Thursday, April 14
8:30 a.m.–10:00 a.m.

Session 5: Epidemiology and Quantitative Microbial Risk Assessment

Acute Illness Associated with Ocean Exposure and Fecal Indicator Bacteria during Dry and Wet Weather: A Longitudinal Cohort Study of Surfers in San Diego, California

Ayse Ercumen
University of California—Berkeley

Abstract

Background: Fecal indicator bacteria levels suggest that freshwater runoff following rainstorms increases ocean contamination, but little is known about whether ocean recreators are at higher risk of acute infections in those conditions. Southern California receives nearly all of its annual rainfall during the winter months, and surfers enter the ocean year-round—even after rainstorms.

Methods: We enrolled 654 surfers in the San Diego area through on-beach and online recruitment during the winters of 2013–14 and 2014–15. We collected surf activity (date, location, times) and illness symptoms (gastrointestinal illness, sinus infections, ear infections, infected wounds) every 7 days using a smartphone- and Web-based application. We classified surf sessions within 0–3 days of rainfall > 0.1 inch in 24 hours as wet weather exposure, and estimated adjusted incidence rate ratios (IRRs) to compare ocean exposure during dry or wet periods to unexposed periods. At two sentinel beaches, we collected daily water samples, measured Enterococcus levels, and matched daily geometric mean values to individual surf sessions at those beaches.

Results: Surfers contributed 33,377 days of observation. Of 10,081 surf sessions, 1,327 followed wet weather. Compared with unexposed periods, exposure to seawater during dry weather increased incidence rates of all outcomes (e.g., gastrointestinal illness IRR=1.30 [0.95, 1.76], earache/infection IRR=1.86 [1.27, 2.73]); exposure during wet weather further increased rates (gastrointestinal illness IRR=1.41 [0.92, 2.17], earache/infection IRR=3.28 [1.96, 5.50]). Enterococcus levels were associated only with illness following wet weather.

Conclusions: Ocean exposure increased rates of acute illness among surfers during the winter months, and exposure following rainstorms further increased illness rates.

Biosketch

Dr. Ayse Ercumen is an epidemiologist at the University of California at Berkeley School of Public Health. Dr. Ercumen received her doctorate degree and master of public health from University of California at Berkeley in Epidemiology, and also has a bachelor's degree in environmental engineering from Massachusetts Institute of Technology and a master's degree from University of California at Berkeley in the same field. Her research interests include drinking and recreational water quality, waterborne infections from exposure to recreational waters, diarrhea transmission and soil-transmitted helminth infections in low-income settings, health impact evaluations of water, sanitation and hygiene (WASH) interventions and waterborne disease associated with piped water distribution networks.

Development of Site-Specific REC Criteria for a Tidal Creek using Peer-Reviewed, Stakeholder-Led QMRA Process

Dustin Bambic
Paradigm Environmental

Abstract

Tecolote Creek is an impaired tidal creek within the limits of the City of San Diego, California. The creek flows through a steep open canyon that is inhabited by a range of wildlife and flows into Mission Bay, a heavily visited beach area. Several years of microbial source tracking showed very low prevalence of human sources and motivated a stakeholder-led process to use QMRA for development of site-specific REC criteria. The stakeholder group includes stormwater, health, regulatory, academic, and nongovernmental agencies. The findings of the process are peer-reviewed by a committee of leading experts in REC water quality, and the group has had close interactions with the U.S. Environmental Protection Agency's Office of Science and Technology and Office of Research and Development. From summer 2013 through the present, the monitoring program has included the quantification of fecal indicator bacteria, source identifiers (HF183, HumBac, and GB124), pathogenic bacteria, protozoa, and human pathogenic viruses (norovirus, enterovirus, and adenovirus) using state-of-the-art approaches (e.g., digital droplet PCR). The source identifier data collected during the study have led to successful elimination of bacteria sources. Over the course of the study, analytical advancements greatly improved virus detection limits, which is key to risk assessment. This could be the first effort in the United States to strive to develop site-specific criteria for a flowing freshwater system, and the stakeholder process can serve as a model for other efforts. The presentation will highlight key lessons learned that will be intriguing to a wide array of audience members.

Biosketch

Mr. Dustin Bambic is a director and professional hydrologist with Paradigm Environmental. He has led projects across the United States related to recreational water quality, including special studies, total maximum daily load implementation plans, and watershed modeling efforts. Mr. Bambic holds bachelor's degrees in physics and mathematics from Western Kentucky University and master's degrees in hydrologic science and environmental engineering from the University of California-Davis.

Preliminary Evidence for Asymptomatic Norovirus Infection Transmission Associated with Swimming at a Tropical Beach

Timothy Wade, PhD
U.S. Environmental Protection Agency

Abstract

Swimming in fecally contaminated water bodies can result in gastrointestinal (GI) infections. However, the pathogenic microorganisms responsible are often unidentified because studies rely on self-reported symptoms. Noroviruses are considered a likely cause because they are resistant to conventional wastewater treatment and can survive in the environment. Symptoms among swimmers usually occur within a few days of exposure, consistent with the short incubation period of noroviruses. In the summer of 2009, we conducted an epidemiology study in Puerto Rico, where we previously reported no association between swimming and GI symptoms. We collected saliva samples from a subset of participants (N=1300) using an oral swab on the day of the beach visit (S1), after 10–12 days (S2), and after approximately 3 weeks (S3) and tested them for IgG antibody responses to two common noroviruses (Norwalk and VA387). An immunoconversion, indicating a potential new infection, was defined a fourfold increase in norovirus-specific median fluorescence intensity (MFI) from the S1 to the S2 sample with the S3 sample remaining at least two times above the baseline (S1) MFI. Approximately 4.7% (N=61) immunoconverted to norovirus. Swimmers who immersed their heads in water had a higher rate of immunoconversion (5.5%) compared to nonswimmers (2.0%) (OR=3.32, 95% CI 1.2-9.5). Immunoconversion to norovirus was not associated with increased GI symptoms, indicating these infections were asymptomatic. This is the first epidemiology study to show an association between norovirus infection and swimming exposure; however, these preliminary findings must be verified with additional sensitivity analyses.

Note: This abstract does not reflect EPA policy.

Biosketch

Dr. Timothy Wade is an epidemiologist with the U.S. Environmental Protection Agency (EPA) in the Office of Research and Development (ORD) at the Human Studies Division in Chapel Hill, North Carolina. He received his master of public health degree in epidemiology and biostatistics in 1998 and his doctorate degree in epidemiology in 2002 from the University of California at Berkeley. Dr. Wade joined EPA ORD in 2003 as a postdoctoral researcher and has been chief of the Epidemiology Branch since 2010. His research focuses on quantifying and measuring the health effects of waterborne contaminants. He has authored and coauthored more than 75 peer-reviewed manuscripts and book chapters and is a section editor for *Current Environmental Health Reports*. Dr. Wade was the lead investigator on a series of epidemiological studies at beach sites across the United States and a series of arsenic studies in Inner Mongolia, China. His additional research interests include the development and application of salivary immunological biomarkers for environmental pathogens, microbial risk assessment, infectious disease modeling, and modeling the health effects of waterborne exposures. Dr. Wade also is an assistant adjunct professor in the Epidemiology Division at the University of North Carolina at Chapel Hill.

Evaluation of the Dry and Wet Weather Recreational Health Risks in a Semi-Enclosed Marine Embayment in Southern California

Sunny Jiang, PhD
University of California—Irvine

Abstract

Recreational beach water quality is currently regulated by the level of fecal indicator bacteria (FIB) for recreational health protection. The validity of these indicators, however, has been questioned in recent years. The poor correlations between FIB and human pathogens can lead to "underprotection" or "overprotection" of public health, which can impact the human health and socioeconomic values of the region. A new source-apportionment quantitative microbial risk assessment (QMRA) approach to risk management, which is based on site-specific conditions, is proposed and was tested at Baby Beach in southern California. The small, semienclosed beach has been suffering from chronic elevated levels of Enterococcus, especially during poststorm conditions. The results of the study show that the median illness risks are meeting the U.S. Environmental Protection Agency recreational water quality criteria of 36 illness cases per 1,000 bathers 100 percent of the time during dry weather conditions, and over 93 percent of the time during wet weather when the stormwater is contaminated by 5 percent sewage. The results imply that complying with current FIB water criteria places unnecessary burdens on the recreational water manager without necessarily managing the recreational water illness (RWI) rate. Optimizing the risks and benefits of recreational beaches requires balancing the RWI with the socioeconomic value of the beaches. A health risk-based approach as implemented in this study can be an important complement to a better health risk management of a nonpoint source recreational beach.

Biosketch

Dr. Sunny Jiang is a professor of environmental engineering at the University of California, Irvine (UCI). She received her master of science and doctoral degrees in marine science from the University of South Florida. She has been a professor at UCI since 1998 and teaches more than 150 students per year. During her career at UCI, she has focused her research on microbiological water quality, water treatment, and quantitative microbial risk assessment. Dr. Jiang has authored over 70 research publications and served on committees to guide the nation's decisions on water reuse.

EVALUATION OF THE DRY AND WET WEATHER RECREATIONAL HEALTH RISKS IN A SEMI-ENCLOSED MARINE EMBAYMENT IN SOUTHERN CALIFORNIA

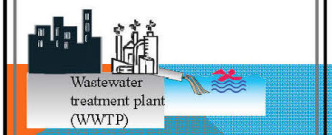
Keah-ying Lim[1], Stella Shao[2], Jian Peng[2], Stanley Grant[1], Sunny Jiang[1]
[1]UNIVERSITY OF CALIFORNIA, IRVINE
[2]COUNTY OF ORANGE

INTRODUCTION

- Recreational health risks are currently regulated based on FIB level in water
- Enterococcus (ENT) is used for marine recreational beach:
  - **ENT level ∝ Illness risk**

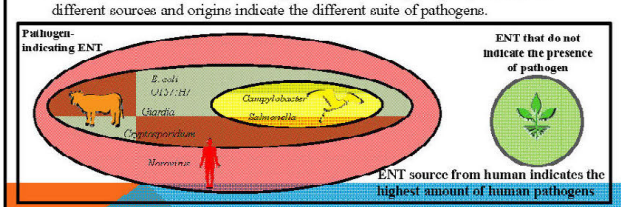
Such relationship is developed and ONLY APPLICABLE for recreational water impacted by wastewater effluent

In recreational water receiving non-point source runoff, ENT level is not proportional to illness risk



ENT SOURCES MATTER

- ENT in water is used to indicate the presence of human pathogens, but ENT of different sources and origins indicate the different suite of pathogens.



Venn diagram of pathogens indicated by ENT

- Stormwater may include a combination of these ENT sources depending on the land use pattern in the watershed

ENT SOURCE APPORTIONMENT QMRA

- QMRA that involves estimating the target pathogen(s) density in water based on the ENT level and source

HAZARD IDENTIFICATION

i.e. ENT level in water = 100CFU/100mL; Based on the land use (source tracking work) of the watershed:

Plant and soil	Gull feces	Human sewage
50%	40%	10%

Target pathogen density =
1. *f*(50CFU/100mL Plant ENT), no pathogens
2. *f*(40CFU/100mL Gull ENT), only *Salmonella* and *Campylobacter*
3. *f*(10CFU/100mL Human ENT), all possible pathogens

EXPOSURE ASSESSMENT
- Volume of water ingested during recreational event

DOSE-RESPONSE ASSESSMENT
- Dose-response models for each target pathogen in each ENT source

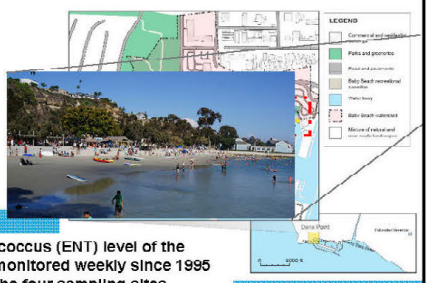
RISK CHARACTERIZATION
- Illness risk attributed to each ENT source
- Overall illness risk due to all the ENT sources

HYPOTHESIS

- Water recreational health risks impacted by stormwater can vary widely depending on the contamination sources of the stormwater.

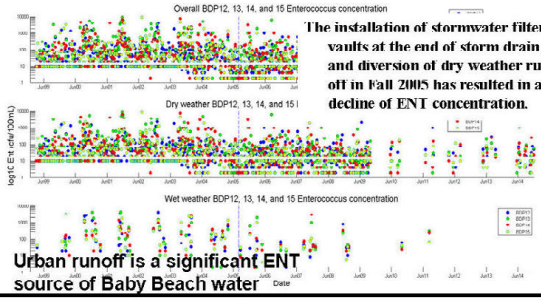
STUDY SITE

- Baby Beach at Dana Point, California
  - 43.4 acres watershed
  - Semi-enclosed beach **receiving only stormwater**, but no sewage
  - Closed down in the past due to high FIB level



Enterococcus (ENT) level of the water monitored weekly since 1995 along the four sampling sites

ENT CONCENTRATION OVERTIME



The installation of stormwater filter vaults at the end of storm drain and diversion of dry weather run-off in Fall 2005 has resulted in a decline of ENT concentration.

Urban runoff is a significant ENT source of Baby Beach water

DRY WEATHER ENT SOURCE IDENTIFICATION AND APPORTIONMENT

- Two ENT sources were identified :
  1. **Bathers' sheddings (characterized as primary sewage)**
  2. **Seabirds' feces**

Vary with season (Based on county's janitors record and lifeguards' log)

		Season	
		Apr-Oct (Dry/Summer)	Nov-Mar (Wet/Winter)
ENT source and apportionment	Bather's shedding	90%	65%
	Seabirds' feces	10%	35%

METHODS

$$D_{rp}^{S} = \frac{ENT_{weather}^{S}}{R_{ENT}^{S} \times 100} \times R_{rp}^{S} \times P_{rp}^{S} \times I_{rp}^{S} \times V$$

D_{rp}^{S} : the dose of each reference pathogen in a specific ENT source

$ENT_{weather}^{S}$: the ENT level in the recreational water contributed by a specific source (S)

R_{ENT}^{S} : is the density of ENT in feces (wet mass) (CFU/g) or in sewage (CFU/L)

R_{rp}^{S} : is the reference pathogen level in feces (wet mass) or sewage (# of pathogens/g or L or genome copies/g or L)

P_{rp}^{S} : is the fraction of human-infectious pathogenic strains in the reference pathogen of a specific source

I_{rp}^{S} : is the prevalence of infection in the non-human source

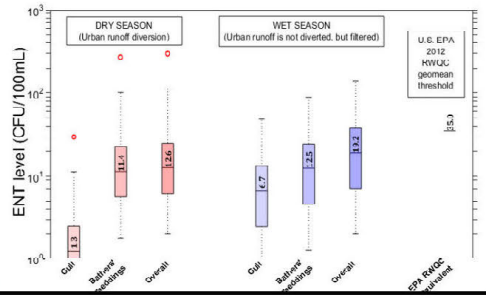
V : is the volume of water ingested (mL).

The illness risk due to each reference pathogen (Ill_{rp}) is calculated based on the published infection dose-response models

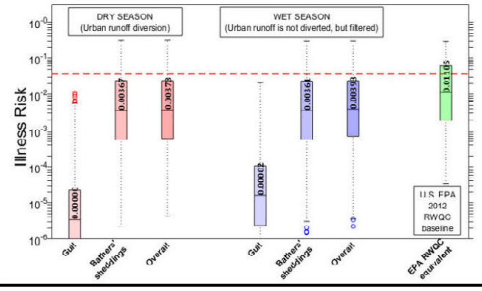
The illness risk due to all the reference pathogen in a single ENT source: $P_{ill}^{S} = 1 - \prod_{rp}(1 - Ill_{rp}^{S})$

The overall illness risk due to multiple ENT sources: $P_{ill} = 1 - \prod_{S}(1 - P_{ill}^{S})$

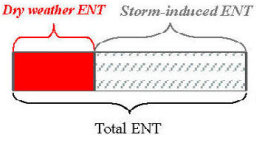
DRY WEATHER ENT APPORTIONMENT



DRY WEATHER RISK



WET WEATHER ENT SOURCE IDENTIFICATION AND APPORTIONMENT



Dry weather ENT apportionment is same as previously described for winter/wet season

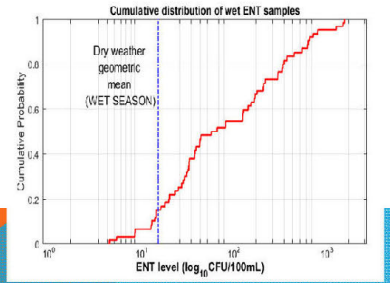
Two ENT sources were assumed for storm-induced ENT:

1. **Primary sewage (contamination of stormwater)**
2. **Non-pathogenic source (i.e. plants and soil origins)**

		Scenarios Analysis							
ENT source and apportionment	Primary sewage	0%	1%	2%	3%	4%	5%	10%	20%
	Non-pathogenic source	100%	99%	98%	97%	96%	95%	90%	80%

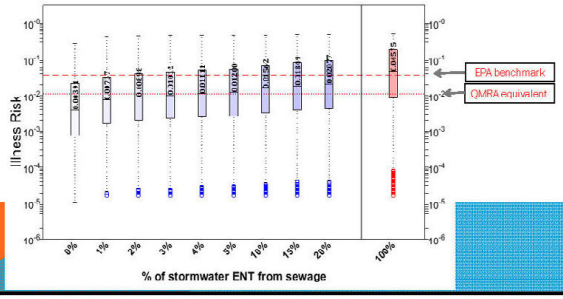
Sauer et al. Water research 2011, 45, (14), 4081-4091

WET WEATHER ENT



Wet weather ENT data were compiled from 1999 to 2011

WET WEATHER RISK



CONCLUSIONS

- Source apportionment QMRA confirms that health risks vary significantly with the proportion and source of the ENT in the water
- Exceeding the ENT numerical concentration standard is not always indicating the violation of the health risk standard
- Health risks are most sensitive to the presence of ENT of human sewage origin
- Enforcing ENT numerical concentration may not be the best approach to manage the recreational health risk

ACKNOWLEDGEMENTS

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Human-Associated Fecal qPCR Measurements and Simulated Risk of GI Illness in Recreational Waters Contaminated with Raw Sewage

Alexandria Boehm, PhD
Stanford University

Abstract

We used quantitative microbial risk assessment to simulate the risk of gastrointestinal (GI) illness associated with swimming in waters containing different concentrations of human-associated fecal markers from raw sewage, HF183 and HumM2. The volume/volume ratio of raw sewage to ambient water was determined by comparing marker concentrations in recreational water to concentrations in raw sewage from 54 geographic locations across the United States. Concentrations of reference GI pathogens in raw sewage, volumes ingested by swimmers, dose-response functions, and fractions of infected that become ill were adopted from previous studies. Simulated GI risk increased with concentration of the human quantitative polymerase chain reaction markers in recreational waters. A benchmark illness rate of 30 GI illnesses per 1000 swimmers occurred at median concentrations of 4200 copies of HF183 and 2800 copies of HumM2 per 100 mL of recreational water. This study establishes a risk-based approach for interpreting concentrations of human fecal markers in ambient waters.

Biosketch

Dr. Alexandria (Ali) Boehm is a professor in civil and environmental engineering at Stanford University. She received her master of science and doctoral degrees in civil and environmental engineering from University of California, Irvine and her bachelor of science degree with honors in engineering and applied science from California Institute of Technology. Dr. Boehm has been working on beach contamination issues for the past 15 years and is actively engaged in research on water and health in developing countries, stormwater contamination, coastal water quality more generally, and biomonitoring of macro-organisms in water using environmental DNA.

Question & Answer Session

Question 1
(Unknown): This question is mostly for Sunny [Jiang]. I followed your logic in that you were able to show for your beach given either stormwater or bather shedding as a pollution source, which is different than sewage. How does that translate into beach management decisions? Say a sample exceeds the standard, can you tell at each beach what the number is specific to that beach that managers can use?

Answer 1
Sunny Jiang: Its very site specific. With EPA's new criteria, it has allowed you to look at the risk as a management approach. If you can show for a specific area you have a number, but the risk isn't about that specific number, there is the potential to implement that as a management strategy. In EPA's criteria they are talking about a model approach. So you can convert that number to 150, which equals the 236.

Comment 1
Phil Scanlan: I gather from all speakers that having sewage in water is not a good idea. In New Jersey we had the largest sewage problem in the nation. I have a book; I'd love all the managers to get a free copy.

Question 2
(Unknown): We have done a lot of work in Milwaukee, and for 50 percent of our urban creeks it is difficult to correlate concentrations to certain flows. Do you have a frame work? We only find a sewage signal after heavy rains, not during dry weather.

Answer 2
Dustin Bambic: We try to sample the storm drains as much we can. Find a source upstream. A lot of GIS [geographic information system] work came out of Santa Barbara. Looking at storm drains is a good place to start, but we haven't found that smoking gun.