What's the cost of NOT implementing the Tentative Order?

Public Health Costs—Orange County

Excess cases of gastrointestinal illness from swimming at bacteria-contaminated beaches

- Direct Cost: $ 6.7 million to $16 million/year (over 20 years = $134 M to $320M)
- Value of not getting sick: $56 million and $136 million/year (20 years = $1 Billion - $2.7 Billion)

Pendleton et al., 2006

Beach Closures

A hypothetical closure of Huntington Beach due to poor water quality:

- One day = losses of $100,000
- One month = losses of $3.5 million
- Three months (summer season) = economic losses of $9 million

Hanemann, M., L. Pendleton, and C. Mohn (November 2005) Welfare Estimates for Five Scenarios of Water Quality Change in Southern California. A Report from the Southern California Beach Valuation Project, at 7-8

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What is the breakdown and timeframe of the costs?

San Diego River

- Cost opinions “contain considerable uncertainties”
- “The budget forecasts… are order-of magnitude estimates.”

CLRP at 113

- “Cost estimates should be considered planning-level only.”

CLRP at 116

San Diego River

- Cost range from $590 M to $ 1.3 Billion
- Includes "Private Property BMPs" ranging in cost from $216 M to $360 M
- Private Party BMPs "are an *optional strategy* and may be considered at the discretion of the individual jurisdictions only if needed to meet load reduction targets."
- Most expensive element of program at lower cost.
- Without Private Property: $374 M -$940M

CLRP at 114

San Diego River

Land costs for Private Party BMPs

- Based on LA County land prices from 2008
- Discounted to 2005 prices
- 2011 prices assumed to be same as 2005 prices

Structural BMP costs

- Structural BMP Prioritization & Analysis Tool developed for LA
- Add in a cost multiplier, 2.0 and 4.0

San Diego River

Nonstructural BMP Costs

- Largely based on number of staff hours
- Copermittees made the estimates
- Large potential savings if volunteers used
  - Pet waste: $100/yr vs. $100/month
- Did not solicit information from stakeholder groups that could implement programs

Chollas Watershed

- Costs not given in a range, no upper/lower limit (see Supporting Doc. 7)
- Costs include $9.6 million for landscape practices, $2 million for outreach
- What about program elements with multiple benefits?

How do you determine "predevelopment"?

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The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff

Robert W. Haile; John S. Witte; Mark Gold; Ron Cressey; Charles McGee; Robert C. Millikan; Alice Glasser; Nina Harawa; Carolyn Ervin; Patricia Harmon; Janice Harper; John Dermand; James Alamillo; Kevin Barrett; Mitchell Nides; Guang-yu Wang

Epidemiology, Vol. 10, No. 4. (Jul., 1999), pp. 355-363.

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The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff

Robert W. Haile,[1] *John S. Witte,*[2] *Mark Gold,*[3] *Ron Cressey,*[4] *Charles McGee,*[5] *Robert C. Millikan,*[6] *Alice Glasser,*[7] *Nina Harawa,*[8] *Carolyn Ervin,*[1] *Patricia Harmon,*[1] *Janice Harper,*[1] *John Dermand,*[1] *James Alamillo,*[3] *Kevin Barrett,*[1] *Mitchell Nides,*[9] *and Guang-yu Wang*[10]

Waters adjacent to the County of Los Angeles (CA) receive untreated runoff from a series of storm drains year round. Many other coastal areas face a similar situation. To our knowledge, there has not been a large-scale epidemiologic study of persons who swim in marine waters subject to such runoff. We report here results of a cohort study conducted to investigate this issue. Measures of exposure included distance from the storm drain, selected bacterial indicators (total and fecal coliforms, enterococci, and *Escherichia coli*), and a direct measure of enteric viruses. We found higher risks of a broad range of symptoms, including both upper respiratory and gastrointestinal, for subjects swimming (a) closer to storm drains, (b) in water with high levels of single bacterial indicators and a low ratio of total to fecal coliforms, and (c) in water where enteric viruses were detected. The strength and consistency of the associations we observed across various measures of exposure imply that there may be an increased risk of adverse health outcomes associated with swimming in ocean water that is contaminated with untreated urban runoff. (Epidemiology 1999;10:355–363)

Keywords: environmental epidemiology, gastrointestinal illness, ocean, recreational exposures, sewage, storm drains, waterborne illnesses, waterborne pathogens.

Runoff from a system of storm drains enters the Santa Monica Bay adjacent to Los Angeles County (CA). Even in the dry months of summer 10–25 million gallons of runoff (or non-storm water discharge) per day enter the bay from the storm drain system. Storm drain water is not subject to treatment and is discharged directly into the ocean. Total and fecal coliforms, as well as enterococci, are sometimes elevated in the surf zone adjacent to storm drain outlets; pathogenic human enteric viruses have also been isolated from storm drain effluents, even when levels of all commonly used indicators, including F2 male-specific bacteriophage, were low.[1]

Approximately 50–60 million persons visit Santa Monica Bay beaches annually. Concern about possible adverse health effects due to swimming in the bay has been raised by numerous interested parties.[2] Previous reports indicate that swimming in polluted water (for example, due to sewage) increases risks of numerous adverse health outcomes (Pruss[3] provides a recent review of this literature). To our knowledge, however, there has never been a large epidemiologic study of persons who swim in marine waters contaminated by heavy urban runoff.

These circumstances provided the motivation to study the possible health effects of swimming in the bay. We present here the main results from a large cohort study of people that addressed the issue of adverse health effects of swimming in ocean water subject to untreated urban runoff.

Methods

DESIGN AND SUBJECTS

The exposures of interest were distance swimming from storm drains, levels of bacterial indicators (total coli-

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Editors' note: See related editorial on page 351 of this issue.

forms, fecal coliforms, enterococcus, *Escherichia coli*) for pathogens that potentially produce acute illness, and human enteric viruses. We studied three beaches located in Santa Monica Bay (CA) that exhibited a wide range of pathogen indicator counts and a high density of swimmers (Santa Monica, Will Rogers, and Surfrider).

Persons who immersed their heads in the ocean water were potential subjects for this study. There was no restriction based on age, sex, or race. We excluded anyone who swam at the study beaches or in heavily polluted areas (that is, Mothers' Beach in Marina del Rey or near the Santa Monica Pier) within 7 days before the study date, or between the date of the beach interview and the telephone follow-up interview. We excluded subjects who swam on multiple days, as one of our primary questions was whether risk of health outcomes was associated with levels of indicator organisms on the specific day a subject entered the water. We targeted persons bathing within 100 yards upcoast or downcoast of the storm drain and persons bathing greater than 400 yards beyond a storm drain.

For this study, 22,085 subjects were interviewed on the beach from June 25 to September 14, 1995, to ascertain eligibility and willingness to participate. We found that 17,253 of these subjects were eligible and able to participate (that is, had a telephone and were able to speak English or Spanish). Of these, 15,492 (90% of the eligible subjects) agreed to participate. They were interviewed about their age, residence, and swimming, particularly immersion of the head into ocean water. The interviewer noted distance from the storm drain (within the categories 0, 1–50, 51–100, or 400 yards), gender, and race of the subject. (Distances from each drain were marked with inconspicuous objects such as beach towels and umbrellas.)

Nine to 14 days after the beach interview, subjects were interviewed by telephone to ascertain the occurrence(s) of: fever, chills, eye discharge, earache, ear discharge, skin rash, infected cuts, nausea, vomiting, diarrhea, diarrhea with blood, stomach pain, coughing, coughing with phlegm, nasal congestion, and sore throat. For this study we defined *a priori* three groupings of symptoms indicative of gastrointestinal illness or respiratory disease. In particular, following Cabelli *et al*,[4] subjects were classified as having highly credible gastrointestinal illness 1 (HCGI 1) if they experienced at least one of the following: (1) vomiting, (2) diarrhea and fever, or (3) stomach pain and fever. We also classified subjects as having highly credible gastrointestinal illness 2 (HCGI 2) if they had vomiting and fever. Finally, we classified subjects as having significant respiratory disease (SRD) if they had one of the following: (1) fever and nasal congestion, (2) fever and sore throat, or (3) coughing with phlegm.

We were able to contact and interview 13,278 subjects (86% follow-up). Of those interviewed, 1,485 were found to be ineligible because they swam (and immersed their heads) at a study beach or in heavily polluted waters between the day of the beach interview and the telephone follow-up. We excluded 107 subjects because they did not confirm immersing their faces in ocean water, leaving 11,686 subjects. One subject had a missing value for age, which we imputed (as the median value among all subjects) for inclusion in the adjusted analyses (discussed below). For the bacteriological analyses, we excluded an additional 1,227 subjects who had missing values, leaving 10,459 subjects. In the virus analyses we included only the 3,554 subjects who swam within 50 yards of the drain on days when viruses were measured (as the samples were collected only at the storm drain).

Collection and Analysis of Samples for Bacterial Indicators

Samples were collected on days that subjects were interviewed on the beaches. Each day, ankle depth samples were collected from each location (0 yards, 100 yards upcoast and downcoast of the drain, and one sample at 400 yards). One duplicate sample per site was collected daily. Samples were collected in sterile 1 liter polypropylene bottles and transferred on ice to the microbiology laboratory. All samples were analyzed for total coliforms, fecal coliforms, enterococcus, and *E. coli*. Densities of total and fecal coliforms and enterococci were determined using the appropriate membrane filtration techniques in Ref 5. *E. coli* densities were determined by membrane filtration using Hach Method 10029 for m-ColiBlue24 Broth.

Collection and Analysis of Samples for Enteric Viruses

For looking at enteric viruses, we collected samples from the three storm drain sites on Fridays, Saturdays, and Sundays, using Method 9510 C g of Ref 5. Ambient pH, temperature, conductivity, and total dissolved solids were measured. Samples as large as 100 gallons chosen to minimize the impacts of seawater dilution were filtered through electropositive filters at ambient pH. Adsorption filters were eluted in the field with 1 liter of sterile 3% beef extract adjusted to pH 9.0 with sodium hydroxide. Field eluates were reconcentrated in the laboratory using an organic reflocculation procedure.[6] All final concentrates were detoxified before analysis.[7]

All samples were analyzed for infectious human enteric viruses in Buffalo green monkey kidney cells (BGMK) by the plaque assay technique. Ten percent of the final concentrate was tested in this manner to determine whether there were a quantifiable number of viruses present. The remaining concentrate volume was divided in half and analyzed using the liquid overlay technique known as the cytopathic effect (CPE) assay.[8] The CPE assay generally detects a greater number of viruses than the plaque assay, but it is not quantitative. Flasks that did not exhibit CPE were considered to be negative for detectable infectious virus. We further examined any flask exhibiting CPE by the plaque-forming unit method to confirm the presence of infectious viruses.

STATISTICAL ANALYSIS

Our analysis addressed two main questions. First, are there different risks of specific outcomes among subjects swimming 0, 1–50, 51–100, and 400 or more yards from a storm drain? If pathogens in the storm drain result in increased acute illnesses, one would expect higher risks among swimmers closer to the drain. Second, are risks of specific outcomes associated with levels of specific bacterial indicators or enteric viruses?

To address the second question, we estimated risks arising from exposure to levels within categories defined *a priori* by existing standards or expert consensus. Specifically, for total coliforms we defined categories using 1,000 and 10,000 colony-forming units (cfu) per 100 ml as cutpoints, which are based on the California Code of Regulations (S.7958 in Title 17).[9] For fecal coliforms we created categories using cutpoints of 200 and 400 cfu per 100 ml, which reflect criteria set by the State Water Resources Control Board.[10] For enterococcus we used cutpoints of 35 and 104 cfu per 100 ml of water, which were established by the U.S. Environmental Protection Agency.[11] Finally, categories for *E. coli* were selected in meetings with staff from the Santa Monica Bay Restoration Project (SMBRP), Heal the Bay, and the Los Angeles County Department of Health Services. These meetings resulted in initially selecting categories based on cutpoints of 35 and 70 cfu per 100 ml, and then subsequently adding categories using cutpoints of 160 and 320 cfu per 100 ml; the latter were added because it is believed that *E. coli* comprises about 80% of the fecal coliforms. Using these knowledge-based categories, however, assumes a homogeneous risk between cutpoints. This might not be a reasonable assumption because the adequacy of these cutpoints is unclear, and because a large percentage of the subjects were in a single (that is, the lowest) category. Therefore, we further explored the bacteriological relations using categories defined by deciles.

In addition to considering total and fecal coliforms separately, we investigated the potential effect of the ratio of total to fecal coliforms. Motivation for this arose from our expectation that the risk of adverse health outcomes might be higher when the ratio is smaller, indicating a relatively greater proportion of fecal contamination. We used categories of this ratio defined by a cutpoint of 5 (where 5 corresponds to there being 5 times as much total as fecal coliform in the water). The human enteric virus exposure was reported as a dichotomous (that is, virus detected *vs* not detected) measure.

We first calculated simple descriptive statistics giving the number of subjects with each adverse health outcome who swam (1) at the prespecified distances from the drain or (2) in water with the prespecified levels of pathogens. From these counts we estimated the crude risk associated with each exposure. We then used logistic regression to estimate the adjusted relative risks of each outcome. For each exposure/outcome combination, we fit a separate model. All models adjusted for the potential confounding of: age (three categories: 0–12 years, 13–25 years, >25 years); sex; beach; race (four categories: white, black, Latino/a, and Asian/multiethnic/other); California *vs* out-of-state resident; and concern about potential health hazards at the beach (four categories: not at all, somewhat, a little, and very).

Results

Table 1 presents results for each of the adverse health outcomes by distance swimming from the storm drain. Across all distances, risks ranged from about 0.001 (that is, 1 per 1,000) for diarrhea with blood to about 0.1 for runny nose. The risk of numerous outcomes was higher for people who swam at the drain (0 yards away), in comparison with those who swam 1–50, 51–100, or >400 yards from the drain. In particular, we observed increases in risk for fever, chills, ear discharge, coughing with phlegm, HCGI 2, and SRD. In addition, the risks for eye discharge, earache, sore throat, infected cut, and HCGI 1 were also slightly elevated. A handful of outcomes exhibited small increased risks among swimmers at 1–50 yards (skin rash) or at 51–100 yards (cough, cough with phlegm, runny nose, and sore throat). Adjusted estimates of relative risk (RR) comparing swimmers at 0, 1–50, or 51–100 yards from the drain with swimmers at least 400 yards away from the drain showed similar relations as the aforementioned patterns of risks (Table 1). Among the positive associations for swimmers at the drain, RRs ranged in magnitude from about 1.2 (eye discharge, sore throat, HCGI 1) to 2.3 (earache), with varying degrees of precision; most of these RRs ranged from 1.4 to 1.6.

In Table 2 we see that the risk of skin rash increased for the highest prespecified category of total coliforms (that is, >10,000 cfu). Furthermore, the adjusted RR comparing swimmers exposed at this level *vs* those exposed to levels ≤1,000 cfu was 2.6. Whereas the RR for diarrhea with blood also suggested a positive association, this result was based on a single adverse health event (as evinced by the wide 95% CIs). When looking at deciles, in relation to the lowest exposure level (that is, the lowest 10%), we observed increased risks of skin rash at all other levels (Figure 1). The adjusted RRs ranged from 1.6 to 6.2, with five of the nine RRs in the 2–3 range. In addition, there were increased risks of HCGI 2 for all deciles except one (the eighth); the corresponding adjusted RRs ranged from 1.4 to 4.7, with varying levels of precision (Figure 1).

When looking at fecal coliforms, we again observed among those in the highest category (that is, >400 cfu) an increased risk for skin rash (Table 3). There were also *slight* increased risks for infected cut, runny nose, and diarrhea with blood in the highest category, as well as for nausea, vomiting, coughing, sore throat, and HCGI 2 in the middle category (200–400 cfu). The adjusted RRs also indicated positive associations for these outcomes (Table 3). When we used deciles to categorize subjects, however, in comparison with the lowest decile, we only observed marginal increased risks for infection and skin rash (not shown). In our investigation of the ratio of

TABLE 1. Adverse Health Outcomes by Distance Swimming from Drain: Number Ill, Acute Risks, Adjusted Relative Risk (RR) Estimates and 95% Confidence Intervals (CI)

	Distance from Drain (in Yards)											
	>400 (N = 3030)*		51–100 (N = 3311)			1–50 (N = 4518)			0 (N = 827)			
Outcome	No. Ill	Risk	No. Ill	Risk	RR (95% CI)†	No. Ill	Risk	RR (95% CI)†	No. Ill	Risk	RR (95% CI)†
Fever	138	0.046	158	0.048	1.06 (0.84–1.34)	208	0.046	1.07 (0.85–1.33)	59	0.071	1.61 (1.16–2.24)
Chills	72	0.024	85	0.026	1.07 (0.77–1.47)	108	0.024	1.05 (0.77–1.42)	31	0.037	1.60 (1.03–2.50)
Eye discharge	61	0.020	59	0.018	0.88 (0.61–1.27)	73	0.016	0.77 (0.55–1.09)	19	0.023	1.15 (0.67–1.98)
Earache	116	0.038	116	0.035	0.89 (0.68–1.16)	136	0.030	0.81 (0.63–1.04)	38	0.046	1.34 (0.91–1.98)
Ear discharge	21	0.007	19	0.006	0.78 (0.42–1.46)	25	0.006	0.80 (0.45–1.44)	13	0.016	2.09 (1.01–4.33)
Skin rash	23	0.008	30	0.009	1.16 (0.67–2.01)	53	0.012	1.50 (0.91–2.46)	4	0.005	0.62 (0.21–1.83)
Infected cut	17	0.006	16	0.005	0.79 (0.40–1.58)	37	0.008	1.51 (0.84–2.69)	6	0.007	1.48 (0.57–3.87)
Nausea	133	0.044	115	0.035	0.77 (0.60–1.00)	143	0.032	0.75 (0.59–0.95)	40	0.048	1.13 (0.78–1.65)
Vomiting	57	0.019	58	0.018	0.97 (0.67–1.40)	63	0.014	0.76 (0.53–1.09)	25	0.030	1.40 (0.85–2.31)
Diarrhea	204	0.067	163	0.049	0.70 (0.56–0.86)	202	0.045	0.69 (0.56–0.84)	53	0.064	1.04 (0.75–1.44)
Diarrhea with blood	7	0.002	2	0.001	0.26 (0.05–1.26)	3	0.001	0.27 (0.07–1.06)	2	0.002	0.87 (0.15–4.57)
Stomach pain	206	0.068	194	0.059	0.85 (0.70–1.05)	271	0.060	0.93 (0.77–1.12)	61	0.074	1.11 (0.82–1.51)
Cough	209	0.069	263	0.079	1.18 (0.97–1.42)	296	0.066	0.98 (0.82–1.18)	55	0.067	1.01 (0.73–1.38)
Cough and phlegm	90	0.030	114	0.034	1.16 (0.88–1.54)	143	0.032	1.09 (0.83–1.43)	39	0.047	1.65 (1.11–2.46)
Runny nose	273	0.090	351	0.106	1.18 (1.00–1.40)	371	0.082	0.95 (0.80–1.12)	74	0.089	1.10 (0.84–1.46)
Sore throat	190	0.063	244	0.074	1.17 (0.96–1.43)	304	0.067	1.12 (0.93–1.35)	59	0.071	1.25 (0.92–1.71)
HCGI 1	102	0.034	96	0.029	0.88 (0.66–1.17)	121	0.027	0.84 (0.64–1.10)	35	0.042	1.21 (0.81–1.82)
HCGI 2	26	0.009	28	0.008	1.04 (0.61–1.79)	32	0.007	0.90 (0.53–1.53)	15	0.018	1.64 (0.84–3.21)
Significant respiratory disease	139	0.046	177	0.053	1.18 (0.94–1.49)	205	0.045	1.03 (0.82–1.23)	63	0.076	1.78 (1.29–2.45)

The total number of swimmers in each category is given in parentheses (N). HCGI1, highly credible gastrointestinal illness with vomiting, diarrhea and fever or stomach pain and fever. HCGT2, highly credible gastrointestinal illness with vomiting and fever only. Significant respiratory disease, fever and nasal congestion, fever and sore throat or coughing with phlegm.
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

total to fecal coliforms, we observed a consistent pattern of higher risks for diarrhea and HCGI 2 as the ratio category became lower (not shown, but available in Ref 12). Because any effect of this lower ratio should be stronger when there was a higher degree of contamination, indicated by total coliform counts in excess of 1,000 or 5,000 cfu, we then restricted our analysis to subjects swimming in water above these levels. In the first case, increased risks with decreasing cutpoints were observed for nausea, diarrhea, and HCGI 2.[12] When we restricted our investigation to subjects in water in which the total coliforms exceeded 5,000 cfu, we observed

TABLE 2. Adverse Health Outcomes by Total Coliform Levels: Number Ill, Acute Risks, Adjusted Relative Risk (RR) Estimates and 95% Confidence Intervals (CI)

	Total Coliforms (cfu/100ml)							
	≤1,000 (N = 7,574)*		>1,000–10,000 (N = 1,988)			>10,000 (N = 757)		
Outcome	No. Ill	Risk	No. Ill	Risk	RR†	No. Ill	Risk	RR†
Fever	368	0.049	88	0.044	0.92 (0.72–1.17)	42	0.055	1.23 (0.87–1.73)
Chills	193	0.025	51	0.026	1.03 (0.75–1.42)	9	0.012	0.51 (0.26–1.01)
Eye discharge	151	0.020	21	0.011	0.46 (0.29–0.74)	15	0.020	0.81 (0.47–1.41)
Earache	270	0.036	66	0.033	0.96 (0.72–1.27)	21	0.028	0.86 (0.54–1.38)
Ear discharge	51	0.007	15	0.008	1.22 (0.67–2.23)	2	0.003	0.46 (0.11–1.93)
Skin rash	65	0.009	14	0.007	0.75 (0.41–1.36)	19	0.025	2.59 (1.49–4.53)
Infected cut	49	0.006	11	0.006	0.97 (0.49–1.91)	3	0.004	0.82 (0.25–2.72)
Nausea	292	0.039	69	0.035	0.94 (0.72–1.24)	18	0.024	0.71 (0.43–1.16)
Vomiting	137	0.018	34	0.017	0.90 (0.61–1.33)	9	0.012	0.64 (0.32–1.29)
Diarrhea	434	0.057	85	0.043	0.80 (0.63–1.03)	33	0.044	0.95 (0.65–1.39)
Diarrhea with blood	8	0.001	2	0.001	1.08 (0.22–5.35)	1	0.001	1.73 (0.19–15.88)
Stomach pain	487	0.064	125	0.063	1.05 (0.85–1.29)	29	0.038	0.69 (0.47–1.02)
Cough	546	0.072	133	0.067	0.90 (0.73–1.10)	51	0.067	0.94 (0.69–1.28)
Cough and phlegm	267	0.035	58	0.029	0.81 (0.60–1.09)	27	0.036	1.03 (0.68–1.57)
Runny nose	703	0.093	170	0.086	0.93 (0.78–1.12)	67	0.089	1.06 (0.81–1.40)
Sore throat	534	0.071	116	0.058	0.83 (0.67–1.03)	47	0.062	0.95 (0.69–1.30)
HCGI 1	242	0.032	54	0.027	0.84 (0.62–1.14)	17	0.022	0.74 (0.44–1.23)
HCGI 2	72	0.010	16	0.008	0.89 (0.51–1.55)	5	0.007	0.83 (0.32–2.12)
Significant respiratory disease	396	0.052	84	0.042	0.80 (0.62–1.02)	42	0.055	1.11 (0.79–1.55)

The total number of swimmers in each category is given in parentheses (N).
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

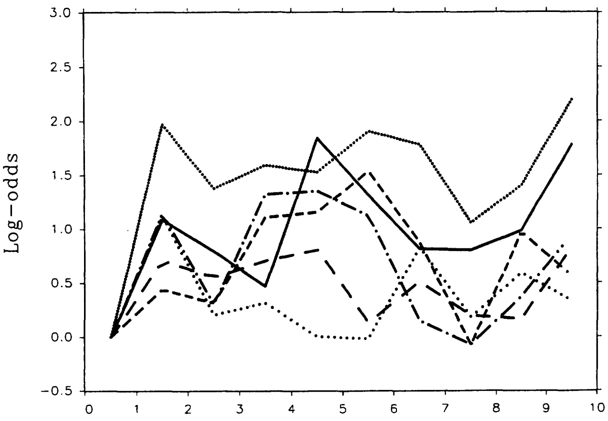

FIGURE 1. Log odds of adverse health outcomes by deciles of exposure for selected bacterial exposures. —, Total coliform and skin rash; – – – ·, total coliform and HCGI 2; · · ·, Enterococci and infected cut; — — —, *E coli* and eye discharge; ···, *E coli* and skin rash; · — ··, *E coli* and infected cut. HCGI 2 = highly credible gastrointestinal illness with vomiting and fever only.

increased risks with eye discharge, ear discharge, skin rash, nausea, diarrhea, stomach pain, nasal congestion, HCGI 1, and HCGI 2.[12] There was a consistent pattern of stronger risk ratios as the cutpoint became lower (when the analyses were restricted to times when total coliforms exceeded 1,000 or 5,000 cfu), with the strongest effects generally observed with the cutpoint of 2, as illustrated in Figure 2 for diarrhea, vomiting, sore throat, and HCGI1.

Table 4 gives results for the relation among enterococci and the adverse health outcomes. Again, we observed an increased risk of skin rash among those in the highest category (that is, >104 cfu). In addition, comparing the highest to other categories of exposure, there

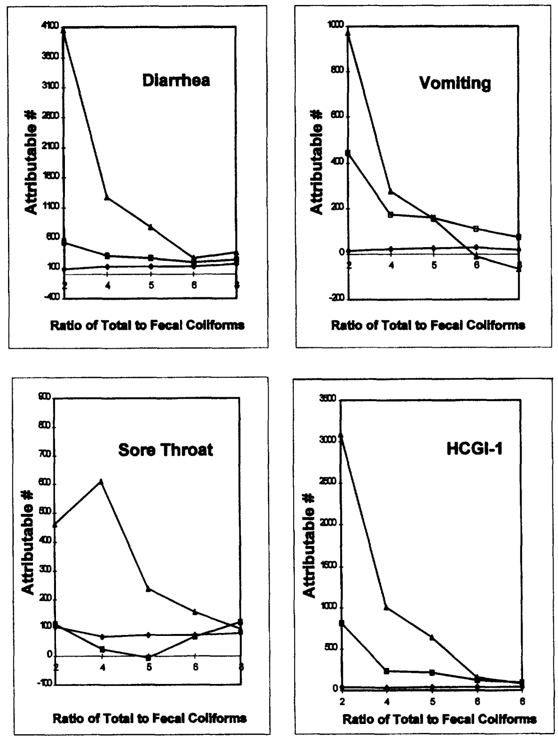

FIGURE 2. Selected attributable numbers/10,000 exposed subjects for total to fecal coliforms. ♦, All days; ■, >1000; ▲, > 5000. HCGI 1 = highly credible gastrointestinal illness with vomiting, diarrhea and fever or stomach pain and fever.

TABLE 3. Adverse Health Outcomes by Fecal Coliform Levels: Number Ill, Acute Risks, Adjusted Relative Risk (RR) Estimates and 95% Confidence Intervals (CI)

	Fecal Coliforms (cfu/100ml)							
	≤200 (N = 8,005)*		>200–400 (N = 768)			>400 (N = 1,636)		
Outcome	No. Ill	Risk	No. Ill	Risk	RR†	No. Ill	Risk	RR†
Fever	381	0.048	39	0.051	1.04 (0.74–1.46)	80	0.049	1.02 (0.80–1.32)
Chills	197	0.025	24	0.031	1.14 (0.74–1.76)	34	0.021	0.78 (0.54–1.14)
Eye discharge	149	0.019	11	0.014	0.70 (0.38–1.31)	30	0.018	0.97 (0.65–1.46)
Earache	275	0.034	26	0.04	0.93 (0.62–1.41)	57	0.035	1.00 (0.75–1.35)
Ear discharge	53	0.007	8	0.010	1.29 (0.60–2.73)	7	0.004	0.56 (0.25–1.24)
Skin rash	69	0.009	5	0.007	0.64 (0.26–1.60)	26	0.016	1.86 (1.17–2.95)
Infected cut	47	0.006	2	0.003	0.40 (0.10–1.65)	15	0.009	1.50 (0.83–2.74)
Nausea	289	0.036	38	0.049	1.29 (0.91–1.84)	57	0.035	0.93 (0.69–1.24)
Vomiting	133	0.017	18	0.023	1.33 (0.81–2.21)	31	0.019	1.07 (0.71–1.60)
Diarrhea	425	0.053	50	0.065	1.17 (0.86–1.60)	81	0.050	0.90 (0.70–1.15)
Diarrhea with blood	7	0.001	1	0.001	1.22 (0.15–10.01)	3	0.002	1.69 (0.42–6.75)
Stomach pain	495	0.062	51	0.066	1.04 (0.77–1.41)	103	0.063	0.98 (0.78–1.23)
Cough	551	0.069	70	0.091	1.34 (1.03–1.74)	117	0.072	1.06 (0.86–1.31)
Cough and phlegm	265	0.033	31	0.040	1.16 (0.79–1.70)	60	0.037	1.10 (0.82–1.47)
Runny nose	722	0.090	72	0.94	1.03 (0.79–1.33)	160	0.098	1.11 (0.93–1.34)
Sore throat	527	0.066	70	0.091	1.40 (1.07–1.82)	106	0.065	0.99 (0.80–1.24)
HCGI 1	239	0.030	28	0.036	1.18 (0.79–1.77)	50	0.031	0.99 (0.72–1.36)
HCGI 2	65	0.008	11	0.014	1.63 (0.85–3.12)	17	0.010	1.13 (0.65–1.95)
Significant respiratory disease	399	0.050	42	0.055	1.08 (0.77–1.50)	85	0.052	1.04 (0.81–1.33)

The total number of swimmers in each category is given in parentheses (N).
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

TABLE 4. Adverse Health Outcomes by Enterococci Levels: Number Ill, Acute Risks, Adjusted Relative Risk (RR) Estimates and 95% Confidence Intervals (CI)

	Enterococci (cfu/100ml)							
	≤35 (N = 7,689)*		>35–104 (N = 1,863)			>104 (N = 857)		
Outcome	No. Ill	Risk	No. Ill	Risk	RR†	No. Ill	Risk	RR†
Fever	371	0.048	84	0.045	0.91 (0.71–1.16)	45	0.053	1.00 (0.72–1.40)
Chills	198	0.026	33	0.018	0.67 (0.46–0.97)	24	0.028	0.94 (0.60–1.48)
Eye discharge	149	0.019	25	0.013	0.69 (0.45–1.07)	16	0.019	1.01 (0.58–1.75)
Earache	270	0.035	57	0.031	0.82 (0.61–1.11)	31	0.036	0.88 (0.59–1.31)
Ear discharge	52	0.007	12	0.006	0.85 (0.45–1.62)	4	0.005	0.53 (0.19–1.51)
Skin rash	74	0.010	13	0.007	0.71 (0.39–1.30)	13	0.015	1.72 (0.89–3.31)
Infected cut	46	0.006	12	0.006	0.95 (0.49–1.82)	6	0.007	0.90 (0.37–2.18)
Nausea	271	0.035	72	0.039	1.07 (0.82–1.41)	41	0.048	1.19 (0.84–1.70)
Vomiting	130	0.017	34	0.018	1.13 (0.77–1.67)	18	0.021	1.20 (0.71–2.04)
Diarrhea	398	0.052	101	0.054	0.99 (0.78–1.25)	57	0.067	1.01 (0.75–1.36)
Diarrhea with blood	8	0.001	0	—	—	3	0.004	2.90 (0.66–12.68)
Stomach pain	464	0.060	126	0.068	1.09 (0.89–1.35)	59	0.069	0.97 (0.72–1.30)
Cough	554	0.072	121	0.065	0.91 (0.73–1.12)	63	0.074	1.00 (0.75–1.34)
Cough and phlegm	266	0.035	59	0.032	0.91 (0.68–1.22)	31	0.036	1.03 (0.69–1.54)
Runny nose	704	0.092	165	0.089	0.96 (0.80–1.15)	85	0.099	1.01 (0.79–1.30)
Sore throat	533	0.069	118	0.063	0.89 (0.72–1.10)	52	0.061	0.80 (0.59–1.09)
HCGI 1	230	0.030	51	0.027	0.92 (0.67–1.26)	36	0.042	1.31 (0.89–1.92)
HCGI 2	67	0.009	14	0.008	0.82 (0.46–1.48)	12	0.014	1.30 (0.67–2.51)
Significant respiratory disease	397	0.052	84	0.045	0.86 (0.67–1.11)	45	0.053	0.98 (0.70–1.37)

The total number of swimmers in each category is given in parentheses (N).
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

were increased risks of nausea, vomiting, diarrhea with blood, HCGI 1, and HCGI 2. Our adjusted RRs suggested similar positive associations, except for diarrhea; although the risk increased from 0.05 to 0.07, the adjusted RR comparing the highest to lowest category was 1.0 (Table 4). When comparing the lowest to higher deciles, we observed increased risks in most categories for infected cut and skin rash (Figure 1). Other adverse health outcomes—infected cut, nausea, diarrhea, diarrhea with blood, HCGI 1, and HCGI 2—exhibited increased risks only in particular quantiles. In comparison with the lowest decile, the risk of each of these outcomes was higher in the 10th decile. For example, the risk for HCGI 2 was 0.007 in the first decile, but 0.015 in the 10th.

Table 5 presents results for *E. coli*. We once again found an increased risk of skin rash in the highest prespecified category (that is, >320 cfu). Furthermore, we observed slight increased risks in this highest category for eye discharge, earache, stomach pain, coughing with phlegm, runny nose, and HCGI 1 (Table 5). In our decile-based analysis, however, we only observed materially increased risks for eye discharge, skin rash, and infection (Figure 1).

Numerous adverse health outcomes exhibited higher risks among subjects swimming on days when samples were positive for viruses (Table 6). In particular, the risk of fever, eye discharge, vomiting, sore throat, HCGI 1, and HCGI 2, and to a lesser extent, chills, diarrhea, diarrhea with blood, cough, coughing with phlegm, and SRD were higher on days when viruses were detected. Our adjusted RR estimates showed similar relations, most ranging from 1.3 to 1.9 (Table 6). Additionally, adjusting for each bacterial indicator (one-at-a-time) also left these results essentially unchanged.[12] As expected, there was an association between presence of virus and fecal coliforms within 50 yards of the drain. The mean density of fecal coliforms when no virus was detected was 234.8 cfu (SD 542.5 cfu); whereas it was 2,233.8 (SD 2,634.1) when viruses were detected (N = 386). The median values were 47.8 and 452.6 cfu, respectively.

Discussion

We observed differences in risk for a number of outcomes when we compared subjects swimming at 0 yards *vs* 400+ yards. Most of the relative risks suggested an approximately 50% increase in risk. Furthermore, as evinced by both the risks and RRs, there is an apparent threshold of increased risk occurring primarily at the drain: no dose response is evinced with increasing closeness to the drain, but there is a jump in risk for many adverse health outcomes among those swimming at the drain. We also found that distance is a reasonably good surrogate for bacterial indicators, with higher levels observed closer to the drain.[12]

For bacterial indicators, we observed a relation among numerous higher exposures and adverse health outcomes. These increases were mostly restricted to the highest knowledge-based categories (no effect was observed below any existing standards). When looking at quantiles, we found higher risks of skin rash and infection at fairly low levels. In contrast with what one might expect, however, there was no clear dose-response pattern across increasing levels of bacteriological exposures.

TABLE 5. Adverse Health Outcomes by E. coli Levels: Number Ill, Acute Risks, Adjusted Relative Risk (RR) Estimates and 95% Confidence Intervals (CI)

	E. coli (cfu/100ml)													
	≤35 (N = 6,104)*		>35–75 (N = 1,620)			>75–160 (N = 1,145)			>160–320 (N = 518)			>320 (N = 991)		
Outcome	No. Ill	Risk	No. Ill	Risk	RR†	No. Ill	Risk	RR†	No. Ill	Risk	RR†	No. Ill	Risk	RR†
Fever	274	0.045	89	0.055	1.22 (0.95–1.56)	61	0.053	1.20 (0.90–1.60)	29	0.056	1.22 (0.81–1.84)	45	0.045	0.98 (0.70–1.37)
Chills	145	0.024	41	0.025	1.00 (0.70–1.44)	28	0.024	1.00 (0.66–1.52)	18	0.035	1.38 (0.82–2.33)	22	0.022	0.79 (0.49–1.26)
Eye discharge	116	0.019	30	0.019	0.99 (0.65–1.49)	14	0.012	0.65 (0.37–1.15)	6	0.012	0.61 (0.26–1.43)	23	0.023	1.36 (0.84–2.19)
Earache	214	0.035	45	0.028	0.75 (0.54–1.04)	33	0.029	0.78 (0.53–1.14)	18	0.035	0.91 (0.55–1.50)	47	0.047	1.25 (0.89–1.77)
Ear discharge	42	0.007	8	0.005	0.60 (0.28–1.28)	5	0.004	0.57 (0.22–1.46)	6	0.012	1.28 (0.52–3.15)	6	0.0066	0.67 (0.27–1.62)
Skin rash	57	0.009	15	0.009	1.01 (0.56–1.80)	7	0.006	0.66 (0.30–1.46)	6	0.012	1.21 (0.49–2.98)	15	0.015	2.04 (1.11–3.76)
Infected cut	42	0.007	7	0.004	0.53 (0.24–1.20)	3	0.003	0.33 (0.10–1.06)	3	0.006	0.66 (0.20–2.19)	9	0.009	1.02 (0.48–2.19)
Nausea	216	0.035	74	0.046	1.22 (0.93–1.61)	34	0.030	0.80 (0.55–1.16)	18	0.035	0.88 (0.53–1.46)	42	0.042	1.03 (0.73–1.47)
Vomiting	107	0.018	31	0.019	1.09 (0.72–1.64)	16	0.014	0.82 (0.48–1.40)	8	0.015	0.87 (0.41–1.85)	20	0.020	1.05 (0.63–1.74)
Diarrhea	310	0.051	101	0.062	1.14 (0.90–1.44)	63	0.055	1.00 (0.75–1.33)	25	0.048	0.80 (0.52–1.23)	56	0.057	0.91 (0.67–1.23)
Diarrhea with blood	5	0.001	3	0.002	2.06 (0.48–8.89)	1	0.001	1.03 (0.12–9.01)	2	0.004	3.98 (0.68–23.21)	0	—	—
Stomach pain	353	0.058	124	0.077	1.28 (1.03–1.59)	70	0.061	1.02 (0.78–1.33)	31	0.060	0.95 (0.64–1.40)	70	0.071	1.06 (0.80–1.40)
Cough	444	0.073	96	0.059	0.81 (0.64–1.02)	86	0.075	1.04 (0.82–1.33)	29	0.056	0.77 (0.51–1.14)	82	0.083	1.14 (0.88–1.48)
Cough and phlegm	226	0.037	41	0.025	0.66 (0.47–0.92)	34	0.030	0.78 (0.54–1.12)	11	0.021	0.53 (0.28–1.00)	43	0.043	1.12 (0.79–1.59)
Runny nose	566	0.093	136	0.084	0.87 (0.71–1.06)	105	0.092	0.96 (0.77–1.20)	38	0.073	0.76 (0.53–1.08)	108	0.109	1.12 (0.89–1.41)
Sore throat	417	0.068	99	0.061	0.86 (0.68–1.08)	82	0.072	1.02 (0.80–1.31)	29	0.056	0.78 (0.52–1.17)	75	0.076	1.04 (0.80–1.37)
HCGI 1	183	0.030	51	0.031	1.03 (0.75–1.42)	30	0.026	0.88 (0.59–1.30)	17	0.033	1.06 (0.63–1.80)	36	0.036	1.12 (0.76–1.64)
HCGI 2	48	0.008	21	0.013	1.55 (0.92–2.64)	8	0.007	0.85 (0.40–1.81)	6	0.012	1.25 (0.51–3.03)	10	0.010	1.04 (0.51–2.13)
Significant respiratory disease	319	0.052	71	0.044	0.82 (0.62–107)	58	0.051	0.96 (0.72–1.28)	21	0.041	0.74 (0.47–1.18)	56	0.057	1.03 (0.76–1.40)

The total number of swimmers in each category is given in parentheses (N).
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

TABLE 6. Number Ill, Risks, and Adjusted Relative Risk (RR) Estimates of Adverse Health Outcomes by Virus

	Viruses				
	No (N = 3,168)*		Yes (N = 386)		
Outcome	No. Ill	Risk	No. Ill	Risk	RR (95% CI)†
Fever	126	0.040	23	0.060	1.56 (0.98–2.50)
Chills	65	0.021	10	0.026	1.25 (0.63–2.50)
Eye discharge	36	0.011	8	0.021	1.86 (0.85–4.09)
Earache	93	0.029	10	0.026	0.92 (0.47–1.80)
Ear discharge	15	0.005	0		
Skin rash	32	0.010	4	0.010	0.97 (0.34–2.82)
Infected cut	31	0.010	2	0.005	0.57 (0.13–2.40)
Nausea	101	0.032	12	0.031	0.93 (0.50–1.73)
Vomiting	44	0.014	10	0.026	1.86 (0.92–3.80)
Diarrhea	130	0.041	21	0.054	1.27 (0.78–2.07)
Diarrhea with blood	2	0.001	1	0.003	5.82 (0.45–75.72)
Stomach pain	191	0.060	23	0.060	0.92 (0.58–1.45)
Cough	181	0.057	28	0.073	1.22 (0.80–1.86)
Cough and phlegm	92	0.029	13	0.034	1.20 (0.66–2.18)
Runny nose	246	0.078	32	0.083	1.01 (0.68–1.49)
Sore throat	198	0.063	32	0.083	1.38 (0.93–2.06)
HCGI 1	72	0.023	15	0.039	1.69 (0.95–3.01)
HCGI 2	22	0.007	6	0.016	2.32 (0.91–5.88)
Significant respiratory disease	133	0.042	21	0.054	1.34 (0.83–2.18)

The total number of swimmers in each category is given in parentheses (N).
* Referent category (RR = 1.0).
† Adjusted for age, sex, beach, race, California *vs* out-of-state resident, and concern about potential health hazards at the beach.

When looking at the ratio of total to fecal coliforms using the entire dataset, no consistent pattern emerged.[12] This is not entirely surprising inasmuch as an analysis of all data points treats all ratios of similar numerical value equally. Thus, for example, even though a ratio of 5 when the total coliforms are very low may not increase risk, the same ratio may be associated with increased risks when the density of total coliforms is above 1,000 or 5,000 cfu. When the analysis was restricted to swimmers exposed to total coliform densities above 1,000 or 5,000 cfu, a consistent pattern emerged, with higher risks associated with low ratios.[12]

This is the first large-scale epidemiologic study that included measurements of viruses. A number of adverse health effects were reported more often on days when the samples were positive, suggesting assays for viruses may be informative for predicting risk. Norwalk-like viruses are a plausible cause of gastroenteritis.[4,13] Enteroviruses, the most common viruses in sewage effluent, can cause respiratory symptoms. Not only are viruses responsible for many of the symptoms associated with swimming in ocean water but also they die off at slower rates in sea water than do bacteria, and they can cause infection at a much lower dose.[14]

Our design substantially reduced the potential for confounding by restricting the study entirely to swimmers and making comparisons between groups of swimmers (for example, defined by distance from the drain) to estimate relative risks. Previous studies looking at the effects of exposure to polluted recreational water (for example, due to sewage outflows) have been criticized for comparing risks in swimmers with risks in nonswimmers.[4,14,15] In these earlier studies, background risks among subjects who swim *vs* those choosing not to swim may differ because there are many other (potentially noncontrollable) exposures/pathways that can produce the symptoms under investigation. By restricting the present study to swimmers, we have reduced potential differences between the background risks of exposed *vs* unexposed subjects (for example, swimmers choosing to swim at the drain *vs* those swimming at the same beach but farther away from the drain). Furthermore, we were able to adjust our relative risk estimates for a number of additional factors (listed above) that could confound the observed relations. Of course, this does not exclude the possibility that residual confounding in these factors, or other unknown factors, might have confounded the observed relations.

Nevertheless, any actual (that is, causal) effects may be higher than we observed in this study because both distance and pathogenic indicators are proxy measures of the true pathogenic agents. Also, recall that we excluded subjects who frequently entered the water at these beaches. If there is a dose-response relation such that higher cumulative exposures are associated with increased risk, then one may infer that persons who frequently enter the water and immerse their heads (for example, surfers) may have a higher risk of adverse health outcomes than the relatively infrequent swimmers included in this study.

In summary, we observed positive associations between adverse health effects and (1) distance from the drain, (2) bacterial indicators, and (3) presence of enteric viruses. Taken together, these results imply that there may be an increased risk of a broad range of adverse health effects associated with swimming in ocean water subject to urban runoff. Moreover, attributable numbers—that is, estimates of the number of new cases of an adverse health outcome that is attributable to the exposure of interest—reached well into the 100s per

10,000 exposed subjects for many of the positive associations observed here.[12] This finding implies that these risks might not be trivial when we consider the millions of persons who visit these beaches each year. Furthermore, the factors apparently contributing to the increased risk of adverse health outcomes observed here are not unique to Santa Monica Bay (similar levels of bacterial indicators are observed at many other beaches). Consequently, the prospect that untreated storm drain runoff poses a health risk to swimmers is probably relevant to many beaches subject to such runoff, including areas on the East, West, and Gulf coasts of North America, as well as numerous beaches on other continents.

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Regional Public Health Cost Estimates of Contaminated Coastal Waters: A Case Study of Gastroenteritis at Southern California Beaches

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We present estimates of annual public health impacts, both illnesses and cost of illness, attributable to excess gastrointestinal illnesses caused by swimming in contaminated coastal waters at beaches in southern California. Beach-specific enterococci densities are used as inputs to two epidemiological dose−response models to predict the risk of gastrointestinal illness at 28 beaches spanning 160 km of coastline in Los Angeles and Orange Counties. We use attendance data along with the health cost of gastrointestinal illness to estimate the number of illnesses among swimmers and their likely economic impact. We estimate that between 627,800 and 1,479,200 excess gastrointestinal illnesses occur at beaches in Los Angeles and Orange Counties each year. Using a conservative health cost of gastroenteritis, this corresponds to an annual economic loss of $21 or $51 million depending upon the underlying epidemiological model used (in year 2000 dollars). Results demonstrate that improving coastal water quality could result in a reduction of gastrointestinal illnesses locally and a concurrent savings in expenditures on related health care costs.

Introduction

Each year between 150 million and nearly 400 million visits are made to California (CA) beaches generating billions of dollars in expenditures, by tourists and local swimmers, and nonmarket values enjoyed mostly by local area residents (*1*, *2*). Nonmarket benefits represent the value society places on resources, such as beaches, beyond what people have to pay to enjoy these resources (see Pendleton and Kildow (*1*) for a review of the nonmarket value of CA beaches). In an effort to protect the health of beach swimmers, the CA State Legislature passed Assembly Bill 411 (AB411) in 1997 with formal guidance and regulations for beach water quality which are formally codified as a state statute (*3*). AB411 requires monitoring of bathing waters for fecal indicator bacteria (FIB, including total coliform (TC), fecal coliform (FC), and enterococcci (ENT)) on at least a weekly basis during the dry season (1 April through 31 October) if the beach is visited by over 50,000 people annually or is located adjacent to a flowing storm drain. Beaches can be posted with health warnings if single-sample or geometric mean standards for TC, FC, and ENT exceed prescribed levels (see Supporting Information (SI) for standards).

Based on AB411 water quality criteria and their professional judgment, CA county health officials posted or closed beaches 3,985 days during 2004 (*4*). Sixty percent (2,408 beach-days) of these occurred at Los Angeles and Orange County (LAOC) beaches (*4*), and nearly all (93%) of the LAOC advisories and closures were caused by unknown sources of FIB. The number of beach closures and advisories in CA (and the country as a whole) rises each year as counties monitor more beaches (*4*). Needless to say, public awareness of coastal contamination issues is growing, and in some cases strongly influencing the development of programs to improve coastal water quality. For example, public pressure on the Orange County Sanitation District (OCSD) prevented them from reapplying for a waiver from the USEPA to release partially treated sewage to the coastal ocean. Instead, OCSD plans to implement a costly upgrade to their sewage treatment plant. New stormwater permits issued by CA Regional Water Boards require counties and municipalities to implement prevention and control programs to meet coastal water quality criteria. The cost of such mitigation measures is difficult to determine, yet cost has been used as an argument in court challenges to the permits (*4*). In 2004 elections, voters in the city of Los Angeles approved a measure to spend $500 million on stormwater mitigation (*5*).

To understand the potential public health benefits of cleaning up coastal waters, we need a better idea of the magnitude of health costs associated with illnesses that are due to coastal water contamination. Several previous studies address the potential economic impacts of swimming-related illnesses. Rabinovici et al. (*6*) and Hou et al. (*7*) focused on the economic and policy implications of varying beach closure and advisory policies at Lake Michigan and Huntington Beach, CA, respectively. Dwight et al. (*8*) estimated the per case medical costs associated with illnesses at two beaches in southern California and used this to make estimates of public health costs at two Orange County beaches. Our study is novel in that it provides the first regional estimates of the public health costs of coastal water quality impairment.

While many different illnesses are associated with swimming in contaminated marine waters, we focus our analysis on gastrointestinal illness (GI) because this is the most frequent adverse health outcome associated with exposure to FIB in coastal waters (*9*, *10*). We estimate daily excess GI based on attendance data, beach-specific water quality monitoring data, and two separate epidemiological models developed by Kay et al. (*11*) and Cabelli et al. (*12*) that model GI based on exposure to fecal streptococci and ENT, respectively. Finally, we provide estimates of the potential annual economic impact of GI associated with swimming at study beaches.

We conduct our analysis using data from 28 LAOC beaches during the year 2000. Together, these beaches span 160 km of coastline (Figure 1, Table S1). We limit our analysis to these beaches and the year 2000 in particular because we were able to obtain relatively complete daily and weekly attendance and water quality data for these beaches during

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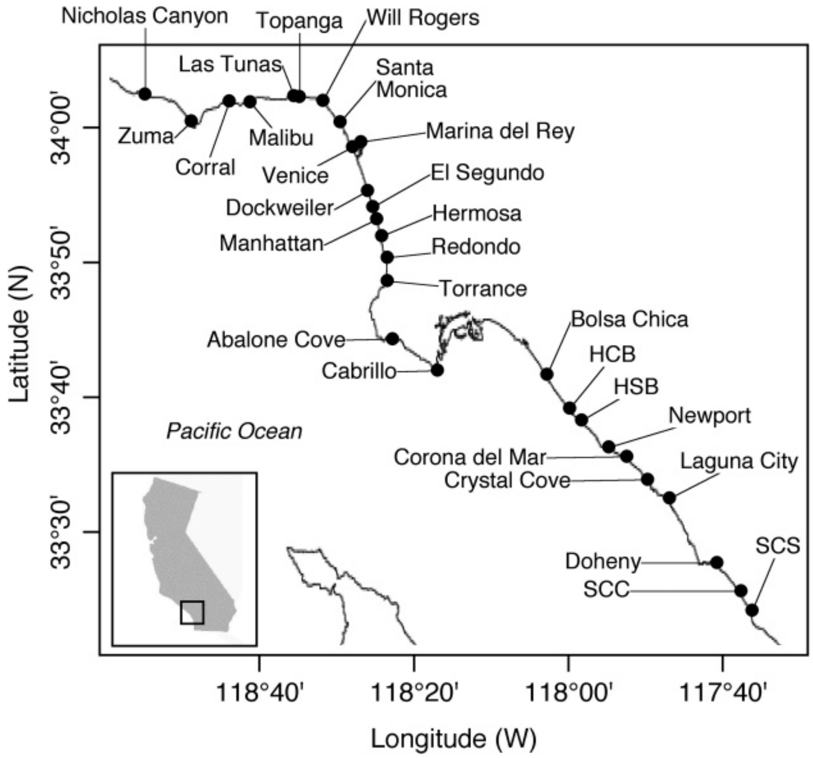

FIGURE 1. The 28 beaches considered in this study. HSB = Huntington State Beach, HCB= Huntington City Beach, SCC = San Clemente City Beach, and SCS = San Clemente State Beach.

this year. The 28 beaches represent a large, but incomplete, subset of the total beach shoreline in LAOC. Large stretches of relatively inaccessible beaches (e.g., portions of Laguna Beach, much of Malibu, and Broad Beach) were omitted from the analysis as were several large public beaches (e.g., Seal Beach and Long Beach) because of paucity of attendance and/or water quality data. The 1999−2000 and 2000−2001 winter rainy seasons were typical for southern CA (*13*), so 2000 was not particularly unique with respect to rainfall. A comparison of inter-annual water quality at a subset of beaches suggests that pollution levels in 2000 were moderate (data not shown). Thus, the estimates we provide can be viewed as typical for the region.

Methods

Number of Swimmers. Morton and Pendleton (*2*) compiled daily attendance data from lifeguards' records and beach management agencies. When data were missing, attendance was estimated using corresponding monthly median weekday or weekend values from previous years. (Table S1 shows the number of days in 2000 when data are available—for most beaches, this number approaches 366.) Because these data are based on actual counts, we do not need to factor in effects due to the issuance of advisories at a particular beach. Only a fraction of beach visitors enter the water. This fraction varies by month in southern CA from 9.56 to 43.62% (Table S2) (*14*). We applied the appropriate fraction to the attendance data to determine the number of individual swimmers exposed to coastal waters. Although research suggests the presence of FIB in sand in the study area (*15*, *16*), we do not consider the potential health risk that may arise from sand exposure because it has not been evaluated.

Water Quality Data. ENT data were obtained from the local monitoring agencies and are publicly available. Local monitoring agencies sample coastal waters at ankle depth in the early morning in sterile containers. Samples are returned to the lab and analyzed for ENT using USEPA methods. When ENT values are reported as being below or above the detection limit of the ENT assay, we assume that ENT densities were equal to the detection limit.

During 2000, monitoring rarely occurred on a daily basis; ENT densities were measured 14−100% of the 366 days in 2000, depending on monitoring site (Table S1). For example, Zuma beach was monitored once per week during the study period, while Cabrillo beach was monitored daily. To estimate ENT densities on unsampled days, we used a Monte Carlo technique. Normalized cumulative frequency distributions of observed ENT densities at each monitoring site were constructed for the 1999−2000 wet season (Nov 1, 1999 through Mar 31, 2000), 2000 dry season (April 1, 2000 through Oct 31, 2000), and the 2000−2001 wet season (Nov 1, 2000 through Mar 31, 2001). ENT densities on unsampled days during 2000 were estimated by randomly sampling from the appropriate seasonal distribution. Because day-to-day ENT concentrations at marine beaches are weakly correlated and variable (*17*), we chose not to follow the estimation method of Turbow et al. (*18*) who assumed a linear relationship between day-to-day ENT densities at two CA beaches. Comparisons between the Monte Carlo method and a method that simply used the monthly arithmetic average ENT density indicated the two provided similar results (data not shown).

The beaches in our study area (Figure 1) are of variable sizes; each beach may include 1−7 monitoring sites (Table S1). If more than one monitoring site exists within the boundaries of a beach, the arithmetic mean of ENT at the sites was used as a single estimate for ENT concentrations within the beach (*19*). There is considerable evidence that ENT densities at a beach vary rapidly over as little as 10 minutes (*17*, *20*). Therefore, even though we used up to 7 measurements or estimates to determine ENT at a beach on a given day, there is still uncertainty associated with our estimate because sampling is conducted at a single time each day.

Dose−Response. Of all the illnesses considered in the literature, GI is most commonly associated with exposure to polluted water (*10*−*12*, *21*−*26*). To estimate the risk of GI

TABLE 1. Dose−Response Models for Predicting GI[a]

name	original model	model converted to excess risk
model C (*12*)	$1000(P - P_o) = 24.2 \log_{10}(\text{ENT}) - 5.1$	$(P - P_0) = (24.2 \log_{10}(\text{ENT}) - 5.1)/1000$
model K (*11*)	$X = \text{Ln}(P/(1 - P)) = 0.201\ (\text{FS} - 32)^{1/2} - 2.36$	$(P - P_0) = (e^X/(1 + e^X)) - P_0$

[a] ENT = enterococci, FS = fecal streptococci. Both ENT and FS are in units of CFU or MPN per 100 mL water. P is the risk of GI for swimmers, P_0 is the background risk of GI.

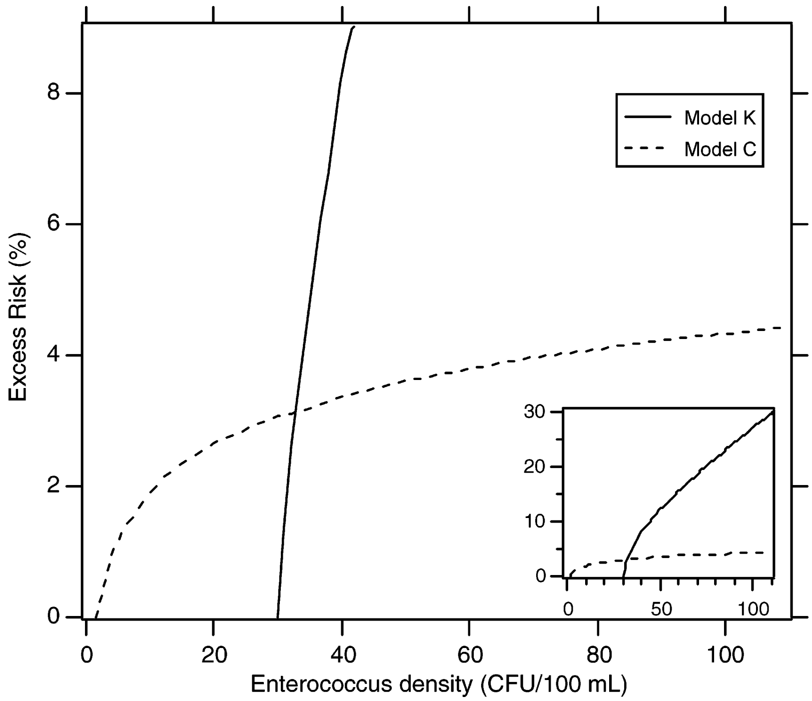

FIGURE 2. Dose−response relationships for the two epidemiological models. Excess risk of GI is shown as a function of ENT density. The inset more clearly shows the differences between the relationship for the randomized trial study (model K (*11*)) and the cohort study (model C (*12*)).

from swimming in contaminated marine waters in southern CA, we utilized two dose−response models (*11*, *12*) (Table 1) developed in epidemiology studies conducted elsewhere (in marine waters of the East U.S. coast and United Kingdom) (*18*, *27*). A local dose−response model for GI would be preferable, but does not exist. Haile et al. (*28*) conducted an epidemiology study at Los Angeles beaches and found that skin rash, eye and ear infections, significant respiratory disease, and GI were associated with swimming in waters with elevated FIB or near storm drains; however, they did not report dose−response models for illness and bacterial densities.

The two dose−response models (hereafter referred to as models C (*12*) and K (*11*)) are fundamentally different in that model C was derived from a prospective cohort study while model K was developed using a randomized trial study. Model C has been scrutinized in the literature (*20, 26, 29*−*31*). Among the criticisms are lack of ENT measurement precision and inappropriate pooling of data from marine and brackish waters. World Health Organization (WHO) experts (*10*) suggest that epidemiology studies that apply a randomized trial design, such as model K, offer a more precise dose−response relationship because they allow for better control over confounding variables and exposure (*26*). Thus, the WHO has embraced model K over cohort studies such as model C for assessing risk. We report GI estimates obtained from both models C and K in our study because they have both been applied in the literature (*8*, *18*), and form the basis for water quality criteria worldwide.

Models C and K were developed in waters suspected to be polluted with wastewater. The source of pollution at our study site during the dry season is largely unknown (*4*), although human viruses have been identified in LAOC coastal creeks and rivers (*32*−*36*) and an ENT source tracking study at one beach suggests sewage is a source (*37*). During the wet season, stormwater is a major source of FIB to coastal waters and Ahn et al. (*38*) detected human viruses in LAOC stormwater. Because we cannot confirm that all the ENT at our study site was from wastewater, there may be errors associated with the application of models C and K. In addition, there is evidence that dose−response relationships may be site specific (*30*). The results presented in our study should be interpreted in light of these limitations.

We converted incidence and odds, the dependent variables reported for model C and K, respectively, into risk of GI (P) (Table 1). P represents total risk of GI to the swimmer, and includes risk due to water exposure plus the background GI rate (P_0). Excess risk was calculated by subtracting the background risk from risk ($P - P_0$). While ENT is the independent variable for model C, model K requires fecal streptococci (FS), the larger bacterial group of which ENT are a subset, as the independent variable. We assumed that FS and ENT represent the same bacteria, following guidance from the WHO (*9*).

Models C and K provide different functional relationships between ENT and excess GI risk (Figure 2). Model C predicts relatively low, constant risks across moderate to high ENT densities relative to model K. At ENT less than 32 CFU/100 mL, model K predicts no excess risk; model C, however, does predict nonzero risks even at these low levels of contamination. The data range upon which each model was built varies considerably. Model C is based on measurements ranging from 1.2−711 CFU/100 mL and model K is based on measurements from 0−35 to 158 CFU/100 mL. We extrapolated models C and K when ENT densities were outside the epidemiology study data ranges. Given the lack of epidemiological data on illlness outside the ranges, extrapolation of the models represents a reasonable method of estimating excess GI.

Excess Illness Due To Swimming. The excess incidence of GI on day i at beach j ($GI_{i,j}$) is given by the following expression:

$$GI_{i,j} = A_{i,j} f_i (P_{i,j} - P_o) \quad (1)$$

$P_{i,j} - P_o$ is the excess risk of GI on day i at beach j as estimated from models C or K (Table 1), $A_{i,j}$ is the number of beach visitors, and f_i is the fraction of swimmers on day i (*14*). We assume P_0 is 0.06—the background risk for stomach pain as reported by Haile et al. (*28*) for beaches within Santa Monica Bay, CA. Daily values were summed across the year or season to estimate the number of excess GI per beach. Seasonal comparisons are useful in this region because of distinct differences between attendance and water quality between seasons. The wet season is defined as November through March and the dry season is defined as April through October. Note that the dry season corresponds to the season when state law mandates beach monitoring (*3*).

Public Health Costs of Coastal Water Pollution. GI can result in loss of time at work, a visit to the doctor, expenditures on medicine, and even significant nonmarket impacts that represent the "willingness-to-pay" of swimmers to avoid getting sick (sometimes referred to as psychic costs). Because there is a lack of information on the costs of waterborne GI, Rabinovici et al. (*6*) used the cost of a case of food-borne GI, $280 (year 2000 dollars) per illness from Mauskopf and French (*39*), as a proxy for the cost of water-borne GI for swimmers in the Great Lakes. The $280 per illness represents the willingness-to-pay to avoid GI and includes both market and nonmarket costs (*6*). Dwight et al. (*8*) conducted a cost of illness study for water-borne GI for two beaches in southern California (Huntington State Beach and Newport Beach) and determined the cost as $36.58 per illness in 2004 dollars based on lost work and medical costs. Discounting for inflation, this amount is equivalent to $33.35 in the year 2000 dollars. This value does not include lost recreational values or the willingness-to-pay to avoid getting sick from swimming. We use the more conservative estimate of Dwight et al. (*8*) to calculate the health costs of excess GI at LAOC beaches. However, we also provide more inclusive estimates of the cost of illness using Mauskopf and French's $280 willingness-to-pay value (*39*). Unless otherwise stated, all costs are reported in year 2000 dollars.

Results

Attendance and Swimmers. Beach attendance was higher during the dry season (from May through October) than in the wet season (November through April) (Figure 3). We estimate that the annual visitation to Los Angeles and Orange County (LAOC) beaches for the year 2000 approached 80 million visits.

Water Quality. Water quality (measured in terms of ENT concentration) varies widely across the beaches in the study. (Figure S1 shows the log-mean of ENT observations at each beach during the dry and wet seasons.) In general ENT densities are higher during the wet season compared to the dry. Water quality problems at a beach may exist chronically over the course of the year or may be confined to particularly wet days when precipitation washes bacteria into storm drains and into the sea. The most serious, acute water quality impairments can result in the issuance of a beach advisory or beach closure. According to CA state law, water quality

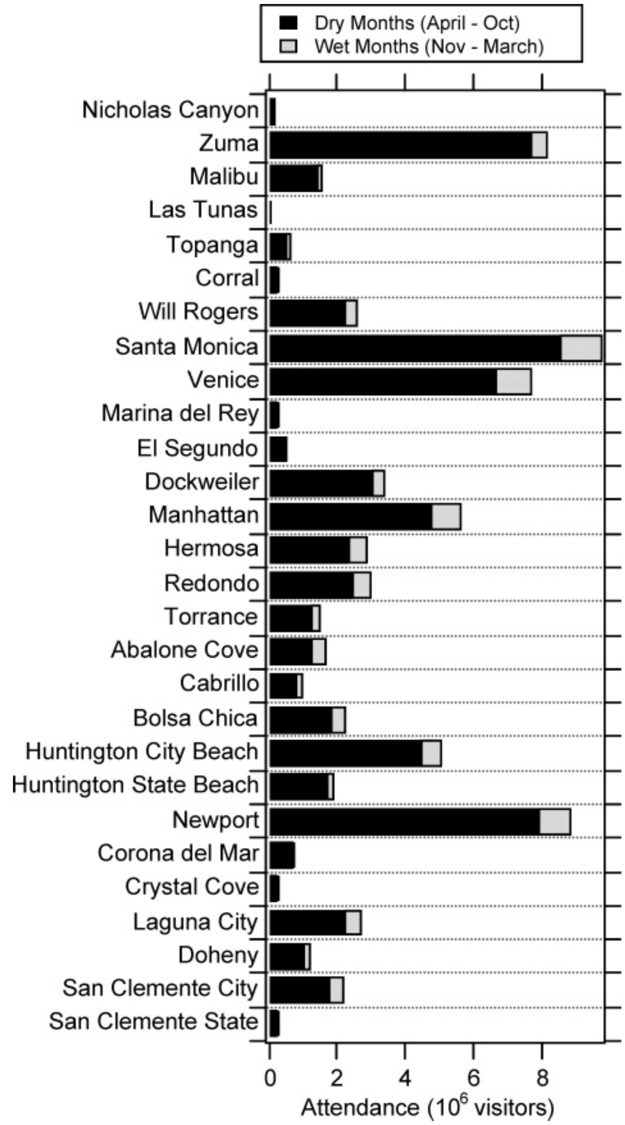

FIGURE 3. Beach attendance during wet and dry seasons 2000.

exceeds safe levels for swimming if a single beach water sample has a concentration of ENT greater than 104 CFU/100 mL. Figure 4 illustrates the percentage of the days for which daily estimated ENT concentrations were in excess of the state single sample standard. Exceedances during the wet months generally outnumber exceedances during the dry months. The exceptions are Corral, Bolsa Chica, and Crystal Cove, which are all relatively clean beaches, even in the wet season. Doheny, Malibu, Marina Del Rey, Cabrillo, and Las Tunas had the worst water quality with over 33% of the daily estimates in 2000 greater than 104 CFU/100 mL, while Newport, Hermosa, Abalone Cove, Manhattan, Torrance, and Bolsa Chica had the best water quality with less than 5% of daily estimates under the standard.

Estimates of Excess GI and Associated Public Health Costs due to Swimming. Figure 5 illustrates estimated annual excess GI at beaches based on models C and K; results are given for dry and wet months. Models C and K both indicate that Santa Monica, the beach with the highest attendance (Figure 3), has the highest excess GI of all beaches during wet and dry seasons. Both models predict that the three beaches with the lowest excess GI were San Clemente State, Nicholas Canyon, and Las Tunas, a direct result of these beaches being among the smallest and least visited in our study area (Figure 3).

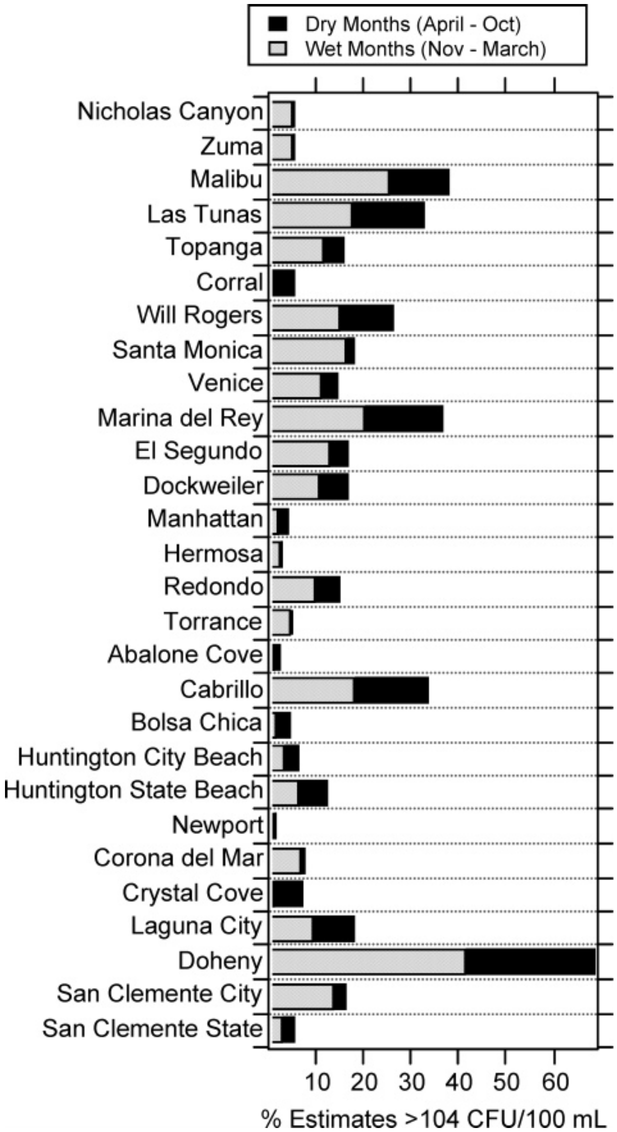

FIGURE 4. Percentage of days on which daily ENT estimates were greater than the CA Department of Health single-sample ENT standard of 104 CFU/100 mL.

There are marked seasonal differences between excess GI predictions. Although water quality is typically worse during the wet season compared to the dry (Figures 4 and S1), more excess GI are predicted for the dry season for most beaches. This result is driven by seasonal variation in attendance (Figure 3). The exceptions are model K predictions for Zuma that indicate 0 and 6647 excess GI during the dry and wet seasons, respectively. Zuma had no ENT densities greater than 32 CFU/100 mL during the dry season, hence the prediction of 0 excess GI.

Numerical predictions of excess GI for the entire year from model C and model K vary markedly between beaches. At 24 beaches, model K predicts between 18% and 700% greater excess GI than model C. The greatest difference in the estimated GI is at Doheny beach where models C and K predict 18,000 and 153,000 excess GI, respectively. At 4 beaches (Zuma, Hermosa, Torrance, and Newport), model K predicts between 1 and 90% lower incidence of GI than model C. These beaches are generally clean with ENT densities below the model K threshold of 32 CFU/100 mL for excess risk.

The public health burden of coastal contamination depends on both attendance and water quality. Figure 6

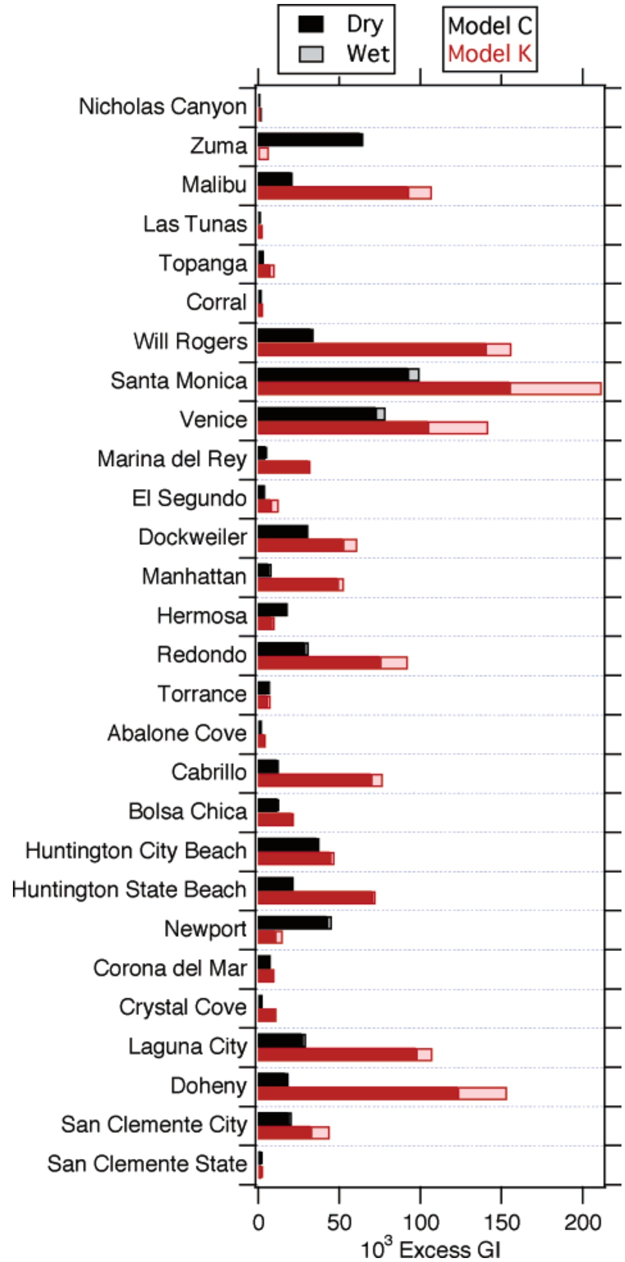

FIGURE 5. Excess GI by beach and season for models C and K.

illustrates how excess GI, based on predictions from models C and K, varies as a function of water quality (percent of daily ENT estimates in exceedance of standard) and attendance. Red, yellow, and green symbols indicate beaches with increasing numbers of GI. If reduction of public health burden is a goal of local health care agencies, then beaches with a red symbol are candidates for immediate action. Nearly all beaches are categorized as high priority during the dry season based on model K (panels A and B). Model C indicates that dry weather mitigation measures at Venice, Zuma, Santa Monica, and Newport, some of the most visited beaches, would significantly reduce the public health burden (panel C), more so than wet weather mitigation measures (panel D).

Another way of prioritizing beach remediation is to examine the risk of GI relative to the USEPA guideline of 19 illnesses per 1000 swimmers (Figure S2). Model K indicates that at 19 and 15 of the 28 LAOC beaches during the wet and dry seasons, respectively, risk is greater than twice the EPA acceptable risk. Model C, on the other hand, indicates that only two beaches (Marina del Rey and Doheny) during the

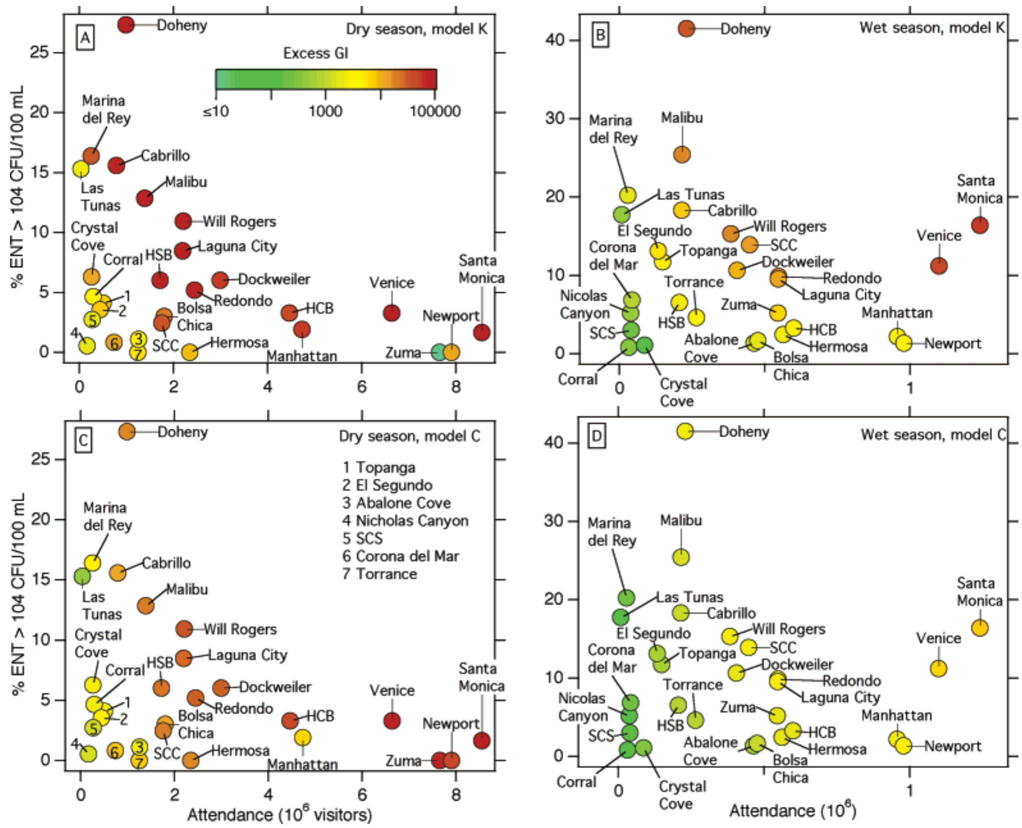

FIGURE 6. Excess GI at each beach as a function of % ENT in exceedance of the single sample standard and attendance. Results for the dry (panels A and C) and wet (panels B and D) seasons are shown for Models K (panels A and B) and C (panels C and D). Beaches are labeled; SCC is San Clemente City Beach, SCS is San Clemente State, HSB is Huntington State Beach, and HCB is Huntington City Beach. In panels A and C, numbers on symbols correspond to beaches, as indicated in the upper right corner of panel C. The color scale in panel A applies to all panels.

TABLE 2. Countywide Public Health Impacts and Costs for Wet and Dry Months (2000)

county/ region	season	GI cases		health costs	
		model C	model K	model C	model K
Los Angeles					
	dry	394,000	804,000	$13,100,000	$28,800,000
	wet	33,800	189,000	$1,130,000	$6,310,000
	total	427,800	993,000	$14,230,000	$35,110,000
Orange					
	dry	185,000	420,000	$6,180,000	$14,000,000
	wet	15,000	66,200	$500,000	$2,210,000
	total	200,000	486,200	$6,680,000	$16,210,000
region total					
	dry	579,000	1,224,000	$19,280,000	$40,800,000
	wet	48,800	255,200	$1,630,000	$8,520,000
	total	627,800	1,479,200	$20,910,000	$51,320,000

dry season, and six (Marina del Rey, Doheny, Santa Monica, Las Tunas, Will Rogers, and Malibu) in the wet season fall into this "high" risk category.

Public Health Costs of Coastal Water Pollution. Table 2 summarizes the number of excess GI and associated public health costs during wet and dry periods by county and season. Based on the conservative cost of illness given by Dwight et al. (*8*), the estimated health costs of GI based on models C and K is over $21 million and $50 million, respectively. If we follow Rabinovici et al. (*6*) and use $280 per GI, the estimated public health impacts are $176 million based on model C and $414 million based on model K. For both LA and OC beaches, county-wide costs obtained using model K yield higher results than those obtained from model C, a direct result of the difference in GI estimates (Figures 5 and 6). Health costs are greater in the dry season compared to the wet suggesting that money may be well spent on dry-weather diversions.

Discussion

A significant public health burden, in terms of both numbers of GI and the costs of GI, is likely to result from beach water quality contamination in southern CA. The corollary to this finding is that water quality improvements in the region would result in public health benefits. Specifically, we make three key findings: (1) removing fecal contamination from coastal water in LAOC beaches could result in the prevention of between 627,800 and 1,479,200 GI and a public health cost of between $21 and $51 million (depending upon the epidemiological model used) each year in the region using the most conservative cost estimates and as much as $176 million or $414 million if we use the larger estimate of health costs (*6*, *39*); (2) even beaches within the same region differ significantly in the degree to which swimming poses a public health impact; and (3) public health risks differ between seasons. Findings (2) and (3) are not surprising given spatio−temporal variation in water quality (*17*, *40*) and attendance within the study site.

A previous study by Turbow et al. (*18*) estimated 36,778 excess HCGI (highly credible GI) per year from swimming at Newport and Huntington State beaches (*8*). Our estimates for the same stretch of shoreline are higher (68,011 and 87, 513 excess GI based on models C and K, respectively). Not only did we use a different measure of illness (GI vs. HCGI) we also used a Monte Carlo scheme to estimate ENT on unsampled days whereas Turbow et al. (*18*) used linear interpolation, and we used higher, empirically determined

(*14*) measures of the percent of beach goers that swim. Dwight et al. (*8*) used Turbow et al.'s (*18*) estimate to determine that the health costs of excess GI at the same beaches were $1.2 million. Our health cost estimates are higher ($2.3 and $2.9 million for models C and K, respectively), due to the higher incidence of ilness predicted by our models.

Beaches with chronic water quality problems are obvious candidates for immediate contamination mitigation. Many beaches in LAOC, however, are relatively clean and meet water quality standards on most days. Clean beaches with moderate to low levels of attendance do not represent a significant public health burden (Figure 6). Nevertheless, public health impacts are still substantial at heavily visited beaches (for instance those with over 6,000,000 visitors per year) even when water quality is good (e.g., Manhattan Beach) (Figure 6). Generally speaking, it will be more difficult to reduce contaminant levels at cleaner beaches. At beaches with high attendance and generally good water quality (like Newport Beach and Zuma), policy managers should continue dry weather source reduction efforts (e.g., education campaigns and watershed management), but should also recognize that the cost of eliminating all beach contamination may outweigh the marginal public health benefits of doing so.

Our estimates of the potential health benefits that might result from removing bacterial contamination from coastal water in LAOC beaches have limitations. First, we focus on a lower bound estimate of the health cost of GI that does not consider the amount a beach goer is willing to pay to avoid getting sick (estimates using higher, but less scientifically conservative estimates also are provided). Second, while we focus on the public health impacts from GI. Exposure to microbial pollution at beaches also increases the chance of suffering from various symptoms and illnesses (*28*, *41*). For instance, Haile et al. (*28*) and Fleisher et al. (*41*) document associations between water quality and respiratory illnesses, acute febrile illness, fever, diarrhea with blood, nausea, and vomiting, and earaches. Third, if the public believes swimming is associated with an increased risk of illness, they may be discouraged from going to the beach, resulting in a loss of beach-related expenditures to local businesses and recreational benefits to swimmers in addition to the loss in health benefits described here. Fourth, we consider GI occurring at a subset of LAOC beaches for which water quality and attendance data were available (Figure 1). Fifth, implicit in our analysis is the assumption that models C and K can be applied to LAOC beaches. Despite these limitations, the results reported here represent the best estimates possible in light of imperfect information. Future studies that establish dose−response relationships for the LAOC region or confirm incidence of swimming GI medically would improve estimates of public health burden and costs.

Acknowledgments

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Note Added after ASAP Publication

The Model C discussion in the Methods section published ASAP July 15, 2006 has been revised. The corrected version was published July 26, 2006.

Supporting Information Available

Tables S1 and S2, Figures S1 and S2, and the California state water quality standards. This material is available free of charge via the Internet at http://pubs.acs.org.

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