UNLOCKING THE NATIONWIDE POTENTIAL FOR WATER REUSE

FRESH RESEARCH INSIGHTS

WRF 5197 RESEARCH TEAM

13 MARCH 2024

WateReuse®

2024 SYMPOSIUM

REMOVING BARRIERS, ELEVATING OPPORTUNITIES

THE Water Research FOUNDATION®

Unlocking the Nationwide Potential of Water Reuse

EPA

$3.25 million
EPA National Priorities Program: Grant 84046201

Year 1 → Year 2 → Year 3 → Year 4

Project Overview

INTEGRATED RESEARCH PLAN

Realizing the full nationwide potential of water reuse will require an integrated research plan and the establishment of technical and social legitimacy through a concerted focus on community acceptance, robust technical design including monitoring and feedback, and implementation of water reuse.

PUBLIC HEALTH (Task A)

- Risk Assessment
- Risk Mitigation

TECHNOLOGY (Task B)

- Process & Performance Modeling
- Real-time Monitoring

DECISION-MAKING (Task D)

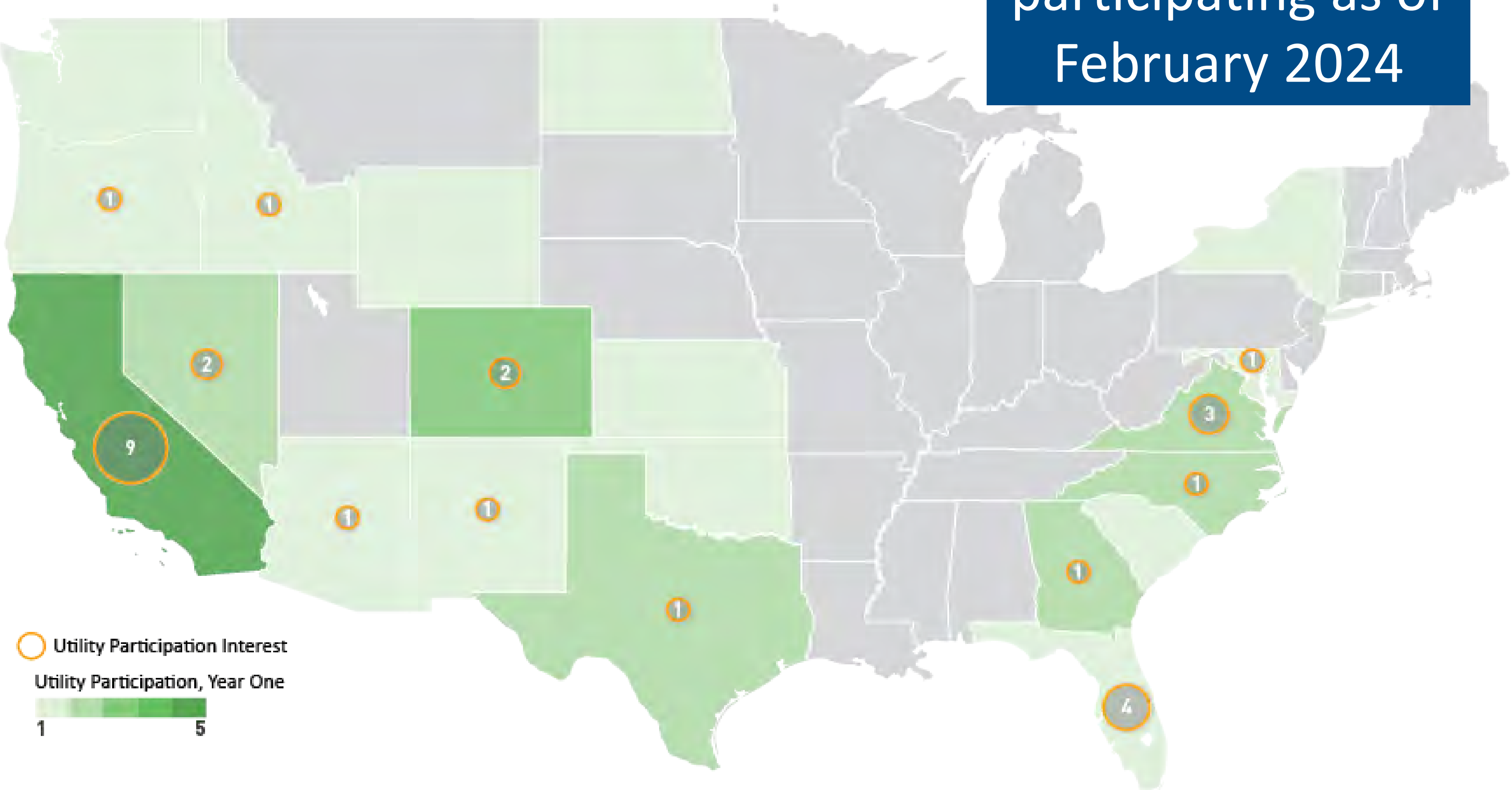
- Sustainability Assessment
- Pathways to Successful Adoption

COMMUNITY (Task C)

- Public Perception
- Community Engagement
- Mapping Water Reuse Potential

A Participatory Process

42 utilities participating as of February 2024



Successful and Sustainable Water Reuse Adoption Pathways (Task D)

Our main goal:

Identify **strategies** and **pathways** to support the **successful implementation** of sustainable water reuse

The Team:

Assoc. Prof. Sherri Cook
University of Colorado Boulder

Prof. Amy Javernick-Will
University of Colorado Boulder

Prakriti Sardana
University of Colorado Boulder

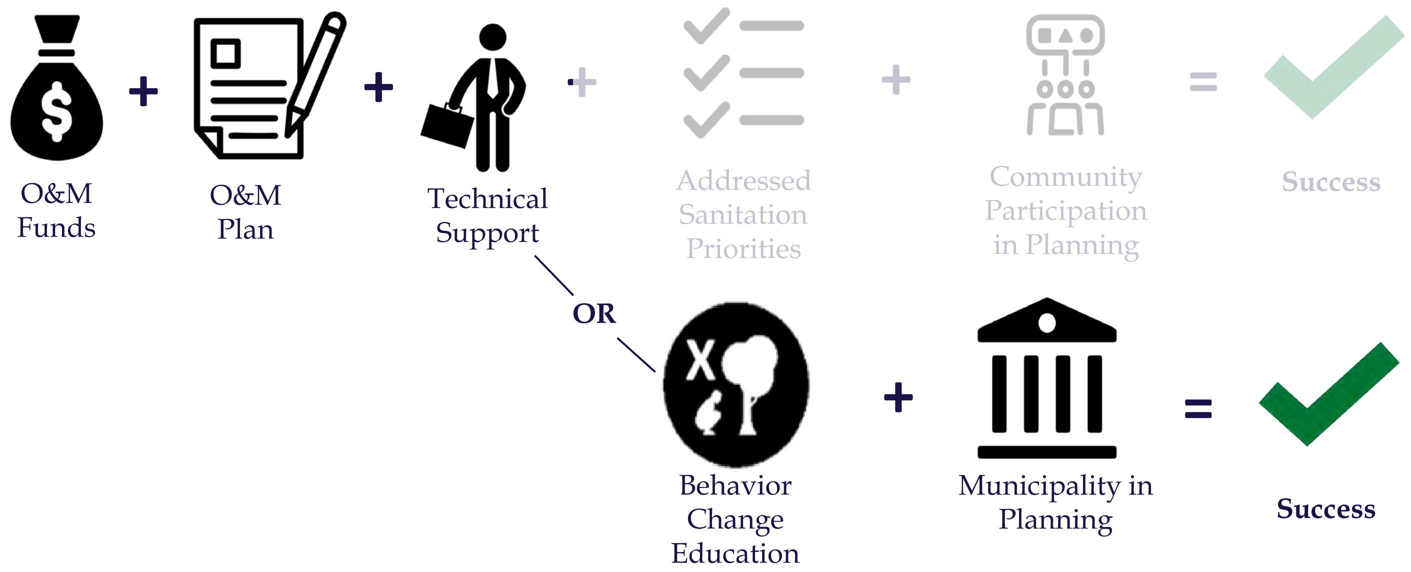
Isabella Cobble
University of Colorado Boulder

Lydia Silber
WateReuse Association

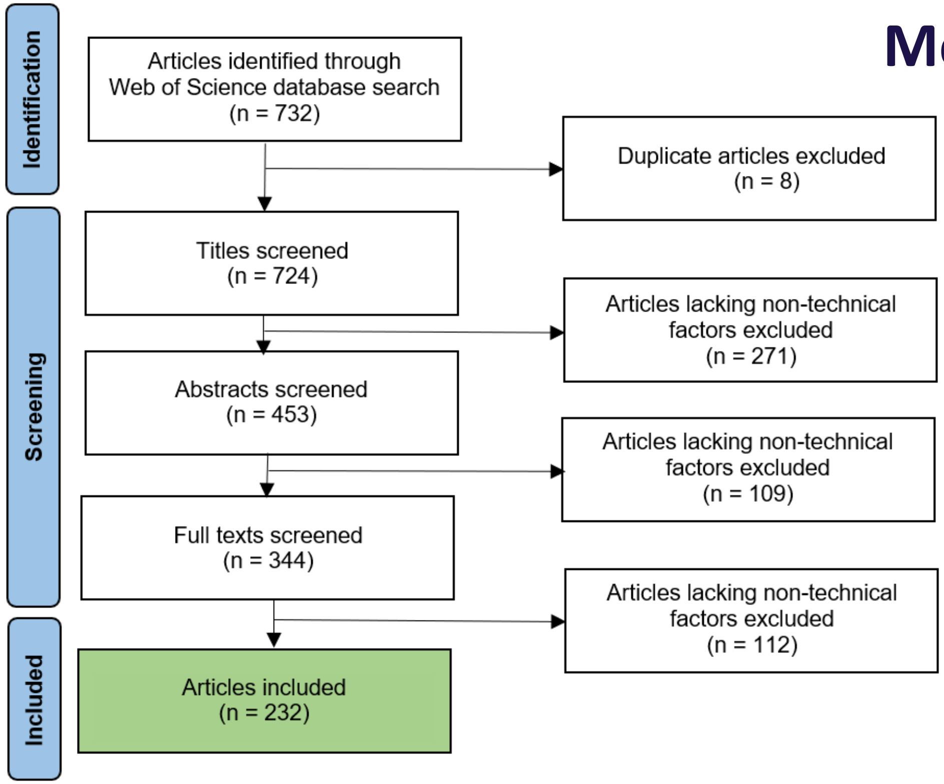
Our goal is to identify ways to leverage enablers and overcome barriers to implement water reuse successfully

A Qualitative Comparative Analysis will combine case knowledge to compare and identify similarities across diverse case studies

Example success pathway: sanitation systems in India



Our first step was to identify a comprehensive list of water reuse enablers and barriers



Methods: Literature Review

Environmental Science & Technology — POLICY ANALYSIS — pubs.acs.org/est

Management Experiences and Trends for Water Reuse Implementation in Northern California

Heather N. Bischel,[†] Gregory L. Simon,[‡] Tammy M. Frisby,[§] and Richard G. Luthy[*,†]

[†]Department of Civil and Environmental Engineering, Stanford University, Stanford, California 94305-4020
[‡]Department of Geography & Environmental Sciences, University of Colorado Denver, Denver, Colorado 80217-3364
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ELSEVIER
Resources, Conservation & Recycling
journal homepage: www.elsevier.com/locate/resconrec
Full length article

Perceived drivers and barriers in the governance of wastewater treatment and reuse in India: Insights from a two-round Delphi study

Lena Breitenmoser[a,1,*], Gabriela Cuadrado Quesada[b,1], Anshuman N[c], Nitin Bassi[d], Nathaniel Bhakupar Dkhar[c], Mayuri Phukan[c], Saurabh Kumar[d], Andraju Naga Babu[c], Anjin Kierstein[e], Paul Campling[f], Christine Maria Hooijmans[b]

[a] Institute for Ecopreneurship, School of Life Sciences, University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Hofackerstrasse 30, 4132 Muttenz, Switzerland
[b] IHE Delft, Institute for Water Education, Westvest 7, Delft, 2611AX, the Netherlands
[c] Water Resources Division, The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi, 110 003 India
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[e] Department of Civil and Environmental Engineering, Bochum University of Applied Sciences, Lennershofstrasse 140, 44801 Bochum
[f] VITO, Vlaamse Instelling voor Technologisch Onderzoek, Boeretang 200, 2400 Mol, Belgium

The Geographical Journal — Royal Geographical Society with IBG
The Geographical Journal, Vol. 179, No. 1, March 2013, pp. 61–73, doi: 10.1111/j.1475-4959.2012.00478.x

Towards effective water reuse: drivers, challenges and strategies shaping the organisational management of reclaimed water in Jordan

GEMMA CARR* AND ROB B POTTER†
*Centre for Water Resource Systems, Vienna University of Technology, Vienna, Austria
E-mail: carr@waterresources.at
†Department of Geography and Environmental Science, School of Human and Environmental Sciences, University of Reading, Reading RG6 6AB

Water Environment Federation — the water quality people

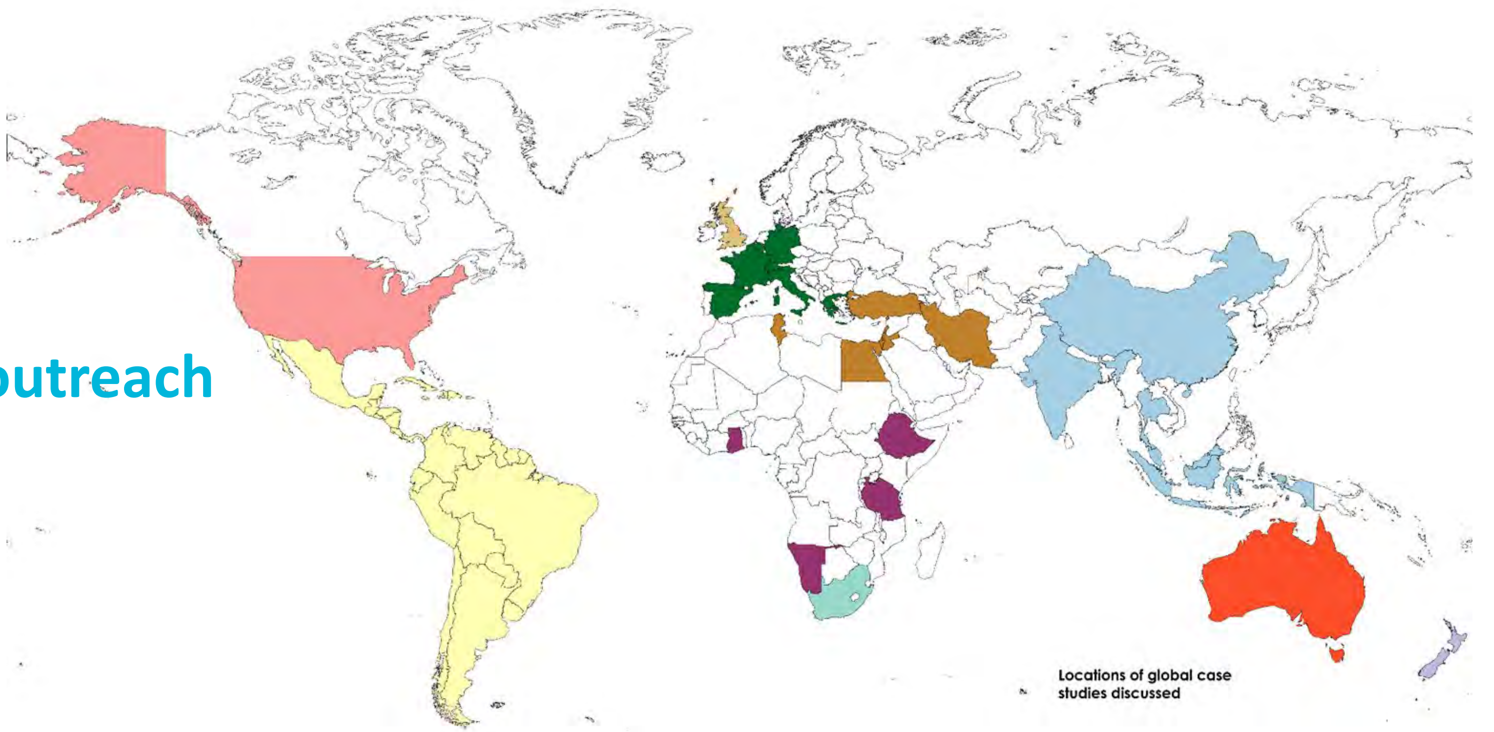
Local resident perceptions of water reuse in Northern Utah

Courtney G. Flint, Kristen R. Koci

We identified 38 enablers of and barriers to water reuse based on worldwide research

Results: Literature Review

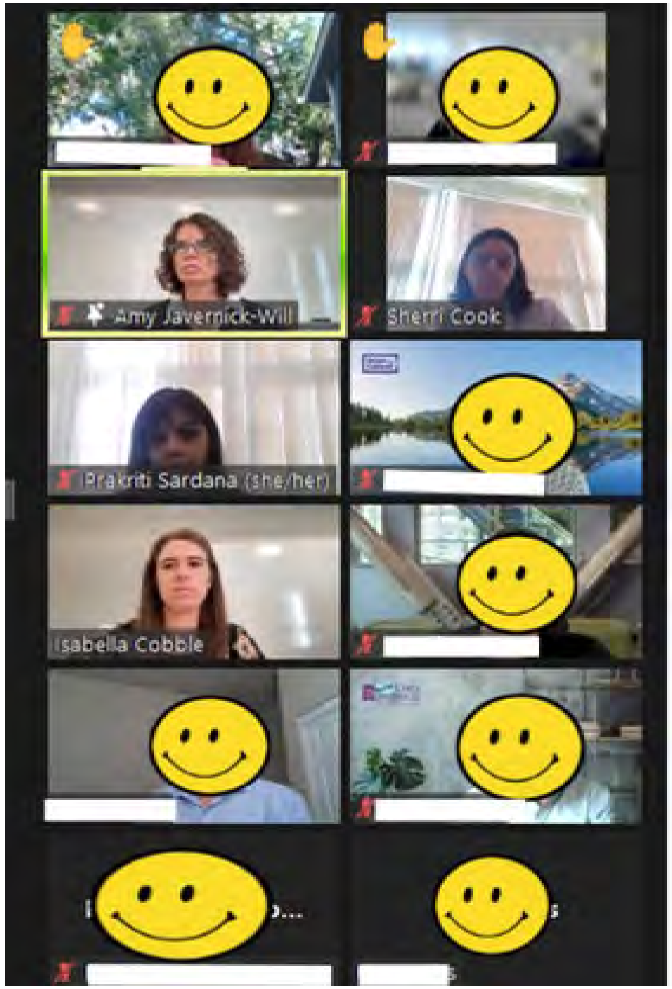
38 factors identified

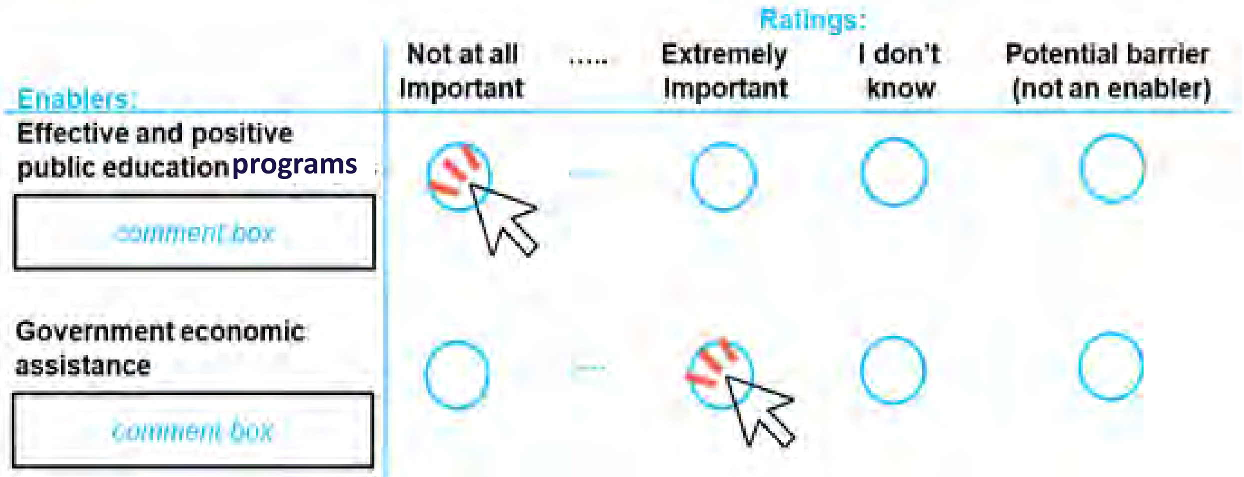


Enablers
- ➢ Trust in information provided
- ➢ Water consumer **education and outreach** programs

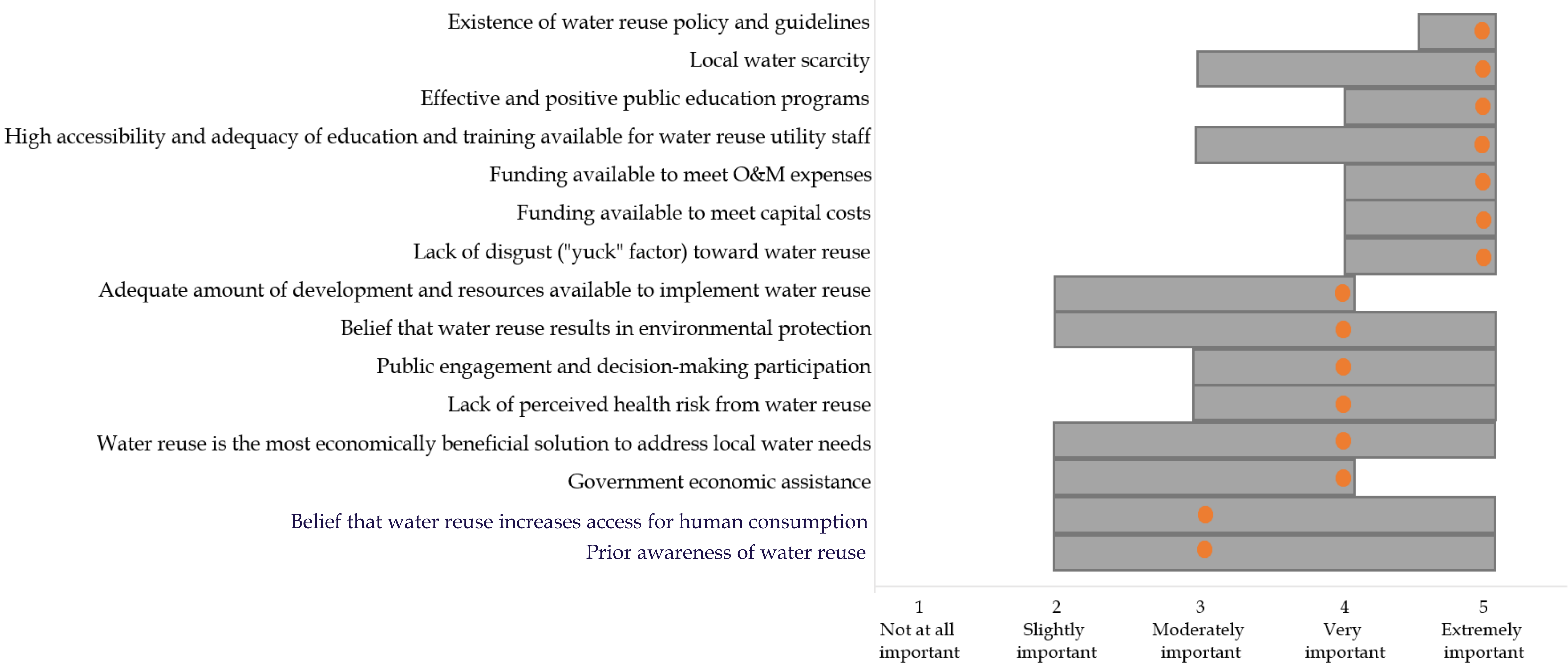
Barriers
- ➢ **Lack of funding** for CAPEX/OPEX
- ➢ Perceived health risk

Expert panel discussions found the list of enablers and barriers to be comprehensive and representative

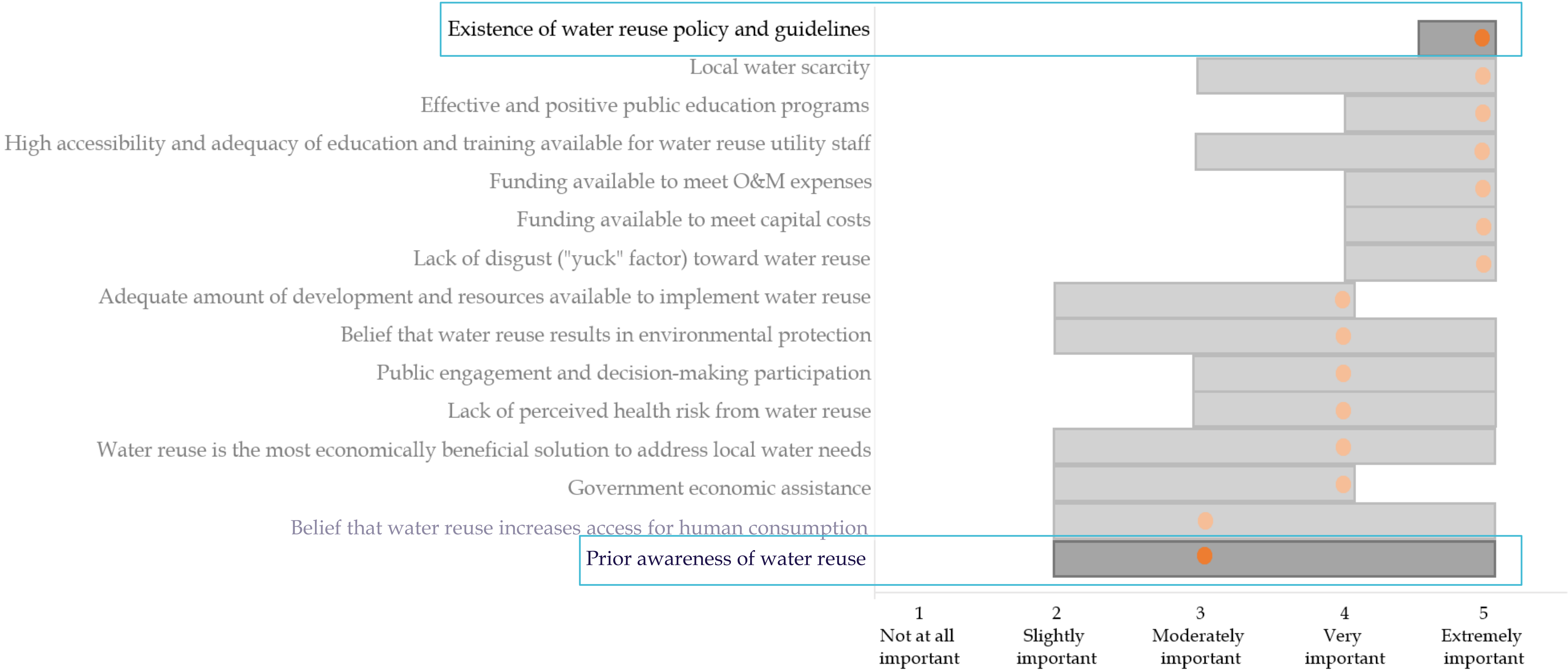




Expert panel discussions identified and prioritized factors relevant to U.S. case studies



Importance of some factors was highly dependent on context and others were universally important



Expert panel discussions helped identify case study and data collection options

We are conducting our case studies by collecting data with site visits, interviews, and ethnographic analysis

Documentation

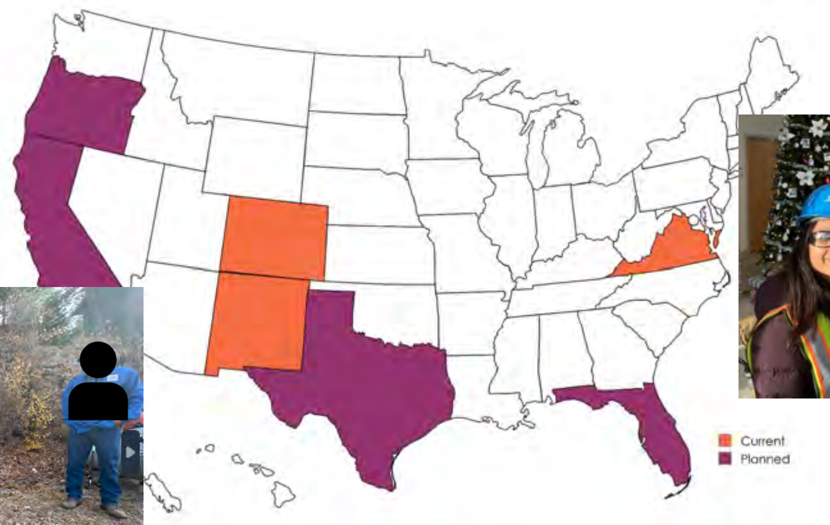
Project or utility websites

News articles

Social media posts

Published reports

Site Visits



Key interviews

Human resources

Public relations

Financial resources

Infrastructural resources

Policy and regulations

Qualitative Comparative Analysis

We will evaluate each case study’s combinations of factors, and identify which provide pathways to success

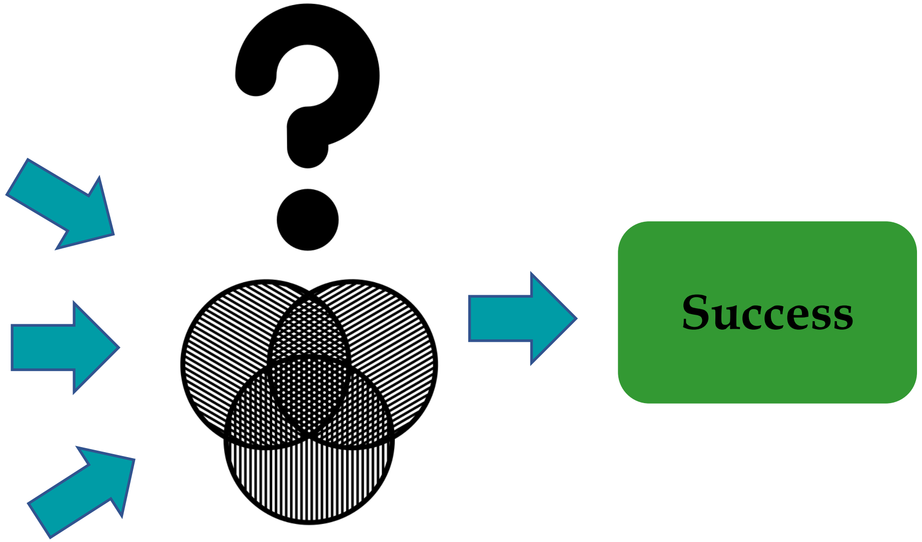
Economic
- Funding for capital costs and O&M expenses
- Government economic assistance
- Water reuse is the most economically beneficial solution to address local water needs
- Water rates based on affordability and willingness-to-pay
- Adequate amount of development and resources available to implement water reuse

Regulatory
- Existence of (enabling) water reuse policy and guidelines

Organizational
- High accessibility and adequacy of education and training needed available for water reuse utility staff
- Public decision-making participation
- Effective and positive public education campaigns programs

Geo-contextual
- Local water scarcity

Public opinion and perception
- Lack of disgust ("yuck" factor) toward water reuse
- Lack of perceived health risk from water reuse
- Prior experience of water reuse
- Belief that water reuse results in environmental protection
- Belief that water reuse results in water access for human consumption
- Demographic indicators



Successful and Sustainable Water Reuse Adoption Pathways (Task D)

Elevating Opportunities

Social Development and Community Engagement (Task C)

Our main question:

How do we keep the social and socio-technical development of water reuse on pace with technological development?

The Team:

Miriam Hacker, PhD
Water Research Foundation

Carolyn Hayek, PhD
Columbia Water Center

Asst. Prof. Khalid Osman
Stanford University

Asst. Prof. Anais Roque
Ohio State University

Assoc. Prof. Caroline Scruggs
Univ. of New Mexico

Lydia Silber
WateReuse Association

Social Development and Community Engagement (Task C)

CURRENT STATUS OF SUBTASKS

TASK C1

In Progress!
~25%

Quantify water availability and identify water reuse potential in the US

- Develop nationwide indices to evaluate potential for various types of reuse
- Use water availability data to populate indices'
- Create Storymap for public and sector access

TASK C2

In Progress!
~75%

Nationwide analysis of social and organizational factors for reuse

- Document and analyze social/organizational factors by type of reuse
- Capture role of media in communicating reuse
- Create Storymap of results for easily accessible findings

TASK C3

In Progress!
~35%

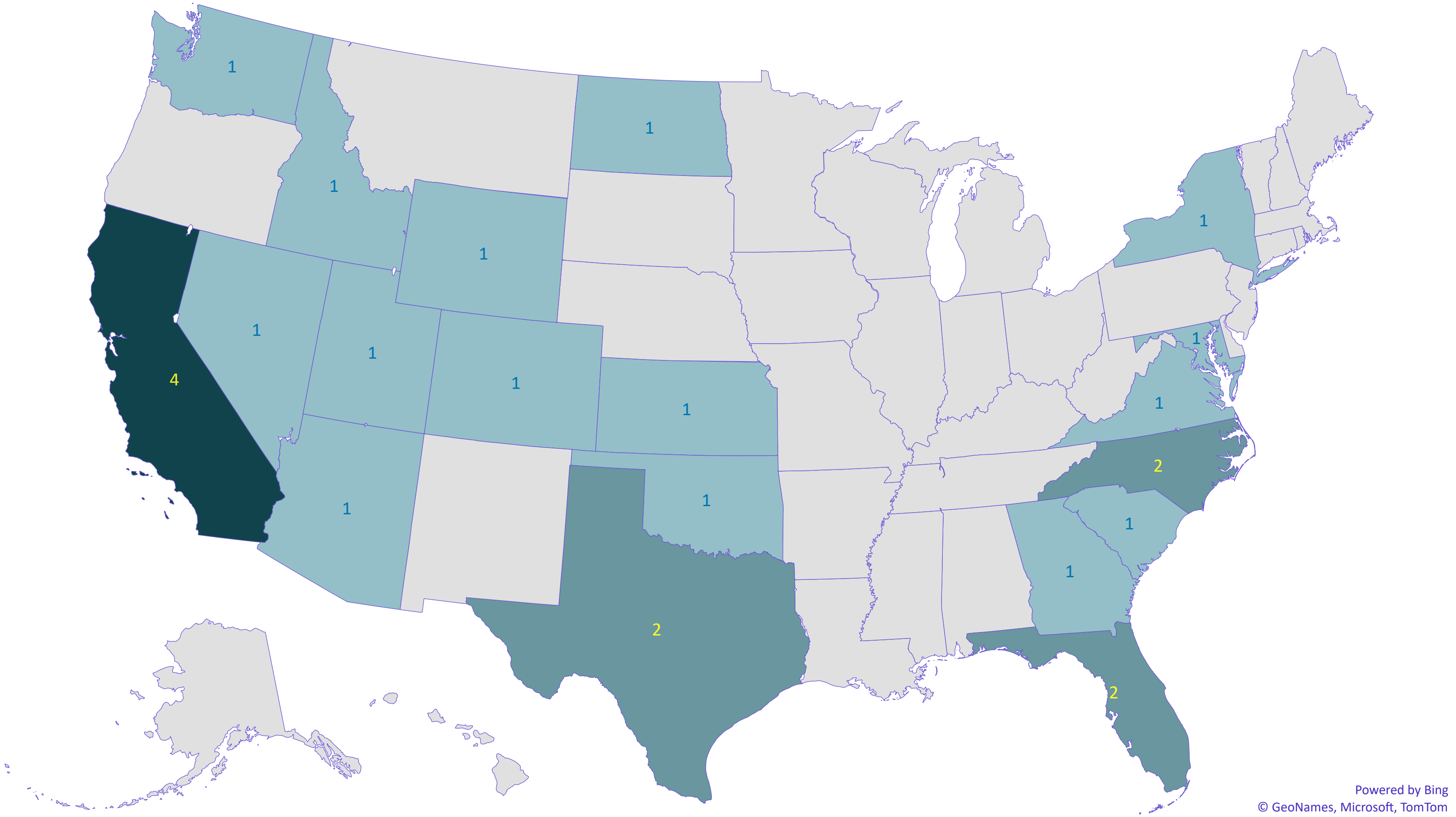
Local analysis of community engagement best practices

- Develop in-depth case studies for social development of reuse
- Work with local utilities to assess community engagement methods
- Develop a compendium of best practices

Social Development and Community Engagement (Task C)

BEST PRACTICES FOR COMMUNITY ENGAGEMENT

Overview of 26 Utility Interviews, by State



Social Development and Community Engagement (Task C)

BEST PRACTICES FOR COMMUNITY ENGAGEMENT

26 Total Interviews

Reuse Application	# Interviews
DPR	4
IPR	11
Municipal NPR	10
Agricultural Reuse	4
Industrial Reuse	5
Onsite Reuse	2

Social Development and Community Engagement (Task C)

BEST PRACTICES FOR COMMUNITY ENGAGEMENT

Types of questions:

- What does engagement look like?
- Who is included in "community" that is being engaged?
- Is there a difference between "community" and "stakeholder"?
- How is "successful" community engagement defined?
- What would be helpful to learn more about engagement?

Social Development and Community Engagement (Task C)

BEST PRACTICES FOR COMMUNITY ENGAGEMENT

"There was a lot of community engagement and outreach to figure out which of the strategies that were proposed best aligned with the community's values.

And that factored into the final kind of selection of the different portfolio or suite of strategies that are now part of the water forward plan." *(Interview 14)*

Social Development and Community Engagement (Task C)

REGIONAL UTILITY WORKSHOPS

Regional Utility Workshops
July-Aug 2024

Works wit Commu Leade
Oct-Nov

Format: Virtual, half-day

Size: 20-25 people

Ideal Participant(s):

- Utility decision-maker
- Utility staff involved in comm

Workshop Goals:

- Introduce engagement spect
- Capacity assessment
- Regional scenario mapping for engagement

Social Development and Community Engagement (Task C)

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Regional Utility Workshops on Community Engagement (WRF 5197 - Task C)

Social Development and Community Engagement (Task C)

Elevating Opportunities

Treatment Models and Risk Mitigation Techniques (Task B)

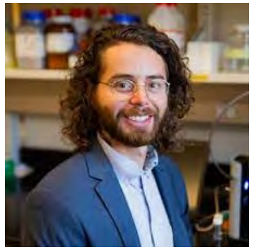
Our Research Goals:

Develop a water reuse treatment plant model leveraging new findings around key processes and pilot experience at field sites.

The Team:

Karl Linden

Julie Korak



Tony Straub

Kylie Boenisch-Oakes

Billy Raseman
Hazen & Sawyer

Chris Bellona
Colorado School of Mines

Tzahi Cath
Colorado School of Mines

Scott Summers

Sheldon Masters

Emma Wilder

Trisha Nickerson

Eric Peterson
Hazen & Sawyer

Kate Newhart
West Point MA

Elliese Wright
Colorado School of Mines

University of Colorado Boulder

Treatment Models and Risk Mitigation Techniques (Task B)

Water Reuse Treatment Plant Model

- Modify the US EPA Water Treatment Plant Model for water reuse context
  - Year 1 and 2
- Integrate 2 new models as feedback
  - New Trace Organic Compound (TrOC) control model
    - Year 2 and 3
  - New Distribution System Water Quality (DS-WQ) Model
    - Year 3 and 4
- Utilize the US EPA Technology Work Breakdown Structure cost model for use in water reuse
  - Year 4

US EPA Water Treatment Plant Model

DBP prediction

- Modeling DOC and UV removal by
  - Coagulation
    - Algorithm developed
  - Ozone / Biofiltration
    - Algorithm developed and programed
  - GAC
    - Algorithm in development and validation
  - Membranes
    - User specified algorithm developed and programed

Pathogens

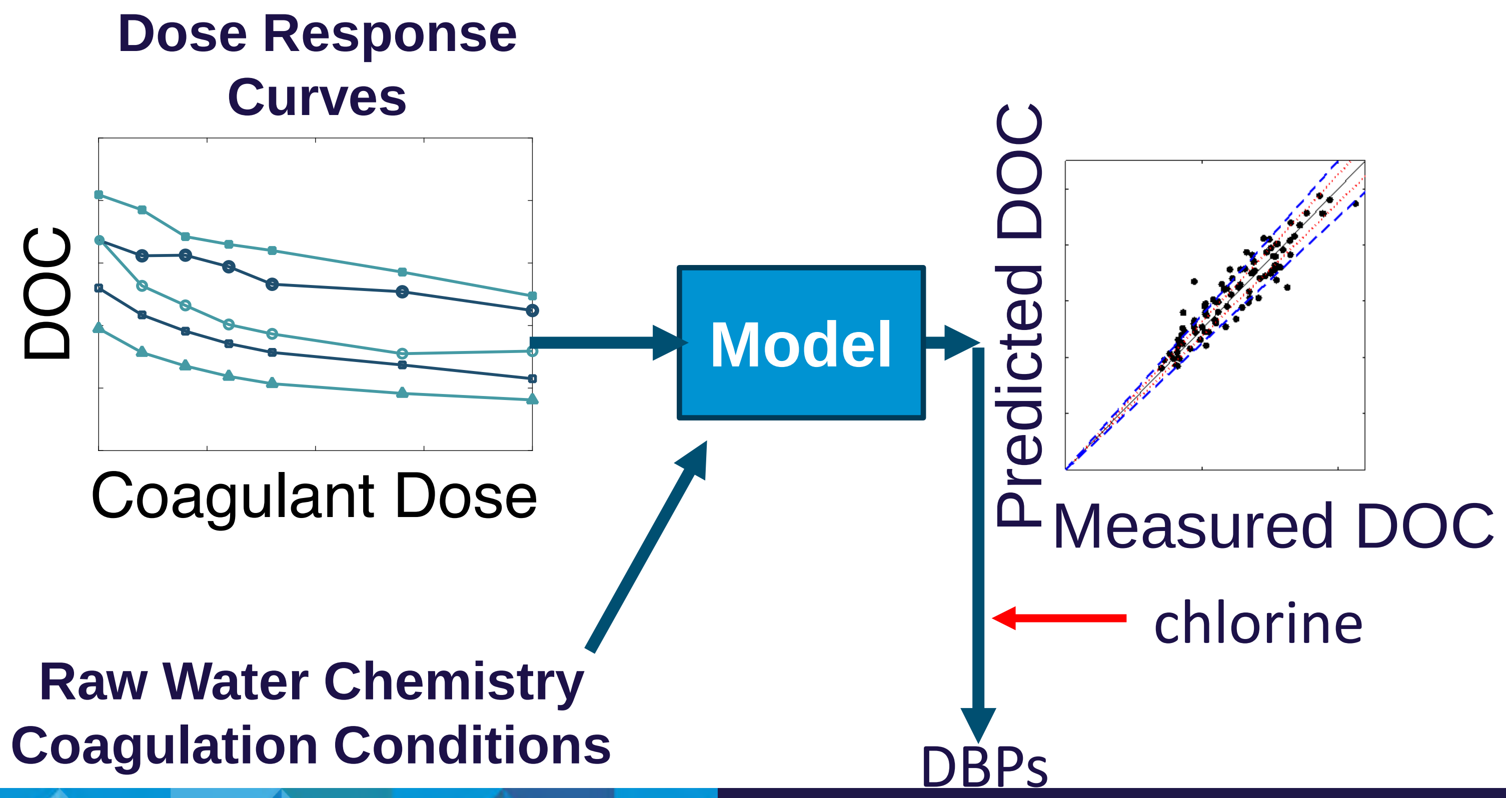
- ***Giardia* and *Crypto***
  - Chlorine, chloramine, ozone & chlorine dioxide
    - Treatment technique approach – credits and CT

Treatment Models and Risk Mitigation Techniques (Task B)

Coagulation Unit Operation

- 17 Unique Waters
- Breadth of Processes
  - Conventional Activated Sludge
  - Nitrification/Denitrification
  - Membrane Bioreactors
  - Trickling Filters

Coagulation Model to Predict Dissolved Organic Carbon (DOC) Removal



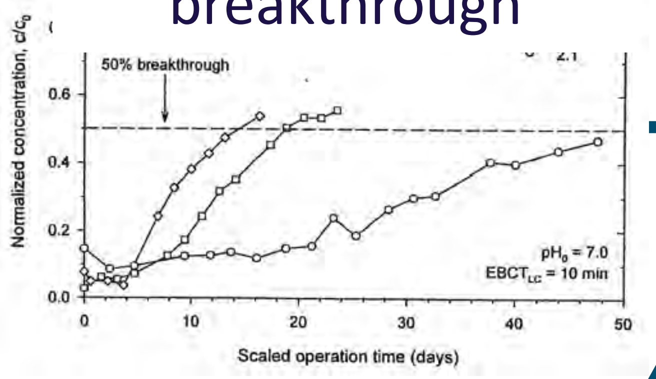
Treatment Models and Risk Mitigation Techniques (Task B)

GAC Adsorption Unit Operation

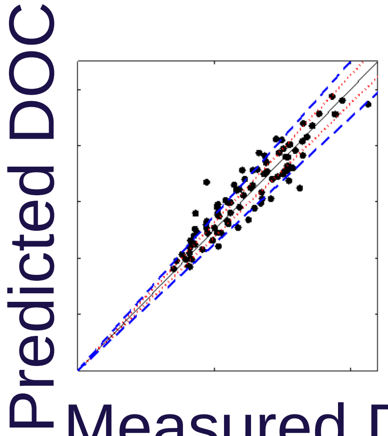
- Treatment assessment
  - TOC, UVA and preformed DBPs and DBP precursors
  - 52 DBPs – 9 regulated and 43 unregulated
- Preformed DBPs
  - Three WWef at the bench sca
- DBP precursors
  - Two pilot plant campaigns
  - Two bench scale studies
  - Scale-up evaluation

GAC Model to Predict Dissolved Organic Carbon (DOC) Removal

Impact of influent DOC and EBCT on breakthrough



Model

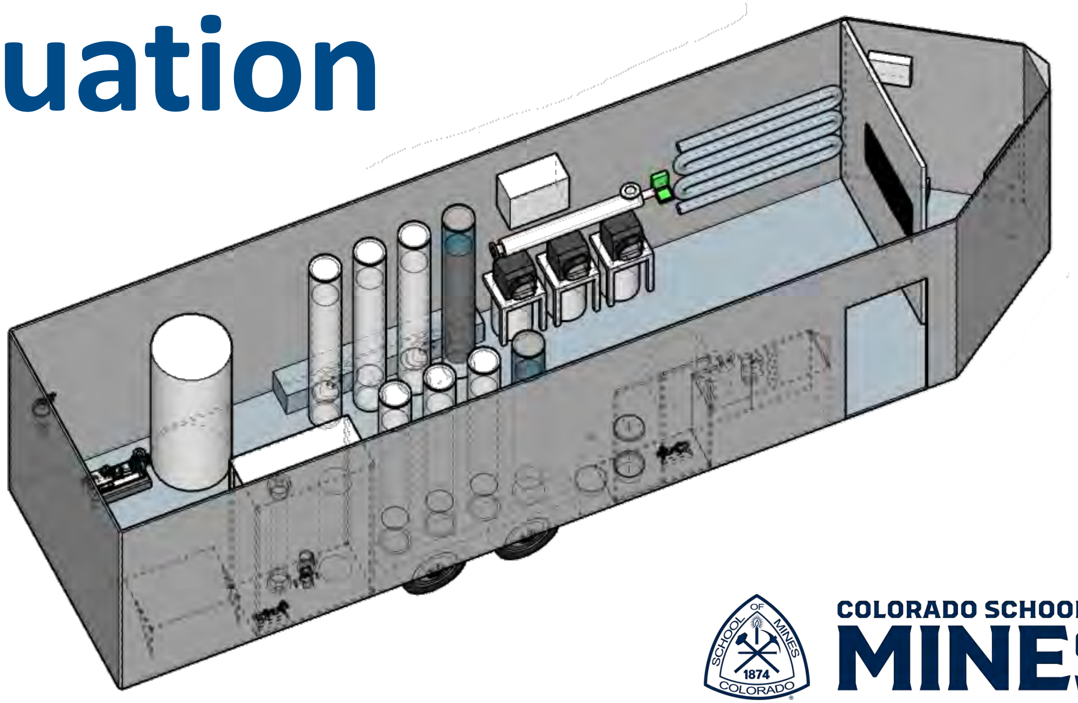


chlorine

DBPs

influent water quality, GAC design and operating Conditions

Mobile Demonstration Lab for Direct Potable Reuse Treatment Trains Evaluation



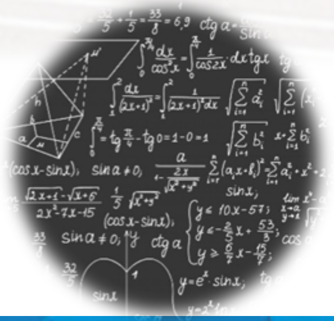
COLORADO SCHOOL OF MINES

An Ultimate Testbed…

Multidisciplinary research
- Engineering
- Applied Math and Statistics
- Computer Science
- Process Control
- Microbiology
- Chemistry

Academic Collaborations
- Colorado School of Mines
- Baylor University
- CU Boulder
- Oak Ridge National Lab
- Stanford University
- Water Research Foundation
- Southern Nevada Water
- West Point Military Academy
- Carollo Engineers

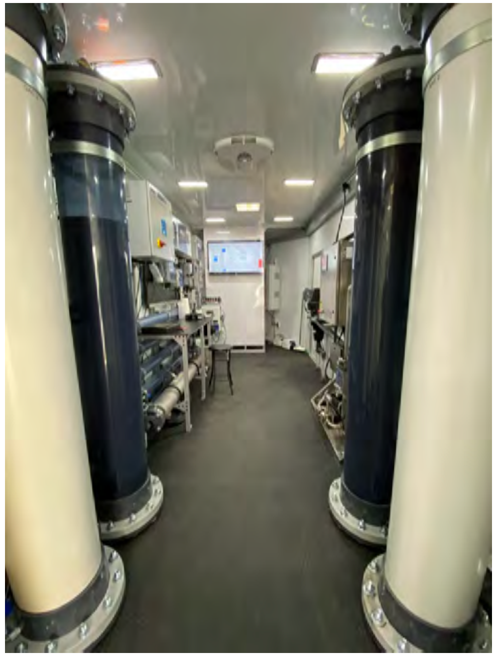
Industrial Collaborations
- Hach
- Aqua Aerobic Systems
- Toray
- Calgon
- CETCO
- ISTI, Inc.
- DUPONT
- Trojan UV
- Rockwell Automation



General Characteristics

- Advanced treatment, producing drinking water from reclaimed municipal water (eight (8) unit processes)
- A train of multiple advanced water treatment processes connected in a flexible manner
- Side-by-side operation of carbon-based and RO-based treatment of the same source of water
- Fully automated, 7,000 gallons/day, 24/7 locally and remotely operated carbon-based system
- Fully automated, 250-750 gallons/day, locally and remotely operated RO-based system



Deployments

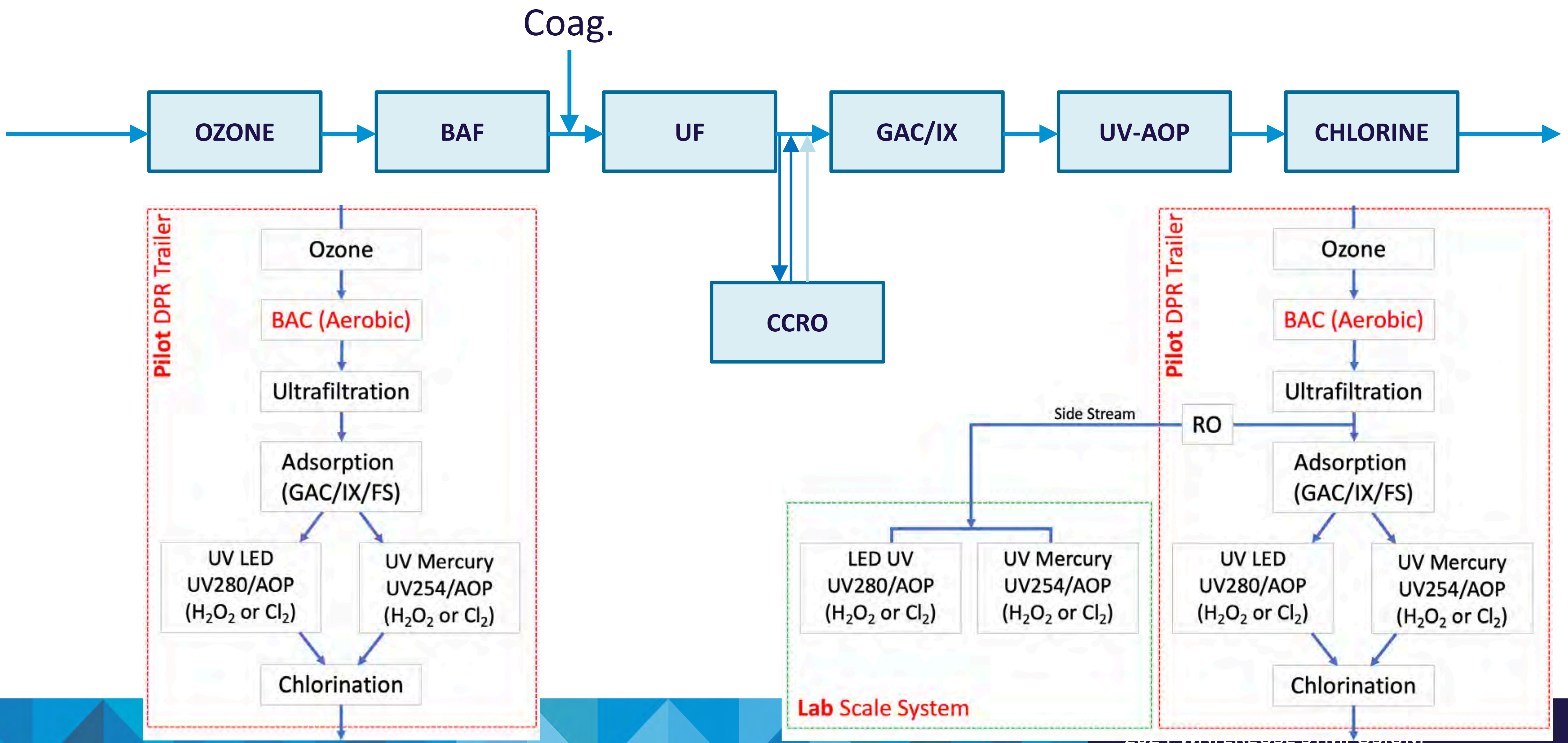
Colorado Springs, JD Phillips (June 2021-June 2022)

Aurora Water, Sand Creek (June 2022- August 2023)

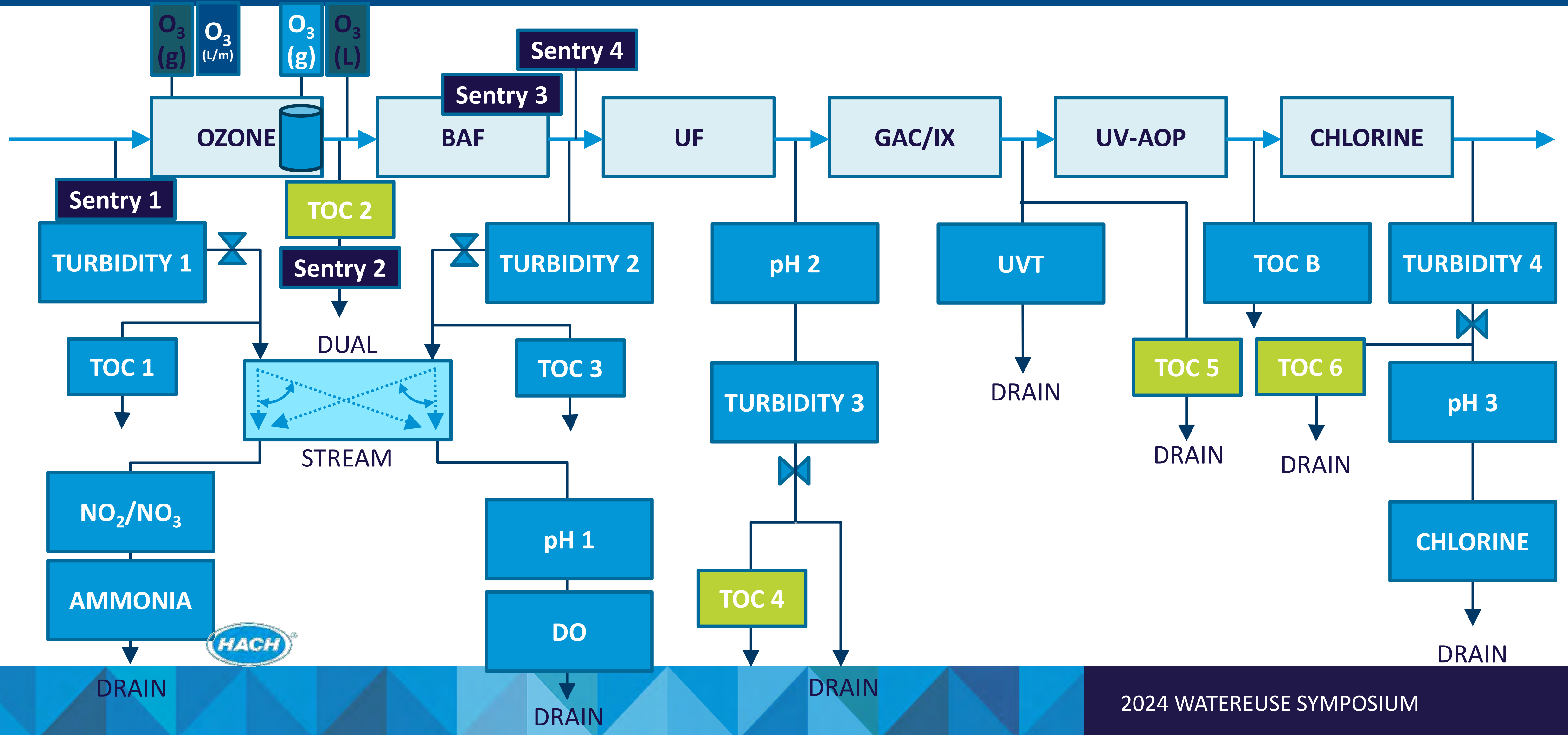
Littleton/Englewood, South Platte Renew (August 2023- Present)

- **Eight (8) unit processes**
- **Fully automated and autonomous**
- **24/7 operation**
- **Supports 4 projects and >7 graduate students**

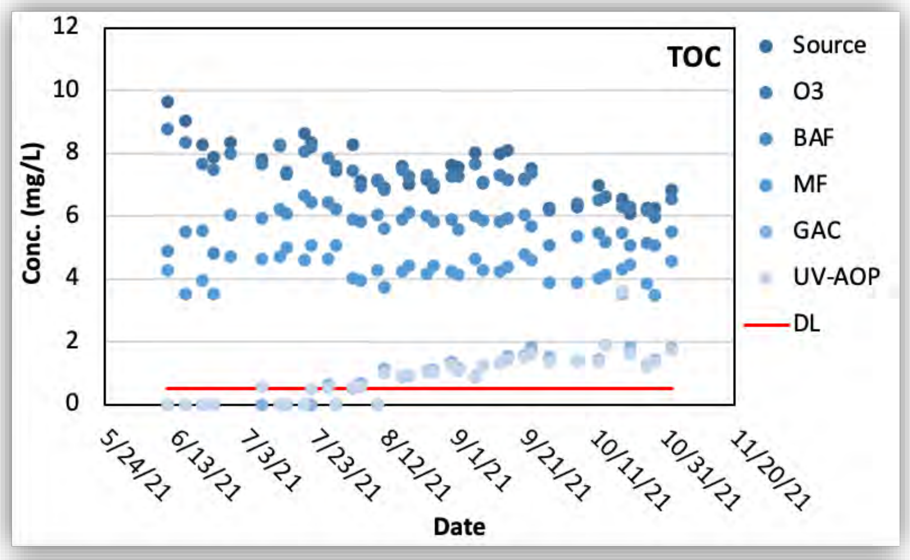
DPR Mobile Demonstration: Water Quality Sensors

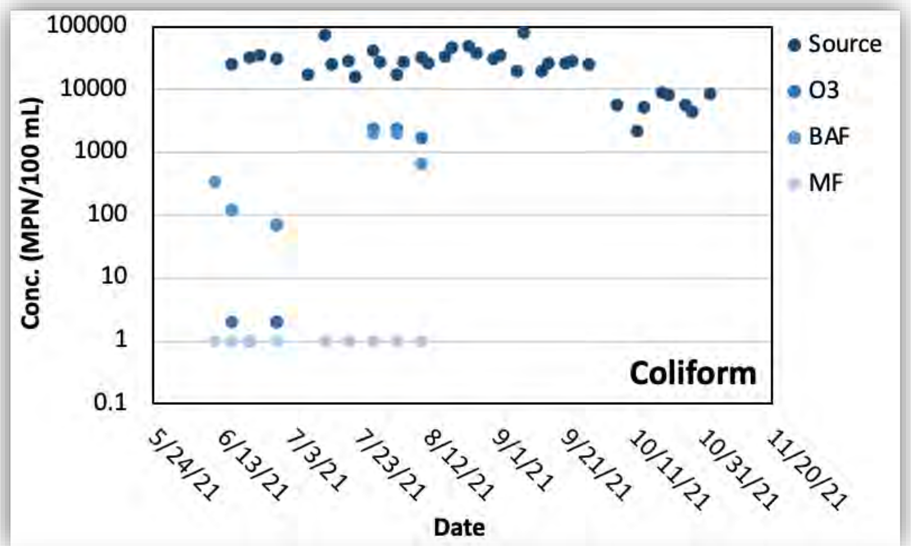


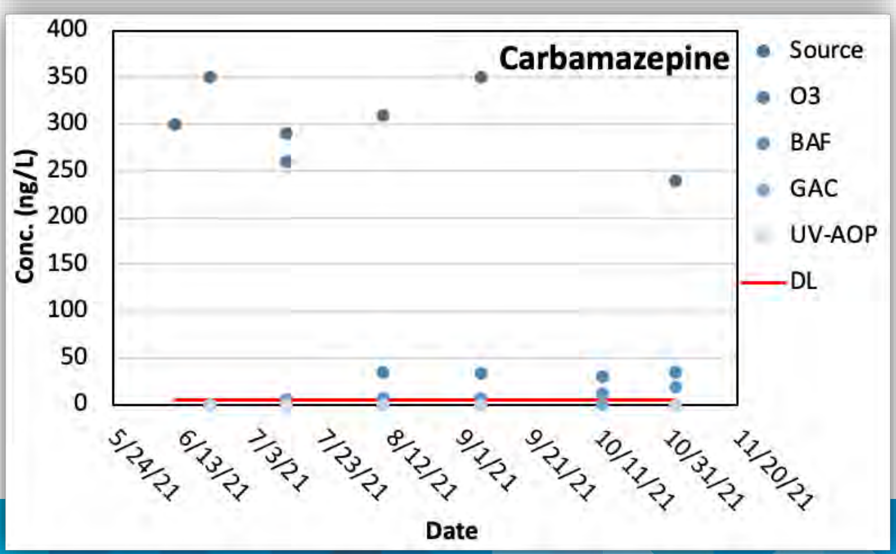
DPR Mobile Demonstration: Water Quality Sensors

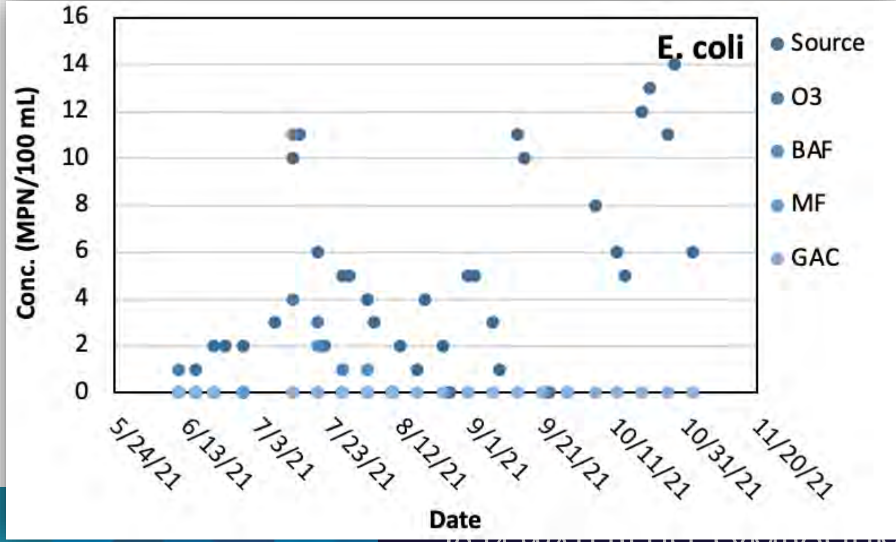


Organics, Nutrients, and Microorganisms

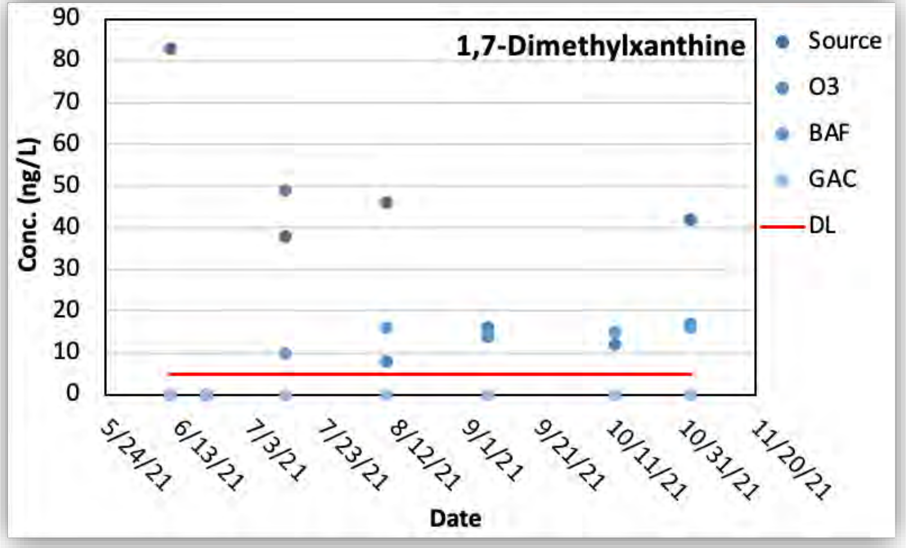


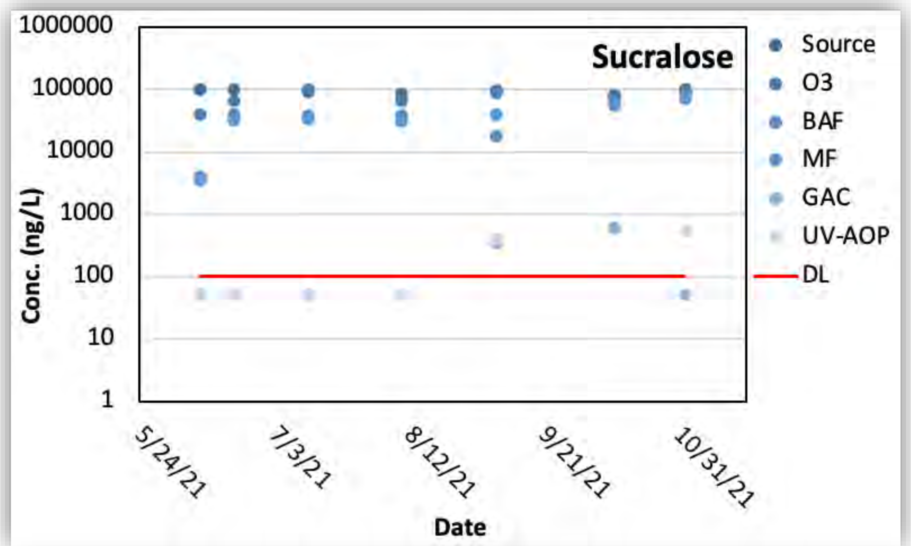


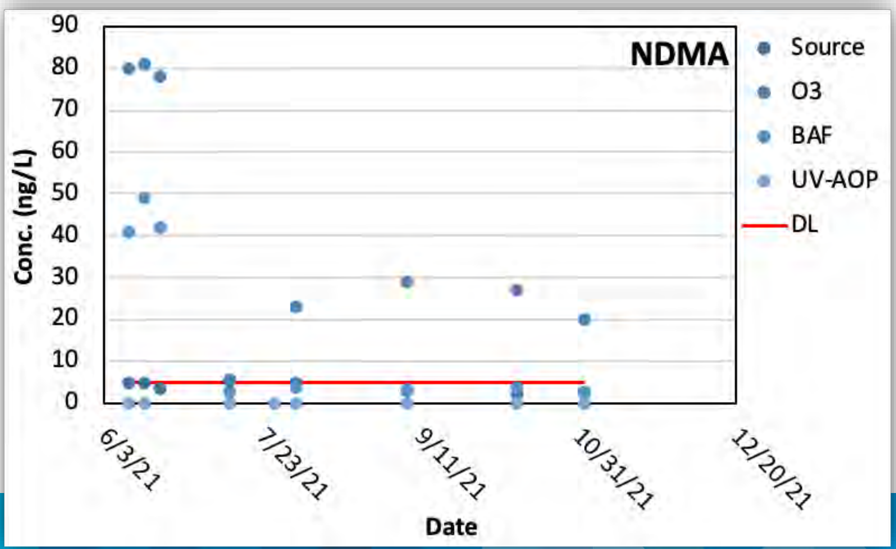


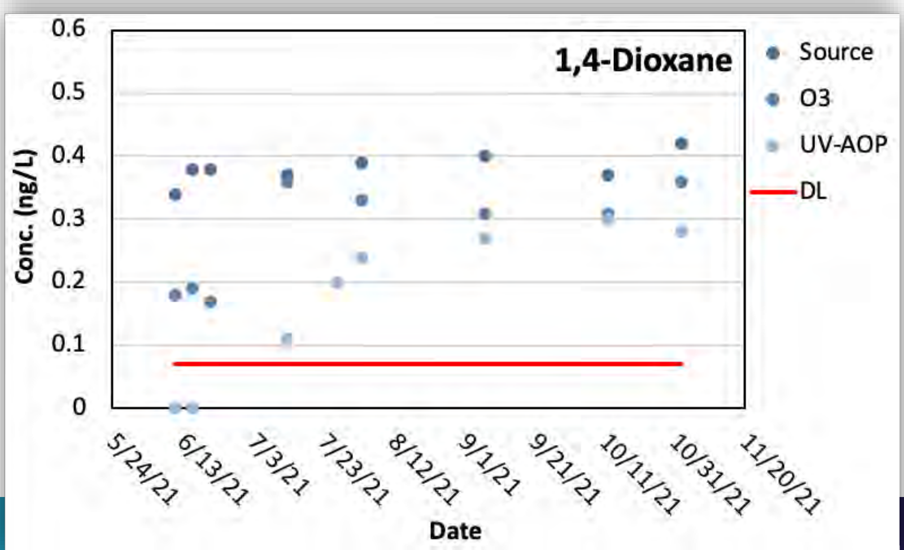


Micropollutants

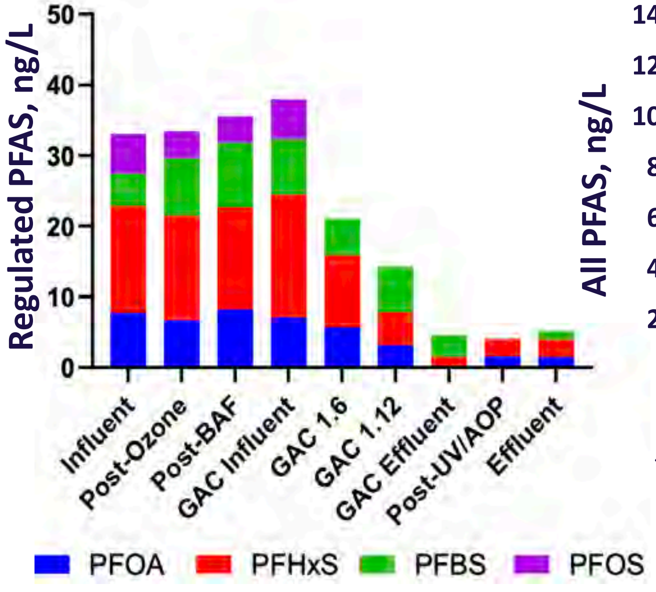


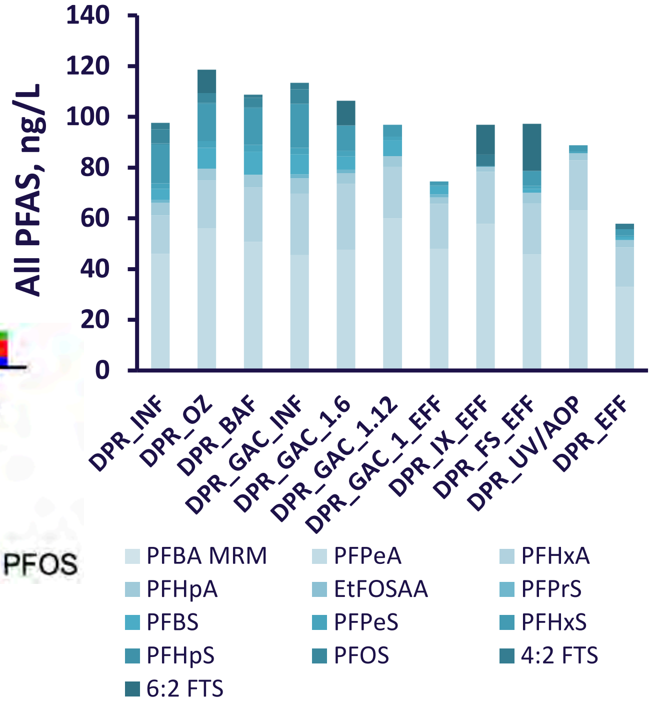


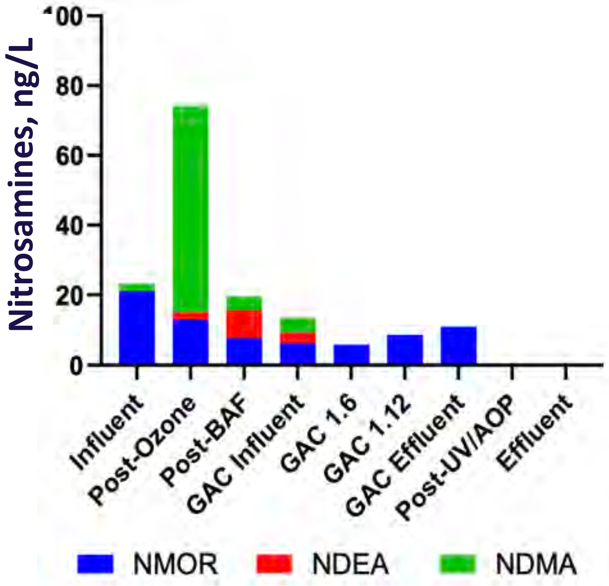


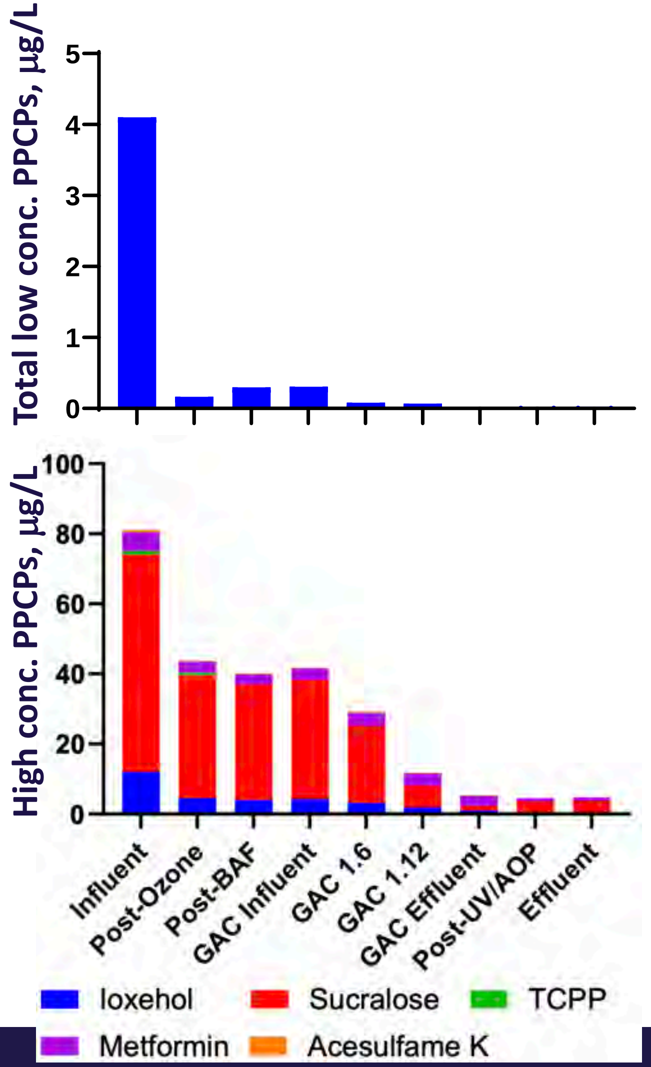


Monitoring of Indicator Compounds and CECs



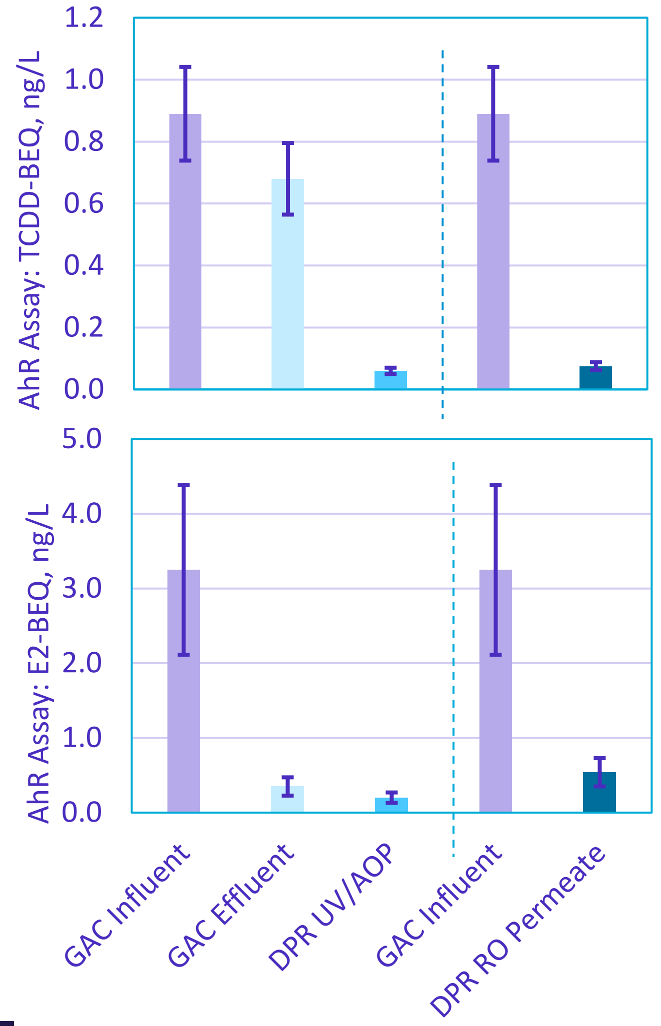






Carbon-Based vs. RO-Based DPR

- ER and AhR environmental bioassays were used to measure environmental toxicity (17β-Estradiol ER standard and TCDD AhR standard)
- A non-RO treatment train with GAC and UV/AOP can reduce activity levels to the same levels as RO treatment…



Treatment Models and Risk Mitigation Techniques (Task B)

Elevating Opportunities

Safeguarding Public Health through Risk Assessment (Task A)

Our Main Question:

Characterizing health hazards associated with water reuse?

The Team:







Eric Dickenson, PhD · *Daniel Gerrity, PhD* · *Katherine Crank, PhD* · *Jessica Steigerwald, PhD*

Southern Nevada Water Authority

Cresten Mansfeldt, PhD
University of Colorado, Boulder

Edmund Seto, PhD
University of Washington

Channah Rock, PhD
University of Arizona

SOUTHERN NEVADA WATER AUTHORITY

University of Colorado Boulder

UNIVERSITY of WASHINGTON

THE UNIVERSITY OF ARIZONA

Safeguarding Public Health through Risk Assessment (Task A) – Overview

Tasks A1 & A2: Wastewater-Based Epidemiology and QMRA

Measure

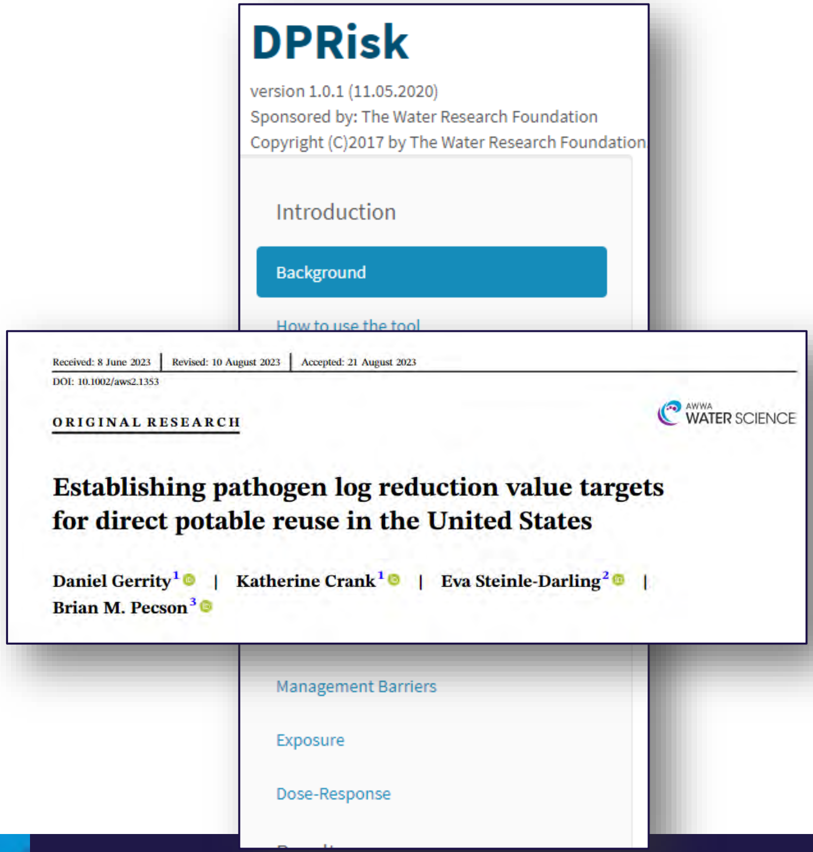
- Pathogens relevant to public health and water reuse in sewage across the nation
- Leveraging existing WBS efforts (WastewaterSCAN, Biobot, CDC NWSS)

Predict

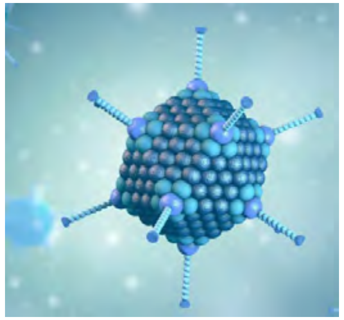
- Factors that influence concentrations
- Sewershed attributes impacting magnitude and variability
- Risks in a variety of scenarios using existing DPRisk tools

Inform

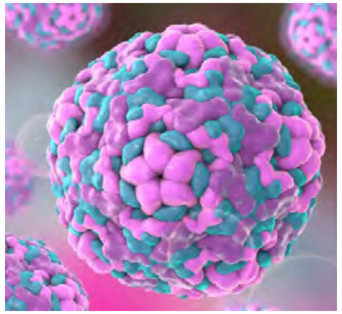
- Outbreak Readiness Response Plan for the One Water Sector
- Communicate findings through publications
- Communicate findings through community participation



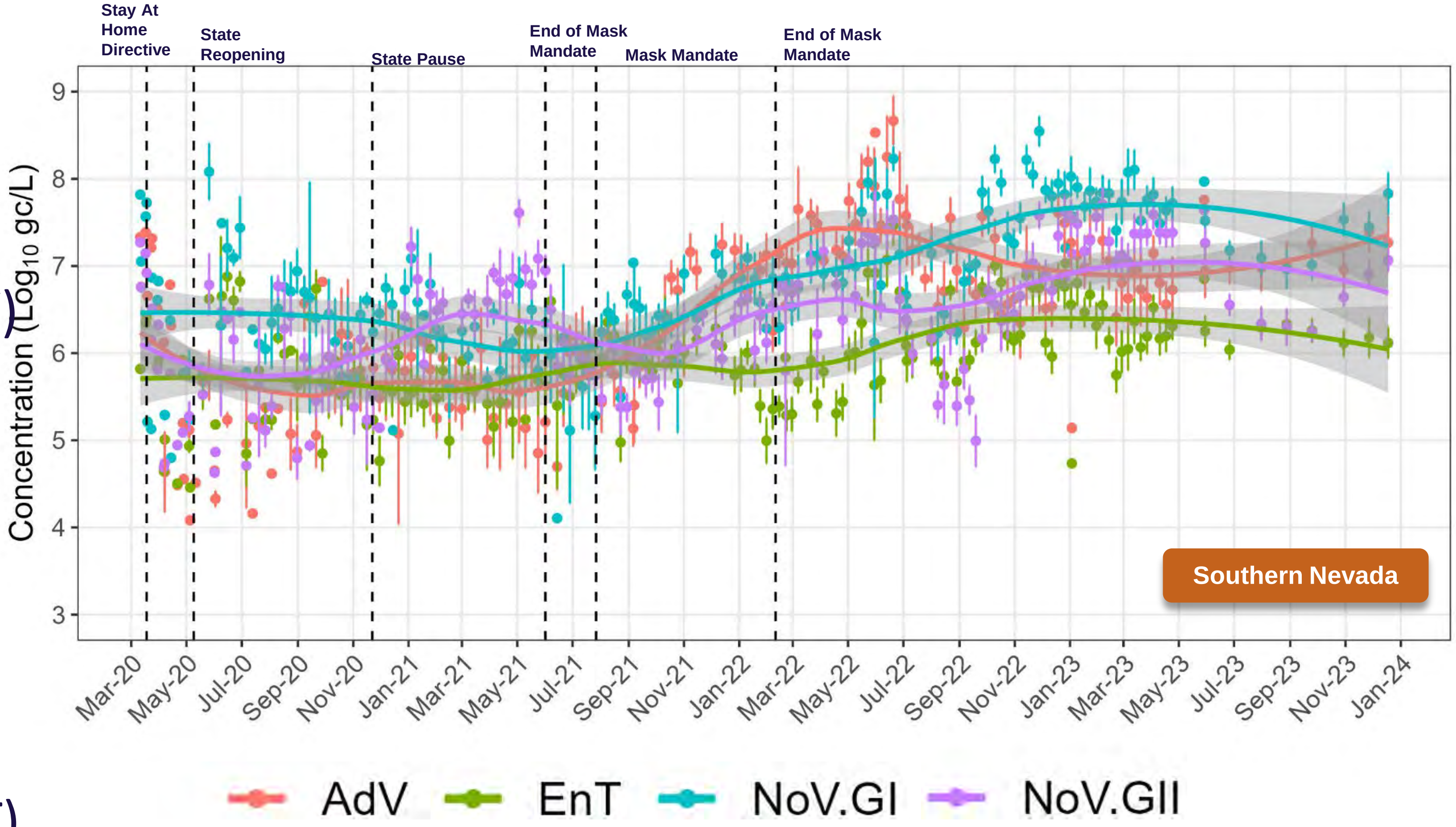
Safeguarding Public Health through Risk Assessment (Task A) – Viral Pathogens

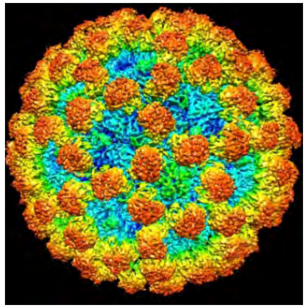


Adenovirus (AdV)

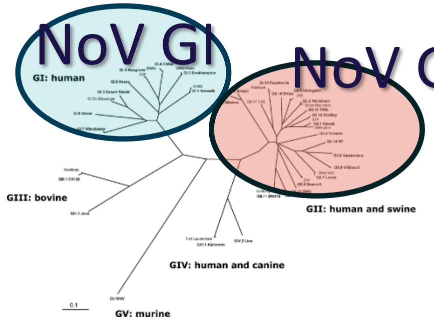


Enterovirus (EnT)





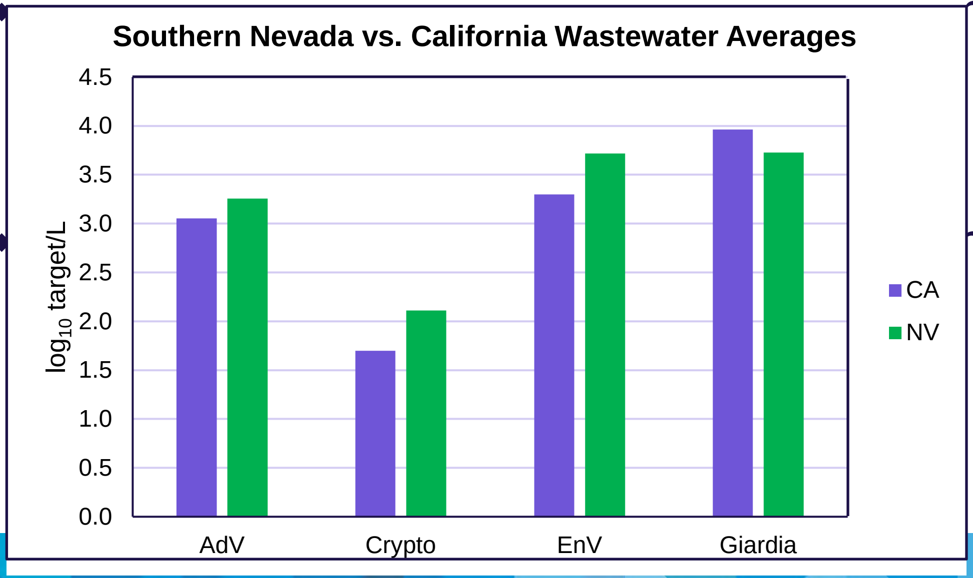
Norovirus

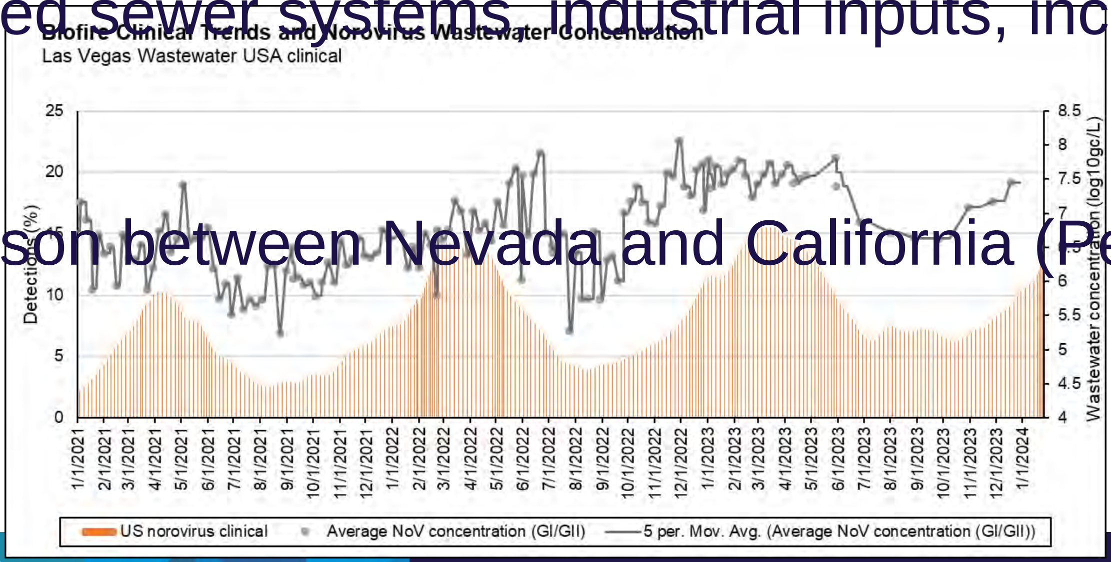


Safeguarding Public Health through Risk Assessment (Task A) – Contextualization

Community characteristics influence wastewater pathogen concentrations

- **Southern Nevada (1,000+ archived samples):** Small vs. large systems, grab v composite, tourism
- **Colorado:** Data from building-level surveillance can inform small-scale DPR pr
- mbined sewer systems, industrial inputs, increa
- nparison between Nevada and California (Pecso

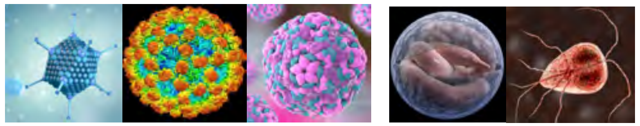




Safeguarding Public Health through Risk Assessment (Task A) – Next Steps

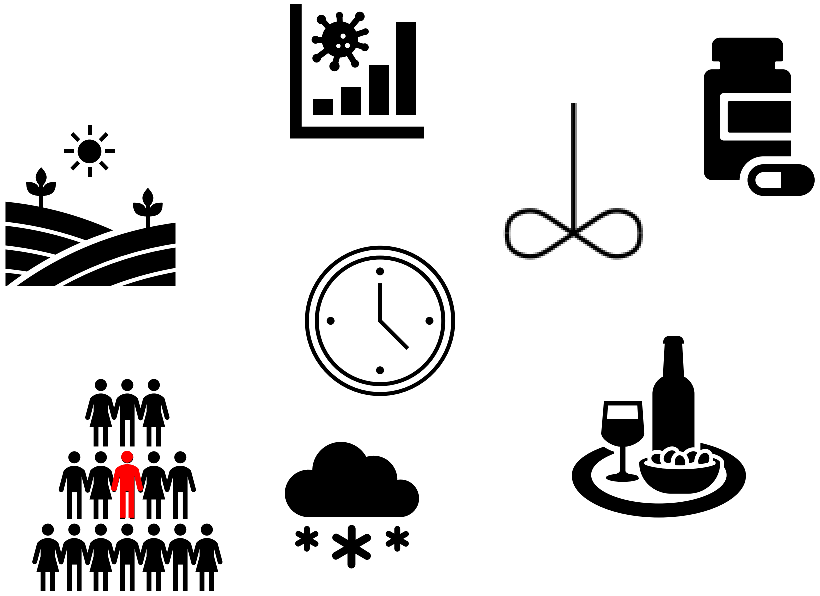
Outcomes reached:

- Comprehensive Southern Nevada dataset for pathogens relevant to reuse:
  - Enteric viruses (culture + molecular)
  - *Giardia & Cryptosporidium*
- Journal publications Pathogen LRV targets for DPR (AWWA Water Science)



Next Steps:

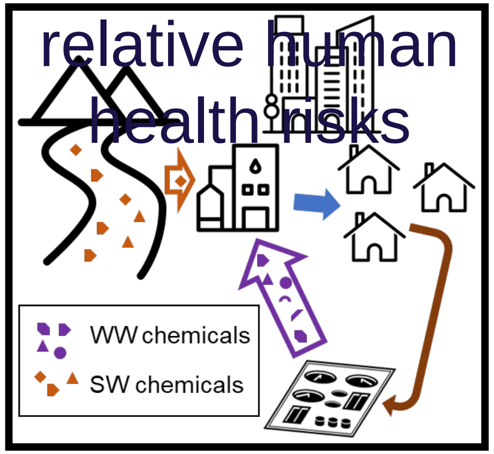
- Comparison of Nevada and Colorado pathogen dataset to ongoing WBS efforts
- Statistical analysis of variables that impact wastewater concentrations
- Communicating findings through case studies and publications
- Outbreak Readiness Response Plan for utilities in the One Water sector



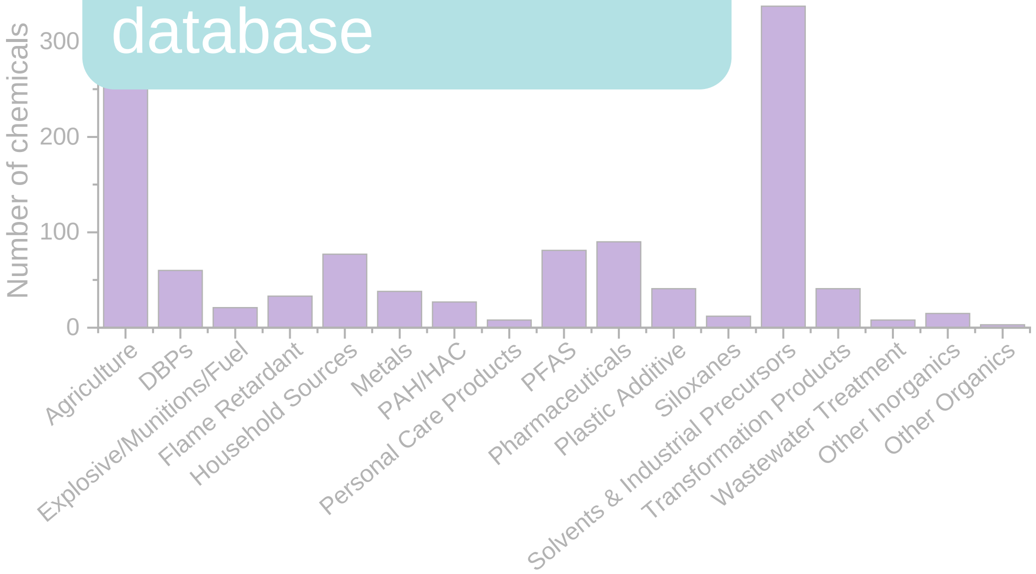
Safeguarding Public Health through Risk Assessment (Task A)

Task A3: Relative Health Impact of Chemicals

Identify chemicals of concern for potable reuse and evaluate their relative human health risks



Step 1: Chemical database



- **Occurrence data** from WW effluents from **the U.S. in the last 10 years**
- Literature search **ongoing** with data collected for over **95% of chemicals** from **96 sources**

- **Metals and other inorganics** have high median and 95th percentile concentration
  - **Boron, barium, strontium, zinc**
- **Agricultural chemicals** have high median concentration but low detection frequency
  - **Acephate, ammonium sulfamate**

Safeguarding Public Health through Risk Assessment (Task A)

Step 2: Identify high impact chemicals

Relative Health Indicator (RHI)

= NonCancer RHI + Cancer RHI

$$NonCancer\ and\ Cancer\ RHI = Toxicity \times Severity \times Exposure$$

$$Toxicity = \frac{0.01 \times 2(L/d)}{70\ (kg) \times Reference\ Dose \times Uncertainty\ Factor}$$

– or –

$$Toxicity = \frac{Cancer\ Slope\ Factor \times 2(L/d)}{70\ (kg)}$$

Variable	Description	Source
Exposure	Concentration in WW	Literature review
Severity	Relative severity for the relevant category of health impact	WHO and World Bank
Reference dose (RfD)	Maximum acceptable oral dose	EPA IRIS
Uncertainty factor	Product of RfD calculation uncertainties	EPA IRIS
Cancer slope factor	Increased cancer risk associated with a lifetime exposure to a chemical	EPA IRIS

Alfredo et al., *Environ. Monit. Assess.*, **2017**, 189, 124.

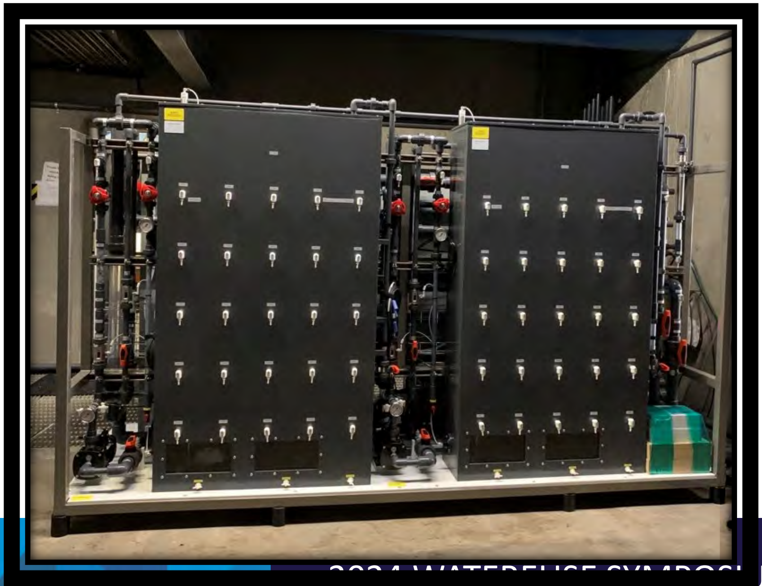
IRIS INTEGRATED RISK INFORMATION SYSTEM

Example:	**Strontium**	**Acephate**
WW occurrence (median)	260 µg/L	36.1 µg/L
RfD	0.6 mg/kg-d	0.004 mg/kg-d
NonCancer severity	0.129 (musculoskeletal/osteoarthritis)	0.01 (nervous system)
Cancer slope	NA	0.0087
Cancer severity	NA	0.29
Cumulative RHI	5.3×10^{-8}	3.5×10^{-6}

Safeguarding Public Health through Risk Assessment (Task A)

Next Steps:

- Compare risk across "**cups of water**" to identify **key chemicals of importance for water reuse**



Safeguarding Public Health through Risk Assessment (Task A)

Elevating Opportunities

Thank you!

CO-PIs

WateReuse · Southern Nevada Water Authority · University of Colorado Boulder · Colorado School of Mines

Research Partners

University of Washington · Army West Point · Stanford · The Ohio State University · UNM

Partners

asdwa · FFAR · NAWI · NACWA · NWRI · DEQ Oklahoma · Idaho Department of Environmental Quality · California Water Boards · US Water Alliance

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