Tuesday, April 21
2:00 p.m.–3:45 p.m.

Session VII: Quantitative Microbial Risk Assessment

QMRA for Recreational Waters

Session Chair: Joan Rose
Michigan State University

Abstract

Waterborne disease and pathogen risks associated with ambient recreational water remain of significant concern. Water quality degradation along coastlines is associated with fecal pollution originating from sewage and non-point sources carrying with it potential health risks to those using the water. Epidemiological studies have examined seasonal risks mostly over a single swimming season to attempt to relate water quality monitoring of mostly indicators with health outcomes, mostly diarrhea. Quantitative microbial risk assessment (QMRA) is now a field which has developed over the last decade and is used to address both probability of infection and community risks. This scientific approach relies on understanding exposures to specific hazards of concern. The new challenges facing the development of a strategy for achieving community goals for water quality and water safety require a greater focus on evidence-based scientific monitoring. Methodologies associated with sampling [e.g. air, water, and surfaces] will need to take into account the level and extent of exposure and be able to interpret this in regard to health outcomes. Future advances in QMRA have begun to address models of the agent and its transmission as well as analytical methods using environmental and epidemiological data. The use of QMRA can be used to set priorities for improving the safety of water and for setting relevant public policy. Examples of recreational QMRAs associated with sewage spills, virus monitoring programs and recreational sites impacted by CSOs will be given. While the conventional National Academy of Sciences approach (4 steps Hazard Identification, dose-response, exposure assessment and risk characterization) will continue to be used, new tools and techniques as well as the issues of sensitive populations will likely modify the risk assessment strategy for microbial contaminants. The use of new microbiological tools for modeling and monitoring and the integration between clinical and environmental microbiology will provide the necessary data through risk assessment frameworks to address predictions and ultimately protection for water basins worldwide and will enable a better assessment of the risk to public health.

Biosketch

Dr. Joan Rose serves as the Homer Nowlin Chair in Water Research at Michigan State University, the Co-Director of the Center for Advancing Microbial Risk Assessment (CAMRA) and the Director of the Center for Water Sciences (CWS). Dr. Rose received her B.S., in 1976 from University of Arizona, her MS from University of Wyoming in 1980 and Ph.D. in Microbiology from the University of Arizona in 1985. She served as a Professor and assistant professor in the College of Marine Science, and College of Public Health, respectively at University of South Florida (USF) from 1990–2002.

Dr. Rose is an international expert in water microbiology, water quality and public health safety publishing more than 200 manuscripts. She has been involved in the investigation of numerous waterborne outbreaks worldwide. Her work has examined new molecular

methods for waterborne pathogens and zoonotic agents such as *Cryptosporidium* and enteric viruses and source tracking techniques. She has been involved in the study of water supplies, water used for food production, and coastal environments as well as water treatment wastewater treatment, reclaimed water and water reuse and quantitative microbial risk assessment. She specifically interested in microbial pathogen transport in coastal systems and has studied the impact of wastewater discharges and climate on water quality. She won the Clarke Water Prize (one of 5 international awards for contributions to water science and technology). In 2008 Dr. Rose won the first Heijin Woo Award for Achievements of Women in the Water Profession, from Intern. Water Assoc. (IWA).

She is currently serving as 1) Chair of the Drinking Water Committee for the Science Advisory Board for the U.S. Environmental Protection Agency 2) Chair of the Specialist Group Health-Related Water Microbiology (IWA).

Advancing QMRA for Recreational Waters

Center for Advancing Microbial Risk Assessment

Co-Directors
Joan Rose MSU
Chuck Haas Drexel

CAMRA
Center for Advancing Microbial Risk Assessment

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Grant # R83236201

CAMRA

Center for Advancing Microbial Risk Assessment

Joan B. Rose
Michigan State Univ
& Charles N. Haas
Drexel Univ.

Carnegie Mellon Univ
Northern AZ Univ.
Univ. Arizona
Univ. Calif Berkeley
Univ. Michigan

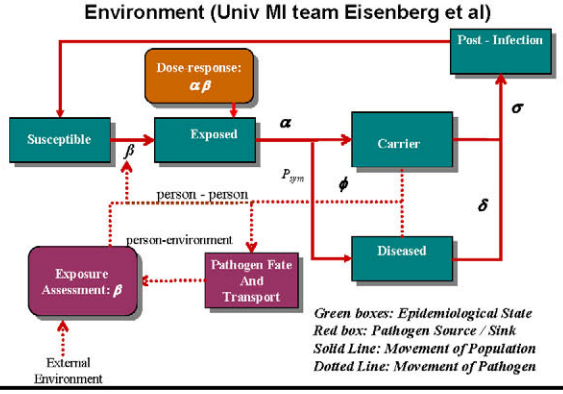
to build a national network for microbial risk knowledge management, learning and transfer, for the community of scientists, and students via educational programs and community of professionals in the field and in our communities.

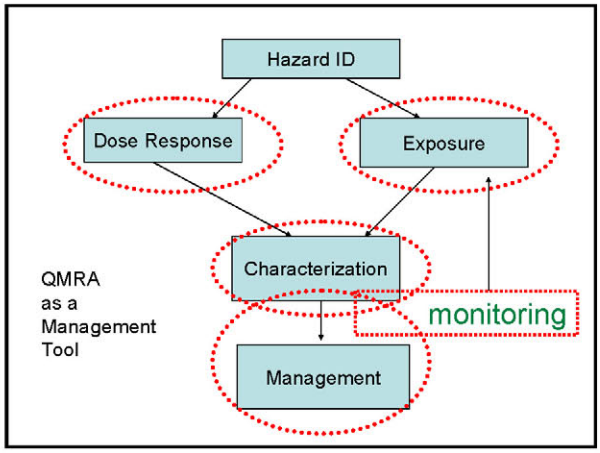
to develop models, tools and information that will be used in a credible risk assessment framework to reduce or eliminate health impacts from deliberate use of biological agents of concern in the indoor and outdoor environment.

Advancing the NATIONAL ACADEMY OF SCIENCES RISK ASSESSMENT PARADIGM

- **HAZARD IDENTIFICATION**
  Types of microorganisms and disease end-points
- **DOSE-RESPONSE**
  Human feeding studies, clinical studies, less virulent microbes and health adults
- **EXPOSURE**
  Monitoring data, indicators and modeling used to address exposure
- **RISK CHARACTERIZATION**
  Magnitude of the risk, uncertainty and variability

Interaction between Disease Transmission and the Environment (Univ MI team Eisenberg et al)





Advances in Dose Response Modeling

- Development of mathematical relationship between dose and probability of response
- Enables low dose extrapolation
- Have Dose-response data for most Class A and B agents

- Exponential

$$p \quad 1 \quad \exp \quad kd$$

- Approximate Beta Poisson

$$p \quad 1 \quad 1 \quad \frac{d\ 2^{1/} \quad 1}{N_{50}}$$

Probability of Infection

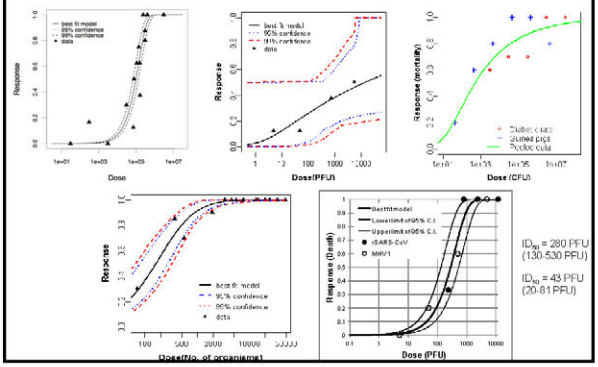
Organism	Best Model	Model Parameters
Echovirus	beta-poisson	$\alpha = 0.374$
		$\beta = 186.69$
Rotavirus	beta-poisson	$\alpha = 0.26$
		$\beta = 0.421$
Adenovirus 0.4172	exponential	r =
Polio1	beta-poisson	$\alpha = 0.1097$
		$\beta = 1524$
Polio3	beta-poisson	$\alpha = 0.409$
		$\beta = 0.788$

Models: $P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-poisson model)

$P_i = 1 - \exp(-rN)$ (exponential)

N=exposure

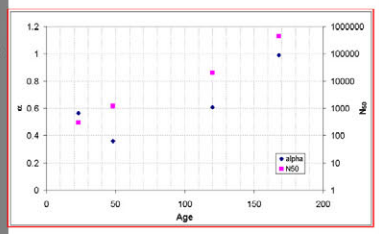
Dose Response Models



Findings: *V. major,* intraperitoneal exposure, mouse model[1]

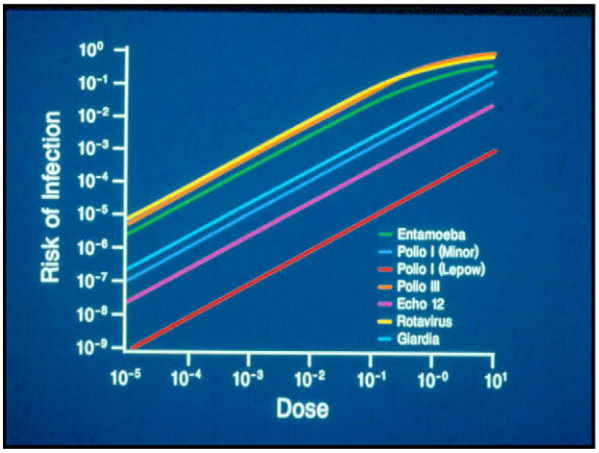
Developed dose-response relation with parameters accounting for host age

- Young suckling mice far more susceptible than mice only 1 to 2 days older
- When trends in susceptibility with age are included, data for different age groups may be pooled

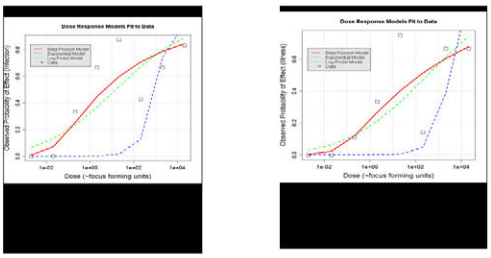


Systematic dependency of dose response parameters to host age -- first finding of its kind

[1] Marshall, R.G., and Gerone, P.J., 1960, "Susceptibility of Suckling Mice to Variola Virus," Journal of Bacteriology, 82(1): 15-19



Molecular-based Dose-Response Models



Rotavirus Focus Forming Unit (FFU) - conversion

- 1 viral particle = 1 genome (Teunis et al.)
- 1 norovirus aggregated particle ≈ 1 rotavirus aggregated particle (Teunis et al.)
- 15,600 rotavirus aggregated particles / 1FFU (Ward et al.)

Norovirus Data Needs

Clinical and Human data

- ✓Excretion rates and time
- ✓Viable infectious units to particles
- ✓Dose-response verification

Comparing Outbreak data to environmental monitoring to modeling information.

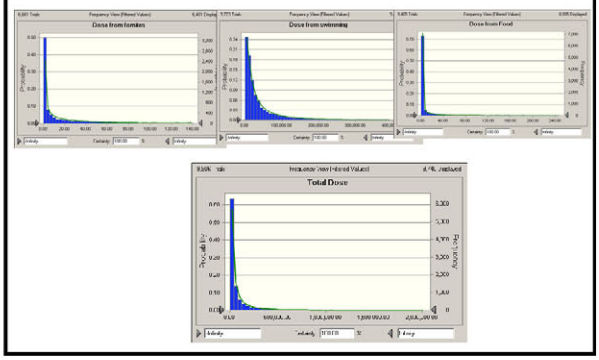
- Continue investigating outbreaks

Advances in Assessing Exposure

- Sources of Exposure
- Quantification of Exposure
- Distributions
- Time-to-exposure Estimates

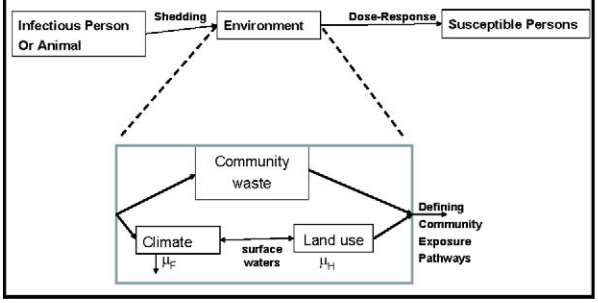
Transmission Routes

Total Doses from various pathways



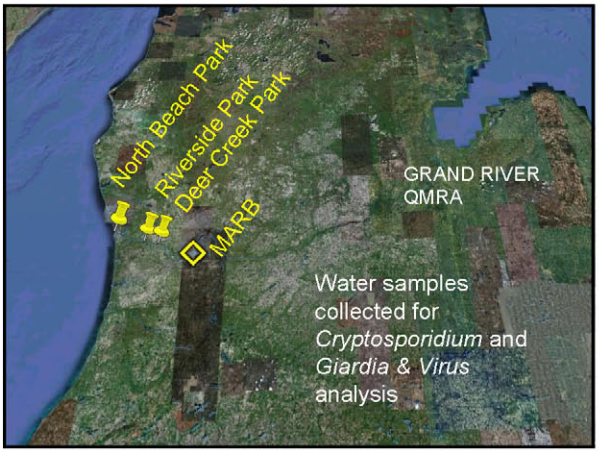
Determining The Quantitative Transmission Pathway

- Addressing the Environment

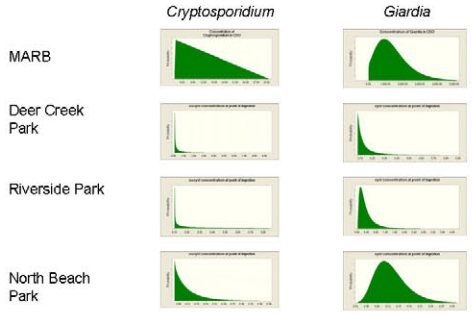


Pathogen specific Sewage impacts: communication and management

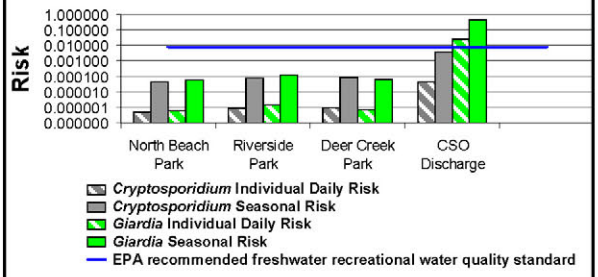
- Assessment of health risks due to *Cryptosporidium* spp. and *Giardia* spp.
  - Probabilistic assessment of maximum risk (Rebecca Ives, MSU)
- Risk Scenario: Children up to age of 16 swimming in recreational areas of Michigan waters that receive CSO discharge
- Crypto and Giardia Dose-response
- Monitoring data
- River flow



(Oo)cyst Distributions



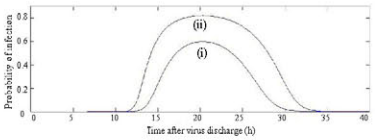
Median Risk of Illness



Viral risks associated with CSOs to the Grand River

(Theng Theng Fong, MSU)

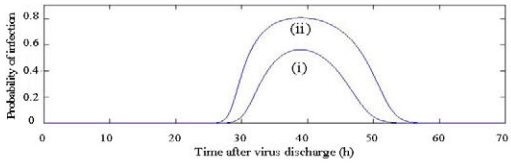
- Adenovirus qPCR monitoring data, river, beaches, parks and CSOs
- USGS flow gauge, River flow, seasonal data, 10 years of data.
- MI DEQ CSO discharge data-base, vol & duration.
- Rotavirus dose-response
- Exposure from swimming (Study by Dufour)
- Transport model from Bacteriophage P22 tracer study (Shen, C., Phanikumar, M.S., Fong, T.T., Aslam, I., Mcelmurry, S.P., Molloy, S.L., Rose, J.B. 2008. Evaluating Bacteriophage P22 as a Tracer in a complex surface water system: The Grand River, Michigan. Environ. Sci. Tech. 2008, 42, 2426-2431)



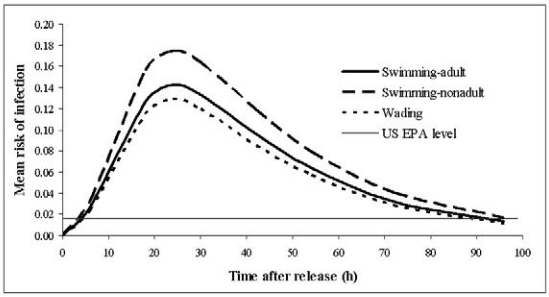
Probability of rotavirus infection versus time after CSO discharge 25 km downstream of discharge point.

Assuming 8/1000 is acceptable risk

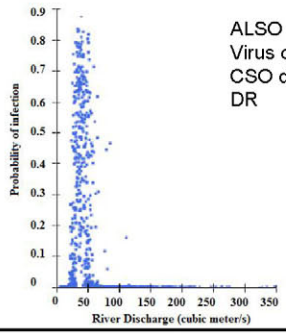
Probability of rotavirus infection versus time after CSO discharge 50 km downstream from discharge point.



Probability of Infection



Uncertainty Analysis



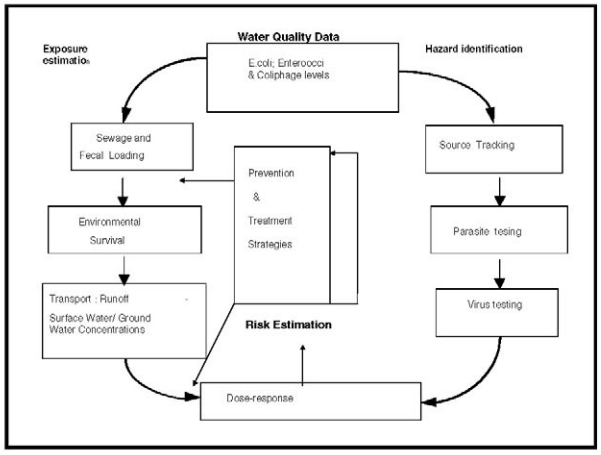
ALSO
Virus concentrations
CSO duration/vol
DR

QMRA & Management Results for CSOs

- Background levels of microbial contaminants recognized, now addressing survival and other sources.
- River Flow has a critical influence on risk.
- Can now address location and time.
- Can improve event monitoring and public health messages.

QMRA pathway forward for recreational use to guide management

- Now have dose-response for all Category A and most B agents.
- Building exposure data on methods, environmental contamination which can now be tied to DR for risk evaluation.
- Addressing outbreak information to test key parameters.
- CAN epidemiological data sets be better used?? Time-to-infection, multiple exposures, modeling exposure to address feasibility of monitoring programs.
- Need to develop more venue-specific risk assessments.
- Need to address unusual exposure pathways (secondary recreation) and health outcomes.
- Climate, climate adaptability, infrastructure investment.



Quantitative Microbial Risk Assessment: Its Role Beyond Criteria to Risk Management

Presenter: Nicholas Ashbolt
USEPA NERL

Authors: Nicholas Ashbolt, Mary Schoen, Susan Petterson, Jeff Soller

Abstract

Day-to-day beach management for pathogens varies across the US and globally, yet we all use very similar microbiological criteria for all recreational waters. As discussed in the companion abstracts, QMRA may be used to "fill-in-the-gaps" where there is no epidemiologic data on beach type and health outcome, to aid in selecting appropriate criteria. Yet there is more we can glean from QMRA studies to aid beach management, particularly in exploring various scenarios of the estimated relative effects of different hazardous events or beach conditions. The results from running the latter scenarios in a QMRA model not only provide information that may aid beach notifications, but also provide information relevant to setting priorities for research and infrastructure changes. Hence, in addition to current multi-linear regression models that provide site specific indicator values (for nowcasting or forecasting of beach microbiology), QMRA can be coupled to hydrological or other ecological models to provide site specific pathogen risk estimates that transparently attempt to account for different behaviors between pathogens and fecal indicators. Examples of these applications will be discussed in the presentation, including: accounting for local epidemiological data in the QMRA, evaluating the potential importance of sediment-borne pathogens, justifying recreation advisories, and the potential role of zoonotic or person-to-person transmission from 'supershedders' in driving health risks to recreators.

Biosketches

Dr. Ashbolt accepted a position as Title 42 Senior Research Microbiologist with the National Exposure Research Laboratory, U.S. EPA Cincinnati in January 2007. Previously he was Head of the School of Civil and Environmental Engineering, the University of New South Wales (UNSW) Sydney. He has 25 years experience in environmental microbiology, undertaking his PhD on the microbiology of composting/Eucalyptus/bark with biosolids and fish wastes, and subsequently researching in the field of environmental pathogen detection, fate and transport. Over the last 10 years has worked in joint Australian-Sweden and European programs developing methods to interpret pathogen data with the aid of quantitative microbial risk assessment within an urban water sustainability framework. This work has contributed to the risk-based approach adopted in the recently published WHO recreational, drinking water and reuse guidelines. He has published 27 book chapters, 105 journal papers and over 100 conference proceedings since he joined UNSW in 1994. In addition to leading quantitative microbial risk assessment activities within the EPA and supporting new recreational criteria, his current research is focused on describing fecal and indigenous microbial pathogens in distribution system biofilms, their interaction with bacteria and amoeba within pipe biofilms, and modeling risks to drinking water consumers from biofilm-associated pathogens and intrusion events in distribution systems.

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QUANTITATIVE MICROBIAL RISK ASSESSMENT: ITS ROLE BEYOND CRITERIA TO RISK MANAGEMENT

Nicholas Ashbolt

National Beaches Conference
April 20-22, 2009 Huntington Beach CA

Office of Research and Development
National Exposure Research Laboratory

EPA United States Environmental Protection Agency

BACKGROUND

- *Emergence of QMRA as a tool for assessing & informing risk management*
  - *WHO: water safety plans*
- *Microbial exposure/infection risks can vary significantly over time*
- *Risk assessments subject to high degrees of uncertainty*
- *Hence probabilistic methods becoming common*
- *Primary point of this paper is to highlight how QMRA can assist in beach management*

1

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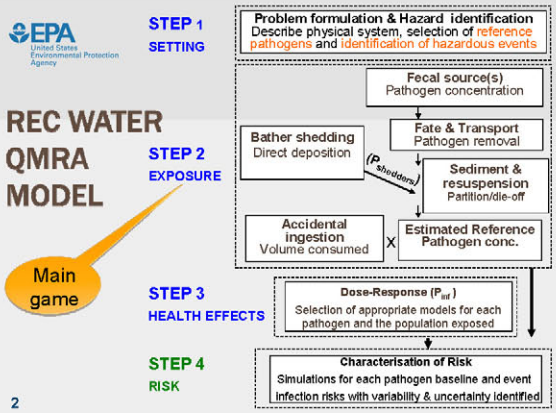
REC WATER QMRA MODEL



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APPLICATIONS FOR QMRA

- QMRA can be coupled to hydrological or other ecological models, and may:
  - Provide site-specific criteria/guidance
  - Account for different fate & transport between pathogens and fecal indicators
- Examples to be discussed include:
  - accounting for local epi data in a QMRA
  - evaluating the significance of sediment-microbes & other common concerns (e.g. gulls)
  - justifying recreation advisories

3

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QMRA & EPI-LINKED STUDIES

- Few examples in the literature – **more NEEDED**
  - Ashbolt *et al.* 1997 Sydney coastal beaches
  - Where estimated viruses yielded highest infection risks, and slightly less than measured in a companion epi study (Harrington *et al.* 1993)
    - 1-7 infections/1000 vs 13 GI /1000

Ashbolt, N. J., C. Reidy, and C. N. Haas. 1997. Microbial health risk at Sydney's coastal bathing beaches, pp:104-111, Proc. 17th Australian Water and Wastewater Association meeting, vol. 2. AWWA, Melbourne.
Harrington, J., D. Wilcox, P. Giles, N. Ashbolt, J. Evans, and C. Kirton. 1993. The health of Sydney surfers: an epidemiological study. Water Science and Technology 27(3-4):175-182.

4

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HUMAN & GULL CONTAMINATION

Bather shedding:

Norovirus
Campylobacter
Cryptosporidium
Salmonella

Gull feces:

Campylobacter
Salmonella

Sediments:
indicators + pathogens?

5

DOHENY B. QMRA INTERIM

See Schoen & Ashbolt poster

- Doheny Beach thought to be gull-impacted
  - Jack Colford's team undertaking epi study
- If the infectious Campylobacters from gulls are low, < 10% of total Campylobacters, then
  - bather fecal shedding risk > gull risk once the human contribution to the total fecal mass > ~5 %
- Nonetheless, est. GI risk < 10 infections /1000 when beachwater enterococci < 104/100 mL

? Precision needed for MST

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DO SEDIMENTS MATTER?

- Following scenarios under investigation by QMRA modeling:
  - **Storing and resuspending pathogens versus indicators**
    - Sediment pathogens probably insignificant if regular inputs of fecal contamination
  - **False +ve**: if enterococci/*E. coli* replicate &/or significantly out persist pathogens
    - Some data supports both of the above

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E.G.: SITE-SPECIFIC MANAGEMENT

- Lake Parramatta, Sydney
- 13 miles east Sydney CBD
- 70% urbanised / 30% bush
- 25 acre (lake) / 1880 acre (watershed)
- Up to 43' (13 m) deep with 6.5' (2 m) surface layer 0.12 M gallons (450 ML) water storage

Roser *et al.* 2007. Application of TMDL and risk assessment principles for pathogen management at an urban recreational lake, p. 420-426, 4th Conf ASABE March 10-14, 2007 San Antonio, Texas.

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GOAL: LAKE SWIMABLE BY 2005

- In 1997 the Upper Parramatta River Catchment Trust initiated work leading to the goal of reopening Lake Parramatta for swimming by 2005, under the banner 'Swim Toward 2005'
- Contracted for a plan in 2004
- Lake closed in 1980 due to fecal coliforms
- And reopened 2006

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PRIMARY BEACH CLASSIFICATION FOR THE SEASON, BUT 'TRAFFIC-SIGNAL' INDICATION ON THE DAY (NHMRC 2005)

Risk Category identified by Sanitary Inspection (susceptibility to faecal influence)	Microbiological Assessment Category (95th percentile enterococci / 100 mL)				
	D >500	C 201-500	B 41–200	A ≤40	Except'l Circumst.
Very high	Very poor	Poor	Follow up	Follow up	Action
High	Very poor	Poor	Follow up	Follow up	Action
Moderate	Poor	Fair	Good	Follow up	Action
Low	Follow up	Fair	Good	Very good	Action
Very low	Follow up	Follow up	Very good	Very good	Action
Exceptional circumstance	Action	Action	Action	Action	

http://www.nhmrc.gov.au/publications/synopses/_files/eh38.pdf

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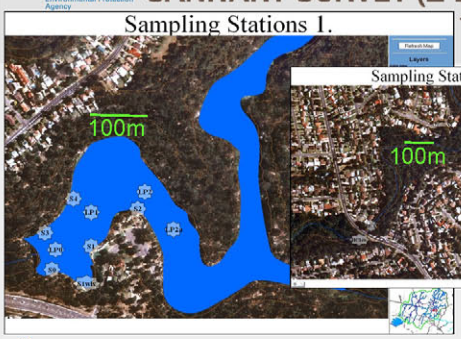
SANITARY SURVEY (2 EVENTS)



1. Dry & wet conditions
2. Lake turnover

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1. DRY WEATHER LAKE QUALITY

Statistic	Entero-cocci	*E. coli*	*C. perf-*	Turb. (NTU)
95th percentile	**19.1**[1]	227	51	3.7
Geometric mean	**2.6**[2]	29	3.0	2.1
Median	2.0	**30**[2]	4.0	2.0
75th percentile	5.9	**68**[2]	9.9	2.7
Sampling occasions	18	18	17	18
No. of measurements	50	50	47	50

[1]NHMRC 2005 (95th percentile <40 enterococci / 100 mL)
[2]ANZECC 2000 (median <150 FC / 100 mL)

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1. RAIN & 2. LAKE TURNOVER HAZARDOUS EVENTS

Dec 2004 Clear Surface (2 m)

Jun 2005 Post Turnover

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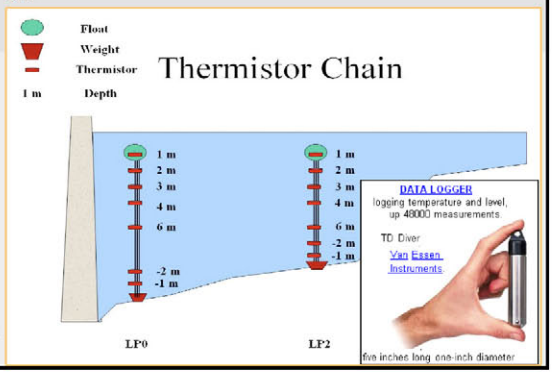
MIXING MODEL TEMP DATA



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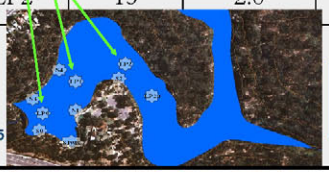
DRY WEATHER WATER QUALITY POST TURNOVER JUNE/3/2005

Station	Turbidity (NTU)	Enterococci 100mL^{-1}	*E. coli* 100mL^{-1}	*C. perfringens* 100mL^{-1}
LP0	12	3.1	17	15
LP1	14	5.2	15	<14
LP2	15	2.0	26	13



i.e. Lake sediments appear to be insignificant contributors

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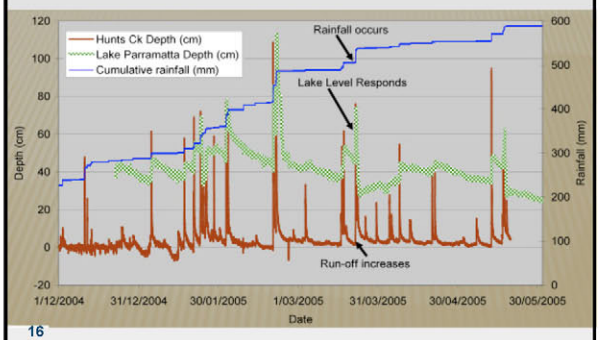
RAIN EVENT LAKE HYDROLOGY



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RAIN-EVENT CHARACTERISTICS

Event numbers	8/9/10	12/13	14/15	17/18
Rainfall Dates	1/23-25	2/1-2	**2/19-20**	3/17-18
Sampling Date	1/26	2/3	**2/21**	3/21
Rainfall (mm)	31	32.5	**70**	16
Gauged Run-off (ML)	53	46	**110**	27
Lake Rise (cm)	6.7/3.1/1.8	31/11	**40/49**	5/9
Enterococci .100mL^{-1}	4.1-16	25-69	**99-127**	1-4
E. coli .100mL^{-1}	49-58	69-162	**200-980**	30-435
C. perfringens .100mL^{-1}	6.4-64	33-150	**33-80**	<1 – 4

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RECONNAISSANCE SAMPLES (DURING RAIN EVENTS)

Station	Date	enterococci 100mL^{-1}	*E. coli* 100mL^{-1}	*C. perf.* 100mL^{-1}	Turbidity (NTU)
Gauging Station Bettington Rd	1/26/05	410	230	91	5.1
	2/5/05	140	93	84	4
	3/21/05	52	63	<10	3.3
Stormwater Drain Bettington Rd	1/26/05	220	870	54	2.1
	3/21/05	37000	$6.9x10^5$	7300	6.6
Redeemer Ck	3/21/05	750	300	<10	2

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PATHOGENS IN COMPOSITE LAKE WATER SAMPLES

Date	*Campy.* 100 mL^{-1}	*Sal.* 100 mL^{-1}	*Crypto.* 10 L^{-1}	*Crypto* Recovery
2/9/05	-	-	<4	29%
2/16/05	-	-	<4	27%
2/21/05	-	-	<4	-
3/9/05	-	-	<4	24%
3/1/05	<0.3	<0.1	-	-
3/14/05	<0.3	>0.1	-	-
4/11/05	<0.3	>0.1	-	-

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MICROBIAL CONTENT OF WATERFOWL SCATS

Composite Sample No.	1	2	3
Enterococci g^{-1} dry wt	71,000	46,000,000	12,000,000
***E. coli* g^{-1} dry wt**	220,000	180,000,000	26,000,000
***C. perfringens* g^{-1} dry wt**	<710	<10	<700
***Campylobacter* g^{-1} dry wt**	**79**	<2	<2
***Salmonella* g^{-1} dry wt**	<0.7	<0.7	**>0.7**
***Cryptosporidium*[3]**	<1	<1	<1

1. Moisture content of waterfowl scats was 84-86%.
2. Scats were composited from 8 different animals per sample.
3. Recovery of ColorSeed *Crypto* QC material was 6, 10 & 17%.

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BATHER RISK ESTIMATES FOR DRY/WET WEATHER & SHEDDING LAKE PARRAMATTA

Infection probability.person^{-1}.exposure^{-1})

Pathogen	Dry	10 mm	40 mm + 3d recovery	Bather shedding
Enterovirus	< 1/M	< 1/M	< 1/M	4/10,000
Campylobacter	< 1/M	**2/1000**	5/10,000	< 1/M
Crypto-Giardia	< 1/M	< 2/10,000	**2/1000**	< 1/M

< 1/M = less than one in a million

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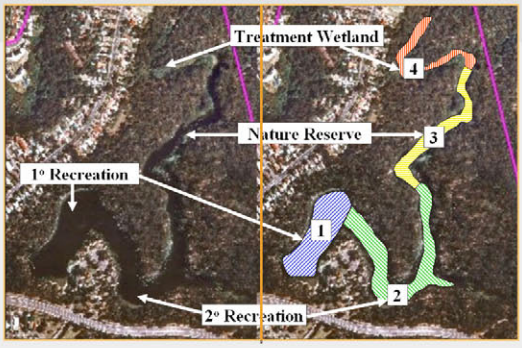
WSP - MANAGEMENT ZONING



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LAKE WATER SAFETY PLAN

- Lake re-opened for swimming December 2006 after waterfowl zones reduced
- TMDL-like basis, but preemptive & focused on risk assessment
- Preceding rainfall trigger for closure:
  - >10 mm rainfall in previous 24 hours
  - recovery for > 10 mm rainfall estimated 1.5 to 4 days or
  - cumulative global radiation exposure of between 40-93 MJ.m^{-2}

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SANITARY SURVEYS MAY EASILY IDENTIFY PATHOGEN RISKS

Photos: H. Salas

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QMRA'S VALUE IS IN EXPLORING SCENARIOS TO AID SANITARY SURVEYS

QMRA is able to:

- Estimate pathogens for alternative scenarios
- Estimate risk of infection for those scenarios
- Identify management targets
- Identify key research gaps
- Prioritize threats/BMP for watersheds
- Evaluate uncertainty of alternative predictive models

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ACKNOWLEDGEMENTS

- University of New South Wales
  - Drs. Roser, Davies & Petterson (Dr. Haas)
- U.S. EPA
  - Dr. Schoen, John Ravenscroft (Dr. Soller)
- Southern Californian Coastal Water Research Project
  - Drs. Weisberg, Griffith, Cao & Ferguson

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SOLAR INACTIVATION

- Solar irradiance required for 90% reduction (S_{90}s) are typically:
  - 2.5-5 MJ.m^{-2} for *E. coli* and F-RNA coliphage
  - 1-2 MJ.m^{-2} enterococci, *Clostridium perfringens* and DNA bacteriophages
- For comparison the radiation on sunny summer days in Sydney is about 20-35 MJ.m^{-2}.d^{-1} and seldom drops below 10 MJ.m^{-2}.d^{-1} in summer
  - Hence stormwater microbial inflows reduced by over five logs and measured T_{90S} (time for 90% reduction due to sunlight) were 1 to 2 days

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Microbial Risk Assessment of the Chicago Area Waterways

Presenter: Geeta Rijal
The Metropolitan Water Reclamation District of Greater Chicago

Authors: T. Glymph, R. Gore, T. Granato, C. Petropoulou, K. Tolson, C. Gerba, R.M. McCuin, L. Kollias, R. Lanyon

Abstract

As part of the Use Attainability Analysis (UAA) Study for the Chicago Area Waterway System (CAWS), the Metropolitan Water Reclamation District of Greater Chicago (District) conducted a quantitative microbial risk assessment (qMRA) at the three major water reclamation plants (WRPs), Calumet, North Side and Stickney. The goal of the study was to assess the gastrointestinal illness (GI) rate from exposure to pathogens during secondary contact recreation in the CAWS during dry and wet weather conditions. The qMRA was divided into four discrete components: (1) microbial sampling totaling 75 samples during dry weather in 2005 and 50 samples during wet weather in 2006 from the North Side, Stickney and Calumet waterways were collected. Samples were collected from upstream, downstream and outfall locations, and concentrations of the indicator microorganisms (fecal coliforms, *E. coli* and *Enterococci*) and representative pathogens (total culturable enteric viruses, viable adenovirus, calicivirus, *Cryptosporidium parvum, Giardia lamblia, Salmonella* and *Pseudomonas aeruginosa*) which are typically present in the feces of humans and other warm-blooded animals were examined; (2) analysis of the dry and wet weather microbial sampling data; (3) establishing exposure and dose parameters from the primary literature and local use surveys; and (4) assessment of the health risk posed from exposure to pathogenic bacteria, viruses and parasites during secondary contact recreation (fishing, pleasure boating and canoeing) in the CAWS during dry and wet weather conditions.

The water quality monitoring results show that the indicator bacteria (fecal coliforms, *E. coli* and *Enterococci*) were the most abundant microbial species detected in the waterway compared to viruses (enteric viruses, adenovirus and calicivirus) and protozoa (*Cryptosporidium and Giardia*) during dry weather conditions. The wet weather samples had a higher frequency of detection of pathogens and higher indicator bacteria concentrations compared to dry weather samples. However, overall concentrations of actual pathogenic organisms in the waterway, representing the spectrum of waterway conditions experienced in a recreational year, were low. The highest rates of GI, which were less than 3 per 1,000 exposures, were associated with recreational use on the Stickney and North Side waterway segments, and the lowest GI rate, which was less than 1 per 1,000 exposures, was associated with recreational use on the Calumet waterway segment. A low probability of developing GI, for secondary contact recreational users in the areas of the CAWS in close proximity to the District's WRP non-disinfected effluents from Stickney, Calumet and North Side, was due to low pathogen concentrations in the waterway..

Biosketch

Dr. Geeta K. Rijal is a Section Head of the Analytical Microbiology and Biomonitoring Section at the Metropolitan Water Reclamation District of Greater Chicago (District). She has a master's degree in environmental science from the University of Philippines at Los Banos, a Master's and a PhD degree in environmental

microbiology from the University of Hawaii. For more than fifteen years, she has worked on water and wastewater and has extensive background and experience in various facets of indicators and pathogens in wastewater, recreation water, biosolids, and river water. At the District, she directs the Analytical Microbiology and Biomonitoring Section, which includes whole effluent toxicity, parasitology, virology, and microbiology laboratories. She is a member of the American Society for Microbiology and a board certified (national registered) microbiologist (NRCM) in clinical and public health microbiology. She is also certified by the Illinois Department of Public Health for microbiological evaluation of water, water supplies, and their sources. She is actively involved with the Water Environment Research Foundation (WERF) serving as a Pathogen Issue Area Team member and a member of the Science and Regulatory Advisory Panel (SRAP) in support of WERF's initiative entitled, "Creating the Tools for Site-specific Biosolids Risk Assessment and Communication Plans." She also participated in the Experts Scientific Workshop on Critical Research and Science Needs for the Development of Recreational Water Quality Criteria in Inland Waters organized through WERF's Pathogens and Human Health research program and supported by the EPA Office of water.

Acknowledgement

- This presentation is based on the final report prepared by GEOSYNTEC CONSULTANTS (55 West Wacker Drive, Suite 1100, Chicago, Illinois 60601).
- The report titled, Dry and Wet Weather Risk Assessment of Human Health Impacts of Disinfection vs. no Disinfection in the Chicago Area Waterways System, is posted on the District web site
- http://www.mwrdgc.dst.il.us/RD/UAA/default.htm.

Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

Microbial Risk Assessment of the Chicago Area Waterways

G. Rijal[1], T. Glymph[1], R. Gore[1], T. Granato[1], L. Kollias[1], R. Lanyon[1], C. Petropoulou[2], K. Tolson[2], C. Gerba[3], & R.M. McCuin[4]

[1]Metropolitan Water Reclamation District of Greater Chicago
[2]GeoSyntec Consultants, Chicago, Illinois
[3]University of Arizona, Tucson, Arizona
[4]Clancy Environmental Consultants, St. Albans, Vermont

Chicago Area Waterway System

Background

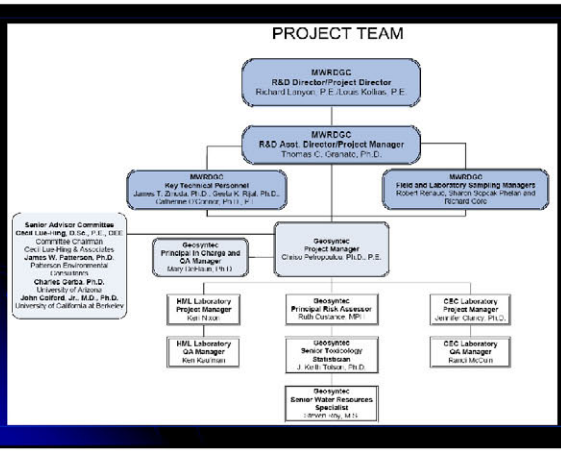
- Use Attainability Analysis (UAA) on the Chicago Area Waterways
- Designated uses of the CAWS include:
  1. Recreational boating
  2. Canoeing
  3. Fishing
  4. Other streamside recreational activities
  5. Aquatic habitat for wildlife

  Swimming and other primary contact recreation is not a designated use of the CAWS
- CAWS bacterial water quality standards
- Study conducted to assist UAA

Study Goal/Objectives

To estimate human health risks from exposure to pathogens during incidental contact recreation in the CAWS during dry and wet weather conditions.

- *Evaluate the impact of the treated effluent from the District's three major WRPs (North Side, Stickney, and Calumet) on the microbial quality of the CAWS.*
- *Estimate health risks to recreational users of the CAWS due to incidental contact pathogen exposure under dry & wet weather conditions.*
- *Quantify any reduction of risk that would result from disinfection of WRP effluents.*



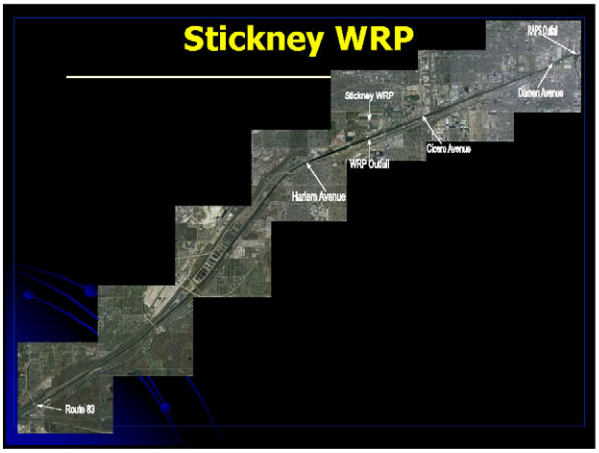
Overview

- Dry/Wet Weather Microbial Sampling
  - 75 samples during dry weather in 2005
  - 50 samples during wet weather in 2006
- Microbial Characterization/Analysis
- Microbial Risk Assessment (MRA)
  1. Exposure Assessment Overview
  2. Dose Response Overview
  3. Risk Characterization Approach
  4. Risk Assessment Results

Water Sampling Training

North Side WRP

Stickney WRP



Calumet WRP

Microbes Analyzed

1) Enteric viruses:
   i) total viruses (EPA Method 600/R-95/178)
   ii) adenovirus (Rodriquez & Gerba et al., 2008)
   iii) *calicivirus* (Rodriquez & Gerba et al., 2008)

2) Protozoa (EPA Method 1623*):*
   i) Viable Cryptosporidium parvum
   ii) Viable *Giardia lamblia*

3) Bacteria
   i) Salmonella spp. (SM 9260D)
   ii) Pseudomonas aeruginosa (SM 9213E)
   iii) Fecal coliforms (SM 9222D)
   iv) Escherichia coli (EPA Method 1103.1)
   v) Enterococci (EPA Method 1106.1).

Risk Calculations

Risk = Exposure x Potency

Concentration

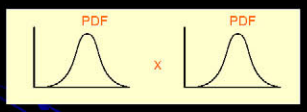
Ingestion Rate

Duration

Dose-Response

Probabilistic Risk Calculation

Input values in the Risk Assessment are represented by a distribution rather than a single number.



= **Distribution of Risks**

Monte Carlo analysis (simulations) used to estimate solutions for mathematical problems with difficult or impossible closed form analytical solutions.

Exposure Data - UAA Survey

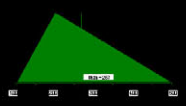
Proportion of Recreational Use

	Northside	Stickney	Calumet
Canoeing	**20.2%**	**1.2%**	**0.5%**
Fishing	**72.2%**	**28.4%**	**47%**
Pleasure Boating[1]	**7.6%**	**70.4%**	**52.5%**

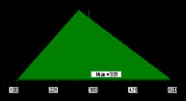
[1]Based on assumptions of 2.5 users per boat

Exposure Duration

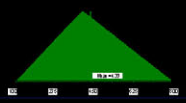
Canoeing - Triangular Distribution
- Minimum 1 hour
- Mode 2 hours
- Maximum 5 hours



Fishing - Triangular Distribution
- Minimum 1 hour
- Mode 3 hours
- Maximum 6 hours



Pleasure Boating - Triangular Distribution
- Minimum 1 hour
- Mode 4 hours
- Maximum 8 hours



Ingestion Rate

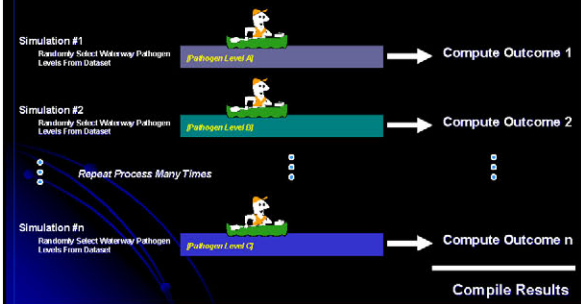
Samples were drawn from each input distribution.

Incidental ingestion of water developed using a lognormal distribution.

Ingestion Results from Simulations (mL/hr)

Percentiles	Boating	Fishing	Canoeing
10%	0.49	0.98	1.21
25%	0.65	1.30	2.02
50%	0.90	1.79	3.52
75%	1.23	2.47	6.15
90%	1.64	3.28	10.16
95%	1.95	3.89	13.84
97.5%	2.26	4.51	17.99
100%	6.43	20.13	30.00

Concentration Data Simulations



Probabilistic Risk Analysis

Simulation Procedure

1) Select a day from waterway concentrations dataset
2) Select an individual's recreation type
3) Select an exposure location
4) Select an exposure duration
5) Select an ingestion rate
6) Develop a dose
7) Determine illness

Results expressed as illnesses per thousand events

CAWS Microbiological Results

- Indicator bacteria (fecal coliform , *E. coli*, and enterococci) were the most abundant microbial species detected compared to *Salmonella* spp, viruses (enteric viruses, adenovirus and norovirus) and protozoa (Giardia and Cryptosporidium) during dry weather condition.
- Wet weather impact- Higher frequency of detection of indicator bacteria and pathogens compared to dry weather condition.
- Low concentration of actual pathogenic organisms (*Salmonella* spp, enteric virus, adenovirus, norovirus, *Giardia* and *Cryptosporidium*).

Total Expected Illnesses[a] per 1,000 Exposures

Exposure Input[b]	North Side	Stickney	Calumet
Dry Weather	0.36	1.28	0.10
Wet Weather	2.78	2.34	0.36
Combined Weather	1.55	1.77	0.21

[a] Includes all primary gastrointestinal illnesses from *E. coli*, *Salmonella*, total enteric viruses, adenoviruses, *Giardia*, and *Cryptosporidium* expected from the waterway exposures.
[b] Waterway concentration inputs for the simulations were randomly selected (bootstrap sampled) from datasets that include the indicated sample sets.

Effect of Disinfection Illnesses per 1000 Exposures

	North Side	Stickney	Calumet
No Disinfection	1.55	1.77	0.21
UV Irradiation	1.32	1.48	0.17
Ozone	1.45	1.65	0.19
Chlorination	1.43	1.63	0.19

Activity Risk Breakdown

	Illnesses per 1,000 Exposures[a]		
Recreational Use	North Side	Stickney	Calumet
Canoeing	2.45	3.19	0.52
Fishing	1.42	1.90	0.31
Pleasure Boating	0.66	1.05	0.14

[a]Combined Wet and Dry Weather Samples

Risk Estimates Uncertainties

- Lack of microbial dose response and ingestion data
- Temporal variability of microbes
- Accounting for PCR adjusted norovirus levels
- Level of conservatism in exposure inputs
- Correlation between usage and weather
- Immunity status in recreational populations
- Potential upsets in outfalls or treatment systems
- Sediment or shoreline soil exposure

Final Remark

- CAWS is a man-made controlled channel.
- Microbe sources to the CAWS-Faulty sewage disposal systems, CSOs, Wild and domestic animal waste, Illegal discharges to drains and sewers, Storm water runoff (*http://www.ChicagoAreaWaterways.org*).
- Wet weather impact.
- Current health risk based on MRA – minimal.
- Disinfection of WRP effluent -marginal effects on overall incidental contact recreational illness rates.

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Aftermath of Study

- EPA comments
- GeoSyntec Responded to EPA comments
- On-going Chicago, Health, Environmental Exposure, and Recreation Study

CHEERS
WATER CHICAGO SPORTS

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A Framework for QMRA: A New WERF-Funded Study

Co-Presenters: Stefan Wuertz
Department of Civil and Environmental Engineering, University of California, Davis
Graham McBride
NIWA (National Institute of Water and Atmospheric Research)

Authors: Stefan Wuertz, Graham McBride, Woutrina Miller, Dustin Bambic

Abstract

Concentrations of fecal indicator bacteria (FIB) as currently used in establishing and implementing recreational water quality criteria do not provide information about the sources of microbial pollution, nor of the pathogens they produce. Also, FIB can persist and multiply in nutrient-rich environmental niches such as biofilms and sand. For these reasons and others, EPA's current water quality criteria are being reviewed. In doing so we are examining the prospects for complementing and extending past and present epidemiological studies by enhancing quantitative microbial risk assessment (QMRA) procedures. This is to be done under a new WERF-funded project. This should provide more informed relationships between FIB, pathogens and sources. The specific objectives are: 1) to identify and address data gaps pertaining to loadings and concentrations of waterborne pathogens and indicators from various discharges to recreational waters, and 2) to compile, analyze and synthesize the data in robust QMRA and waterborne risk management frameworks. Sampling will be directed toward discharges-of-concern (e.g., influents and effluents of CSOs and CAFOs), rather than receiving waters.

The difficulties in quantifying pathogens include (1) even the most comprehensive monitoring toolkit cannot measure all pathogens of concern, (2) those pathogens that are targeted can be difficult to detect and quantify (especially norovirus), (3) lack of pathogen detection is not necessarily evidence of absence of pathogenicity, and (4) pathogens that are detected by methods that do not require culturing might not be infective. Therefore we propose to supplement collected pathogen and indicator data (*Salmonella, Vibrio cholerae, V. parahaemolyticus, Campylobacter jejuni, Bacteroidales, Enterococcus, Cryptosporidium, Giardia, Toxoplasma gondii,* adenoviruses, enteroviruses, noroviruses, rotaviruses, and FIB) with alternative indicators including host-specific Bacteroidales which allow for identification and quantification of animal sources. A conditional probability model for the determination of true proportions of animal-specific fecal pollution in a water sample has been developed by the research team.

Developing robust QMRA requires capturing and quantifying data for many variables including contributing fecal sources, types of pathogens, individual exposure levels, dose responses, and differential immunity. To adequately inform risk management, QMRA must proceed through six steps: (i) establish the context; (ii) identify the hazards (pathogens); (iii) assess exposures; (iv) assess dose-response; (v) characterize risks; and (vi) communicate those risks. The risk characterization step is the "engine room", in which "Monte Carlo" modeling is usually performed, by making repeated random draws from statistical distributions of the key variables, accounting for both variability (e.g., in individuals' exposure durations) and uncertainty (especially in the form of the dose-response relationship for individual pathogens). A key feature of our approach is that the QMRA does *not* depend on gaining pathogen data from receiving waters. Rather, these data are *predicted* using influent and effluent data, and appropriate environmental models. These predictions are used to quantify individuals' exposures, in step (iii).

Results of our QMRA modeling should be useful in informing the basic structure of new water quality criteria. Other aspects of risk management could also be considered including analyses of when models could be used to make *real-time* predictions of recreational water quality.

Biosketch

Dr. Wuertz is a professor in the Department of Civil & Environmental Engineering at the University of California, Davis. He has more than 13 years of experience in environmental biotechnology and engineering. He received his B.Sc. in microbiology from National University of Ireland, Galway, and his Ph.D. in environmental sciences from University of Massachusetts. He holds an advanced degree (habilitation) in environmental biotechnology from Technical University of Munich, Germany. Dr. Wuertz specializes in biofilm systems in wastewater treatment, the use of molecular tools to describe microbial communities and biological processes, and developing methodology to detect low-level pathogens in the environment combined with microbial source tracking. Prior to moving to Davis in 2001, he served as Administrative Director of a National Center of Excellence for Biological Wastewater Treatment at the Technical University of Munich. He has been a recipient of a 2-year fellowship from the European Union to study genetics of heavy metal resistance in bacteria. Currently, Dr. Wuertz is Editor of the international journal *Water Research*.

A Framework for QMRA: A New WERF-Funded Study

Stefan Wuertz[1], Graham McBride[2], Woutrina Miller[3], Dustin Bambic[4]

[1] Dept. of Civil & Environmental Engineering, University of California, Davis
[2] NIWA (National Institute of Water and Atmospheric Research), New Zealand
[3] Department of Pathology, Microbiology & Immunology, School of Veterinary Medicine, University of California, Davis
[4] AMEC Earth & Environmental, Nashville, TN

Quantification of pathogens and sources of microbial indicators for QMRA in recreational waters

(start date: April 2009)

- **Research team organizational chart**

International QMRA and risk assessment community

Facilities and agencies monitoring water quality worldwide

UC Davis
S. Wuertz, W. Miller, P. Conrad, B. Byrne

NIWA
G. McBride, R. Stott

AMEC
Dustin Bambic

Objectives

- 1) To identify and address data gaps pertaining to source loadings and concentrations of waterborne pathogens and indicators from various sources into recreational waters
- 2) To compile, analyze and synthesize the data in quantitative microbial risk assessment (QMRA) models and waterborne risk management frameworks

→ Support efforts in the next 18 months to revise current health-based recreational ambient water quality criteria under the Clean Water Act

Monitoring toolkit to inform QMRA

- Pathogens

  Salmonella, *Vibrio cholerae*, *V. parahaemolyticus*, *Campylobacter jejuni*, *Cryptosporidium*, *Giardia*, *Toxoplasma gondii*, adenoviruses, enteroviruses, noroviruses and rotaviruses

- Fecal indicator bacteria

  E. coli and *Enterococcus* (IDEXX or standard methods)

  Enterococcus (by qPCR)

- Alternative indicators (source identifiers)

  Host-specific *Bacteroidales* genetic markers in viable cells only and as total DNA (= viable and cell-compromised cells, extracellular DNA)

Phase 1

- Collect available data from field surveys (e.g. TMDL studies) using alternative indicators that are library- and geographically-independent, such as quantitative PCR assays for *Bacteroidales*, to relate presence of fecal indicator bacteria and pathogens with host-specific fecal pollution
- Meta-analysis to analyze what is known regarding the types, concentrations, and loadings of waterborne pathogen and indicator organisms in recreational waters
- Laboratory and field studies designed to provide important supplemental data on pathogen and indicator organisms

Field Sampling

Spiked surrogates!

100-L water sample

Hollow Fiber Ultrafiltration

Pathogen analysis by culture-based and microscopy methods

Pathogen and *Bacteroidales* analysis by qPCR

It is important that sampling be representative of conditions during which recreation occurs.

Animal Source Loadings

We will prioritize fecal sampling efforts based on

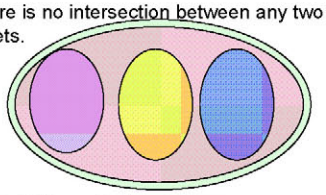
- 1) animal species deemed most likely to contribute significantly to the watershed fecal load, and
- 2) animal species for which there is the least information available in the current literature.

Phase 2

- Apply a probabilistic model to microbial source identifiers such as fecal *Bacteroidales*, whereby the prevalence of gene copies of a specific genetic marker is used to predict true concentrations of host-specific fecal markers, and estimate animal-specific fecal loads into recreational waters.
- Choose QMRA approaches for use in a variety of resource management settings.

Microbial source tracking: ideal qPCR assays

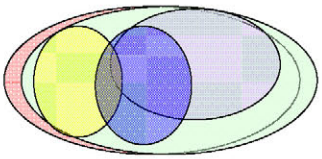
- Each primer set will detect ALL the *Bacteroidales* specifically from its corresponding host. It will NOT detect any DNA from other hosts.
- Thus there is no intersection between any two specific primer sets.



All theoretical Bacteroidales
human assay
universal fecal Bac assay
cow assay
dog assay

In reality

- In reality, the primer sets are not absolutely specific. For example, the human assay will not only detect most of *Bacteroidales* cells from human, but also a few from other hosts.



All theoretical Bacteroidales
human assay
universal assay
cow assay
dog assay

Therefore,

- it is important to account for the inherent uncertainty associated with any source tracking assay.
- qPCR assays yield quantitative data → needs quantitative conditional probability analysis to account for measurement errors and other uncertainties

(Dan Wang, UC Davis)

Concept behind the Model: Law of Total Probabilities

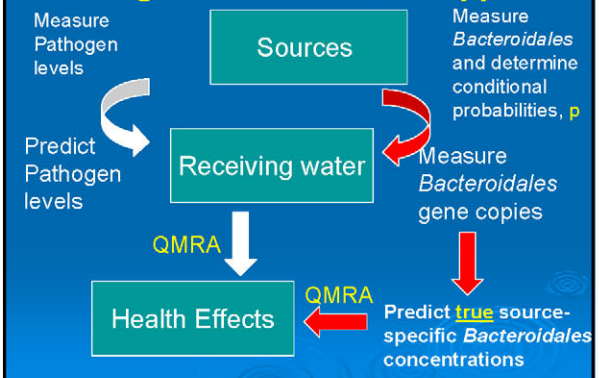
Measured genetic marker concentration by human specific assay

= DNA originating from human source and amplified by human-specific assay
+ DNA originating from cow source and amplified by human-specific assay
+ DNA originating from dog source and amplified by human-specific assay
+ DNA originating from other sources and amplified by human-specific assay
+ measurement error

Output of model

- We can estimate the distribution of probability *p* and error *e* using individual fecal samples from specific hosts.
- With *p* and *e*, we can predict the true value of the concentration of a gene marker with a confidence interval.
- This predicted value can be used in further analysis, like input into TMDL models or to inform QMRA

Envisaged 2-tiered QMRA approach



QMRA

- Focus on influent/effluent as inputs, *not* receiving water
- Use distributions of environmental (model) results to aid characterize **variability** of exposure
- Use published dose-response relationships—with caution
  - *must* understand what "dose" means!
- Characterize **uncertainty** in dose-response
  - may increase risk estimates
- Outputs
  - risk profile
  - averaged risk
- One size does *not* fit all

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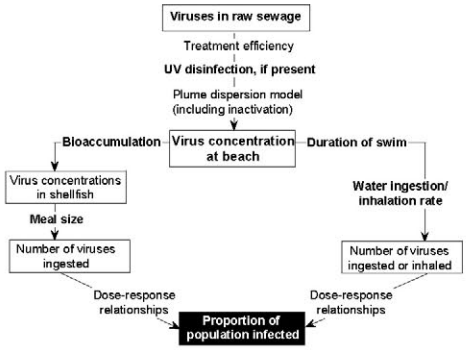
Calculation sequence—Christchurch



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Example results: Christchurch

South New Brighton

RAW SHELLFISH CONSUMPTION: NORMAL NONCONSERVATIVE ROTAVIRUS

	Summer				Winter			
	2 km		3 km		2 km		3 km	
	no UV	UV	no UV	UV	no UV	UV	no UV	UV
Min	0	0	0	0	0	0	0	0
50%ile	0	0	0	0	0	0	0	0
90%ile	0	0	0	0	0	0	0	0
95%ile	0	0	0	0	1	0	0	0
98%ile	0	0	0	0	4	1	2	1
99%ile	0	0	0	0	6	2	3	1
99.8%ile	1	1	0	0	15	6	7	3
Max	2	1	0	0	16	7	8	4
IIR(%)	0.0005	0.0002	0.0000	0.0000	0.0244	0.0052	0.0089	0.0032

Integers are cases per 1000 exposures

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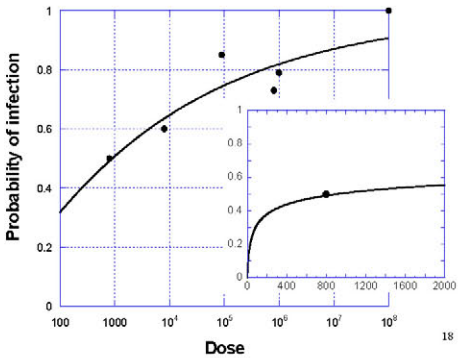
Dose-response—*Campylobacter*



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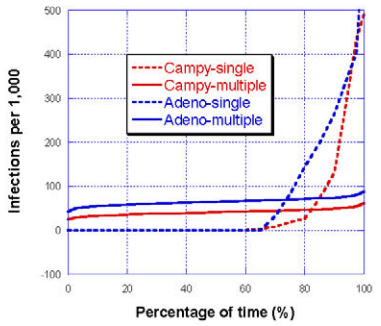
Calculated infection risks

(Till *et al.*, 2008, *J. Water & Health* **6**(4): 443-460; www.mfe.govt.nz/publications/water/microbiological-quality-jun03/)



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The challenge

- How to associate **pathogen risk profiles** with **FIB criteria**?
  - use the *profiles of risk* versus *profiles of FIB concentrations*?
- How to differentiate risks from animal versus human fecal material? (and **feral animals & birds** versus **farmed animals**?)

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Acknowledgements

Funding:

- Water Environment Federation (WERF)

Discussion slides

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Model Calibration: Estimation of Parameters: Probability p

The conditional probability p and measurement error e are estimated by using individual fecal samples.

p(h/H) = conditional probability that DNA is amplified by human assay given that it is human derived

$= \frac{C(h)}{C(H)} = \frac{C(h)}{C(u)}$ for individual human fecal sample

= measured q-PCR ratio of human assay over universal assay

Similarly, we can estimate p(d/H), p(c/H), and p(o/H) =1-p(h/H)-p(d/H)-p(c/H)

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Quantitative Microbial Risk Assessment: A Primer and Potential Applications for Nationally Applicable Water Quality Criteria

Presenter: Jeffrey Soller
Soller Environmental

Authors: Jeffrey Soller, Nicolas Ashbolt

Abstract

Recreational water quality criteria in the United States and many countries worldwide are based on the results of epidemiologic studies. Epidemiological investigations are particularly valuable in this regard because the observed results provide quantitative linkages between water quality as measured by bacterial indicators of fecal contamination (e.g., *E. coli*, enterococci) and adverse health effects in individuals who are exposed to pathogens in fecally contaminated waters. However, there exist many combinations of waterbody types and fecal pollution sources for which epidemiological data is lacking and the scientific justification to extrapolate existing epidemiological results beyond the types of waters and fecal pollution sources investigated is not well developed. One complementary approach to epidemiology that has been suggested for understanding risks associated with water contact recreation is Quantitative Microbial Risk Assessment (QMRA). QMRA is a process that is used to evaluate the likelihood of adverse human health effects from estimated doses of specific pathogens, modeled or measured at the point(s) of exposure. This presentation will provide an overview of QMRA, summarize the processes used to conduct QMRA investigations, discuss the limitations of QMRA, and describe several possible ways that QMRA could be useful within the context of developing new or revised water quality criteria in the United States and/or implementing new or revised criteria.

Biosketch

Mr. Soller is an environmental scientist with more than 14 years of water quality experience. He is the Principal Scientist at Soller Environmental, LLC where his work focuses on conducting analysis and providing insight to facilitate local, state, and federal regulatory decision making at the interface of science and environmental policy related to waterborne contamination. Mr. Soller is the author of 17 peer-reviewed papers and over 75 technical reports. Mr. Soller holds an M.S. in Operations Research from the University of CA, at Berkeley, and a B.S. in Chemistry and Mathematics from Carnegie Mellon University. He is a member and former Science Policy Fellow of the American Association for the Advancement of Science.

Quantitative Microbial Risk Assessment: A Primer and Potential Applications for Water Quality Criteria and Standards

Jeffrey Soller
Soller Environmental, Berkeley, CA

National Beaches Conference
Huntington Beach CA
April 20-22, 2009

Outline

- Provide a review of QMRA
  - Components
  - Process
  - Summarize state of the science and limitations
- Summarize motivation for using QMRA in water quality criteria / standard context
- Offer perspectives on how QMRA could provide flexibility in water quality standards
- Answer questions

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What is QMRA and why use it?

- (Q)MRA: A science-based, formal process to estimate human health risks from exposures to microbial pathogens
- Epidemiology can not always provide sufficient sensitivity to measure risks directly using human health data
  - Recreational waters impacted by low occurrence, high severity pathogens
- To predict relative risks for future scenarios and/or evaluate benefits of alternative management actions (treatment, mitigation, BMPs)
- To complement available epidemiologic database
  - Many possible permutations of sources of contamination and water characteristics: not practical to consider all via epidemiology

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Considerations for framing an assessment

- Which pathogen(s) (*hazard identification*)?
- How many pathogens are individuals or populations exposed to (*exposure assessment)* and from what scenarios (hazardous events)?
- What are the adverse health effects of interest?
- What is the relation between exposure and health effects (*dose-response evaluation*)?
- How does variability (temporal, spatial, inherent) and/or uncertainty impact our understanding or interpretation of risk?
- Do properties that are unique to microorganisms or infectious diseases such as person-person transmission and/or immunity need to be accounted for?
- What methods are appropriate / needed to characterize risk?

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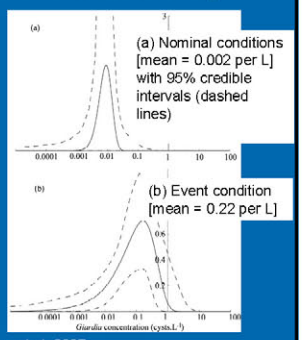
Representative data used in QMRA: Exposure assessment (*Giardia* concentration)

Count	Analysed Vol (L)
0	137.5
3	125
2	125
2	125
0	125
0	125
1	122.25
Count	**Analysed Vol (L)**
8	16.25
9	9.25
8	65
7	67.5
9	92.5
1	110
3	130.75
4	134
5	105
2	76.25

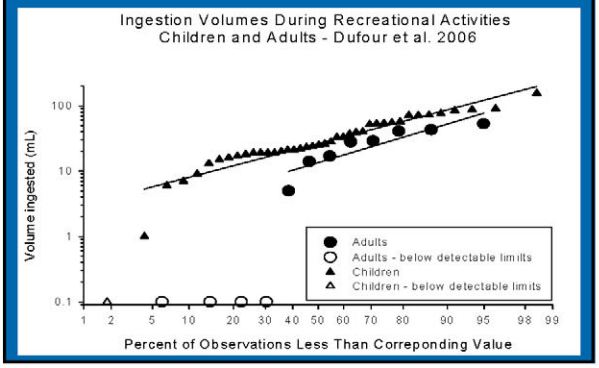
Nominal data

Event affected data

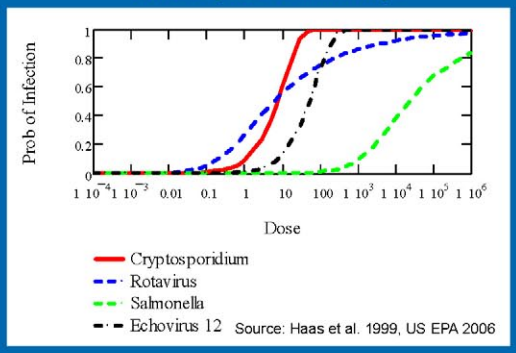


Source: Petterson et al. 2007

Representative data used in QMRA: Volume of water ingested during recreation



Representative Data used in QMRA Dose-response relationships



Overview of QMRA: State of the science – current research focus

- Person-person transmission
- Inter-dependent exposure pathways
- Differential susceptibility in population
- "Super-spread" events
- Geographical and temporal variability
- Characterizing uncertainties
- *Cryptosporidium*, *E. coli* O157 and noroviruses
- Emerging, reemerging and zoonotic pathogens
- Pathogens with low occurrence but high severity

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Overview of QMRA: Limitations

- Pathogen specific (epidemiologic studies generally focus on broad spectrum disease)
- Easiest to conduct and clearest to interpret when comparing relative risk of two or more scenarios
- Characterizing exposure is difficult: uncertainty and variability
- Dose-response relations are needed, limited availability
- QMRAs are numerical simulation studies: best when anchored to observable data
- Subjectivity in model and parameter selection
- Differential susceptibility is important and little quantitative information is available

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Motivation for using QMRA in water quality criteria / standard context

- Water quality criteria (federal), standards (State), and regulatory values and non regulatory guidelines worldwide have traditionally been primarily based on epidemiologic data
- 1986 Nationally recommended water quality criteria
  - Accounted for two water types (fresh waters, marine waters)
  - Employed health protective assumption that all fecal sources are equivalent to POTW effluent in terms of risk to public health
  - Issues from stakeholders (perceived or real): "Criteria are not appropriate in my watershed / state because…."
    - → Different fecal indicator sources (birds, animals, urban runoff, sand, etc.)
    - → Different water types or conditions (tropical, flowing/inland waters, environmental strains of indicator organisms, etc.)

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Motivation for using QMRA in water quality criteria / standard context

- What happened?
  - Resistance to implement and delayed implementation
    - → Some cases > 20 years
    - → Other cases TC, FC still in standards
- Potential solution: provide flexibility (off-ramps) in standards to address issues / perceived issues
- QMRA recommended in Airlie House report as one promising approach

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What has been suggested for AWQC?

- Types of water of interest
  - Fresh vs. Marine
  - Temperate vs. Subtropical vs. Tropical
  - Non-flowing vs. Flowing (Inland vs. Coastal)
- Sources of contamination of interest
  - Untreated or poorly treated human: sewage
  - Untreated human: bathers
  - POTW effluent impacted
  - Urban runoff
  - Combination of urban runoff / animals
  - Agricultural: Cattle (grazing)
  - Agricultural: CAFOs/AFOs (including but not limited to feedlot/dairy cattle, swine and poultry)
  - Wildlife (apart from avian)
  - Birds

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What epidemiologic data are available or are likely to be available?

Is it likely there will be epidemiologic data to evaluate risks associated with these sources

Source	Freshwater	Marine	Tropical or Inland
Human - POTW	Epi	Epi	Epi
Human - poorly / untreated	-	Epi	?
Urban runoff	?	Epi	-
Urban runoff/wildlife	-	?	-
Cattle	-	NA	-
Swine	-	NA	-
Poultry	-	NA	-
Gulls/birds	-	Epi	-

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Insufficient epidemiologic data to address all suggestions

- Research question: Which of the various sources of fecal contamination (rows in table) and/or water types (columns in table) are "different from each other" in terms of health risk?
- Working hypothesis: At a given level of an appropriate indicator organism, the risk to humans is less if a waterbody is impacted by a non-human source as compared to a human source.

Role for QMRA in water quality standards

- It is not practical to conduct epidemiologic studies in all water type / source combinations
- QMRA is a complimentary technical approach that could be used to fill epidemiologic holes
  - Scientifically defensible
  - Technical basis for infectious disease modeling is strong and well documented in literature
    - Quantitative methods to characterize the human health risks associated with exposure to pathogens published since 1970s
    - QMRA is a growing field in scientific literature
  - Consistent metric (health protection)

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Considerations for QMRA in water quality standards

- QMRA would need to be fecal source dependent
  - Sentinel pathogens will vary depending on whether the source is human or non-human
- To gain broad acceptance, QMRA models and tools should be linked or "anchored" to the available epidemiologic data

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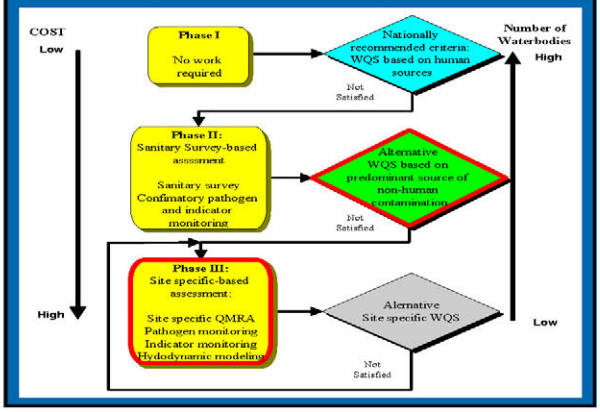
Concept for QMRA use in Water Quality Standards



Issues that need to be addressed

- To what extent will flexibility be provided for hazardous events (rainfall) and how to capture in QMRA?
- Need appropriate microbial indicator for each source of interest
- Need linkage(s) between indicators (that we measure) and pathogens (that cause illness)
- Need to understand uncertainty in epidemiologic-based relations between water quality and health to ensure QMRA can provide similar precision

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Final thoughts

- QMRA is a well developed, scientifically accepted tool that could be useful to fill holes where no epidemiological data exist, until new epidemiological data are developed, and/or where epidemiological studies may not be practical or appropriate
- QMRA could provide substantial flexibility in water quality standard setting
- Numerous issues still need to be resolved in the short term for QMRA to be practical for water quality standard implementation

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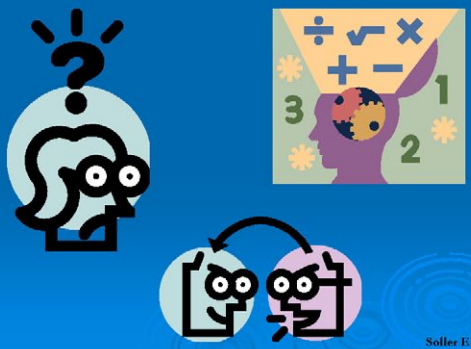
Questions / Comments



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EPA Update on Recreational Criteria Development Efforts

Denise Keehner
USEPA OST

Biosketch

Denise Keehner is the Director of the Standards and Health Protection Division in the Office of Science and Technology in the Office of Water. The division she manages in the Headquarters Office is responsible for the Water Quality Standards Program, the Beach Program, and, the Fish Advisory Program. Denise has been in this position since May 2003. Prior to her joining the Office of Water, Denise was the Director of the Biological and Economic Analysis Division (BEAD) in the Office of Pesticide Programs (OPP) and the acting Director of the Environmental Fate and Effects Division in OPP. She has been with U.S. EPA at Headquarters for 26 years and has served in management positions since 1985.

EPA Objectives and Status on Recreational Criteria Activities

National Beach Conference
Huntington Beach CA
April 21, 2009

Denise Keehner, Director
Standards & Health Protection Division
Office of Science and Technology/Office of Water
US EPA

EPA's Objective

- New recreational water criteria for all waters by 2012
  - Including freshwater rivers, streams and lakes
- Why?
  - 2012 is Consent Decree deadline
  - BEACH Act requires new criteria for coastal rec waters
  - Incorporate new science—over 20 long years since 1986 criteria; CWA requires updates "from time to time"
  - Improve scientific foundation and implementation based on what we've learned over the past 20 plus years
  - Ease implementation for BEACH Act states: no double standards
  - Makes providing protection for downstream rec waters easier

2

EPA's Major Research Areas per Critical Path Science Plan

- Epidemiology Studies and Quantitative Microbial Risk Assessment (QMRA)
- Site Characterization: Sanitary Surveys
- Indicators/Methods Development and Validation
- Modeling
- Addressing Application to:
  - >Coastal (marine) waters
  - >Great Lakes
  - > Inland Waters- rivers, streams, lakes

3

EPA Epi Studies So Far

- 2002-2004 Freshwater National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water Studies at four Great Lakes Beaches
  - Indicators/Methods studied: Enterococci (qPCR and culture), *Bacteroides* (qPCR), chemical indicators
- 2005 Marine NEEAR Study in Biloxi, MS (interrupted study)
  - Indicators/Methods studied: Enterococi (qPCR and culture), *Bacteroides* (qPCR), chemical indicators
- 2007 Marine NEEAR Studies in Goddard, RI and Fairhope, AL
  - Indicators/Methods studied: Enterococci (qPCR and culture), *Bacteroides*, total and human-specific (qPCR), *E.coli* (qPCR), *Clostridium* spp. (qPCR), coliphage (antibody assay)
- Avalon Marine Epi Study 2007/2008—cooperative project with SCWWRP

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EPA-Supported Epi Studies

- 2007 and 2008 SCCWRP Studies at Avalon Beach, CA
  - Impacted by mixed sources of fecal contamination including bird droppings, urban runoff, and leaking sanitary sewers (human source)
- 2008 SCCWRP Continuation Study at Doheny Beach, CA
  - Predominately a non-human source (birds and runoff)
- Technical support for future epi studies with SCCWRP and University of PR

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EPA Epi Studies Planned for 2009

- "Urban runoff" impacted marine waters in a temperate region – Surfside Beach, SC
- POTW-impacted marine waters in a tropical region - Boquerón Beach, PR

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Urban Runoff Epi Study

- Site Selection Criteria
  - Source predominantly from urban runoff (no POTWs, no CSOs, no SSOs)
  - Minimum enterococci standard exceedance rate of 15%
  - Subject to at least one rain event/month
  - Swimming season > 90 days
  - Attendance > 300 beachgoers per weekend day
  - Beach located in a county with pop density > 100/sq mi
  - Available raw monitoring data for fecal coliform or enterococci for 2006 & 2007
  - Urban coverage for the beach watershed > 70%

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Tropical Epi Study

Site Selection Criteria

- Officially designated recreational area near large population center
- Large attendance (300 - 400 swimmers/day)
- Broad age range (children, teenagers, and adults)
- Generally meets applicable water quality standards with a range of concentrations
- Contaminated by identified human source of pollution
- Swimming season > 90 days
- Located in a tropical region as defined in the Consent Decree

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Site Selection Process

Urban runoff

- Narrowed list of potential beaches from **178** to **5** through a categorical process of elimination
- Collected site characterization data - Fall/Winter 2008
- Considered logistic and other site-specific aspects to prioritize sites

Tropical

- Evaluated potential locations in Puerto Rico, Hawaii, Guam and South Florida
- Focused efforts on finding a treated wastewater-impacted beach
  - Allows for comparison of health risks in tropical climate vs. temperate climate

Re-analyzing 2002-2004 Epi Water Quality Samples

- Re-analyze NEEAR Water Study archived samples
  - *E. coli* by qPCR
  - Revised *Bacteroides* by qPCR

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Agricultural Animal QMRA

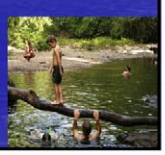
- Conduct QMRA to estimate illness at a freshwater location primarily impacted by agricultural animal sources (e.g., bovine, swine, poultry)
- Data collection – Summer 2009
- QMRA – Fall 2009

EPA Inland Waters Efforts

- Literature review to determine
  - Fate and behavior of pathogens and indicators
  - Microbial ecology and persistence
  - Indicator performance

Note: EPA/OW synchronized water skiing team→

- Analyze samples from EPA's National Rivers & Streams Survey for additional indicators by molecular methods
  - 2,200 sample locations



- Perform additional research if feasible based upon input from WERF's Inland Waters Experts Workshop

Schedule & Timing

- All research must be complete by December 15, 2010
- New/revised criteria must be finalized by October 15, 2012

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Policy/Criteria Development

- Meeting October 2012 deadline means beginning now internal EPA discussions of likely policy and science policy options
- Also means, as promised, that EPA will engage stakeholders as we move forward
  - Today's Beach Conference is part of this effort.
  - Next stakeholders meeting in September 2009

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BEACH Conference Discussions

- The ongoing research relating to recreational criteria is transforming how we view beach monitoring, notification, and assessments.
- Keep this research in mind as you imagine how your beach program might look and function, in the not-too-distant future.
- Now is the time to share your viewpoints with your peers and EPA.

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For More Information

- EPA's Rec Criteria and Beach Web Pages
  - www.epa.gov/waterscience/criteria/recreation
    - Experts Scientific Workshop Report and Executive Summary
    - Critical Path Science Plan
    - Criteria Development Plan & Schedule
  - www.epa.gov/beaches
    - BEACH Act text
    - Grants information
    - Beach Guidance Document
    - Local beach information
  - www.epa.gov/waterscience/criteria/humanhealth/microbial/#wqs
    - BEACH Act rule
      - Technical fact sheets
- LISA CHRIST
  - 202-566-8354 or christ.lisa@epa.gov

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