sample all outfalls as they flow only during heavy rain, when the rain stops they quickly stop flowing, and some outfalls are hard to safely access during heavy rain. During 2020 rain events (no CSOs included) 12 outfalls could be sampled (Table 3). Of the 12 sampled outfalls, five were positive for human marker. None of the outfalls had flow during dry weather. (See outfall maps and assay values in Appendix A.) The outfalls north of the swimming area should continue to be investigated for human sources of fecal pollution given their close proximity to the beach.

Table 3. Outfalls sampled during 2020.

Outfall	# Samples	# Positive Human	% Positive
BB OUT3	2	1	50
BB OUT4	1	0	0
BB OUT5	2	0	0
BB OUT6	1	0	0
BB OUT8	3	1	33
BB OUT9	3	0	0
BB OUT11	3	2	67
BB OUT12	1	0	0
BB RAVINE N	5	4	80
BB RAVINE S	4	1	25
SOCCER OUT	3	0	0
LOCUST OUT	4	0	0

Beach Remediation – Before 2008, Bradford Beach was categorized as an impaired water body due to an excess of advisory/closure days during the swim season. After 2008, outfall rain garden basins and other remediation efforts were in use at the beach to reduced *E. coli* counts in swimming water and increase the number of open swim days. To evaluate the effectiveness of remediation, pre- and post-remediation *E. coli* monitoring results (n=892) from Milwaukee Health Department records were used to compare *E. coli* levels before and after remediation (Figure 4). Since the amount and number of days with rainfall can greatly influence the overall evaluation of *E. coli* levels, we compared months with high rainfall averages (HI; ranging from 3.2" – 10.9") and months with low rainfall averages (LO; ranging from 0.6" – 2.9") separately. We found that during the recreational season, post-remediation samples had significantly lower mean *E. coli* concentrations in both high average rain months and low average rain months (June HI ($p < 0.001$); June LO ($p < 0.001$); July HI ($p < 0.001$); July LO ($p < 0.001$); August HI ($p < 0.001$); August LO ($p < 0.001$)). Thus, the remediation actions taken at Bradford Beach were effective at reducing *E. coli* concentrations in swim water. See the remediation fact sheet in Appendix C for more information.

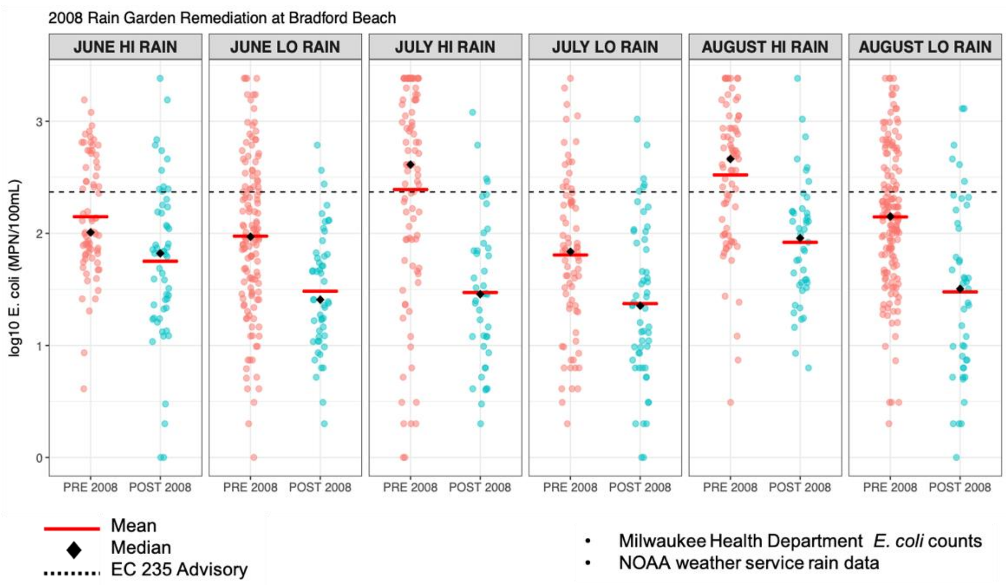

Figure 4. Log10 E. coli concentrations pre- and post-remediation. Months are separated into higher average rain and lower average rain categories. Pre-remediation samples (n=600) were selected from years 2003-2007. Post-remediation samples (n=292) were selected from years 2010-2020.

<u>*Sand reservoir for E. coli*</u> – On two days in August 2020, paired sand and water samples were collected to test sand as an *E. coli* reservoir. For both sample-types *E. coli* was measured using microbial plate counts and qPCR. Culture methods, which are more sensitive than qPCR showed low concentrations of *E. coli* in both sand and water. Overall, cultured *E. coli* was present in low concentration in 100% of sand (n=6) and 100% of water (n=6) samples. Using qPCR *E. coli* was not detected in sand or water because levels were likely below the limit of quantification of 450 CN/100 ml water and 4500 CN/g of sand, which includes both viable and non-viable but intact cells. Gull-2 was detected in 17% of sand samples and 33% of water samples. Although Gull-2 was not detected frequently, the marker concentration was high when it was detected and therefore the computed means are high (Figure 5). In these limited samples, culturable *E. coli* was consistently present. Previous work at Bradford Beach with a larger number of samples has shown levels approximately an order of magnitude higher in sand (Cloutier et al., 2017), and the consistent detection of *E. coli* suggests sand continues to serve as a reservoir for *E. coli*, however, that reservoir may only influence water quality during times when cells have accumulated. Prior work has demonstrated that the Gull-2 marker is more abundant in gull waste than *E. coli* but decays much more quickly. Therefore, these low levels of *E. coli* may be indicative of residual gull contamination (Cloutier et al., 2017). The Gull-2 marker and *E. coli* did not show a relationship to each other in sand or water, likely because of the mix of recent and past gull fecal contamination. Grain size of sand may also influence *E. coli* survival by provided high surface area or retaining moisture in fine grain size. In contrast, large grain sized particles may allow pore water to be more effectively delivered to the surface water but are less likely to erode in wave action (Vogel et al., 2016) An assessment of Braford Beach sand showed 38% of the sand fell into a 'fine' to 'very fine' (250 um – 106 um) particle size. Most of the remaining particles were well distributed among larger sizes up to 'fine gravel'. These data will be useful when considering grain size for future management approaches.

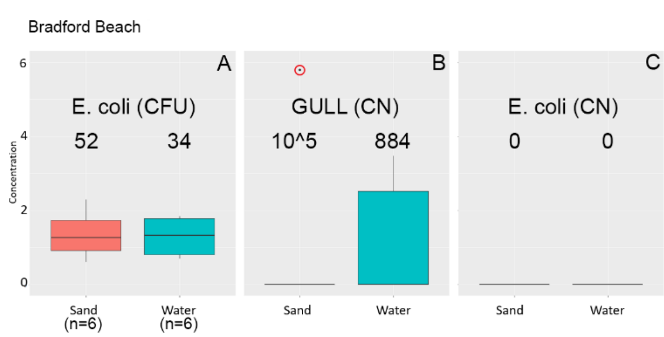

Figure 5. Box plots and mean concentration for sand (n=6) and water (n=6) samples from Bradford Beach A) E. coli plate counts B) Gull-2 indicator QPCR C) E. coli QPCR. Sand values are in CFU or CN/100 g of sand. Water values are in CFU or CN/100 ml of water.

Nowcast (Virtual Beach) modeling – The 2017-2018 Nowcast model-based forecasting of *E. coli* concentrations at Bradford Beach was a poor predictor of *E. coli* monitoring results that the Milwaukee Health Department recorded for the same day (Pearson's correlation r = 0.09). Nowcast results missed all the MPN beach advisory days (*E. coli* ≥235 MPN/100 mL) and recommended beach advisories on four days when *E. coli* counts were well under the advisory limit. (Nowcast predictions were made available by Todd Miller, University of Wisconsin-Milwaukee). The success of statical modeling is influenced by several factors, including the frequency of contamination and the data available for calibrating the model, therefore, this approach may work better at some beaches compared with others.

McKinley Beach

Figure 6. McKinley Beach replicate sampling sites. (Google Earth, 2019)

Study Area

McKinley Beach (Figure 6) is a high energy beach remodeled into a pocket shape during the 1980's. Previously there was frequent damage to the area due to high lake levels and high wave action that targeted the beach because of an adjacent breakwater on the south end of the beach. Rocks from Milwaukee's deep tunnel project were used to shelter the beach from additional damage, but the pocket shape of the protected beach may have contributed to a problem with rip currents forming in the remodeled swim area. The beach was closed in 2020 after several drownings occurred and currently Milwaukee County is doing a safety study at McKinley Beach. Archived and new samples were collected in knee-deep water from replicate sampling site. GPS coordinates from south to north are listed in Table 4.

Table 4. GPS coordinates of McKinley Beach sampling sites.

Site	North	West
MCK_1	43° 3'10.13"	87°52'54.80"
MCK_2	43° 3'12.48"	87°52'54.22"
MCK_3	43° 3'13.16"	87°52'51.52"

Results and Discussion

<u>*Fecal pollution sources when E. coli exceeds standards (does not include CSO or blending events)*</u> – The highest recreational health risk in beach water is associated with high concentrations of human-associated fecal indicator markers because they are proxies for sewage contamination which may contain human viral and bacterial pathogens. To evaluate the human health risk when *E. coli* counts are above the recreational warning limit of 235 CFU/100 mL in beach water samples, the samples were tested for host-associated fecal indicator markers, including human (HF183 and Lachno3), gull (Gull-2), and dog (DogBact) marker. Samples are only considered positive for human contamination if **both** human markers are present in the sample. Gull- and dog-associated fecal markers are less likely to be associated with any human pathogens and, therefore, are less of a risk to swimmers (Soller et al., 2010; Soller et al., 2014; Brown et al., 2017).

The Gull-2 marker was the most frequent and most abundant host-specific genetic marker found in samples collected in lowflow (86%; 6 of 7) and rain (53%; 10 of 19) conditions (Figure 7). Human markers were found occasionally at low concentrations near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered). In lowflow conditions, two of the samples were positive for both HF183 and Lachno3 and were therefore categorized as human contaminated. In rain conditions, one sample was positive for both human markers and was considered human contaminated. DogBact marker was found in 3 of 7 lowflow (43%) and 5 of 19 rain (26%) samples at McKinley Beach. Dogs are not allowed on McKinley Beach, however, there is a rocky area that abuts McKinley where dogs play. Water movement from this area could be the source of dog marker at McKinley. In addition, during rain events storm runoff may wash dog feces from walkways to the beach.

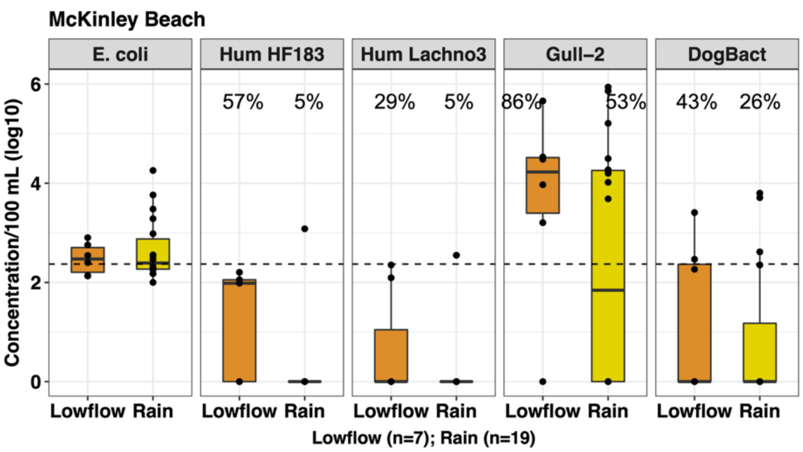

Figure 7. Boxplots of log10 concentrations of E. coli (CFU/100 mL) and host-associated fecal indicators (CN/100 mL) in samples when E. coli is above the advisory limit. Dashed line is 235 (advisory limit) and is also near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) for fecal indicator markers. The percentage of samples positive for each marker is shown.

<u>*Assessment of gull fecal pollution*</u> – From 2008-2020 McKinley Beach water was tested in a variety of weather conditions for Gull-2 marker. For this analysis, all samples were used, regardless of *E. coli* levels since the analysis was intended to understand distribution of gull waste. Of the 21 days tested for Gull-2, 12 days were positive (57%) and detection occurred under rain and lowflow conditions, demonstrating that gull fecal pollution was widespread and impacted water quality regardless of weather condition.

<u>*Ruminant marker (samples includes CSO and blending events)*</u> – Human pathogens can be associated with cattle waste (Soller et al., 2010) and approximately 79% of the Milwaukee River watershed is rural land use in the upstream region. McKinley Beach water was tested for ruminant-associated fecal indicator marker (BacR) in samples (n=10) taken while the Milwaukee River discharge was elevated and/or dates following high concentrations of BacR measured at the Milwaukee River sampling site. None of the samples tested were positive for BacR marker. Note that the Milwaukee River discharge was not elevated during these sampling days and there were no CSOs. The BacR marker has been detected in the nearshore and off other AOC beaches at times when Milwaukee River flows were high, but McKinley beach water samples had not been collected on those days. After

heavy rains that extend to rural areas north of Milwaukee, a conservative monitoring approach could monitor for BacR at all AOC beaches. Regional pollution does bring cattle waste down the Milwaukee River and the river plume impacts the beaches in certain weather conditions (McLellan et al., 2020). However, heavy rain conditions are often associated with CSOs or trigger a pre-emptive water quality advisory based on rainfall amounts, and thus the beaches are already closed, so further action may not be necessary.

Outfalls – Sewage pollution at McKinley Beach can result from sewage leaking into local stormwater outfalls (Sauer et al., 2011; Sercu et al., 2011). There is one submerged stormwater outfall that terminates north of the swimming beach directly into Lake Michigan (not directly into the swimming area). It is difficult to sample the outfall as it is submerged and therefore markers can dilute quickly. During 2020 rain events the outfall was sampled five times. None of the 2020 samples were positive for human marker. A sample taken in 2018, during a CSO, had high concentrations for HF183 and Lachno3, however this human marker signal could have originated from river water delivered through the harbor. Thus, the outfall does not appear to be a current source of sewage contamination. In the future, a manhole directly preceding the outfall could be sampled to avoid the dilution issue. (See outfall maps and assay values in Appendix A.)

Sand reservoir for E. coli – On two days in August 2020, paired sand and water samples were collected to test sand as an *E. coli* reservoir. For both sample-types *E. coli* was measured using microbial plate counts and qPCR. Each method showed *E. coli* was present in both sand and water. Using culture techniques, *E. coli* was present in 100% of sand (n=6) and water (n=6) samples. Using qPCR *E. coli* was detected in 33% of sand samples and 83% of water samples. Gull-2 was detected in 33% of sand samples and 0% of water samples. Although Gull-2 was not detected frequently, the marker concentration was high when it was detected and therefore the means are high (Figure 8). Despite the limited samples, sand appears to be a reservoir for *E. coli* as these results are similar to more extensive studies in past years at Bradford Beach. Prior work has demonstrated that the Gull-2 marker is more abundant in gull waste than *E. coli* but decays much more quickly. Therefore, these low levels of *E. coli* may be indicative of residual gull contamination (Cloutier et al., 2017). The Gull-2 marker and *E. coli* did not show a relationship to each other in sand or water. An assessment of McKinley Beach sand showed 46% fell into a 'fine' to 'very fine' (250 um – 106 um) particle size. Most of the remaining particles were well distributed among larger sizes up to 'fine gravel'. These data will be useful when considering grain size for future management approaches.

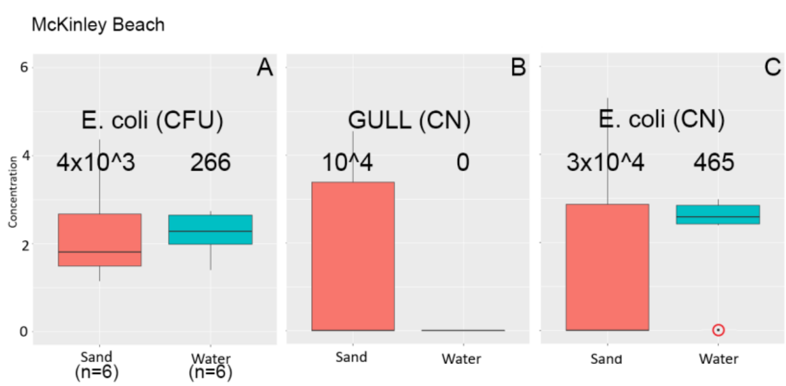

Figure 8. Box plots and mean concentration for sand (n=6) and water (n=6) samples from McKinley Beach A) E. coli plate counts B) Gull-2 indicator QPCR C) E. coli QPCR. Sand values are in CFU or CN/100 g of sand. Water values are in CFU or CN/100 ml of water.

South Shore Beach

Figure 9. South Shore Beach replicate sampling sites. (Google Earth, 2019)

Study Area

South Shore Beach (Figure 9) suffers frequent beach closings due to elevated levels of *E. coli*. According to the Annual Beach Report issued in 2011 by the National Resources Defense Council (Dorfman and Rosselot, 2011) South Shore Beach was named one of the top 10 offenders in the nation for "persistent contamination problems". From 2015-2019 advisories ranged from a high of 68% (2015) to a low of 31% (2019) and closures ranged from a high of 28% (2015) to a low of 5% (2019) (WDNR, 2015-2019 Beach Monitoring Reports). South Shore beach has poor water circulation due to a series of breakwaters that protect the area but reduce flushing of the beach with cleaner water from the lake. Additionally, it is located next to a marina with boats moored a few meters away from the beach and it is adjacent to a parking lot with a boat ramp that abuts the north end of the beach. These factors make it a poor swimming area. However, there is an area 200 meters south of the beach's current location where there is an opening in the breakwater and consistently lower *E. coli* concentrations in the water. This new location is referred to as the proposed-South Shore Beach swimming area in this document.

Archived and new samples were collected in knee-deep water from replicate sampling site. GPS coordinates from south to north are listed in Table 5.

Table 5. GPS coordinates of South Shore Beach sampling sites.

Site	North	West
SS_Curr_1	42°59'40.68"	87°52'51.71"
SS_Curr_2	42°59'42.25"	87°52'52.42"
SS_Curr_3	42°59'44.05"	87°52'53.28"
SS_Prop_1	42°59'33.50"	87°52'42.68"
SS_Prop_2	42°59'34.55"	87°52'43.65"
SS_Prop_3	42°59'36.35"	87°52'44.67"

Results and Discussion

Fecal pollution sources when E. coli exceeds standards (does not include CSO or blending events) – The highest recreational health risk in beach water is associated with high concentrations of human-associated fecal indicator markers because they are proxies for sewage contamination which may contain human viral and bacterial pathogens. To evaluate the human health risk when *E. coli* counts are above the recreational warning limit of 235 CFU/100 mL in beach water samples, the samples were tested for host-associated fecal indicator markers, including human (HF183 and Lachno3), gull (Gull-2), and dog (DogBact) marker. Samples are only considered positive for human contamination if **both** human markers are present in the sample. Gull- and dog-associated fecal markers are less likely to be associated with any human pathogens and, therefore, are less of a risk to swimmers (Soller et al., 2010; Soller et al., 2014; Brown et al., 2017).

South Shore Beach (current swimming area):

The Gull-2 marker was the most frequent and most abundant host-specific genetic marker found in samples collected in lowflow (91%; 30 of 33) and rain (92%; 11 of 12) conditions (Figure 10). In these samples human markers were found frequently, but usually at low concentration near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered). In lowflow conditions, 12 samples were positive for both HF183 and Lachno3 markers and therefore considered human contaminated. In rain conditions, seven of the samples were also positive for both markers and considered human contaminated. DogBact marker was found in 5 of 31 lowflow (16%) and 4 of 11 rain (36%) samples at current South Shore Beach. Dogs are not allowed on the beach, but all park areas that directly abut the beach are open to dogs.

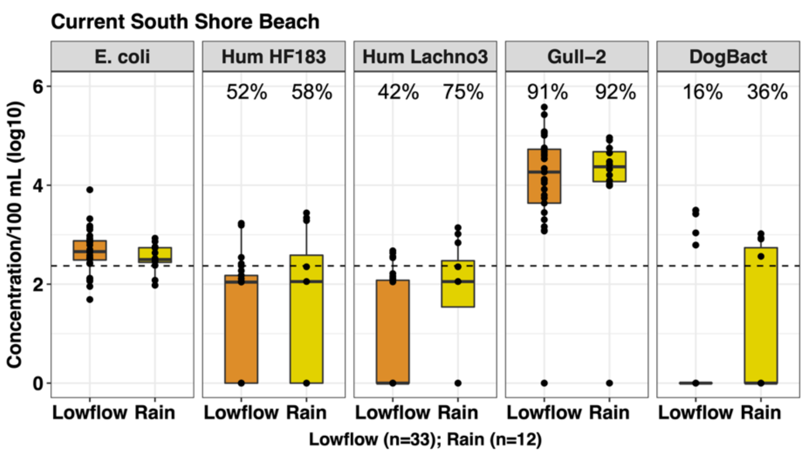

Figure 10. Boxplots of log10 concentrations of E. coli (CFU/100 mL) and host-associated fecal indicators (CN/100 mL) in samples when E. coli is above the advisory limit. Dashed line is 235 (advisory limit) and is also near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) for fecal indicator markers. The percentage of samples positive for each marker is shown.

Assessment of gull fecal pollution – From 2013-2020 current South Shore Beach water was tested in a variety of weather conditions for Gull-2 marker. For this analysis, all samples were used, regardless of *E. coli* levels since the analysis was intended to understand distribution of gull waste. Of the 58 days tested for Gull-2, 52 days were positive (90%), demonstrating that gull fecal pollution was widespread and impacted water quality regardless of weather condition.

Ruminant marker (samples includes CSO and blending events) – Human pathogens can be associated with cattle waste (Soller et al., 2010) and approximately 79% of the Milwaukee River watershed is rural land use in the upstream region. Current South Shore Beach water was tested for ruminant-associated fecal indicator marker (BacR) in samples (n=30) taken while the Milwaukee River discharge was elevated and/or dates following high concentrations of BacR measured at the Milwaukee River sampling site. While these conditions only encompass a small portion of the beach season, the purpose of the analysis was to determine if there was evidence that agricultural runoff could reach the AOC beaches. A total of 10% of samples tested were positive for BacR marker. The 3 positive samples were from one date during a heavy rain period with CSOs. After heavy rains that extend to rural areas north of Milwaukee, a conservative monitoring approach could monitor for BacR at all AOC beaches. Regional pollution does bring cattle waste down the Milwaukee River and the river plume impacts the beaches in certain weather conditions (McLellan et al., 2020). However, heavy rain conditions are often associated with CSOs or trigger a pre-emptive water quality advisory based on rainfall amounts, and thus the beaches are already closed, so further action may not be necessary.

<u>*Beach Remediation*</u> – In 2017, green infrastructure was constructed in the parking lot at South Shore Park adjacent to the swimming beach. The area now contains rain gardens, bioswales, trees and storm pipe drainage to the green infrastructure to limit direct stormwater pollution to the lake. To evaluate the effectiveness of remediation, pre- and post-remediation *E. coli* monitoring results (n=367) from Milwaukee Health Department records were used to compare *E. coli* levels before and after remediation (Figure 11). Since the amount and number of days with rainfall can greatly influence the overall evaluation of *E. coli* levels, as well as the point in the season, each month was binned into either high (HI; ranging from 4.3" – 10.9") or low (LO; ranging from 0.9" – 2.9") average rainfall. For example, we compared the *E. coli* levels for a particular month (e.g., June) from all years with high rainfall averages (i.e., HI) pre and post remediation. We found that during the recreational season, post-remediation samples did not have significantly lower mean *E. coli* concentrations in months with either low average rain or high average months (June HI ($p = 0.24$); June LO ($p = 0.88$); July HI ($p < 0.01$) note that **post-remediation** was significantly **higher** in this category; July LO ($p = 0.69$); August HI ($p = 0.52$); no post-remediation years fell into the August LO category). Thus, the green infrastructure installed in the parking lot does not appear sufficient to reduce *E. coli* levels in the current South Shore Beach swimming area. See the remediation fact sheet in Appendix C for more information.

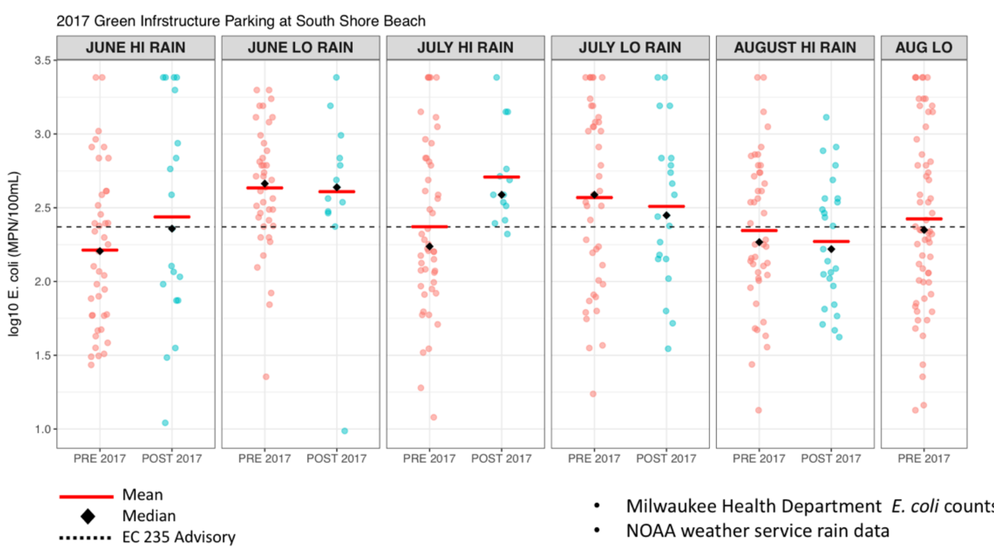

Figure 11. Log10 E. coli concentrations pre- and post-remediation. Months are separated into higher average rain and lower average rain categories. Pre-remediation samples (n=276) were selected from years 2005-20016. Post-remediation samples (n=91) were selected from years 2018-2020.

<u>South Shore Beach (proposed swimming area):</u>

The Gull-2 marker was the most frequent and most abundant host-specific genetic marker found in samples collected in lowflow (82%; 14 of 17) and rain (58%; 7 of 12) conditions (Figure 12). In these samples human markers were found frequently, but at low concentration near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered). In lowflow conditions, four samples were positive for both HF183 and Lachno3 markers and therefore considered human contaminated. In rain conditions, two of the samples were also positive for both markers and considered human contaminated. DogBact marker was found in 1 of 17 lowflow

(6%) and 4 of 12 rain (33%) samples at proposed South Shore Beach. Dogs are not prohibited in the area and dog walking is common along a trail just west of the proposed swim area.

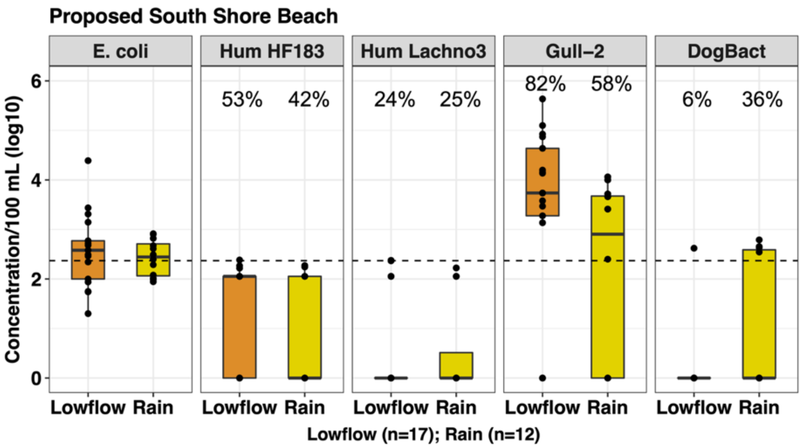

Figure 12. Boxplots of log10 concentrations of E. coli (CFU/100 mL) and host-associated fecal indicators (CN/100 mL) in samples when E. coli is above the advisory limit. Dashed line is 235 (advisory limit) and is also near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) for fecal indicator markers. The percentage of samples positive for each marker is shown.

<u>*Assessment of gull fecal pollution*</u> – From 2013-2020, proposed South Shore Beach water was tested in a variety of weather conditions for Gull-2 marker. For this analysis, all samples were used, regardless of *E. coli* levels since the analysis was intended to understand distribution of gull waste. Of the 45 days tested for Gull-2, 31 days were positive (69%) and detection occurred under rain and low flow conditions, demonstrating that gull fecal pollution was widespread and impacted water quality regardless of weather condition.

<u>*Ruminant marker (samples includes CSO and blending events)*</u> – Human pathogens can be associated with cattle waste (Soller et al., 2010) and approximately 79% of the Milwaukee River watershed is rural land use in the upstream region. Proposed South Shore Beach water was tested for ruminant-associated fecal indicator marker (BacR) in samples (n=25) taken while the Milwaukee River discharge was elevated and/or dates following high concentrations of BacR measured at the Milwaukee River sampling site. While these conditions only encompass a small portion of the beach season, the purpose of the analysis was to determine if there was evidence that agricultural runoff could reach the AOC beaches. 16% of samples tested were positive for BacR marker. The four positive samples were from a heavy rain period with CSOs. After heavy rains that extend to rural areas north of Milwaukee, a conservative monitoring approach could monitor for BacR at all AOC beaches. Regional pollution does bring cattle waste down the Milwaukee River and the river plume impacts the beaches in certain weather conditions (McLellan et al., 2020). However, heavy rain conditions are often associated with CSOs or trigger a pre-emptive water quality advisory based on rainfall amounts, and thus the beaches are already closed, so further action may not be necessary.

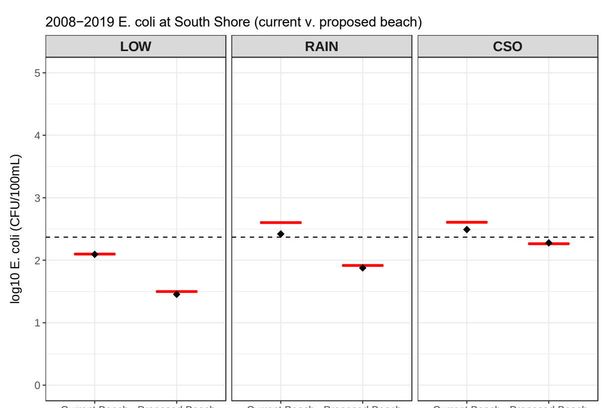

Figure 13. E. coli concentrations (CFU/100 mL) at South Shore current and proposed swim areas 2008-2019. Red line=mean, black diamond=median, dotted line=advisory limit of ≥235 CFU/100 mL.

<u>South Shore *current* versus *proposed* swim areas</u>

South Shore beach has poor water circulation (due to a breakwall) and its proximity to a marina make it a poor swimming area. Water circulation and exchange with clean water is lower than an open water beach. Redesignating the swimming area to 200 meters south of its current location, where there is an opening in the breakwater, is an alternative to the current swimming area that could provide consistently lower *E. coli* concentrations at South Shore Beach as seen in Figure 13. The log10 mean concentrations of *E. coli* are significantly lower at the proposed swim area in all conditions – lowflow ($p < 0.001$), rain ($p < 0.001$), and CSO ($p < 0.001$). Additionally, in lowflow conditions (when people swim) the mean and geomean *E. coli* concentrations are well below the advisory limit at the proposed swim area, while both are above the limit (mean = 235 CFU/100 mL and geomean = 126 CFU/100 mL) at the current swim area.

The mean concentrations for raw *E. coli* values (i.e., not log10 transformed) show the proposed swim area is 2-fold better in lowflow, 10-fold better in rain, and 3-fold better in CSO conditions (Table 6). Importantly, the geomean of the proposed swim area is within the 2012 EPA recreational water quality limit of 126 E. coli/100 mL, except under CSO conditions, where the limit is exceeded. In contrast, the current swim area does not meet this criterion under lowflow, rain, or CSO conditions.

Table 6. Comparison of means for E. coli levels and comparison of geomean E. coli levels.

2008-2019 mean *E. coli* CFU levels			
	Low	Rain	CSO
Current	496	2447	1127
Proposed	213	233	404
~Difference	2x	10x	3x

2008-2019 Geometric mean *E. coli* CFU counts			
	Low	Rain	CSO
Current	141	571	406
Proposed	37	93	184

Bay View Beach

Figure 14. Bay View Beach replicate sampling sites. (Google Earth, 2019)

Study Area

Bay View Park Beach (Figure 14) is a natural Milwaukee County beach in the city of St. Francis. The beach is more isolated than the other AOC beaches and abuts the Oak Leaf Trail. There is vegetation between the trail and the sandy beach. At the south end of the beach there are two submerged stormwater outfalls. One outfall pipe is buried and extends from beneath a former CSO gate to approximately 50 feet past a breakwater that protects the beach area. The other outfall is just south of the CSO gate and discharges near the shoreline.

Archived and new samples were collected in knee-deep water from replicate sampling site. GPS coordinates from south to north are listed in Table 7.

Table 7. GPS coordinates of Bay View Beach sampling sites.

Site	North	West
BV_1	42°59'5.88"	87°51'57.84"
BV_2	42°59'10.32"	87°52'3.02"
BV_3	42°59'14.55"	87°52'11.00"

Results and Discussion

Fecal pollution sources when E. coli exceeds standards (does not include CSO or blending events) – The highest recreational health risk in beach water is associated with high concentrations of human-associated fecal indicator markers because they are proxies for sewage contamination which may contain human viral and bacterial pathogens. To evaluate the human health risk when *E. coli* counts are above the recreational warning limit of 235 CFU/100 mL in beach water samples, the samples were tested for host-associated fecal indicator markers, including human (HF183 and Lachno3), gull (Gull-2), and dog (DogBact) marker. Samples are only considered positive for human contamination if **both** human markers are present in the sample. Gull- and dog-associated fecal markers are less likely to be associated with any human pathogens and, therefore, are less of a risk to swimmers (Soller et al., 2010; Soller et al., 2014; Brown et al., 2017).

The Gull-2 marker was the most frequent and most abundant host-specific genetic marker found in samples collected in lowflow conditions (67%; 10 of 15) and was common in rain conditions (53%; 8 of 15) (Figure 15). In these samples, HF183 was detected relatively frequently in both lowflow and rain conditions. Additionally, in rain conditions HF183 was at high concentration in 47% of the samples. However, Lachno3 was not detected in lowflow samples and was generally at low concentration near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) in rain samples. In lowflow conditions, none of the samples were positive for both HF183 and Lachno3 markers and therefore none are considered human contaminated. In rain conditions, eight of the samples were positive for both markers and are considered human contaminated. DogBact marker was found in 3 of 15 lowflow (20%) and 7 of 15 rain (47%) samples at Bay View Beach. Dogs are allowed on the beach.

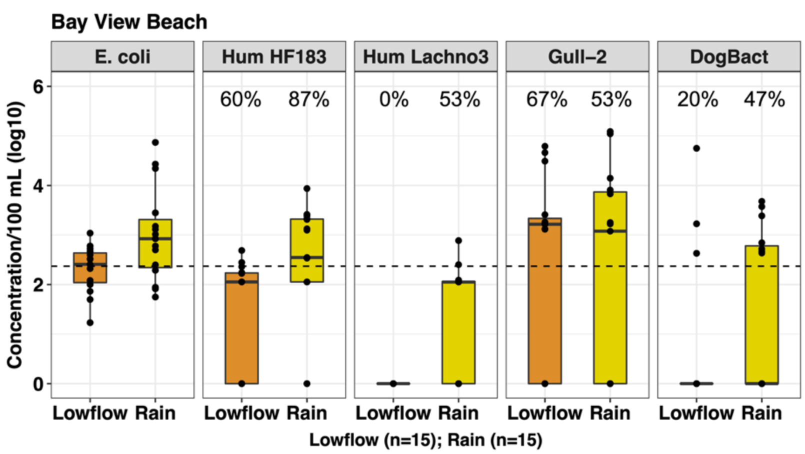

Figure 15. Boxplots of log10 concentrations of E. coli (CFU/100 mL) and host-associated fecal indicators (CN/100 mL) in samples when E. coli is above the advisory limit. Dashed line is 235 (advisory limit) and is also near the limit of quantitation (113 or 225 CN/100 mL depending on sample volume filtered) for fecal indicator markers. The percentage of samples positive for each marker is shown.

Assessment of gull fecal pollution – From 2012-2020, Bay View Beach water was tested in a variety of weather conditions for Gull-2 marker. For this analysis, all samples were used, regardless of *E. coli* levels since the analysis was intended to understand distribution of gull waste. Of the 25 days tested for Gull-2, 15 days were positive (60%) and detection occurred under rain and lowflow conditions, demonstrating that gull fecal pollution was widespread and impacted water quality regardless of weather condition.

Ruminant marker (samples includes CSO and blending events) – Human pathogens can be associated with cattle waste (Soller et al., 2010) and approximately 79% of the Milwaukee River watershed is rural land use in the upstream region. Bay View Beach water was tested for ruminant-associated fecal indicator marker (BacR) in samples (n=9) taken while the Milwaukee River discharge was elevated and/or dates following high concentrations of BacR measured at the Milwaukee River sampling site. While these conditions only encompass a small portion of the beach season, the purpose of the analysis was to determine if there was evidence that agricultural runoff could reach the AOC beaches. None of samples tested were positive for BacR marker. After heavy rains that extend to rural areas north of Milwaukee, a conservative monitoring approach could monitor for BacR at all AOC beaches. Regional pollution does bring cattle waste down the Milwaukee River and the river plume impacts the beaches in certain weather conditions (McLellan et al., 2020). However, heavy rain conditions are often associated with CSOs or trigger a pre-emptive water quality advisory based on rainfall amounts, and thus the beaches are already closed, so further action may not be necessary.

Outfalls – Sewage pollution at Bay View Beach can result from sewage leaking into local stormwater outfalls (Sauer et al., 2011; Sercu et al., 2011). There are two outfalls that terminate near the beach and discharge directly into Lake Michigan. BV_OUT01 discharges south of the swim area near the shoreline. BV_OUT02 also discharges south of the swimming beach but is located on the open-water side of a breakwater. It is physically difficult to sample both outfalls – BV_OUT01 is inaccessible due to beachside erosion and high lake levels and BV_OUT02 is submerged and only accessible by boat. As both outfalls discharge below the water level, markers can dilute quickly. Previous data from 2008-2016 (the BV_OUT01 outfall was accessible before 2017) show that the BV_OUT01 was a persistent source of source of sewage contamination during rain when stormwater is released from the outfall and an intermittent source of source of contamination during lowflow conditions (Appendix A Table 14). Therefore, it is likely that during heavy rains BV_OUT01 will contaminate the swimming area with sewage and may intermittently contaminate beach water in lowflow conditions. BV_OUT02 is currently under investigation. Neither outfall discharges directly into the swimming area. (See outfall maps and assay values in Appendix A.)

3.0 MODELING

Results and Discussion

Regional pollution reaches beaches during heavy rain events
Past work in our laboratory using field surveys and hydrodynamic modeling demonstrated regional pollution reaches beaches during heavy rain events (Bravo et al., 2018). This model uses an estimated loading of fecal coliforms from the river based on historical datasets. In this work we used high resolution empirical data of *E .coli* and human fecal indicator bacteria collected across the event hydrograph at the estuary for input into the model. Using real measurements as the input to the hydrodynamic model provides a more quantitative estimate of the amount of fecal pollution that reaches the beaches. We examined the level of pollutants that reached one beach north of the estuary (Bradford Beach) and one to the south of the estuary (South Shore Beach). Beaches were considered impacted when modeling results predicted *E. coli* at or exceeding the recreational water quality standard of 235 CFU/100 ml or modeling results predicted HF183 levels greater than the limit of quantitation of 225 CN/100 ml. During heavy rains (>6.35 cm), with some events accompanied by a CSO, measured peak concentrations at the estuary ranged from 105 to 10,200 CFU/100 mL for *E. coli* and 9,278 to 191,000 CN/100 mL for HF183 marker.

Model simulations showed *E. coli* above recreational water quality standards at beaches during 3 of 13 of the model runs, with *E. coli* not reaching beaches during light rain events (Table 8). Of the three events where beaches experienced increased *E. coli* concentrations and thus exceeded water quality standards, South Shore Beach was impacted for all three events, while Bradford Beach exceeded water quality standards during just one event.

Table 8. Events measured and modeled peak concentrations of E. coli and HF183 at the harbor and beaches within the AOC.

				Measured		Modeled					
Event	Date	Event Type	Rain (cm)	Estuary		Harbor		Bradford		South Shore	
				E. coli CFU/100 ml	HF183 CN/100 ml	E. coli CFU/100 ml	HF183 CN/100 ml	E. coli CFU/100 ml	HF183 CN/100 ml	E. coli CFU/100 ml	HF183 CN/100 ml
1	3/26/18-3/30/18	Thaw	0.86	66	NA	0.71	NA	1.1	NA	4	NA
2	4/12/18-4/15/18	Rain	6.8	105	NA	0.83	NA	0.01	NA	4	NA
3	5/1/18-5/9/18	Rain	3.8	135	41660	9.2	NA	0.72	NA	5.7	NA
4	5/20/18-5/24/18	Rain	1.5	30	NA	-	-	-	-	-	-
5	6/18/18-/6/25/18	CSO	6.1	5100	166764	28	240	1	12	700	17000
6	7/20/18-7/24/18	Rain	2.1	680	NA	4.8	NA	0.25	NA	11	NA
7	10/22/18-10/24/18	Baseflow	0	75	NA	-	-	-	-	-	-
8	3/13/19-3/20/19	Thaw/CSO	1.2	6510	191064	960	25000	110	2600	2200	45000
9	4/16/19-4/18/19	Baseflow	0.25	27	NA	2	NA	0.38	NA	1.7	NA
10	4/29/19-5/4/19	Rain	4	80	1617	12	NA	0.25	NA	31	NA
11	7/18/19-7/23/19	Rain	7.1	7000	9278	740	200	440	130	490	190
12	8/26/19-8/29/19	Rain	3.9	1760	1381	3.8	4.1	4	5	0	0
13	9/13/19-9/17/19	CSO	6.5	10200	161681	50	560	150	1800	0	16

A subset of events (five rain, including three events with CSOs) were additionally run to predict concentrations of the human-specific HF183 marker. For all events modeled, concentrations of both *E. coli* and human-specific fecal indicators were elevated in the harbor. The HF183 marker was detected above the limit of quantitation at one or both beaches for all the CSO events, however, *E. coli* was above 235 CFU/100 mL in only two of the three CSO events. This pattern was consistent with the observation that the HF183 marker was one to two orders of magnitude higher than *E. coli* when there was a CSO, whereas during rainfall with no CSO, the HF183 marker was elevated in only select events. These inconsistent patterns during rainfall might suggest there are unrecognized SSOs occurring in municipalities that are not reported to beach monitoring agencies, in this case the City of Milwaukee Health Department.

In general, HF183 above 100,000 CN/100 mL resulted in beach delivery of this marker above the limit of quantification. The two beaches modeled were not always affected equally and contaminant delivery was highly influenced by meteorological and lake conditions. For example, during the June 2018 CSO event, there was a predominant northeastern wind that forced plume contaminants south to South Shore Beach, with minimal impact to Bradford. Modeling of rain events without a CSO did not produce HF183 levels above the limit of quantification, but did suggest low levels of human contamination would reach local beaches under some conditions.

Validation of model results

To compare modeling output with empirical data collected at the beach, we analyzed samples from multiple days during a June 2018 CSO to determine the levels of the HF183 human marker and *E. coli* (Figure 16). The timing of the HF183 marker and *E. coli* concentrations measured in the nearshore at South Shore Beach aligned with the peaks of these contaminants predicted by the model. Both *E. coli* and HF183 marker were at approximately twice the concentrations predicted by the model. At Bradford Beach, HF183 marker was detected in field samples early in the CSO, which did not coincide with model predictions. These findings could indicate sewage sources released from other locations, such as outfalls nearby the beach. The model demonstrated a low spike of HF183 marker at Bradford Beach several days later in the event, beginning on June 26; however, levels were predicted to be below the limit of detection and field sampling did not extend past June 25th. All three CSO events modeled predicted the HF183 marker concentration remaining detectable at beaches 5-12 days past the end of an event, with levels dropping generally after day 3 (see all model figures in Appendix B).

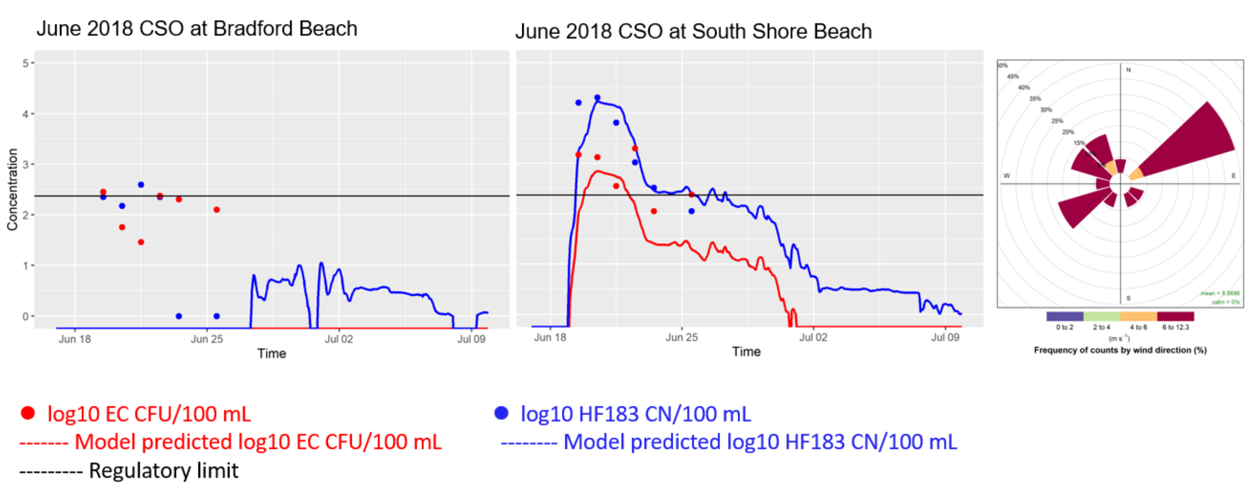

Figure 16. E. coli (EC) and HF183 marker concentrations measured in water samples and predicted from hydrodynamic modeling at Bradford Beach and South Shore Beach. The wind rose depicts daily average wind speed and direction over the period shown, which was predominately from the northeast, resulting in a greater impact at South Shore Beach.

4.0 BEACH ACTION VALUE

E. coli is the fecal indicator bacteria used as a proxy to warn of possible pathogen contamination in Wisconsin recreational waters. The Beach Action Value (BAV) that is used to inform the public of possible swimming risk is an *E. coli* count of ≥ 235 CFU/100 mL in beach water. In water samples from Milwaukee's AOC beaches, we found that gulls, not humans, were the primary source of *E. coli* when counts were ≥ 235 CFU/100 mL (Section 2.0). Gull indicator marker was present in 53 to 92 percent of samples dependent on beach. Health risks associated with exposure to water contaminated with gull feces is substantially lower than the risk if contaminated by sewage (Schoen and Ashbolt, 2010; Soller et al., 2014). At Great Lakes beaches human enteric viruses, which are associated with sewage contamination, account for the majority of GI illnesses (Soller et.al., 2010). Since the risk at these AOC beaches is not sewage associated in most circumstances, the BAV could be raised, resulting in a reduction of advisory days and moving closer to removal of the beach closings (recreational restrictions) BUI.

Using a dataset from samples collected 2008-2020, we found that changing the *E. coli* BAV to ≥ 500 CFU/100 mL did not increase the chances that swimmers would come into contact with sewage contaminated water at the AOC beaches (Figure 17). Samples categorized as contaminated with sewage were positive for 2 human markers (HF183 and Lachno3 and/or Lachno2).

Health Risk Comparison

Bradford Beach: In lowflow conditions, there were three human positive samples (dark red dots) but only one of the three was captured by the 235 BAV (dark blue dots). That sample was also captured by the 350 and 500 BAVs. Gull positive samples were interspersed throughout, regardless of whether *E. coli* counts were above (dark blue) or below (light blue) the designated BAV. In rain conditions, there was only one human positive sample and none of the BAVs captured it. Therefore, for both weather conditions, a BAV ≥ 500 CFU/100 mL was as effective as a BAV ≥ 235 CFU/100 mL at limiting risk to swimmers.

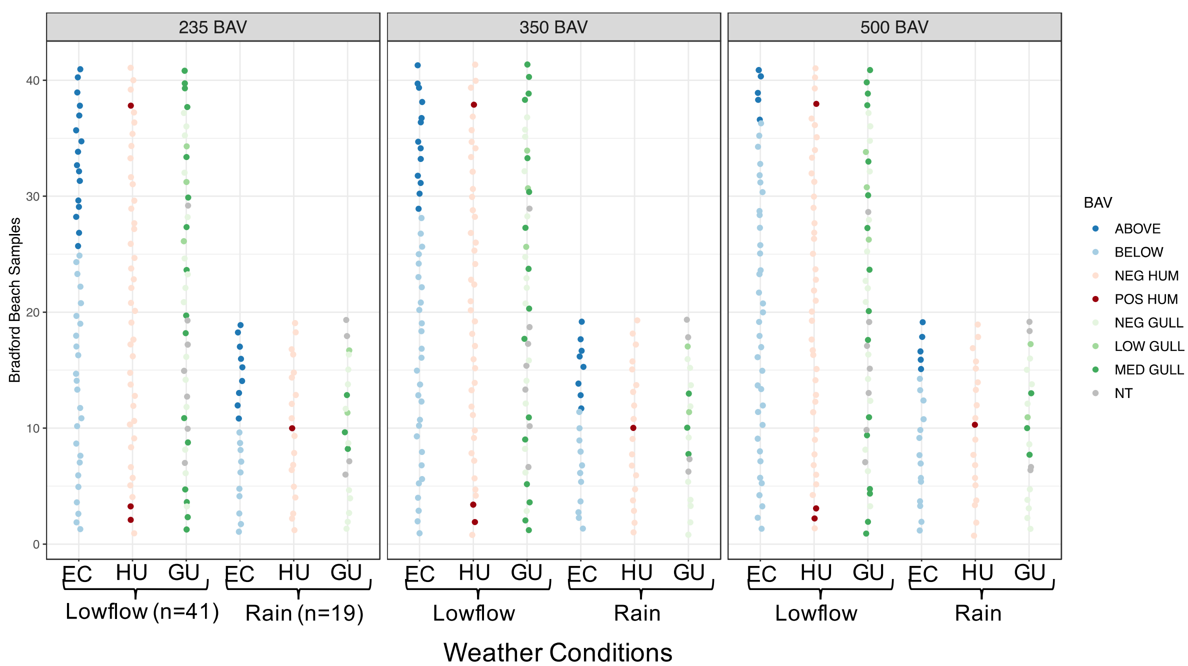

Figure 17a. Bradford and Beach samples contaminated by human (HU) or gull (GU) markers at different BAV values in lowflow and rain conditions. E. coli (EC) counts were above (dark blue) or below (light blue) the BAV category at the top of the box. HU categorized as negative, positive, or below limit of quantitation (BLQ). GU categorized as negative (0), low (1-1000), medium (>1,000), high (≥50,000), or not tested (NT). No CSO/SSO in dataset.

South Shore Beach (current): In lowflow and rain conditions, samples were frequently positive for human and gull when *E. coli* was below the BAV and when *E. coli* was above the BAV. In these samples, 235 BAV was not a good indicator of low-risk water quality. The water is not worse at 500 BAV, however, there is clearly a persistent source of contamination.

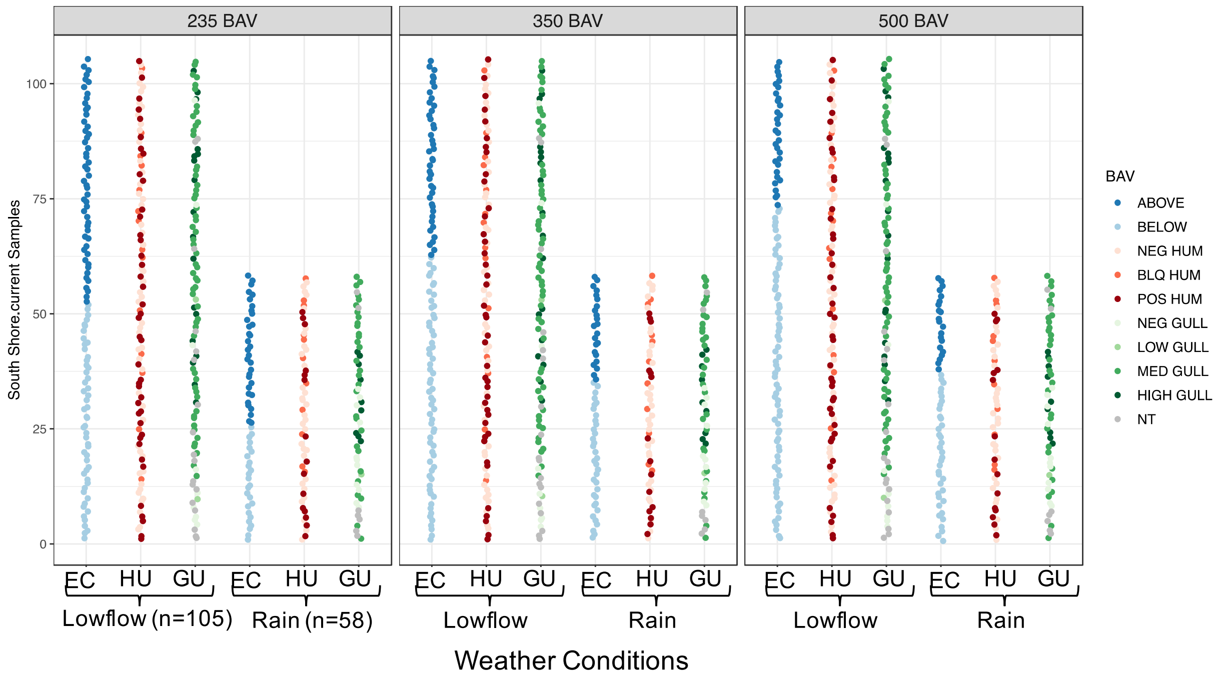

Figure 18b. South Shore beach samples contaminated by human (HU) or gull (GU) markers at different BAV values in lowflow and rain conditions. E. coli (EC) counts were above (dark blue) or below (light blue) the BAV category at the top of the box. HU categorized as negative, positive, or below limit of quantitation (BLQ). GU categorized as negative (0), low (1-1000), medium (>1,000), high (≥50,000), or not tested (NT). No CSO/SSO in dataset.

Other AOC beaches: Results for all AOC beaches show that changing the BAV from 235 to 500 would not increase the health risk to recreators at any of the beaches, since both BAVs capture higher-risk days with approximately the same frequency. Charts for the other AOC beaches are available in Appendix B.

Applying a modified BAV for assessing beach removal targets need to be made on a case-by-case basis. As indicated in the Bay View Beach summary, the outfall nearby has documented sewage contamination and therefore it is not recommended that the increased BAV of 500 *E. coli* per 100 ml be used to assess this beach, despite the finding that the beach is also heavily impacted by gull fecal pollution. Similarly, the persistent detection of human markers at South Shore Beach warrants further investigation to identify possible explanations, and increasing the BAV to 500 should not be considered until the human marker source(s) are contained.

Percent Reductions in Advisory Days when using a modified BAV

Historical data: A survey of the beach monitoring records from the Milwaukee Health Department showed a **reduction** in the average number of yearly advisory days ranging from a low of 43% (Bay View) to a high of 55% (Bradford) if the BAV was changed from 235 to 500 (Table 9). Monitoring data from 2010-2020, was reviewed to compare the number of days *E. coli* counts were ≥ 235 MPN/100 mL to the number of days counts were ≥ 500 MPN/100 mL, and the reduction in advisory days was calculated. This analysis did not include preemptory closings due to weather conditions as only the monitoring data were considered. The reduction in advisory days was substantial in many years at all beaches.

Table 9. Percent reduction in advisory days based on changing the E. coli BAV from 235 to 500.

Bradford Beach			
	advisory >235	advisory >500	reduction in advisory days
2010	13	7	46%
2011	7	5	29%
2012	10	3	70%
2013	9	3	67%
2014	13	8	38%
2015	4	2	50%
2016	6	1	83%
2017	5	2	60%
2018	3	0	100%
2019	0	0	NA
2020	1	1	0%
Ave	**6.45**	**2.91**	**55%**

McKinley Beach			
	advisory >235	advisory >500	reduction in advisory days
2010	8	3	63%
2011	4	1	75%
2012	5	2	60%
2013	8	2	75%
2014	15	5	67%
2015	36	21	42%
2016	13	7	46%
2017	24	15	38%
2018	24	10	58%
2019	3	1	67%
2020	5	3	40%
Ave	**13.18**	**6.36**	**52%**

South Shore Beach			
	advisory >235	advisory >500	reduction in advisory days
2010	32	25	22%
2011	20	16	20%
2012	28	13	54%
2013	19	11	42%
2014	43	25	42%
2015	49	34	31%
2016	29	18	38%
2017	18	15	17%
2018	34	20	41%
2019	18	11	39%
2020	26	13	50%
Ave	**28.73**	**18.27**	**36%**

Bay View Beach			
	advisory >235	advisory >500	reduction in advisory days
2010	7	4	43%
2011	9	7	22%
2012	8	4	50%
2013	0	0	NA
2014	4	3	25%
2015	1	1	0%
2016	2	1	50%
2017	2	2	0%
2018	7	2	71%
2019	0	0	NA
2020	4	1	25%
Ave	**4.00**	**2.27**	**43%**

2010-2020 Milwaukee Health Department *E. coli* counts (MPN/100 mL)

Advisory Day Reductions at South Shore Beach current and proposed swimming areas

The current and proposed South Shore swim areas both showed a 50% reduction in advisory days when the *E. coli* BAV was changed to 500 CFU/100 mL (Table 10). Archived data (2014-2016) from the McLellan lab was reviewed to compare the percent of advisory reductions at the two possible South Shore swim locations. The data was limited to the swim season of each year and CSO/SSO dates were not included in the dataset. Although the higher BAV did not result in a greater percent reduction of advisory days at the proposed swim area, the area did have fewer advisory days in each of the three years reviewed. In 2017, both sites were sampled 17 days during the swim season. The current beach was ≥ 235 CFU/100 mL for 8 of the 17 days (47% advisories) while the proposed area was ≥ 235 for only three days (18% advisories). The results support the conclusion from Section 2 that the proposed swim area is preferrable to the current swim area.

Table 10. BAV reduction in advisory days at current and proposed South Shore swim areas

South Shore Beach.current				South Shore Beach.proposed			
	advisory >235	advisory >500	reduction in advisory days		advisory >235	advisory >500	reduction in advisory days
2014 (n=21)	10	5	–> 50%	2014 (n=19)	0	0	–> 0%
2015 (n=22)	16	9	–> 44%	2015 (n=23)	9	5	–> 44%
2016 (n=17)	8	3	–> 63%	2016 (n=17)	3	1	–> 67%
Average	**11.33**	**5.67**	**–> 50%**	**Average**	**4.00**	**2.00**	**–> 50%**

Using an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (for rainfall ≤ 1 inch), when assessing the Beach Closings (Recreational Restrictions) target, the number of days that the AOC beaches are ranked as open during the swim season will increase. This change to the BAV will improve reaching the targets for BUI removal and has been suggested in 'Best Management Practices' (see section 5). In the future, using an *E. coli* BAV of ≥ 500 CFU/100 mL for acceptable water quality monitoring results would increase the opportunity for people to recreate at beaches since they are open more frequently. However, before this change is implemented the issue of persistent human marker contamination in the current and proposed swim areas must be resolved.

5.0 MANAGEMENT ACTIONS AND BEST MANAGEMENT PRACTICES

The following is a list of suggested **Management Actions** and **Best Management Practices** for Milwaukee's AOC beaches. Suggestions are based on the results presented in this document and were presented to the AOC Beaches Workgroup for their consideration. Best Management Practices are likely to be non-AOC actions and are recommended to Milwaukee County Parks for reducing *E. coli*. Management Actions are defined as recommendations that should be considered by the AOC Program.

Suggested Management Actions

Management Actions Summary Table

Bradford Beach	Beach nourishment and rain garden restoration
McKinley Beach	Gull deterrent on seawalls
South Shore-current	Relocate swim area to South Shore-proposed
South Shore-proposed	Remodel rocky beach as swimming area
Bay View Beach	No management actions

(details in discussion points below)

Bradford Beach

- Beach restoration actions to maintain a high-quality recreation area
  - Addition of beach sand to eliminate depressions/erosion where standing water or wet sand may lead to persistent *E. coli* sources that can be delivered to the water
  - Restore rain garden basins for continued prevention of runoff discharge across the beach

McKinley Beach

- Deter gulls from resting on seawalls surrounding the swim area
  - Note: Due to the McKinley rip current, distressed swimmers are known to climb the seawall boulders to escape the water. This situation should be considered when deciding on gull deterrents

South Shore Beach-current

- Relocation of swimming area to South Shore Beach-proposed
  - Replace beach with pedestrian area that utilizes trees and bushes as runoff buffer zones and a design that discourages swimming, gulls, runoff, and erosion

South Shore Beach-proposed

- Remodel rocky beach as swimming area

Bay View Beach

- No management actions

Suggested Best Management Practices

Best Management Practices Summary Table

	Lifeguards	Gull Abatement	Sand Grooming	Beach Nourishment	*Cladophora* Removal	Seasonal *E. coli* Monitoring	BAV 500 CFU	Outfall Monitoring	Clear Safety Signage
Bradford Beach	X	X	X	X	X	X	X	X	X
McKinley Beach	X	X	X		X	X	X	X	X
South Shore-current		X	X		X	X	X		X
South Shore-proposed		X	X		X	X	X		X
Bay View Beach		X				X	X	X	X

(details in discussion points below)

Bradford Beach

- Lifeguards
- Easy to understand safety advisory postings and informative lifeguards
  - High bacteria
  - Rip current warning flags with kiosk signage that visually warns of drowning
    - Use National Weather Service rip current forecasts
- Gull abatement
  - Patrol dogs
  - Educate beach goers (post Milwaukee County ordinance information about prohibiting feeding gulls and waterfowl disturbances as well as proper placement of trash cans to reduce beach waste).
- Sand grooming to limit establishment of *E. coli* reservoirs
- Routine removal of *Cladophora*
- Utilize an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (when rainfall ≤ 1 inch) when assessing the Beach Closings (Recreational Restrictions) target
- Beach nourishment (if not accepted as management action) - Add sand to reduce standing water
- Routine outfall monitoring for human fecal indicator genetic markers (a sewage proxy)
  - 12 beach (7 with rain gardens), ravine, soccer, and locust outfalls
    - Check on baseflow days for outfalls with sewage contaminated dry weather flow
    - Check on rain days for sewage pollution in stormwater runoff
    - Remove unused equipment and barriers to outfall #7 (making it accessible for monitoring)
- Up-the-pipe investigation and repair when beach or adjacent outfalls are contaminated with sewage, as indicated by the presence of human marker in outfall or contributing manhole samples

McKinley Beach

- Keep beach closed until swimmer safety is assessed
- Lifeguards
- Easy to understand safety advisory postings and informative lifeguards
  - High bacteria
  - Rip current warning flags with kiosk signage that visually warns of drowning
    - Use National Weather Service rip current forecasts
- Gull abatement

    - Spikes, wires or netting on seawall (see important additional info in management actions)
    - Educate beach goers (post Milwaukee County ordinance information about prohibiting feeding gulls and waterfowl disturbances as well as proper placement of trash cans to reduce beach waste).
- Sand grooming to limit establishment of *E. coli* reservoirs
- Routine removal of *Cladophora*
- Utilize an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (when rainfall ≤ 1 inch) when assessing the Beach Closings (Recreational Restrictions) target
- Routine monitoring for human fecal indicator genetic markers (a sewage proxy) at the manhole preceding the submerged outfall
    - Manhole contributing to submerged outfall
        - Check on baseflow days for outfalls with sewage contaminated dry weather flow
        - Check on rain days for sewage pollution in stormwater runoff
- Up-the-pipe investigation and repair when adjacent outfall is contaminated with sewage, as indicated by the presence of human marker in outfall or contributing manhole samples

South Shore-current (BMPs until swim area is relocated)

- Easy to understand safety advisory postings
    - High bacteria
- Gull abatement
    - Patrol dogs
    - Educate beach goers (post Milwaukee County ordinance information about prohibiting feeding gulls and waterfowl disturbances as well as proper placement of trash cans to reduce beach waste).
- Sand grooming to limit establishment of *E. coli* reservoirs
- Routine removal of *Cladophora*
- Once the persistent human marker issue has been resolved, utilize an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (when rainfall ≤ 1 inch) when assessing the Beach Closings (Recreational Restrictions) target

South Shore-proposed

- **Prior** to swim area relocation
    - Milwaukee Health Department seasonal *E. coli* monitoring
- **Post** relocation
    - Easy to understand safety advisory postings
        - High bacteria
    - Gull abatement
        - Patrol dogs
        - Educate beach goers (post Milwaukee County ordinance information about prohibiting feeding gulls and waterfowl disturbances as well as proper placement of trash cans to reduce beach waste).
    - Sand grooming to limit establishment of *E. coli* reservoirs
    - Routine removal of *Cladophora*
    - Once the persistent human marker issue has been resolved, utilize an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (when rainfall ≤ 1 inch) when assessing the Beach Closings (Recreational Restrictions) target

Bay View Beach

- Easy to understand safety advisory postings
    - High bacteria

- Gull Abatement
    - Educate beach goers (post Milwaukee County ordinance information about prohibiting feeding gulls and waterfowl disturbances as well as proper placement of trash cans to reduce beach waste).
- Designate dog swimming area at southern part of beach
- Routine outfall monitoring for human fecal indicator genetic markers (a sewage proxy)
    - 1 submerged, frequently inaccessible, outfall
        - Check on baseflow days for outfalls with sewage contaminated dry weather flow
        - Check on rain days for sewage pollution in stormwater runoff
- Up-the-pipe investigation and repair when adjacent outfall is contaminated with sewage, as indicated by the presence of human marker in outfall or contributing manhole samples
- Once the sewage contaminating outfall has been repaired, utilize an *E. coli* advisory BAV of 500 CFU/100 mL instead of 235 CFU/100 mL (when rainfall $\leq$ 1 inch) when assessing the Beach Closings (Recreational Restrictions) target

6.0 DECISION TREE

Detailed analysis of beach and river data helped refine the decision process that precedes beach advisories and closures in Milwaukee, Wisconsin. River plume dynamics, *E. coli* sources, bacterial pollutant peaks, and human fecal indicator bacteria were used to evaluate health risk associated with recreation at the city's beaches. The revised guidelines (Figure 18) will keep the recreating public safe while possibly reducing the number of days the beaches are in advisory or closed during the swim season. Reducing the number of advisory or closed days will move the AOC closer to removal of the beach closings (recreational restrictions) BUI. The refined decision tree was presented to the AOC Beaches Workgroup and the Milwaukee Health Department for their consideration. See the *Beach Closure Decision Tree* policy brief in Appendix D for more information.

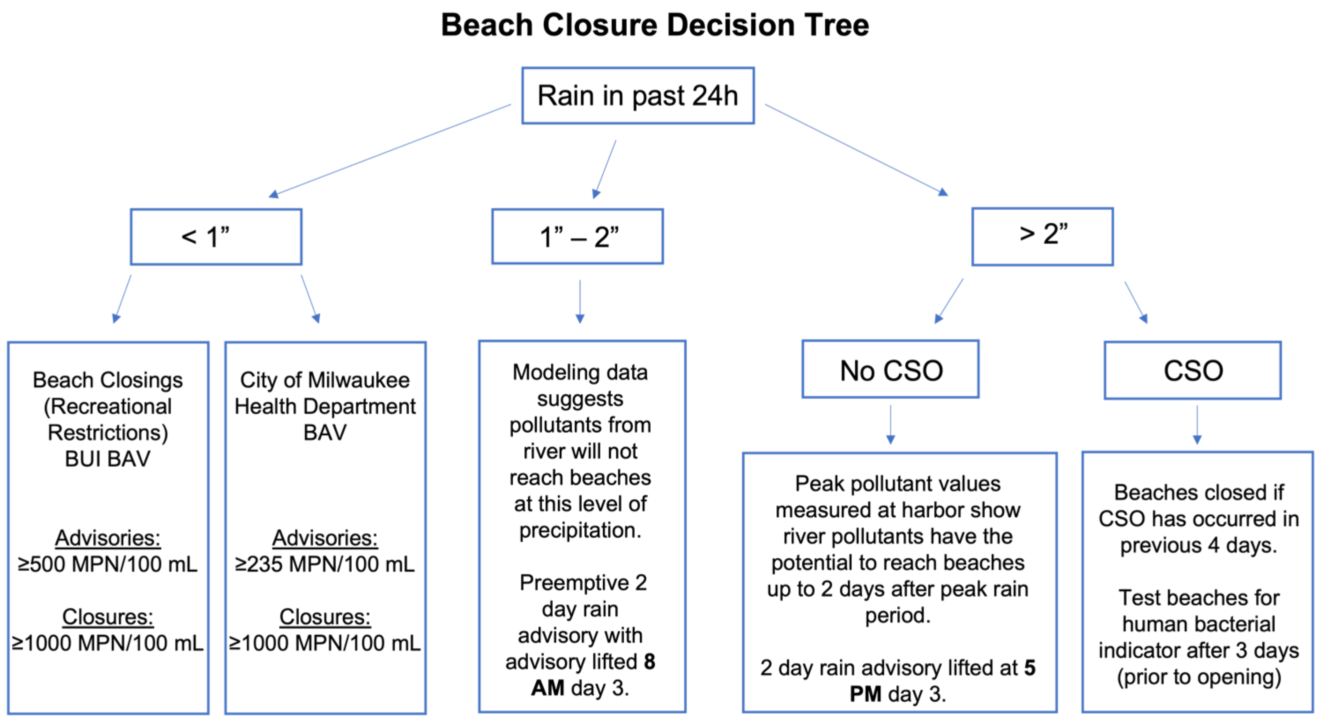

Figure 19. Refined beach advisory and closure decision tree

To refine the decision tree that the Milwaukee Health Department uses to issue beach advisories and closures, we evaluated the following questions in this study:

1. When *E. coli* counts are at the advisory limit, are the sources of *E. coli* a risk to swimmers?

E. coli is the fecal indicator bacteria used as a proxy to warn of possible sewage contamination in Wisconsin recreational waters. The Beach Action Value (BAV) that is used to inform the public of possible swimming risk is an *E. coli* count of ≥ 235 CFU/100 mL in beach water. In water samples from Milwaukee's AOC beaches we found that gulls, not humans (sewage), were the primary source of *E. coli* when counts were ≥ 235 CFU/100 mL (Section 2.0) – gull feces is a substantially lower health risk than sewage (Schoen and Ashbolt, 2010; Soller et al., 2014). Gull indicator marker was present in 53 to 92 percent of samples dependent on beach. Additionally, we found that changing the *E. coli* BAV to ≥ 500 CFU/100 mL did not increase the chances that swimmers would come into contact with sewage contaminated water at these beaches (Section 4, Figure 17a and b). In future, a BAV of ≥ 500 CFU/100 mL would increase opportunity for people to recreate at beaches that are open more frequently.

2. How many inches* of rain must fall before it is likely that the plume from Milwaukee's three rivers will reach the beaches?

When it rains 1" or more within a 24-hour interval, Milwaukee beaches are posted with advisories for two days and advisories are removed the 3rd day at 5 PM. However, our modeling suggests that pollutants from the rivers will not reach the beaches at this level of precipitation (Section 3, Table 8). For rain of 1"-2" in a 24-hour interval, the advisory could be lifted the morning of the 3rd day as local runoff, not regional pollution, is the source of high *E. coli* counts in beach water. The low-risk sources of *E. coli* in local runoff are birds and other wildlife. An exception to this pattern is if there is a nearby stormwater outfall with sewage contamination; in this case, the water should be tested for human fecal markers before removing the advisory.

3. If rainfall is more than two inches, how long will it take pollutants from the rivers/harbor to reach the beaches?

In heavier rains (>2" in 24 hours), river plumes can reach specific AOC beaches dependent on hydrodynamic conditions. After an intensive rain period it can take two days for bacterial pollutants from river plumes to reach beaches in Milwaukee. Table 11 shows the heaviest rains generally happen 24 hours before bacteria peak. Therefore, the advisory should be not lifted until 5 PM on day three as pollution sources are not limited to local runoff and could contain dilute levels of undocumented upstream sewage overflow.

Table 11. Peak pollutant concentrations, inches of rain on the corresponding day, and inches of rain 24 hours before the pollutant peak. Data is from sequential ISCO sampling 2009-2019 at Jones Island station. No CSOs or SSOs included in the dataset. Green = 0 – 1"; yellow = 1 – 2"; red = >2".

Date of peak	Peak EC (CFU/100mL)	Peak HUM (CN/100mL)	Peak Day Rain (in)	Previous Day Rain (in)	48 hr Rain Total (in)
9/11/2014	25	1751	0.01	0.3	0.31
7/8/2015	25400	4413	0	0.67	0.67
5/1/2019	80	1617	0.86	0.01	0.87
5/4/2018	135	41660	0.36	0.59	0.95
5/29/2013	1890	54089	0	1.17	1.17
7/28/2011	510	3472	0.4	0.81	1.21
5/14/2010	520	11381	0	1.23	1.23
9/9/2015	2090	4822	0.49	0.79	1.28
6/9/2009	1560	12102	0	1.29	1.29
5/23/2013	1730	4083	1.2	0.09	1.29
6/13/2015	1530	9922	0.02	1.28	1.3
10/24/2009	1960	22363	0	1.33	1.33
4/7/2010	360	59699	0.13	1.43	1.56
4/25/2010	670	9322	1.45	0.27	1.72
8/27/2019	1760	1381	0.52	1.67	2.19

4. In what circumstances are human fecal indicator bacteria present at the beaches?

Human fecal bacteria indicator markers warn of possible sewage contamination. After a CSO, human indicator markers can be found at Milwaukee beaches for up to **five** days after the overflow ends (Appendix B, Table 15). CSOs are often accompanied by SSOs. If these SSOs happen in upstream communities, they may not be reported to the City of Milwaukee but they can contribute to the human fecal indicator signal at Milwaukee's beaches. As sewage pollution carries a high risk to human health, a conservative approach should be taken after CSOs. Beaches should be closed if a CSO has occurred in the previous four days and beaches should be tested for human fecal bacterial indicators after three days, prior to opening the beach. (Beaches could be tested for human fecal indicator marker before three days when a CSO is considered a minor overflow in the river system **(≤ 10 MG).** If no human signal is detected, the beach can be opened.)

**Rain is reported in inches rather than centimeters in section 6.0*

7.0 MATERIALS AND METHODS

Beach sampling.
Three replicate samples were collected at each beach located south, middle, and north of the swim area. Grab samples were collected from 2008-2020 during a variety of weather events, including lowflow, light rain, heavy rain, and CSOs. Water was collected knee-deep in clean 1-liter Nalgene bottles along south to north transects; site maps and coordinates are in “Beach Summary” section. Some beach samples were concurrent with high frequency automated sampling in the estuary and on the Milwaukee River. Outfalls were sampled in wet and dry weather throughout the summer and fall by collecting flowing water discharged from outfalls into clean 1-liter Nalgene bottles or first collected in buckets if outfalls were submerged. In the case of submerged or partially submerged outfalls, samples were collected as close to the outfall pipe as possible. All samples were kept on ice and transported to the laboratory where they were processed for culture-based analysis and filtered for subsequent DNA extractions.

River, estuary and harbor sampling.
Water samples were collected during lowflow and rain events using a high-frequency automated ISCO sampler in the Milwaukee Estuary at Jones Island and on the Milwaukee River at the Cherry Street bridge. ISCO samples were collected over a 24-hour period and kept on ice during the collection process. Grab samples were collected from the Milwaukee harbor (coordinates: 43° 1'34.20"N, 87°52'54.90"W). All samples were kept on ice and transported to the laboratory where they were processed for culture-based analysis and filtered for subsequent DNA extractions.

Sand sampling
Berm sand was collected in sterile Whirl-Pak bags adjacent to the south, middle, and north water collection sites at Bradford and McKinley beaches. All samples were kept on ice and transported to the laboratory where they were immediately processed. To isolate cells from sand, 45 g of berm sand was shaken in 450 ml of sterile water for two minutes by hand. Extracts were filtered for microbial plate count analysis (1, 10, or 100 mL depending on expected *E. coli* levels) and for DNA extraction procedures 100 mL was filtered. Dry sand weight was determined after a 24 hr drying period at 45° C. A sieve shaker was used to determine the range of sand particle size by shaking approximately 130 g of sand through stacked sieves (sizes 4, 10, 20, 30, 40, 60, 140, and 200) for 10-15 minutes and weighing the amount of sand retained in each sieve.

Culture-based Analysis
Grab samples were processed and analyzed within four hours of collection. Samples collected with the automated sampler were held for a maximum of 24 hours on ice before analysis. Samples were filtered through a 0.45 micromillimeter pore-size nitrocellulose filter (47-mm diameter, Millipore, Billerica, MA). Filters were transferred to modified mTEC (membrane-thermotolerant *E. coli*) or mEI (membrane-Enterococcus Indoxy-ß- D-Glucoside) agar plates and incubated using standard EPA methods (USEPA, 2002; USEPA, 2014). Plates were removed after 24 hours and bacterial counts were reported as colony forming units (CFU)/100 mL.

DNA extraction and qPCR analysis
Samples were filtered and stored for future DNA extraction. A volume of 200 mL – 400 mL of sample was filtered onto a 0.22 micromillimeter pore-size mixed cellulose esters filter (47-mm diameter, Millipore, Billerica, MA). Filters were folded, placed in 2-mL screw cap tubes, and stored at -80° C prior to extraction. Samples were extracted using the MPBIO FastDNA SPIN Kit for Soil (MP Biomedicals, Santa Anna, CA)) and eluted with 150 microliters of DNase/Pyrogen-Free Water (DES). Quantitative polymerase chain reaction (qPCR) was carried out as previously described (Templar et al., 2016) using an Applied Biosystems StepOne Plus Real-Time PCR System Thermal Cycling Block (Applied Biosystems; Foster City, CA) and Taqman hydrolysis probe chemistry. Previously published primers and probe were used for human *Bacteroides* (HB assay that targets the HF183 marker) (Templar et al., 2016), human *Lachnospiraceae* (Lachno3) (Feng et al., 2018), *Catellicoccus*

marimammalium (Gull-2) (Lu et al., 2008, Sinigalliano et al., 2010), and dog *Bacteroides* (DogBact) (Dick et al., 2005; Sinigalliano et al., 2010) assay.

Metadata and meteorological measurements

Milwaukee Health Department *E. coli* counts (MPN/100 mL) were collected from the beach monitoring archive at *dnr.wi.gov*. Daily precipitation values were averaged from local rain gauges from the Milwaukee Metropolitan Sewerage District (MMSD). For precipitation categorization, lowflow bin was < 0.4/24h if lab metadata described rain as "light" and rain bin was ≥ 0.4"/24 h). Additional weather data, including hourly precipitation, wind speed, and wind direction were retrieved from the NOAA Climate Data Online System at the Milwaukee Mitchell Airport Station (Station ID 14839). Average wind direction was calculated in R using vector functions as established in Grange 2014. Wave data was collected from the NOAA Great Lakes Global Forecasting System (GLGFS). Geospatial data used was from the Wisconsin Department of Natural Resources GIS Open Data Portal.

Data analysis

The R suite of packages was used for all statistical analysis. All tests were considered significant at $p <= 0.05$.

The primary source(s) of *E. coli* were assessed in beach water samples with CFU counts ≥235/100 mL. Each beach has three sampling sites (biological replicates) and at least 2 of the 3 samples had to be ≥235CFU/100 mL for the collection date to be used in this analysis. Samples (n=154) were analyzed by qPCR for fecal markers HB (HF183), Lachno3, Gull-2, and DogBact. Boxplots of results were binned into precipitation categories of lowflow (<0.4/24h if lab metadata described rain as "light") or rain (≥0.4"/24 h).

Yearly records from NOAA NOWData for Mitchell Airport (https://nowdata.rcc-acis.org/mkx/) were used to pick above and below average rain months from the 2000-2020 monthly averages. Three years were picked pre- and post-remediation in both high and low rain categories for June, July, and August. *E. coli* counts (MPN/100 mL) for the same pre- and post-remediation months were collected from Milwaukee Health Department. To assess a significant difference in pre- and post-remediation *E. coli* concentration, the means were compared using Welch's independent sample t-test which accommodates unequal variance and sample size.

Bradford Beach was used to evaluate correlations between Gull-2 concentration and local weather and wave conditions as the site had a similar proportion of samples that were positive (54%) or negative (46%) for Gull-2 marker. In contrast for South Shore beach, >90% of the samples tested were positive. The Spearman's rank correlation (rho) was used to determine correlations between Gull-2 concentration and amount of precipitation, wind speed, wind direction, wave direction, wave period, and significant wave height.

To understand how bacterial pollutants may impact the nearshore during different weather events, we used a hydrodynamic model to illustrate the fate of both *E. coli* and HF183 marker at the nearshore. The model was previously constructed and validated in a collaboration with Dr. Hector Bravo (Bravo et al., 2017) and was adapted by Dr. Bahram Khazaei for data used in a 2018-2019 Milwaukee River plume study (McLellan et al., 2020). For this AOC beaches project model data was analyzed at beach and estuary sites following the initial model run. Using GIS, model coordinates and data attributes were geocoded to a grid of the study area. Grid cells were then selected for site specific analyses. The South Shore grid cell used was selected to be between two McLellan lab sampling locations at the current and proposed swim areas, and empirical data from the sites was averaged to compare to modeling results. To evaluate water quality benchmarks, the recreational water quality limit for *E. coli* (235 CFU/100mL) and the limit of quantification for the HF183 marker (225 CN/100mL) were used.

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Appendix A

*Table 12. Summary of samples used in different surveys for **Beach Closings Management Actions Project Assessments.***

Samples Table

	Bradford			McKinley			South Shore Current			South Shore Proposed			Bay View			Harbor		
	Rain	Lowflow	Mixed	Rain	Lowflow	Mixed	Rain	Lowflow	Mixed	Rain	Lowflow	Mixed	Rain	Lowflow	Mixed	Rain	Lowflow	Mixed
E. coli Sources	9	15	–	19	7	–	15	30	–	17	12	–	12	18	–	–	–	–
CSOs/SSOs	–	–	32	–	–	23	–	–	32	–	–	32	–	–	18	–	–	41
Ruminant	–	–	25	–	–	10	–	–	30	–	–	25	–	–	9	–	–	–
Remediation	–	–	893	–	–	–	–	–	367	–	–	–	–	–	–	–	–	–
Sand/Water	–	12	–	–	12	–	–	–	–	–	–	–	–	–	–	–	–	–
Nowcast	–	–	54	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

* EC source 2008-2019 (MCK had to go back to 2008. The other beaches went back to 2014.). EC counts >235 for at least 2 of 3 replicate sites. No CSOs
* CSOs 2008 and 2018. Persistance of sewage contamination and model validation (2018)
* Ruminant samples 2013-2018. MKE River high dicharge or RUM at MKE ISCO.
* Remediation samples 2004-2020. High Rain v Low Rain months. EC counts from MHD. Rain from NOAA weather service
* Sand/Water samples 2020.
* Nowcast 2017-2018. EC from MHD. Nowcast from Todd Miller

455 Total McLellan lab samples (Some overlap.)
1314 Total MHD samples

Figure 20. Stormwater outfalls surveyed at Bradford Beach. There are 6 additional outfalls on the south end of the beach that were not surveyed for this project.

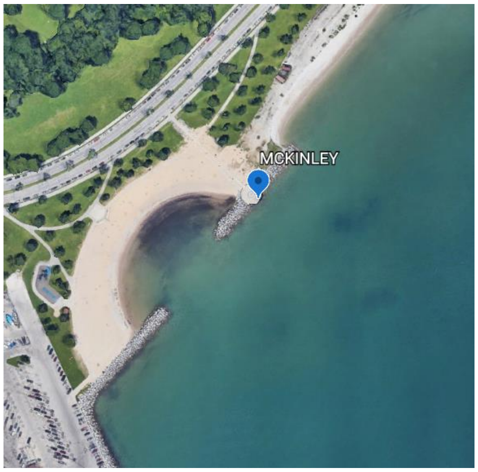


Figure 21. McKinley Beach stormwater outfall. The outfall is submerged.

Table 13. Genetic marker values per 100 mL of sample from AOC beach outfalls. Row highlighted in yellow was collected during a CSO.

FT Number	Date	Site	LACHNO3 HUMAN LACHNOSPIRACEAE (CN/100ml)	HF183 HUMAN BACTEROIDES (CN/100ml)	E. COLI (CN/100ml)
26660	10/12/20	BB OUT03	4796	14409	45333
26670	10/22/20	BB OUT03	0	BLQ	224
26671	10/22/20	BB OUT04	0	BLQ	665
26664	10/12/20	BB OUT05	294	BLQ	1043
26672	10/22/20	BB OUT05	0	0	677
26673	10/22/20	BB OUT06	BLQ	BLQ	0
26478	8/11/20	BB OUT08	0	0	0
26661	10/12/20	BB OUT08	12842	19117	509
26674	10/22/20	BB OUT08	0	0	0
26479	8/11/20	BB OUT09	0	0	0
26662	10/12/20	BB OUT09	0	BLQ	327
26675	10/22/20	BB OUT09	0	0	0
26480	8/11/20	BB OUT11	1887	291	2891
26663	10/12/20	BB OUT11	0	838	8376
26676	10/22/20	BB OUT11	33464	668	6444
26481	8/11/20	BB OUT12	BLQ	0	0
26482	8/11/20	BB RAVINEN	912	1822	21047
26642	9/29/20	BB RAVINEN	0	BLQ	2434
26647	9/30/20	BB RAVINEN	441	2765	93302
26655	10/12/20	BB RAVINEN	2227	2141	26657
26677	10/22/20	BB RAVINEN	6369	1183	11178
26483	8/11/20	BB RAVINES	0	BLQ	1340
26648	9/30/20	BB RAVINES	370	373	5873
26656	10/12/20	BB RAVINES	0	1813	40927
26678	10/22/20	BB RAVINES	0	BLQ	6677
26641	9/29/20	LOCUST OUT	0	0	20814
26649	9/30/20	LOCUST OUT	0	0	35361
26658	10/12/20	LOCUST OUT	0	1657	0
26680	10/22/20	LOCUST OUT	0	BLQ	343
26651	9/30/20	SOCCER OUT	0	0	5691
26657	10/12/20	SOCCER OUT	0	3132	88842
26679	10/22/20	SOCCER OUT	0	342	4115
NL 547	8/28/18	MCK OUT	1457	2052	603
26484	8/11/20	MCK OUT	0	0	0
NL 779	8/15/20	MCK OUT	0	0	0
26643	9/29/20	MCK OUT	0	0	0
26650	9/30/20	MCK OUT	0	0	0
26659	10/12/20	MCK OUT	0	0	0

Figure 22. Bay View Beach stormwater outfalls BV_OUT01, BV_OUT02 and old CSO gate.

Table 14. 2008-2016 BV_OUT01 assay results for FIB and genetic markers. FIB measured in colony forming units/100 mL and genetic markers measured in copy number/100 mL. Rows in red are positive for both human markers (Lachno3 and HB (HF183)).

FT	DATE	SITE	WEATHER	enterococci (CFU/100ml)	E. coli (CFU/100ml)	fecal coliform (CFU/100ml)	LACHNO3 (CN/100ml)	HB (CN/100ml)	E. COLI (CN/100ml)
4287	4/11/08	BV OUT	CSO	52	13	NA	225	1657	4949
4518	5/30/08	BV OUT	Heavy rain	1600	6400	NA	1092	3196	1476
4553	6/5/08	BV OUT	heavy rain	770	160	NA	426	1105	1140
4679	6/9/08	BV OUT	CSO/SSO	1200	3600	NA	65301	187543	14070
4701	6/10/08	BV OUT	CSO	800	2100	NA	2482	11816	1595
4775	6/11/08	BV OUT	CSO	180	430	NA	4297	11923	2264
4801	6/12/08	BV OUT	CSO	370	210	NA	1770	8576	842
4820	6/13/08	BV OUT	CSO	5000	1050	NA	499	5088	1696
4915	6/14/08	BV OUT	CSO	71	360	NA	2476	13253	1076
4938	6/15/08	BV OUT	CSO	260	190	NA	811	4854	458
4950	6/16/08	BV OUT	post CSO	23	160	NA	332	969	1043
5036	6/24/08	BV OUT	lowflow	174	96	NA	0	225	0
5404	7/23/08	BV OUT	lowflow	71	216	NA	0	0	387
5918	9/4/08	BV OUT	2.18	17000	14000	NA	245	2988	13547
6569	4/27/09	BV OUT	1.90	2400	900	NA	517	2278	435
6652	4/29/09	BV OUT	0	40	110	NA	5638	16741	1462
6861	6/8/09	BV OUT	1.26	420	140	NA	0	1151	545
7051	6/19/09	BV OUT	3.61	400	1800	NA	583	3884	2015
10855	6/22/11	BV OUT	0.27	12800	19200	NA	4225	17509	21291
10930	6/24/11	BV OUT	0	410	320	NA	0	0	323
11007	6/30/11	BV OUT	0	21	149	NA	0	0	242
11193	7/26/11	BV OUT	0	16	76	NA	0	0	0
11417	8/23/11	BV OUT	0	44	61	NA	0	0	0
11621	9/28/11	BV OUT		122	210	NA	0	0	456
13777	4/12/13	BV OUT	CSO/SSO	40	10	NA	2982	6723	476
16209	6/11/14	BV OUT	heavy rain	6400	3700	27000	379	1398	889
16490	6/17/14	BV OUT	heavy rain	7000	2900	NA	1063	3137	3189
16557	6/18/14	BV OUT	CSO	18500	3800	NA	257	2599	2785
16736	6/20/14	BV OUT	light rain	770	450	NA	2046	6067	896
16802	6/23/14	BV OUT	light rain	8100	3560	19700	296	1830	3244
16829	6/24/14	BV OUT	post rain	5000	1630	7200	0	731	894
16844	6/27/14	BV OUT	lowflow	120	40	560	0	225	0
16891	7/1/14	BV OUT	heavy rain	500	490	2800	0	509	551
17023	7/7/14	BV OUT	owflow; 0.21"	1340	1460	18100	264	4517	2338
17037	7/14/14	BV OUT	post rain	210	120	1500	0	855	225
17070	7/15/14	BV OUT	light rain	620	680	3600	0	734	795
17131	7/17/14	BV OUT	lowflow	21	20	54	0	0	0
17198	7/22/14	BV OUT	lowflow	29	26	2600	0	0	0
17222	8/1/14	BV OUT	lowflow	81	101	680	0	0	388
17242	8/7/14	BV OUT	lowflow	8	74	290	0	0	BLQ
17676	8/22/14	BV OUT	post rain	390	620	3600	0	343	754
17755	8/28/14	BV OUT	pre rain	291	192	540	0	225	228
17777	9/9/14	BV OUT	lowflow	61	111	310	0	0	0
17823	9/10/14	BV OUT	heavy rain	1800	1500	12000	2887	26672	3470
17928	9/11/14	BV OUT	post rain	120	220	280	0	225	315
21893	9/6/16	BV OUT	lowflow	19	8	290	0	247	0

Appendix B

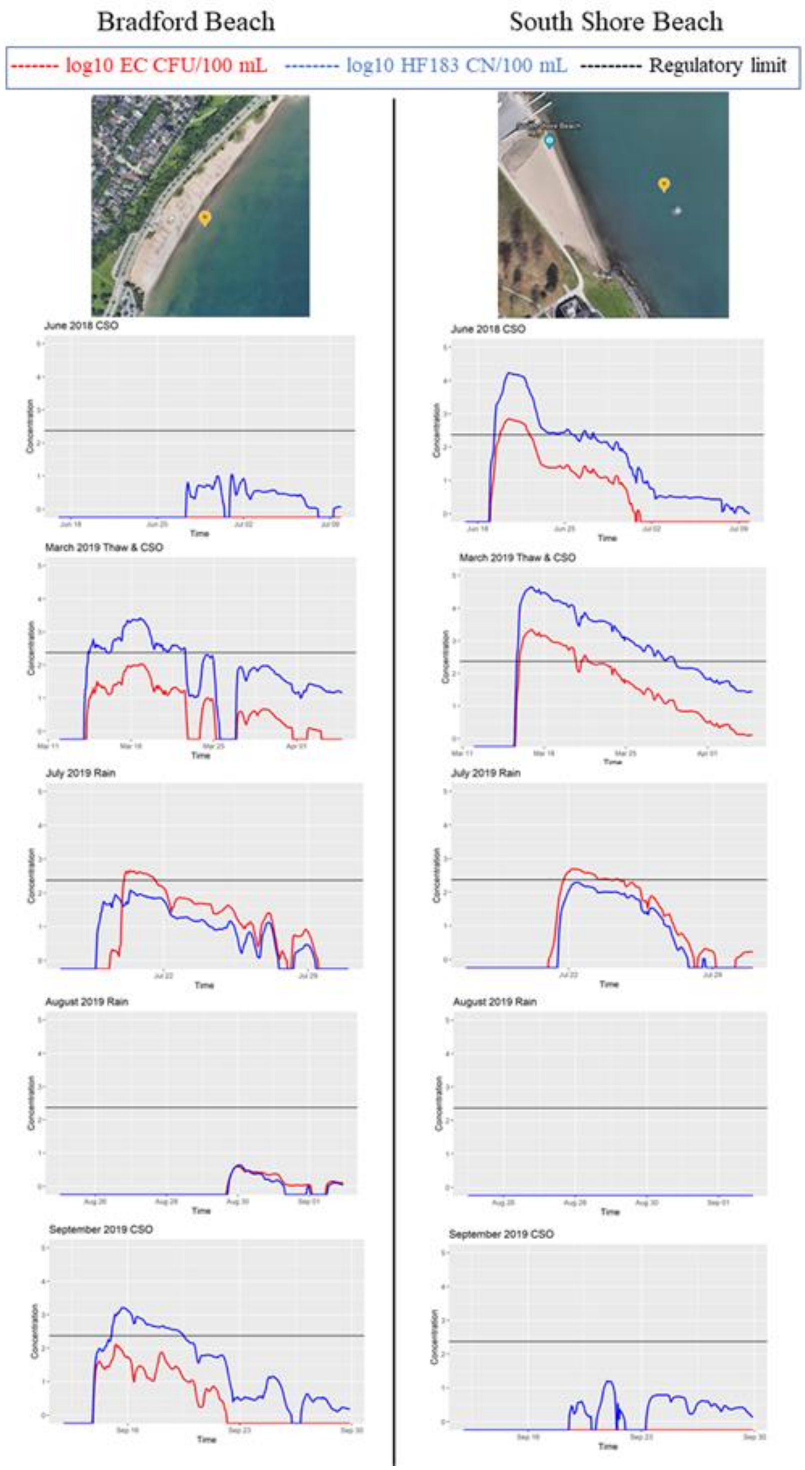


Figure 23. E. coli (EC) and HF183 marker concentrations predicted from hydrodynamic modeling at Bradford Beach and South Shore Beach. Modeled from rain event data with and without CSOs.

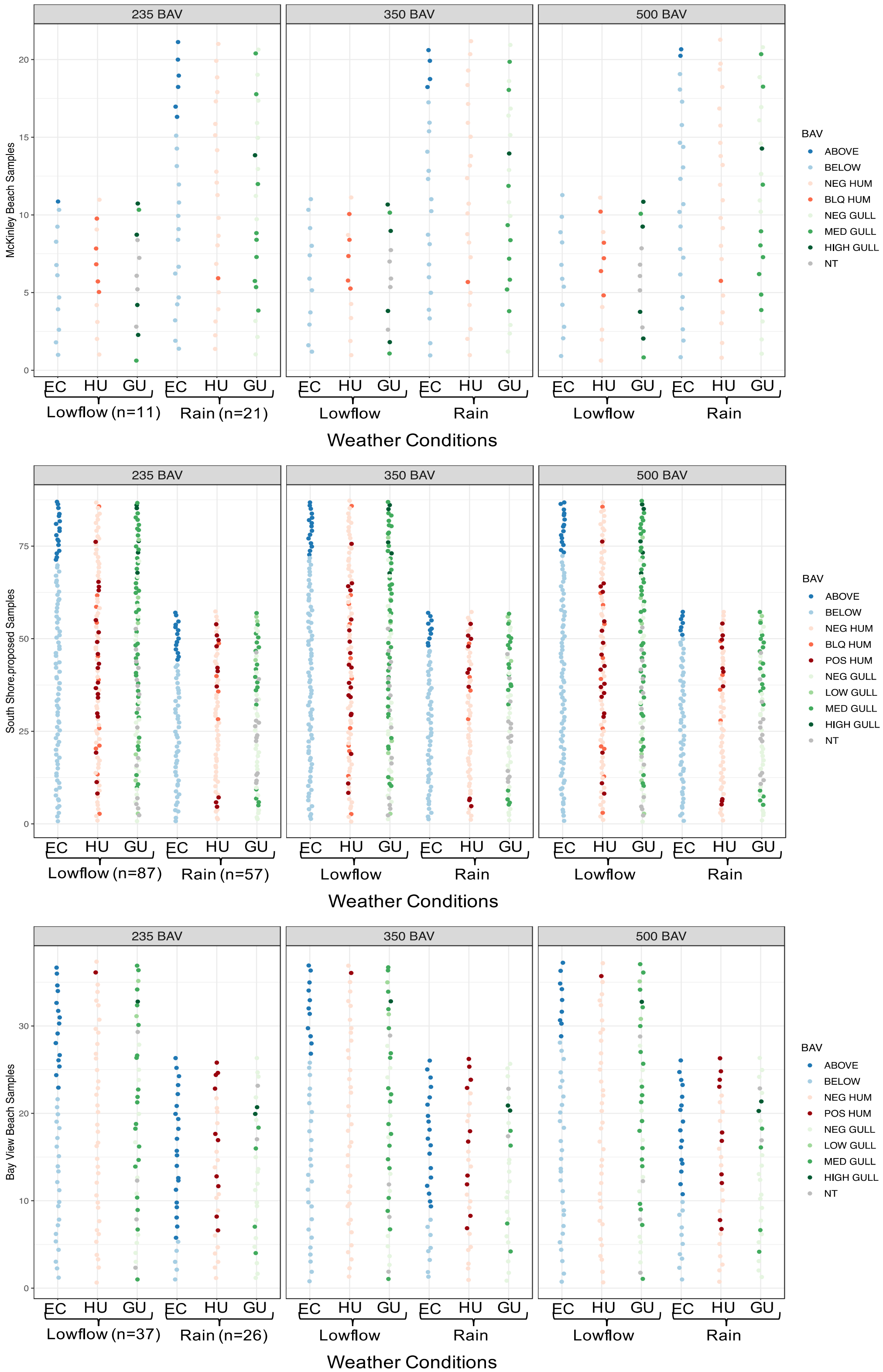


Figure 24. McKinley, proposed South Shore, and Bay View beach samples contaminated by human (HU) or gull (GU) markers at different BAV values in lowflow and rain conditions. E. coli (EC) counts were above (dark blue) or below (light blue) the BAV category at the top of the box. HU categorized as negative, positive, or below limit of quantitation (BLQ). GU categorized as negative (0), low (1-1000), medium (>1,000), high (≥50,000), or not tested (NT). No CSO/SSO in dataset.

Table 15. Duration of human marker signal after CSO begins. These are CSO events when beaches were sampled on enough post-CSO dates to be assessed for pollution longevity.

Dates when Human Markers were detected at AOC beaches 4-6 days after CSO			
Bradford Beach	6/9/08-6/14/08	7/23/10-7/29/10	–
McKinley Beach	6/9/08-6/13/08	7/23/10-7/27/10	–
current_South Shore	6/9/08-6/16/08	6/18/14-6/24/14	6/19/18-6/23/18
proposed_South Shore	6/9/08-6/16/08	6/18/14-6/24/14	6/19/18-6/23/18
Bay View Beach	6/9/08-6/15/08	6/18/14-6/23/14	–

Appendix C – Remediation Fact Sheet

AOC beach remediations **fact sheet**. Available at: https://sites.uwm.edu/mclellanlab/publications/#policy

Milwaukee AOC Beach Remediation

Overview of the Assessment

Remediation projects on two Lake Michigan beaches in Milwaukee, Wisconsin were evaluated for the impact they had on *E. coli* concentrations in beach water.

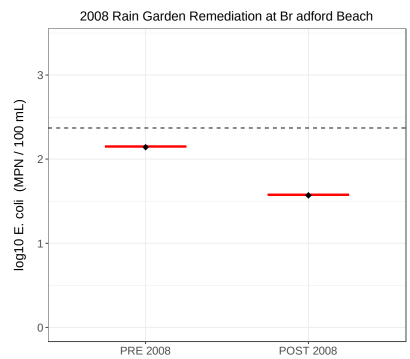
Assessment Questions

Are *E. coli* concentrations in beach water lower after remediation projects were completed at two of Milwaukee's **Area of Concern (AOC)** beaches?

Did the amount of precipitation during swim season impact the effectiveness of remediation?

Bradford Beach

Overall concentrations of *E. coli* found in beach water sampled PRE and POST 2008 rain garden installation at Bradford Beach stormwater outfalls.



Main Findings

Post-remediation beach water samples from **Bradford Beach** had a lower average *E. coli* concentration during the recreational season after the installation of rain gardens. Analysis by t-test showed the lower post-remediation average was statistically significant. Thus, remediation efforts at Bradford Beach were successful at lowering overall *E.coli* concentrations in beach water.

Additionally, the average *E. coli* concentration was significantly lower in both low and high rain swim months after remediation.

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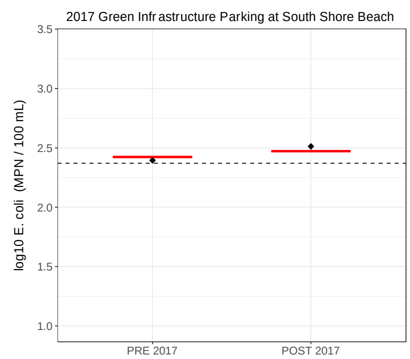
South Shore Beach

Concentrations of *E. coli* found in beach water sampled PRE and POST 2017 green infrastructure parking lot installation adjacent to the South Shore swimming area.



Figures: The *E. coli* counts (MPN/100 mL) were provided by Milwaukee Health Department and rain data was collected from NOAA weather service. Red line = average; black diamond = median; dotted line = *E. coli* advisory limit of 235 CFU/100 mL water sample

Note: The same datasets were used to analyze differences in average E. coli *concentrations in low rain versus high rain months during the swim season. Full results are available in the* ***Beach Closings Management Actions Project*** *final report.*

Post-remediation beach water samples from **South Shore Beach** showed a slightly higher average *E. coli* concentration during the recreational season compared with pre-remediation, but these differences were not statistically significant. However, it is important to note that there were only three years of sampling at the beach post-remediation and the findings may have been influenced by the high water levels of Lake Michigan in those years. By these data, the green infrastructure parking lot does not appear to be adequate in reducing *E. coli* concentrations in beach water and additional management measures are needed.

UWM School of Freshwater Sciences **July 2021**

More Information

Milwaukee, Wisconsin has four AOC beaches on Lake Michigan, and two of those beaches have undergone remediation efforts to help reduce *E. coli* counts in beach water. Stormwater runoff, moist sand, gulls, and mats of *Cladophora* algae can all be sources of *E. coli* in beach water.

In 2008 rain gardens were constructed around Bradford Beach stormwater outfalls to facilitate infiltration into the sand, thus naturally filtering the polluted stormwater that previously ran directly across the beach to the swimming area. Since then, beach sand is groomed on a daily basis and dogs are used to patrol the beach for gulls. Beach grooming and gull abatement reduce the *E. coli* concentration in sand and decrease the possibility that sand will be a reservoir of *E. coli* that continually pollutes beach water.

In 2017 a green infrastructure parking lot was constructed at South Shore Park adjacent to the swimming beach. The lot contains rain gardens, bioswales, trees and storm pipe drainage to limit direct stormwater pollution to the lake. The parking lot undoubtedly reduces runoff pollutants such as motor oil, chemicals, and sediments from reaching the water and it provides healthy ecosystem services. However, South Shore beach has poor water circulation (due to a breakwater) and its proximity to a marina make it a poor swimming area. The lake doesn't flush the beach with fresh water as it would an open lake beach. Redesignating the swimming area to 500 feet south of its current location, where there is an opening in the breakwater, is an alternative that could provide consistently lower *E. coli* concentrations at South Shore Beach. More information can be found in our information sheet *South Shore Beach: Improving beach health for swimming and recreation*.

Management strategies to keep beach water *E. coli* concentrations low

- Continue or begin gull abatement using patrol dogs, high grasses, educating beach goers and other deterrents.
- Continue beach grooming and minimize standing water with beach nourishment (replenishing sand) to limit establishment of *E. coli* reservoirs.
- Remove *Cladophora* mats.
- Monitor stormwater outfalls when present at beaches. Check outfalls for flow in dry weather and sewage contamination in stormwater runoff.

Green Infrastructure parking lot at South Shore Park. Photo by Deb Dila

This review was funded by the Great Lakes Restoration Initiative through Wisconsin Department of Natural Resources.

Data review was conducted by the McLellan lab at the University of Wisconsin-Milwaukee School of Freshwater Sciences. More information can be found in the final report which will be posted at https://sites.uwm.edu/mclellanlab/publications/

E. coli *concentrations were from the Milwaukee Health Department beach monitoring program archived at dnr.wi.gov and rain data was from NOAA weather service.*

Great Lakes RESTORATION

WISCONSIN DEPT. OF NATURAL RESOURCES

UNIVERSITY of WISCONSIN UWMILWAUKEE School of Freshwater Sciences

Appendix D – Beach Closure Decision Tree

Beach closures **policy brief.** Available at: https://sites.uwm.edu/mclellanlab/publications/#policy

Policy Brief August 30, 2021

Beach Closure Decision Tree

New data analysis helps refine Milwaukee Health Department's beach management plan

Key Message: Detailed analysis of beach and river data helped refine the decision process that precedes beach advisories and closures. River plume dynamics, *Escherichia coli* (*E. coli*) sources, pollutant peaks, and human fecal indicator bacteria were used to evaluate health risk associated with recreation at beaches in Milwaukee, Wisconsin.

Good Safety, Good Swimming

Beach closings and recreational restrictions due to high bacterial levels is a beneficial use impairment (BUI) for Milwaukee's urban beaches in the Milwaukee Estuary Area of Concern (AOC). To lift the impairment and delist the beaches, each public swimming beach within the AOC must meet one of the requirements below:

- Be open for at least 90% of the swimming season (between Memorial Day and Labor Day) averaged over a previous 5-year period based on Wisconsin Coastal Beach monitoring protocols for *E. coli* with BMPs in place.

OR

- Public swimming beaches within the AOC are meeting EPA's 2012 recreational water quality criteria over a 3-year period.

Alternatives to the above conditions can be used when sources of bacterial contamination to the beaches are known and controlled through BMPs. These alternatives can be found in the 'Beach Closings' section of the 2020 Removal Target Updates for the Milwaukee AOC.

Can current safety criteria be improved

Questions

- When *E. coli* counts are at the advisory limit, are the sources of *E. coli* a risk to swimmers.
- How many inches of rain must fall before it is likely that the plume from Milwaukee's 3 rivers will reach the beaches.
- If rainfall is more than 2 inches, how long will it take pollutants from the rivers/harbor to reach the beaches.
- In what circumstances are human fecal indicator bacteria present at the beaches.

Bacteria

E. coli is the fecal indicator bacteria used as a proxy to warn of possible sewage contamination in Wisconsin recreational waters. The Beach Action Value (BAV) that is used to inform the public of possible swimming risk is an *E. coli* count of ≥ 235 CFU/100 mL in beach water. In water samples from Milwaukee's AOC beaches we found that gulls, not humans, were the primary source of *E. coli* when counts were ≥ 235 CFU/100 mL. Gull indicator marker was present in 53-92 percent of samples dependent on beach. Additionally, we found that changing the *E. coli* BAV to ≥ 500 CFU/100 mL did not increase the chances that swimmers would come into contact with sewage contaminated water at these beaches. In future, a BAV of ≥ 500 CFU/100 mL would increase opportunity for people to recreate at beaches that are open more frequently.

Regional Hydrodynamic Modeling

When it rains 1" or more within a 24-hour interval, Milwaukee beaches are posted with advisories for 2 days and advisories are removed the 3rd day at 5 PM. However, our modeling suggests that pollutants from the rivers will not reach the beaches at this level of precipitation. For rain of 1"-2" in a 24-hour interval, the advisory could be lifted the morning of the 3rd day as local runoff, not regional pollution, is the source of high *E. coli* counts in beach water. The low-risk sources of *E. coli* in local runoff are birds and other wildlife. An exception to this pattern is if there is a nearby stormwater outfall with sewage contamination; in this case, the water should be tested for human fecal markers before removing the advisory.

Policy Recommendation: Use revised decision tree for beach advisories and closures. When assessing the Beach Closings (Recreational Restrictions) BUI, use BAV of 500 MPN-or-CFU/100 mL for advisories instead of 235 MPN-or-CFU/100 mL.

Pollutant Delivery

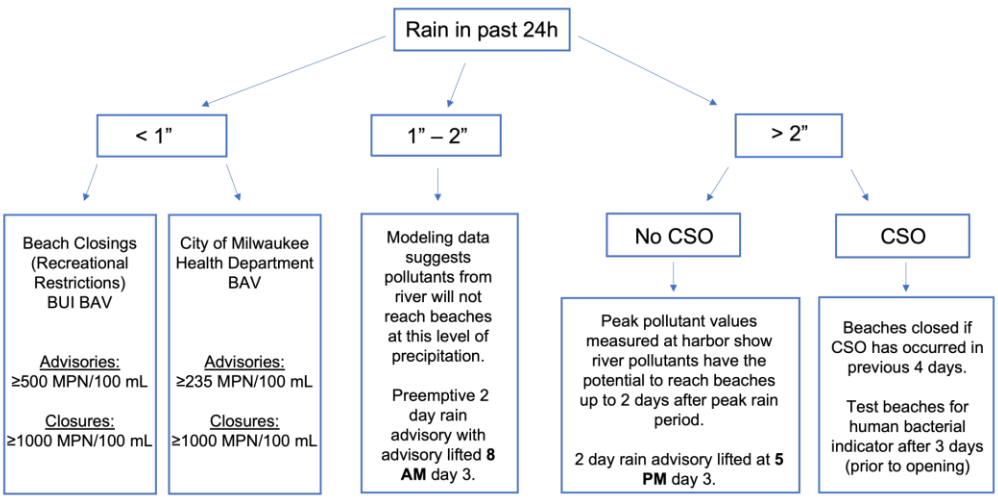
In heavier rains (>2" in 24 hours), river plumes can reach specific AOC beaches dependent on hydrodynamic conditions. After an intensive rain period it can take 2 days for bacterial pollutants from river plumes to reach beaches in Milwaukee. Therefore, the advisory should be not lifted until 5 PM on day 3 as pollution sources are not limited to local runoff and could contain dilute levels of undocumented upstream sewage overflow.

Sewage Indicators and CSOs

Human fecal bacteria indicator markers warn of possible sewage contamination. After a CSO, human indicator markers can be found at Milwaukee beaches for up to **5** days after the overflow ends. CSOs are often accompanied by SSOs. If these SSOs happen in upstream communities, they may not be reported to the City of Milwaukee but they can contribute to the human fecal indicator signal at Milwaukee's beaches. As sewage pollution carries a high risk to human health, a conservative approach should be taken after CSOs. Beaches should be closed if a CSO has occurred in the previous 4 days and beaches should be tested for human fecal bacterial indicators after 3 days (prior to opening the beach).

Beaches could be tested for human fecal indicator marker before 3 days when a CSO is considered a minor overflow in the river system **(≤ 10 MG).** If no human signal is detected, the beach can be opened.

Beach Closure Decision Tree



Conclusions

Following these revised guidelines will keep the recreating public safe while possibly reducing the number of days the beaches are in advisory or closed during the swim season. Reducing the number of advisory or closed days will move the AOC closer to removal of the beach closings (recreational restrictions) BUI.

Additional Readings

- Dila et al., 2021. Beach Closings Management Actions Project. Final Report
- Wisconsin Department of Natural Resources, Office of the Great Waters, 2020. Removal Target Updates for the Milwaukee Estuary Area of Concern. Page 22
- McLellan et al., 2018. Sewage loading and microbial risk in urban waters of the Great Lakes. Elem Sci Anth, 6.
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