Addressing disease surveillance needs for marine recreational bathers

David Turbow

ABSTRACT

Contamination of the nearshore marine environment contributes to a high burden of illness among recreational bathers. Disease surveillance activities carried out by local, state, and territorial agencies in the United States are at present voluntary and passive. Several gaps in the existing regulatory framework for beach management and public health protection are highlighted in this paper. The need for disease surveillance of marine bathers is established. A demonstration is made of how surveillance activities can be used to guide risk management and gauge the effectiveness of current water contact standards. Recommendations are offered for agencies to improve surveillance and protect public health. A foundation is presented on which to develop a model marine health code.

Key words | disease surveillance, marine contamination, recreational water illness, risk management

David Turbow
College of Health Sciences,
TUI University, 5665 Plaza Drive,
3rd Floor, Cypress, CA 90630,
USA
E-mail: *dturbow@tuiu.edu*

INTRODUCTION

Disease surveillance of marine bathers is necessitated by both the scope of the beach water contamination problem and the magnitude of the number of individuals exposed to it. In this article, weaknesses in risk management practices at marine beaches in California and the United States are analyzed to illustrate the need for disease surveillance.

Coastal water contamination is a problem of major public health significance worldwide (Shuval 2003). Bathing in sewage contaminated water can lead to gastrointestinal illness (GI), infections of the eyes, ears, and sinuses, and skin rashes (see reviews by Pruss 1998; Mugglestone 2000; Henrickson *et al.* 2001). Exposure to storm drain runoff also poses substantial risks to marine bathers (Haile *et al.* 1999; Dwight *et al.* 2004).

Marine water contact recreation is an extremely popular activity. In the United States, more than 129 million beach visits occur annually in southern California alone (Dwight *et al.* 2007). A high proportion of beachgoers enjoy bathing in the ocean. Up to 45% of total beachgoers make contact with sea water on a given day, depending upon the location and the season of the year (Dwight *et al.* 2007; Hannemann *et al.* 2004).

Health risks to bathers are attributable in part to contamination events which prompt beach closures. Shoreline contamination events occur frequently in urbanized areas and are strongly associated with patterns of rainfall and urban runoff (Dwight *et al.* 2002; Noble *et al.* 2003). In recent years, there has been a high frequency of beach closures in many areas. County health officials in California posted warnings or closed beaches 3,985 times in 2004 (Natural Resources Defense Council 2005; Given *et al.* 2006). Between 627,800 and 1,479,200 gastrointestinal illnesses are likely to be experienced annually by bathers at beaches in Los Angeles and Orange counties alone due to exposure to coastal water contamination. The economic burden of illness for that region associated with beach water contamination has been estimated at $21 million to $51 million due to lost work, medical costs, and expenditures on medicine (Given *et al.* 2006).

There is little evidence to suggest that recreational water illnesses are being systematically addressed at the national

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level. Federal officials in the U.S. monitor waterborne illnesses associated with drinking water as part of their national notifiable system of disease surveillance. However, recreational waterborne disease surveillance is a voluntary, and arguably underutilized activity carried out by state, local, and territorial authorities (Yoder *et al.* 2004; Craun *et al.* 2006).

Waterborne disease outbreak (WBDO) investigations are routinely carried out for public swimming pools, freshwater lakes, spas, and water parks but not for marine waters (Craun *et al.* 2006). Not only is it difficult to identify a pathogen in sea water, but it is also challenging for health officials and health care providers (HCPs) to properly engage and follow-up with adversely affected individuals at marine beaches.

Exposure assessments are conducted to better understand the risks of specific adverse health outcomes. For example, The U.S. Centers for Disease Control and Prevention and the U.S. Environmental Protection Agency have undertaken efforts to better understand health risks to marine bathers by implementing the National Environmental Exposure Assessment Research (NEEAR) Water Study.

Despite efforts at carrying out exposure research, a large number of recreational water illnesses (RWIs) for marine waters currently go uncaptured by the national surveillance system (Henrickson *et al.* 2001). Underreporting of waterborne illness in general is also a substantial hurdle in collecting complete data (Yoder *et al.* 2004). Quantifying the burden of marine illnesses in particular is compounded by the fact that the Waterborne Disease Outbreak System (WBDO) for recreational illnesses is focused upon identifying disease outbreaks rather than endemic illnesses.

WATER CONTACT STANDARDS AND CLEAN WATER LEGISLATION

One of the fundamental goals of The Federal Water Pollution Control Act of 1948 is to regulate the discharge of waste, such that the surface waters of the U.S. are "fishable and swimmable". The "swimmability" clause of federal clean water legislation clearly entails a notion of human health protection. The formation of microbiological recreation standards involves making a determination of the concentration of organisms in the water that pose a significant level of health risk to bathers (Cabelli *et al.* 1983). Epidemiologic evidence has provided the foundation of recreational water contact standards.

Because it is not possible to completely remove all harmful substances from water, federal marine water contact standards in the United States are based upon a notion of acceptable risk. Current standards are derived from the results of prospective studies linking the measured density of enterococci (ENT) bacteria in sea water to the excess risk of contracting gastrointestinal illness (Cabelli *et al.* 1982, 1983; United States Environmental Protection Agency 1986). Standards for total coliform and fecal coliform are based on the recommendations from the National Technical Advisory Committee (NTAC). NTAC evaluated studies conducted during the late 1940s and early 1950s by the Public Health Services.

In spite of technological advancements, the standard setting process itself contains some weaknesses. Environmental and sampling variability can complicate the numerical standard setting process. Epidemiological surveys linking bacterial indicator density to bather morbidity are difficult to replicate (Esfratiou 2001), and temporal and spatial variation in indicator organism density make it difficult to relate measured water quality to times and locations of bathing (Fleisher 1990*a*, *b*). Measurement error attributable to limited precision in the indicator enumeration process may bias assessments of the relationship between indicator organism density and risk of adverse health outcomes (Fleisher 1990*b*). Such weaknesses have been addressed in part through more recent efforts to conduct epidemiology studies at non-point source impacted beaches (Colford *et al.* 2007). Also, more epidemiology studies are in progress for the purpose of updating ambient water quality criteria. However, federal water contact standards for enterococci have not yet been updated.

The Beaches Environmental Assessment and Coastal Health Act of 2000 mandated that coastal states assess potential human health risks resulting from exposure to pathogens in coastal recreation waters. Coastal states are required to adopt water quality criteria and standards for pathogens and pathogen indicators (United States Environmental Protection Agency 2002). To protect the health of

marine bathers at beaches with annual attendance of 50,000 or more, local health officials in the State of California routinely monitor the shoreline for enterococci and other fecal indicator bacteria. Health officials use California Assembly Bill 411 (AB 411) and federal standards of acceptable risk to evaluate monitoring data (California Health and Safety Code Subsection 115880). The principal aims of AB 411 are mainly to standardize monitoring and reporting procedures. California's Health and Safety Code was modified by California Assembly Bill 538 (AB 538) to require that the State Water Resources Board and the State Department of Health Services develop source investigation protocols for storm drains that produce bacteriological standard exceedances. The protocols specified under AB 538 require methods to be developed for the purpose of identifying the location and biological origins of sources of bacteriological contamination, as well as the establishment of a timeline for completion of source investigations.

Thus there is an abundance of water quality legislation in place to protect the health and safety of bathers. But the legislation is primarily focused on limiting the discharge of waste or strengthening monitoring and reporting requirements. Unfortunately, the safety of marine waters cannot always be determined via current risk management practices. Health officials and decision makers can use disease surveillance to help establish whether the goal of "swimmability" and other measurements of human health protection are met.

RISK MANAGEMENT POLICY AND ITS SHORTCOMINGS

In this section, vulnerabilities are identified in the current risk management scheme at public beaches. Despite efforts to ensure the safety of recreational waters through monitoring and regulation of waste discharge, there is no binding federal legislation requiring health agencies to participate in disease surveillance of marine bathers. At present efforts to monitor coastal waters and regulate waste discharge are separate from illness tracking activities.

Health care providers are expected to notify health officials of individuals who present with reportable conditions. A health care provider may provide information to a public health agency about an individual who visited a hospital emergency room after contracting Shigellosis or Dysentery. Health care providers may elect to wait until a disease cluster has been detected before reporting adverse events to health officials. If surveillance is lacking, then disease clusters will not be detected.

Beachgoers may also erringly assume that the water with which they make contact is safe for swimming. In actuality, open beaches do not constitute a guarantee of illness prevention. Federal authorities in the United States set the level of acceptable risk to the public at nineteen cases of gastrointestinal illness per 1,000 bathers attributable to contact with sea water. Empirical research suggests that under such a scenario thousands of bathers may become ill from exposure to pathogens in sea water at public beaches on days when beach water quality is in full compliance with state and federal standards (Turbow *et al.* 2003; Given *et al.* 2006).

An examination of risk management practices at public beaches in the State of California reveals several vulnerabilities. Officials analyze monitoring data that were collected during rapidly changing, complex environmental conditions. Risk management is practiced under conditions of inherent uncertainty. The existing protection scheme used by health

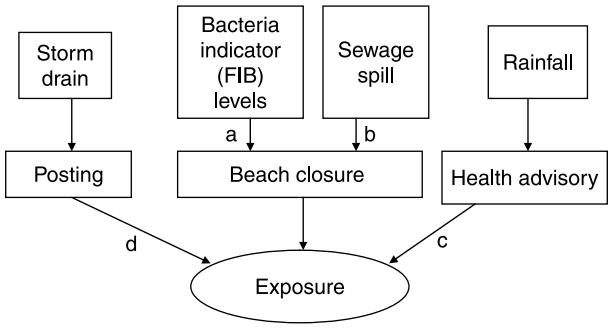

Figure 1 | Protecting Marine Recreational Bathers. Four weaknesses in the existing scheme of public health protection may result in bathers being exposed to beach water contamination. Beach Closure Error (scenario a) - A time lag between sampling and enumeration can create a situation in which a beach manager fails to close a beach when dangerous levels of contamination are present. Sewage Spill Alert Time Lag (scenario b): Beach managers may not receive information about a sewage spill in time to warn bathers to stay out of the water. Ineffective Advisory (scenario c): A post-rainfall health advisory issued countywide by health officials may reach only a small fraction of the intended audience, resulting in a large number of bathers exposed to contamination. Ineffective Posting (scenario d): Health officials post signs conspicuously on lifeguard towers at the beach or near storm drain outfalls in an attempt to deter potential bathers from entering contaminated water. The warnings may only reach a small fraction of beachgoers.

officials in the State of California for beaches with more than 50,000 annual visitors is illustrated in Figure 1.

Sampling practices vary considerably in terms of frequency at the county level in California. Within any single jurisdiction, officials may elect at their discretion to sample for fecal indicator bacteria at particular beaches more frequently than at other beaches. Officials are not required to sample beach water on a daily basis for enterococci. Quantitative analysis and human judgment are often used together as bases for difficult decisions on whether or not to close beaches and issue health advisories. Counties may or may not share data on adverse health outcomes experienced by marine bathers.

Officials decide whether to close beaches or issue health advisories when fecal indicator bacteria levels exceed thresholds of acceptable risk (Figure 1(a)). Using conventional methods, 18–24 hours may be required to enumerate fecal indicator bacteria (United States Environmental Protection Agency 2000). Fecal indicator bacteria levels can vary substantially over short time periods in marine waters. Errors in the beach closure decision making process are common when based upon 18–24 hour old samples due to rapid environmental change and measurement uncertainty (Kim & Grant 2004; Rabinovici *et al.* 2004). Rapid methods of fecal indicator bacteria detection have proven to be useful for obtaining reliable estimates of freshwater quality within two hours (Wade *et al.* 2006). However, rapid detection methods have not been widely implemented for marine waters.

Health officials in California close a beach irrespective of fecal indicator bacteria levels in the event that a sewage spill is reported (Figure 1(b)) (California Health and Safety Code Subsection 115880). But because sewage spills are not always detected or reported in a timely manner, considerable delays in the public notification process may occur. A large number of bathers may be exposed to pathogens in contaminated beach water due to the time lag between the time that a contamination event occurs and the time required to restrict beach usage.

The practice of issuing countywide health advisories (ADVs) following rainfall events constitutes another imperfect public health protection measure (Figure 1(c)). Health officials routinely issue advisories via newspapers, radio broadcasts, and the internet to notify the public that contact with ocean water within 72 hours of a rainfall is unsafe due to hazardous bacteria levels (California Health and Safety Code Subsection 115880). In contrast to more use-restrictive measures of marine bather protection in which conspicuous warning signs or tape are physically present, health advisories essentially leave beaches "open" to the public. During post-rainfall periods, fecal indicator bacteria levels in the nearshore waters can be greatly elevated (Dwight *et al.* 2002; Noble *et al.* 2003) thus presenting potential health risks to bathers. Because health advisories issued after rainfall events are not site specific, many people may not be aware that a health advisory has been issued. The extent to which potential bathers are aware of health advisories and comply with recommendations by avoiding contact with the water is an important topic of study.

A fourth incomplete safety protection measure is the practice of "postings" by officials (Figure 1(d)). A posting refers to the placement of a conspicuous warning sign with the intention of warning the public about health hazards associated with swimming in contaminated water (California Health and Safety Code Subsection 115880). Officials routinely post permanent warning signs near flowing storm drains along the coastline or when fecal indicator bacteria levels exceed state standards for acceptable risk. As with health advisories, the extent to which the public heeds postings may be low. Empirical evidence suggests that postings mainly serve as a passive management tool and do not deter potential bathers from entering coastal waters impaired by storm drain runoff (Pendleton 2001).

A NEEDED SHIFT IN PUBLIC HEALTH PROTECTION

Health agency compliance with environmental monitoring requirements does not completely ensure health protection for marine bathers. In this section, an explanation basis is provided for a needed directional shift from "front end" bather health protection policies towards more integrative "back end" policies.

Federal and state risk management practices at marine beaches may be arbitrarily categorized into "front-end" (i.e. "pre-exposure") methods and "post-exposure" methods (Figure 2). Pre-exposure methods are those set in place to prevent illness before public beach visitation and contact with marine water has occurred. For example, many epidemiology

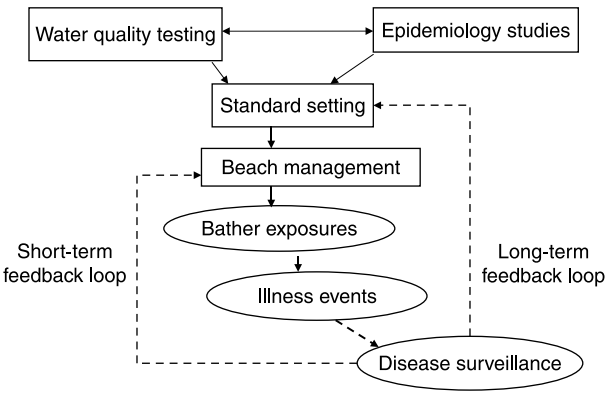

Figure 2 | Use of Disease Surveillance Data to Inform Decision Making and Standard Setting. Beach managers rely upon water quality data and water contact standards to protect public health of marine bathers. Valuable information is omitted from the current beach management scheme. In the suggested policy model (illustrated here by dashed lines), health officials are required to conduct disease surveillance activities. Surveillance data are used to inform beach management decisions (short-term feedback loop). Analysis of surveillance data are used to gauge the appropriateness of acceptable risk thresholds and to inform the standard-setting process (long-term feedback loop).

studies have been conducted to quantify the risk of illness to marine bathers from exposure to microbial contamination.

Efforts to improve the speed and accuracy of water quality measurements are also front-end in nature. For example, recent technological developments demonstrate that fecal indicator bacteria can be detected rapidly in water (Wade *et al.* 2006). In addition to monitoring the shoreline for fecal indicator bacteria, beach managers may also use new water quality forecasting tools that are based upon environmental variables to manage bathing risks (Morrison *et al.* 2003; Kim & Grant 2004). Scientists periodically conduct epidemiology studies under the guidance of policy-makers for the purposes of defining ambient water quality criteria. The health studies and the standard setting process that ensues are front-end methods of bather protection. Arguably, the overwhelming emphasis of scientific research on coastal water quality contamination in the United States and related policy analysis has been on front-end protection.

But we must also consider the fate of those individuals who have become ill due to contact with contaminated marine water despite well-intentioned health protection measures. And there is a need to better understand spatial and temporal patterns of such adverse health outcomes. One post exposure method of health protection is the collection of illness data on marine bathers.

Disease surveillance is potentially useful to beach managers and other stakeholders for several purposes. Disease surveillance efforts can be used to identify time-space clusters of disease (Figure 2). Surveillance data can also be linked to environmental monitoring data through Geographic Information Systems (GIS), remote sensing, or pollutant dispersal models so as to better understand the factors that impact spatial and temporal patterns of recreational water illnesses.

The analysis of surveillance data can justify the need for expanded water quality monitoring. For example, officials may discover a need to sample for viruses at particular locations where several illnesses have been reported within a short period of time. The findings of surveillance analysis can also be used to justify the need to remediate environmentally contaminated sites (Figure 2 short term feedback loop).

Also, the analysis of surveillance data permits a more complete understanding about whether current risk management practices yield an "acceptable" number of illnesses. Surveillance data can be analyzed over long time scales to inform the standard-setting process itself. Ultimately, surveillance may be used as a valuable tool to guide risk management and to prevent subsequent exposure events in unsafe recreational waters.

HURDLES IN REPORTING AND SURVEILLANCE

There is a need to better understand the extent to which health officials incorporate surveillance data in managing bathing risk at marine beaches. It will be a challenge to expand surveillance on a large scale in coastal recreational waters. For example, to initiate the reporting process, illnesses must be detected and systematically entered into a database. An individual presenting with an illness could potentially enter the reporting process through various pathways. For example, a clinical laboratory may submit a specimen to a state authority. Alternatively, a specimen may be submitted directly to a state, commercial, hospital, or outpatient facility.

Despite several opportunities for officials and health care providers to document illnesses, there are several obstacles to achieving improved surveillance. Health

officials may seek to identify waterborne disease outbreaks rather than patterns of endemic illness. Health outcome data that has been collected may be dropped from further analysis if a large number of people do not present in a short period of time. Further, those individuals presenting with non-specific symptoms will be disregarded.

Another potential hurdle to disease surveillance is related to self-efficacy. An official may feel that it is unrealistically challenging to link a particular exposure event in the ocean to a specific illness outcome. If a health care provider or health agency official does not feel that a health outcome can be definitively linked to an exposure event, then further investigation into the presumed cause of the event may not be initiated. Indeed, for several health outcomes, such as diarrheal illness, the potential for numerous confounding factors exists, such as exposure to non-water related risk factors and person to person transmission.

Due in part to a lack of surveillance, there is a wide disparity between the high number of exposures that occur among the population of marine bathers and the number of confirmed illness cases. A hypothetical burden of illness is illustrated in Figure 3 (adapted from the U.S. Centers for Disease Control and Prevention burden of illness pyramid). In order for an illness to be captured in a disease surveillance system, an unbroken chain of events must occur. The victim must seek the care of a health care provider (HCP). Health care providers in coastal areas are not required to ask illness victims about marine bathing. Compounding this problem is that many health care providers may not have access to sufficiently sensitive diagnostic tests to confirm a marine recreational water illness. To confirm the etiology of disease, a health care provider must order appropriate serological tests, an endeavor which may require stool specimens and/or serological confirmation from an outside laboratory. Health care providers may deem such diagnostic tests impractical, expensive or inconclusive.

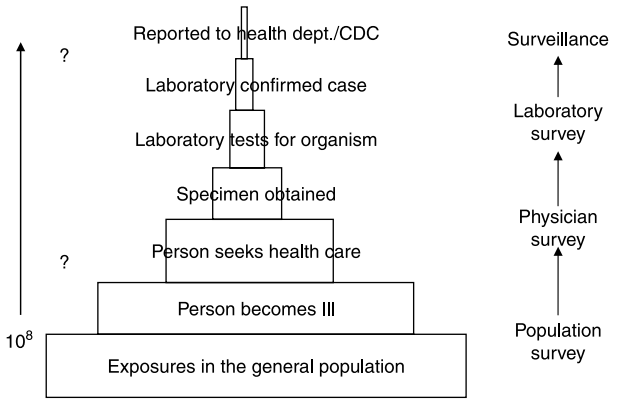

Figure 3 | Burden of Illness Pyramid for Marine Recreational Bathers. Adapted from the Centers for Disease Control and Prevention. The wide base of the bottom two bars of the pyramid (exposures in the general population) compared to the narrow width of the top bar of the pyramid (unknown number of confirmed cases) illustrates the current lack of disease surveillance data for marine bathers. A mandate for disease surveillance data collection would help reduce the disparity between the high number of exposures and the relatively low and unpublished number of confirmed cases.

Laboratory services of state level public health departments may receive a very low number of laboratory specimens from marine bathers under current surveillance strategies. Even if a specimen is collected, an individual presenting to a health care provider with a suspected bathing-related illness may not be shedding pathogens in sufficient concentrations for a positive serological diagnosis to be made. Fixation assays can be conducted for illnesses caused by waterborne pathogenic viruses. However, the results may not yield a sufficient rise in titer between acute and convalescent sera to provide health officials with enough information to deem a particular sample evidence of infection.

Thus there are numerous hurdles in identifying and documenting marine recreational water illnesses among a population of exposed individuals. The burden of illness for marine bathers can be represented visually as a wide-based pyramid. There is a sharp contrast between the small proportion of documented illness "cases" at the top of the pyramid and the proportionately large total number of exposed individuals at the bottom of pyramid. Host immunity and susceptibility partially account for the difference between the number of exposures in the general population and the number of illnesses.

OVERCOMING THE HURDLES

Although the challenges of disease surveillance for marine bathers are admittedly formidable, several efforts have been made by local health agencies and non-profit organizations to monitor recreational water illnesses. In California, San

Diego County Department of Environmental Health initiated a program to relate the times and locations of self-reported illnesses to water quality impairment at beaches in its jurisdiction (County of San Diego 2000). Also, Surfrider Foundation, a non-profit organization, maintains a self-reported ocean illness database. Swimmers and surfers who have experienced adverse health outcomes after contact with the water can complete a web-based ocean illness survey posted on the organization's website. Communication between the beach user and the organization is facilitated by virtue of the simple, user-friendly format of the survey.

One of the impediments to current disease surveillance is the low speed of communication between the health officials and the public. Despite the potential for rapid communication with the public, many health agencies currently rely upon telephone hotlines, facsimile or mail based systems as a means of contact with illness victims. Health agencies could adopt web-based surveys to more effectively reach out to those people who may have become ill after contact with contaminated beach water, but would not have otherwise documented their ailments. The internet also provides a rapid and practical means of communication between individuals who do not necessarily live close to the beach and health officials. Health studies employing web-based methods of disease investigation have proven particularly useful for drinking water and foodborne illnesses (Kuusi *et al.* 2004; Fox *et al.* 2005; Wethington & Bartlett 2006).

Web-based methods of disease investigation are also useful for studying recreational water illness in marine recreational waters (Turbow *et al.* 2008). Information gathered about the location and times of recreational water illnesses in marine bathers can be rapidly transmitted over the internet and automatically entered into a database. Through this process, spatial and temporal patterns of illness can be examined by health agencies and the burden of illness associated with marine bathing can be better understood.

Following is a list of useful process evaluation questions that could be presented to local health authorities who are responsible for protecting the health of marine bathers in coastal areas:

1. To what extent does your agency use disease surveillance in managing bathing risk at beaches under your jurisdiction?
2. Does your agency currently employ diagnostic tests sensitive enough to confirm recreational water illnesses in marine bathers?
3. How many specimens taken from marine bathers are sent from your department to state and federal authorities annually?
4. To what extent does your agency monitor endemic rates of diarrheal illness in marine bathers?
5. How would you rate the level of local interagency communication and data sharing on recreational water illness in marine bathers?
6. To what extent does your agency employ web-based technologies to identify recreational water illness in marine bathers?
7. How would you rate the level of communication between health care providers and health agencies with respect to recreational water illness in marine bathers?
8. In what ways do you feel that communication between health care providers and health agencies could be improved with respect to recreational water illness in marine bathers?
9. To what extent does your agency employ sewage plume trackers or other ocean observing systems for bather protection in your jurisdiction?
10. To what extent does your agency employ rapid methods of fecal indicator bacteria detection in its environmental monitoring program?
11. How much would it cost to implement a pilot public health program in your jurisdiction to monitor recreational water illness in marine bathers?

RECOMMENDATIONS

Health agencies should initiate and/or expand disease surveillance of marine bathers. Under the current regulatory scheme, the United States Environmental Protection Agency's definition of recreational waters defers to States the responsibility of regulating commercial waters of public swimming pools and their disinfection. Because a large number of marine bathers may be exposed to pathogenic microorganisms in water and become ill, disease surveillance in marine recreational waters should extend beyond

the Council of State and Territorial Epidemiologists to include additional efforts by the United States Environmental Protection Agency and the United States Centers for Disease Control and Prevention.

Improving testing programs and public warning systems is an important endeavor which can lead to heightened accuracy of beach closures and more effective risk communication. Further exploration should be made of the costs, effectiveness and feasibility of implementing rapid methods of fecal indicator bacteria detection in marine waters.

The public health protection focus for risk management at beaches should extend beyond the goals of improving water quality testing programs and improving public warning systems towards improving water quality. Improvements in water quality can be achieved through remediation to reduce health risks from marine contact recreation. Coincident with environmental remediation activities and efforts to expedite and improve the accuracy of water testing programs should be a mandate for disease surveillance of marine bathers.

To heighten public awareness of the health implications of coastal water contamination, information concerning recreational water illness in marine bathers should be posted on governmental websites alongside analogous information about the risks of recreational water illness associated with swimming pools, hot tubs, and spas. In the United States, a model aquatic health code was called for by the Council of State and Territorial Epidemiologists in 2006. An analogous model marine health code should also be created.

The speed and level of coordination with which health data on marine bathing is transmitted should be improved. Agencies should more widely adopt internet-based methods of data collection for recreational waterborne disease surveillance. The internet provides an affordable, high-technology tool to elicit useful information about when and where recreational water illnesses occur. The internet can also serve as a direct means of contact between individuals and health care providers (Wethington & Bartlett 2006). In the United States, there has been a shift at many levels of government from pen and paper technology towards electronic communication and data sharing in the health care arena. The use of electronic technologies facilitates improvements in data sharing, stakeholder engagement, risk communication, and risk management. Health officials can benefit from improvements in the data transmittal process to monitor and prevent illnesses at marine beaches.

Health agencies should establish as a goal to estimate endemic rates of diarrheal illness and other adverse health outcomes experienced by marine bathers. Health Care Providers in coastal areas could be required to ask questions of illness victims concerning presumed exposure to coastal water contamination. Similar recommendations have been made for physicians with respect to the need for improved drinking water surveillance. Further examination of the costs and benefits of pilot public health programs are needed.

Web-based technologies should be set in place to help identify time/space clusters of disease. Efforts to monitor illnesses in marine bathers should be encouraged by state and federal agencies in the United States. Cooperative efforts between government, non-profit organizations and other entities should be promoted to monitor waterborne illness.

CONCLUSION

Several weaknesses inherent to current risk management practices at public beaches necessitate disease surveillance. To date, the thrust of risk management at public beaches in the United States has been on regulating discharge, environmental monitoring, and re-defining ambient water quality criteria. By incorporating disease surveillance into risk management strategies at marine beaches, the goals of environmental quality improvement and bather protection can be secured simultaneously. Health agencies would likely benefit from a systematic evaluation of their bather protection programs based on the criteria described in this article. The recommendations set forth may be used as a template for a new model marine health code.

REFERENCES

Cabelli, V., Dufour, A., McCabe, L. & Levin, M. 1982 Swimming-associated gastroenteritis and water quality. *Am. J. Epidemiol.* **115**, 606–616.

Cabelli, V., Dufour, A., McCabe, L. & Levin, M. 1983 A marine recreational water quality criterion consistent with indicator concepts and risk analysis. *J. Water Pollut. Control Federation* **55**, 1306–1314.

California Health and Safety Code, Subsection 115880. California Assembly Bill 411, Statutes of 1997, Chapter 765. An Act to Amend Sections 115880, 115885, and 115915 of the Health and Safety Code, Relating to Public Beaches. Sacramento, CA: California State Assembly, 1998.

County of San Diego 2000 Ocean Illness Survey Report. Prepared by the County of San Diego Department of Environmental Health. Available at: http://www.co.san-diego.ca.us/deh/lwq/beachbay/pdf/ois_final.pdf Accessed May 11th, 2007.

Colford, J., Wade, T., Schiff, K., Wright, C., Griffith, J., Sandu, S., Burns, S., Sobsey, M., Lovelace, G. & Weisberg, S. 2007 Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. *Epidemiology* **18**, 27–35.

Craun, M., Craun, G., Calderon, R. & Beach, M. 2006 Waterborne outbreaks reported in the United States. *J. Water Health* **4**(Suppl. 2), 19–30.

Dwight, R., Semenza, J., Baker, D. & Olson, B. 2002 Association of urban runoff with coastal water quality in Orange County, California. *Water Environ. Res.* **74**, 82–90.

Dwight, R., Baker, D., Semenza, J. & Olson, B. 2004 Health effects associated with recreational coastal water use: urban versus rural California. *Am. J. Public Health* **94**, 565–567.

Dwight, R., Brinks, M., SharavanaKumar, G. & Semenza, J. 2007 Beach attendance and bathing rates for Southern California beaches. *Ocean Coast Manage.* **50**, 847–858.

Esfratiou, M. 2001 Managing coastal bathing water quality: the contribution of microbiology and epidemiology. *Mar. Pollut. Bull.* **42**, 424–432.

Fleisher, J. 1990*a* The effects of measurement error on previously reported mathematical relationships between indicator organism density and swimming-associated illness: a quantitative estimate of the resulting bias. *Int. J. Epidemiol.* **19**, 1100–1106.

Fleisher, J. 1990*b* Conducting recreational water quality surveys: some problems and suggested remedies. *Mar. Pollut. Bull.* **21**, 562–567.

Fox, L., Ocfemia, M., Hunt, D., Blackburn, B., Neises, D., Kent, W., Beach, M. & Pezzino, G. 2005 Emergency survey methods in acute Cryptosporidiosis outbreak. *Emerg. Infect. Dis.* **11**, 729–731.

Given, S., Pendleton, L. & Boehm, A. 2006 Regional public health cost estimates of contaminated coastal waters: a case study of gastroenteritis at Southern California beaches. *Environ. Sci. Technol.* **40**, 4851–4858.

Haile, R., Witte, J., Gold, M., Cressey, R., McGee, C., Millikan, R., Glasser, A., Harawa, N., Ervin, C., Harmon, P., Harper, J., Dermand, J., Alamillo, J., Barrett, K., Nides, M. & Wang, G. 1999 The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology* **10**, 355–363.

Hannemann, M., Pendleton, L., Mohn, C., Hilger, J., Kurisawa, K., Layton, D. & Vasquez, F. 2004 *Using Revealed Preference Models to Estimate the Affect of Coastal Water Quality on Beach Choice in Southern California*. National Oceanic and Atmospheric Administration, Minerals Management Service; The California State Water Resources Control Board, California Department of Fish and Game, Sacramento, CA, USA.

Henrickson, S., Wong, T., Allen, P., Ford, T. & Epstein, P. 2001 Marine swimming-related illness: implications for monitoring and environmental policy. *Environ. Health Perspect.* **109**, 645–650.

Kim, J. & Grant, S. 2004 Public mis-notification of coastal water quality: a probabilistic evaluation of posting errors at Huntington Beach, California. *Environ. Sci. Technol.* **38**, 2497–2504.

Kuusi, M., Nuorti, J., Maunula, L., Miettinen, I., Pesonen, H. & von Bonsdorff, C. 2004 Internet use and epidemiologic investigation of gastroenteritis outbreak. *Emerg. Infect. Dis.* **10**, 447–450.

Morrison, A., Coughlin, K., Shine, J., Coull, B. & Rex, A. 2003 Receiver operating characteristic curve analysis of beach water quality indicator variables. *Appl. Environ. Microbiol.* **69**, 6405–6411.

Mugglestone, M. 2000 A review of the health effects of sea bathing water. In: *Web Report W2* (Stutt & Rushton, L. eds.) Institute for Environment and Health. Leicester, UK. Available at: http://www.silsoe.cranfield.ac.uk/ieh/pdf/w2.pdf. Accessed May 11th, 2007.

Natural Resources Defense Council 2005 *Testing the Waters 2005: A Guide to Water Quality at Vacation Beaches*. NRDC, New York. Available at: http://www.nrdc.org/water/oceans/ttw/titinx.asp. Accessed May 11th, 2007.

Noble, R., Weisberg, S., Leecaster, M., McGee, C., Dorsey, J., Vainik, P. & Orozco-Borbon, V. 2003 Storm effects on regional beach water quality along the southern California shoreline. *J. Water Health* **1**, 23–31.

Pendleton, L. 2001 Managing beach amenities to reduce exposure to coastal hazards: storm water pollution. *Coastal Management* **29**, 239–252.

Pruss, A. 1998 Review of epidemiological studies on health effects from exposure to recreational water. *Int. J. Epidemiol.* **27**, 1–9.

Rabinovici, S., Bernkopf, R., Weinn, A., Coursey, D. & Whitman, R. 2004 Economic and health risk trade-offs of swim closures at a Lake Michigan Beach. *Environ. Sci. Technol.* **38**, 2737–2745.

Shuval, H. 2003 Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment. *J. Water Health* **1**, 53–64.

Turbow, D., Osgood, N. & Jiang, S. 2003 Evaluation of recreational health risk in coastal waters based on Enterococcus densities and bathing patterns. *Environ. Health Perspect.* **111**, 598–603.

Turbow, D., Kent, E. & Jiang, S. 2008 Web-based Investigation of Water Associated Illness in Marine Bathers. *Environ. Res.* **106**, 101–109.

United States Environmental Protection Agency 1986 *Ambient Water Quality Criteria for Bacteria*. Government Printing Office, Washington, DC, EPA/440/5-84-002.

United States Environmental Protection Agency 2000 *Improved Enumeration methods for the Recreational Water Quality Indicators: Enterococci and Escherichia coli*. U.S. Government Printing Office, Washington, DC, EPA/821/R-97-004.

United States Environmental Protection Agency 2002 *Implementation Guidance for Ambient Water Quality Criteria for Bacteria*. U.S. Government Printing Office, Washington, DC, EPA/823/B-02-003.

Wade, T., Calderon, R., Sams, E., Beach, M., Brenner, K., Williams, A. & Dufour, A. 2006 Rapidly measured indicators of recreational water quality are predictive of swimming-associated gastrointestinal illness. *Environ Health Perspect.* **114**, 24–28.

Wethington, H. & Bartlett, P. 2006 Usage and data collection patterns for a novel web-based foodborne disease surveillance system. *J. Environ. Health.* **68**, 25–29.

Yoder, J., Blackburn, B., Craun, G., Hill, V., Levy, D., Chen, N., Lee, S., Levy, D. & Beach, M. 2004 Surveillance for waterborne-disease outbreaks associated with recreational water-United States, 2001–2002. *Morb. Mortal. Wkly. Rep.* **53**(SS08), 1–22.

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