United States Environmental Protection Agency

Fit-for-Purpose Water Updates and Life Cycle Comparisons of Non-Potable Water Reuse Scenarios

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February 24, 2020

Office of Research and Development
Center for Environmental Solutions and Emergency Response

“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

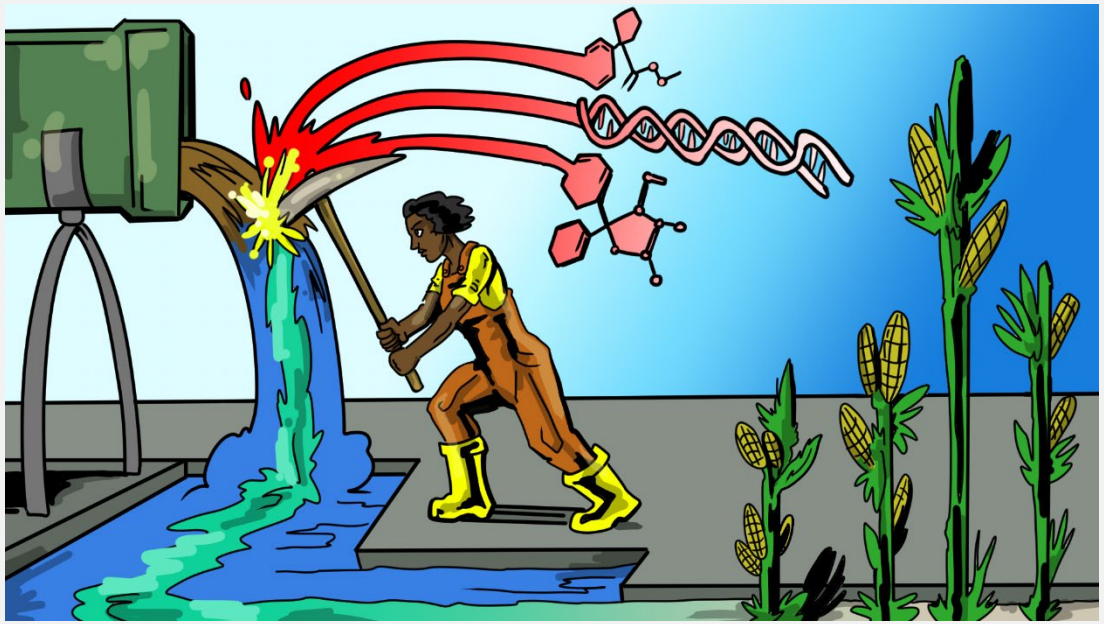
	Historic	*Future*
Relationship to Economy	Provide cost-effective water services	Part of circular economy
Functional Objective	Comply with regulations	Produce useful products
Optimization Functions	Infrastructure Cost	Water, energy, materials
Water Supply	Remote	Local
Systems Components	Separate drinking, 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

21st Century Wastewater Infrastructure should:

Safely Produce Resources

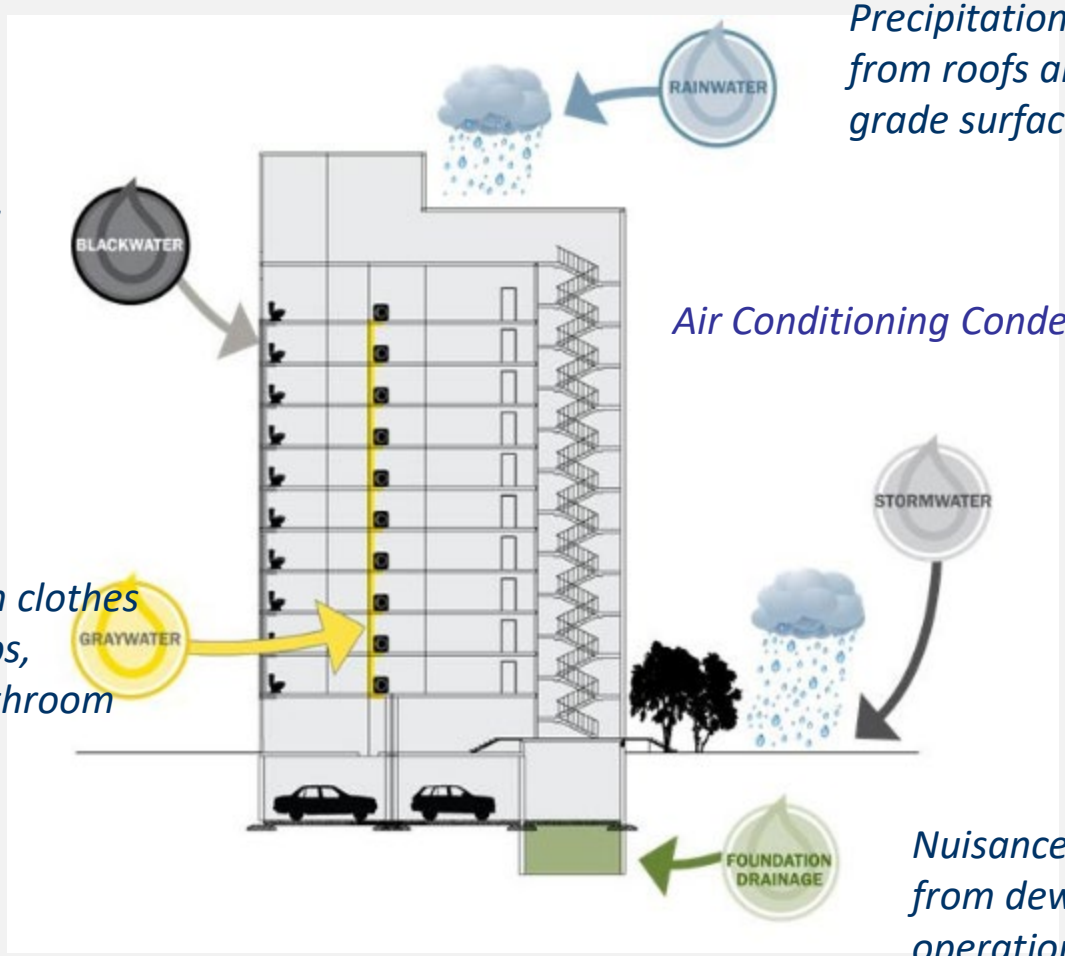
(materials, energy, & information)



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

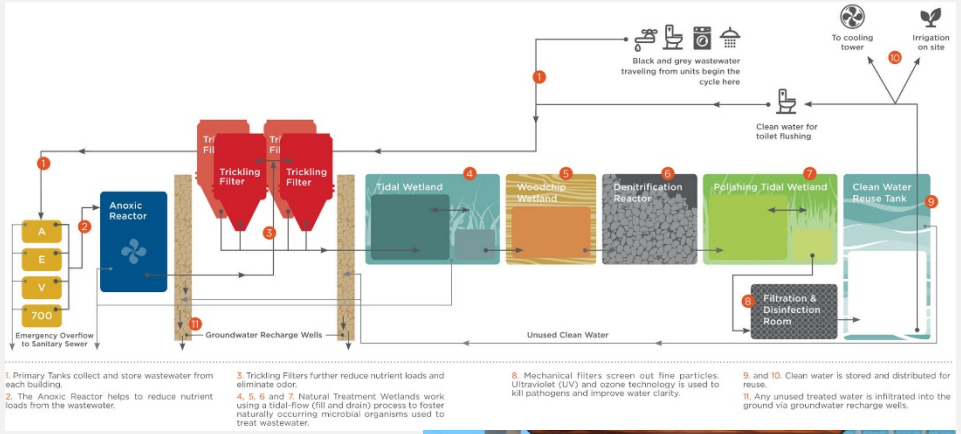
Nuisance groundwater from dewatering operations

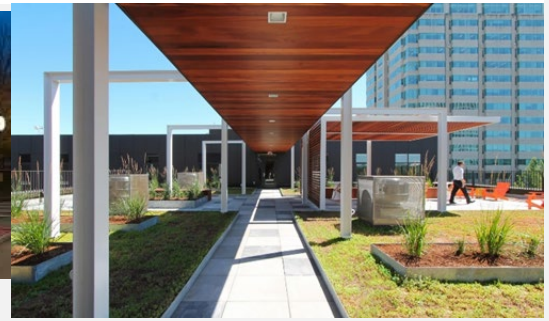
Increasing Building Scale Reuse Across US

The Solaire, Battery Park, NYC

25,000 gpd of wastewater
Membrane Bioreactor
Toilet Flushing, cooling, irrigation

Hassalow on Eighth Portland





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

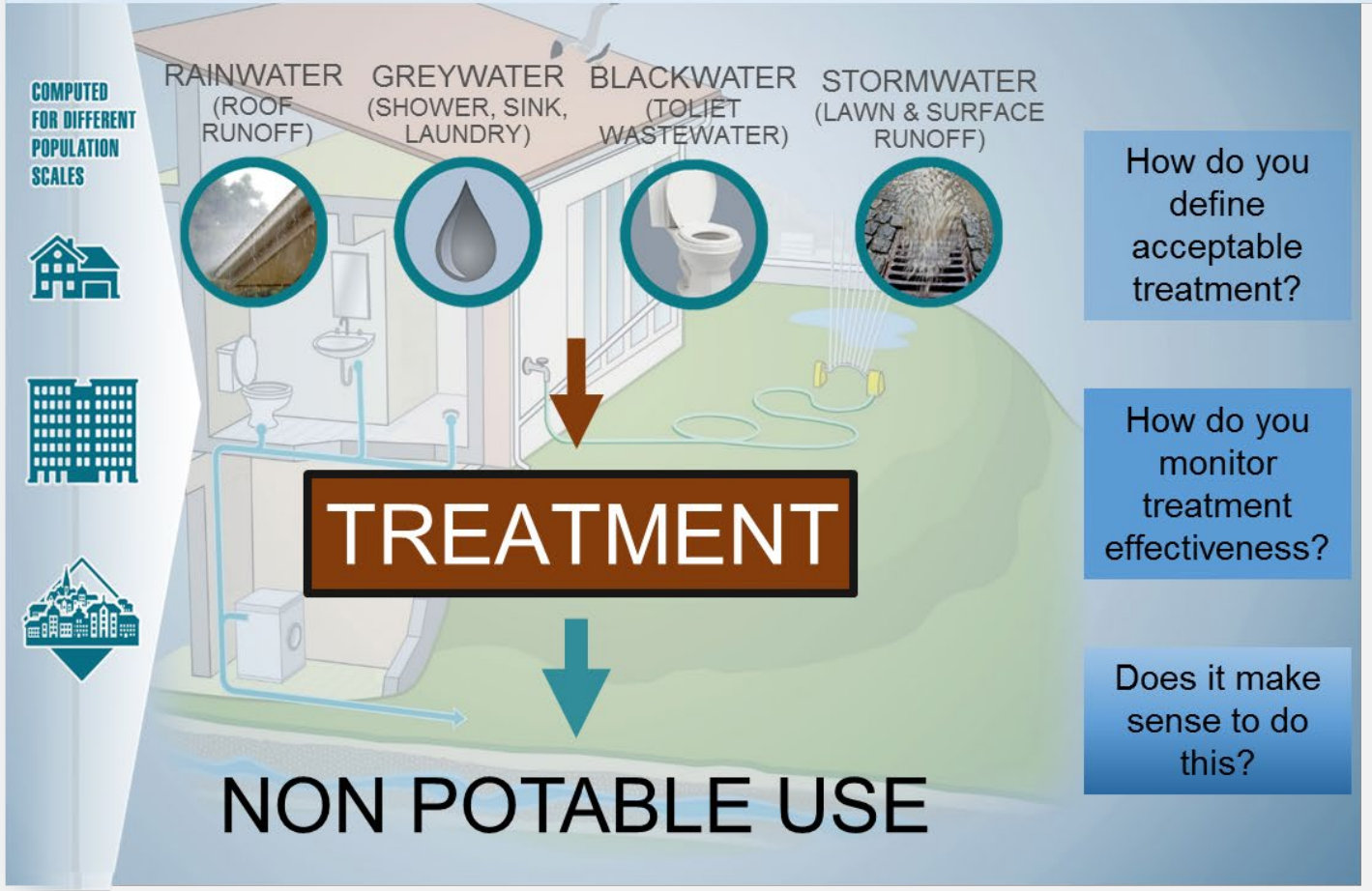
181 Fremont, San Francisco

5,000 gpd greywater
Membrane bioreactor
Toilet flushing

gpd - gallons per day

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

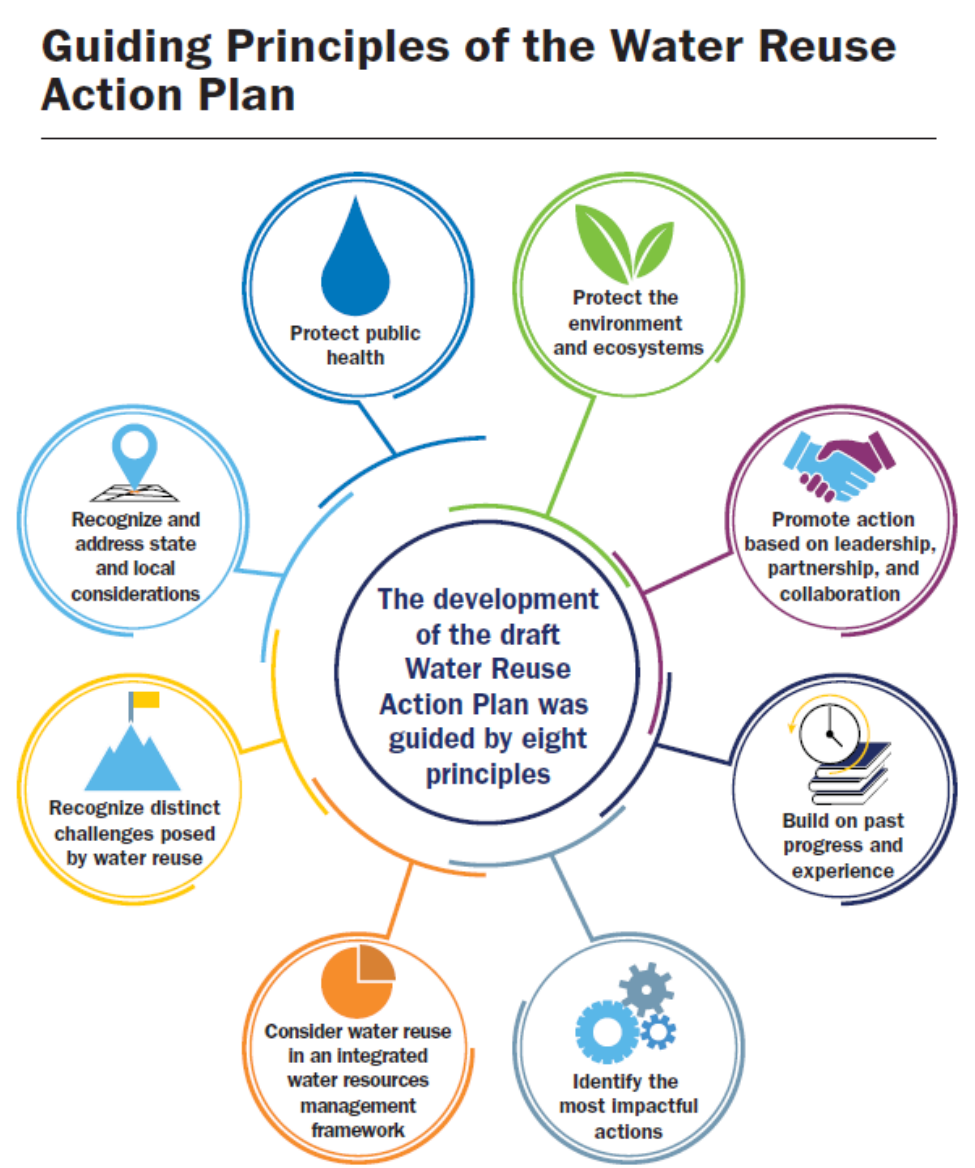
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

National Blue Ribbon Commission for Onsite Non-potable Water Systems

WATER ENVIRONMENT & REUSE FOUNDATION WERF

US Water Alliance

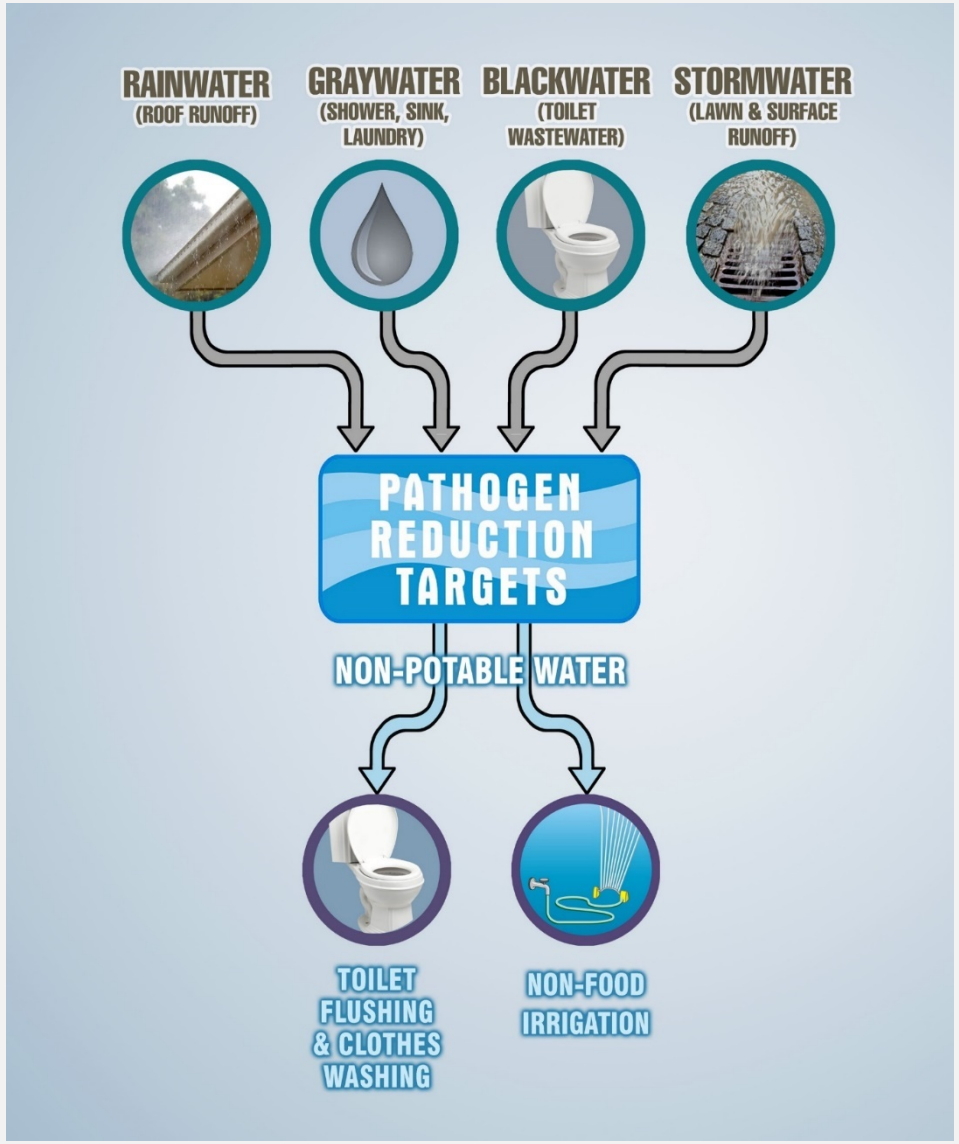
Report



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

Does it make sense to do this?

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



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

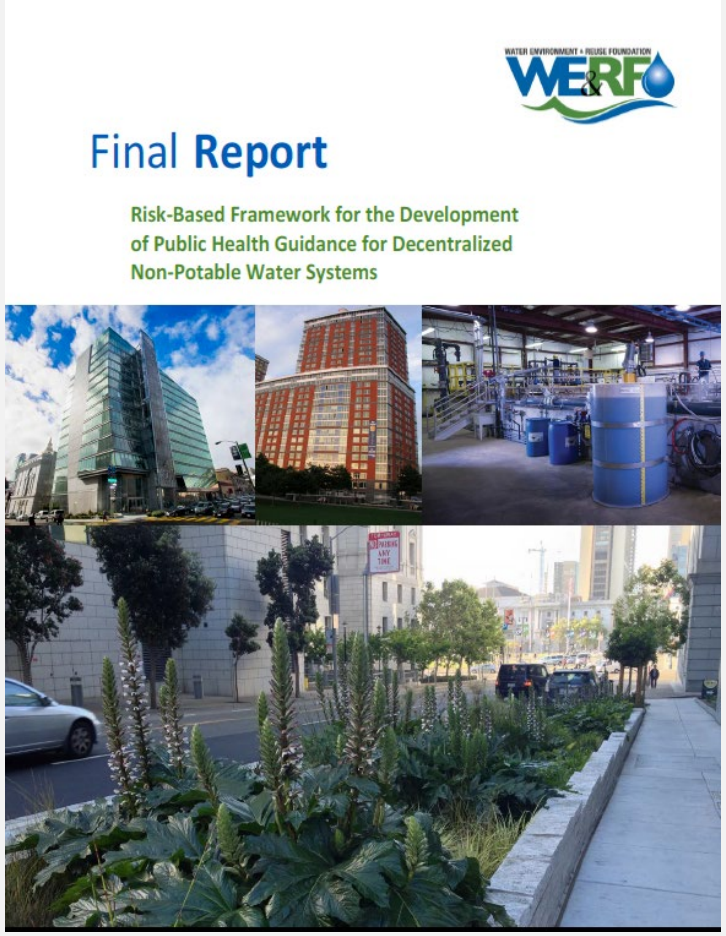
(roof runoff, stormwater, graywater, blackwater)

End Use

Non-Potable

Potable

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

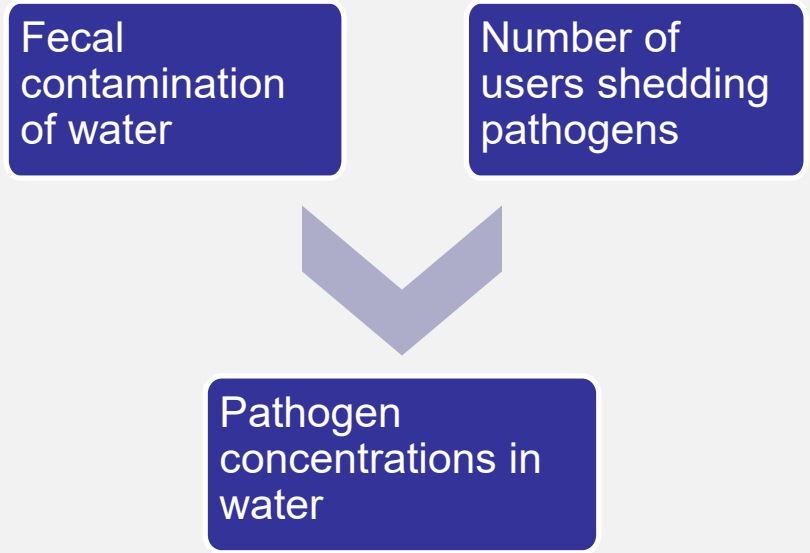


Water Use Scenario	Log$_{10}$ Reduction Targets for 10^{-4} (10^{-2}) Per Person Per Year Benchmarks		
Domestic Wastewater or Blackwater	**Enteric Viruses**	**Parasitic Protozoa**	**Enteric Bacteria**
Unrestricted irrigation	8.0 (6.0}	7.0 (5.0)	6.0 (4.0)
Indoor use	8.5 (6.5)	7.0 (5.0)	6.0 (4.0)
Graywater			
Unrestricted irrigation	5.5 (3.5)	4.5 (2.5)	3.5 (1.5)
Indoor use	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			
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

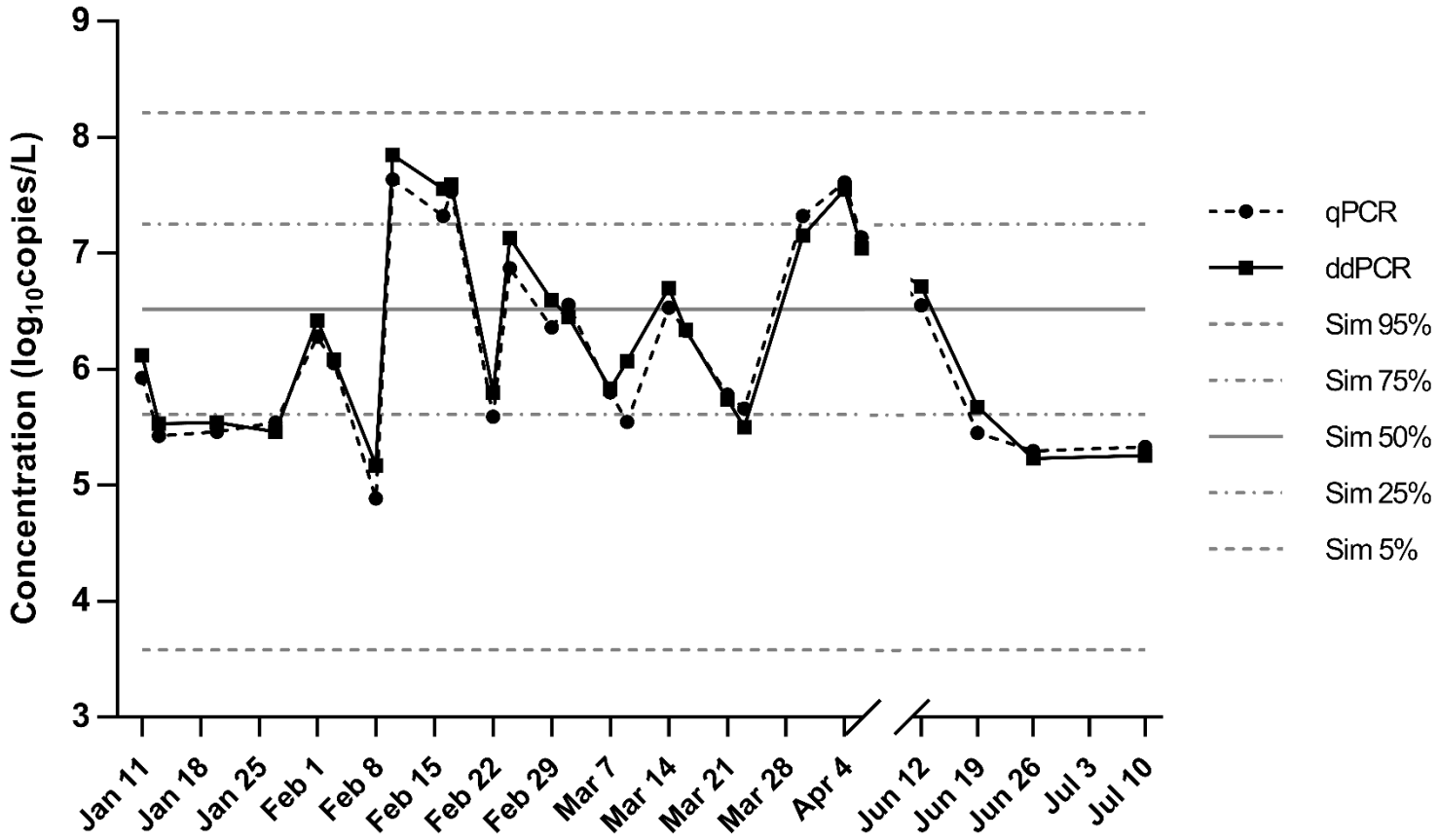
Pathogen Density Characterization: WW and GW

- 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



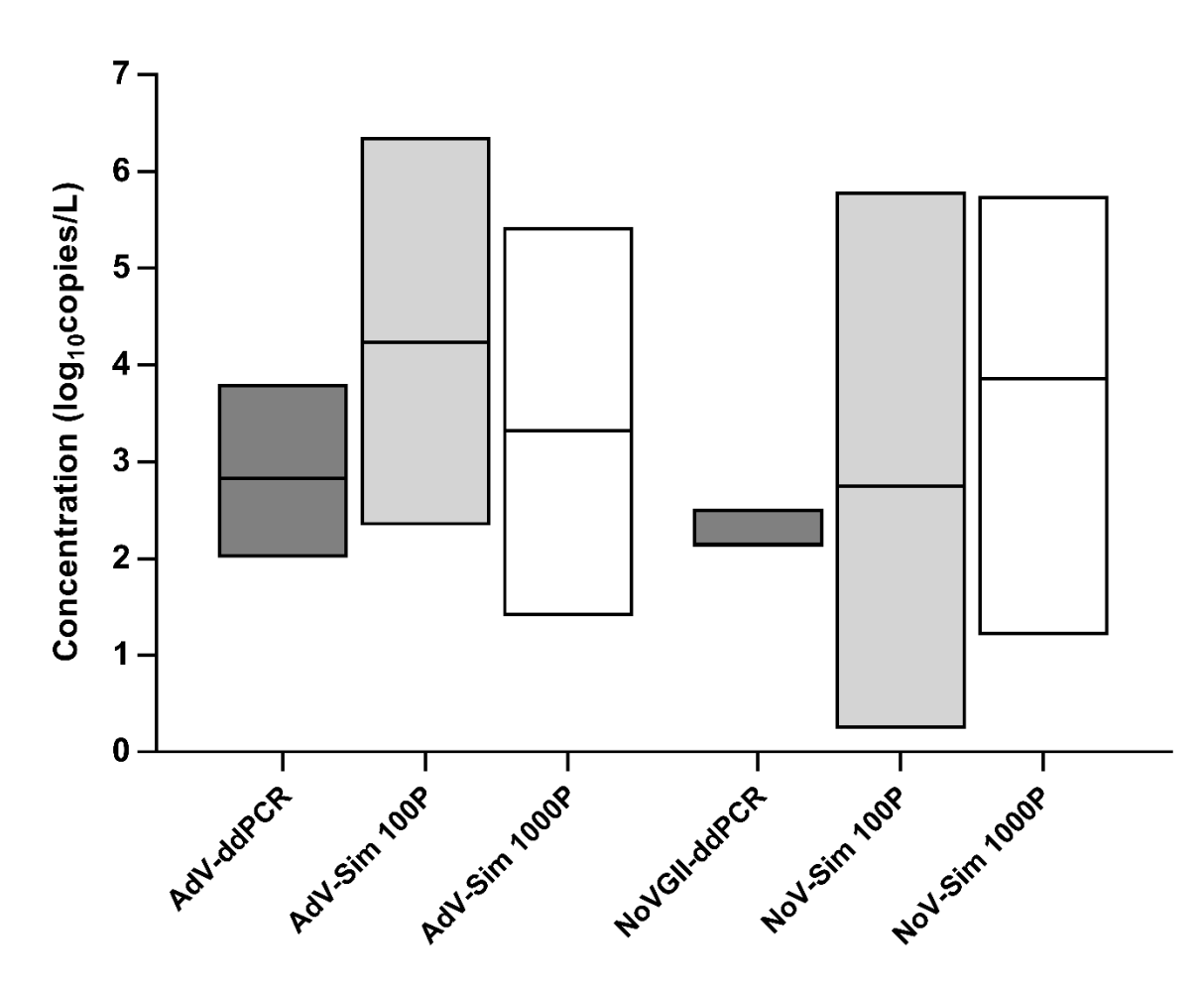
Jahne et al. (2017) Microbial Risk Analysis 5, 44-52

NoVGII 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%

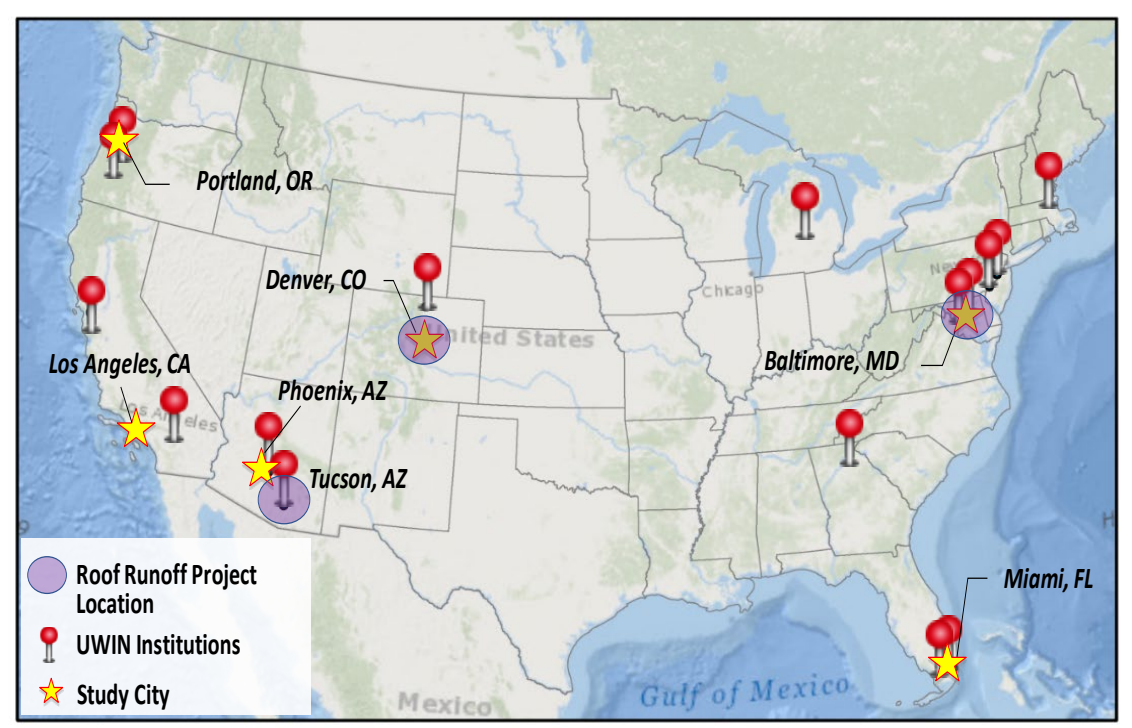
Simulation Occurrence	AdV	NoVGII
100 person	0%-7%	22-68%
1000 person	11-30%	98-100%

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

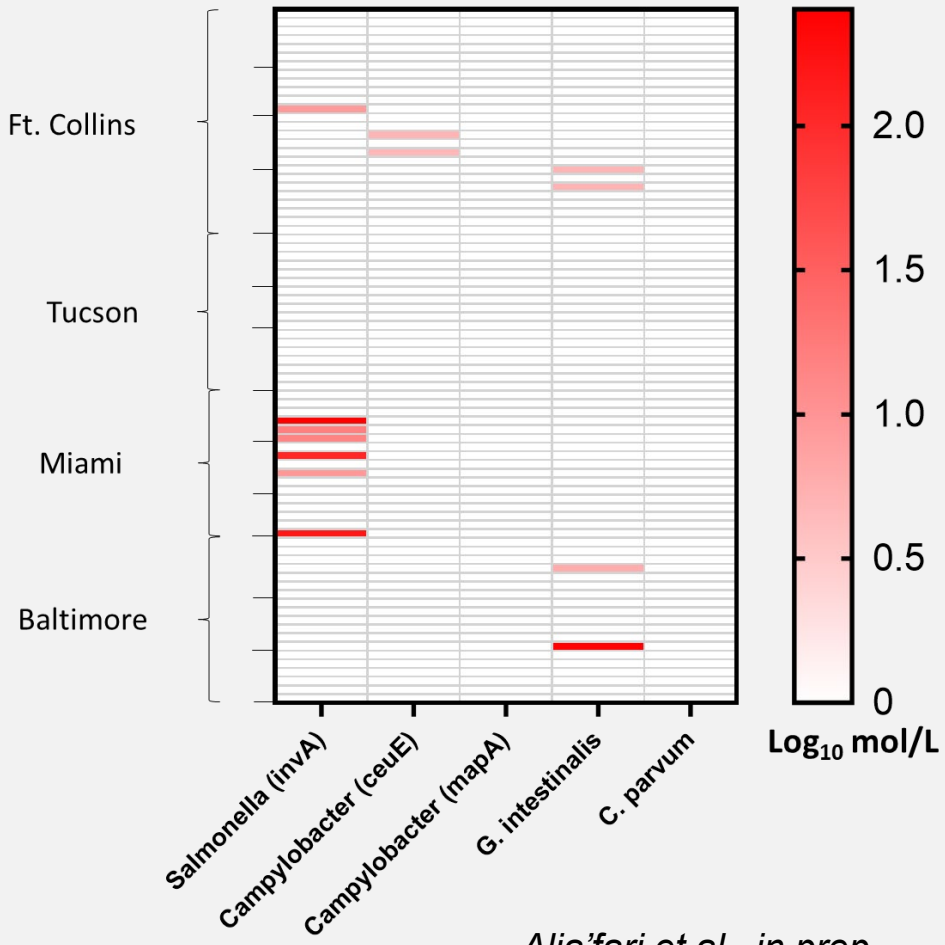
Jahne et al. (2020) Water Research 169, 115213

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)

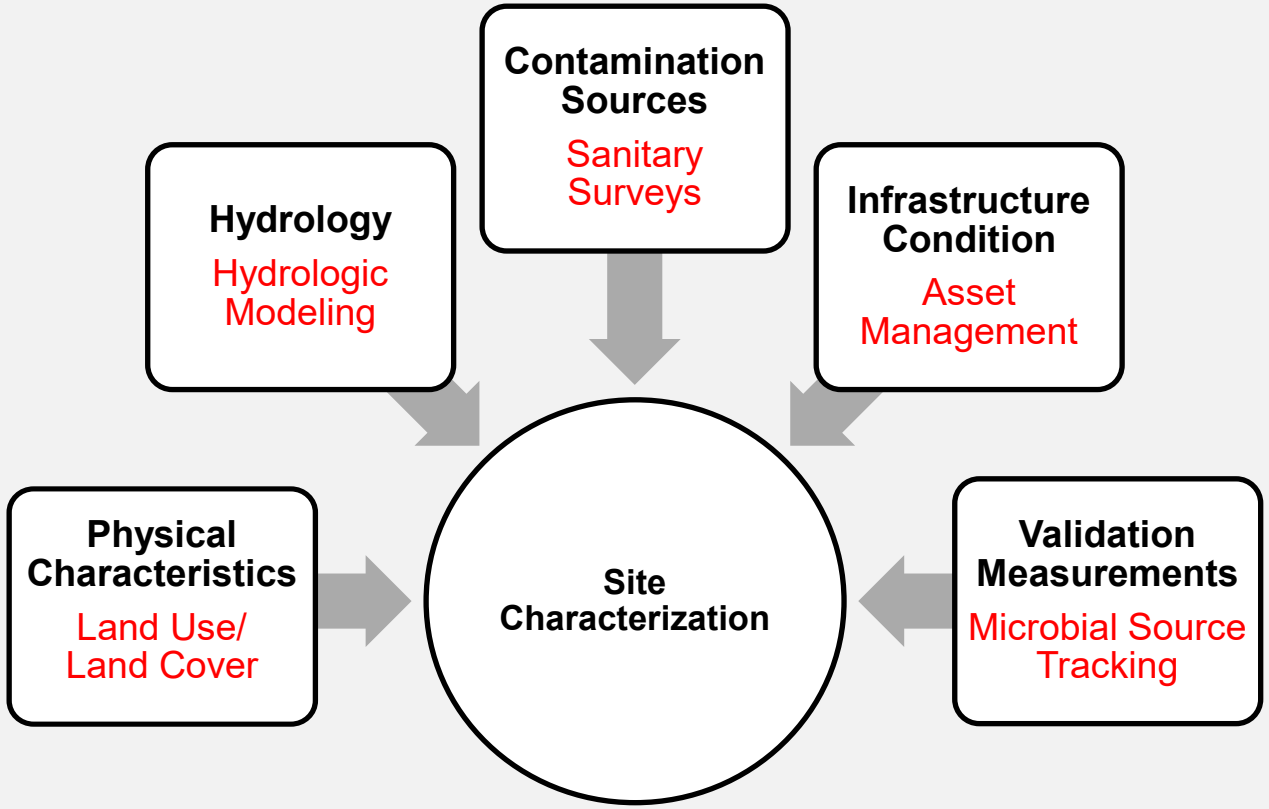


Alja'fari et al., in prep.

- 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

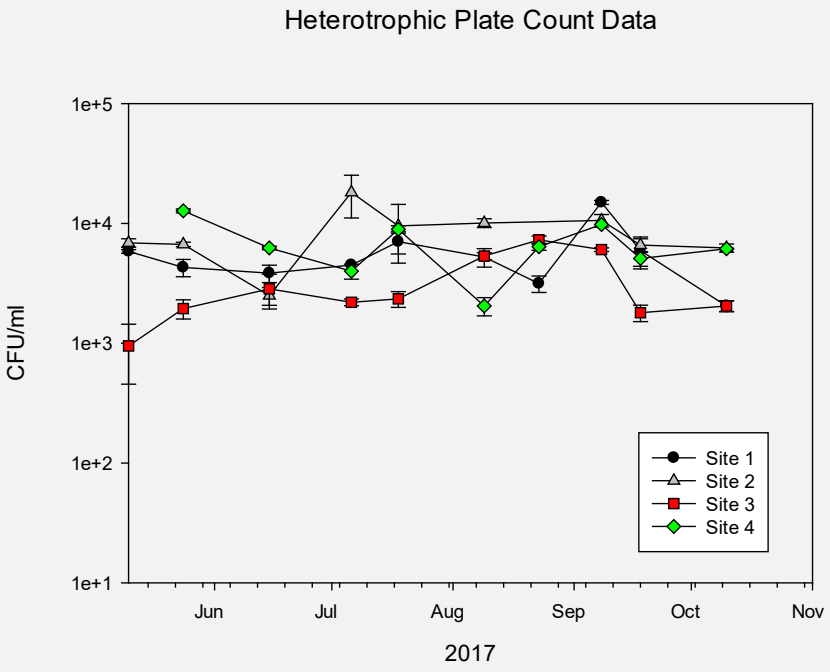
Pathogen Density Characterization: Stormwater

- 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?



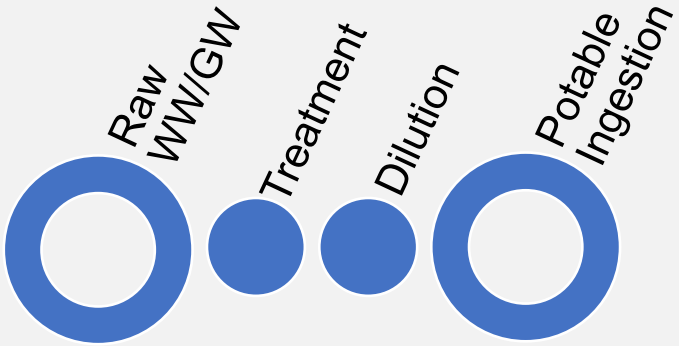
Additional Source Water: AC Condensate

- 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

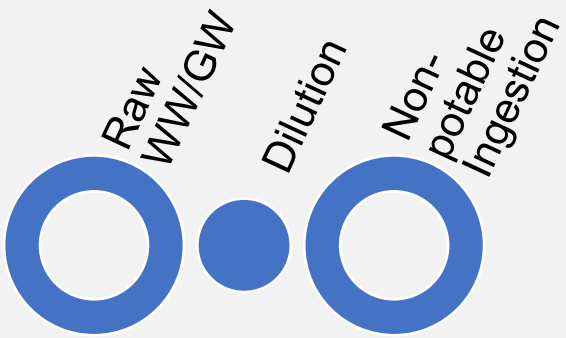


Exposure Assessment: Cross Connections

- Two unique scenarios for non-potable water systems:



Reclaimed to potable



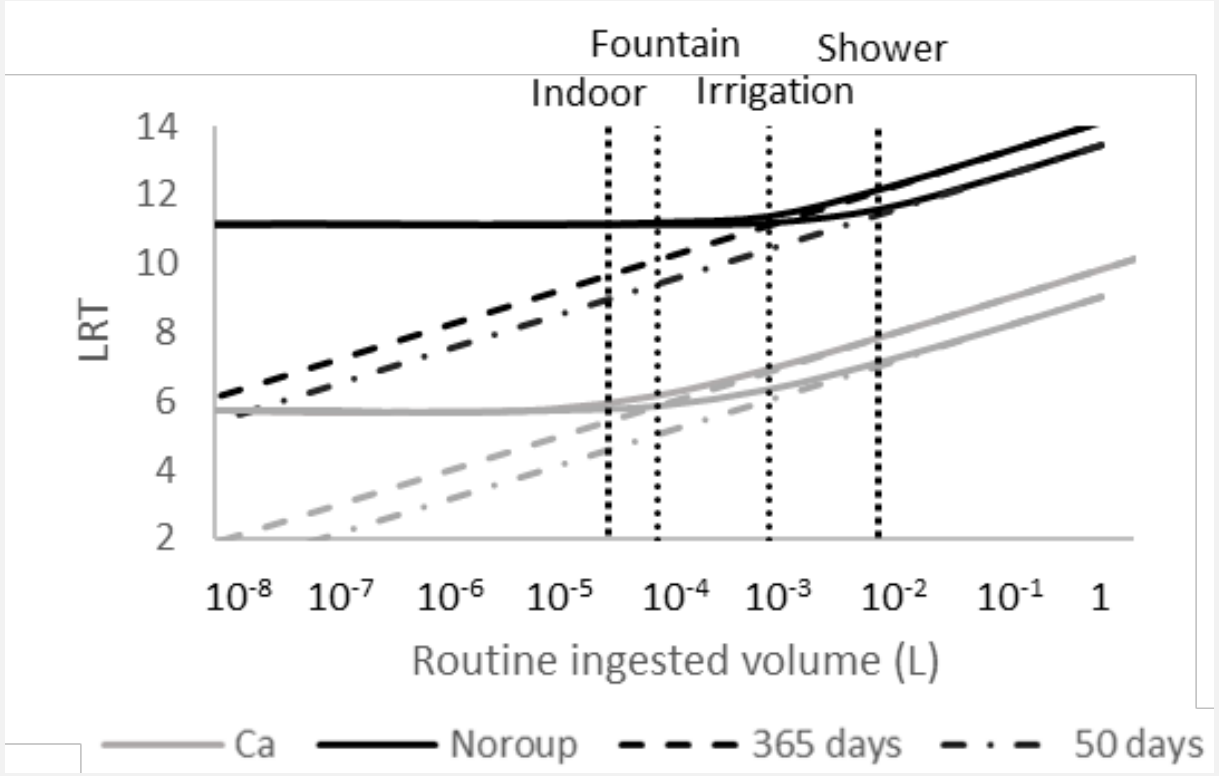
Raw to non-potable

- Included ingestion 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

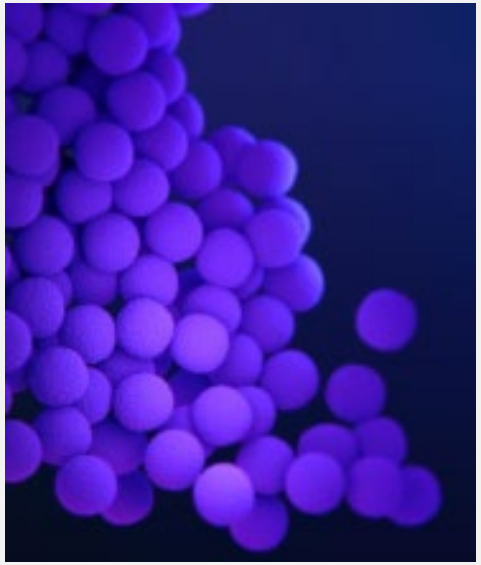
- Non-potable exposures are poorly characterized – how sensitive are LRTs?
  - Importance of safety factor
- For what range of exposures are previous LRTs appropriate?
  - $<10^{-5}$ L for daily use
  - $<10^{-4}$ L for weekly use
- How does estimated exposure from other uses compare?
  - Decorative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



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

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

QMRA of 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}/ 3,200 G d^{-1})	1×10^{-3}
GW Business (1,590 L d^{-1}/420 G d^{-1})	1×10^{-4}
GW Business (15,900 L d^{-1}/ 4,200 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}/ 5,070 G d^{-1})	2×10^{-1}

Schoen, Jahne, Garland (2019) 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.

ONWS Risk-Based Treatment Literature

MA Jahne, ME Schoen, JL Garland, NJ Ashbolt. 2017 Simulation of enteric pathogen concentrations in locally collected greywater and wastewater for microbial risk assessments. Microbial Risk Analysis 5,. 44-52 https://www.sciencedirect.com/science/article/pii/S235235221630038X. ORD-017709

ME Schoen, J Garland . 2017 Review of pathogen treatment reductions for onsite non-potable reuse of alternative source waters Microbial Risk Analysis 5, 25-31

ME Schoen, NJ Ashbolt, MA Jahne, JL Garland. 2017 Risk-Based Enteric Pathogen Reduction Targets for Non-Potable and Direct Potable Use of Roof Runoff, Stormwater, and Greywater. Microbial Risk Analysis 5, 32-43 http://dx.doi.org/10.1016/j.mran.2017.01.002 ORD-017866

ME Schoen, MA Jahne, JL Garland. 2018. Human health impact of cross-connections in non-potable reuse systems. Water 10(10), 1352

ME Schoen, MA Jahne, J Garland, 2018 Human health impact of non-potable reuse of distributed wastewater and greywater treated by membrane bioreactors Microbial Risk Analysis 9, 72-8

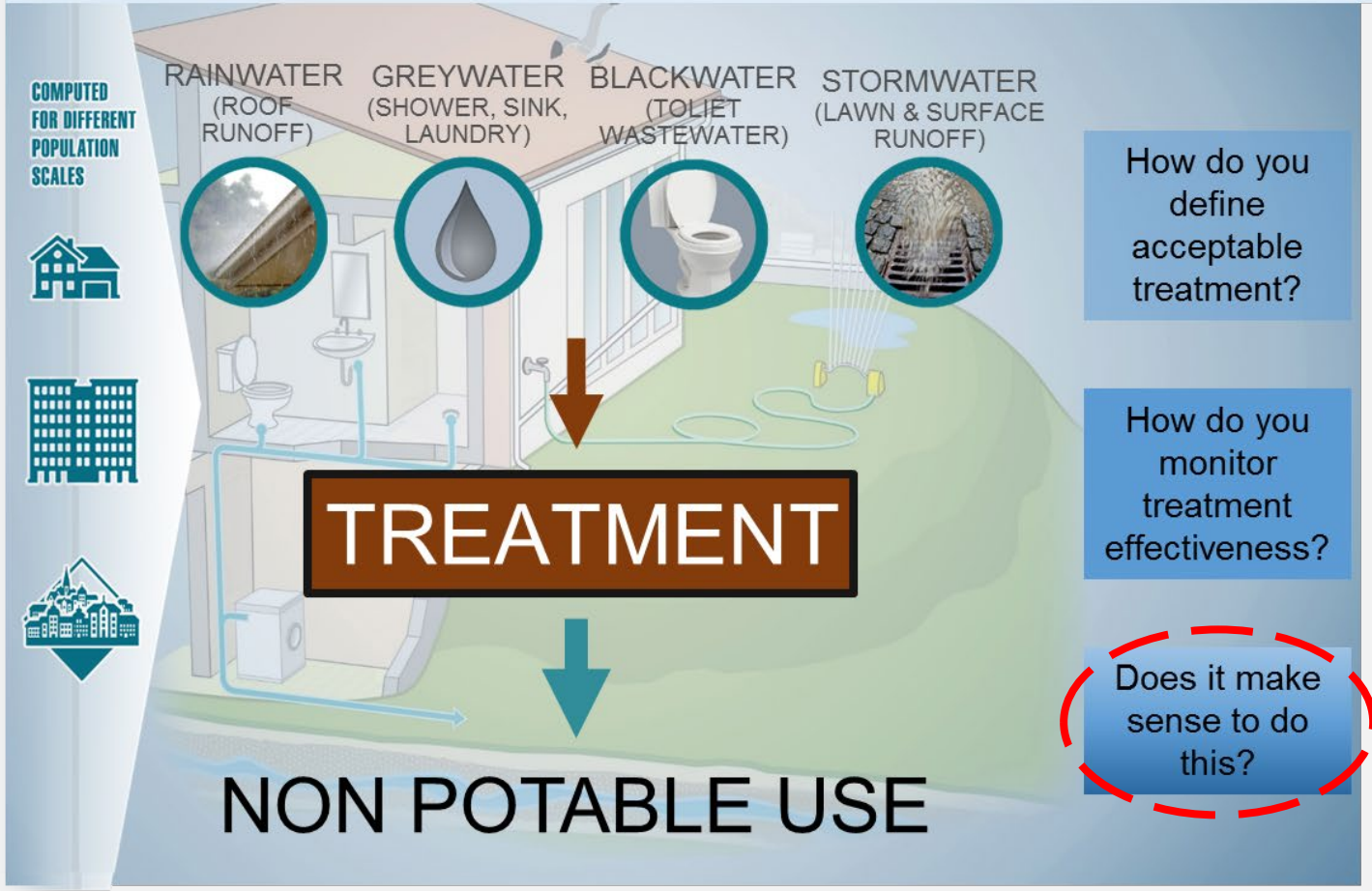
ME Schoen, MA Jahne, J Garland 2020 A risk-based evaluation of onsite, non-potable reuse systems developed in compliance with conventional water quality measures. Journal of Water and Health 18 (13) 331-344

MA Jahne, NE Brinkman, SP Keely, BD Zimmerman, EA Wheaton, and JL Garland. 2020. Droplet digital PCR quantification of norovirus and adenovirus in decentralized wastewater and greywater collections: implications for water reuse Water Research 169:113-213

M E. Schoen, M A Jahne, and JL Garland. 2020 Enteric pathogen treatment requirements for non-potable water reuse when exposure data is limited Environmental Science & Technology Letters (on-line)

FINDING NEW WATER

Alternative Water Reuse



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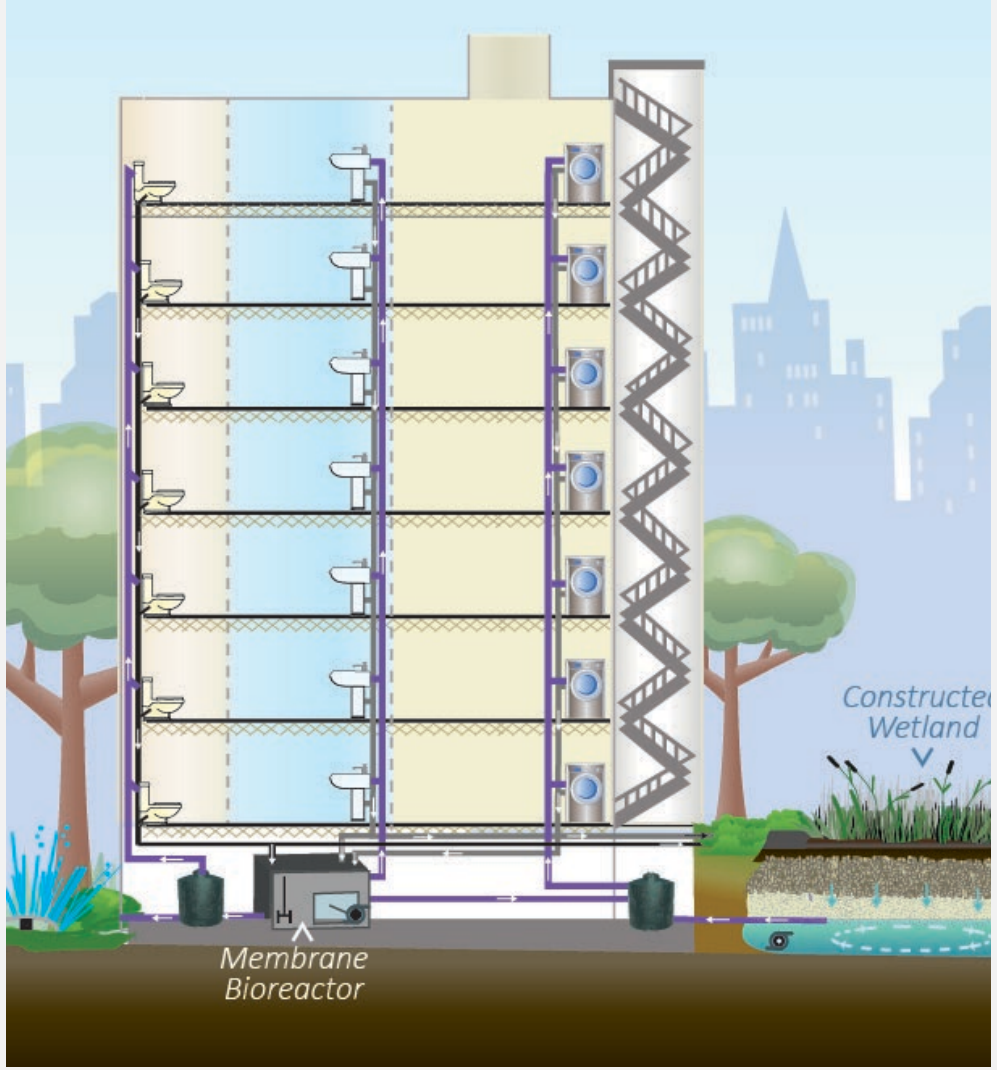
WATER ENVIRONMENT & REUSE FOUNDATION WERF

US Water Alliance

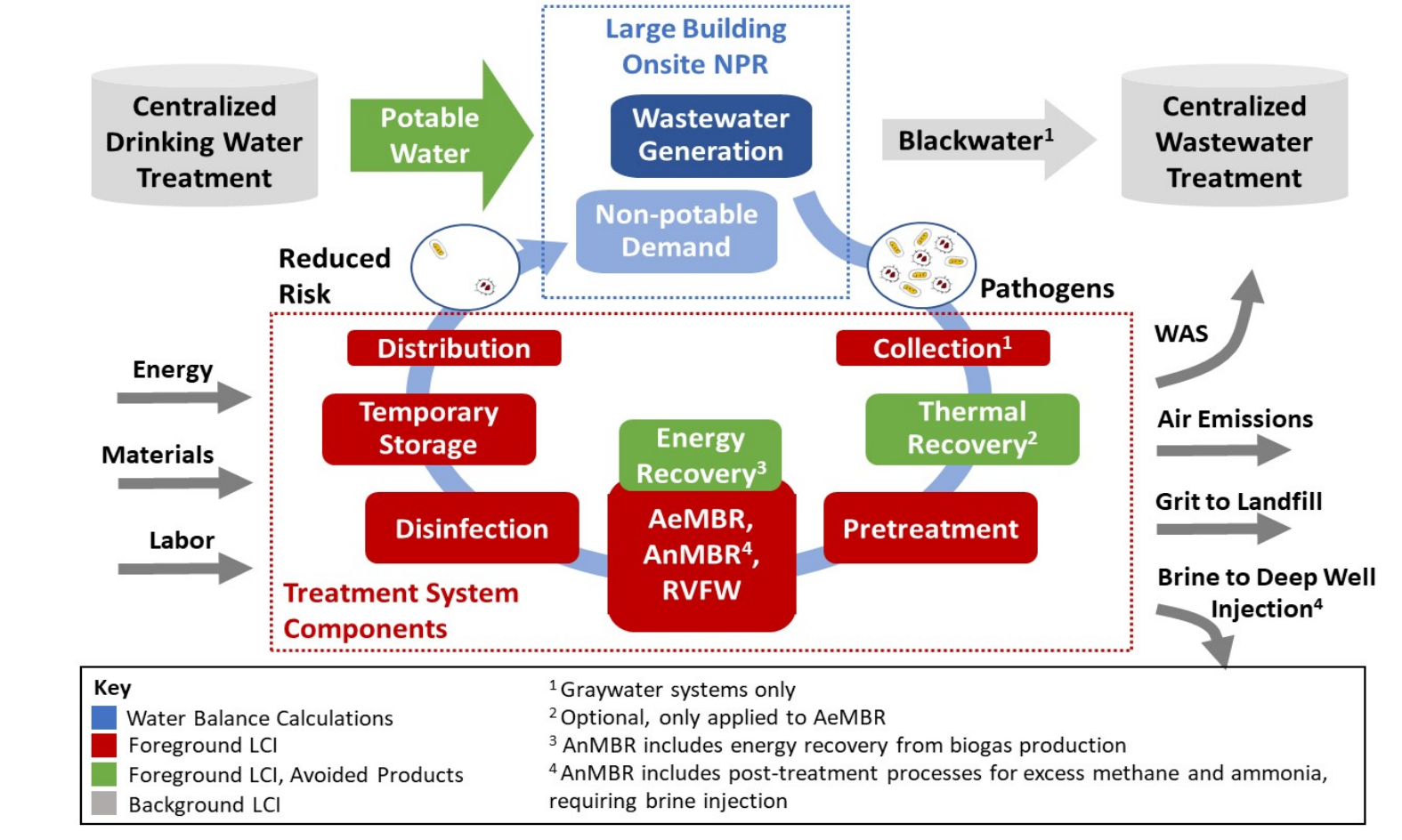
Report

Project Background



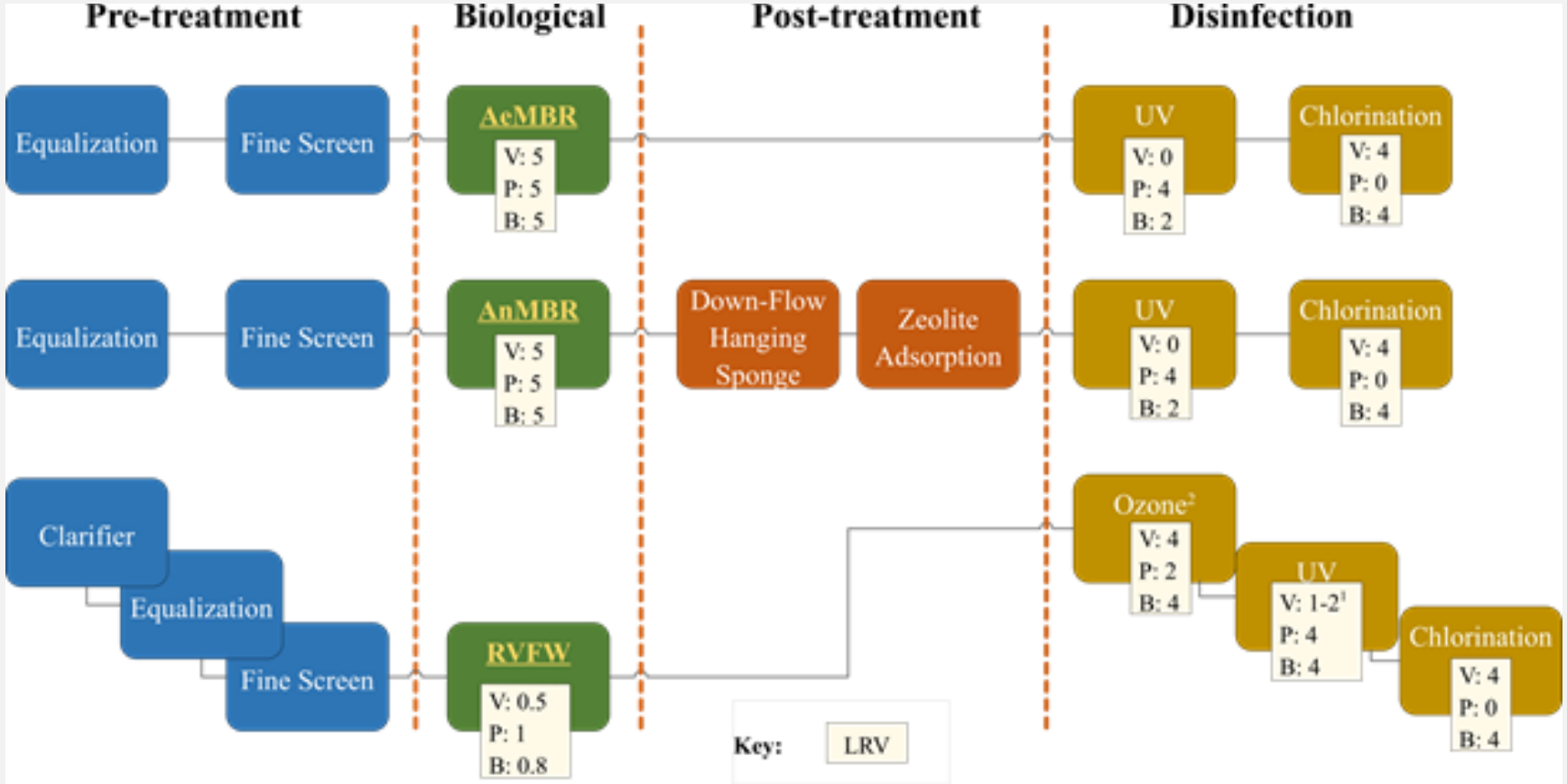
- Project team has completed several life cycle assessment (LCA) and cost studies on decentralized NPR configurations
- Latest study focused on large urban buildings in San Francisco, treating mixed wastewater or source separated graywater with aerobic membrane bioreactor (MBR)
- Work expanded to an EPA web-based calculator

Life Cycle Approach



Analyze cost and environmental impact of systems treating mixed wastewater and source separated graywater for onsite NPR (0.01-0.016 MGD). Integrated results with microbial risk assessment.

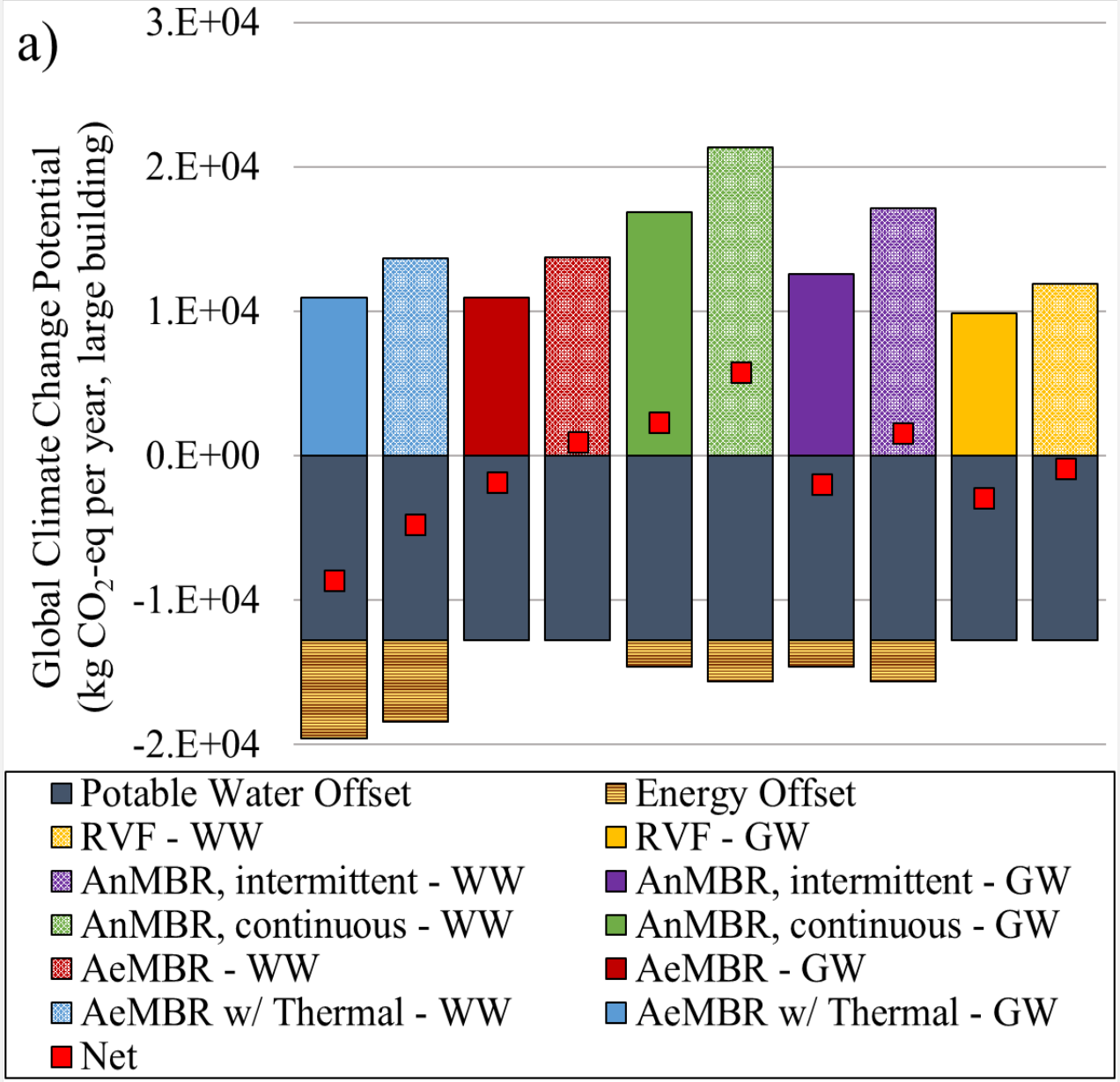
Life Cycle Approach



[1] UV virus LRV varies due to application of different UV doses for mixed WW and GW RVFWs.
[2] The ozone disinfection process only applies to the RVFW system treating mixed wastewater.

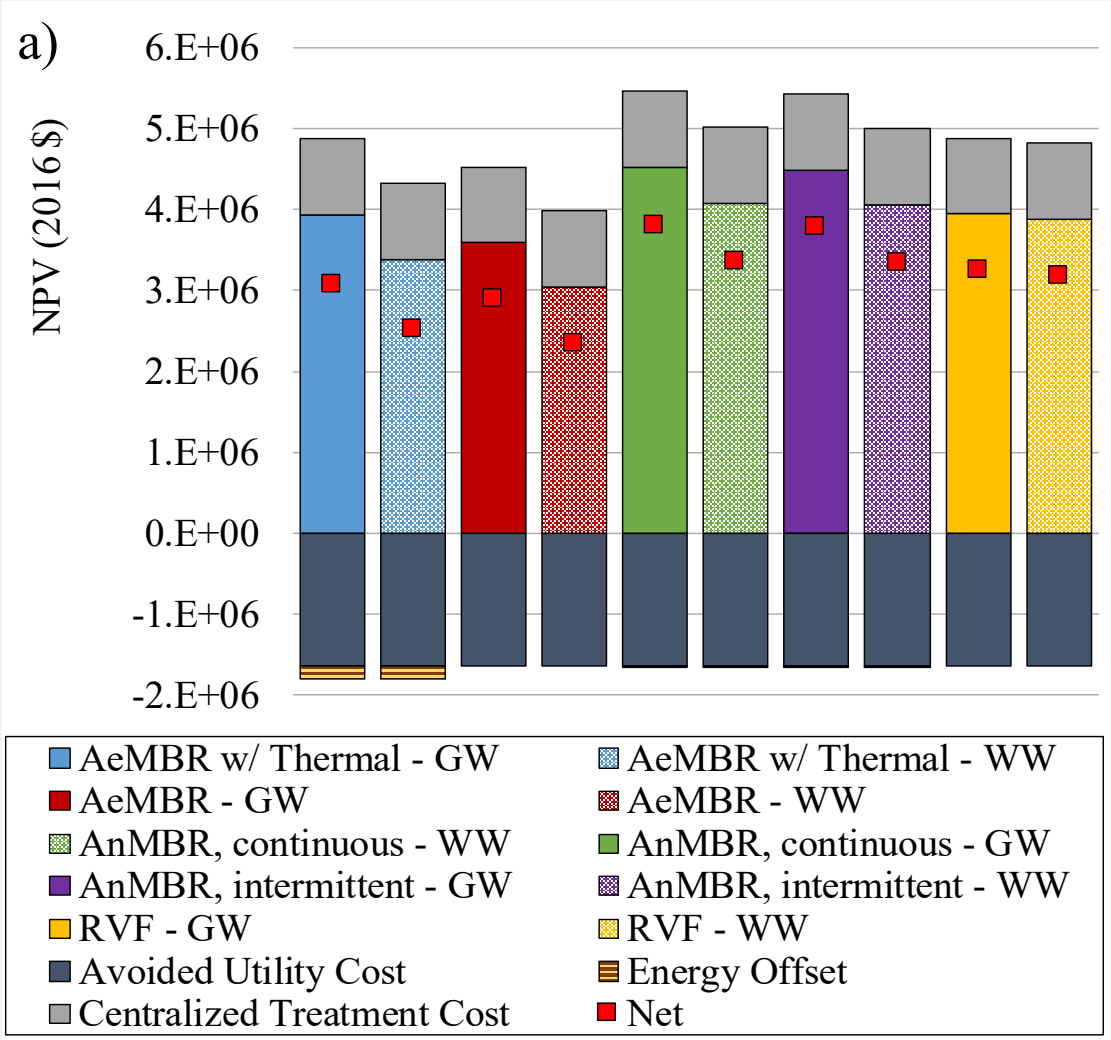
Analyze cost and environmental impact of systems treating mixed wastewater and source separated graywater for onsite NPR (0.01-0.016 MGD). Integrated results with microbial risk assessment.

Global Warming Potential Findings



From Arden et al. 2020

System Cost (Net Present Value)



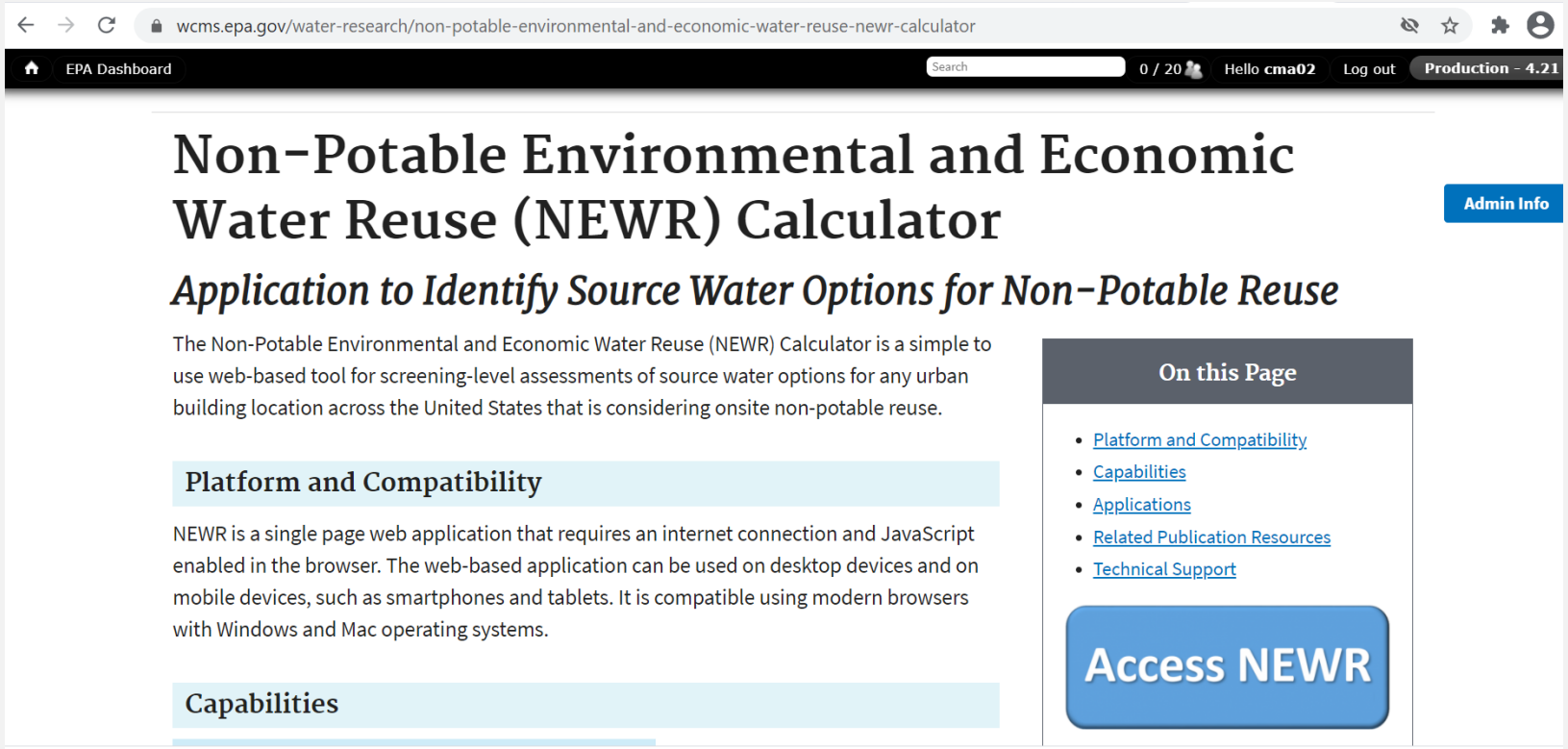
From Arden et al. 2020

Integrated Assessment Findings

- Displacement of drinking water (and associated impacts) is key to realizing net benefit of onsite NPR systems.
- It is important to match the scale of the treatment system to NPR demand.
  - Maximize potable demand offset but don't treat more water than you can use.
- Mixed Wastewater AeMBR is the most economical treatment option.
- AnMBR and RVFW each require additional pre- or post-treatment processes that add to system cost/impact.
  - Temporary bias of MBR given commercial maturity?
- Cost of additional piping network drives up the cost of the GW system.
- The benefits of thermal recovery depend on which heat energy is offset and the life cycle impacts of regional electricity production
  - In general offsetting either electricity or natural gas hot water heating will yield GHG benefits

NEWR Demonstration

NEWR – Non-potable Environmental and Economic Water Reuse Calculator



Research Questions:

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

Intended Audience

- Building developers can use the calculator as an initial screening tool prior to a more detailed engineering design analysis
- Urban communities interested in implementing NPR at the building-scale
- Certification institutions such as Green Building Council
- Research scientists investigating NPR options

NEWR

Non-Potable Reuse Building-Scale Calculator

Specify ZIP Code

Enter a 5 digit ZIP Code to start: 55403

The Non-Potable Reuse (NPR) Building-Scale Calculator can help identify environmentally and cost effective options for on-site NPR based on user selected geography, building specifications, source water type, and end use. Follow the prompts to explore building-scale NPR opportunities in your region. The Calculator is intended for buildings with 50 or more residential and/or office occupants.

Next

Location

Non-Potable Reuse Building-Scale Calculator

Building Characterization

Select Building Type

- (●) Mixed Use (30% commercial, 70% residential)
- ( ) Residential
- ( ) Commercial

Specify # Building Occupants

- (●) Large Building (1100)
- ( ) Medium Building (550)
- ( ) Small Building (110)
- ( ) Number of Occupants (recommended minimum value is 50)

Specify # Floors in Building

4

Enter Building Footprint

20000

Previous

Next

Building Characterization

NEWR

Non-Potable Reuse Building-Scale Calculator

Source Water Characterization

Select Source Water Option

- [x] Rainwater

Enter portion of the building footprint that is allocated to rainwater harvesting:

20000

- [x] Air Conditioning Condensate
- [x] Wastewater

Incorporate Thermal Recovery Unit?

- (•) Yes, Natural Gas Hot Water Heater
- ( ) Yes, Electric Hot Water Heater
- ( ) No

Select Wastewater Collection Type

- ( ) Mixed Wastewater (treated with Aerobic MBR)
- (•) Separated Graywater (treated with Aerobic MBR)

Specify Building Water Use Efficiency

- (•) High Efficiency
- ( ) Standard Efficiency

Previous

Source Water Characterization

NEWR – Non-potable Environmental and Economic Water Reuse Calculator

Methods & Resources

End Use Characterization

Select Recycled Water Use Type

- [x] Toilet Flushing
- [x] Outdoor Irrigation

High Water Use

1000

Medium Water Use

Enter irrigated area in sf

Low Water Use

Enter irrigated area in sf

- [x] Laundry
- [ ] Other (gpd)

Previous

Next

End Use Characterization

User Interface: Zip Code Data

NEWR – Non-potable Environmental and Economic Water Reuse Calculator: Results

Methods & Resources | Show data entered | New Calculation

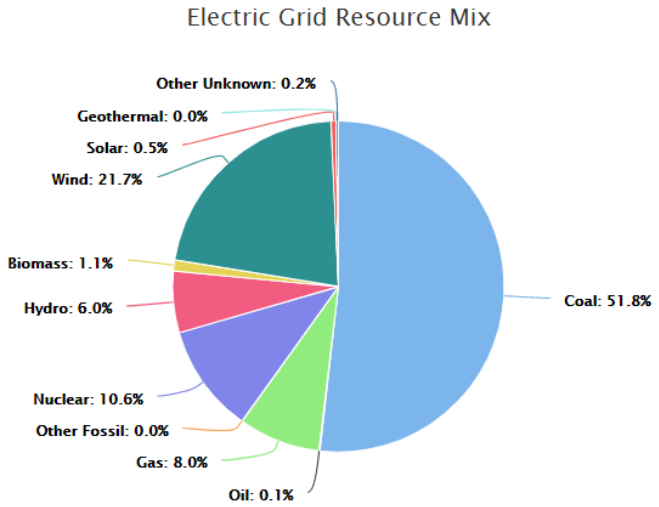
ZIP Code Data | Water Availability & Demand | Global Warming Potential | Total Energy Demand | Fossil Fuel Depletion | Water Consumption | Water Scarcity | Cost (Net Present Value)

ZIP Code Data for 55403

Month	Rainfall (inches)	AC Condensate Harvesting Potential (gal/cfm)	Reference Evapotranspiration (inches)
January	0.00	0.0000	0.67
February	0.00	0.0000	0.93
March	0.00	0.0011	2.19
April	0.00	0.019	3.88
May	3.46	0.13	5.46
June	4.25	0.85	5.96
July	3.98	1.51	6.46
August	3.98	1.22	5.42
September	2.99	0.68	4.06
October	2.09	0.015	2.64
November	0.00	8.00e-4	1.22
December	0.00	0.0000	0.60

Water Scarcity Factor	1.28	
Natural Gas Rate	0.30	$/1000 cf
Electricity Rate	0.12	$/kWh
Water Supply Rate	5.30	$/1000 gallons

eGRID Subregion - MRO West



User Interface: Water Availability and Demand

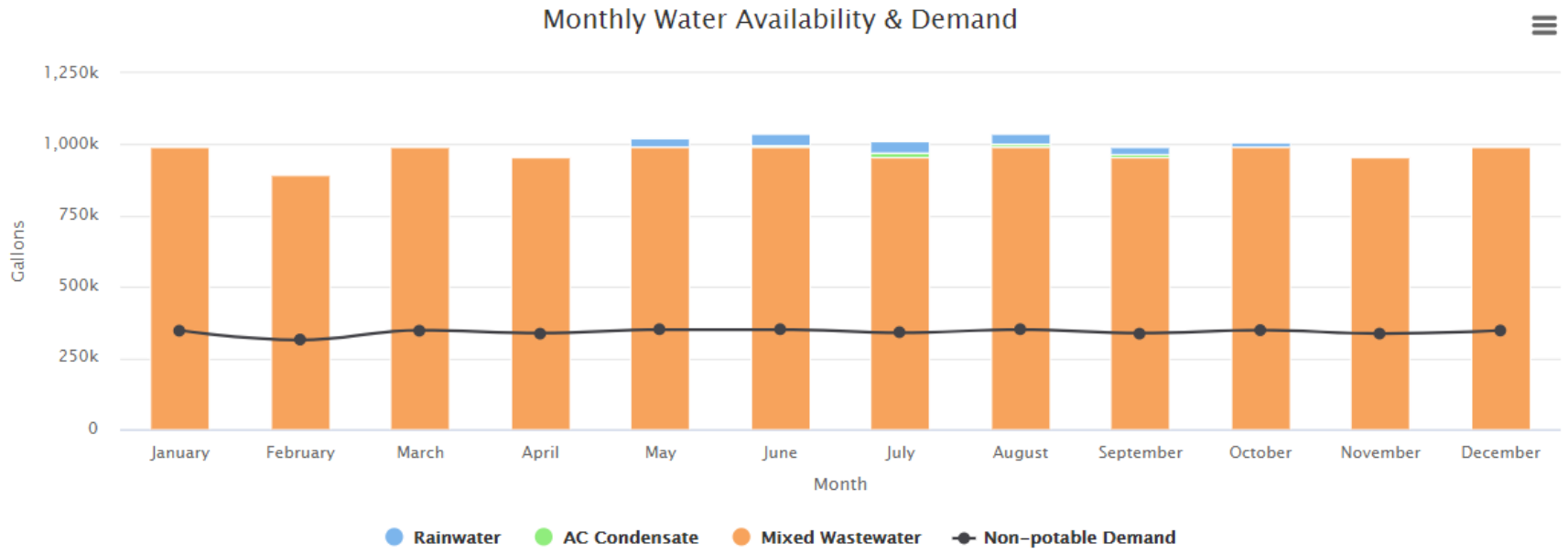
NEWR – Non-potable Environmental and Economic Water Reuse Calculator: Results

Methods & Resources | Show data entered | New Calculation

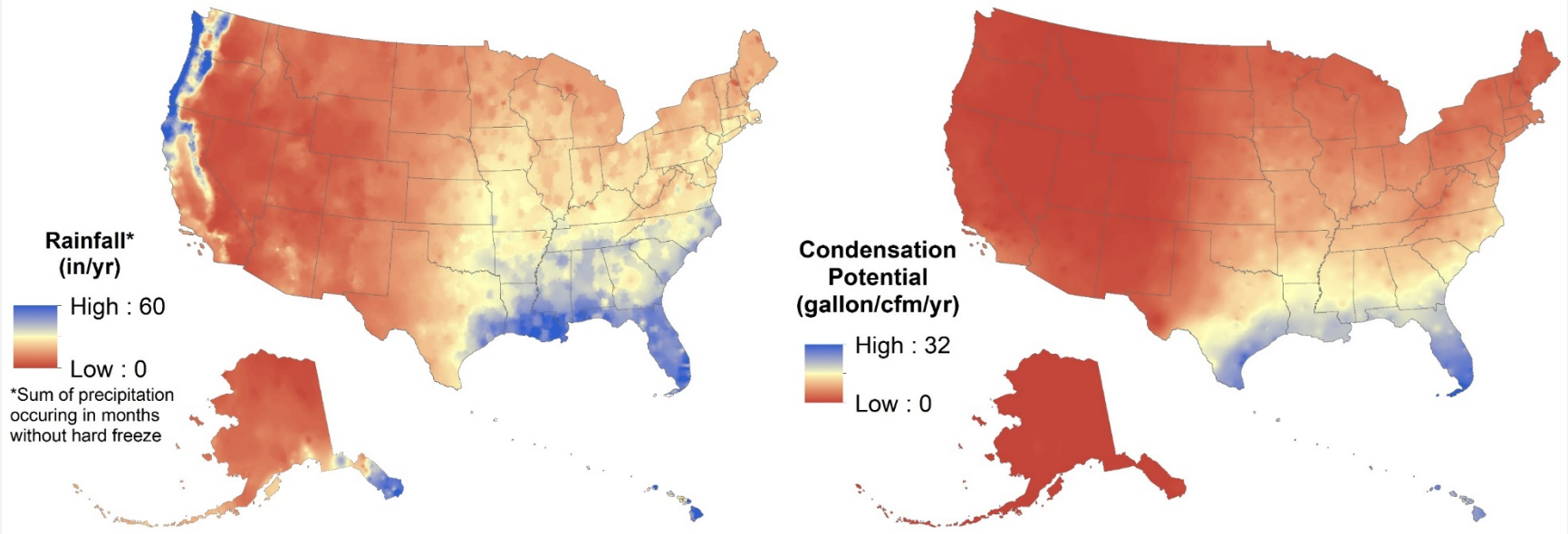
ZIP Code Data	Water Availability & Demand	Global Warming Potential	Total Energy Demand	Fossil Fuel Depletion	Water Consumption	Water Scarcity	Cost (Net Present Value)

Water Availability & Demand

○ By Source Water Type ◉ Combined Source Water Types



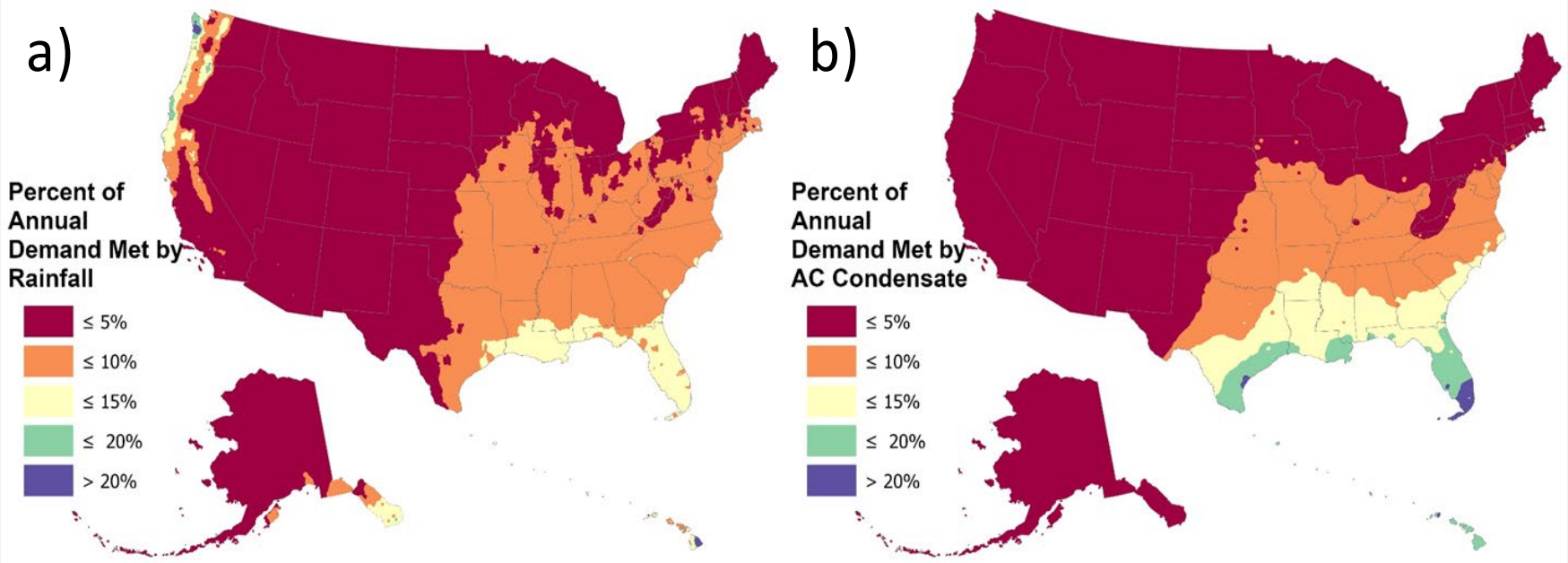
RWH and ACH Availability Models



- Long-term monthly data
- Filtered for hard freeze (TMY3 data, >4 consecutive hours with temperatures <28˚F)

- Relative humidity (RH) model
- Function of outdoor RH, indoor RH, % outdoor air
- TMY3 data used (~2000 stations)

Percent of Annual Non-Potable Demand Met



Mixed WW and GW systems always meet non-potable demand under modeled conditions.

Scenario Generation

Simulation Parameter	Simulation Set 1 – "Large Building"	Simulation Set 2 – "Large Building –AWWA"	Simulation Set 3 – "Random Generator"	Note (Units):
Geographic Coverage				
Geographic Coverage	Entire U.S.	AWWA Cities[a]	Entire U.S.	see Figure S1 for Simulation Set 1, Figure S11 for Simulation Set 3
# of ZIP Codes	40,873	3,382	1,276	
NEWR Inputs				
Building Type	Mixed Use	Mixed Use	Mixed Use	70% residential, 30% commercial
Building Occupants	1,100	1,100	min = 50 max = 1,100	count (persons)
Building Floors	19	19	min = 2 max = 20	count (floors)
Building Footprint/Occ.	18.2	18.2	min = 10 max = 20	Used to constrain area/occupant ratio (ft^2/person)
Building Footprint	20,000	20,000	min = 500 max = 22,000	Calculated as building occupants x area/occupant (ft^2)
Irrigated Area	0	0	min = 0% max = 100%	High water use area as a percentage of total building footprint (ft^2)

a – each of the 234 cities included within AWWA's 2019 rate survey (AWWA, 2019)
b – for Simulation Set 3, water balance results represent simulated ranges, not maximum ranges based on NEWR inputs
c – SWA = Source Water Availability

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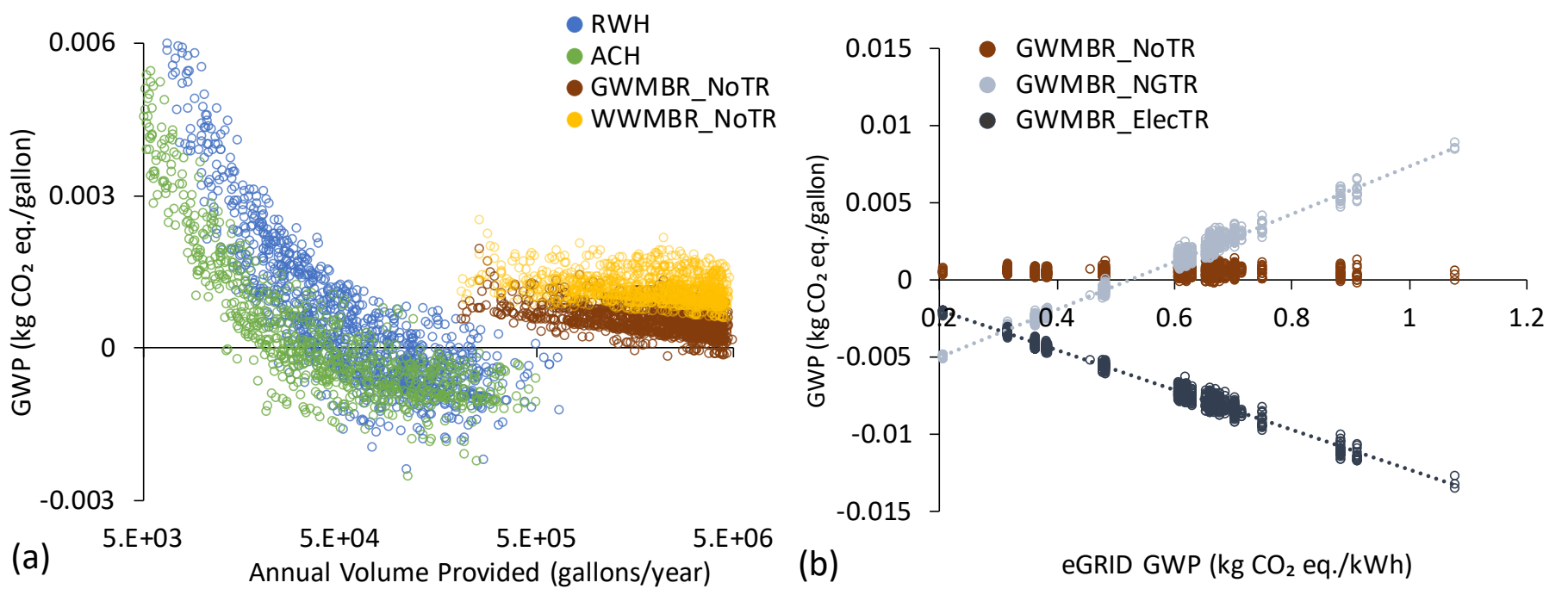
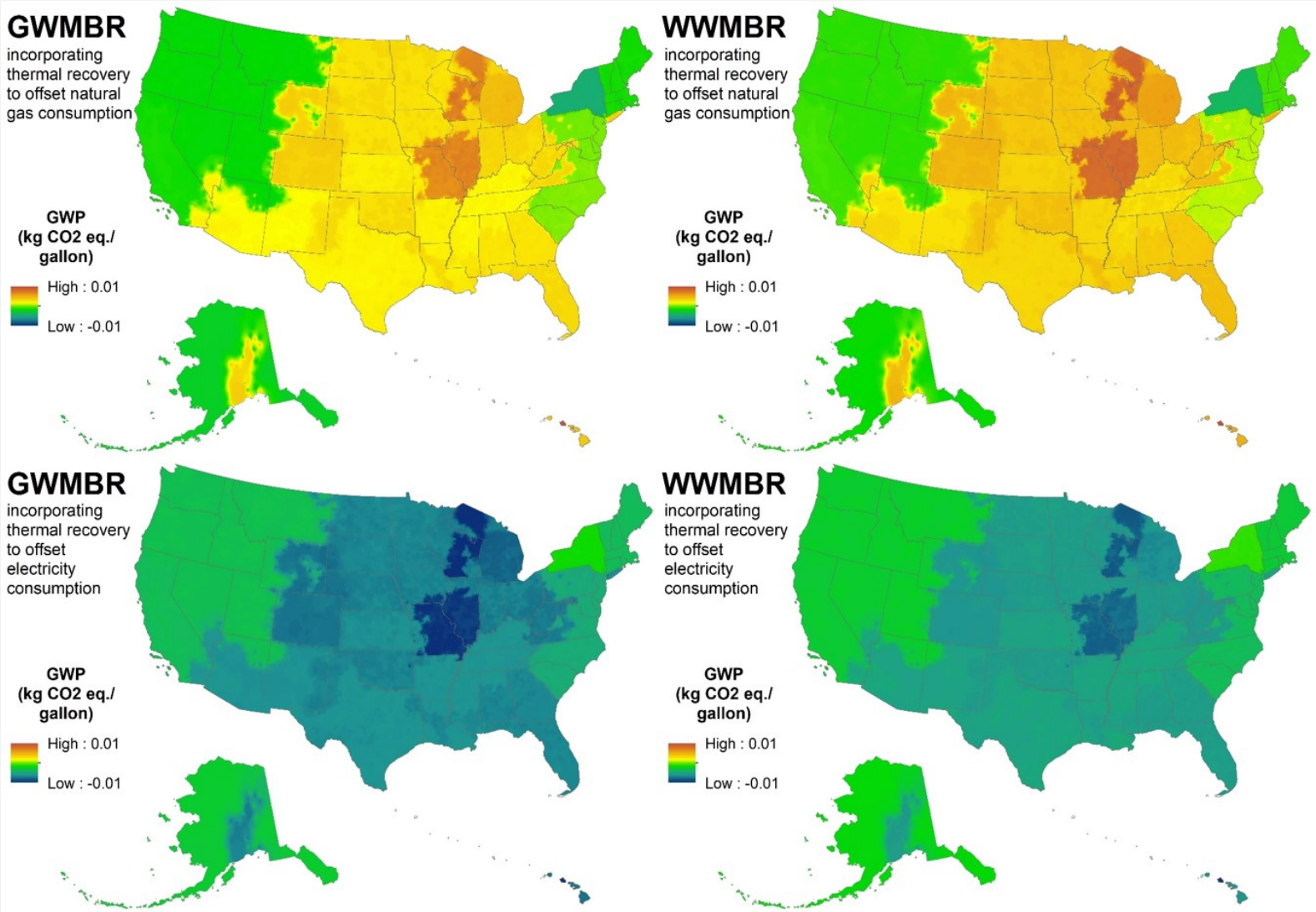
Global Warming Potential Across Source Waters, Variable Location and Building Characteristics



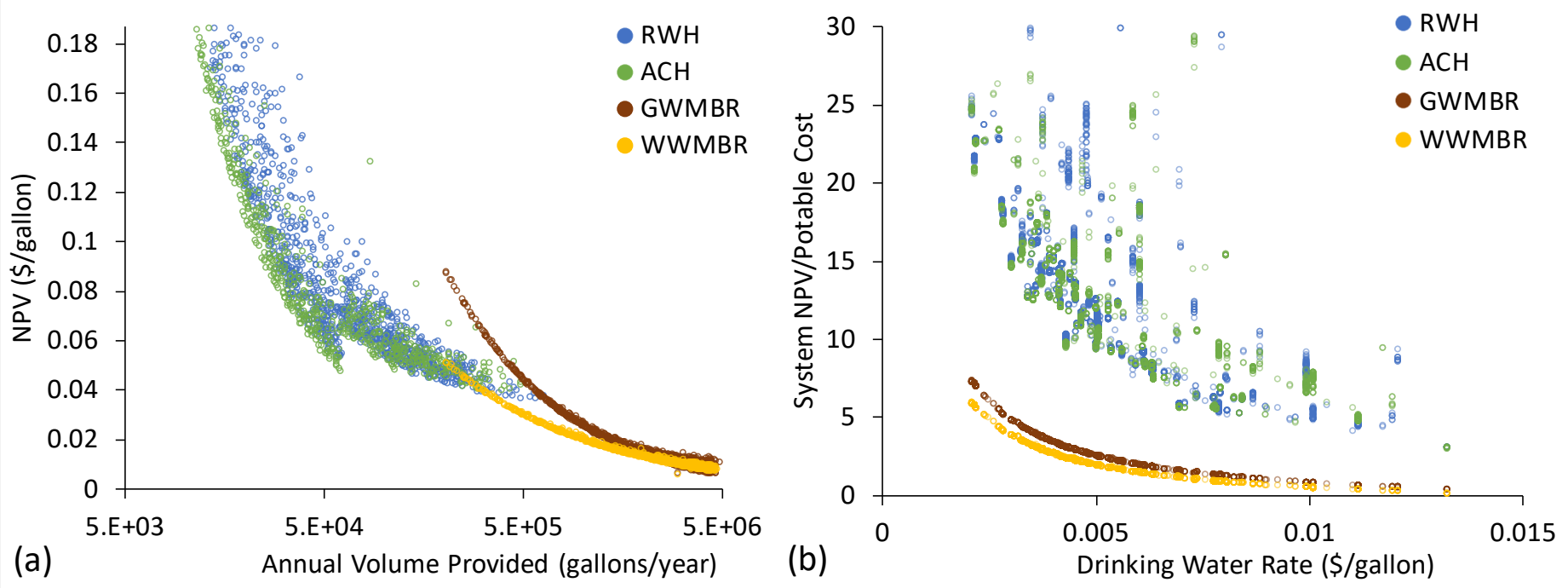
- Equal area grid – uniform geographic coverage
- 50-1,100 occupants
- 10-20 ft^2/occupant (500-22,000 ft^2)
- 2-20 floors

Fixed Building Global Warming Potential Across Source Waters

(With thermal recovery offsetting NG (top) and electricity (bottom))



Net Present Value Across Source Waters, Variable Location and Building Characteristics



Summary of Geospatial Analysis

- In most areas of the country, rainwater and AC condensate provide less than 10% of non-potable needs for large buildings
  - Where available, these water sources can provide an environmentally beneficial, but costly, option for reuse
- Wastewater and graywater provide 100% of the demand
  - Energy demands for treatment lead to environmental impacts, especially in areas with carbon intensive energy grids
  - Can be a cost effective source, especially where drinking water costs are high
- Planning and design of non-potable systems needs to be regionally specific and the NEWR tool provides local developers a quantitative, screening level assessment of the relative costs/benefits

Next Steps With NEWR

- **Public release**

  https://wcms.epa.gov/node/258471/revisions/1005723/view

- **Model improvements**
  - Combined source waters (e.g., linking rainwater and condensate collection, storage)
  - Alternative source waters (stormwater, foundation drainage) & end uses (cooling tower)
  - Expansion to community scale scenarios
  - Improved estimates of impacts on sewer flow, including potential reductions in CSOs/eutrophication

- **Targeted, collaborative applications to different metropolitan areas**
  - San Francisco, Greater Cincinnati
  - City of New York

ONWS LCA/LCC Literature

Arden, S., Morelli, B., Cashman, S., Ma, C., Jahne, M. and Garland, J. (2021) Onsite Non-potable Reuse for Large Buildings: Environmental and Economic Suitability as a Function of Building Characteristics and Location. Water Research 191 116635. doi:10.1016/j.watres.2020.116635.

Arden, S., Morelli, B., Schoen, M., Cashman, S., Jahne, M., Ma, C., Garland, J. (2020). Human health, economic and environmental assessment of onsite non-potable water reuse systems for a large, mixed-use urban building. Sustainability. 12, 5459. doi:10.3390/su12135459.

Morelli, B. and Cashman, S. (2019). Life cycle assessment and cost analysis of distributed mixed wastewater and graywater treatment for water recycling in the context of an urban case study. EPA/600/R-18/280

Ghimire, S. R., Johnston, J. M., Garland, J., Edelen, A., Ma, X. C., & Jahne, M. (2019). Life cycle assessment of a rainwater harvesting system compared with an AC condensate harvesting system. *Resources, Conservation and Recycling*, 146, 536-548.

Morelli, B., Cashman, S., Ma, X(C)., Garland, J., Bless, D., Jahne, M. September 2019. Life Cycle Assessment and Cost Analysis of Mixed Wastewater and Graywater Distributed Treatment for Non-Potable Reuse in San Francisco. WEFTEC conference proceeding paper. Chicago, IL.

Cashman, S., Ma, X(C)., Mosley, J., Garland, Crone, B., Xue, X. 2018. Energy and greenhouse gas life cycle assessment and cost analysis of aerobic and anaerobic membrane bioreactor systems: Influence of scale, population density, climate, and methane recovery. *Bioresource Technology*, 254, 56–66.

Cashman, S., Mosley, J., Ma, X(C)., Garland, J., Cashdollar, J., Bless, D. 2016. Life Cycle Assessment and Cost Analysis of Water and Wastewater Treatment Options for Sustainability: Influence of Scale on Membrane Bioreactor Systems. EPA report: EPA/600/R-16/243.

United States Environmental Protection Agency

Disclaimer

This research was part of the U.S. Environmental Protection Agency (U.S. EPA) Office of Research and Development's Safe and Sustainable Water Resources (SSWR) Program. The findings and conclusions in this presentation have not been formally disseminated by the EPA and should not be construed to represent any Agency determination or policy.

Ancillary Slides

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

New LRTs for Intermediate-Size and Business

Existing

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)

New

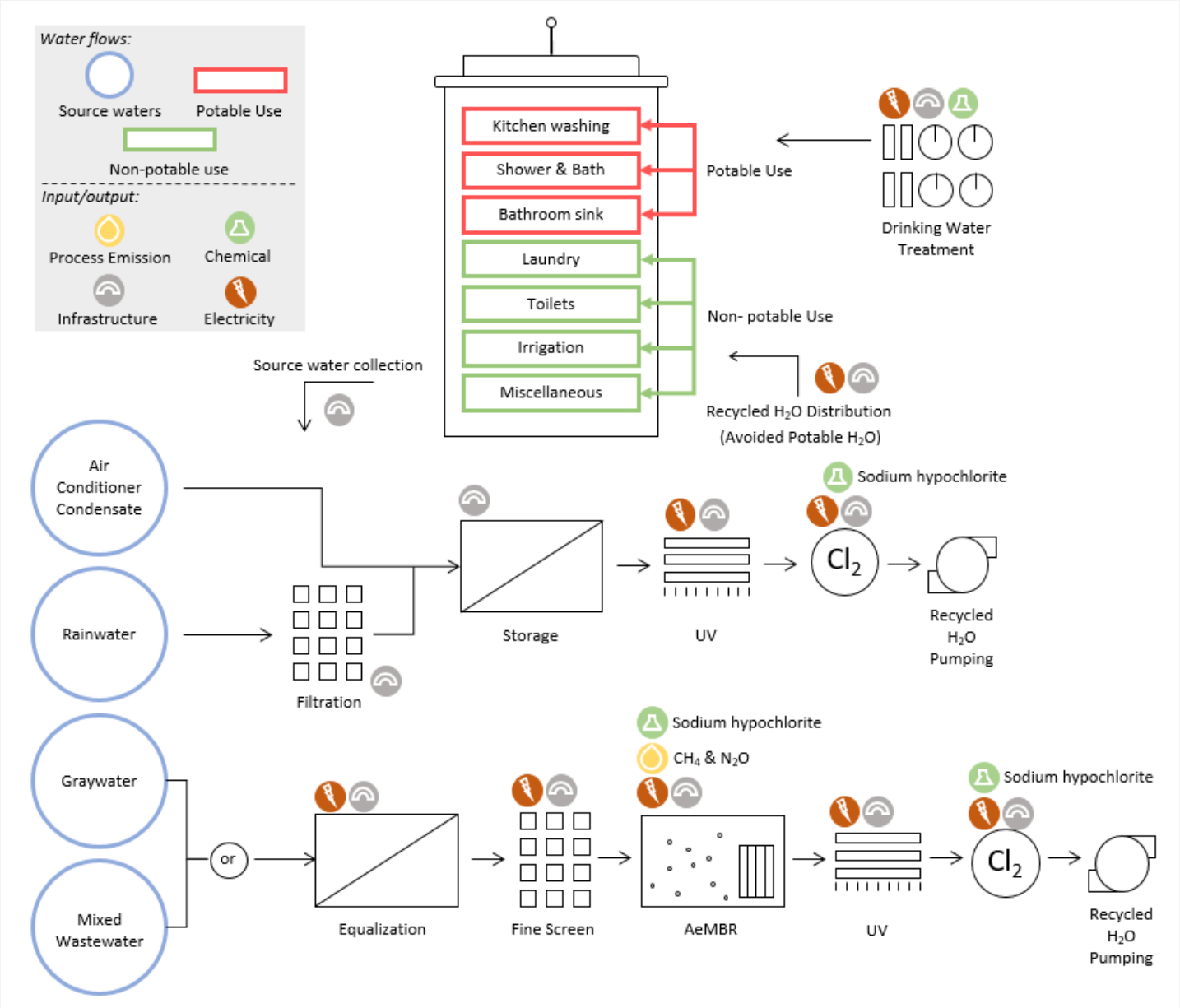
Table 5 | LRTs for NSF 350-scale onsite systems given the 10^{-4} (10^{-2}) infection ppy benchmark assuming upper-bound/lower-bound dose–response relationships summed across all treatment units including disinfection[a,b,c]

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)

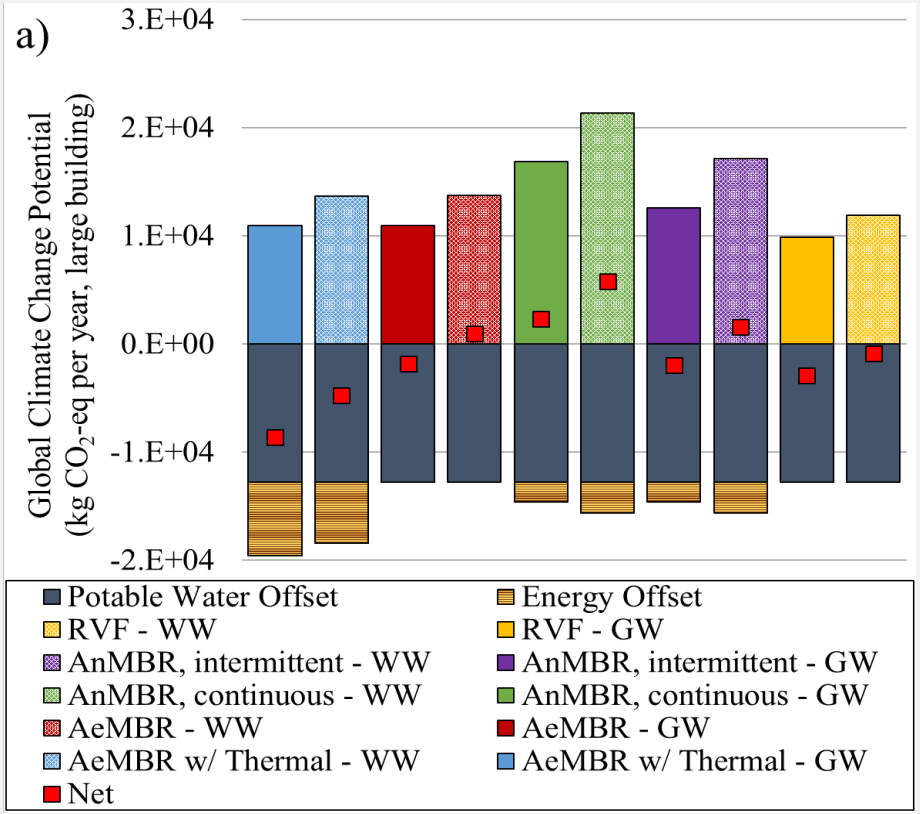
Schoen, Jahne, Garland (2019) J Water Health 18(3), 331-344

System Types



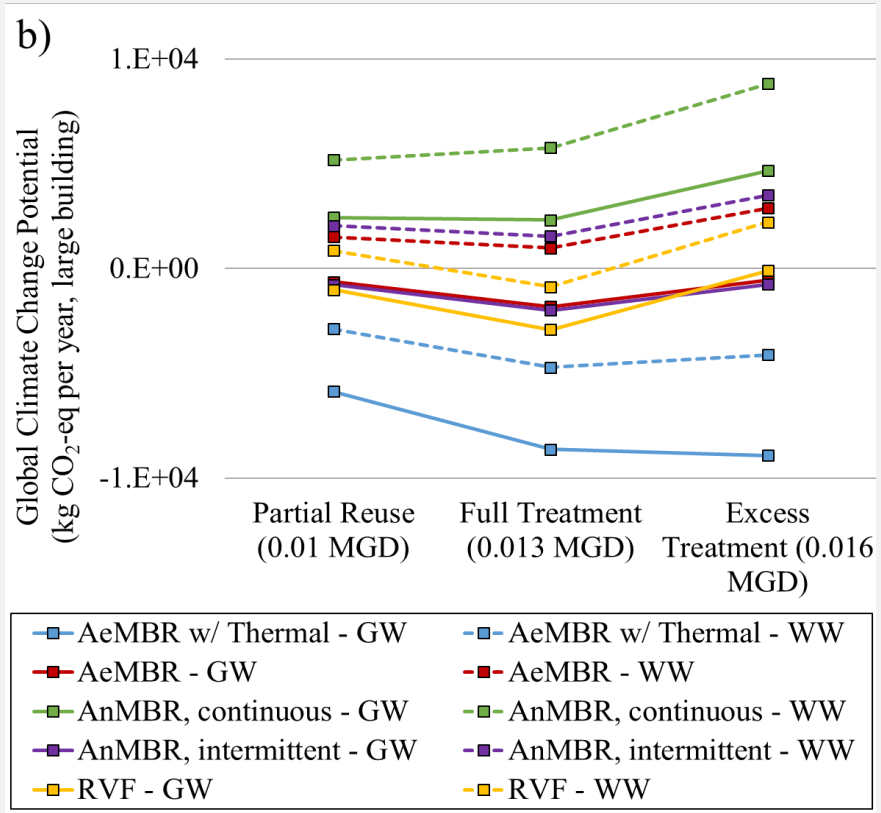
Global Warming Potential Findings

a – Technology selection



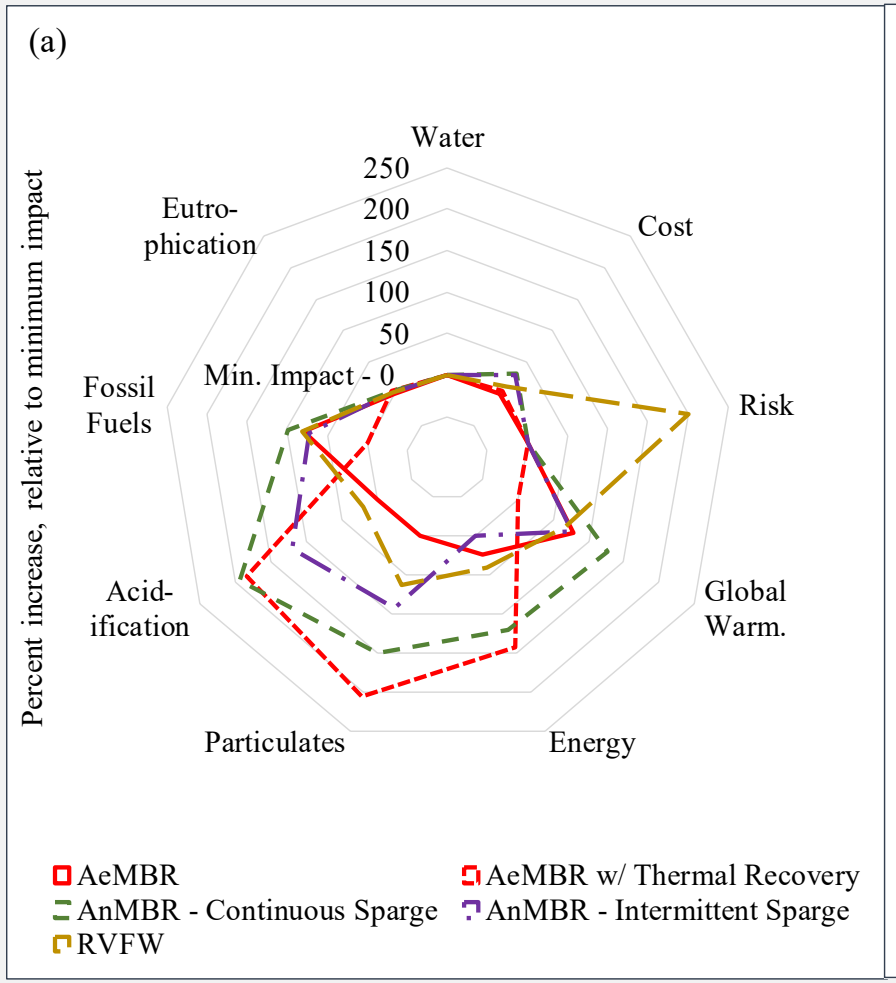
From Arden et al. 2020

b – Treatment capacity

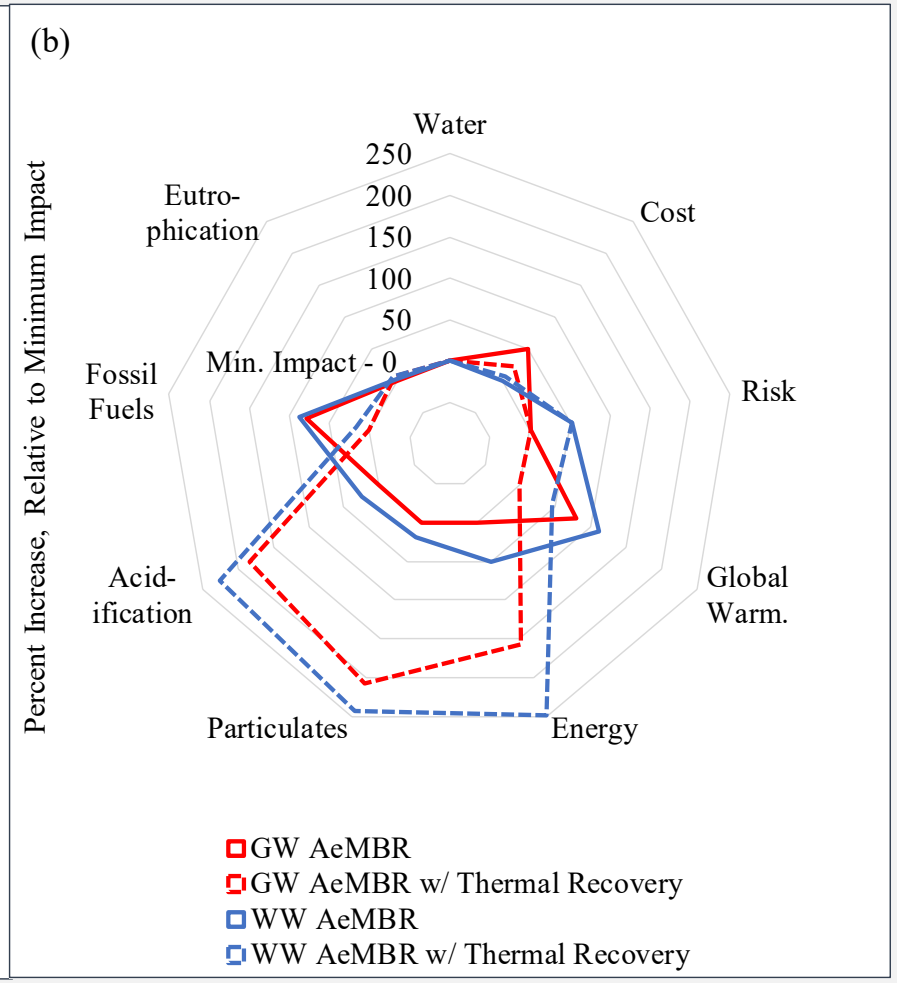


Integrated Assessment Findings

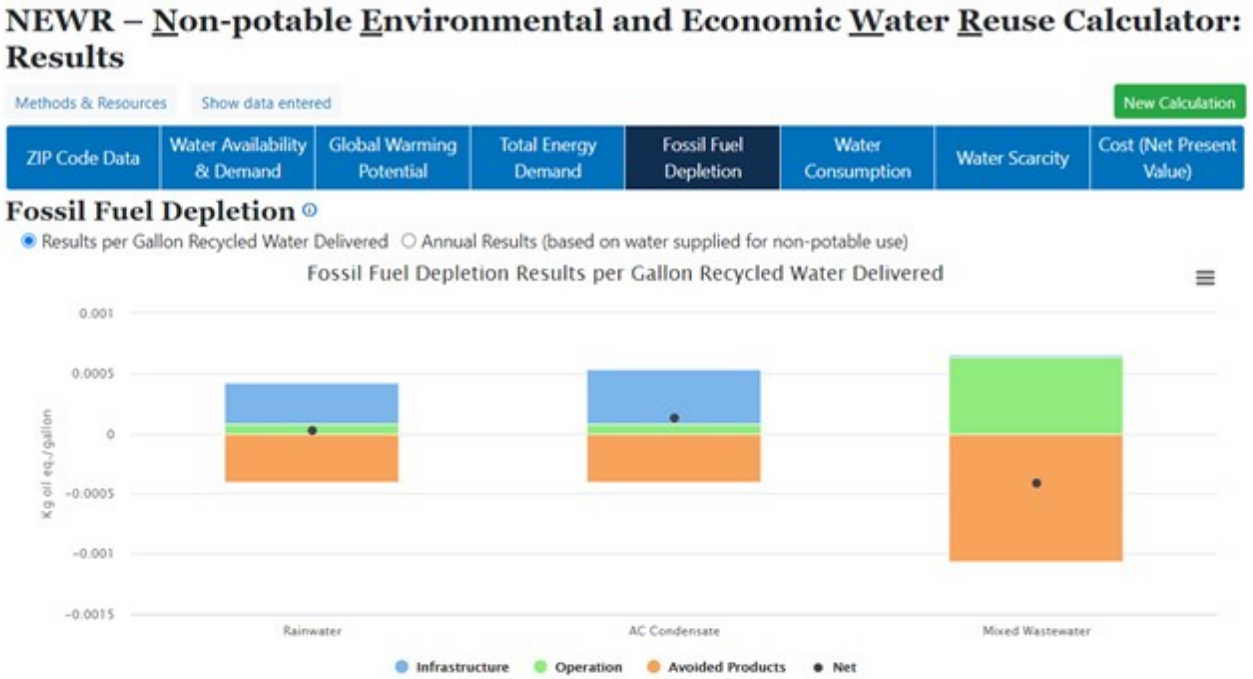
a - GW treatment options



b – AeMBR treatment options



User Interface: Fossil Fuel Depletion



Fossil Fuel Depletion Results per Gallon Recycled Water Delivered (kg oil eq./gallon)

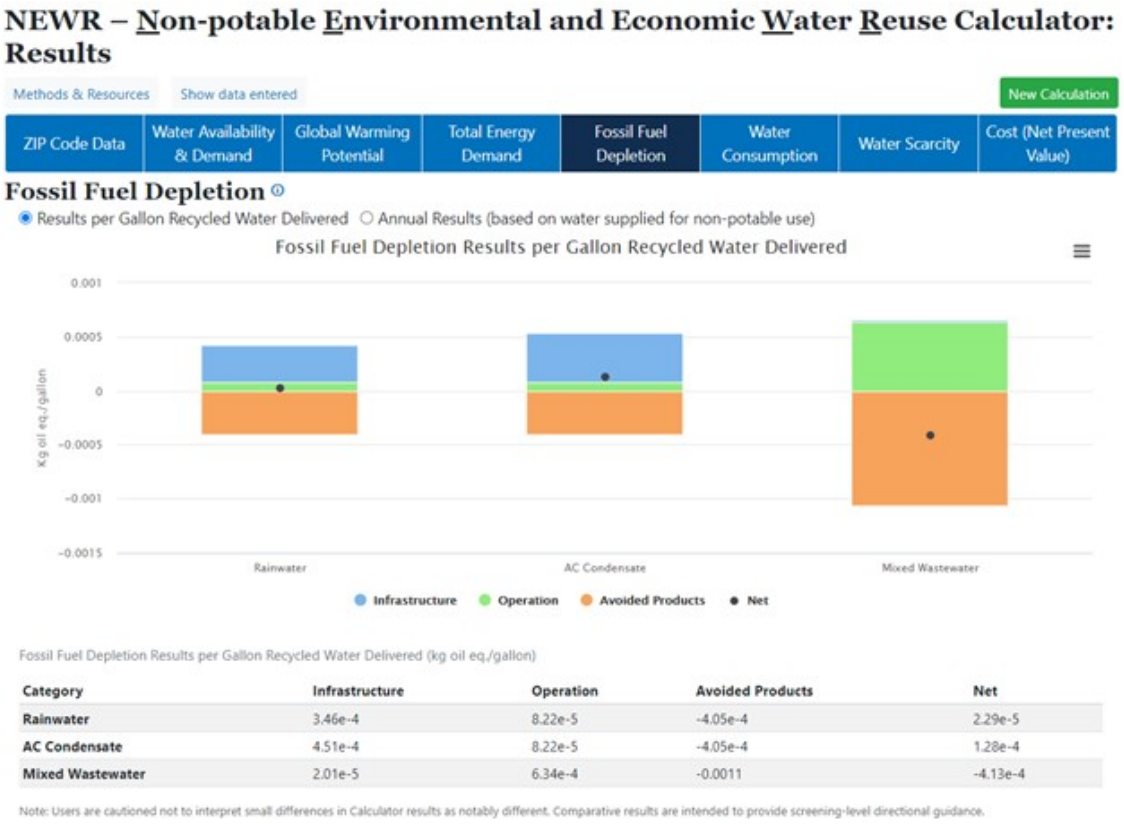
Category	Infrastructure	Operation	Avoided Products	Net
Rainwater	3.46e-4	8.22e-5	-4.05e-4	2.29e-5
AC Condensate	4.51e-4	8.22e-5	-4.05e-4	1.28e-4
Mixed Wastewater	2.01e-5	6.34e-4	-0.0011	-4.13e-4

Note: Users are cautioned not to interpret small differences in Calculator results as notably different. Comparative results are intended to provide screening-level directional guidance.

Infrastructure = all capital equipment for treatment, collection, and distribution
Operation = electricity and chemicals for treatment and disinfection
Avoided products = displaced drinking water requirements and hot water heating requirements (MBR with thermal recovery)

User Interface: Fossil Fuel Depletion

Result per gallon and per year



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