# Tracking sources of bacterial contamination in stormwater discharges from Mission Bay, California

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## ABSTRACT

Sources of the indicator bacteria total coliform, fecal coliform, and enterococcus were investigated in stormwater flows discharging to Mission Bay, a heavily used aquatic park in San Diego, California. Stormwater flows were targeted because long-term receiving water monitoring of the bay indicated that wet-weather discharges were the predominant source of bacterial contamination. Exceedences in water quality objectives established by the State of California for body-contact recreation most often occurred in the east bay, where the least amount of circulation and largest quantities of stormwater discharges occur. Unlike the wet-weather results, nearly all of the 89 storm drains that discharge to the bay either did not have flowing freshwater or did not contain exceedingly high bacteria densities during dry weather. Upstream tracking during multiple storm events on two of the largest watersheds draining to the bay showed that sources of indicator bacteria were diffuse and widespread. Densities were as high at the head of each watershed as they were at the mouth, where both discharged to the bay. Every reach in each creek exceeded State of California water quality objectives and had densities similar to surface flows measured prior to entering the separate municipal storm sewer system from urban land uses such as residential, commercial, and industrial, as well as open lands.

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## INTRODUCTION

Bacterial contamination has been responsible for degraded water quality throughout the country (U.S. EPA 1996). In California, the degradation of bathing water quality due to bacterial contamination has resulted in between 600 and 1,300 beach closures or advisories annually from 1992 to 1997 (NRDC 1998). The majority of these beach closures occurred in southern California, a region that experienced 14 million beachgoer days in 1998, which are more visitors than the rest of the country's beaches combined (Schiff *et al.* 2001).

Storm drains have been identified as potentially large sources of the bacteria that are discharged to receiving waters around the country (U.S. EPA 1996). This is particularly true in California where sanitary sewer and storm drain sewer systems are separate. Therefore, storm drain discharges are not treated before they discharge across the beach directly into water-contact zones. In southern California, fecal indicator bacteria have been measured in storm drain discharges during both wet (Schiff 1997, Schiff and Stevenson 1996) and dry weather (Gold *et al.* 1990, 1992). In fact, beaches directly in front of storm drains had bacteria densities that exceeded State of California water quality objectives 20 times more frequently than beaches distant from storm drains during the summer of 1998 (Noble *et al.* 2000).

The next logical sequence for investigating bacterial impacts on beach water quality is to start examining potential sources of the bacteria in storm drain discharges. These sources might include sanitary sewer overflows or leakages into the storm drain system, illicit connections or illegal discharges, septic tank leakages, contributions from other warm-blooded animals, or tainted sediments that have been resuspended.

The objective of this study was to identify whether wet-weather discharges were the predominant source of bacterial contamination to receiving waters between 1987 and 1994. A second objective was to track the potential sources of indicator bacteria within the watershed. The goal of these objectives was to provide environmental managers with the information they need to make decisions that will improve receiving water quality.

# METHODS

## Study Site

The receiving water investigated in this study was Mission Bay, California, an enclosed water body extending over 4,600 acres with 26 miles of shoreline (Figure 1). Mission Bay is a heavily used aquatic park, constructed in 1956 after the coastal wetland was dredged to a mean water depth of 8 feet. The entrance to the bay is located on the west side and its extremely narrow shape inhibits the mixing of bay waters with open coastal waters. In addition, large sections of the east bay have restricted baywide circulation due to islands and causeways. The result of this configuration is poor circulation and poor dilution for assimilating pollutant inputs.

## Data Collection

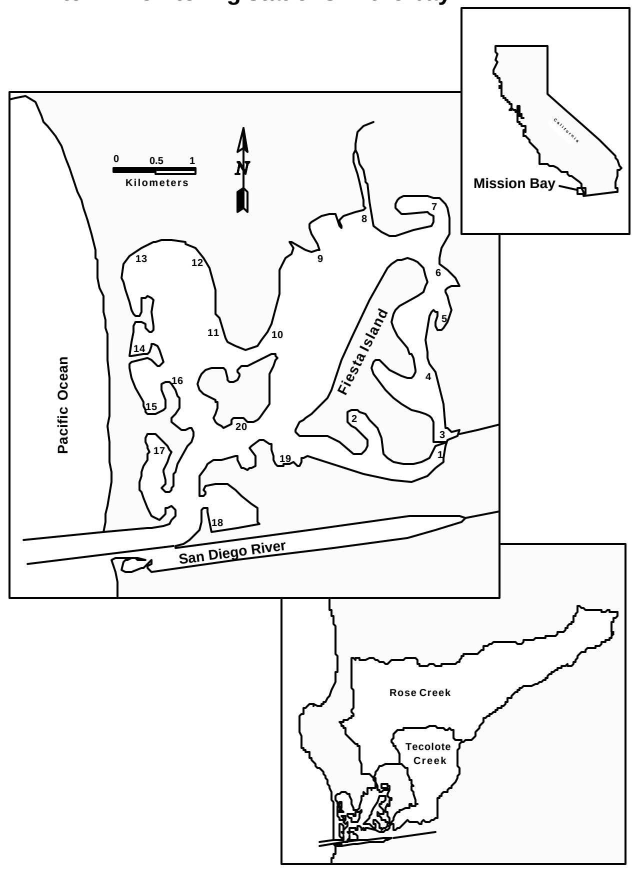
### *Historical Monitoring Program*

The City of San Diego currently monitors 20 shoreline stations weekly within Mission Bay (Figure 1). Samples have been collected and analyzed using membrane filtration techniques for total coliform and fecal coliform since 1987, with the addition of enterococcus in 1992. Standard storm drain sampling and upstream tracking methodologies were used to measure these indicators with the following exceptions: (1) multiple tube fermentation techniques were used rather than membrane filtration due to the increased turbidity that occurs in stormwater samples, and (2) extended dilution ranges ($10^0$ to $10^6$ MPN/100 mL) were used to minimize problems associated with upper level detection limits.

### *Storm Drain Sampling*

Eighty-nine storm drain outfalls ranging in size from 18-inch pipe to 100-foot concrete-lined trapezoidal channels discharge to Mission Bay. In this study, storm drain sampling studies were designed and conducted to assess the contribution of indicator bacteria from these storm drain outfalls. All 89 storm drain outfalls discharging to Mission Bay were surveyed during non-storm conditions and, if flowing, were sampled for microbiological analysis and other field screening procedures including pH, methylene blue active substances (MBAS), conductivity, and copper

**FIGURE 1. Map of Mission Bay in San Diego, California, including Tecolote Creek and Rose Creek watersheds. Numbers indicate long-term monitoring stations in the bay.**




(U.S. EPA 1992). Sites sampled during dry weather were resampled during wet weather.

### *Sediment Sampling*

Sediments were sampled three times at each of the 20 monitoring sites established by the City of San Diego to assess sediments as a sink/source of bacterial contamination. Only 17 sites consistently yielded samples (i.e., had sediment), and all samples were taken during low tides. The first set of samples was collected during dry weather, three days prior to any significant rainfall for the season. The second set of samples was collected two weeks following a large late-season storm (1.10 inch), but immediately preceding a second equally large rainfall event (1.20 inch). The third set of samples was collected on the next low tide following the end of this large storm. Total coliform, fecal coliform, and enterococcus were measured by creating slurries of sediments (1 gm wet weight) in sterile culture media (100 mL), and then were analyzed in the same manner as a turbid water sample.

*Upstream Tracking*

The two largest tributaries to Mission Bay were examined during four storm events to determine whether specific sources within the watersheds could be isolated for treatment and/or source control. The two tributaries included Rose Creek and Tecolote Creek (Figure 1), each with a unique mix of land uses and drainage areas that could contribute to the overall indicator bacteria load (Table 1). Two distinctly different techniques were used for conducting upstream tracking.

The first upstream tracking technique divided each tributary into specific reaches between subwatersheds, then resampled these locations along the main channels between three and five times during an event. Tecolote Creek was divided into seven reaches; Rose Creek was divided into six reaches. The goal was to identify whether any of these subwatersheds significantly contributed to the bacteria density during an event and thus warranted additional investigation.

The second upstream tracking technique started at the headwaters of the Rose Creek tributaries, isolating 20 small catchments of single land uses to evaluate individual sources of bacterial contamination. Land use types included residential (n=5), commercial (n=5), industrial (n=5), and open lands (n=5). Each catchment ranged from 1 to 4 acres and did not include any sewer lift stations or major sewer trunk lines. Open lands contained no structures or sewer lines, but were comprised of undeveloped city and county parks, a state recreation area, and federal property with restricted access (i.e., a U.S. Navy base). Surface flows from each of these land use sites were sampled prior to their entering the storm sewer system. Samples were collected between one and three times during three separate storm events and were analyzed for total coliforms, fecal coliforms, and enterococcus.

## Data Analysis

**TABLE 1. Land use within the two largest watersheds discharging urban runoff to Mission Bay, San Diego, California.**

| | Tecolote Creek | | Rose Creek | |
|---|---|---|---|---|
| Land Use | Acres | % of Total | Acres | % of Total |
| Residential | 3,049 | 51 | 3,688 | 16 |
| Commercial | 873 | 15 | 3,558 | 15 |
| Industrial | 64 | 1 | 1,894 | 8 |
| Open | 1,947 | 33 | 13,384 | 60 |
| Total | 5,929 | 100 | 22,974 | 100 |

Water quality objectives established by the State of California (SWRCB 1997) were used for comparing bacteria densities measured during this study. These objectives were: (1) no single sample for total coliform is to exceed 10,000 MPN/100 mL, or the geometric mean density of five samples is not to exceed 1,000 in a four-week period; and (2) no single sample for fecal coliform is to exceed 1,000 MPN/100 mL, or the geometric mean density of five samples is not to exceed 200 MPN/100 mL in any four-week period. A provisional standard had been set by the State of California for enterococcus at a level not to exceed 24 MPN/100 mL. Although additional regulatory standards exist for fecal indicator bacteria in the surface waters that support commercial shellfishing areas of the state, these standards were not applied because no commercial shellfishing beds were found within the bay.

Historical monitoring data were analyzed by assessing temporal and spatial trends to evaluate the magnitude of the impact from stormwater discharges. Temporal trends were accomplished by calculating monthly geometric mean densities of indicator bacteria over a seven-year period for the east and west sides of Mission Bay. Spatial comparisons were made by calculating the seven-year geometric mean densities for 20 separate receiving water monitoring sites. To incorporate the impact due to stormwater runoff, the seven-year geometric mean densities were calculated separately for wet days and dry days. Wet days were defined as any sample collected within 48 h of the recorded rainfall. Rainfall records were obtained from the National Weather Service at San Diego International Airport (Lindbergh Field), located approximately two miles south of Mission Bay. Relationships between bacteria densities and rainfall were further examined during wet days using Spearman Rank correlation tests (Zar 1984). Long-term temporal and spatial trends were compared to State of California water quality objectives.

Storm drain sampling was designed to make dry weather/wet weather comparisons or to make spatial comparisons among subwatersheds. Dry weather/wet weather comparisons were qualitative since they were made at multiple sites, but without replication. Spatial comparisons among subwatersheds were quantitative since multiple samples over multiple storms were collected. Geometric mean densities of indicator bacteria for the entire wet season were used for these comparisons since no apparent relationship had been established between flow and bacteria density, or differences in bacteria densities among storms within a season. Differences among subwatersheds were determined either by Mann-Whitney t-tests for pairwise comparisons or by Kruskal-Wallis ANOVA tests for multiple comparisons; both tests are nonparametric since sampling was non-random and variance was non-homogeneous (Zar 1984).

## RESULTS

### Patterns in Bacterial Contamination from Historical Monitoring

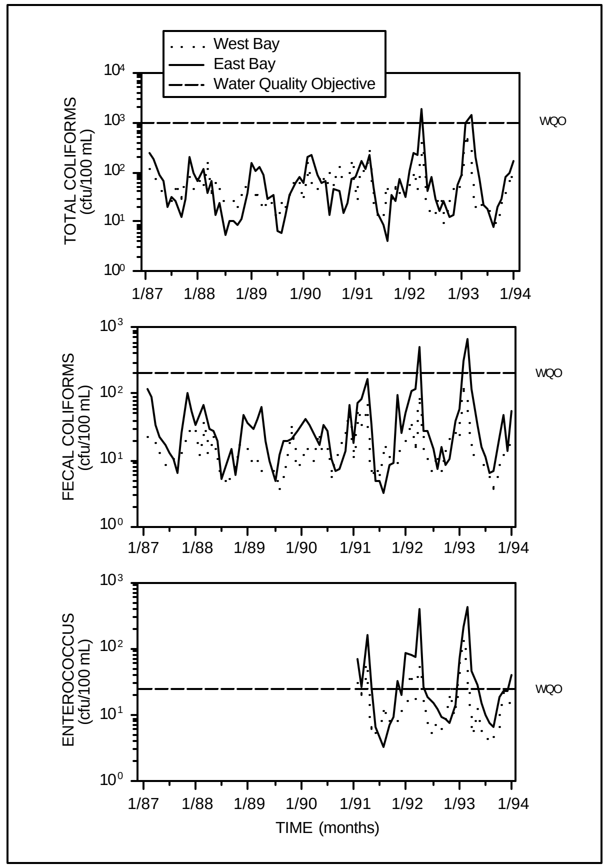
Seasonal cycles in Mission Bay water quality were evident, with extremes peaking in winter (Figure 2). Based upon over 7,300 samples taken between 1987 and 1994, the highest monthly geometric mean densities of total coliform ($10^3$ to $10^4$ cfu/100 mL), fecal coliform ($10^2$ cfu/100 mL), and enterococcus ($10^2$ cfu/100 mL) occurred from December through March, which are historically the wettest months of the year in San Diego. In each year, the lowest monthly geometric mean densities occurred from May through August. Differences between the winter and summer months ranged over two orders of magnitude. Monthly summaries of fecal indicator bacteria frequently showed that levels exceeded water quality standards in the bay during the winter.

Densities of fecal indicator bacteria were higher from the east bay than the west bay, especially during the winter months (Figure 2). Monthly geometric mean densities of fecal coliform and enterococcus in the east bay were as much as one order of magnitude higher than the west bay during the wet season. During the dry season, fecal indicator bacteria densities were relatively similar between the eastern and western halves of Mission Bay.

Geometric mean densities of total coliform, fecal coliform, and enterococcus were always higher during wet days than during dry days for every station monitored between 1987 and 1994 (Figure 3). During dry days, the mean densities of these indicators showed no strong spatial relationship. During wet days, however, Station 3 was clearly the most impacted site. Densities of fecal indicator bacteria remained high, moving northward toward Station 8, where a second noticeable increase in geometric mean densities of coliforms and enterococcus occurred. Station 3 is situated at the mouth of Tecolote Creek, a large urbanized watershed located in the innermost portion of east Mission Bay, and Station 8 is at the mouth of Rose Creek, another large urbanized watershed.

A significant correlation was found between rainfall and fecal indicator bacteria densities from east Mission Bay (Table 2). In particular, fecal coliform and enterococcus were significantly positively correlated with rainfall quantities at Stations 1 through 9, where the least amount of mixing occurs, but some of the largest quantities of runoff are discharged. Fewer significant relationships existed between total coliform and rainfall quantities. Nonetheless, the three highest measurements at each station throughout Mission Bay occurred on wet days after large storm events.

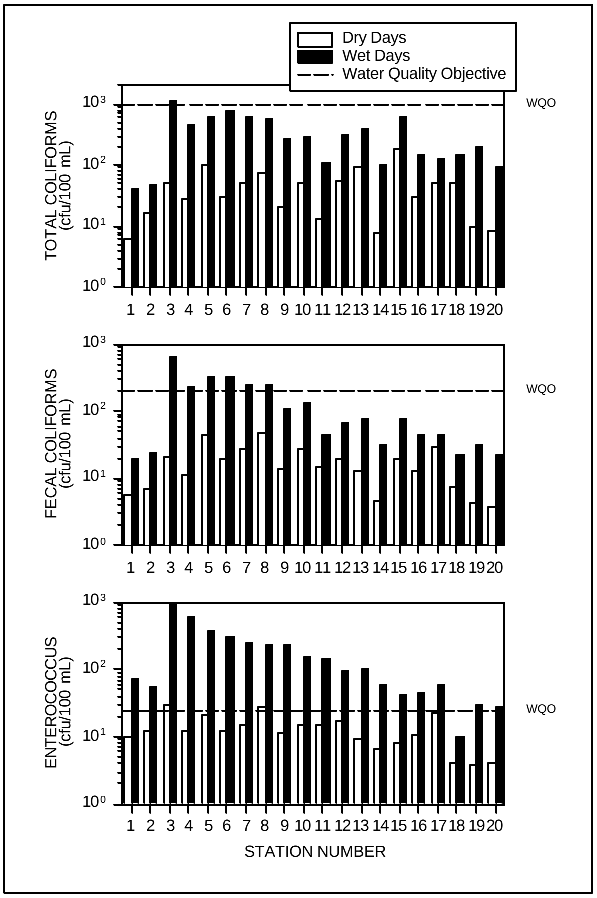
**FIGURE 2. Monthly geometric mean densities of indicator bacteria in the western and eastern halves of Mission Bay, California, relative to State of California water quality objectives for body-contact recreation.**




### Storm Drain Sampling

Twenty-two of the 89 storm drains that empty into Mission Bay were flowing during dry weather. Only half of these storm drains contained measurable densities of indicator bacteria. Of the storm drains with flow and detectable bacteria, only one was discharging freshwater (the others were discharging seawater), and flows were less than one gallon per minute. The density of enterococcus at this site was $10^4$ MPN/100 mL and the density of total coliform was $10^6$ MPN/100 mL. While these measurements have the potential to impact the water quality of Mission Bay, the actual impact was small since the nearby receiving water monitoring station did not measure noticeably high densities of enterococcus or coliforms the following day.

**FIGURE 3. Geometric mean densities of total and fecal coliform (1987-1994) and enterococcus (1991-1994) at 20 different stations located in Mission Bay, California. Mean densities are stratified into dry days and wet days (< 48 h after recorded rainfall).**




All 22 of the storm drains with dry-weather flows were revisited during wet weather at least once in the following storm season. All 22 storm drains contained effluents with high bacteria densities of total coliform (median = $10^5$ MPN/100 mL), fecal coliform (median = $10^4$ MPN/100 mL), and enterococcus (median = $10^3$ MPN/100 mL) that were well above State of California water quality objectives.

*Sediment Sampling*

Levels of fecal indicator bacteria in sediments of Mission Bay responded to inputs of stormwater runoff, but did not appear to represent a long-lasting source of fecal indicator bacteria to bay waters (Table 3). The densities of fecal coliform and enterococcus were all low or below reporting limits during dry weather. Samples collected one day following a large storm produced significantly increased densities for each of the indicator bacteria in sediments compared to samples taken immediately preceding the storm. The average increase from pre- to post-storm sampling was $10^2$ MPN/100 mL. Densities of fecal coliform and enterococcus increased by a factor of $10^1$ MPN/100 mL to $10^5$ MPN/100 mL depending upon the site; the largest increases were at stations nearest the largest stormwater inputs (Stations 3 and 8).

*Upstream Tracking*

Upstream tracking along the Tecolote Creek watershed in Mission Bay indicated that no single subwatershed overwhelmingly contributed the majority of bacteria to the total stormwater discharge. The concentrations of indicator bacteria were as high at the head of Tecolote Creek as they were at the mouth where it discharges into Mission Bay (Figure 4). This finding demonstrated that the high bacteria densities observed in the discharges were not the result of a point source (e.g., a broken sanitary sewer line). Rather, the densities of bacteria were high throughout the watershed indicating a diffuse, widespread source. Further, densities of indicator bacteria were uniformly above State of California water quality objectives for all three indicator bacteria from the head to the mouth of Tecolote Creek.

Similar to Tecolote Creek, the densities of indicator bacteria were as high at the head of the Rose Creek watershed as they were at the mouth of the channel (Figure

**TABLE 2. Spearman rank correlation coefficients for rainfall quantities *versus* density of indicator bacteria in samples taken from 20 receiving water stations in Mission Bay, California within 48 h of recorded rainfall between 1987 and 1994. Significant relationships indicated by * (P < 0.05); highly significant realtionships indicated by ** (P < 0.01).**

| | Rainfall *versus* | | |
|---|---|---|---|
| Station No. | Total Coliform | Fecal Coliform | Enterococcus |
| 1 | 0.356** | 0.393** | 0.599* |
| 2 | 0.228 | 0.330** | 0.405** |
| 3 | 0.163 | 0.530** | 0.597** |
| 4 | 0.393** | 0.463** | 0.534** |
| 5 | 0.329* | 0.384** | 0.375** |
| 6 | 0.171 | 0.307** | 0.319* |
| 7 | 0.295* | 0.560** | 0.448** |
| 8 | 0.340** | 0.375** | 0.476** |
| 9 | 0.186 | 0.156 | 0.445** |
| 10 | 0.233 | 0.198 | 0.205 |
| 11 | 0.069 | 0.14 | 0.077 |
| 12 | 0.166 | 0.23 | 0.136 |
| 13 | -0.026 | 0.015 | -0.096 |
| 14 | 0.083 | 0.165 | 0.119 |
| 15 | 0.337** | 0.178 | 0.141 |
| 16 | 0.059 | 0.113 | 0.11 |
| 17 | 0.152 | 0.195 | -0.064 |
| 18 | 0.171 | 0.19 | 0.075 |
| 19 | 0.104 | 0.039 | 0.056 |
| 20 | 0.218 | 0.444** | 0.122 |

**TABLE 3. Densities of fecal coliform and enterococcus (MPN/wet g) in sediments during dry weather, during the wet season prior to a large storm event, then immediately following the event. Samples were collected at 17 sites located along beaches in Mission Bay, San Diego, California.**

| | Fecal Coliform | | | Enterocoucus | | |
|---|---|---|---|---|---|---|
| Station No. | Dry | Pre-Storm | Post-Storm | Dry | Pre-Storm | Post-Storm |
| 1 | < 30 | < 300 | 2,300 | < 3 | 930 | 24,000 |
| 2 | < 30 | < 300 | < 300 | < 3 | 11,000 | 230 |
| 3 | < 30 | < 300 | 4,600,000 | 11,000 | 930 | 1,100,000 |
| 4 | < 30 | < 300 | 2,300 | < 3 | 2,400 | 240,000 |
| 5 | 90 | < 300 | 4,300 | 240 | < 30 | 93,000 |
| 6 | < 30 | 1,500 | 24,000 | < 3 | 24,000 | 110,000 |
| 7 | < 30 | 1,500 | < 300 | < 3 | 23,000 | 24,000 |
| 8 | < 30 | 2,300 | 240,000 | < 3 | 46,000 | 240,000 |
| 9 | < 30 | < 300 | 7,500 | < 3 | 230 | 24,000 |
| 10 | < 30 | < 300 | 4,300 | < 3 | < 30 | 2,400 |
| 11 | < 30 | < 300 | < 300 | < 3 | < 30 | < 30 |
| 12 | < 30 | < 300 | 4,300 | 4 | < 30 | 24,000 |
| 13 | < 30 | < 300 | 900 | 4 | < 30 | 2,400 |
| 14 | < 30 | 110,000 | 400 | 4 | 46,000 | 2,400 |
| 15 | < 30 | 400 | 2,100 | < 3 | < 30 | 230 |
| 16 | < 30 | < 300 | 1,500 | < 3 | 430 | 230 |
| 17 | < 30 | < 300 | 900 | < 3 | 2,400 | < 30 |

5). The densities of total coliform, fecal coliform, and enterococcus were all within an order of magnitude between the two sites. The main difference between the head of the Rose Creek tributary and the Tecolote Creek tributary is that the head of Rose Creek is completely non-urban, with no sewer lines or lift stations. In fact, this portion of the watershed is restricted from public access.

Not only did non-urban flows contribute equally high densities of indicator bacteria to urban stormwater, but the densities of all three indicator bacteria exceeded State of California water quality objectives regardless of land use type (Figure 6). Enterococcus and total coliform were routinely one to two orders of magnitude above water quality objectives from surface flows off small catchments of representative commercial, industrial, residential, and non-urban land uses. Densities of fecal coliform were slightly reduced at commercial and industrial sites relative to residential and non-urban land uses, but geometric mean densities were still above water quality objectives.

## DISCUSSION

The sources of fecal indicator bacteria in stormwater discharges are numerous and widespread. In San Diego, we could not attribute exceedences of water quality objectives to easily distinguishable locations such as broken sanitary sewer lines, sewer overflows, illicit connections, illegal discharges, leaking septic tanks, or contaminated sediments. Instead, we observed that indicator bacteria densities were as high at the head of our watersheds as at the mouth of the channel, without appreciable increases from tributaries or sub-watersheds. Furthermore, the contribution of indicator bacteria from non-urban land uses were similar to surface flows measured from different urban land uses such as residential, commercial, and industrial areas.

Other programs have observed large densities of indicator bacteria in stormwater discharges from other parts of San Diego, southern California, and around the nation. San Diego has a larger, ongoing stormwater municipal National Pollutant Discharge Elimination System (NPDES) monitoring program that characterizes representative land uses around the county. Results from that monitoring program indicated that the bacteria densities we observed in the Mission Bay watershed were actually slightly reduced from the surrounding areas in the region (Table 4). Data from similar monitoring programs in neighboring Los Angeles County show geometric mean densities of indicator bacteria have maintained levels above

**FIGURE 4. Geometric mean densities (± 1 standard deviation) of indicator bacteria measured along different creek reaches during storm events on Tecolote Creek, San Diego, California.**

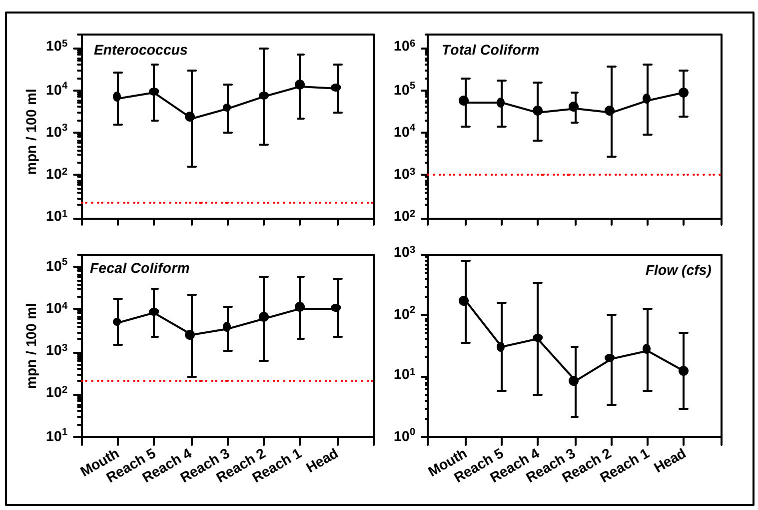


**FIGURE 5. Geometric mean densities (± 1 standard deviation) of indicator bacteria in wet-weather discharges at the head and mouth of Rose Creek. The head of Rose Creek is entirely non-urban while the lower reaches are mostly urbanized.**

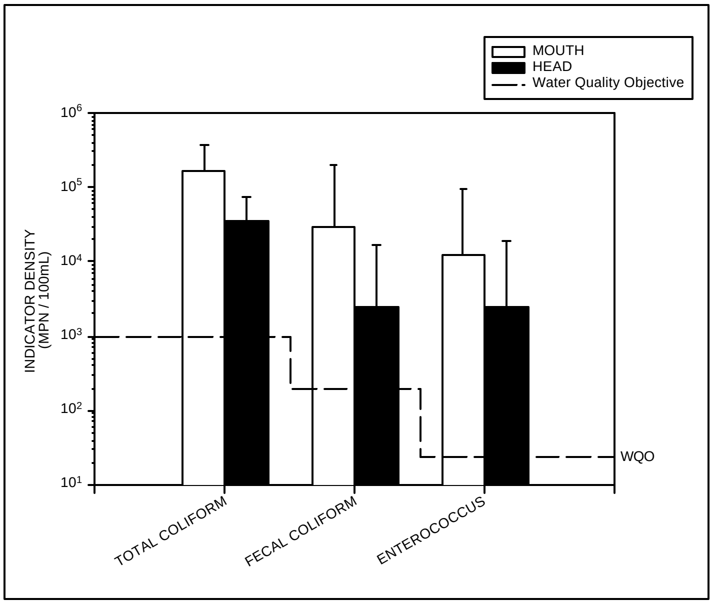
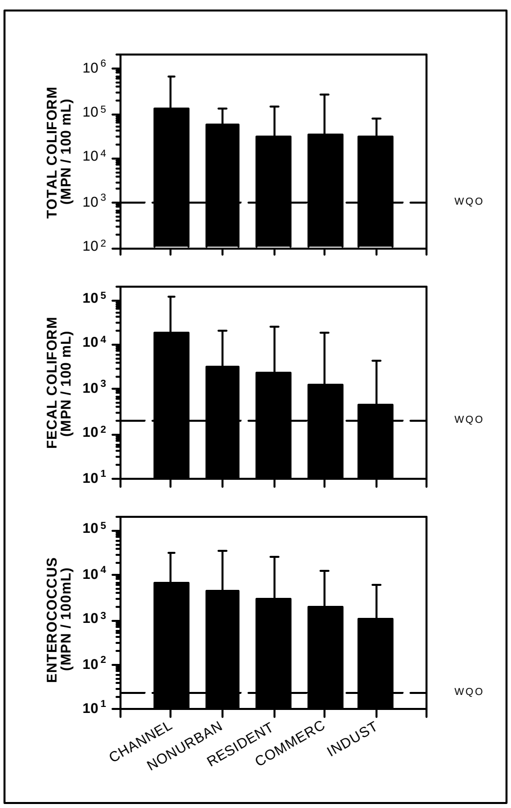



**FIGURE 6. Geometric mean densities (± 1 standard deviation) of indicator bacteria in surface flows during storm events, prior to entering the separate municipal storm sewer system, for different urban and non-urban land uses in San Diego, California.**




$10^4$ MPN/100 mL since 1994 (Schiff 1998). In fact, the problem of indicator bacteria in stormwater has been known since the National Urban Runoff Program in the 1980s (NURP 1983). Median densities of fecal coliform in stormwater were estimated to be $10^4$ to $10^5$ MPN/100 mL from over 16 sites and 125 storm events around the country.

Large numbers of indicator bacteria may not be the result of human sources of contamination. In San Diego, the County Department of Health Services has determined through DNA typing that fecal contamination along the open coast is the result of seals and sea lions, which haul out near popular swimming beaches (personal communication). Similarly, in Buttermilk Bay, Massachusetts, 67% of the mass balance in fecal coliform bacteria was the result of waterfowl (Weiskel *et al.* 1996). In contrast, other investigators have demonstrated that stormwater does carry human-specific virus and may pose a real health risk. In Florida, an outbreak of Hepatitis A was due to sewage-contaminated stormwater (Vonstille *et al.* 1993). In southern California, attenuated human polio virus has been measured in wet-weather discharges to Santa Monica Bay (Noble *et al.* 1998).

The risk of contracting an illness from wet-weather discharges is unknown. Very few epidemiological studies have been conducted to relate the risk of contracting swimming-related illnesses to the density of indicator bacteria (Cabelli 1983). Instead, most of the State of California water quality objectives were based upon historical, technology-based limits. The thorough epidemiological studies that have been conducted, such as those in Santa Monica Bay, were conducted during the summer months (SMBRP 1996, Haile *et al.* 1999). Summer season investigations are appropriate since this is the period of time when the largest number of swimmers visits the beach and the public is most at risk. However, extrapolating the risk during summer months when storm drain flows are unnatural, to the winter months when storm conditions are present, may not be appropriate. In Mission Bay watersheds such as Tecolote Creek, flows rise from below 0.04 cfs to greater than 2,000 cfs in less than one hour.

The difficult issues that face stormwater managers in San Diego are similar to those facing stormwater managers around the nation (Schueler 1999). The levels of indicator bacteria in stormwater discharges routinely exceed water quality objectives and the current public health framework mandates the closure of beaches or issuance of swimming advisories. Beach closures and advisories result in loss of revenue to the city and surrounding businesses since the perception, real or unknown, is that an increased risk exists for swimming-related illness. However, the solutions for reducing stormwater bacteria loads are immense since they are a ubiquitous problem and remediation is very costly.

**TABLE 4. Comparison of median indicator bacteria densities in stormwater runoff from Mission Bay (this study), San Diego County (KLI 1995), Los Angeles County (LACDPW 1998), and around the nation (U.S. EPA 1983).**

| | Enterococcus (1000 /100 mL) | | | | Fecal Coliform (1000 /100 mL) | | | | Total Coliform (1000 /100 mL) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Com | Ind | Resid | Open | Com | Ind | Resid | Open | Com | Ind | Resid | Open |
| Mission Bay | 3.7 | 2.2 | 2.7 | 9.8 | 2.5 | 0.5 | 4 | 3.7 | 26 | 30 | 175 | 125 |
| San Diego Co. Region | 34 | 36 | 35 | 5.7 | 7.6 | 10 | 24 | 9.2 | 75 | 64 | 76 | 39 |
| Los Angeles Co. Region | Mixed land use; 205 | | | | Mixed land use; 120 | | | | Mixed land use; 500 | | | |
| Nationwide Urban Runoff Program | No data | | | | Mixed land use; 21 | | | | No data | | | |

From the viewpoint of the stormwater manager, if he/she were able to reduce their contribution of bacterial contamination to zero, the contribution of bacteria from non-urban areas would still result in beach closures because the regulatory framework does not discriminate between human and non-human sources of indicator bacteria.

City of San Diego officials have initiated actions to reduce bacterial contamination to Mission Bay. First, they are replacing most of the sewer trunk lines surrounding Mission Bay with less permeable and more durable materials. Second, they are removing a nearby biosolids processing facility. Third, they are removing many of the smaller storm drains and combining them into a single, but larger outfall. Plans for a larger capacity outfall are being developed to reroute storm flows around the bay to the open coast. Fourth, they have installed an interceptor system that diverts almost all dry-weather and initial storm flows to the sanitary sewer. The effectiveness of these costly infrastructure developments will be evaluated over the next several years.

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## ACKNOWLEDGEMENTS

The authors wish to acknowledge John Leppart (City Manager, City of San Diego); Robert Cain (Engineering and Development Dept, City of San Diego); Patty Vainik (Environmental and Technical Services Department, City of San Diego); John Chaffin, Richard Epipane, Rick Amador and laboratory personnel (Water Production Department, City of San Diego); and Richard Gersberg (San Diego State University) for their assistance and guidance on this study. This project was funded by the City of San Diego.