

Technical Report 449  
March 2005

# Recreational Water Contact and Illness in Mission Bay, California



John M. Colford Jr.  
Timothy J. Wade  
Kenneth C. Schiff  
Catherine Wright  
John F. Griffith  
Sukhminder K. Sandhu  
Stephen B. Weisberg

*Southern California Coastal Water Research Project*

# Recreational Water Contact and Illness in Mission Bay, California

John M. Colford, Jr.<sup>1</sup>  
Timothy J. Wade<sup>2</sup>  
Kenneth C. Schiff<sup>3</sup>  
Catherine Wright<sup>1</sup>  
John F. Griffith<sup>3</sup>  
Sukhminder K. Sandhu<sup>1</sup>  
Stephen B. Weisberg<sup>3</sup>

<sup>1</sup>*University of California Berkeley  
School of Public Health  
140 Warren Hall  
Berkeley, CA 94720*

<sup>2</sup>*Southern California Coastal Water Research Project  
7171 Fenwick Lane  
Westminster, CA 92683*

<sup>3</sup>*United States Environmental Protection Agency  
National Health and Environmental Effects Research Laboratory  
Research Triangle Park, NC 27711*

March 11, 2005

Technical Report #449

## **FOREWORD**

This investigation was a collaboration between the Southern California Coastal Water Research Project and the University of California, Berkeley School of Public Health. This project was funded by the City of San Diego through a Supplemental Environmental Project (ACL No.2001-094) and the San Diego Regional Water Quality Control Board through the Clean Up and Abatement Fund (SWRCB Contract No. 02-166-190-0). The conclusions represent those of the authors and are not necessarily the position of the City of San Diego, the State of California, or the U.S. Environmental Protection Agency (U.S. EPA). Mention of trade names does not constitute an endorsement by the City of San Diego or the State of California.

## ACKNOWLEDGEMENTS

We would like to thank the many organizations that helped with data collection and/or sample processing on this project. Fecal indicator bacterial analysis using traditional methodologies was coordinated by Ric Amador and Laila Othman at the City of San Diego Metropolitan Wastewater Department Microbiology Laboratory (San Diego, CA). Rich Haugland and Al Dufour of the U.S. EPA provided the protocols and some filtration equipment for analysis of enterococcus and *Bacteroides* using quantitative polymerase chain reaction (QPCR). The QPCR was conducted by Charles LaCerra of EMSL, Inc. (Westmont, NJ). Virus and coliphage measurements were coordinated by Mark Sobsey of the University of North Carolina (Chapel Hill, NC). The human health data collection was coordinated by Susan Burns and Jackie Hayes at the UC Berkeley Survey Research Center (Berkeley, CA). Data management and analytic support were provided in part by Srikesh Arunajadai and Shannon Carr at the UC Berkeley School of Public Health.

The authors also wish to acknowledge the invaluable guidance provided by the independent scientists of the project Steering Committee (in alphabetical order):

Rebecca Calderon	United States Environmental Protection Agency
Richard Gersberg	San Diego State University
Michele Ginsberg	San Diego County Department of Environmental Health
Mark Gold	Heal the Bay
Charles McGee	Orange County Sanitation District
John Witte	University of California, San Francisco

We would also like to acknowledge the support of our contract managers, Christina Arias and Leslie Dobalian, from the San Diego Regional Water Quality Control Board; and advice from Ruth Kolb from the City of San Diego and Clay Clifton from the San Diego County Department of Environmental Health.

## ABSTRACT

Fecal indicator bacteria are routinely monitored at marine recreational bathing beaches to assess the public health risk of contracting swimming-related illness. There have been numerous epidemiology studies that demonstrated the relationship of indicator bacteria to health risk, but they have been mostly conducted on beaches impacted by point sources with known human fecal contributions. Few studies have examined this relationship at beaches where non-point sources are the dominant fecal input source.

Here, we present an epidemiology study conducted in Mission Bay, California, where nearly 20% of the historic routine bacterial samples failed water quality standards but the dominant fecal source appears to be non-human. The study focused on three primary questions: (1) Did water contact increase the risk of illness during the two weeks following exposure to water? (2) Among those individuals with water contact, were there associations between illness and measured levels of traditional indicators of water quality? and (3) Among those individuals with water contact, were there associations between illness and measured levels of non-traditional indicators of water quality?

The project was designed as a cohort study. Nearly 8,800 participants were recruited from the six most popular swimming beaches in Mission Bay on weekends and holidays during the summer of 2003. Each participant provided their current state of health and degree of water exposure on their day at the beach. On the same day, water quality was monitored for traditional fecal indicator bacteria (enterococcus, fecal coliforms, total coliforms). A subset of samples was also measured for non-traditional indicators, including new methods for measuring traditional indicators (chromogenic substrate or quantitative polymerase chain reaction [QPCR]), new bacterial indicators (*Bacteroides*), and viruses (somatic and male-specific phage, adenovirus, Norwalk-like virus).

Ten to 14 days later, the participants were contacted by phone and interviewed about symptoms of illness that occurred since their visit to the beach. They were queried about multiple types of illness: gastrointestinal illnesses (diarrhea, nausea, stomach pain, cramps, vomiting, highly credible gastrointestinal illness 1 or 2 [HCGI-1 or HCGI-2]); respiratory illnesses (cough, cough with phlegm, nasal congestion or runny nose, sore throat, significant respiratory illness); dermatologic outcomes (skin rash, infected cuts or scrapes); and non-specific symptoms (fever, chills, eye irritation, earache, ear discharge, eye irritation or redness). Multivariate analysis was conducted to assess relationships between health outcomes and degree of water contact or levels of water quality indicators. These analyses were adjusted for confounding covariates such as age, gender, and ethnicity.

Of the measured health outcomes, only skin rash and diarrhea were consistently significantly elevated in swimmers compared to non-swimmers. For diarrhea, this risk was strongest among children 5 to 12 years old. The risk of illness was uncorrelated with levels of traditional water quality indicators. Of particular note, the state water quality thresholds were not predictive of swimming-related illnesses. Similarly, no correlation

was found between increased risk of illness and increased levels of most non-traditional water quality indicators. A significant association was observed between the levels of male-specific coliphage and HCGI-1, HCGI-2, nausea, cough, and fever, but we interpret these associations cautiously because so few participants were exposed to the water at times when male-specific coliphage was detected.

While we found that traditional fecal indicators were ineffective predictors of health effects, it is difficult to extrapolate this finding beyond Mission Bay. Mission Bay is unusual in that it has been subjected to thorough cleanup activities that source tracking studies confirm leave human fecal sources as only a minor contributor. Moreover, Mission Bay has an unusually long hydraulic residence time compared to other coastal systems, which affects the age and viability of waterborne fecal material. This study, though, does suggest the need for further evaluation of traditional indicators in circumstances where non-point sources are the dominant fecal contributors.

## Table of Contents

	page
Foreword.....	<i>i</i>
Acknowledgements.....	<i>ii</i>
Abstract.....	<i>iii</i>
<b>INTRODUCTION.....</b>	<b>1</b>
<b>MATERIALS AND METHODS .....</b>	<b>3</b>
Sampling Sites .....	3
Water Quality Data Collection.....	4
<i>Laboratory Methods.....</i>	<i>5</i>
Epidemiological Data Collection.....	6
<i>Beach recruitment.....</i>	<i>7</i>
<i>Follow-Up CATI Interview .....</i>	<i>7</i>
<i>Health Outcomes Measured.....</i>	<i>7</i>
Data Analysis .....	8
<i>Water Quality.....</i>	<i>8</i>
<i>Epidemiology .....</i>	<i>8</i>
<b>RESULTS .....</b>	<b>11</b>
Water Quality.....	11
<i>Traditional fecal indicator bacteria.....</i>	<i>11</i>
<i>Non-traditional fecal indicator bacteria.....</i>	<i>13</i>
<i>Virus Measurements.....</i>	<i>14</i>
<i>Effectiveness of compositing.....</i>	<i>15</i>
Epidemiology.....	17
<i>Health Outcomes for Swimmers versus Non-swimmers .....</i>	<i>18</i>
<i>Relationship between Health Outcomes and Water Quality.....</i>	<i>25</i>
<i>Time in Water.....</i>	<i>27</i>
<b>DISCUSSION .....</b>	<b>28</b>
<b>STUDY CONCLUSIONS.....</b>	<b>30</b>
<b>LITERATURE CITED .....</b>	<b>32</b>
<b>APPENDICES .....</b>	<b>35</b>

## INTRODUCTION

Fecal indicator bacteria are monitored routinely at marine recreational bathing beaches to assess the public health risk of contracting swimming-related illnesses. In southern California, more than 85,000 samples are collected and over \$3 million is spent annually to assess public health risk using these bacterial tests as indicators of fecal contamination (Schiff *et al.* 2002). The focus on bacteria as a public health monitoring tool is predicated on the relationship between the density of fecal indicator bacteria and the occurrence of illnesses in the swimming population.

Numerous studies have demonstrated the relationship between fecal indicator bacteria at beaches and the occurrence of swimming-related illnesses (Prüss 1998, Wade *et al.* 2003). Prominent among these studies are Cabelli (1979 and 1983) who observed a relationship between enterococcus and illness rates at several beaches around the country, and Haile *et al.* (1999) who observed an increase in swimming-related illnesses and enterococcus, fecal coliforms, and total coliforms at beaches in Santa Monica Bay, California. These studies were the focal point for the establishment of water quality thresholds at marine beaches using fecal indicator bacteria in the United States and the State of California, respectively.

While these previous epidemiology studies successfully demonstrated the value of fecal indicator bacteria, virtually all of these studies were conducted at locations where human sewage was the predominant contamination source. Haile *et al.* (1999) was the only study to have focused on urban runoff as a source, but even this non-point source was known to contain human sources of fecal contamination. Most of the beach water quality problems in California are attributable to non-point source runoff (Noble *et al.* 2003, Schiff *et al.* 2003), and it is less clear that the health relationships for bacterial indicators will remain the same when non-human sources predominate (Calderon *et al.* 1991). Since animals shed bacterial indicators without some of the accompanying human pathogens, there is considerable uncertainty in extrapolating present water quality thresholds that are based on the risk of swimming-associated illnesses to non-point source situations. A poor correlation between bacterial indicators and virus concentrations has been found when examining urban runoff (Jiang *et al.* 2001, Noble and Fuhrman 2001), in contrast to the significant relationships that have been found when examining water bodies influenced by human sources, such as septic tanks (Lipp *et al.* 2001).

Here, we present an epidemiology study conducted in Mission Bay, California, where state water quality standards have historically been exceeded more than 20% of the time (Schiff and Kinney 2002). Several million dollars have been expended to remove human contamination from the Mission Bay by inspecting and repairing the sanitary sewerage system surrounding the bay and diverting the largest storm drains away from the bay. As a result, recent source tracking studies suggest that human fecal material constitutes a minor proportion of fecal inputs to the Bay (City of San Diego and MEC/Weston 2004). However, exceedances of California's water quality standards continue to occur (Hanley 2002).

The goal of this study was to examine the health effects of swimmers and their relationship to water quality indicators in this system where non-human fecal sources are dominant. The study attempted to answer two primary questions:

- Did water contact increase the risk of illness in the two weeks following exposure to water in Mission Bay during the summer of 2003?
- Among those individuals with water contact, were there associations between illness and measured levels of traditional indicators of water quality?

In addition, we addressed a third question about whether there were associations between illness and measured levels of several nontraditional indicators of water quality. New laboratory methods, particularly nucleic acid-based methods, are promoted as monitoring tools because they are faster, cheaper, or more specific than traditional methods of measuring fecal indicator bacteria that rely on culture- or growth-based endpoints. The efficacy of any new public health monitoring tool can only be evaluated through an epidemiological study that documents its relationship to the incidence of swimming-related illness.

Specifically, we tested a rapid method for measuring bacteria and several measures of viruses. Whereas traditional measurement methods for bacteria are slow ( $> 18$  hrs), we included a nucleic acid-based technique that provides results in less than four hours (Noble and Weisberg et al. In Press). Similarly, virus measurements have been an inefficient monitoring tool to date because of inefficient recovery methods, expense of detection methods, and length of time for obtaining results. Culture-independent, nucleic acid-based techniques allow measurements that are faster, less costly, and more specific. These methods have not been previously evaluated in an epidemiology study.

## MATERIALS AND METHODS

This project was designed as a cohort study (NRC 2004). Six of the most popular swimming beaches in Mission Bay were targeted every weekend and holiday from Memorial Day to Labor Day during the summer of 2003. Participants were recruited each sampling day and, after giving consent, their current state of health and degree of exposure to the water were recorded. Water quality was measured at multiple sites and over multiple time periods on the same days as the epidemiological data. Ten to 14 days later, the participants were contacted by phone and interviewed about symptoms of illness that occurred after their visit to the beach. The resulting data were tested for significant differences in illness between swimmers and non-swimmers. Among the participants that swam, the probability of illness was regressed against various measures of water quality exposure. The specific methods used in this study are described below and are organized into four sections: sampling sites, water quality data collection, epidemiological data collection, and data analysis.

### Sampling Sites

The study sites were selected based on a pilot study conducted in the summer of 2002. Aerial photography, supplemented with on-the-beach enumeration of swimmers for groundtruthing (to confirm the findings of the aerial survey), was used to identify the locations and times of greatest swimmer activity. Hourly images from 9:00 AM to 6:00 PM were collected on 10 days at 10 different swimming areas in Mission Bay. The pilot study identified the most effective times and locations for maximizing the number of potential study participants.

Recruitment of beach-goers occurred at six Mission Bay beaches on weekends and holidays, beginning Memorial Day weekend and continuing through Labor Day weekend, 2003 (Figure 1). Recruitment took place between 12:00 PM and 4:00 PM each weekend day. Water quality samples were collected at the same six beaches. A total of 18 sites were targeted, with the number of sites per beach ranging from two to five, depending upon the length of beach and anticipated swimming activity (Table 1). Data were collected on 29 of 32 targeted sampling dates; three days were excluded from sampling (June 9, 17, and 18, 2003) due to inclement weather and significantly reduced beach usage.

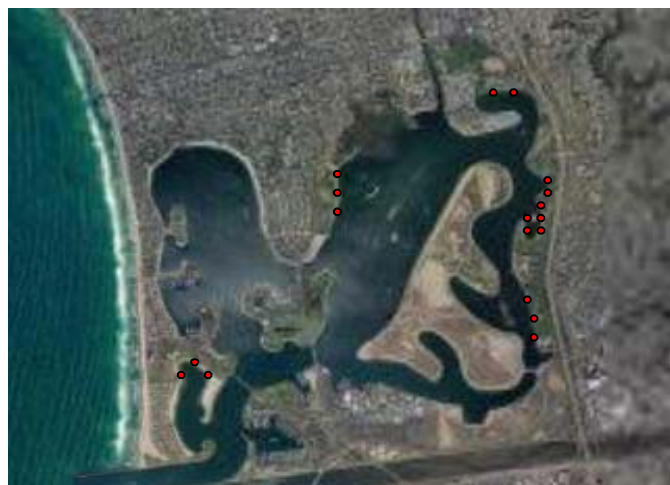


Figure 1. Map of study sites.

**Table 1. Study sites used for water quality sampling during the Mission Bay epidemiology study. Latitude and longitude in NAD83 datum.**

Beach	Site Number	Latitude	Longitude
Visitor Center	1	32.47.19N	117.12.55W
Visitor Center	2	32.47.30N	117.12.54W
Tecolote Shores	1	32.46.34N	117.12.54W
Tecolote Shores	2	32.46.46N	117.12.61W
Tecolote Shores	3	32.46.61N	117.12.66W
Leisure Lagoon	1	32.47.02N	117.12.67W
Leisure Lagoon	2	32.46.93N	117.12.62W
Leisure Lagoon	3	32.46.96N	117.12.58W
Leisure Lagoon	4	32.47.07N	117.12.55W
Leisure Lagoon	5	32.47.15N	117.12.58W
De Anza	1	32.47.81N	117.12.71W
De Anza	2	32.47.80N	117.12.78W
Crown Point	1	32.47.36N	117.13.86W
Crown Point	2	32.47.24N	117.13.85W
Crown Point	3	32.47.15N	117.13.90W
Bonita Cove	1	32.46.12N	117.14.72W
Bonita Cove	2	32.46.17N	117.14.79W
Bonita Cove	3	32.46.16N	117.14.89W

## Water Quality Data Collection

Twelve types of water quality measures were collected during this study. Three were traditional indicators (enterococcus, total coliforms, fecal coliforms) measured by traditional methods (membrane filtration [MF]). Three were the same indicators measured using the newer chromogenic substrate (CS) method. One was enterococcus measured by a new method, quantitative polymerase chain reaction (QPCR). The final five were new indicators (*Bacteroides*, somatic coliphage, male-specific coliphage, adenovirus, and Norwalk-like virus).

Water quality samples were collected at one of three temporal intensities, depending on indicator, which was necessitated by differences in sample volume, laboratory effort, and cost of the various methods (Table 2). The greatest sampling intensity occurred at all 18 sites hourly from 12:30 PM to 3:30 PM. These samples were analyzed by MF for total and fecal coliforms, and for enterococcus using the CS method. The second sampling intensity was also at all 18 sites, but only twice daily (12:30 PM and 2:30 PM). These samples were analyzed for enterococcus and *Bacteroides spp.* using QPCR. The third sampling intensity was a composite sample at each beach, once daily. The composite samples were comprised of the individual sites within each beach at the 12:30 PM sampling interval. These samples were analyzed for total and fecal coliforms (*E. coli*) using CS, enterococcus using MF, somatic and male-specific phage, and adenovirus and Norwalk-like virus.

Samples for analysis of total coliforms, fecal coliforms, and enterococcus were collected in 125 mL sterilized high-density polyethylene (HDPE) bottles. Composite samples for these

constituents were created by pouring the 125 mL HDPE bottles into a single 500 mL sterilized HDPE bottle. Samples for phage were collected in 1L sterilized HDPE bottles, while samples for analysis of virus were collected in 5 x 4L cubitainers. All samples were placed on ice in the dark and transported to the laboratory for processing within six hours. Sample analysis for total coliforms, fecal coliforms, and enterococcus was initiated within the six-hour holding time for these measurements.

Samples for *Bacteroides* and enterococcus QPCR analysis were collected as described by Brinkman *et al.* (2003). Samples for QPCR adenovirus and Norwalk-like virus were first amended with 50mM final concentration MgCl before being passed through glass fiber filters (GF/F) (Whatman, Clifton, NJ) using positive pressure. Following concentration, all filters were stored at  $-80^{\circ}\text{C}$  until shipment to the analytical laboratory. Frozen filters were shipped to the laboratory in a cryoshipper containing liquid nitrogen to maintain the integrity of the nucleic acid material. Water samples for phage analysis were stored overnight at  $4^{\circ}\text{C}$  before shipment to the laboratory on ice via overnight express.

### Laboratory Methods

Enterococcus was measured using three different techniques. Individual samples from each site were measured using Enterolert™ chromogenic substrate and the Quantitray 2000™ system (IDEXX Westbrook, ME), while composite samples were measured using the 24-hour EPA Method 1600 (m-EI). The third technique used to measure enterococcus was QPCR (Brinkman *et al.* 2003). Unlike the membrane filtration or chromogenic substrate techniques that rely on growth-based endpoints, QPCR relies on amplification of unique DNA sequences to estimate the number of bacterial cells in the original sample (Brinkman *et al.* 2003; Haugland. *In press*). This technique is currently being used by the U.S. EPA in their National Epidemiology Study.

Total coliforms and fecal coliforms were measured using two different techniques. In individual samples, total and fecal coliforms were enumerated by membrane filtration using APHA Method 9222B (m-Endo) and APHA Method 9222D (M-FC), respectively. In composite samples, total and fecal coliforms (*E. coli*) were enumerated using Colilert-18™ chromogenic substrate and Quantitray 2000™ system (IDEXX, Westbrook, ME).

The QPCR method also was used to measure *Bacteroides*, a group of fecal obligate anaerobic bacteria that cannot survive for extended periods in oxygenated environments (Bernhard and Field 2000; Bernhard *et al.* 2003). Measurements of this indicator were performed simultaneously with QPCR measurements of enterococcus.

F+ and somatic coliphages were detected and quantified in 1 L volumes of water by a modification of USEPA Method 1601 for enrichment and spot-plating that provides a Most Probable Number (MPN) estimate of coliphage concentration. One-liter sample volumes were supplemented with 0.05M MgCl<sub>2</sub>, host bacteria were added (*E. coli* Famp for F+ coliphages or *E. coli* CN-13 for somatic coliphages), the sample was quickly divided into aliquots of three replicate volumes each of 300, 30, and 3 mL, and these volumes were enriched overnight at  $36^{\circ}\text{C}$ . A small volume of each enrichment culture was spotted onto an agar medium lawn of host bacteria and incubated for 4 hours at  $36^{\circ}\text{C}$  and scored for the presence of coliphages. The number of enrichment cultures that were positive for coliphages were used to compute an MPN concentration.

Analysis of Norwalk-like viruses and adenoviruses on GF/F filters was conducted by molecular methods. Three-quarter pieces of the first 75% of frozen filters with DNA concentrates were eluted and extracted using 1.5% beef extract elution, PEG precipitation, and viral-NA extraction/purification using GITC lysis buffer and Qiagen midi columns, followed by ethanol precipitation. A 2.5 µl volume of the final 50 µl of total concentrate was analyzed using semi-nested PCR. A one-ninth portion of the remaining 25% frozen Whatman GF/F filters was eluted and extracted using lysis buffer directly, followed by purification using the Qiagen plant kit. Of the final 50 µl volume of nucleic acid extract, 5 µl (10%) was used for (RT)-PCR analysis of each virus (human adenovirus, genogroup I norovirus, and genogroup II norovirus).

**Table 2. Methods, analytical laboratories, and sampling intensity used for water quality measurements during the Mission Bay Epidemiology Study.**

Parameter	Method	Analytical Laboratory	Sampling intensity
Enterococcus	EPA 1600	City of San Diego	Beach composite once per day
Enterococcus	96 well Quantitray	City of San Diego	Hourly sample at every site
Enterococcus	Quantitative PCR	EMSL	Two samples per day at each site
Fecal Coliforms	APHA Method 9222D	City of San Diego	Hourly sample at every site
Fecal Coliforms ( <i>E. coli</i> )	96 well Quantitray	City of San Diego	Beach composite once per day
Total Coliforms	APHA Method 9222B	City of San Diego	Hourly sample at every site
Total Coliforms	96 well Quantitray	City of San Diego	Beach composite once per day
Bacteroides	Quantitative PCR	EMSL	Two samples per day at each site
Somatic Phage	Modified EPA 1601	University of North Carolina	Beach composite once per day
Male-specific Phage	Modified EPA 1601	University of North Carolina	Beach composite once per day
Adenovirus 40 and 41	Quantitative PCR	University of North Carolina	Beach composite once per day
Norwalk-like Virus	Quantitative PCR	University of North Carolina	Beach composite once per day

## Epidemiological Data Collection

Three study instruments were developed for this project including: (1) an interviewer-administered screening form to assess eligibility and desire to participate; (2) a self-administered questionnaire (SAQ) that was completed by study subjects before they left the beach for the day; and (3) a computer-aided telephone interview (CATI) questionnaire administered to study participants approximately two weeks following their visit to a Mission Bay beach (Appendix 1). The study instruments, in addition to the study protocol and consent form, were approved by the Committee for the Protection of Human Subjects at U.C. Berkeley prior to study initiation.

### *Beach Recruitment*

Interviewers canvassed the study beaches, approaching individuals and groups to determine their interest in and eligibility to participate in the study. Eligibility criteria included: (1) no previous participation in the study; (2) at least one family member of the household at the beach was 18 years old or older; (3) home address in the United States, Canada, or Mexico (interviews were conducted in either English or Spanish); and (4) had not swam (face or head under water) in the ocean or in a lake in the previous seven days. If an individual or household was eligible and agreed to participate, the interviewers obtained signed consent from the individual or all participating adult members of the household. Adults gave signed consent for children under 18. Participants were then asked for their names, their contact information, and their city and state of residence. The household data also contained the background variables of the recruited households, including household size and the language that was used to obtain consent. During the screening process, each participant was assigned a non-informative identification code. Interviewers marked the screening form to identify the water quality sampling site that corresponded best with the location of the individual or family on the beach. Participants were given an incentive (beach ball) and asked to complete the SAQ prior to their departure that day.

The SAQ consisted of 18 questions concerning possible exposures at the beach (i.e., swimming, other activities, food and beverages, other exposures) and exposures or illnesses experienced during the 2-3 days prior to the beach visit. The survey took no longer than 15 minutes to complete. Participants who failed to complete the survey at the beach were contacted within three days by telephone interviewers, and their surveys were completed over the phone. Participants that completed the survey at the beach were given additional incentives (water bottles and beach balls).

### *Follow-Up CATI Interview*

Between 10 and 14 days following their beach visit, participants were telephoned and asked to complete a 10- to 15-minute interview. This interview consisted of the following types of questions: (1) demographic information, including race, income, education level; (2) swimming and other exposures since the interview day; (3) existing health problems potentially related to the study outcomes (e.g., chronic diarrhea); and (4) acute health conditions (gastrointestinal, respiratory, skin, eye, or ear) experienced since the visit to the beach. If acute illnesses were experienced, a series of questions were asked to determine whether the subject had to restrict normal activities (missed work or school, or other activities) and whether they visited a doctor, clinic, or other medical facility for the illness. As with the previous interviews, the head of household answered questions for children under 18.

### *Health Outcomes Measured*

The health outcomes quantified through the CATI interview included gastrointestinal illness, respiratory symptoms, dermatologic symptoms, and other non-specific symptoms. Gastrointestinal illness included nausea, vomiting, diarrhea, and stomach pains or cramps. In addition, two categories of highly credible gastrointestinal illness (HCGI) were measured. HCGI-1 was defined as either: (1) vomiting plus diarrhea or fever; or (2) cramps and fever. HCGI-2 was defined as vomiting plus fever. Respiratory outcomes included cough, cough with phlegm, nasal congestion or runny nose, sore throat, and significant respiratory disease (SRD). SRD was defined as: (1) fever plus nasal congestion; or (2) fever plus sore throat; or (3) cough with phlegm. Dermatologic outcomes included skin rashes and infected cuts or scrapes. Non-

specific symptoms included fever, chills, redness or eye irritation, earache, and ear discharge or drainage.

## Data Analysis

### *Water Quality*

Water quality analysis focused on assessment of swimmer exposure, including: (1) identification of the ranges of fecal indicator bacteria densities among beaches; (2) determining whether the compositing strategy within a beach adequately represented the beach average as determined by individual samples at multiple sites across a beach; and (3) correlating the different indicator organisms and methods to ascertain if the densities were providing redundant or unique information relative to swimmer exposure.

### *Epidemiology*

Two principal epidemiological analyses were conducted. The first was a model to evaluate whether there was a significant difference in illness rate between swimmers and non-swimmers. Swimming risk (i.e., swimmers compared to non-swimmers) was contrasted for multiple definitions of “swimming,” including: “any water contact,” “water up to the shoulder,” “water on the face,” “face under the water,” “water in the mouth,” and “swallowed water.” These definitions were designed to reflect qualitatively different levels of exposure to the water.

The second analysis was a model that examined whether there was a significant relationship between the risk of illness in swimmers and water quality (as measured water quality indicators). These models were constructed for each of the measured water quality indicators using numerous approaches for swimmer exposure, including incremental changes for daily geometric mean for all sites at a beach, daily geometric mean for the site(s) nearest the swimmer, and geometric mean for just those site(s) and time(s) nearest the swimmer. Additionally, state water quality thresholds for enterococcus were examined using dichotomous cutpoints ( $>35$  vs.  $\leq 35$  and  $>104$  vs.  $\leq 104$ ) for evaluating risk. In all models involving indicators, a value of zero was used for water quality exposure values below the detection limit.

All analyses were conducted as both univariate and multivariate models. The multivariate models included potential confounding factors as covariates. The covariates examined were age category (0-5, 5-12, 12-30,  $>30$ ), gender, ethnicity, allergies, history of swimming again after the beach interview, history of collecting shells at the beach, history of digging or having one’s body buried in the sand, history of playing with seaweed or algae, history of chronic illnesses (gastrointestinal, asthma, or chronic skin conditions), contact with other sick people, use of insect repellent at the beach, use of sunblock at the beach, history of showering immediately after swimming, consumption of raw or undercooked eggs or meat, income, and consumption of food while at the beach. All variables, except age, were categorized as 1 or 0. Race was collapsed into two categories, white and non-white.

All analyses were conducted using the same basic model that is being used in the U.S. EPA BEACHES study. This is a nested interaction model that allows linear combinations of variables to be estimated. This permits comparisons among swimmers while retaining non-swimmers in the model, as well as comparisons among swimmers versus non-swimmers. The components of the model are:

$p$  = probability of illness

(NOTE: “  $p / (1-p)$  “ defines the odds of illness

$X_1=1$  if any contact with water; 0 otherwise

$X_2$  is the water quality measure

$X_3$  is a 1/0 indicator of other exposure (body contact, head under water, etc.)

Non-swimmers= $\alpha$

$$\ln(p/(1-p)) = \alpha + \beta_1 x_1 + \beta_2 (x_1 * x_2) + \beta_3 x_3 + \beta_4 (x_3 * x_2)$$

(NOTE: The model reduces to  $\ln(\text{odds}) = \alpha$  when all other variables are set equal to “0”, i.e., the situation representing non-swimmers.

$$\text{Swimmers-any contact} = \alpha + \beta_1 x_1 + \beta_2 (x_1 * x_2)$$

$$\text{Swimmers-other contact} = \alpha + \beta_1 x_1 + \beta_2 (x_1 * x_2) + \beta_3 x_3 + \beta_4 (x_3 * x_2)$$

In the multivariate analyses, a backwards deletion procedure (Rothman and Greenland 1998) was used to identify factors that most affected the water quality/illness relationship. This procedure uses the following algorithm:

- (1) The full model is fit with all covariates.
- (2) The estimate of interest is saved (e.g., coefficient for association between water quality and illness)
- (3) The first covariate in the list is removed, and then the model is refit
- (4) The estimate of interest is saved.
- (5) The percentage change between the estimate in Step 2 and the estimate in Step 4 is calculated.
- (6) The procedure is repeated for all covariates in list
- (7) After all models have been fit, determine the covariate that had the smallest impact on the water quality/illness relationship (i.e., the smallest percent change). This covariate is removed completely.
- (8) Repeat Steps 3-7 until removal of any single additional covariate produces a change greater than 10% (or some other pre-specified criterion) in the fully adjusted water quality/illness relationship. In this study, a change greater than 10% was used as the criterion for stopping the removal of covariates.

The advantage of this procedure is that it focuses on the exposure/outcome relationship and selects the covariates that are the strongest confounders of this key relationship. This is in contrast to traditional stepwise procedures that focus on the significance, or strength, of the association between the covariate and the outcome (rather than the association between the exposure and the outcome). The disadvantage is that each model can require extremely long times to complete. For example, many of the models required more than one week to complete (running 24 hours/day).

The risk of illness output from the models was expressed as an odds ratio. For models comparing swimmers and non-swimmers, the odds ratio can be interpreted as the odds of a specific illness in swimmers divided by the odds of illness in non-swimmers. Odds ratios (statistically) significantly greater than 1.0 are indicative of illness elevated for swimmers compared to non-swimmers. For models assessing the association between water quality among swimmers, the odds ratios can be interpreted as the increase in the odds of illness per defined unit of increase in the water quality measure among swimmers. The odds ratios were calculated by exponentiating the regression coefficient provided by the model output.

Attributable risk calculations were performed for health outcomes that were significantly increased in swimmers compared to non-swimmers. Attributable risk is a measure of excess risk. For this study, models adjusted for relevant covariates (see above) were used to estimate the percentages of swimmers and non-swimmers ill for any health outcomes with a statistically significant elevated adjusted odds ratio. The adjusted attributable risk estimates were determined by estimating adjusted probabilities of swimmers and non-swimmers from a multivariate logistic model, weighting the covariates at the mean value for each covariate. The adjusted attributable risk was then calculated as the difference between the probability of illness among swimmers with mean levels of covariates and non-swimmers with mean levels of covariates. These results are expressed as the number of excess cases of illness seen among 1,000 swimmers (along with a 95% confidence interval of this estimate).

Emphasis is placed on the multivariate (adjusted) results throughout the report because they correct for confounding from substantial differences in ethnicity, age, beach, and other covariate distributions. The univariate results, though, are provided in Appendices 2 and 3 for the adjusted odds ratios and attributable risk calculations.

## RESULTS

### Water Quality

A total of 1,897 water samples were collected during the survey, with the sampling schedule and number of samples differing among microbial indicators (Table 3). All intended samples were collected, with the exception of those on June 9, 17, and 18, when drizzle led to a lack of swimmers and sampling was curtailed. With the exception of one sample for traditional indicators that was spilled and four virus samples that were compromised in the freezing/thawing process, every sample collected was analyzed successfully in the laboratory.

**Table 3. Number of samples processed for each beach by indicator type.**

Beach	Traditional Fecal Indicators	PCR-based Fecal Indicators	Phage	Virus
Bonita Cove	324	131	25	24
Crown Point	324	132	23	22
De Anza Cove	207	88	26	25
Leisure Lagoon	539	219	24	23
Tecolote Shores	304	132	24	24
Visitors Center	200	88	24	23
Total	1897	790	151	141

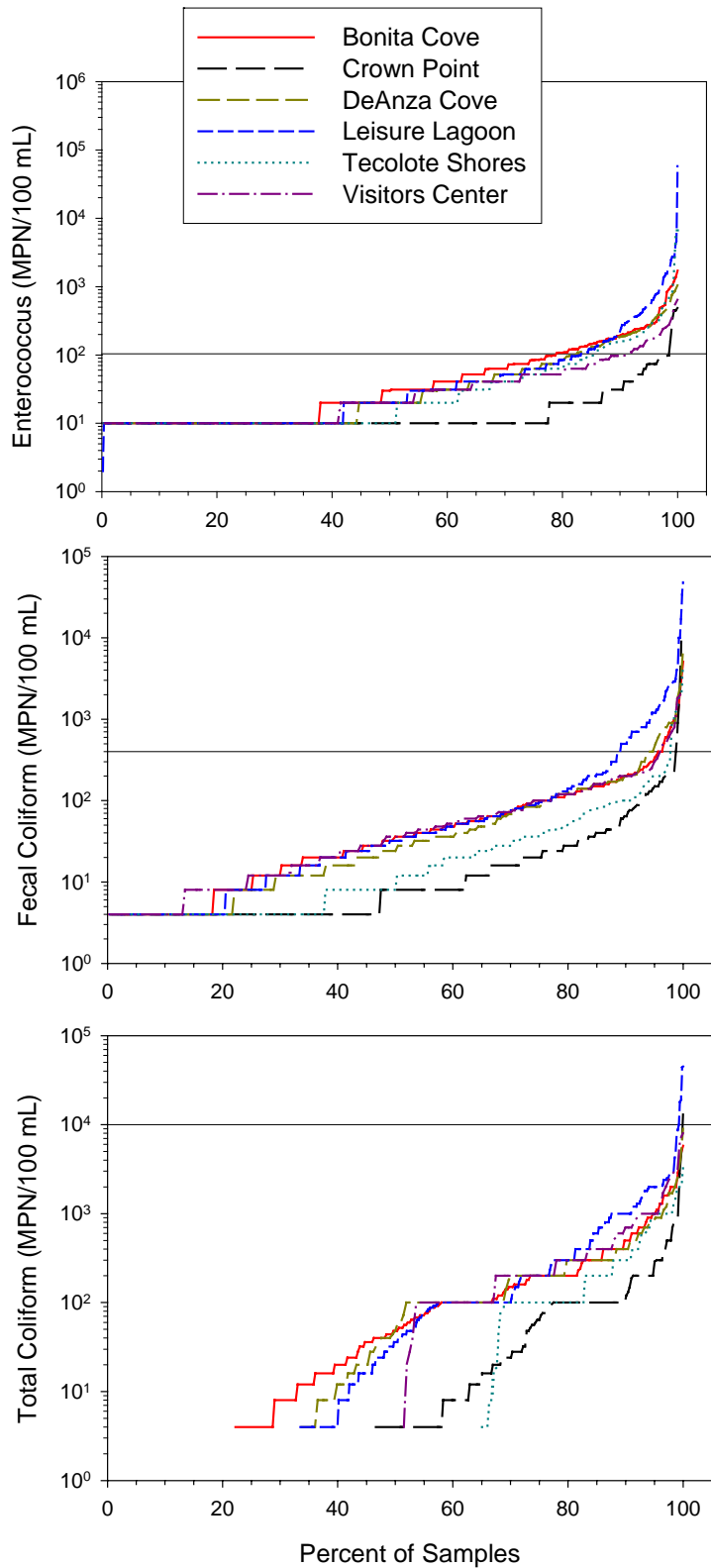
#### *Traditional fecal indicator bacteria*

A wide range of traditional bacterial densities were measured over the course of the study (Table 4). The majority of samples had quantifiable levels of enterococcus, fecal coliform, and total coliform; between 16% and 40% of the samples were below the method detection limits, depending upon the indicator. Maxima for all three bacterial indicators ranged to  $10^5$  MPN/100mL. About 16% of all samples that measured traditional fecal indicator bacteria exceeded state water quality thresholds, with enterococcus accounting for most of the exceedances (96%) and total coliforms the least (2%).

**Table 4. Range of concentrations for traditional water quality indicators (number/100 mL) and frequency of exceedance (N=1,897) of the State of California's water quality threshold.**

	No. of Samples Below RL	Geomean	Maximum	No. of Samples Exceeding Threshold	State Water Quality Threshold
Enterococcus-CS	585	29	57,940	265	>104
Fecal Coliform	304	25	48,000	99	>400
Total Coliform	808	102	45,000	5	>10,000
Total:Fecal Ratio	-	-	-	75	Total:Fecal < 10 When Total > 1,000

The lowest average concentrations occurred at Crown Point (Figure 2), where less than 6% of the enterococcus values exceeded state water quality thresholds. The highest densities of



**Figure 2. Cumulative distribution frequency for enterococcus, fecal coliform, and total coliform by study beach. The horizontal line indicates the state's water quality threshold (see table 4).**

enterococcus were observed at Leisure Lagoon with maximum densities reaching 57,940 MPN/100mL. The greatest frequency of water quality exceedances occurred at Bonita Cove. More than 21% of the samples collected at this beach exceeded state water quality thresholds.

*Non-traditional fecal indicator bacteria*

A wide range of non-traditional bacterial densities were measured over the course of the study (Table 5). The majority of samples had quantifiable levels of enterococcus and *Bacteroides*, with 6% and 37% of the samples below method detection limits, respectively. Maxima for both bacterial indicators ranged from 10<sup>5</sup> to 10<sup>6</sup> MPN/100mL. For enterococcus, 42% of samples exceeded the state water quality threshold. There is no state water quality threshold for *Bacteroides*.

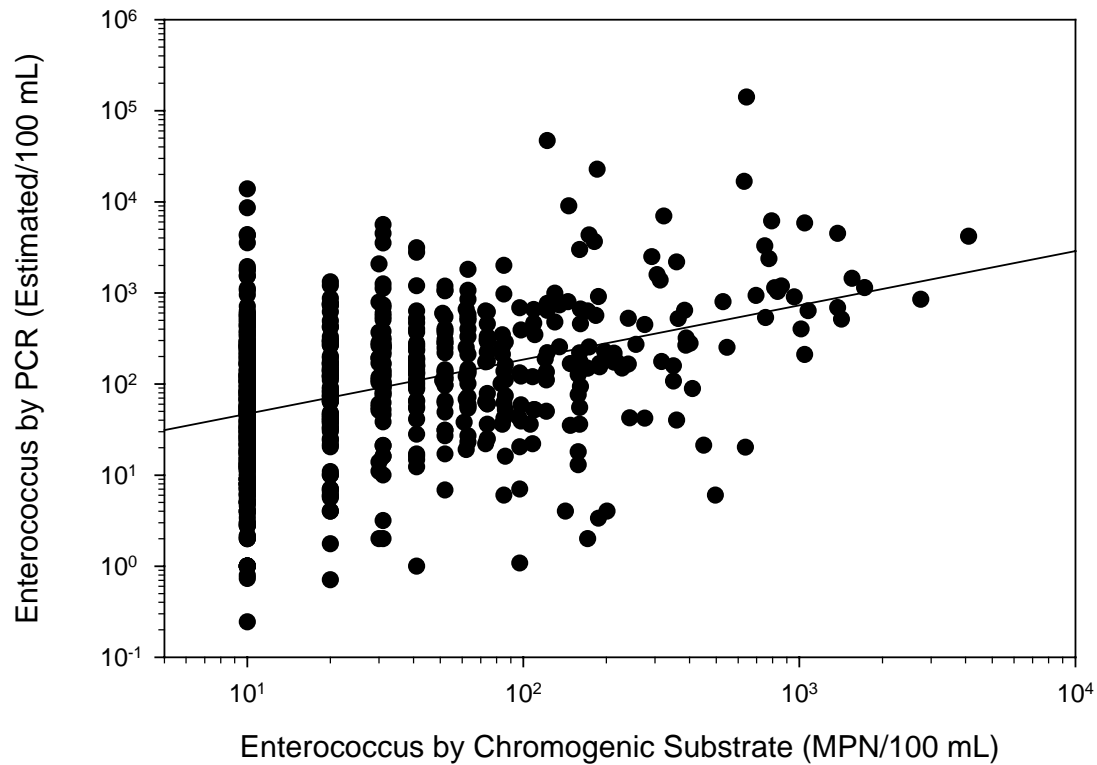
**Table 5. Range of concentrations (number/100 mL) for non-traditional fecal indicator bacteria. QPCR = quantitative polymerase chain reaction.**

	No. of Samples Below RL	Geomean	Maximum	No. of Samples Exceeding Threshold	State Water Quality Threshold
Enterococcus-QPCR	46	65	141,053	351	>104
Bacteroides	294	102	3,718,815	-	-

Only minimal correlation was found among traditional and non-traditional fecal indicator bacteria indicators (Table 6). The best relationships were among the traditional indicator bacteria, particularly the coliform groups. The worst relationships were for *Bacteroides*, which might be expected since they are functionally a different group of microorganisms. For enterococcus, the relationship between the growth-based assay and the nucleic acid-based technology was not strong (Figure 3). QPCR overestimated the enterococcus density compared to the growth-based assays, possibly due to the presence of non-viable DNA, which are only measured by PCR.

**Table 6. Correlation coefficients between traditional and non-traditional fecal indicator bacteria. CS= chromogenic substrate; QPCR = quantitative polymerase chain reaction.**

	Fecal Coliform	Enterococcus-CS	Enterococcus-QPCR	Bacteroides
Total Coliform	0.51	0.40	0.28	0.01
Fecal Coliform		0.35	0.17	0.01
Enterococcus-CS			0.24	0.24
Enterococcus-QPCR				0.01



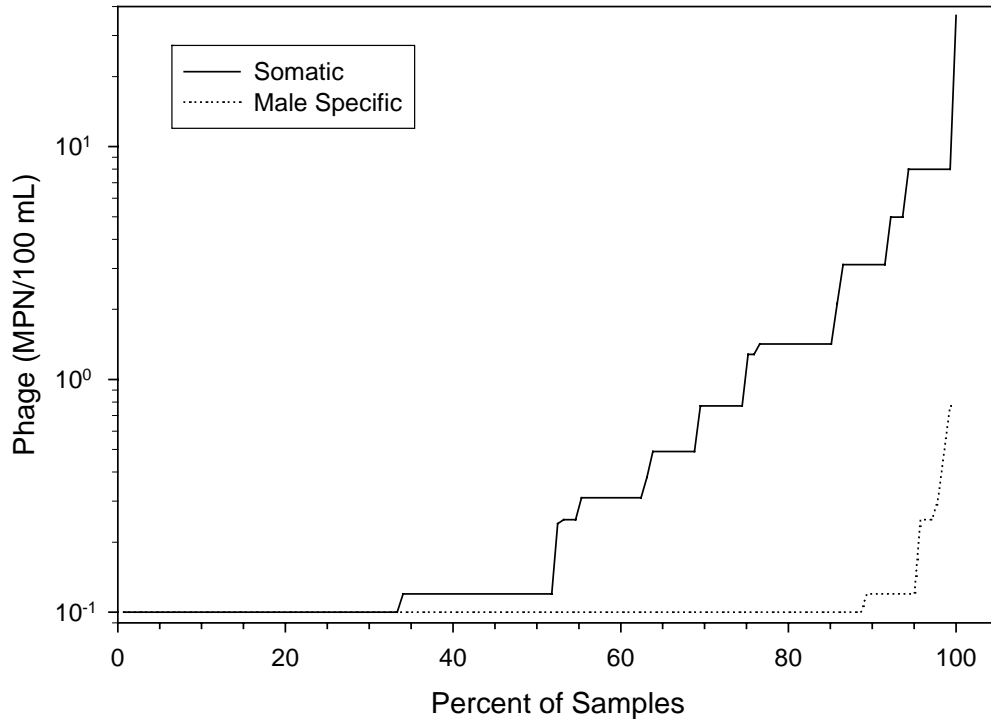
**Figure 3. Comparison between enterococcus using traditional growth-based assay (chromogenic substrate) versus the non-traditional nucleic acid-based (QPCR) technology.**

*Virus Measurements*

Virtually no pathogenic virus was detected in the samples collected from Mission Bay over the course of the study (Table 7). There were no detectable Norwalk-like virus and only a single sample detected for adenovirus. The majority of samples had quantifiable levels of somatic phage, but not for male-specific phage, which is more strongly associated with human fecal material (Figure 4). Roughly 68% of the samples had detectable levels of somatic phage and maximum concentrations were observed near 36 MPN/100 mL. Male-specific phage was detected in 11% of the samples and maximum concentrations reached only 1 MPN/100 mL.

**Table 7. Range of concentrations (number/100 mL) for virus measurements.**

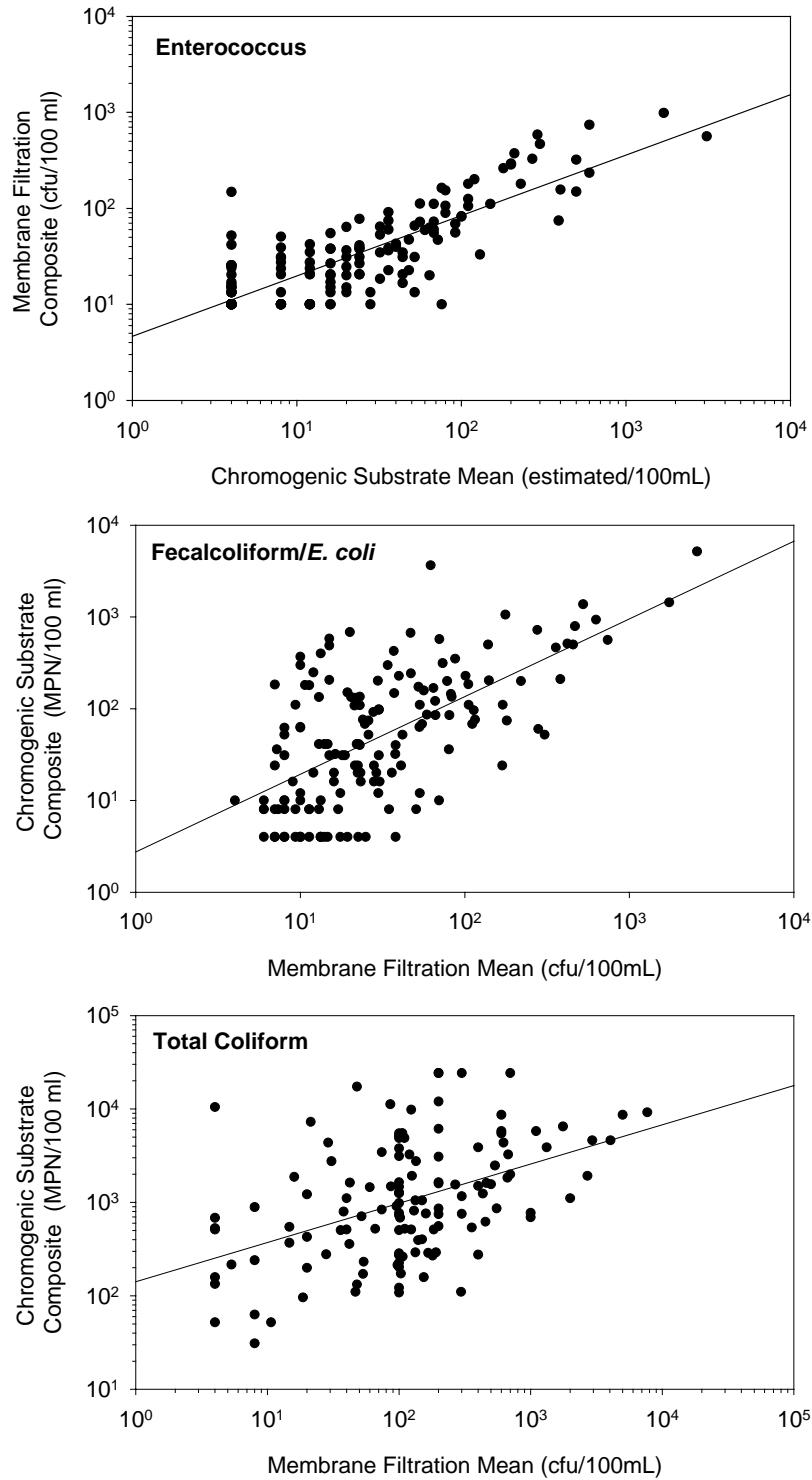
	<b>Total No. of Samples</b>	<b>No. of Samples Below RL</b>	<b>Geomean</b>	<b>Max</b>
Adenovirus	151	150	-	0.01
Norwalk-like Virus	151	151	-	-
Male-specific Phage	141	125	0.2	0.78
Somatic Phage	141	45	0.6	36.6



**Figure 4. Cumulative distribution frequency for somatic and male-specific phage in Mission Bay during the study.**

#### *Effectiveness of compositing*

Comparisons of composite samples to averages of individual grab samples for a site indicated that compositing was effective in representing beach-wide water quality for enterococcus (Figure 5). Compositing described 69% of the variability in the individual grab sample arithmetic means ( $r^2 = 0.69$ ), and the y-intercept closely approximated the origin. This relationship was considered quite reasonable considering laboratory duplicate analysis described 61% of the variability observed between paired laboratory analyses from the same sample container using the same (chromogenic substrate) method ( $r^2 = 0.61$ ). Significant relationships existed for composite samples versus the arithmetic mean of individual grab samples ( $r^2 = 0.39$ ) for the fecal coliforms. Fecal coliform comparisons may be hindered because the chromogenic substrate method quantifies *E. coli* while the membrane filtration quantifies the entire fecal coliform group. The weakest relationship between composite samples and the arithmetic mean of individual grab samples was for total coliform ( $r^2 = 0.06$ ).



**Figure 5. Comparison of compositing versus the arithmetic mean of individual grab samples for enterococcus, fecal coliform/E. coli, and total coliform. Composite and grab samples were analyzed using either the chromogenic substrate or membrane filtration methodologies.**

## Epidemiology

A total of 12,469 individuals and 5,062 households were enrolled in the study. Of these, 8,797 (71%) of the enrolled participants and 3,501 (69%) of the households completed the follow-up telephone interview (Tables 8 and 9). Fifty-seven percent (n=4,971) of those that completed the follow-up interview were swimmers, compared to 3,742 non-swimmers. Non-swimmers were largely comprised of teens and adults aged 12 and older. In contrast, swimmers were roughly evenly divided among age groups with the majority (n=1,461, 29%) being 5 to 12 years old. There were slightly more males (54%) than female (45%) participants, which remained similar among swimmer and non-swimmer categories. Participants were dominated by Hispanic (54%) and white (28%) ethnicities.

Tabulations of participant responses (all beaches combined and separately by beach) to questions regarding sociodemographic characteristics, and exposures prior to, during, and following their visit to the beach can be found in Appendices 4, 5, 6 and 7, respectively.

**Table 8. Individual sociodemographic characteristics collected from study participants at all beaches from Mission Bay.**

Characteristic	Surveyed Participants							
	All		Swimmers		Non-swimmers		Missing	
	(N = 8,797 )		(N = 4,971 )		(N = 3,742)		(N = 84)	
	n	%	n	%	n	%	n	%
Age								
0 - 5	1,214	13.8	870	17.5	326	8.7	18	21.4
5.1 - 12	1,808	20.6	1,461	29.4	332	8.9	15	17.9
12.1 - 30	2,366	26.9	1,215	24.4	1,127	30.1	24	28.6
30.1 - 55	2,928	33.3	1,251	25.2	1,654	44.2	23	27.4
>55	332	3.8	76	1.5	253	6.8	3	3.6
Missing	149	1.7	98	2.0	50	1.3	1	1.2
Gender								
Male	4,761	54.1	2,624	52.8	2,100	56.1	37	44.0
Female	3,948	44.9	2,292	46.1	1,609	43.0	47	56.0
Missing	88	1.0	55	1.1	33	0.9	0	0.0
Race								0.0
White	2,495	28.4	1,181	23.8	1,307	34.9	7	8.3
African American	369	4.2	165	3.3	194	5.2	10	11.9
American Indian/Alaskan Native	62	0.7	35	0.7	27	0.7		
Asian/Pacific Islander	463	5.3	177	3.6	281	7.5	5	6.0
Hispanic/Latino	4,723	53.7	3,052	61.4	1,616	43.2	55	65.5
Mixed Race	407	4.6	241	4.8	163	4.4	3	3.6
Other	227	2.6	96	1.9	128	3.4	3	3.6
Missing	51	0.6	24	0.5	26	0.7	1	1.2

**Table 9. Household sociodemographic characteristics collected from study participants at all beaches from Mission Bay.**

Characteristic	Surveyed Participants N = 3,501 Households)	
	n	%
Household size (# of persons)		
1	1,269	36.2
2	649	18.5
3	532	15.2
4	511	14.6
5	290	8.3
6	140	4.0
7	68	1.9
>8	42	1.2
Missing	0	0.0
Country of Residence (HH)		
United States	3,170	90.5
Mexico	66	1.9
Canada	2	0.1
Missing	263	7.5
Average Annual Income (HH)		
< 10,000	284	8.1
10,001 to 20,000	639	18.3
20,001 to 30,000	444	12.7
30,001 to 40,000	360	10.3
40,001 to 50,000	294	8.4
50,001 to 60,000	231	6.6
60,001 to 70,000	181	5.2
70,001 to 80,000	210	6.0
80,001 to 100,000	229	6.5
>100,000	309	8.8
Missing	321	9.2

### *Health Outcomes for Swimmers versus Non-swimmers*

Only two of the 14 health outcomes evaluated had an odds ratio that was consistently significantly elevated across all water exposures after adjustment for covariates (Table 10). The two outcomes for which there was increased risk were skin rash and diarrhea. Complete results for all health outcomes and all definitions of water exposure can be found in Appendix 2.

While the risk of diarrhea was significantly increased among swimmers compared to non-swimmers, the risk was greatest in a narrow age band (Table 11). Five- to 12-year-old children had at least double the odds of this health outcome after any water contact compared to non-swimmers of the same age. The elevated odds ratio in this age group was seen across multiple definitions of water exposure ranging from “any water contact” to “swallowed water.”

The risk of diarrhea was greater in Caucasian swimmers than in Hispanic swimmers, particularly among those who reported swallowing water (Table 12). The risk of diarrhea was significantly elevated for all ages of Caucasians after swallowing water, but was highest in Caucasian swimmers aged 5 to 12 years old. Although the risk of diarrhea was not statistically significantly elevated in Hispanic swimmers, the greatest odds ratios were observed in the 5- to 12-year-old age group. In contrast to the ethnic differences observed for diarrhea, the risk of skin rash was comparable between Caucasians and Hispanic swimmers despite increased water exposure. Odds ratios for skin rash were greatest in the 0- to 5-year-old age group compared to other age groups. When comparing ethnicity, odds ratios for skin rash were always greatest in Hispanic swimmers compared to Caucasians of the same age group.

**Table 10. Adjusted odds ratios (swimmers vs. non-swimmers) for health outcomes using various definitions of water exposure. Bolded numbers indicate statistical significance.**

Health Outcome	Adjusted OR (95% CI)		
	Any Water Contact	Water on Face	Swallow Water
<b>Gastrointestinal</b>			
Diarrhea	<b>1.36 (1.04-1.78)</b>	<b>1.54 (1.16 – 2.06)</b>	<b>1.89 (1.34 – 2.66)</b>
HCGI-1	0.96 (0.68-1.37)	1.03 (0.71 – 1.50)	1.01 (0.62, 1.66)
HCGI-2	0.93 (0.49-1.75)	1.10 (0.57 – 2.13)	1.12 (0.51, 2.45)
Nausea	0.88 (0.64-1.23)	1.11 (0.77, 1.61)	1.41 (0.91, 2.17)
Cramps	1.07 (0.81-1.42)	1.14 (0.86, 1.51)	<b>1.53 (1.08, 2.15)</b>
Vomiting	0.85 (0.58-1.26)	0.92 (0.61, 1.37)	0.86 (0.49, 1.52)
<b>Skin Rash</b>	<b>2.25 (1.60-3.16)</b>	<b>2.39 (1.72 – 3.31)</b>	<b>2.11 (1.37 – 3.24)</b>
<b>Eye Irritation</b>	1.19 (0.93 – 1.52)	1.29 (0.99 – 1.68)	<b>1.69 (1.23 – 2.30)</b>
<b>Ear</b>			
Earache	0.96 (0.65-1.44)	1.00 (0.64 – 1.56)	1.10 (0.63 – 1.93)
Ear Discharge	0.40 (0.16-1.01)	0.47 (0.19 – 1.13)	0.82 (0.22 – 3.00)
<b>Fever</b>	0.96 (0.70-1.32)	1.04 (0.74 – 1.47)	1.15 (0.76 – 1.75)
<b>Respiratory</b>			
SRD	1.08 (0.80-1.45)	1.03 (0.75 – 1.43)	0.99 (0.62 – 1.57)
Sore Throat	0.89 (0.69-1.16)	0.96 (0.71 – 1.32)	0.87 (0.56 – 1.34)
Cough	0.74 (0.54-1.02)	0.77 (0.54 – 1.11)	0.82 (0.47 – 1.41)

**Table 11. Health outcomes by age group and water exposure.**

	Any Water Exposure			
	Age Group (years)			
	0 - 5	>5 - 12	>12 - 30	>30
<b>Gastrointestinal</b>				
Diarrhea	0.75 (0.40 - 1.40)	<b>2.80 (1.07 - 7.27)</b>	1.71 (0.96 - 3.05)	1.28 (0.85 - 1.93)
HCGI-1	0.86 (0.45 - 1.59)	1.33 (0.56 - 3.14)	0.73 (0.36 - 1.44)	1.37 (0.60 - 3.15)
HCGI-2	0.74 (0.31 - 1.75)	2.26 (0.28 - 18.45)	0.64 (0.15 - 2.74)	2.10 (0.30 - 14.73)
Nausea	1.90 (0.62 - 5.83)	1.40 (0.52 - 3.79)	0.46 (0.26 - 0.83)	1.11 (0.63 - 1.95)
Cramps	1.20 (0.53 - 2.70)	1.61 (0.77 - 3.37)	0.57 (0.34 - 0.94)	1.51 (0.93 - 2.43)
Vomiting	0.58 (0.31 - 1.10)	1.59 (0.54 - 4.68)	0.68 (0.31 - 1.47)	1.45 (0.64 - 3.30)
<b>Skin Rash</b>	<b>5.86 (1.81 - 19.0)</b>	<b>3.26 (1.30 - 8.15)</b>	1.60 (0.89 - 2.86)	<b>1.84 (1.04 - 3.25)</b>
<b>Eye Irritation</b>	0.53 (0.27 - 1.04)	1.84 (0.94 - 3.61)	1.21 (0.81 - 1.82)	1.23 (0.80 - 1.88)
<b>Ear</b>				
Earache	0.86 (0.31 - 2.39)	1.14 (0.37 - 3.49)	0.62 (0.30 - 1.25)	1.47 (0.73 - 2.96)
Ear Discharge	0.12 (0.01 - 1.66)	0.22 (0.03 - 1.59)	0.58 (0.14 - 2.37)	0.63 (0.10 - 3.86)
<b>Fever</b>	0.68 (0.39 - 1.16)	1.67 (0.67 - 4.15)	0.83 (0.44 - 1.56)	1.44 (0.73 - 2.84)
<b>Respiratory</b>				
SRD	0.63 (0.32 - 1.22)	1.23 (0.57 - 2.66)	1.01 (0.58 - 1.75)	1.43 (0.86 - 2.35)
Sore Throat	0.74 (0.33 - 1.69)	1.21 (0.57 - 2.57)	0.82 (0.51 - 1.30)	0.90 (0.61 - 1.35)
Cough	0.52 (0.27 - 1.02)	0.84 (0.38 - 1.87)	0.78 (0.41 - 1.49)	0.84 (0.49 - 1.45)

(Table 11 Continued). Health outcomes by age group and water exposure.

	Water On Face			
	Age Group (years)			
	0 - 5	>5 - 12	>12 - 30	>30
<b>Gastrointestinal</b>				
Diarrhea	0.92 (0.49 – 1.74)	<b>3.11 (1.19 – 8.15)</b>	<b>2.40 (1.31 – 4.38)</b>	1.15 (0.69 – 1.90)
HCGI-1	1.07 (0.57 – 2.00)	1.24 (0.52 – 2.98)	0.84 (0.40 – 1.77)	0.93 (0.31 – 2.77)
HCGI-2	0.95 (0.40 – 2.28)	2.48 (0.30 – 20.33)	0.95 (0.21 - 4.27)	0.53 (0.03 – 8.01)
Nausea	1.97 (0.72 – 5.42)	1.35 (0.52 – 3.51)	0.59 (0.30 – 1.16)	1.31 (0.65 – 2.63)
Cramps	1.51 (0.67, 3.40)	1.84 (0.88 - 3.83)	0.61 (0.36 - 1.03)	1.23 (0.73 - 2.06)
Vomiting	0.75 (0.39 – 1.42)	1.64 (0.55 – 4.89)	0.84 (0.39 – 1.83)	0.97 (0.34 – 2.79)
<b>Skin Rash</b>	<b>6.96 (2.14 – 22.62)</b>	<b>3.67 (1.47 – 9.17)</b>	1.49 (0.86 – 2.57)	<b>2.19 (1.21 – 3.95)</b>
<b>Eye Irritation</b>	0.54 (0.27 – 1.08)	1.88 (0.96 – 3.70)	1.39 (0.90 – 2.16)	1.25 (0.75 – 2.08)
<b>Ear</b>				
Earache	0.57 (0.18 – 1.79)	1.15 (0.37 – 3.60)	0.68 (0.31 – 1.48)	2.16 (0.97 – 4.83)
Ear Discharge	0.20 (0.02 – 2.39)	0.33 (0.05 – 2.24)	0.46 (0.11 – 1.98)	0.97 (0.20 – 4.64)
<b>Fever</b>	0.74 (0.40 – 1.35)	1.78 (0.70 – 4.51)	1.23 (0.62 – 2.46)	0.76 (0.28 – 2.09)
<b>Respiratory</b>				
SRD	0.57 (0.29 – 1.14)	1.29 (0.58 – 2.84)	0.99 (0.55 – 1.79)	1.39 (0.76 – 2.53)
Sore Throat	0.73 (0.29 – 1.80)	0.88 (0.39 – 1.98)	1.22 (0.71 – 2.11)	0.98 (0.58 – 1.64)
Cough	0.42 (0.20 – 0.89)	0.93 (0.41 – 2.10)	0.80 (0.39 – 1.68)	0.99 (0.51 – 1.90)

	Swallow Water			
	Age Group (years)			
	0 - 5	>5 - 12	>12 - 30	>30
<b>Gastrointestinal</b>				
Diarrhea	0.97 (0.47 - 2.01)	<b>5.30 (1.96 - 14.33)</b>	1.76 (0.79 - 3.91)	1.78 (0.86 - 3.66)
HCGI-1	0.61 (0.25 - 1.49)	1.72 (0.65 - 4.59)	1.34 (0.49 - 3.67)	0.70 (0.08 - 6.29)
HCGI-2	0.74 (0.23 – 2.36)	2.83 (0.32 – 24.83)	0.92 (0.13 – 6.46)	3.15 (0.18 – 54.04)
Nausea	2.27 (0.76 – 6.81)	2.29 (0.84 – 6.23)	0.56 (0.21 – 1.46)	2.08 (0.81 – 5.33)
Cramps	2.05 (0.88 – 4.78)	<b>2.51 (1.18 – 5.33)</b>	0.52 (0.23 – 1.18)	1.83 (0.85 – 3.92)
Vomiting	0.41 (0.14- 1.18)	2.15 (0.57 – 8.13)	1.27 (0.43 – 3.77)	1.13 (0.12 – 10.12)
<b>Skin Rash</b>	<b>10.42 (2.34 - 46.40)</b>	<b>4.10 (1.39 - 12.09)</b>	1.15 (0.46 - 2.86)	1.32 (0.39 - 4.46)
<b>Eye Irritation</b>	0.89 (0.41 – 1.92)	<b>2.87 (1.44 – 5.71)</b>	1.48 (0.82 – 2.67)	1.53 (0.72 – 3.25)
<b>Ear</b>				
Earache	0.25 (0.03 – 2.18)	2.09 (0.65 – 6.78)	0.78 (0.26 – 2.28)	0.89 (0.18 – 4.30)
Ear Discharge	tf	tf	tf	tf
<b>Fever</b>	0.73 (0.36 – 1.45)	2.36 (0.88 – 6.28)	1.51 (0.64 – 3.55)	1.04 (0.22 – 4.91)
<b>Respiratory</b>				
SRD	0.62 (0.24 – 1.57)	1.18 (0.46 – 3.03)	1.03 (0.41 – 2.55)	0.71 (0.15 – 3.25)
Sore Throat	0.81 (0.26 – 2.50)	1.03 (0.42 – 2.52)	0.90 (0.38 – 2.10)	0.69 (0.25 – 1.86)
Cough	0.44 (0.15 - 1.32)	1.34 (0.48 - 3.70)	1.50 (0.53 - 4.27)	tf

**Table 12. Adjusted odds ratios (swimmers vs. non-swimmers) for diarrhea and skin rash using various definitions of water exposure, stratified by racial category and age group.**

	Any Water Exposure		Water on Face		Swallow Water	
	Caucasian	Hispanic	Caucasian	Hispanic	Caucasian	Hispanic
<b>Diarrhea</b>						
All Ages	<b>2.16 (1.49 – 33.13)</b>	0.98 (0.64 – 1.52)	<b>2.38 (1.46 – 3.89)</b>	1.16 (0.77 – 1.74)	<b>3.92 (2.34 – 6.56)</b>	1.37 (0.83 – 2.28)
0 – 5	1.73 (0.56 – 5.36)	0.68 (0.26 – 1.76)	2.01 (0.56 – 7.27)	1.06 (0.42 – 2.68)	<b>5.47 (1.38 – 21.62)</b>	1.10 (0.38 – 3.19)
>5 – 12	4.90 (0.64 – 37.32)	2.70 (0.61 – 12.06)	5.84 (0.70 – 48.51)	2.09 (0.60 – 7.27)	<b>8.53 (1.06 – 68.47)</b>	3.02 (0.82 – 11.16)
>12 – 30	2.33 (0.98 – 5.55)	1.20 (0.50 – 2.86)	<b>3.17 (1.09 – 9.24)</b>	1.87 (0.79 – 4.45)	<b>3.66 (1.08 – 12.44)</b>	1.70 (0.49 – 5.91)
>30	<b>1.96 (1.19 – 3.23)</b>	0.69 (0.33 – 1.44)	1.79 (0.85 – 3.76)	0.62 (0.28 – 1.38)	<b>3.32 (1.22 – 9.03)</b>	0.88 (0.27 – 2.86)
<b>Skin Rash</b>						
All Ages	<b>2.44 (1.81 – 3.27)</b>	<b>2.09 (1.42 – 3.08)</b>	<b>2.39 (1.72 – 3.31)</b>	<b>2.19 (1.41 – 3.39)</b>	<b>2.11 (1.37 – 3.24)</b>	<b>2.01 (1.20 – 3.35)</b>
0 – 5	<b>5.86 (1.81 – 19.00)</b>	<b>12.05 (1.64 – 88.84)</b>	<b>6.96 (2.14 – 22.62)</b>	<b>12.01 (1.59 – 90.47)</b>	<b>10.42 (2.34 – 46.40)</b>	<b>12.54 (1.58 – 99.30)</b>
>5 - 12	<b>3.26 (1.3 – 8.15)</b>	2.69 (0.96 – 7.53)	<b>3.67 (1.47 – 9.17)</b>	<b>3.24 (1.14 – 9.21)</b>	<b>4.10 (1.39 – 12.09)</b>	2.95 (0.98 – 8.86)
>12 - 30	1.60 (0.89 – 2.86)	1.39 (0.67 – 2.86)	1.49 (0.86 – 2.57)	1.52 (0.69 – 3.35)	1.15 (0.46 – 2.86)	1.23 (0.39 – 3.94)
>30	<b>1.84 (1.04 – 3.25)</b>	1.09 (0.53 – 2.22)	<b>2.19 (1.21 – 3.95)</b>	1.51 (0.67 – 3.40)	1.32 (0.39 – 4.46)	1.23 (0.35 – 4.33)

The calculated attributable risks (Table 13) for diarrhea estimated an excess of 11.1 cases of diarrhea per 1,000 swimmers who had any contact with the water in Mission Bay during the study period. This risk increased as the intensity of water exposure increased, with 16.1 per 1,000 among those who reported facial contact with water and 27.2 cases per 1,000 swimmers who reported swallowing water. Children aged 5 to 12 years old had the greatest attributable risk for diarrhea following swimming. For example, this age group showed an estimated excess of 27.4 cases per 1,000 among children with any water contact, an excess of 31.9 cases per 1,000 among those with facial contact with the water, and an excess of 59 cases per 1,000 among those who swallowed water. Excess cases of skin rash were highest in the 0- to 5-year-old age group, ranging from an excess of 46.8 per 1,000 with any water contact to 56.2 per 1,000 swimmers in this age group who swallowed water.

**Table 13. Frequency (percent) reporting illness and calculated attributable risk (per 1,000 swimmers).**

<b>Diarrhea</b>		<b>Percent ill - Adjusted</b>	
	<b>Adjusted Attributable Risk (95% CI) (expressed as excess cases per 1,000 swimmers)</b>	<b>Non-swimmers</b>	<b>Swimmers</b>
<b>Any Water Contact</b>			
All Ages	11.1 (0.0 - 22.1)	3.20	4.31
0 - 5	-14.1 (-47.7 - 18.5)	6.01	4.60
>5 - 12	27.4 (-8.9 - 63.7)	1.59	4.33
>12 - 30	14.3 (-7.0 - 35.6)	2.09	3.51
>30	10.0 (-8.6 - 28.6)	3.74	4.75
<b>Water on Face</b>			
All Ages	16.1 (3.6 - 38.6)	3.10	4.71
0 - 5	-4.2 (-36.7 - 28.4)	5.27	5.69
>5 - 12	31.9 (2.1 - 61.7)	1.58	4.78
>12 - 30	26.4 (-2.6 - 5.54)	1.98	4.62
>30	5.2 (-15.1 - 25.6)	3.73	4.25
<b>Swallow Water</b>			
All Ages	27.2 (8.9 - 45.6)	3.25	5.97
0 - 5	-1.6 (-42.5 - 39.4)	6.09	5.93
>5 - 12	59.0 (15.0 - 103.0)	1.48	7.38
>12 - 30	18.5 (-13.6 - 50.6)	2.55	4.40
>30	26.4 (-15.7 - 68.4)	3.63	6.28

(Table 13 Continued). Frequency (percent) reporting illness and calculated attributable risk (per 1,000 swimmers).

<b>Skin Rash</b>		<b>Percent ill - Adjusted</b>	
	<b>Adjusted Attributable risk (95% CI) (expressed as excess cases per 1,000 swimmers)</b>	<b>Non-swimmers</b>	<b>Swimmers</b>
<b>Any Water Contact</b>			
All Ages	19.0 (10.9 – 27.1)	1.58	3.48
0 – 5	46.8 (26.2 – 67.4)	1.02	5.70
>5 - 12	34.1 (15.8 – 52.3)	1.59	4.99
>12 - 30	10.9 (-2.3 – 24.1)	1.88	2.97
>30	10.6 (0.2 - 21.0)	1.27	2.31
<b>Water on Face</b>			
All Ages	22.6 (13.6 – 31.6)	1.69	3.95
0 - 5	52.1 (31.3 - 72.9)	0.93	6.14
>5 - 12	38.7 (20.4 - 57.0)	1.53	5.41
>12 - 30	10.8 (-4.3 - 25.9)	2.28	3.36
>30	15.0 (2.1 - 27.8)	1.30	2.80
<b>Swallow Water</b>			
All Ages	18.0 (3.7 – 32.3)	1.69	3.49
0 - 5	56.2 (-5.5 - 118.0)	0.64	6.3
>5 - 12	39.4 (5.0 - 73.7)	1.34	5.28
>12 - 30	3.1 (18.1 – 24.2)	2.08	2.39
>30	4.1 (-16.8 – 25.1)	1.34	1.75

**Relationship between Health Outcomes and Water Quality**

No correlation was observed between increased risk of illness and increased levels of traditional water quality indicators including enterococcus, fecal coliform, or total coliform. Using diarrhea as an example, odds ratios were not statistically significantly elevated due to increases in enterococcus (Table 14). The lack of relationship resulted despite numerous approaches to water quality exposure (i.e., combining or separating sites at a beach) or calculation of indicator metrics (i.e., daily geomean, daily maxima, or various cutpoints). Of particular note, the state water quality thresholds did not correlate with an increased risk of illness (Table 15).

Additionally, no correlation was found between increased risk of illness and levels of Bacteroides, enterococcus using rapid methods (QPCR), human pathogenic virus (adenovirus and Norwalk-like virus), or somatic phage. The relationship with viruses was difficult to evaluate, though, because no human pathogenic virus was found and adenovirus was only found in one sample. While low virus counts do not allow evaluation of a potential relationship with the two symptoms that were elevated in swimmers (skin rash and diarrhea), the low counts were consistent with the absence of increased health risk for the other health outcomes evaluated.

Significant associations between the levels of male-specific coliphage and HCGI-1, HCGI-2, nausea, cough, and fever were observed (Table 16). However, a low number of participants were exposed to the water at times when male-specific coliphage was detected (Table 17). Therefore, the relationships between male-specific coliphage and various outcomes should be interpreted cautiously. Results for all health outcomes for various indicator and water exposure levels are presented in Appendix 3.

**Table 14. Adjusted odds ratio for diarrhea after two weeks for various water quality exposure metrics for enterococcus. The unit change in exposure in these models was set to represent a change of (ln 30). There were no statistically significant results.**

	<b>Any Water Contact</b>	<b>Water on Face</b>	<b>Swallow Water</b>
Ln Daily Geomean @ Station Level	0.57 (0.30 – 1.07)	0.66 (0.32 – 1.34)	0.21 (0.05 – 0.85)
Ln Daily Geomean @ Beach Level	0.77 (0.33 – 1.80)	0.62 (0.24 – 1.60)	0.31 (0.06 – 1.59)
Ln Daily Max @ Station Level	0.67 (0.45 - 1.02)	0.77 (0.47 – 1.24)	NA
Ln Daily Max @ Beach Level	0.99 (0.71 – 1.38)	0.93 (0.64 – 1.34)	NA

**Table 15. Adjusted odds ratios for health outcomes using two dichotomous measures of exposure to enterococcus.**

Health Outcome	Adjusted OR (95% CI)	
	> 35 vs. ≤ 35	> 104 vs. ≤ 104
<b>Gastrointestinal</b>		
Diarrhea	1.01 (0.73-1.39)	1.22 (0.85-1.76)
HCGI-1	0.74 (0.51-1.06)	1.13 (0.73-1.75)
HCGI-2	0.69 (0.38-1.25)	0.80 (0.37-1.73)
Nausea	0.78 (0.51-1.20)	1.12 (0.65-1.92)
Cramps	0.91(0.66-1.24)	1.36 (0.95-1.95)
Vomiting	0.67 (0.43-1.03)	1.13 (0.67-1.92)
<b>Skin Rash</b>	0.83 (0.61-1.15)	1.00 (0.67 – 1.49)
<b>Eye Irritation</b>	0.97 (0.72-1.32)	0.77 (0.53-1.11)
<b>Ear</b>		
Earache	1.08 (0.68-1.70)	1.18 (0.70-2.00)
Ear Discharge	1.15 (0.30-4.36)	0.94 (0.19-4.62)
<b>Fever</b>	0.92 (0.65-1.31)	0.89 (0.58-1.37)
<b>Respiratory</b>		
SRD	0.96 (0.67-1.37)	1.13 (0.73-1.73)
Sore Throat	1.10 (0.80-1.50)	1.15 (0.77-1.72)
Cough	0.65 (0.40-1.05)	0.51 (0.25-1.03)

**Table 16. Adjusted odds ratios for various health outcomes after two weeks for water exposures (per unit increase) to male-specific coliphage. Statistically significant results are shown in bold face type.**

**Any Water Contact**

Health Outcome	Adjusted OR (95% CI)
<b>Gastrointestinal</b>	
HCGI-1	<b>1.26 (1.06, 1.48)</b>
HCGI-2	<b>1.43 (1.13, 1.82)</b>
Nausea	<b>1.34 (1.16, 1.55)</b>
Diarrhea	1.14 (0.97, 1.35)
Cramps	1.04 (0.83, 1.32)
Vomiting	1.21 (0.96, 1.53)
<b>Skin Rash</b>	1.00 (0.77, 1.31)
<b>Eye Irritation</b>	1.14 (0.95, 1.36)
<b>Fever</b>	<b>1.25 (1.09, 1.44)</b>
<b>Ear</b>	
Earache	Too few
Ear Discharge	Too few
<b>Respiratory</b>	
SRD	1.05 (0.85, 1.31)
Cough	<b>1.22 (1.02, 1.48)</b>
Sore Throat	1.04 (0.83, 1.30)

**Table 17. Association of male-specific coliphage (defined as >0.10 cfu) with diarrhea.**

	Diarrhea Reported	No Diarrhea Reported	Total
Male-specific Phage Present (>0.10 cfu)	8	153	161
Male-specific Phage Absent	195	3,878	4,073
Total	203	4,031	4,234

*Time in the water*

We also examined whether swimmers with prolonged water exposure (>1 hour) to Mission Bay had an elevated risk of illness compared to non-swimmers and found an OR of 1.44, 95% CI 1.08-1.92. This result is similar to that found in Table 10 for swimmers with any water contact compared to non-swimmers (1.36, 95% CI 1.04-1.78), suggesting a small but insignificant increase in the risk from prolonged exposure.

Among swimmers with greater than 1 hour of water exposure, the odds ratio for a 30-unit (3.4 log) increase in enterococcus was 0.74 (0.23-2.36). This result is similar to that seen for the risk of diarrhea among swimmers (defined as “any water contact”) exposed to enterococcus (0.57, 95% CI 0.30-1.07) for exposure measured as the ln of the daily geomean at the station level (Table 14).

## DISCUSSION

Unlike most previous marine recreational epidemiology studies, this study found no relationship between illness rates and fecal indicator bacteria densities despite investigating numerous exposure measures. Wade *et al.* (2003) systematically reviewed 27 highly relevant marine recreational water epidemiology studies and found an increase in relative risk with increasing fecal indicator concentrations, particularly for enterococcus. For example, the observed increase in risk of swimming-associated illnesses from both Cabelli *et al.* (1982) and Haile *et al.* (1999) was highly correlated with increasing enterococcus concentrations. In virtually all of the studies summarized by Wade *et al.* (2003), however, water quality was impacted by known sources of human fecal contamination. The relationship with enterococcus, or any other fecal indicator bacteria, did not exist in Mission Bay, and one explanation for this difference may be the predominance of non-human fecal sources in Mission Bay. While animal sources can also harbor disease-causing agents, they are less likely to serve as vectors for human disease (NRC 2004).

The use of bacterial indicators as a predictor of swimming-associated illnesses is based on the presumption that they have survival properties similar to the pathogens they are intended to mirror. This presumption is less likely to remain true when circulation is restricted and residence times increase, which can be days to weeks in Mission Bay (Largier *et al.* 2003). Increased survival, and perhaps even regrowth of fecal indicator bacteria, has been suggested in sediments and wrack lining beaches including Mission Bay (Weiskel *et al.* 1996, City of San Diego/MEC Weston 2004). Regardless, the lack of relationship of non-human sources of fecal indicator bacteria to health risk suggests that the 28 water contact advisories posted at beaches in Mission Bay during the course of this study were misleading from a public health perspective, but were required by law.

It is arguable whether the viral measures in our study were better indicators of health risk and could be used in place of bacterial indicators for health risk assessments in Mission Bay. We found that increasing density of male-specific phage was correlated with increased incidence of several health outcomes, including HCGI-1, HCGI-2, nausea, cough, and fever. This is consistent with the success of this measure in freshwater application (Lee *et al.* 1997). However, we interpret these associations cautiously because male-specific coliphage were not detected often and so few subjects were exposed to the water at those times.

The human-specific viruses we measured in Mission Bay were rarely detected, which corresponds well with our low rates of swimming-associated illnesses. We did not encounter high virus counts that would have allowed us to assess their effectiveness as predictors in the positive direction. Moreover, even interpretation of viruses as negative predictors is compromised by technology limitations. We used the most advanced techniques available, but quantifying virus particles in seawater is difficult because DNA and RNA are lost due to complexation and interferences when concentrating and extracting nucleic acid material. Thus, we cannot be certain that the low levels we

observed were due to their absence from the system or from difficulties in recovering viruses that were present. However, our results do suggest that these non-bacterial measures have the potential to be more effective than traditional bacterial indicators as predictors of illness when non-human sources are dominant.

While we found that traditional fecal indicators were ineffective predictors of health effects in this study, it is difficult to extrapolate this finding beyond Mission Bay. Mission Bay is unusual in that it has been subjected to extensive cleanup activities and source tracking studies have identified that human fecal sources are now only a minor contributor to the overall bacterial load (City of SD/MEC Weston 2004). Our study, though, does suggest the need for further evaluation of traditional fecal indicator bacteria in circumstances where non-point, non-human contributions are the dominant fecal source.

It is important not to extrapolate our results beyond our study conditions. We would expect to see an increase in health risks, and likely an association with water quality indicators, if large sources of untreated human fecal material entered the Bay. Such a situation could occur when sewage overflows spill into the Bay.

Finally, we examined swimming-related illnesses during dry weather. No epidemiological data at any beach currently exists for health risks associated with swimming at these beaches following wet-weather events.

## STUDY CONCLUSIONS

The Mission Bay Epidemiology Study was successfully implemented, collecting sufficient water quality data and recruiting sufficient numbers of participants. Based on the resulting data, the answers to our study questions can be summarized as follows:

- *Water contact moderately increased the risk of illness in the two weeks following exposure to water in Mission Bay during the summer of 2003.*

Two of the 14 health outcomes evaluated had an odds ratio that was significantly elevated after adjustment for covariates. The probability of skin rash and diarrhea was consistently significantly elevated in swimmers compared to non-swimmers in Mission Bay during the summer of 2003. The probability of more severe health outcomes such as highly credible gastrointestinal illnesses (HCGI-1 or HCGI-2) and significant respiratory disease (SRD) were not significantly elevated in swimmers compared to non-swimmers.

- *Among those individuals with water contact, there were no associations between illness and measured levels of traditional indicators of water quality.*

No correlation between increased risk of illness and increased levels of traditional water quality indicators (including enterococcus, fecal coliform, or total coliform) was found. This resulted despite numerous approaches to water quality exposure (combining or separating sites at a beach) or calculation of indicator metrics (daily geometric mean or maxima, various cutpoints, etc.). Of particular note in this study, the state water quality thresholds were not predictive of swimming-related illnesses.

- *Among those individuals with water contact, there were no associations between illness and measured levels of any non-traditional indicators of water quality except for male-specific coliphage.*

No correlation between increased risk of illness and increased levels of *Bacteroides*, enterococcus using rapid methods (QPCR), human pathogenic virus (adenovirus and Norwalk-like virus), or somatic phage was found. Since traditional enterococcus methods were unsuccessful at predicting swimming-associated illnesses, it is not surprising that the newer, more rapid methods were equally unsuccessful. Virtually no human pathogenic virus was found; adenovirus was only quantified in one sample. A significant association between the levels of male-specific coliphage and HCGI-1, HCGI-2, nausea, cough, and fever was observed. We interpret these associations cautiously, however, because so few subjects overall were exposed to the water at times when male-specific coliphage was detected.

The findings from Mission Bay are unique in this field, largely because Mission Bay may be a unique circumstance. Certainly, many other enclosed marine beaches, particularly in California, suffer from impaired water quality due to non-point sources of bacteria and poor circulation. However, it is premature at this time to extrapolate the findings from the current study to other enclosed marine beaches, especially if significant source identification work has not been accomplished. Moreover, the epidemiological findings from Mission Bay were collected from periods of dry weather and no known sewage spills. We would expect to see an increase in health risks, and likely an association with water quality indicators, if large sources of untreated human fecal material entered the Bay. No epidemiological data currently exists for health risks associated with swimming at these beaches following wet-weather events.

## LITERATURE CITED

- Bernhard, A.E. and K.G. Field. 2000. Identification of nonpoint sources of fecal pollution in coastal waters by using host-specific 16S ribosomal DNA genetic markers from fecal anaerobes. *Applied and Environmental Microbiology* 66: 1587-1594.
- Bernhard, A.E., T. Goyard, M.T. Simonich and K.G. Field 2003. Application of a rapid method for identifying fecal pollution sources in a multi-use estuary. *Water Research* 37: 909-913.
- Brinkman, N.E., R.A. Haugland, L.J. Wymer, B. Murulrrdhara, R.L. Whitman and S.J. Vesper. 2003. Evaluation of a rapid, quantitative real-time PCR method for enumeration of pathogenic *Candida* cells in water. *Applied and Environmental Microbiology* 69: 1775-1782.
- Cabelli, V.J. 1976. Indicators of recreational water quality. *In.*: A. Hoadley and B. Dutka (eds.), Indicators / Health Hazards Associated with Water. Philadelphia: ASTM 222.
- Cabelli V.J. 1983. Health effects criteria for marine recreational waters. U.S. Environmental Protection Agency. Cincinnati, OH.
- Cabelli, V.J., A.P. Dufour, M.A. Levin, L.J. McCabe and P.W. Haberman. 1979. Relationship of microbial indicators to health effects at marine bathing beaches. *American Journal of Public Health* 69: 690-696.
- Cabelli, V.J., A.P. Dufour, L.J. McCabe and M.A. Levin. 1982. Swimming-associated gastroenteritis and water quality. *American Journal of Epidemiology* 115: 606-16.
- Calderon, R.L., E.W. Mood and A.P. Dufour. 1991. Health effects of swimmers and nonpoint sources of contaminated water. *International Journal of Environmental Health Research* 1: 21-31.
- City of San Diego and MEC/Weston. 2004. Mission Bay Clean Beaches Initiative Bacterial Source Identification Study. City of San Diego and MEC Analytical Systems-Weston Solutions, Inc., San Diego California. Prepared for the State Water Resources Control Board, Sacramento, CA.
- Haile, R.W., J.S. Witte, M. Gold, R. Cressey, C. McGee, R.C. Millikan, A. Glasser, N. Harawa, C. Ervin, P. Harmon, J. Harper, J. Dermand, J. Alamillo, K. Barrett, M. Nides and G.-Y. Wang. 1999. The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology* 10: 355-363.
- Hanley, Y. 2002. Impact of rainfall on microbiological water quality of Mission Bay, California. Masters Thesis. San Diego State University, School of Public Health. San Diego, CA. 106 pp.

Haugland, R.A. *In press*. Rapid Measurement of Bacterial Fecal Indicators In Surface Waters by Quantitative Polymerase Chain Reaction (qPCR) Analysis. *Applied Microbiology*.

Jiang, S., R.T. Noble and W. Chu. 2001. Human adenoviruses and coliphages in urban-runoff impacted coastal waters of southern California. *Applied and Environmental Microbiology* 67: 179-184.

Largier, John. 2003.

Lee, J.V., S.R. Dawson, S. Ward, S.B. Surman and K.R. Neal. 1997. Bacteriophages are better indicator of illness rates amongst users of a white water course fed by a lowland river. *Water Science and Technology* 35: 165-170.

Lipp, E.K., R. Kurz, R. Vincent, C. Rodriguez-Palacios, S.R. Farrah and J.B. Rose. 2001. The effects of seasonal variability and weather on microbial fecal pollution and enteric pathogens in a subtropical estuary. *Estuaries* 24: 266-276.

Noble, R.T. and J.A. Fuhrman. 2001. Enteroviruses detected by reverse transcriptase polymerase chain reaction from the coastal waters of Santa Monica Bay, California: low correlation to bacterial indicator levels. *Hydrobiologia* 460: 175-184.

Noble, R.T., S.B. Weisberg, M.K. Leecaster, C.D. McGee, J.H. Dorsey, P. Vainik and V. Orozco-Borbón. 2003. Storm effects on regional beach water quality along the southern California shoreline. *Journal of Water and Health* 1: 23-31.

Noble, R.T. and S.B. Weisberg. 2005 *In press*. A review of technologies for rapid detection of bacteria in recreational waters. *Journal of Water and Health*.

National Research Council (NRC). 2004. Indicators for waterborne pathogens. National Academies Press. Washington, DC.

Prüss, A. 1998. Review of epidemiological studies on health effects from exposure to recreational water. *International Journal of Epidemiology* 27: 1-9.

Rothman K. and S. Greenland. 1998. *Modern Epidemiology*, 2<sup>nd</sup> edition. Lippincott-Raven, PA.

Schiff, K., J. Morton and S. Weisberg. 2003. Retrospective evaluation of shoreline water quality along Santa Monica Bay beaches. *Marine Environmental Research* 56: 245-253.

Schiff, K., S. Weisberg and V. Raco-Rands. 2002. Inventory of ocean monitoring in the Southern California Bight. *Environmental Management* 29: 871-876.

Schiff, K and P. Kinney. 2001. Tracking sources of bacterial contamination in stormwater discharges from Mission Bay, California. *Water Environment Research* 73: 534-542.

Wade, T.J., N. Pai, J.N.S. Eisenberg and J.M. Colford, Jr. 2003. Do US EPA water guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. *Environmental Health Perspectives* 111: 1102-1109.

Weiskel, P.K., B.L. Howes, and G.R. Heufelder. 1996. Coliform contamination of a coastal embayment: Sources and transport pathways. *Environmental Science and Technology* 30(6): 1872-1881.

## **APPENDICES**

- Appendix 1: Mission Bay Human Subjects Protocol, Study Instruments, and Consent Form
- Appendix 2: Health Outcomes vs. Water Exposure Analyses
- Appendix 3: Health Outcomes vs. Water Quality Indicator & Water Exposures Analyses
- Appendix 4: Sociodemographic Characteristics of Study Population
- Appendix 5: Participant Responses to Questions Regarding Exposures and Illness Prior to Beach Visit
- Appendix 6: Participant Responses to Questions Regarding Exposures During Beach Visit
- Appendix 7: Participant Responses to Follow-up Questions Regarding Exposures Following Beach Visit