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# Estimating the economic burden from illnesses associated with recreational coastal water pollution—a case study in Orange County, California

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## Abstract

A cost-of-illness framework was applied to health and income data to quantify the health burden from illnesses associated with exposure to polluted recreational marine waters. Using data on illness severity due to exposure to polluted coastal water and estimates of mean annual salaries and medical costs (adjusted to 2001 values) for residents of Orange County, California, we estimated that the economic burden per gastrointestinal illness (GI) amounts to $36.58, the burden per acute respiratory disease is $76.76, the burden per ear ailment is $37.86, and the burden per eye ailment is $27.31. These costs can become a substantial public health burden when millions of exposures per year to polluted coastal waters result in hundreds of thousands of illnesses. For example, exposures to polluted waters at Orange County's Newport and Huntington Beaches were estimated to generate an average of 36,778 GI episodes per year. At this GI illness rate, one can also expect that approximately 38,000 more illness episodes occurred per year of other types, including respiratory, eye, and ear infections. The combination of excess illnesses associated with coastal water pollution resulted in a cumulative public health burden of $3.3 million per year for these two beaches. This paper introduces a public health cost variable that can be applied in cost-benefit analyses when evaluating pollution abatement strategies.

**Keywords:** Valuing morbidity impacts; Coastal; Beach; Water quality; Economic burden of illness; Recreational marine waters; Gastroenteritis; Acute respiratory disease; Cost of

illness

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## 1. Introduction

A large body of epidemiological research has shown that exposure to recreational waters contaminated with human and animal waste can result in several types of illnesses including gastroenteritis (GI), acute respiratory disease (ARD), and eye, ear and skin infections (Saliba and Helmer, 1990, Prüss, 1998, Haile et al., 1999 and Dwight et al., 2004). These illnesses are caused by enteric bacteria, viruses and protozoa that are found primarily in human wastewater, and are not endemic to recreational waters. The majority of these illnesses are self-limiting and place little demand on the health care system, and yet they are debilitating to various degrees, which can result in associated costs. Several researchers have suggested that illnesses associated with coastal water pollution can have significant health and economic impacts on society (Fleisher et al., 1998, Gerba et al., 1996, Henrickson et al., 2001, Saliba and Helmer, 1990, Corbett et al., 1993 and Haile et al., 1999). A recent study estimated that globally polluted coastal waters generate 120 million excess GI episodes and 50 million ARD episodes every year, resulting in $12 billion per year in public health costs (Shuval, 2003).

Domestic sewage discharged along coastlines has historically been the primary source of marine coastal water pollution for recreational bathing beaches in the USA. However, with few exceptions, most sanitation facilities across the United States have been upgraded to comply with USA federal law. The attention of policy makers is now being focused on the potentially larger problem of untreated urban runoff. Urban runoff contains a mixture of non-point source pollutants that are suspended in water from irrigation runoff, households, and storm events, as well as contributions of raw sewage from degrading infrastructure and accidental spills. Research of high density urban and industrial landscapes show infectious and toxic pollutants are routinely released into runoff waters (Bay and Greenstein, 1996, Gold et al., 1991 and Field et al., 1993).

Urban runoff is of particular concern in the Southern California region of the USA where the large population and vast expanse of impermeable surfaces generates large volumes of polluted runoff water that can discharge onto popular coastal beaches. Untreated urban runoff is considered the most significant source of water pollution impacting Southern California's coastal waters, estuaries and bays (Southern California Coastal Water Research Project, 1991, California Resource Agency, 1997, Schafer and Gossett, 1998 and Noble et al., 2000; Dwight et al., 2002).

In one large-scale epidemiological study of illnesses associated with polluted recreational marine waters, researchers measured the severity of the resulting illnesses by evaluating length of illness, and whether or not the subjects had to see a doctor (Fleisher et al., 1998). Values were collected for four illness types (GI, ARD, eye and ear infections), and the data were used to ascertain the severity of the water-associated illnesses. The researchers concluded that excess illnesses associated with recreational waters have a significant impact on public health.

Understanding the severity of symptoms and estimating the economic impact from recreational water-related illnesses is important because the information can aid the decision making process related to pollution abatement strategies. To illustrate the utility of this approach, we estimated the economic impact on public health from exposure to polluted coastal water at two popular beaches.

# 2. Methods

In order to quantify the health costs per water associated illness, we applied the 'cost-of-illness' framework to health data on illness-related lost activity days and medical care use generated from an epidemiological study of recreational coastal water users (Fleisher et al., 1998), and to annual income data and medical care costs for residents of Orange County, California (USDC, 2004; Nichol, 2001). We then show in an example how these results can be used to estimate the annual public health burden for recreational beaches by combining our cost per illness results with published results of a model that estimated the number of water associated GI illnesses for a specific site (Turbow et al., 2003).

To calculate the cost per water-associated illness, we used the cost-of-illness approach which focuses on health damages, or costs following the onset of illness (Berger et al., 1994). This is an attractive method for estimating economic values for morbidity effects because it uses actual data of financial costs directly measured in a market setting, such as lost earnings and medical services from illness (Kenkel, 1994).

The variables in the model include estimates of illness severity (proportion of persons with lost normal-activity-days, and proportion requiring a medical visit per illness episode) for each type of illness; the average annual salary of the population; the proportion of illnesses that require professional medical attention; and the medical costs associated with an illness.

## 2.1. Data

Data on illness severity came from the only published measures of illness severity for illnesses associated with contaminated recreational water (Fleisher et al., 1998). The values were collected during randomized intervention follow-up epidemiological studies conducted at four beaches in the United Kingdom. For our cost-of-illness valuation, we only used health data from subjects classified as bathers, and censored data from non-bathers. Subjects were adult volunteers (>18 years) and the final cohort ($n$=548) had a mean age of 32 years; 54% were male. Although several types of illnesses have been associated with exposure to waterborne pathogens, including some rare but severe illness (Saliba and Helmer, 1990 and Prüss, 1998), the current study was restricted to GI, ARD, ear and eye ailment illness outcomes as a conservative estimate of the total burden of illness.

Subjects in the study by Fleisher et al. (1998) were considered to have an illness only if they reported a composite of certain symptoms known to be associated with a particular illness lasting for over 24 h, or if there was clinical confirmation of symptoms. Subjects were classified as having GI if they reported experiencing vomiting or diarrhea, or all cases of nausea, indigestion, diarrhea or vomiting that were accompanied by a fever. Subjects were classified as having ARD if they reported experiencing at least one symptom from each of the following three categories: (1) fever; (2) headache and/or body-aches and/or unusual fatigue and/or anorexia; and (3) sore throat and/or runny nose and/or dry or productive cough. Subjects were classified as having an ear ailment if they showed clinical evidence of ear infection or inflammation by medical examination, or if the subject reported ear pain with or without discharge. Subjects were classified as having an eye ailment if they reported incidence of sore, red, eyes with or without discharge.

For each of the four illness types, Fleisher et al. (1998) provides estimates of the proportion of illnesses that resulted in lost normal activity, from 1 to 3 days ($A_{i,j}$, where $i$=days of lost normal activity [1,2,3], and $j$=illness type [GI, ARD, Ear, Eye]), as well as the proportion of illnesses that required medical care ($C_j$) (Table 1). These estimates are relevant to the cost-of-illness model because only a small proportion of exposed persons become ill and only a relatively small proportion of those who become ill lose a day or more of normal activity or seek medical care. For example, Table 1 indicates that only 9.3% of persons with a GI illness episode lose one day of normal activity and only 12% seek any medical care.

Table 1.

Illness severity measures ($A$ and $C$) for water-associated illnesses

| | GI | ARD | Ear | Eye |
|---|---|---|---|---|
| Proportion of illnesses with 1 day lost activity ($A_1$) | $0.093_{1,GI}$ | $0.074_{1,ARD}$ | $0.023_{1,Ear}$ | $0.042_{1,Eye}$ |
| Proportion of illnesses with 2 days lost activity ($A_2$) | $0.04_{2,GI}$ | $0.148_{2,ARD}$ | $0.023_{2,Ear}$ | $0.083_{2,Eye}$ |
| Proportion of illnesses with 3 days lost activity ($A_3$) | $0.014_{3,GI}$ | $0.037_{3,ARD}$ | $0.023_{3,Ear}$ | No report |
| Proportion of ill persons that go to a doctor ($C$) | $0.12_{Dr,GI}$ | $0.222_{Dr,ARD}$ | $0.209_{Dr,Ear}$ | $0.042_{Dr,Eye}$ |

GI, gastroenteritis; ARD, acute respiratory disease; ear, ear ailments; eye, eye ailments; Dr, medical attention sought. Data from Fleisher et al. (1998).

Data on income-per-day in 2001 were calculated from the average annual wage in Orange County of $39,895 in that year (USDC, 2004). This figure was divided by 240 work-days per year to estimate an income-per-workday of $166.23. Data were reported as days of lost-normal-activity, but not every day of lost-normal-activity is equal to a day of lost wages. Therefore, we multiplied 'income-per-day' by the proportion of work days in a year (240 work days/365 days), yielding $109.30 income-per-day in Orange County, CA. We did not include costs from lost leisure time in this analysis due to lack of data. However these costs should be included in a full valuation model because people invest a lot of time and money in their vacations, so a disrupted vacation from a recreational-water-related illness can have greater value loss than just the lost income value.

The medical expense for each illness episode that required a medical visit includes the costs of physicians' fees, medications and patient co-payments. This value was estimated at $102.00 per visit in 1998 dollars based on the average value from Nichol (2001). For the model this was adjusted to $108.98 to account for inflation to the year 2001.

## 2.2. Valuation method

The cost-per-illness ($F$ ($)) was calculated for each type of illness as follows—Eq. (1) is the overall model used to calculate the cost-per-illness:

$$F = L + M \quad (1)$$

where: $L$=lost income per illness episode ($) and $M$=medical costs ($).

The lost income per illness episode term in Eq. (1) was calculated from:

$$L = \left( \sum_{i=1}^{3} (iA_{ij}) \right) D \quad (2)$$

where: $A_{ij}$ is the proportion of exposed persons experiencing $i$ days of lost normal activity for each illness ($j$), and $D$ is the income per work day ($).

The proportion of lost days of normal activity for 1, 2, or 3 days ($i$=[1,2,3]) and illness type ($j$=[GI, ARD, Ear, Eye]) for each illness episode are referenced from the epidemiology study in Table 1. For example, using the data for GI in Table 1, the proportion of lost days per illness episode is calculated as: (1 day×0.093)+(2 days×0.040)+(3 days×0.014)=0.215 day. This amount is multiplied by the income-per-workday to equal $23.50 in lost income per GI illness episode. The calculation for each of the four illnesses is shown in Table 2.

Table 2.

Public health cost from coastal water pollution in california's newport and huntington beaches

| **Item** | **Type of illness** | | | | **Location-specific** |
|---|---|---|---|---|---|
| | **GI** | **ARD** | **Ear** | **Eye** | **Estimates** |
| *Proportion lost days/illness* | | | | | |
| 1 day | 0.093 | 0.074 | 0.023 | 0.042 | |
| 2 days | 0.04 | 0.148 | 0.023 | 0.083 | |
| 3 days | 0.014 | 0.037 | 0.023 | 0.00 | |
| Total lost days/illness[a] | 0.215 | 0.481 | 0.138 | 0.208 | |
| Effective daily income[b] | | | | | $109.30 |
| Lost income/illness | $23.50 | $52.57 | $15.08 | $22.73 | |
| Proportion medical visit/illness | 0.12 | 0.222 | 0.209 | 0.042 | |
| Medical cost/visit | | | | | $108.98 |
| Medical cost/illness[c] | $13.08 | $24.19 | $22.78 | $4.58 | |
| Total cost/illness | $36.58 | $76.76 | $37.86 | $27.31 | |
| Illness relative rates[d] | 1 | 0.337 | 0.551 | 0.303 | |
| Annual GI illness rate[e] | | | | | 36,778 per year |
| Estimated illness costs[f] | $1,345,339 | $951,378 | $767,221 | $304,335 | |
| Total costs | $3,368,273 | | | | |

[a] Total lost days/illness=$\Sigma iA_{i,j}$, where $i$=number of days, $A_{i,j}$=proportion of type $j$ illness with lost

activity day (from Fleisher et al., 1998).

[b] Effective daily income=(Annual Salary/240 work days/year)×(240 work days/365 total days). Median annual salary in Orange County, CA=$39,755 (USDC, 2004).

[c] Medical cost/illness, $M=C_jE$, where $C_j$=proportion of type *j* illness resulting in medical visit (from Fleisher et al., 1998) and *E*=cost of visit. Average cost of medical visit = $108.98 (Nichol, 2001).

[d] Illness relative rates compared to GI illness rates, $R_j=D_j/D_{GI}$, where $D_j$=rate of illness type *j* and $D_{GI}$=the rate of GI illness (from Fleisher et al., 1998).

[e] Annual GI illness incidence estimated for Huntington and Newport Beaches in Orange County (Turbow et al., 2003).

[f] Estimated illness costs=GI illness rate×(illness relative rate)*j*×(total cost/illness)*j*.

Medical costs (*M* ($)) for each illness episode are calculated from:

$$M=C_jE \tag{3}$$

where *C* is the proportion of exposed persons requiring medical attention for each illness type (*j*), and *E* ($) is the medical expense per visit. The proportion of bather illness episodes that required a person to seek medical attention is shown in Table 1, derived from Fleisher et al. (1998). Each of these proportions was multiplied by the average cost of a doctor visit ($108.98) based on Nichol (2001). For example, the average medical cost of a GI illness episode is equal to (0.012×$108.98) =$13.08 (Table 2).

## 2.3. Site-specific example

To estimate the health cost to the public from exposure to polluted coastal water, the cost-of-illness estimate for each type of illness occurrence was multiplied by their respective estimates of illness episodes for an exposed population at a specific site during a specified period of time. A recent publication presented a model to estimate number of GI illness episodes that occurred from 1998 to 2000 at Huntington and Newport Beaches in Orange County, California (Turbow et al., 2003). These two adjacent recreational beaches are world-renowned vacation destinations that host an estimated 5.5 million coastal water exposures annually (County Sanitation Districts of Orange County, 1996).

The sample beaches receive pollution from two primary sources: treated domestic sewage and untreated urban runoff. The Orange County Sanitation District (OCSD) discharges around 900 million liters-per-day of treated domestic sewage year-round into the ocean from an outfall that is 8 km directly offshore from these beaches. Another primary source of surf zone pollution is the discharge of untreated urban runoff from the Santa Ana River, which drains over 2600 $km^2$ of one of the world's most highly developed watersheds.

The time period of Turbow et al. (2003) study was a representative period in Southern California with low average rainfall and relatively low concentrations of faecal indicator organisms in coastal waters. The parameters used in the model to estimate the number of illness occurrences included historical enterococcus density data collected by the OCSD approximately three times per week at 305 m intervals along the beach for a 31-month study period; population at risk of exposure; and illness risk estimates. The population at risk was estimated using data on aggregate beach attendance provided through local lifeguard agencies and fire departments, and reports on the proportion of beachgoers who bathe at different times of the year at the beaches. The enterococcus density–illness relationship used in the model was derived from the cohort studies conducted by Cabelli et al. (1983). These incidence risk estimates were used because they were the basis for the current US EPA guidelines for recreational water quality in United States. For more information on the water quality data for these beaches over time and the model parameters, please refer to Turbow et al. (2003).

The illness occurrence model developed by Turbow et al. estimated that 95,010 GI illnesses occurred from coastal water pollution at these two beaches during the study period (31 months). That is equivalent to 36,778 GI illnesses per year from recreational water use in Newport and Huntington Beaches during a typical year. This suggests the coastal waters in this area generate a persistent low level of unreported illnesses that results in tens of thousands of illness events annually. With this estimate of the annual number of GI illness events, the cumulative public health burden can be calculated by multiplying the cost-per-illness by the estimated number of illness episodes per year (Table 2).

Data from Turbow et al. (2003) related only to GI illnesses. In order to calculate the public health costs associated with the other illness types, study data from Fleisher et al. (1998) was used to calculate the relative rates ($R_j$) for each of the other illness.

# 3. Results

## 3.1. Cost per illness

Table 2 shows the estimated cost per illness calculated using the cost-of-illness model. The estimated health costs are $36.58 per GI episode, $76.76 per ARD episode, $37.86 per ear ailment, and $27.31 per eye ailment.

## 3.2. Cumulative public health cost

Health costs associated with individual illness episodes are a substantial public health burden when extrapolated to popular recreational beaches that attract millions of recreators per year. Table 2 indicates a $1.3 million public health cost from GI illnesses associated with polluted recreational waters at Newport and Huntington Beaches in a typical year. The public health cost from ARD episodes is $951,378 per year, from ear ailments is $767,221 per year, and from eye ailments is $304,335 per year. The annual cumulative public health burden for these two beaches is equal to $3.3 million.

The US EPA's current water quality standard for recreational marine waters, which was recently adopted by California, has a threshold illness rate for GI of 1.9% (Cabelli, 1989). This water quality criterion was adopted by the US EPA based on a series of epidemiological studies conducted over six years at beaches in Boston Harbor, New York City, and a lake in Louisiana (Cabelli et al., 1983). Therefore, we also calculated the health costs that would occur if the recreational coastal waters of Huntington and Newport Beaches were to exactly meet the accepted US EPA and California State standard for indicator bacteria for a 1-year period, thereby calculating the cost of the current standard at a popular recreational beach. Under these assumed conditions, one would expect a GI illnesses rate of 1.9% (Cabelli, 1989), or an estimated 78,515 excess GI episodes per year (Turbow et al., 2003). Using this GI illness rate, the cumulative public health cost for GI illnesses would be $2.87 million per year. The annual public health burden would be $2.03 million for ARD, $1.63 million for ear ailments, and more than $649,000 for eye ailments. The total public health cost for Newport and Huntington Beaches would be greater than $7 million annually, if coastal water quality complied exactly with US EPA standards for an entire year.

# 4. Discussion

The United States spends considerable resources to ensure that food and drinking water meet stringent health and safety standards for pathogens and toxins to the point that they pose a relatively low health risk. However, water quality standards for recreational waters, especially marine waters, are much less stringent with an acceptable risk level of 1.9 GI illnesses/100 exposures (Cabelli, 1989). Although people do not drink ocean water on purpose, accidental ingestion does occur frequently when undertaking recreational activities in the ocean.

GI illnesses have been the primary illness investigated in epidemiology studies of drinking-water associated illnesses because that is the most prominent illness that results from drinking polluted water. However, when people are immersed in polluted recreational water, they can contract a range of illnesses because all portals of entry into the body are exposed when swimming. Therefore, the US EPA's acceptable rate for GI illness of 1.9% in recreational marine waters should actually be considered conservatively as an illness rate of 1.9% GI+0.64% ARD+1.05% Ear+0.58% Eye, for an overall illness rate of 4.17% when water quality is at the accepted standard.

For the purpose of data validation, we conducted a search of the following databases MEDLINE, BIOSIS, and ABI/INFORM Global for peer-reviewed publications on GI illness severity and cost-of-illness. The most relevant citations are summarized in Table 3. Only a few water-related studies measured some of the variables used in our cost-of-illness model. Therefore, we also investigated studies of GI illnesses attributed to causes other than contaminated water. This was done because the source of an infectious agent should not influence the severity of the resulting illness. This assumption is supported by an epidemiological study where subjects reported no statistical difference between water-exposed and unexposed subjects in the duration of illnesses, illness percentages seeking medical attention, and time lost from normal daily activity (Fleisher et al., 1998).

Table 3.

Comparative measures of illness severity for gastroenteritis

| **References** | **Number of days Ill** | **Stay-at-home illnesses (*A*)** | **Lost days** | **Doctor visits (*C*)** |
|---|---|---|---|---|
| Fleisher et al., 1998[a] | 4.1 (mean) | 0.201 | At least 1 day | 0.12 |
| | | | Lost normal activity | |
| Cabelli et al., 1979[a] | nr | | 0.50 of cases stayed home or saw a doctor | |
| Garthright et al., 1988 | nr | 0.52 | 1 day | 0.083 |
| | | | Restricted activity | |
| Gerba et al., 1996[a] | 5–8 (typical) | nr | nr | nr |
| Hardy et al., 1994[b] | 5.4 (mean) | nr | nr | 0.10 |
| Payment et al., 1991[a] | 1.9 (mean) | nr | nr | nr |
| Wit et al., 2000[c] | nr | 0.15 | 2 days (median) | 0.22 |
| | | | Lost work-days | |
| Wit et al., 2001[c] | 6 (median) | 0.60 | 3.1 days (mean) | 0.20 |
| | | | Lost work-days | |

nr=no report.

[a] Studies of water-associated illnesses.

[b] Studies conducted on children.

[c] Studies of non-water-associated illnesses.

No previous cost-per-illness studies have been conducted on illnesses associated with polluted recreational waters, so in order to review the evidence, a literature search of cost-per-illness investigations of illnesses from other sources such as food-borne infections was undertaken. Table 4 lists the citations that provided a calculated cost-per-illness; however, there are important methodological differences between citations in the types of subjects they studied and the complexity of the models they used. The estimated costs-per-illness values generated in this study are supported by a comparison to cost-per-illness values generated in the other studies, and even suggest that our results may be low by a factor of ten. This is due to the restrictive cost values used in our model, as well as from the restrictive model itself, which has only two health cost variables: Lost income ($L$) and Medical costs ($M$).

Table 4.

Comparative cost-per-illness citations

| **Citations** | **Cost-per-illness** |
|---|---|
| *Gastroenteritis* | |
| Our results with data from Fleisher et al, 1998[a] | $36.58 |
| Frühwirth et al., 2001[b] | $225–2,198[c] |
| Garthright et al., 1988[d] | $322–521[e] |
| Hardy et al., 1994[b] | $202[e] |
| Liddle et al., 1997[c] | $354–1,403[c] |
| Scott et al., 2000 | $218[c] |
| *Acute respiratory disease* | |
| Our results with data from Fleisher et al., 1998[1] | $76.76 |
| Carabin et al., 1999[lk] and [lk] | $409[c] |
| Ray et al., 1999 | $34–1,978[e] (medical costs only) |
| *Influenza* | |
| Nichol, 2001 | $387.33 |

[a] Investigated water-associated illnesses.

[b] Investigated children.

[c] Published results in foreign currency were converted to US dollars at the year of publication, and then adjusted to 2001 dollar values due to inflation.

[d] Investigated all vectors including waterborne pathogens.

[e] Published results were adjusted to 2001 US dollar values due to inflation.

[f] Investigated Gastroenteritis and Acute Respiratory Disease illnesses combined.

Our cost-per-illness model was limited in comparison to Scott et al. (2000), who investigated many types of costs associated with food-borne infections. Their model included direct medical costs, direct non-medical costs, indirect costs of lost productivity, and intangible costs of impaired quality of life. The researchers found the largest cost component was lost income (87.4%), which was the primary component in our model.

Not included in our cost-per-illness model, due to absence of data, are the personal out-of-pocket expenses associated with having a prescription filled after a doctor visit, or the costs of self-medication. The majority of the illnesses being investigated (88% for GI) do not necessitate a visit to the doctor or hospital, so symptom relief is primarily left to the individual. When ill, many people purchase some form of medication, whether a pharmaceutical product or chicken soup. The US Centers for Disease Control and Prevention reports that a large unmeasured portion of the personal costs associated with the common cold are for over-the-counter medications (Centers for Disease Control and Prevention, 2002).

Also, we did not include the costs associated with rare and severe illnesses such as hepatitis, which can have very high associated health costs, including, perhaps, mortality costs in addition to morbidity costs. The rates and severity of the rare and severe illnesses associated with polluted recreational waters are not well understood, and should be considered in future investigations.

In the literature there is some discrepancy as to the value of the $A_{i,j}$ term, which can have a pronounced effect on the cost-per-illness estimates produced. Shown in Table 3; Wit et al. (2000) reported that a low 15% of GI illnesses resulted in lost work-days, while both Wit et al. (2001) and Garthright et al. (1988) reported greater than 50% of subjects lost at least one day of work from being ill with GI. Cabelli et al. (1979) reported 'about 50% of cases either stayed home or had to visit a doctor', however, we were not able to use this result in our model because stay-at-home days was not segregated from doctor visits. There is also a range in the reporting of $[C_j]$ with a low of 8.3% of patients seeing a doctor (Garthright et al., 1988), and a high of 22% of patients seeing a doctor from a GI illness (Wit et al., 2000) (Table 3).

During the construction of our cost-per-illness model, we considered a range of potential influences. For example, the Santa Monica Bay epidemiological study reported 48% of summer beach-swimmers are children 12 years or younger (Haile et al., 1996). With half of the exposed population being children, one might think the estimated lost wages would decrease because children are typically not employed. However, studies at day-care centers have found that a sick child requires a caretaker to remain at home from work, and thus results in loss of productivity, as if the caretaker were ill themself (Hardy et al., 1994, Liddle et al., 1997 and Carabin et al., 1999). This scenario does not hold true when one of the parents is a stay-at-home caretaker.

We tried to consider the fact that many people receive paid sick-leave when they stay at home from work (Kenkel, 1994). With no survey data on the subjects who received paid sick-leave to use in our calculations, we considered illnesses to result in either lost income unadjusted for paid sick leave, or an equivalent lost opportunity cost because paid sick-leave would be unavailable at a later time. Further, if a sick person is paid for time not worked, then the economic burden is simply shifted to the employer who pays for a day of non-productivity.

We were also restrictive in several respects in our site-specific public health burden example shown in Table 2. First, we used lower-bound cost-per-illness estimates generated using data from Fleisher et al. (1998), as opposed to higher values produced in other studies of non-water associated illnesses (Table 4). Second, we used conservative relative illness rate ratios for the different illness types ($R_j$) (Fleisher et al., 1998), as opposed to using higher illness rates for ARD found in other studies. Third, we incorporated results from Turbow et al. (2003) which used the US EPA risk model to generate an annual GI illness rate.

The ratio of illness rates ($R_j$) for ARD compared to GI (Fleisher et al., 1998) should be considered conservative because of the restrictive criteria the investigators used to define the illnesses. Several epidemiological studies with less restrictive definitions have found that respiratory symptoms are more commonly reported from exposure to polluted waters than GI symptoms (Prüss, 1998, Haile et al., 1999 and Dwight et al., 2004). Some studies reported respiratory illnesses rates twice that of GI rates (Seyfried et al., 1985 and Haile et al., 1999). Had we used these higher rates of respiratory illness in our public health burden example, the resulting estimated costs for ARD would be six times greater.

The relative ratios of illness rates ($R_j$) for the four illness types were generated by subjects exposed to a known source of domestic sewage (Fleisher et al., 1998). Each pollution source has its own profile of pathogens; therefore the ratios of the different illnesses ($R_j$) should change relative to exposure to different pollution sources (i.e. raw or treated domestic sewage, urban or agricultural runoff, boat bilge). Studies of subjects exposed to untreated urban runoff from Southern California produced an illness rate ratio ($R_j$) (Haile et al., 1999 and Dwight et al., 2004) that differs from the ($R_j$) reported by subjects exposed to treated domestic sewage (Fleisher et al., 1998). Basically, $R_j$ is different for each of the numerous epidemiology studies. When comparing illness ratios ($R_j$) between exposure to treated domestic sewage versus exposure to untreated urban runoff, urban runoff (Haile et al., 1996 and Dwight et al., 2004) can generate twice as many sinus/respiratory infections than GI infections, as well as higher rates of ear and skin infections, as can result from exposure to treated domestic sewage. However, some of these illness rates may be an artifact due to the different criteria used for illness classification by the various studies. Much additional research is needed in this area. For example, do illness rates and ratios for a given faecal indicator concentration vary according to the provenance of contamination (e.g. treated sewage cf. untreated urban runoff).

Further, our public health burden estimates are most likely conservative because the estimate of annual GI occurrences used in our example was generated using a risk model (Turbow et al., 2003) that includes GI illness rates based on Cabelli et al. (1983), which has a less steep entercoccus density-GI illness dose-response than that derived from the studies by Fleisher et al. (1996), which forms the basis of the risk model recently adopted by the World Health Organization (WHO, 2003). The WHO risk model was developed using results by Kay et al., 1994 and Fleisher et al., 1996, and is detailed in Kay et al. (2004). Had Turbow et al. (2003) used the newly adopted risk model, the annual GI illness rate would have been greater, and consequentially would have produced a greater annual public health burden.

Several studies have also reported that children are more susceptible to water-borne pathogens than adults (Prüss, 1998, Saliba and Helmer, 1990, Gerba et al., 1996 and Haile et al., 1999). Similarly, tourists not exposed to local pathogens also report higher illness rates than local populations (Prüss, 1998). Consideration of these factors in a risk model would increase the public health cost estimates.

For an upper-bound comparison to our public health burden results, we used data from Nichol (2001), who reported the cost-per-illness for influenza-type symptoms is equal to \$387.33 per episode (Table 4). This value is much greater than the estimated cost-per-illness values we report. With this higher cost-per-illness value used in our example at Newport and Huntington Beaches in Table 2, we would expect a cumulative public health burden greater than \$14.2 million per year for GI illnesses alone. This value is significantly greater than the \$1.3 million we report for GI's cumulative public health burden.

For ARD we found a comparative study that reported a cost-per-illness for ARD of \$409 per episode (Carabin et al., 1999) (Table 4). This value is five times greater than that estimated in Table 2. When this upper-bound cost-per-illness value is multiplied by the number of illnesses used in our applied example in Table 2, a cumulative public health cost for ARD illnesses would be greater than \$5 million per year.

# 5. Conclusion

It is well established that exposure to polluted recreational waters can pose a significant public health risk (Saliba and Helmer, 1990 and Prüss, 1998). These water-related illnesses can have significant associated symptoms and can be of great public health consequence (Fleisher et al., 1998). Our analysis quantified the health costs associated with water-pollution-related illnesses and found these illnesses can result in a significant financial burden to the individual who contracts an illness.

Furthermore, these costs accumulate into large public health burdens for recreational beaches that attract millions of people per year. From the example in Table 2 using only two Southern California beaches, with water quality well within the US EPA and California State water quality standard, we estimated that millions of dollars per year in health costs are incurred from a range of illnesses suffered by the ocean-swimming public.

The cumulative health burden example is based on only one small area (less than 14 km) of California's vast coastline, which is extensively used by the recreating public. Similar public health costs are most likely being incurred at other public beaches across the country where hundreds of millions of people annually enjoy the nations' recreational waters. This analysis shows that even when coastal water bacterial levels are well below the current standard, the resulting health risk can produce a large health and economic burden. Therefore, from both a public health and an economic perspective, we recommend that the current accepted illness rate should be re-evaluated. In defense of the current standard, it was created as a suggested minimum with the expectation that local health officials would enact more restrictive standards to protect the public (Cabelli, 1989).

Values generated in this study may be most helpful for decision-makers conducting cost-benefit analysis of pollution control options. Public officials are aware of the high costs associated with pollution controls and law enforcement. They also know that closed beaches due to pollution have substantial associated costs in lost recreational values and lost business revenues. Until now, these were the only economic parameters decision makers had for their consideration. The addition of a public health value helps identify the more accurate overall costs that are associated with coastal water pollution, which may lead to a wider array of pollution control options.

For example, in Southern California's Orange County, officials were concerned about the cost of a $350,000 diversion project that pumps and siphons 2.5 million gallons per day of urban runoff (representing 95% of the contaminated dry-flow runoff to Huntington state and city beaches) into the sewage treatment facility for the summer months (Reyes, 2001). Untreated urban runoff discharged onto these beaches has been shown to be a major source of pollution in the recreational coastal waters throughout the year (Noble et al., 2000 and Dwight et al., 2002). Results from this study show that if the overall illness rate is decreased even slightly by the diversion, the annual financial benefit to the public could amount to millions of dollars. Decision makers will be able to justify large project costs for pollution control measures or source-reduction policies by the greater public benefit gained by taking preventative action. Reduction of non-point source pollution is a valuable component of an integrated strategy to protect public health (Gaffield et al., 2003). However, these health burden values in a risk-benefit analysis are not large enough in and of themselves to justify funding hundreds of millions of dollars for pollution prevention programs.

Research is needed to obtain data on actual lost income per illness, and other medical and non-medical costs associated with the illnesses, by eliciting direct values from surveyed individuals. When possible, epidemiology investigations of water-associated illnesses should include follow-up cost-of-illness and contingent valuation questions needed to determine the site-specific health costs. Research is also needed to better define $R_j$ adjustments (ratio for the different illness types) that are generated by exposure to different pollution sources and different concentrations. We present this cost-per-illness model not as a definitive cost projector, but as a template to be augmented by future investigations.

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## References

Bay and Greenstein, 1996 S.M. Bay and D.J. Greenstein, Toxicity of dry weather flow from the Santa Monica Bay watershed, *Southern California Academy of Sciences* **95** (1996) (1), pp. 33–45.

Berger et al., 1994 M. Berger, G. Blomquist, D. Kenkel and G. Tolley, Framework for valuing health risk. In: George Tolley, Donald Kenkel and Robert Fabian, Editors, *Valuing Health for Policy*, The University of Chicago Press, Chicago (1994).

Cabelli, 1989 V.J. Cabelli, Swimming-associated illness and recreational water quality criteria, *Water Science and Technology* **21** (1989) (2), pp. 13–21. Abstract-EMBASE | Abstract-Compendex

Cabelli et al., 1979 V.J. Cabelli, A.P. Dufour, M.A. Levin, L.J. McCabe and P.W. Haberman, Relationship of microbial indicators to health effects at marine bathing beaches, *American Journal of Public Health* **69** (1979) (7), pp. 690–696. Abstract-EMBASE | Abstract-MEDLINE

Cabelli et al., 1983 V.J. Cabelli, A.P. Dufour, L.J. McCabe and M.A. Levin, A marine recreational water quality criterion consistent with indicator concepts and risk analysis, *Journal WPCF* **55** (1983) (10), pp. 1306–1314. Abstract-EMBASE | Abstract-Compendex

California Resource Agency, 1997 California Resource Agency, California's ocean resources management program, California's ocean resources: an agenda for the future, *Water Quality* (1997) (Chapter 5B).

Carabin et al., 1999 H. Carabin, T.W. Gyorkos, J.C. Soto, J. Penrod, L. Joseph and J.P. Collet, Estimation of direct and indirect costs because of common infections in toddlers attending day care centers, *Pediatrics* **103** (1999) (3), pp. 556–564. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE | **Full Text** via CrossRef

Centers for Disease Control and Prevention, 2002 Centers for Disease Control and Prevention, 2002. Disease Information (www.cdc.gov).

Corbett et al., 1993 S.J. Corbett, G.L. Rubin, G.K. Curry and D.G. Kleinbaum, The health effects of swimming at Sydney beaches, *American Journal of Public Health* **83** (1993) (12), pp. 1701–1706. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE

County Sanitation Districts of Orange County, 1996 County Sanitation Districts of Orange County, 1996. Water-contact ocean recreation in Orange County, study conducted by MEC Analytical Systems, Inc.

Dwight et al., 2002 R.H. Dwight, J.C. Semenza, D.B. Baker and B.H. Olson, Association of urban runoff with coastal water quality in Orange County California, *Water Environment Research* **74** (2002) (1), pp. 82–90. Abstract-EMBASE | Abstract-GEOBASE | Abstract-Elsevier BIOBASE | Abstract-OceanBase | Abstract-MEDLINE

Dwight et al., 2004 R.H. Dwight, D.B. Baker, J.C. Semenza and B.H. Olson, Health effects associated with recreational water use in urban vs. rural California, *American Journal of Public Health* **94** (2004) (4), pp. 565–567. Abstract-EMBASE | Abstract-MEDLINE

Field et al., 1993 R. Field, M. O'Shea and M.P. Brown, The detection and disinfection of pathogens in storm-generated flows, *Water Science Technology* **28** (1993) (3–5), pp. 311–315. Abstract-EMBASE | Abstract-Compendex | Abstract-GEOBASE | Abstract-FLUIDEX

Fleisher et al., 1996 J.M. Fleisher, D. Kay, M.D. Wyer, R.L. Salmon and F. Jones, Non-enteric illnesses associated with bather exposure to marine waters contaminated with domestic sewage: the results of a series of four intervention follow-up studies, *American Journal of Public Health* **86** (1996), pp. 1228–1234. Abstract-Elsevier BIOBASE | Abstract-MEDLINE

Fleisher et al., 1998 J.M. Fleisher, D. Kay, M.D. Wyer and A.F. Godfree, Estimates of the severity of illnesses associated with bathing in marine recreational waters contaminated with domestic sewage, *International Journal of Epidemiology* **27** (1998), pp. 722–726. Abstract-EMBASE | Abstract-GEOBASE | Abstract-MEDLINE | **Full Text** via CrossRef

Frühwirth et al., 2001 M. Frühwirth, K. Berger, B. Ehlken, I. Moll-Schüler, S. Brösl and I. Mutz, Economic impact of community- and nonsocomially acquired rotavirus gastroenteritis in Australia, *The Pediatric Infectious Disease Journal* **20** (2001) (2), pp. 184–188. **Full Text** via CrossRef

Gaffield et al., 2003 S.J. Gaffield, R.L. Goo, L.A. Richards and R.J. Jackson, Public health effects of inadequately managed stormwater runoff, *American Journal of Public Health* **93** (2003) (9), pp. 1527–1533. Abstract-EMBASE | Abstract-MEDLINE

Garthright et al., 1988 W.E. Garthright, D.L. Archer and J.E. Kvenberg, Estimates of incidence and costs of intestinal infectious diseases in the United States, *Public Health Reports* **103** (1988) (2), pp. 107–115. Abstract-EMBASE | Abstract-MEDLINE

Gerba et al., 1996 C.P. Gerba, J.B. Rose, C.N. Haas and K.D. Crabtree, Waterborne rotavirus: a risk assessment, *Water Research* **30** (1996) (12), pp. 2929–2940. SummaryPlus | **Full Text + Links** | PDF (1062 K)

Gold et al., 1991 Gold, M., Bartlett, M., Dorsey, J., McGee, C., 1991. Storm drains as a source of surf zone bacterial indicators and human enteric viruses to Santa Monica Bay. Santa Monica Bay Restoration Project, August.

Haile et al., 1996 Haile, R.W., et al., 1996. An epidemiological study of possible adverse health effects of swimming in Santa Monica Bay. Final Report. Santa Monica Bay Restoration Project, p. 86.

Haile et al., 1999 R.W. Haile *et al.*, The health effects of swimming in ocean water contaminated by storm drain runoff, *Epidemiology* **10** (1999) (4), pp. 355–363. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE | **Full Text** via CrossRef

Hardy et al., 1994 A.M. Hardy, D.R. Lairson and A.L. Morrow, Costs associated with gastrointestinal-tract illness among children attending day-care centers in Houston, Texas, *Pediatrics* **94** (1994) (6), p. 1091. Abstract-EMBASE | Abstract-MEDLINE

Henrickson et al., 2001 S.E. Henrickson, T. Wong, P. Allen, T. Ford and P.R. Epstein, Marine swimming-related illness: implications for monitoring and environmental policy, *Environmental Health Perspectives* **109** (2001) (7), pp. 645–650. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE

Kay et al., 1994 D. Kay, J.M. Fleisher, R.L. Salmon, F. Jones, M.D. Wyer, A.F. Godfree, Z.

Zelenauch-Jacquotte and R. Shore, Predicting the likelihood of gastroenteritis from sea bathing: results from a randomized exposure, *Lancet* **344** (1994) (904–909).

Kay et al., 2004 D. Kay, J. Bartram, A. Prüss, N. Ashbolt, M.D. Wyer, J.M. Fleisher, L. Fewtrell, A. Rogers and G. Rees, Derivation of numerical values for the World Health Organization guidelines for recreational waters, *Water Research* **38** (2004), pp. 1296–1304. SummaryPlus | **Full Text + Links** | PDF (242 K)

Kenkel, 1994 D. Kenkel, Cost of illness approach. In: George Tolley, Donald Kenkel and Robert Fabian, Editors, *Valuing Health for Policy*, The University of Chicago Press, Chicago (1994).

Liddle et al., 1997 J.L. Liddle *et al.*, Rotavirus gastroenteritis: impact on young children, their families and the health care system, *Medical Journal of Australia* **167** (1997) (6), pp. 304–307. Abstract-EMBASE | Abstract-MEDLINE

Nichol, 2001 K. Nichol, Cost benefit analysis of a strategy to vaccinate healthy working adults against influenza, *Archives of Internal Medicine* **161** (2001) (5), pp. 749–759. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE | **Full Text** via CrossRef

Noble et al., 2000 R.T. Noble *et al.*, A regional survey of the microbiological water quality along the shoreline of the Southern California Bight, *Environmental Monitoring and Assessment* **64** (2000), pp. 435–447. Abstract-EMBASE | Abstract-GEOBASE | Abstract-Elsevier BIOBASE | Abstract-OceanBase | **Full Text** via CrossRef

Payment et al., 1991 P. Payment, L. Richardson, J. Siemiatycki, R. Dewar, M. Edwardes and E. Franco, A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards, *American Journal of Public Health* **81** (1991), pp. 703–708. Abstract-EMBASE | Abstract-MEDLINE

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

Ray et al., 1999 N.F. Ray, J.N. Baraniuk, M. Thamer, C.S. Rinehart, P.J. Gergen, M. Kaliner, S. Josephs and Y.H. Pung, Healthcare expenditures for sinusitis in 1996: contributions of asthma, rhinitis, and other airway disorders, *The Journal of Allergy and Clinical Immunology* **103** (1999) (3–1), pp. 408–414. Abstract-EMBASE | Abstract-MEDLINE

Reyes, 2001 D. Reyes, Seasonal diversionary tactics, *Los Angeles Times* (2001).

Saliba and Helmer, 1990 L.J. Saliba and R. Helmer, Health risks associated with pollution of coastal bathing waters, *World Health Statistics Quarterly* **43** (1990), pp. 177–184.

Schafer and Gossett, 1998 Schafer, H., Gossett, R., 1998. Storm runoff in Los Angeles and Ventura Counties. Final Report to California Regional Water Quality Control Board. Southern California Coastal Water Research Project, Long Beach, CA. June.

Scott et al., 2000 W.G. Scott, H.M. Scott, R.J. Lake and M.G. Baker, Economic cost to New Zealand of foodborne infectious disease, *New Zealand Medical Journal* **113** (2000) (1113), pp. 281–284. Abstract-MEDLINE

Seyfried et al., 1985 P.L. Seyfried, R.S. Tobin, N.E. Brown and P.F. Nes, A prospective study of swimming-related illness I. Swimming-associated health risk, *American Journal of Public Health* **75** (1985), pp. 1068–1070. Abstract-EMBASE | Abstract-MEDLINE

Shuval, 2003 H. Shuval, Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment, *Journal of Water Health* **01** (2003), pp. 53–64. Abstract-MEDLINE

Southern California Coastal Water Research Project, 1991 Southern California Coastal Water Research Project, 1991. Surface runoff to the Southern California Bight. in: Annual Report, Long Beach, CA, pp. 19–28.

Turbow et al., 2003 D. Turbow, N. Osgood and S. Jiang, Evaluation of recreational health risk in coastal waters based on Enterococcus densities and bathing patterns, *Environmental Health Perspectives* **111** (2003) (4), pp. 598–603. Abstract-EMBASE | Abstract-Elsevier BIOBASE | Abstract-MEDLINE

US Department of Commerce, 2004 US Department of Commerce, 2004. Bureau of Economic Analysis, Regional Accounts Data, Local Area Personal Income, Average wage per job in 2001, California, Orange County (www.bea.gov/bea/regional/reis/drill.cfm).

WHO, 2003 WHO, *Guidelines for safe recreational water environments, coastal and fresh waters* **vol. 1**, World Health Organization, Geneva, Switzerland (2003) p. 253.

Wit et al., 2000 M.A.S.de Wit, A.A.M. Hoogenboom-Verdegaal, E.S.M. Goosen, M.J.W. Sprenger and M.W. Borgdorff, A population-based longitudinal study on the incidence and disease burden of gastroenteritis and *Campylobacter* and *Salmonella* infection in four regions of the Netherlands, *European Journal of Epidemiology* **16** (2000), pp. 713–718.

Wit et al, 2001 M.A.S. de Wit, M.P.G. Koopmans, L.M. Kortbeek, N.J. van Leeuwen, I.M. Bartelds and Y.T.H.P. van Duynhoven, Gastroenteritis in sentinel general practices, The Netherlands, *Emerging Infectious Diseases* **7** (2001) (1).

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