Water & Risk:
Thinking Broadly In A Shrinking World

Jay L. Garland, PhD
Office of Research & Development
United State Environmental Protection Agency

November 19, 2019
Global Water & Food Safety Summit
College Park, MD

My Extraterrestrial Perspective

“The river of intellectual progress is not defined purely by the steady flow of good ideas…..it follows the topography…carved out by external factors. ….the river may back up for a while, but the dams eventually break.”

The Ghost Map, Steven Johnson

“Many ideas grow better when transplanted into another mind other than the one where they sprang up”

Oliver Wendell Holmes

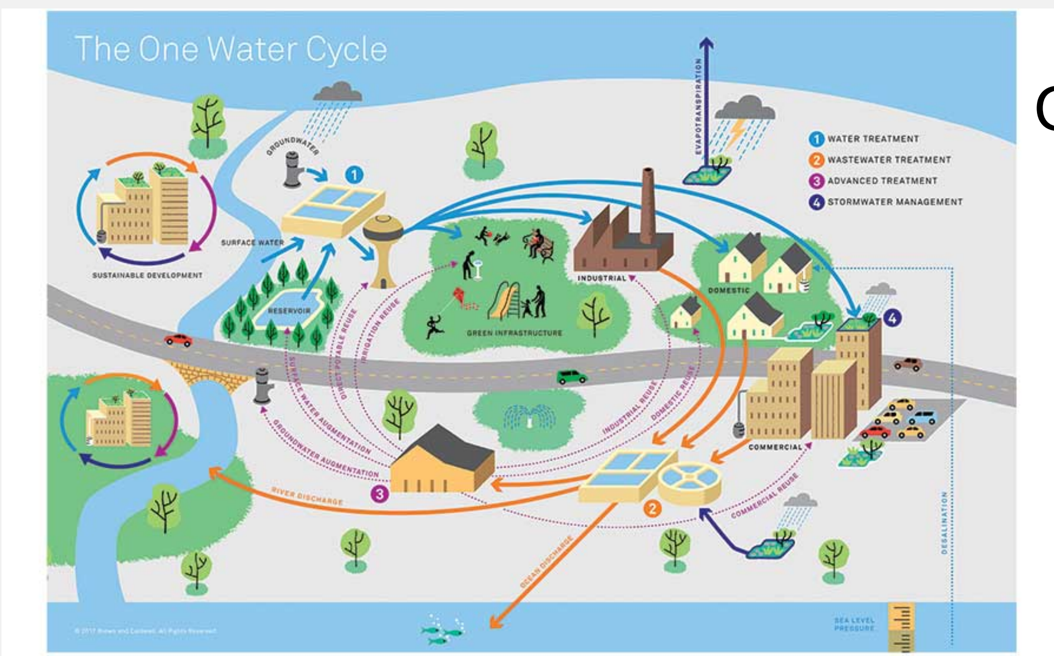
“If we knew how to live on Mars, we'd know how to reduce our footprint on Earth. Space colonization is the Rosetta stone for earthly sustainability because it's entirely about living in the absence of ecosystem services. The Moon, Mars and the asteroids are a great experimental laboratory that we're ignoring at our own peril.”

Karl Schroeder

Thinking Broadly

Focus on the environment

in a Shrinking World



One Water

“Tightening” cycles

A range of water types

United States Environmental Protection Agency

One Health…

…recognizes that the **health** of people is **connected** to the health of animals and the environment. It is a **collaborative**, **multisectoral**, and **transdisciplinary** approach—working at the local, regional, national, and global levels—with the goal of achieving optimal health outcomes….

CDC

….is an approach to **designing** and **implementing** programmes, policies, legislation and research in which **multiple sectors communicate** and **work together** to achieve better public health outcomes.

WHO .

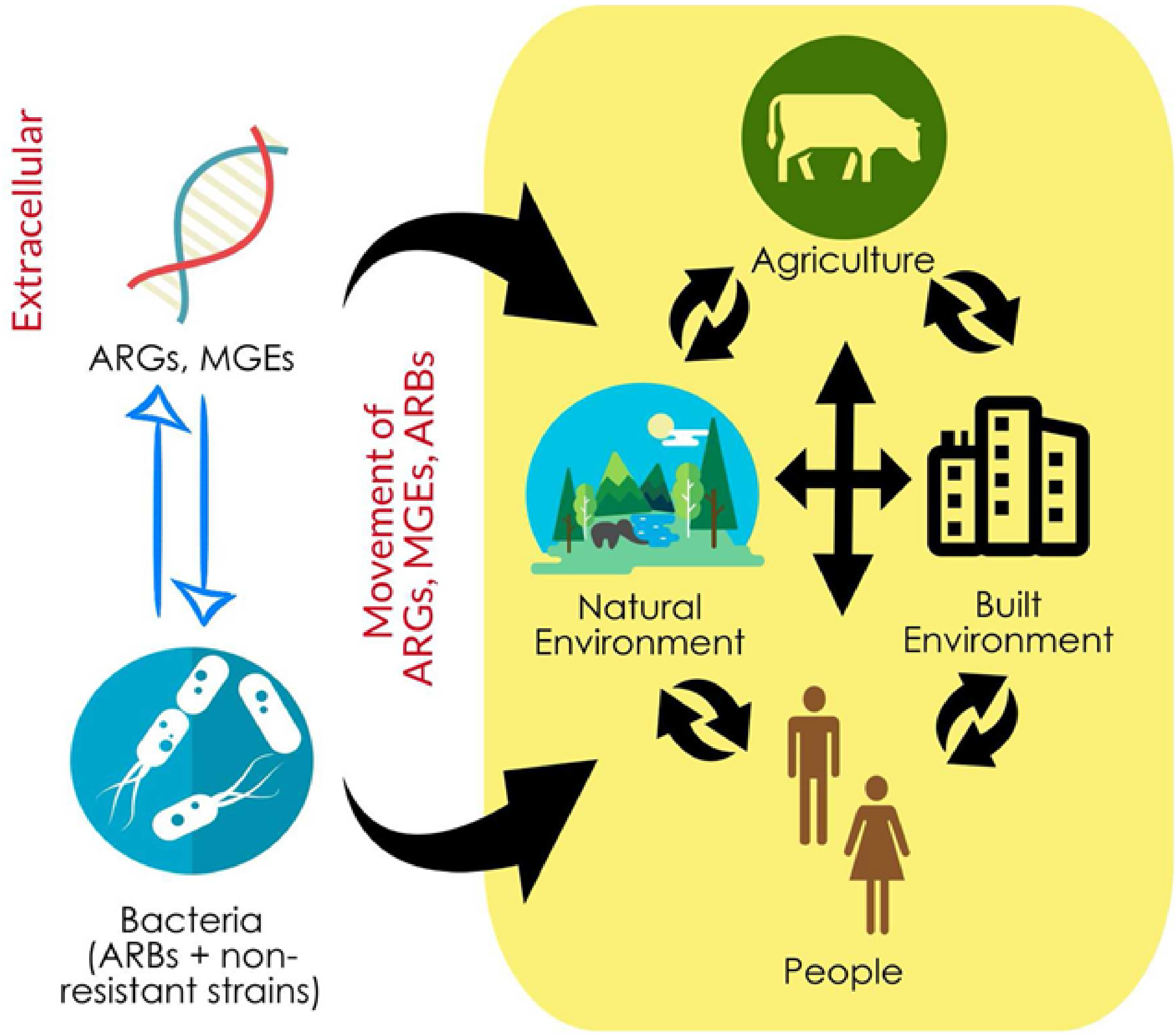
…an integrative effort of multiple disciplines working locally, nationally, and globally to attain optimal health for people, animals and the environment…..the **health** of each is **inextricably connected** to the others"

American Veterinary Medical Association

“….[a review of] scientific investigations claiming to adhere to the One Health concept clearly reveals that they only mention the environment and its biotic and abiotic components as the scene of the transmission”

“…lack of communication between human and veterinary medicine….and agronomy, ecological, environmental and evolutionary science”

Destoumieux-Garzon et al. 2018. The One Health Concept: 10 years old and a long road ahead. Frontiers in Veterinary Science, 5:14



Vikesland et al. 2017. EST

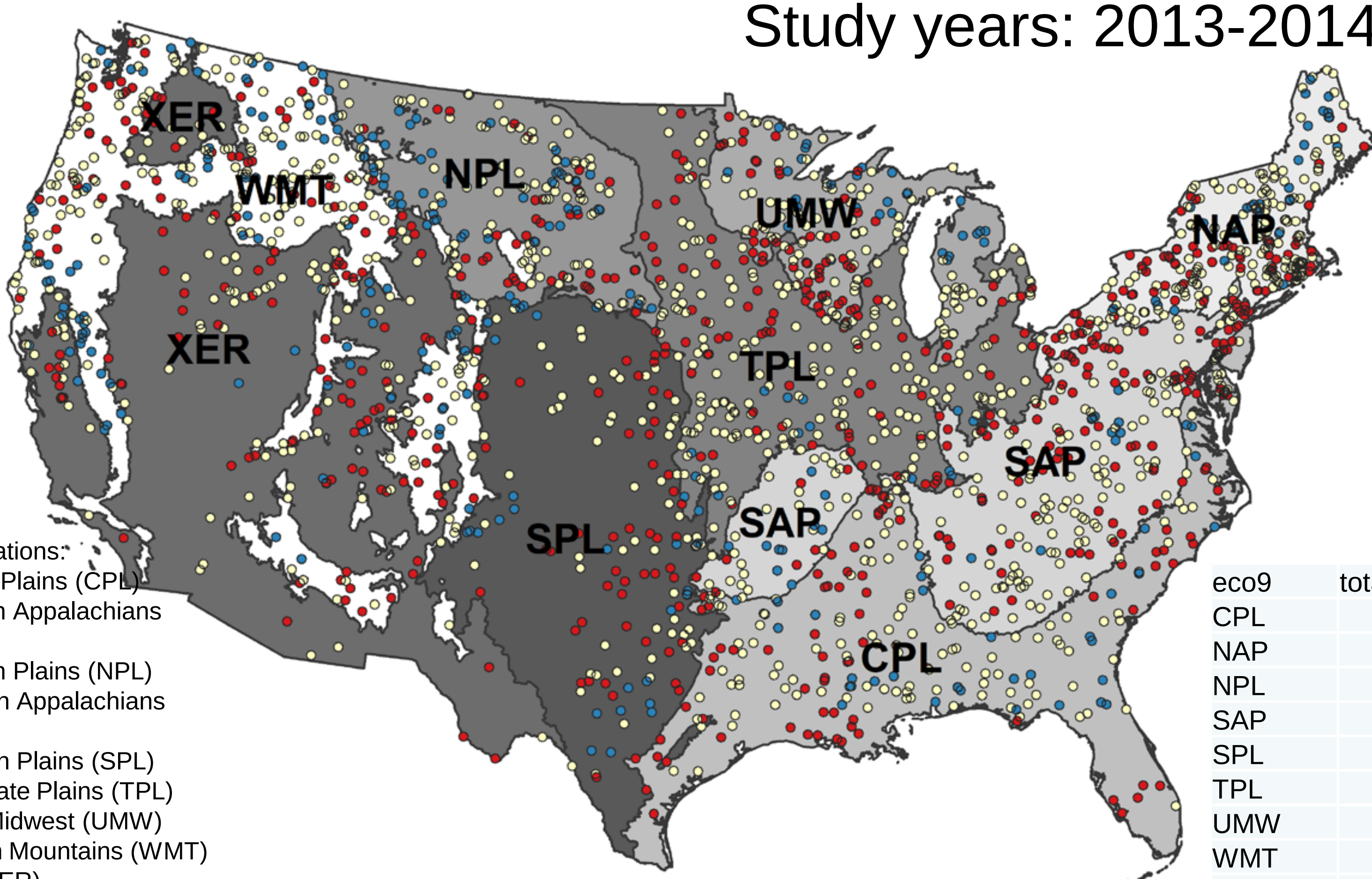
“The **addition of an environmental surveillance component** to truly complete the One Health platform and add to our understanding of the movement of pathogens and resistant genes across the three domains of One Health.”

2017 Scientific Advisory Board

United States Environmental Protection

National River and Streams Assessment (NRSA)

Study years: 2013-2014



Abbreviations:
Coastal Plains (CPL)
Northern Appalachians (NAP)
Northern Plains (NPL)
Southern Appalachians (SAP)
Southern Plains (SPL)
Temperate Plains (TPL)
Upper Midwest (UMW)
Western Mountains (WMT)
Xeric (XER)

eco9	total km
CPL	198824
NAP	138082
NPL	27108
SAP	289341
SPL	38818
TPL	185850
UMW	101648
WMT	186538
XER	44017

(ECO9 Regions Shown; blue is reference; yellow is intermediate; red is impacted)

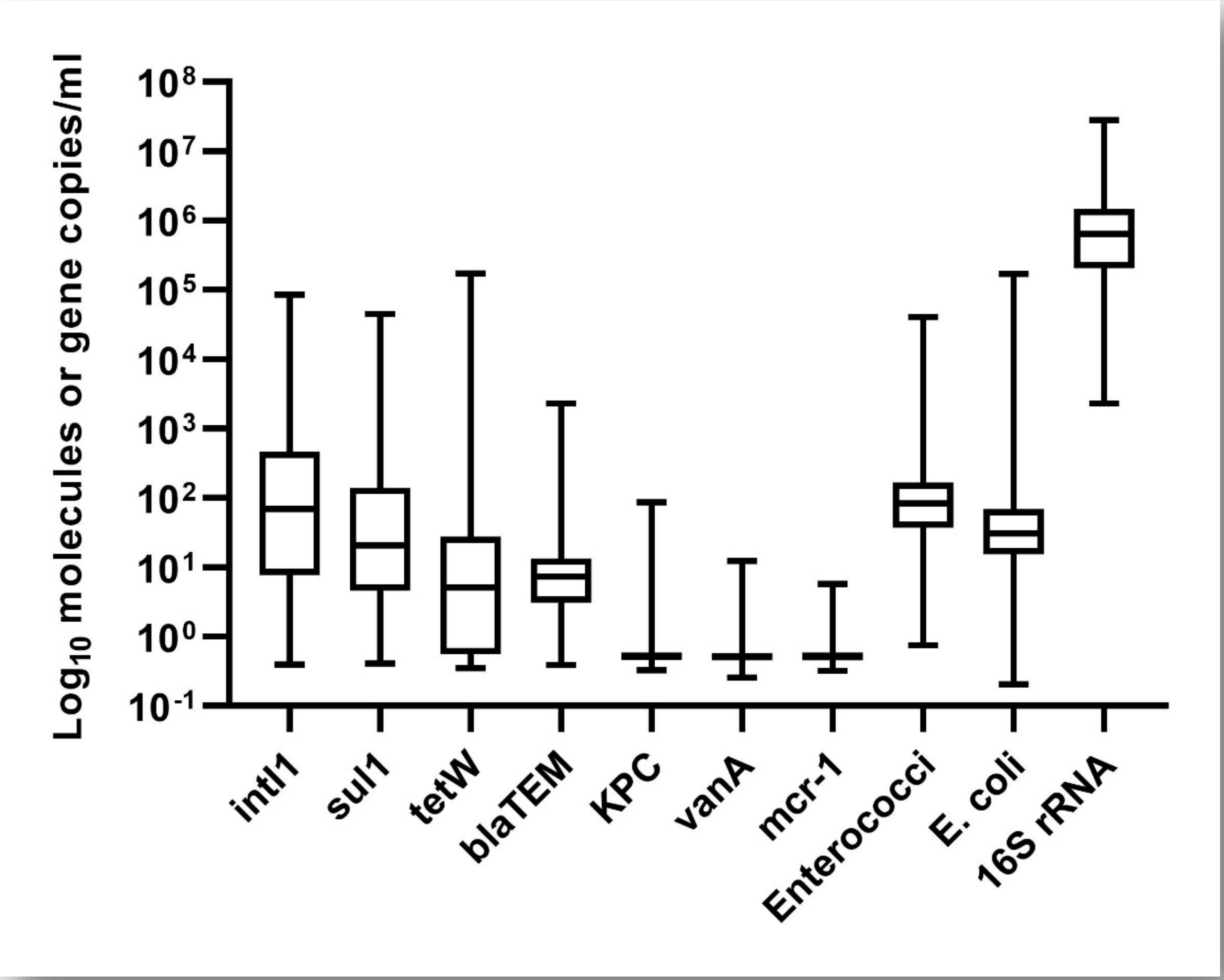
https://www.epa.gov/national-aquatic-resource-surveys

Approach for Genes

- Enterococcus US EPA Method 1609 was used for sample processing
  - QAQC (holding time standards)
  - Filtered 50 mL water samples collected as part of the NRSA
  - Bead beating was used to disrupt cells
- DNA was extracted using GeneRite DNA-EZ kit
- Droplet digital PCR (ddPCR, BioRad) was used to quantify specific gene targets
  - A well contains thousands of droplets (nanoliter endpoint PCR reactions)
  - Bayesian statistics was used to estimate final concentrations and credible intervals
- Survey weights were used to calculate the weighted means per mL
- Genes included in the study:

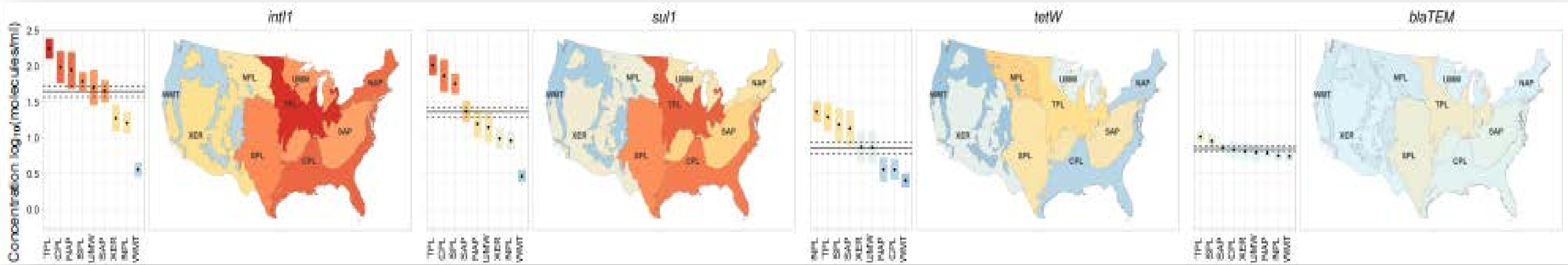
class 1 integron-integrase (intI1)
sulfonamide resistance (sul1)
tetracycline resistance (tetW)
beta-lactam resistance (blaTEM)
carbapenem resistance (KPC-Klebsiella pneumoniae carbapenemase)
vancomycin resistance (vanA)
colistin resistance (mcr-1)
16S and 23S rRNA

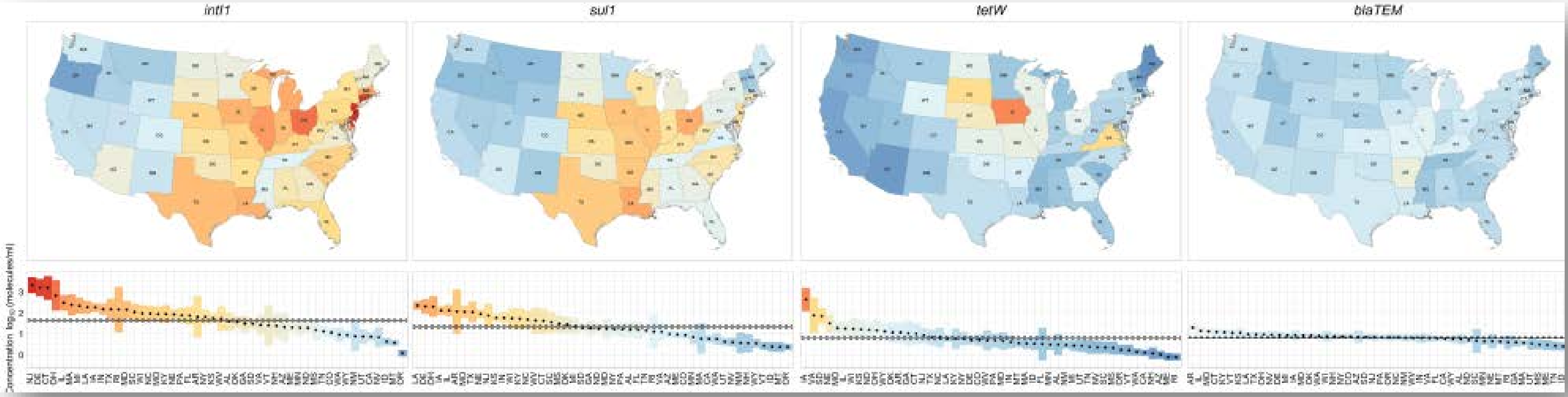
Gene Concentrations



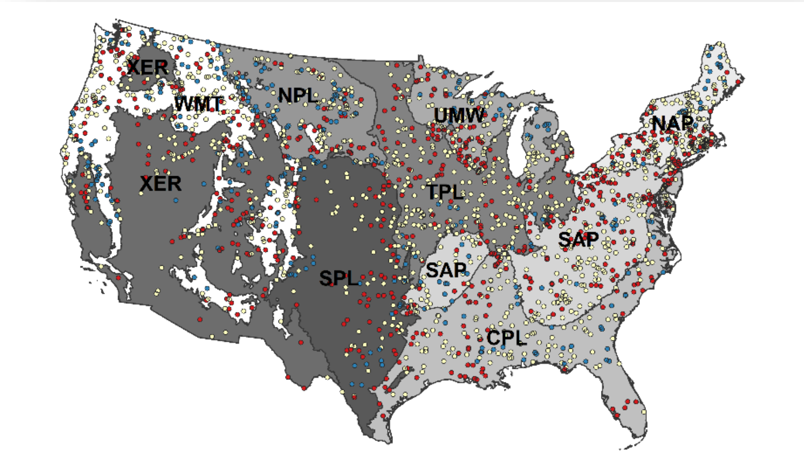
Geospatial Analysis Of Genes

intl1 sul1 tetW blaTEM



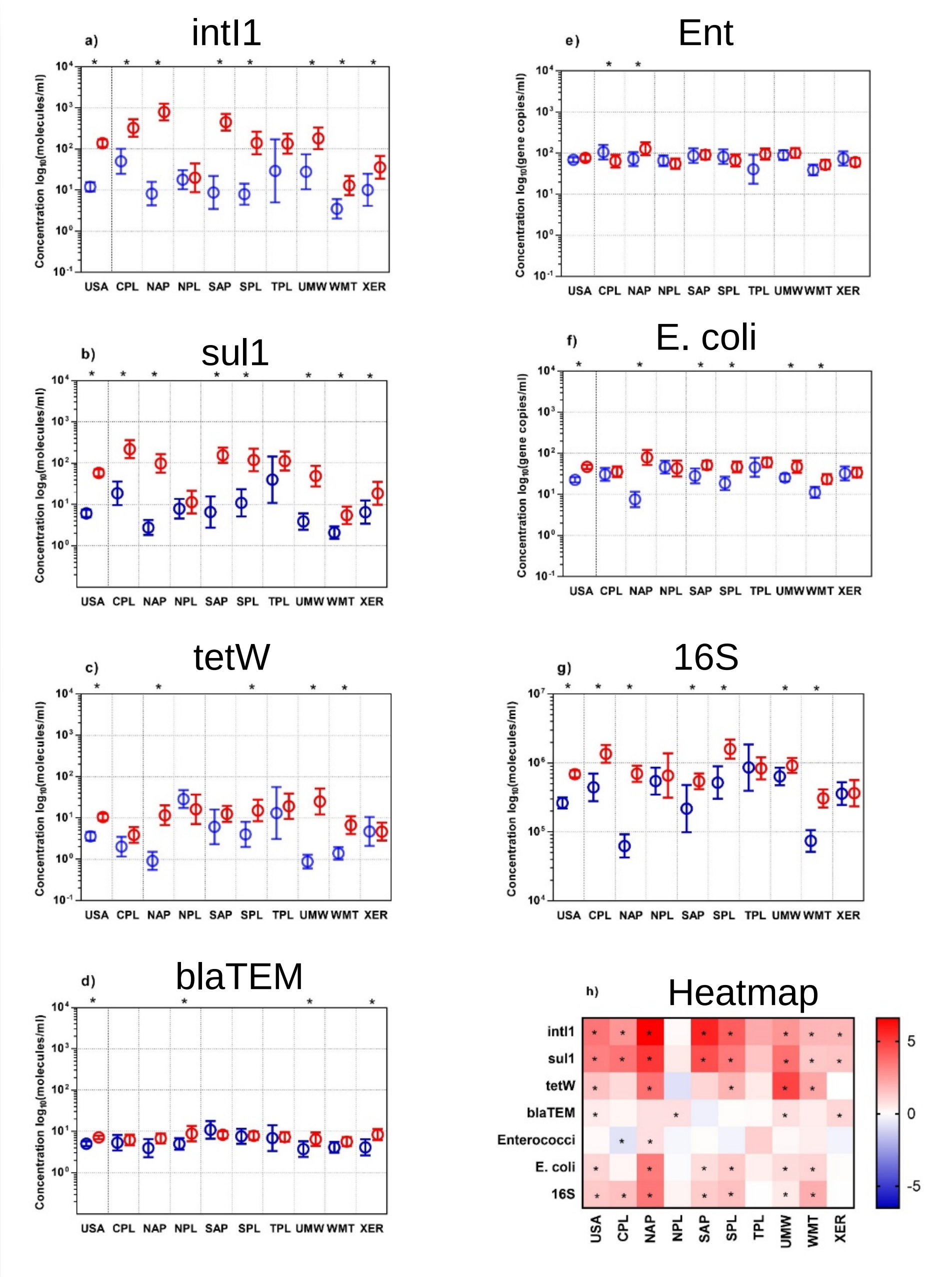


Impacted vs Reference



ECO9 Regions Shown; blue is reference; yellow is intermediate; red is impacted

Filter criteria
Total P (µg/L)
Total N (µg/L)
Cl– (µeq/L)
$SO4^{2-}$ (µeq/L)
ANC (µeq/L) , DOC (mg/L)
Turbidity (NTU)
Riparian Disturbance Index
% fine substrate

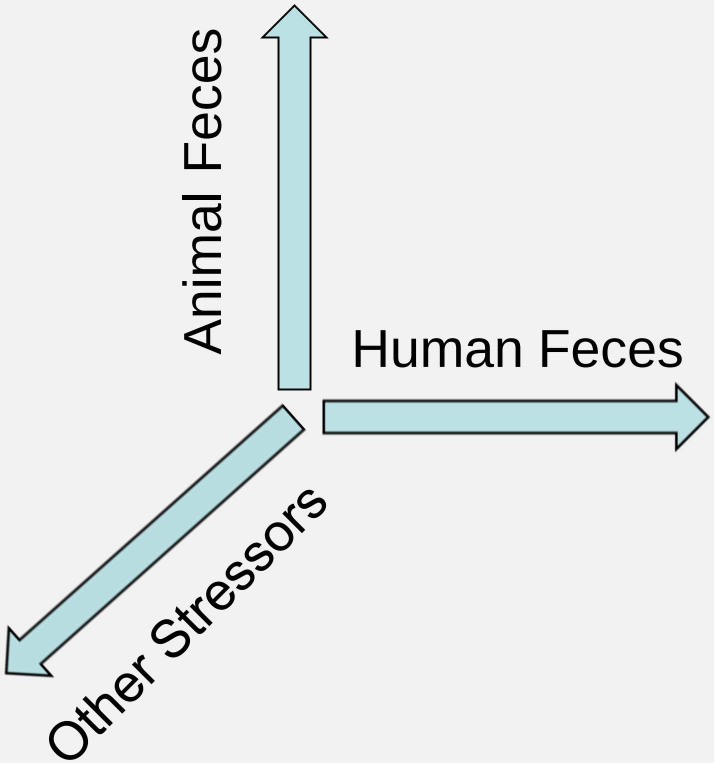


Current/Next Steps

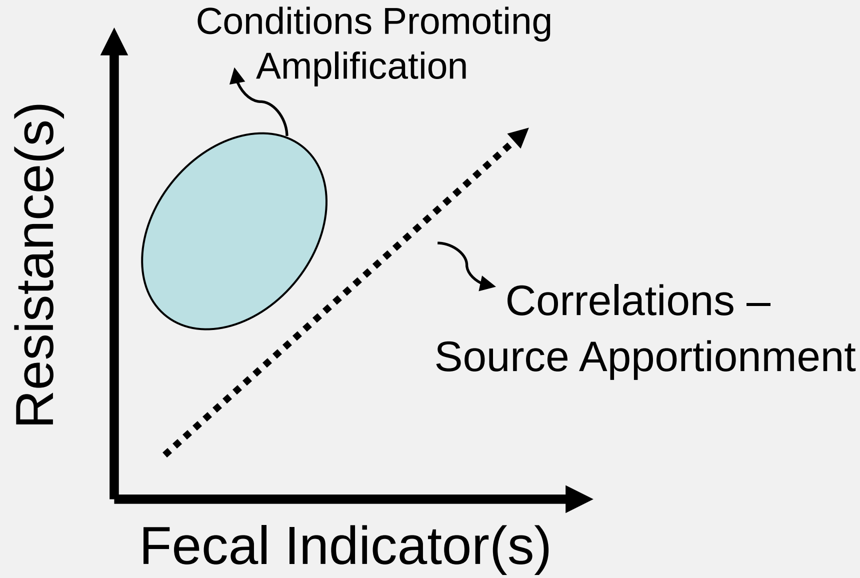
- Expand analysis of NRSA to include more specific predictors of AMR occurrence, amplification
  - Remain focused on quantitative assessment of genes
  - Increase targets, both ARGs and fecal source trackers
  - Pilot metagenomics effort with NARMS

- Targeted National Scale Study in collaboration with NARMS to evaluate the flow of resistance across food chain-environment-human

Designing the Study



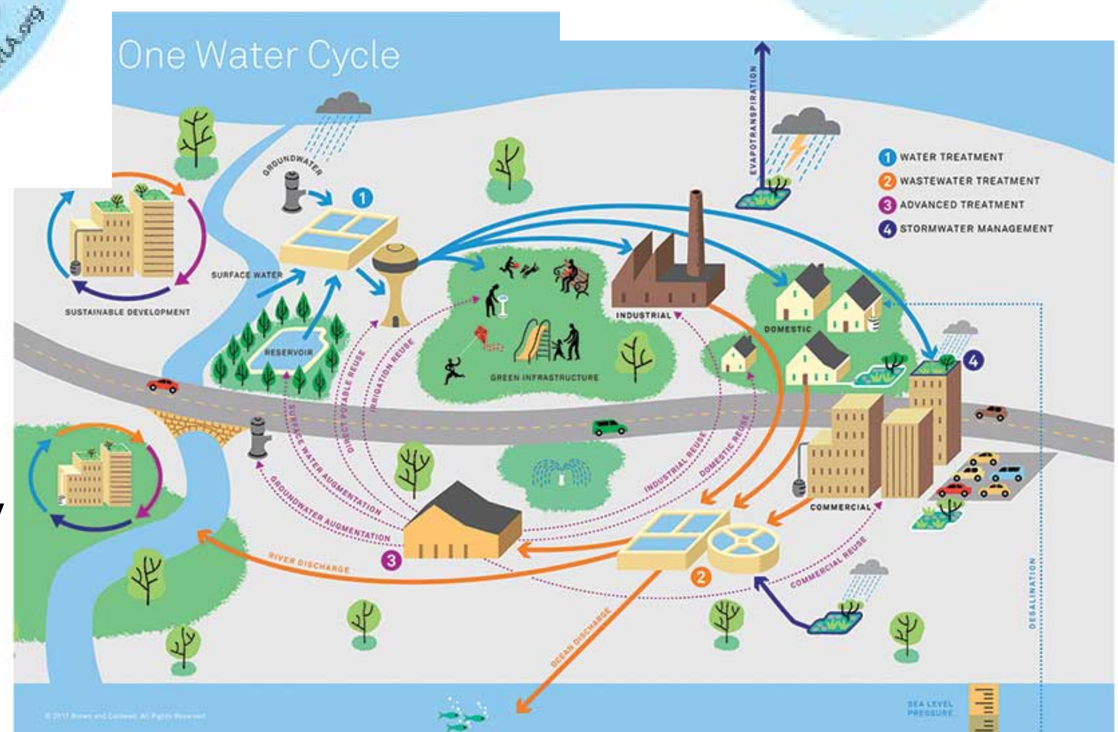
Linkage to Existing NARMS Sampling Network



Broad Perspective
Interdisciplinary

Linking Different
Waters

Various Cycles,
Planned Holistically



“General availability of water and other materials, relative to demand, and the general lack of treatment technologies and monitoring/autonomous control capabilities”

“The main factors that resulted in the development of the current urban water management system no longer exist.”

G.T. Daigger, S. Sharvelle, M. Arabi, and N.G. Love. 2019. Progress and Promise Transitioning to the One Water/Resource Recover Integrated Urban Water Management Systems J. Environ. Eng. 145(10):04019061

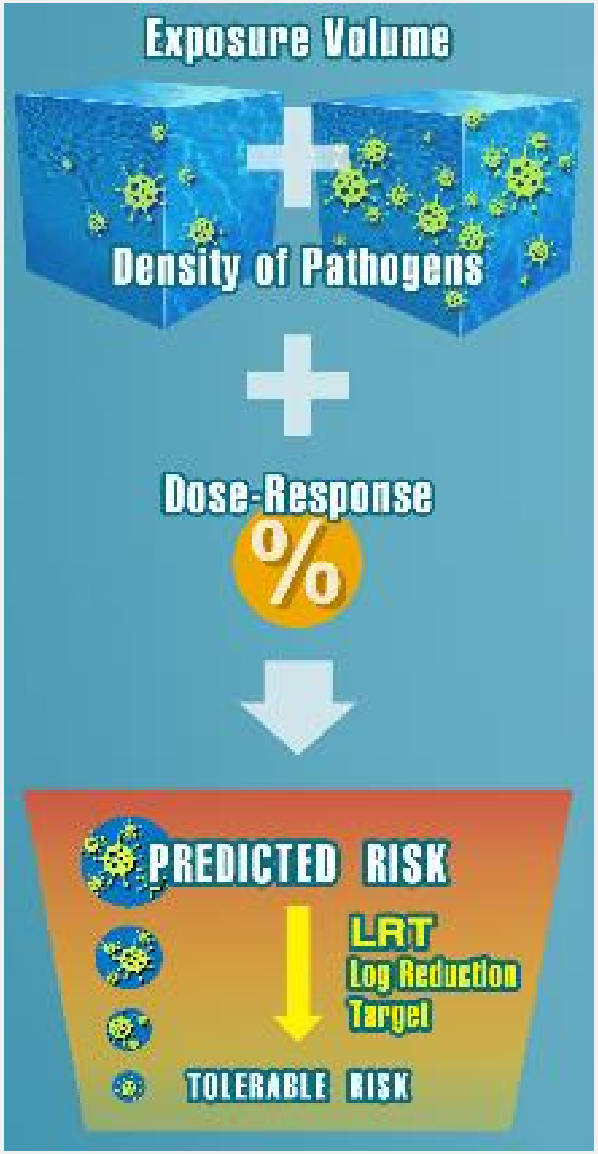
Transitions in the Water Sector

	Historic	*Future*
Relationship to Economy	Provide cost-effective water services	Part of circular economy
Functional Objective	Comply with regulations	Produce useful products
Optimization Functions	Infrastructure Cost	Water, energy, materials
Water Supply	Remote	Local
Systems Components	Separate drinking, storm, waste	Integrated, multipurpose
System Configuration	Centralized	Hybrid (C & Distributed)
Financing	Volume Based	Service Based
Institutions	Single-purpose utilities	Water cycle utilities
System Planning	“Plumb up” the planned city	Linked to city planning

G.T. Daigger, S. Sharvelle, M. Arabi, and N.G. Love. 2019. Progress and Promise Transitioning to the One Water/Resource Recover Integrated Urban Water Management Systems J. Environ. Eng. 145(10):04019061

EPA United States Environmental Protection Agency

Assessing Risks In One Water
Quantitative Microbial Risk Assessment



"Source" waters

(roof runoff, storm water, graywater, blackwater)

End Use

Non-Potable

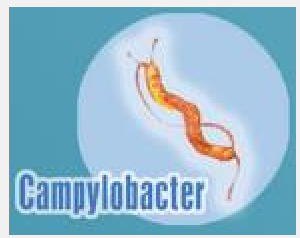
Potable

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

EPA United States Environmental Protection Agency

Reference Pathogens Needed

Each class will have different standards for necessary reductions in reused water

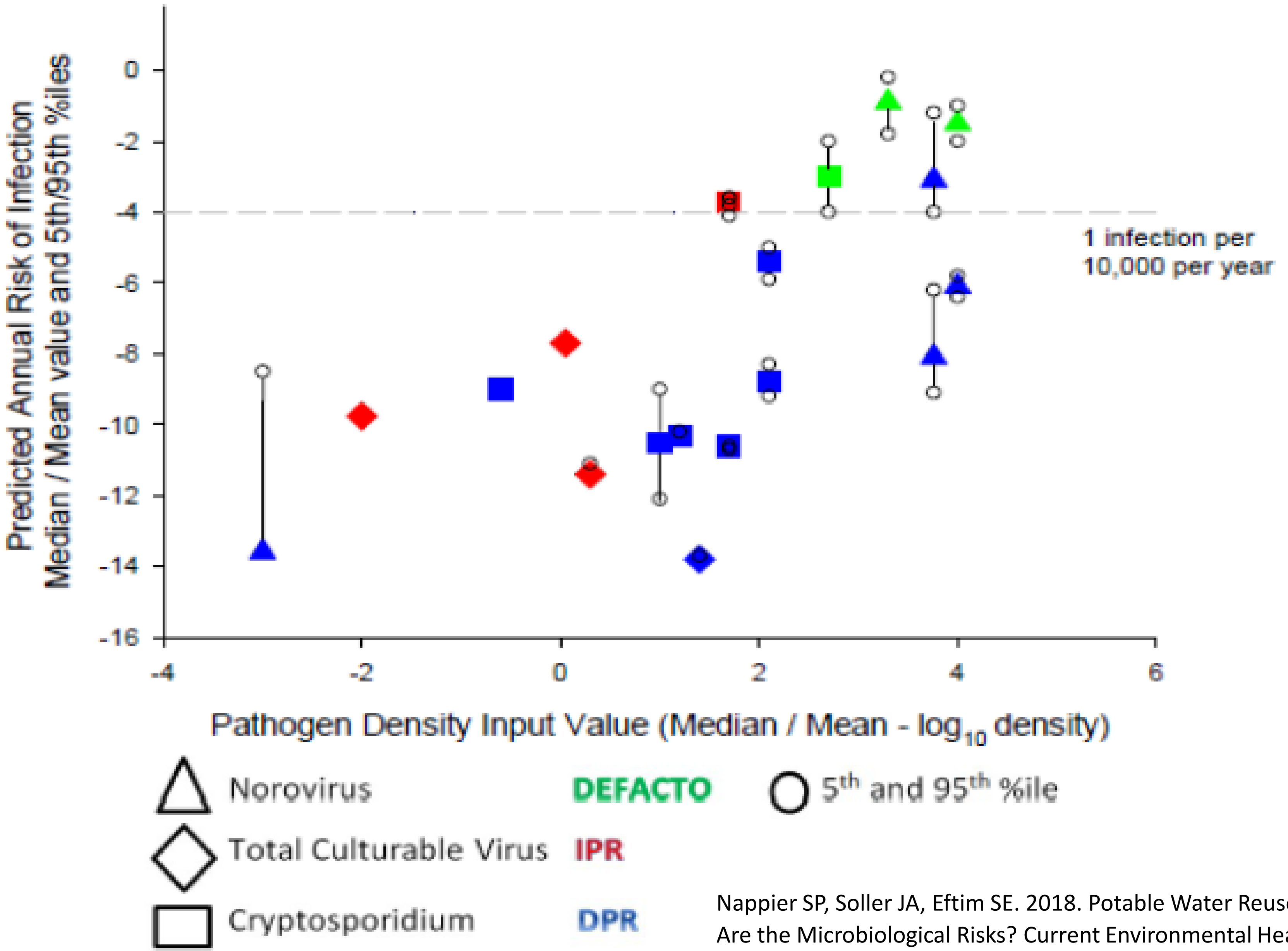


Viruses | Bacteria | Parasites/Protozoa

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

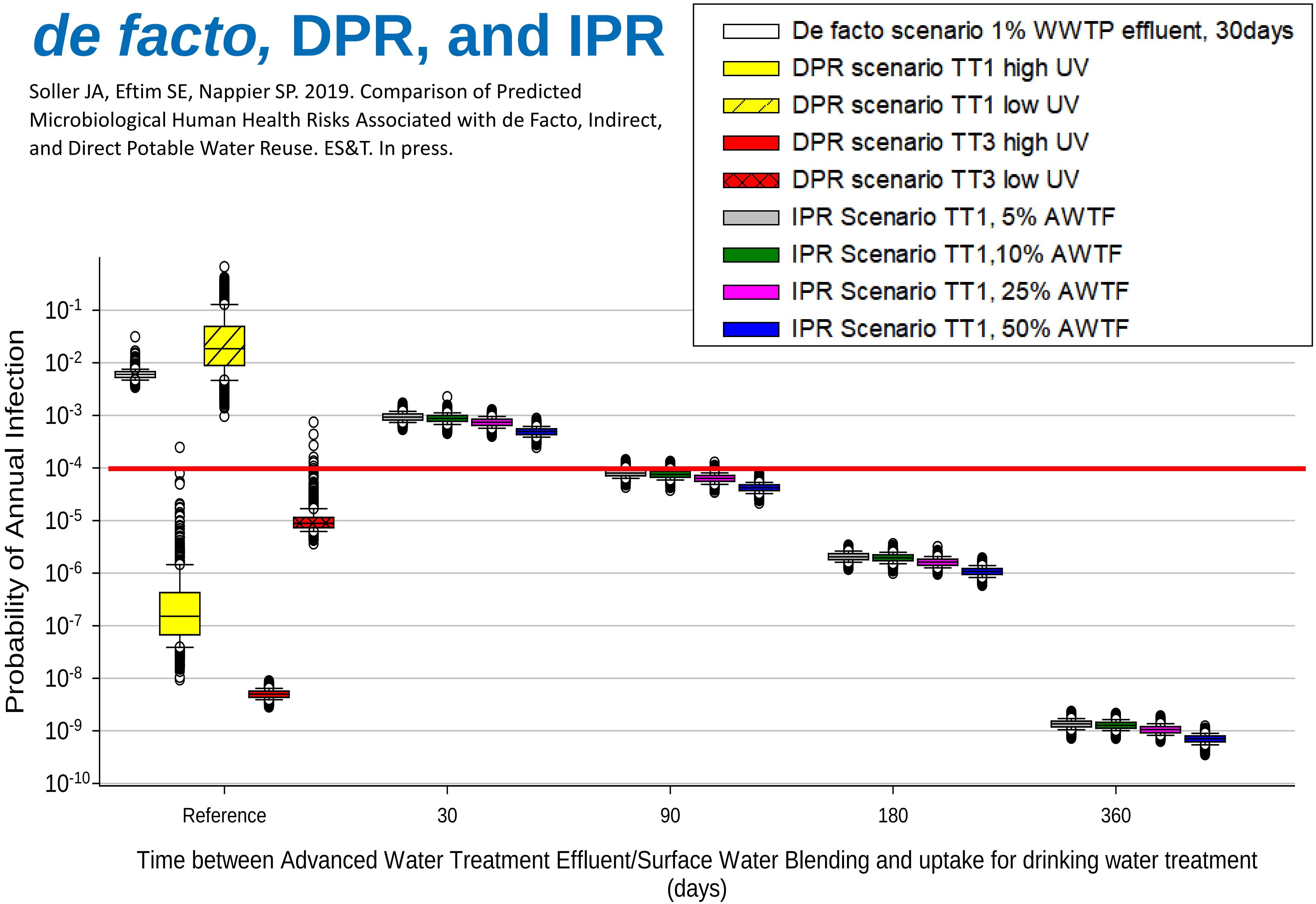
Comparison of Published Potable Reuse Risk Studies



Nappier SP, Soller JA, Eftim SE. 2018. Potable Water Reuse: What Are the Microbiological Risks? Current Environmental Health Reports. 5, 283–292.

Comparison of predicted annual risks: *de facto*, DPR, and IPR

Soller JA, Eftim SE, Nappier SP. 2019. Comparison of Predicted Microbiological Human Health Risks Associated with de Facto, Indirect, and Direct Potable Water Reuse. ES&T. In press.



Results Summary (1)

De facto

- Most *de facto* reuse scenarios resulted in infection risks above 10^{-4}/year.
- Simulations with environmental retention time greater than 90 days prior to drinking water treatment plants intake were generally needed to achieve risks below the benchmark.
- Additional treatment barriers may be needed at conventional drinking water treatment plants to achieve the 10^{-4} risk benchmark, when wastewater effluent makes up a portion of the source water.
- NoV estimates associated with surface waters could overestimate viral densities as the molecular methods used detects both infectious and non-infectious virions.

Results Summary (2)

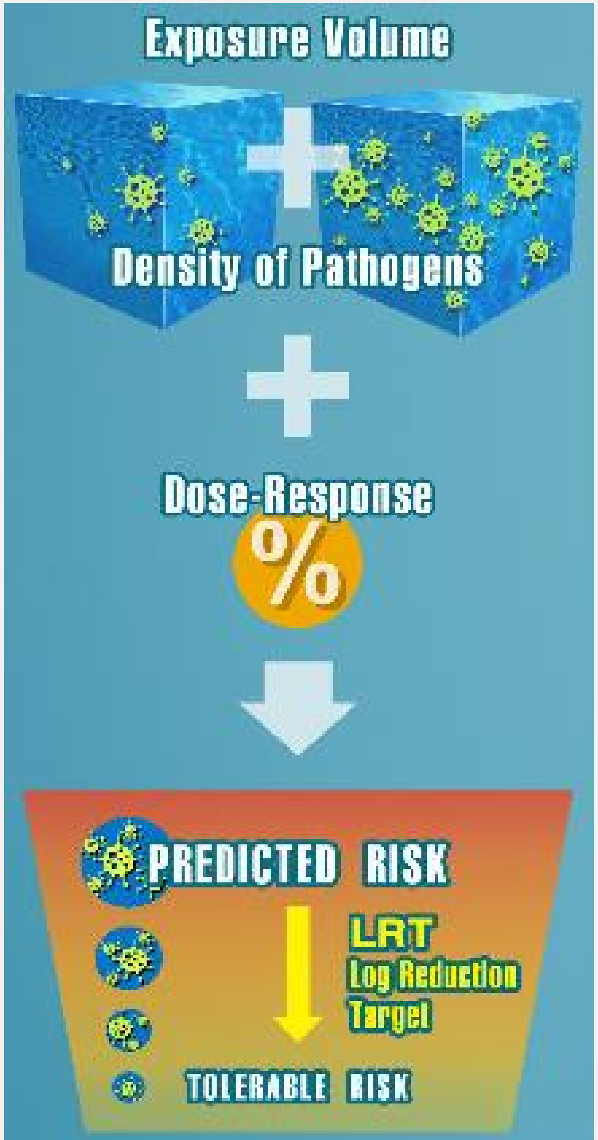
IPR (surface water augmentation)

- The *de facto* component of the surface water was an important determinant of health risk, even when blended with the AWTF product water.
- In the IPR scenarios evaluated, there is a need for retention times of ~90 days or greater in the reservoir to achieve risk reductions associated with the 10^{-4} benchmark.
- Although IPR risks appear higher than DPR, IPR scenarios provide benefits from public health and water management perspectives.

Overall Considerations

- One of the first evaluation of DPR, IPR, and *de facto* reuse scenarios using a consistent set of model input parameters including up-to-date raw wastewater pathogen densities, modeled pathogen decay rates, and dose-response relationships for reference pathogens.
- Analyses suggest microbiological risks associated with properly planned reuse scenarios (DPR and IPR) are lower than *de facto* reuse ingestion scenarios.
- Simulations for *de facto* reuse and IPR scenarios suggest contributions as low as 1% of treated wastewater effluent in surface water can have human health risk implications from a drinking water perspective.

Assessing Risks In One Water
Quantitative Microbial Risk Assessment



"Source" waters

(roof runoff, storm water, graywater, blackwater)

End Use

Non-Potable

Potable

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

Buildings Produce Water

Precipitation collected from roofs and above-grade surfaces

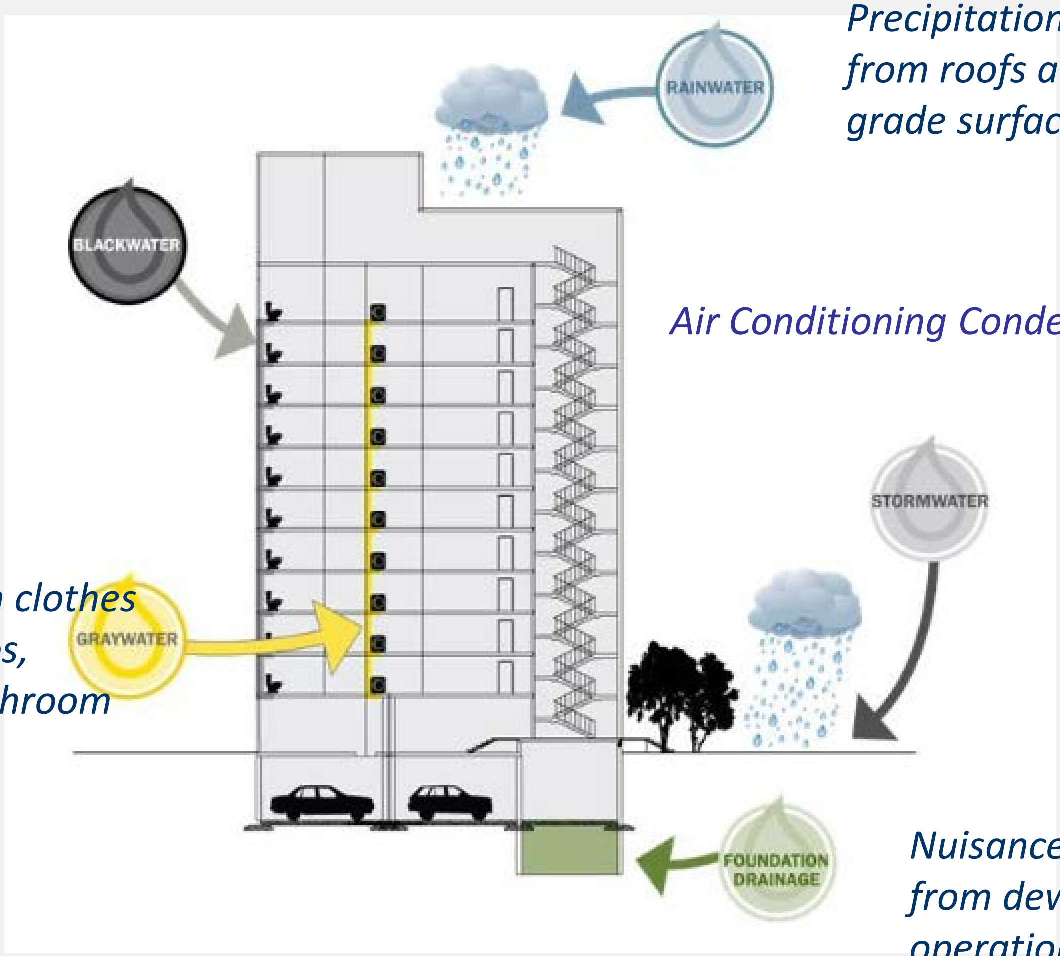
Wastewater from toilets, dishwashers, kitchen sinks, and utility sinks

Air Conditioning Condensate

Precipitation collected at or below grade

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

Nuisance groundwater from dewatering operations



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

181 Fremont *San Francisco*

- 706,000 sf mixed-use building
- 5,000 gpd graywater treatment
- Membrane bioreactor system
- Estimated commissioning: Late 2018
- Drivers:
  - Sustainability goals
  - LEED

Salesforce Tower: San Francisco, CA

1.6 million ft^2 office building

Utilizes: MBR blackwater system for up to 30,000 gpd

Application: Toilet flushing, irrigation, and cooling

Estimated commissioning: Early 2019

Drivers:

- Sustainability goals
- LEED certification
- Utilize existing dual-plumbing

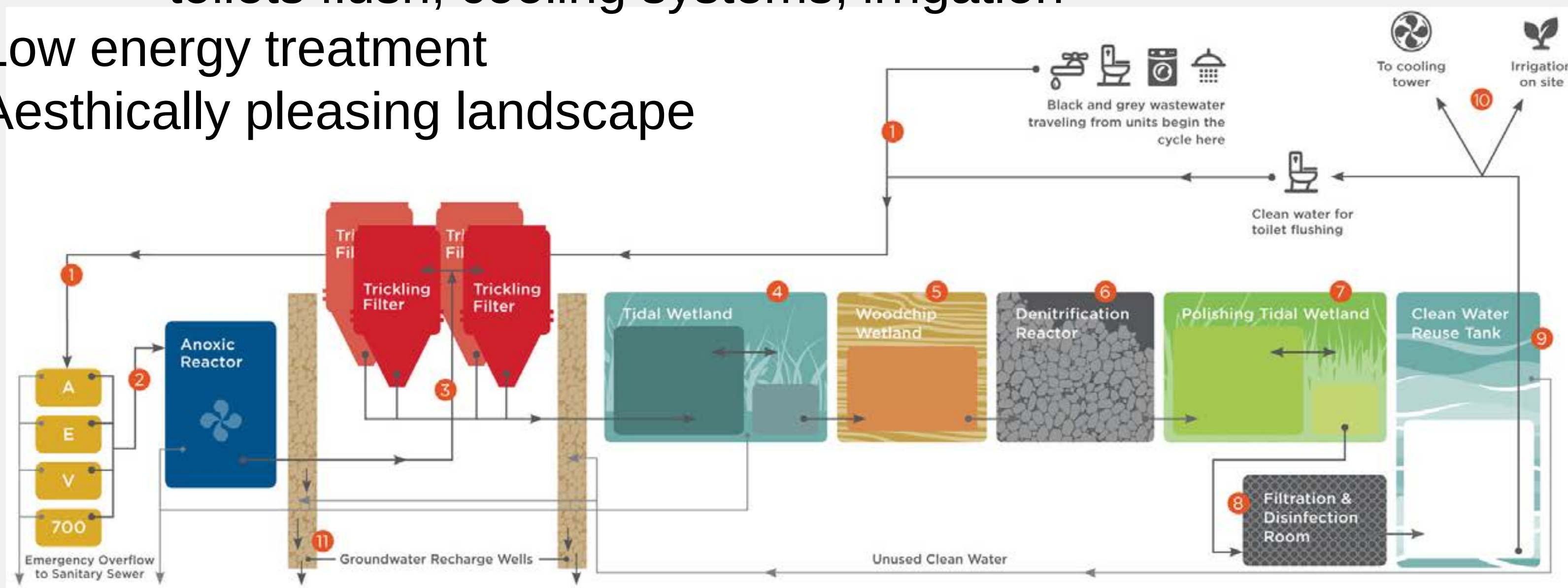
Hassalo on Eighth *Portland, Oregon*

60,000 gallons of wastewater per day

toilets flush, cooling systems, irrigation

Low energy treatment

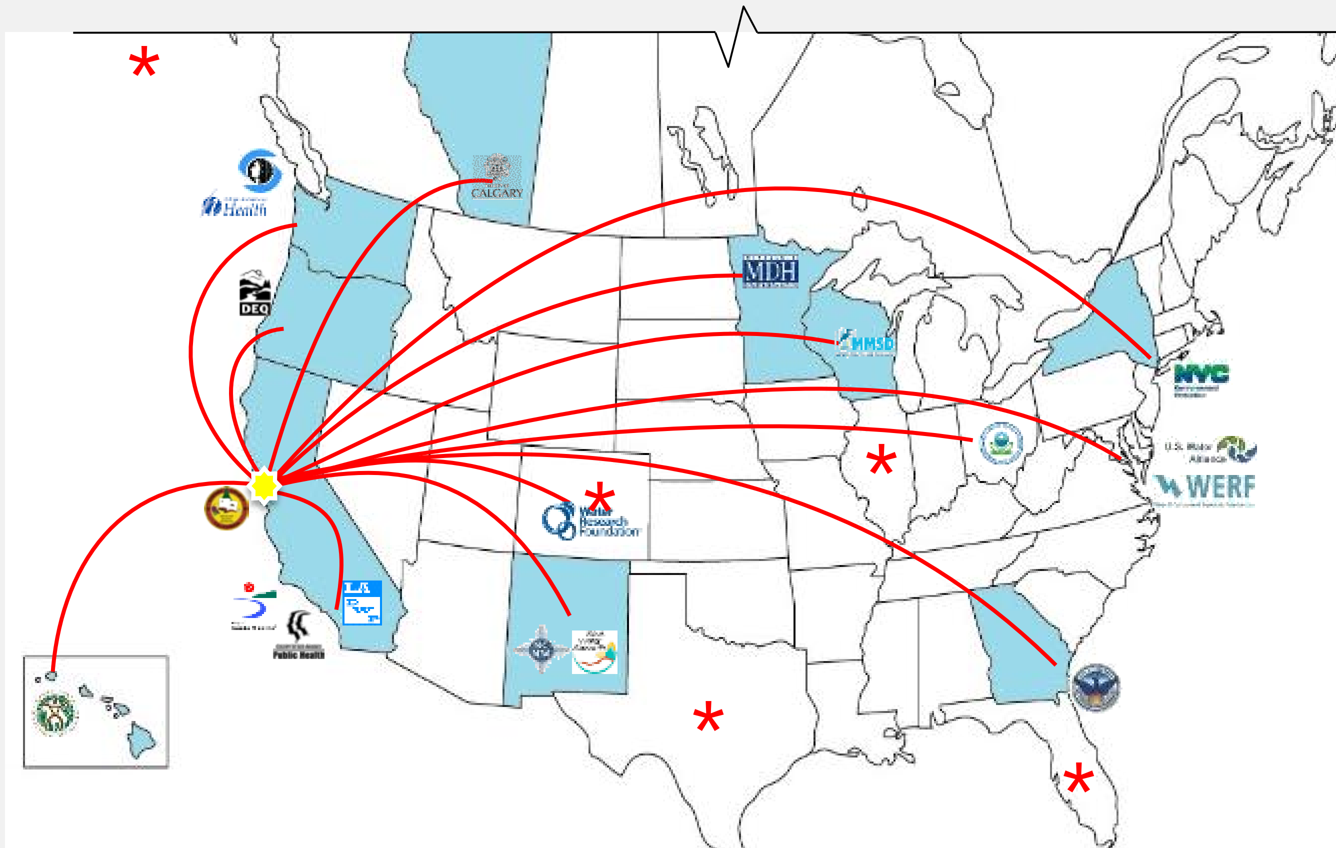
Aesthically pleasing landscape



EPA United States Environmental Protection Agency

Problem Formulation

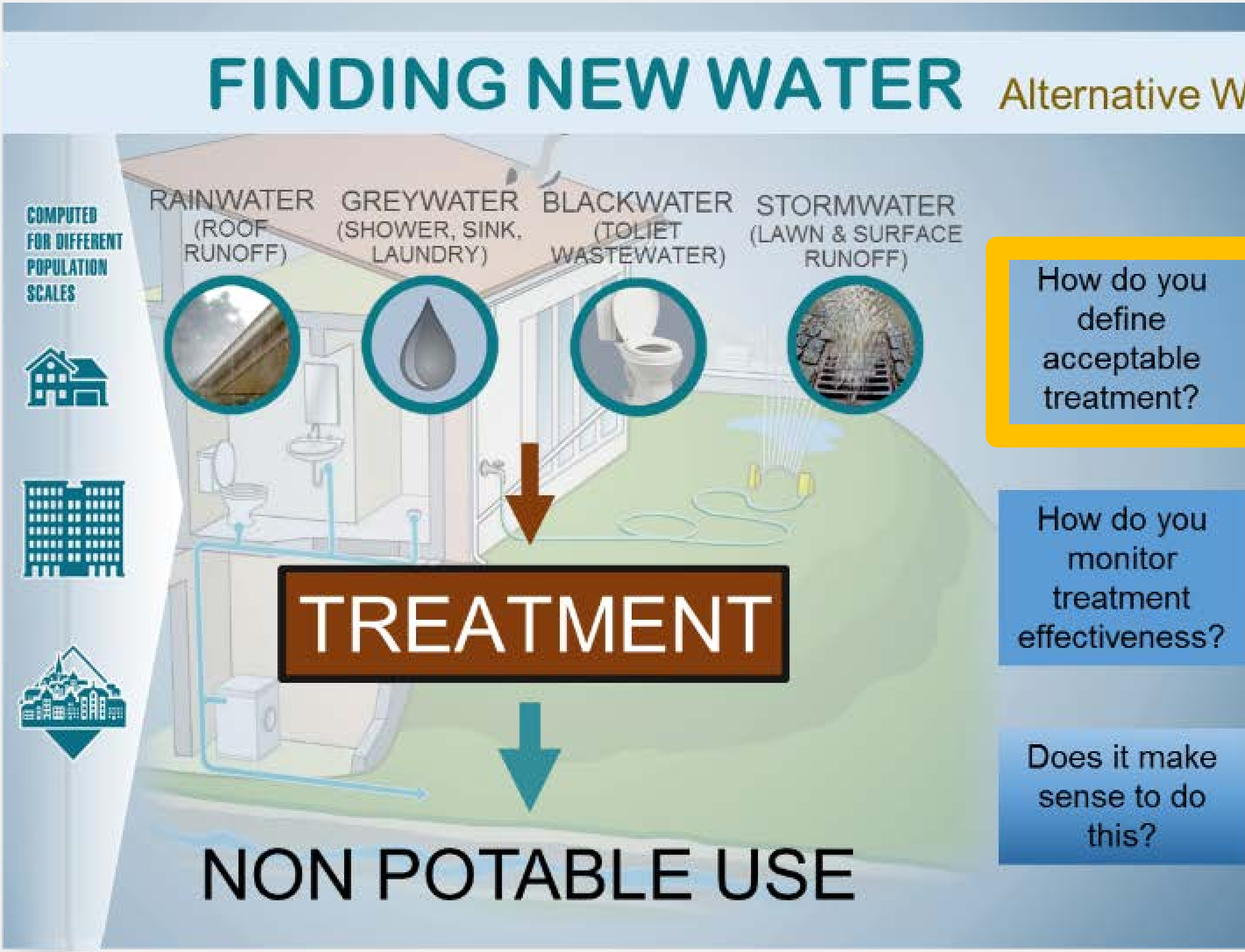
- Stakeholder (utilities & public health agencies) meeting in 2014
- Local management programs are needed
- Water quality parameters and monitoring are needed to protect public health



US Water Alliance

EPA United States Environmental Protection Agency

Second Challenge



Partners

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

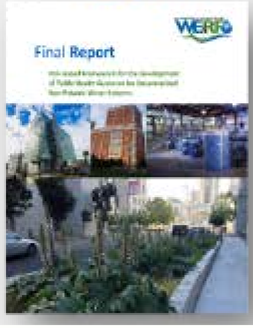
National Blue Ribbon Commission for Onsite Non-potable Water Systems

Water Environment + Reuse Foundation WE&RF

US Water Alliance

The Water Research Foundation

...port



WateReuse

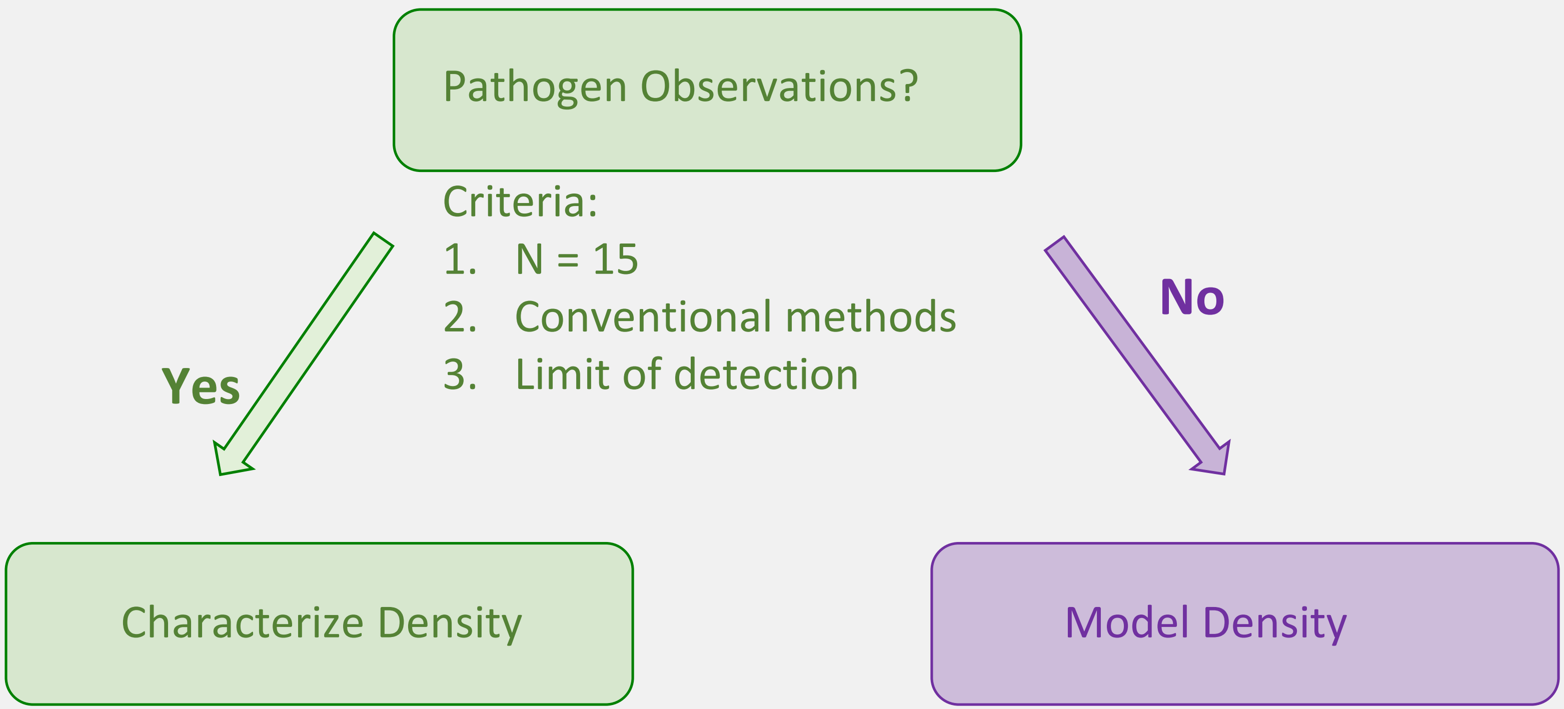
QMRA Results - Log Reduction Targets

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) Risk-based enteric pathogen reduction targets for non-potable and direct potable use fo roof runoff, stormwater, and greywater. Microbial Risk Analysis. 5, 32-43

United States Environmental Protection Agency

Critical First Step in Modeling: Estimating Initial Pathogen Density



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

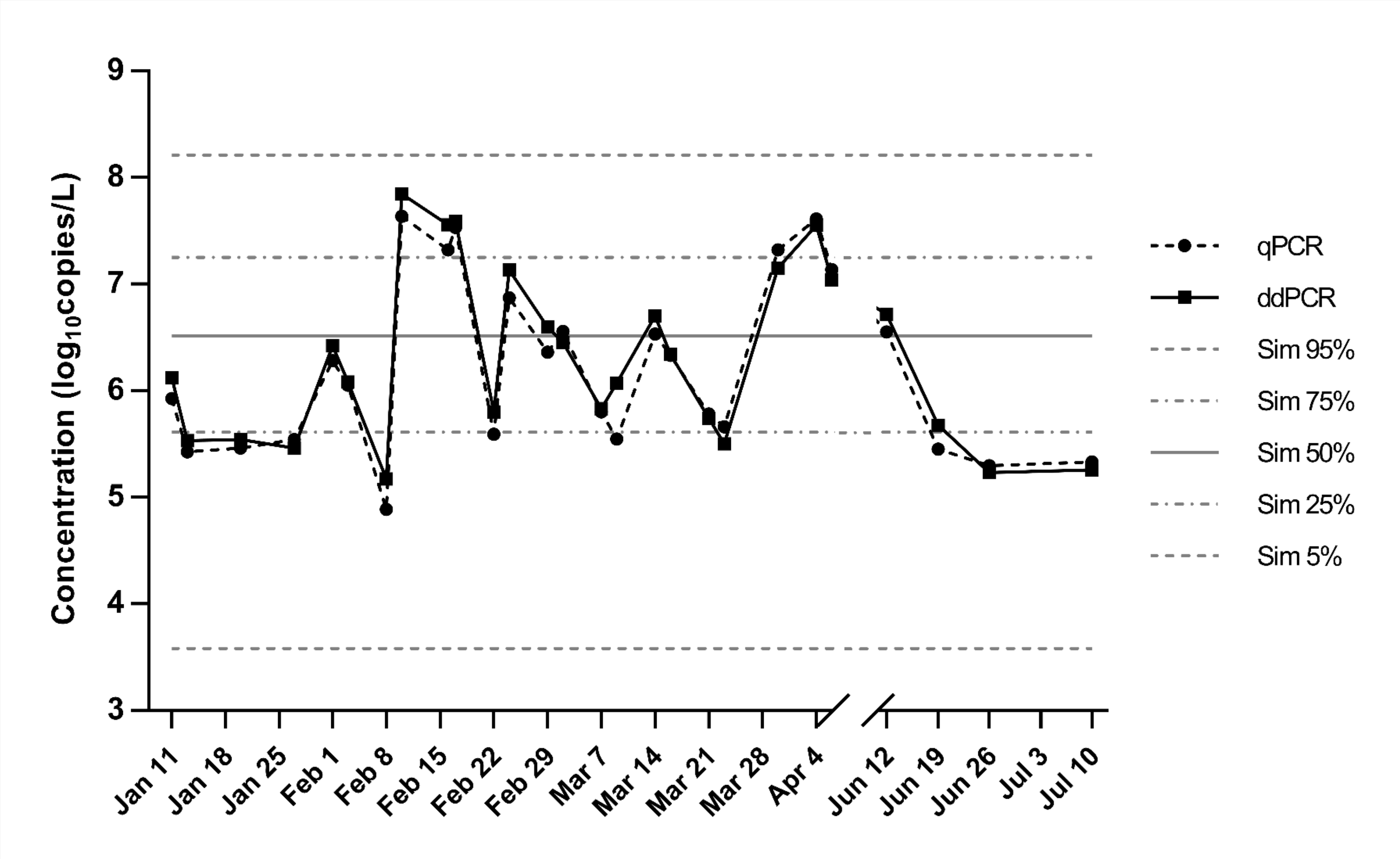
Pathogen concentrations in water

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

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

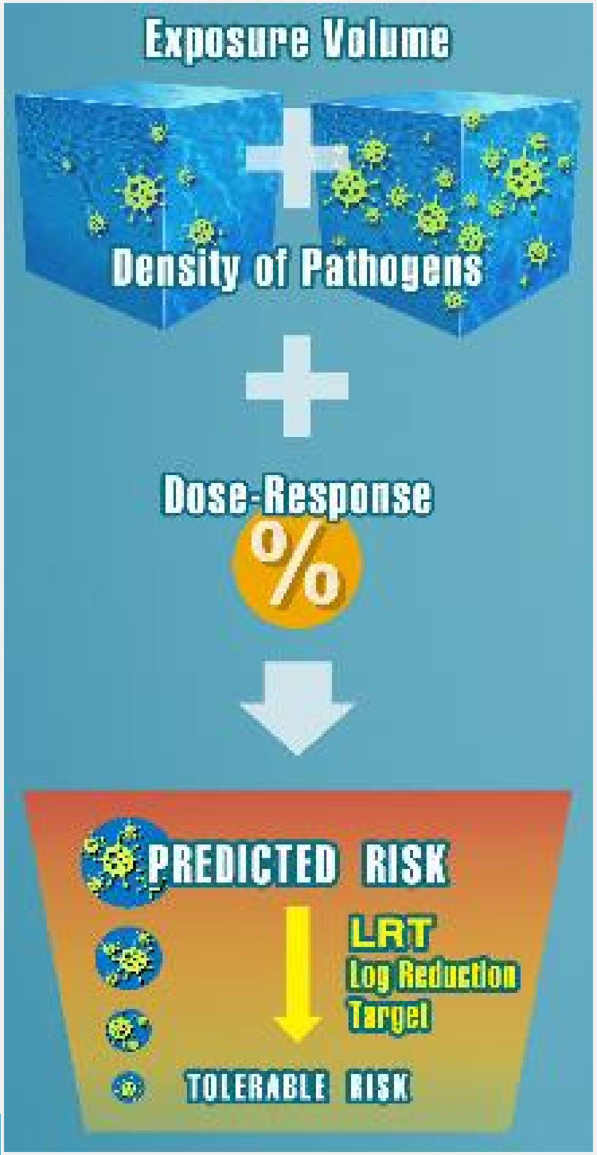
EPA United States Environmental Protection Agency

Result: Model Adequately Brackets Building Scale Wastewater Measures



Jahne et al. (Water Research 2019: onlinev)

Quantitative Microbial Risk Assessment (QMRA)



"Source" waters

food processing wastewater (animal, plant)

End Use

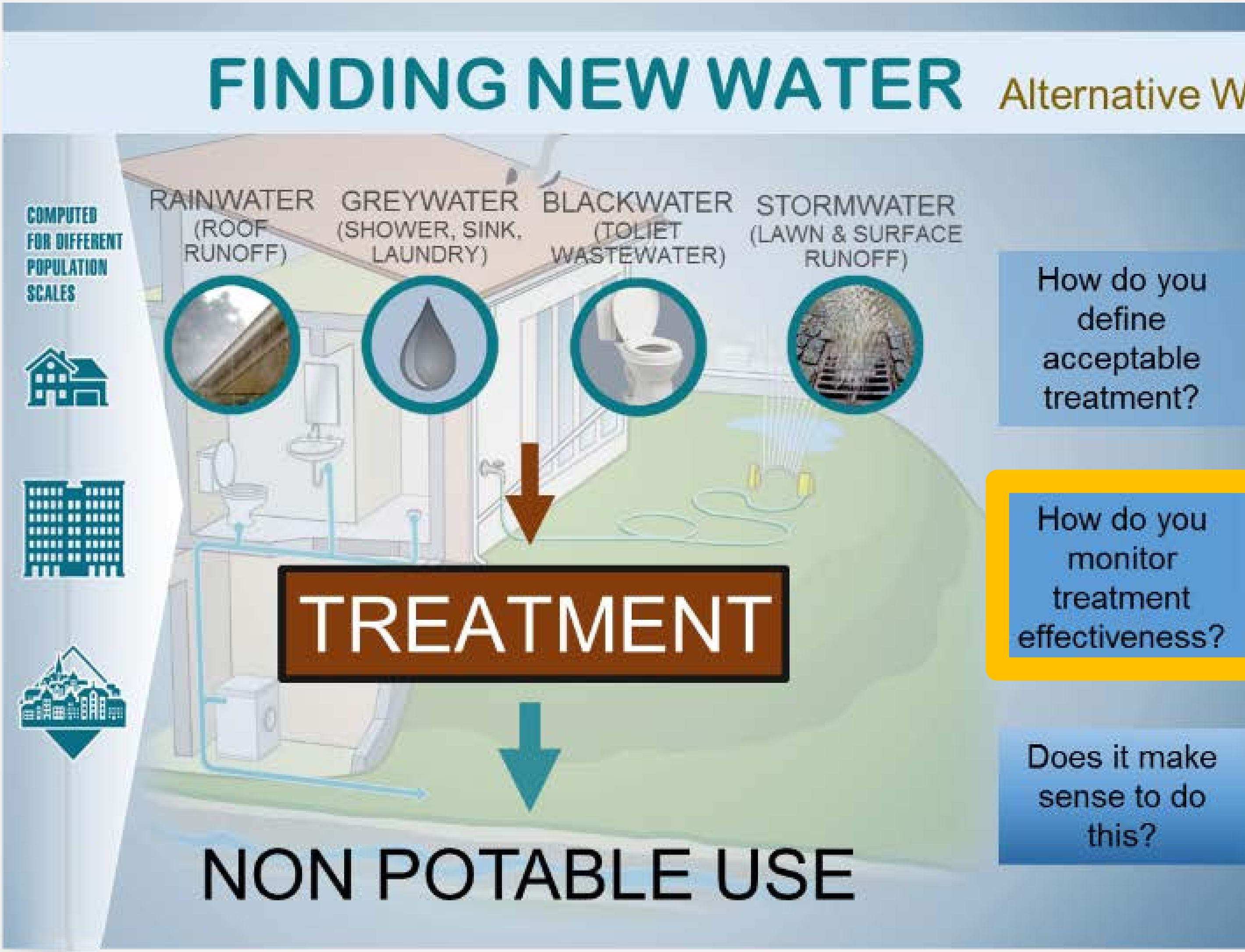
Non-Potable

Potable

Reuse in the Facility

Current Collaboration with Tyson Foods

Second Challenge



Partners

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

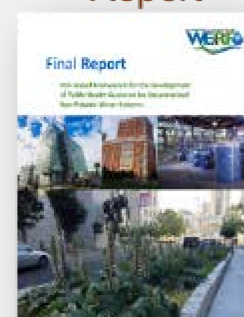
National Blue Ribbon Commission for Onsite Non-potable Water Systems

WE&RF

US Water Alliance

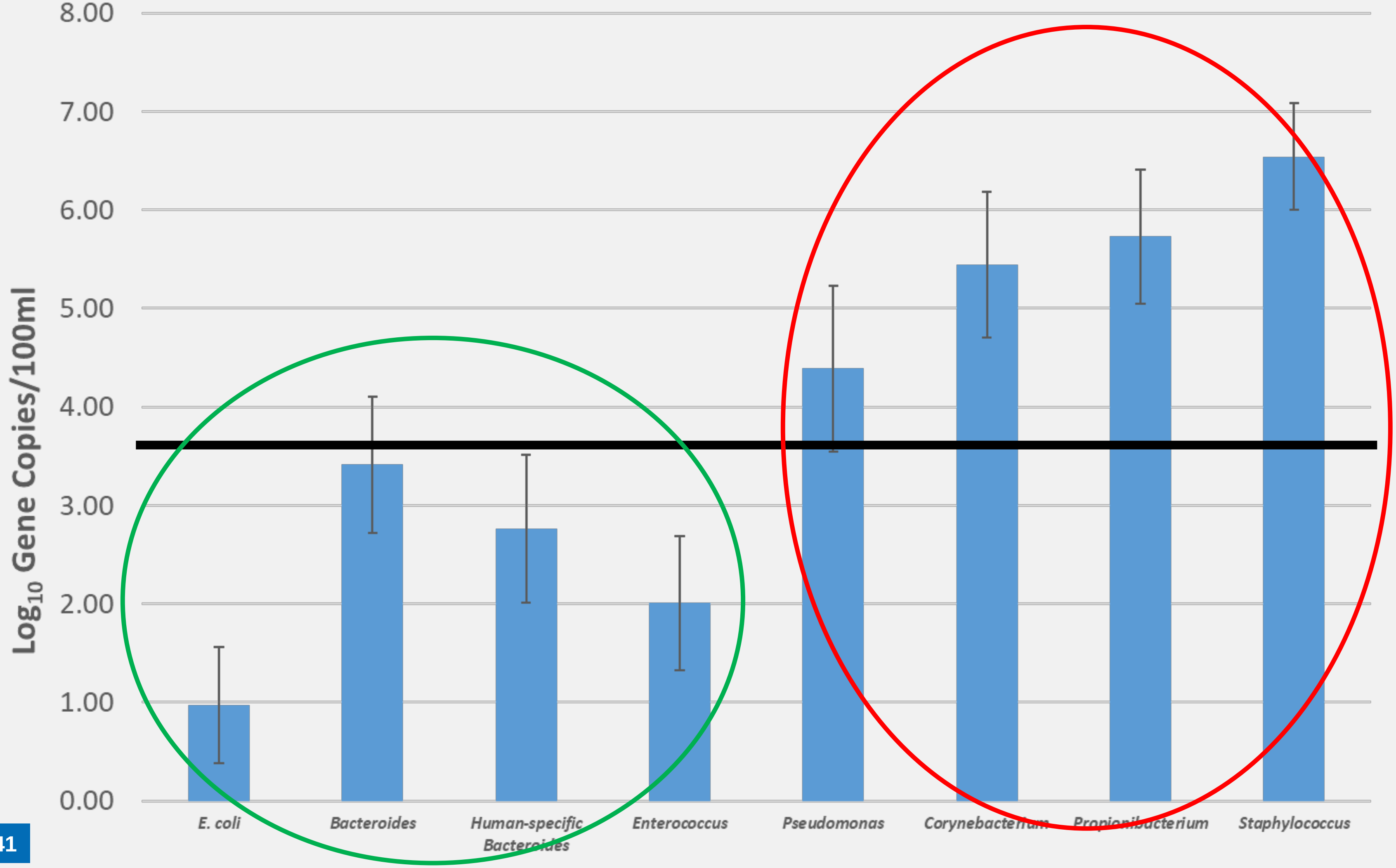
The Water Research Foundation

...port



WateReuse

Quantification of Proposed Bacterial Surrogates in Laundry Graywater



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

Graywater (16S rRNA) Microbiome

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

Collaborators

- *Sharon Nappier, **US EPA Office of Water***
- *Nichole Brinkman, Michael Jahne, Scott Keely*, Emily Anneken, Brian Zimmerman, Brian Crone, Cissy *Ma* ***EPA-ORD***
- *Mary Schoen Soller Environmental*
- Paula Kehoe and the entire **National Blue Ribbon Commission**, On-site Non-Potable Reuse
- Matt Small, Charlotte Ely, Eugenia McNaughton, Andrew Lincoff, Jack Berges, Kate Pinkerton, Jennifer Siu, Peter Husby, Amy Wagner, Kevin Ryan, Erica Yelensky, Valentino Stagno-Cabrera ***EPA Region 9***
- Sybil Sharvelle, Susan De Long ***Colorado State University***
- Marsha Sukardi, Taylor Chang, Darrell Anderson, Maurice Harper ***SFPUC***

Contact

Jay Garland, PhD

Center for Environmental Solutions and Emergency Response

US EPA Office of Research and Development

513-569-7334

garland.jay@epa.gov

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

Final Thoughts

- Need more “transplanting of ideas” in the design phase of studies to fully realize One Health goals
  - Pilot effort to incorporate surface water monitoring into NARMS

- Managing risk within a changing water sector emphasizes:
  - Defining treatment requirements for a variety of fit-for-purpose systems (including within food systems)
    - Direct pathogen measurements to improve model inputs
  - Mining the microbiome for improved surrogates for monitoring treatment