Metropolitan Water Reclamation District of Greater Chicago

Welcome to the June Edition
of the 2024
M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

- Remote attendees' audio lines have been muted to minimize background noise.
  For attendees in the auditorium, please silence your phones.
- A question and answer (Q/A) session will follow the presentation.
- For remote attendees, please use "**Chat**" only to type questions for the presenter. For other issues, please email Pam to SlabyP@mwrd.org.
  For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question.
- The presentation slides will be posted on the MWRD website after the seminar.
- This seminar has been approved by the ISPE for one PDH and is pending approval by the IEPA for one TCH. Certificates will be issued only to participants who attend the entire presentation.

Charles N. Haas
L.D. Betz Professor of Environmental Engineering
Drexel University

Charles N. Haas is the L.D. Betz Professor of Environmental Engineering, at Drexel University, where he has been since 1991. He was also Head of the Department of Civil, Architectural and Environmental Engineering from 2004-2020. He received his BS (Biology) and MS (Environmental Engineering) from the Illinois Institute of Technology and his PhD in Environmental Engineering from the University of Illinois at Urbana- Champaign. He has served on the faculties of Rensselaer Polytechnic Institute and the Illinois Institute of Technology prior to joining Drexel. He co-directed the USEPA/DHS University Cooperative Center of Excellence – Center for Advancing Microbial Risk Assessment (CAMRA). He is a distinguished fellow of the **IWA**, and a fellow of the American Academy for the Advancement of Science, the Society for Risk Analysis, the **ASCE**, the American Academy of Microbiology, and the **AEESP**. He is a Board Certified Environmental Engineering Member by eminence of the **AAEES**. In 2021, he was elected to the National Academy of Engineering. Over his career, Professor Haas has specialized in the assessment of risk from and control of human exposure to pathogenic microorganisms, and in particular the treatment of water and wastewater to minimize microbial risk to human health.

Environmental Pathogen Engineering

Seminar - Metropolitan Water Reclamation District of Greater Chicago

Charles N. Haas

L.D. Betz Professor of Environmental Engineering
Drexel University

June 28 2024

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Aside

At many times in my career, my research has been motivated by MWRGC issues. Many notables to thank, including:

- Cecil Lue-Hing
- Richard Lanyon
- Prakasam Tata
- Tom Granato
- Jim Bertucci

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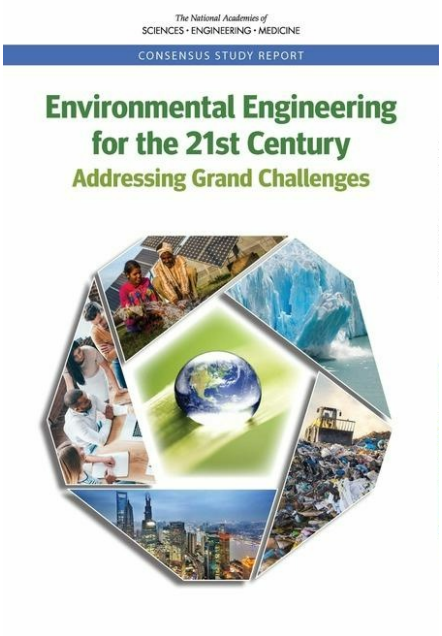
What is Environmental Engineering?



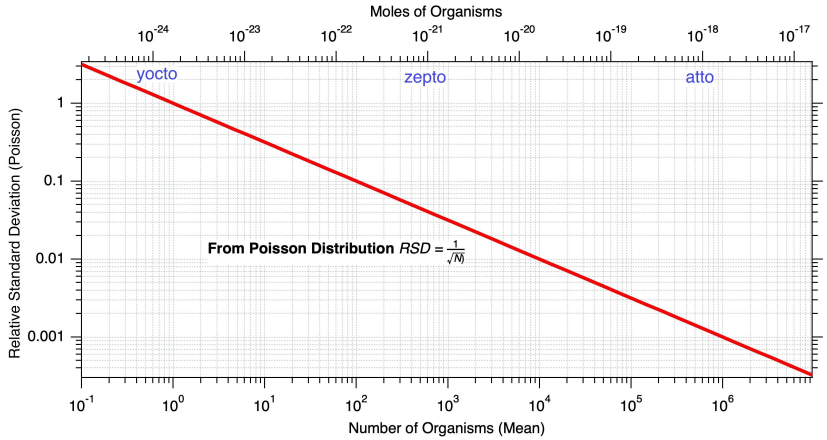
"The discipline of environmental engineering has no single, widely agreed-upon definition."

"The design of systems, processes and policies to reduce human impact on the ecosystem and to provide healthful air, water and land for people and the ecosystem"

What is Environmental Pathogen Engineering

"The design of systems, processes and policies to reduce human impact **of pathogens** on the ecosystem and to provide healthful **(with respect to pathogens)** air, water and land for people and the ecosystem"

Why?



1. We are concerned about exposure to small numbers of pathogens even in a single short interval (will return to this point)
2. Much lower on a "mole" basis than any chemical contaminants of interest
3. Pure stochastic variability becomes important
   - Superimpose upon this - analytical variability, intrinsic variability from sources and transport ...

So probabilistic thinking becomes essential!

Other Differences Between Pathogens and Chemicals

- The amount exposed from the environment is amplified *in vivo* by multiplication (in competition with host responses) to a larger body burden.
- For some pathogens, excretion or exhalation can result in more organisms in the environment, and secondary cases (contagion). **People can be both sources and receptors**.
- Adverse effects can result from a single exposure, so we must consider short term variability rather than relying on averaging.
- Host responses may mitigate or exacerbate effects.
- Analytical methods are often more difficult and tedious (this is changing).

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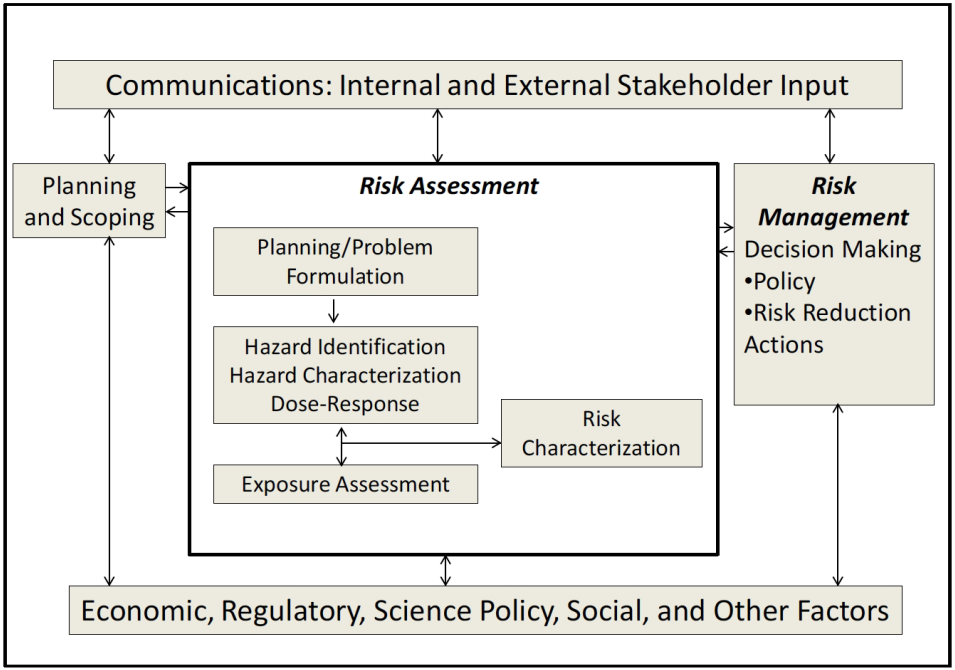
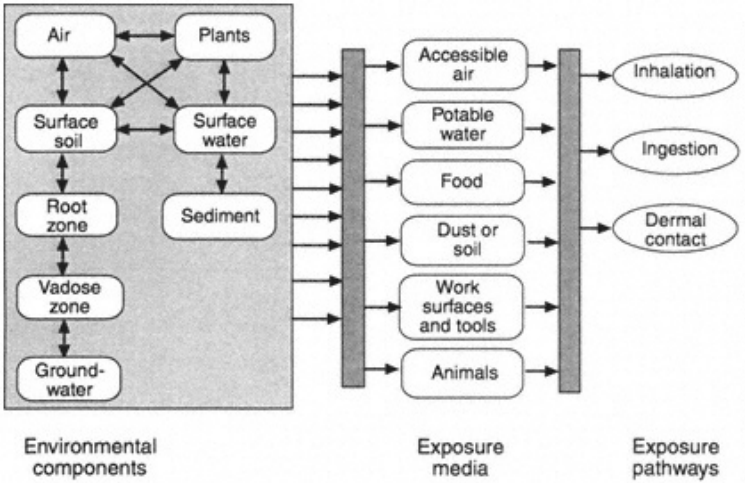
Risk Assessment Framework



National Research Council (NRC) (2009). Science and Decisions: Advancing Risk Assessment. Washington, DC: National Academies Press.

Exposure Assessment: Source-Transport-Receptor Paradigm

Generic Approach



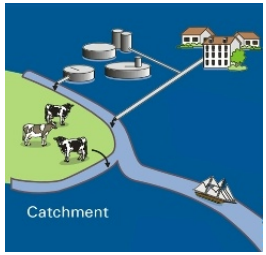
Eisenberg, J.N.S., and T.E. McKone. 1998.
Environmental Science and Technology 32: 3396–3404.

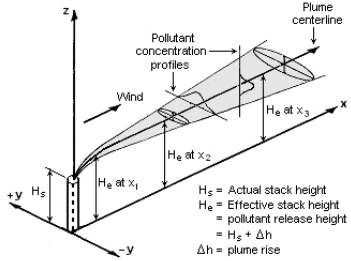
For EnvPE

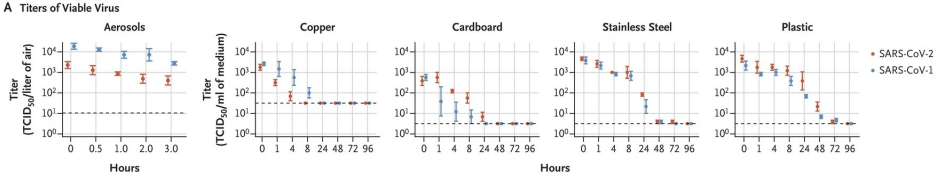
- People as sources
- Indoor environment
- Fomites

What we need to know

- What is the source strength/duration/frequency?
- How does it get transported to the receptor (and portal of entry)?
- How does it get attenuated (or amplified) in transport?







Design, and Reliability of Interventions

A First Order Approach

If Exposure/Risk is Not Acceptable:

"multiple barriers" (first use, Velz, 1970)

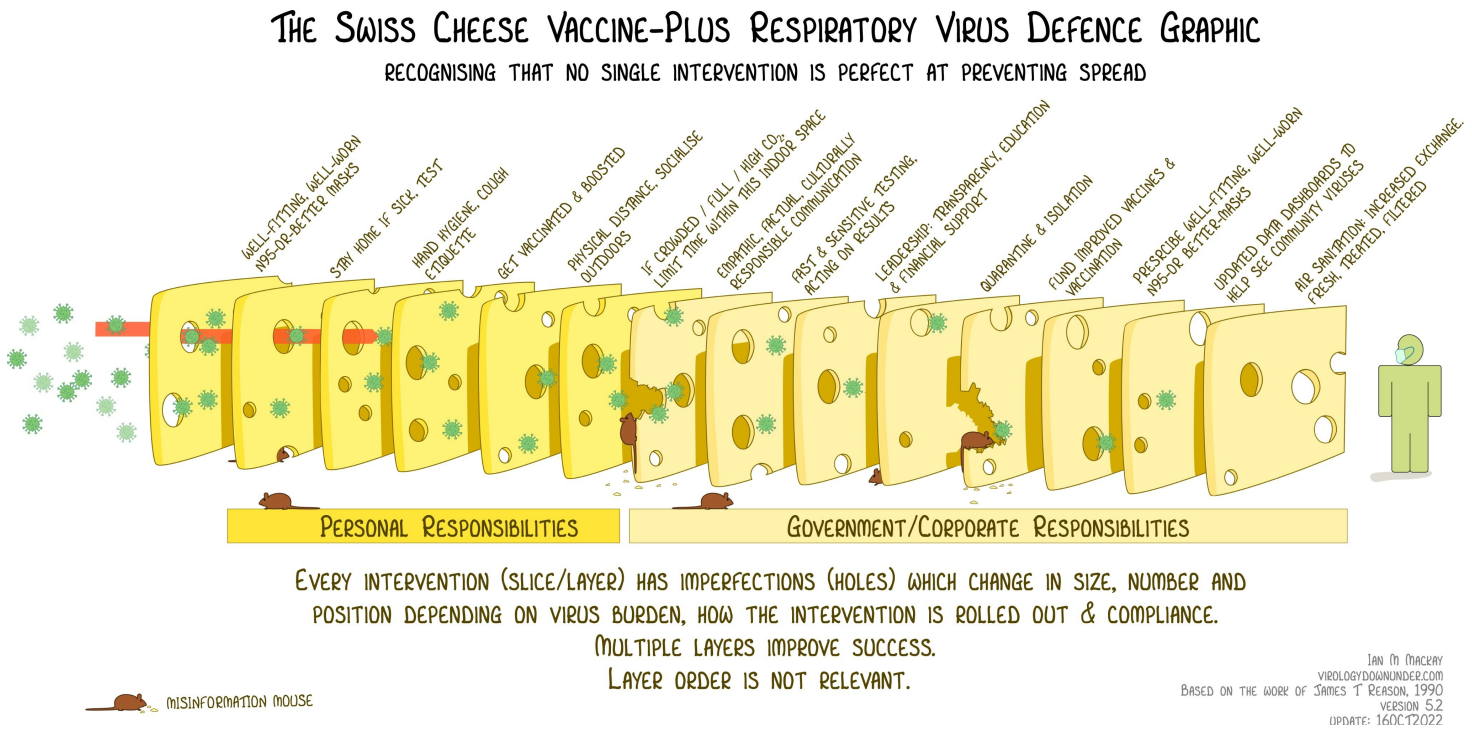
Table 1. Computation of reliability using redundant process approach

	Virus	Giardia	Cryptosporidium
Secondary Effluent (#/L)	10	100	10
Treatment Goal (#/L)	4.50E-07	1.40E-05	6.50E-05
Safety Factor	10	10	100
Required Logs Removal	8.35	7.85	7.19
SEQUENCE 1			
Lime Treatment	1	2	0
Recarbonation	0	0	0
Sedimentation-Filtration	1	1.5	1
Granular Activated Carbon	1	0.3	0.3
Advanced Chemical Oxidation	6	3	1.5
UV Disinfection	3	1	1
Chlorination	5	2	0.2
Logs Removal-Total	17	9.8	4
Logs Removal-1 Failure (*)	11	6.8	2.5
SEQUENCE 2			
Microfiltration	0.5	5	5
Reverse Osmosis	4	5	5
Advanced Chemical Oxidation	6	3	1.5
UV Disinfection	3	1	1
Chlorination	5	2	0.2
Logs Removal-Total	18.5	16	12.7
Logs Removal-1 Failure (*)	12.5	11	7.7

(*) assuming that the most efficient process is out of service (no removal)

Haas, Charles N., and R. Rhodes Trussell. 1998. "Frameworks for Assessing Reliability of Multiple, Independent Barriers in Potable Water Reuse." Water Science and Technology 38 (6).

Alternate Meme



Barriers from a Probabilistic Framework

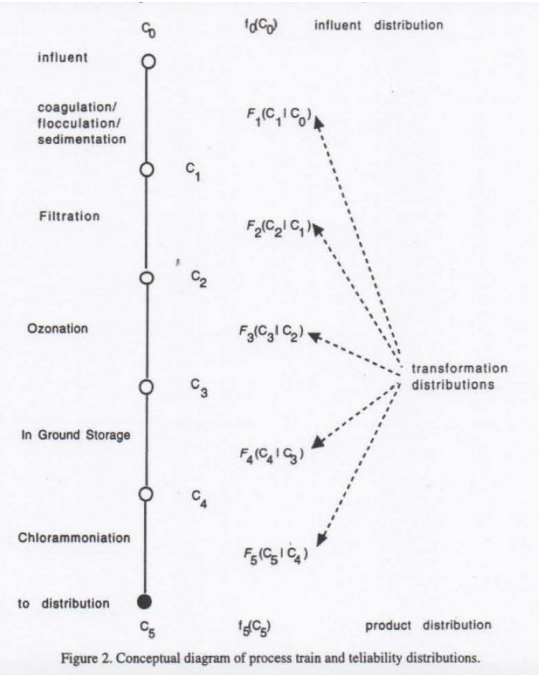


Figure 2. Conceptual diagram of process train and teliability distributions.

more about this later

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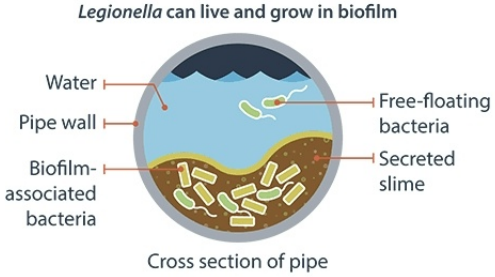
Potential for Environmental Amplification



source: CDC

Pathogens **2015**, *4*, 390-405; doi:10.3390/pathogens4020390

OPEN ACCESS

pathogens

ISSN 2076-0817

www.mdpi.com/journal/pathogens

Review

Environmental (Saprozoic) Pathogens of Engineered Water Systems: Understanding Their Ecology for Risk Assessment and Management

Nicholas J. Ashbolt

And water can be a vehicle for persistence and growth of respiratory pathogens

And Fungi Remain a Great Unknown

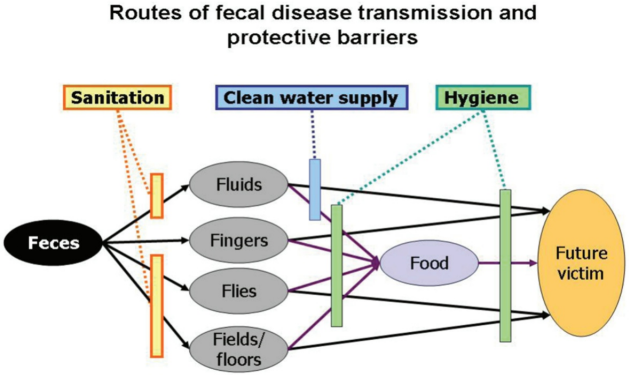
1.6 million deaths worldwide

MINI REVIEW
published: 12 February 2019
doi: 10.3389/fmicb.2019.00214

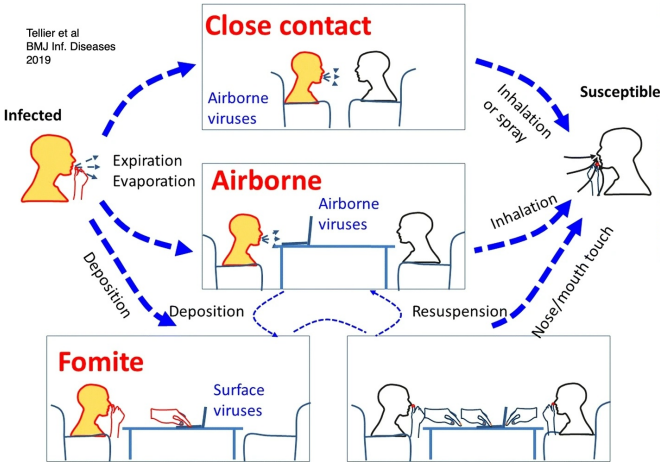
The Still Underestimated Problem of Fungal Diseases Worldwide

Fausto Almeida[1], Marcio L. Rodrigues[2,3] and Carolina Coelho[4,5]**

Infected Individuals (Humans + Animals) as Sources



(Sources: Wagner and Lanoix 1959, World Bank Group 2013)



Speaking as Aerosol Generation

International Journal of *Environmental Research and Public Health*

MDPI

Article

Aerosol Release by Healthy People during Speaking: Possible Contribution to the Transmission of SARS-CoV-2

Thomas Eiche [1,*] and Martin Kuster [2]

Received: 2 November 2020; Accepted: 3 December 2020; Published: 5 December 2020

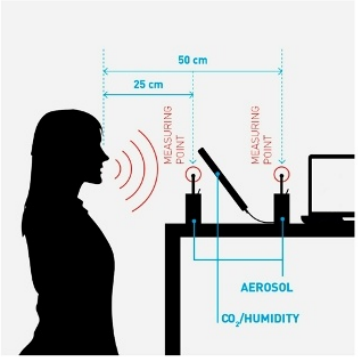


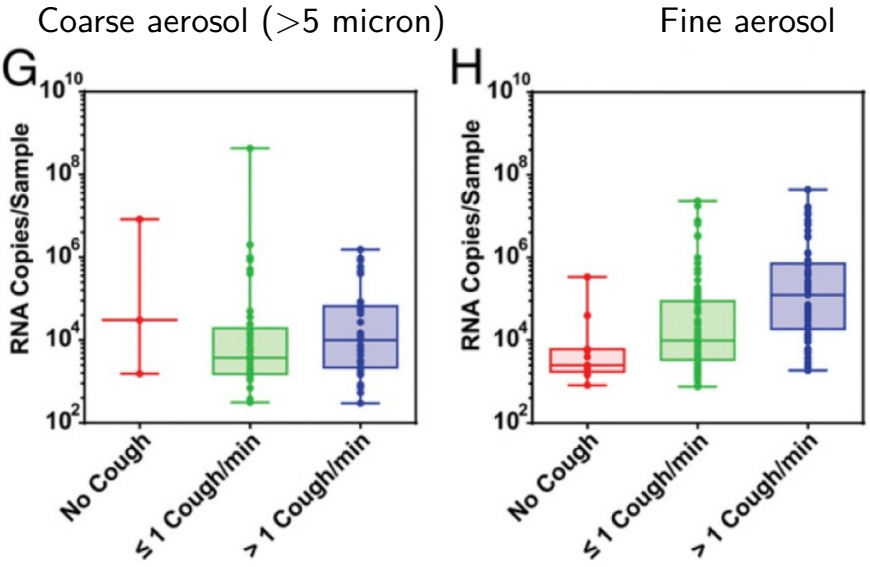
Table 4. Amount of liquid released over one hour, by activity.

Activity	Mean Concentration	Breathing Volume	Liquid Volume
Breathing	1.28 nL/m^3	0.72 m^3/h	0.92 nL/h
Speaking	1.67 nL/m^3	1.375 m^3/h	2.30 nL/h
Raised Voice	4.44 nL/m^3	1.375 m^3/h	6.11 nL/h

Occurrence of Virus in Influenza Patient Aerosols

Yan et al., 2018, PNAS, https://www.ncbi.nlm.nih.gov/pubmed/29348203

30-min sample of breath of infected volunteers recite alphabet at 5, 15, 25 min



SARS-CoV-2

VIEWPOINT: COVID-19

Reducing transmission of SARS-CoV-2

Masks and testing are necessary to combat asymptomatic spread in aerosols and droplets

By **Kimberly A. Prather[1], Chia C. Wang[2,3], Robert T. Schooley[4]**

Respiratory infections occur through the transmission of virus-containing droplets (>5 to 10 μm) and aerosols (≤5 μm) exhaled from infected individuals during breathing, speaking, coughing, and sneezing. Traditional respiratory disease control measures are designed to reduce transmission by droplets produced in the sneezes and coughs of infected individuals. However, a large proportion of the spread of coronavirus disease 2019 (COVID-19) appears to be occurring through airborne transmission of aerosols produced by asymptomatic individuals during breathing and speaking (*1*–*3*). Aerosols can accumulate, remain infectious in indoor air for hours, and be easily inhaled deep into the lungs. For society to resume, measures designed to reduce aerosol transmission must be implemented, including universal masking and regular, widespread testing to identify and isolate infected asymptomatic individuals.

Humans produce respiratory droplets ranging from 0.1 to 1000 μm. A competition between droplet size, inertia, gravity, and evaporation determines how far emitted droplets and aerosols will travel in air (*4*, *5*). Larger respiratory droplets will undergo gravitational settling faster than they evaporate, contaminating surfaces and leading to contact transmission. Smaller droplets and aerosols will evaporate faster than they can settle, are buoyant, and thus can be affected by air currents, which can transport them over longer distances. Thus, there are two

PHOTO: SERGEI FADEICHEV/TASS V... IMAGES

Models for Indoor Air Fate & Transport

- Well mixed box models
- CFD (with Lagrangian particle tracking)
- Can incorporate decay, deposition

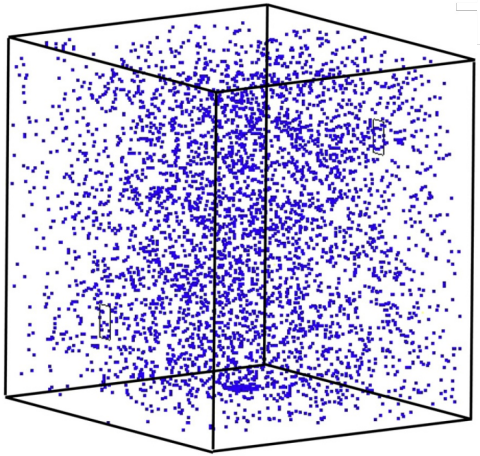


Fig. 3. Particle locations at the end of the particle tracking time, 1237 s for case 12.

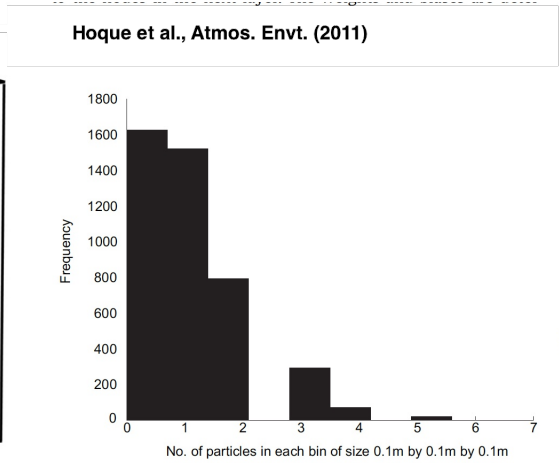


Fig. 5. Histogram showing the frequency of the number of particles when the room is broken down into small bins of size (0.1 m × 0.1 m × 0.1 m) at the end of case 12.

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Evolution in Sophistication of Dose Response Models

Haas, Charles N. 2015. "Microbial Dose Response Modeling: Past, Present, and Future." Environmental Science & Technology 49 (February): 1245–59. ********doi.org/10.1021/es504422q.

0^{th} **Generation** ~~Minimal Infectious Dose~~

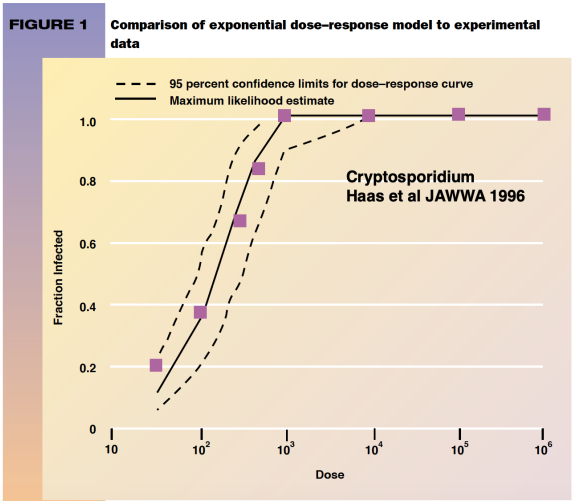
1^{st} **Generation** **E.g. exponential, beta-Poisson** Wells-Riley

2^{nd} **Generation** Phenomenological modifications for host or dose characteristics

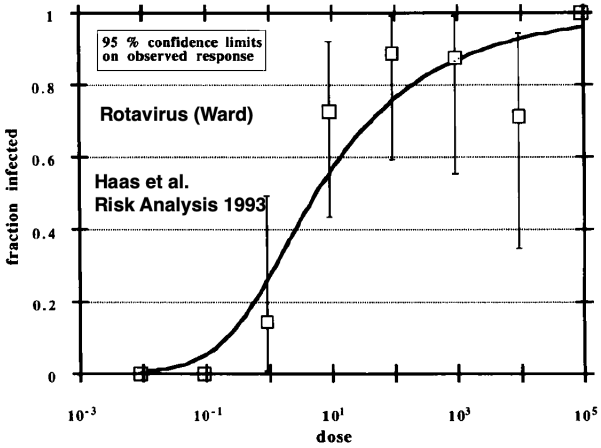
3^{rd} **Generation** Phenomenological incorporation of incubation time

Beyond Mechanistic incorporation of details of host-pathogen interactions

First Generation Models



Exponential: $p = 1 - exp(-k \cdot d)$



Approximate beta-Poisson:

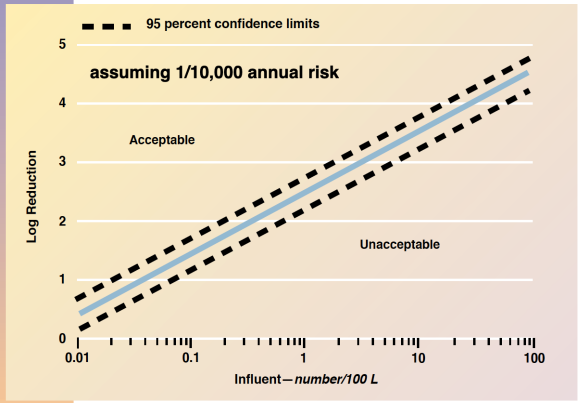
$$p = 1 - \left[1 + \frac{N}{N_{50}}\left(2^{1/\alpha} - 1\right)\right]^{-\alpha}$$

- metric is average dose
- low dose linearity
- no threshold

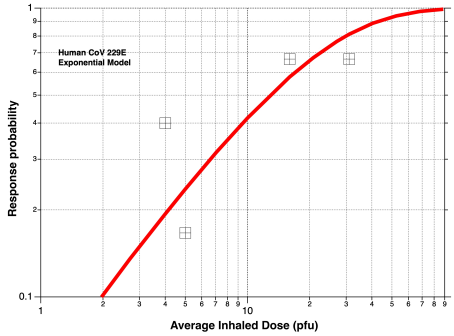
How Clean is Safe?

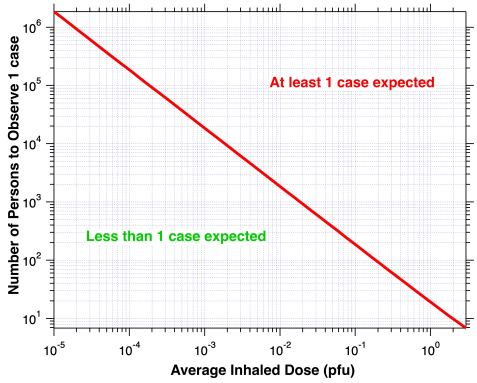
Cryptosporidium

FIGURE 4 **Relationship of influent *Cryptosporidium* concentration and logreduction by treatment necessary to produce acceptable water**



HCoV 229E





We do know potency of SARS-CoV-2

Though need data on strain variations

- Haas, Charles N. 2021. "Action Levels for SARS-CoV-2 in Air: Preliminary Approach." Risk Analysis n/a (n/a). ********doi.org/10.1111/risa.13728.
- Parhizkar, Hooman, Kevin G. Van Den Wymelenberg, Charles N. Haas, and Richard L. Corsi. 2022. "A Quantitative Risk Estimation Platform for Indoor Aerosol Transmission of COVID-19." Risk Analysis 42 (9): 2075–88. https://doi.org/10.1111/risa.13844.

Multiscale issues

At the level of an individual host

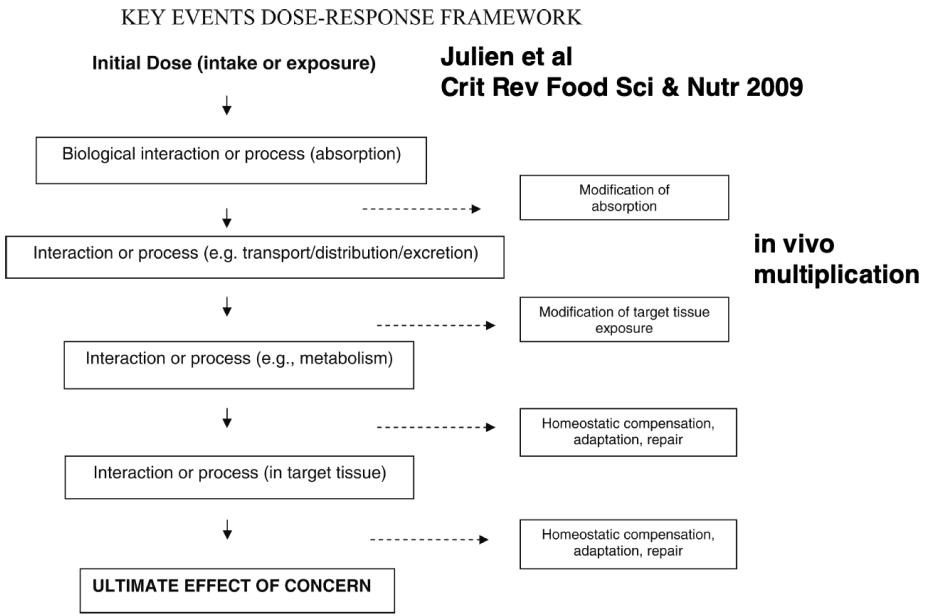


Figure 2 The Key Events Dose-Response Framework organizes available information on the multiple kinetic and dynamic events that occur between an initial dose and the effect of concern. Events are indicated generically here; but, for a given pathway, many specific kinetic and dynamic events may occur.

Dynamics via Gen 3 Dose Response

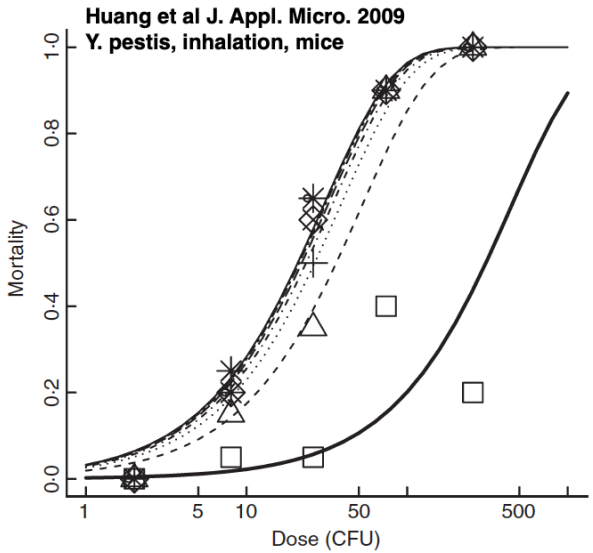


Figure 3 Exponential dose–response model with inverse-power TPI dependency (curves) compared to observed mortalities against doses (points) from the study of Rogers *et al.* (2007). (□, ——) day 3, (△, - - -) day 4, (+, ·····) day 5, (×, -·-·) day 6, (◇, – – –) day 7, (○, —·—) day 8, (*, ——) day 9.

Multiscale issues

At the level of population

A method for incorporating a time-dose-response model into a *Giardia lamblia* outbreak

Bidya Prasad, Michael O. Ryan and Charles N. Haas

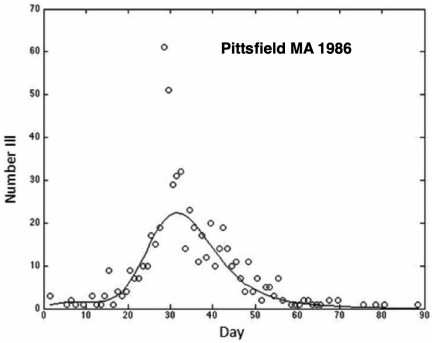


Figure 5 | The best-fit outbreak model: the lognormal exposure distribution convoluted with the beta-Poisson with exponential-reciprocal incubation distribution.

Journal of Water and Health | 15.4 | 2017

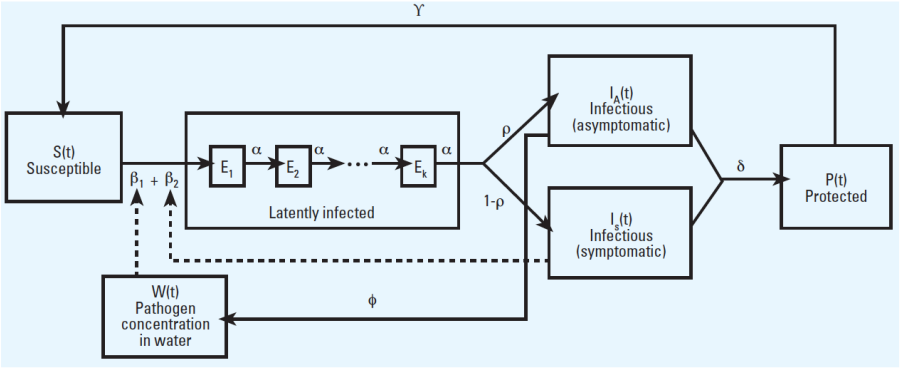


Figure 1. Schematic diagram of transmission model. t, independent variable representing time. Solid lines represent movement of individuals from one state to another. Dashed lines represent movement of pathogens either directly from infectious host to susceptible host or indirectly via the environment. State variables and parameters are defined in the text. **Eisenberg et al., EHP (2002)**

Role of Molecular Biology

Haas, ES&T 2020

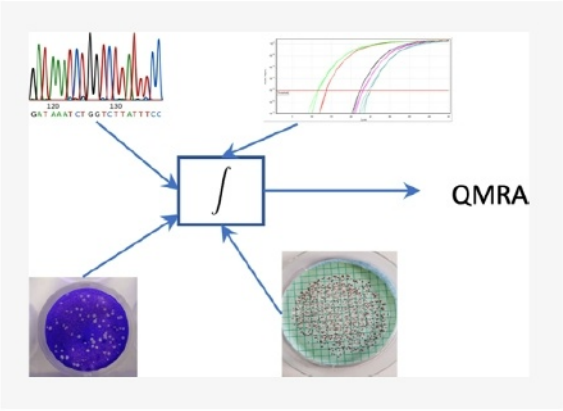


Table 1. Summary of Methods Performance

attribute	culture	q/ dPCR	amplicon sequencing	shotgun metagenomic sequencing
What pathogens?	N[a]	N[a]	Y[d]	Y[d]
How many?	Y[b]	Y[b]	N[e]	N[e]
Are they viable?	Y	N	N	N
Are they infectious?	?[c]	N	N	Y[f]

[a]Unless what to look for is known. [b]The issue of VBNC organisms occurs. [c]Depending on the specificity of the method. [d]Performance for rare taxa uncertain. [e]Further work on the standardization for absolute quantification is needed. [f]Detection of key genes is possible.

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Probabilistic Reuse

Water Research 122 (2017) 258–268

Reliability of pathogen control in direct potable reuse: Performance evaluation and QMRA of a full-scale 1 MGD advanced treatment train

Brian M. Pecson [a, *], Sarah C. Triolo [a], Simon Olivieri [b], Elise C. Chen [c], Aleksey N. Pisarenko [c], Chao-Chun Yang [d], Adam Olivieri [e], Charles N. Haas [f], R. Shane Trussell [c], R. Rhodes Trussell [d]

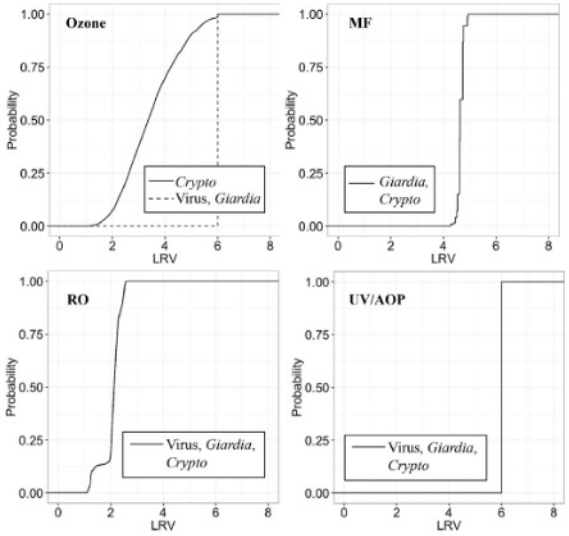


Fig. 2. Process performance probability distributions.

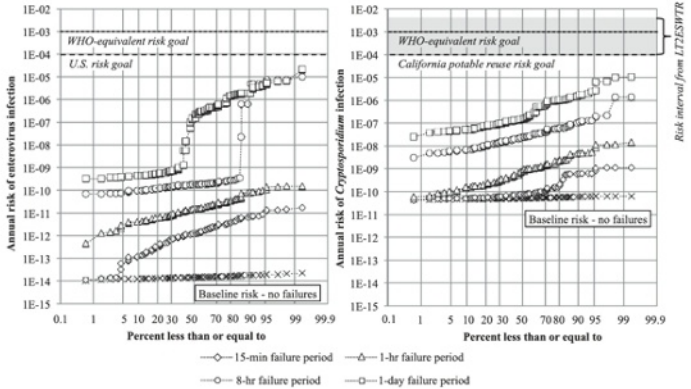


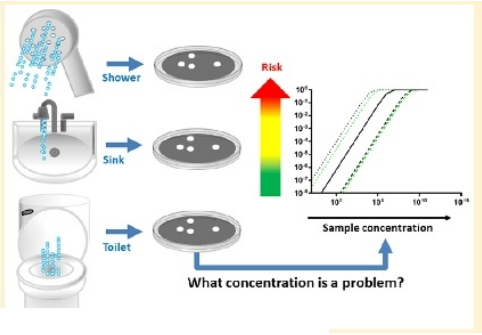
Fig. 4. Results of risk simulation under baseline conditions (no failures) and with up to 1 day of failure per process per year for enterovirus (left) and *Cryptosporidium* (right). Risk targets include U.S. risk goal of 10^{-4} (virus), WHO risk goal of 10^{-3} (equivalent to 10^{-6} DALYs per person per year), California potable reuse risk goal of 10^{-4} (*Cryptosporidium*), and the range of risks associated with compliance with EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) for *Cryptosporidium*.

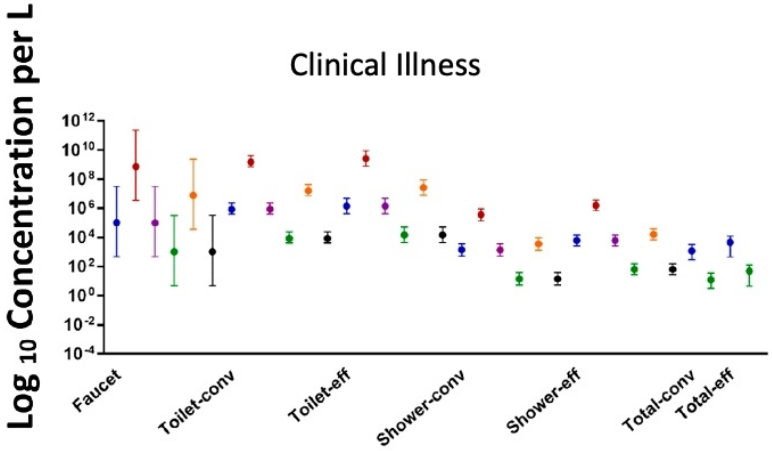
Household *Legionella*

ES&T 2019

Risk-Based Critical Concentrations of *Legionella pneumophila* for Indoor Residential Water Uses

Kerry A. Hamilton,[*,†,‡] Mark T. Hamilton,[§] William Johnson,[∥] Patrick Jjemba,[∥] Zia Bukhari,[∥] Mark LeChevallier,[∥] Charles N. Haas,[⊥] and P. L. Gurian[⊥]





- 10^{-4} annual risk
- 10^{-4} per exposure risk
- 10^{-4}/(365*f) per exposure risk
- 10^{-6} DALY annual risk
- 10^{-6} DALY per exposure risk
- 10^{-6}/(365*f) DALY per exposure risk

Occupational Risk to Workers

Risks from *Ebolavirus* Discharge from Hospitals to Sewer Workers

Charles N. Haas[1], Taylor Rycroft[1]*, Kyle Bibby[2], Leonard Casson[2]

WATER ENVIRONMENT RESEARCH • April 2017

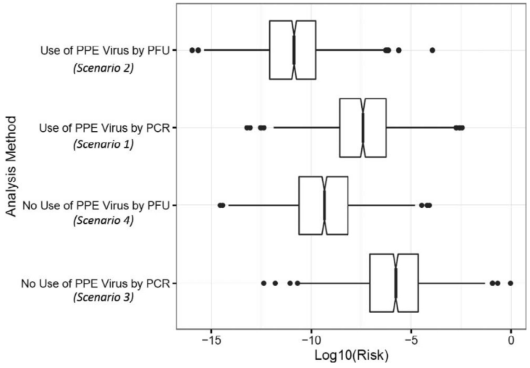


Figure 4—Box and whisker plot of $\log_{10}$ risk (1000 trials).

The results of this QMRA suggest that the potential risk that sewer workers face when operating in a wastewater collection system downstream from a hospital treating an Ebola patient warrants further attention. While an acceptable risk of EVD illness has not yet been defined, under the least favorable conditions in which PPE is not worn and EBOV RNA copies are deemed as virulent as PFUs (Scenario 3: NoPPE_Gene), the median potential risk of developing EVD illness from inhalation exposure to EBOV-contaminated aerosols in the sewer is approximately 10 –5.77 (with a first to third quartile range of 10 –7.06 to 10–4.65), a value higher than many risk managers may be willing to accept. Thus, current WHO and CDC guidance for EBOV liquid waste disposal—to dispose in the sanitary sewer without further treatment—may be insufficiently protective of sewer worker safety.

Fomite Risk — Tim Julian COVID

Environmental Science & Technology Letters

Community Transmission of SARS-CoV-2 by Surfaces: Risks and Risk Reduction Strategies

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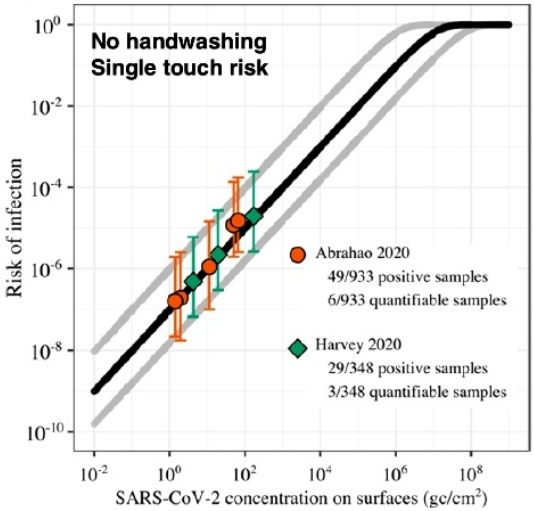
Cite This: https://dx.doi.org/10.1021/acs.estlett.0c00966

- Concentration of SARSCoV-2 RNA on public surfaces [gene copy number (gc) cm^{-2}]
- Conversion of SARS-CoV-2 RNA to infective decay rate of the infectious virus on the surface
- The transfer of the virus from surface-to-hand and from hand-to mucous membranes
- The probability of infection for a given dose (P_{inf}) was estimated using an exponential dose–response model



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Conclusions & Research Needs

- There are important concepts for considering pathogens that could merit the recognition of EnvPE as an identifiable subset of EnvE
- Concepts from molecular biology, occupational hygiene, medicine, public health and exposure sciences need to be integrated
- Opportunities for innovation in measurement, modeling, and synthesis exist
- New problems (venues, pathogens) will drive innovation
- But we can bring the unique mindset of engineering (quantitative analysis, solution of problems by decomposition, . . .), and should not be afraid to do so
- **Protection of public health is too important to just be limited to physicians**

Acknowledgments

Students/Former Students, particularly

- Kerry Hamilton
- Yin Huang
- Mark Weir
- Bidya Prasad
- Tim Bartrand

Colleagues/Collaborators at Drexel and Elsewhere

- Joan Rose
- Chuck Gerba
- Patrick Gurian
- Bakhtier Farouk
- Brian Pecson
- Adam Olivieri
- Rhodes Trussell
- #sciencetwitter

Funding & Professional Organizations (*)

- WRF
- EPA
- NSF
- NWRI (*)
- NASEM (*)