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A 30 Year Assessment of Fecal Indicator Bacteria (Escherichia coli and Enterococci) Along the Shoreline of Santa Monica Bay, California

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A 30 Year Assessment of Fecal Indicator Bacteria (*Escherichia coli* and Enterococci) Along the Shoreline of Santa Monica Bay, California

by

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A 30 Year Assessment of Fecal Indicator Bacteria (*Escherichia coli* and Enterococci) Along the Shoreline of Santa Monica Bay, California

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GLOSSARY

CWA	Clean Water Act
EPA	Environmental Protection Agency
TMDL	Total Maximum Daily Load
FIB	Fecal indicator bacteria
SMB	Santa Monica Bay
NPDES	National Pollutant Discharge Elimination System
EMD	Environmental Monitoring Division (City of Los Angeles)
DHS	Department of Health Services (Los Angeles County)
LACSD	Los Angeles County Sanitation District
BC	Beach city (City of Redondo Beach, City of Manhattan Beach, and City of Hermosa Beach)
CFU	Colony forming unit
MPN	Most probable number
CSMP	Coordinated Shoreline Monitoring Plan
BMP	Best management practice
LFD	Low-flow diversion
MGD	Millions of gallons per day
SMC LFD	Santa Monica Canyon low-flow diversion
ND	Non-detects
KW	Kruskal-Wallis Test
LID	Low impact development

Acknowledgments

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ABSTRACT

Santa Monica Bay and its vast beaches are important Los Angeles icons, while also providing significant ecosystem services to over millions of recreational visitors annually. Contaminated runoff from numerous watersheds surrounding the Bay, especially the 87% urbanized Ballona Creek Watershed, have historically resulted in poor water quality along areas of the Bay shoreline. Decades of monitoring for fecal indicator bacteria (FIB) along the Bay's shoreline has been associated with NPDES wastewater discharge and stormwater programs. Many projects have been implemented throughout the watersheds (e.g. sewer improvements, biofiltration systems, low-flow diversions (LFDs)) to lessen flows of runoff from contaminating surf zone recreational waters. Despite decades of monitoring, there has been no long-term assessment of trends in shoreline FIB, especially in response to implementation of projects to improve water quality. The goal of this study was to assemble 30 years of monitoring data (1988-2017) for *E. coli* and enterococci to assess trends along the entire shoreline of Santa Monica Bay. Data were analyzed by calculating rolling 30-day geometric means, and comparing means by geographic subdivision, between wet and dry weather, and over time. Resulting trends for both *E. coli* and enterococci were: 1) concentrations peaked around 2005 when many stations shifted to sampling points where runoff mixed directly with surf zone water; 2) after 2005, concentrations fell to present levels, especially at beaches where LFDs were implemented; 3) concentrations were extremely variable during the 2016-17 wet season; 4) the north and central areas of the Bay, impacted by runoff from the Ballona Creek and Malibu Creek Watersheds, had greater concentrations relative to the south area; and 5) dry weather concentrations were steadily low, whereas wet weather displayed a higher degree of variability and may present a more significant challenge to meet water quality standards going forward. Implementation of LFDs and other best management practices to restrict polluted runoff from flowing into the surf zones of the Bay's beaches most likely improved water quality throughout the Bay.

INTRODUCTION

Recreational Water Quality

Recreational beaches provide an essential financial resource upon which many coastal communities rely, with national beach visitation generating between $6-30 billion per year to the economy (Pendleton 2007). If water quality is poor at these beaches, swimmers and others have a greater risk of exposure to water borne pathogens and subsequent illnesses, leading to economic losses. Recreational water use in the U.S. accounts for an estimated 90 million cases of waterborne illnesses per year with an associated annual cost of $2.9 billion attributed to medical cost and productivity loss (Deflorio-Barker et al. 2018). With such a huge economic impact, it is of the highest priority that there be safe and swimmable surface waters throughout the country.

Beach waters are susceptible to contamination from polluted runoff and sewage, especially prior to the 1972 Clean Water Act (CWA). For example, a 1942 pollution survey was conducted along the shoreline of Santa Monica Bay to determine the extent of fecal pollution from a screening facility located at the site of the present Hyperion Wastewater Treatment Plant. Using *E. coli* in samples of water taken along the shoreline, results determined that shoreline water was contaminated with sewage to a dangerous degree. As a result, five miles of shoreline was quarantined lying on either side of the Hyperion site (Bureau of Sanitary Engineering 1943). Since that time, federal and state legislation has been enacted to improve beach water quality.

Under the CWA, the U.S. EPA developed water quality criteria for the states (U.S. EPA, n.d.). Water bodies where standards are not met are added to the 303(d) list of impaired waters. They are then required to develop a Total Maximum Daily Load (TMDL), a plan identifying the maximum amount of each pollutant a body of water can receive while still meeting the standards (U.S. EPA, n.d.). TMDLs serve as a planning tool and regulatory strategy to bring water bodies back into compliance.

Recreational water quality standards are based on measured values of fecal indicator bacteria (FIB) (Ashbolt et al. 2001). Pathogens can be difficult to quantify directly, so FIB are measured in its place, with higher concentrations representing a greater chance of the presence of pathogens. Three groups of FIB historically have been tested to assess water quality, and include total coliforms, fecal coliforms (or direct measurements of *E. coli*), and enterococci. Enterococci are the preferred indicators based on epidemiological studies and are considered the most reliable for marine waters (U.S. EPA 2012).

Sources of FIB impacting recreational waters include sewage, feces of warm-blooded animals, trash, rotting vegetation, and polluted urban runoff (Ashbolt et al. 2001, Dorsey 2010). Runoff is introduced into beach waters via freshwater outlets, like storm drains and creek mouths, and leads to elevated levels of FIB and their associated pathogens (Ackerman et al. 2005; Noble et al. 2000), especially during wet weather (Noble et al. 2003).

Santa Monica Bay

Santa Monica Bay (SMB) is an embayment west of Los Angeles, whose beaches are an economically vital resource to the region (Figure 1) (Dojiri et al. 2003). Numerous watersheds surround SMB, the largest being the Malibu Creek and Ballona Creek watersheds (Figure 2). Malibu Creek drains a primarily rural watershed, whereas Ballona Creek drains a more urbanized setting (Figure 3). The Ballona Creek Watershed is 87% urbanized (Abramson 2014) and the largest watershed draining into the Bay. Runoff from this watershed is increased due to extensive impervious surfaces (California Regional Water Quality Control Board 2011).

Polluted urban runoff is introduced into beach waters through the mouths of creeks and storm drains. A study conducted in SMB showed elevated FIB levels and a greater chance of swimmer illness within a closer proximity to storm drains and other freshwater outlets along the shoreline (Haile et al 1999), and this risk increases further during wet weather (Schiff et al. 2016).

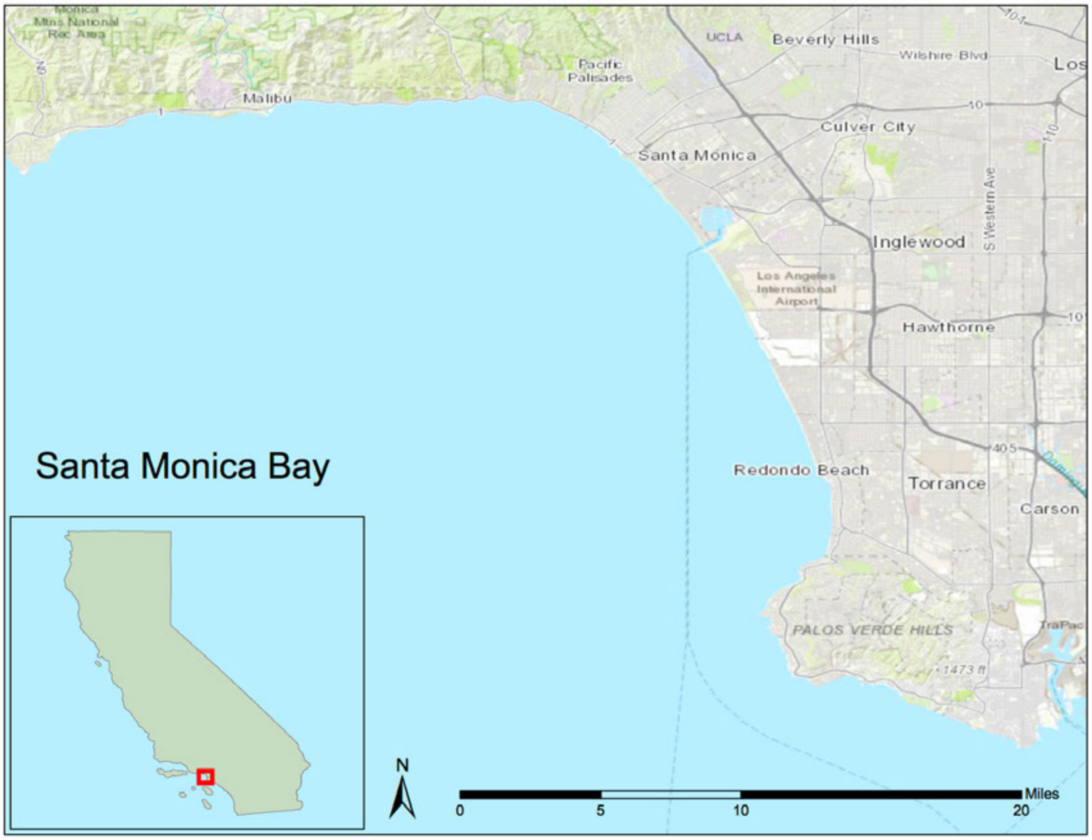

Figure 1. Map of Santa Monica Bay.

Storm events have repeatedly been shown to lead to increased levels of FIB in coastal waters (Griffith et al. 2009; Noble et al. 2003). Wet weather is frequently defined as a day with ≥ 0.1 inches of rain plus the three following days. This threshold is consistent with a study conducted in SMB examining the relationship between rainfall and beach bacterial concentrations where there was no observable rainfall effect for storms having less than 2.5 mm (approximately 0.098 inches) of rainfall (Ackerman & Weisberg 2003). FIB levels normally returned below water quality standards within three days.

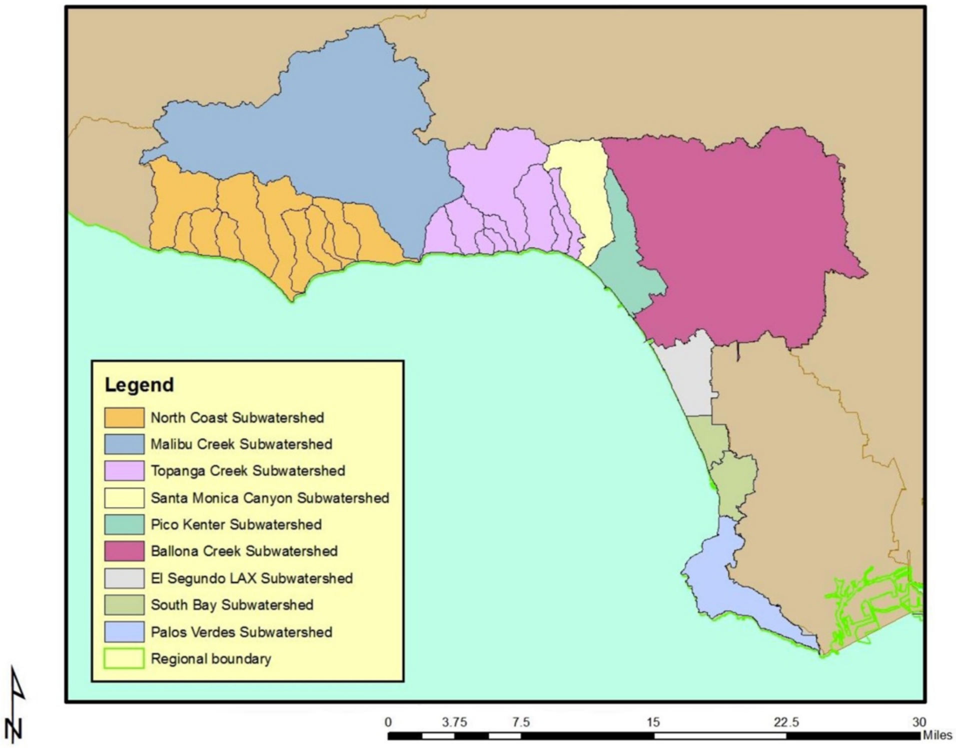

Figure 2. Santa Monica Bay Watersheds map. Image source: California Regional Water Quality Control Board- Los Angeles Region. 2011. State of the Watershed- Report on Water Quality.

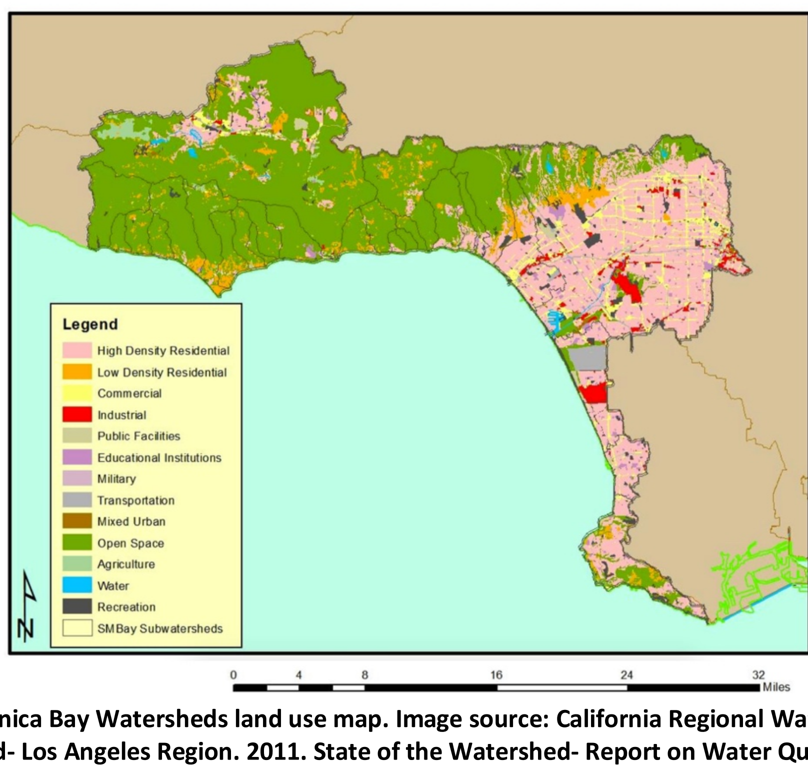

Figure 3. Santa Monica Bay Watersheds land use map. Image source: California Regional Water Quality Control Board- Los Angeles Region. 2011. State of the Watershed- Report on Water Quality.

Shoreline Monitoring of FIB in Santa Monica Bay

Several agencies conduct shoreline monitoring of FIB as part of the U.S. EPA and State of California NPDES programs to monitor storm water and wastewater discharges. These agencies include the City of Los Angeles' Environmental Monitoring Division (EMD), the Los Angeles County Department of Health Services (DHS), the Los Angeles County Sanitation District (LACSD), and the beach cities (BC) (City of Redondo Beach, City of Manhattan Beach, and City of Hermosa Beach). Monitoring locations are situated near high recreational use areas and sources of urban runoff, i.e. mouths of storms drains and creeks. Shoreline water samples typically are collected daily to weekly and tested for concentrations of total coliforms, *E. coli* or fecal coliforms, and enterococci. In the late 1980's to early 2000's, membrane filtration methods of quantification were used that reported values as colony forming units/100 ml (CFU/100 ml) (U.S. EPA 2002a, 2002b). However, in the early 2000's the various agencies switched to the use of chromogenic substrate methods of quantification, where values are reported as the most probable number/100 ml (MPN/100 ml) (American Public Health Association 2012). Water quality is then determined through comparison with numeric standards established by the State of California (CLA 2015).

In 1998, SMB beaches were found to have excessive levels of FIB and were added to the 303(d) list of impaired waters. As a result, TMDLs were developed for bacteria for wet weather and dry weather conditions. These TMDLs established numeric targets based of the three groups of FIB: total coliform, *E. coli* (or fecal coliforms), and enterococci (Table 1). The numeric targets include single sample and rolling 30-day geometric mean limits (CLA & CLA 2004; CLA 2015). The TMDLs triggered action to organize monitoring efforts and reduce FIB to bring SMB into compliance.

Table 1. TMDL single sample and rolling 30-day geometric mean numeric limits for FIB.

Single Sample Limits	Rolling 30-Day Geometric Mean Limits
10, 000 total coliform/100 ml	1, 000 total coliform/100 ml
400 *E. coli* (or fecal coliform)/100 ml	200 *E. coli* (or fecal coliform)/100 ml
104 enterococci/100 ml	35 enterococci/100 ml

On November 1, 2004, the various sampling agencies began participating in the Coordinated Shoreline Monitoring Plan (CSMP). The CSMP established consistency in monitoring by organizing sampling among the different entities. The plan was developed to comply with monitoring requirements for the wet and dry weather FIB TMDLs. Historically, sites were sampled a certain distance from sources of urban runoff, approximately 25-50 yards away. However, as part of the CSMP, all stations were to set to be sampled at point-zero, which is defined as the point where freshwater from a storm drain or creek mouth initially mixes with receiving ocean waters (CLA & CLA 2004).

To reduce FIB in SMB, a variety of best management practices (BMPs) have been implemented along the shoreline and throughout the watershed. Most of these BMPs included sewer improvements, biofiltration systems, and low-flow diversions. The latter was found to be among the most effective means at reducing FIB (Dorsey 2010) and as a result, increasing beach attendance in SMB (Atiyah et al. 2013).

Low-flow diversions (LFDs) prevent runoff from flowing into the ocean by intercepting flow in the storm drains and diverting it to the sanitary sewer system for eventual treatment at wastewater facilities (Figure 4). In the past, these structures were only operational during the dry season from April 1 through October 31. By approximately 2009, they became operational year-round during dry weather conditions. In the case of a rain event, they are shut down and flow is allowed to discharge to the ocean. Three days after the storm passes, they are turned back on to once again divert flow. The majority of diversions deal with an average drain flow of 0.43 MGD, with a range from 0.3-4.2 MGD (CLA 2004). The Santa Monica Canyon (SMC) LFD is the largest of the diversions and operates automatically with the assistance of a rubber dam located in the open concrete-lined channel leading to the beach. When the water during wet weather reaches a level of 3 ft, the dam automatically deflates allowing flow to pass over this structure and onto the adjacent beach and surf zone. Once the storm passes and the water levels returns to 1.5 ft, the dam re-inflates and runoff once again is diverted into the sewer (personal communication, Wing Tam, City of Los Angeles Watershed Protection Division, and the Los Angeles County Department of Public Works).

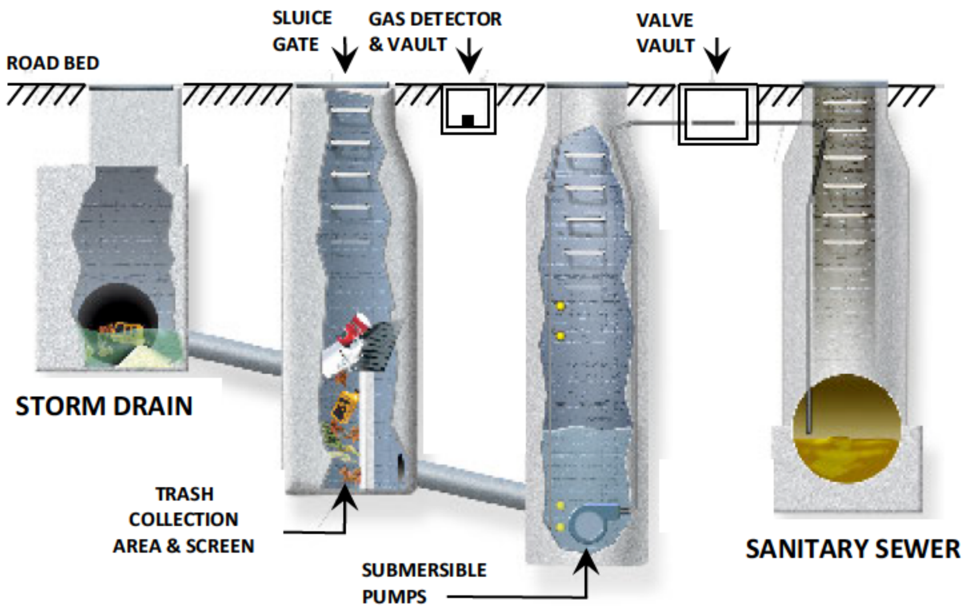

Figure 4. Diagram of a low flow diversion structure used by the City of Los Angeles. (Image source: www.lastormwater.org).

Research Goal—This Study

Despite decades of legislation, funding, and monitoring, a long-term assessment of FIB shoreline data does not exist. This information is needed to measure the effectiveness of projects and practices designed to diminish loads of FIB introduced into SMB. The goal of this research was to evaluate long-term concentrations of FIB along the shoreline of SMB based on the study questions and working hypotheses presented in Figure 5.

The general approach in addressing these questions, and testing associated hypotheses, involved assembling all available SMB shoreline monitoring data for enterococci and *E. coli* over the last 30 years, and then establishing the trends in FIB concentrations over this period for various Bay regions and weather conditions (dry vs. wet). This period of time was selected in part due to raw monitoring data available and also to sufficiently account for the period before implementation of LFDs, the first of which became operational in 1993. Enterococci and *E. coli* concentrations were used for this study, and not total coliforms, since the U.S. EPA no longer uses this latter FIB group for water quality criteria (U.S. EPA 2012).

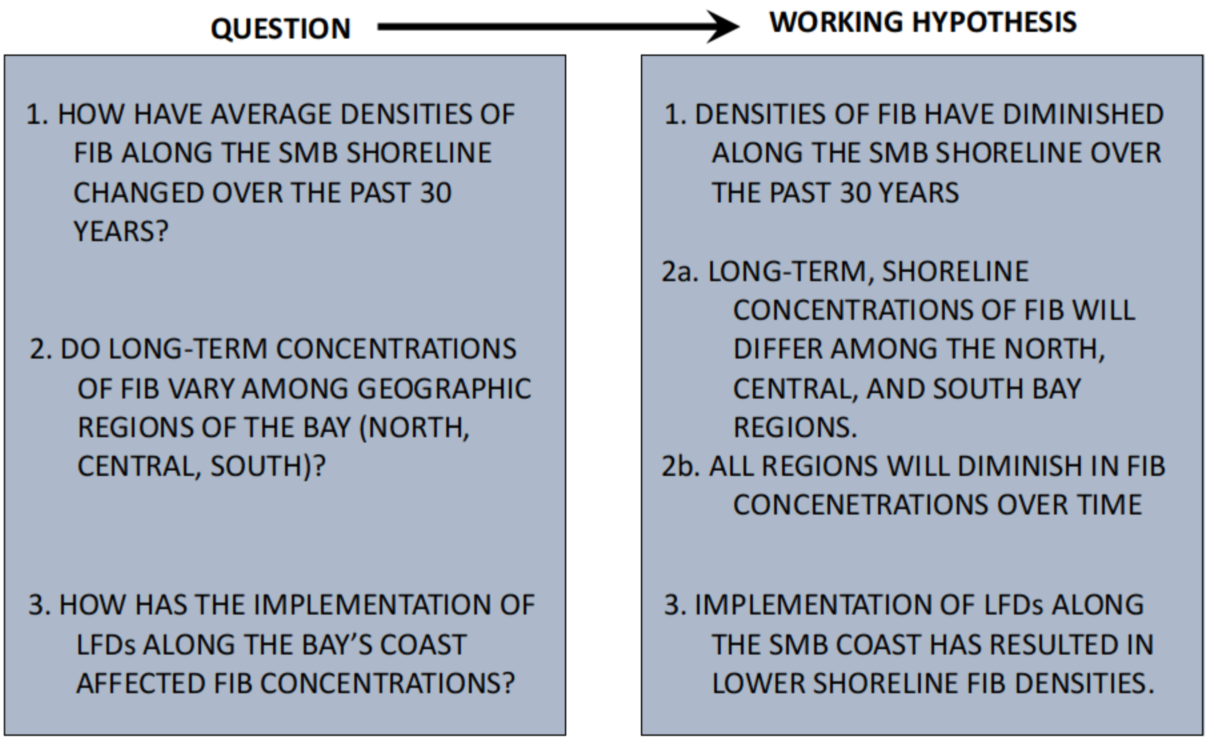

Figure 5. Study questions and their associated hypotheses to assess trend of FIB along the shoreline of Santa Monica Bay over a 30-yr period.

METHODS

Study Site

SMB was divided into three geographic regions (Figure 6, Table 2) based on the spatial structure and persistence of stormwater runoff plumes from the Malibu Creek and Ballona Creek subwatersheds that can extend alongshore greater than 10 km and persist for about 3 days (Washburn et al., 2003). The South Bay region comprises several smaller watersheds (Figures 2, 3), so their runoff plumes are relatively smaller compared to those flowing from the Ballona Creek and Malibu watersheds.

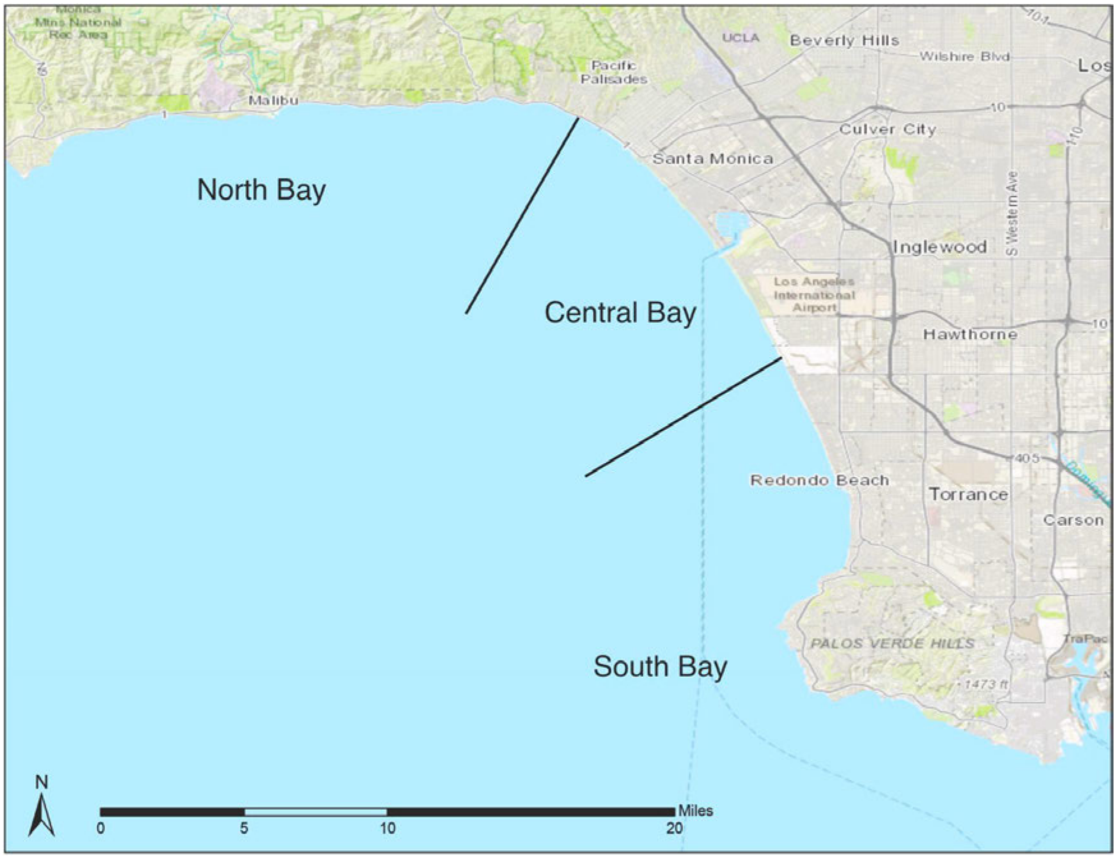

Figure 6. Geographic regions of Santa Monica Bay used for this study based on the movement of storm water plumes flowing from the Ballona Creek and Malibu watersheds.

Data Compilation

Raw monitoring data for enterococci and *E. coli* along with associated rain data were provided by Heal the Bay and EMD, and spanned from 1988 through 2017, a total of 30 years. Monitoring data originated from shoreline monitoring programs conducted by the EMD, DHS, LACSD, and BC (Table 2). Daily rain data, used to distinguish between wet and dry weather, were measured at the National Weather Service Los Angeles International Airport rain gauge. Additional rain data from EMD monitoring were used to fill several historical gaps (January 1988 to May 1992, and October 1994 to January 1995). Wet weather days were defined as a day with $\geq$ 0.1 inches of rain plus the three following days.

Over the study period, there were numerous changes to monitoring locations, including stations eliminated, new stations added, shifting sampling locations, or changing of a station's designation or lead sampling agency. Small-scale changes mainly consisted of moving the sampling distance from the outlets of storm drains, creeks, or rivers. Some of the most substantial changes came on November 1, 2004 as part of the CSMP (CLA and CLA 2004). At this time, additional monitoring locations were added and all new and existing locations adjacent to freshwater outlets were sampled at point-zero, the location where the discharge from a storm drain or creek initially mixes with receiving ocean waters.

Table 2. Number of sampling sites, responsible monitoring agencies, and the number of low flow diversions in each of the three regions of Santa Monica Bay partitioned for this study.

Geographic Region	Boundaries	No. of Stations	Associated Monitoring Agencies	No. of LFDs
North Bay	Point Dume to Temescal Canyon	29	EMD & DHS	5
Central Bay	Santa Monica Canyon to Dockweiler State Beach	28	EMD & DHS	13
South Bay	Manhattan Beach to Outer Cabrillo Beach	24	EMD, DHS, LACSD, & BC	6

The data set was reduced from more than 150 stations over the study period to 81 after older stations were combined or grouped under existing stations (Figure 7; Appendix A). This approach included combining stations with the same geographic coordinates or similar location descriptions, the grouping of pre- and post- point-zero stations, and site locations that overlapped among multiple agencies. Stations at Mother's Beach in Marina del Rey were excluded from the study because they were in a different environmental setting. Mother's Beach is an enclosed beach having poor water circulation, unlike SMB's shoreline that is exposed to waves and currents.

The units for measured values of enterococci and *E. coli* reported herein are given as "organisms/100 ml" since two methods were used to enumerate FIB over the 30-yr study period. Monitoring prior to around 2002 used membrane filtration where fecal coliforms and enterococci were reported as "(CFU)/100 ml". After this time, monitoring agencies switched to the chromogenic substrate method using Idexx Corporation materials, where concentrations of enterococci and *E. coli* were reported as "(MPN)/100 ml". A 1-1 data translation was used between *E. coli* and older fecal coliform data as approved by the Los Angeles Regional Water

Quality Control Board in 2002 (CLA and CLA 2004). Non-detects (ND) were recorded as various values (from 1-10) depending on FIB group, agency responsible, or time within study period. To create a consistent ND throughout the dataset, all values less than or equal to 10 were set equal to 5. Analyst errors were deleted from the dataset. Values reported as greater than or less than a certain threshold value, had their signs dropped with the value reported as is. The final uniform dataset consisted of approximately 150,000 data points for each set of enterococci and *E. coli* data.

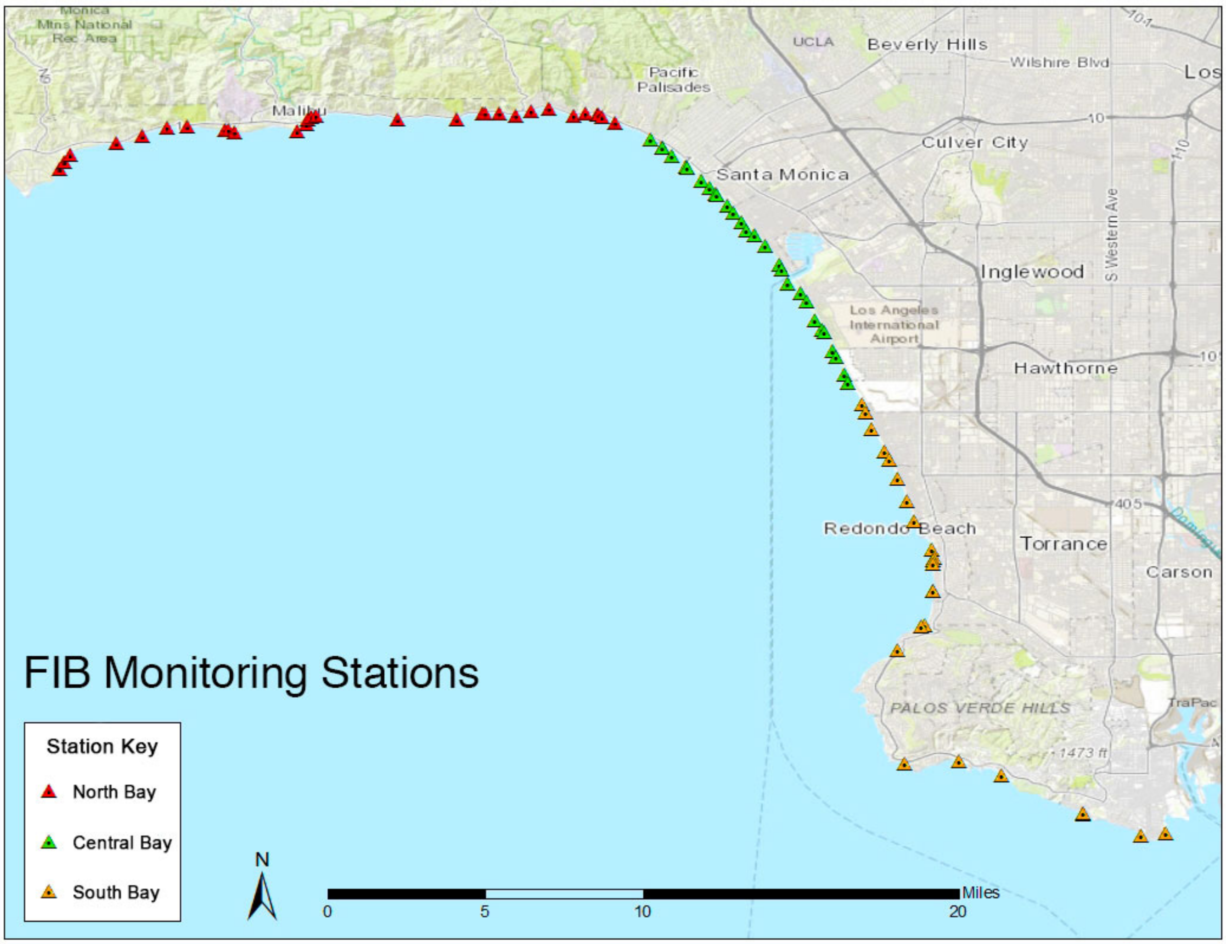

Figure 7. Location of the final 81 sampling locations used in this study. Metadata for each is provided in Appendix A.

Low-Flow Diversions

To assess the effectiveness of LFDs, data from the nearest downstream FIB monitoring stations were examined. LFD information (e.g. location, implementation date, dates of operation) was provided by Los Angeles County Flood Control District and the City of Los Angeles' Watershed Protection Division. Criteria to include a LFD in this study were defined by the following: 1) it must divert runoff for treatment that would otherwise flow unencumbered into coastal waters, and 2) it must be located no more than 0.5 mi from the beach. LFDs further inland, mainly those associated with enclosed beaches, and self-treatment LFDs were excluded. Self-treatment LFDs do not divert flow into the sewers, but rather treat on site and LFDs further inland are more susceptible to additional stormwater inputs between the structures and beach waters. Based on these criteria, 27 LFDs were included in this study (Figure 8 4; Appendix B). The SMC LFD was selected as the LFD/station for an independent assessment since it is the largest LFD structure along the Bay's shoreline and has a consistent set of monitoring data from its associated downstream monitoring site.

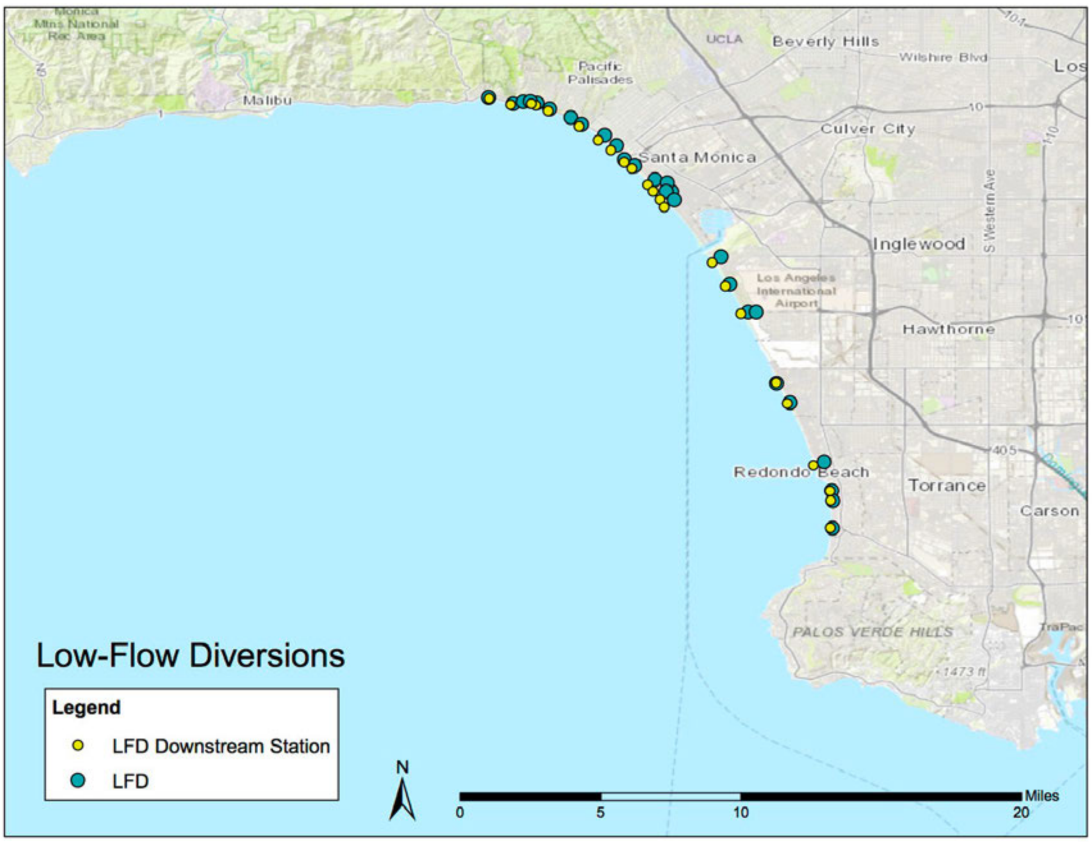

Figure 8. Location of the 27 low-flow diversions and associated monitoring stations assessed in this study.

Data Analysis

Rolling 30-day geometric means were calculated and graphed over time from 1988 through December 2, 2017 for enterococci and *E. coli* as follows:

1. all stations (wet weather, dry weather, and all weather combined);
2. the three geographic regions of the Bay (north, central, south): wet weather, dry weather, and all weather combined;
3. stations downstream of all LFDs during dry weather (these structures are only operational during dry weather); and
4. the station downstream of the SMC LFD during dry weather.

Trends were constructed using MATLAB software. Only data points through December 2, 2017 were included in trends and statistical analysis, so that all points contained the full 30-day time frame in their calculation. Since the trend data were not normally distributed, the non-parametric Kruskal-Wallis (KW) test was used to test the differences between dry and wet weather trends among the three geographic regions of the Bay and pre- and post-implementation of the SMC LFD dry weather trends.

RESULTS

Bay Wide

Wet weather concentrations for both bacterial groups were consistently higher than dry weather (Table 3, Figures 9 and 10). Trends for both FIB groups were relatively constant beginning in 1988, then peaked around the shift to point-zero sampling (November 1, 2004). Levels decreased shortly thereafter up until the 2016-17 wet season. At this time, values became highly variable with peaks and lows, most noticeably during wet weather conditions.

The enterococci rolling 30-day geometric mean concentrations averaged from 9.9 to 41.0 organisms/100 ml with the greatest average occurring during wet weather (Table 3). Early enterococci concentrations remained relatively consistent up until they exhibited a peak around the point-zero sampling shift (Figure 9). Following this point, concentrations diminished, continuing a downward trend until the 2016-17 wet season. At this time, concentrations displayed considerable variability, with wet weather data exhibiting both the highest and lowest values of the study period (52.6 and 5.7 organisms/100 ml, respectively).

The *E. coli* rolling 30-day geometric mean values averaged from 34.3 to 73.9 organisms/100 ml with the greatest values occurring during wet weather (Table 3). All *E. coli* trends were fairly constant from 1988 to about 1995, but then experienced a prolonged increase to the time of the point-zero sampling shift (Figure 10). After 2004, levels fell but did not reach earlier values measured in the late 1980's to mid 1990's. The 2016-17 wet season again showed substantial variability, predominantly for wet weather. Wet weather also showed several smaller increases and decreases for several years leading up to this point.

Table 3. Descriptive statistics for enterococci and *E. coli* Bay wide trends for wet weather, dry weather, and all weather combined.

	n	Average Geometric Mean ± S.D. (organisms/100ml)	Range (organisms/100ml)
Enterococci:			
All weather	9652	12.3 ± 1.6	6.7-13.6
Wet weather	1516	41.0 ± 5.3	5.7-52.6
Dry weather	8136	9.9 ± 1.1	6.7-10.9
***E. coli*:**			
All weather	9652	38.4 ± 6.1	29.1-49.3
Wet weather	1516	73.9 ± 9.3	26.7-113.4
Dry weather	8136	34.3 ± 6.0	25.1-44.1

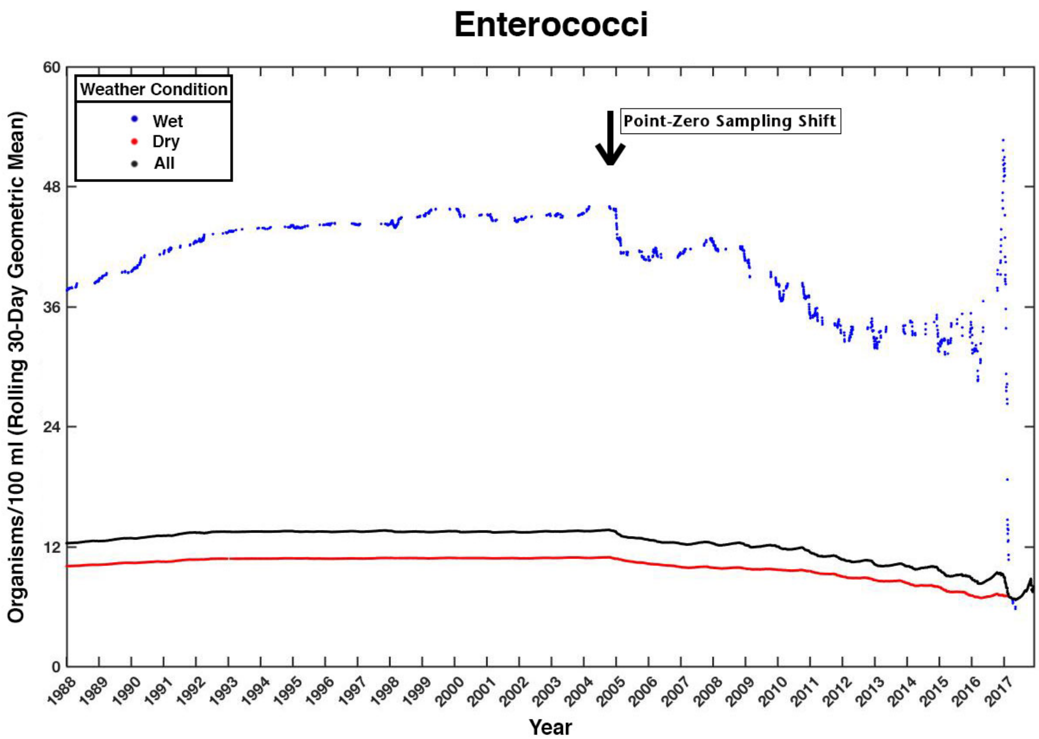

Figure 9. Enterococci rolling 30-day geometric mean values for SMB shoreline monitoring stations plotted over time for wet, dry, and all weather combined.

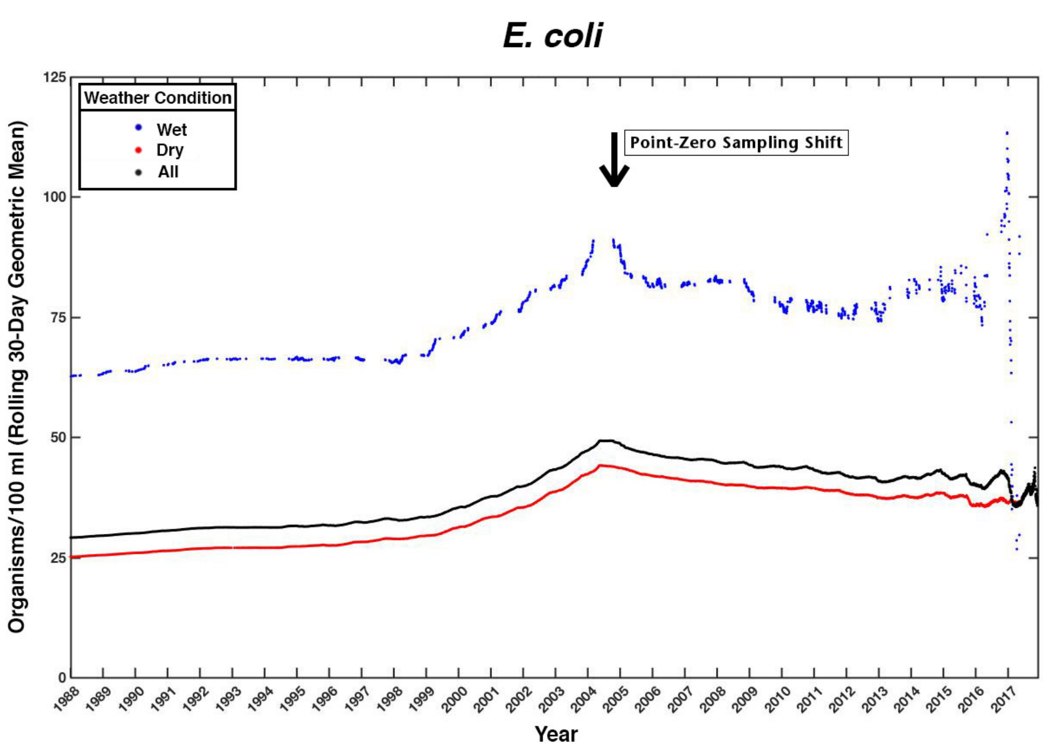

Figure 10. *E. coli* rolling 30-day geometric mean values for SMB shoreline monitoring stations plotted over time for wet, dry, and all weather combined.

North, Central, and South Bay Regions

Concentrations for each of the two bacterial groups among the three Bay regions all differed significantly when comparisons were made for wet and dry weather (Figures 11 and 12, Table 4). As with the Bay wide trends, wet weather concentrations for both bacterial groups were greater than dry weather for all regions of the Bay. Central Bay exhibited the highest wet weather measures for both bacterial groups. North Bay had the highest dry weather levels for enterococci and Central Bay had the highest for *E. coli*. South Bay had the lowest bacterial levels for both weather conditions.

Central Bay wet weather enterococci concentrations were over the TMDL numeric limit (35 organisms/100ml) for nearly the entire duration of the study period (Figure 11). Levels only dipped below the limit in early 2017 around the period of intense wet weather variability. North Bay wet weather enterococci values started above the limit, dipped below the limit around 2010-11, and then spiked back up in 2016-17. Dry weather enterococci values for all three regions stayed below the limit for the complete time period.

Both dry and wet weather *E. coli* concentrations of the three regions of the Bay were below the TMDL numeric limit (200 organisms/100ml) for nearly the whole study period (Figure 12). The exception was wet weather in Central Bay. It started below the limit, began to steadily increase around 2010, passing the limit around the time of the 2016-17 wet season.

Table 4. Average geometric means ± S.D. for wet and dry weather of the three regions of the Bay and results of the KW test comparing wet and dry weather trends among the various geographic regions.

	Average Geometric Mean ± S.D. (organisms/100 ml)					
	North	**Central**	**South**	**KW Test Statistic**	***p***	**Post-hoc Test Results**
Enterococci:						
Wet	45.5 ± 10.4	63.1 ± 7.7	24.2 ± 2.4	3626.7	<0.001 for all	C>N>S
Dry	12.5 ± 2.4	10.2 ± 1.0	7.9 ± 0.5	7,004.0	<0.001 for all	N>C>S
***E. coli*:**						
Wet	91.0 ± 9.3	128.5 ± 27.7	35.2 ± 6.9	3056.3	<0.001 for all	C>N>S
Dry	45.5 ± 5.6	45.2 ± 10.8	19.9 ± 4.9	15210.1	<0.01 to 0.001	C>N>S

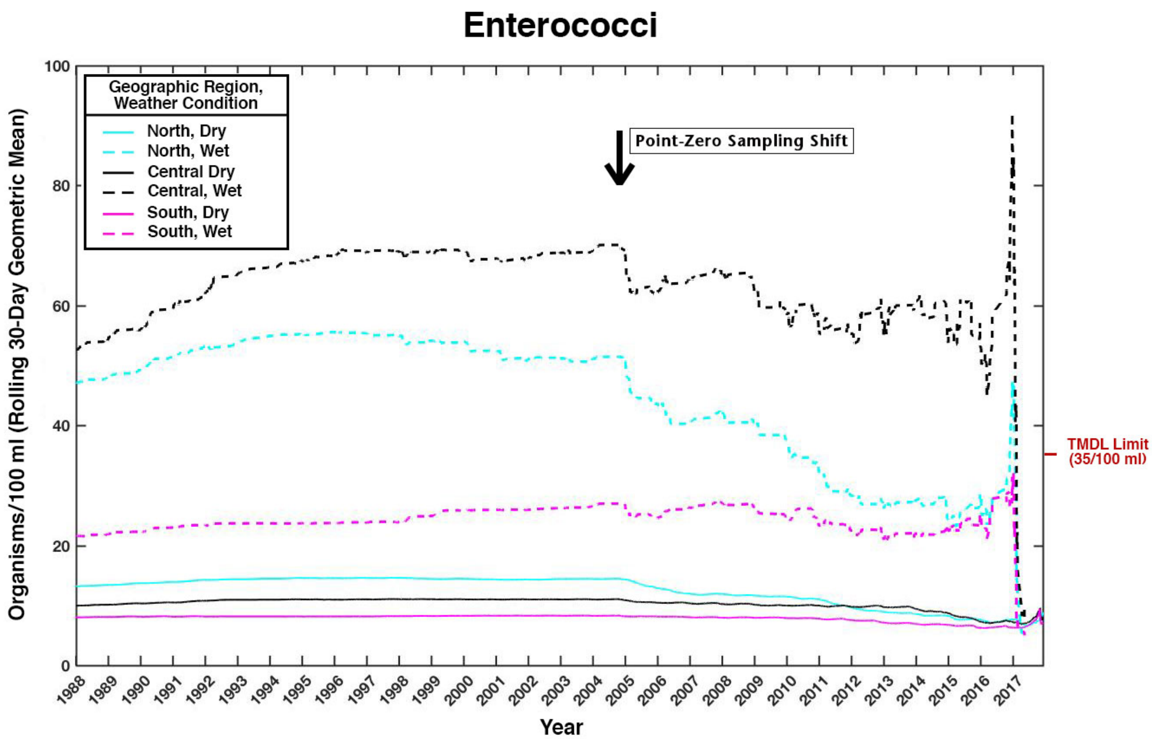

Figure 11. Wet and dry weather enterococci values for shoreline monitoring stations among geographic regions of SMB plotted over time. The enterococci rolling 30-day geometric mean numeric limit for the SMB Beaches Bacterial TMDL is shown in red to the right (35 organisms/100 ml).

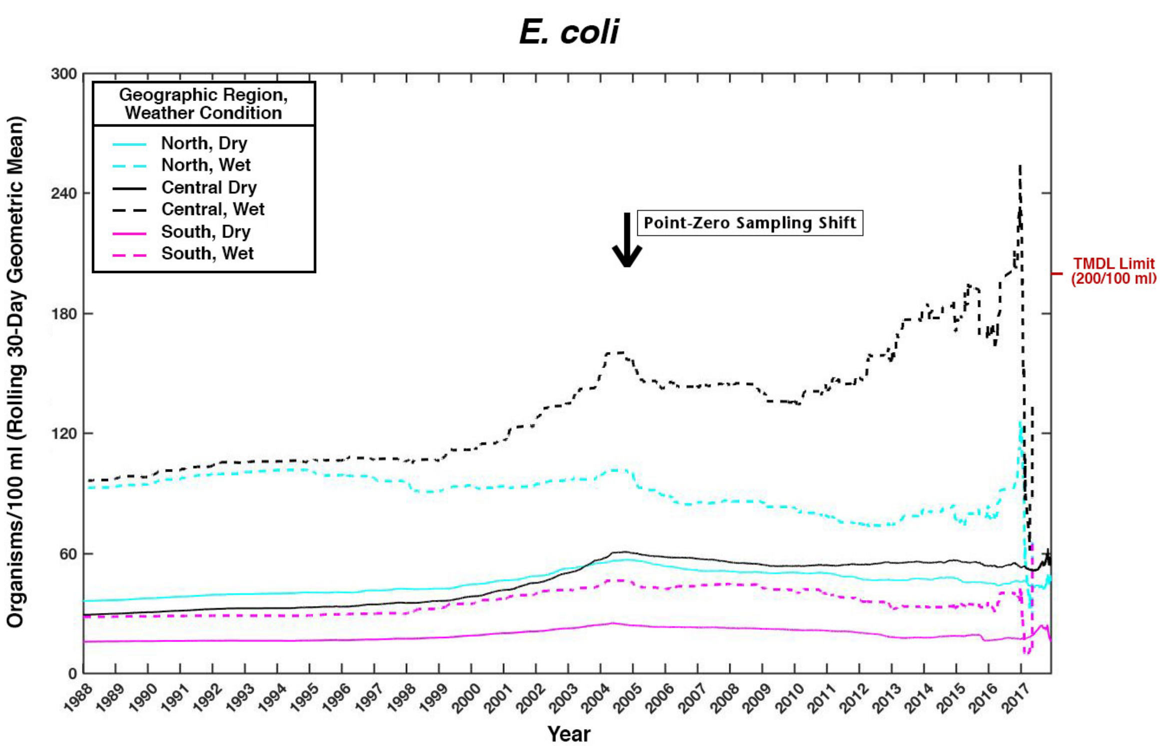

Figure 12. Wet and dry weather *E. coli* values for shoreline monitoring stations among geographic regions of SMB plotted over time. The *E. coli* rolling 30-day geometric mean numeric limit for the SMB Beaches Bacterial TMDL is shown in red to the right (200 organisms/100 ml).

Low-Flow Diversions

Dry weather concentrations of enterococci at stations downstream of the LFD sites were relatively constant until about 2005 when they began to diminish (Figure 13, Table 5), presumably reflecting the implementation of the LFD units from about 2001-2007. A similar trend occurred for the SMC LFD, which became operational in 2003. Here, the post-implementation average concentration (10.33 ± 3.2 organisms/100 ml) was significantly less (KW test statistic= 4,571.9, *p*= <0.001) than that for the pre-implementation (17.1 ± 0.7) (Table 6).

Similar to the Bay wide trends, dry weather *E. coli* levels at all stations downstream of LFDs and at the SMC LFD station exhibited a pattern where concentrations ramped up and peaked around the time of the point-zero sampling shift (Figure 14, Table 5). After this time, concentrations for both trends diminish, though never return to levels as low as in the late 1980's to the mid 1990's. Post-implementation *E. coli* concentrations at the SMC LFD (83.0 ± 10.4 organisms/100 ml) were found to be significantly higher (KW test statistic= 845.3, *p*= <0.001) than pre-implementation (76.3 ± 5.1) (Table 6).

Table 5. Descriptive statistics for enterococci and *E. coli* LFD dry weather trends.

	n	Average Geometric Mean ± S.D. (organisms/100ml)	Range (organisms/100ml)
Enterococci:			
Dry weather	6802	10.2 ± 1.3	6.9-11.3
***E. coli*:**			
Dry weather	6802	51.3 ± 10.5	33.4-68.8

Table 6. Results of the KW test comparing dry weather FIB concentrations downstream of the SMC LFD before and after implementation.

	SMC LFD Pre-Implementation		SMC LFD Post-Implementation				
	n	**Average Geometric Mean ± S.D. (organisms/100ml)**	**n**	**Average Geometric Mean ± S.D. (organisms/100ml)**	**KW Test Statistic**	**Post-hoc Test Results**	***p***
Enterococci: Dry Weather	2897	17.1 ± 0.7	3316	10.33 ± 3.2	4,571.9	Before > After	<0.001
***E. coli*:** Dry Weather	2897	76.3 ± 5.1	3316	83.0 ± 10.4	845.3	Before < After	<0.001

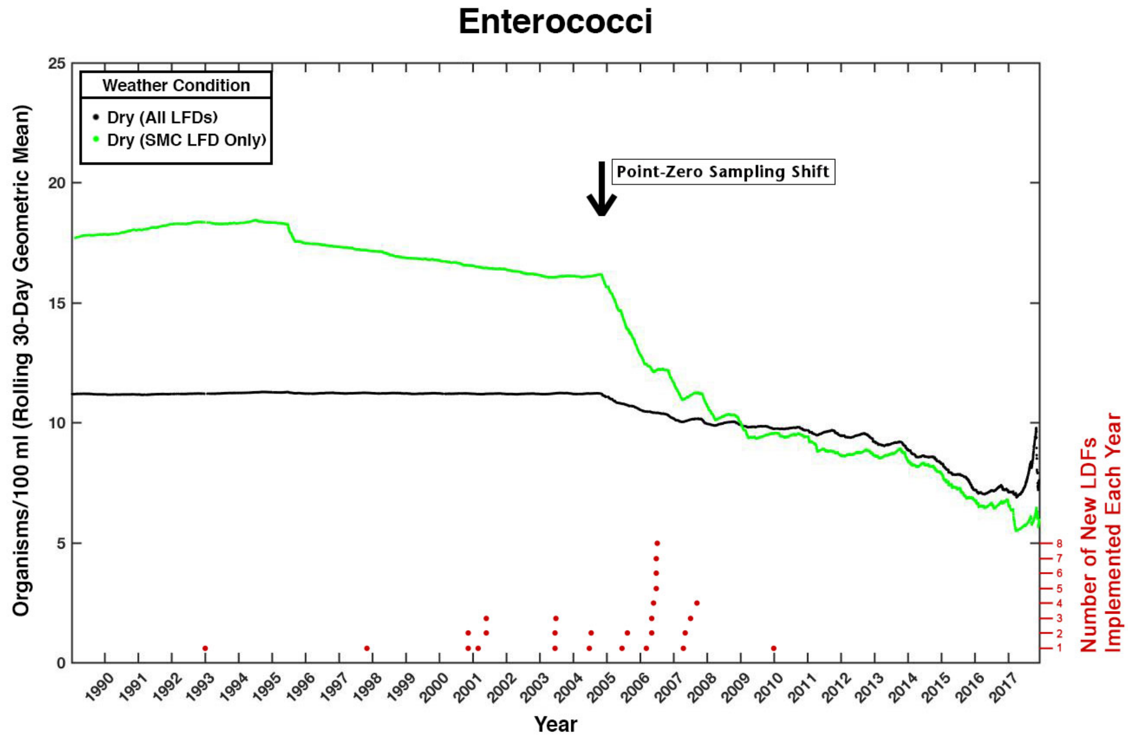

Figure 13. Dry weather enterococci values for all LFD downstream monitoring stations combined and the SMC LFD downstream monitoring station plotted over time. The number of new LFDs implemented each year is shown in red at the bottom of the figure.

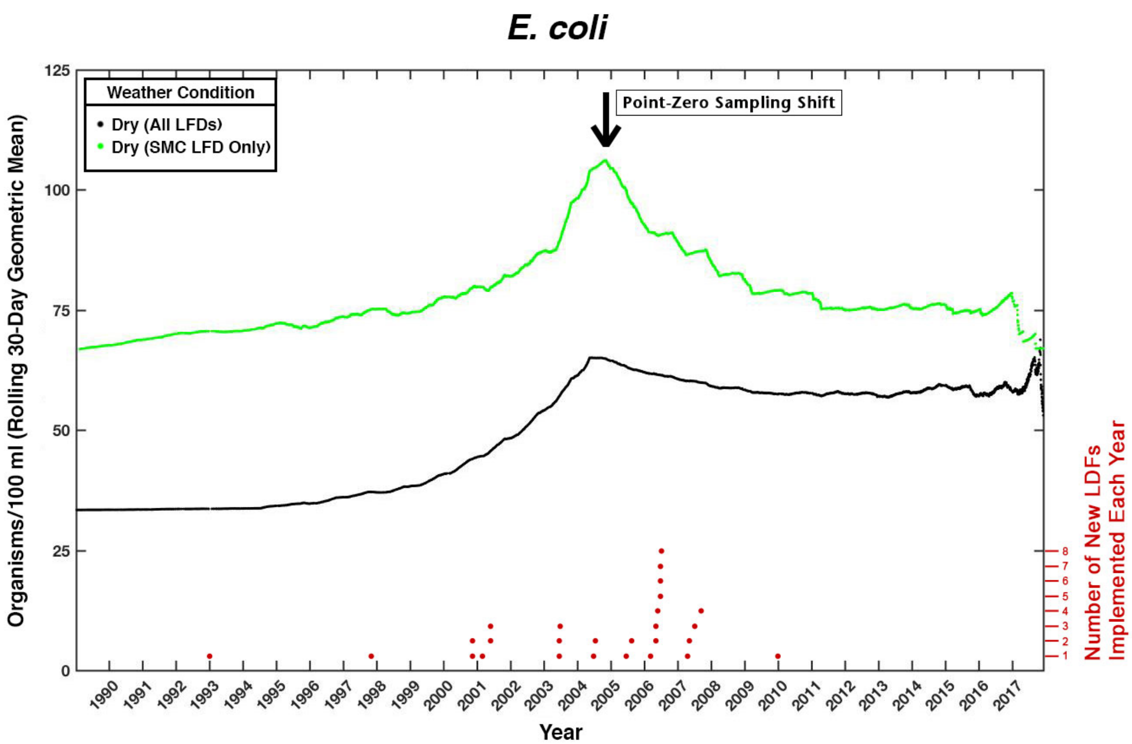

Figure 14. Dry weather *E. coli* values for all LFD downstream monitoring stations combined and the SMC LFD downstream monitoring station plotted over time. The number of new LFDs implemented each year is shown in red at the bottom of the figure.

DISCUSSION

While several studies have examined long-term (ranging from 3-10 years) bacterial pollution as an indicator of water quality, there appears to be no other published work that spans multiple decades (Mallin et al. 2000; Inamdar et al. 2002; Rodrigues et al. 2011; Thoe et al. 2018). Long-term assessment of *E. coli* and enterococci trends are essential to help evaluate the effectiveness of projects and practices designed to reduce recreational beach water pollution, especially as it relates to each indicator's regulatory limits such as TMDLs. These TMDLs act as a maximum limit for SMB recreational water standards, in which various entities work together to bring beach waters into compliance by lowering the bacteria levels in the waters draining into SMB. TMDLs have been established for both wet and dry weather, with wet weather permitted more allowable exceedance days annually than dry. TMDL exceedances were not investigated as part of this study. Rather, bacterial levels over the study period were simply compared to their numeric targets.

Enterococci

The U.S. EPA determined enterococci is the preferred indicator for marine waters (EPA 2012). Enterococci concentrations in the Bay were consistently higher during wet weather conditions. Elevated bacterial levels due to rainfall has been demonstrated in previous studies (Griffith et al. 2009; Noble et al. 2003). This is due to increased contaminated urban runoff introduced in the form of stormwater plumes running from the watersheds into the Bay.

Bay wide enterococci levels for all three weather conditions were relatively steady from the late 1980's through the early 2000's, until they then showed a small peak in late 2004. This peak can be partly attributed to the shift to point-zero sampling in November 2004. At this time, sampling distance was shifted from about 25-50 yards from a storm drain or creek mouth to directly at the point where discharge initially mixes with receiving ocean water. It has been previously demonstrated that higher FIB counts exist within a closer proximity to storm drains (Haile et al 1999). Bay wide long-term trends for both indicators support that assessment.

Following the peak in 2004, concentrations began to diminish, presumably due in part to the implementation of LFDs along the shoreline, the majority of which became operational between 2003-2008. The SMC LFD, in particular, showed decreased enterococci concentrations following implementation. Bay wide concentrations continued a downward trend for over a decade, up until the 2016-17 wet season. At this time, concentrations fluctuated considerably, most noticeably for wet weather, which displayed both the highest and lowest values of the study period. Additional data from subsequent years is required to assess how the trends may stabilize over time.

The variability of the 2016-17 wet season may be attributed to a variation in precipitation over the preceding years. Southern California has an arid environment, characterized by long dry periods with a shorter and variable wet season. Consequently, contaminants build up on land during these dry periods and are then washed into coastal waters during rain events, leading to increased water quality problems (Noble et al. 2003). This issue becomes further intensified by heavy storms following extended periods of drought, as demonstrated by the 2016-17 wet season. During this period, the years of drought were trailed by substantial storms acting as a flushing mechanism, washing the accumulation of contaminants out into the Bay. This consequence was most apparent in the Central Bay, due to the influence of contaminant plumes introduced into beach waters via Ballona Creek.

Central Bay had the highest wet weather enterococci concentrations of the three geographic regions for nearly the entire duration of the study period, only fluctuating during the intense variability of the 2016-17 wet season. The high wet weather FIB counts in Central Bay were expected due to the presence of the widespread impervious surfaces throughout the Ballona Creek Watershed. South Bay had the lowest enterococci levels for all weather conditions, likely due to its smaller and less urbanized watersheds (Figure 3). North Bay was found to have the significantly greatest average for dry weather enterococci levels, though the averages for the three regions of the Bay were all fairly close, biologically speaking, only differing by less than 5 organisms/100 ml.

Dry weather enterococci levels for all three geographic regions and South Bay wet weather remained below the TMDL numeric limit (35 organisms/100 ml) for the entire study period. Only North and Central Bay wet weather conditions appeared to surpass the TMDL target for an extended period of time. North Bay wet weather concentrations surpassed the limit at the beginning of the study period, began dropping following the point-zero sampling shift, and eventually dipped below the TMDL limit around 2010 where it remained up until the 2016-17 wet season variability. Central Bay wet weather started off and continued above the limit, only briefly dipping below during the 2016-17 wet season variability. These results suggest wet weather, specifically in Central Bay, may present an ongoing challenge to achieving TMDL limits for enterococci.

E. coli

E. coli has been a commonly used indicator for water quality for decades and remains part of the U.S. EPA's recommended indicators of recreational water quality (EPA 2012). Like enterococci, wet weather concentrations of *E. coli* levels were steadily higher than dry weather for all geographic conditions. The pattern of the Bay wide *E. coli* trend was similar to enterococci in that it peaked around the shift to point-zero sampling, decreased shortly after, and displayed considerable variation during the 2016-17 wet season.

The noticeable difference between the two bacterial groups was that *E. coli* exhibited a prolonged ramp up to the point-zero sampling shift for about the previous five years. Part of this ramp up could be attributed to a change in quantification methods from membrane filtration, which measures fecal coliforms, to chromogenic substrate (using the Idexx Corporation's Colilertmedia), which measures *E. coli*. The quantification methods change for *E. coli*, which came into effect around 2002, has a tendency to overestimate values (personal communication, Ioannice Lee, City of Los Angeles, Environmental Monitoring Division). Pisciotta et al. 2002 compared densities of *E. coli* in marine and freshwater samples using both the chromogenic substrate (with Colilert media) and membrane filtration. They found that similar results were obtained in freshwater samples, but for marine water, estimates of *E. coli* densities ranged up to two orders of magnitude greater. This result probably reflected the increased number of marine species able to grow in the Colilert media, such as species of *Vibro*, leading to false positives.

Following the shift to point-zero sampling, concentrations fell but never again reached levels as low as in the late 1980's - early 1990's, as the decline was less than the prolonged ramp up. Even for the SMC LFD trend, a decline in enterococci levels was apparent following implementation, though post-implementation average geometric mean was greater than pre-implementation. The switch in quantification methods, possibly overestimating values, and shifting closer to the source of runoff both likely factor into the increased *E. coli* trends.

Regarding TMDLs for *E. coli*, only the Central Bay during wet weather was briefly over the numeric limit during the 2016-17 wet season. Similar to enterococci, South Bay had the lowest *E. coli* concentrations for both wet and dry weather conditions, with wet weather even lower than North and Central Bay dry weather.

BMPs

LFDs were found to improve recreational beach water quality and appear to play a key role in this study. However, these systems are utilized only during dry weather conditions. The decreasing bacterial trends, particularly for wet weather, indicate other BMPs throughout SMB's watersheds have contributed to reducing contaminated runoff from flowing into beach waters. Low impact development (LID) has recently been identified as a preferred approach to stormwater management. LID incorporates a variety of green-architectural design approaches and BMPs that promote natural infiltration to reduce bacteria and other contaminants, while also reducing the volume of stormwater runoff eventually reaching the beach (U.S. EPA 2012, CLA 2016). This method of infiltration using vegetated swales and rain gardens has been shown to be an effective mean of reducing bacterial concentrations (Burkhard 2018).

Conclusions

This work suggests LFDs, along with other BMPs designed to restrict polluted runoff from flowing into beach waters, have been effective at reducing FIB concentrations at SMB beaches. Dry weather FIB levels appear to be steadily low, whereas wet weather levels, especially in Central Bay, exhibited a higher degree of variability and may present a more significant challenge to meet water quality standards going forward. LID projects and practices may be key in addressing wet weather flow. Implementation of biofiltration systems, particularly throughout the Ballona Creek Watershed, could be a cost-effective approach to reduce FIB concentrations during all weather conditions, while the increased vegetation and associated biodiversity would provide additional ecosystem services to urban areas. These proposed projects should be accompanied by careful monitoring both up and downstream to gauge their efficiency and refine designs.

In addition, further research is needed to examine the recreational coastal water quality implications of climate change. The 2016-17 wet season displayed intense variability in FIB concentrations, as the accumulation of contaminants, which built up during an extended dry period, was subsequently flushed into coastal waters due to heavy storms. Climate change may lead to increased precipitation intensity and variability. The frequency of heavy rainfall events, as well as extreme drought has been projected to likely increase (Bates et al. 2008). This increase in extreme weather conditions could potentially exacerbate FIB pollution in recreational beach waters. For this reason, it is important that LID systems continue to be deployed throughout the Bay's watershed, and that shoreline FIB trends be monitored to determine these runoff control measures.

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Appendix A

ID	Latitude	Longitude	Location Description	Historical Station Designations	Agency	Sampling Periods
SMB-O-1	34.01359	-118.79179	Unnamed Creek, projection of Zumirez Dr. (Little Dume)		EMD	Jan '10- Dec '17
SMB-1-6	34.01691	-118.78973	Walnut Creek outlet, projection of Wildlife Road		EMD	Jan '05- Dec '17
SMB-1-7	34.02024	-118.78656	Paradise Cove Pier at Ramirez Canyon Creek mouth (point-zero)	Jan '89- Dec '91: DHS (007); Jan '92- June '94: DHS (9); Jul'94- Dec '94: DHS (008); Jan '95- Oct '04: DHS (006) Paradise Cove, adjacent to west side of Pier (through 10/04)	DHS	Jan '89- Dec '17
SMB-1-8	34.02527	-118.76579	Escondido Creek, just east of Escondido State Beach		EMD	Jan '05- Dec '17
SMB-1-9	34.02871	-118.75350	Latigo Canyon Creek mouth (point-zero)	Jan '89- Dec '91: DHS (006) 26000 Block, Latigo Shore Drive; Jan '92- June '94: DHS (8) 26000 Block; Jul'94- Dec '94: DHS (007) 26610 Latigo Shore Dr. Malibu; Jan '95- Oct '04: DHS (005) Latigo Canyon Creek entrance (through 10/04)	DHS	Jan '89- Dec '17
SMB-1-10	34.03264	-118.74212	Solstice Canyon at Dan Blocker County Beach		EMD	Jan '05- Dec '17
DHS (005a)	34.03320	-118.73314	Corral State Beach		DHS	Jan '95- Aug '00
SMB-O-2	34.03143	-118.71597	Unnamed Creek, adjacent to public stairway at 24822 Malibu Rd.		EMD	Jan '10- Dec '17
SMB-1-11	34.03134	-118.71427	Puerco State Beach at creek mouth (point-zero)	Jan '89-Dec '91: DHS (005) 25000 Block, Malibu Rd.; Jan '92- June '94: DHS (7) 25000 Block; Jul'94- Dec '94: DHS (006) Coral Beach 25500 PCH; Sep '00- Oct '04: DHS (004) Puerco Beach, 25500 Pacific Coast Hwy (at lifeguard station) (through 10/04)	DHS	Jan '89-Dec '94, Sep '00- Dec '17
SMB-1-12	34.03042	-118.71126	Marie Canyon storm drain at Puerco Beach, at 24572 Malibu Rd.		EMD	Jan '05- Dec '17
DHS (003)	34.03071	-118.68262	Malibu Point (aka SMB-MC-1)	Jan '89- Dec '91: DHS (004); Jan 92- June '92: DHS (6) Malibu Lagoon west side; Jul '94- Dec '94: DHS (005)	DHS	Jan '89- Dec '17
S1	34.03430	-118.67838	Surfrider Beach (breach point) (aka SMB-MC-2)		EMD	Jul '94- Dec '17
DHS (003a)	34.03637	-118.67796	Surfrider Beach (second point)- weekly	Jan '92- June '94: DHS (5) Malibu Lagoon, east side; Jul '94- Dec '94: DHS (004) Surfrider	DHS	Jan '92- Aug '00
DHS (002)	34.03714	-118.67600	Malibu Pier- 50 yards east (aka SMB-MC-3)	Jan '92- June '94: DHS (4) 22956 PCH, east of pier; Jul'94- Dec '94: DHS (003) Malibu Pier	DHS	Jan '92- Dec '17
SMB-1-13	34.03780	-118.67388	Carbon Beach at Sweetwater Canyon		EMD	Jan '05- Dec '17
SMB-1-14	34.03607	-118.63659	Las Flores State Beach at Las Flores Creek (point-zero)	Jan '89-June '94: DHS (003) Mouth of Las Flores Creek- DHS station; Jul '94- Dec '94: DHS (002) Las Flores Beach, 21150 PCH- DHS station; Jan '95- Mar '99: DHS (001a) Las Flores Beach (through 10/04)- DHS station	EMD	Jan '89- Mar '99, Jan '05- Dec '17

DHS (001)	34.03641	-118.60952	Big Rock Beach at 19948 PCH stairs (aka SMB-1-15)	Jan '89- June '94: DHS (002); Jul '94-Dec '94: DHS (001)	DHS	Jan '89- Dec '17
S1-Old	34.03924	-118.59779	West of house at 19324 PCH and west of Pena Creek. 1.1 miles west of Topanga Cyn Blvd. Sample on west side of groin.		EMD	Jan '88- Jun '92
SMB-1-16	34.03906	-118.59665	Pena Creek at Las Tunas County Beach		EMD	Jan '05- Dec '17
SMB-1-17	34.03903	-118.58984	Tuna Canyon		EMD	Jan '05- Dec '17
S2	34.03781	-118.58261	Topanga Beach at creek mouth (aka SMB-1-18)	Feb '89- June '94: DHS (001) - DHS station	EMD	Feb '89- Dec '17
S2-Old	34.04005	-118.57514	East end of Charthouse restaurant parking lot. 0.25 miles east of Topanga Cyn Blvd		EMD	Jan '88- Jun '92
SMB-2-1	34.04122	-118.56703	Castlerock storm drain at Castle Rock Beach		EMD	Jan '05- Dec '17
SMB-2-2	34.03784	-118.55578	Santa Ynez drain at Sunset Blvd.		EMD	Jan '05- Dec '17
DHS (101)	34.03911	-118.55059	Will Rogers State Beach at 17200 PCH (1/4 mile east of Sunset drain) (aka SMB-2-3)		DHS	Jul '94- Jan '98, March '98-Arp '15, Sep '15- Dec '17
SMB-2-5	34.03832	-118.54521	Will Rogers State Beach at Bel Air Bay Club drain near fence (point-zero)	Jul '94- Oct '04: DHS (102) 16801 Pacific Coast Highway, Bel Air Bay Club (chain fence) (through 10/04)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
S3-Old	34.03854	-118.54424	Opposite fence at east side of boats at Bel Air Beach Club. 0.1 mile east of Bayclub Dr., and 0.7 miles east of sunset Blvd.		EMD	Jan '88- Jun '92
SMB-2-4	34.03755	-118.54284	Will Rogers State Beach at Pulga Canyon storm drain (point-zero)	Feb '89- June '94: DHS (101) Pulga Storm Drain 50 yards west & DHS (102) Pulga Storm Drain 50 yards east Jul '94- Oct '04: S3 Pulga Canyon storm drain 50 yards east (through 10/04)	EMD	Feb '89- Dec '17
SMB-2-6	34.03471	-118.53660	Will Rogers State Beach at Temescal Canyon drain (point-zero)	Jul '94- Oct '04: DHS (103) Will Rogers State Beach - Temescal Canyon, 25 yards east of drain (through 10/04)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
SMB-2-7	34.02685	-118.52061	Will Rogers State Beach at Santa Monica Canyon drain (point-zero)	Feb '89- June '94: DHS (103) Santa Monica Canyon storm drain, west & DHS (104) Santa Monica Canyon storm drain, east- both DHS stations; Jul '94- Oct '04: S4 Santa Monica Canyon, Will Rogers State Beach (through 10/04)	EMD	Feb '89- Dec '17
S4-Old	34.02323	-118.51538	East side of Santa Monica Swim Club and opposite west fence of yellow house, opposite large palm trees		EMD	Jan '88- Jun '92
DHS (104a)	34.02331	-118.51520	Santa Monica Beach at San Vicente Bl.	Jul '94- Dec '94: DHS (104)	DHS	Jul '94- Nov '95, Jan '96-Aug '00
SMB-3-1	34.01963	-118.51070	Santa Monica Beach at Montana Ave. drain (point-zero)	Jul '94- Dec '94: DHS (105); Jan '95- Oct '04: DHS (104) Santa Monica at Montana Ave. (25 yards. so. of drain) (through 10/04)	DHS	Jul '94- Nov '95, Jan '96- Dec '17

SMB-3-2	34.01453	-118.50423	Santa Monica Beach at Wilshire Blvd. drain (point-zero)	Jul '94- Dec '94: DHS (106) Wilshire Blvd; Jan '95- Oct '04: DHS (105) Santa Monica at Arizona (in front of the drain) (through 10/04) (now Wilshire)	DHS	Jul '94-Nov '95, Jan '96- Dec '17
S5-Old	34.01415	-118.50389	Opposite 21-story skyscraper at Wilshire Blvd. Next to Lifeguard tower #12		EMD	Jan '88- Jun '92
SMB-3-3	34.00827	-118.49738	Santa Monica Municipal Pier (point-zero)	Feb '89-Apr '89: DHS (105) Santa Monica Pier, north & DHS (106) Santa Monica Pier, south- both DHS stations; May '89- June '94: DHS (106) Santa Monica Pier, south- DHS station; Jul '94- Oct '04: S5 Santa Monica Municipal Pier- 50 yards southeast (through 10/04)	EMD	Feb '89- Dec '17
SMB-3-4	34.00509	-118.49338	Santa Monica Beach at Pico/Kenter storm drain (point-zero)	Feb '89- Apr '89: DHS (107) Pico/Kenter storm drain, north & DHS (108) Pico/Kenter Storm Drain, south- both DHS stations; May '89-June '94: DHS (106) Pico/Kenter Storm Drain, north & DHS (107) Pico/Kenter storm drain, south- both DHS stations; Jul '94- Oct '04: S4 Santa Monica Beach at Pico/Kenter storm drain (through 10/04)	EMD	Feb '89- Dec '17
DHS (106)	34.00225	-118.49084	Santa Monica Beach at Strand St. (in front of the restrooms) (aka SMB-3-9)	Jul '94-Dec '94: DHS (107)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
S6-Old	34.00168	-118.49022	Opposite second restroom, which is tan with a brown roof. Next to lifeguard tower #24. 0.3 mile south of Pico storm drain		EMD	Jan '88- Jun '92
SMB-3-5	33.99650	-118.48527	Ocean Park Beach at Ashland Ave. drain (point-zero)	Feb '89- Apr '89: DHS (109) Ashland Av storm drain, north & DHS (110) Ashland Av. storm drain, south- both DHS stations; May '89- Jun '94: DHS (108) Ashland Av. storm drain, north & DHS (109) Ashland Av. storm dram, south- both DHS stations; Jul '94-Dec '94 DHS (108) Ashland Av. storm drain, north- DHS station & S7 Ashland Av. storm drain, south; Jan '95- Aug '00: DHS (106a) Ashland Av. storm drain, north- DHS station & S7 Ashland Av. storm drain, south; Aug '00-Oct '04: S7 Ashland Av storm drain, south (through 10/4)	EMD	Feb '89- Nov '95, Jan'96- Dec '17
SMB-3-6	33.99323	-118.48238	Venice City Beach, at the Rose Ave. storm drain		EMD	Jan '05- Dec '17
DHS (107)	33.98897	-118.47877	Venice City Beach at Brooks Ave. drain (aka SMB-3-7)	Jul '94-Dec '94: DHS (109)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
SMB-3-8	33.98518	-118.47670	Venice City Beach at Windward Ave. drain (point-zero)	Jan '89- Apr '89: DHS (111) Windward storm drain, north & DHS (112) Windward storm drain, south-both DHS stations; May '89-Jun '94: DHS (110) Windward storm drain, north & DHS (111) Windward storm	EMD	Jan '89- Dec '17

				drain, south- both DHS stations; Jul '94- Oct '04: S8 Venice City Beach at Windward Av.- 50 yards north (through 10/04)		
S7-Old	33.98321	-118.47300	Opposite restroom, which is tan with a brown roof. 0.1 miles north of County Lifeguard Headquarters (an octagonal shaped building). The station is near lifeguard tower #21		EMD	Jan '88- Jun '92
DHS (108)	33.97800	-118.46773	Venice Fishing Pier- 50 yards south (aka SMB-2-8)	Jul '94- Dec '94: DHS (110)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
S8-Old	33.96983	-118.46128	Opposite Outrigger St. Opposite blue and gray four-story building. The station is 0.70 miles north of Marina channel concrete wall		EMD	Jan '88- Jun '92
DHS (109)	33.96728	-118.46048	Venice City Beach at Topsail St. (aka SMB-2-9)	Oct '94- Dec '94: DHS (111)	DHS	Oct '94- Nov '95, Jan '96- Dec '17
SMB-BC-1	33.96075	-118.45761	Dockweiler State Beach at Ballona Creek mouth (point-zero)	Jan '89- Apr '89: DHS (201)- DHS station; Jul '94- Oct '04: S10 Ballona Creek entrance- 50 yards south (through 10/04)	EMD	Jan '89- Apr '89, Jul '94-Oct '04, Nov '04- Aug '14
S11	33.95646	-118.45184	Dockweiler State Beach at Culver Blvd. drain (aka SMB-2-10)		EMD	Jul '94- Dec '17
S9-Old	33.95300	-118.44913	Opposite south end of fence, south of condominium complex. The station is 0.7 miles south of Ballona Creek channel. The station is halfway between lifeguard towers #43 and #44		EMD	Jan '88- Jun '92
SMB-2-11	33.94436	-118.44516	North Westchester storm drain at Dockweiler State Beach		EMD	Jan '05- Dec '17
S10-Old	33.94001	-118.44184	South of groin, 0.15 mile south of State Maintenance Building. The distance from station #9 to station #10 is 1.00 mile. The distance from station #10 to Imperial storm drain is 0.75 mile		EMD	Jan '88- Jun '92
DHS (110)	33.93870	-118.44100	Dockweiler State Beach at World Way (south of D&W jetty) (aka SMB-2-12)	Jul '94- Sep '94: DHS (116) Epinard St. extended, Playa del Rey; Oct '94- Dec '94: DHS (116) World Way extended, Playa del Rey	DHS	Jul '94- Nov '95, Jan '96- Dec '17
SMB-2-13	33.93006	-118.43713	Dockweiler State Beach at Imperial Hwy drain (point-zero)	Jan '89-Apr '89: DHS (202) Imperial Hwy storm drain, north & DHS (203) Imperial Hwy storm drain, south- both DHS stations; May '89-Dec '91: DHS (116) - DHS station; Jan '92-Jun '94: DHS (117) -DHS station; Jul '94-Oct' 04: S12 Imperial HWY storm drain- 50 yards north (through 10/04)	EMD	Jan '89- Dec '17

S11-Old	33.92740	-118.43551	South of groin, opposite the south end of Hyperion (C-8) building. The distance from station #10 to station #11 is 0.95 miles, or 0.2 mile south of Imperial storm drain		EMD	Jan '88- Jun '92
DHS (111)	33.91893	-118.43159	Hyperion Treatment Plant One Mile Outfall (aka SMB-2-14)	Jul '94- Dec '94: DHS (117) Opposite Hyperion, 1m marker	DHS	Jul '94- Nov '95, Jan '96- Dec '17
DHS (112)	33.91561	-118.42973	Dockweiler State Beach at Grand Ave. drain (aka SMB-2-15)	Jan '89-Apr '89: DHS (204) Grand Ave. storm drain, north & DHS (205) Grand Ave. storm drain, south; Jul '94-Dec '94: DHS (118)	DHS	Jan '89-Apr '89, Jul '94- Nov '95, Jan '96- Dec '17
S12-Old	33.90550	-118.42341	Opposite 45th St., El Porto section of Manhattan Beach. 1.6 Miles north of Manhattan Beach pier		EMD	Jan '88- Jun '92
S13	33.90180	-118.42200	Manhattan State Beach at 40th Street (aka SMB-5-1)		BC	Jul '94- Dec '17
DHS (113)	33.89446	-118.41893	Manhattan Beach at 28th St. drain (aka SMB-5-2)		DHS	Jan '02- Dec '17
SMB-5-3	33.88381	-118.41323	Manhattan Beach Pier drain (point-zero)	Jul '94- Oct '04: S14 Manhattan Beach Pier- 50 yards south (through 10/04)- EMD station	BC	Jul '94- Dec '17
S13-Old	33.88003	-118.41083	Opposite Mediterranean style house with a red tile roof. Opposite 6th St. in Manhattan Beach. 0.3 mile south of Manhattan Beach pier. 1.4 miles north of Hermosa Beach pier		EMD	Jan '88- Jun '92
DHS (114)	33.87137	-118.40726	Hermosa City Beach at 26th St. (aka SMB-5-4)	Jul '94- Dec '94: DHS (119)	DHS	Jul '94- Nov '95, Jan '96- Dec '17
S15	33.86120	-118.40297	Hermosa Beach Pier- 50 yards south (aka SMB-5-5)	Jan '88- Jun '92: S14 South side of Hermosa Pier- EMD station	BC	Jan '88- Jun '92, Jul '94- Dec '17
DHS (115)	33.85191	-118.39971	Herondo Street storm drain- (in front of the drain) (aka SMB-6-1)	Jul '94- Dec '94: DHS (120) -DHS station	EMD	Jul '94- Nov '95, Jan '96- Dec '17
SMB-6-2	33.83868	-118.39125	Redondo Municipal Pier 100 yards south	Jan '89-Apr '89: DHS (206) Redondo Pier, north & DHS (207) Redondo Pier, south- both DHS stations; May '89- Dec '89: DHS (117) Redondo Pier, north & DHS (118) Redondo Pier, south- both DHS stations; Jan '92- Jun '94: DHS (118) Redondo Pier, north & DHS (119) -both DHS stations; Jul '94- May '13: S16 Redondo Municipal Pier, south side - EMD station *overlap from Nov '04- May '13 with RB monitoring	BC	Jan '89- Dec '17
S15-Old	33.83525	-118.39047	Opposite end of stairway of restroom at the south end of the Redondo Beach Veterans Park. 0.25 mile south of Redondo Beach Pier. The pier sample is taken at the south side of the Redondo Beach pier		EMD	Jan '88- Jun '92
SMB-6-3	33.83384	-118.39082	Redondo State Beach at Sapphire Street		BC	Nov '04- Dec '17

DHS (116)	33.83227	-118.39098	Redondo State Beach at Topaz St. - north of jetty (aka SMB-6-4)	Jul '94- Dec '94: DHS (121)	DHS	Jul '94- Nov '96, Jan '96- Dec '98, Apr '99- Dec '17
S16-Old	33.81983	-118.39088	Opposite south end of concrete ramp at Avenue "I" in Redondo Beach		EMD	Jan '88- Jun '92
SMB-6-5	33.81982	-118.39107	Torrance Beach at Avenue I drain (point-zero)	Jan '89- Apr '89: DHS (208) Ave I storm drain, north & DHS (209) Ave I storm drain, south- both DHS stations; Jul '94- Oct '04: S17 Redondo State Beach at Ave I (through 10/04) -EMD station	BC	Jan '89-Apr '89, Jul '94- Dec '17
S18	33.80435	-118.39466	Malaga Cove, Palos Verdes Estates - at trail outlet (aka SMB-6-6)		BC	Jul '94- Dec '17
LACSDM	33.80342	-118.39613	Malaga Cove, Palos Verdes Estates - at rocks (aka SMB-7-1)	Jan '88- Jun '92: S17 at the rocks at the bottom of the emergency road at Malaga Cove. 0.60 mile south of concrete ramp opposite Via Riviera in Torrance- EMD station	LACSD	Jan '88- Jun '92, Jan '97- Dec '00, Dec '01 (Sampled only once), Jan '02- Dec '17
LACSDB	33.79290	-118.40700	Palos Verdes (Bluff) Cove, Palos Verdes Estates (aka SMB-7-2)		LACSD	Jan '97- Dec '00, Dec '01 (Sampled only once), Jan '02- Dec '17
LACSD1	33.74090	-118.40400	Long Point, Rancho Palos Verdes (aka SMB-7-3)		LACSD	Jan '97- Nov '97 (Entero only), Dec '97- Apr '98, May '98- Mar '99 (Entero only), Apr '99- Dec '17
LACSD2	33.74159	-118.37919	Abalone Cove Shoreline Park (aka SMB-7-4)	Jan '89- Apr '89: DHS (210) Abalone Cove- DHS station	LACSD	Jan '89, Apr '89, Jan '97, Feb '97- Mar '99 (Entero only), Apr '99- Dec '17
LACSD3	33.73557	-118.35948	Portuguese Bend Cove, Rancho Palos Verdes (aka SMB-7-5)		LACSD	Jan '97, Feb '97- Oct '97 (Entero only), Nov '97- Feb '98, Mar '98 (Entero only), Apr '98- May '98, Jun '98- Oct '98 (Entero only), Nov '98- Dec '17
LACSD5	33.71756	-118.32211	Royal Palms State Beach (aka SMB-7-6)		LACSD	Jan '97- Oct '97, Nov '97- Apr '98, May '98- Mar '99 (Entero only), Arp '99- Dec '17
DHS (211)	33.71773	-118.32182	White Point		DHS	Jan '89- Apr '89
LACSD6	33.70760	-118.29536	Wilder Annex, San Pedro (aka SMB-7-8)		LACSD	Jan '97, Feb '97- May '97 (Entero only), Jun '97- Aug '97, Sep '97- Oct '97 (Entero only),

						Nov '97, Dec '97- Mar '99 (Entero only), Apr '99- Dec '17
LACSD7	33.70889	-118.28401	Cabrillo Beach, ocean side (aka SMB-7-9)	Jan '89- Apr '89: DHS (212) Outer Cabrillo Beach	LACSD	Jan '89- Apr '89, Jan '97- Mar '97, Apr '97- Jan '98 (Entero only), Feb '98- Apr '98, May '98- Mar '99 (Entero only), Apr '99- Dec '17

EMD = Environmental Monitoring Division (City of Los Angeles)
DHS = Department of Health Services (Los Angeles County)
LACSD = Los Angeles County Sanitation District
BC = Beach Cities (City of Redondo Beach, City of Manhattan Beach, City of Hermosa Beach)

Appendix B

Project	Latitude	Longitude	FIB Monitoring Station	Location	Construction Completion Date	Agency
Ashland Avenue (phase 2)	33.99938	-118.48150	SMB-3-5	103 Ashland Ave, Santa Monica, CA. 90405	6/10/06	LACFCD
Avenue I	33.81952	-118.38983	SMB-6-5	Esplanade & Avenue I, Redondo Beach, CA. 90277	2/16/06	LACFCD
*Electric Avenue Pump Plant	33.99303	-118.47265	DHS (107)	314 Brooks Ave, Venice, CA. 90291	4/15/01	LACFCD
Herondo Street	33.85359	-118.39416	DHS (115)	445 1/2 Herondo St, Hermosa Beach, CA. 90254	8/16/05	LACFCD
Manhattan, 28th & The Strand	33.89424	-118.41874	DHS (113)	Strand @ 28th St., Manhattan Beach, CA. 90266	3/26/07	LACFCD
Parker Mesa/Castlerock	34.04168	-118.56723	SMB-2-1	PCH and Coastline Dr., Los Angeles, CA. 90272	4/10/07	LACFCD
Pershing Drive, Line C	33.93091	-118.43329	SMB-2-13	Imperial Hwy w\o Pershing, Playa del Rey, CA. 90045	4/17/06	LACFCD
Playa del Rey	33.95964	-118.44743	S11	Culver Blvd & Pershing Dr., Playa Del Rey, CA. 90045	4/15/01	LACFCD
Pulga Canyon	34.03876	-118.54240	SMB-2-4	16510 Pac. Coast Hwy, Los Angeles, CA. 90272	6/22/04	LACFCD
Rose Avenue (phase 2)	33.99765	-118.47510	SMB-3-6	300 Rose Ave, Venice, CA. 90291	6/14/05	LACFCD
Santa Ynez	34.03837	-118.55471	SMB-2-2	17310 Sunset Blvd, Pacific Palisades, CA. 90272	6/22/06	LACFCD
Westchester	33.94533	-118.44287	SMB-2-11	8184 Vista del Mar, Playa del Rey, CA. 90293	7/29/04	LACFCD
Marquez Avenue	34.03951	-118.54944	N/A	17015 PCH, Los Angeles, CA 90272 (intersection of Marquez Ave & PCH)	7/15/06	CLA
Bay Club Drive	34.03963	-118.54581	SMB-2-5	230 Arno Way., Los Angeles, CA 90272 (intersection of Bay Club & Arno Way)	1/24/01	CLA
Temescal Canyon	34.03588	-118.53572	SMB-2-6	15733 Temescal Canyon, Los Angeles, CA 90291(intersection Temescal Cyn & PCH-Parking Lot)	6/23/03	CLA

Palisades Park	34.03124	-118.52484	N/A	15100 Pacific Coast Hwy, Los Angeles, CA 90272	11/28/00	CLA
Santa Monica Canyon	34.02783	-118.51937	SMB-2-7	152 W. Channel Rd, Los Angeles, CA 90402 (intersect of West Channel Rd & PCH)	6/10/03	CLA
Thornton Avenue	33.99323	-118.47571	N/A	Intersection of Thornton Pl / Main St / Royal CT, Los Angeles, CA 90291	11/28/00	CLA
Venice Pavilion	33.98869	-118.47153	SMB-3-8	Intersection of Windward Ave & Main St., Los Angeles, CA	6/10/03	CLA
Imperial Highway	33.93091	-118.42917	SMB-2-13	Imperial Hwy West of Pershing Dr., Playa del Rey, CA 90045	4/15/06	CLA
Montana Avenue	34.02223	-118.50745	SMB-3-1	Montana Avenue	6/30/07	CSM
Wilshire Blvd	34.01680	-118.50121	SMB-3-2	Wilshire Boulevard	8/31/07	CSM
Santa Monica Pier (SMURRF)	34.00957	-118.49717	SMB-3-3	Santa Monica Pier (SMURRF)	10/1/97	CSM
Pico-Kenter (SMURRF)	34.00638	-118.49191	SMB-3-4	Pico-Kenter (SMURRF)	1/1/93	CSM
Redondo Beach Pier	33.83878	-118.39025	SMB-6-2	Redondo Beach Pier	5/15/06	RB
Sapphire Drain	33.83361	-118.38968	SMB-6-3	Sapphire St. & Catalina Ave	12/31/09	RB
Manhattan Beach Pier	33.88435	-118.41181	SMB-5-3	Manhattan Beach Blvd and Ocean Ave	6/15/06	MB

*Electric Avenue LFD is a pump plant, opposed to all other stand-alone LFDs

LACFD = Los Angeles County Flood Control District
CLA = City of Los Angeles Watershed Protection Division
CSM = City of Santa Monica
RB = City of Redondo Beach
MB = City of Manhattan Beach