

AN ABSTRACT OF THE THESIS OF

Mitchell V. Brinks for the degree of Master of Public Health in Public Health
presented on November 21, 2007.

Title: Health Risk of Bathing in Southern California Coastal Waters

Abstract approved:

Anna K. Harding

Bathers exposed to microbiological contamination in coastal waters have an excess risk of gastrointestinal and respiratory illness. The disease burden associated with this risk may be considerable in Southern California, where 50 million annual beach visitors recreate in coastal waters that receive billions of gallons of polluted discharges from nearby urban areas.

The goal of this study was to estimate the risk and disease burden of gastrointestinal and respiratory illness from bathing in the coastal waters of Southern California and to identify areas and periods of especially high risk.

For 2000 – 2004, gastrointestinal and respiratory illness rates were estimated with a simulation model that utilized water quality, beach attendance, and bathing rate data, along with three published dose-response relationships.

An estimated 689,000 to 4,003,000 episodes of gastrointestinal illness and 693,000 episodes of respiratory illness occurred each year at Southern California beaches during the study period. The majority of illnesses (57% – 80%) occurred during the summer season. A relatively small proportion of beaches (12 of 67) accounted for half of all illnesses. Only small fluctuations in the annual health burden were observed.

Coastal water contamination is a serious health risk for bathers at Southern California beaches. Although coastal waters are more contaminated during the winter, most contamination related illnesses occur during the summer months due to large seasonal increases in bathing populations. California's marine water contact standards may be inadequate to protect the health of bathers.

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Health Risk of Bathing in Southern California Coastal Waters

by

Mitchell V. Brinks

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Mitchell V. Brinks, Author

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CONTRIBUTION OF AUTHORS

Mitchell V. Brinks constructed the study, collected, compiled and interpolated the data, conducted the analysis, and led the writing

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This thesis is dedicated to my mother, Caroline, who has been an endless source of faith, love, and wisdom.

Health Risk of Bathing in Southern California Coastal Waters

Chapter 1

INTRODUCTION

The Southern California coastline is one of the most important coastal regions in the United States. More than 16 million residents have been attracted to the region by its desirable climate, ample employment offerings, and plentiful recreational opportunities (U.S. Census Bureau 2006) (Figure 1.1). The coastline receives over 150 million tourist visits each year, which makes this area one of the most popular vacation destinations in the United States (Dwight *et al.* 2007). Visitors to these beaches contribute 12 billion dollars annually to the coastal economy, which anchors California's state economy (fifth largest in the world compared to other nations) (Hanneman *et al.* 2004; State of California 2007).

Contamination Sources

The large and rapidly expanding population of Southern California imposes enormous demands on its coastal environment. Extensive urbanization throughout the region prevents the natural soil percolation of rainfall (Basnyat *et al.* 1999; Bay *et al.* 2003; Dojiri *et al.* 2003; Lee *et al.* 2003; Walesh 1989). Consequently, high volumes of surface drainage (urban runoff) are discharged along the coastline after

rainfall events, which leads to increased contamination levels in coastal waters
(Ackerman *et al.* 2003;

Ahn *et al.* 2005; Dwight *et al.* 2002; Mallin *et al.* 2000; Noble *et al.* 2003; Schiff *et al.* 2003). Southern California's coastal waters also receive large volumes of sewage discharges from rivers, which receive discharges directly from treatment plants. Major sewage discharge treatment plants in this region contribute 240 million gallons per day (m/g/d) of mixed primary (Orange County Sanitation District), 175 m/g/d of advanced primary (Point Loma Treatment Plant), 775 m/g/d of secondary (International Water Treatment Plant and Joint Water Pollution Control Treatment Plants), and 130 m/g/d of tertiary sewage (Hyperion Treatment Plant) (City of Los Angeles 2007; City of San Diego 2007; County of Los Angeles 2007; OCSD 2005) (Figure 1.2). Many manufacturing and other commercial facilities in the region discharge industrial wastewater via both runoff and sewage infrastructure. In addition, the 350 km coastline is home to five major commercial shipping ports (including the two largest port facilities in the United States, located in Long Beach), over 35,000 small private and commercial vessels, and over one third of the U.S. Naval fleet, at the San Diego Bay Naval Base, all of which discharge waste into these coastal waters (U.S. Department of Transportation 2005).

Health Risk for Bathers

Coastal waters contaminated by the types of discharges found in Southern California may pose significant health risks for bathers, according to epidemiologic studies in coastal waters conducted around the world with a wide range of contamination sources (Cabelli *et al.* 1982; Dwight *et al.* 2004; Haile *et al.* 1999; Kay *et al.* 1994; Pruss *et al.* 1998). Three epidemiologic investigations conducted in

California confirm that bathers in the region experience considerable health risk (Colford *et al.* 2007; Dwight *et al.* 2004; Haile *et al.* 1999). Both runoff and sewage wastes in Southern California contain pathogenic organisms found in human and animal fecal waste. As most of the many potential human pathogens can become waterborne, and both ingestion of organisms and full-body external exposure are common, the potential range of illnesses resulting from these organisms is vast. Pathogens in contaminated coastal waters may cause gastroenteritis, respiratory illness, conjunctivitis, otitis, dermatitis, osteomyelitis, meningitis, cellulitis, hepatitis, renal failure, septicemia, and death in bathers (Alexander *et al.* 1992; Bosch *et al.* 1998; Fattal *et al.* 1986; Fleisher *et al.* 1996; Griffin *et al.* 2003; Wade *et al.* 2003; Zmirou *et al.* 2003). Given the volume of waste discharged and the popularity of Southern California beaches among bathers, the health risks posed by contaminated coastal waters in Southern California may be considerable, (Dwight *et al.* 2007).

Epidemiologic Relationships

The ability to quantify health risk for bathers from contaminated coastal water is greatly benefited by the epidemiologic relationships reported in landmark studies by Cabelli *et al.* (1982) and Kay *et al.* (1994). These large prospective investigations were initiated in response to observations by the U.S. Environmental Protection Agency and the World Health Organization that there was a paucity of scientific data upon which to base recreational water quality guidelines (Cabelli *et al.* 1979; Cabelli *et al.* 1982; Kay *et al.* 1994). The Cabelli *et al.* (1982) study, conducted in conjunction with the U.S. EPA, was a prospective cohort study that investigated the

health risk of bathing at beaches in New York, Boston, and New Orleans (Cabelli *et al.* 1982; EPA 1986). Conducted during the summers of 1973 to 1978; the study included 25,442 participants who were recruited as family groups and categorized in swimmer or nonswimmer groups (based on their self-reported water exposure status). Levels of indicator bacteria in chest-deep water was measured three to four times a day at two sites at each beach (distance between sites is unspecified), and phone interviews were conducted 8 to 10 days after bathing to assess the health status of the participants. Exposure level data was analyzed by grouping study days when the pollution levels, as indicated by the mean indicator densities in the water, were similar. Eighteen groups of study days were used for the study's risk analysis, with each group of days represented many bathing days (two of an initial total of 21 study day groups were excluded due to no reported gastroenteritis episodes among non-swimmers and one group was excluded due to an unusually low non-swimmer rate). The investigators reported a statistically significant relationship between enterococcus levels and the rate of reported gastroenteritis among bathers. The current U.S. EPA and California water quality guidelines are based on the relationship reported by Cabelli *et al.* (1982) (EPA 1986; State of California 1999).

Kay *et al.* conducted a randomized controlled trial to determine the health risk of bathing in contaminated coastal waters at four beaches in the United Kingdom (Kay *et al.* 1994). This study was constructed to address concerns raised by the World Health Organization (WHO) about methodological weaknesses of previous water quality associated health risk investigations. The trial was conducted from 1989 to 1992 and included 1306 adult volunteers whose pretrial health status was

evaluated with a medical examination that included an assessment for non-water-related gastroenteritis risk factors (types of food intake, illness among family members, etc.). Participants were randomized for exposure status, and those assigned to the water exposure group were closely monitored to ensure that water quality measurements were made at the time and location of bathing. Water quality measurements were taken every thirty minutes during the trial every 20 meters along the bathing beach and bathers were assigned to the water quality measurement taken at the site and time that they bathed. The randomized control design of this investigation was intended to minimize misclassification bias, especially bias from the rapid variability of bacteria levels in coastal waters. Follow-up health-status examinations were performed one week after exposure and written questionnaires were conducted three weeks after exposure. Kay *et al.* reported statistically significant associations between levels of fecal streptococcus and rates of gastroenteritis and respiratory illness among bathers. These relationships now serve as the basis of WHO (for gastroenteritis) and European Union (for gastroenteritis and respiratory illness) water quality guidelines (EP/CEU 2006; WHO 2003).

Significant concerns about the accuracy of the Cabelli *et al.* (1982) relationship were raised after subsequent investigations reported that environmental enterococcus levels may fluctuate rapidly (Boehm *et al.* 2002; Cheung *et al.* 1991). Variability of enterococcus levels in coastal waters may introduce misclassification bias when exposure levels are measured on a relatively infrequent basis. Fleisher (1991) concluded that this misclassification bias, together with the inherent imprecision in monitoring techniques, may have led the Cabell *et al.* (1982)

relationship to underestimate health risk by as much as 57% (Fleisher *et al.* 1990; Fleisher 1991; Jones *et al.* 1990). Another concern about the Cabelli *et al.* (1982) investigation arises from the study's inclusion of a brackish water lake as a study site, where the salinity was an order of magnitude below that of the coastal study sites. As indicator organism survival is strongly affected by salinity, a marked alteration of health risk relationships may occur in water with such disparate salinity levels (Dufour *et al.* 1984). Unlike the findings at Cabelli *et al.*'s (1982) marine bathing sites, no association between enterococcus levels and health risk was found at the brackish water lake study site. However, data from the lake study site was combined with data from the other sites for the health risk analysis, potentially leading to a further underestimation of health risk. The aforementioned concerns about the health risk relationships reported by Cabelli *et al.* (1982) together with the inherent weaknesses associated with nonrandomized study design have led the WHO, the European Union, and many national public health agencies to recognize the Kay *et al.* (1994) relationship as the preferred basis for water quality guidelines.

The Cabelli *et al.* (1982) study retains statistical strength due to the large number of participants and the long duration of the study (Cabelli *et al.* 1982). As well, Wymer *et al.* (2005) has criticized the Kay *et al.* (1994) study's use of a mean log density of the indicator organism to represent a bather's exposure level (this criticism is largely based on statistical methodology arguments and is available, as is the response by members of the Kay *et al.* study group, in the accompanying references) (Kay *et al.* 2006; Wyer *et al.* 1999; Wymer *et al.* 2005). Importantly, the Cabelli *et al.* (1982) study remains relevant here because it underlies California's

water quality guidelines, and because estimates derived from the Cabelli *et al.* relationship allow a more direct evaluation of public health policy in the region (EPA 1986; State of California 1999).

Public Health Efforts

Southern California has attempted to address concerns about the health risk posed by coastal water contamination with investments in wastewater treatment infrastructure and by strengthening water quality regulations. Infrastructure investments include billions of dollars appropriated to augment wastewater treatment facilities, to redirect runoff to treatment facilities prior to discharge, and to improve the circulation of relatively enclosed water bodies along the coastline. Water quality guidelines were revised with the passage of California Assembly Bill 411 in 1999 to add the enterococcus bacteria as a mandatory water quality indicator organism and to require water quality monitoring at beaches with both more than 50,000 annual visitors and summer season urban runoff (State of California 1999). Southern California now conducts more than 80,000 total water quality tests, at a cost of over 30 million dollars each year (Leecaster *et al.* 2001; Schiff *et al.* 2002). California public health agencies issue thousands of beach closures and advisories annually in response to high contamination levels reported by monitoring programs. These closures and advisories both limit the use of these valuable recreational resources and potentially avoid thousands of illnesses (NRDC 2006).

Little evidence, however, exists to confirm that California's current public health policies are effectively protecting bathers from the health risk of contaminated

coastal waters. Presently, neither the level of health risk nor the geographic or temporal distribution of the regional health risk from coastal water contamination in Southern California is known. California's state and local jurisdictions provide little standardization for techniques used to monitor beach visitor populations, calculate bathing rates, establish water quality monitoring schedules, or determine public health notifications regarding pollution hazards. Also, neither government nor scientific agencies conduct ongoing surveillance of illnesses among bathers. The lack of quantification and characterization of this health risk forces public health policy makers to use very uncertain science to guide decisions. Quantifying and characterizing the health risk associated with seasonal peaks in beach attendance may allow public health officials to anticipate periods appropriate for greater public health scrutiny. In addition, a better understanding of the influence of weather on this health risk may help guide use of measures such as rainfall-related bathing advisories and important treatment strategies for urban runoff. Quantifying the effectiveness of California's current water quality guidelines may provide the information necessary to improve them. Determining the distribution of this health risk among beaches, and the association of health risk with adjacent land use patterns, may also contribute to changes in public health policy to better protect swimmers..

Simulation Modeling

Simulation modeling analysis may be an effective way to quantify and characterize the health risk of bathing in coastal waters, and therefore to guide public health policy. Simulation models have been utilized in many investigations related to

water quality and associated health risks. Modeling investigations have predicted the temporal and geographic fluctuations of coastal water enteric bacteria levels and evaluated the likelihood of public health violations from high levels of these bacteria (Canale *et al.* 1993; Guillaud *et al.* 1993). The effect of swimming on enteric bacteria levels in recreational water has also been modeled (Eisenberg 2002). Other applications of modeling techniques include estimating dispersion patterns of pathogens in surface runoff plumes and characterizing the fate of pathogens from various types of discharges, which may clarify the role of runoff and sewage discharges in the contamination of coastal waters (Connolly *et al.* 1999; Dwight *et al.* 2002; Roberts 1997). Modeling techniques have also been used to assess the ability of water quality monitoring programs to correctly identify water quality threshold exceedances in Southern California (Boehm *et al.* 2002; Leecaster *et al.* 2001).

In addition to the important epidemiologic relationships discussed previously (Cabelli *et al.* and Kay *et al.*), simulation modeling of health risks to bathers requires detailed data describing the rate and level of exposure of bathers to contaminated coastal waters. Exposure-rate estimates require detailed data for beach visitation and estimates of the bathing (water exposure) rates for beach visitors to quantify the actual number of beach visitors at risk for illness associated with coastal water contamination. Bather exposure-level estimates require detailed data for the contamination levels in the coastal waters of concern, incorporating the most refined geographic and temporal data possible.

Data Sources

Historically, beach visitation in Southern California has been reported by several sources. The U.S. Lifesaving Association (USLA), using lifeguard crowd-size estimates, estimated annual beach visitation in California to total 123 million annual visits (USLA 2006). A phone survey conducted by the National Oceanic and Atmospheric Administration (NOAA) estimated the total at 151 million annual visits (Leeworthy 2001). Using U.S. EPA estimates of per-mile beach visitation in Southern California, Kildow *et al.* (2001) estimated that 153 million visitors arrive at this coastline annually (Kildow *et al.* 2001). However, these estimates include neither data describing the temporal distribution nor data describing the geographic distribution of these visits.

Until recently, bathing rate estimates in Southern California were available from two random sample phone surveys and one technical report. One random sample phone survey by NOAA estimated annual mean bathing rates to be 47% (Leeworthy and Wiley 2001); however, bathing rate was not a primary focus of the study (Leeworthy personal communication 2005). A computer-assisted random sample phone survey of Southern California residents reported estimated monthly average bathing rates to range from 43% in the summer months to 10% during February (Hanneman *et al.* 2004). A technical report, based on surveying the opinions of coastal-related businesses and government agencies in Orange County, reported bathing rate estimates that ranged from 38% during the April to September months down to 17% during the months from October to March.

Exposure-level data derived from coastal water contamination levels have become increasingly available over the last several years, as California regulatory

requirements and other factors have prompted an increase in the activity of water quality monitoring programs. Water quality data vary in the frequency with which it is available throughout the year, across years, and among beaches. The large volume of data has not been broadly compiled, nor have data gaps been interpolated to allow regional modeling of health risk.

Detailed data for beach visitation rates, bathing rates, and coastal water contamination levels in Southern California were compiled and interpolated for the purpose of the health risk analysis in the manuscript that follows. The database containing these data was described and analyzed in detail in an associated investigation by Dwight *et al.* (2007). This database includes the daily number of visitors at every Southern California beach for the five years from 2000 through 2004 (Dwight *et al.* 2007). The database also estimates the frequency with which beach visitors entered the water (bathing rate) and were exposed to coastal water contamination. The bathing rate data were derived from the direct observation of bathing activity by professionally trained lifeguards; a source that may provide more accurate bathing rate estimates than those previously available (Figure 1.3). The bathing rate at each beach in Southern California may be estimated from this database. The resulting 125,000 daily bathing rate values provide the requisite characterization of the exposure rate at Southern California beaches for health risk modeling analysis (Figure 1.4).

Water contamination levels in Southern California were also characterized in the database underlying the manuscript that follows. The water quality database includes 500,000 enterococcus contamination measurements from 187 monitoring

stations along the Southern California coastline for the five years from 2000 to 2004. This detailed water quality database provides the requisite exposure-level data to pursue health risk modeling.

The detailed and comprehensive database on beach attendance, bathing rate, and water quality underlying this analysis provides the requisite data input for modeling health risk using the Cabelli *et al.* and Kay *et al.* epidemiologic relationships. Applying these epidemiologic relationships in the setting of Southern California coastline beaches allows a broad regional estimate of the health risk of bathing in Southern California coastal waters as well as an evaluation of its distribution and modifying influences.

Figures



Figure 1.1 Southern California Coastline (the combined coastlines of Los Angeles, Orange, and San Diego Counties). Inset: Southern California region within the state boundaries of California.



Figure 1.2 Major Sewage Outfalls in Southern California; Joint Water Pollution Control Treatment Plant (JWPCTP), Los Angeles City Hyperion Treatment Plant (Hyperion), Orange County Sanitation District Treatment Plant (OCSD), Point Loma Treatment Plant (PLTP), International Water Treatment Plant (IWTP).

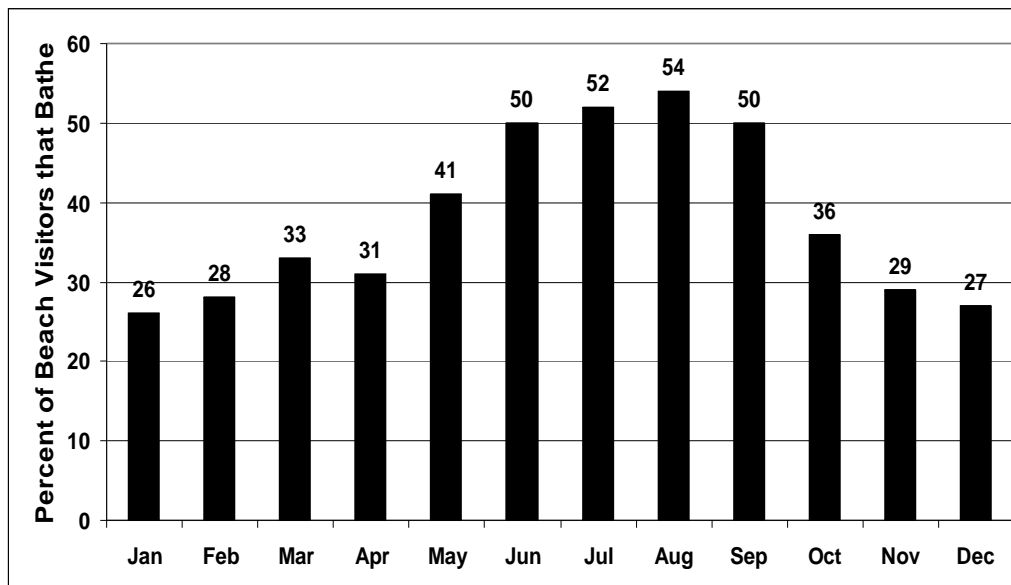


Figure 1.3 Fraction of Beach Visitors that Bathe (Actual Water Contract) by Month for Southern California Beaches, 2001-2004. (adapted from Dwight *et al.* 2007)

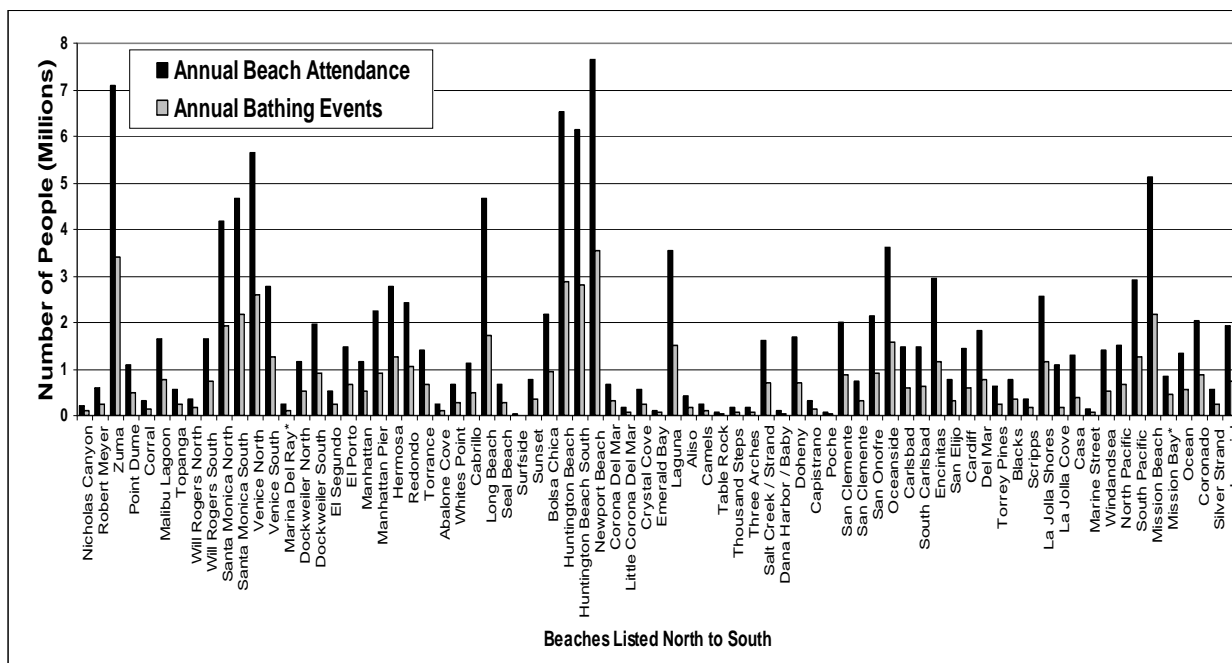


Figure 1.4 Distribution of Annual Beach Attendance and Bathing Events at Southern California Beaches, 2000 – 2004. (adapted from Dwight *et al.* 2007)

Chapter 2

HEALTH RISK OF BATHING IN SOUTHERN CALIFORNIA COASTAL WATERS

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Abstract

Urbanized areas often discharge large volumes of contaminated waste into coastal waters, placing bathers at nearby beach areas at risk. This investigation estimated the number of gastrointestinal and respiratory episodes among bathers at Southern California beaches with a simulation model that utilized water quality, beach attendance, and bathing rate data, along with three published concentration-response relationships. An estimated 689,000 to 4,003,000 episodes of gastrointestinal illness and 693,000 episodes of respiratory illness occurred each year. The majority of illnesses (57% – 80%) occurred during the summer season due to large seasonal increases in bathing populations. As 71% of gastroenteritis episodes were estimated to occur when the water quality was considered safe for bathing, California's marine water contact standards may be inadequate to protect the health of these bathers.

Introduction

Coastal water contamination in Southern California may be responsible for a considerable disease burden. The 350 kilometer coastline from Los Angeles to San Diego is a popular recreational destination for the region's 16 million residents as well as national and international tourists. Each year, over 100 million visitors arrive at these beaches and participate in recreational activities such as swimming, surfing, and diving.^{1,2} Contamination in Southern California coastal waters may threaten the health of these bathers. Fecal contamination levels at these beaches frequently exceed regulatory standards and force public health officials to issue hundreds of advisories against bathing every year.³ Even when regulatory standards are not exceeded, chronic low level water contamination is common throughout the region. The significant health risk that may result from these coastal water contamination problems deserves further investigation, especially in light of the large populations at risk in Southern California.

The two primary sources of coastal water contamination in Southern California are urban runoff and treated domestic sewage. The dense pattern of roadways, parking lots, and buildings associated with Southern California's heavy urbanization accelerates the transit of large volumes of surface runoff to coastal discharge sites.^{4,5,6} This urban runoff can carry a wide variety of microbial contaminants, and bathers near runoff discharge sites experience increased rates of gastrointestinal, respiratory, eye, ear, and skin illnesses.^{7,8,9} The large populations in these urbanized areas also generate an enormous volume of domestic sewage (over one billion gallons/day), which is discharged along this coastline. Although sanitation agencies treat much of this waste to

remove pathogens, significant levels of pathogenic bacteria, viruses, and protozoa survive treatment and are released into the coastal environment.^{10,11}

To protect bathers from the health risk posed by water contamination, California adopted new water quality standards in 1998 based on guidelines provided by the U.S. Environmental Protection Agency (EPA).^{12,13} The EPA guidelines were derived from prospective cohort studies conducted in the U.S. from 1973 to 1977 by Cabelli *et al.* in which bathers and nonbathers at beaches with varying water quality were monitored for illness following their beach visit.¹⁴ Cabelli *et al.* reported a significant relationship between enterococcus levels in coastal waters and the risk of gastroenteritis for bathers, which estimates that California's maximum acceptable risk of gastroenteritis (1.9%) will be reached at an enterococcus level of 35 colony-forming units (cfu)/100 ml.¹³

Another landmark study on the health risk of bathing was conducted in the U.K. from 1989 to 1992 by Kay *et al.*¹⁵ The Kay *et al.* investigation reported significant relationships between fecal streptococcus levels and the risk of both gastroenteritis and acute febrile respiratory illness (AFRI).¹⁶ These relationships now provide the foundation for water quality guidelines from the World Health Organization (WHO) and European Union (EU).^{17,18}

The findings of Cabelli *et al.*, Kay *et al.*, and many other epidemiological investigations^{19,20,21,22} demonstrate that coastal water contamination can result in a significant health risk to bathers. The magnitude of this health risk in Southern California is suggested by investigations conducted by Turbow *et al.*, who estimated that over 37,000 annual episodes of gastroenteritis occurred at two of the region's beaches, and by Given *et al.* who estimated that 630,000 to 1.48 million annual episodes of gastroenteritis occurred at 29 of the region's beaches in 2000.^{23,24} The current study expands beyond previous investigations to estimate the disease burden for the entire Southern California region over five years of varying weather and water quality conditions. The current study also includes estimates for one of the non-gastrointestinal illnesses associated with water contamination and utilizes direct observations of bathing populations to estimate exposure rates.

Methods

This study examined the health risk of bathing at the 67 beaches along the 350 kilometer coastline of Southern California from January 2000 through December 2004. More than 16 million people live within the 9,082 square miles of the three counties (Los Angeles, Orange, and San Diego) that form the study region.

Study Population

Beach attendance data from January 2000 through December 2004 were collected from records at lifeguard agencies (76%), parks departments (16%), and environmental health departments (8%). 122,409 daily beach attendance values were utilized in the analysis. Attendance at coastal piers, parks, and boardwalks was excluded from this

analysis because visitors to these areas may be unlikely to enter the water. The use of daily observations to determine beach attendance captures the effects of rainfall, temperature, and other important influences on this model input.

Monthly average bathing rates were derived from long-term data sets recorded independently at Del Mar and Oceanside beaches in San Diego County (lifeguards at these beaches estimated beach attendance and the number of people entering the water (bathers) daily). These bathing rates were utilized when estimating the number of bathing events at all of the study beaches.

The utilization of these bathing rates for all of the study beaches is supported by the many shared characteristics of these beaches, including their similar seasonal patterns of attendance, their open sandy geography, their close proximity to vehicular and pedestrian access sites, and the similar climatic patterns and coastal water temperatures across these three contiguous coastal counties.

The number of daily bathing events at each beach was estimated by multiplying each daily beach attendance value by the corresponding monthly bathing rate. The number of bathing events does not necessarily represent the total number of individuals who bathe, as visitors may make multiple trips to the beach (and bathe) each year. Therefore, this analysis assumed that the probability of illness associated with any single bathing event was independent of other bathing events. Detailed descriptions of the methods used to determine beach attendance, bathing rate, and bathing event data are available elsewhere.²⁵

Water Quality

Water quality data (enterococcus levels) were compiled by the various monitoring agencies in the region. This study made use of 56,215 reported enterococcus level measurements from 187 monitoring stations to interpolate daily enterococcus levels.. Enterococcus monitoring was conducted weekly for 70% of monitoring values used in the analysis and more frequently (variably from three to seven times per week) for the remainder of monitoring values. When water quality data were reported as being above or below a detection limit, the detection limit value was used for analysis. When water quality data were unavailable, values for missing data of less than seven sequential days were estimated using cubic spline interpolation (73 % of values), Interpolation using the cubic spline method was preferred for this analysis because the prediction error can be made small even when using low degree polynomials.²⁶ The arithmetic mean also tends to give unbiased results and has been recommended for use in this setting, but the cubic spline method was used here as it is a more precise interpolation method.²⁷ Values for missing data of seven or more sequential days were estimated via regression using data from the nearest monitoring station where the data available at the station with known data and the station with missing data had a coefficient of determination greater than 0.6 (R^2) (9 % of values). Our analysis of these imputations methods did not suggest that they were likely to introduce bias.

The enterococcus value measured at each monitoring site was assumed to represent the mean enterococcus exposure level for bathers at the beach area adjacent to that site. When multiple monitoring sites were located at a beach, the bathers at that beach were assumed to be evenly distributed among the monitoring sites. This per-monitoring station unit of analysis permits a high-resolution analysis of exposure.

Health Risk

Multi-year data sets of water quality, beach attendance, and bathing rates were integrated into a simulation model along with published concentration-response relationships between enterococcus levels and gastroenteritis and AFRI rates. For each day of the study, each concentration-response relationship was applied to the enterococcus level at each of the 185 water quality monitoring stations to estimate the risk of illness at the beach area adjacent to that station. The number of bathers at each beach area was then multiplied by the risk of illness to yield the estimated number of illnesses at each beach area for each day of the study.

The seasonal distribution of illnesses was evaluated using summer (May - Oct.) and winter (Nov. - Apr.) seasonal divisions, which were based on historical precipitation patterns. The geographic distribution of illnesses was evaluated for using beach areas designated by current jurisdictional boundaries. The term enterococcus was substituted for the term fecal streptococcus for the purposes of this study in accordance with WHO practices.¹⁷ The use of the general term “gastroenteritis” is supported by the similar definitions for this term used in the Cabelli *et al.* relationship (defined as any episode of vomiting or disabling diarrhea or any episode of either a stomachache or nausea accompanied by a fever) and in the Kay *et al.* relationship (defined as any episode of vomiting or diarrhea (defined as three or more bowel movements per day) or any episode of either indigestion or nausea accompanied by a fever).^{14,15} AFRI was defined as a febrile illness accompanied by a headache, body aches, unusual fatigue, or anorexia and either a sore throat, runny nose, or cough.¹⁶

The excess risk of gastroenteritis was estimated using the formula from Cabelli *et al.*: episodes of gastroenteritis per 1000 bathers = $12.2 \log(m) + 0.2$ where m is the mean enterococcus density/100 ml seawater (Figure 2.1).¹⁴ The Kay *et al.* relationship describes the log_n odds of acquiring gastroenteritis (b) as $b = 0.20102(c - 32)^{1/2} - 2.3561$, where c is the fecal streptococcus density/100 ml of seawater to which an individual is exposed.^{15,27} The excess probability of gastroenteritis (p) for that individual is then calculated by the formula $p = (1 / (1 + \exp(-b))) - 0.0866$ (Figure 2.1). Following Kay *et al.*, the relationship between risk of gastroenteritis and the individual level of exposure was capped at the risk level that was obtained at the highest level of exposure observed in the original investigation (158 cfu/100 ml).¹⁵ In accordance with WHO guidelines and Kay *et al.*, the corresponding relationship specified risk of gastroenteritis, taking into account a lognormal probability density function (PDF) for (highly variable) levels of individual bather exposure around a given measured enterococcus value.^{17,28} This risk adjustment yields nonzero risks of gastroenteritis given a fecal streptococcus level below the 32 cfu/100ml (the lowest level at which the original Kay *et al.* study reported increased risk of gastroenteritis). In accordance with WHO guidelines, a 0.813 standard deviation for enterococcus levels was used with the PDF (which was derived at European bathing beaches). The AFRI relationship, which describes the risk of AFRI based on enterococcus levels, was estimated based on 97 concentration-response pairs from Figure 1 in Fleisher *et al.* (Figure 2.1).¹⁶

Due to data limitations, specifically the availability of only a single monitoring value at a beach area per day, our analysis was restricted to the use of single samples within the concentration-response relationship, which, while an unbiased minimum

variance estimate, may introduce significant sampling error and is likely to overestimate the risks to bathers. This lack of multiple samples for each sampling location and day imposes this limitation, which highlights the potential benefit of more comprehensive water quality monitoring for estimates of health risks.

Beach closure and advisory data were considered when estimating the number of exposures at each beach and for each day. To capture the expected reduction in bathing events in response to these measures, no bathers were assumed to have entered the water during beach closures and water contamination advisories. When only a section of a beach was affected by a closure or advisory, bathing populations were reduced proportionate to the length of beach affected. Beach closure and advisory data were compiled by health agencies in each county.

Results

Study Population

Southern California beaches attracted an average of 129 million visits during each year of the study. Most of these visits (76%) occurred during the summer. Nearly half of all visits (48%) occurred on weekends and large peaks in attendance were frequently observed during holidays. More than half (51%) of the total beach attendance occurred at just 15 of the 67 study beaches. The mean percentage of beach visitors that entered the water ranged from a low of 26% in January to a high of 54% in August, with gradual transitional periods in the spring and fall.

An average of 56 million annual bathing events (when beach visitors were exposed to coastal water) occurred during each year of the study. Approximately 84% of all bathing events occurred during the summer, and 45% of all bathing events occurred at 15 highly attended beaches.

Water Quality

Enterococcus levels often peaked across large groups of beaches after rainfall events. Twenty one percent of coastal water enterococcus monitoring levels exceeded California's 35 cfu/100 ml marine water contact standard during the study (Table 2.1), and 11 % of monitoring values exceeded the 104 cfu/100 ml single sample standard (which is a 75% confidence interval around the 35 cfu/100 ml standard). The California water quality standard (35 cfu/100 ml) was exceeded during an average of 34% of winter days and 14% of summer days. Enterococcus levels during the winter (mean = 170 cfu/100 ml) were more than three-fold higher on average, than during the summer (mean = 47 cfu/100 ml).

Health Risk

Application of the Cabelli *et al.* (C) and Kay *et al.* (K) relationships yielded estimates of 689,000 (C) and 4,003,000 (K) mean annual episodes of gastroenteritis (Table 2.2). Figure 2.2 graphically depicts how the seasonal variation in contamination levels and daily illness counts demonstrated opposing cyclical patterns, with contamination levels peaking during the winter and daily illness rates peaking during the summer. Summer accounted for over three fourths (80% (C) and 76% (K)) of

gastroenteritis episodes, due to large seasonal increases in bathing populations. The summer season's dominant contribution to disease burden totals was evident through all the years of the study and at all of the study beaches. In spite of fluctuations in mean annual contamination levels, the annual number of gastroenteritis episodes varied little from year to year (mean = 689,000; range = 652,000 to 719,000; std. dev. = 26,000 (C) and mean = 4,003,000; range = 3,736,000 to 4,274,000; std. dev. = 232,000 (K)). The stability in the total annual number of illnesses was due to the large proportion of illnesses that occur the summer, when consistently dry weather and low levels of coastal water contamination are found in the region. Most of the estimated number of gastroenteritis episodes (71% (C) and 61% (K)) occurred when water quality met California's 35 cfu/100 ml enterococcus standard (Table 2.2).

The estimated mean annual risk of gastroenteritis was 1.26% (C) and 7.30% (K) (Table 2.2). The risk of gastroenteritis was higher during the winter (1.55% (C) and 10.62% (K)) than during the summer (1.19% (C) and 6.65% (K)). Gastroenteritis risk levels at individual beaches ranged from 0.53% to 2.34% (C) (Figure 2.3) and from 2.32% to 19.39% (K). The 1.9% maximum acceptable risk guideline for gastroenteritis in California was exceeded by 21% (C) and 76% (K) of water quality values.

Approximately one half of the estimated gastroenteritis disease burden (52% (C) and 50% (K)) occurred at the 12 most highly attended beaches. Many highly attended beaches are located in heavily populated Los Angeles County, and this county and three neighboring beaches in northern Orange County (Huntington city and state beaches and Newport city beach) contributed approximately 60% (61% (C) and 60% (K)) of all

gastroenteritis episodes (Figure 2.3). The estimated annual number of gastroenteritis episodes at individual beaches ranged from 140 episodes to 46,200 episodes (C) and 634 episodes to 265,800 episodes (K).

Application of the AFRI relationship yielded an estimate of 693,000 mean annual episodes of AFRI (range= 631,000 to 776,000; std. dev. = 55,000) (Table 2.2). The summer peaks in the number AFRI episodes (57% of AFRI episodes) were attenuated relative to the summer peaks in the number of gastroenteritis episodes. The attenuation of AFRI peaks was due to the higher minimum threshold for increased risk in the AFRI relationship (60 cfu/100 ml), which was exceeded less frequently by lower summer contamination levels. The estimated mean annual AFRI risk level was 1.26% (0.86% in the summer and 3.32% in the winter). Twelve highly attended beaches (predominantly in Los Angeles County) accounted for 50% of AFRI episodes. The estimated annual number of AFRI episodes at individual beaches ranged from 34 to 82,200 episodes.

Discussion

Coastal water contamination in Southern California represents a considerable public health risk. The five years of water quality data analyzed demonstrate both persistent low level contamination and recurring peaks in contamination levels, each of which pose a significant health risk to bathers. The magnitude and distribution of these health risks are driven primarily by the size of bathing populations at these beaches, where 56 million visitors recreate in coastal waters every year. The predominant influence of the size of bathing populations on the seasonal distribution of these health risks is demonstrated by the large peaks in daily illness rates during the summer, when

large numbers of visitors arrive at these beaches to swim, dive, and surf in coastal waters. The summer peaks in daily illness rates occur in spite of the much higher contamination levels (and associated risk) that occur during the winter, when increased rainfall flushes contaminated urban runoff into these coastal waters.^{5,6} Furthermore, the disease burden associated with water contamination accumulates rapidly at beaches with large bathing populations, even when these beaches are characterized by relatively low levels of contamination. In fact, 12 highly attended beaches account for half of the region's total disease burden from coastal water contamination.

The large gastroenteritis and AFRI disease burdens estimated in this analysis raise questions about the effectiveness of California public health policy regarding recreational coastal waters. Of concern is the high acceptable risk level for gastroenteritis (1.9%, or 35 cfu/100ml enterococcus) in current guidelines. A meta-analysis by Wade *et al.* concluded that support for the current guideline could be derived from their finding that health risk studies with indicator densities below the current guideline were associated with lower risk of gastrointestinal illness than studies with indicator densities above this guideline.²² However, this meta-analysis also reported elevated risk of gastrointestinal illness in the studies with indicator densities below the current guideline (relative risk = 1.36), which is consistent with the conclusion of this analysis; that in settings of very high numbers of exposed bathers, even low levels of risk accumulate into a large disease burden.

The 1.9% gastroenteritis risk level was provided by the EPA with the expectation that local health officials would lower this level to further reduce health risk at their beaches.^{13, 29} This risk level has been reduced elsewhere (e.g. the state of Hawaii, where

the maximum acceptable risk level is 1.05% (or 7 cfu/100ml enterococcus)). California has not enacted policies to lower this risk level and this analysis estimates that as a result, 500,000 (C) to 2.4 million (K) bathers experience gastroenteritis each year from exposure to coastal waters that are defined as safe by current standards (Table 2.2).

More stringent acceptable risk guidelines would have little impact on health risk without an accompanying reduction in coastal water contamination levels. The high rate of water quality violations in Southern California (14,200/year) did not decrease during the five years of the study, which suggests that current efforts to reduce these contamination levels have not been successful. California's efforts to mitigate water pollution have often been focused on chronically contaminated beaches that pose the highest risk to individual bathers (e.g. Doheny: mean annual risk = 3% (C), gastroenteritis episodes =13,000 annually (C)). However, it is important to recognize that the majority of this region's water contamination related illnesses originate from highly attended beaches that generally have low levels of contamination (e.g. Zuma: risk = 1.3%, gastroenteritis episodes = 45,000 annually (C)). Thus, reducing contamination to very low levels at highly attended beaches will have the greatest impact on the regional disease burden.

The accuracy and validity of the data for beach attendance, bathing rate, and water quality are critical to the reliability of these health risk estimates. This analysis utilized the most comprehensive compilation of beach attendance data for this region to date. The methods used to determine beach attendance in this region yield estimates that have been found to be within 10% of true attendance values.³⁰ The bathing rate data used in this analysis were the first to be derived from direct observation of the bathing activity

of beach visitors in this region. The validity of these bathing rates is supported by the strong correlation ($p < 0.01$) between the two sources for these data as well as their agreement with the bathing rate in California that was determined by the National Oceanic and Atmospheric Administration (NOAA) (annual mean of current study = 43% vs. NOAA annual mean = 47%).² Water quality data were based on standardized techniques and was analyzed over an unprecedented five years of data. However, water quality monitoring at the beaches in this region is frequently conducted at less than daily intervals. This limited schedule of water quality monitoring may mask significant health risks, given the large bathing populations at risk and the demonstrated inability of low frequency monitoring to identify hazardous peaks of water contamination levels.³¹ In spite of these limitations, the conclusions of this analysis are similar to the conclusions of other investigations into the health risk of bathing in Southern California.^{23,24}

Direct corroboration of this study's health risk estimates is limited because of the lack of formalized surveillance programs for these illnesses. However, the conclusions of our analysis are supported by the significant risks of gastroenteritis associated with bathing that were reported in the three major epidemiologic investigations conducted California coastal waters (and respiratory illness in two of these three studies).^{8,9,32} Analysis of data from an internet based self-reporting program in California also found seasonal distribution patterns of illnesses that were very similar to those found in this analysis, with peaks in illness counts occurring during the summer months, especially at high attendance beach areas.³³

The differing relationships reported by Cabelli *et al.* and the Kay *et al.* (and consequently the differing estimates for health risk in this analysis) are generally

attributed to differences in their study design. The randomization of the Kay *et al.* study, and this study's precise monitoring of exposure levels for individual bathers have been described in scientific reviews of these investigations as key influences leading to these differences.^{20, 34, 35} The established epidemiologic strengths of randomized study design lend support to the relationship reported from Kay *et al.* investigation. Many scientists and regulatory bodies (including the WHO, the EU, and many other national health agencies) have noted these strengths and concluded that the Kay *et al.* relationship represents the strongest foundation upon which to base water quality guidelines.^{17,18,36,37} However, the Cabelli *et al.* study underlie current water quality guidelines in California and throughout much of the United States, and thus remains an important measure of health risk in this setting

The conservative methods used in this analysis may have led to a significant underestimation of the true disease burden. For example, in this study's application of the Kay *et al.* relationship, the enterococcus exposure level was "capped" at 158 cfu/100 ml (the highest enterococcus level observed in the original investigation).¹⁵ Therefore, no additional risk was assumed beyond the risk at the 158cfu/100 ml level from the 28,390 water quality samples that exceeded this level during the study (linear extrapolation of the Kay *et al.* relationship beyond this level would have increased the estimated annual number of gastroenteritis episodes by 47%). In addition, the restrictive definitions of gastroenteritis and AFRI used in these concentration-response relationships exclude many other illnesses associated with water contamination, including other forms of gastrointestinal and respiratory illness, diseases of the eyes, ears, and skin, and often fatal central nervous system and systemic infections.^{16,38} Moreover, the current study did not

consider the elevated risk of gastroenteritis for children (odds ratio of 1.85 relative to adult bathers), who comprise approximately half of the visitors to Southern California beaches.^{29,38} The estimates reported here also exclude the health risk at the numerous bathing beaches inside coastal bays and harbors in the region, which may be considerable given that limited summer data at a subset of these beaches yielded annual estimates of 7,800 (C) to 43,100 (K) episodes of gastroenteritis and 6,000 episodes of AFRI.

The primary limitation to the interpretation of these results stems from the fact that the three concentration-response relationships used in this analysis were derived from studies conducted in sewage-contaminated waters,^{14,15,16} whereas urban runoff is the primary source of water contamination in Southern California.^{5,6} The applicability of these relationships in this setting is supported by two points. First, the coastal waters of Southern California are impacted by sewage in offshore discharges, river discharges, and urban runoff. Urban runoff in this region often carries significant volumes of untreated sewage from leaking pipeline infrastructure, illegal discharges, and other sources of waste. The result is that many beaches in Southern California regularly experience water contamination levels that are much higher than those measured in the original Cabelli *et al.* and Kay *et al.* studies. Second, two meta-analyses and two systematic reviews of the epidemiologic evidence from recreational marine water studies conducted under a wide range of contamination sources concur that enterococcus levels consistently demonstrate a significant relationship with the risk of gastroenteritis for bathers.^{19,20,21,22}

In summary, coastal water contamination in Southern California is associated with a considerable health risk regardless of the concentration-response relationship used for analysis. The large number of illnesses that occur when bathers recreate in coastal

waters with “acceptable” contamination levels raise significant concerns about current water quality standards. Highly attended beaches deserve a greater emphasis in future pollution remediation efforts as these beaches account for the majority of contamination related illnesses. By quantifying the scale and distribution of health risk in this important coastal region, this study may provide a greater understanding of the important public health issue of recreational water quality, both nationally and internationally.

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Tables

Table 2.1 The number and percentage of coastal water quality monitoring values associated with a risk of illness greater than 1.9%*, using three concentration-response relationships, Southern California, 2000 - 2004.

<u>Period</u>	<u>Concentration - response relationships</u>		
	Gastroenteritis (Cabelli <i>et al.</i>)	Gastroenteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness
Annual (%)	14,204 (21)	51,912 (76)	10,003 (15)
Summer (%)	4,449 (12)	25,273 (74)	2,430 (7)
Winter (%)	10,157 (30)	26,638(78)	7,573 (22)

* California water quality standards define 1.9% as the maximum acceptable risk of gastroenteritis for bathers

Table 2.2 Number of illness episodes and disease incidence among bathers exposed to coastal water contamination, using three concentration-response relationships, Southern California, 2000 – 2004.

	<u>Concentration - response relationships</u>		
	Gastroenteritis (Cabelli <i>et al.</i>)	Gastroenteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness
<u>Episodes of illness</u>			
Annual	689,000	4,003,000	693,000
Summer (%)	551,000 (80)	3,060,000 (76)	398,000 (57)
Winter (%)	138,000 (20)	943,000 (24)	295,000 (43)
Annual, when enterococcus level < 35cfu/100ml (%)*	491,000 (71)	2,434,000 (61)	0 (0)
<u>Disease incidence[†]</u>			
Annual	1.26%	7.30%	1.26%
Summer	1.19%	6.65%	0.86%
Winter	1.55%	10.62%	3.32%

* California marine water contact standards define coastal water enterococcus levels under 35 colony forming units (cfu)/100 ml as associated with an acceptable risk of gastroenteritis for bathers.

[†]Disease incidence is expressed as the estimated percentage of bathers who become ill.

Table 2.3 (Parts A, B, and C); Estimated annual number of illness episodes and disease incidence*, using three concentration – response relationships, for bathers exposed to coastal water contamination at individual beaches in Southern California, 2000 - 2004.

Part A)

	<u>Mean annual number of illness episodes</u>			<u>Mean annual disease incidence</u>		
	<u>Gastro-enteritis (Cabelli <i>et al.</i>)</u>	<u>Gastro-enteritis (Kay <i>et al.</i>)</u>	<u>Acute Febrile Respiratory Illness</u>	<u>Gastro-enteritis (Cabelli <i>et al.</i>)</u>	<u>Gastro-enteritis (Kay <i>et al.</i>)</u>	<u>Acute Febrile Respiratory Illness</u>
Los Angeles County beaches						
Nicholas/Robert Meyer	4,627	25,532	2,971	1.42	7.84	0.91
Zuma	45,336	229,400	7,486	1.32	6.72	0.21
Point Dume	9,193	64,745	17,826	1.82	12.88	3.54
Corral	1,963	11,400	1,345	1.49	8.65	1.02
Malibu	11,648	77,766	20,139	1.54	10.31	2.67
Topanga	2,742	16,872	3,648	1.11	6.87	1.48
North Will Rogers	2,677	17,734	3,489	1.71	11.38	2.24
South Will Rogers	13,154	96,746	30,761	1.79	13.21	4.20
North Santa Monica	32,138	210,800	41,188	1.69	11.15	2.17
South Santa Monica	21,128	117,121	15,369	0.99	5.52	0.72
North Venice	28,584	151,067	13,667	1.10	5.86	0.53
South Venice	20,235	127,936	24,240	1.62	10.27	1.94
North Dockweiler	6,788	39,870	6,369	1.35	7.96	1.27
South Dockweiler	9,874	54,930	7,905	1.12	6.24	0.89
El Segundo	13,516	79,591	13,499	1.53	9.02	1.53
Manhattan County	8,025	48,234	10,966	1.50	9.07	2.06
Manhattan Pier	5,119	28,049	4,535	0.57	3.13	0.50
Hermosa	14,816	80,875	8,958	1.17	6.42	0.71
Redondo	13,369	79,989	11,081	1.27	7.64	1.05
Torrance	4,826	22,623	947	0.74	3.49	0.14
Whites Point	3,437	21,494	4,279	1.27	7.98	1.58
Cabrillo	4,825	25,768	2,492	1.00	5.34	0.51
Long	27,293	159,065	18,457	1.50	8.77	1.01
Los Angeles County total	305,314	1,787,606	271,618	1.31	7.67	1.16

Part B)

	<u>Mean annual number of illness episodes</u>			<u>Mean annual disease incidence</u>		
	Gastroenteritis (Cabelli <i>et al.</i>)	Gastroenteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness	Gastro- enteritis (Cabelli <i>et al.</i>)	Gastro- enteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness
Orange County beaches						
Seal	4,064	24,830	4,523	1.48	9.09	1.65
Surfside	131	634	34	1.15	5.55	0.30
Sunset	3,905	18,022	177	1.10	5.07	0.05
Bolsa Chica	9,254	49,023	6,658	1.01	5.36	0.72
Huntington City	34,537	201,200	30,467	1.19	6.98	1.05
Huntington State	39,693	265,800	82,209	1.42	9.54	2.95
Newport	31,306	150,740	15,953	0.88	4.25	0.45
Corona Del Mar	3,264	17,112	2,098	1.03	5.43	0.66
Little Corona	1,074	6,063	760	1.36	7.69	0.96
Crystal Cove	2,497	12,330	1,012	1.08	5.36	0.44
Emerald Bay	613	2,965	137	1.12	5.44	0.25
Laguna	15,159	80,813	13,758	1.01	5.39	0.91
Aliso	2,877	14,637	1,943	0.96	4.89	0.65
Table Rock	186	775	70	0.67	2.82	0.25
Thousand Steps	1,153	5,076	515	0.69	3.08	0.31
Dana Point	9,904	63,581	15,793	1.41	9.05	2.25
Doheny	12,680	95,189	33,666	2.04	15.37	5.43
Capistrano	2,432	15,613	3,158	1.63	10.49	2.12
Poche	796	6,613	3,113	2.34	19.49	9.17
San Clemente City	12,930	77,984	14,988	1.47	8.91	1.71
San Clemente						
State	3,193	15,102	1,337	1.00	4.77	0.42
Orange County total	191,649	1,124,102	232,371	1.18	6.97	1.44

Part C)

	<u>Mean annual number of illness episodes</u>			<u>Mean annual disease incidence</u>		
	Gastro- enteritis (Cabelli <i>et al.</i>)	Gastro- enteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness	Gastro- enteritis (Cabelli <i>et al.</i>)	Gastro- enteritis (Kay <i>et al.</i>)	Acute Febrile Respiratory Illness
San Diego County beaches						
San Onofre	10,047	57,211	9,501	1.10	6.31	1.04
Oceanside	23,030	135,406	19,857	1.46	8.58	1.25
Carlsbad	7,421	46,312	11,763	1.25	7.84	1.99
South Carlsbad	7,676	42,037	6,710	1.21	6.67	1.06
Encinitas	14,674	88,189	23,339	1.26	7.61	2.01
San Elijo	5,411	36,807	7,689	1.72	11.71	2.44
Cardiff State	7,650	47,679	10,511	1.46	9.12	2.01
Del Mar	9,718	55,838	8,734	1.31	7.57	1.18
Torrey Pines	4,675	32,696	7,711	1.89	13.22	3.11
Blacks	1,840	9,846	1,869	0.54	2.91	0.55
Scripps	892	3,882	194	0.53	2.32	0.11
La Jolla Shores	12,875	61,983	7,595	1.11	5.35	0.65
La Jolla Cove	2,283	12,040	2,202	1.22	6.45	1.18
Casa/Children's	2,379	13,404	3,399	0.76	4.33	1.09
Marine	916	4,882	245	1.19	6.36	0.31
Windansea	1,380	6,299	361	0.70	3.23	0.18
North Pacific	11,254	73,483	12,808	1.72	11.26	1.96
South Pacific	13,694	76,592	14,278	1.09	6.14	1.14
Mission	27,559	147,643	22,593	1.29	6.92	1.05
Ocean	6,774	35,988	5,884	1.21	6.44	1.05
Coronado	9,739	50,136	5,074	1.16	5.98	0.60
Silver Strand	1,722	7,406	761	0.71	3.08	0.31
Imperial	8,408	45,297	5,554	1.20	6.47	0.79
San Diego County total	192,017	1,091,057	188,633	1.24	7.04	1.21
Southern California total	688,980	4,002,765	692,622	1.26	7.30	1.26

* Disease incidence is expressed as the estimated percentage of bathers who become ill.

Figures

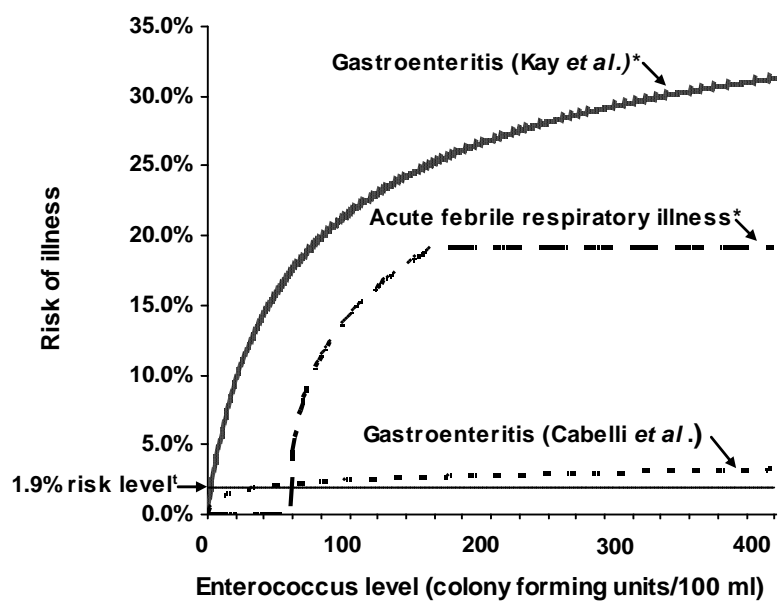


Figure 2.1 Risk of illness among bathers as a function of coastal water enterococcus levels, from three concentration-response relationships.

* Exposure levels for the Kay *et al.* gastroenteritis risk curve and the acute febrile respiratory illness risk curve were capped at 158 enterococcus colony forming units/100 ml.

† California's marine water contact standards designate 1.9% (solid line) as the maximum acceptable risk of gastroenteritis among bathers.

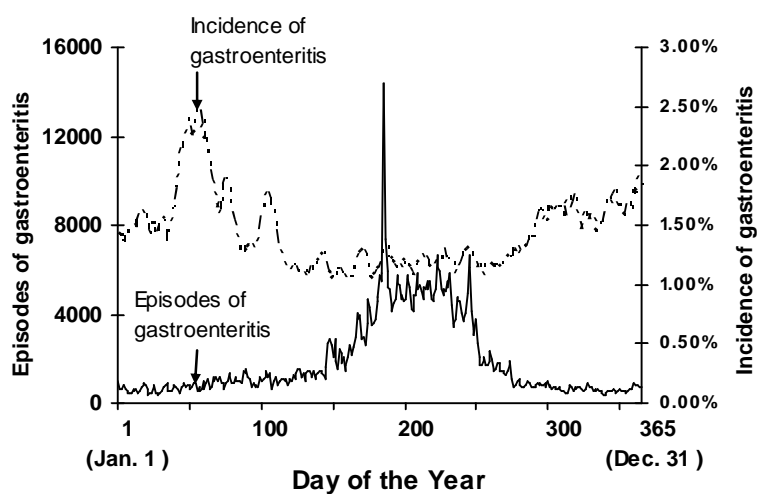


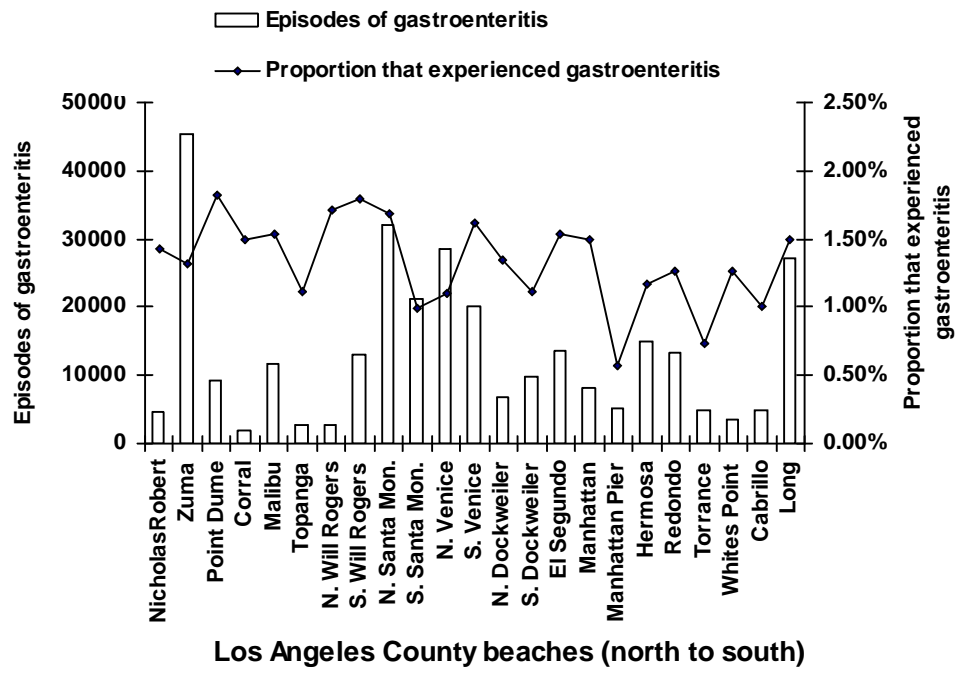
Figure 2.2 Estimated mean daily number of episodes (solid line) and mean daily incidence* (dotted line) of gastroenteritis among bathers exposed to coastal water contamination in Southern California, 2000 – 2004.[†]

* Disease incidence is expressed as the estimated percentage of bathers who become ill.

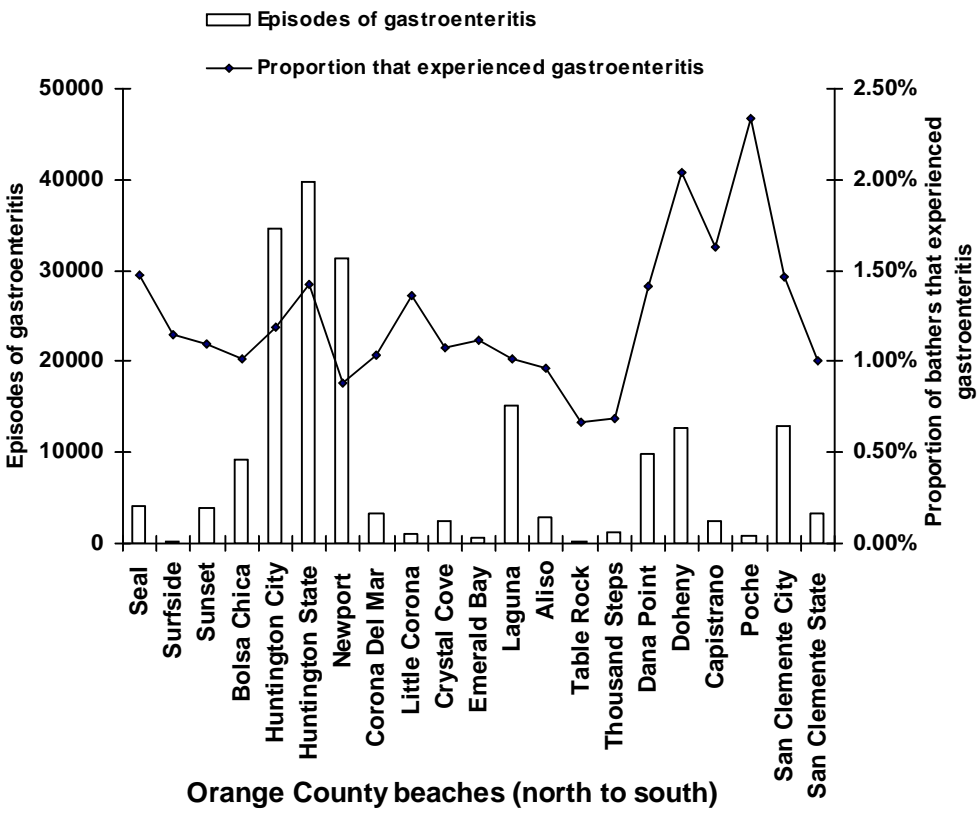
[†] The values in this figure were determined using the relationship between enterococcus levels and the risk of gastroenteritis from Cabelli *et al.* (1982).

Footnote; The peak in incidence of gastroenteritis around day number 180 was due to high beach attendance and bathing rates during the Fourth of July weekend.

Part A)



Part B)



Part C)

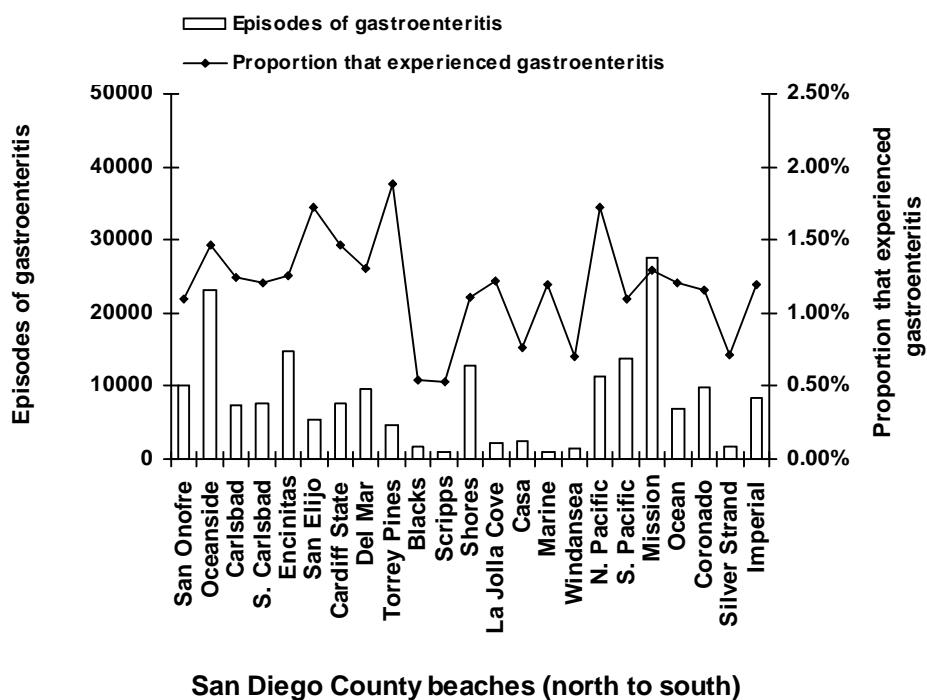


Figure 2.3 Estimated mean annual number of episodes of gastroenteritis and mean annual incidence* of gastroenteritis at individual beaches in Southern California, 2000 – 2004 (Parts A, B, and C).[†]

* Disease incidence is expressed as the estimated percentage of bathers who become ill.

[†] The values in this figure were determined using the relationship between enterococcus levels and the risk of gastroenteritis from Cabelli *et al.* (1982).

Appendix to Health Risk of Bathing in Southern California Coastal Waters

Estimation of the Excess Likelihood of Gastroenteritis from Kay *et al*

We follow [Kay et al 2004] to derive the relationship between enterococcus sample values and risk. Within this section, we discuss the functional form and parameters for several components that jointly define this relationship.

Dose Response Relationship given Exposure Level

Following [Kay et al 2004], we assumed that, given exposure of an individual to a specific enterococcus concentration c , the excess likelihood $p(c)$ of gastroenteritis is given by:

$$p(c) = \begin{cases} \frac{1}{1 + e^{-b(c)}} - 0.0866 & c \geq 32 \\ 0 & \text{otherwise} \end{cases}$$

where $b(c)$ is the natural log of the odds of gastroenteritis at concentration c , defined as

$$b(c) = 0.20102\sqrt{c-32} - 2.3561 .$$

Thus, for $c \geq 32$

$$p(c) = \frac{1}{1 + e^{-(0.20102\sqrt{c-32} - 2.3561)}} - 0.0866$$

Probability Distribution in Exposure Concentration

Distribution

We assumed that individuals at a given sampling location and day are exposed to a wide range of enterococcus levels, where the likelihood density of exposure to enterococcus level c is lognormally distributed, with the log of c having mean m and standard deviation s :

$$y(c) = \frac{1}{s\sqrt{2\pi}} e^{-(\log_{10} c - m)^2 / 2s^2}$$

Distribution Parameters

For our distribution parameters, we assumed a constant value for s equal to that used by the World Health Organization guidelines on recreational bathing ($s=.8103$) [Kay et al 2004].

By contrast to the fixed value of s , we assumed a mean m of $\log_{10}c$ that varies daily for each sample location. Specifically, we made use of historical data that specified sample $m_i(t)$ for each sample location and day t . As described in the body of the paper,

some of these values were imputed. For a given day t , we assumed a value for m that was the log (base 10) of the measured sample $m_i(t)$ as; thus, $m = \log_{10} m_i(t)$. As a limitation of our approach, we note that while the log of a single sample is an unbiased minimum-variance estimate for the mean of the log transformed values, the use of a single-sample estimate of m does lead to high variance in this estimate due to sampling error. The high variance associated with the use of a single sample can significantly bias risk estimates in the direction of higher risk. While it would be preferable to use the geometric mean of many samples to estimate m , the dataset only had recorded at most a single sample point for each sample location and day.

Excess Likelihood of Gastroenteritis at Sampling Location

Given a mean m and standard deviation s of the \log_{10} transformed concentration c , we express the excess likelihood of contracting gastroenteritis through exposure at any exposure c within a range $[c_a, c_b]$ of concentration values c as $\phi(m, s)$ where

$$\phi(m, s) = \int_{\max(c_a, 32)}^{c_b} p(c) y(c) d \log_{10} c = \int_{\max(c_a, 32)}^{c_b} \left(\frac{1}{1 + e^{-(0.20102\sqrt{c-32}-2.3561)}} - 0.0866 \right) \left(\frac{1}{s\sqrt{2\pi}} e^{-(\log_{10} c - m)^2 / 2s^2} \right) d \log_{10} c$$

Transforming from a $\log_{10} c$ measure to a c measure, we obtain

$$\phi(m, s) = \int_{\max(c_a, 32)}^{c_b} \left(\frac{1}{1 + e^{-(0.20102\sqrt{c-32}-2.3561)}} - 0.0866 \right) \left(\frac{1}{\ln(10)cs\sqrt{2\pi}} e^{-(\log_{10} c - m)^2 / 2s^2} \right) dc$$

To estimate the entirety of the excess likelihood of gastroenteritis, we integrate the above over the range from $c_a=0$ to $c_b=+\infty$. Thus

$$\phi(m, s) = \int_{32}^{\infty} \left(\frac{1}{1 + e^{-(0.20102\sqrt{c-32}-2.3561)}} - 0.0866 \right) \left(\frac{1}{\ln(10)cs\sqrt{2\pi}} e^{-(\log_{10} c - m)^2 / 2s^2} \right) dc$$

The integration of $\phi(m, s)$ was carried out numerically for the fixed value of s specified above and for each integer value of $0 \leq m \leq 200$, for those m where $m \text{ MOD } 5 = 0$ for $200 \leq m \leq 1000$, and for those integers m where $m \text{ MOD } 1000 = 0$ for $1000 \leq m \leq 200,000$. For $m > 200,000$, the value of $\phi(m, s)$ was assumed to be the same as that obtaining at $m=200,000$. In between the risk estimates computed through numerically integration, the values of $\phi(m, s)$ were linearly interpolated.

Estimation of Number of Excess Cases of Illness

Given the definition for $\phi(m, s)$, we estimated the number of excess cases of illness from exposure on a given day t at a given sampling location i as the following:

$$g_i(t) = d_i(t) \phi(m_i(t), s)$$

Where

$d_i(t)$ is the number of bathers estimated to be bathing at sample location i on day t (derived below)

$m_i(t)$ is sample value for sample location i on day t .

s is an empirically estimated standard deviation of the \log_{10} sample values. As noted in the paper, lacking direct data to estimate this, we used the value .8103 adopted for the WHO guidelines for recreational waters.

Estimation of Number of Bathers per Sampling Location

$d_i(t)$ is defined as a product of the number of beachgoers for the beach in which sampling location i is found, and a coefficient giving the fraction of those beachgoers who are present at this sample location. Specifically,

$$d_i(t) = D_{B(i)}(t)\alpha_{B(i)}(i)$$

Where

$\alpha_b(i)$ is the fraction of beachgoers on beach b who are present at sampling location i . For the present paper, all sample locations within a given beach are assumed to include an equal fraction of the beach's population; that is,

$$\alpha_b(i) = \frac{1}{|\{l \in \text{SampleLocations} \mid B(l) = b\}|}$$

$D_b(t)$ is the number of bathers for beach b on day t .

$B(i)$ is a function mapping sample locations to beaches

Estimation of Number of Bathers per Beach

We further estimate the $D_b(t)$ (the daily number of bathers on beach b on day t) as the product of the historically recorded number of beachgoers for the beach on that day and coefficients expressing the fraction of beachgoers entering the water and the effect of beach closures.

$$D_b(t) = n_b(t)\gamma(M(t))\lambda_b(t)$$

Where

$n_b(t)$ is the number of beachgoers at beach b on day t , which is drawn from historical records.

$M(t)$ is a function mapping days to months.

$\gamma(m)$ is a function giving the estimated fraction of beachgoers who bathe during month m . The function is as follows:

January:	0.2559
February:	0.2797
March:	0.3287
April:	0.3077
May:	0.4144
June:	0.4976
July:	0.5218
August:	0.5438
September:	0.4996
October:	0.3562
November:	0.2928
December:	0.2657

$\lambda_b(t)$ is a coefficient giving the fraction of normal bathers who bathe on day t on beach b due to any closures or advisories in effect for that beach on that day. This coefficient was estimated from historical data on the spatial extent of closures & advisories.

Chapter 3

CONCLUSIONS

Conclusions

Several issues warrant expansion beyond the discussion in the preceding manuscript. For example, our ability to effectively assess the health risk of coastal water contamination suffers significant limitations due to commonly utilized approaches to health risk evaluation. In the United States, these health risks are generally considered in relation to the U.S. EPA water quality guidelines and their established 1.9% acceptable risk level (Ahn *et al.* 2005; EPA 1986; Noble *et al.* 2003; Schiff *et al.* 2003; Turbow *et al.* 2003; Wade *et al.* 2003). However, both the U.S. EPA water quality guidelines and the 1.9% acceptable risk level are based on rather arbitrary historical guidelines, which may undermine the validity of these reference points as foundations for health risk evaluations (Cabelli *et al.* 1979; Cabelli *et al.* 1983; EPA 1976; EPA 1986; EPA 2007). The U.S. EPA guidelines are based on investigations by Stevenson *et al.* regarding the health risk of bathing in the Ohio River, Lake Michigan, and the coastal waters of Long Island, conducted from 1948 to 1950 (Stevenson *et al.* 1953). From these investigations, Stevenson *et al.* reported an appreciable increase in illness among bathers at the lake and river study sites when total coliform levels exceeded 2400 cfu/100 ml (notably, no increased health risk was observed at the coastal bathing site).

Water quality guidelines developed in 1968 by the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Board, and adopted by the U.S. EPA in 1976, were based on the risk relationships observed by Stevenson *et al.*

(1953) (EPA 1976; NTAC 1968; Stevenson *et al.* 1953). However, in an effort to translate the Stevenson *et al.* health risk relationship to a more fecal-specific organism, federal regulators reevaluated water quality to compare the levels of total and fecal coliform bacteria in the Ohio River, eight years after the original study. The subsequent Ohio River investigation found that 18% of total coliforms in the Ohio River were fecal specific, so the NTAC concluded that a detectable increase in health risk could be expected at fecal coliform levels of 400 cfu/100 ml (NTAC 1968). An additional measure of safety was introduced by reducing the 400 cfu/100 ml level by half, to 200 cfu/100 ml. Thus, a 200 cfu/100 ml maximum acceptable fecal coliform contamination level was established in 1976 U.S. EPA water quality guidelines (EPA 1976).

The U.S. EPA revised recreational coastal water quality guidelines again in 1986, using the epidemiologic relationship from the Cabelli *et al.* (1982) investigation to determine acceptable risk levels for bathers (Cabelli *et al.* 1982; EPA 1986). In the development of updated guidelines, regulators estimated that the historical 200 cfu/100 ml fecal coliform guideline level would correspond to a 1.9% risk level of gastroenteritis for bathers. The U.S. EPA then established the 1.9% risk level as the central tenet to new guidelines, concluding that there was little other information to support an alteration of the established acceptable level of risk (EPA 1986) (Table 3.1). This guideline was established as a minimal guideline, with the expectation that local health officers would promulgate more restrictive standards based on the specific conditions at beaches under their supervision (Cabelli *et al.* 1983).

Both the historical nature of the current acceptable risk level and the conclusions of the preceding manuscript (that this risk level is too high and allows too large of a

health burden from coastal water contamination) indicate that the current acceptable risk level for gastroenteritis among bathers deserves reevaluation. Indeed, public health agencies in other states and countries have adopted water quality guidelines based on epidemiologic research that they consider superior to the relationship underlying current U.S. EPA guidelines (ANZ 2000; EP/CEU 2006; MNHW 1992; Salas 2000; WHO 2003).

Many public health agencies have also developed more complex guidelines, including guidelines which address influences on health risk in addition to coastal water contamination levels of enterococcus and total and fecal coliforms (ANZ 2000; EP/CEU 2006; MNHW 1992; State of Hawaii 2004; WHO 2003) (Table 3.2). A panel of U.S. EPA water quality experts recently concurred with this perspective and recommended a reevaluation of current U.S. EPA water quality guidelines (EPA 2007). This reevaluation is proposed to address both concerns about the current acceptable risk level and the use of environmental assessment paradigms to assess health risk.

The complex considerations intrinsic in a reevaluation of current water quality-related public health policy would benefit considerably from a broader assessment of the resulting regional health risk and the health burden that accumulates as a result of this health risk. The current state of scientific evidence is limited to measurements of bacterial contamination levels, intermittent estimates of the level of health risk in selected beach areas, and two estimates of the resulting health burden at selected beach areas over short time periods (Given *et al.* 2006; Haile *et al.* 1996; Noble *et al.* 2003; Schiff *et al.* 2003; Turbow *et al.* 2003). While these sources of scientific evidence are important, they cannot answer important questions about the public health effects of coastal water

pollution. A clear articulation of the many elements of this public health issue will be critical for effective discussions by scientific, governmental, and advocacy groups (EPA 2007). For example, broad regional and multi-year measures of the risk that bathers experience may be of significant importance to health risk discussions. Quantifying the regional cumulative health burden from coastal water contamination may clarify both the scientific and the social acceptability of the current level of health risk for the diverse participants anticipated to engage in future deliberations on this issue. The beach-specific risk levels and health burdens from water contamination will be of great interest to locally invested participants and will allow local residents, scientists, and health officials to interpret these findings in light of areas with which they are familiar. Beach areas and times deserving increased public health scrutiny may be indicated by estimating the geographic distribution of risk and quantifying the health risk during holiday weekends, during the popular summer season, and after rainfall events.

Immunologic Influences on Health Risk

Variability in individuals' susceptibility to illness may also exert important, but as yet difficult-to-quantify, effects on the health risk of bathing in coastal waters. The epidemiologic investigations underlying current water quality guidelines allowed only healthy adults to participate (Cabelli *et al.* 1982; Kay *et al.* 1994). However, beach visitors in Southern California are drawn from a general U.S. population base that may be much more susceptible to illnesses than were the subjects of the Cabelli *et al.* (1982) and Kay *et al.* (1994) investigations. Potential beach visitors in Southern California include susceptible subpopulations of children under 18 years old (22%) (U.S. Census Bureau

2000), the elderly (13%) (CDC 2003), pregnant mothers whose fetuses may be vulnerable to infection-related injury (2%) (Ventura *et al.* 2001), people with diabetes mellitus (6%) (U.S. Census Bureau 2000), people with severe cardiovascular disease (7 %) (AHA 2007), and people with immunosuppression due to a variety of etiologies including cancer, lung disease, and AIDS. Susceptible and immunosuppressed subpopulations are likely to experience higher rates of illness (Gerba *et al.* 1996; Wade *et al.* 2006), more severe illnesses (Gangarosa *et al.* 1992; Schmitz *et al.* 1983), and more opportunistic infections (Kovacs *et al.* 2000; Rusin *et al.* 1997; Schuster *et al.* 2004) than would a population of healthy adults. In fact, some have suggested that immunosuppressed individuals should be advised to avoid the potentially extensive exposure to pathogens associated with the full external body (and wound) exposure and potential ingestion exposure that characterizes recreational bathing.

While all relatively susceptible groups are likely to experience a higher risk of illness than that described in the risk level assumed by current water quality guidelines, children form the group of greatest public health concern (Haile *et al.* 1996). Children tend to spend more time in the water than adults and consequently tend to experience higher recreational water exposure levels than adults. The resulting higher exposure levels for children, in concert with their increased susceptibility to illness, results in a greater risk for children relative to adults for all studies that have included children (Wade *et al.* 2003). Studies with measured health risks for children reported an approximately twofold greater risk of illness from contaminated recreational water in children relative to adults (Cabelli *et al.* 1983; Fattal *et al.* 1987). Given that children comprise approximately 50% of all bathers, the increased susceptibility among children

may imply that the preceding manuscript's large health burden estimates among Southern California bathers would have been substantially increased if increased illness rates among children were considered. This important concern has been recognized by the U.S. EPA and other scientists who have recommended that the increased health risk for children be a central consideration in future epidemiologic research and water quality guidelines (EPA 2007; Wade *et al.* 2003).

Bathers' immune responses to recurrent water contamination exposures may also exert an important influence on illness rates (Eisenberg *et al.* 1998). Up to 80% of visitors at these beaches reside in Southern California (Haile *et al.* 1996). Different immune responses may be induced by different patterns of exposure. Tourists may be more likely to make frequent beach visits during a short period, while local residents may make rare, intermittent, or frequent beach visits throughout the year (Johnson *et al.* 1990; Rubin *et al.* 1987). For example, local residents who are dedicated surfers or who are children on summer holiday may make dozens of trips to the beach in a year. Frequent inoculums by coastal water pathogens might fatigue immune systems and increase susceptibility to illness. Conversely, frequent coastal water pathogen exposures could familiarize an individual's immune system with pathogens and lessen susceptibility to illness. The wide range and fluctuating levels of pathogens in coastal waters may potentially limit the influence of immunologic familiarity on the associated health risk (Cabelli *et al.* 1983). These influences on health risk will be challenging to quantify, but newly developing techniques of health risk modeling have made significant progress in this effort.

Sources of Additional Disease Burden

The secondary transmission of pathogens acquired while bathing in coastal waters may also deserve further investigation (Eisenberg *et al.* 1996; Soller *et al.* 2007). The causative pathogens for many bathing-associated illnesses, including norovirus, adenovirus, and enterovirus species, are rather durable and highly contagious (Fayer *et al.* 1998; Griffin *et al.* 2003; Keswick *et al.* 1985). The highly transmissible norovirus is frequently identified as a cause of bathing-associated gastroenteritis and as a causative agent in epidemic outbreaks of gastroenteritis, including workplace, restaurant, nursing home, and swimming-related outbreaks (Becker *et al.* 2000; Fankhauser *et al.* 1998; Koopman *et al.* 1982). Adenoviruses and enteroviruses are probable agents for many bathing-related respiratory infections and gastrointestinal illnesses and are associated with community outbreaks of gastroenteritis, conjunctivitis, and dermatitis (Schmitz *et al.* 1983). Infected bathers return to their homes, workplaces, and schools to form a source for more-generalized dissemination of these pathogens (Eisenberg *et al.* 2002). In addition to the large number of bathers with symptomatic illnesses, pathogens may also be disseminated from the sizable number of bathers who may experience asymptomatic infections (Baron 1982; Rockx 2002; White 1986). Secondary attack rates for adenovirus, Norwalk virus, and enterovirus infections are frequently reported as approximately 50% within households (Chang *et al.* 2004; Huen *et al.* 1987; Morens and Pallansch *et al.* 1995). If just 10% of the bathers estimated to become ill from bathing in Southern California's coastal waters each year transmit illnesses to other individuals, as many as 400,000 additional gastrointestinal illnesses may result. In response to related concerns, the U.S. EPA has recommended a revised framework for risk assessment in

recreational waters that would incorporate considerations of secondary transmission of pathogens (ILSI 2000).

Applicability of Epidemiologic Relationships in Southern California

The difference in contamination sources between the beaches in Southern California and the beaches where the Cabelli *et al.* (1982) and Kay *et al.* (1994) epidemiologic relationships were derived may limit the applicability of these relationships to bathers in Southern California. The beaches studied in the original investigations are considered as predominantly contaminated by sewage, while Southern California beaches experience their highest contamination levels from urban runoff contamination (Cabelli *et al.* 1982; Dwight *et al.* 2002; Kay *et al.* 1994; Noble *et al.* 2003; Schiff *et al.* 2003). However, coastal waters at beaches adjacent to urban centers generally experience contamination from a mixture of sewage and runoff, which makes simple classifications problematic. For example, the Cabelli *et al.* (1982) investigation was conducted at beaches adjacent to large metropolitan centers (New York, Boston, and New Orleans) where, in addition to sewage, urban runoff likely contributed significantly to coastal water contamination. Reminder to make these kinds of changes throughout. The Kay *et al.* (1994) study was also conducted at beaches adjacent to cities with populations of over 100,000, where urban runoff may also have been a significant problem. Further challenges to a simplistic classification of contamination sources for Southern California waters arises from the large volumes of sewage that leak into runoff discharges and are then discharged into area rivers. As well, the preceding manuscript notes that most of the health burden resulting from coastal water contamination occurs

during the summer season, when runoff discharges are low and sewage discharges into rivers and outfall pipes are the predominant source of coastal water contamination.

It has also been observed that coastal waters contaminated primarily by urban runoff pose significant health risks for bathers, and that these health risks are associated with the level of the enterococcus bacteria. Investigators in Southern California reported that bathers at beaches who were exposed to water contaminated by urban runoff experienced greater risks of gastroenteritis and respiratory symptoms (Dwight *et al.* 2004; Haile *et al.* 1999). Haile *et al.* (1999) also reported that during the dry summer season, rates of gastroenteritis and other illnesses among bathers were significantly correlated with the level of enterococcus bacteria. In addition, Dwight *et al.* (2004) found that significantly higher rates of gastroenteritis and other illnesses among bathers in California were associated with increased urbanization of the discharging watershed and with rainfall events (which characteristically occur during the winter season in California).

The heterogeneous and varying sources of waste in urban runoff continue to represent significant challenges to public health risk assessment. In addition to fecal waste from leaking sewage infrastructure, urban runoff may include fecal waste from household pets and wild animals, fecal waste from livestock and farming operations, and nonfecal wastes. Domestic animals may shed the potentially pathogenic enterohemorrhagic *Escherichia coli*, *Toxoplasma gondii*, *Cryptosporidium parvum*, and other organisms into runoff at variable levels depending on their presence in the discharging watershed (Griffin *et al.* 1991; Ramirez *et al.* 2004; Slifko *et al.* 2000). Wild animals, such as rats, deer, and birds, when present in the discharging watershed, may

also shed human pathogens into runoff (Martinez *et al.* 1993; Slifko *et al.* 2000). In the heavily urbanized watersheds of Southern California, the fecal wastes from household pets and rodents, which number in the millions, may be of greater concern than waste from wild animals (County of Los Angeles 2006). Further investigation of the relationship between urban runoff and health risk will be critical, as popular beach areas are often located adjacent to large population centers and are frequently affected by urban runoff discharges.

Anticipated Research

The U.S. EPA anticipates, in the next few years, several investigations regarding the health risk of bathing in Southern California (SCCWRP 2007). Sites anticipated for the U.S. EPA study include Malibu and Avalon beaches in Los Angeles County, and Doheny beach in Orange County. The study is currently being designed as a prospective cohort study to examine the association of health risk with levels of traditional indicator bacteria, other candidate indicator organisms, and pathogenic viruses. The prospective study design will be used due to EPA stipulations, in spite of concerns voiced over inherent weaknesses in this study design relative to randomized study designs. The candidate indicator bacteria to be monitored include bacteroides and *Enterococcus faecalis* (host-specific markers for bacteroides, including human, dog, and cow markers, will also be evaluated). Candidate viral indicator organisms include F+ and somatic phage, which are thought to have similar environmental survival characteristics to important viral pathogens such as adenoviruses and noroviruses (Leclerc *et al.* 2000). Viral pathogens such as adenovirus and norovirus will also be monitored. The levels of

these organisms will be measured by traditional culture methods and by more-rapid techniques, including polymerase chain reaction methods, which hold the promise to shorten delays between monitoring events and public health responses to elevated contamination levels (Wade *et al.* 2006). Pathogens identified as important indicators of health risk by the U.S. EPA investigation may offer a means to bypass some of the challenging assumptions about the relationships between indicators and pathogens that current risk assessment strategies require (Cabelli *et al.* 1983).

Further research using the database that underlies the preceding manuscript may add to our understanding of several other important influences on the health risk of bathing. The strong influence of fluctuations in bathing rates on health risk deserves further investigation, as this influence may exert the greatest effect on both the temporal and the geographic distribution of these health risks. Elucidating the timing and intensity of health risk in relation to contamination peaks due to rainfall may refine the public health response relative to the influence of weather. Coastal land use patterns, including geology, slope, vegetation, number of drainage channels, and extent of surface area occupied by agriculture, natural landscape, or urbanized areas, are likely to exert a significant influence on health risk (Mallin *et al.* 2000; SCCWRP (b) 2007). Be sure to make this change in the Bibliography. Public health officials may be better able to anticipate risk levels associated with continuing urbanization in the region as accompanying influences on water quality, such as impervious surface area and the size of the human population in the discharging watershed, are quantified (Basnyat *et al.* 1999; Bay *et al.* 2003; Dojiri *et al.* 2003; Goonetilleke *et al.* 2005). Efforts to grade the influence that various land use discharges have on the health risk of bathing in affected

waters is incorporated into the World Health Organization's water quality assessment program and promises to be an important consideration in the development of future U.S. EPA guidelines (EPA 2007; WHO 2003).

The economic costs resulting from the health burden associated with coastal water contamination also deserves further investigation. Health care expenditures, lost productivity and deterioration of the perceived quality of beaches are cost categories that have been investigated previously. Dwight *et al.* (2005) estimated that the cost of health care expenditures and lost productivity exceeds 3 million dollars each year for two area beaches in Southern California. Given *et al.* estimated that these costs range from 21 to 51 million dollars a year at a group of 26 Southern California beaches (Given *et al.* 2006). Coastal water contamination also exerts significant affects on the perceived quality of these beaches among potential beach visitors (Pendleton 2001). As a 12 billion-dollar-a-year coastal tourism economy depends on the desirability of these beaches, even a small detrimental effect related to water contamination may have significant economic implications (Hanneman *et al.* 2004; Hilger and Hanneman 2006, King 1999; Leeworthy *et al.* 2007). We anticipate further investigation into the economic burden of this health burden as improved "cost-of-illness" estimates, from ongoing epidemiologic studies, become available. With preliminary analysis using "cost-of-illness" estimates from Dwight *et al.* (2005), the health burden estimates in the preceding manuscript would be associated with annual costs of 53 million dollars for AFRI and 25 million to 146 million dollars for gastroenteritis (depending on which epidemiologic model is applied). Quantifying these costs will contribute to a better

understanding of the financial and social costs of this health risk by the many private, corporate, and governmental bodies that participate in related health policy development.

Further modeling analysis of the database underlying the preceding manuscript may also quantify the public health benefit resulting from beach closures and advisories. The preliminary findings of this analysis suggest that beach closures and advisories are not reliably instituted when exceedances of water quality guidelines occur. Our analysis further suggests that restrictive beach closure measures are regularly instituted in response to reported sewage spills, even though sewage spills are often not associated with elevated contamination levels. While beach advisories are more frequently instituted in response to high contamination levels in Southern California, the rate of advisories was much lower than the estimated rate of water quality guideline exceedances (approximately 12% of all water quality exceedances were associated with a beach advisory). The public health benefit of beach closures and advisories appears to be small, as our preliminary analysis suggests that they reduce the health burden in the region by less than 2%. The apparent limitations of beach closures and advisories at reducing health risk may give cause to a reevaluation of current expectations of the role of closures and advisories as an important public health response to coastal water contamination.

General Implications

The health risk for bathers in Southern California appears to be very large and much greater than would likely be considered acceptable from a public health or general societal perspective. The modeling estimates derived from both the Cabelli *et al.* (1982) and the Kay *et al.* (1994) epidemiologic models both agree that this disease burden is

large. These estimates also agree in a geographically expanded framework, with smaller scale analyses performed by other investigators (Given *et al.* 2006; Turbow *et al.* 2003). The health risk associated with bathing in coastal waters may well be the largest source of water-associated illness in the U.S., if other domestic coastal areas have similar scale health risks. The scale of this health risk deserves great attention from the public and from health officials. After years of limited research, greater allocation of available resources to further investigate and remedy this health risk is clearly indicated.

The many features shared by the Southern California coastline and other important coastal areas throughout the world support the generalizability of this investigation's health risk characterizations to other coastal areas. Coastal areas are home to half of the world's population and are often among a country's most important economic and social resources. Many highly attended beach regions around the world are also located alongside densely populated urban areas (Figure 3.1). As is true in Southern California, many popular coastal tourism destinations around the world experience a warm, temperate climate, with popular summer holiday seasons and lower attendance periods during the cooler winter season, which is characterized by increased rainfall. As in Southern California, many urbanized coastal areas must also contend with treating runoff and sewage discharges, assess the coastal water contamination that results from these discharges, and manage the consequent health risk for bathers.

Coastal water quality guidelines in many countries around the world are also based on the Cabelli *et al.* and Kay *et al.* relationships, which facilitates the generalizability of the findings of this investigation. The Cabelli *et al.* relationship underlies water quality guidelines in 49 out of 50 U.S. states (NRDC 2006) and much of

Latin America (Salas 1986). The Kay *et al.* relationship also underlies water quality guidelines for the European Union, Australia, New Zealand, and other countries with guidelines based on WHO recommendations (ANZ 2000; EP/CEU 2006; Kamizoulis *et al.* 2004; WHO 2003).

The immense popularity of beaches as tourist destinations heightens the urgency for worldwide investigation into the health risk of bathing in coastal waters. More than 2 billion tourists visit beaches every year, and many of these beaches experience significant coastal water contamination (Shuval *et al.* 2003). The global health risk from recreational bathing in contaminated coastal water has been estimated to lead to 120 million episodes of gastroenteritis and 50 million episodes of respiratory illness each year (Shuval *et al.* 2003). Governments around the world address this health risk with many billions of dollars in expenditures each year, yet little evidence is available to ensure that investments in coastal water quality efforts effectively protect the health of bathers. The urgency for a clearer understanding of the health risk from bathing in coastal waters will continue to grow as the world's population grows and increasing numbers of people visit and recreate in coastal waters.

Tables

Table 3.1 1986 U.S. Ambient Water Quality Criteria for Bacteria in Marine Recreational Waters (Adapted from EPA 1986).

Single Sample Maximum Allowable Density

	Associated Swimming Associated Gastroenteritis Rate per 1000 Swimmers	Steady State Geometric Mean Indicator Density	Designated Beach Area (upper 75% C. L.)	Moderate Full Body Contact Recreation (upper 82% C. L.)	Lightly Used Full Body Contact Recreation (upper 90% C.L.)	Infrequently Used Full Body Contact Recreation (upper 95% C.L.)
Enterococci (cfu/100 ml seawater)	19	35	104	158	276	501

Notes:

- 1) Calculated to nearest whole number using equation:
(mean enterococci density) = $\text{antilog}_{10} \text{ illness rate/ 1000 people} - 0.20/12.17$
- 2) Geometric mean based on a statistically sufficient number of samples
(generally not less than 5 samples equally spaced over a 30-day period)
- 3) During the EPA studies log standard deviation was 0.7 for marine water. Each jurisdiction should establish its own standard deviation for its conditions, which would then vary the single sample limit.

Table 3.2 WHO Classification Matrix for Integrating Microbial Water Quality as Measured by Enterococci Density with Sanitary Inspection Category. (adapted from the World Health Organization’s guidelines for safe recreational-water environments, coastal and fresh-waters) (WHO 2003)

		Microbial Water Quality Assessment Category (95 th percentile intestinal enterococci/100 ml)				Exceptional circumstances
		A ≤40	B 41–200	C 201–500	D >500	
Sanitary Inspection Category (susceptibility to faecal influence)	Very low	Very good	Very good	Follow up ¹	Follow up ¹	Action
	Low	Very good	Good	Fair	Follow up ¹	
	Moderate	Good ²	Good	Fair	Poor	
	High	Good ²	Fair ²	Poor	Very poor	
	Very high	Follow up ²	Fair ²	Poor	Very poor	
Exceptional circumstances		Action				

Notes:

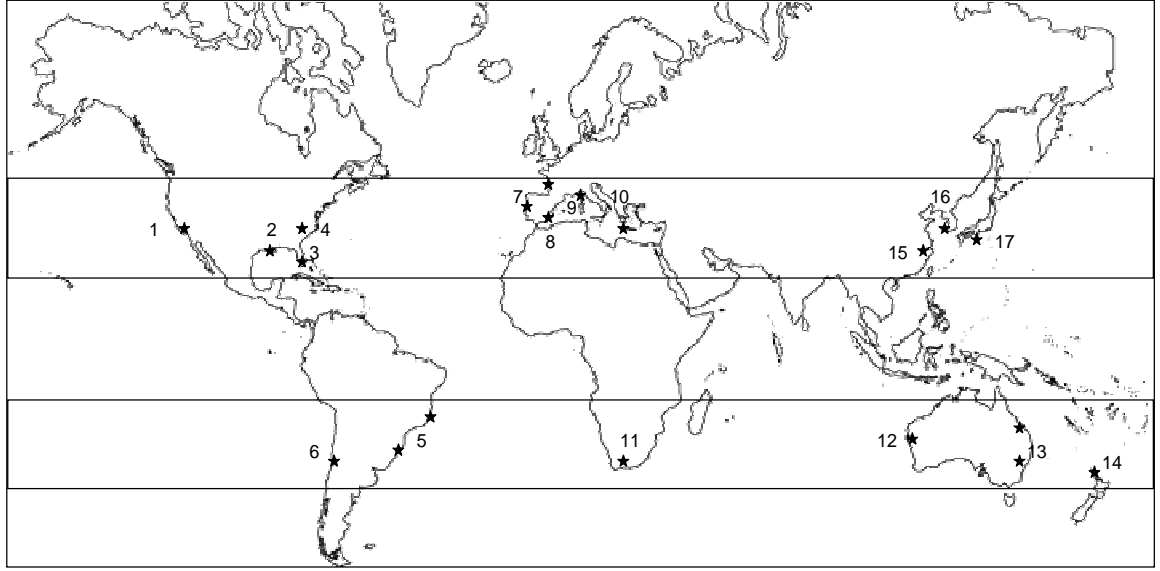
¹ implies non-sewage sources of faecal indicators (e.g., livestock), and this should be verified (section 4.6.2).

² indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most commonly associated with Combined Sewer Overflow (CSO) presence. These results should be investigated further and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include “event” periods. Confirm analytical results. Review possible analytical errors (see section 4.6.2).

³ In certain circumstances, there may be a risk of transmission of pathogens associated with more severe health effects through recreational water use. The human health risk depends greatly upon specific (often local) circumstances. Public health authorities should be engaged in the identification and interpretation of such conditions (section 4.6.5).

⁴ Exceptional circumstances (see section 4.6.5) relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

Figures



Popular Coastal Tourism Areas Listed (starred locations) Include;

- | | | |
|--------------------------------------|--|--|
| 1) Southern California | 7) Atlantic Coast of France, Spain, and Portugal | 13) Southeast coast of Australia (Sydney area) |
| 2) Texas Coastal Islands | 8) Barcelona and east coast of Spain | 14) Auckland area, New Zealand |
| 3) Southern Florida coast | 9) South of France and Italian Coastline | 15) Fuzhou, China |
| 4) Carolina and Virginia Coast | 10) Greek Islands | 16) Pusan, South Korea |
| 5) Recife and Rio De Janiero, Brazil | 11) Cape Town South Africa | 17) Osaka, Japan |
| 6) Santiago coast, Chile | 12) Perth, Australia | |

Figure 3.1 Major Coastal Tourism Areas Located in Temperate Climate Zones

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Appendix:

Beach Attendance and Bathing Rates for Southern California Beaches

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Abstract:

Annual beach attendance was collected for 75 beaches along the 350 km of coastline in Southern California for the years 2000-2004. On average, over 129 million beach visits occurred each year, with the majority (54%) of visits occurring at only 15 beaches.

Almost half of all visits (48%) occurred on weekends. Beach attendance displays distinct seasonality with 53% of visits occurring in June, July and August. On average only 45% of individuals attending the beach have physical contact with the coastal waters; water exposure rates are low (26%) during colder winter months, and peak during warmer summer months (54%). An average of 56 million recreational bathing events occurs in Southern California's coastal waters every year. Coastal tourism and recreation generates the majority of Southern California's annual \$24 billion Ocean Economy. Our quantification and statistical analysis of the ebb and flow of beach visitations across the region produces important values that have direct implications for beach management, tourism, public health and the environment. These data may allow beach managers information needed for appropriate resource allocations such as necessary lifeguard or

police protection on particular days of the year at individual beach locations, and or provide information on infrastructure demands and the potential need for improvements at particular beaches.

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Keywords:

Beach attendance; Bathing rates; Swimming rates; Recreational marine waters;

Introduction:

The beaches of Southern California are world renowned recreational destinations that attract millions of visitors annually and are a major contributor to the regional economy [1, 2]. A recent study of California's Ocean Economics quantified tourism and recreation as generating 79% of ocean related employment [3]. When describing the Gross State Product produced by Ocean Economics, the report found 59% of the money came from tourism and recreation. While areas such as construction, living resources, minerals, and ship building may receive public attention, their overall contribution to California's Ocean Economy is relatively small accounting for 7.5% combined. California's Ocean Economy is the largest in the United States, and Southern California generates more than half of the State's total market value in excess of \$24 billion annually. However, there has been no detailed quantification or analysis of the number

of beach visitors utilizing the vital beach resources. A better understanding of the recreational use patterns of these beaches is necessary for effective beach management, economic development, and efforts to address public health and environmental concerns.

General annual beach attendance values have been generated in a few reports, but unfortunately these crude estimates do not reflect the temporal and geographic variation inherent in these events. Greater detail in the distribution and magnitude of beach visitations allow for more appropriate decision making. The U.S. Lifesaving Association collects and reports visits to many beaches across the country, with 123 million beach visits reported for the Southern California region in 2005 alone [3]. In a commissioned report on the economic value of California's coastal areas, researchers reported an average of 100 million annual beach visits to Southern California beaches [1]. In another report researchers estimate Southern California annual beach attendance to equal 151 million visits [4].

In addition to quantifying the number of beach visitors, it is also important to understand the number of beach visitors who recreate in the coastal waters. The majority of beach visitors do not swim in the coastal waters, enjoying their visit in other ways. An investigation conducted in Newport and Huntington Beaches in Orange County estimated that only 27% of beach visitors enter the water during the warmer season between April and September. This value decreases to 18% between October and March [5]. Another report estimated bathing rates of beach visitors to range between 43% in the summer months down to 9.56% in February [6]. These results were generated by a random sample phone survey, and not through direct observations of beach visitors. Another

study reported a mean annual bathing rate for California of 47%; this result too was generated by a random sample phone survey [4, 7].

In order to advance the field with a comprehensive and quantitative assessment of recreational water-use for the entire coastal region of Southern California, a study investigator visited all agencies and beach locations in charge of beach attendance. Five years (2000-2004) of data for 75 beaches were collected and analyzed. This is the most comprehensive study to date and provides objective measures of the magnitude and temporal/geographic variation of recreational marine water use in Southern California.

Methods:

Beach Attendance

All agencies responsible for collecting beach attendance data (BA) along the 350 km coast of Southern California were systematically visited by a study investigator. Data from all major beaches in Los Angeles, Orange and San Diego Counties were recorded manually or electronically for 1,824 days from January 2000 through December 2004 and compiled in an Excel spread sheet. 134,125 daily beach attendance values were subjected to mathematical modeling. Data were compiled from records at lifeguard agencies (76%), parks departments (16%), and environmental health departments (8%). Data were derived from direct observation (73%), from parking, hotel, and camping receipts (19%) and from electronic counters (8%).

A beach was defined as any coastal shoreline area recognized as such by a supervising governmental agency (75 beaches met this inclusion criteria). Some beach areas were broken down into several small beaches, such as in Mission Bay and

Encinitas, both in San Diego County. The data for these few beaches areas were combined and reported as single beach locations. For some other areas there were several small beaches that were well defined, but due to low attendance levels, the monitoring agencies combined attendance data into a single value. Combining data for multiple beaches only changes the unit of analysis and does not alter numeric results.

Cubic spline interpolation [8] was used to estimate missing values for short periods (< 6 days) of missing data (4% of values). This method of interpolation approximates the generally smooth and continuous seasonal and daily fluctuations in attendance levels evident throughout the study period. Longer periods of missing data (18%) were estimated using regression from the nearest beach that had a regression value of > 0.6 during periods when attendance at both beaches was available. The rate of correlation between adjacent beaches was highly significant.

Southern California has several beaches located in bays and harbors keeping them sheltered from the open ocean. These beaches are popular for families with small children because there are no hazardous waves or currents. Unfortunately, two of the larger recreational bay areas do not record attendance data, and two others only report summertime data (which is when the majority of beach usage occurs). This lack of data will cause a modest underestimation in the total values generated. There are also several smaller beaches along the vast Southern California coastline that are not under the surveillance of lifeguards or other monitoring agencies. The lack of data for these smaller beaches will also result in a more conservative estimate of total beach attendance.

Bathing Rates

Bathing Rates (BR) were derived from long-term data sets produced independently at Del Mar and Oceanside Beaches, two San Diego County beaches where lifeguards estimated the number of beach visitors, as well as the number of people who entered the water. Bathers are defined as individuals actively engaged in water-contact recreation such as swimming and surfing. The daily Oceanside Beach data set from 2001 through 2004 had few missing data points (3.4%), the Del Mar Beach data set from 2002 through 2004 had 28% missing data points. Data from the two beaches were significantly correlated ($P < 0.01$); therefore, the monthly averages were generated by combining both data sets ($n = 2,192$ total days). The daily BR values were used to calculate the mean BR per month.

We make the assumption that the multi-year BR recorded daily at two individual San Diego County beaches is applicable to all the beaches in the study area. This assumption of uniformity is supported by the distinct seasonal pattern of beach attendance being observed at all beaches. Further, meteorological conditions greatly influence BR (as well as BA) and the climatic patterns and coastal water temperatures are similar across these three contiguous coastal Counties. The vast majority of the beaches along the Southern California coastline are similarly open, white sand beaches with varying levels of amenities, and thus Oceanside and Del Mar beaches are appropriate representative beaches for the Southern California region.

Bathing Events

The number of Bathing Events (BE) per beach was calculated by applying the BR per month (percentage of beach visitors who swim) to each day's BA per beach.

Equation: $BE = (BA) * (BR)$

(BE = Bathing Events; BA = Beach Attendance; BR = Bathing Rate)

In calculating BE, we excluded attendance values from BA that represent a population unlikely to swim, such as those at adjacent parks, piers, and boardwalks. This data was included in the annual BA values to accurately represent total number of visitors, but was removed for the analysis of BE, as to not over-estimate exposure events. From 2000 through 2004, a total of 14,442,567 beach visitors were subtracted from the calculation of BE; roughly 2.9 million visits per year.

Results:

Beach Attendance by Day

Beach attendance demonstrated dramatic increases on weekends when compared to work days of the week (Figure 1), with almost half of all beach visits (48%) occurring on Saturdays and Sundays. Holidays also showed large increases in beach visitation. These temporal variations are accounted for in our analysis and calculations because we used attendance data at the daily level.

Beach Attendance by Season

Beach attendance patterns show large variations between seasons with more than half (53%) of all visits occurring during the three summer months (Figure 2). The distribution followed a seasonal sinusoidal curve. This smooth attendance pattern was consistent across years as well across beach locations.

Beach Attendance by Year

Integration of beach attendance for each year did not reveal significant deviation from the mean over the five years studied. Southern California experienced a wide range of general weather patterns during the study period with high levels of rainfall one year and drought in another. Regardless of the large variations in winter weather, annual attendance rates remained relatively stable since the majority of visits occur during the summer months which were consistently warm and dry. However, from 2000 to 2004 there was a slight 5% increase in annual attendance for Southern California beaches. This trend may result from general population growth in the region, or from standard deviation in the data.

Data analysis revealed an annual mean of 129 million beach visits in Southern California (Table 1). This does not represent 129 million individual people going to the beach, but rather the total number of visits that occur per year. The number of individual beach visitors is lower because a portion of the values are generated by people who frequently visit the beach throughout the year.

Beach Attendance by Location

The 129 million annual beach visits are disproportionately distributed along the coast with the majority occurring at a few beach locations; one third of all attendance occurs at the top six beaches, and the majority (54%) occur at only 15 out of the 75 beaches investigated (Table 1, Figure 3). Annually, 40% of all Southern California visits occur at Los Angeles beaches and the remaining visits are evenly distributed between Orange and San Diego Counties.

The Los Angeles County beaches with the highest attendance levels are Zuma (5.5% of total Southern California attendance), Santa Monica (3.7%), Venice (4.4%), and Long Beach (3.2%). There are also relatively high attendance levels along the stretch of beaches that include Dockweiler (1.5%), El Porto (1.2%), Manhattan (0.9%), Hermosa (2.2%), Redondo (1.9%) and Torrance (1.1%) beaches. All of these beaches (with the exception of Zuma and Long Beach) are contiguous and are located inside the Santa Monica Bay. In Orange County, the beaches with the highest attendance levels are Huntington Municipal (5.1%), Huntington State (4.8%) and Newport (6.0%) beaches, which account for 55% of all beach visits in Orange County. These three beaches are also contiguous. Beach attendance is much lower and more evenly distributed along the coast in San Diego County, where only Mission Beach (3.8%) experienced attendance levels comparable to those seen at beaches in the other two counties.

Bathing Rates by Month

Bathing rates show dramatic seasonal variability, with rates ranging from a low of 26% during January to a high of 54% in August (Figure 4). These monthly bathing rates were consistent across the five years analyzed.

The rates of both bathing and beach attendance demonstrated very similar seasonal fluctuations. Low rates during the winter months of December, January, and February were followed by a transitional period to high rates during the summer months of June, July and August. The concurrent increases in beach attendance and bathing rates amplifies the seasonal fluctuations when calculating the number of bathing events.

Bathing Events by Year

The model computed over 56 million yearly bathing events in Southern California's recreational marine waters when beach visitors have physical water contact (Table 1, Figure 2, and Figure 3). This value does not represent 56 million individuals, but rather the total number of exposure events per year. The number of people who bathe each year is lower because a portion of events result from individuals who frequent the beach throughout the year. For example, an individual dedicated surfer alone can account for over 300 annual events.

Bathing Events by Location

Because bathing events are a direct function of attendance, the distribution of bathing events across beaches is determined by attendance patterns (Figure 3). Beaches with the most visitors also have the highest number of bathers.

Discussion:

Through extensive data collection, mathematical interpolation and modeling, this study quantifies beach attendance and bathing rates for the entire region of Southern California over five years. The analysis revealed several distinct and consistent temporal and geographic patterns of beach visitation and bathing rates. These results portray the ebb and flow of the human tide as the beach going public utilizes the recreational beaches in Southern California. These beaches are very popular destinations for millions of people, and the overall attendance levels are predicted to increase as the population in the region continues to grow rapidly beyond the current 15 million people living in Los Angeles, Orange and San Diego Counties [9].

Although the beaches of Southern California are popular tourist destinations, it is interesting to note the majority of beach visitors are local residents. One study conducted at Santa Monica Beach in Los Angeles County reported 88% of summer beach visitors are California residents, and 78% are with their families [10].

The annual attendance values we present are supported by all three reports previously discussed [1, 3, and 4]. The values we present for monthly bathing rates are greater in value and detail than previously reported due to the more comprehensive data sets derived from direct observations that we used to calculate our values. The consistency of data over several years of daily observations lends further support for the validity of the results presented.

The use of observational data to measure attendance introduces inherent errors due to different people making daily estimates, and other potential influences on the data collection process. However, a study of the accuracy of beach attendance estimates by lifeguard observations at several beaches in Southern California found these estimates to be within 10% of actual values [11]. Another researcher also reported lifeguard estimation procedures to be accurate [12]. Further support for the validity of the data comes from the consistency of annual totals generated each year. The values presented here are slightly conservative due to missing data for smaller beaches and bays.

Conclusions:

Currently there is no established method for measuring beach attendance. Agencies would benefit from a standardized protocol for measuring beach attendance, and a protocol to distribute this data to supervisory agencies and to the State government to facilitate access to this valuable information. Agencies are currently charged with

recording daily beach attendance data, so it would be more effective to coordinate their diligent efforts and make it accessible for public analysis.

The results from this study will have important implications for future policy related to beach management, public health, urban planning, environmental sciences, and economic development. For example, the data can support effective decision making among businesses in the tourist industry by allowing them to better target their advertising, event locations, and promotions. Economists will be able to use this data to better estimate the significant economic contribution of coastal tourism on the economy, and to help prioritize infrastructure investments for the development of this economy. With coastal tourism and recreation accounting for the majority of Southern California's \$24 billion annual Ocean Economy [3], it is important to have accurate data on the temporal and geographic distribution of the beach going public. Environmental scientists concerned with public exposure to coastal water pollution will benefit by having a better understanding of when and where people are going in the water. Regional water quality managers and public health officials will benefit from having more refined and precise data to rely upon to ensure the safe enjoyment of this important recreational resource. Knowledge of when and where people use recreational marine waters combined with historical pollution data for individual beaches can help with proactive decision making in an effort to avoid public health risks. Regional water quality managers may use these results to justify increasing or decreasing resource allocations based on actual need. Beach managers such as lifeguards and local police may be able to use the daily beach-specific data to help protect public safety. Comprehensive beach usage data provides beach managers with information and perspective for resource allocation decisions. This

information also helps with understanding the magnitude of demand and impacts the infrastructure may be experiencing. Data may also help managers understand if certain areas are being under or over utilized. These data provide a sound foundation for many potential applications in future analysis.

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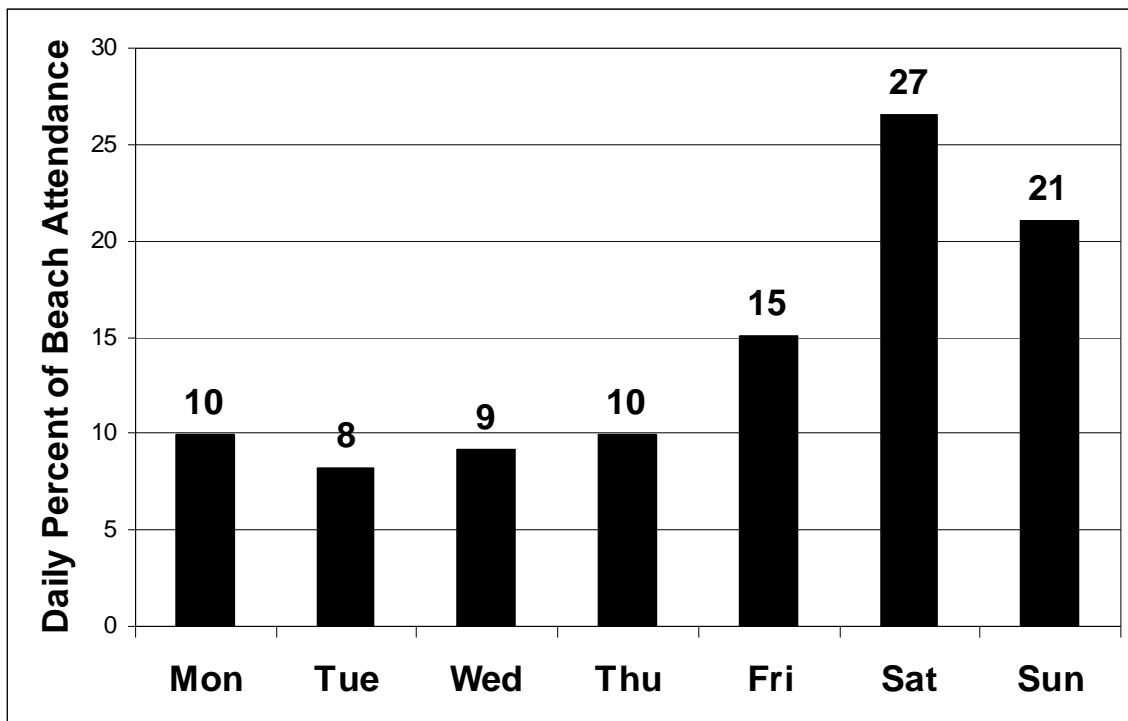
Figures

Figure 1 Distribution of Beach Attendance by Day of the Week for Southern California Beaches (2000-2004)

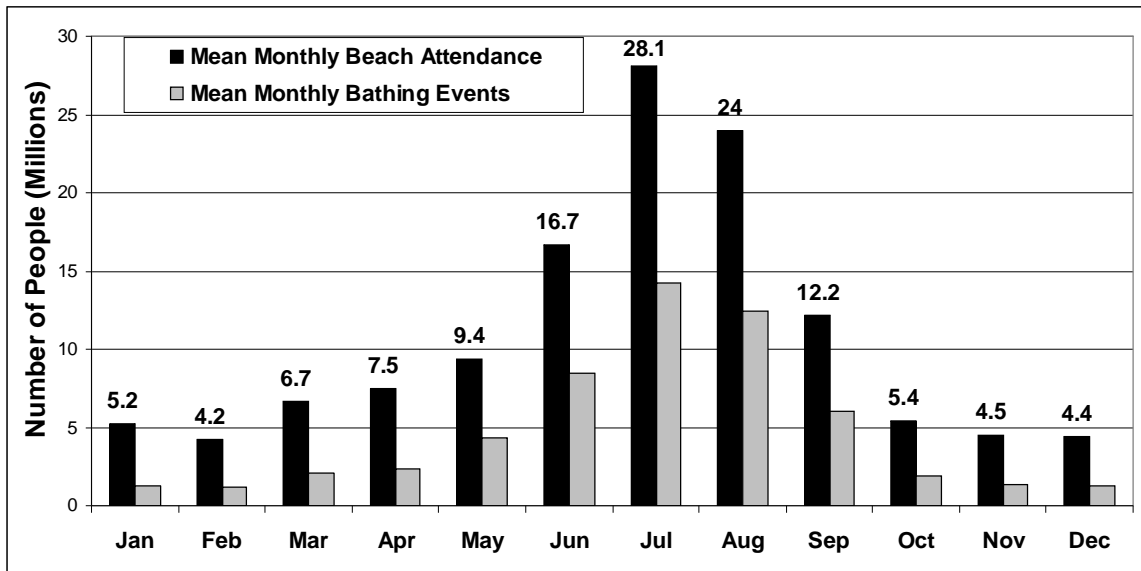


Figure 2 Distribution of Mean Beach Attendance and Bathing Events by Month for Southern California Beaches (2000-2004)

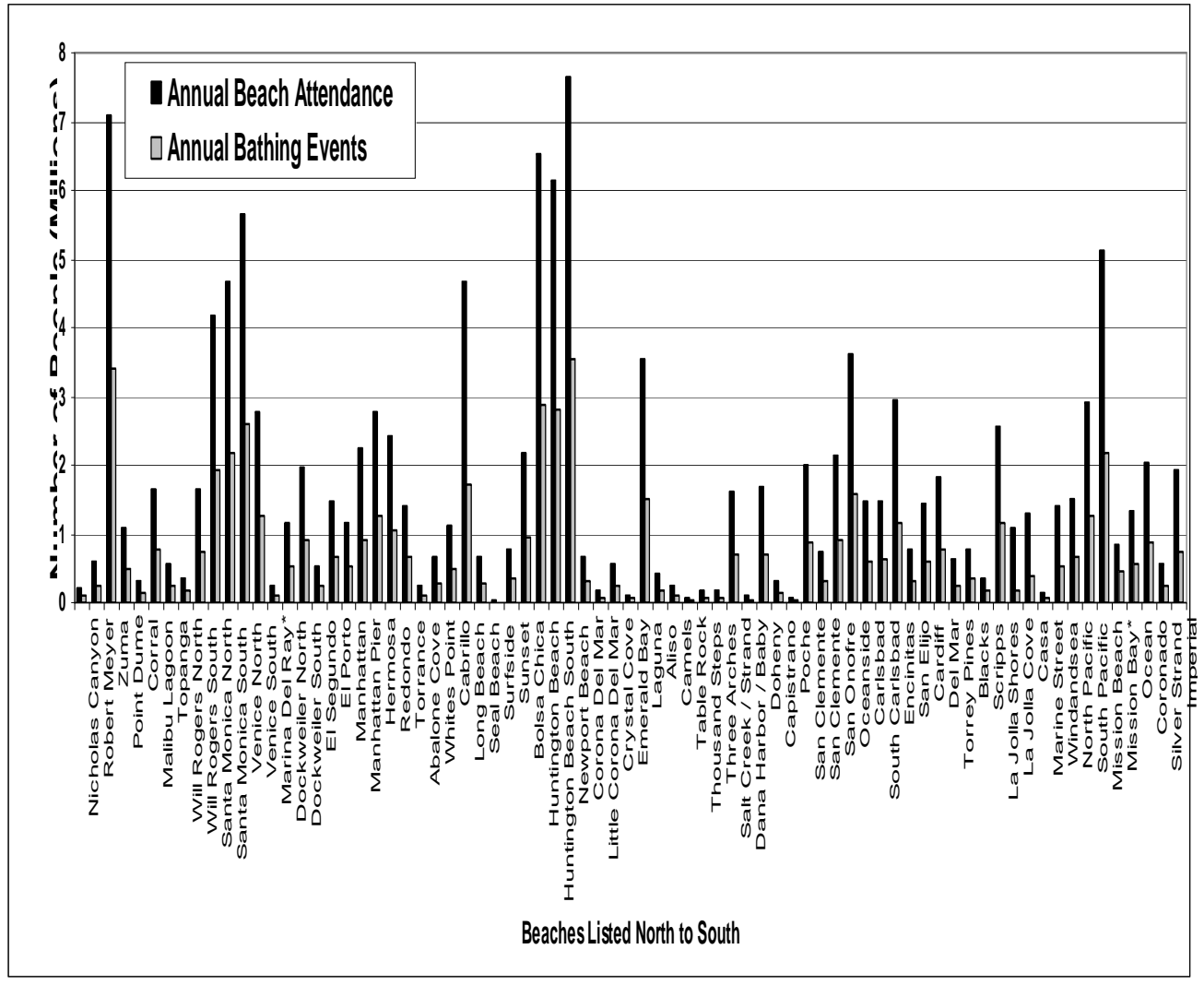


Figure 3 Distribution of Mean Beach Attendance and Bathing Events along the Southern California Coastline (2000-2004)

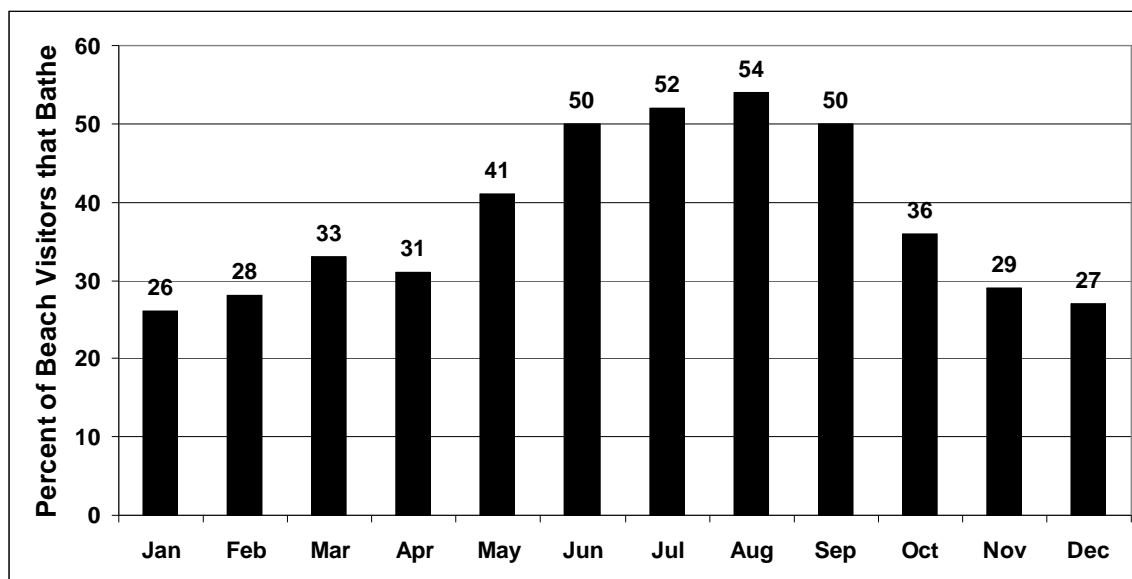


Figure 4 Fraction of Beach Visitors that Bathe (Actual Water Contract) by Month for Southern California Beaches (2001-2004).

Tables

Table 1: Mean Annual Beach Attendance and Annual Bathing Events at Southern California Beaches (2000-2004)

	Beach	Avg. Attendance	Avg. Bathing Events
Los Angeles County			
1	Nicholas Canyon	200,939	87,512
2	Robert Meyer	572,635	238,736
3	Zuma	7,060,397	3,418,831
4	Point Dume	1,097,965	502,781
5	Corral	281,301	132,156
6	Malibu Lagoon	1,649,174	755,371
7	Topanga	562,640	249,608
8	Will Rogers North	357,062	159,678
9	Will Rogers South	1,645,770	753,378
10	Santa Monica North	4,175,148	1,936,991
11	Santa Monica South	4,657,450	2,167,452
12	Venice North	5,636,961	2,592,990
13	Venice South	2,773,460	1,249,211
14	Marina Del Ray*	264,071	118,570
15	Dockweiler North	1,154,544	524,552
16	Dockweiler South	1,945,238	921,343
17	El Segundo	516,848	226,596
18	El Porto	1,468,813	656,250
19	Manhattan	1,165,681	532,318
20	Manhattan Pier	2,246,525	900,810
21	Hermosa	2,784,884	1,263,281
22	Redondo	2,406,484	1,073,001
23	Torrance	1,406,660	647,159
24	Abalone Cove	232,979	95,210
25	Whites Point	656,988	269,762
26	Cabrillo	1,126,306	497,208
27	Long Beach	4,720,897	1,714,316
	Total: Los Angeles	52,767,820	23,685,067
Orange County			
28	Seal Beach	651,917	275,040
29	Surfside	27,163	11,460
30	Sunset	769,722	355,694
31	Bolsa Chica	2,159,722	952,978
	Huntington Harbor	no data	no data
32	Huntington Beach	6,520,415	2,887,141
	Huntington Beach		
33	South	6,153,388	2,808,517
34	Newport Beach	7,642,140	3,562,128
	Newport Harbor	no data	no data
35	Corona Del Mar	676,585	315,356

36	Little Corona Del Mar	169,146	78,839
37	Crystal Cove	551,317	230,229
38	Emerald Bay	124,224	55,046
39	Laguna	3,544,917	1,510,996
40	Aliso	434,648	192,615
41	Camels	248,395	110,074
42	Table Rock	62,164	27,506
43	Thousand Steps	186,305	82,559
44	Three Arches	186,305	82,559
45	Salt Creek / Strand	1,611,061	711,754
46	Dana Harbor / Baby	102,068	46,140
47	Doheny	1,681,520	713,726
48	Capistrano	331,739	149,957
49	Poche	76,581	34,614
50	San Clemente	2,009,468	884,011
51	San Clemente	735,044	316,974
	Total: Orange	36,655,954	16,395,912
San Diego County			
52	San Onofre	2,134,093	908,932
53	Oceanside	3,600,026	1,587,661
54	Carlsbad	1,475,721	591,819
55	South Carlsbad	1,480,664	632,497
56	Encinitas	2,936,325	1,167,458
57	San Elijo	782,996	314,839
58	Cardiff	1,449,819	610,926
59	Del Mar	1,806,303	768,895
60	Torrey Pines	635,847	249,219
61	Blacks	766,030	338,546
62	Scripps	345,908	175,289
63	La Jolla Shores	2,557,401	1,162,002
64	La Jolla Cove	733,833	188,459
65	Casa	1,323,010	394,292
66	Marine Street	148,206	76,692
67	Windandsea	1,420,487	539,317
68	North Pacific	1,512,818	666,687
69	South Pacific	2,902,424	1,256,841
70	Mission Beach	5,138,661	2,176,426
71	Mission Bay*	849,608	437,276
72	Ocean	1,328,447	573,244
73	Coronado	2,034,266	867,635
74	Silver Strand	549,207	244,520
75	Imperial	1,931,760	737,871
	Total: San Diego	39,843,860	16,667,343
	Total: So. California	129,267,634	56,748,323

* = Summer time data only

