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A regional survey of the microbiological water quality along the shoreline of the Southern California Bight

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ABSTRACT

A regional survey of the microbiological water quality along the shoreline of the Southern California Bight (SCB), from Point Conception south to Ensenada, Mexico, was conducted during August, 1998, by 36 agencies under the coordination of the Southern California Coastal Water Research Project (SCCWRP). Microbiological water quality was assessed by calculating the percentage of shoreline mile-days that exceeded bacterial indicator thresholds for total and fecal coliforms, total/fecal ratios, and enterococci. Sample sites were selected using a stratified random sampling approach, with the SCB recreational shoreline divided into six strata: high- and low-use sandy beaches, high- and low-use rocky shoreline, and perennial and ephemeral freshwater outlets. Samples were collected on a weekly basis at a total of 253 sites, beginning on August 2, 1998, and continuing for five weeks. Samples were analyzed by 22 participating laboratories using their normal methods (multiple tube fermentation, membrane filtration, Colilert®, and/or Enterolert®). All laboratories met testing criteria established through intercalibration exercises and quality control check samples distributed during the sampling period. Nearly 95% of the shoreline mile-days did not exceed daily and monthly bacterial indicator thresholds, demonstrating good bacteriological water quality along the SCB shoreline. Freshwater outlets, comprised mainly of storm drains, had the poorest water quality with 60% and 40% of the shoreline miles exceeding monthly and daily thresholds, respectively. Freshwater outlets were also more likely to demonstrate exceedences by multiple indicators at a single site, and repeat exceedences at sites over the five-week period. Compared with the southern California beaches, Mexican beaches had nearly 5 times the number of exceedences for total and fecal coliforms, and nearly 8 times the number of exceedences for total/fecal ratios.

INTRODUCTION

The SCB, (Figure 1), stretching from Point Conception southward to Cabo Colnett, Baja California, is a world-renowned recreational resource. Southern California beaches annually attract more than 175 million people to sunbathe, surf, swim, and skin and scuba dive (USLA 1998). This region is densely populated, with nearly 20 million people inhabiting coastal areas, a number that is projected to increase 20% by the year 2010 (NRC 1990). With such activity and population stress, the microbiological water quality of the coastal waters of southern California can be impacted by pathogenic bacteria, viruses, and protozoans, especially from freshwater outlets.

Currently, 22 organizations in southern California collectively analyze approximately 82,300 samples annually from 510 sites to assess the extent of microbiological contamination (Schiff *et al.* 1998). Despite this intense monitoring, program objectives are different for each of the organizations. Public health agencies tend to focus on high-use sandy beaches and on “problem areas,” such as freshwater outlets (which include storm drains, creeks, and rivers). In contrast, bacteriological monitoring programs for many wastewater discharge agencies focus upon tracking movements of effluent plumes discharged from deep-water outfalls, and the possible impacts of the effluent on adjacent coastal shorelines. Data generated from these various programs represent only 7% of the southern California

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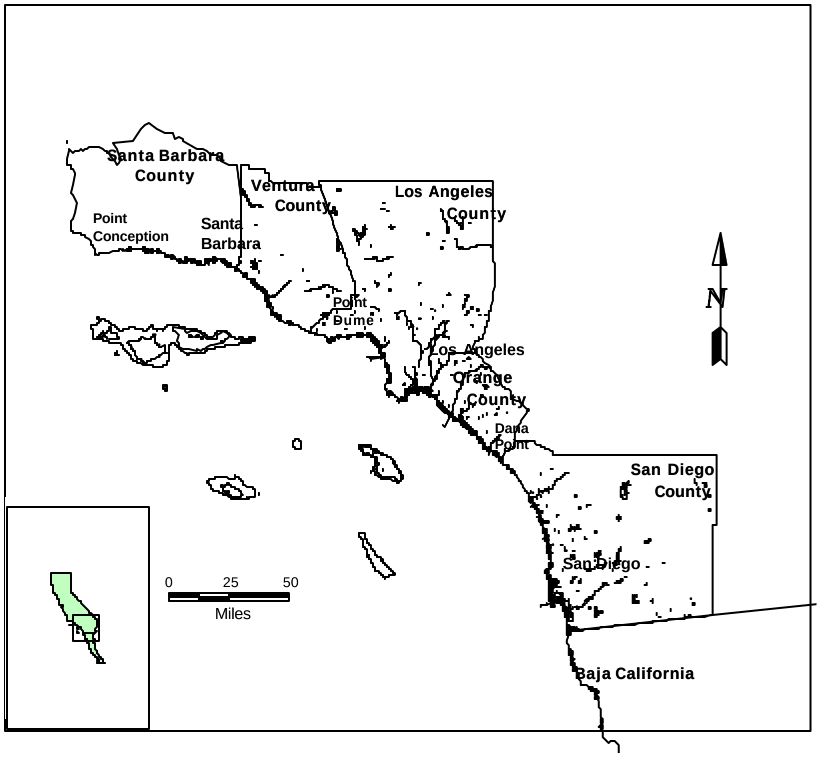
FIGURE 1. Sampling sites (•) for regional survey of microbiological water quality along the shoreline of the Southern California Bight.



shoreline, and cannot be integrated easily to produce a bight-wide assessment due to different sampling strategies, indicators, and analytical methods.

All of the laboratories that perform routine monitoring of bacteriological water quality along the SCB shoreline coordinated their efforts during August, 1998, to assess the overall microbiological condition along the shoreline of the bight. Three objectives were established for this project: (1) to determine the percentage of shoreline mile-days in the SCB that exceeded bacterial indicator thresholds; (2) to compare the three bacterial indicators commonly measured in California; and (3) to determine the relation between bacterial indicators and the detection of human enteric virus genomes. Here, we present results of the first objective, an assessment of the bacteriological water quality along the SCB shoreline, and an initial examination of the second objective by comparing the response of the bacterial indicators.

METHODS

Site Selection

The study area, the Southern California Bight, included approximately 690 miles of shoreline from Point Conception in Santa Barbara County to Estero Bay, Baja California Sur (Figure 1). Of this stretch, only about 270 miles, or 39%, were available and accessible to the public for recreation; the rest was unreachable due to the presence of private land, ports and marinas, military property, or steep cliffs. Sampling sites were selected using a stratified random approach with the recreational shoreline divided into six strata: high- and low-use sandy beaches, high- and low-use rocky shoreline, and perennial and ephemeral freshwater outlets (Table 1). High-use sandy beaches were defined as those with lifeguard services, and high-use rocky shoreline as popular surfing or diving areas. A total of 81 freshwater outlets within the SCB were identified as either perennial or ephemeral based upon whether water flowed year-round or seasonally, respectively. From the total list, we selected those freshwater outlets that account for 99% of the gauged runoff entering the SCB. These were comprised mostly of storm drains. Storm drains, in this context, consist mostly of concrete-lined drainages of urban runoff.

The number of sites allocated to each stratum was that necessary to achieve a 95 ± 5% confidence interval around estimates of areal extent. Sites were allocated separately by county, with the number of sites within a stratum, within a county, allocated proportionally to the percentage of SCB shoreline type within a county. To avoid clustering of sites, a systematic component was added based upon methods used in the National Stream Survey (Messer *et al.* 1986, Overton 1987). Freshwater outlets were sampled at a random and/or a point zero location. Thirty-six sample sites at perennial freshwater outlets were positioned randomly within 100 yards of the mouth, and 30 were perennial point-zero sites (at the mouths of the drains). Ephemeral freshwater outlets were only sampled at point zero. As a supplemental overlay, sites were added for sampling by volunteer groups along U.S. high-use sandy beaches, and by Mexican scientists along high-use sandy beaches and freshwater outlets.

Field and Laboratory

Samples were collected weekly for five weeks beginning August 2, 1998. Samples were taken at ankle depth on an incoming wave in sterile bottles, placed on ice, then transported to the laboratories for analysis within 6 h of collection. Total and fecal coliforms were measured at all sites, and enterococci at about 70% of the sites depending upon the capability of the participating organization respon-

TABLE 1. Allocation of Bight '98 shoreline microbiology samples among sampling strata.

Strata	Base Sample Sites	Mexican Sites	Volunteer Sites
High–use Sandy Beaches	48	19	20
Low–use Sandy Beaches	26		
High-use Rocky Shoreline	19		
Low-use Rocky Shoreline	16		
Ephemeral Freshwater Outlets	29		
Perennial Freshwater Outlets	66	10	
Total	204	29	20

sible for that site. Enterococci were not measured at either the volunteer or Mexican sites.

Samples were analyzed using one of three techniques: multiple tube fermentation (MTF), membrane filtration (MF), or substrate technology tests (e.g., Colilert®, Enterolert®), according to procedures outlined by the American Public Health Association (1995).

All participating laboratories took part in a series of intercalibration and performance exercises designed to assess and control variability introduced into the project by using multiple laboratories and methods. Each laboratory was required to achieve specific accuracy and comparability goals before participation in the regional survey. Details of the quality assurance intercalibration exercises can be found in McGee *et al.* (1998). The average difference among methods was 6%, and among laboratories was 2%, demonstrating that variability between laboratories and between methods met study goals (McGee *et al.* 1998). During the course of the study, two sets of quality control (QC) check samples were distributed among the participating laboratories, and all laboratories passed the quality control requirements.

Data Assessment

Three types of bacterial indicators: total coliforms, fecal coliforms, and enterococci were assayed, providing information for four indicator thresholds (the three previously mentioned plus the total coliform-fecal coliform ratio, referred to as total/fecal ratios from this point forth). Total/fecal ratios are used to show the percentage of the total coliforms comprised of fecal coliforms; i.e., coming from the guts of warm-blooded animals. Two sets of thresholds were used, one based upon daily measurements, and the other from monthly averages (does not include total/fecal ratios, Table 2). Both sets of thresholds were derived from a combination of State of California draft beach closure thresholds, established in response to Assembly Bill 411 (AB 411) legislation, Statutes of 1997, Chapter 765, Health and Safety Code 115880, and the California Ocean Plan (1990). In AB411, bacterial indicator levels are referred to as "State standards" as they are set by State statutes and regulations. In the California Ocean Plan (1990), bacterial indicator levels are referred to as "water quality objectives." Here, the term "thresholds" will refer to any bacterial indicator level determined by state, local, or federal standards, proposed standards, or ocean water quality objectives.

The assessment of shoreline conditions focused upon estimating the percent of shoreline-miles that exceeded a threshold of concern. Data from indicator comparisons (laboratories where multiple methods were run simultaneously), and Mexican waters were not used for the overall assessment of shoreline conditions of southern California. In instances where only daily thresholds were used to estimate the percent of shoreline-miles exceeded, a threshold of concern, we use the term "shoreline mile-days." In instances where both daily and monthly thresholds were used to estimate the percent that exceeded, we report the results as shoreline-miles. We also present a comparison of shoreline conditions between Mexico and the United States at beaches and freshwater outlets.

Estimating the percent of shoreline miles or shoreline mile-days was accomplished for each of the strata and for the shoreline as a whole using a ratio estimator. Detailed information on the statistical design can be found in Thompson (1992). Statistical differences between populations of interest were defined on the basis of non-overlapping confidence intervals. Use of the ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes a negligible spatial covariance, an assumption that appears warranted based upon preliminary examination of the data. This assumption is conservative in that its violation would lead to an overestimation of

TABLE 2. Indicator thresholds used in the Shoreline Microbiology Study. GM = geometric mean over 30 d period.

Indicator	Daily Threshold (cfu or MPN per 100 mL)	Monthly Threshold (cfu or MPN per 100 mL)
Total Coliforms	10,000	20% of samples >1, 000
Fecal Coliforms	400	200 (GM)
Enterococci	104	35 (GM)
Total/Fecal Ratio	When TC >1,000 and TC/FC $\leq$ 10 Also, when TC >1,000 and TC/FC $\leq$ 5	

the confidence interval (Stevens and Kincaid 1997).

RESULTS

Approximately 95% of the shoreline miles along all of the SCB met bacterial indicator thresholds, indicating good water quality over the course of the study (Figure 2). This high frequency of good region-wide bacteriological water quality was consistent regardless of whether daily or monthly thresholds were used (Figure 2). Poor water quality was found at the point-zero sites at freshwater outlets where nearly 60% and 40% of the shoreline-miles exceeded monthly and daily thresholds, respectively, for at least one indicator. The probability of exceeding a threshold differed among indicators, with enterococci exceeding indicator thresholds most frequently, especially at the point zero freshwater outlet sites, followed by fecal coliforms, total/fecal ratios, and total coliforms, in that order (Table 3). Analyses of data using daily versus monthly thresholds demonstrated very similar results throughout the study, regardless of the stratum or indicator examined. Therefore, the majority of the results discussed will focus on the results using the daily thresholds, as they will be the basis for many future beach closure and management decisions. Also, even though we used two total/fecal ratio criteria, less than 10 and less than 5, the results were very similar (Table 3).

Rarely were all four indicator thresholds exceeded at a single site. When all four indicator thresholds were exceeded, it occurred only at the freshwater outlets, and accounted for only 0.1% of the shoreline mile-days along the southern California coast (Table 4). Likewise, when two or three bacterial indicator thresholds were exceeded at a site, it usually occurred at a freshwater outlet. Few sites repeatedly exceeded bacterial indicator thresholds for two or more weeks of the survey (data not shown). Repeat exceedences were seen most commonly for enterococci.

Although 75% of the shoreline mile-days in Mexico met bacterial indicator thresholds, the beaches in Mexico were more likely to exceed bacterial indicator thresholds than the beaches in the U.S. (Table 5). The probability of exceeding the thresholds for both total and fecal coliforms on sandy beaches in Mexico was five times that for sandy beaches in the U.S. In contrast, the probability of exceeding indicator thresholds, including total/fecal ratios, at freshwater outlets was similar both

FIGURE 2. Percent of southern California shoreline miles, by shoreline type, that met all bacterial indicator thresholds in August 1998.

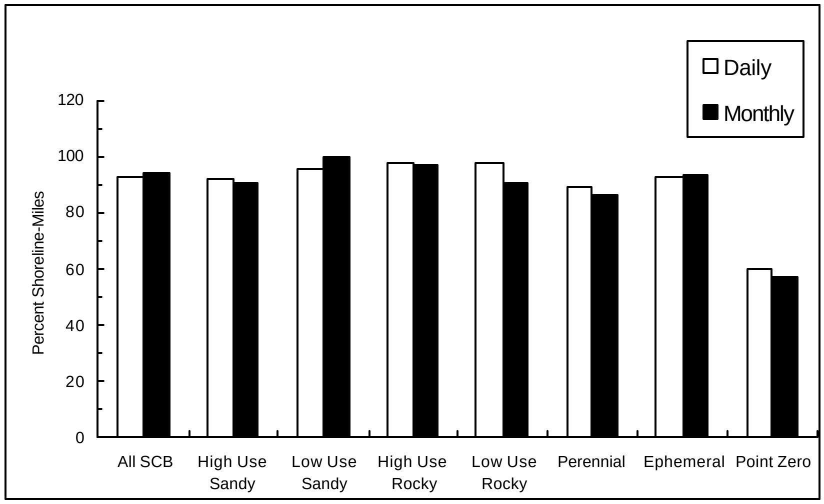


TABLE 3. Percent of shoreline mile-days exceeding daily bacterial indicator thresholds.

Strata	Enterococci	Fecal Coliforms	Total Coliforms	TC:FC <10	TC:FC <5
High-use Sandy	6.1	2.5	0	1.4	1.3
Low-use Sandy	1.2	2.8	2.2	2.1	2.1
High-use Rocky	2.4	0	0	0	0
Low-use Rocky	2.1	0	0	0	0
Ephemeral	5	2.7	0	4	2.7
Perennial (random)	5.7	6.9	1.7	5.4	2.5
Point Zero	34.2	24.8	12	21.8	17.6
All SCB	4.9	2.9	0.7	2.1	1.8

TABLE 4. Percent of shoreline mile-days exceeding daily thresholds for multiple indicators; based upon the subset of sites at which all indicators were measured.

Strata	All 4	Any 3	Any 2	Any 1
High-use Sandy	0	0.4	1.8	7.8
Low-use Sandy	0	2.2	2.2	4.1
High-use Rocky	0	0	0	2.4
Low-use Rocky	0	0	0	2.1
Ephemeral	0	1.7	4.1	7.3
Perennial (Random)	0.8	3	5.2	10.9
Point Zero	5.8	18.3	26.7	40
All SCB	0.1	1.2	2.3	7

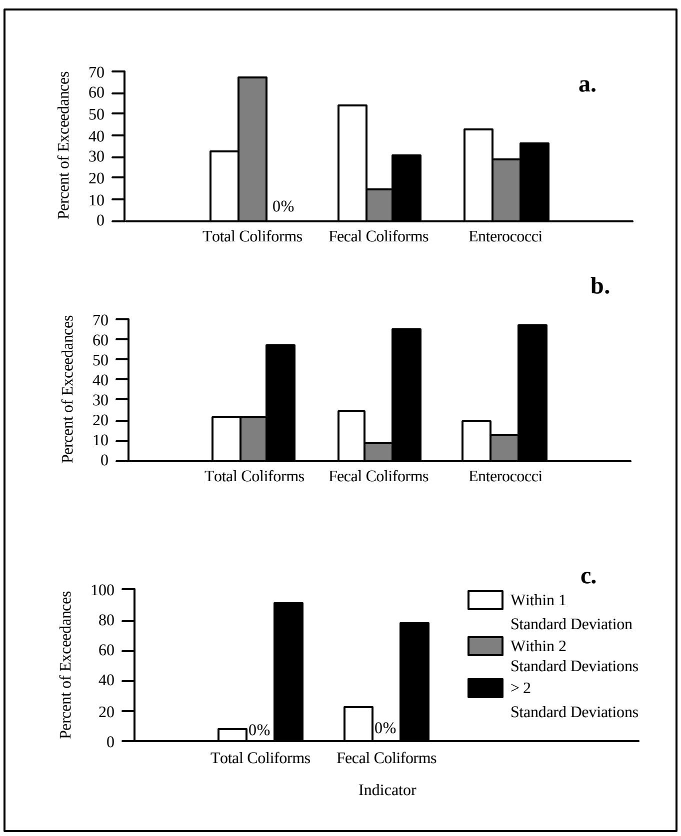
TABLE 5. Percent of threshold exceedences in Mexico and the United States.

Indicator	Total Coliforms	Fecal Coliforms	TC:FC<10
Sandy Beaches			
Mexico	2.6	25.3	16.5
United States	0.5	5.3	2.1
Perennial Freshwater Outlets			
Mexico	12.7	32.7	21.8
United States	12	24.8	21.8

north and south of the border (Table 5). The magnitude of threshold exceedences differed considerably between the freshwater outlets, other strata, and Mexican beaches (Figure 3).

Approximately 40% of the measurements along the southern California shoreline away from freshwater outlets were within measurement error of thresholds (one standard deviation) as determined by intercalibration exercises. In contrast, two-thirds of the freshwater outlet samples taken along southern California shoreline that exceeded a bacterial indicator threshold did so within two standard deviations. More than 80% of the Mexican samples that exceeded bacterial indicator thresholds exceeded by more than two standard deviations regardless of whether the sample was collected on a beach or at a freshwater outlet.

FIGURE 3. Percent of exceedences within 1, 2, or greater than 2 standard deviations for a) United States shoreline (combined sandy and rocky shoreline sites), b) United States Freshwater Outlets, and c) combined Mexican sample sites. One standard deviation was used as an expression of the measurement error, as determined by intercalibration exercises.



DISCUSSION

Approximately 95% of the southern California shoreline demonstrated good bacteriological water quality during August 1998. Except for those locations immediately adjacent to freshwater outlets, most of the threshold exceedences were temporally sporadic and were not repeat exceedences at the same site. Freshwater outlets, which constitute only a small fraction of the southern California coastline, had consistently poor bacteriological water quality. Most of the exceedences at freshwater outlets were for multiple indicators and occurred repeatedly throughout the five-week study period. The probability of exceeding bacterial indicator thresholds at freshwater outlets was similar north and south of the border, although the magnitude of exceedence was higher in Mexico. Most of these outlets are storm drain systems that can receive a variety of upstream inputs, including organic debris, non-human fecal matter (e.g., dogs), accidental sewage spills, illicit sewage connections, leachate from septic systems, and runoff from homeless populations. Storm drains in southern California are independent from sewer systems and their flows receive no treatment or disinfection prior to ocean discharge.

Urban runoff is a large contributor of microorganisms to storm drains, but it is not the sole source of fecal contamination. Waterfowl and marine mammals also can contribute bacterial contamination, particularly at the mouths of freshwater outlets where lagoons and embayments serve as good habitats for wildlife. Many of the freshwater outlets sampled for this study exhibit these characteristics, and are likely to be impacted by animal fecal contamination. These local observations are consistent with the results of studies in other locations. For example, in Massachusetts, an estimated 67% of the coliforms in Buttermilk Bay were derived from waterfowl (Weiskel *et al.* 1996).

While this study is the first to quantify the effect in an unbiased, regional context, it is not the first to conclude that storm drains are areas of concern. High levels of indicator bacteria have been found routinely in storm drain effluents, affecting shoreline bacteriological water quality near these sources throughout southern California. A recent epidemiological study performed in Santa Monica Bay linked poor bacteriological water quality of storm drains to an increased risk of illness for people swimming near flowing drains (Haile *et al.* 1999). During dry weather, Gold *et al.* (1992) reported elevated counts of enterococci and total and fecal coliforms in several storm drains in Santa Monica Bay. Indicator bacteria sampled from storm drain effluents during wet weather commonly exceed State water quality objectives (Schiff 1997). High densities of indicator bacteria are reflected in gradients of coliforms and enterococci in the receiving waters of Santa Monica Bay (Gold *et al.* 1990). These observations are not unique to southern California; urban runoff yields consistently high densities of fecal coliforms in many metropolitan areas (U.S. EPA 1986).

This study is also not the first to find poor microbiological water quality along the Mexican coast (Segovia-Zavala and Orozco-Borbón 1986), though it is the first to use consistent sampling approaches to compare the relative microbiological water quality at United States and Mexican beaches. Previous bacteriological studies in this area have found that the main inputs of total and fecal coliforms to the area are from storm drains and wastewater discharges along the shoreline (Orozco *et al.* 1994, Segovia *et al.* 1995). In this study, thresholds were exceeded five times more often along Mexican than United States beaches, and the magnitude of exceedence was also higher at Mexican beaches and outlets. This is likely due to the presence of human fecal contamination along Mexican beaches, where much of the sewage reaches the beach untreated. This is supported by the total/fecal ratios, where fecal coliforms often comprised more than 10% of the total coliform group. This information provides valuable baseline information that can be used to assess progress in efforts by Mexican authorities to improve their shoreline bacteriological water quality. Water contamination in the northwestern coastal area of Baja California results from rapid urban and industrial growth, and a lack of infrastructure to treat municipal wastewater, mainly near the cities of Tijuana and Ensenada. Wastewater discharges increase during summer months with an increase in tourism, while stormwater runoff is the principal source in winter (Orozco-Borbón and Sañudo-Wilhelmy 1988). The Mexican government has already taken actions to reduce bacteriological pollution of coastal waters by adopting new pollution limits, and establishing dates for initiating discharge quality control programs. Additionally, it is improving the existing infrastructure, as well as constructing new facilities to collect, treat, and dispose of sewage from the rapidly growing population in the region.

Three laboratory techniques, membrane filtration, multiple tube fermentation, and fluorescent substrate technology, are all used for routine monitoring by different laboratories in southern California. The intercalibration exercises, conducted before the study began, were the first to compare all of these methods on marine samples and demonstrated that all of the techniques provided comparable results (McGee *et al.* 1998). The intercalibration exercises also enabled us to calculate measurement error associated with bacteriological sampling. Measurement error may be an important factor when examining exceedence of bacterial indicator thresholds. The intercalibration aspect of this study documented that the standard deviation associated with replicate laboratory analyses was nearly 50% that of the measured value at concentrations near the State of California's existing or proposed bacterial thresholds (Table 2). More than two-thirds of threshold exceedences observed in this study, particularly those from samples collected away from storm drains, were within measurement error. The magnitude of measurement error reflects the inherent shortcomings in current bacterial measurement technologies.

One of the most striking results of this study was the difference in response between types of bacterial indicators. For example, the enterococci threshold proposed under the AB411-mandated regulations was exceeded approximately twice as often as the proposed fecal coliform threshold, and three times as often as the present total coliform threshold. In areas away from freshwater outlets, 60% of the exceedences were for enterococci alone. Only 13% of the samples that exceeded one of the indicator thresholds exceeded all indicator thresholds, demonstrating little overlap between the indicators. There was overlap between indicator exceedences only near freshwater outlets, where 27% of the exceedences were for enterococci alone, 11% were for fecal coliforms alone, and 30% exceeded for both enterococci and fecal coliforms. A similar result was reported by Kebabjian (1994), where he analyzed the results of 728 samples from 14 sites near storm drains in Santa Monica Bay, California. However, he showed that the fecal coliform threshold was exceeded more often than the enterococci threshold.

These differences and recent statutory changes will affect the beach posting and closure actions of local (usually county) health departments in the near future. The new proposed regulations for the State of California, written in response to AB411, require measurement of three indicators (total and fecal coliforms, and enterococci) and posting of certain beaches when single sample numeric thresholds are exceeded. For the last few decades, California State law has required the use of total coliforms as the indicator to determine recreational water quality. In the event of exceedences, decisions to post or restrict access to the shoreline have been at the discretion of the local health officer. Under the new requirements, posting will be required at beaches adjacent to storm drains that flow during the summer whenever they fail to meet any one of the new single sample thresholds from April to October. Beach closure remains at the discretion of the local health officer, as does posting at beaches not adjacent to storm drains.

The results of this study indicate that the proposed thresholds could lead to a substantial increase in the number of samples exceeding bacterial indicator thresholds and thereby failing State standards. This may increase the number of beaches posted or closed, based solely upon the percentage of shoreline mile-days exceeding indicator thresholds. Exceedence of the total coliform threshold amounted to 0.7% of shoreline mile-days, while exceedence of *any* of the four indicator thresholds amounted to 7% of the shoreline mile-days, or 10 times those of total coliforms alone (Table 4).

This study also demonstrated the importance of coordinated water quality monitoring, and the positive products possible from dialogue among city, state, county, and local agencies and institutions. As mentioned earlier, public health and permit-based monitoring programs associated with wastewater outfalls have different objectives. Merging resources between these programs, as was done for this study, would be a more effective use of public funds. Further, stormwater and watershed management and monitoring must be integrated into shoreline microbiology monitoring networks. Schiff *et al*. (1998) pointed out that storm water impacts could be the unifying issue for monitoring recreational waters in southern California. Joining together monitoring resources from these various programs under a set of unifying regulations would provide a powerful means to better understand and manage water quality of shoreline waters along our coast.

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