Science to Inform the Development of Decentralized Non-Potable Water Systems

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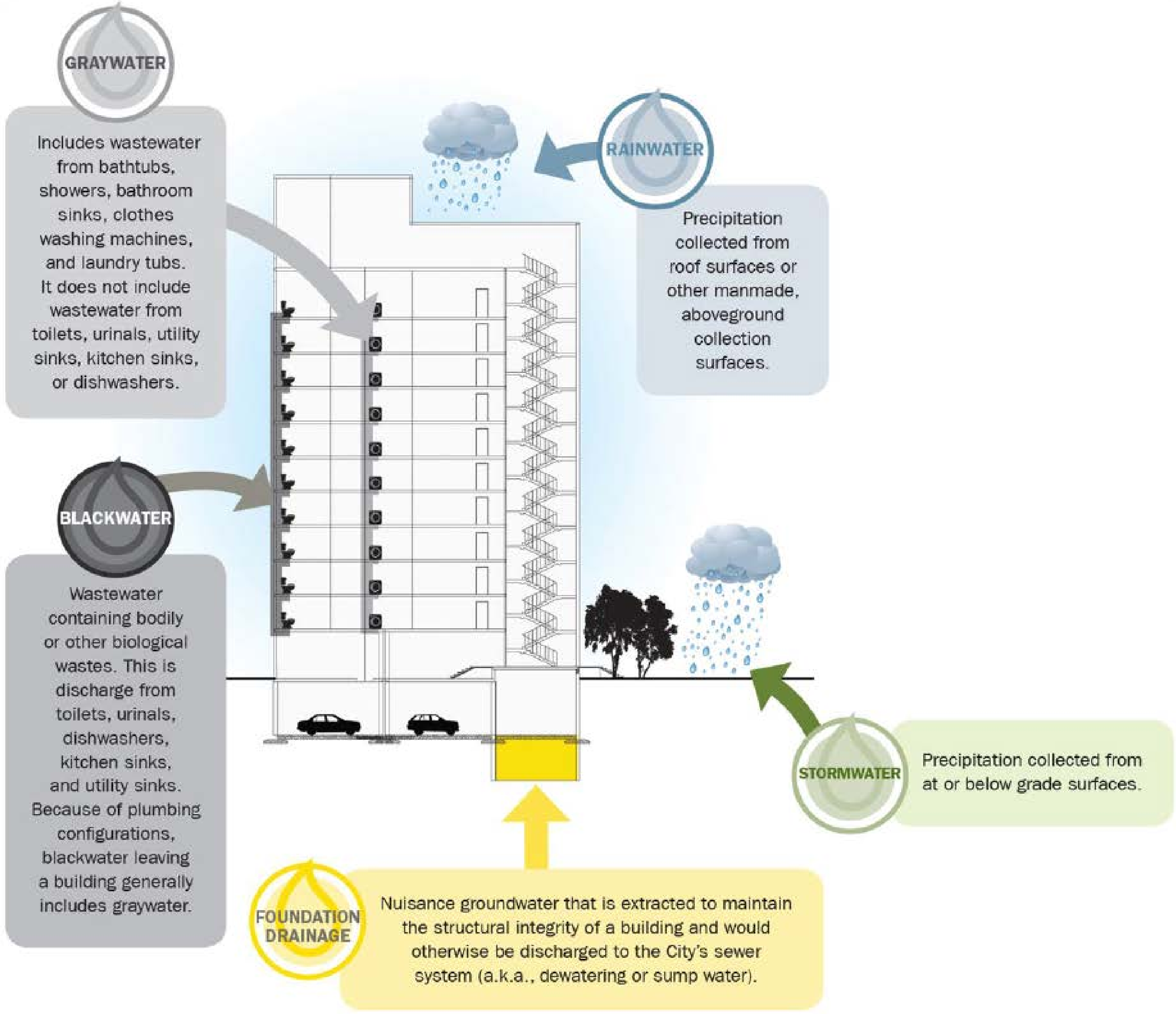
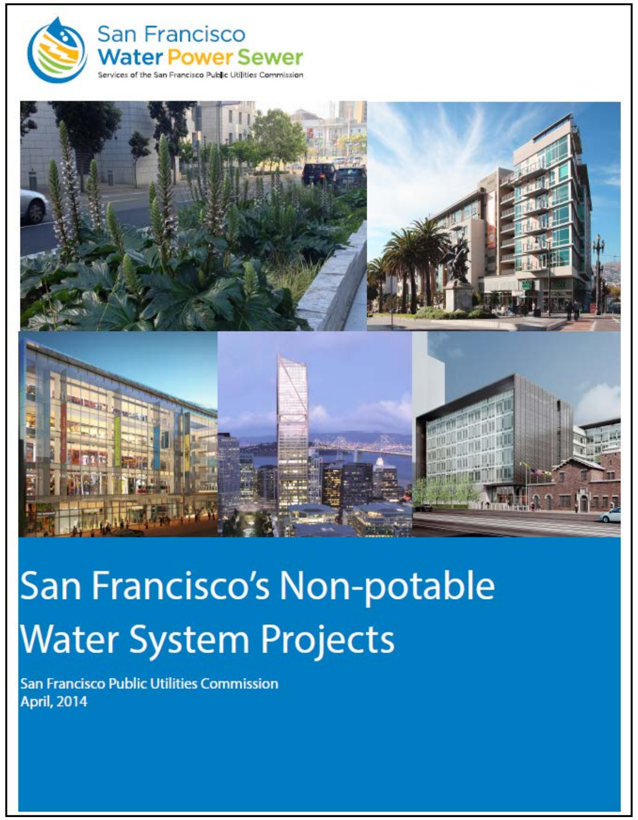
Overview

- Increasing interest in decentralized nonpotable water systems DNWS)
    - Direct (Water shortage)
    - Indirect (Gateway to Broader Innovation?)
        - Integrated Sustainability Assessment to provide broader context for decision making

- A New Paradigm for Defining & Monitoring Performance
    - A Risk Based Approach using Quantitative Microbial Risk Assessment (QMRA) to define treatment requirements to meet acceptable risks
    - Performance Monitoring Not Indicator Based Water Quality Monitoring
        - On-line, non-biological surrogates linked to treatment requirements
        - Alternative microbiological targets for validation (infrastructure microbiome?)





Source: SFPUC

Why?

The Low Hanging Fruit of Conservation Are Picked

Anything benefit beyond increased access to water?

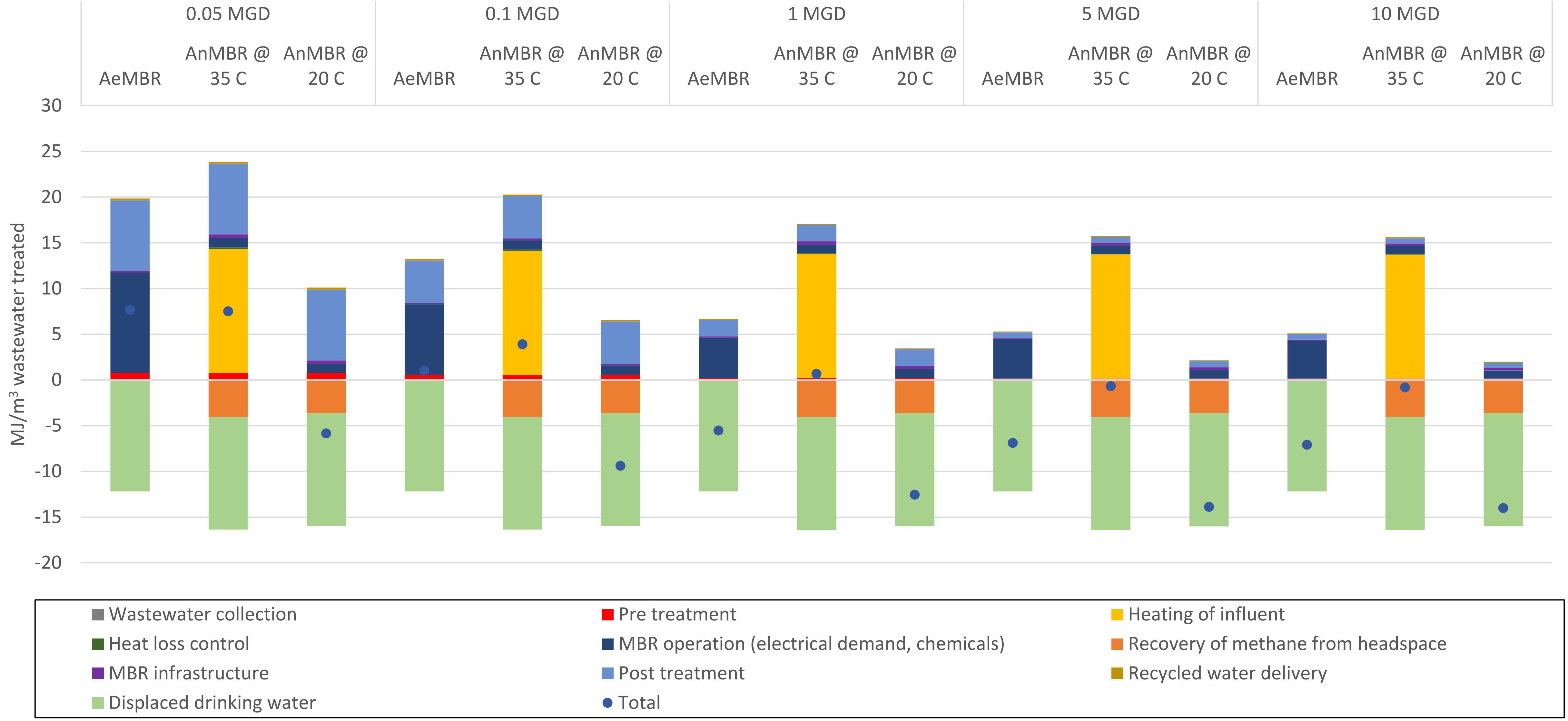
Source: SFPUC

Scale and Land Use Type Scenarios

	Land Use Type	0.05MGD (500 ppl served)	0.1MGD (1,000 ppl served)	1MGD (10,000 ppl served)	5MGD (50,000 ppl served)	10MGD (100,000 ppl served)
100,000 #ppl/sqm	High density urban	0.005 sqm	0.01 sqm	0.1 sqm	0.5 sqm	1 sqm
50,000 #ppl/sqm	Multi family	0.01 sqm	0.02 sqm	0.2 sqm	1 sqm	2 sqm
10,000 #ppl/sqm	Single family	0.05 sqm	0.1 sqm	1 sqm	5 sqm	10 sqm
2,000 #ppl/sqm	Semi-rural single family	0.25 sqm	0.5 sqm	5 sqm	N/A	N/A

sqm = square mile; ppl = people; MGD = million gallons per day

AeMBR and AnMBR Energy Demand Comparison for Multi Family Land Use (MJ/m^3 Wastewater Treated)



Where we are now with DNWS….

- State health departments and regulatory agencies need guidance on appropriate water quality standards
- Current water quality standards are not risk based
- Everyone has been looking to others for development of standards

NWRI Panel To Develop A Framework for Decentralized Non-Potable Water Systems

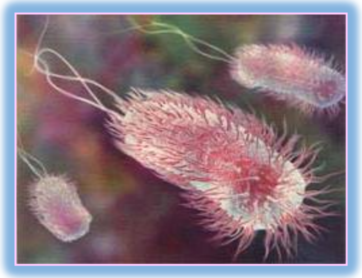
- Provide additional information and guidance to state and local health departments that allows these agencies to consider development of a DNWS program that adequately protects public health
- Developed to address non-single residence applications (multi-user buildings and district/neighborhood scale)
- Source waters
  - Blackwater, Graywater, Domestic wastewater, Roof runoff, Stormwater, Condensate, Foundation water
- Nonpotable end uses
  - Toilet flushing, Clothes washing, Cooling tower, Unrestricted-access municipal irrigation

Risk-based Pathogen Reduction Targets

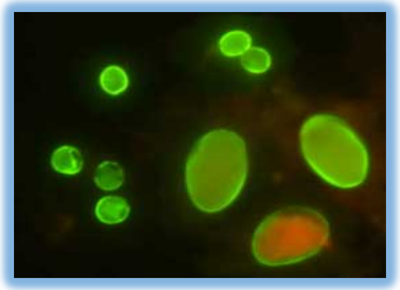
- “risk-based” targets attempt to achieve a specific level of protection (a.k.a. tolerable risk or level of infection)
  - 10^{-4} infections per person per year (ppy)
  - 10^{-2} infections ppy
- Example: WHO (2006) risk-based targets for wastewater reuse for agriculture

Risk-based Pathogen Reduction Targets

Viruses
(*Norovirus*)



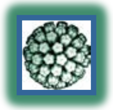
Bacteria
(*Campylobacter*)

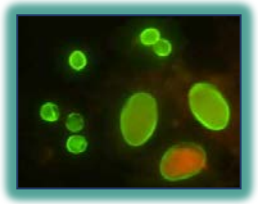


Parasitic protozoa
(*Cryptosporidium* & *Giardia*)

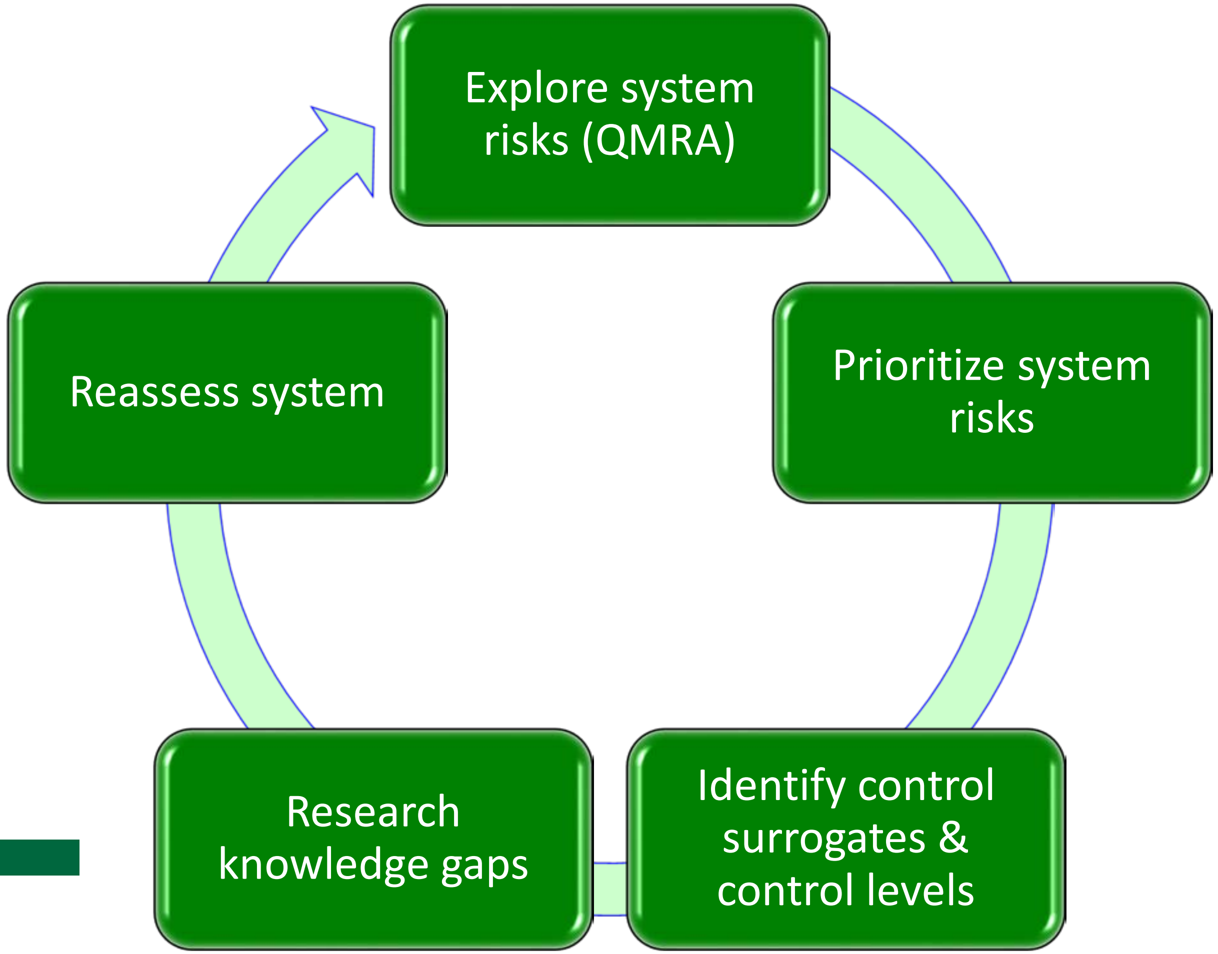
Log_{10} Reduction Targets (LRTs) =

Log_{10} (density pre-treatment) - Log_{10} (density post-treatment)

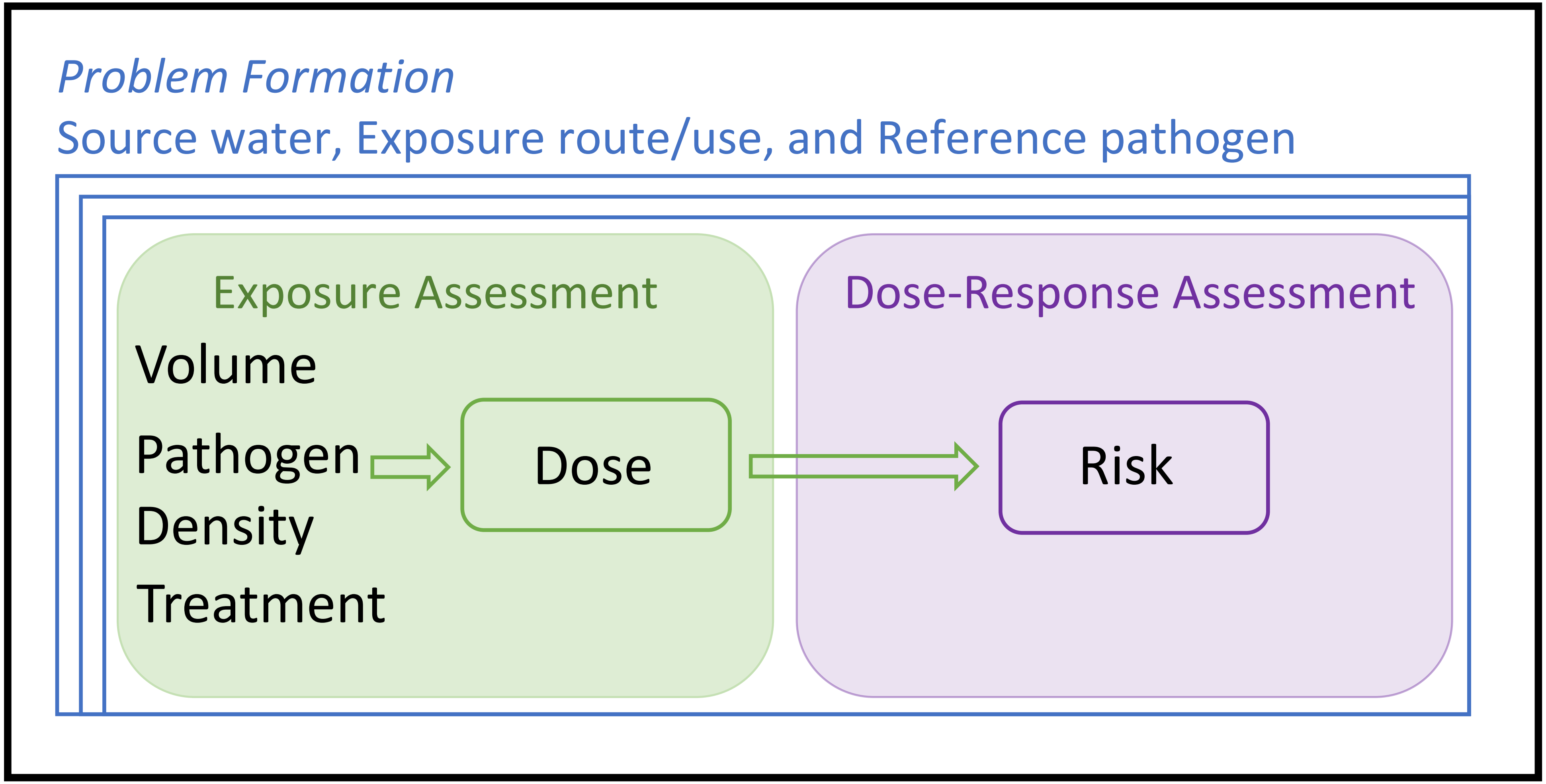





QMRA – Analytic Framework



Quantitative Microbial Risk Assessment



Exposure Routes and Volumes

Use	Volume (L)	Days per year	Fraction of pop.
Home			
Toilet flush water	0.00003	365	1
Clothes washing	0.00001	100	1
Accidental ingestion or Cross-connection	2	1	0.1
Municipal irrigation and dust suppression	0.001	50	1
Drinking	2	365	1

(NRMMC et al. 2006)

Epidemiology Approach for Blackwater/Greywater

Fecal contamination of water

- Fecal indicator concentration in water
- Indicator content of raw feces

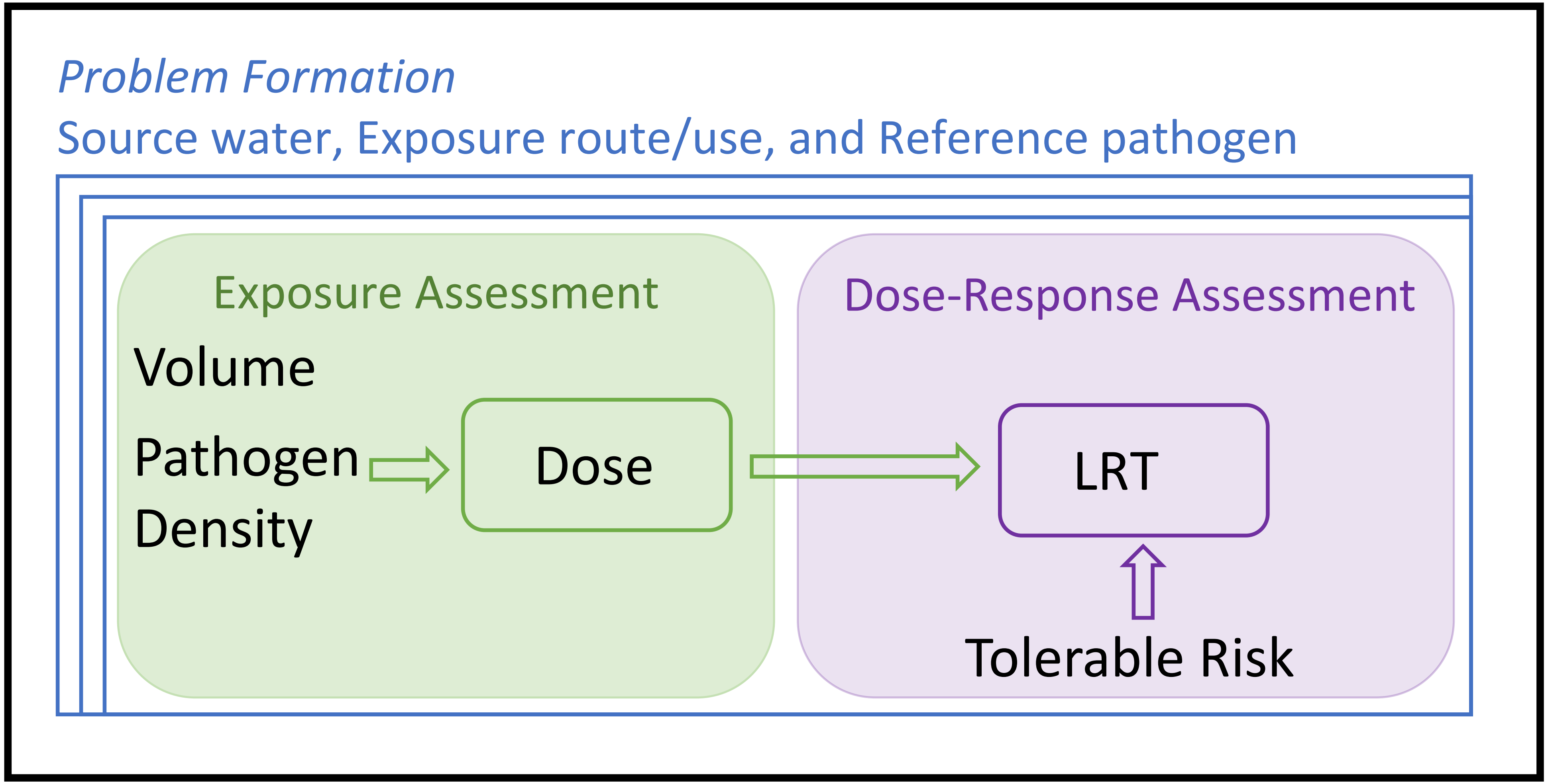
Number of users shedding pathogens

- Population size
- Infection rates
- Pathogen shedding durations

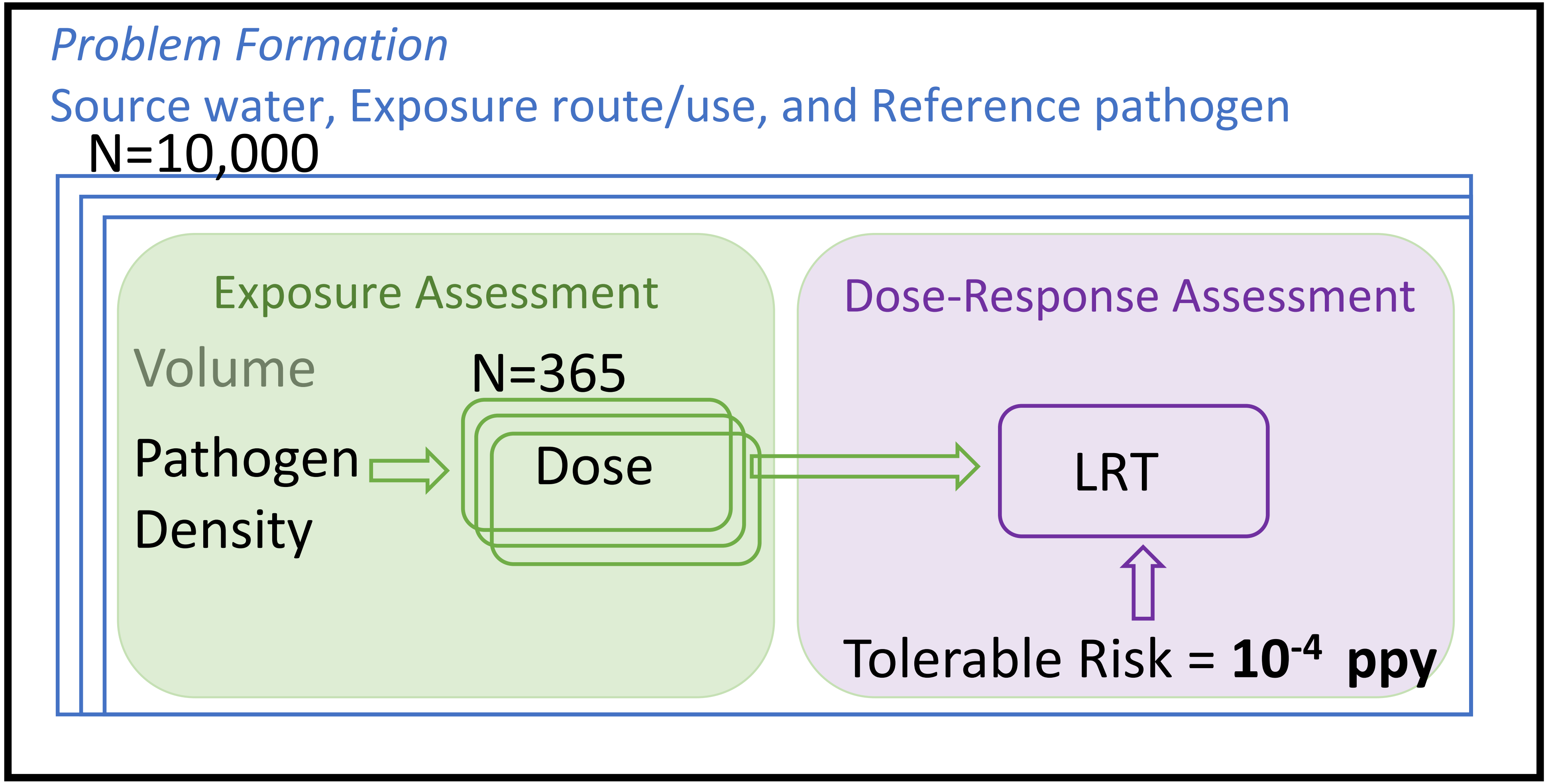
Pathogen concentrations in water

- Pathogen densities in feces during an infection
- Dilution by non-infected individuals

Quantitative Microbial Risk Assessment



QMRA Monte Carlo Simulation



	Norovirus (gc)[a]	*Adenovirus* (TCID50)	*Rotavirus* (FFU)	*Cryptosporidium* (oocysts)[b]	*Giardia* (cysts)	*Campylobacter* (CFU)	*Salmonella* (CFU)
Municipal Wastewater							
Municipal	9.0/8.7/6.2	5.6	-	6.4/6.3/5.5	-	5.1	1.1
Home use	9.3/8.9/6.4	6.7	-	7.7/7.4/6.8	-	6.1	3.3
Drinking	13.1/12.8/10.2	9.7	-	10.5/10.4/9.6	-	9.2	5.2
Greywater 1000-person collection							
Municipal	8.4/8.1/5.6	-	6.4	4.5/4.2/3.6	3.4	3.7	1.2
Home use	8.8/8.5/6.0	-	6.4	4.5/4.2/3.6	3.8	3.7	1.6
Drinking	12.6/12.3/9.8	-	10.6	8.8/8.5/7.9	7.6	8.0	5.4
Greywater 5-person collection[c]							
Municipal	7.7/7.4/4.9	-	5.9	0/0/0	0	0	0
Home use	7.8/7.8/5.0	-	6.3	0/0/0	0	0	0
Drinking	12.4/12.0/9.5	-	10.5	0/0/0	0	0	0
Stormwater – 10^{-1}							
Municipal	8.0/7.7/5.1	4.6	-	5.4/5.3/4.5	-	4.1	0.1
Home use	8.3/7.9/5.4	5.7	-	6.6/6.4/5.8	-	5.1	3.3
Drinking	12.1/11.7/9.3	8.7	-	9.5/9.4/8.6	-	8.2	4.2
Stormwater – 10^{-3}							
Municipal	6.0/5.7/3.2	2.6	-	3.4/3.3/2.5	-	2.1	0
Home use	6.2/5.9/3.4	3.7	-	4.7/4.4/3.8	-	3.1	1.2
Drinking	10.1/9.8/7.3	6.7	-	7.5/7.4/6.6	-	6.2	2.2
Rainwater							
Municipal	-	-	-	-	-	3.1	3.5
Home use	-	-	-	-	-	3.3	3.5
Drinking	-	-	-	-	-	7.3	7.7

[a]Hypergeometric model/Averaged results/Fractional Poisson

[b]Fractional Poisson/Averaged results/Exponential model

[c]99th%ile for protozoans and bacteria is approx. equal to the 95th%ile of the 1000-person system

Alternative 10^{-2} Risk Benchmark

	Norovirus (gc)[a]	Adenovirus (TCID50)	Rotavirus (FFU)	Cryptosporidium (oocysts)[b]	Giardia (cysts)	Campylobacter (CFU)	Salmonella (CFU)
Municipal Wastewater							
Municipal	7.0/6.7/4.2	3.6	-	4.4/4.3/3.5	-	3.1	-
Home use	7.2/6.8/4.3	4.7	-	5.6/5.4/4.7	-	4.0	-
Greywater 1000-person collection							
Municipal	6.4/6.1/3.6	-	4.2	2.5/2.3/1.6	-	1.7	-
Home use	6.7/6.3/3.9	-	3.8	2.5/2.2/1.6	-	1.7	-
Stormwater – 10^{-1}							
Municipal	5.9/5.7/3.1	2.6	-	3.4/3.3/2.5	-	2.1	-
Home use	6.2/5.8/3.4	3.7	-	4.6/4.4/3.7	-	3.0	-
Stormwater – 10^{-3}							
Municipal	3.9/3.7/1.1	0.6	-	1.4/1.3/0.5	-	0.1	-
Home use	4.2/3.8/1.4	1.7	-	2.6/2.4/1.7	-	1.0	-
Rainwater							
Municipal	-	-	-	-	-	-	1.5
Home use	-	-	-	-	-	-	1.5

[a]Hypergeometric model/Averaged results/Fractional Poisson

[b]Fractional Poisson/Averaged results/Exponential model

[C]99^{th}%ile for protozoans and bacteria is approx. equal to the 95^{th}%ile of the 1000-person system

Summary of QMRA Modeling

- Two detailed EPA-ORD publications will be submitted for peer review journal shortly
  - NWRI panel will use as part of their framework document to be published at the end of summer
- Greatest Uncertainties
  - Cross connection/accidental exposures
  - Dose response model for viruses
  - Highly variable pathogen data for stormwater
  - Real lack of data for pathogens in rainwater in US

Achieving Pathogen LRTs

Barrier	Example log removal credit			
	Virus	Bacteria	Protozoa	Factors
Depth filtration		0.25 – 1	0.5	
Cartridge filtration				
Diatomaceous earth	0.4 – 3[a]	0.1 – 3[a]	3.5 – 7[a]	DE grade
Microfiltration	1 (0 – 3.2)[b]	6 – 7[a]	4 – 7[a]	Membrane age
Ultrafiltration	6.2 (5.4 – 7.9)[b]	7.1 – 8.3[a]	6 – 7[a]	Membrane age
Reverse osmosis	2.7 - 7	4 - 6	5 - 6	Membrane seals
Advanced oxidation	6	6	6	

[a] AWWARF (2001) Removal of Emerging Waterborne Pathogens, AWWA Research Foundation.

[b] U.S. EPA (2005) Membrane Filtration Guidance Manual, EPA 815-R-06-009, Office of Water, Cincinnati, OH.

Monitoring

- Routine monitoring of indicator organisms does not provide real time information required for operation of DNWS
  - Cost prohibitive
- A new monitoring approach:
  - Start-up and Commissioning
    - Validation monitoring
      - Performance target confirmation via challenge testing (or endogenous organisms?)
  - Operational Monitoring
    - Ongoing verification of system performance
    - Continuous observations
    - Surrogate parameters correlated with LRTs
  - Controls for out of specification

Biological Organisms to Confirm Log Reduction Targets

- Measure pathogens
  - Hundreds of potential pathogens
  - Sporadic occurrence
  - Can be expensive
  - Negative results
- Measure biological surrogates that represent pathogens
  - Typical surrogates (fecal indicator organisms) too dilute
  - Spike with surrogate, calculate reduction
    - Challenge to spike large systems
  - Endogenous microbes as alternative biological surrogates

Alternative Biological Surrogate Criteria

- Endogenous to the system
- Relate to pathogen removal
- Consistently present in influent
- Present in high concentrations to allow a dynamic range of log removal
  - Target log reductions
    - Bacteria: 3 – 6 $\log_{10}$
    - Virus: 6 - 8 $\log_{10}$

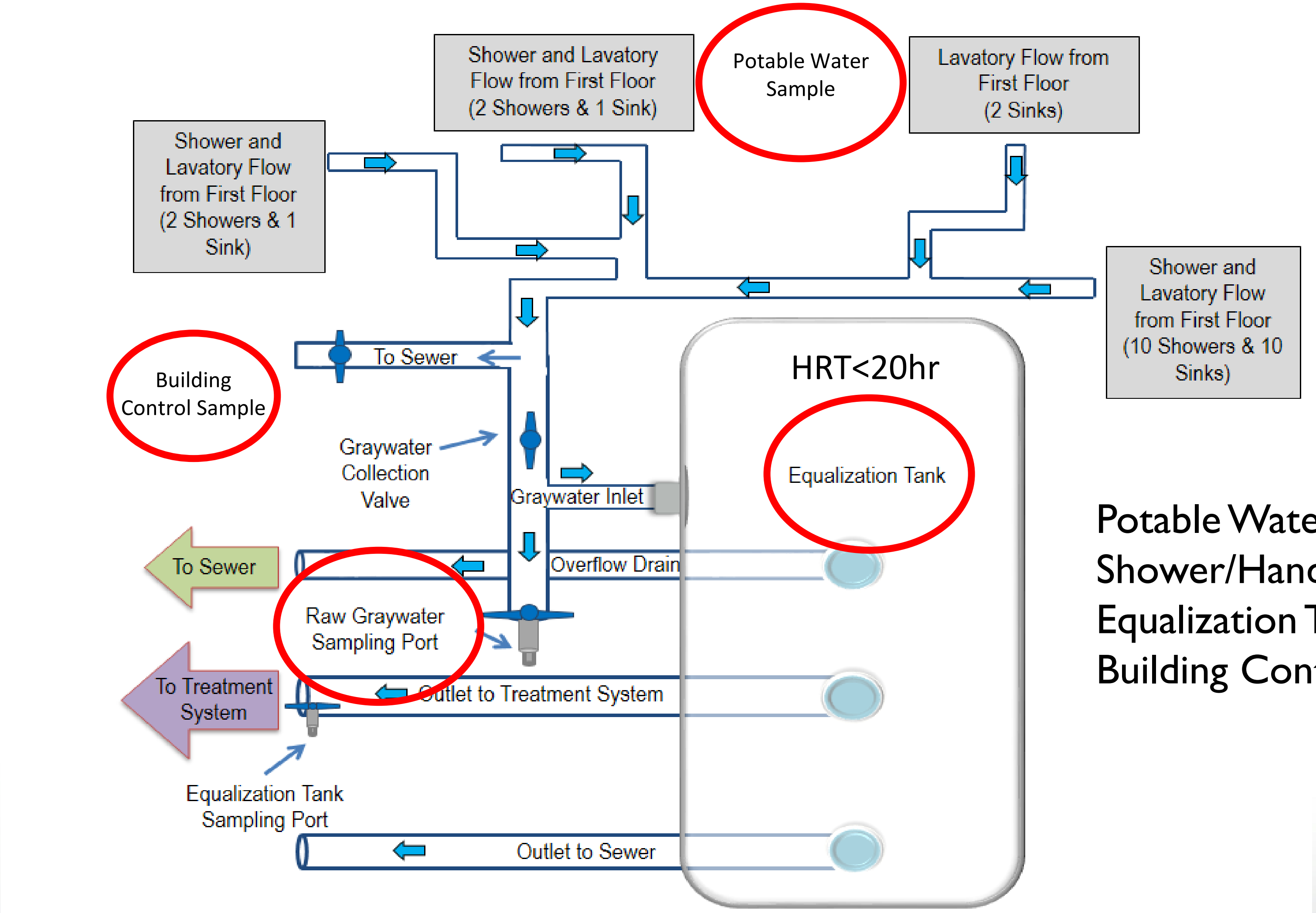
Research Strategy to Identify Alternative Biological Surrogates

- **Discovery of alternative biological surrogates**
  - What microbes are present in the DNWS?
- **Quantify alternative biological surrogates**
  - How abundant are the candidate surrogates?
  - Are the candidate surrogates consistently present in the influent of the DNWS?
- **Establish log reduction profiles of alternative biological surrogates during various treatment processes**
  - Compare to log reduction profiles of pathogens

Bacterial Community in Graywater

- Graywater sources
  - Dormitory at Colorado State University (CSU, Ft. Collins, CO)
    - 14 residence halls = 14 showers, 14 sinks
    - 28 person capacity
    - Composited in 946 L equalization tank
  - Athletic laundry facility at the University of Cincinnati (UC, Cincinnati, OH)
    - Launder ~10-30 garments per wash
    - Collected water directly from washing machines
- Bacterial communities analyzed by pyrosequencing 16S rRNA gene
  - Classification to genus level

CSU Graywater System

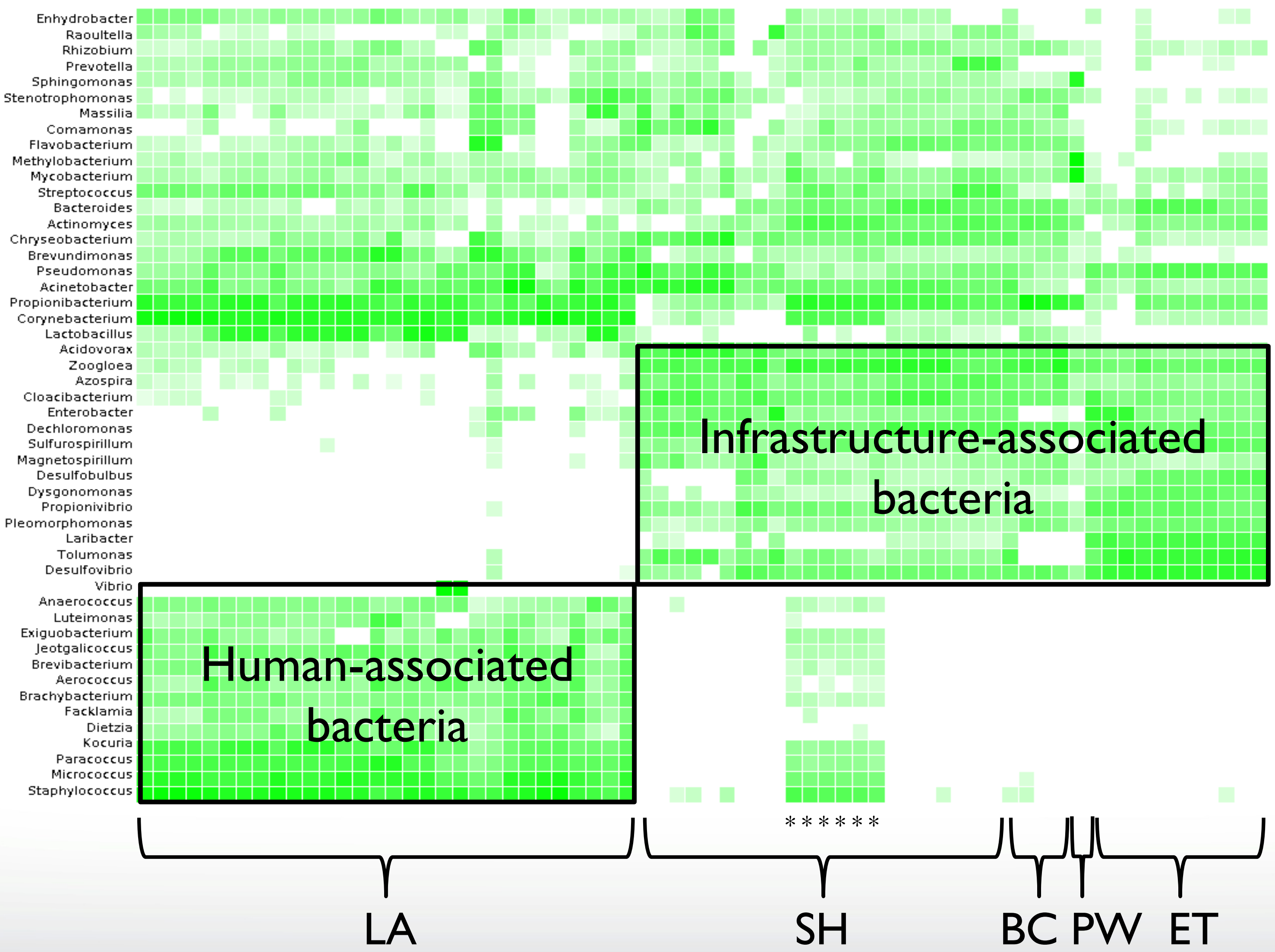


Potable Water (PW): n=1
Shower/Handwash (SH): n=18
Equalization Tank (ET): n=6
Building Control (BC): n=3

UC Commercial Washer

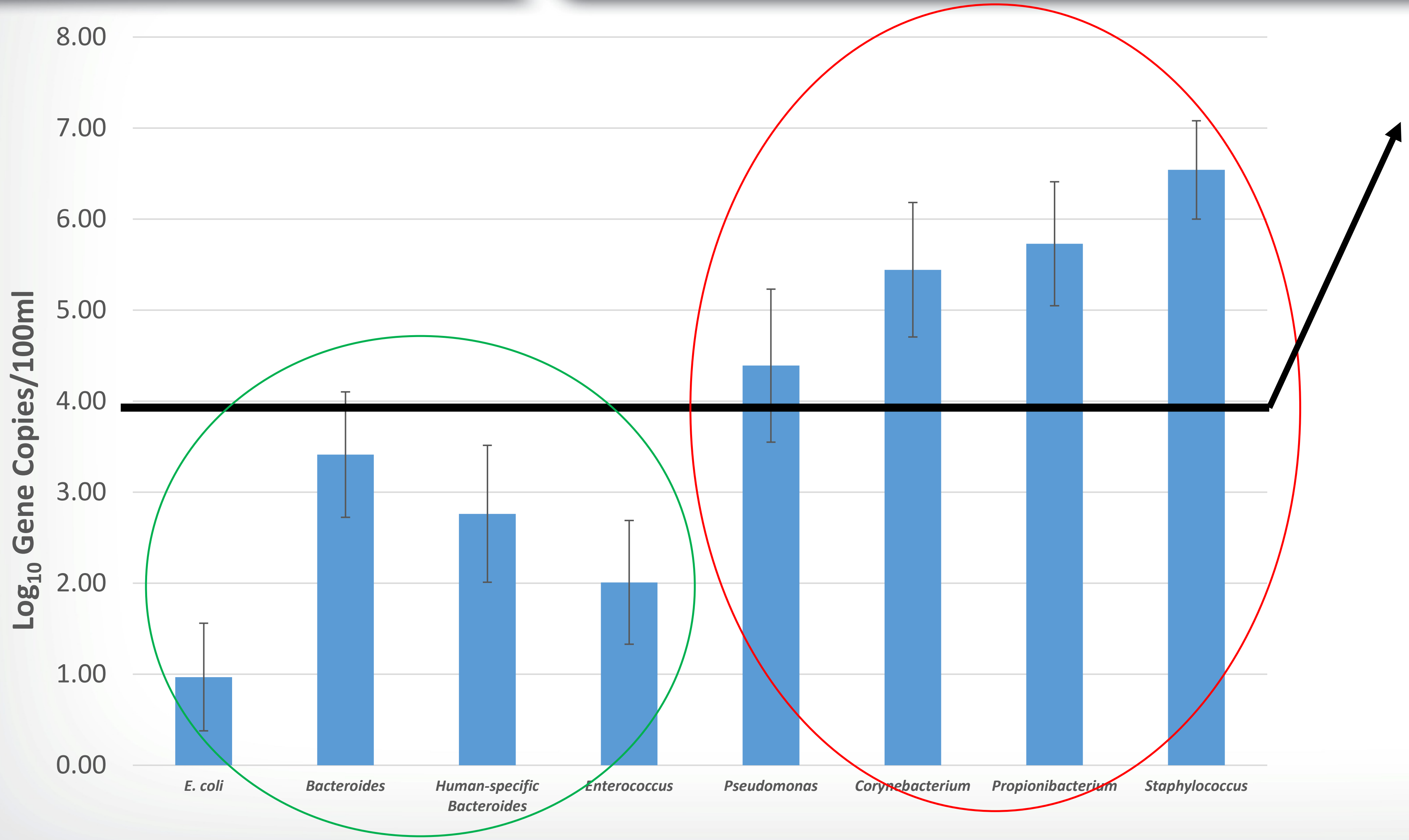
Laundry (LA): n=24

Log_{10}-scale Heat Map of Top 50 Genera Detected in Graywater



Keely et al. 2015. *Journal of Applied Microbiology* 119: 289

Quantification of Candidate Bacterial Surrogates in Laundry Graywater



Influenced by:

LRT
Tolerable risk level
Detection Limit

Zimmerman et al. 2014. *Environmental Science and Technology* 48, 7993

Summary (Bacteria)

- Skin-associated bacteria are the most abundant bacteria in laundry graywater
  - Present but variable in graywater recycling system
- Enterococci and *E. coli* levels not sufficiently high to quantify 4 $\log_{10}$ reduction
  - Can only measure average of 1-2 $\log_{10}$ reduction
- Endogenous bacteria can measure up to 6.4 $\log_{10}$ reduction
- Infrastructure-associated bacteria are the most abundant bacteria in graywater recycling systems
  - Abundant genera from ET could be alternative surrogates

Viral Community in Blackwater

- **Why consider bacteriophage?**
  - Viruses that infect bacteria, modulate function
  - Abundant – 10-100x more than bacteria
  - Relevant to viral pathogens, similar size, structure
- **Challenges for community analysis**
  - No universal gene
  - Need to remove prokaryotes, archaea and eukaryotes

National Blue Ribbon Commission to Accelerate Adoption of On-Site Water Reuse *(US Water Alliance and SFPUC)*

- Serve as a clearinghouse to exchange policies, **best management practices**, procedures, and **standards** for onsite water reuse systems;
- Identify **new business models** for water utilities as communities deploy onsite water systems;
- Create a **forum for collaboration** between water utilities and state public health agencies to prepare policy statements recommending guidelines and best management practices to encourage development of local onsite water systems;
- Develop and propose national policy and regulatory **guidelines** for onsite water systems, including water quality criteria, monitoring and reporting requirements, and operational and permitting strategies for consideration by state agencies and the US Environmental Protection Agency; and
- Identify additional **research needs** in the field of onsite water systems.

First Meeting: December 2016 Complete Activities: Mid year 2018