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# Risk-Based Guidance for Decentralized Non-Potable Water Systems

*Michael Jahne*
*Jahne.Michael@epa.gov*

**Office of Research and Development**
Center for Environmental Solutions and Emergency Response, Water Infastucture Division, Biological Contaminants Branch

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# Collaborators

- **Mary Schoen (Soller Environmental)**
- **Jay Garland (EPA-ORD)**

- Nichole Brinkman (EPA-ORD)
- Scott Keely (EPA-ORD)
- Emily Anneken (EPA-ORD)
- Brian Zimmerman (EPA-ORD)
- Nicholas Ashbolt (U. Alberta)

- Partner Facilities and Personnel
- EPA-Region 9 Lab

- NWRI Independent Advisory Panel
- National Blue Ribbon Commission

# Learning Objectives

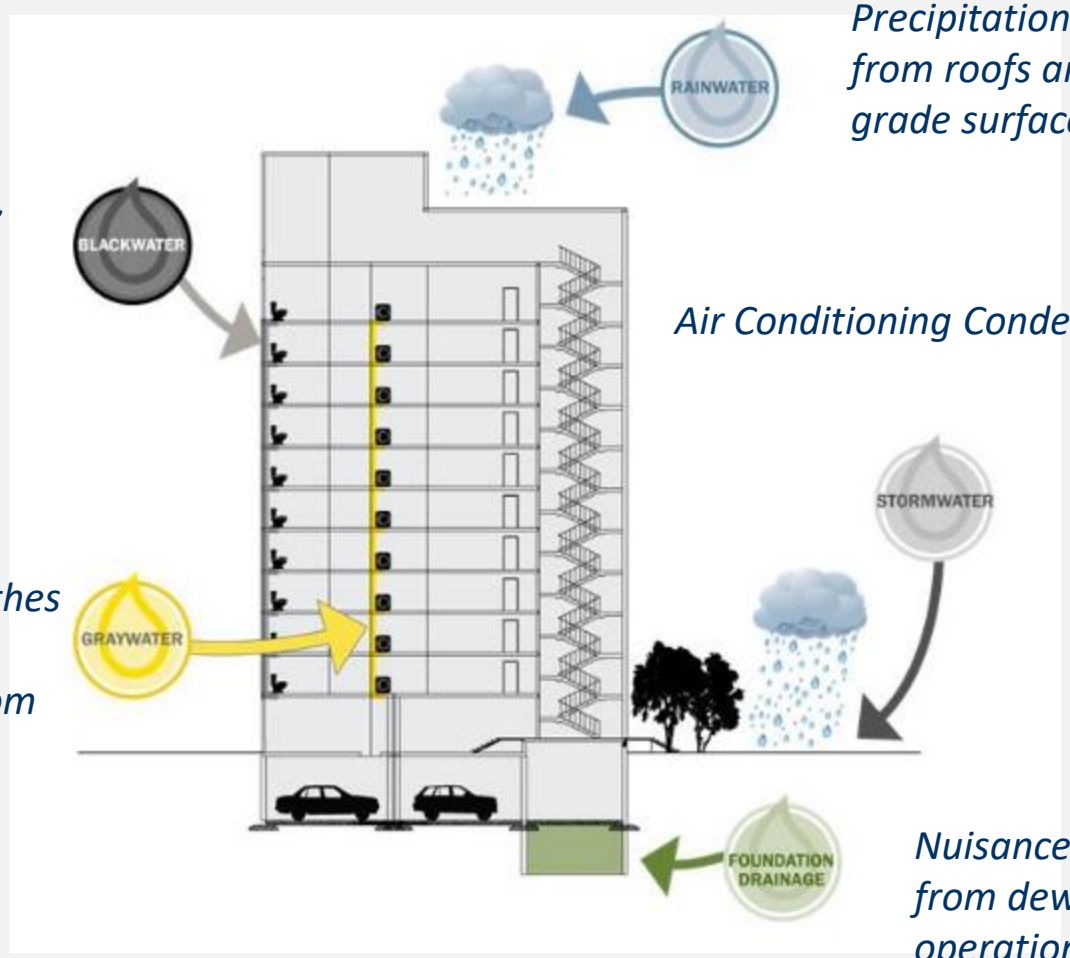
- Rationale and Approach for Quantitative Microbial Risk Assessment (QMRA)

- Application of QMRA to Define Treatment Guidance for Fit-for Purpose Non-potable Water Reuse

# Motivation: From Waste to Resource

*Precipitation collected from roofs and above-grade surfaces*

*Wastewater from toilets, dishwashers, kitchen sinks, and utility sinks*




*Air Conditioning Condensate*

*Precipitation collected at or below grade*

*Wastewater from clothes washers, bathtubs, showers, and bathroom sinks*

*Nuisance groundwater from dewatering operations*

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# Potential Benefits of Onsite Reuse

- **Water scarcity** (finding more water)
- **Efficiency**
  - Treating water only as needed for its end use application (fit-for purpose)
  - Reusing water close to the source, avoiding construction of recycled water pipeline
  - Defers capital costs of large-scale infrastructure
- **Reduces pollution and loading** to sewers and water bodies
- **Increases resiliency and adaptability** of our water and wastewater infrastructure
- Generates **green space** in urban corridors
- Meets and exceeds **green building goals**

# The Solaire: Battery Park, NYC


**Produces**: 25,000 gallons per day (gpd) of wastewater

**Utilizes**: Membrane bioreactor (MBR) treatment

**Application**: Toilet flushing, cooling, irrigation

**Operating**: Since 2004

**Primary Driver**: Reduced wastewater flow


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# San Francisco Public Utilities HQ

**Rainwater Harvesting System**

- 25,000 gallon cistern
- Reuse for irrigation

**Wetland Treatment System**

- Collects and treats building's wastewater
- Reuse for toilet flushing
- 5,000 gpd capacity

# 181 Fremont San Francisco

- 706,000 sf mixed-use building
- 5,000 gpd graywater treatment
- Membrane bioreactor system
- Drivers:
  - Sustainability goals
  - LEED

# Salesforce Tower San Francisco

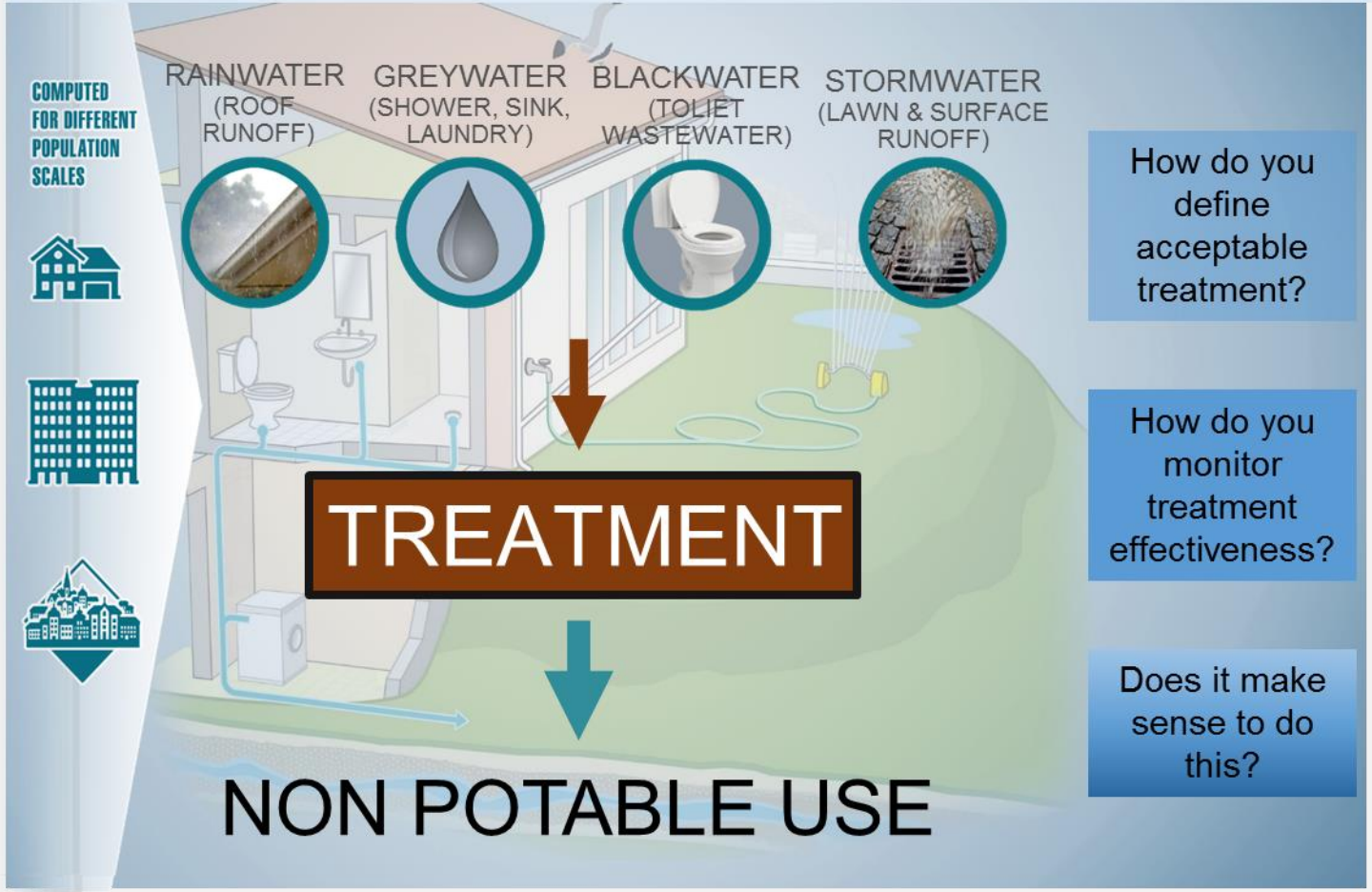
- 1.6 million $ft^2$ office building
- MBR blackwater system for up to 30,000 gpd
- Toilet flushing, irrigation, and cooling
- Drivers:
  - Sustainability goals
  - LEED certification
  - Utilize existing dual-plumbing

# Hassalo on Eighth Portland, OR

- 60,000 gallons of wastewater per day
- Toilet flushing, cooling systems, irrigation
- Low energy treatment
- Aesthetically pleasing landscape

# FINDING NEW WATER

## Alternative Water Reuse




How do you define acceptable treatment?

How do you monitor treatment effectiveness?

Does it make sense to do this?

Partners

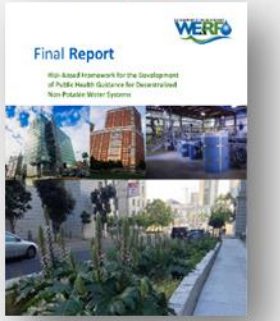
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

National Blue Ribbon Commission for Onsite Non-potable Water Systems

WATER ENVIRONMENT + REUSE FOUNDATION WE&RF

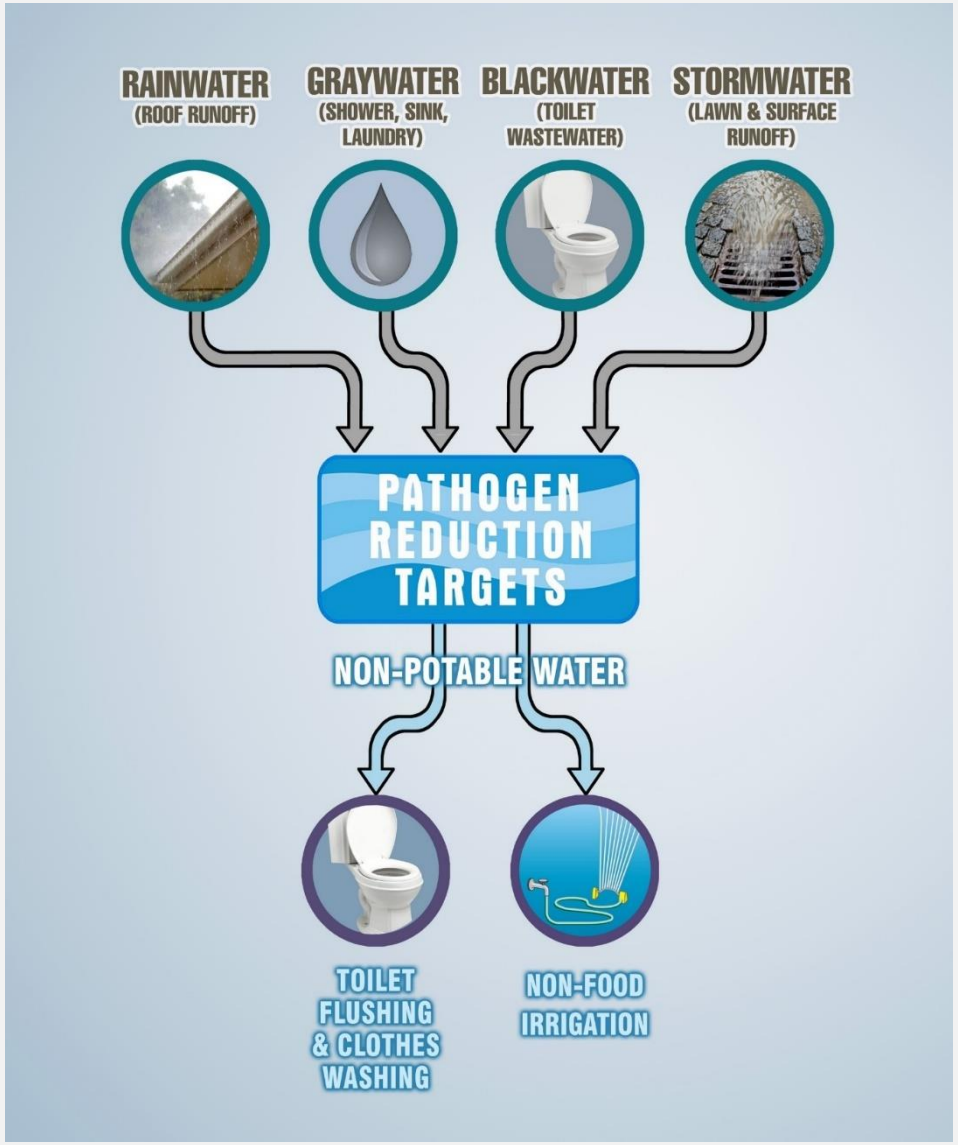
US Water Alliance

Report



# How do you define acceptable treatment?

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



# Graywater Use to Flush Toilets
## *Varying Standards*

| | $BOD_5$ (mg $L^{-1}$) | TSS (mg $L^{-1}$) | Turbidity (NTU) | Total Coliform (cfu/ 100ml) | *E. Coli* (cfu/ 100ml) | Disinfection |
|---|---|---|---|---|---|---|
| **California** | 10 | 10 | 2 | 2.2 | 2.2 | 0.5 – 2.5 mg/L residual chlorine |
| **New Mexico** | 30 | 30 | - | - | 200 | - |
| **Oregon** | 10 | 10 | - | - | 2.2 | - |
| **Georgia** | - | - | 10 | 500 | 100 | - |
| **Texas** | - | - | - | - | 20 | - |
| **Massachusetts** | 10 | 5 | 2 | - | 14 | - |
| **Wisconsin** | 200 | 5 | - | - | - | 0.1 – 4 mg $L^{-1}$ residual chlorine |
| **Colorado** | 10 | 10 | 2 | - | 2.2 | 0.5 – 2.5 mg/L residual chlorine |
| **Typical Graywater** | 80 - 380 | 54 -280 | 28-1340 | $10^{7.2}$ –$10^{8.8}$ | $10^{5.4}$ –$10^{7.2}$ | N/A |

**Meeting standards means reducing the presence of pathogens by orders of magnitude – this informs "log reduction" targets**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# National Sanitation Foundation 350 Water Quality for Graywater Use for Toilet Flushing

| Parameter | Class R[a] | | Class C[b] | |
|---|---|---|---|---|
| | Test Average | Single Sample Maximum | Test Average | Single Sample Maximum |
| $CBOD_5$ (mg/l) | 10 | 25 | 10 | 25 |
| TSS (mg/l) | 10 | 30 | 10 | 30 |
| Turbidity (NTU) | 5 | 10 | 2 | 5 |
| *E. coli* (MPN/100 ml) | 14 | 240 | 2.2 | 200 |
| pH (SU) | 6.0-9.0 | | 6.0-9.0 | |
| Storage vessel residual chlorine (mg/l) | ≥ 0.5 - ≥ 2.5 | | ≥ 0.5 - ≥ 2.5 | |

[a] Class R: Flows through graywater system are less than 400 gpd
[b] Class C: Flows through graywater system are less than 1500 gpd

- Standardization is an improvement, but not risk based.
- **What do those levels of *E. coli* mean in terms of risk?**


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# Approach: Developing Risk-based Pathogen Reduction Targets

- "Risk-based" targets attempt to achieve a specific level of protection (aka tolerable risk or level of infection)
  - $10^{-4}$ infections per person per year (ppy)
  - $10^{-2}$ infections ppy

- Example: World Health Organization (2006) risk-based targets for wastewater reuse for agriculture

# 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

# What is QMRA?

- **Q**uantitative **M**icrobial **R**isk **A**ssessment
- Framework and approach that brings information and data together with mathematical models to address the spread of microbial agents through environmental exposures
- Estimates the likelihood of human infection following exposure to microbial pathogens

# Reasons for QMRA (EPA 2014)

- To assess the **potential for human risk** associated with exposure to a known pathogen;
- To determine **critical points for control**;
- To determine **specific treatment processes** to reduce, remove, or inactivate pathogens;
- To predict the **consequences of various management options** for reducing risk;
- To identify and prioritize **research needs**;
- To assist in **epidemiological investigations**.

*EPA-820-R-14-009: Microbiological Risk Assessment (MRA) Tools, Methods, and Approaches for Water Media*

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# QMRA Process

- Before: Problem formulation
- Four iterative steps:
  - Hazard identification
  - Hazard characterization
  - Exposure assessment
  - Risk characterization
- After: Risk management

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# Hazard Identification

- General information about the agents capable of causing adverse health effects and to which human exposure is possible
  - Microbiological characteristics of the pathogen
    - Life stages, infectivity, virulence traits
  - Epidemiological information
    - Mode of transmission, latency/incubation period
  - Clinical information
    - Symptoms, clinical outcomes, vulnerable populations

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# Hazard Characterization

- Describe the agents' dose-response: the relationship between the magnitude of exposure and the severity of health impacts
  - Dose-response models
    - Mathematical functions derived for specific pathogens
  - Low-dose extrapolation
    - Dose corresponding to acceptably low risk is needed from high dose animal studies or outbreak data

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# Exposure Assessment

- Estimate the extent of potential human exposure to the hazard
  - Exposure pathways
    - Ingestion, inhalation, contact
  - Environmental fate and transport
    - Measurements and modeling
  - Amount, frequency, length of time of exposure
    - Observation and literature review

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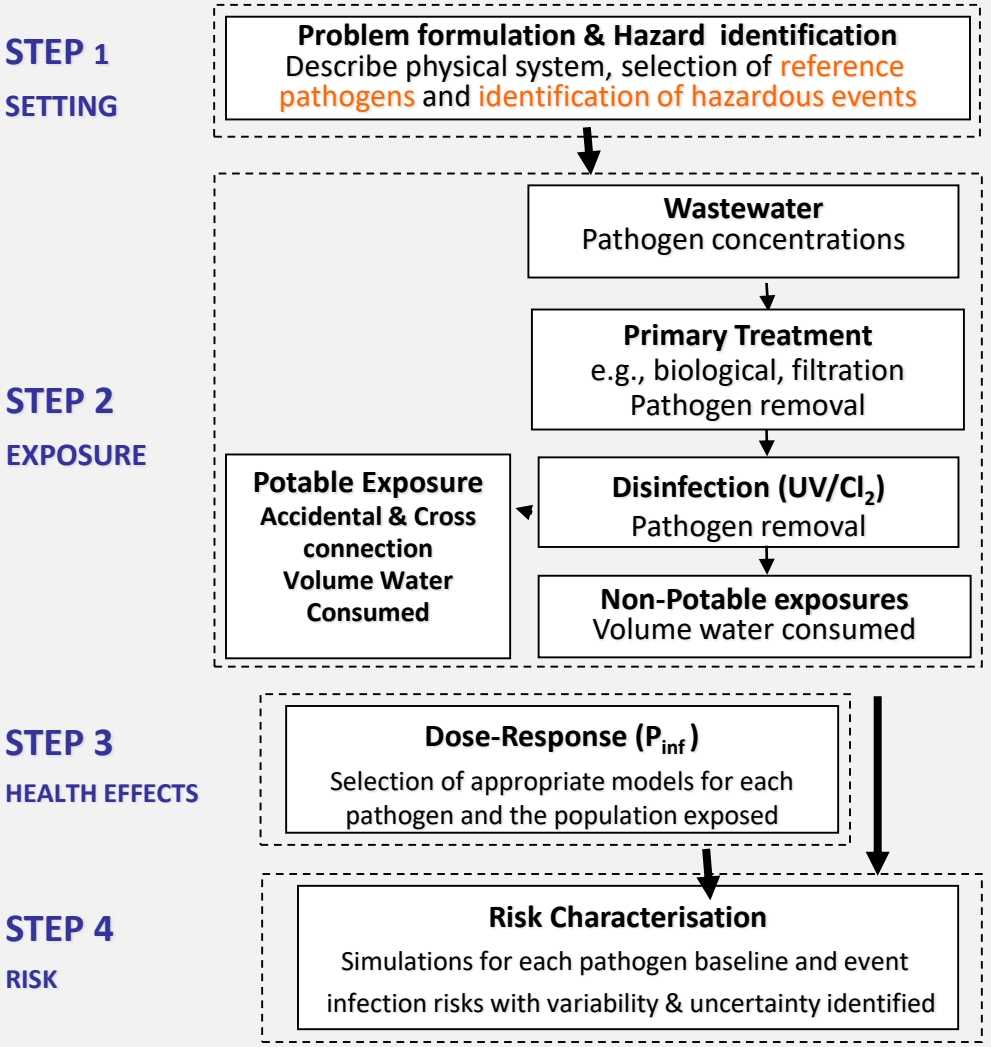
# Risk Characterization

- Synthesis of information generated in other phases into an estimate of quantitative risk
  - Point estimate
    - Single risk estimate based on discrete exposure and dose-response inputs
  - Probabilistic estimate
    - Parameters expressed as probability distribution and their variability propagated through to model output
      - Uncertainty in input parameters and variability of individuals
      - Allows sensitivity analysis

# Water Reuse QMRA





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# Hazard Identification

- Reference pathogens needed for each pathogen class


Viruses Bacteria Parasites/ Protozoa


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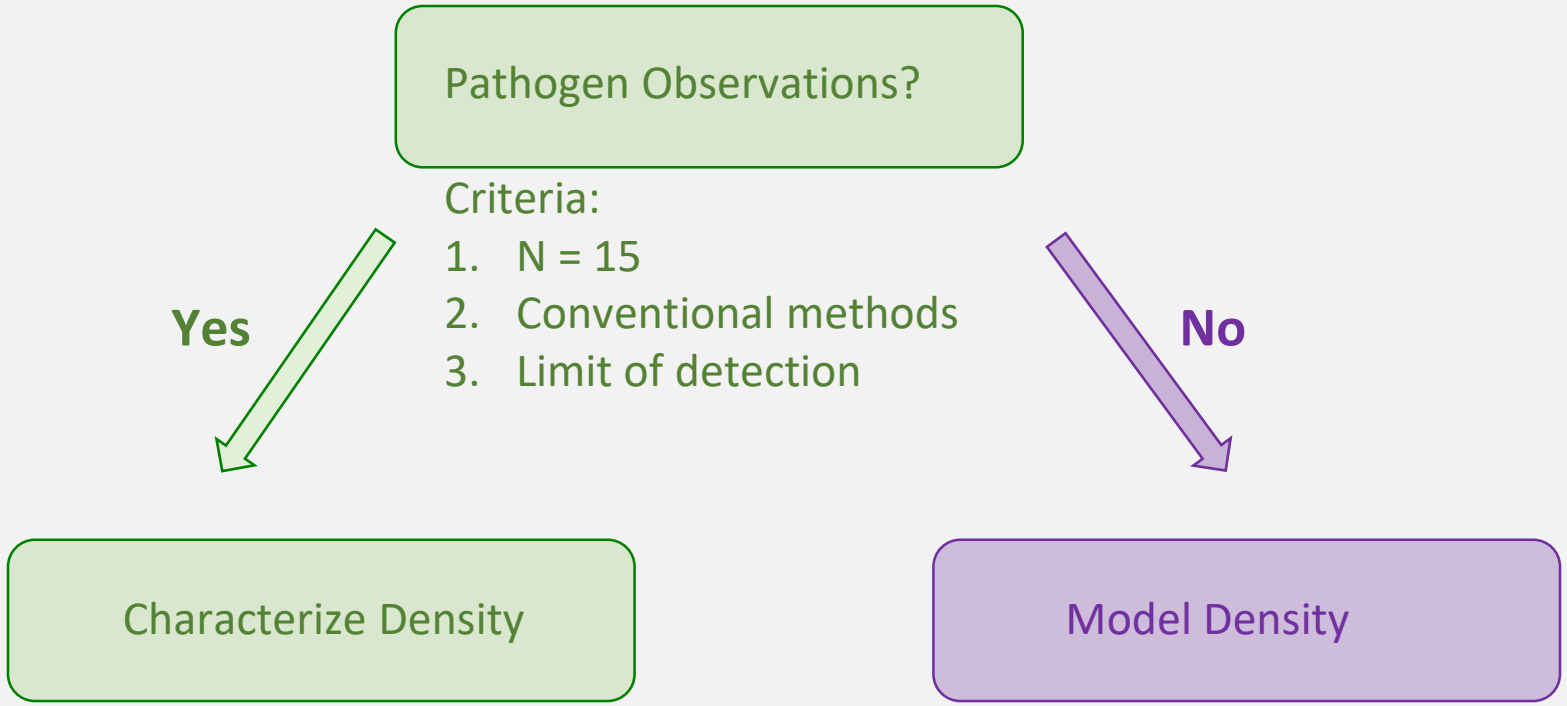
# Initial Pathogen Densities




*Limited availability of data on pathogen levels for all of the water types*

# Pathogen Density Characterizations

- Stormwater: dilutions of municipal wastewater
- Roof runoff: animal fecal contamination
- Onsite graywater and wastewater: epidemiology-based simulation
  - Pathogen infections intermittent in small populations
  - Limited dilution effects

# Epidemiology-Based Approach

**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

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

# Pathogen Shedding in Feces

```
  [1] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 [31] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 [61] 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 [91] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[121] 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[151] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[181] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[211] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[241] 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[271] 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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[331] 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[361] 0 0 0 0 0
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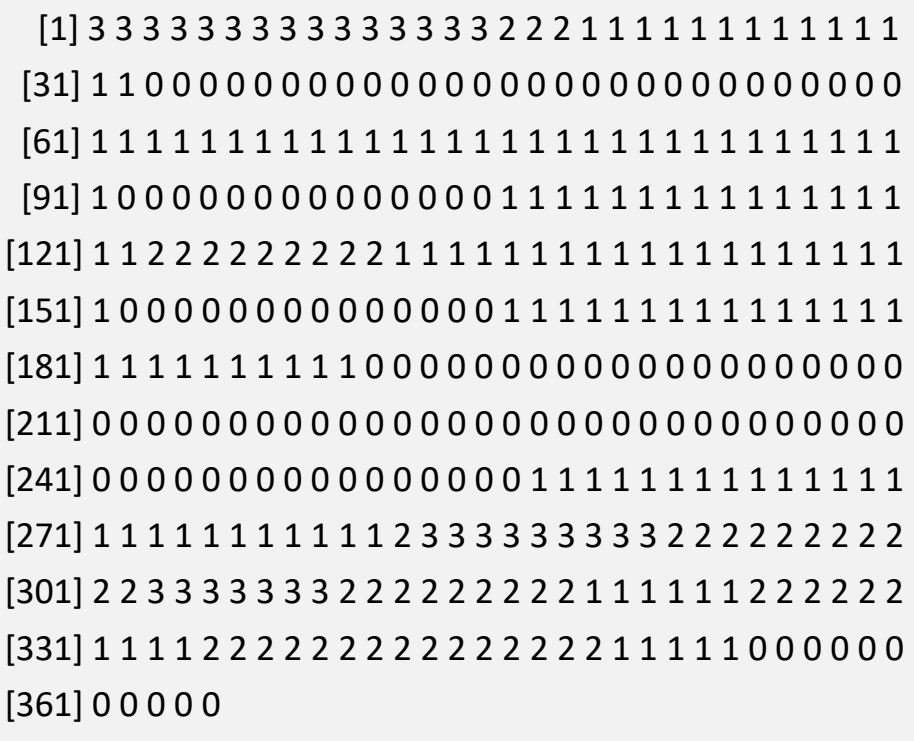


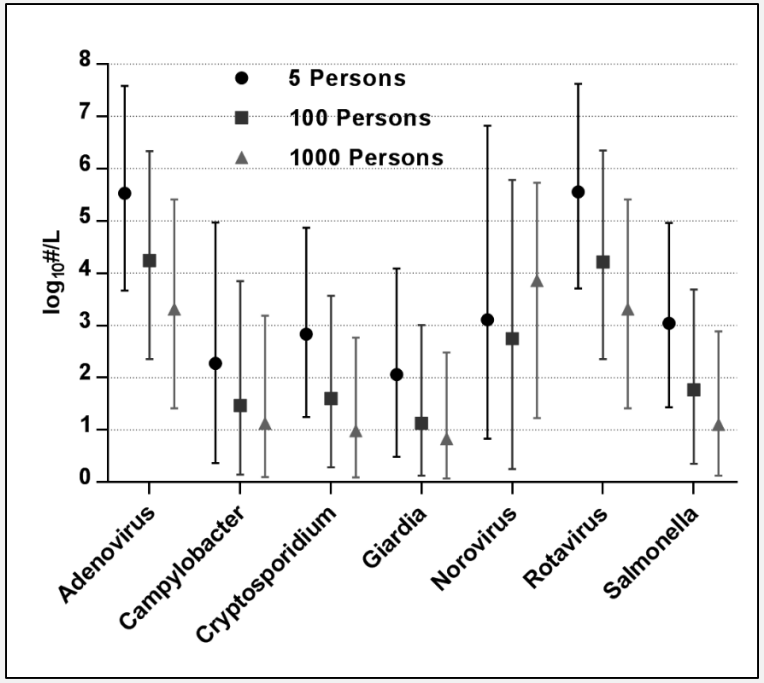
# Pathogen Simulation Results

| | 5 persons | | | 100 persons | | | 1000 persons | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5% | **50%** | 95% | 5% | **50%** | 95% | 5% | **50%** | 95% |
| *Adenovirus* | 0% | **0%** | 1% | 0% | **2%** | 7% | 11% | **20%** | 30% |
| *Campylobacter* | 0% | **0%** | 0% | 0% | **0%** | 13% | 8% | **27%** | 49% |
| *Cryptosporidium* | 0% | **0%** | 0% | 0% | **0%** | 6% | 0% | **10%** | 25% |
| *Giardia* | 0% | **0%** | 0% | 0% | **0%** | 53% | 24% | **73%** | 100% |
| *Norovirus* | 0% | **0%** | 12% | 22% | **45%** | 68% | 98% | **100%** | 100% |
| *Rotavirus* | 0% | **0%** | 1% | 0% | **2%** | 7% | 10% | **19%** | 30% |
| *Salmonella* | 0% | **0%** | 0% | 0% | **0%** | 12% | 5% | **23%** | 43% |

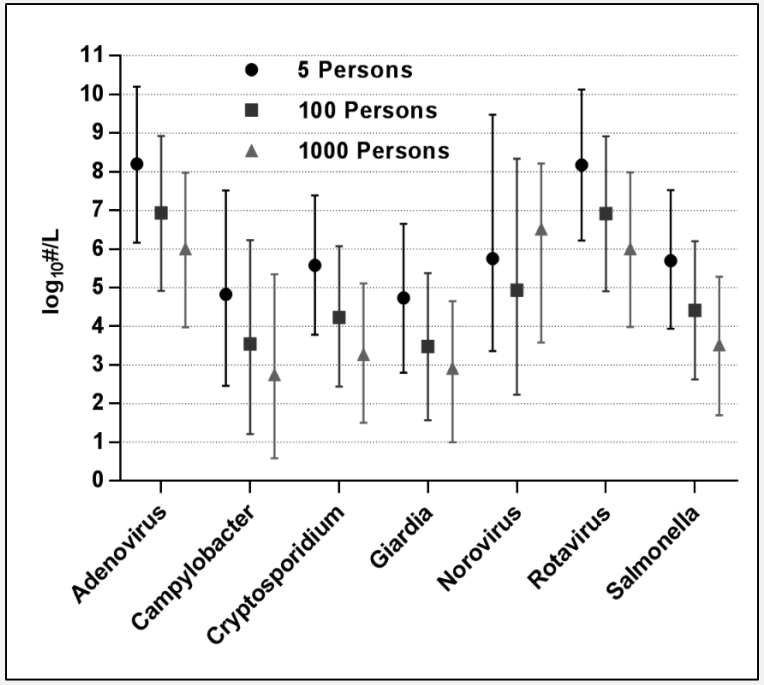
- Pathogen infections intermittent in small populations
- Frequency of pathogen occurrence increases with scale
  - –Infections become likely to overlap

# Pathogen Simulation Results

Graywater




Wastewater




- Small populations have limited wastewater dilution
- As population ↑, frequency ↑ and concentrations ↓

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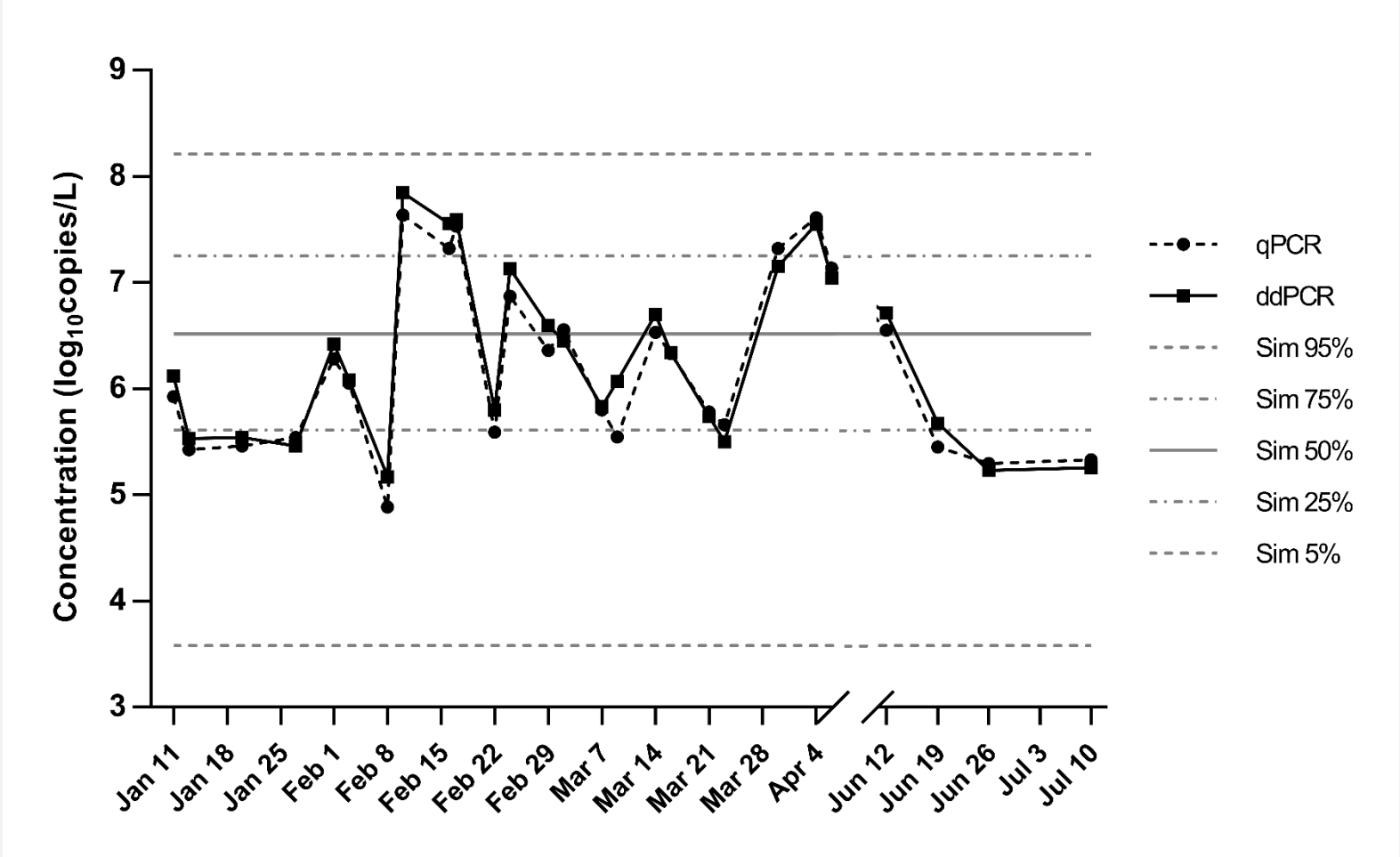
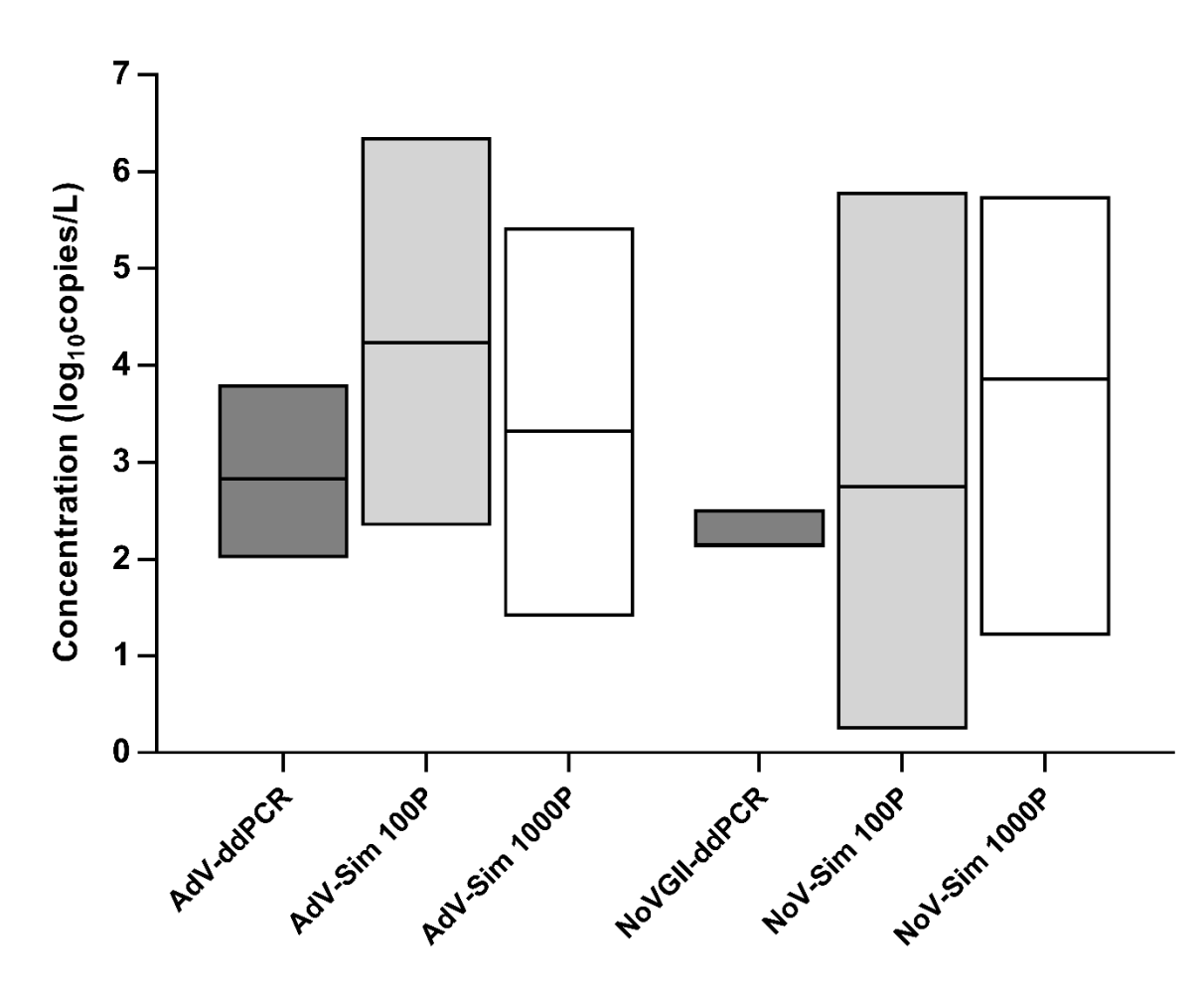
# Model Validation Measurements

- 3 decentralized systems
  - 2 graywater (GW1 office building; GW2 residential)
  - 1 wastewater (WW1 office building)
  - 500-1000 occupants
- 3 pathogen targets
  - Norovirus (NoVGI, NoVGII) and adenovirus (AdV)
- 2 analysis methods
  - qPCR / RT-qPCR
  - ddPCR / RT-ddPCR

# NoVGII in Onsite Wastewater



# 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% |

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# Summary: Model Validation Measurements

- Simulation performed well at characterizing these sites, although limited quantifiable data for graywater
- LRTs based on simulation results appear reasonable in context of pathogen observations
- Pathogen monitoring may be insufficient to fully evaluate the risks of decentralized water reuse
  - Improved method sensitivity is needed
  - Simulation model can provide an alternative approach

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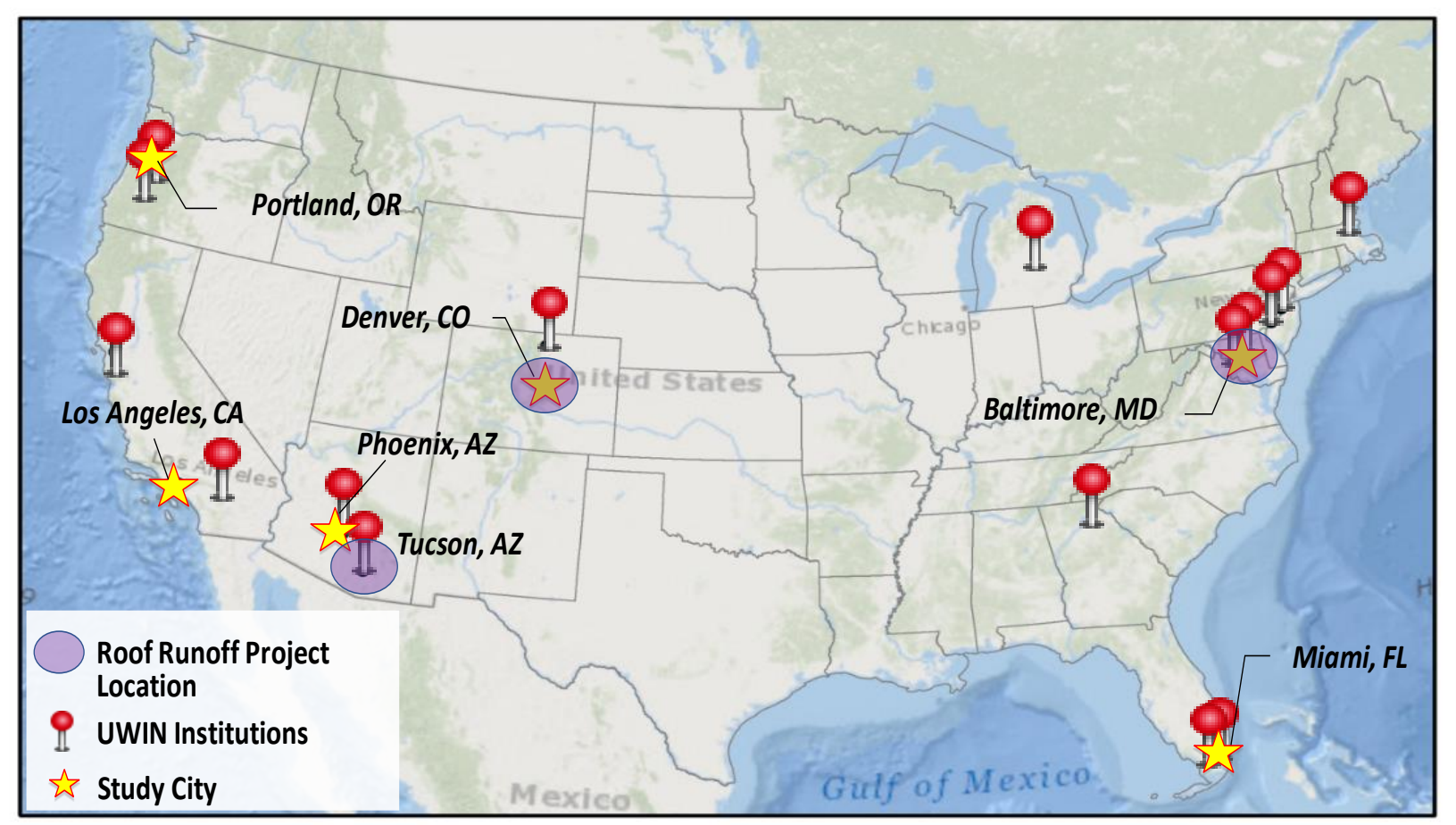
# Next Steps: "Off The Roof" Study

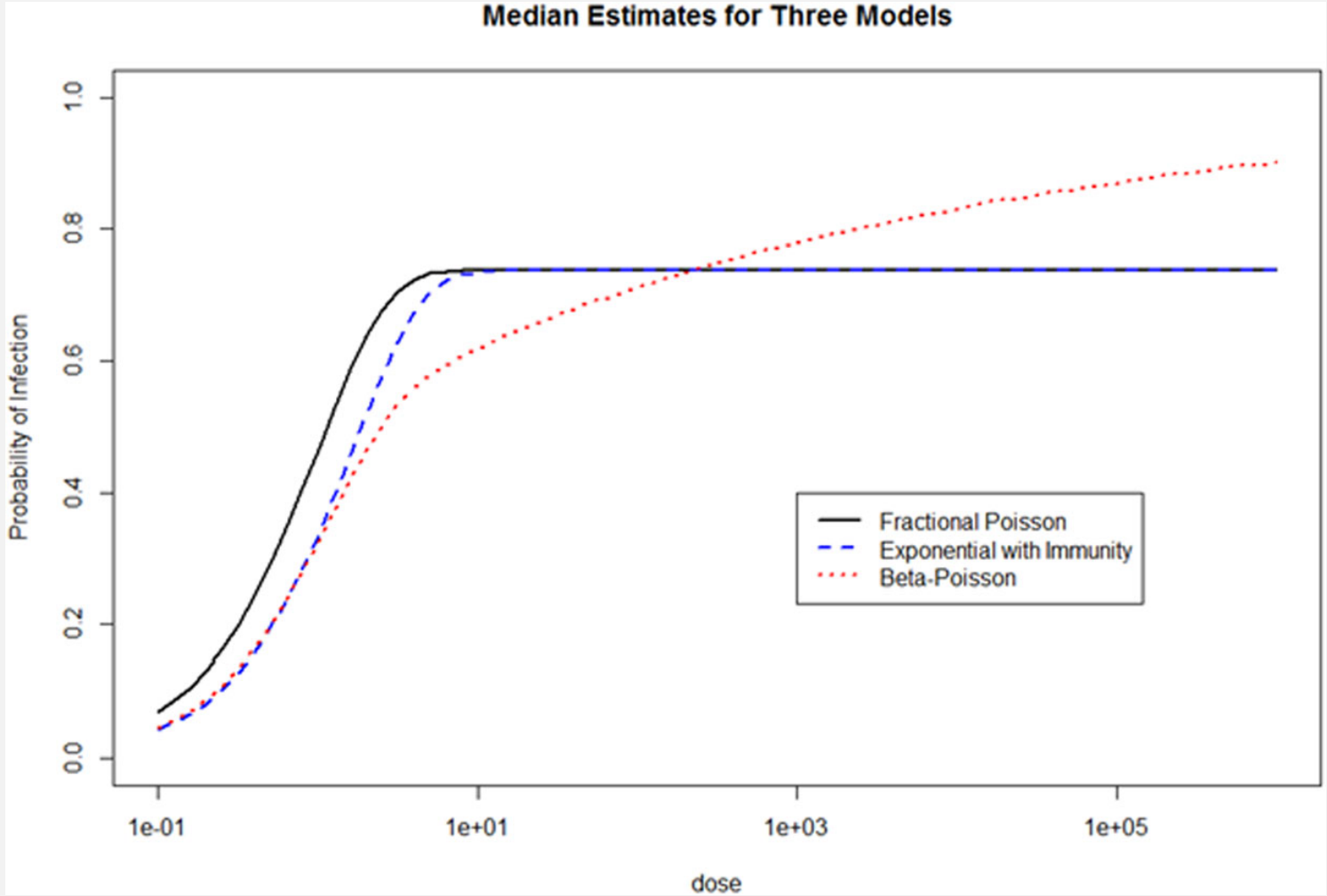


# Hazard Characterization

## Dose-Response Relationships

| Reference Pathogen | Model | Parameters | Parameter Values | Units | Reference | Susceptible fraction |
|---|---|---|---|---|---|---|
| *Norovirus* GI | Hypergeometric | alpha<br>beta | 0.04<br>0.055 | gc | (Teunis et al. 2008) | 1 |
| *Norovirus* (GI & GII.4) | Fractional Poisson | P<br>u | 0.72<br>1106 | gc | (Messner et al. 2014) | 1 |
| *Cryptosporidium* spp. | Fractional Poisson | P | 0.737 | oocysts | (Messner and Berger 2016) | 1 |
| *Cryptosporidium* spp. | Exponential | r | 0.09 | oocysts | (U.S. EPA 2005) | 1 |

# Example Dose-Response




*Messner and Berger (2016) Risk Analysis 36(10), 1969-1982*

# Exposure Assessment

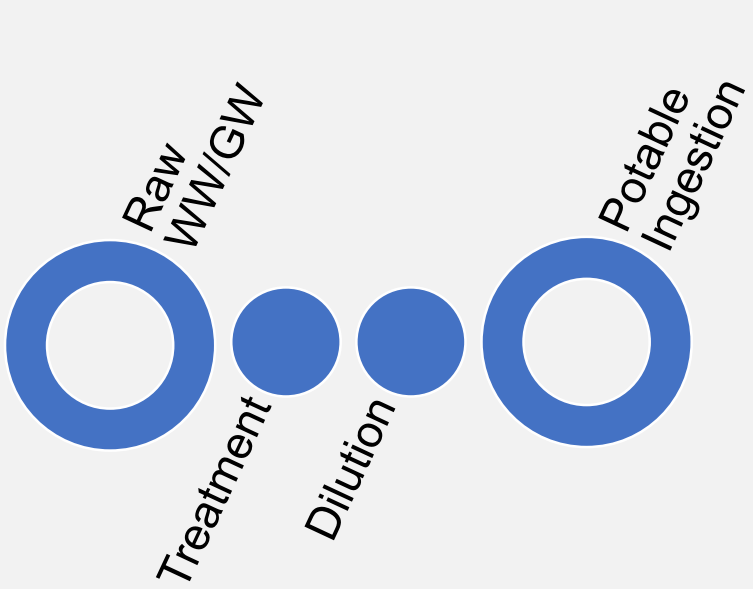
## Ingestion Volumes

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

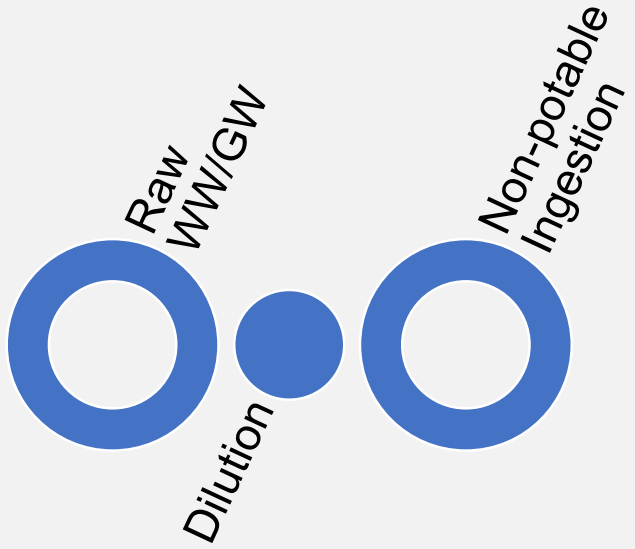
NRMMC, EPHC, AHMC (2006). Australian guidelines for water recycling: managing health and environmental risks (Phase 1).

# Cross-Connection QMRA

- Two unique scenarios for non-potable water systems
- What event durations, intrusion dilutions, and fractions of users exposed are considered “safe”?
- Is the built-in safety factor sufficient?

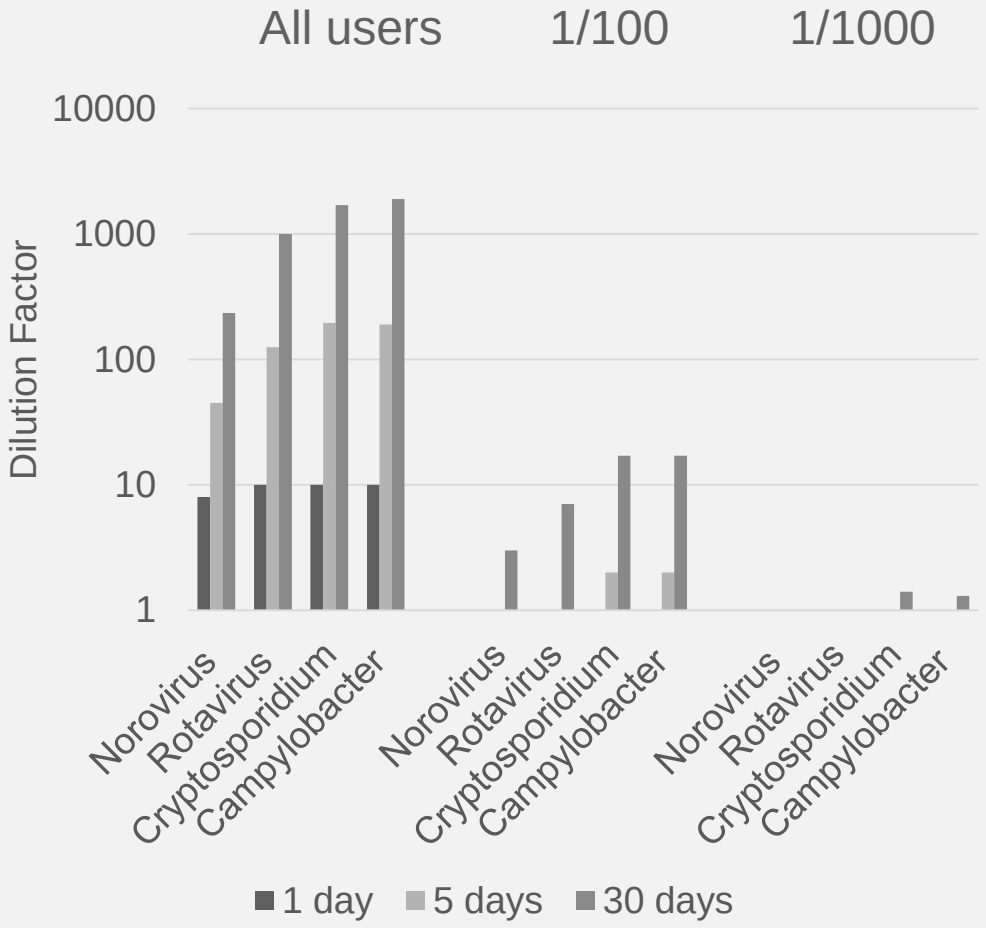



**Reclaimed to potable**

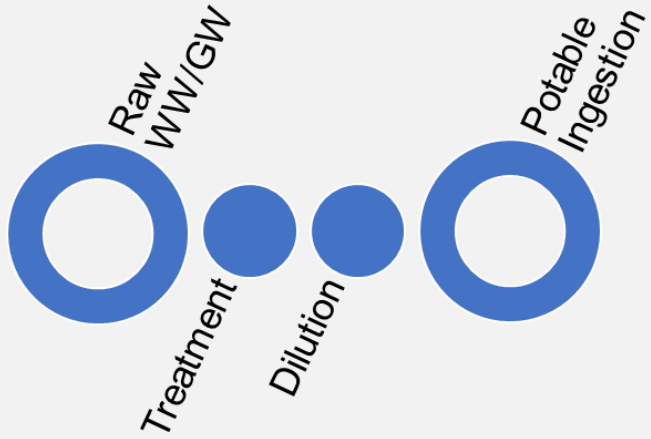



**Raw to non-potable**

# When are Reclaimed to Potable events OK?

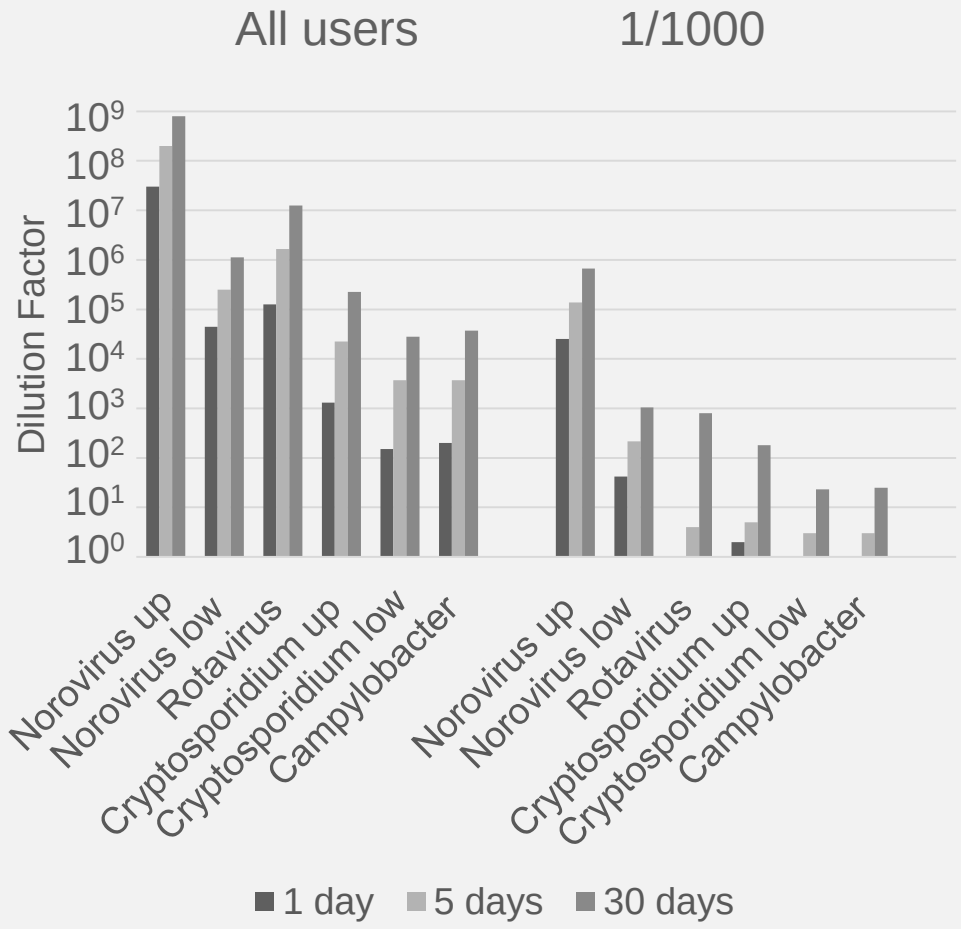



- When there is moderate dilution **or** a small fraction of the population is exposed




*Schoen et al. (2018) Water 10, 1352-1366*

# When are WW to Non-potable events OK?




- When there is moderate dilution **and** a small fraction of the population is exposed


*Schoen et al. (2018) Water 10, 1352-1366*

# Summary: Cross-Connection QMRA

- Generally low risks for short duration (<5-day); small exposed population (<1%); and high intrusion dilution (>1:1,000)
- Higher risks for cross-connection of waste-/graywater to reclaimed water than for reclaimed to potable
  - Small exposure volume but high pathogen load
- Built-in protection effective for short-term, low magnitude reclaimed to potable cross-connection events
  - There is <1 log decrease in LRTs if ingestion safety factor is omitted

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# Next Steps: Exposure Sensitivity Analysis

- Goal:
  - Inform selection of pathogen LRTs for poorly characterized uses
- Approach:
  - Investigate sensitivity of LRT to volume ingested
  - Summarize existing LRTs for non-potable uses
  - Calculate LRTs for additional well or poorly characterized uses
    - Vehicle washing, shower, decorative fountain

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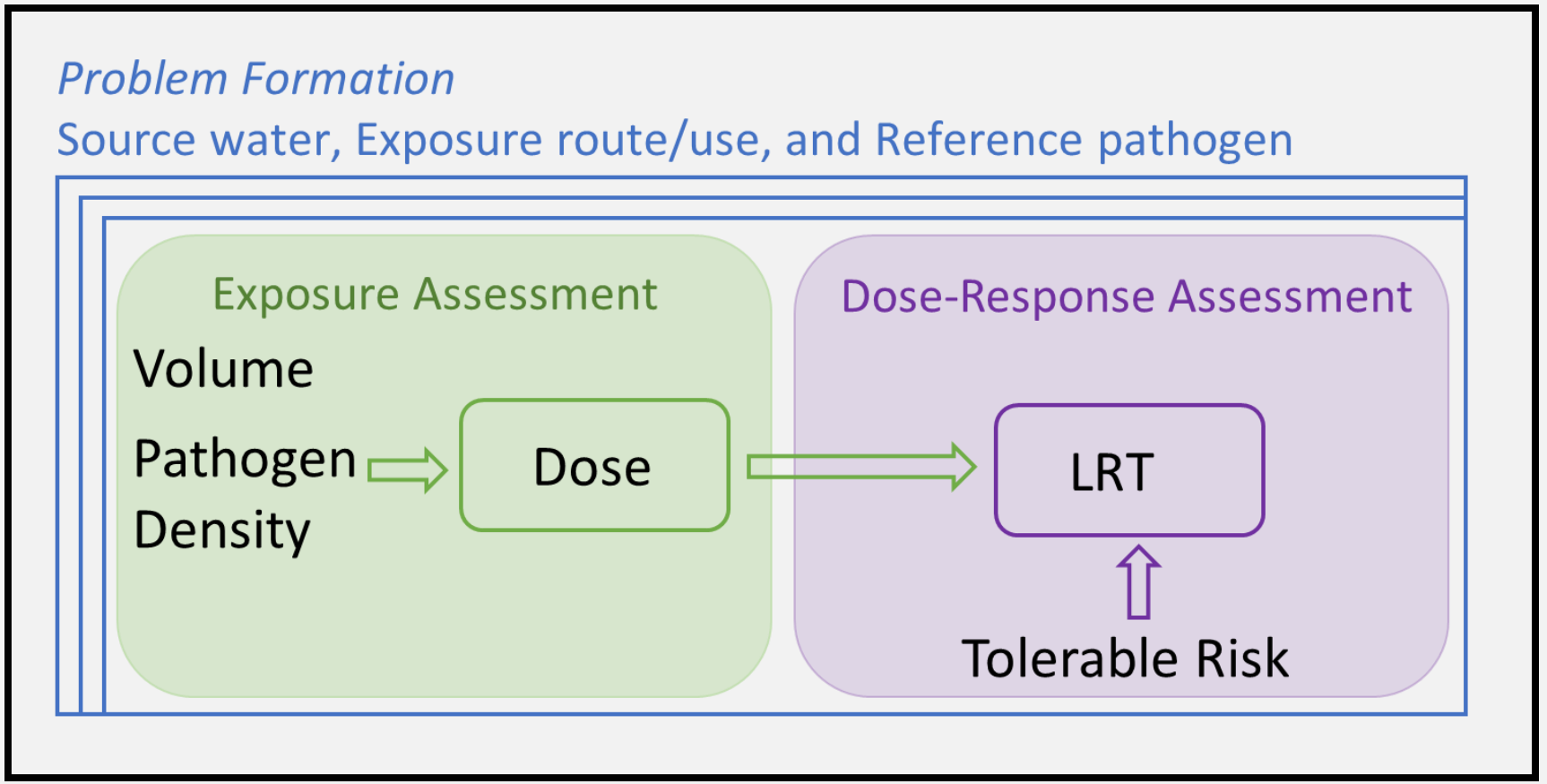
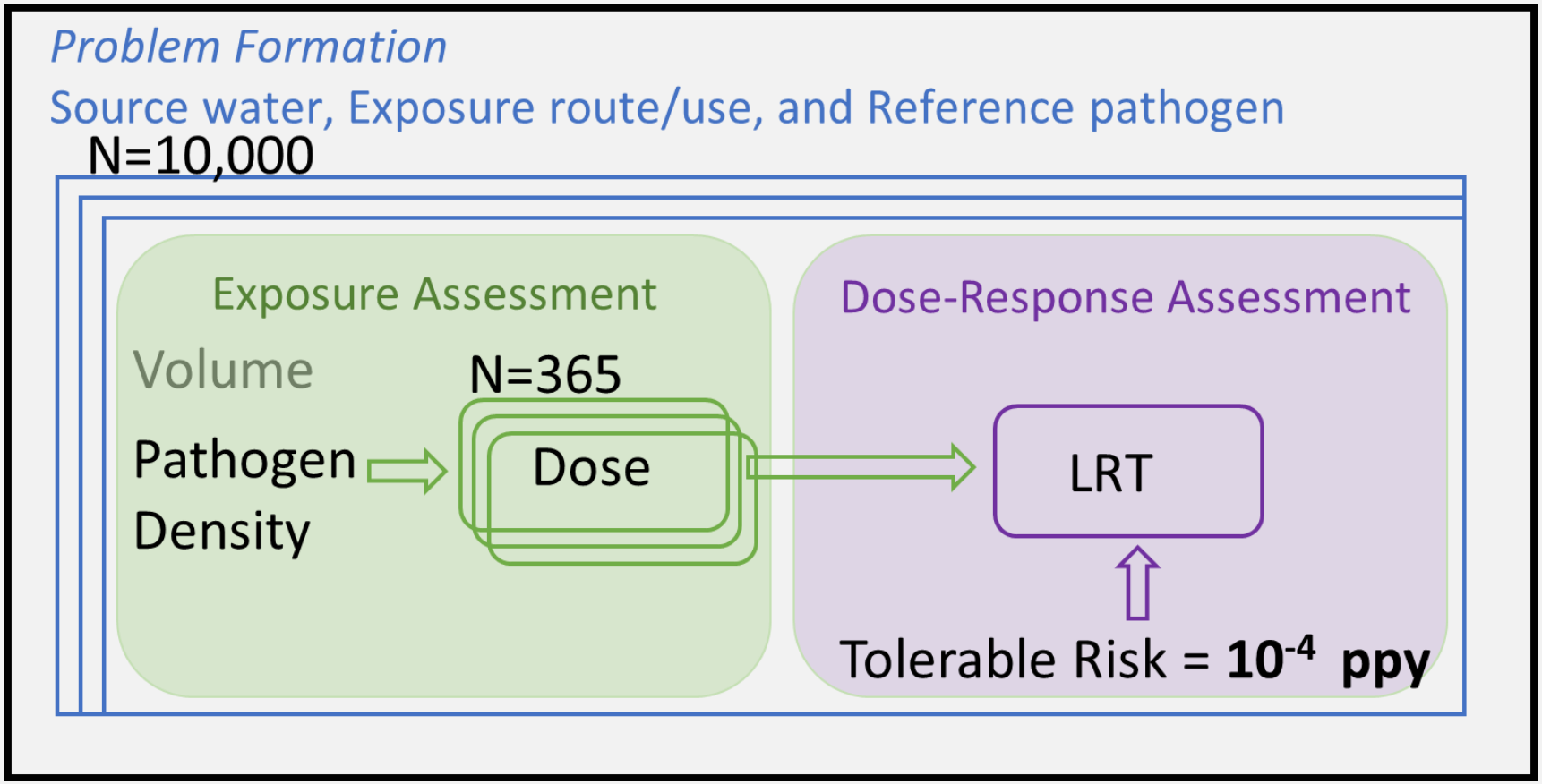
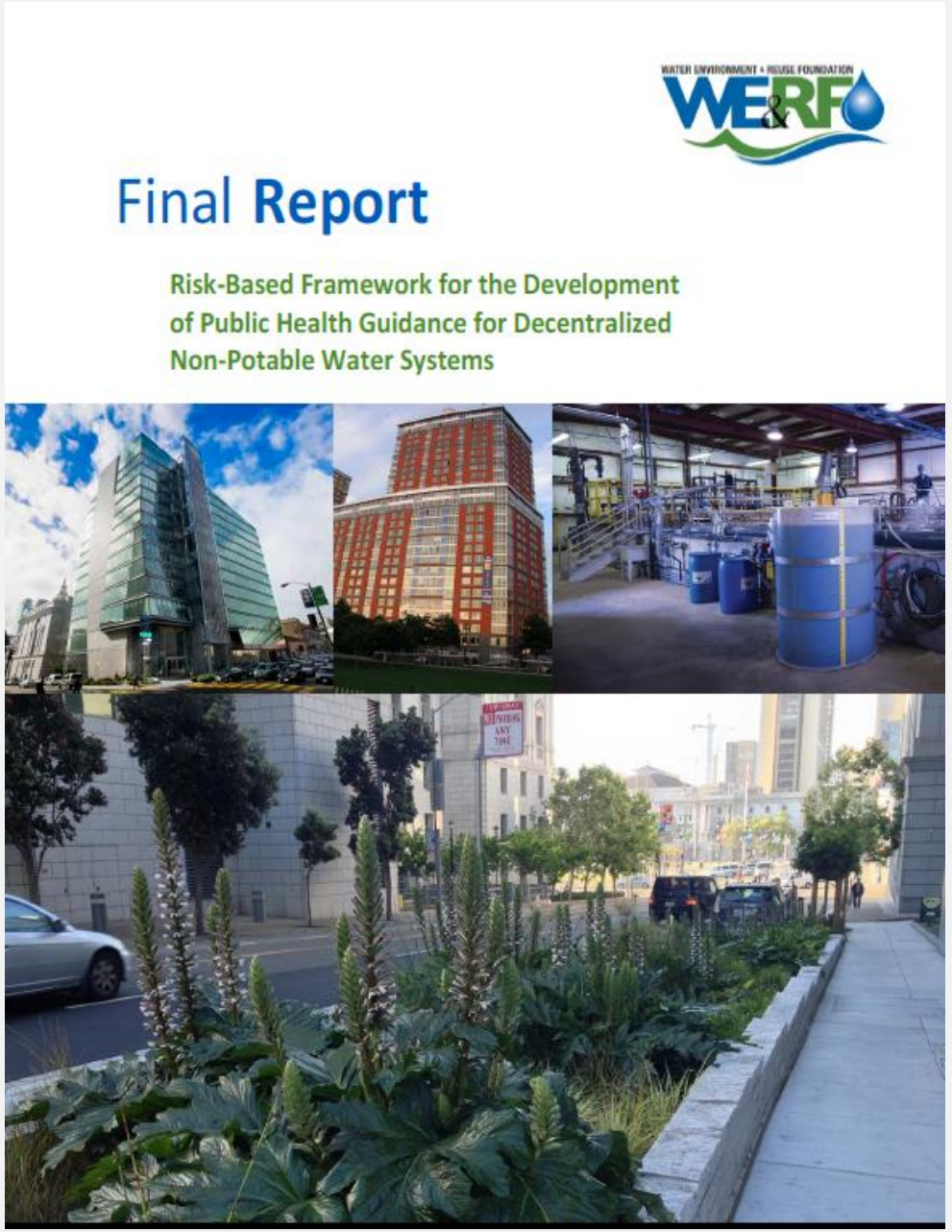
# Risk Characterization



# Risk Characterization



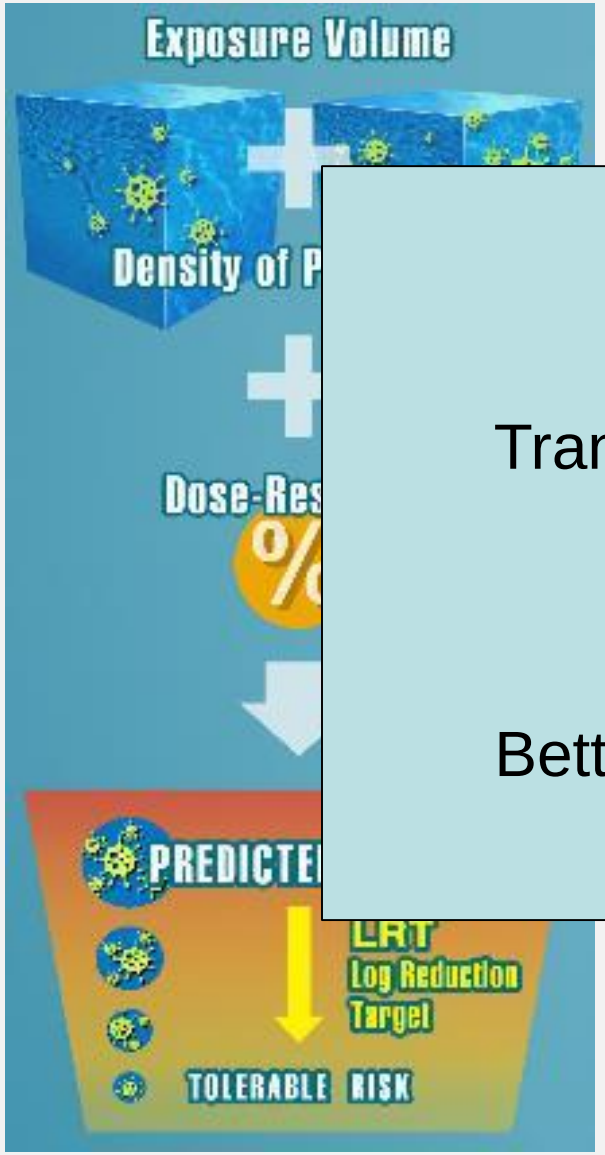
# QMRA Results



| Water Use Scenario | $Log_{10}$ 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*

# Quantitative Microbial Risk Assessment




"Source" waters

A Structured Framework

Transparent Underlying Assumptions

Flexible and Adaptable

Better Accounting for Range of Risks

Potable



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# Areas for Improvement

- Refinement of model inputs
  - Initial pathogen concentrations, exposure volumes (including accidental ingestion), acceptable level of risk
- Definition of system performance
  - Improved library of log reduction values for key unit processes
- Monitoring (for validation purposes)
  - Simple surrogates for viral and protozoan removal

# Ongoing and Future Work

- Additional source water characterizations
  - –Model validation: rainwater and stormwater
  - –New source type: air conditioning condensate
- Additional fit-for purpose applications
  - –Shower/bathing: ingestion and dermal exposure
- Additional research areas
  - –Monitoring approaches
  - –Life-cycle assessment and cost analysis

# Resources for Additional Information

**QMRA**

- Center for Advancing Microbial Risk Assessment (CAMRA)
- Microbial Risk Assessment (MRA) Tools, Methods, and Approaches for Water Media

**Onsite Non-Potable Water Programs**

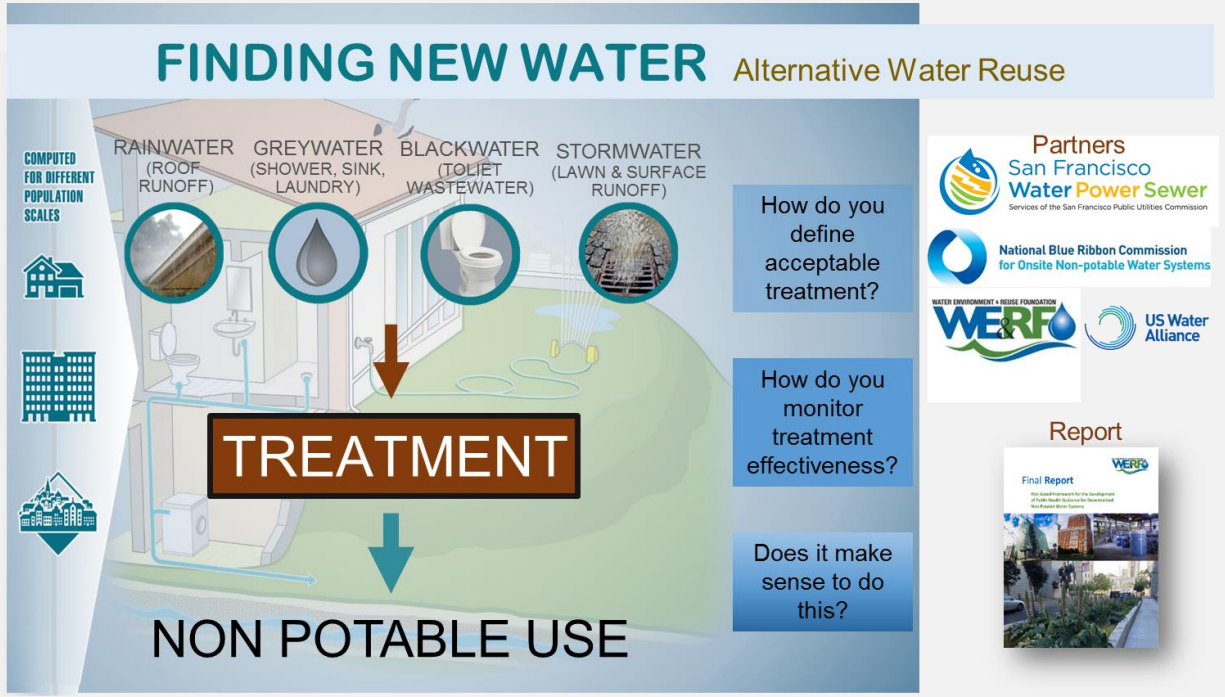
- National Blue Ribbon Commission for Onsite Non-Potable Water Systems

**EPA Water Reuse Research**

- Onsite Non-Potable Water Reuse Research Website
- Onsite Non-Potable Water Reuse Research Technical Brief
- Water Reuse Research Website
- Water Reuse Action Plan

# Thank you – Questions?

jahne.michael@epa.gov

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