Microbial Risk Assessment of Onsite Non-Potable Water Reuse: Updates and Implications

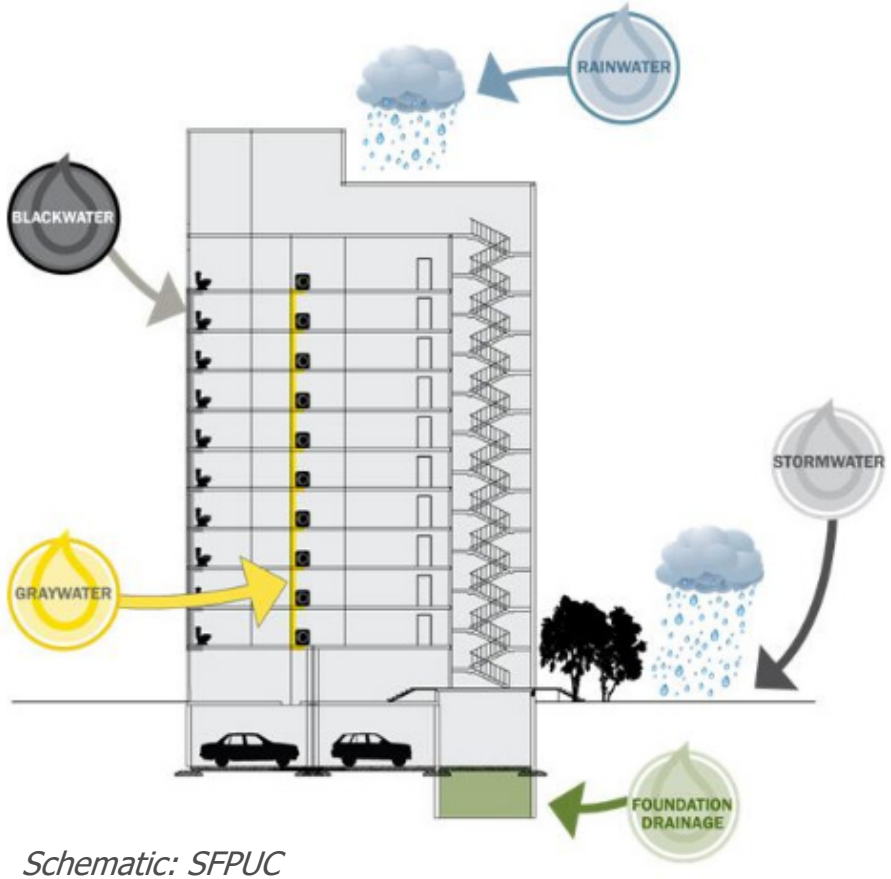
February 10–11, 2021
#AWWAvirtualsummit
awwa.org/feb-summit

Michael Jahne, Mary Schoen, Jay Garland
U.S. EPA, Office of Research and Development
Soller Environmental

virtual summit
AWWA
PFAS | PATHOGENS | SUSTAINABILITY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

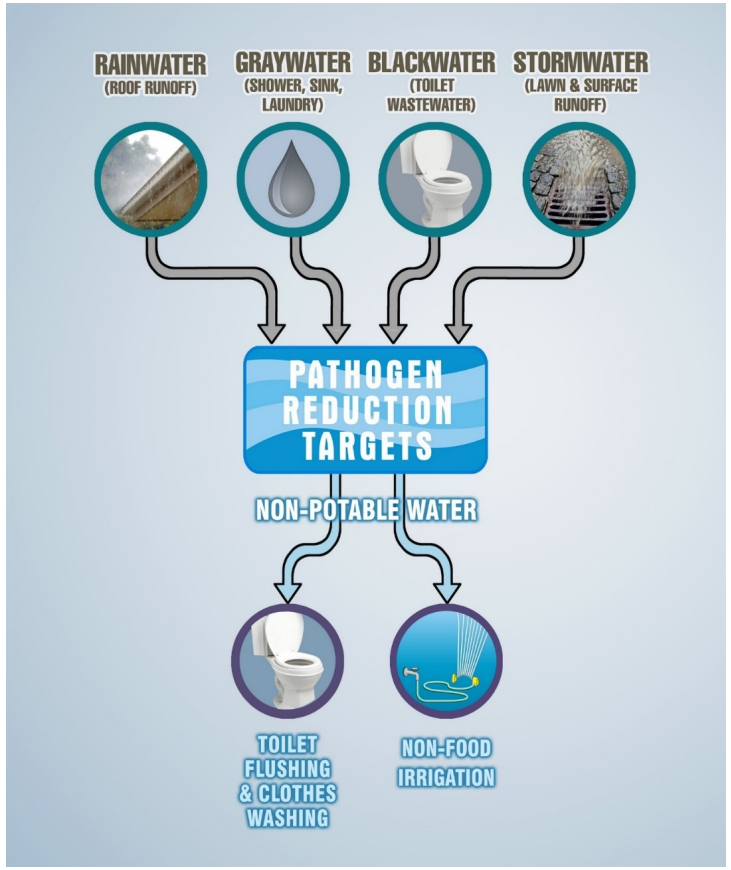
Motivation: From Waste to Resource



Schematic: SFPUC

National Blue Ribbon Commission for Onsite Non-potable Water Systems

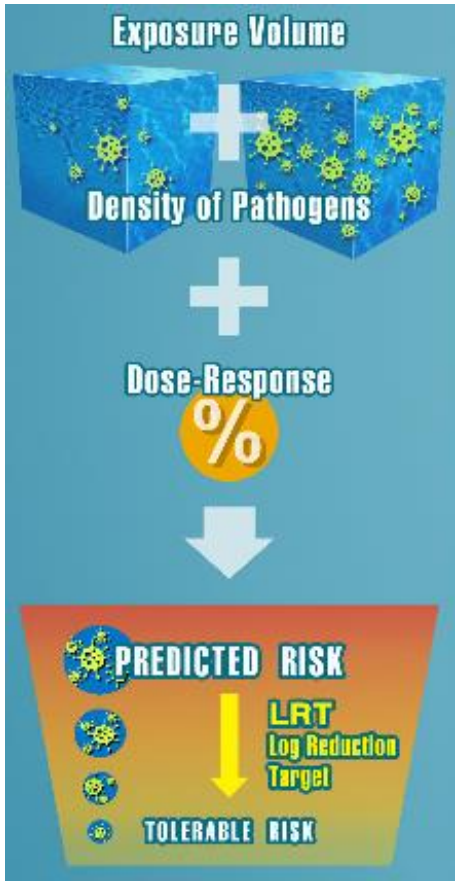
How Do You Define Acceptable Treatment?



- Quality of alternative source waters?
- Scaling effects for decentralized systems?
- Fit-for-purpose water?

Approach: Risk-based Pathogen Reduction Targets

Quantitative Microbial Risk Assessment



"Source" Waters

(roof runoff, stormwater, graywater, blackwater)

End Use

Non-Potable

Potable

A Matrix of
Log Reduction Targets
To Define
Fit-For-Purpose Reuse

WATER ENVIRONMENT + REUSE FOUNDATION WE&RF

Final **Report**

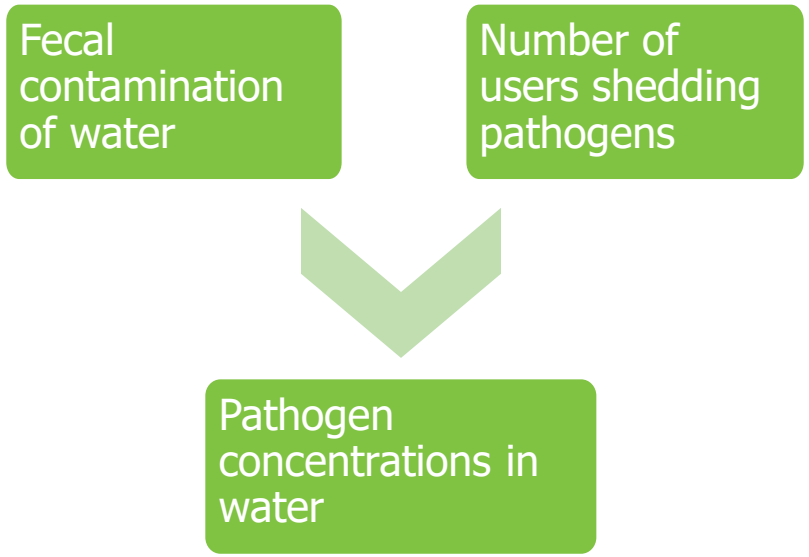
Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems

Water Use Scenario	Log10 Reduction Targets for 10^{-4} (10^{-2}) Per Person Per Year Benchmarks[b,i]		
	Enteric Viruses[c]	Parasitic Protozoa[d]	Enteric Bacteria[e]
Domestic Wastewater or Blackwater			
Unrestricted irrigation	8.0 (6.0)	7.0 (5.0)	6.0 (4.0)
Indoor use[f]	8.5 (6.5)	7.0 (5.0)	6.0 (4.0)
Graywater			
Unrestricted irrigation	5.5 (3.5)	4.5 (2.5)	3.5 (1.5)
Indoor use[g]	6.0 (4.0)	4.5 (2.5)	3.5 (1.5)
Stormwater (10^{-1} Dilution)			
Unrestricted irrigation	5.0 (3.0)	4.5 (2.5)	4.0 (2.0)
Indoor use	5.5 (3.5)	5.5 (3.5)	5.0 (3.0)
Stormwater (10^{-3} Dilution)			
Unrestricted irrigation	3.0 (1.0)	2.5 (0.5)	2.0 (0.0)
Indoor use	3.5 (1.5)	3.5 (1.5)	3.0 (1.0)
Roof Runoff Water[h]			
Unrestricted irrigation	Not applicable	No data	3.5 (1.5)
Indoor use	Not applicable	No data	3.5 (1.5)

Sharvelle et al. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems
Schoen et al. (2017) Microbial Risk Analysis 5, 32-43

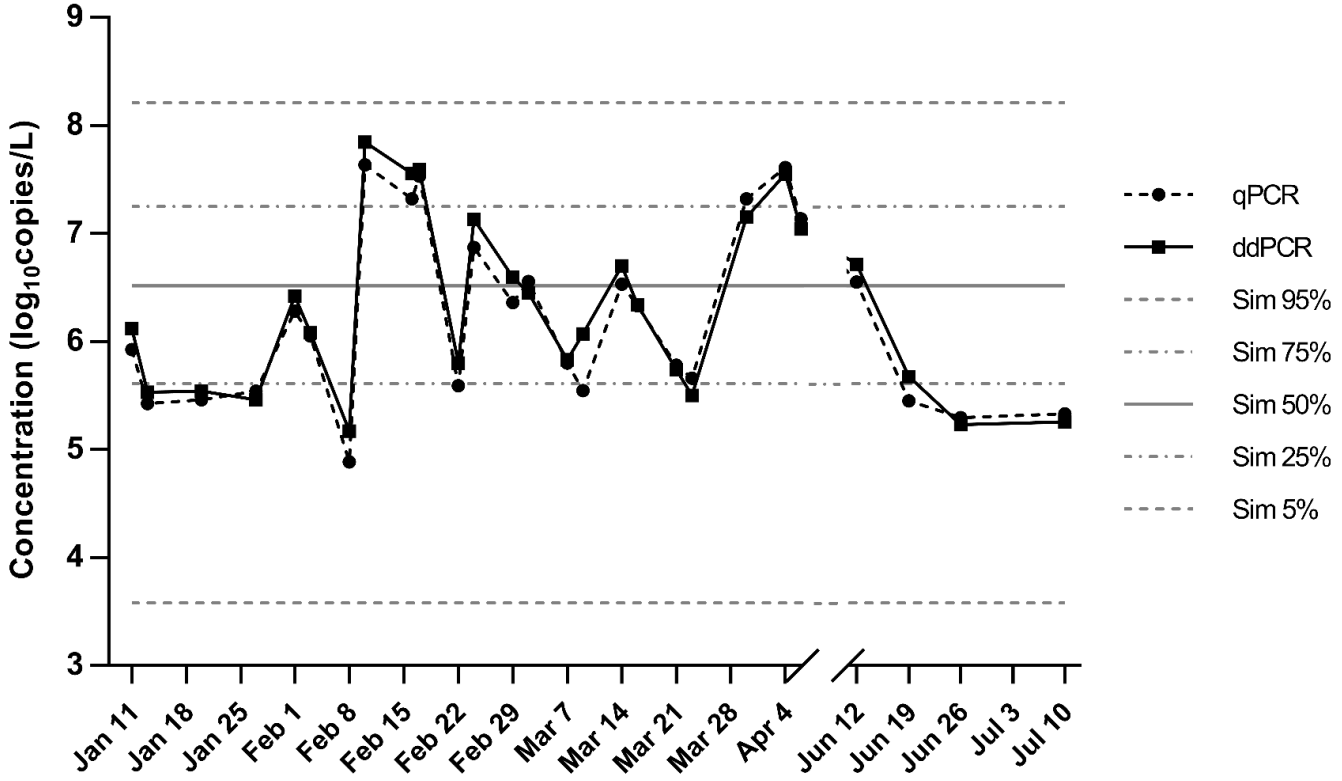
Pathogen Density Characterization: Onsite WW and GW

- Previously modeled using epidemiology-based simulation
  - Pathogen infections intermittent in small populations
  - Limited dilution effects
- Model validation measurements
  - 3 decentralized systems (500-1000 occupants): 2 graywater, 1 wastewater
  - 3 pathogen targets: norovirus GI and GII, adenovirus
  - 2 analysis methods: qPCR/RT-qPCR, ddPCR/RT-ddPCR



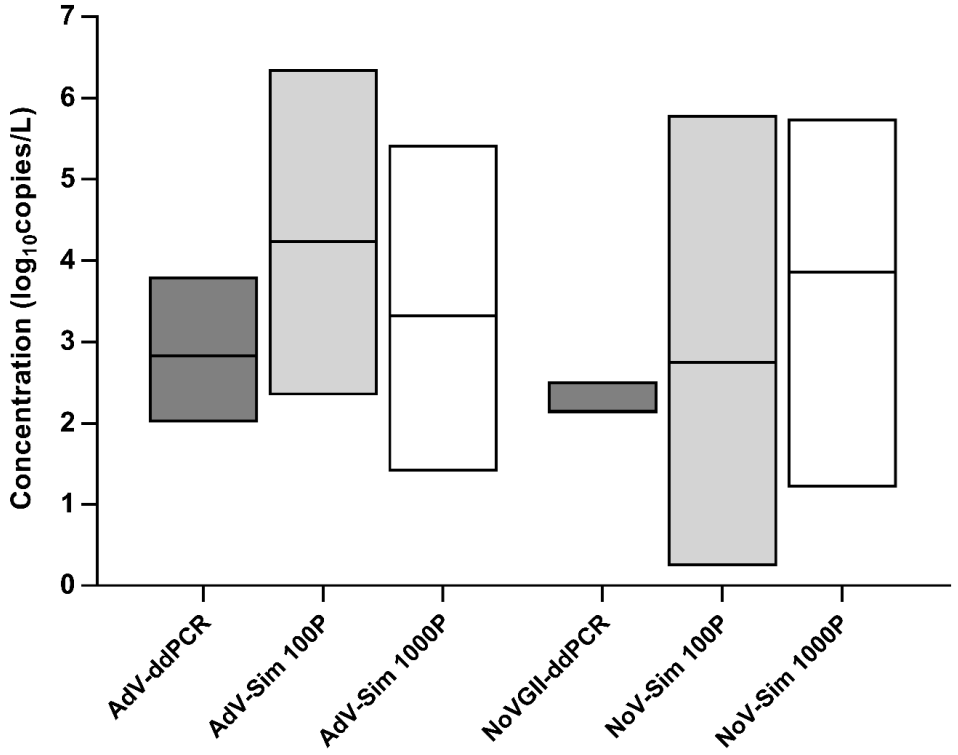
Jahne et al. (2017) Microbial Risk Analysis 5, 44-52

Norovirus GII in Onsite Wastewater



Jahne et al. (2020) Water Research 169, 115213

ddPCR Graywater Concentrations



Quantifiable Samples	AdV		NoVGII	
	qPCR	ddPCR	qPCR	ddPCR
GW1 (n=33)	0%	15%	0%	6%
GW2 (n=17)	0%	12%	0%	0%

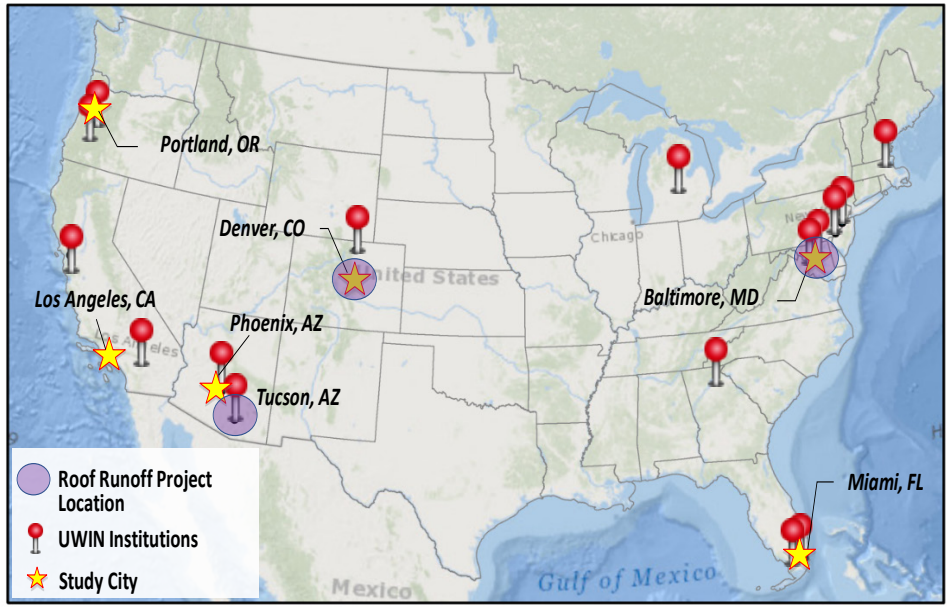
Simulation Occurrence	AdV	NoVGII
100 person	0%-7%	22-68%
1000 person	11-30%	98-100%

Simulation %<LOQ	AdV		NoVGII	
	qPCR	ddPCR	qPCR	ddPCR
100 person	55%	1%	57%	43%
1000 person	81%	10%	31%	13%

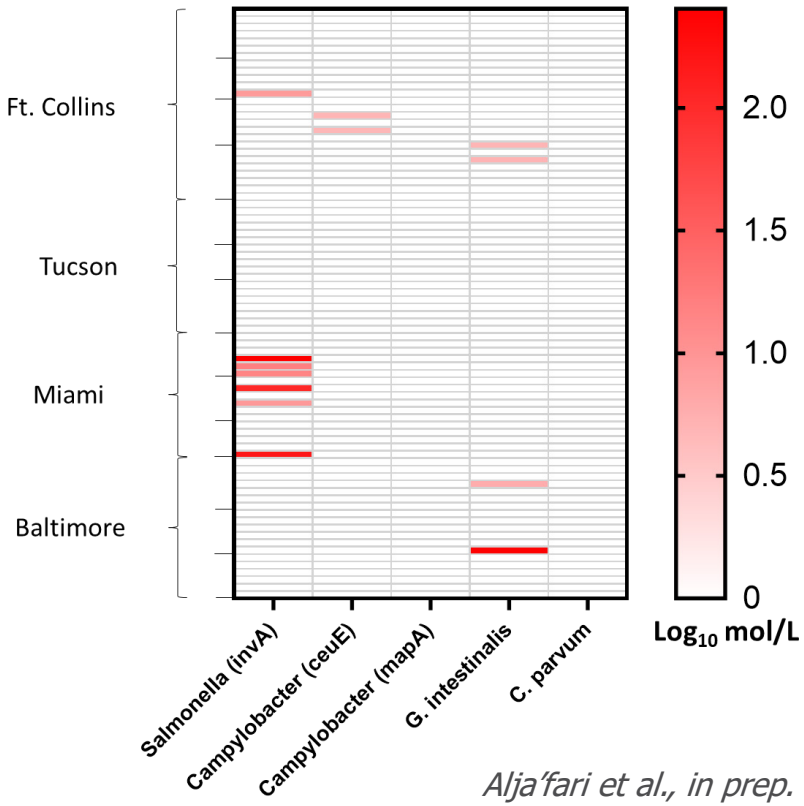
Jahne et al. (2020) Water Research 169, 115213

Pathogen Density Characterization: Roof Runoff

- Previously modeled based on animal fecal contamination
  - Limited to gull feces
  - Limited to bacterial pathogens
- "Off the Roof" Study
  - 80 samples
  - 4 cities
  - 13 rain events



Pathogen Results (ddPCR)

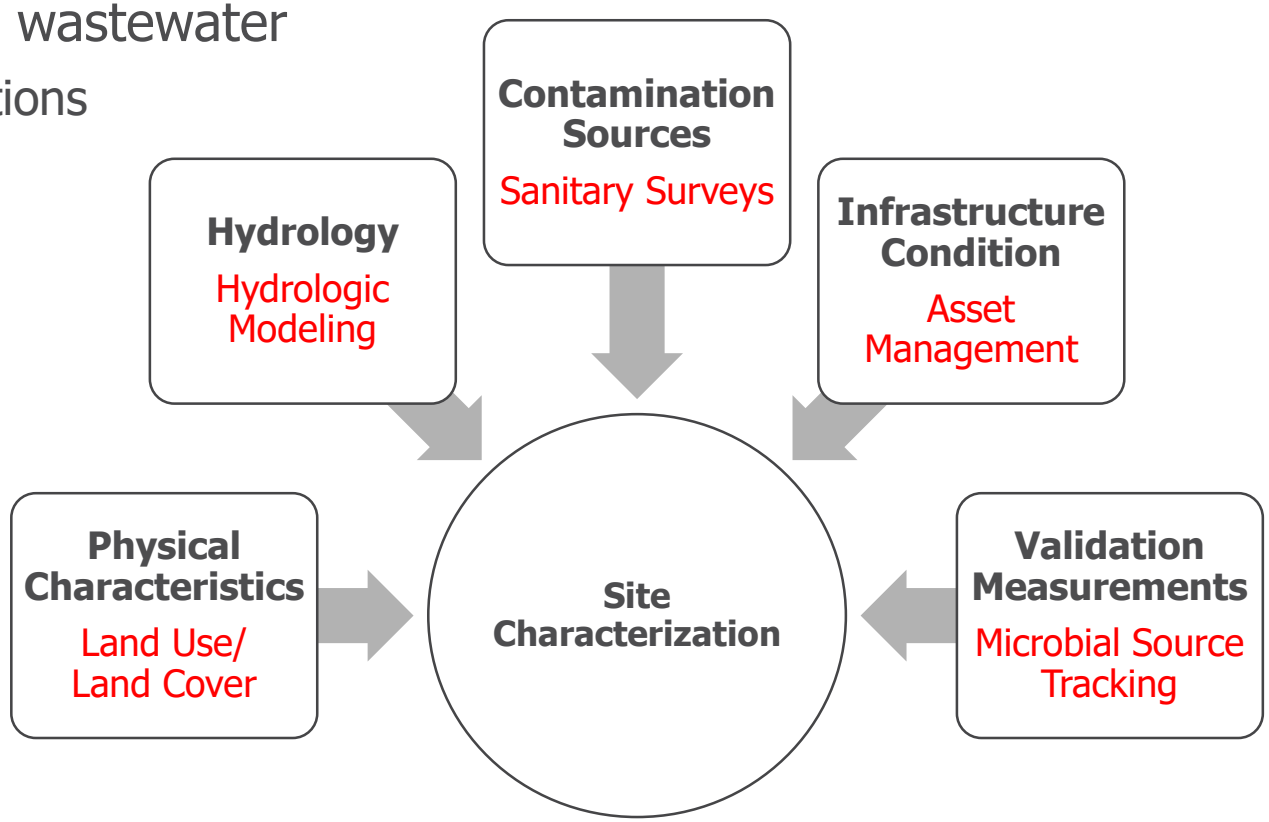


Alja'fari et al., in prep.

- Measured bacteria within modeled range
  - Positive results > model median; maxima < 95th%
  - Lower detection than in model
- Protozoan detections are new
  - High max concentration, others lower
  - 5% positive = 4 samples from different sites
  - Signals that LRT necessary, but data limited

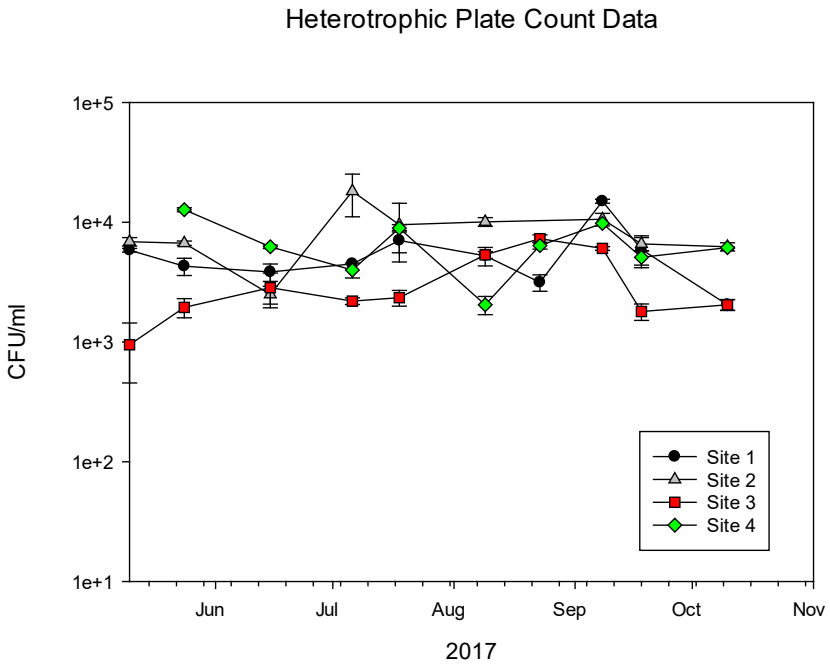
Pathogen Density Characterization: Stormwater

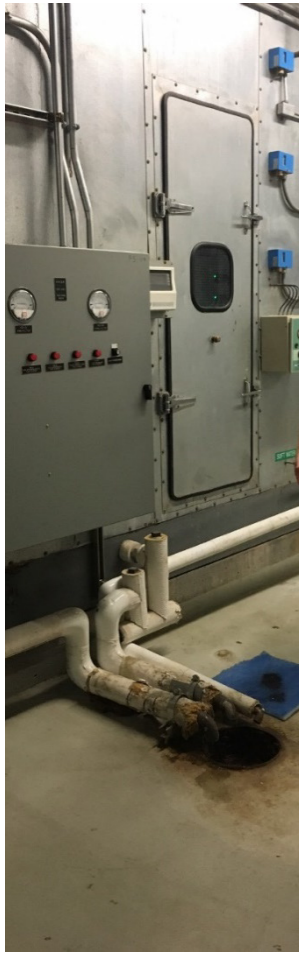
- Estimated based on dilutions of municipal wastewater
  - Highly variable quality across sites/conditions
  - Limited direct pathogen monitoring data
  - Versatile, generalized approach
- Provides flexibility but also ambiguity:
  - Which is right for my project?



Additional Source Water – AC Condensate

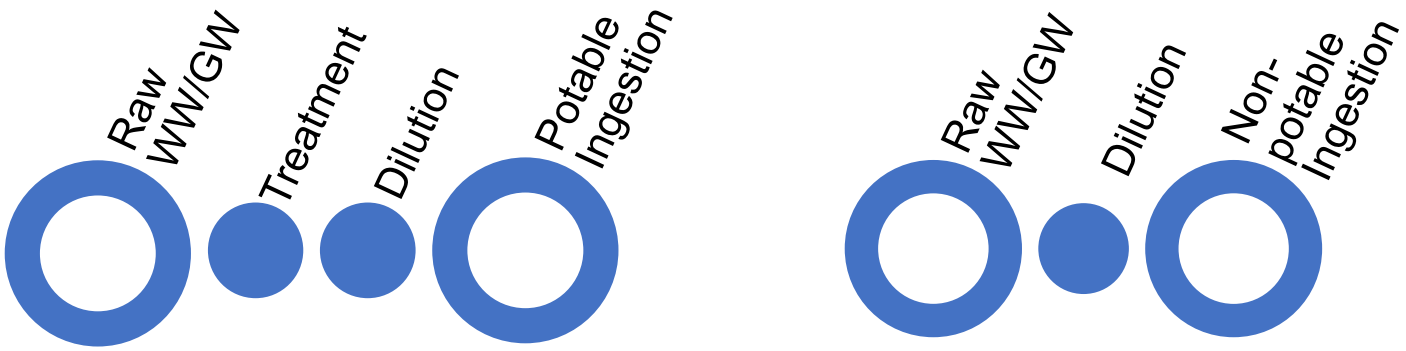
- Significant quantities of high-quality water
- Climate conditions that drive AC use correlate with water scarcity
- But is it safe?
  - Chemistry: metals leached from components
  - Microbes: *Legionella* and *Mycobacterium* spp.
- Pilot at EPA campus
  - High HPC counts
  - Several opportunistic pathogen detections (condensate and biofilm)
  - Expanding data collection under WRAP





Exposure Assessment: Cross Connections

- Two unique scenarios for non-potable water systems:



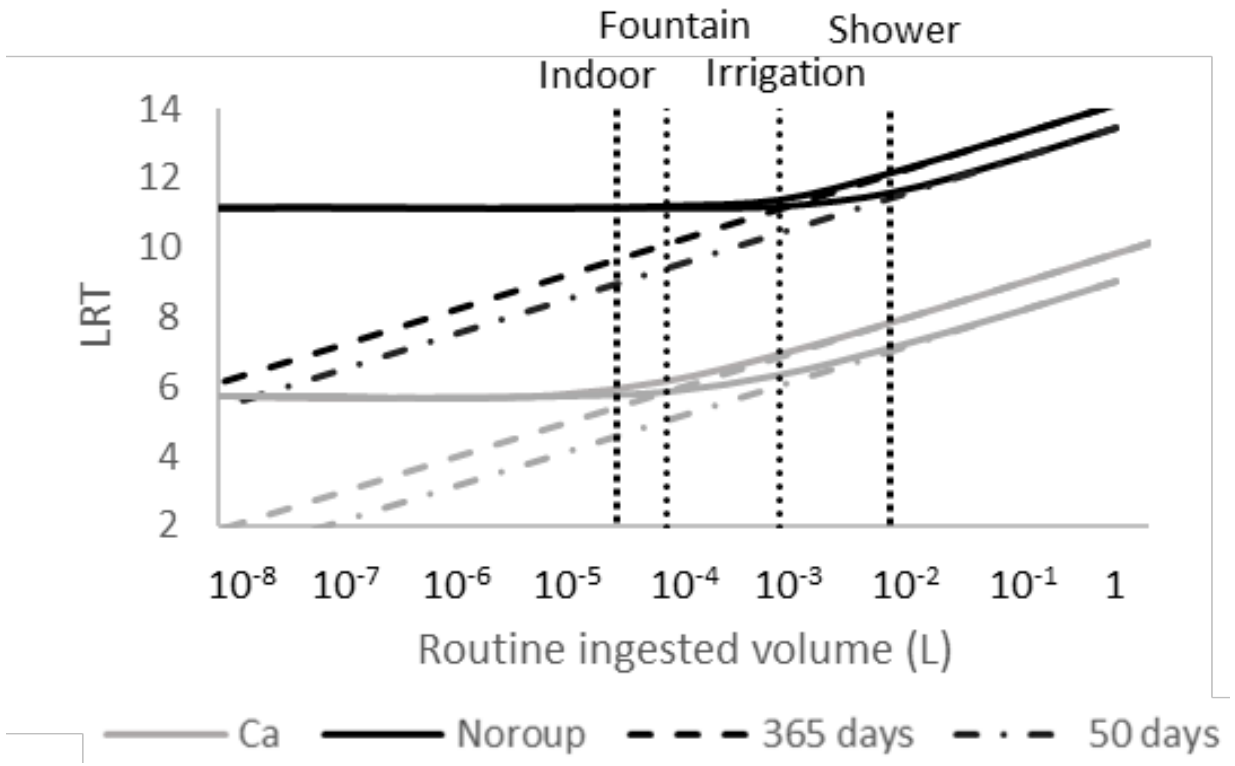
Reclaimed to potable **Raw to non-potable**

- Included safety factor for indoor use – under which conditions are it protective?
  - Short duration (<5-day); small exposed population (<1%); high intrusion dilution (>1:1,000)

Schoen, Jahne, Garland (2018) Water 10(10), 1352

Exposure Assessment: Additional End Uses

- Non-potable exposures are poorly characterized – how sensitive are LRTs?
  - Importance of safety factor
- For what range of exposures are previous LRTs appropriate?
  - $<10^{-5}$ L for daily use
  - $<10^{-4}$ L for weekly use
- How does estimated exposure from other uses compare?
  - Decorative fountains and vehicle washing within range
  - Bathing/showering outside range



Schoen, Jahne, Garland (2020) Environ. Sci. Technol. Lett. 7(12), 943-947

New LRTs for Bathing/Showering Use

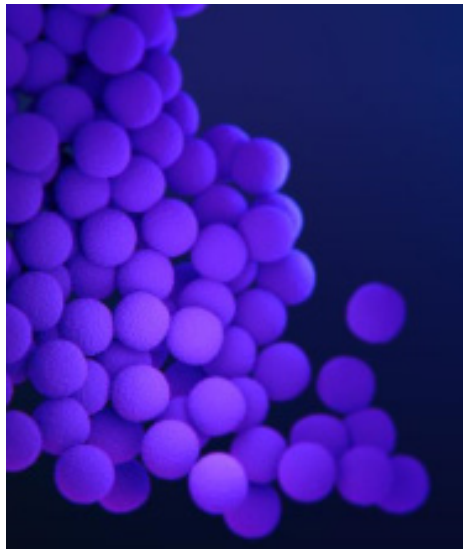
- Likely driven by direct ingestion but consumption patterns highly variable
- Assumed similar to swimming, adjusted to shower duration

Water (Capacity)	Norovirus	Cryptosporidium	Campylobacter
WW (1000-person)			
Indoor[a] or vehicle washing/decorative fountain	11.2/8.4	6.8/5.9	6.0
Municipal irrigation[c]	10.5/7.7	6.9/6.0	6.1
Shower[d]	12.1/9.3	8.7/7.7	7.9
GW (1000-person)			
Indoor[a] or vehicle washing/decorative fountain[b]	8.8/6.0	4 .5/3.6	3.7
Municipal irrigation[c]	8.4/5.6	4 .5/3.6	3.7
Shower[d]	10.3/7.5	6.5/5.6	5.7

Schoen, Jahne, Garland (2020) Environ. Sci. Technol. Lett. 7(12), 943-947

Exposure Assessment: *S. aureus*/MRSA

- High concentrations in wastewaters/graywaters ~ 10^5 CFU/L
- Additional considerations for antimicrobial resistance in QMRA
  - Genetic exchange, including during treatment
  - Delayed impacts following colonization
  - Clinical severity of illness
- Are LRTs protective?
  - May result in low infection risks, but doesn't capture health outcomes (e.g., illness vs. death)
  - Address with disability adjusted life year (DALY), 10^{-6} ppy benchmark



Schoen et al., in prep.
Image: CDC

Model Application: NSF350 Systems

- Do systems in compliance with indicator-based standards achieve acceptable levels of risk?
- Modeled process LRVs and associated risks for approved systems:
  - Aerobic and moving-bed membrane bioreactors (MBR); added chlorine disinfection

    Have performance data; estimate risk
  - Septic tank and recirculating synthetic sand filter (RSF) with UV disinfection

    No performance data to assess

MBR + Chlorine System

Risk Varies with Influent Type

System	Annual probability of infection
GW Residential (600 L d^{-1}/ 160 G d^{-1})	1×10^{-6}
GW Residential (12,100 L d^{-1} /3200 G d^{-1})	1×10^{-3}
GW Business (1590 L d^{-1}/420 G d^{-1})	1×10^{-4}
GW Business (15,900 L d^{-1} /4200 G d^{-1})	2×10^{-4}
WW Residential (946 L d^{-1} /250 G d^{-1})	3×10^{-4}
WW Residential (19,200 L d^{-1} /5070 G d^{-1})	2×10^{-1}

Schoen, Jahne, Garland (2020) J. Water Health 18(3), 331-344

New LRTs for Intermediate-Size and Business

Table 1 | Non-potable indoor use LRTs for single- and multi-family residences for healthy adults given the 10^{-4} (10^{-2}) infection ppy benchmark for onsite WW and GW[a]

	Water (capacity)	Virus	Protozoa	Bacteria
Large/district	WW (192,000 L d^{-1}/ 50,000 G d^{-1})[b]	8.5 (6.5)	7.0 (5.0)	6.0 (4.0)
NSF ⇨	WW (5,700 L d^{-1} or 1,500 G d^{-1})	NA (NA)	NA (NA)	NA (NA)
Single-family	WW (946 L d^{-1}/250 G d^{-1})[c]	7.5 (NA)	0 (0)	0 (0)
Large/district	GW (121,000 L d^{-1}/ 32,000 G d^{-1})[b]	6.0 (4.0)	4.5 (2.5)	3.5 (1.5)
NSF ⇨	GW (5,700 L d^{-1} or 1,500 G d^{-1})	NA (NA)	NA (NA)	NA (NA)
Single-family	GW (600 L d^{-1}/160 G d^{-1})[c]	5.0 (NA)	0 (0)	0 (0)

Table 5 | LRTs for NSF 350-scale onsite systems given the 10^{-4} (10^{-2}) infection ppy benchmark assuming upper-bound/lower-bound dose–response relationships summed across all treatment units including disinfection[a,b,c]

Water	Virus	Protozoa	Bacteria
Residential			
WW	10.5/8.0 (9.0/6.0)	6.5/6.0 (4.5/4.0)	NR (NR)
GW	8.5/5.5 (6.5/3.5)	4.0/3.5 (2.0/1.5)	NR (NR)
Business			
GW	8.0/4.5 (6.0/2.5)	3.0/2.5 (1.0/0.0)	NR (NR)

- Intermediate residential reduced from large scale/district, but greater than single-family
- Business lower than residential given different pathogen characterization (sinks only)

Schoen, Jahne, Garland (2020) J. Water Health 18(3), 331-344

Conclusions

- Risk-based treatment targets are designed to remove enteric pathogens to protect human health.
- LRTs are sensitive to the input water type, intended use, and accidental ingestion.
- Improved pathogen characterizations support previous LRTs and provide data to update.
- Built-in safety factor protective for short-term, low magnitude cross-connection events.
- Existing LRTs can be extended to other uses with small exposure volumes, under certain conditions.
- Additional considerations necessary to incorporate skin pathogens and antimicrobial resistance in QMRA.
- Fecal indicator-based treatment systems have a variable predicted level of public health protection.
- New LRTs for bathing/showering as well as intermediate-sized and business systems.

Thank You

Collaborators

Jay Garland (EPA-ORD)

Mary Schoen (Soller Environmental)

Nichole Brinkman (EPA-ORD)

Scott Keely (EPA-ORD)

Emily Wheaton (EPA-ORD)

Brian Zimmerman (EPA-ORD)

Nicholas Ashbolt (U. Alberta)

Sybil Sharvelle (CSU)

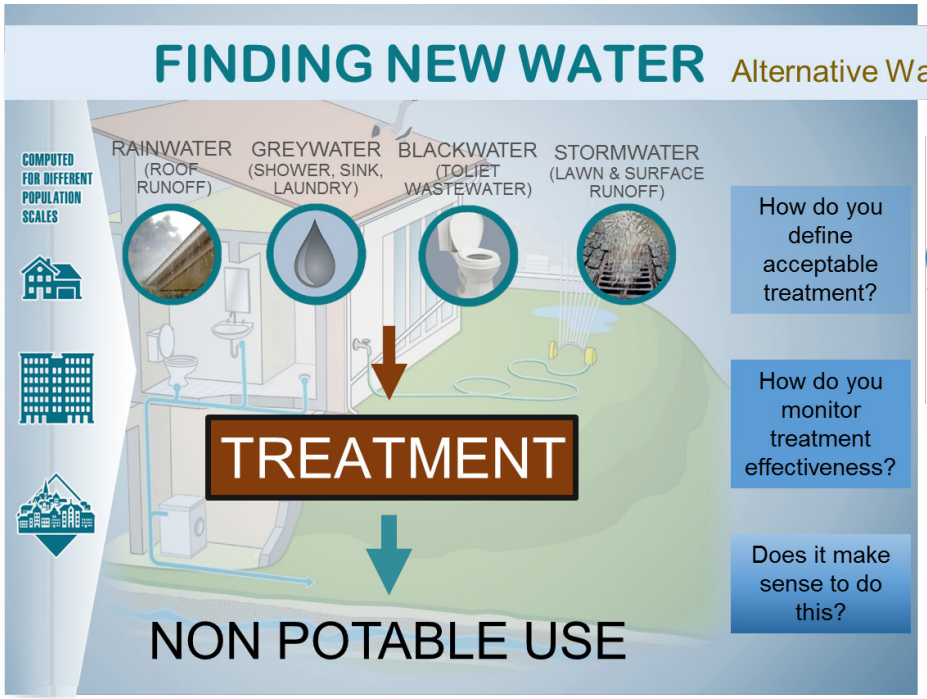
Jumana Alja'fari (CSU)

Partner Facilities and Personnel

EPA-Region 9 Lab

NWRI Independent Advisory Panel

National Blue Ribbon Commission



Partners

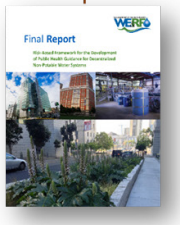
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

National Blue Ribbon Commission for Onsite Non-potable Water Systems

WERF

US Water Alliance

Report



Disclaimer: The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.