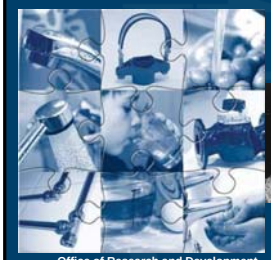
MRA Research Activities to Support Drinking Water Standards



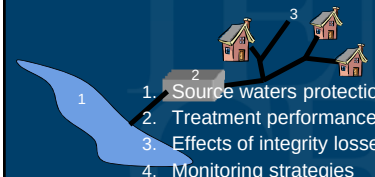
Nicholas J. Ashbolt

Bethesda North Marriott Hotel and Conference Center in Bethesda Maryland, April 8-10, 2008

Office of Research and Development
National Exposure Research Laboratory

Quantitative Microbial Risk Assessment (QMRA)

Provides information for managing safe water

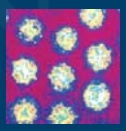


1. Source waters protection targets
2. Treatment performance needs
3. Effects of integrity losses
4. Monitoring strategies

1

QMRA *(continued)*

…and provides information for identifying/prioritizing research needs



- Contaminant sources
- Pathogens of concern
- Characterization of exposures
- Prevention approaches and control technologies

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Research steps for undertaking QMRA

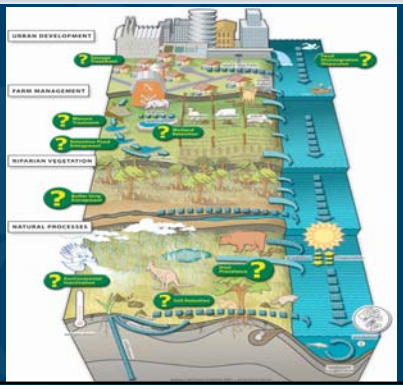
- Describe system conceptual model
  - –Including various hazardous events that could be managed and reference pathogens to study
- Compile & use existing data for a tier 1 QMRA
  - –If risk appears unacceptable and not immediately manageable, collect new data to reduce uncertainties
- Increase tier of MRA until uncertainties acceptable
- The above identifies major research gaps to be filled

3

……..for example

CONCEPTUAL MODEL OF A WATERSHED

Water and Particulates | Particulates | ? Size proportional to knowledge gap



Ferguson *et al.* (2003) J.AWWA 95:92-102

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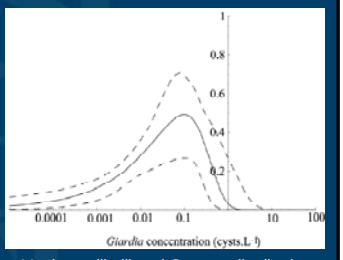
Count	Volume (L)
8	16.25
9	9.25
8	65
7	67.5
9	92.5
1	110
3	130.75
4	134
5	105
2	76.25
0	137.5
3	125
2	125
2	125
0	125
0	125
1	112.25

PDF for the *Giardia* cyst densities in raw water



Maximum likelihood Gamma distribution $\lambda = 0.41$ and $\rho = 0.24$ (solid line) and 95% Bayesian credible intervals (dashed lines) constructed from posterior MCMC samples

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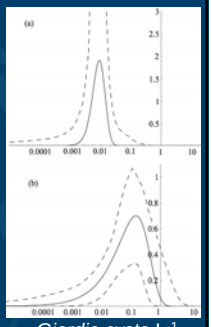
Count	Analysed Vol (L)	
0	137.5	
3	125	
2	125	Nominal data
2	125	
0	125	
0	125	
1	122.25	
Count	**Analysed Vol (L)**	
8	16.25	
9	9.25	
8	65	Event data
7	67.5	
9	92.5	
1	110	
3	130.75	
4	134	
5	105	
3	76.25	

PDFs for variability & uncertainty in *Giardia*

(a) Nominal conditions [λ = 0.002 ρ = 4.48]

(b) Event conditions [λ = 0.22, ρ = 0.72]



Giardia cysts.L^{-1}

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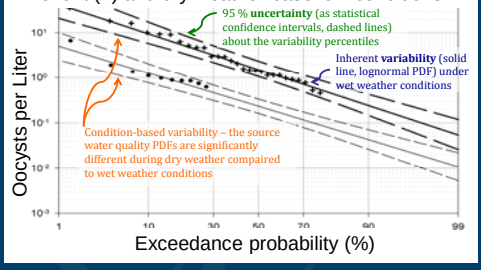
Variability & Uncertainty in watershed *Cryptosporidium* densities

Cryptosporidium (oocysts/L) in a river during rainfall event (+) and dry weather baseflow conditions



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Now that was the straight forward part!

- In full-scale treatment works and distribution, pathogen densities of concern are below current detection limits
  - –e.g. < 1 enteric virus per million Liters ≅ 10^{-4} risk
- Hence, surrogates are used to validate treatment performance and integrity of drinking waters
  - –E.g. particle-size (1-20μm) removal, C.t disinfectant
- But there is added uncertainty in extrapolating from surrogate to pathogen behavior

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Research needs at treatment

- Very frequent sampling is required to identify events of concern at treatment works
- It is simply not possible to sample sufficient volumes of finished water for microbes
- Hence, we are reliant upon on-line instrumentation to provide action levels
  - –QMRA can provide information to support the setting of action levels

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Monitoring required to verify at the 95% confidence level that failure events do not significantly add to risk when compared to nominal treatment performance

Nominal $\log_{10}$ reduction	#/year	Monitoring interval
0.05	1	1 year
1	30	1 week
2	300	1 day
3	3,000	3 hours
4	30,000	15 min
5	300,000	2 min
6	3,000,000	10 sec
7	30,000,000	1 sec

i.e. a 100,000 m³/d plant treatment with a disinfection system designed for 7 log inactivation of viruses, must monitored every 3 liters to be 95% confident that all water was sufficiently treated

Smeets (2008)

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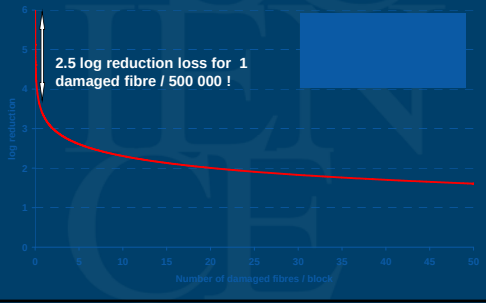
Impact of a single fibre break in Ultra-Filtration treatment

Performance of UF blocks *vs* number of damaged fibres

Source: USEPA (2005) Membrane Filtration Guidance Manual. EPA 815-R-06-009



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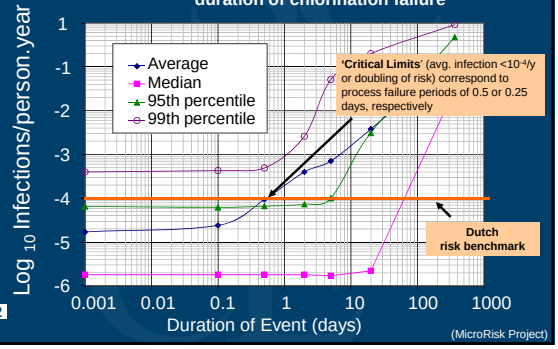
Short-Term Events are Important

***Campylobacter* annualized infection risk vs duration of chlorination failure**



(MicroRisk Project)

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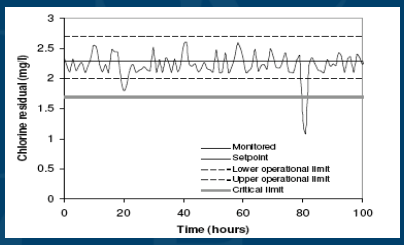
Simulated example of critical limits, operational limits, set-points and monitoring chlorine disinfection



At 80 hours the operator needed to take corrective actions, such as starting emergency chlorination of the distributed water, in order to achieve the health-based target over the total period

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Research needs for distribution

- How to interpret *E. coli* detects?
- Develop better means to identify the frequency and duration of 'intrusion' events, and to sample associated pathogens
- Understand the occurrence of biofilms & amoeba that promote opportunistic pathogen densities of concern
  - E.g. growth of human-infectious *Mycobacterium* & *Legionella* strains

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Public Health implications of Coliforms in distribution systems

- Various coliforms grow in pipe biofilms
  - Incl. *Citrobacter*, *Enterobacter*, *Klebsiella* species
  - Latter include fecal coliform members
  - Hence importance of using *E. coli* as the fecal indicator in follow-ups
- Of the 3-8% of systems that have MCL non-acute (TC) violations, only 10% have acute violations (*E. coli* present in ~0.5% of Total Coliform Rule samples)

Need to be able to separate growth from an intrusion event …

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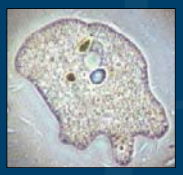
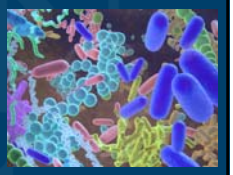
Biofilm pathogen research

Biofilms sequester fecal pathogens and allow the growth of opportunistic pathogens





Biofilm-like sampling device

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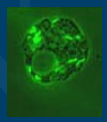
Opportunistic Pathogens

(continued)

- Various *Legionella* strains
- *Mycobacterium avium, M. ulcerans*
- *Burkholderia pseudomallei*
- *Helicobacter pylori*
- *Campylobacter* spp.
- *Afipia, Bosea* & *Criblamydia* spp.

- **All grow associated with amoeba in biofilms and may be active but non-culturable**

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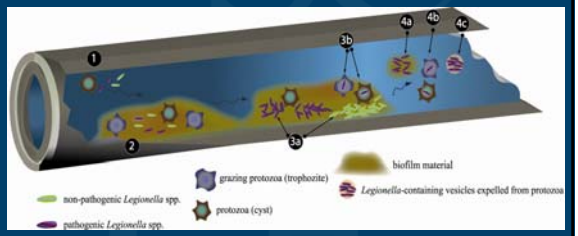
Conceptual model of *Legionella* in piped water (Lau & Ashbolt)



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SO TO SUMMARIZE THE PROCESS

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Typical QMRA Drinking Water Model

STEP 1

Problem Formulation & Hazard Identification
Describe physical system, selection of reference pathogens and identification of hazardous events

STEP 2

Source water
Pathogen concentration

Treatment
Pathogen removal

Ingress
Pathogen intrusion

Distribution
Pathogen die-off ?

Exposure
Water consumption, inhalation

STEP 3

Dose-Response
Selection of appropriate models for each pathogen and the population exposed

STEP 4

Risk Characterization
Simulations for each pathogen (baseline and events): Estimation of risks, variability and uncertainty

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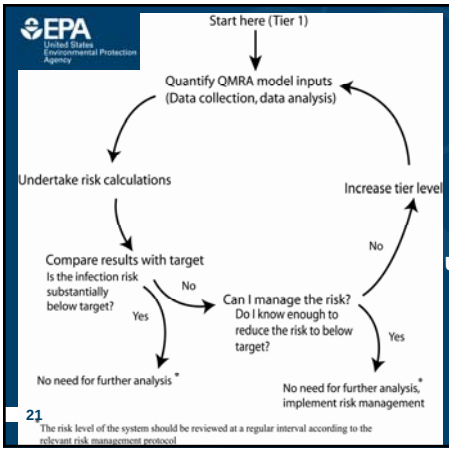

Iterative tiered approach for undertaking QMRA

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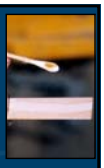
EPA Research Goals for Biofilms



- Identify the possible significance/occurrence of *Legionella* and novel pathogens in distribution biofilms
  - –Specific focus on virulence up-regulation in *Legionella* associated with biofilm/amoeba growth, and
  - –Sampling pathogens with a biofilm-like device
- Role of ABNC cells in biofilms using animal dose-response models and disinfection efficacy studies
- Add biofilm/pathogen issues to EPA-Net model and provide missing key QMRA data inputs for piped water

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Acknowledgment

Special thanks to the many international colleagues who have worked with me on distribution system microbiology and EPA post doctorate, Dr. Helen Lau

Disclaimer: This presentation does not necessarily reflect official Agency policy

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