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# Microbiological water quality at non-human influenced reference beaches in southern California during wet weather

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ABSTRACT

Although urban wet weather discharges may have elevated concentrations of fecal indicator bacteria impacting water quality at swimming beaches, not all of these bacteria may arise from human sources. In this study, the contribution of non-human fecal indicator bacteria was quantified by sampling coastal reference beaches in southern California. Samples were collected at beaches near stormwater discharges from undeveloped watersheds and analyzed for total coliform, *Escherichia coli*, and enterococci. Surfzone samples exceeded water quality thresholds >10 times more frequently during wet weather than dry weather. Exceedences were greatest <24 h following rainfall, then steadily declined on successive days. Early season storms exceeded thresholds more frequently, and by greater magnitude, compared to late season storms. Large storms exceeded thresholds more frequently than smaller-sized storms, partly due to the breaching of sand berms. When discharges did reach the surf zone, bacterial concentrations in the wave wash were correlated with watershed bacterial flux.



## 1. Introduction

Beaches in southern California are a valuable recreational resource for swimming, surfing, and other body contact activities. For example, greater than 175 million beach-goers visit southern California beaches annually, more than all other parts of the country combined (Schiff et al., 2001). This year-round activity results in tremendous economic revenue estimated at more than $9 billion annually in ocean related activities for the region (NRC, 1990).

Fecal indicator bacteria (total coliform, *Escherichia coli*/fecal coliform, and enterococci) are used to monitor the water quality of marine beaches because they have been shown to correlate with swimming related illness. For example, Cabelli (1982) demonstrated that increases in concentrations of enterococci correlated with an increase in the risk of highly credible gastrointestinal illness among swimmers on beaches in New Jersey. In Santa Monica Bay, California, Haile et al. (1999) observed an increase in the relative risk for diarrhea with blood and highly credible gastrointestinal illness in swimmers exposed to higher concentrations of enterococci.

While the water quality at most beaches in southern California meets water quality thresholds established by the State during dry weather, several beaches have impaired water quality based on routine fecal indicator bacteria monitoring. Noble et al. (2000) conducted a regional study of all southern California beaches and found that approximately 5% of the shoreline exceeded water quality thresholds for fecal indicator bacteria during the summer of 1998. This level of exceedence was not randomly distributed. More than half of the exceedences occurred near storm drains that discharge across the beach. A retrospective analysis of fecal indicator bacteria based on five years of daily beach monitoring during dry weather in Santa Monica Bay found similar results, with over half of the water quality exceedences occurring in front of storm drains (Schiff et al., 2003).

The microbial water quality of beaches in southern California drastically changes following rainstorms. Noble et al. (2003a,b) repeated their 1998 summer study, but sampled following a significant rainfall event during the winter of 1998–1999. In this case, over half of all beaches exceeded fecal indicator bacteria water quality thresholds. This frequency of impaired water quality jumped to nearly 90% when these beaches were located in front of storm drains. Similarly, Schiff et al. (2003) observed a doubling of microbial water quality exceedences between dry and wet weather, even though wet weather represented less than 10% of the year.

There are many sources of bacteria that could potentially be found in storm drains that discharge to beaches. Some of these sources may be of human origin including sewage spills, leaking sanitary sewage systems, faulty septic systems, or illicit discharges and illegal dumping (Geldreich, 1978). However, many bacteria may actually arise from natural sources. Fecal indicator bacteria

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such as total coliform, *E. coli*/fecal coliform and enterococci are a component of the gut microflora of all warm-blooded animals, including domesticated dogs and cats, and wild birds and mammals (Grant et al., 2001; Oshiro and Fujioka, 1995). Furthermore, fecal indicator bacteria may have extended survival or even regrow in beach sediments and wrack (Valiela et al., 1991; Weiskel et al., 1996; Desmarais et al., 2002; Gruber et al., 2005; Anderson et al., 2005). Therefore, the reference condition for bacterial water quality, including those beaches that are located at the mouth of undeveloped watersheds, is likely not zero. In fact, some shoreline managers use the level of contributions from undeveloped watersheds as the benchmark for water quality from developed watersheds in the Los Angeles region (LARWQCB, 2002). Unfortunately, the contributions of fecal indicator bacteria from undeveloped watersheds to reference beaches are largely unknown, which complicates this approach for assessing public health risk or beach management. Understanding this uncertainty is paramount because current use of reference beaches for regulation are focused on a minimum number of sites.

The goal of this study was to assess the microbial water quality at reference beaches following wet weather events in southern California through measurements of fecal indicator bacteria. Reference beaches were defined as those beaches located at the mouth of undeveloped watersheds and whose bacterial contributions are minimally influenced by human activities. These data can then be used by public health agencies and beach managers for making informed decisions about the reference condition of microbial water quality during wet weather. A series of secondary objectives were also addressed during this study to enhance our ability to decipher processes that can influence reference beach water quality during wet weather. These objectives included assessments of: (1) beach water quality over time following rainfall to determine how long elevated concentrations of fecal indicator bacteria persist; (2) the influence of storm size and seasonality on beach water quality; (3) the relationship between land-based inputs and microbial water quality at reference beaches; (4) the relationship between watershed size and microbial water quality; and (5) the influence of lagoonal systems on microbial water quality at reference beaches.

## 2. Methods

Six coastal reference beaches in southern California were selected for assessment of water quality during wet weather. Reference beaches were selected based on four criteria: (1) each reference beach must be an open beach with breaking waves; (2) each reference beach must have a freshwater input; (3) the freshwater input must come from a watershed of similar size to nearby beaches that receive wet weather inputs from urban watersheds; and (4) the watershed discharging to the reference beach must be >93% undeveloped.

The six reference beaches were: (1) Point Mugu State Beach located at the mouth of Big Sycamore Creek in Ventura County; (2) Deer Creek Beach located at the mouth of Deer Creek in Ventura County; (3) Leo Carrillo State Beach located at the mouth of Arroyo Sequit Creek in Los Angeles County; (4) Dan Blocker Beach located at the mouth of Solstice Creek in Los Angeles County; (5) San Onofre State Beach located at the mouth of San Onofre Creek in San Diego County; and (6) San Mateo Beach located at the mouth of San Mateo Creek in San Diego County (Table 1, Fig. 1). All six reference beaches are open with breaking waves and have freshwater inputs. The six watersheds that discharge to these reference beaches range from 3 to 346 $km^2$, which is within the 25th and 75th interquartile range of watershed area for all of the watersheds that drain to impacted, urbanized beaches in southern California. Five of the watersheds that drained to the reference beaches were between 97% and 100% undeveloped, while one (San Mateo) was 93% developed, based on land use data compiled by the US Geological Survey and University of California Santa Barbara (Davis et al., 1998). Deer Creek was the smallest watershed and had the least amount of human activity, while San Mateo Creek was the largest watershed and had the greatest amount of human activity.

### 2.1. Sampling

The primary sampling location was in the ocean immediately in front of the freshwater input at the so-called "wave wash" where the watershed discharge initially mixes with the ocean waves. All samples were collected between ankle and knee depth on an incoming wave. The secondary sampling location was in the watershed discharge as it crossed the beach at the closest sample able location prior to mixing with the ocean.

Samples at the primary sampling sites were measured for fecal indicator bacteria and salinity. Samples at the secondary sampling sites were measured for fecal indicator bacteria, salinity and flow. A subset of samples at secondary sites was collected for analysis of human enteric virus to detect or rule out the presence of human contributions of fecal pollution. Samples were collected in sterile 250 ml polystyrene bottles (bacterial analysis, salinity analysis) or 4 l polyethylene carboys (enterovirus analysis) following Standard Methods 1060 protocol for aseptic sampling techniques (APHA, 1995). Samples were transported on ice to the laboratory for analysis. Flow was measured using a hand held velocity meter (Marsh-McBirney, Inc., Frederick, MD) and estimates of wetted cross-sectional area.

Sampling focused on wet weather during the Fall and Winter of 2004–2005 and 2005–2006. Wet weather sampling criteria included three or more days of antecedent dry period and predicted minimum rainfall estimates of 0.10 in. Four samples were collected per site corresponding to the day of the storm (defined as within 24 h of recorded rainfall) and the three days following recorded rainfall (four days of sampling in total). Storms were targeted based on two factors; size of storm and seasonality. Size of storm was stratified into small storm events (less than mean daily rainfall) and large storm events (greater than mean daily rainfall) based on historical rainfall at the nearest rain gage. Seasonality was stratified into early season (before December 31st) and late season (after January 1st) storm events. Storm season in southern California is defined as October 15th to April 15th. To summarize, six reference beaches were sampled over the course of four days during five different storm events for a total of 120 sampling events.

Concentrations of total coliforms, *E. coli*, and enterococci were measured using kits supplied by IDEXX Laboratories, Inc. (Westbrook, ME). Concentrations of total coliforms and *E. coli* were measured using the Colilert-18™, while enterococci was measured using Enterolert™. Samples were heat-sealed into Quanti-Tray/2000™ pouches and incubated overnight per the manufacturer's instructions and subsequently inspected for positive wells. Conversion of positive wells to a most probable number (MPN) was done following Hurley and Roscoe (1983). Samples taken at Big Sycamore Beach, Deer Creek Beach, Dan Blocker Beach and Leo Carrillo State Beach were analyzed at the City of Los Angeles laboratory facilities (El Segundo, CA). Samples collected from San Onofre State Beach and San Mateo Beach were analyzed at Weston Solutions Laboratories (Carlsbad, CA).

All discharge samples from the first day of flow were analyzed for human enterovirus. The purpose of this analysis was to reduce the chance that human sewage was a source of indicator bacteria at each site. Since these viruses only infect and multiply in humans through the oral-fecal route, their detection is a reliable marker for