United States Environmental Protection Agency

EPA Tools & Resources Webinar: Alternative Water Sources to Augment Water Supplies

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US EPA Office of Research and Development

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Challenge

- Existing regulatory frameworks for water use are narrowly defined
  - Ground and surface water sources treated to drinking water quality
  - Delegation of other configurations to states
- Increasing water demands drive the need for alternative water supplies
  - Potable reuse of municipal wastewater
  - Onsite water systems
  - Industrial reuse
  - Produced water use
- How do we expand these opportunities while protecting human health?
  - States and industry seeking scientifically-defensible risk-based guidance

Overview

- Terminology: Alternative waters vs water reuse
  - All water is reused on Earth, planned reuse focuses on alternative waters than those traditionally used (surface water, groundwater)

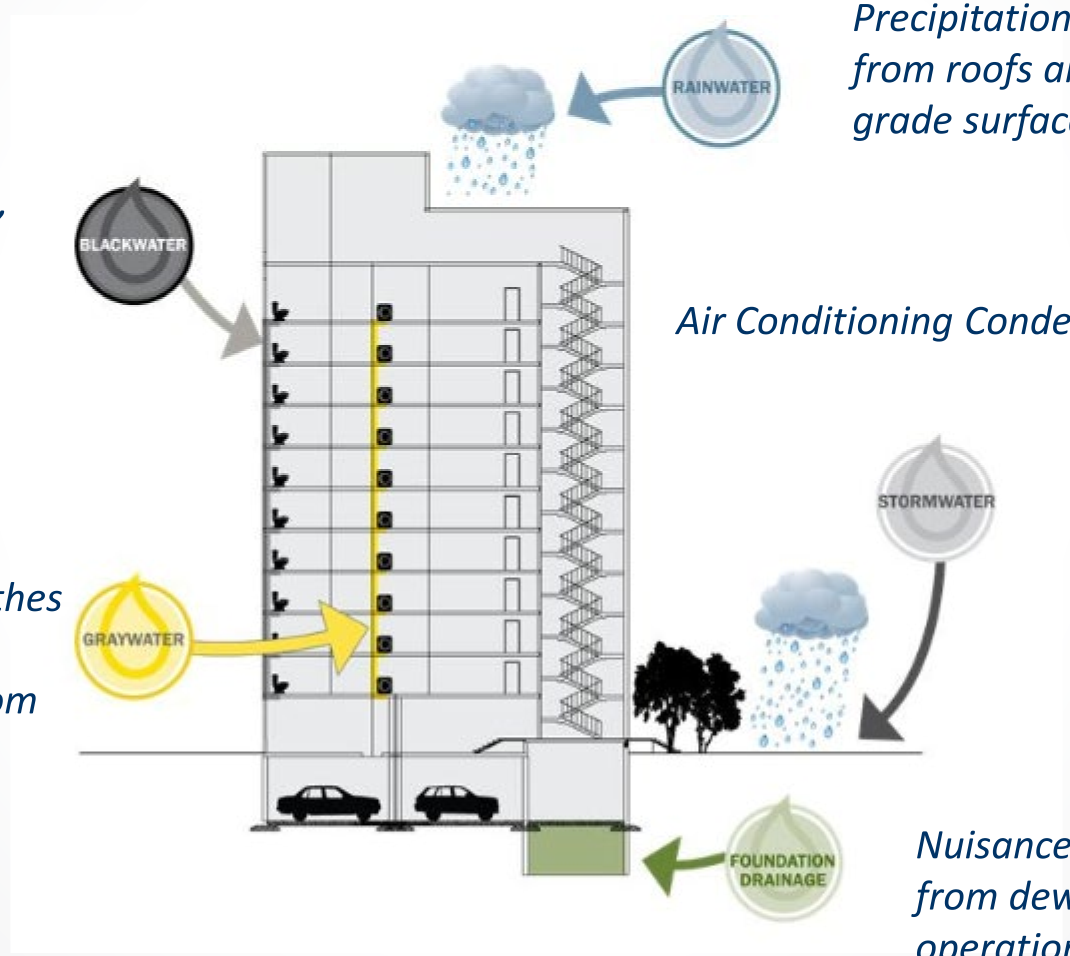
- Expand (and sustain) available water by using alternative waters based on risk-based fit-for-purpose treatment
  - Define necessary treatment for safe use
  - Verify treatment performance
  - Examine life cycle costs/impacts of different strategies

- ORD has applied the same scientific framework to various alternative waters
  - Building-scale reuse of domestic ”wastewater” done initially, most developed
  - More recently involved with food processing wastewater, produced water

Onsite Non-Potable Water Systems

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

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



Precipitation collected from roofs and above-grade surfaces

Air Conditioning Condensate

Precipitation collected at or below grade

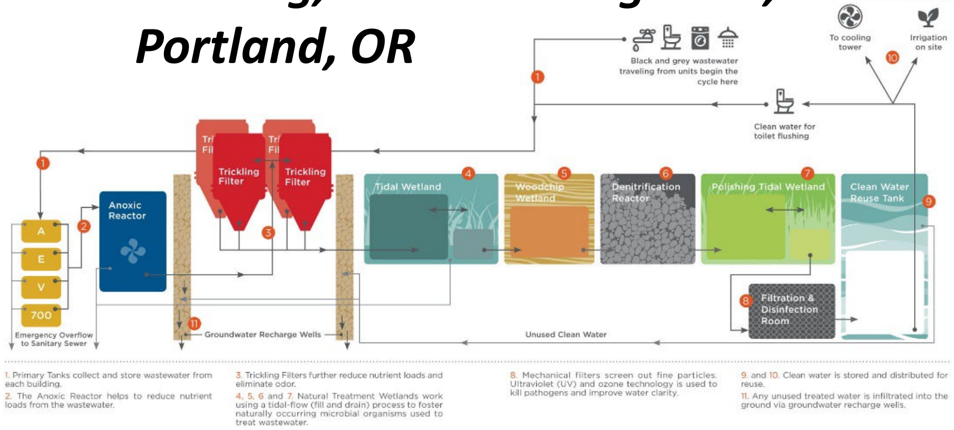
Nuisance groundwater from dewatering operations

Increasing Building Scale Reuse across US

The Solaire apartment building, Battery Park, NYC

25,000 gpd (gallons per day) of wastewater
Membrane Bioreactor
Toilet flushing, cooling, irrigation

Hassalow on Eighth multi-building, mixed-use high rise, Portland, OR



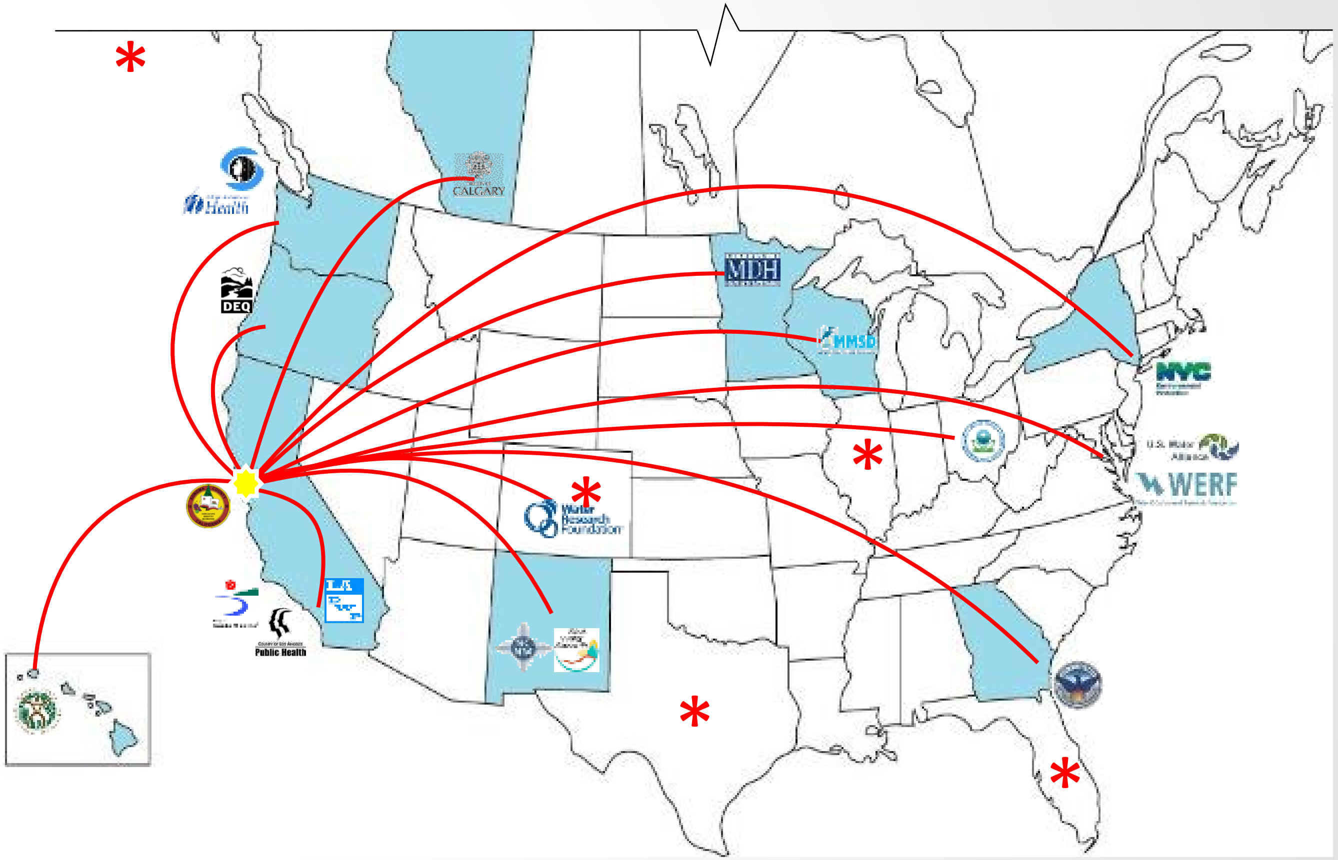
60,000 gpd wastewater
Treatment includes landscaping
Toilet flushing, cooling, irrigation

181 Fremont mixed-use skyscraper, San Francisco, CA

5,000 gpd greywater
Membrane bioreactor
Toilet flushing

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

Quantitative Microbial Risk Assessment (QMRA)

Sources of Water

(roof runoff, stormwater, graywater, blackwater)

End Use

Non-Potable

Potable

Structured Framework

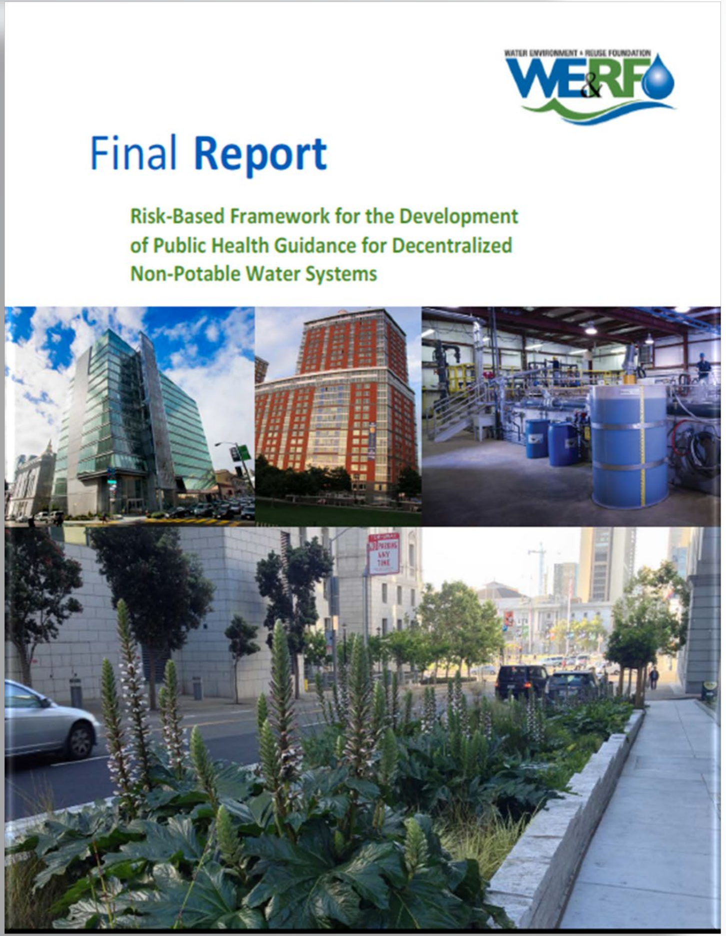
Transparent Underlying Assumptions

Flexible and Adaptable

Approach: Developing Risk-Based Pathogen Reduction Targets

- "Risk-based" targets attempt to achieve a specific level of protection (aka tolerable or acceptable risk)
  - 1:10,000 infections per person per year (ppy)
  - 1:100 illnesses ppy
  - 1:1,000,000 disability adjusted life years (DALY) ppy

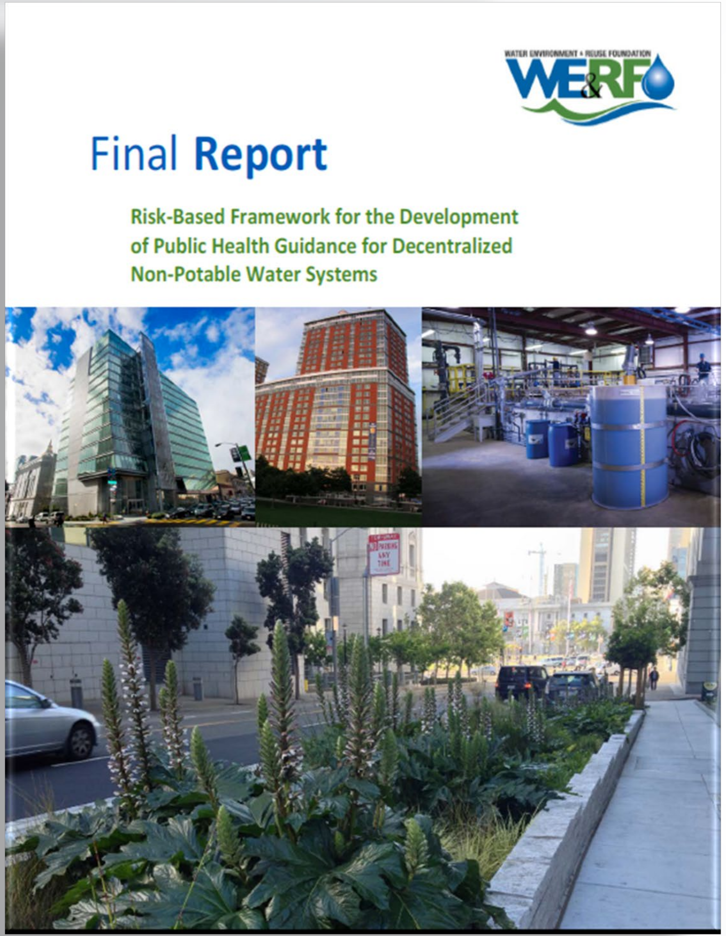
- Pathogen log reduction targets (LRTs)
  - 10-fold removal needed by treatment to meet selected health benchmark



Sharvelle et al. (2017) Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems

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)

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			



Risk-based approach increasingly adopted

California, Colorado, Washington State

Austin (TX), San Francisco CA)

Or actively considered

Arizona, Hawaii, Oregon

Potential integration with building codes

International Code Council (ICC)

International Association of Plumbing & Mechanical Officials (IAPMO)

National Sanitation Foundation (NSF)

Sharvelle et al. (2017) Risk-Based Framework fo
Schoen et al. (2017) Microbial Risk Analysis 5, 32-43

State of the Science Report

- New scientific resource for states adopting risk-based reuse
  - Joint product of ORD and OW Water Reuse Program
- Describes QMRA framework for water reuse and current parameter assumptions
  - Reference pathogens to consider
  - Pathogen density characterizations in reuse sources of water (municipal and onsite)
  - Exposure estimates for potable and non-potable uses
  - Pathogen dose-response models
  - Risk characterization approaches
- Includes computed log-reduction targets, and information needed for new calculations
- Summarizes related policy decisions and future research needs

Environmental Science & Technology Letters

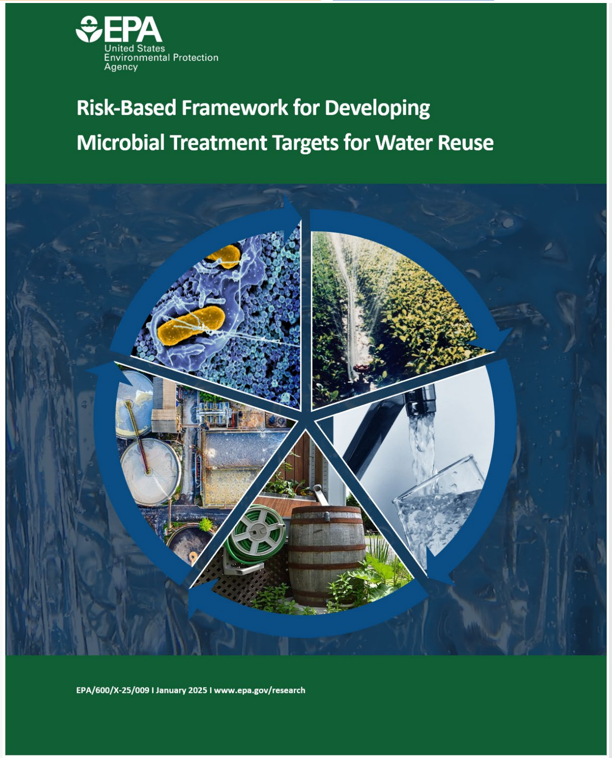
Jahne et al. 2024

pubs.acs.org/journal/estlcu Letter

Microbial Treatment Targets for Potable and Nonpotable Water Reuse – A Comprehensive Update and Harmonization

Michael A. Jahne,* Mary E. Schoen, Jay L. Garland, Sharon P. Nappier, and Jeffrey A. Soller

Cite This: https://doi.org/10.1021/acs.estlett.4c00512 Read Online



Risk-Based Framework for Developing Microbial Treatment Targets for Water Reuse

Water Use in Protein Processing

- Protein processing operations include animal slaughtering, meat and poultry product production, and/or rendering of byproducts
- Facilities utilize large volumes of water for hair/hide/feather removal, carcass washing, chilling, trimming and cutting, cooking, cleaning and sanitation, etc.
- Hundreds to thousands of gallons per thousand pounds live weight killed; beef > pork > poultry in overall use
- Resulting wastewater may contain blood, viscera, soft tissue, bone, urine, feces, soil, and cleaning/sanitation agents
- Wastewater is typically treated onsite and discharged to municipal wastewater treatment plants or surface waters following NPDES permits

Water *Re*use in Protein Processing

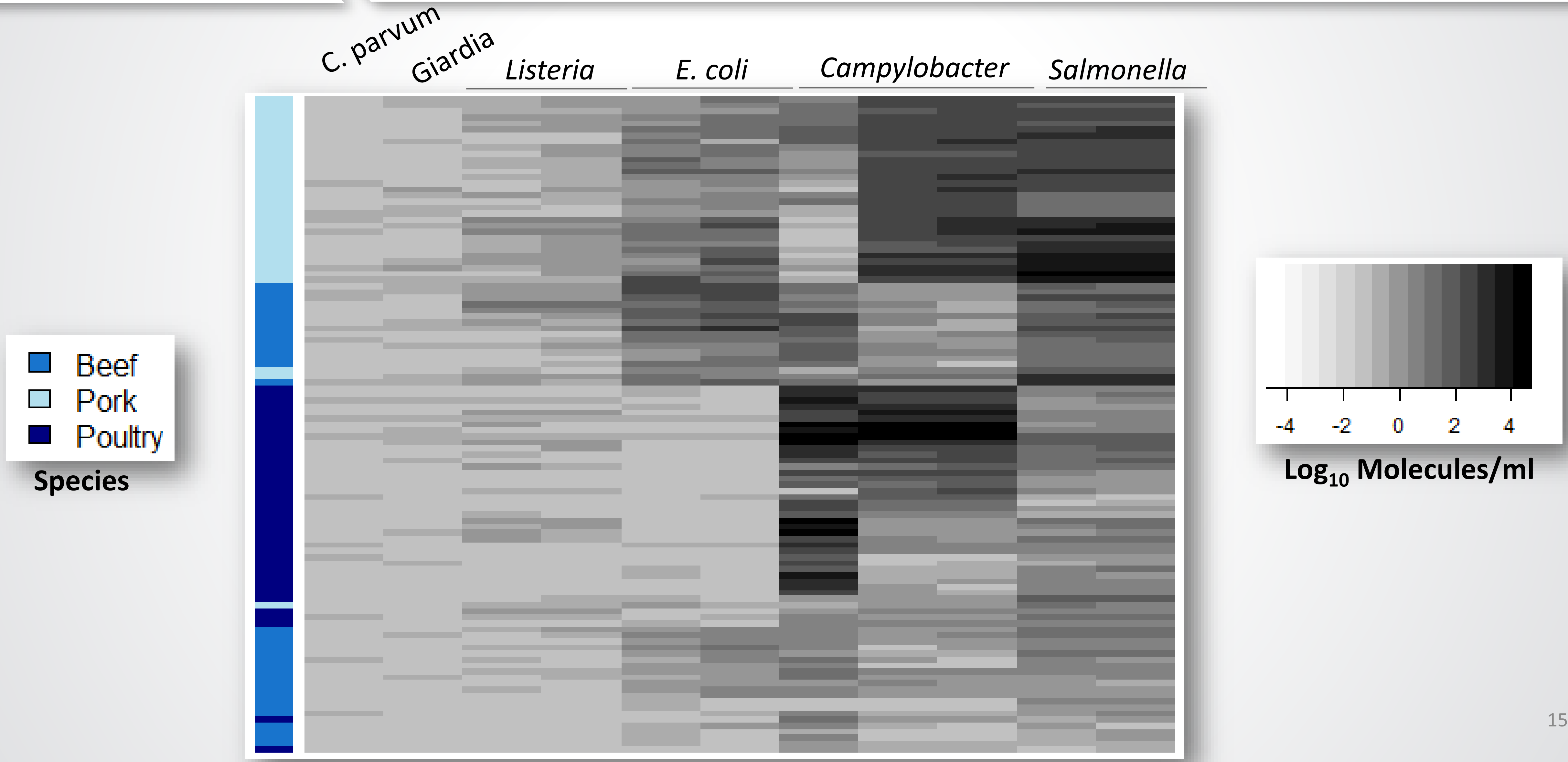
- Broad water reuse for most purposes, including in processes that involve product contact (but not in product formulation), is also allowed provided:
  - *"Reconditioned water that has never contained human waste and that has been treated by an **onsite advanced wastewater treatment facility**"*
  - *"complies with National Primary Drinking Water Standards" – i.e.*, that the reconditioned water is **potable**
  - and that contacted products and surfaces undergo a final rinse with non-reconditioned water
- **However, treatment requirements for potable reuse of this unique source of water have not been clearly defined**
  - Microbial regulations tied to source water – e.g., Surface Water Treatment Rule
  - Similar challenges to direct potable reuse of municipal wastewater (DPR)

9 CFR Part 416

Tyson Project Objectives

- **Task 1: Source Characterization**
  - Focus on microbial contaminants likely to drive treatment train
  - Include conventional contaminants (biochemical oxygen demand, solids, oil & grease, nitrogen)
  - Since moving towards potable use, secondary assessment of industry-specific chemicals (antibiotics, hormones, cleaning compounds
- **Task 2: Treatment Target Development**
  - Based on microbial contaminants: quantitative microbial risk assessment (QMRA) to develop pathogen log reduction targets (LRTs)
- **Task 3: Treatment Train Configurations**
  - Identify unit processes to meet LRTs
  - Additional consideration of conventional contaminants and chemicals; does treatment train for microbials manage these or need additional unit process(es)
  - Will not provide actual engineering design

Microbial Loads



LRT Results

	Salmonella	*Campylobacter*	Pathogenic *E. coli*	*Listeria*	*Giardia*	*Cryptosporidium*	Norovirus
Beef	8.2	11.4	6.8	*8.9*	*6.5*	*7.7*	n/a
Pork	10.7	13.3	7.1	*8.7*	*7.3*	*7.7*	n/a
Poultry	8.7	15.8	*2.8*	*9.2*	*0*	*0*	n/a
Combined	10.3	14.7	7.2	*9.3*	*7.1*	*7.5*	n/a
WW-DPR	9.5	11	n/a	n/a	9.5	10.5	14.5

**italics indicate greater uncertainty for rare pathogens*

Hazard Comparison

VH - Very High	H - High	M - Medium	L - Low	I - Inconclusive	No Data		Authoritative	Screening	*QSAR Model*

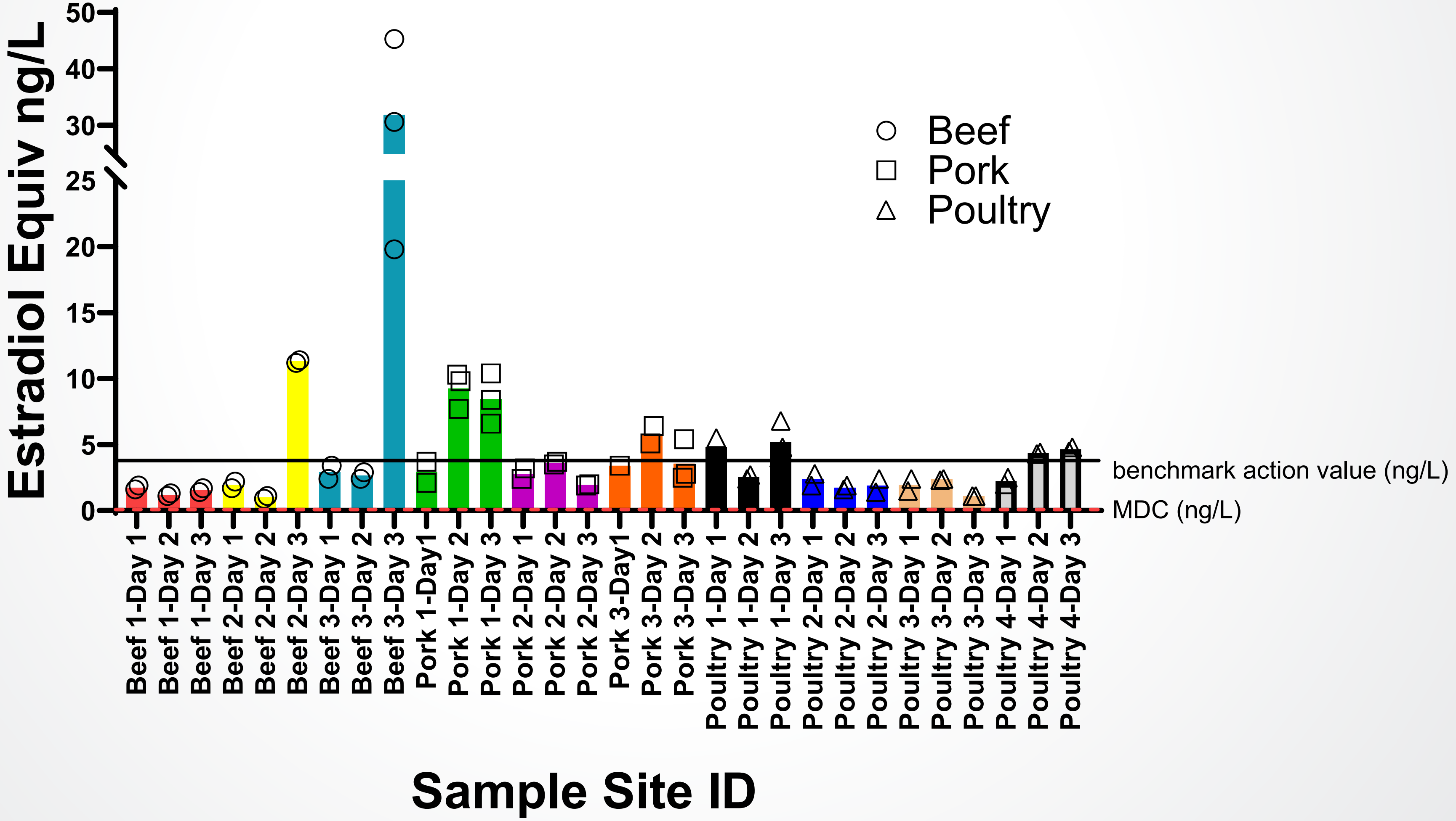
Name	Human Health Effects															Ecotoxicity		Fate	
	Acute Mammalian Toxicity								Neurotoxicity		Systemic Toxicity								
	Oral	Inhalation	Dermal	Carcinogenicity	Genotoxicity Mutagenicity	Endocrine Disruption	Reproductive	Developmental	Repeat Exposure	Single Exposure	Repeat Exposure	Single Exposure	Skin Sensitization	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation
Norethindrone	L			VH	VH	H	H	H								L	VH		L
Didecyldimethylammonium	H	I	I	I	L	L	I	L	I	I	I	I	I	I	I	I		M	H
7,4'-Dihydroxyisoflavone	M				L	H		H	M							H	VH		L
Estrone	L	I	L	VH	VH	H	H	H	H	I	H	I	I	I	I	H	VH	M	M
(S)-Lactic acid	M	L	L	I	L	L	I	H	L	I	L	I	I	VH	VH	L	L	L	L
17beta-Estradiol	L			VH	VH		H				H					VH	VH		L
Estriol	L				L	H	H	H								H	VH		L
Levonorgestrel	L				L	H	H	H								VH			I
Medroxyprogesterone	M				L	L	M	H								H	M		L
17alpha-Ethinylestradiol	M			VH	VH		H				H					H	VH	H	H
Diethylstilbestrol	M	I	I	VH	VH	H	H	H			H	M	H	I	I	H	H		M

U.S. EPA CompTox Cheminformatics Modules
https://www.epa.gov/comptox-tools/cheminformatics

Next step: Assess removal needs by comparing observed concentrations to reported toxicity thresholds

Bioassays

Estrogen Receptor Assay



Background: Produced Water (PW)

- **Produced water**
  - Wastewater byproduct of oil and gas extraction
  - Complex mixture containing *formation fluid* and *chemical additives* used in production and maintenance
- **Characteristics**
  - Variable by basin/formation, production type, and well life stage
  - Typically ranges 1-100X oil volume
  - Potential contaminants:
    - salts
    - hydrocarbons
    - organics
    - metals
    - naturally occurring radioactive material
    - additives and transformation products
    - others

Risk-Based Treatment of Produced Water

Problem: Oil and gas development generates large volumes of water that exceed the capacities of current in-field reuse and deep well disposal options, promoting interest in off-field reuse. However, the quality and toxicity of raw and treated produced waters remain poorly characterized to inform necessary risk assessments.

Region 6 Priorities Addressed:
- **Produced Water**

Actions:

- Characterize the composition and toxicology of produced waters to inform risk-based treatment needs
- Assess the performance of treatment trains using effects-based, non-targeted, and computational approaches
- Develop tools for users to conduct further analysis of scenarios of interest

Results:

- Fit-for-purpose treatment guidance for potential off-field uses
- User tools for screening-level risk characterization and prioritization

Impact: Providing states with risk-based treatment guidance as they develop produced water reuse programs

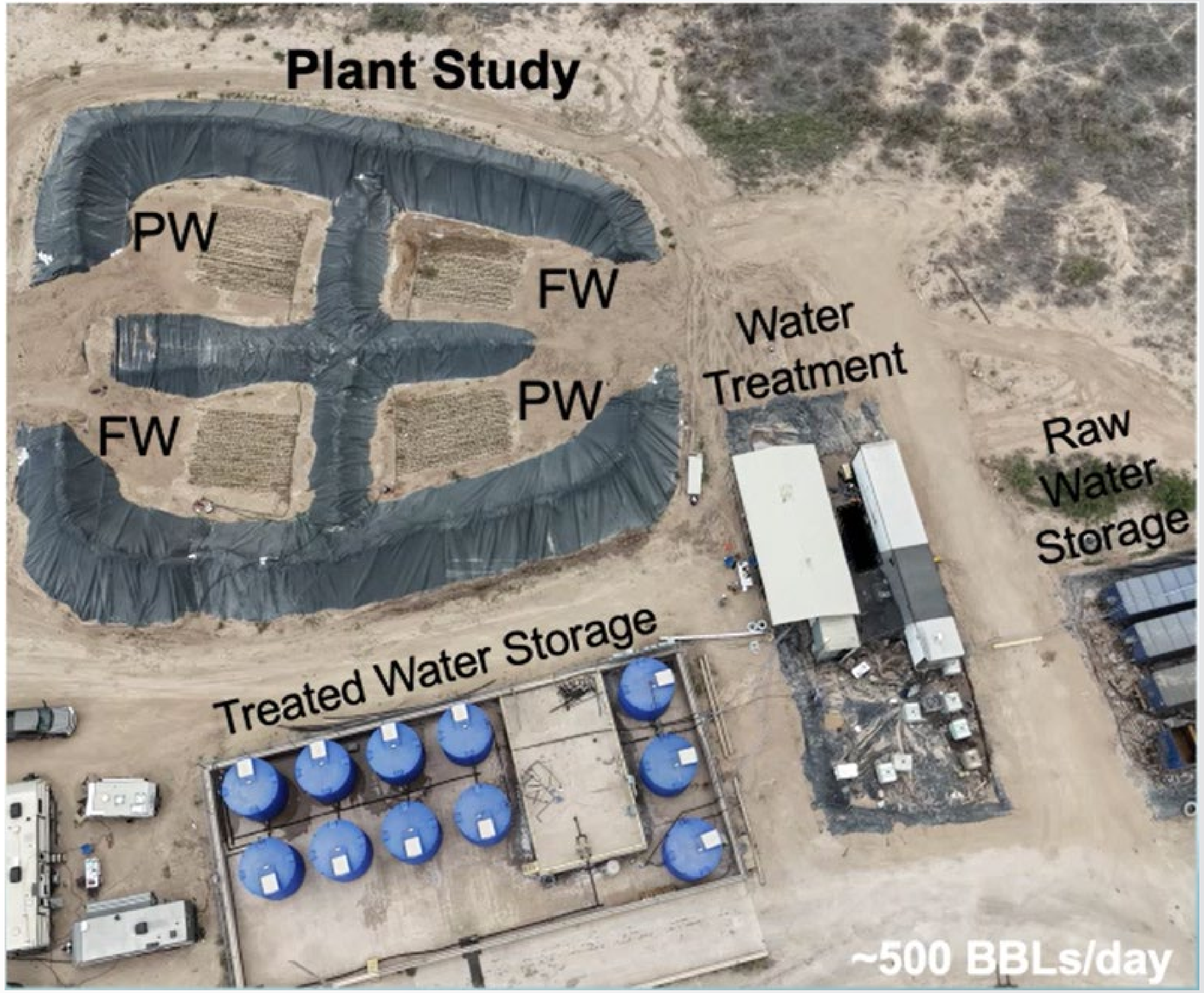
POC: *Michael Jahne (ORD-CESER)*

Tool Development

- **Quantitative Hazard, Risk, and Toxicological Evaluation Tool (QHRTET)**
- High-throughput exploration and screening-level risk characterization to support decision making from complex data
  - User-supplied datasets (e.g., from produced water studies)
  - FracFocus chemical disclosure database
- Links to EPA CompTox resources for prioritization of compounds or sites
  - Physicochemical properties and environmental fate and transport information
  - Human and ecological toxicity data (*in vivo, in vitro, in silico*)
  - Product-chemical functional usage relationships and safety data
  - Curated lists of available water quality standards and benchmarks
- Open source, ‘R’ Shiny web-based app
  - Anticipated release in 2025 Q4

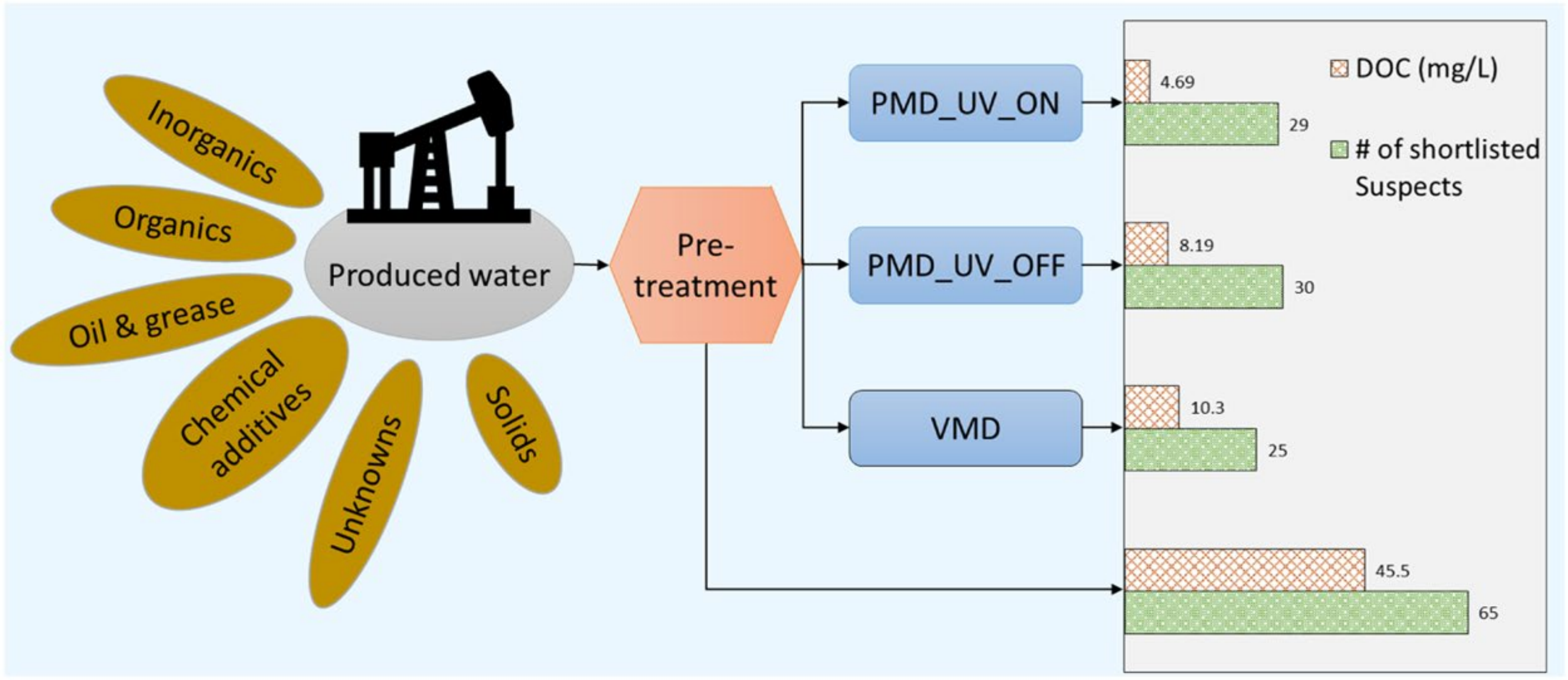
CSM Treatment Pilot

- New study in progress: Field-scale including crop irrigation
- Industry and academic partners
  - PWR, NGL, Exxon, CSM, Colorado State
- Adding new effects-based methods for endocrine disruption and aquatic toxicity



NMSU Treatment Pilot

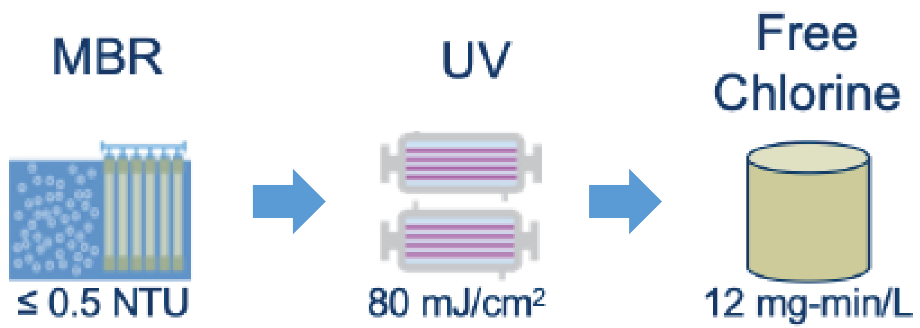
- Cartridge filtration + membrane distillation (MD)
  - Comparing vacuum (VMD) and photocatalytic (PMD)
- Non-targeted analysis (NTA) and toxicity prediction



Delanka-Pedige et al. (2024) *Journal of Hazardous Materials* 471:134436

Risk-Based Treatment: Putting it Together

Example Treatment Trains for Indoor Use of Onsite Wastewater/Blackwater



Pathogens	LRV Achieved by Treatment Process			Total LRV Achieved	LRV Required for Indoor Use
	MBR	UV	Free Cl_2		
Enteric Virus	1.0	3.5[b]	4.0	8.5	8.5
Giardia	2.5	6.0	--	8.5	7.0
Crypto	2.5	6.0	--	8.5	7.0
Bacteria	4.0	6.0[d]	4.0	14	6.0

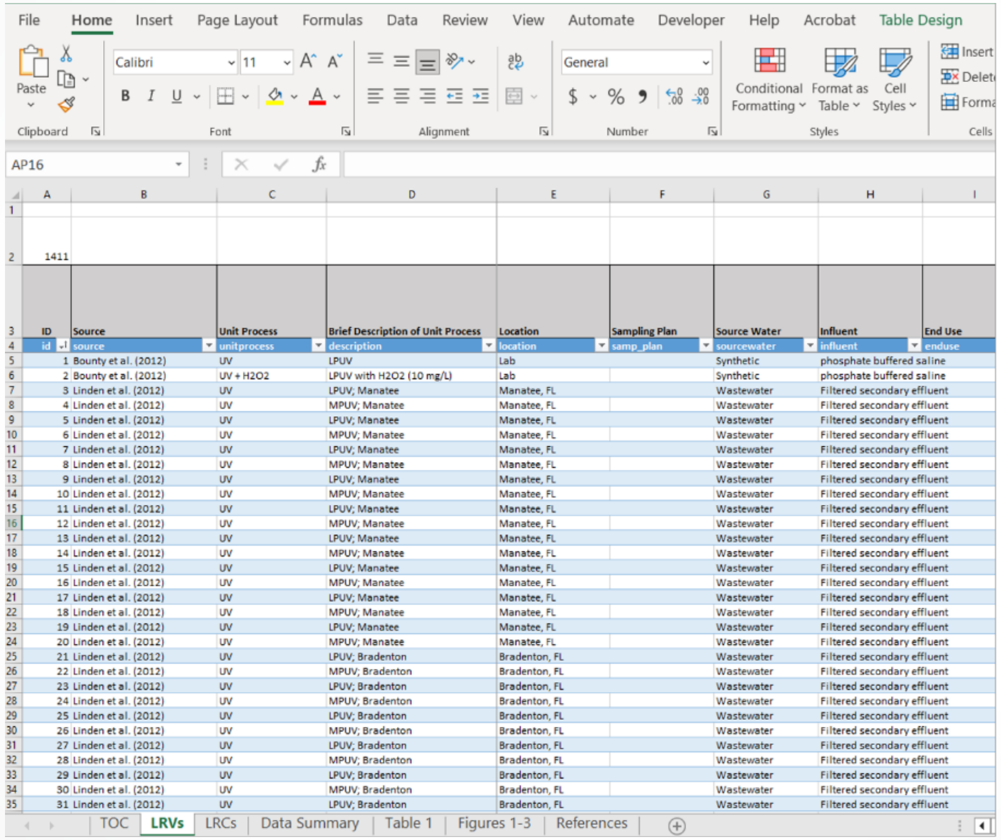
Sum of reduction values must meet LRTs

MBR = Membrane bioreactor (compact biological treatment)
UV = Ultraviolet disinfection
LRV = Log reduction value (pathogen removal achieved by process)

NBRC (2023) “Health Risk-based Benchmarks for Onsite Treatment of Water”

Unit Process Log Reduction Value (LRV) Database for Water Reuse Practitioners

- Intended as a quick access resource
- LRCs and LRVs compiled for unit processes typical of onsite reuse systems
- Also compiled extensive list of process attributes
- Database available in the publication link



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ID	Source	Unit Process	Brief Description of Unit Process	Location	Sampling Plan	Source Water	Influent	End Use
id	source	unitprocess	description	location	samp_plan	sourcewater	influent	enduse
1	Bounty et al. (2012)	UV	LPUV	Lab		Synthetic	phosphate buffered saline	
2	Bounty et al. (2012)	UV + H2O2	LPUV with H2O2 (10 mg/L)	Lab		Synthetic	phosphate buffered saline	
3	Linden et al. (2012)	UV	LPUV; Manatee	Manatee, FL		Wastewater	Filtered secondary effluent	
4	Linden et al. (2012)	UV	MPUV; Manatee	Manatee, FL		Wastewater	Filtered secondary effluent	
5	Linden et al. (2012)	UV	LPUV; Manatee	Manatee, FL		Wastewater	Filtered secondary effluent	
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21	Linden et al. (2012)	UV	LPUV; Bradenton	Bradenton, FL		Wastewater	Filtered secondary effluent	
22	Linden et al. (2012)	UV	MPUV; Bradenton	Bradenton, FL		Wastewater	Filtered secondary effluent	
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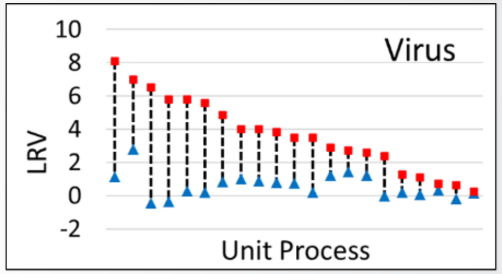
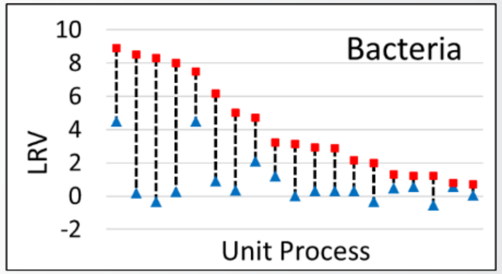
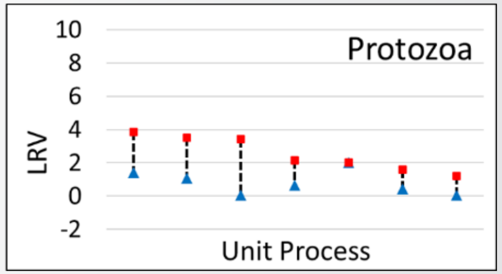






Science Direct publication

DPR Treatment Train Example

Treatment Train	Pathogen	Unit Process Log Reduction Credits						Total Log Reduction
		CAS	MF	RO	High Dose UV	$ESB+Cl_2$		
TTA	Virus	1.9	0	2	6	4		13.9
	Cryptosporidium	1.2	4	2	6	0		13.2
	Giardia	0.8	4	2	6	3		15.8
	Bacteria[a]	1.9	3	2	6	4		16.9
		CAS	O_3	BAF	UF	High Dose UV	$ESB+Cl_2$	
TTB	Virus	1.9	6	0	0	6	4	17.9
	Cryptosporidium	1.2	1	0	4	6	0	12.2
	Giardia[b]	0.8	3	0	4	6	3	16.8
	Bacteria	1.9	2	0	3	6	4	16.9

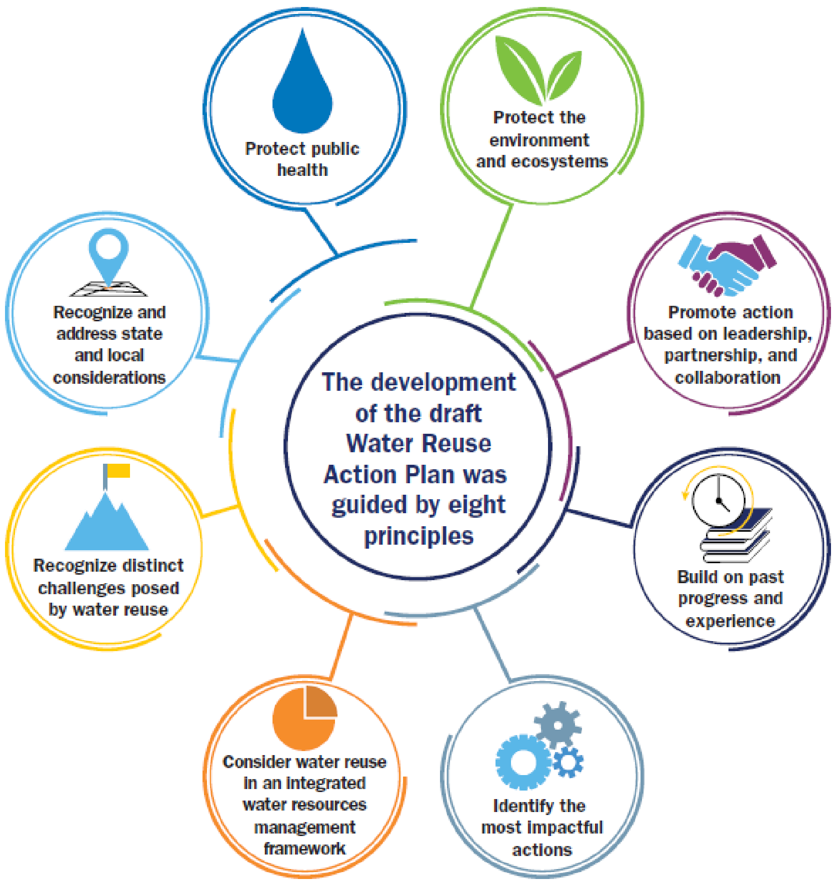
Soller et al. (2018) Water Research 128, 286-292

Monitoring Approach

- Moving away from end point, water quality monitoring
  - Costly, slow response time
  - Low, variable pathogen levels provide difficult analytical challenges
- To unit process performance metrics as key critical control points
  - Process-specific surrogates (i.e. transmembrane pressure, UV levels, etc.)
  - More real-time data for rapid, remote response
- More operational testing needed to develop and validate surrogate approaches

Why do this?

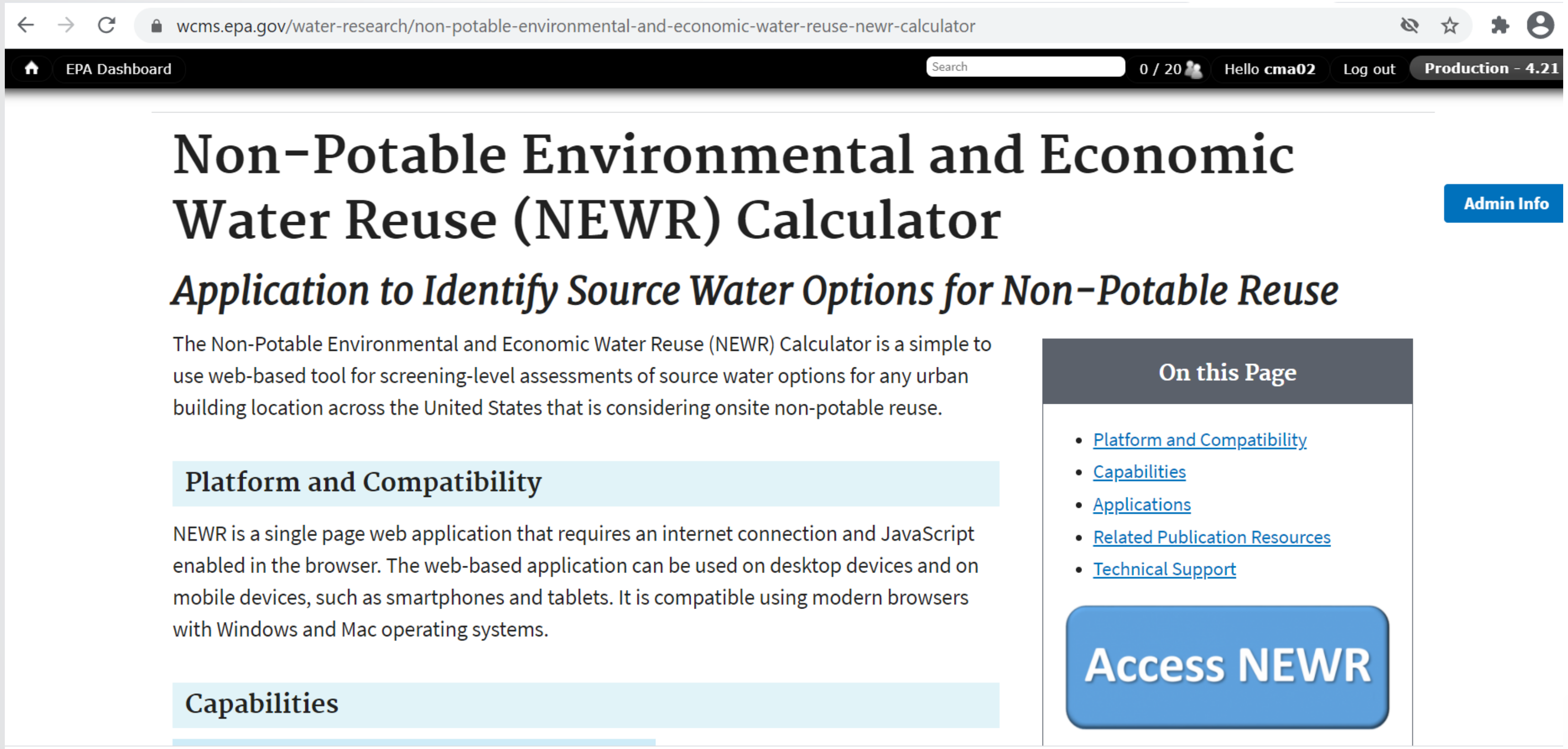
Guiding Principles of the Water Reuse Action Plan



Source: www.epa.gov/sites/production/files/2019-09/documents/water-reuse-action-plan-draft-2019.pdf

- Avoid burden-shifting with respect to economic and environmental impacts
- System level assessment of decentralized systems, including impacts on existing centralized infrastructure

Non-potable Environmental and Economic Water Reuse (NEWR) Calculator


wcms.epa.gov/water-research/non-potable-environmental-and-economic-water-reuse-newr-calculator

EPA Dashboard | Search | 0 / 20 | Hello cma02 | Log out | Production - 4.21

Non-Potable Environmental and Economic Water Reuse (NEWR) Calculator

Admin Info

Application to Identify Source Water Options for Non-Potable Reuse

The Non-Potable Environmental and Economic Water Reuse (NEWR) Calculator is a simple to use web-based tool for screening-level assessments of source water options for any urban building location across the United States that is considering onsite non-potable reuse.

On this Page

- Platform and Compatibility
- Capabilities
- Applications
- Related Publication Resources
- Technical Support

Access NEWR

Platform and Compatibility

NEWR is a single page web application that requires an internet connection and JavaScript enabled in the browser. The web-based application can be used on desktop devices and on mobile devices, such as smartphones and tablets. It is compatible using modern browsers with Windows and Mac operating systems.

Capabilities

Access NEWR

Research Questions:

What is the most environmentally and cost-effective source water(s) to meet large building non-potable water needs?

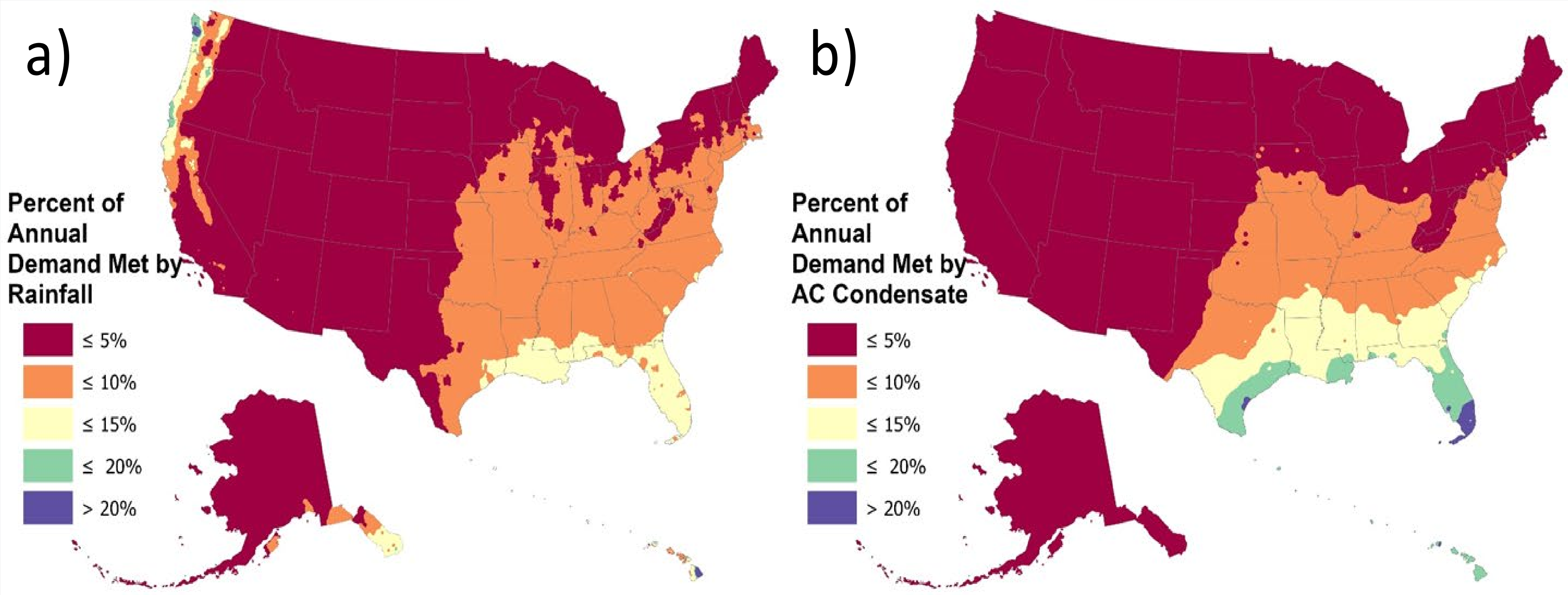
Target audiences:

Planners and Developers

Impact:

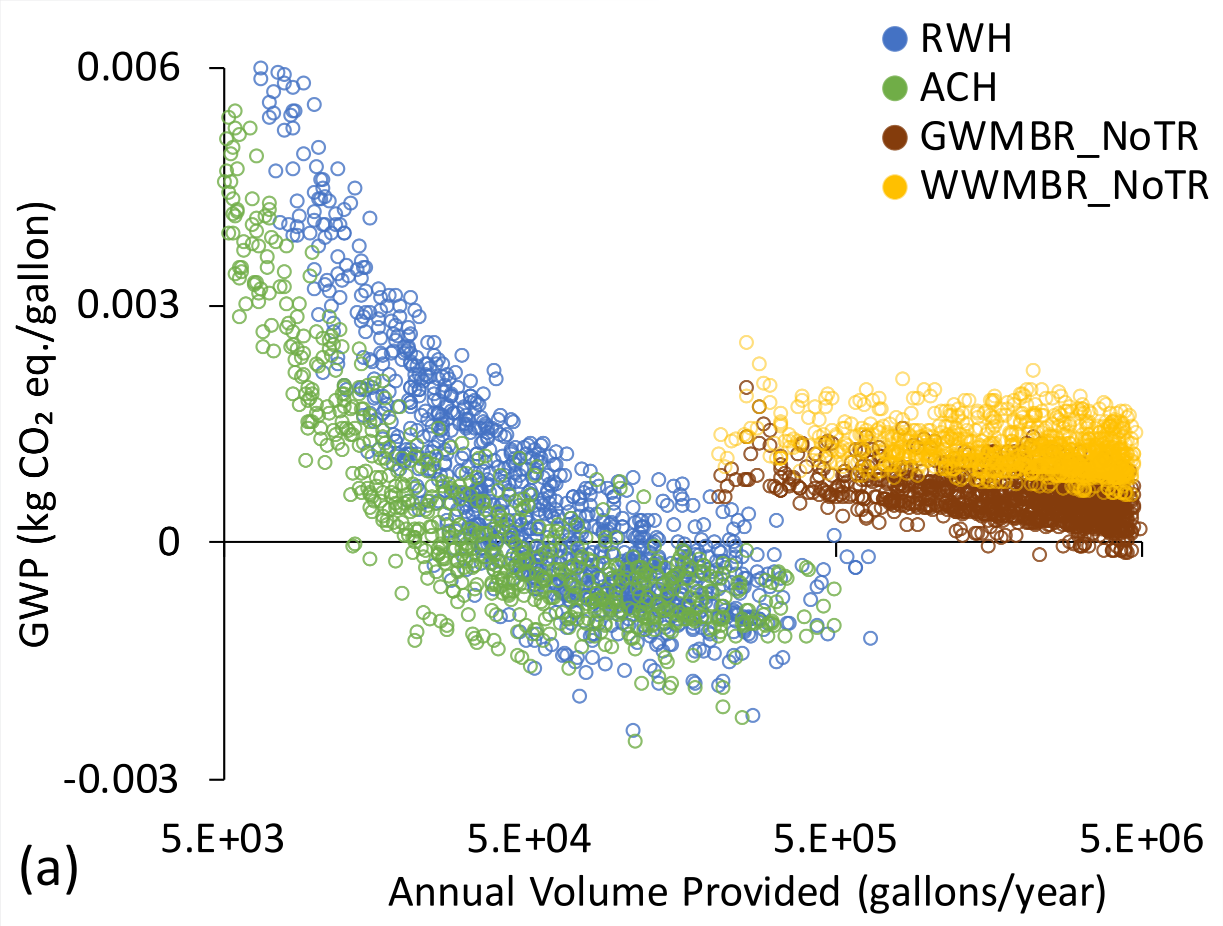
Inform effective reuse strategies

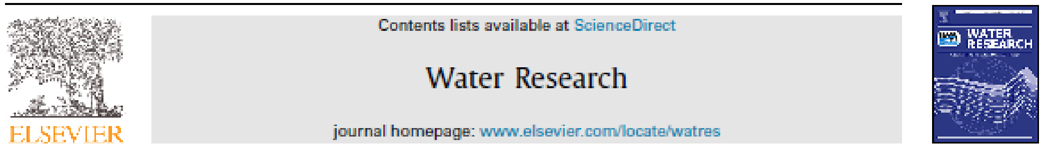
Percent of Annual Non-Potable Demand Met



Mixed wastewater and graywater systems always meet non-potable demand under modeled conditions

Scale influence impacts, cost
Reuse in larger building a viable option





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Onsite Non-potable Reuse for Large Buildings: Environmental and Economic Suitability as a Function of Building Characteristics and Location

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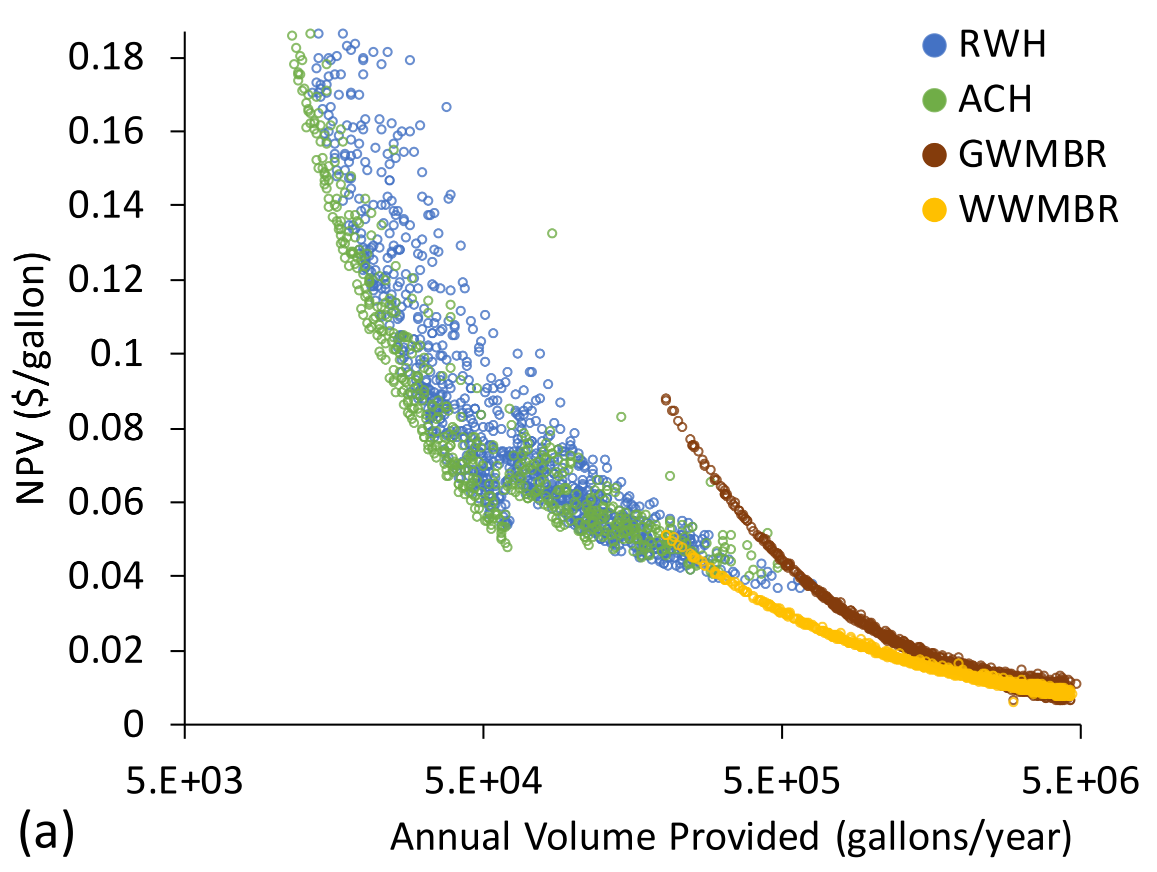


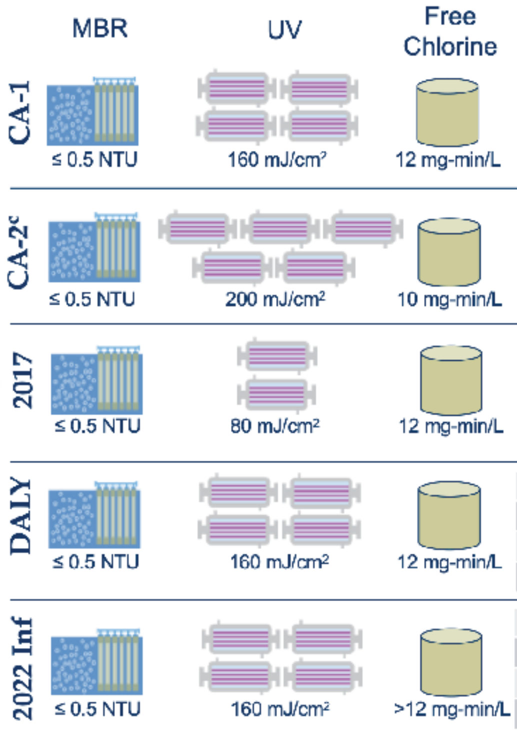
LRT Analysis – Effect of Treatment Train Design

Table 3. Indoor Use LRT Summary

Source Water	Virus[1] 2017	Virus[1] CA	Virus[1] DALY	Virus[1] 2022	Protozoa 2017	Protozoa CA (Giardia)	Protozoa CA (Crypto)	Protozoa DALY	Protozoa 2022	Bacteria 2017	Bacteria CA	Bacteria DALY	Bacteria 2022
Onsite Wastewater	8.5	8.0	10.0	11.5	7.0	6.5	5.5	6.5	7.0	6.0	n/a	5.5	7.5
Graywater	6.0	6.0	7.5	9.0	4.5	4.5	3.5	4.0	4.5	3.5	n/a	3.5	5.5
Stormwater (10^{-1} dilution)	5.5	7.0	8.0	9.5	5.5	5.5	4.5	6.0	6.5	5.0	n/a	5.5	6.5
Stormwater (10^{-3} dilution)	3.5	n/a	6.0	7.5	3.5	n/a	n/a	4.0	4.5	3.0	n/a	3.5	4.5
Stormwater (10^{-4} dilution)	n/a	n/a	5.0	6.5	n/a	n/a	n/a	3.0	3.5	n/a	n/a	2.5	3.5
Roof Runoff	n/a	n/a	n/a	n/a	n/a	1.5	n/a	1.0	2.0	3.5	n/a	3.5	5.0

[1] Norovirus is the reference viral pathogen for 2017, DALY, and 2022; adenovirus is the reference viral pathogen for CA.

Example Treatment Trains for Indoor Use of Onsite Wastewater/Blackwater



Train	Pathogens	LRV Achieved by Treatment Process: MBR	UV	Free Cl_2	Total LRV Achieved	LRV Required for Indoor Use
CA-1	Enteric Virus	1.0	3.0[a]	4.0	8.0	8.0
	Giardia	2.5	6.0	--	8.5	6.5
	Crypto	2.5	6.0	--	8.5	5.5
	Bacteria	n/a	n/a	n/a	n/a	n/a
CA-2[c]	Enteric Virus	1.0	4.0[a]	3.0	8.0	8.0
	Giardia	2.5	6.0	--	8.5	6.5
	Crypto	2.5	6.0	--	8.5	5.5
	Bacteria	n/a	n/a	n/a	n/a	n/a
2017	Enteric Virus	1.0	3.5[b]	4.0	8.5	8.5
	Giardia	2.5	6.0	--	8.5	7.0
	Crypto	2.5	6.0	--	8.5	7.0
	Bacteria	4.0	6.0[d]	4.0	14	6.0
DALY	Enteric Virus	1.0	6.0[b]	4.0	11.0	10.0
	Giardia	2.5	6.0	--	8.5	6.5
	Crypto	2.5	6.0	--	8.5	6.5
	Bacteria	4.0	6.0	4.0	14.0	5.5
2022 Inf	Enteric Virus	1.0	6.0[b]	5.0	12.0	11.5
	Giardia	2.5	6.0	--	8.5	7.0
	Crypto	2.5	6.0	--	8.5	7.0
	Bacteria	4.0	6.0	5.0	15.0	7.5

[a] Credit achieved using adenovirus as reference pathogen

[b] Credit achieved using norovirus as reference pathogen

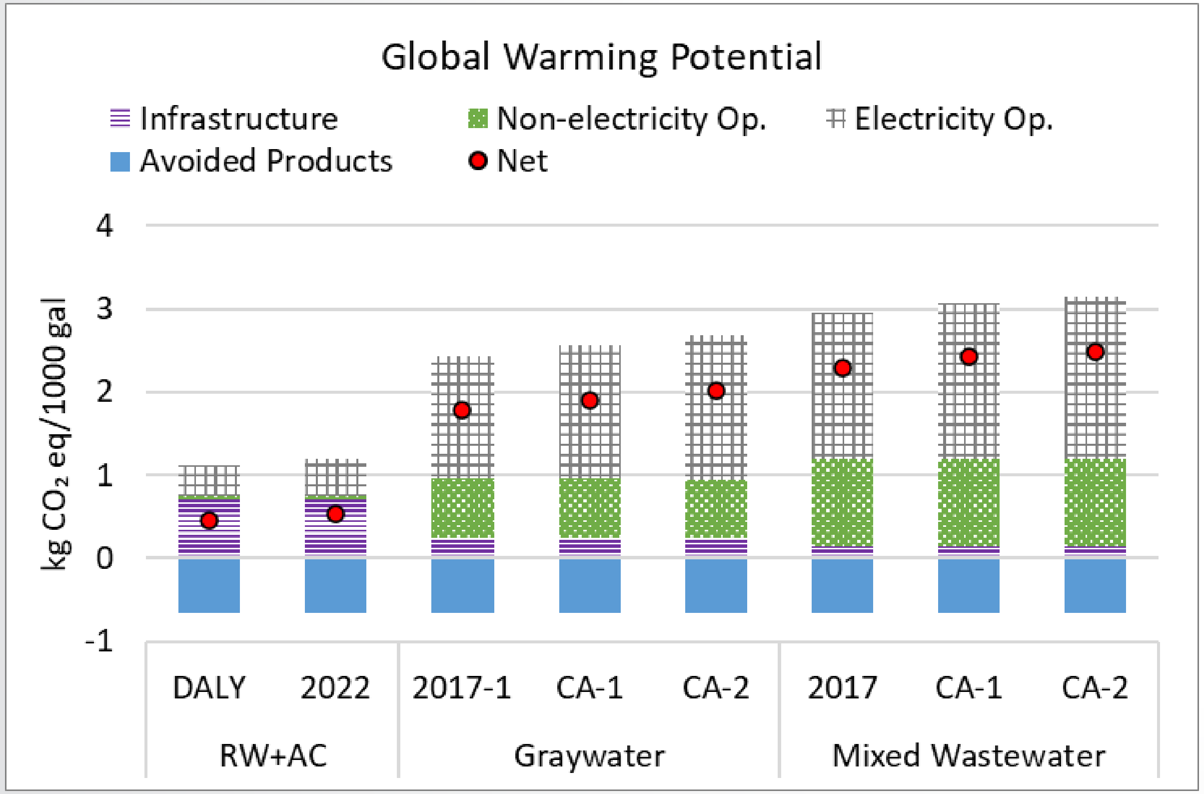
[c] California regulators have specified one model treatment train (CA-1) for wastewater, but may allow alternatives that meet the LRTs including train CA-2

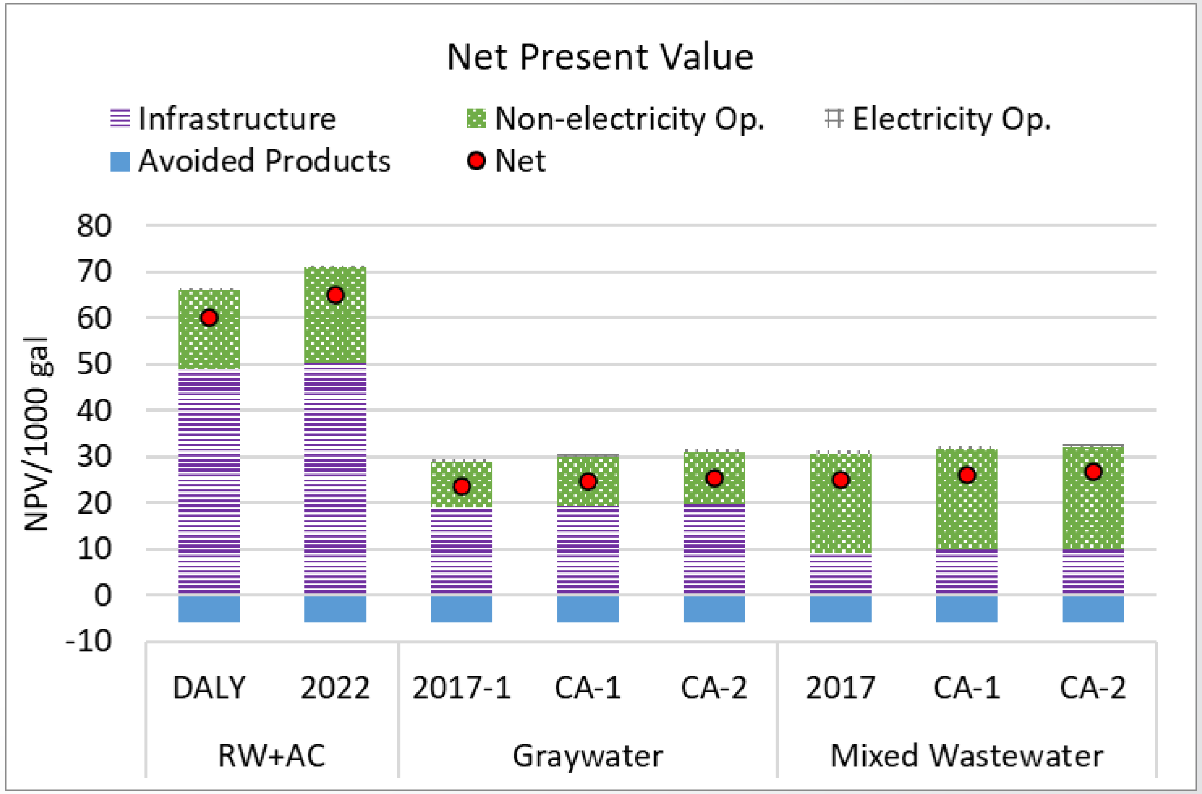
[d] Assumes 3-4 LRV bacterial credit per 40 mJ/cm² UV reactor based on WaterVal

Our results indicate these differences in treatment trains (the degree of disinfection) have minimal impacts

LRT Analysis – Contributions

- Modeled large building in Washington, DC to evaluate specific contributions
- Results show little influence of changing LRT set
- Source water and system type more important than LRT set





Summary

- **Significant development and impact of risk-based modeling to inform treatment**
  - Harmonized set of pathogen log-reduction target values for **domestic related potable, nonportable reuse**
    - Currently being reviewed for posting by the National Blue Ribbon Commission for Onsite Water Systems
  - Risks characterization developed for **food processing wastewater**, and treatment trains drafted in preparation for pilot studies
  - Developing/applying chemical risk assessment tools for **produced water**

- **Increasing focus on defining (LRV) and monitoring system performance**
  - Pilot scale treatment systems for food processing, produced water
  - Incorporating risk-based framework into growing building scale reuse systems

- **System level tools are available to help planners and developers**
  - Regional differences are important consideration for most efficient approaches
  - Primary treatment (oxidation of organic matter, removal of nutrients) remains a large driver of energy use and cost
  - Heat recovery systems to reduce costs and improve efficiency
  - Resiliency

Impact

- Collaborations with key stakeholder groups
  - New Mexico Produced Water Research Consortium
  - National Blue-Ribbon Commission for Onsite Water Systems
- Partnerships with industry
  - CRADAs: Tyson Foods, WaterGen
  - Produced water: NGL, PWR, Exxon
- Technical support for states
  - CA, CO, ID, KS, MN, NM, OH, WA
- Working with code agencies
  - IAPMO, NSF, ARCSA

EPA Expected Water Reuse Products (FY25-26)

Product Title	Delivery
• Toxicological evaluation of produced water intended for beneficial use outside of the oilfield	FY25 Q2
• Biogeochemical risks during Managed Aquifer Recharge	FY25 Q4
• Characterizing the effectiveness of natural or engineered pre-treatments for indirect potable water reuse	FY25 Q4
• Decentralized Non-potable Water Reuse: Adoption and expansion of the NEWR (Non-Potable Environmental and Economic Water Reuse) tool	FY26 Q1
• Integrated risk assessment to inform treatment guidance for complex water matrices	FY26 Q4
• Risk characterization of atmospheric water collections	FY26 Q4
• Investigation of microbial surrogates and indicators for different types of treatment processes	FY26 Q4
• Characterization of chemical water quality and applicability of chemical surrogates for assessing treatment performance in water reuse	FY26 Q4

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