Fecal indicator bacteria concentrations after rainfall events: Evaluating the 72-hour rain advisory period

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Abstract

Fecal Indicator Bacteria (FIB) concentrations in beach water were monitored after rainfall events to evaluate the Los Angeles Department of Public Health's 72-hour advisory period, which discourages swimming in contaminated waters. Samples were collected at an open beach at Playa del Rey, where coastal mixing occurs normally, and a nearby closed beach known as Mother's Beach, where mixing of contaminated water is limited. Water samples were collected at several strategic locations at both beaches for five days after a rain event, for two rain events. For each sample, concentrations of an indicator of fecal bacteria, *Enterococci*, were analyzed by employing the Most Probable Number (MPN) method. At the open beach, some sites exceeded threshold *Enterococci* concentrations at the 72-hour mark. At the closed beach, bacteria concentrations exceeded thresholds up to 5 days after a rain event. Changes in concentrations may depend on local water circulation and transport. In both beaches, 72 hours was not adequate to ensure the decrease of FIB concentration to safe levels.

Introduction

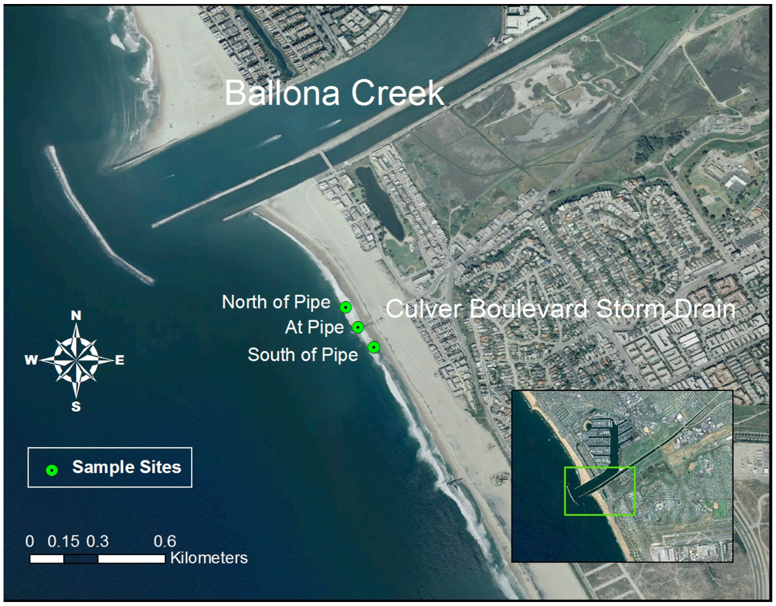
Contamination of coastal waters is at its worst after periods of rainfall (Dwight). Rainwater carries fecal matter and other pollutants from the watershed into the ocean via storm drains and streams, which deposited directly onto the beach or surf zone. Fecal contamination in the coastal surf zone is a problem that afflicts swimmers with increased levels of gastrointestinal and respiratory problems (Haile). The Los Angeles Department of Public Health (LADPH) suggests that elevated bacteria concentrations may continue for up to 72 hours after rainfall ends (LADPH). They recommend that beach-goers avoid contact with ocean water for that period (also known as the rain advisory period). In some cases (e.g. in popular swimming destinations around the Santa Monica Bay), the LADPH instructs lifeguards to forbid swimming during the advisory period. LADPH's 72-hour figure does not take into account other factors that may influence bacterial removal such as the movement of local water parcels or the geography of the beach. The objective of this project is to evaluate the 72-hour advisory period, taking into account these factors.

As their name suggests, FIB (fecal indicator bacteria) are indicators used to detect the presence of fecal contamination in water. The presence of FIB correlates with harmful microbes associated with fecal contamination (Colford). Monitoring FIB concentrations is the method of choice for gauging fecal contamination and associated pathogens in water bodies (US EPA). FIB concentrations decrease over time due to two primary factors: physical processes (e.g. mixing of contaminated with uncontaminated waters or transport of runoff away from the site) and biological processes (e.g. natural death of FIB over time) (Hanes, Ferguson). This work will mainly consider concentrations of FIB due to physical mechanisms.

Studies concerning FIB contamination have lead to restoration and mitigation projects along the Southern California coast (Dorsey) , the majority of them addressing increased concentrations after rain events (Dwight). FIB contamination of water bodies may result from factors other than rain events; areas outside of Southern California have experienced contamination as a result of fertilized cropland runoff and other land use practices (Solecki).

Methodology

Study Sites



We studied two beaches with contrasting geographies; both are located within the Santa Monica Watershed. The analysis of two beach types allows us to start to address differences in post-storm FIB concentrations between a closed beach system and an open beach, and if the current 72-hour advisory period is sufficient for both. We hope that our evaluation of open versus closed beach systems will have implications for similar environments suffering from fecal contamination problems.

Figure 1. Map of Playa del Rey and sampling sites.

The first beach is a segment of Playa del Rey (Figure 1), just south of the mouth of Ballona Creek. This beach is considered an open beach; its coastal waters are unwalled and have direct access to the ocean. Much of the urban runoff from the watershed is fed to this area via the creek. Additionally, there is a large storm drain in the sampling area that delivers urban runoff right onto the coast. The second beach, Mother's Beach in Marina del Rey (Figure 2), is approximately four miles from Playa del Rey. On the other hand, Mothers Beach is a closed beach; it is surrounded by walls and its waters do not easily mix with the open ocean. In addition, it is a man-made beach contained within the marina. Although it is small and lacks visible storm drains, its geography and protection from open ocean currents might cause FIB concentrations to behave differently than in an open beach system.

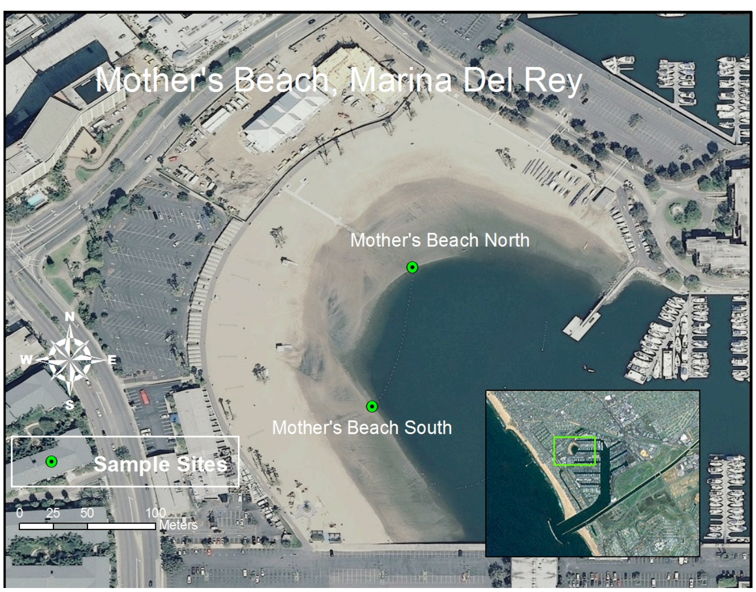


Figure 2. Map of Mother's Beach and sampling sites.

There were three sampling sites at Playa del Rey. The first was located at the Culver Boulevard Storm Drainage Pipe (33.956326 N, -118.452461 W). The second was located north of the first, between the storm drain pipe and the mouth of Ballona Creek (33.958893 N, -118.453995 W). The third was located south of the storm drain pipe (33.953594 N, -118.450569 W). There were two sampling sites at Mother's Beach; they were located at each end of the designated swimming area (33.981415 N, -118.457176 W) (33.980415 N, -118.457596 W).

Collecting and Testing Water Samples

Samples were collected after two rain events. The first rain event (event 1) occurred from March 16 to March 18. The second rain event (event 2) occurred from March 25 to March 26. For each rain event, the first sample was collected the morning after the rain event ended; samples were collected daily for up to five days at each of the five sites. One duplicate sample was collected every day, from a different sampling site. The duplicate data were averaged with the data from the same site and time. Salinity was also recorded at each of the five sites using a portable refractometer.

During the first rain event, samples were not collected for the first day after the rain event ended due to supply issues. Additionally, sample data for the second day after rain were not included in figures due to error in the dilution process. Thus, for the first event, we used data from Day 3 to Day 6 after the rain event ended.

In this experiment, we used 125 mL glass bottles to collect our samples. When collecting the samples, the collector reached 12-18 inches under the surface, holding the bottle mouth downward. Then, in a single motion, the bottle was rotated with the mouth facing up and taken out of the water. Enough water was collected to leave about 1 inch of air space from the top. The bottle was covered and kept in a cooler, 1-4º C. The samples were stored for no more than six hours before processing them for quantification of FIB.

Enterococci was chosen as our fecal indicator bacteria. It can be easily detected and the test methods were affordable and accessible in our laboratory. *Enterococci* concentrations were quantified via the Most Probable Number (MPN) method. It produces results within a 24 hour period. This method is approved by the U.S. EPA and is used worldwide in testing beach water quality. At the laboratory, each 100 mL water sample is added to a Quanti-Tray® with the reagent Enterolert®. Each Quanti-Tray® provides 200 FIB colony counts without diluting the 100 mL sample. The concentration of *Enterococci* was calculated using the MPN Method (i.e. referring to the MPN table).

N.B.: Since no dilution was used for both events (except Day 2 of event 1, which was discarded), if the FIB concentration (CFU/100 mL) was beyond Quanti-Tray capacity, we used maximum possible number (2419.6 CFU/ 100 mL) for a conservative estimate.

Results

FIB Concentrations

For event 1, FIB concentrations at all sites at the open beach were above safe threshold levels on day 3 (Figure 2.1). All sites reached safe concentrations on days 4 and 5; but on day 6, safe threshold levels north and south of the pipe were exceeded.

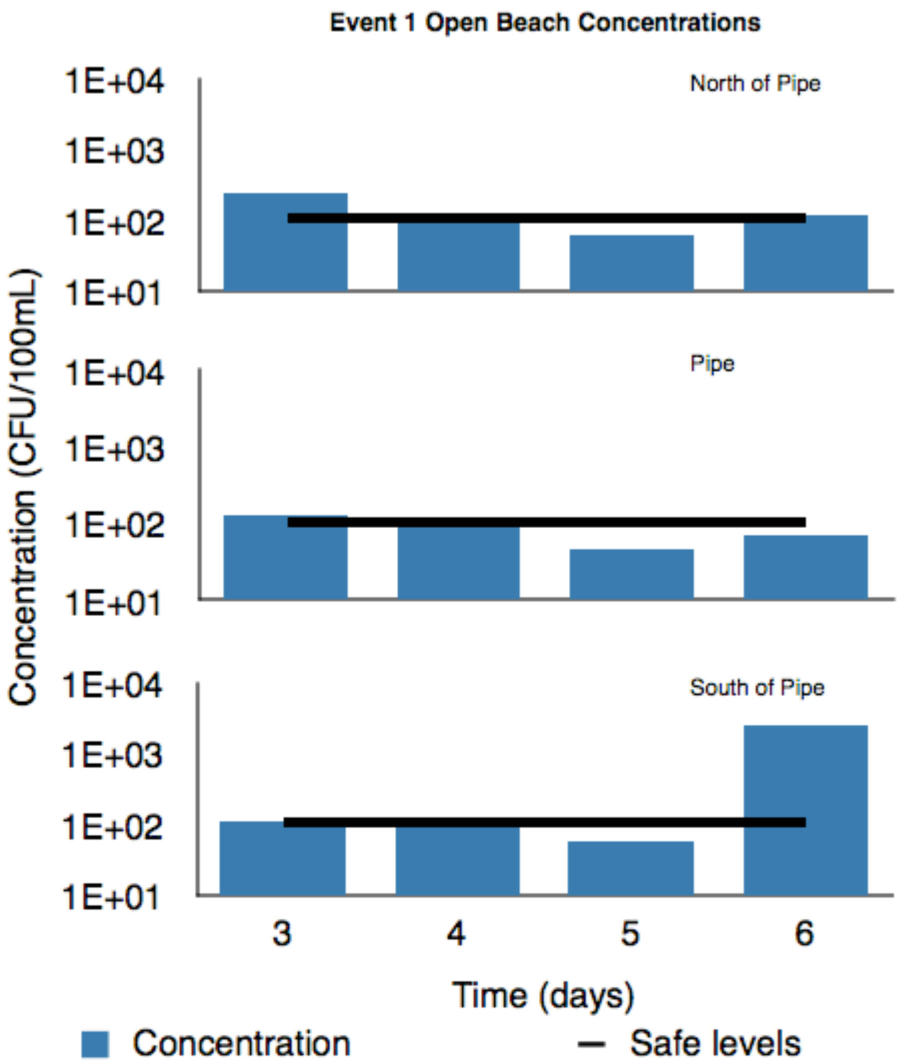


Figure 2.1.

Concentrations at both closed beach sites were above safe threshold levels on day 3 (Figure 2.2). At the north site, concentrations were consistently above safe threshold levels throughout the sampling period. At the south site, concentrations exceeded safe threshold levels again on day 6.

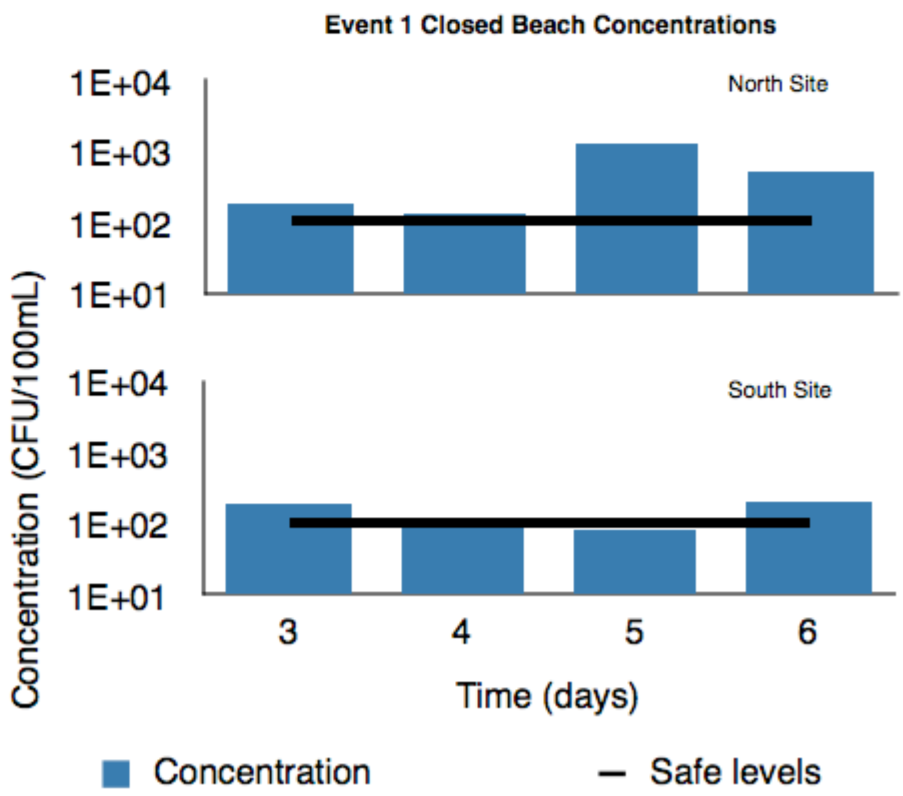


Figure 2.2.

For event 2, at the open beach, FIB concentrations north of the pipe and at the pipe were above safe threshold levels on day 3. Concentrations at both sites remained above safe levels throughout the sampling period. At the south site, concentrations exceeded safe threshold levels on day 4, but returned to safe levels on day 5.

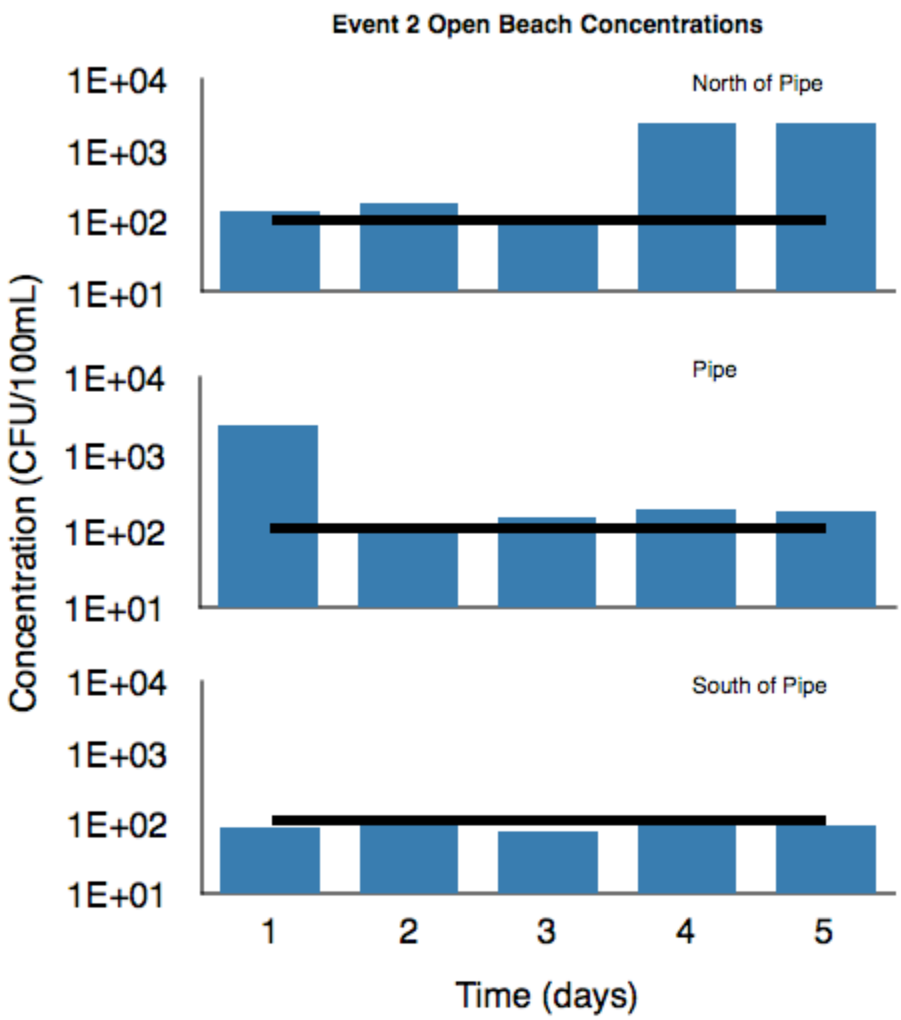
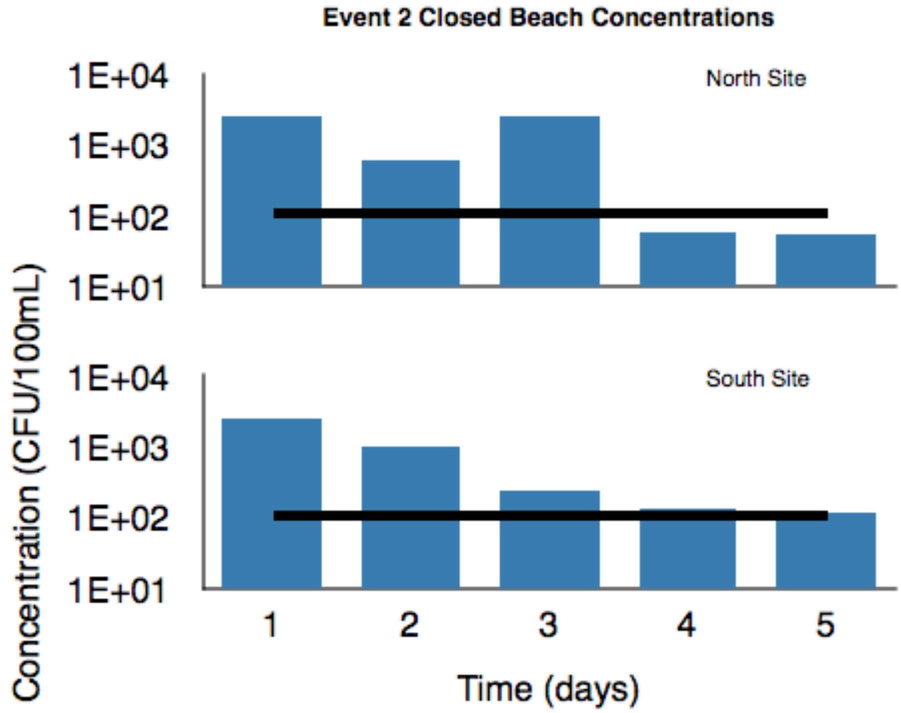


Figure 3.1.

At both closed beach sites, concentrations were above safe threshold levels on day 3. At the south site, concentrations remained above safe levels throughout the sampling



period.
Figure 3.2.

Salinity

A correlation between salinity and FIB concentrations during event 1 was not observed because we were unable to collect samples until day 3. During event 2, all sites from both beaches had low salinity with high FIB concentrations on the first day after the storm event. By day 2, salinity rose to relatively stable levels for each beach. FIB concentrations decreased at the pipe and at both sites at Mother's Beach (Figure 4.1-2). FIB concentrations at Playa Del Rey north and south of the pipe increased just slightly.

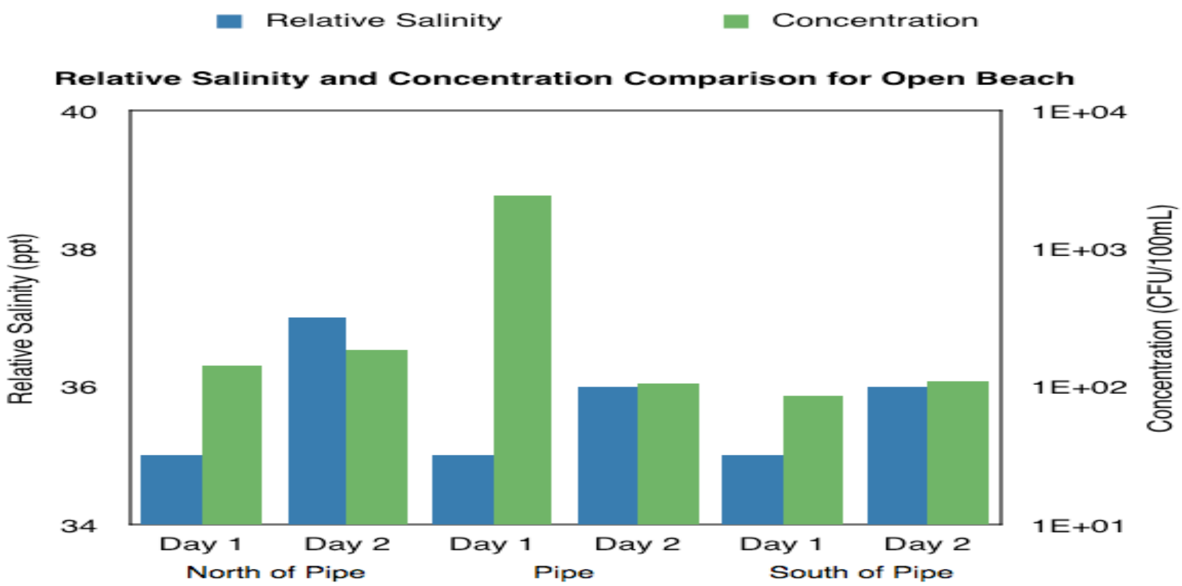


Figure 4.1.

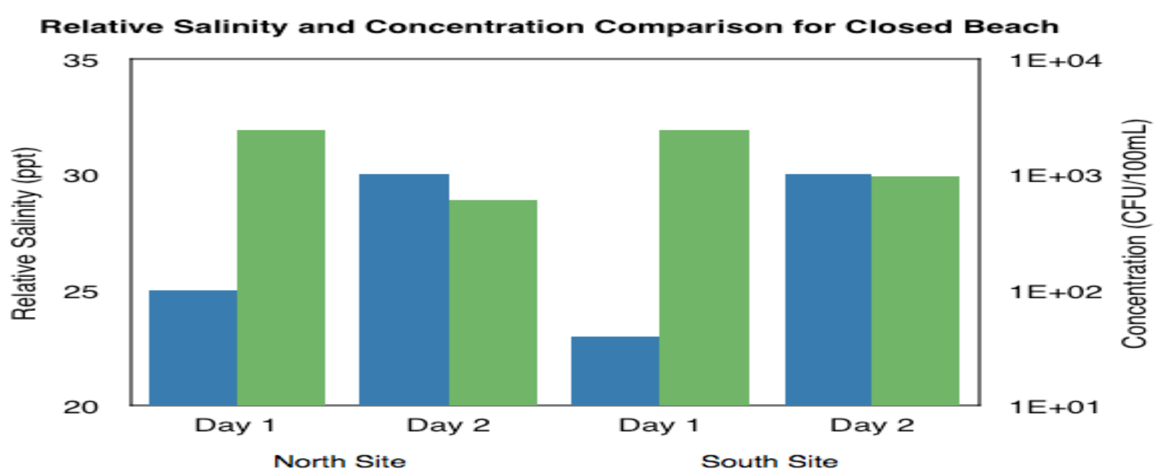


Figure 4.2.

Discussion

Currents as Possible Transport Mechanism at Open Beach

There is a clear difference in the removal and transport processes at an open and closed beach. We suggest that the open beach currents present at Playa Del Rey are the reasons for these differences. FIB concentrations varied spatially and temporally during both events. Our data suggest that currents may act as the primary transport mechanism of FIB and are responsible for day to day variations in FIB concentrations.

We expected the ocean currents to disperse the FIB quickly and evenly among the coast. Had this been the case, data would show an overall decreasing trend at each of the three locations as the currents carried the FIB away and mixed it with adjacent coastal water. Instead, some decreases in FIB concentration were followed by spikes that brought concentrations above safe levels. Assuming there was no additional input of FIB into the system, the concentration spikes indicate that the FIB do not mix and dilute with the surrounding water as expected, but might instead travel with a specific parcel of water. This water parcel would be characterized by a certain FIB concentration and maintain that concentration until natural degradation processes occur within.

To investigate this possible transport mechanism, we collected data on current direction at Playa Del Rey from the Southern California Coastal Ocean Observing System (SCCOOS). The data describes the current direction for the period during and after both rain events. We plotted the current direction against time to see if the direction of the current might correspond with the spikes in FIB concentration (Figure 5.1-2). We compared days with FIB concentration spikes north and south of the pipe to the direction the currents were moving on the days just before these spikes.

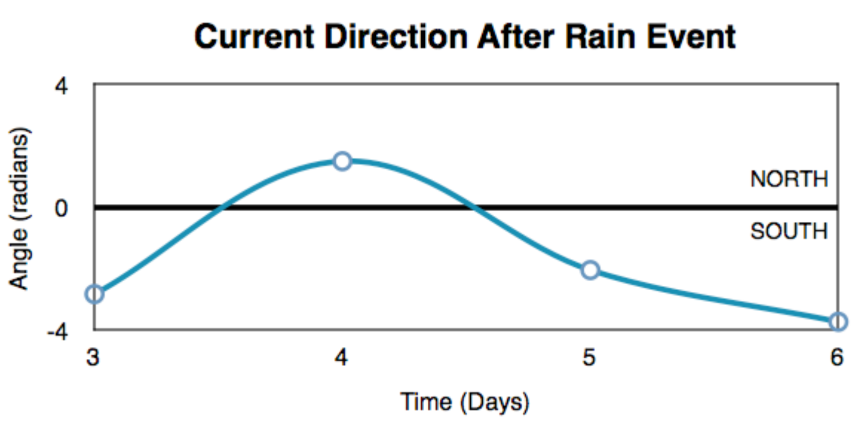


Figure 5.1.

During event 1 (Figure 5.1), currents moved north on day 4, but then turned and headed south on days 5 and 6, corresponding to a spike in FIB concentration south of the pipe day 6. On day 5, the currents faced south and continued that direction until Day 6. It is likely that this transported the FIB towards the south.

During event 2 (Figure 5.2), a spike in FIB concentration occurred north of the pipe on days 4 and 5. We suggest that this spike was caused by the previous days' north facing currents (days 1-3). It is important to note that during days 4 and 5, while there was a spike in FIB concentration north of the pipe, the current direction changed and began to face south. This might explain the slight increase at the pipe on days 4 and 5 as the parcel containing FIB began to move southward again. Together, these analyses support the idea that FIB may travel as a plume and not mix evenly with the surrounding ocean.

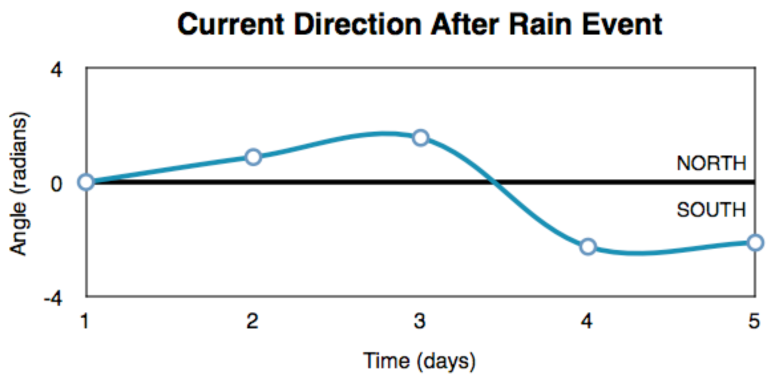


Figure 5.2.

Current direction as a primary factor in the transport of FIB is only a possible theory based on our observations. There is evidence to suggest that there is a correlation, but current speed would play a major role as well. The first event takes only 24 hours for southward currents to cause an accumulation of FIB south of the pipe. Comparing this to event 2, we see it takes about 72 hours of northward currents to cause a spike north of the pipe. This may be due to factors that we did not measure such as the speed, size and frequency of the currents.

Effect of Tide Height on FIB Concentrations at Closed Beach

We examined the relationship between tide height and FIB concentrations at our closed beach sites using National Oceanic and Atmospheric Administration (NOAA) tidal heights of the water column in meters. Since no tidal height information is provided for the closed beach, tidal height information from the open beach is used to approximate that of the closed beach. The recorded tidal heights are consistent with our concentrations for both events. To simplify our results, we averaged the daily FIB concentrations at both closed beach sites and obtained the Average Closed Beach (ACB) concentrations shown. For event 1 (Figure 6.1), tide levels throughout the sampling period remained relatively stable at a height of approximately 1.5 meters. Meanwhile, the ACB concentrations also remained relatively constant (σ = 256.32 CFU/100mL).

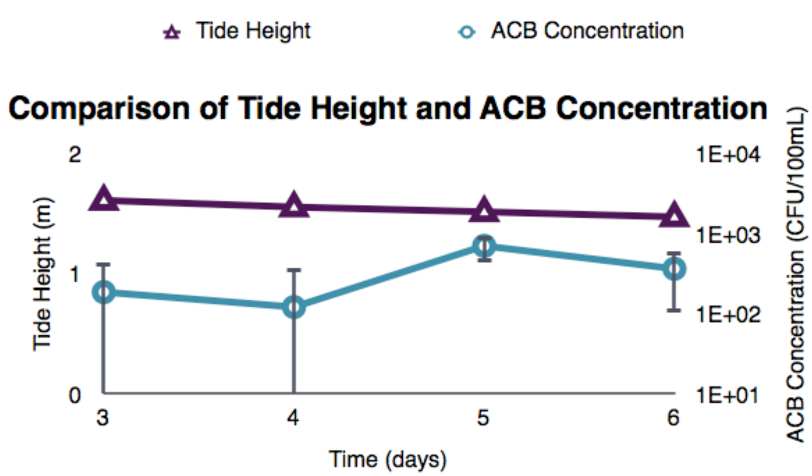
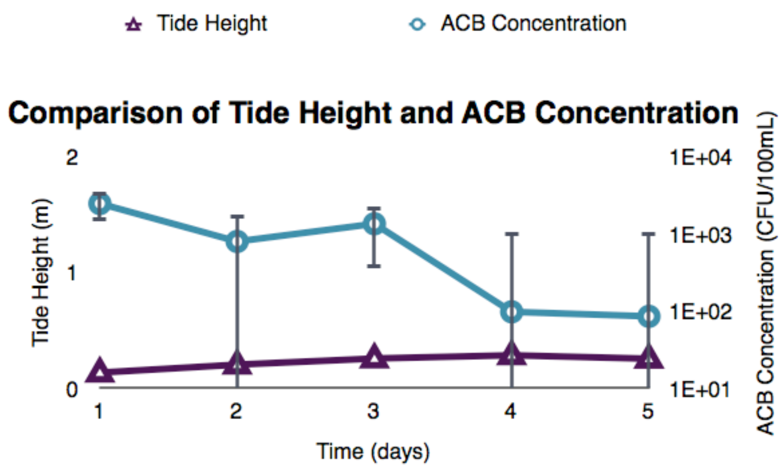


Figure 6.1.



For event 2 (Figure 6.2), tide levels remain relatively constant at approximately 0.2 meters. Meanwhile, ACB concentrations exhibit a decaying trend (σ = 975.69 CFU/100mL).

Figure 6.2.

During event 1 (Figure 6.1), the relatively high tide height of approximately 1.5 meters corresponds to an overall persistence in average FIB concentrations during the sampling time. During event 2, the relatively low tide height of approximately 0.2 meters corresponds to a decrease in average FIB concentrations over time. Beach sediment, especially in closed beaches, contains high concentrations of FIB (Lee). A high water column on top of this sediment could serve as a protective layer, shielding the bacteria from UV radiation, and therefore preventing significant decreases in FIB concentrations. Moreover, the combined effect of a higher water table and a shallow slope, as found in Mother's Beach, could lead to a dislodging of sequestered FIB in sediment. Thus, the reintroduction of FIB from sediment could also lead to elevated levels of FIB. In contrast, the decreasing pattern seen during event 2 (Figure 6.2) may be attributed to the very low tide. FIB reintroduction is prevented by the decreased area of sediment exposed to water. Similarly, the lack of UV radiation protection provides environmental conditions conducive to a decreasing behavior. Thus, the data suggest that tide height may be a significant factor affecting FIB concentrations and net decreasing trends.

Salinity

Salinity was measured to determine the possible relationship between salinity and FIB concentration. The average salinity found in ocean water is 35 ppt, but our values can only be considered relative to each other due to calibration error in the use of the portable refractometer.

We expect the strongest negative correlation between salinity and FIB concentrations right after a storm due to the large input of fresh, contaminated rainwater. Salinity data showed that the large influx of rainwater is highly contaminated with FIB. Since salinity reached an approximately stable level after the second day, we were not able to subsequently correlate salinity to FIB concentrations for days 3 through 6. The inverse relationship observed within the first two days indicates that low salinity could be used as an initial identifier of runoff plumes.

Conclusions

Between both events, there were FIB concentrations that exceeded the safe level at the 72-hour mark at every site. FIB Concentrations at Playa del Rey demonstrated strong spatial and temporal variation. It is likely that ocean currents at an open beach play a significant role in FIB transport and contributed to the sporadic changes in FIB concentrations. FIB concentrations at Mother's Beach may be associated with tide height. A higher water column may allow FIB to persist longer than 72 hours after rain events end. Decreasing FIB concentrations over time support a possible need for two separate advisories: one for closed beaches, and a longer one for open beaches.

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Appendix

Table A.1. Site locations for data collection

Site 1	Playa del Rey North of Pipe
Site 2	Playa del Rey at Pipe
Site 3	Playa del Rey South of Pipe
Site 4	Mother's Beach North
Site 5	Mother's Beach South

Table A.2. Amount of precipitation for each day in both rain events

Event	*Date*	*Inches*
1	3/16/2012	NA
	3/17/2012	0.75
	3/18/2012	0.01
2	3/25/2012	0.91
	3/26/2012	0.04

Table A.3. Data for Event 1 (3/16/2012-3/18/2012)

Date	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*
3/20	240.0	124.6	111.2	180.9	185
3/21	100.3	91.2	95.9	102.7	102.7
3/22	60.3	45.9	56.9	82.8	82.6
3/23	117.8	67.4	2419	517.2	196.8

Table A.4. Data for Event 2 (3/25/2012-3/26/2012)

Date	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*
3/26	141.18	2419.6	85.2	2419.6	2419.6
3/27	182.9	104.55	109.0	601.5	960.6
3/28	106.7	149.7	72.85	2419.6	228.2
3/29	2419.6	190.0	119.0	57.5	134.0
3/30	2419.6	178.0	88.9	55.2	112.15