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Storm Effects on Regional Beach Water Quality Along the Southern California Shoreline

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Storm effects on regional beach water quality along the southern California shoreline

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ABSTRACT

Two regional studies conducted during dry weather demonstrated that the Southern California Bight (SCB) shoreline has good water quality, except near areas that drain land-based runoff. Here, we repeat those regional studies 36 h after a rainstorm to assess the influence of runoff under high flow conditions. Two hundred and fifty-four shoreline sites between Santa Barbara, California and Ensenada, Mexico were sampled using a stratified-random sampling design with four strata: sandy beaches, rocky shoreline, shoreline adjacent to urban runoff outlets that flow intermittently, and shoreline adjacent to outlets that flow year-round. Each site was sampled for total coliforms, fecal coliforms (or *E. coli*), and enterococci. Sixty percent of the shoreline failed water quality standards after the storm compared to only 6% during dry weather. Failure of water quality standards increased to more than 90% for shoreline areas adjacent to urban runoff outlets. During dry weather, most water quality failures occurred for only one of the three bacterial indicators and concentrations were barely above State of California standards; following the storm, most failures were for multiple indicators and exceeded State of California standards by a large margin. The condition of the shoreline in Mexico and the United States was similar following rainfall, which was not the case during dry weather.

Key words | coliform, enterococcus, indicator bacteria, runoff, stormwater

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INTRODUCTION

Land-based runoff is increasingly being recognized as a source of fecal bacteria and a public health concern at swimming beaches. Noble *et al.* (2000) found that 60% of the Southern California Bight (SCB) shoreline areas receiving urban runoff fail State of California (CA) water quality standards. Lipp *et al.* (2001*a*) demonstrated that the highest indicator bacteria concentrations in Charlotte Harbor, FL occur at sites near where urban streams enter the estuary. Mallin *et al.* (2000) found that fecal coliform concentrations in South Carolina were directly correlated with the percent of impervious surface in the watershed. Human viruses are consistently found in southern California's urban runoff (Jiang *et al.* 2001, Noble and Fuhrman 2001) and Haile *et al.* (1999) demonstrated that illness rates more than double when swimming at beaches near urban runoff outlets.

The effect of urban runoff on beach water quality is even more severe following rain events. More than half of the beach water quality failures in Santa Monica Bay, California, are associated with rain events, even though it typically rains less than 15 days per year (Schiff *et al.*, in press). Several researchers have found significant correlations between beach bacterial concentration and river discharge (Solo-Gabrielle *et al.* 2000; Dwight *et al.* 2002). Rainfall effects are also apparent on an interannual basis as both Lipp *et al.* (2001*b*) and Boehm *et al.* (2002) have demonstrated higher beach bacterial concentrations during El Niño years.

While these studies have demonstrated increases in bacterial concentration associated with wet weather runoff, they are mostly based on integrating existing public health monitoring data, which are focused on high use beaches and not designed to assess the spatial extent of stormwater influence. The question of spatial extent is particularly important in southern California, where the rainfall influence on beach water quality is perceived as severe enough that the health departments routinely issue warnings to avoid recreational water contact for at least 3 days following a storm. Here, we present a survey in which 1000 km of the SCB shoreline was synoptically sampled the day after a storm to assess the spatial influence of rainfall on regional water quality.

METHODS

Samples were collected along the shoreline of the SCB at 254 sites between Point Conception, California, and Punta Banda, Mexico (Figure 1). All sites were sampled between 06.00 and 10.00 h on 22 February 2000, approximately 36 h after a storm that deposited ca. 3–7 cm of precipitation over the entire study region. These were the same sites sampled by Noble *et al.* (1999, 2000) during two previous dry weather regional water quality surveys along the shoreline of the SCB (Figure 1). These sites were selected using a stratified random approach, with strata corresponding to four shoreline types: sandy beach, rocky shoreline, perennial urban runoff outlets, and ephemeral urban runoff outlets. Although the basic sample allocation scheme was stratified random, a systematic component was added to minimize clustering of sample sites along the shore. This was accomplished using an extension of the National Stream Survey sampling design of Messer *et al.* (1986) and Overton (1987). The term ‘urban runoff outlets’ is used to describe storm drains, creeks, and rivers that contribute freshwater/stormwater inputs to the coastal Pacific Ocean. A total of 81 urban runoff outlets that convey 99% of the total freshwater input to the SCB were identified and differentiated as perennial or ephemeral based upon whether water flowed year-round or seasonally, respectively. Sample sites within the perennial and ephemeral water outlet strata were selected using two methods. First, sites were selected at a random distance within 100 m of the mouth of the outlet (random sites). Second, a site was placed on the beach at a location as close to the mouth of the outlet as possible (referred to as the point zero site). At the perennial urban runoff outlets, random sites were placed around 39 of the 40 outlets, and point zero sites were placed at 30 of the 40 perennial outlets. At the ephemeral outlets, 36 random sites and 29 point zero sites were sampled from the 41 possible systems.

Samples were collected in sterile sample bottles or Whirl-Pak bags from ankle-deep water on an incoming wave just prior to receding, with the sampler positioned downcurrent from the bottle and the mouth of the bottle facing into the current. After the sample was taken, the bottle was tipped to decant enough sample to ensure 2 to 5 cm of airspace in the sample bottle. The bottle was then tightly capped, stored on ice in the dark, and returned to the laboratory in time to begin analysis within 6 h of sample collection. All samples were tested for total coliforms (TC), fecal coliforms or *E. coli* (FC), and enterococci (EC). Collection and processing of samples in a short period was accomplished through cooperative efforts of 21 organizations that conduct routine monitoring of southern California’s beaches. Each participating laboratory used their established analytical methods for sampling processing, which include membrane filtration (MF), multiple tube fermentation (MTF), and the defined

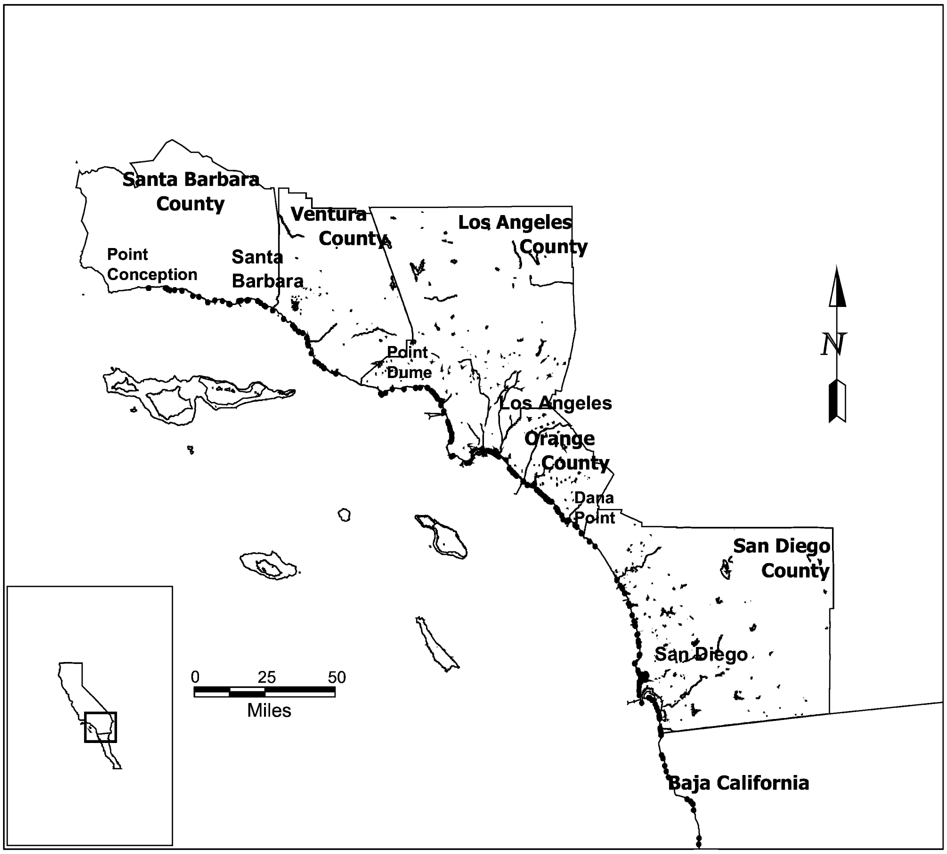

Figure 1 | Map of the Southern California Bight depicting the shoreline, counties, and land features of southern California and sampling sites (black dots).

substrate technology test kits, Colilert® and Enterolert™ (IDEXX Laboratories, Inc., Portland, ME). All analyses were performed using techniques as outlined in *Standard Methods* (1995) or following manufacturer's instructions. Comparability among laboratories and among methods was confirmed prior to the study through a series of intercalibration studies (Noble *et al.* 2003). To enhance reliability of comparisons between studies conducted during wet and dry conditions, each laboratory processed samples from the same sites as they did in the two previous dry weather regional surveys (Noble *et al.* 1999, 2000).

The assessment of shoreline condition focused on estimating the percent of shoreline miles that exceeded a threshold of concern. The State of CA daily single-sample water quality standards for TC, FC, EC and the TC:FC ratio were used as thresholds (Table 1). The percent of shoreline exceeding the thresholds was estimated for each strata and for the shoreline as a whole using a ratio estimator (Thompson 1992).

Table 1 | State of California single sample daily bacterial indicator thresholds

Indicator	Daily limits (cfu or MPN per 100 ml)*
Total coliforms	10,000
Fecal coliforms	400
Enterococci	104
Total coliform:fecal coliform ratio	When total coliforms are $> 1{,}000$, and TC:FC≤ 10

*cfu: colony forming units; MPN: most probable number

Table 2 | Rainfall quantity for locations in Southern California (in centimetres) and duration (in hours) for the storm sampled during the Storm Study (2/20/00–2/21/00). Also included is antecedent rainfall information

Location	**Time rain started (2/20)**	**Time rain stopped (2/21)**	**Duration of storm (h)**	**Rainfall (cm)**	**Days since last rain**	**Rainfall from most recent storm (cm)**	**Duration of most recent storm (h)**
San Ysidro	6:00 am	9:00 pm	40	7.19	3	0.41	9
Plaza Bonita Rd	6:00 am	4:00 am*	47	3.91	2.5	0.41	23
Fashion Valley	5:00 am	8:00 pm	40	5.11	3	0.71	23
San Onofre	5:00 am	9:00 pm	41	2.79	3	0.30	21
Encinitas	5:00 am	1:00 am*	46	2.69	3	0.41	14
Carlsbad	5:00 am	12:00 am	44	4.09	3	0.51	21
Oceanside	5:00 am	4:00 pm	36	3.63	3	0.30	15
Santa Ana River	6:00 am	4:00 pm	34	4.09	NA	0.00	
Coyote Creek	6:00 am	3:00 pm	33	3.23	NA	0.00	
Point Vicente	6:00 am	8:00 pm	39	3.91	3	1.30	14
Malibu	7:00 am	5:00 pm	35	5.61	3	1.30	18
Oxnard Airport	5:00 am	11:00 am	31	7.06	3	0.43	14
Ventura	4:00 am	12:00 pm	33	7.21	3	0.84	14
Sea Cliff	4:00 am	12:00 am	45	7.47	3	1.09	13
Lechuza Patrol	6:00 am	12:00 pm	31	7.80	3	1.30	17
Point Hueneme	4:00 am	11:00 am	32	4.75	3	0.33	17
Santa Barbara	4:00 am	3:00 am*	48	6.88	3	0.94	13
UCSB	5:00 am	10:00 pm	42	7.34	>19	0.00	
Overall range			31–48 h	2.69–7.8 cm	3 days	0–1.3 cm	9–23 h

*Rain stopped on 2/22.
NA: No data available

RESULTS

The rainfall event that preceded sampling deposited between 2.5 and 7.0 cm throughout the study area, with the highest quantity measured near the Los Angeles–Ventura County border (Table 2). Duration of the rainfall event averaged 39 h. A smaller storm that produced rainfall quantities between 0.1 and 1.25 cm preceded this storm event by 3 days.

More than half (58%) of the SCB shoreline exceeded at least one of the indicator bacteria thresholds (Table 3). Beach areas immediately in front of perennially flowing

Table 3 | Percent of shoreline miles that exceeded State of California water quality standards in the Southern California Bight

	Enterococci	Fecal coliforms	Total coliforms	Total:fecal ratio<10	Any indicator
Ephemeral point zero	52	26	11	22	52
Ephemeral	38	13	3	11	38
Rocky	34	19	6	7	34
Sandy	59	42	31	18	62
Perennial	67	28	20	17	67
Perennial point zero	87	43	33	30	87
All SCB	56	36	24	16	58

Table 4 | Percent of shoreline that exceeded single or multiple bacterial indicator standards

	Any indicator	Only one indicator	Any two indicators	Any three indicators	All four indicators
Ephemeral point zero	52	19	11	19	4
Ephemeral	38	13	14	8	3
Rocky	34	8	19	4	5
Sandy	62	14	10	33	5
Perennial	67	29	13	18	8
Perennial point zero	87	40	3	27	17
All SCB	58	15	12	26	5

urban runoff outlets had the highest frequency of threshold failures (87%). The rocky shoreline strata had the lowest frequency of failures (34%).

EC was the indicator bacteria that exceeded state water quality standards most often, with nearly 100% of the samples that failed standards exceeding for EC (Table 3). EC exceeded water quality standards at twice the frequency of FC. Approximately three-quarters of the samples failed water quality standards for more than one bacterial indicator during the Storm Study (Table 4). The highest frequency of multiple indicator threshold failures occurred at the perennial point zero sites (Table 4).

The vast majority of water quality exceedences, regardless of indicator type, were significantly above the water quality thresholds. Using method-specific estimates of laboratory variability developed during the intercalibration exercise (Noble *et al.* 2003), we found that 77% of the samples exceeding water quality standards for EC did so by more than one standard deviation of measurement error. Similarly, 42% and 53% of the TC and FC failures

Table 5 | Comparison of the percentage of total shoreline miles that failed State of California water quality standards in Mexico and the United States following a storm event

	Enterococci	Fecal coliforms	Total coliforms
Mexico			
Sandy beach	63	32	11
Point zero	80	50	20
Entire shoreline	66	36	15
United States			
Sandy beach	66	42	31
Point zero	87	43	33
Entire shoreline	61	36	24

Table 6 | Median indicator concentrations in the United States and Mexico following a storm (reported as MPN or cfu/100 ml)

	Enterococci	Total coliforms	Fecal coliforms
Beach			
Mexico	330	490	220
United States	130	900	80
Urban Runoff Outlets			
Mexico	310	1,450	515
United States	228	1,400	80

exceeded the standard by more than a standard deviation of measurement error.

The failure of California's water quality standards along the Mexican shoreline were similar to that found in the United States (Table 5). For example, 63% and 66% of the shoreline along beaches failed the EC threshold in Mexico and the United States, respectively. Median indicator concentrations of samples that failed standards were also similar between the United States and Mexico, except for FC. FC concentrations were noticeably lower in the United States at both urban runoff outlets and beaches (Table 6).

DISCUSSION

Non-point runoff concerns are exacerbated in southern California because its rivers are highly modified stormwater conveyance systems that are independent of the sewage treatment systems, so urban runoff flows unimpeded to the ocean. When storm events occur, runoff plumes can become large oceanographic features that extend for many kilometers (Bay *et al.* 1999, Hickey and Kachel, in press). Moreover, southern California has an arid environment with a short rainy season and long dry periods when the rivers provide minimal runoff. Thus, bacteria and other contaminants accumulate on land between storms, enhancing runoff quality concerns compared to temperate areas where rainfall is more frequent.

The storm effect on water quality is well illustrated by comparison with results from the two dry weather regional surveys that sampled at the same sites (Noble *et al.* 1999, 2000). The extent of shoreline that exceeded water quality standards during this study was nearly 10 times higher than in the two dry weather studies (Figure 2). This increase was observed across all shoreline types and among all bacteria indicator types (Figures 2 & 3). Moreover, the magnitude of the exceedences was much greater during this study. During dry weather, two-thirds of the threshold failures were attributable to failure of a single bacterial indicator and most of those failures were barely above the indicator threshold. In contrast, two-thirds of the threshold failures during wet weather were for multiple indicators in which at least one indicator was twice the allowable standard (Figure 4). Because we used a regionally applied, stratified-random sampling design, we have not only further demonstrated the importance of rainfall as a component of urban runoff, but we have also demonstrated that rainfall events have region-wide impacts on coastal water quality in southern California.

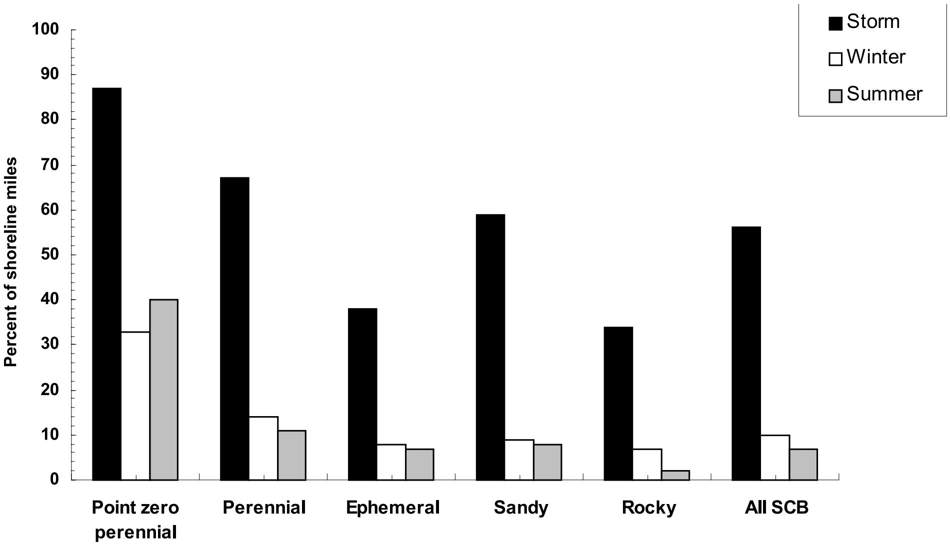

Figure 2 | The extent of water quality threshold exceedences in the Southern California Bight during the summer and winter studies (dry) compared with the present storm study (wet), by shoreline type.

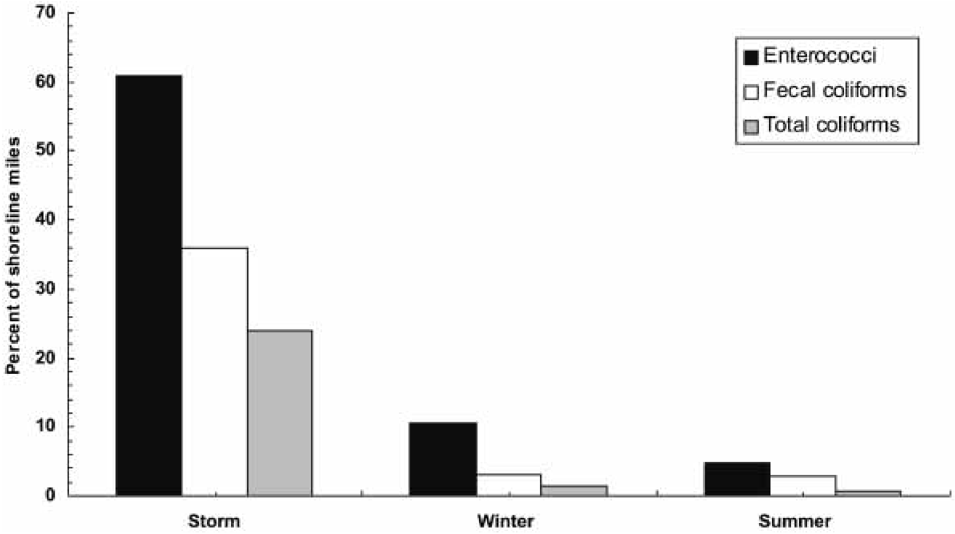

Figure 3 | The extent of water quality threshold exceedences among indicator bacteria in the Southern California Bight during the summer and winter studies (dry) compared with the storm study (wet).

Another difference between wet and dry weather conditions was the comparability in water quality between Mexican and US waters. During dry weather, water quality standards were exceeded five times more often on Mexican beaches than on US beaches (Noble *et al.* 2000). In contrast, we found that during wet weather there was no difference in the percentage of impacted shoreline between Mexican and the United States. While the better dry weather water quality in the US is probably a reflection of their more extensive sewage treatment systems, the comparable wet weather water quality probably reflects the lack of urban runoff treatment in either country. Still, there were some differences between the countries during wet weather. Median FC and EC levels were higher along

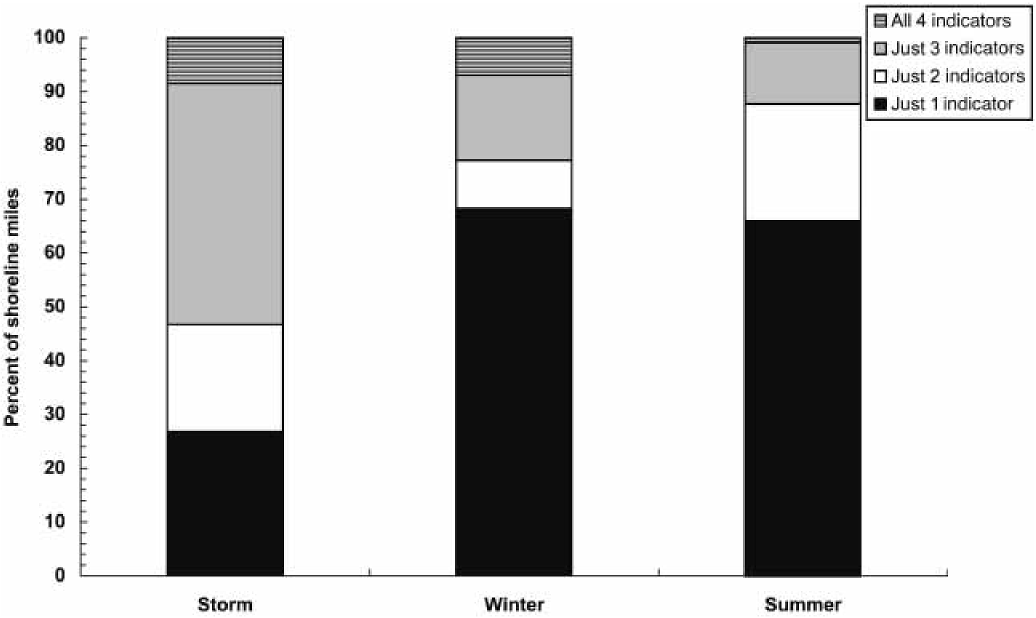

Figure 4 | Relative frequency of single and multiple bacterial indicator threshold exceedences in the Southern California Bight during the summer and winter studies (dry) compared with the storm study (wet).

Mexican shoreline, regardless of whether samples were taken at an open beach or near an urban runoff outlet (Table 6). These results could be due to the fact that Mexican runoff contains contributions of fresh human fecal contamination from untreated sewage (Noble *et al.* 2000).

The public health risk of the high indicator bacteria concentrations observed in this study are unclear, particularly if the source material has a large animal contribution. Most studies relating bacterial indicator levels to illnesses rates have been conducted at locations where the primary source of bacteria is human sewage rather than urban runoff. The only epidemiological study that focused on the human health concerns associated with urban runoff was conducted in Santa Monica Bay, CA and was limited to assessing health effects of dry-weather runoff (Haile *et al.* 1999). Currently, most public health agencies in southern CA issue countywide warnings to avoid recreational water contact following all storms of 1.25 cm or greater. Our findings of high, spatially extensive indicator bacteria counts suggest that warnings on large spatial scales are appropriate, but additional epidemiological studies to evaluate the health effects of wet-weather urban runoff are advisable to further support these management actions.

CONCLUSIONS

- Storm events have a dramatic regional effect on the beach water quality of southern California.
- During large storm events, indicator bacteria levels are orders of magnitude higher than during dry weather.
- The indicator bacteria, enterococci, exceeded State of California water quality standards more often than total coliforms or fecal coliforms.
- Urban runoff outlets, both in Mexico and the United States, are primary sources of contaminated runoff, with 90% of sites near urban runoff outlets failing water quality standards during a storm event.

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