Russell Avenue Slip Technical Report

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Summary:
The McLellan lab has monitored the presence and abundance of fecal indicator bacteria (FIB) and human fecal bacteria in the Russell Avenue slip since 2008. The combined sewer overflow (CSO) outfall that discharges into the slip may be a source of sewage under non-CSO conditions. The source of human indicators detected near the Russell Avenue slip was investigated. Field visits were done to track the storm water and sanitary pipes that were in proximity of the slip. Previous data was examined to identify patterns of human fecal bacteria near the Russell Avenue slip and their relationship to rainfall and lake conditions. Sampling was conducted along a transect from the Russell Avenue slip to South Shore beach, with intensive sampling performed during 2014-2015 bathing seasons. These data were analyzed to determine if the Russell Avenue CSO outfall is a source of fecal bacteria to the beach. The slip is definitely a source of human fecal bacteria to the beach under CSO conditions. However, although sporadic high levels of human markers were observed in the slip under non-CSO conditions, a corresponding elevation of human markers was not necessarily seen at the Yacht Club sample location or either the existing or proposed beach locations. Low levels of human indicators (near the limit of method detection) were often present at the existing beach location when no human markers were observed in the slip. Thus, a minor source of human fecal inputs still needs to be identified.

Introduction:
The presence of the human indicators *Bacteroidales* (HB) and *Lachnospiraceae* (Lachno2) has been used as evidence of human fecal contamination. South Shore Beach and the Russell Avenue (RA) slip sampling sites have a history of human indicators present during not only Combined Sewer Overflow (CSO) events, but during rain and baseline conditions as well. Determining the source of the human indicators is a challenge because there is no clear spatial or temporal pattern pointing to a specific location of origination or set of influential conditions.

Our investigation attempted to answer the following questions: 1) what are the potential contributors of human fecal pollution to the RA slip? 2) is the RA CSO outfall a continuous or variable source of sewage to the environment, and what factors drive these fluxes? 3) is the RA CSO outfall the source of the human fecal bacteria found at South Shore Beach? and 4) what are other possible sources of human fecal contamination at SS Beach?

The RA slip has a combined sewer overflow (CSO) outfall located on the south wall. Human indicators have been detected directly at the outfall's opening in the surface water and at the mouth of the slip. (Samples designated "RUSSAVE 50" are collected in the slip directly in front of the CSO outfall, either at the surface or slightly submerged; "RUSSAVE 100" samples are collected at the very end of the slip where Lake Michigan water mixes in.) However, the presence of human indicators is variable over both short and long timescales, and it is unclear whether or not the RA slip is a source of contamination to the sample sites adjacent to the yacht club and South Shore beach. A number of other potential sources of human fecal contamination are located in proximity: a marina located between the RA slip and extends to just south of South Shore Beach and filled with docked watercrafts during the summer; a yacht club with restroom facilities; an outfall located to the south at Bay View Park that has also been found to have a sewage signal; daily effluent from the Jones Island WRF; and South Shore Pavilion, which was originally constructed over 80 years ago and may have failing laterals or sewer connections. The RA slip is located downhill from a park, where there are paved parking lots, residential housing and apartment complexes. Multiple sources could contribute to the human fecal contamination that is ultimately detected at the beach. If a sewage source to the RA slip can be identified, investigations into whether it is a constant source or if specific conditions such as weather or lake level conditions affect these sources, should be pursued.

Figure 1. Map of Russell Ave Slip, Yacht Club, and South Shore Beach sampling sites

The McLellan Lab has two sample sites located by the outfall in the RA slip, as well as two along the shoreline by the South Shore Yacht Club, three at South Shore Beach and three at a previously proposed "new beach" (also called "Rocky Beach"), located approximately 150 m further south (Figure 1).

South Shore beach experiences a significant number of warnings and closures due to elevated levels of *Escherichia coli* (*E. coli*) each summer during the bathing season, with the current location of the beach typically having significantly higher levels than at the proposed location for a new beach to the south (Figure 2). Boxes in Figure 2 show the quartile ranges (25-75%) for *E. coli* CFU/100 mL for the two beaches from the 2013-2015 bathing seasons under baseline (no rain), light rain, and heavy rain conditions. On average, a rain event results in *E. coli* concentrations exceeding the recreational water quality standard of 235 CFU/100 at the existing location, but not at the proposed site. Note that CSO events were excluded from this dataset.

In fall of 2015, we conducted a series of field investigations to identify the source of the human fecal bacteria and determine if weather or lake conditions affect the concentrations of these bacteria. Since human indicators have been detected previously near the RA outfall, one source of human fecal indicator bacteria (HFIB) may be coming from stormwater connections to the outfall. Investigations were done to intensively examine the sewer infrastructure in proximity of the slip. Comparisons between rainfall and lake levels over the span of sample collection dates were used to identify if any correlations exist.

Milwaukee Metropolitan Sewerage District (MMSD) facilitated tracking numerous sanitary and stormwater pipes located in the area above the RA slip (see Figure 3). Water collection by both grab samples and an automated sampler were used to determine if human indicators were present and at what concentration.

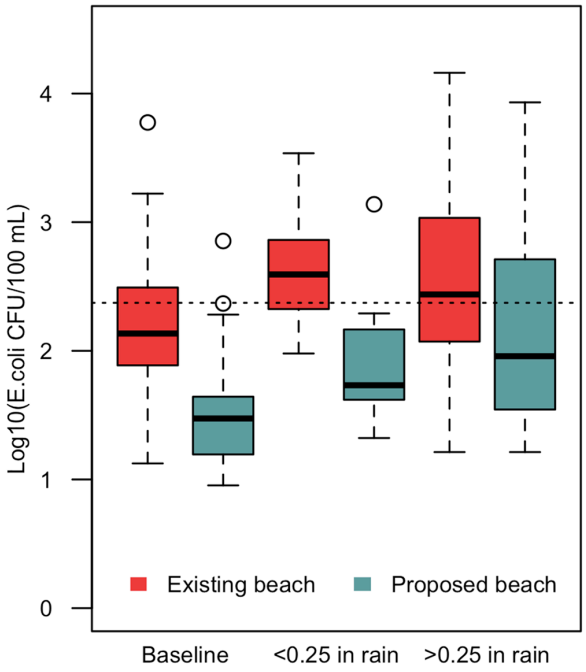


Figure 2. E. coli concentrations at South Shore beach for the existing and proposed locations under different weather conditions (2013-2015).

Potential Contributors of HFIB to the Russell Avenue Slip

With the assistance of MMSD, we explored the flow in sanitary and stormwater sewer pipes near the RA Slip, the structure of the Near Surface Collector (NSC) and its connection to the CSO outfall, an additional outfall in the slip across from the CSO outfall, and potential connections to the old KK River Flushing tunnel at the west end of the slip.

Stormwater and sanitary sewer flows. The first access point to the stormwater system is a manhole on the corner of East Ontario Street and South Shore Drive as shown in Figure 3. Here, there is a 15" stormwater pipe that discharges into the outfall structure below the gate for the near surface collector. During the initial visit, the manhole at the first access point was opened to identify pipes leading up to this site and determine the direction from which they are coming. One pipe, originating from the north on South Shore Drive, drains to this site. A pipe coming from the west had been bulkheaded (blocked with cement), as well as another bulkheaded pipe from the northeast that was from curbside catch basins. MMSD installed an automated sampler at this location on October 21, 2015 and collected water during rain events on October 28, 2015 and November 6, 2015.

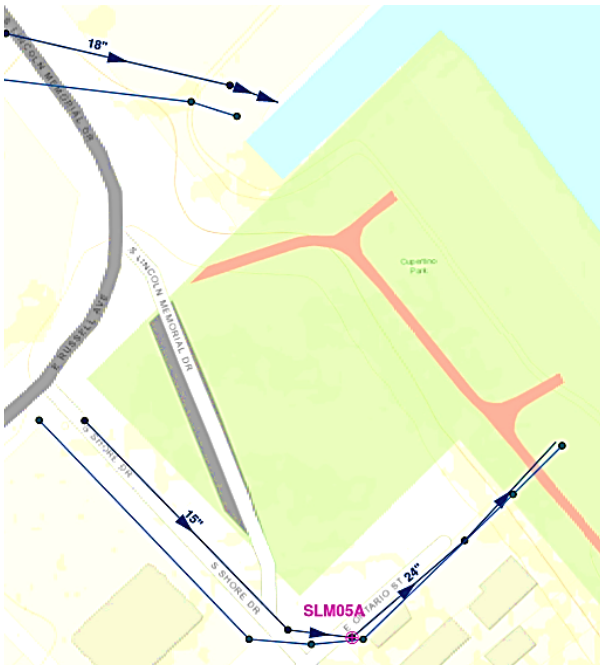


Figure 3. Ontario Street and S. Shore Street manholes, including location of inline sampler (SLM05A). Image source: Milwaukee Metropolitan Sewerage District

MMSD aided in a second investigation on December 7, 2015 that examined the 24" sanitary sewer pipe adjacent to the 15" stormwater pipe that housed the sampler at site SLM05A. This sanitary sewer pipe serves a large apartment complex on the corner of South Shore Drive and Lincoln Memorial Drive.

During this visit it was confirmed that the sanitary pipe from the apartment building flows north into another sanitary pipe running west along Lincoln Memorial Drive, parallel to the CSO system, and showed no connection to the stormwater pipes. Seven other nearby manholes were investigated as potential sources of human fecal contamination to the RA outfall, but were eliminated due to either lack of flow, or flow in the wrong direction.

Dye testing was performed on a terminal manhole (likely the first in the line of the stormwater system, or an overflow?) at the intersection of Russell Ave. and Lincoln Memorial Ave., located in the grass directly above the KK Flushing Tunnel; but no dye was observed in the slip, and water flowed west into the CSO system. A visual inspection of this manhole was performed with a submersible camera (Dec 8, 2015) and provided evidence that there was no connection or opening to the east.

Near Surface Collector. An initial examination of the NSC provided visualization of the system components, including the gate leading to the CSO outfall. Standing water was visible on both sides of the chamber-- from lake water intrusion on the outfall side, and presumably stormwater-sanitary sewage on the collector side. The gate of the Russell Avenue CSO from the NSC should remain closed unless there is a CSO event in which the inline storage system ("deep tunnel") reaches capacity. MMSD records show that the RA CSO outfall discharged five times from 2011-2015: 6/21/11 (1 MG), 4/10/13 (1 MG), 4/18/13 (1 MG), 6/18/14 (0.5 MG), and 4/10/15 (1 MG). Residual combined sewage/stormwater in the tunnel between the NSC and CSO outfall may therefore be a residual source of human indicators that would be expected to decrease with time from the most recent CSO and could be driven by local seiche and changes in lake levels.

RA Slip Stormwater Outfall. We investigated an additional outfall on the north side of the RA slip as another potential source of sewage contamination. We tracked the pipes leading to this outfall with the MMSD field crew, and found that the outfall drains a very limited area including two parking lots to the north. Based on MMSD maps and field

observations, only stormwater lines connect to this outfall. One sample collected from that outfall in Aug. 2015 revealed high FIB concentrations but no human fecal indicators.

KK Flushing Tunnel. The KK Flushing Tunnel, located at the western end of the RA slip, formerly served to transport Lake Michigan water to an upstream location of the KK River in order to displace dirty water and sewage that would stagnate there during periods of low flow. As such, the tunnel should be filled with lake water and should not be a source of fecal pollution to the slip. However, decreasing lake levels could result in an efflux of water from the tunnel along a reduced pressure gradient, potentially contaminating the slip with any fecal bacteria that were introduced to the tunnel upstream. This scenario has a low likelihood of occurrence, but was examined to eliminate all possible sources. A utility manhole that provided access to the flushing tunnel was observed directly above the flushing tunnel, at the bottom of a hill ~10 m below the terminal stormwater outfall on Russell Ave and Lincoln Memorial described above. The manhole was bolted to prevent opening, likely due to the probability of surcharge from that manhole during high lake levels.

Contributions from Upstream Sources (Sampling and Analysis Results)

Inline sampling upstream of RA outfall. During the time frame that the automated sampler was set up, two rain events occurred that triggered collection from sampling site SLM05A. Following a 0.53" rain event on October 27th, and 0.34" of rain on October 28th, the first set of inline samples were collected on October 28. The second collection date (November 6, 2015) occurred after 0.24" of rain. The automated sampler collected two samples on each date, one after the initial rainfall ("first flush"), labeled SLM05A01, followed by a second collection a short time later, SLM05A02 (Figure 4 and Table 1).

Samples were collected from all three sites (SLM05A, RUSSAVE50 and RUSSAVE100) on October 28th, 2015. The latter two were collected as grab samples by the McLellan lab. Only inline samples were collected on Nov 6. The "first flush" from SLM05A showed higher amounts of fecal contamination during both rain events, which would be expected as that contains any remnants of fecal matter that may have been sitting within the pipes. The water samples collected from East Ontario Street and South Shore Drive, at sample site SLM05A, had high concentrations of the HB marker present and very low (limit of detection) concentrations of Lachno2. We believe that this type of mismatch in human indicators is typically due to raccoon waste. On October 28, the sample site RUSSAVE50, which is right outside the CSO outfall, had no detectable human indicators. Sample site RUSSAVE100, at the end of the slip, had only low levels (at the limit of detection) of the HB marker (Table 1). During the second field visit, raccoon stool was found in a stormwater pipe just upstream of where the automated sampler was installed. Thus it is likely that this fecal material contributed to the positive HB but negative Lachno2 results. Raccoon waste would not explain the results on November 6, 2015 and in the RA slip since both markers were detected at similar levels.

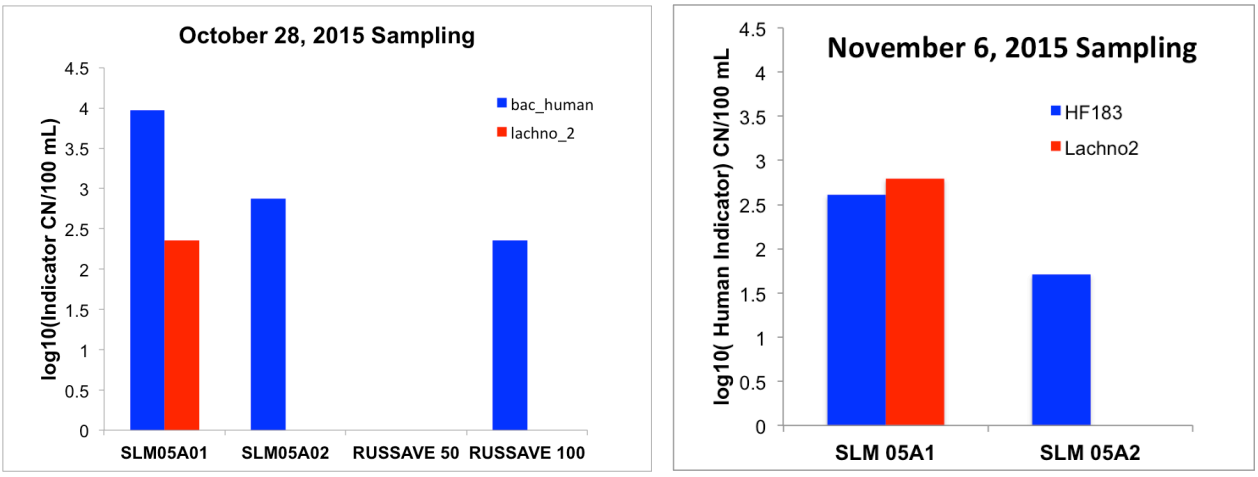


Figure 4. Human indicator marker densities in A) stormwater (inline sampling) and RA slip, Oct. 28 and B) stormwater, Nov 6.

Table 1. Human indicator results from Russell Avenue slip and SLM05A sample sites on Oct 28 and Nov 6 sampling dates.

	Sampling Sites	HB	Lachno2
October 28, 2015	SLM05A01	9280	225
	SLM05A02	740	0
	RUSSAVE50	0	0
	RUSSAVE100	225	0
November 6, 2015	SLM05A01	405	624
	SLM05A02	BLD	0

Near Surface Collector. Water was collected from the NSC on December 7, 2015 and analyzed only for *E. coli*, enterococcus, and fecal coliforms by plate counts and human indicators by qPCR. All of these indicators were at or near zero (1 fecal coliform/100 mL was detected), suggesting that the water contained there presently does not harbor significant levels of sanitary sewage.

RA Slip Outfall. We were unable to collect samples from the non-CSO outfall that drains to the RA slip during our fall sampling, but one sample was collected on Aug 10 2015, along with samples from RUSSAVE 50 and RUSSAVE 100. This outfall was negative for human indicators, but had high levels of E. coli and enterococci, as did the two sites within the slip (Figure 5). This is unlikely to be a source of human indicators in general, as it appears to be more newly constructed pipes and only drains parking lots. It may be consistent source of FIB during rain events though.

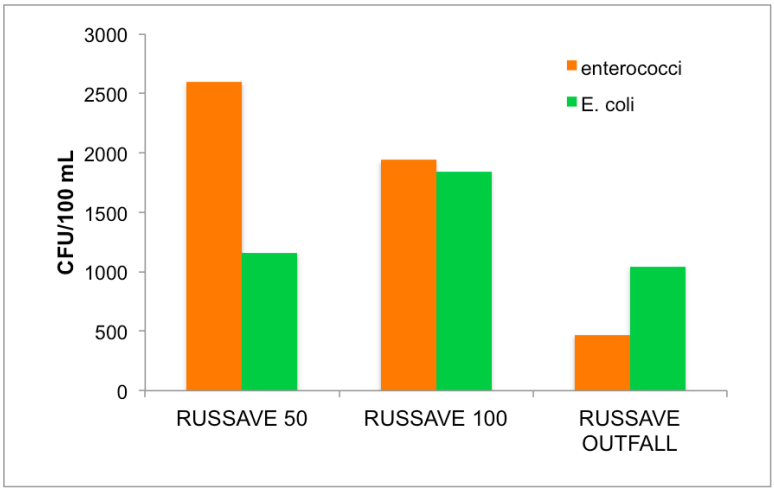


Figure 5. Enterococci and E. coli counts for the non-CSO outfall and sites within the RA slip

KK Flushing Tunnel. The manhole to the tunnel was removed on Dec 7, 2015 and visually examined. This structure led to a chamber that was filled with water and a large amount of floating trash, including food wrappers and a large tackle box. The origin of these items is likely from the slip, confirming that there is flow from the lake/slip into the tunnel. FIB counts in tunnel water were extremely low, ranging from 0-8 CFU/100 mL. While this one sample cannot rule out the flushing tunnel as a source of human fecal inputs, it seems unlikely. The absence of human indicators for this and NSC water was confirmed with qPCR.

Russell Ave CSO Outfall is a Variable Sewage Source

Historical Data Trends. We compiled all available human indicator data on samples collected from Russell Ave between 2011 and 2015. Through a Sea Grant project (2014-2015), the RA slip was sampled frequently during the bathing season. Only one CSO event occurred during the summer sampling (Table 2). A CSO event also occurred in April both years prior to commencing summer sampling. In 2014 the outfall appeared to be a variable source of sewage, testing highly positive for both HB and Lachno2 immediately following a CSO event (highlighted in orange), with positive and negative results occurring intermittently until August, after which only one weakly positive result for RUSSAVE 100 was observed. The overall trend appeared to be a decrease in the quantity of human indicators (when present) with time post-CSO,

suggesting that there could be remnants from the June CSO event that slowly washed out. In 2015, no summer CSO occurred, and no obvious trends were present. Human indicators were negative or at detection limits for the majority of samples. A blending event occurred on November 18 that would not have resulted in releases from the CSO outfall. However, HFIB levels were the highest recorded in 2015, suggesting that discharge from the blending event to the harbor may be a potential source of HFIB to the slip in addition to the CSO outfall.

Table 2. *Human indicator qPCR results from Russell Avenue slip 2014-2015. Data is color-coded by event type: grey=rain, red=CSO, orange=post CSO, green=blending, non-shaded=baseline.*

	HB (*Bacteroidales*)		**Lachno2 (*Lachnospiraceae*)**	
Date	**RUSSAVE 50**	**RUSSAVE100**	**RUSSAVE 50**	**RUSSAVE 100**
6/9/14	736	607	347	607
6/11/14	301	355	682	355
6/12/14	4275	3157	3376	3157
6/17/14	416	490	399	490
6/18/14	13249793	4353781	35196512	4353781
6/19/14	14169	17173	23437	17173
6/20/14	8489	7712	9470	7712
6/23/14	226	BLD	273	BLD
6/24/14	0	0	0	0
6/27/14	0	0	0	0
7/1/14	2901	1741	1642	1741
7/2/14	BLD	BLD	0	BLD
7/7/14	0	BLD	360	BLD
7/14/14	1107	675	586	675
7/15/14	694	591	482	591
7/16/14	329	BLD	BLD	BLD
7/17/14	BLD	0	0	0
7/22/14	0	0	0	0
8/1/14	0	0	0	0
8/7/14	0	233	0	233
8/21/14	0	0	0	0
8/22/14	0	0	0	0
8/28/14	0	0	0	0
9/9/14	0	0	0	0
9/10/14	0	0	0	0
9/11/14	0	0	0	0
4/10/15		NOT	SAMPLED	
5/21/15	0	0	109	0
5/26/15	BLD	BLD	0	BLD
6/1/15	597	BLD	275	BLD
6/12/15	BLD	0	BLD	0
6/19/15	0	0	0	0
6/23/15	0	0	0	0
6/29/15	0	0	0	0
7/7/15	0	0	0	0
7/13/15		0		0
7/14/15	0	0	0	0
7/23/15	0	BLD	0	BLD
7/24/15	0	BLD	0	BLD
7/25/15	696	696	865	696

7/26/15	0	0	0	0
7/27/15	0	0	0	0
7/30/15		554		554
8/5/15	2752	524	3567	524
8/10/15	0	BLD	0	BLD
8/11/15	3012	0	4968	0
8/17/15	0	226	0	226
8/18/15	262	0	0	0
8/31/15	0	BLD	0	BLD
10/20/15		0	0	0
10/22/15	0	0	0	0
10/28/15	0	0	0	0
11/18/15	1080	2772	5055	2772
11/19/15	8626	7564	7756	7564

Effects of Rain Events. Samples were taken from the RA slip during baseline (no rain), light rain, heavy rain, and post rain events to determine if there was a relationship between precipitation amount and the concentration of indicators. The question to be answered was: does rain drive sewage contamination; and if so, do heavier rains result in higher HFIB levels? It would be expected that if the source of the human fecal bacteria to the outfall were coming from a sanitary pipe, it would be present during wet and dry periods because the contamination source would be constant. Rain could either increase flows in the pipe, driving sewage outward into the slip, or dilute a consistent sewage signal.

Under nearly all conditions, human indicators were detectable, but below the threshold to be considered positive for sewage. We have previously used a minimum threshold for concern because human markers are prevalent almost ubiquitously at low levels in urban waters such as rivers. These thresholds (1000 CN/100 ml for HB and 1500 CN/100 ml for Lachno2) are shown in Figure 6 as the dashed blue and red lines on the graphs. On average, RUSSAVE 50 had a strong sewage signal only during and immediately after CSO events. When samples taken during these events are removed, the mean values for human markers are below the threshold level under all conditions. Furthermore, the concentration of human markers under different conditions did not correlate with FIB, suggesting that fresh sewage is not the source of the FIB. For detailed data on individual sampling days, see Appendix A, which includes transect plots of all sampling dates for which qPCR was run for human fecal markers. Baseline, heavy rain, and post rain conditions showed similar trends in human fecal indicator abundance, with average values below the threshold to be considered sewage contamination but within the range of quantification. Concentrations at RUSSAVE 50 generally tended to be higher than RUSSAVE 100, which suggest contamination is originating from the RA slip but that the contamination may be residual sewage from the most recent CSO event.

Lake Level Impacts. We also explored the possibility that lake water levels could affect the concentration of indicators present in the slip, with the hypothesis that lower lake levels would correlate to higher HFIB concentrations. The tunnel leading up to the CSO is filled with lake water to support the tunnel, so the water levels between the CSO gate and outfall opening may fluctuate with the lake's water levels. A higher lake level should force lake water back into the pipe, filling it completely; but low lake levels might result in outflow of water. Lake level effects on the CSO outfall can be visualized on a daily basis; on some days the outfall is completely submerged and on others, the opening is partially visible.

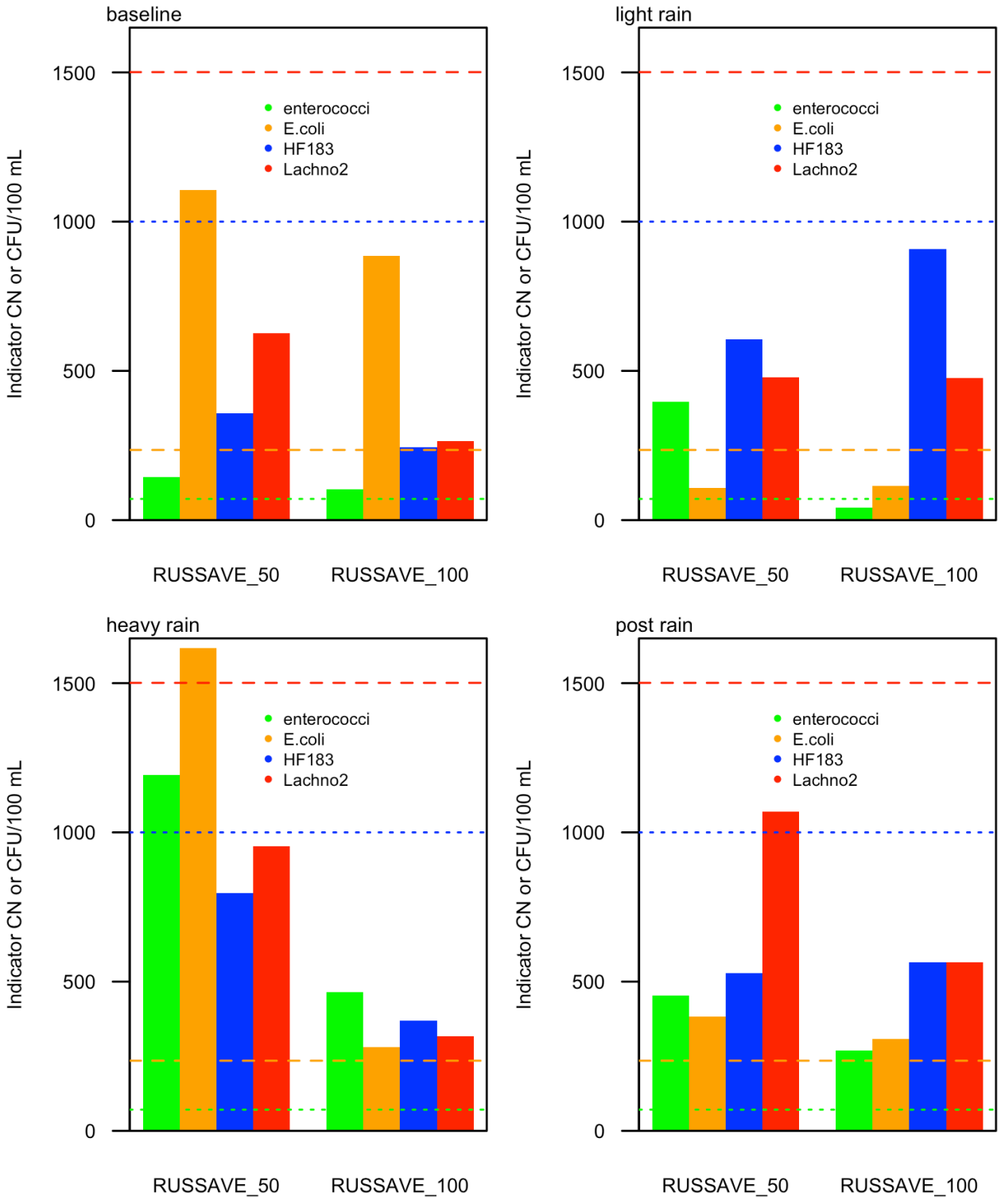


Figure 6. FIB and HFIB concentrations at the Russell Avenue slip under different weather conditions (no rain/baseline, light rain, heavy rain (>0.5"), and post rain).

Samples collected at the slip from 2011-2015 were analyzed for HB and Lachno2 markers and compared to mean lake levels to determine if any correlation exists (Figure 7). Among the years sampled, 2015 had the highest water level and

the lowest concentrations of human indicators. The lake's water level has been gradually increasing over the past four years, which may be the cause of lower incidence of HFIB in the slip in 2015, in addition to the absence of a summer CSO event. Lower human indicator presence during higher water levels may be because the lake water inside the CSO outfall is too high to allow outflow of residual contamination. These results can be verified by continued collection of samples under different lake levels. Blending events (shown in green in Figure 7) are included to show that discharges from rivers and/or effluent from Jones Island may reach the slip during high flow storm events.

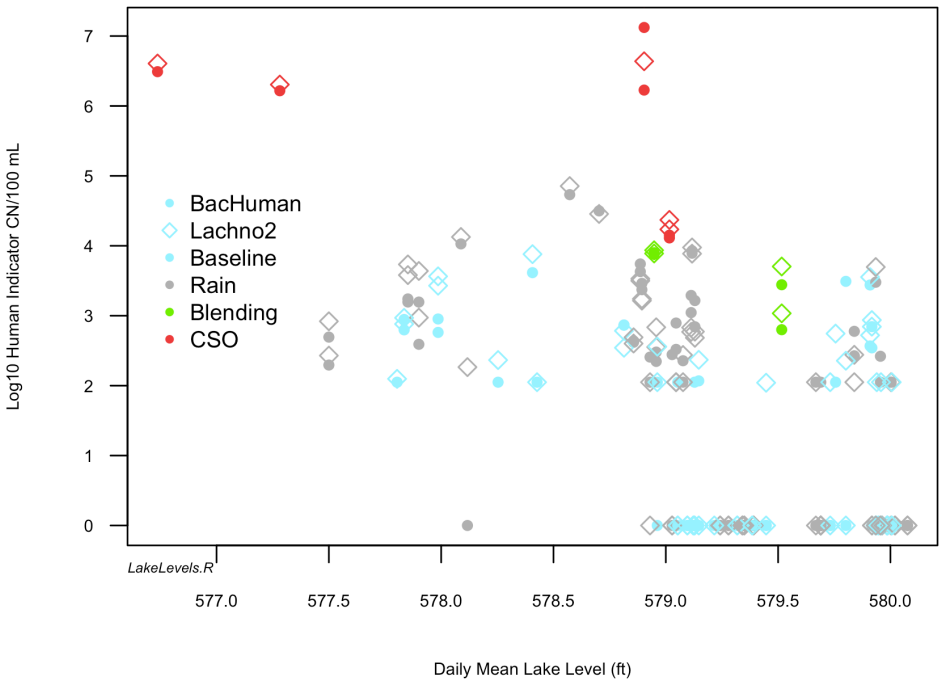


Figure 7. Lake Michigan water levels and human fecal marker concentrations at the Russell Avenue slip. Lake levels are given in feet; human markers are shown as log10 copy number per 100 mL

Potential Impacts on South Shore Beach

South Shore beach experiences frequent health advisories and closing due to elevated *E. coli* levels (>235 CFU/mL). Shore birds such as geese and gulls contribute a large portion of this pollution, but the wading zone often has detectable HFIB as well. The source of the HFIB is still unknown, but the RA CSO outfall may be a potential source, even during non-CSO events. A transect from the RA slip, to the South Shore Yacht Club, along the existing beach location and the proposed beach location (see Figure 8A-B for *E. coli* counts) was sampled frequently (~weekly) throughout the 2014-2015 bathing seasons. Plate count assays (enterococci and *E. coli*) were done for all samples, and selected samples were also analyzed for HFIB.

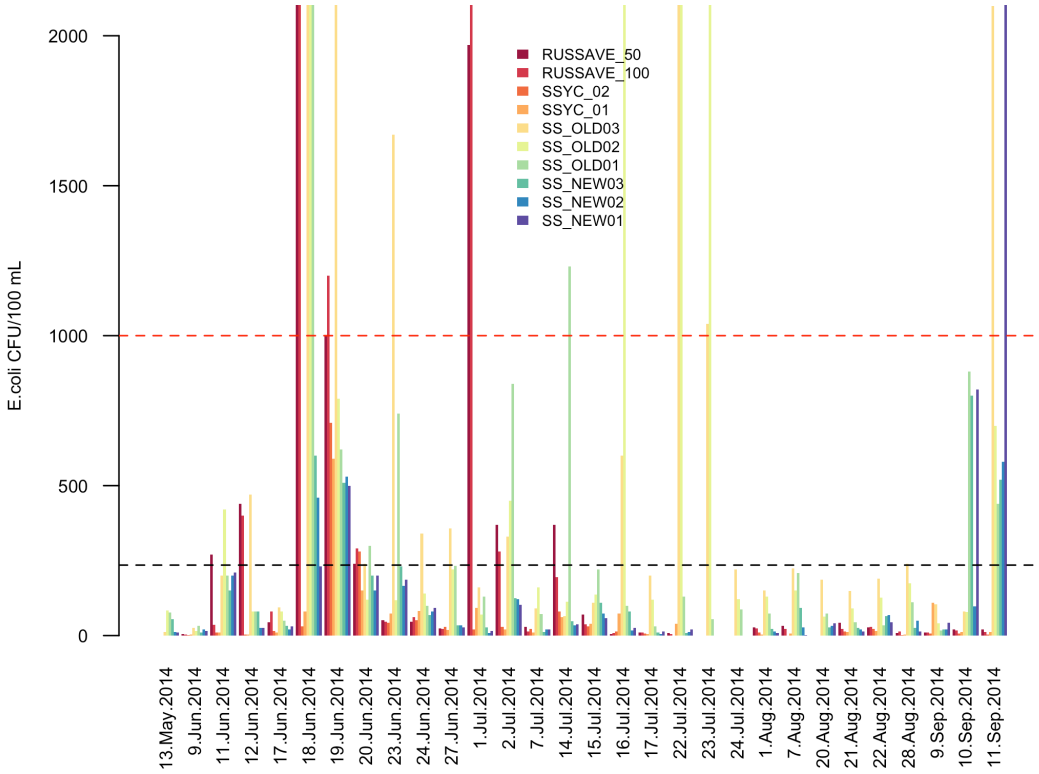
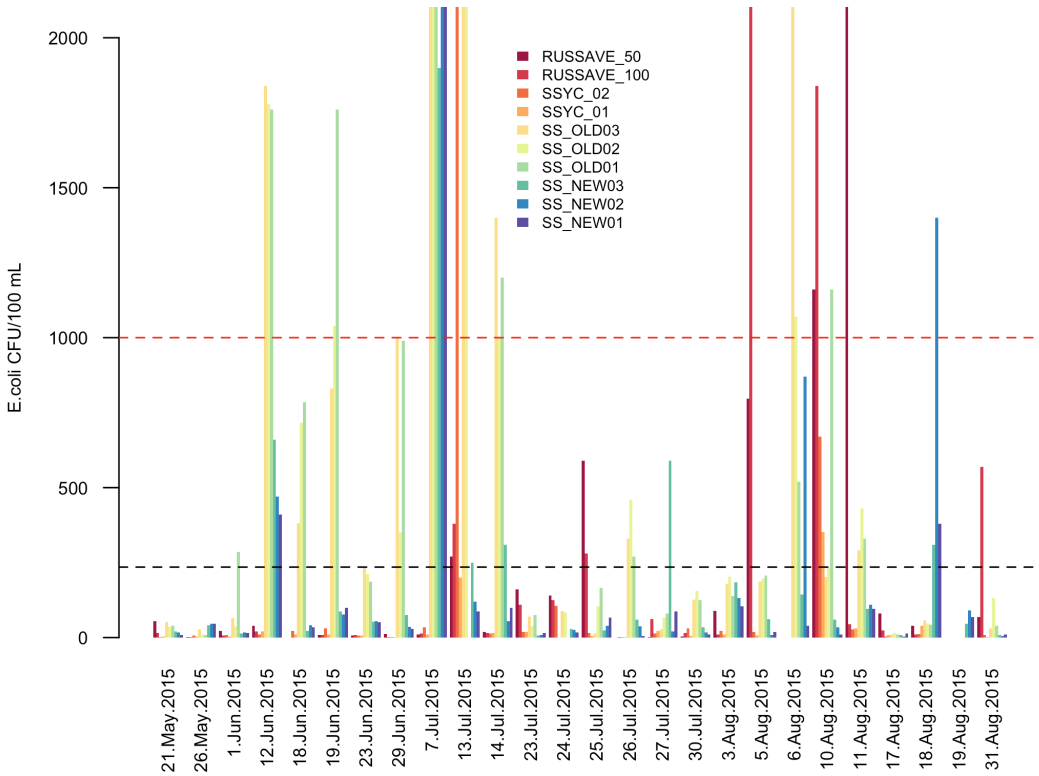


Figure 8. Transect plots of E.coli CFU/100 mL in water samples from the Russell Avenue Slip to South Shore beach for all sampling days in A) 2014 and B) 2015. EPA regulations for health advisory (235 CFU/mL) and beach closing (1000 CFU/100 mL) are shown as dashed lines.



Figures 9A-9C provide additional information on HFIB on the ranges of HFIB from samples collected 2011 through 2015 under A) CSO, B) baseline and C) rain conditions. (Transect plots showing FIB and HFIB for individual sampling days are available in Appendix A.) If the RA CSO outfall were a consistent source of sewage that contributed to HFIB at South Shore beach, trends should show significantly higher concentrations at RUSSAVE 50, slightly lower concentrations at RUSSAVE 100 due to mixing with lake water, and continually lower HFIB levels from the Yacht Club sites, to the "SS OLD" sites to the "SS NEW" beach. However, this trend was observed only under CSO conditions (Figure 7A). Even during CSO events, the Yacht Club samples had lower HFIB concentrations compared to "Old Beach, " suggesting that there is an additional source of HFIB to the beach. The CSO conditions provide a reference for true sewage contamination, which can be recognized by closely coupled HB and Lachno2 concentrations, with slightly higher Lachno2 compared to HB. Under baseline conditions, the median HFIB concentrations were actually *higher* than median values measured in the RA slip, and the two HFIB were not closely matched. Median values at all sites were also typically near the limit of detection for the assays. This suggests that sewage is sporadically entering the RA slip from the CSO outfall, but it is unlikely that the CSO outfall is the low-level source of FIB observed frequently at the beach locations. An interesting observation is that the South Shore Beach sites SS OLD3 and SS OLD2 (closest to the marina and boat ramp) were rarely negative for HFIB under rain conditions, suggesting either an additional trace source of human sewage, or cross-reactions from animal fecal material with both human assays. Alternative sources (SS Beach Pavilion laterals, parking lot bathrooms, yacht club pump station) should be investigated for their impacts on the beach.

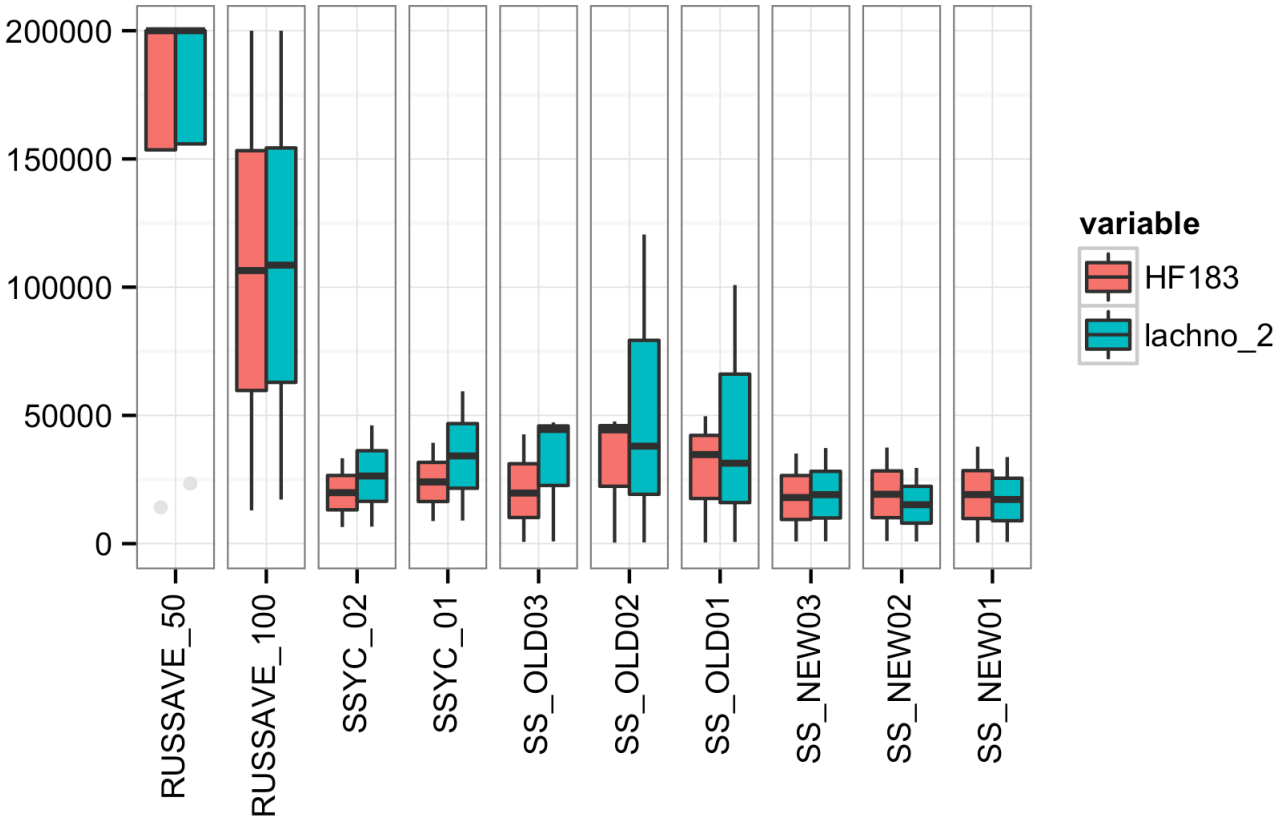


*Figure 9A. Human indicator concentrations (CN/100 mL) for all sites in Russell Avenue Slip to South Shore Beach transect (2011-2015). A) Data for samples collected during CSO events: a maximum of 200,000 is used to show detail in beach samples; maximum values for the slip were >1,000,000.Boxes show the interquartile range (25-75%), with the dark line representing the median value. Whiskers extend to 1.5*IQR, and all other values are shown as outliers.*

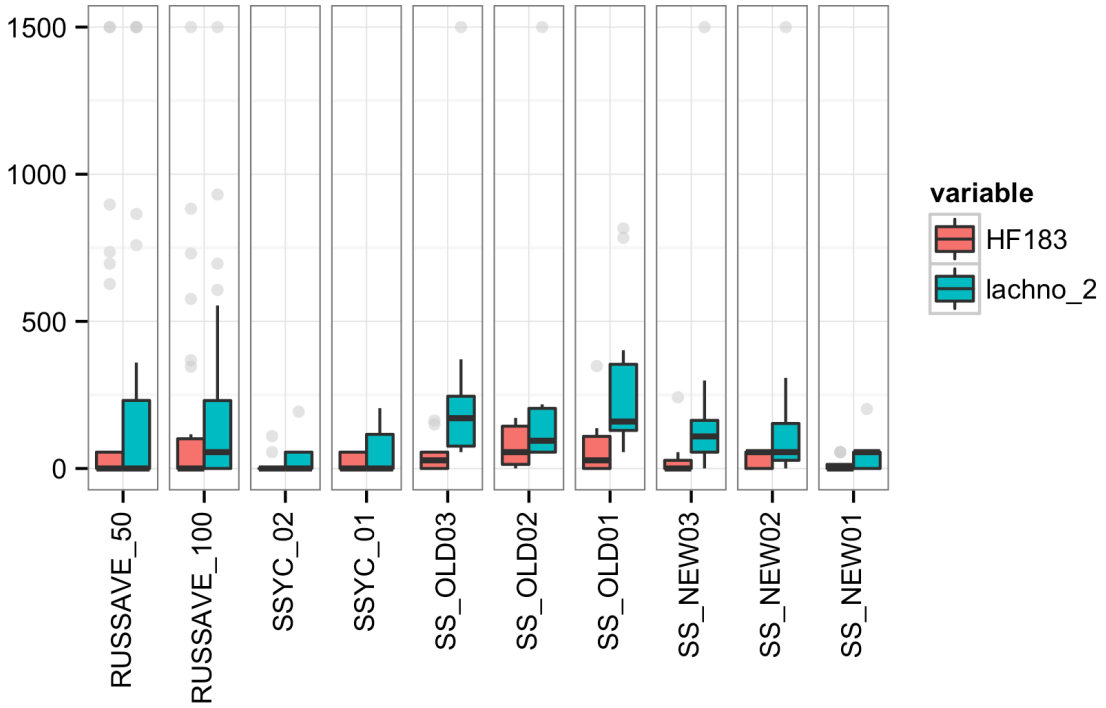
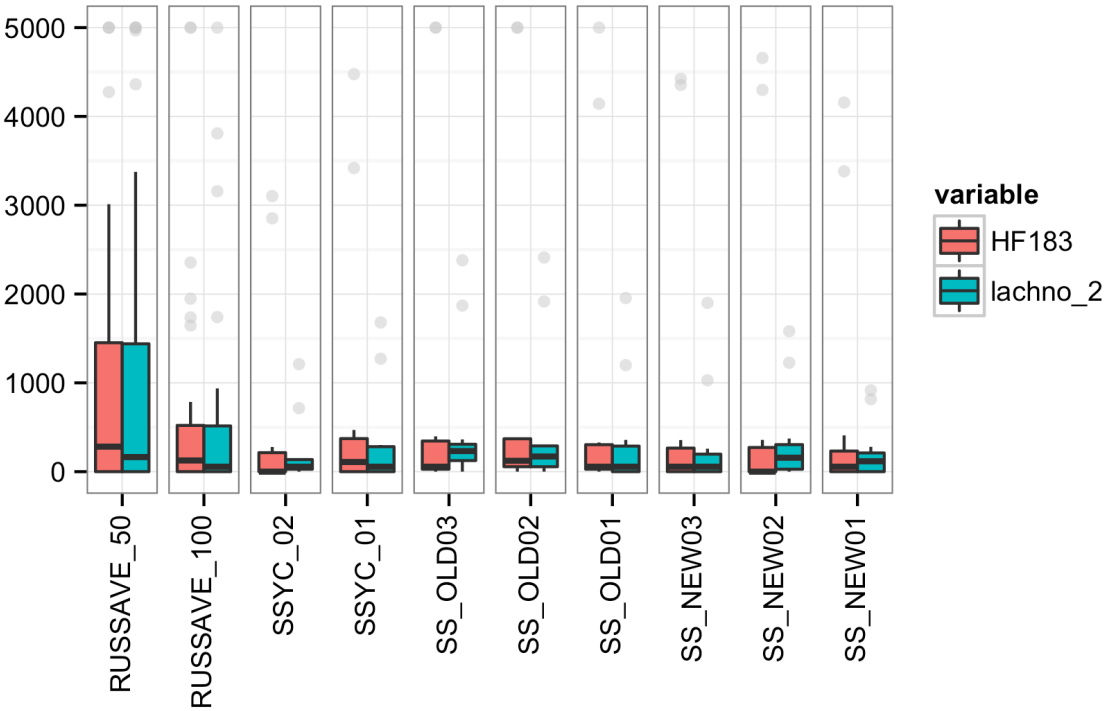


Figure 9B and 9C. Human indicator concentrations (CN/100 mL) for all sites in Russell Avenue Slip to South Shore Beach transect (2011-2015). Data for samples collected during B) baseflow and C) rain events. Note that the maximum values on figures 9B and 9C are ~2 orders of magnitude lower than in figure 9A.



Jones Island Effluent and Harbor as HFIB Source

Millions of gallons of treated effluent are released from Jones Island WWRF every day. Effluent is sanitized through chlorination, which should reduce or eliminate the growth of bacteria contained in the effluent. However, this process does not destroy DNA, and is less effective at inactivating Gram positive bacteria (e.g., *Lachnospiraceae*) compared to Gram-negative bacteria (e.g., *E. coli*). Depending on flow volumes and movement of currents within the Milwaukee Harbor, JI effluent may be transported south toward the RA slip and South Shore Yacht Club. This might result in low viable counts for *E. coli*, but detection of human markers. Concentrations of human markers at South Gap, the harbor location closest to the RA Slip, tended to be lower than effluent, as would be expected from dilution. This source should be further investigated further for the potential for residual signal to reach the Yacht Club and existing beach location.

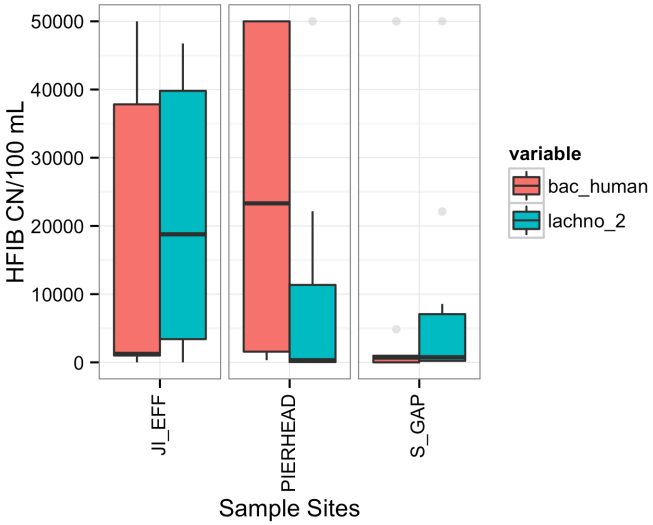


Figure 3. Copy numbers of HFIB/100 mL in Jones Island Effluent, at the Pierheads in Milwaukee Harbor, and at the South Gap southern opening in the breakwater wall near RA Slip. Harbor samples were taken under non-CSO conditions.

Conclusions and Recommendations

Sources to RA CSO outfall. The results of the two field investigations concluded that the human fecal contamination is likely not coming from a source above the Russell Avenue CSO outfall structure. There was an extensive search of nearby stormwater and sanitary sewers, none of which appeared to be a potential source of contamination. As mentioned previously, it is likely that the indicators detected in inline samples during the light rain events were a result of cross-reaction with bacteria in the raccoon feces observed in the pipes on the second visit. However, the initial sampling showing the presence of both markers remains unexplained; but levels are not atypical for the majority of stormwater pipes in the city. The low levels combined with the large dilution effect in the CSO outfall structure could partially explain some, but not all of the occurrences in detecting human markers. Negative HFIB results from the stormwater outfall, KK Flushing Tunnel and even within the NSC suggest that the outfall is not a consistent source of human fecal indicators to the slip.

Effect of Lake Levels. Based on 2014 summer data following the June CSO event, the HFIB detected are likely coming from remnants in the tunnel between the Near Surface Collector and the CSO outfall, essentially the remains of combined sewage released during a CSO event. Since the lake water is in direct contact with water inside the tunnel, any fecal contamination may eventually make its way out into the lake as the lake level fluctuates. Continuing to monitor the Russell Avenue outfall and slip may lead to discovering any correlations between the data and lake levels.

Is the RA Outfall the source of sewage at South Shore Beach? The outfall is likely the source of high HFIB concentrations at the beach following a CSO event, but does not appear to be a consistent source of HFIB during either rainfall or baseline conditions. Future work characterizing whole microbial communities from the outfall and the beaches may help to clarify if and when the outfall impacts the beach, and if there are other, more dominant sources of sewage impacting the beach.

"New" vs. "Old" Beaches. One clear trend in the data is that any impacts from fecal pollution-- human sewage, gulls, wildlife, or unknown inputs—are lower at the rocky beach ~150 m south of the current swimming beach. This trend has been observed consistently for over a decade in both studies by the McLellan Lab and the City of Milwaukee Health Department. We hypothesize that this is due in part to distance from potential sources (shorebirds, yacht club, RA slip, Jones Island), but heavily influenced by the higher degree of water exchange at this site. During swimming season, alongshore currents dominate water movement at SS Beach, essentially moving water north and south in a narrow band near the wading zone. However, at the proposed beach location ("SS New"), the opening in the breakwater wall allows water to flow directly toward the center of the beach and create an offshore transport of pollution.

Recommendations. Years of data and observation reveal a complex problem that is likely a combination of several factors, including time from most recent CSO event, lake levels, wind and current direction, and other confounding sources (possibly boat/marina waste). Hydrologic modeling of the slip coupled with consistent sampling may help to better identify if the slip (from the outfall) is a source, or if it is receiving contamination from other sources that become trapped within the slip.

Each summer there are many sail boats docked throughout the marina near the Russell Avenue slip and nearby, South Shore Yacht Club provides a waste pumping station. These boats and pumping station may be potential sources of contamination both to the slip and to the beach. Collecting samples closer to stationed yachts or the pumping station may help identify leaks. Another potential way to rule out boat waste as a potential source would be to sample after ice thaw in spring, before the watercrafts are docked, with continuous sampling into fall after they have been removed. During these time frames there will be no use of the pumping station and all watercraft will be out of the water, eliminating the presence of a potential source. Boats using marinas on California's coast, such as in the San Diego marina, are mandated to add fluorescein to their sanitary tanks, including any boats visiting the marina. This requirement could be pursued through the County Parks.

Finally, we recommend that the swimming beach be moved 150 m south to reduce the potential for human exposure to pollution inputs. This would result in a significantly higher number of swimming days during the season and health risks from low levels of sewage would be diminished (i.e. on days where FIB is within limits), and would also result in economic and social benefit to the Bay View community.

References:

National Oceanic and Atmospheric Administration. *Tides/Water levels*. Date accessed: December 23, 2015. <http://www.co-ops.nos.noaa.gov/waterlevels.html?id=9087057>

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