Unlocking the Nationwide Potential of Water Reuse

EPA Grant Number: 84046201-0, CFDA 66.511
Project Title: Unlocking the Nationwide Potential of Water Reuse
Period Covered by the Report: Y2, September 1, 2023 – August 31, 2024
Date of Report: September 1, 2024
Investigators: PI: Miriam Hacker; Co-PIs: Eric Dickenson, Karl Linden, Tzahi Cath
Institutions: The Water Research Foundation, University of Colorado-Boulder (CU Boulder), Southern Nevada Water Authority (SNWA), Colorado School of Mines (Mines)

Objective of Research

This research aims to unlock the full nationwide potential of water reuse by aligning the development of science and technology with advances in social and organizational development of opportunities and barriers. Activities for this project are organized into four major research areas, the expected results of which will provide practitioners with user-friendly tools and materials to advance water reuse in their own community. The four major areas are organized by tasks, listed below:

- Task A: Safeguarding Public Health through Risk Assessment
- Task B: Treatment Models and Risk Mitigation Techniques
- Task C: Social Development and Community Engagement
- Task D: Successful and Sustainable Water Reuse Adoption Pathways

Additional information about the objectives of these tasks is in Appendix A This project is implemented through an engaged process. The Research Team works with Project Partners, Participating Utilities and two Advisory Committees (Social and Technical). A map of these is shown in Appendix B.

Progress Summary and Accomplishments

At the end of Year 2, the project is approximately 30% complete. The sections below provide an overview of project activities and accomplishments.

Task A: Safeguarding Public Health through Risk Assessment

Subtask A1.1 - Leverage existing and future sample biobanks.

- Analysis of the Southern Nevada wastewater biobank has been completed, with over 1200 samples analyzed for viruses relevant to water reuse applications including Norovirus GI, GII, Enterovirus, and Adenovirus. A separate one-year long wastewater sampling campaign was completed in Southern Nevada, specifically for Cryptosporidium and Giardia, protozoal pathogens relevant to water reuse.
- Contract laboratory enumeration of culturable/infectious Adenovirus and Enterovirus to create genome copies:infectious unit ratios, a critical parameter for water reuse risk assessments, was completed. The results from the analysis of the existing Southern Nevada biobank have been accepted for publication for the *Environmental Science: Water Research & Technology* special issue on wastewater surveillance.
- Beyond Southern Nevada, work has begun on translating the existing/future wastewater data generated by the CDC's National Wastewater Surveillance System via WastewaterSCAN into actionable data for use in water reuse applications.

Subtask A1.2 - Assess the expanded dataset for spatial and temporal trends

- Southern Nevada-specific dataset has been analyzed for spatial and temporal trends with results published in the aforementioned manuscript. Analysis has begun on the WastwaterSCAN dataset,

for comparison purposes and for the development of an expanded dataset for analysis of spatial and temporal trends.

Subtask A2.1 - Integrate the Task A1 pathogen dataset into DPRisk to quantify the risk implications of spatial, temporal, and sewershed-specific variables.

- Parameterization has begun for a QMRA for a *de facto* reuse system in Southern Nevada. Parameters include raw wastewater concentrations of pathogens distributions developed in task A1, wastewater treatment log-reduction values, literature-reported decay rates for pathogens, time traveled to point of exposure, drinking water treatment plant pathogen log reduction values. Independent variables include projected future Lake Mead lake levels (which impacts the percent of *de facto* reuse at the drinking water treatment plants), and seasonality. Dependent variables will be risk of gastrointestinal illness.

Subtask A3.1 - Building the chemical universe.

- A chemical universe was compiled consisting of over 1,100 chemicals in 17 use categories with potential relevance to water reuse. Chemicals were identified from a range of sources including EU REACH database, WHO guidelines for drinking water, U.S. Department of Health and Human Services 15th Report on Carcinogens, U.S. EPA Contaminant Candidate Lists 4 and 5, U.S. EPA Integrated Risk Information System (IRIS) database, and Water Research Foundation (WRF) Project 4960.

- A subset of chemicals primarily comprised of those housed in the IRIS database were selected for initial literature review of wastewater occurrence data. Additional chemicals of interest from the EPA Unregulated Contaminant Monitoring Rule lists 5 and 6, WRF project 4960, and chemicals with high toxicity have been added to the initial literature review list. Occurrence data was compiled from full scale secondary and tertiary treated wastewater effluents and advanced treatment trains.

Subtask A3.2 - Identifying health risk reductions.

- Toxicity information for chemicals with occurrence data from subtask A3.1 was obtained from the Risk Assessment Information System (RAIS) database compiled by the US Department of Energy and Office of Environmental Management. Information on critical health effects for the same group of compounds was obtained from the EPA IRIS database, EPA Office of Pesticide Programs, EPA Provisional Peer-Reviewed Toxicity Values database, and the Agency for Toxic Substances and Disease Registry.

Task B: Treatment Models and Risk Mitigation Techniques

Subtask B1.1 - Data gathering and existing algorithm assessment.

- A four-page document, Contaminants of Concern for Reuse, was developed and sent out to Task A3, B1, and B2 team members for review. The document contains a list of specific compounds (and microbes) that are relevant for reuse based on state regulations and guidance, including surrogates. Based on this list, an assessment of existing treatment algorithms and development of new ones will be carried out for the trace organic contaminant models. This list also will define for team members which specific contaminants should be prioritized for bench and pilot work.

- The existing drinking water treatment algorithms for dissolved organic carbon (DOC) and ultraviolet (UV) removal and DBP precursors control by coagulation, biological filtration (BioF), granular activated carbon (GAC) and membrane treatment – including microfiltration (MF) and reverse osmosis (RO) - were evaluated under wastewater effluent (WWef) conditions. The algorithms for coagulation, BioF and GAC were found not to be acceptable for use in a water reuse context. For MF and RO, the DOC removal is set by the user, and it was decided this approach was still

appropriate for water reuse, given the range of membrane types and materials. In addition to the coagulation of effluent organic matter (EfOM), data is also being gathered for 18 metals of interest.

Subtask B1.2 - Update existing and develop new predictive algorithms.

- Data gathering efforts to support updating existing predictive algorithms and development of new predictive algorithms was finished for BioF and GAC and new algorithms were developed using the results of over 75 runs each. A run is defined as a set of water quality and operational conditions for a treatment process at bench, pilot, or full scale. The error analysis and cross validation effort for the BioF algorithms has been completed and that for GAC is in progress.
- Data gathering efforts to support updating existing predictive algorithms for coagulation are complete. Experimental data from jar tests have been collected for over 25 waters, each with a range of coagulant doses. The final coagulation algorithm predicting carbon removal has been developed and documentation is drafted.

Subtask B2.1 - Integrate predictive algorithms into a comprehensive model.

- Several metals have been identified as problematic and as such have been included in the contaminants of concern list. We have changed the name and the approach of the Trace Organic Compound (TrOC) model to include metals and renamed it Specific Contaminant (SCon) removal model (SCRM).

Subtask B2.2 - WrTP Model Desktop Validation

- Discussions have started on modifications that will be needed in the control system of the direct potable reuse (DPR) trailer in order to enable validation of the Water Reuse Treatment Plant (WrTP) model.

Subtask B3.1 - Operate pilot-scale treatment processes for data collection

- Full time operation (24 hours, 7 days a week) of the DPR demonstration system continued at South Platte Renew (Littleton, CO), treating tertiary effluent through ozonation, biologically active filtration (BAF), ultrafiltration (UF), adsorption (GAC, ion exchange, and Fluorosorb®), ultraviolate with advanced oxidation (UV-AOP), and chlorination.
- During this period, the lop-pressure UV system (oversized) was replaced by two new UV systems: the first is a smaller low-pressure UV set of reactors (Trojan) and the second is a UV-LED reactor. Experiments are underway to characterize the new UV systems. The team also conducted several RO experiments with UF effluent as the RO feed. Major focus was on the removal of PFAS and comparing PFAS removal with RO vs. adsorption.
- The DPR trailer was deployed at a new test site at Metro Water Recovery in mid-May 2024 and is going through integration into the plant's infrastructure; Metro Water Recovery is a very large (200 MGD) wastewater treatment plant in Denver, CO. Other than the fact that the plant is much bigger than any previous DPR test sites, it produces secondary effluent, not tertiary. This makes the operation of such DPR system much more challenging.

Task C: Social Development and Community Engagement

Subtask C1.1 - Review literature on methodologies and approaches.

- An initial kick-off meeting with the Technical Advisory Committee (a subgroup of the broader PACs) happened in October 2023 with the main purpose of consolidating what has been learned from the literature review to develop a conceptual framework. A manuscript is being developed.

Subtask C1.2 - Compile publicly available data sources to quantify water reuse potential and environmental drivers.

- The research team collaborated with the University of Washington's eScience Institute Data Science for Social Good Program (DSSG) for Summer 2024 to compile, clean and consolidate over 60 publicly available datasets that correspond to eight major drivers that might motivate a community to adopt water reuse.

Subtask C1.3 - Create an index relating water challenges to water reuse benefits.

- The research team is currently working on finalizing data proxies for each of the eight drivers: Economic Development, Ecosystem Protection, Infrastructure Resiliency, Water Services Provision, Community Health, Nutrient Management, Supply Resiliency, Combined Sewers.

Subtask C2.1 - Comprehensively review the literature.

- Literature has been pulled from academic sources (e.g. Web of Science), and repositories from WRF, WateReuse, and EPA. After filtering with exclusion criteria, there are a little over 200 papers related to social and organizational factors associated with water reuse. A manuscript has been submitted to WIRES Water in September 2024.

Subtask C2.3 - Convene representatives at regional workshops to co-produce needs.

- This subtask is actually associated with Task C3 – the community engagement component of the study. One virtual workshop was held in July 2024 with utility representatives from Florida and Georgia to discuss initial results from utility interviews (Subtask C3.1) and to co-create best practices for participation/engagement. Plans are being made to do an in-person workshop in California and South Carolina in Y3.

Subtask C3.1 - Co-produce an assessment method for community engagement approaches.

- A total of 25 interviews were conducted between October 2023 and January 2024 with utilities about their approach to community and stakeholder engagement for water reuse projects. Interview recordings have been transcribed and qualitatively analyzed via thematic coding by the research team and are currently going through interrater reliability testing to ensure that codes have been consistently applied. These findings are being used with participants in regional workshops (Subtask C2.3).

Task D: Successful and Sustainable Water Reuse Adoption Pathways

Subtask D1.1 - Systematically identify, characterize, and calibrate drivers and barriers to water use with experts.

- Factors from peer-reviewed literature were identified through deductive and inductive coding and then were collated to synthesize differences and similarities across water reuse contexts and cases analyzed. The team conducted an expert panel in September 2023 (virtual) to discuss and rate the importance of factors that could be analyzed with case studies.

Subtask D1.2 - Rigorous cross-case comparison of water reuse projects to identify pathways to successful implementation.

- The team completed data collection (including site visits) for three case studies. Each case study included a desk review (i.e., reviewing grey and peer-reviewed literature, websites, and social media), touring each facility, meeting with multiple utility stakeholders, and conducting five topical interviews. The team has identified the next five case studies and have commenced communication with three of them to initiate the interview and site visit process.

Subtask D2.2 - Develop a sustainability assessment framework.

- A model framework has been selected for conducting a sustainability assessment. The model framework integrates treatment process modeling, comparative life cycle assessment methodology, social evaluation criteria (Subtask D1.2), and previously developed decision support

tools. Initial evaluation of the framework resulted in commencing a systematic literature review on definitions and measurements for resilience in water and wastewater to assure comprehensive sustainability approach and initiate life cycle inventory calculations (e.g., energy use for treatment processes).

Subtask D3.1 - Convene experts to evaluate regional differences and barriers.

- The first expert panel (subtask D1.1) was conducted and involved experts rating the importance of identified factors in enabling water reuse success, through a questionnaire, followed by a virtual discussion. This provided a platform for experts to discuss the importance of factors based on their ratings, as well as discuss ideas for data collection in our case studies.

Subtask D3.2 - Ensure inclusion of under-resourced communities.

- The three case studies conducted thus far include projects servicing low-income communities.

Future Activities

Task A: Safeguarding Public Health through Risk Assessment

- Analysis of the National wastewater databank will continue, comparing national and local data and converting solids-based to liquids-based pathogen concentrations. A draft of the *Outbreak Readiness Response Plan* will also be completed in the next reporting period.
- The development of a Quantitative Microbial Risk Assessment (QMRA) for a de facto reuse system in Southern Nevada is underway.
- Work on building a chemical universe database will continue, focusing on adding toxicity data for chemicals based on regulatory guidelines or available toxicity data.

Task B: Treatment Models and Risk Mitigation Techniques

- The team will finalize the constituents to be evaluated and will continue the comprehensive review of water reuse-based treatment data and algorithms that predict the performance processes under drinking water (DW) conditions.
- The research team will begin to integrate predictive algorithms into a comprehensive model: Water Reuse Treatment Plant (WrTP) model.
- Long-term experiments will be conducted in collaboration with Metro Water Recovery to determine removal of dissolved organic nitrogen and dissolved organic phosphorous. In parallel, performance of DPR trains (RO-based and carbon-based) when treating secondary effluent compared to tertiary effluent will be assessed.

Task C: Social Development and Community Engagement

- A manuscript correlating water challenges to drivers and potential benefits from water reuse will be finalized and published.
- Data associated with capture potential and drivers will be cleaned, converted and merged into an index. An analysis will be done to determine redundancies in the datasets for the team to remove before creating the final dataset. The final dataset will be validated with historical data of water reuse in the US (WEF). After validation, the dataset will undergo a spatial and/or cluster analysis to understand geospatial trends between drivers and types of water reuse for the maximization of co-benefits.
- The research team is working with sections of the WateReuse Association to organize and facilitate regional, in-person workshops to co-create best practices for community engagement. The team is currently in the process of drafting two manuscripts based on the perception literature review, and on findings from utility interviews conducted in Y2.

Task D: Successful and Sustainable Water Reuse Adoption Pathways

- A manuscript has been written for submission to a journal publication. The research team will continue to engage partners to conduct case studies, focusing on the three case studies that have already been contacted.
- The research team will continue to generate design algorithms and mathematical equations that quantify the life cycle inventory of material, chemical, energy, and labor requirements for various treatment processes (e.g., activated carbon adsorption).

Publications/Presentations

Publications

- (Accepted) Crank, Katherine, Katerina Pappa, Casey Barber, Kai Chung, Emily Clements, Wilbur Frehner, Deena Hannoun, Travis Lane, Christina Morrison, Bonnie Mull, Edwin Oh, Phillip Wang, and Daniel Gerrity. "Pathogen and Indicator Abundance, Trends, and Statistical Distributions in Wastewater during and after the COVID-19 Pandemic." *Environmental Science: Water Research & Technology*. Submitted July 2024.
- (Under Review) Scruggs, Caroline and Miriam Hacker. "A Review of Social and Organizational Barriers to Water Reuse in the United States." *WIREs Water.* Submitted September 2024.
- (Under Review) Sardana P., Javernick-Will, A., & Cook, S. M. (2024). "Facilitators and Barriers of Global Water Reuse: A Systematic Literature Review." *ACS ES&T Water*. Submitted August 2024.

Presentations

- Panel Presentation, "Unlocking the Nationwide Potential for Water Reuse: Fresh Research Insights," 2024 Annual WateReuse Symposium, Denver, CO. Presenters: Julie Korak (UC Boulder), Tzahi Cath (Mines), Miriam Hacker (WRF), Prakriti Sardana (UC Boulder), Katherine Crank (SNWA), Jessica Steigerwald (SNWA).
- Technical tours to the DPR demonstration trailer during the 2024 Annual WateReuse Symposium in Denver. Three buses (~120 people) visited the trailer and received presentations about the various projects conducted in the trailer.
- Presentation, "Constructing a Drivers-Based Framework for Assessing Water Reuse Potential", 2024 Annual WateReuse Symposium, Denver, CO. Presenters: Carolyn Hayek (Columbia) and Miriam Hacker (WRF)
- Presentation, "Unlocking Utility Engagement for Innovative Water Systems: Water Reuse in the United States", 2024 IWA World Water Congress, Toronto, Canada. Presenters: Miriam Hacker (WRF)

Workshops

- "Empowering Community Engagement in Water Reuse Projects: A focus on Southeast US" – Virtual. July 22, 2024.

Supplemental Keywords

Water reuse, risk assessment, treatment models, community engagement, sustainable adoption

Relevant Websites

https://www.waterrf.org/unlocking-nationwide-potential-water-reuse
https://watereuse.org/research/unlocking-potential-research/

Appendix A. Task Summaries

Task A: Safeguarding Public Health through Risk Assessment

Task A aims to better quantify and characterize the microbial and chemical risks of water reuse through three research objectives: 1) apply lessons learned from wastewater-based epidemiology (WBE) conducted during the COVID-19 pandemic to potable reuse applications, 2) communicate this new knowledge through potable and agricultural reuse case studies developed within an existing quantitative microbial risk assessment (QMRA) tool, and 3) assess whether existing approaches for mitigating chemical risks overlook specific compounds or compound classes that are unique to water reuse applications.

Task B: Treatment Models and Risk Mitigation Techniques

Task B will develop an Integrated Water Reuse Treatment Plant Model (WrTP) and an advanced process control system through three objectives: 1) Develop models for individual and combined treatment processes relevant to water reuse that result in predictions of process performance (i.e., predictive algorithms), 2) Integrate predictive algorithms into a model that evaluates a treatment train's ability to meet microbial and chemical water quality goals while also considering cost, and 3) Demonstrate predictive algorithms at pilot scale with a techno-economic analysis (TEA) of predictive machine learning algorithms for real-time risk mitigation of common and advanced reuse treatment processes.

Task C: Social Development and Community Engagement

Task C will support the social and organizational advancement of water reuse through three main objectives: 1) creating an index to identify water reuse potential in the United States with a water equity lens, 2) compiling organizational and social considerations for reuse at a national scale, and 3) developing a compendium of best practices for community engagement through case studies.

Task D: Successful and Sustainable Water Reuse Adoption Pathways

Task D aims to identify strategies to support adoption of sustainable water reuse through three main objectives: 1) identify drivers and pathways to water reuse success using qualitative comparative analysis on cases of attempted or implemented projects, 2) characterize the landscape of water reuse opportunities by using quantitative sustainable design to evaluate planned and potential projects, and 3) identify strategies for tailoring water reuse capacity-building efforts that are sensitive to contextual differences.

Appendix B. Project Implementation Partners

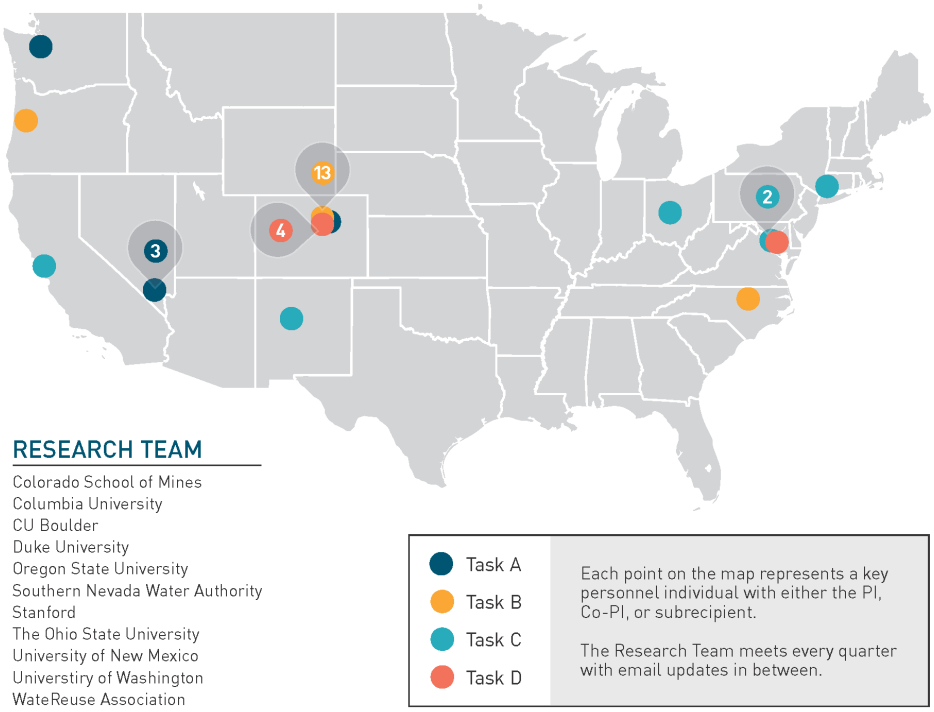


Figure 1. Map of research team members across all four tasks.

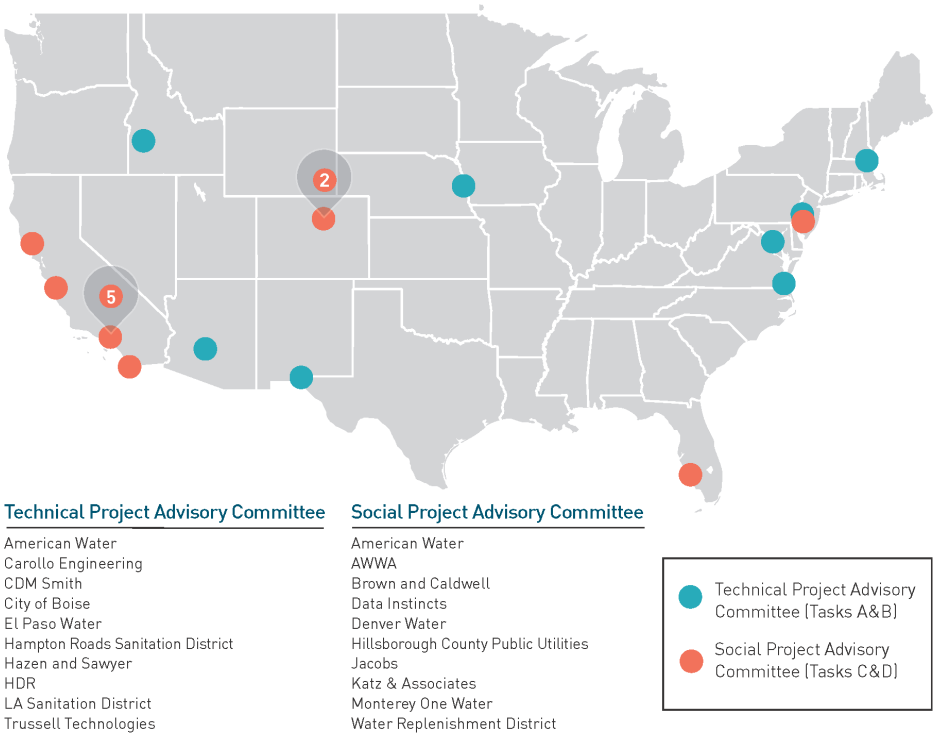
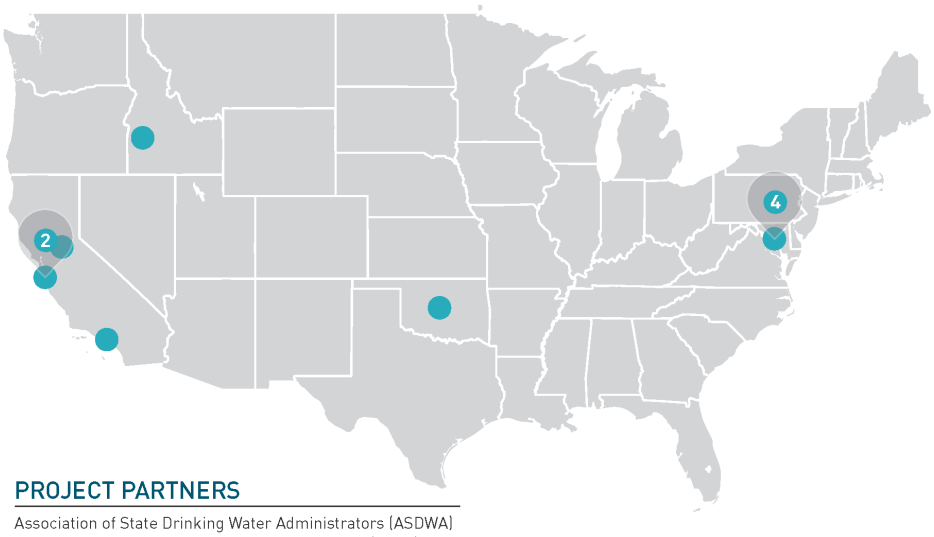


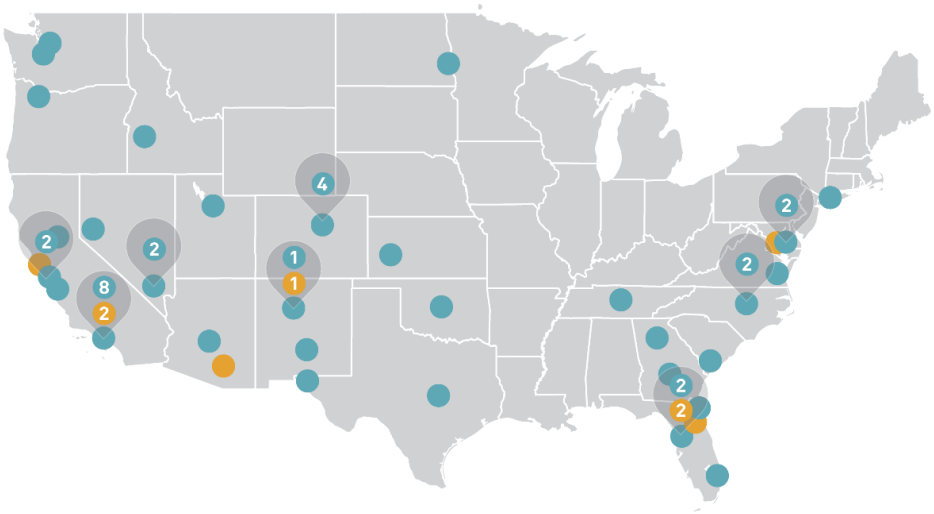
Figure 2. Map of Project Advisory Committee members across all four task areas.



PROJECT PARTNERS

Association of State Drinking Water Administrators (ASDWA)
The Foundation for Food & Agriculture Research (FFAR)
National Alliance for Water Innovation (NAWI)
National Association of Clean Water Agencies (NACWA)
National Water Research Institute (NWRI)
Oklahoma Department of Environmental Quality (OK DEQ)
State of Idaho Department of Environmental Quality (ID DEQ)
State Water Resources Control Board of California (SWB-CA)
Pacific Institute (PacInst)
US Water Alliance (USWA)

Figure 3. Map of project partners across all four task areas.



Utility Participation
Utility Participation Interest

Participation includes providing wastewater samples (Task B), hosting the mobile DPR unit (Task B), agreeing to interviews on utility engagement practices (Task C), and agreeing to interviews on factors for successful adoption (Task D).

Utility names are not listed to protect anonymity of data collection. Each point represents an organization that has either expressed interest in participation (via a letter of support) or agreed to actively participate.

Figure 4. Map of participating utilities across all four task areas since project start