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# ADVANCES in WATER RESEARCH

A Publication of The Water Research Foundation

# Ozone

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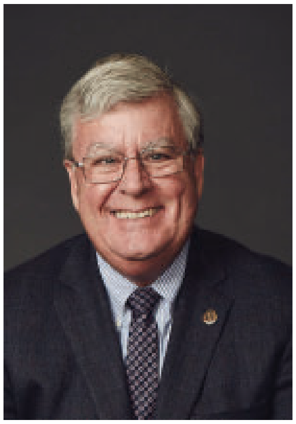
VIEWPOINT

# Adaptation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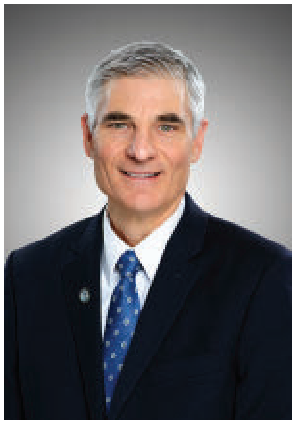
Peter Grevatt

**The water sector is continuously implementing strategies** to enhance its ability to meet the changing needs of the communities it serves. Water professionals are always working to keep a step ahead of the varied risks, challenges, and opportunities facing the sector. Openness to adaptation is an integral part of these efforts. The Water Research Foundation (WRF) is here to support our subscribers and partners as they work to adapt to the ever-changing circumstances they face.

Many tools and strategies must be deployed to enable the water sector to adapt. We must be open to exploring new technologies and innovations, while also modifying existing technologies for new uses. We must remain open to adjusting and improving our practices to appeal to a more diverse workforce and empower the exciting new leaders we attract to the sector. Utilities lead the way in exploring alternative water supplies to help address rapid shifts in climate and water availability, and we must continually review our overall management practices to ensure we are accounting for uncertainties and building flexibility into our planning efforts and programs.

This issue of *Advances in Water Research* demonstrates a broad range of adaptation practices used across the water sector. The articles “Ozone: A Journey Upwards” and “Proving an Innovative Advanced Treatment Concept: Desalination Research on Cooling Tower Blowdown” focus on innovative ways that existing treatment processes can be applied to manage new and different challenges. “A Vulnerability Assessment Case Study” and “Innovation in Action: Innovation vs. innovation” both showcase concepts and practices that enable utilities to adapt in the moment or plan for the future. By implementing these and other adaptation strategies, the sector is transforming how it does things and is building stronger, more resilient communities.

The use of science to expedite and enhance the adaptation process has become embedded in the culture of the water sector. WRF research allows water sector professionals to anticipate, prepare for, and stay a step ahead of the changes around us. Adaptation takes energy, commitment, and focus. Every day, the water sector leverages these resources to maintain a readiness to meet the challenges of the future. We look forward to continuing our work together as we deliver the essential research that energizes the water sector on its adaptation journey.

Michael R. Markus, PE
Chair, Board of Directors

Peter Grevatt, PhD
Chief Executive Officer

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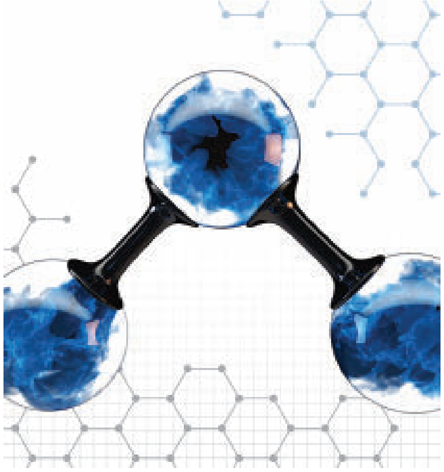
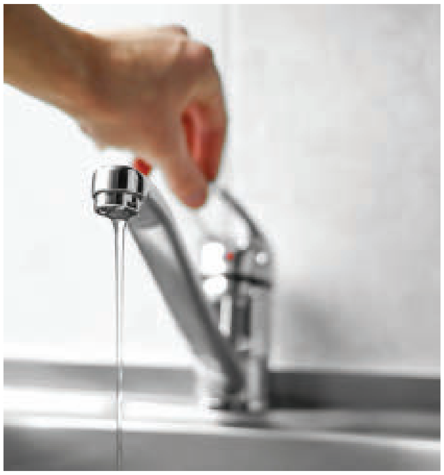
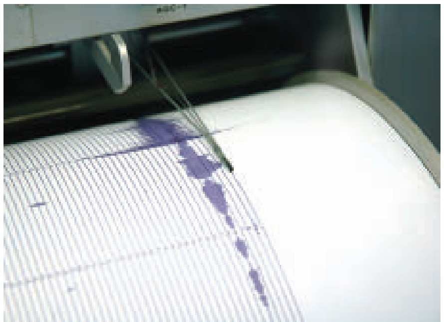
VOL. 32 NO. 2

THE Water Research FOUNDATION®

The Water Research Foundation (WRF) is the leading research organization advancing the science of all water to meet the evolving needs of its subscribers and the water sector. WRF is a nonprofit, educational organization that funds, manages, and publishes research on the technology, operation, and management of drinking water, wastewater, reuse, and stormwater systems—all in pursuit of ensuring water quality and improving water services to the public.







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RESEARCH

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# BY THE NUMBERS

**This installment of By the Numbers provides statistics on the use of ozone-biological activated carbon (BAC) treatment in potable reuse applications. For more information on ozone, see the article, Ozone: A Journey Upwards.**

Ozone-BAC has the potential to produce high-quality effluent at a lower cost while avoiding brine stream production and discharge issues. Bukhari et al. (2022) compared ozone-BAC and reverse osmosis (RO) systems by measuring various water quality parameters.

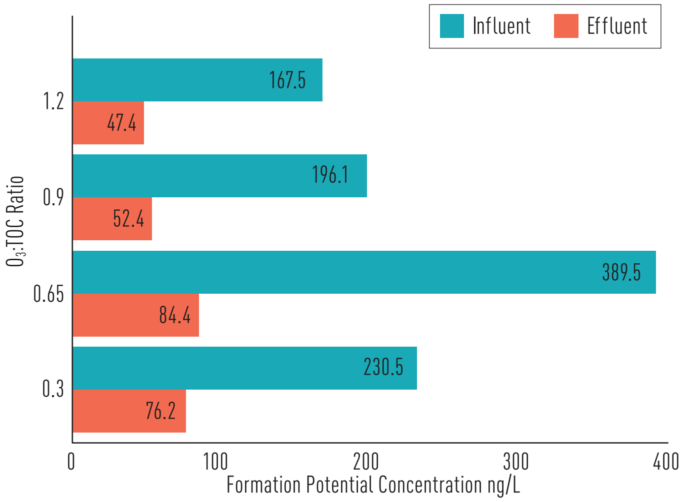
### Water Quality Parameters Analyzed

| Parameter | Reporting Limit | Parameter | Reporting Limit |
|---|---|---|---|
| Total Organic Carbon (TOC) | 0.05 mg/L | Bromide | 20 µg/L |
| Dissolved Organic Carbon | 0.05 mg/L | Trihalomethanes (THMs; total and individual) | 0.5 µg/L |
| Assimilable Organic Carbon | 10 µg/L | Total Haloacetic Acids (HAAs; total and individual) | 1 µg/L |
| UV at 254 nm | 0.01 $cm^{-1}$ | Nitrosamines | 2 ng/L |
| Ammonia | 0.02 mg $NH_3$ (N/L) | Formation Potential THMs (Total and individual) | 0.5 µg/L |
| Nitrate (N) | 0.01 mg $NO_3^-$ (N/L) | Formation Potential HAAs (Total and individual) | 1 µg/L |
| Nitrite (N) | 0.1 mg $NO_2^-$ (N/L) | Nitrosamine Formation Potential | 2 ng/L |
| Orthophosphate (P) | 0.25 mg $PO_4^{3-}$ (P/L) | Fluorescence Excitation Emission Matrix | Raman Units |
| Bromate | 5 µg/L | Adenosine Triphosphate (ATP) (on BAC media) | 0.6 µg ATP/dry weight g medium |

Source: Adapted from Bukhari et al. 2022

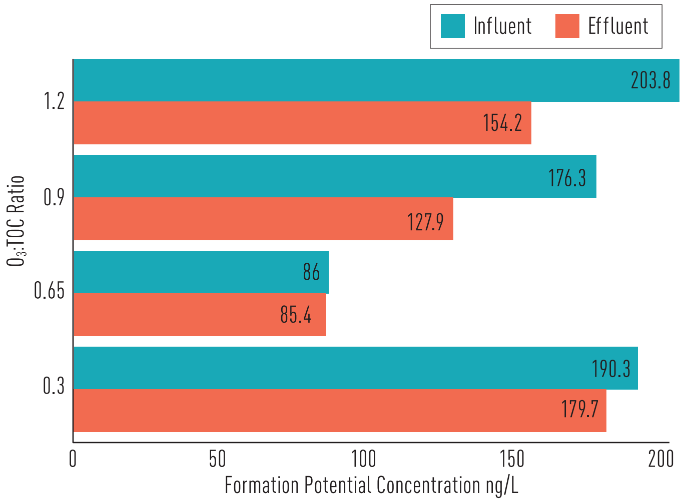
Ozone optimization pilot testing was conducted at one facility to determine the optimal ozone dose for maximizing oxidation of organics while minimizing byproduct formation. Ozonation decreased the formation potential of various disinfection byproducts, including N-nitrosodimethylamine (NDMA) and trichloroacetic acid (TCAA) during pilot testing.

### NDMA Formation Potential



Source: Adapted from Bukhari et al. 2022

### TCAA Formation Potential



Source: Data from Bukhari et al. 2022

Full-scale examination of effluent water quality was conducted for eight locations at six facilities using ozone-BAC and RO treatment schemes.

### Summary of Sampling Locations

| Facility ID | System Type | Description (age at end of monitoring) | # Sampling Events |
|---|---|---|---|
| BAC 1 | $O_3$+BAC | GAC 10 Years Old | 4 |
| BAC 2 | $O_3$+BAC | GAC 1.7 Years Old | 5 |
| BAC 3A | BAC | GAC 3.7 Years Old | 4 |
| BAC 3B | BAC | GAC 3.2 Years Old | 3 |
| BAC 3C | $O_3$+BAC | GAC 3.2 Years Old | 4 |
| BAC 3D | $O_3$+BAC | GAC 0.9 Years Old | 4 |
| RO 1 | ($O_3$+MF) RO | 3.2 Years Old (CSM RE 8040 FE) | 4 |
| RO 2 | (MF) RO | 3.5 Years Old (CSM FLR) | 4 |

$O_3$: Ozonation; BAC: Biologically activated carbon; MF: Microfiltration; RO: Reverse osmosis; GAC: Granular activated carbon; CSM: Customer satisfaction membranes

Source: Adapted from Bukhari et al. 2022

**35 to 38%**

TOC removal achieved in the BAC systems

The levels of the total trihalomethanes (TTHMs) and five haloacetic acids (HAA5) were higher in the RO system effluents than the BAC system effluents.

| TTHM | HAA5 |
|---|---|
| **<5 µg/L** in BAC systems | **Not detectable** in the BAC systems |
| **3–13 µg/L** in RO systems | **~1 µg/L** in RO systems |

Overall, this study indicates that ozone-BAC may be a promising option for potable reuse applications. The research helps fill key knowledge gaps related to operational potential of the system and consequences for the overall effluent quality.

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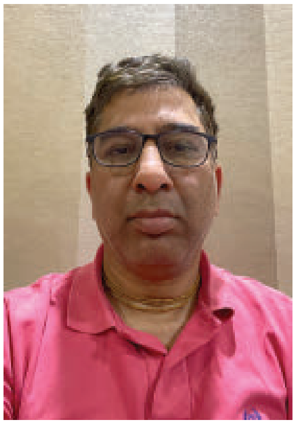
# Interview with Dr. Mari Winkler, Dr. Zhiwu (Drew) Wang, and Dr. Ramesh Goel

## Innovation and Collaboration: Nitrogen Reduction


**Dr. Mari Winkler**


**Dr. Zhiwu (Drew) Wang**


**Dr. Ramesh Goel**

Nitrogen (N) is one of the leading sources of pollution in wastewater. Its discharge into oceans has harmful consequences for the environment, economy, and human health. To combat this problem, Dr. Mari Winkler, Dr. Zhiwu (Drew) Wang, Dr. Ramesh Goel, a philanthropic organization, and Everett Water Pollution Control Facility teamed up with The Water Research Foundation (WRF) to pilot four innovative technologies. The comparative technology pilot will evaluate four process intensification technologies to reduce N in wastewater, while maintaining lower energy footprints, before being discharged to receiving waterbodies.

Dr. Mari Winkler is a civil and environmental engineer who is serving as an associate and John R. Kiely Endowed Professor at the University of Washington. She has over 15 years of experience in the wastewater sector and was the 2015 recipient of WRF's Paul L. Busch Award.

Dr. Zhiwu (Drew) Wang is an environmental engineer who is serving as an assistant professor at Virginia Tech and is the Director of the Center for Applied Water Research and Innovation (CAWRI). He has 20 years of experience in the wastewater sector.

Dr. Ramesh Goel is an environmental engineer who is serving as a professor in civil and environmental engineering at the University of Utah. He has 16 years of experience in the wastewater sector.

WRF spoke with Dr. Winkler, Dr. Wang, and Dr. Goel to gain a better understanding of their work in N reduction and the role innovation plays.

**Why is nitrogen reduction your area of research?** Dr. Winkler: Wastewater treatment systems use 3% of the energy consumed in the United States, largely due to aeration requirements as oxygen-hungry microorganisms convert ammonia to dinitrogen gas in biological treatment systems. Ammonia removal is crucial, as ammonia is toxic to mammals and causes a myriad of environmental problems if discharged into waterbodies. One of my major research themes has, therefore, focused on an emerging technology using the activity of a special group of microorganisms: anaerobic ammonia oxidizing (anammox) bacteria, which are capable of ammonia removal without oxygen.

Dr. Wang: Nitrogen is the second largest pollutant after organics in need of removal from wastewater because it leads to water eutrophication and algal blooms. As a wastewater researcher, N reduction is thus a primary focus area of my research.

Dr. Goel: My doctoral and postdoctoral trainings were in N management, which is one of the 14 grand challenges identified by the Academy of Engineers. My surface water quality research also shows that N can often be the limiting nutrient to support algal growth. Hence, I am excited about N research.

**What different technological approaches are you testing to remove nitrogen from wastewater?** Dr. Winker: We are testing two novel approaches involving two differently functioning microbe combinations. One approach utilizes the cooperation of anammox and complete ammonia oxidizing (comammox) bacteria, and the other approach utilizes the anammox bacteria and ammonium oxidizing archaea (AOA). In addition to employing novel combinations of microorganisms, we are testing two new immobilization techniques: (a) free-floating hydrogel encapsulated microorganisms and (b) microbial membrane coating. We are also investigating two local heating methods that only heat the immobilized cells (not the water), which should enhance their activity substantially at the cooler temperatures of mainline treatment stages.

Dr. Wang: The conventional partial nitritation/anammox technology that has been established for sidestream N reduction does not work well in mainstream wastewater to address the challenge of maintaining successful partial nitritation at ambient temperature. My team got around this problem by incorporating a partial denitrification step to convert nitrate produced from unsuccessful partial nitritation to nitrite for successful anammox.

Dr. Goel: We are testing anammox, both suspended and attached growth, methane-assisted denitrification, granular reactor technology, and partial denitrification.

**What are the benefits (ecological, social, and/or financial) of reducing discharge concentrations and loads entering coastal waterbodies?** Dr. Wang: Reducing N loading entering coastal waterbodies can minimize the economic loss in the fishery and tourism industries, as well as mitigate eutrophication-caused problems like hypoxia and anoxia, habitat degradation, alteration of food web structure, loss of biodiversity, and increased frequency, spatial extent, and duration of cyanobacterial harmful algal blooms.

**You are partnering with the Everett Water Pollution Control Facility on this project. What impacts could this project have on the water sector beyond the City of Everett?** Dr. Winkler: The main purpose of this project is to test novel technologies for efficient and low-cost nitrogen reduction. Since efficient and low-cost nitrogen reduction is a global issue in the sector, our case studies in the City of Everett can be applied globally.

Dr. Wang: Many U.S. coastal cities do not perform N reduction during wastewater treatment. Therefore, the experience earned from this demonstration project in the City of Everett can be applied to other coastal cities for upgrading their N reduction capacity at reduced energy and chemical demands.

**What do you see as the biggest challenge utilities must overcome to reduce nitrogen concentrations entering coastal waterways?** Dr. Wang: How to economically and sustainably incorporate N reduction technology into the existing treatment trains is a major hurdle for utilities.

Dr. Goel: Utilities will need to overcome challenges like temperature fluctuations and the operational expertise and training needed to operate innovative treatment systems.

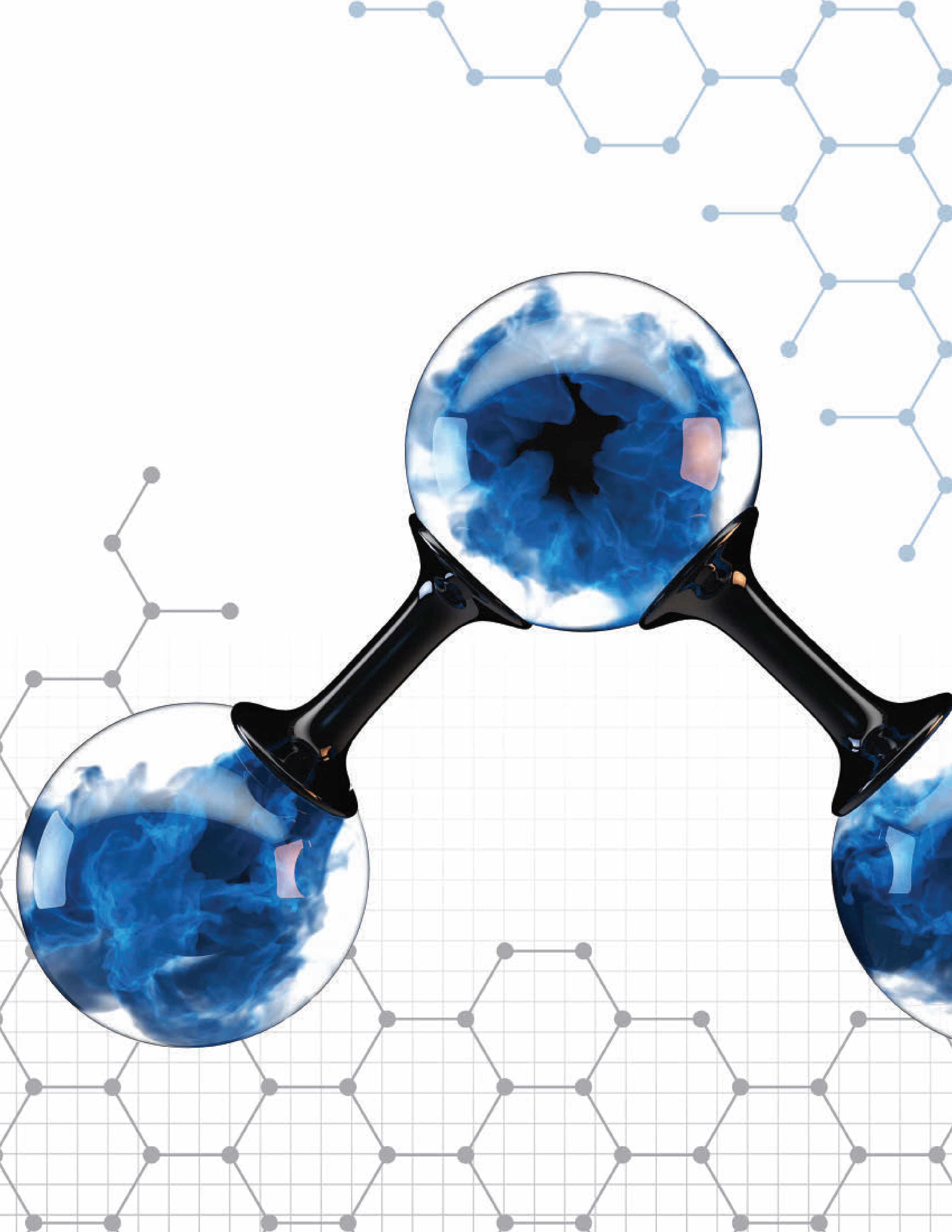
**This project brings together three academic institutions, one utility, and other experts across the sector. In what ways does working in this type of collaborative environment impact your research?** Dr. Goel: We get to learn a lot from each other. This is applied research, so the potential of moving the research from the lab to the field is very high in this case. Onsite operation of pilot-scale reactors is also possible because we get a lot of help from the utility in terms of sampling and analysis.

**This project looks at novel approaches to nitrogen reduction in wastewater. What role do you see innovative technologies playing in the municipal water sector's future?** Dr. Winkler: The energy and carbon source requirements are two of the major challenges for efficient nitrogen reduction. Innovative technologies that can achieve efficient nitrogen reduction with limited energy and carbon consumption will become the trend and will likely replace the conventional technologies in the municipal water sector.

Dr. Wang: These innovative technologies contribute to sustainable development by enabling water resource recovery facilities to do more pollutant removal with less input of footprint, cost, energy, and chemicals.

**How can utilities and universities better partner with one another to collectively address the water sector's challenges?** Dr. Winkler: Any solution to address the challenges will involve theoretical understanding and the practical application of a technology that universities and the utilities have their different strengths with.

Dr. Goel: Universities can provide innovative ideas and utilities can guide how these ideas could be implemented. Universities need to understand customer markets, needs, and operational challenges.



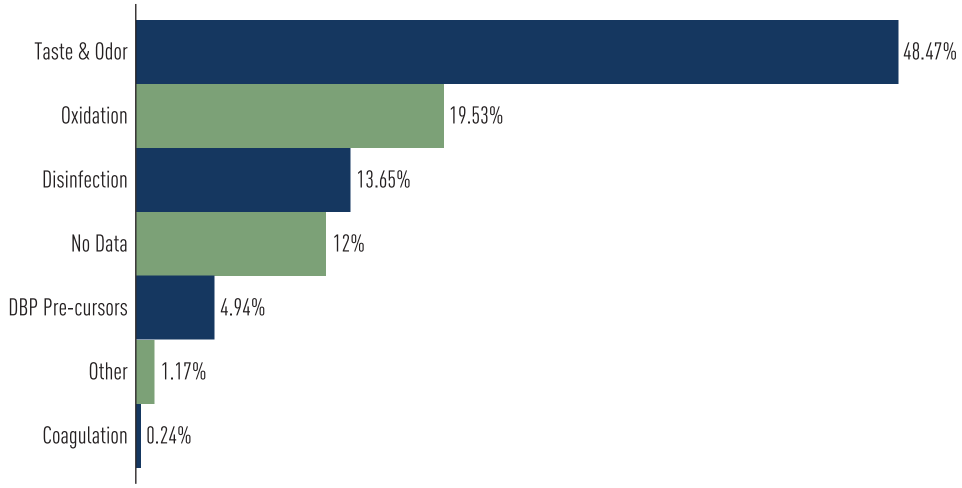
# Ozone: A Journey Upwards

## Ozone is a popular choice for meeting disinfection and oxidation needs in drinking water and wastewater treatment.

By Erin Partlan, The Water Research Foundation; and
Eric Wert, Southern Nevada Water Authority

**It is especially important for** applications like *Cryptosporidium* inactivation and treatment of taste and odor (T&O) compounds that are resistant to chlorine-based treatment (Figure 1). In addition to disinfection, ozone provides other benefits such as oxidation of micropollutants, enhanced coagulation/flocculation efficiency, and oxidation of iron and manganese (Snyder et al. 2007, Loeb et al. 2012). Following the oxidation of organics, chlorine demand is often reduced, which subsequently decreases the formation of disinfection byproducts (DBPs) like trihalomethanes and haloacetic acids.

However, ozone can also form DBPs like bromate in waters containing background bromide concentrations. Under the Stage 1 Disinfectants and Disinfection Byproducts Rule, the U.S. Environmental Protection Agency has established a maximum contaminant level of 0.01 mg/L for bromate (EPA 2010). Advances in process optimization and chemical pre-treatment help mitigate bromate



Source: Data courtesy of the International Ozone Association

**Figure 1. Primary treatment objectives for ozonation based on survey of 425 North American drinking water utilities**

formation by reducing the ozone dose and blocking formation pathways (Snyder et al. 2011).

Ozone is sometimes paired with other unit processes for enhanced treatment outcomes. For example, hydrogen peroxide addition accelerates ozone decomposition into hydroxyl radicals for contaminant oxidation. In another common treatment pairing, the synergy between ozone and biofiltration creates an effective multi-barrier approach. Biofiltration can remove natural organic matter, T&O compounds, and inorganic/organic contaminants. WRF recently published *Biofiltration Guidance Manual for Drinking Water Facilities*, which provides comprehensive information on the design, operation, optimization, and monitoring of biofilters (Brown et al. 2020). In addition, *Optimization of Ozone-BAC Treatment Processes for Potable Reuse Applications* (Bukhari et al. 2022) addresses the design and considerations of ozone/biofiltration for potable reuse projects.

During the treatment of wastewater, especially for practical or beneficial reuse, ozone has been used for disinfection and the removal of micropollutants (Snyder et al. 2007, Oneby et al. 2010). When trace organic compounds are considered in wastewater treatment design, ozone is a more economical option than advanced oxidation with hydrogen peroxide or separation via reverse osmosis (Rosenfeldt et al. 2006). However, the higher ozone dosages needed to treat wastewater increase concern over the formation of bromate.

Ozone offers significant value to the water sector. It is a multifunctional process that can be applied to meet numerous water treatment objectives, some simultaneously. The research being conducted today extends ozone's One Water application and ensures efficiency and efficacy.

## WRF Research

WRF HAS SPONSORED OZONE research for over 30 years across drinking water, wastewater, and water reuse applications. Early research focused on characterizing the nature of ozonation, including its ability to inactivate *Giardia* and *Cryptosporidium*, in addition to its use as a coagulant aid. Research also focused on optimizing ozone delivery. Significant work was done to evaluate ozone as an alternate disinfectant for the avoidance of DBPs created by chlorination, and then to understand ozone's role in generating DBPs such as N-nitrosodimethylamine (NDMA)

## Solutions in the Field:

### Southern Nevada Water Authority

**The Southern Nevada Water Authority (SNWA) selected ozone in the** 1990s as their state-of-the-art treatment option in response to public interest for advanced water treatment following *Cryptosporidium* concerns. Ozone is installed at both SNWA's Alfred Merritt Smith Water Treatment Plant (Figure 2) and River Mountains Water Treatment Facility for a combined installed ozone capacity of 900 MGD.

The ozone system was designed to provide *Cryptosporidium* inactivation based on the WRF research report *Evaluation of* Cryptosporidium *Inactivation in Natural Waters* (Oppenheimer et al. 2000). In addition to disinfection, SNWA also observed improved coagulation/flocculation efficiency and reduced trihalomethane formation following ozone implementation. If cyanobacterial blooms occur in SNWA's source water at Lake Mead, ozone is relied upon to address any concerns regarding T&O and/or cyanotoxins.

SNWA has contributed heavily to research on bromate formation and control, producing several reports with WRF, including Snyder et al. (2011), Wert et al. (2016), and Wert (forthcoming). Research at SNWA on chemical control strategies found that chlorine-ammonia pre-treatment can reduce bromate formation by up to 95%. This pre-treatment approach continues to be applied at full-scale for effective bromate control.

Source: Wert et al. 2016

**Figure 2. Porous stone diffusers at the Alfred Merritt Smith Water Treatment Facility operated by SNWA**

and bromate. WRF has partnered on this body of work with the American Water Works Association (AWWA), the International Ozone Association (IOA), the Compagnie Generale des Eaux (CGEaux), the California Energy Commission, Abu Dhabi (UAE) Department of Energy, and others.

In 1991, WRF published *Ozone in Water Treatment: Application and Engineering* (Langlais 1991) in cooperation with CGEaux. This state-of-the-science manual details fundamentals, case studies, engineering, and implementation of ozone treatment systems. It builds off of France's experience as an early adopter of ozone and focuses on applications in both the United States and Europe. The manual continues to be a resource for ozone researchers and implementers.

WRF has published over 90 reports on ozone treatment, which support the advancement and adoption of the technology, especially as both challenges and opportunities arise. In recent years, WRF's ozone research has focused on advancing biofiltration for drinking water and water reuse, examining efficacy of oxidizing cyanotoxins and cyanobacteria cells, and developing bromate control strategies.

## Process Optimization and Validation

IN 2005, AWWA PUBLISHED *OZONE in Drinking Water Treatment: Process Design, Operation, and Optimization* (Rackness 2005), which details the four primary components of an ozone system: feed-gas oxygen supply, ozone generation, ozone contactor, and off-gas destruct system. Early conventional processes used multi-chamber reactors combined with fine bubble diffusers for ozone introduction. In this scheme, ozone is introduced into one chamber, and contact time continues as water containing ozone and hydroxyl radicals moves through the remaining baffled contactor chambers.

In the early 2000s, sidestream injection (SSI) emerged as a popular alternative to fine bubble diffusion (FBD) due to improved ozone mass transfer efficiency, dosing consistency, ease of dosing validation, and elimination of confined space entry to maintain diffusers. SSI involves adding ozone gas to 20% of the plant water flow rate and then recombining with the other 80% of the water flow rate to begin the disinfection zone where ozone contact time (CT) credit is targeted.

*Effect of Ozone Dissolution on Bromate Formation, Disinfection Credit, and Operating Cost* (Wert et al. 2016) explored disinfection credits for both FBD and SSI ozone contactors, and the effects on bromate mitigation due to more efficient ozone delivery. SSI resulted in higher compliance CT than FBD at similar ozone doses and also resulted in lower bromate formation for equal CT. Minimizing time spent in the sidestream after injection can maximize ozone exposure in the combined flow to both achieve higher disinfection credit and reduce bromate formation.

The development of alternative frameworks to understand ozone dosing is of high interest for both DBP avoidance and regulatory compliance. Particularly in water reuse scenarios, crediting log removal values is essential for approval of treatment train design. One promising framework is dosing ozone proportional to total organic carbon (TOC). Bukhari et al. (2022) found that an ozone:TOC ratio of 0.9 was optimal for maximizing oxidation for treatment objectives and minimizing DBP formation, including bromate production.

## Protecting Public Health

THOUGH OZONE IS A VERY effective disinfectant and oxidant that does not lead to chlorinated DBP formation, it is important to consider the carcinogenic toxicity of bromate formed through ozonation (Cotruvo and Bull 2006, Cotruvo et al. 2012). *Modes of Action for Bromate-Induced Health Effects and Bromate Formation in Conventional and Advanced Water Treatment* (Rosenfeldt et al. 2021) directly addresses pathways for bromate toxicity alongside pathways for the formation of bromate through disinfection. The project goal was to provide a basis for toxicologically based limits for bromate regulation. In the study of bromate effects in rats, genotoxic effects were not caused by doses up to twice the drinking water standard. It's further noted that rats are five times more susceptible than humans to changes that affect thyroid hormones. As the current maximum contaminant limit goal (MCLG) of zero (EPA 2010) is based on a genotoxic interpretation of bromate toxicity, these findings may support re-examination of the MCLG.

Bromate control strategies aim to block different formation pathways using chemical pre-treatment, creating a balance between meeting treatment objectives and controlling bromate formation. In the ongoing project *Impact of Bromate Control on Ozone Oxidation/Disinfection and Downstream Treatment Processes in Potable Reuse* (Wert, forthcoming), the research team is examining three methods of bromate control and their impacts on disinfection. Upstream removal of dissolved organic carbon (DOC) by enhanced coagulation (EC), powdered activated carbon (PAC), and combined EC/PAC is being evaluated to improve ozone efficiency and minimize bromate formation. Chemical control strategies that include preformed monochloramine and combined hydrogen peroxide and ozone dosing are being evaluated for bromate mitigation potential.

> Ozone has been implemented to combat cyanobacteria-related water quality concerns

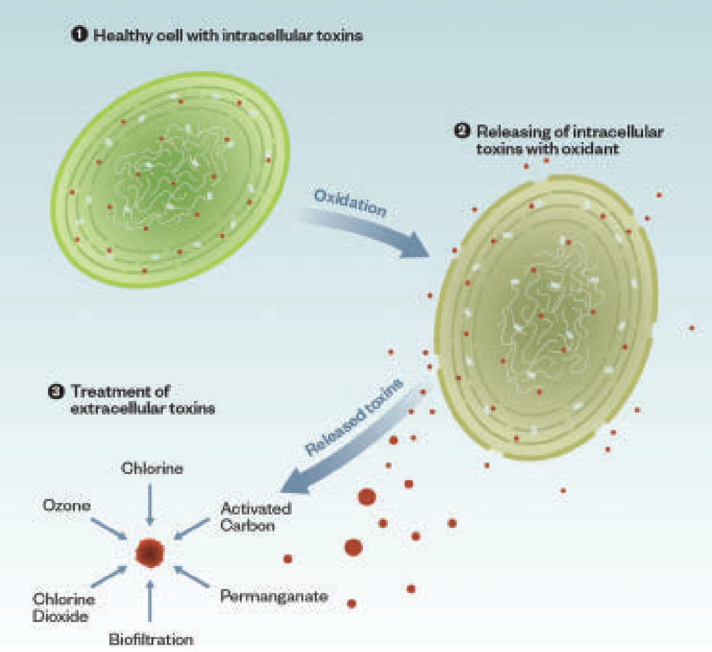
To ensure disinfection and pathogen inactivation under increased ozone efficiency, the research team is exploring multiple frameworks for prediction. Importantly, established CT relationships may not capture microbial inactivation in low ozone and $O_3/H_2O_2$ scenarios. Alternate frameworks include kinetic models and surrogate frameworks ($O_3$/DOC and $UV_{254}$). Lastly, the team will conduct pilot, demonstration, and full-scale testing based on bench-scale results. The team expects to develop a report including guidance on how to best balance treatment objectives while minimizing bromate production.

## Tackling New Challenges

AS A STRONG OXIDANT, OZONE HAS many potential applications for water treatment. With increasing concern over cyanobacteria blooms in drinking water sources, ozone is being considered as a potential solution for treatment within drinking water facilities and drinking water sources. Recently, ozone has been implemented to combat cyanobacteria-related water quality concerns (i.e., cyanotoxins, T&O compounds) at drinking water utilities in Johnson County, KS; Oregon, OH; Salem, OR; and Toledo, OH.

During treatment of cyanobacteria cells, there is concern that oxidation could increase microcystin concentrations due to lysis of cyanobacterial cell walls. *Release of Intracellular Cyanotoxins During Oxidation of Naturally Occurring and Lab-Cultured Cyanobacteria* (Wert et al. 2019a) found that free chlorine and ozone dosing both released and then subsequently oxidized microcystins. The results promote consideration of a multi-barrier approach to combat intracellular (cell bound) cyanotoxins during drinking water treatment (Figure 3).

Source control strategies to prevent or mitigate cyanobacteria blooms can be challenging to implement due to the volume and area requiring treatment. The ongoing WRF projects *Developing Guidance for Evaluation and Implementation for Control of HABs in Source Water* (Wert et al., forthcoming) and *Utility Responses to Cyanobacterial/Cyanotoxin Events: Case Studies and Lessons Learned* (Owen, forthcoming) have identified the need to develop improved strategies to combat blooms in source waters. In the future, ozone nanobubble technology may be able to help mitigate cyanobacteria issues directly in source waters. For example, where nanobubble aeration can be used to increase dissolved oxygen, ozone can be used similarly for both oxidation and oxygenation. Technology developers are already considering ozone when creating solutions for waterbody remediation, and ozone may be a viable technique for open water treatment in the near future.



Source: Wert et al. 2019b

**Figure 3. Schematic of release and treat approach to cyanotoxin management**

## Educational Partnerships

PARTNERSHIPS HELP TO ADVANCE the science related to ozone. For example, the International Ozone Association (IOA) has collaborated with WRF on several projects focused on ozone applications. The IOA also produces educational resources including the peer-reviewed journal *Ozone: Science & Engineering*, the magazine *Ozone News*, and annual conferences. The IOA is currently developing materials focused on improving operator training with courses expected to cover ozone/oxygen safety and dissolved ozone measurement. More information about IOA and the 2022 Conference can be found on IOA's website (IOA 2021).

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# Interview with a Researcher:

## Erik Rosenfeldt, Associate Vice President and Director of Drinking Water Process Technology at Hazen

**How did you get started with research on ozone processes for water treatment?** My first exposure to ozone was working with Urs von Gunten at EAWAG, the Swiss Federal Institute of Aquatic Science and Technology. As part of my PhD, I published a comparison of UV/$H_2O_2$ and ozone/$H_2O_2$ advanced oxidation processes (AOPs). Since then, I have focused on AOPs broadly, including developing a hydroxyl radical formation model for UV treatment based on a similar model for ozone produced at EAWAG, and working on the fundamentals of background radical scavenging.

**You led the project *Modes of Action for Bromate-Induced Health Effects and Bromate Formation in Conventional and Advanced Water Treatment* (Rosenfeldt et al. 2021). What hurdle does bromate formation pose to plants looking to adopt ozone?** In high-bromide source waters, which include reuse streams, bromate control strategies are critical for process implementation. In lower-bromide waters, and most drinking water sources meet this criteria, meeting the regulatory limit of 10 micrograms/liter of bromate is relatively easily achievable with established mitigation strategies. However, if the limit were to be lowered, that would impede the adoption of ozone for drinking water treatment.

**What do you see as the future of ozone?** The multifunctional aspect of ozone makes it a smart choice when considering unknown contaminants. While some compounds are less amenable to ozone oxidation, many that are recalcitrant to conventional disinfection are easily oxidized with ozone. Additionally, oxidation is a strong technique for reducing compound toxicity since small changes can affect biocompatibility. Adopting ozone to meet current needs is an investment against future constituents of emerging concern.

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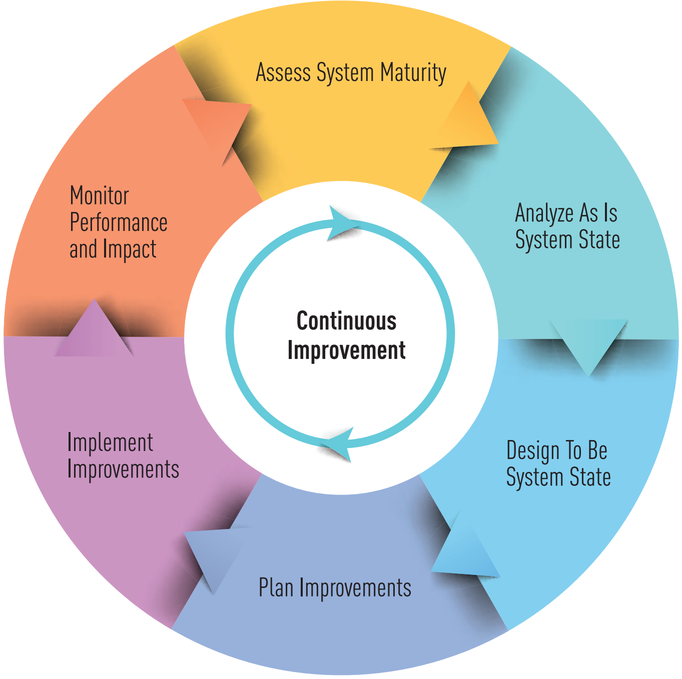
# Innovation vs. innovation

**Articles about innovation often refer to the big "I" and** the little "i." The former being the game-changing technology that creates a whole new paradigm, product, or process, and the latter being the incremental improvements that can be achieved through continuous experimentation and application of new research and ideas.

"I" is disruptive and hard to predict, but it can deliver outstanding results. During the pandemic, the water sector collaborated with health professionals to take the science of wastewater-based epidemiology for SARS-CoV-2 from an idea to a global phenomenon. The Water Research Foundation (WRF) International Summit on SARS-CoV-2 in Wastewater in April 2020 identified information that could be acted on immediately, as well as the key research priorities to support implementation of the method as a reliable measure to predict trends of COVID-19. One year later, a global update highlighted the many ways that the data were being used to support health actions in the United States, Europe, Australia, Africa, and Asia. Additionally, two research projects have been delivered: *Interlaboratory and Methods Assessment of the SARS-CoV-2 Genetic Signal in Wastewater* (Pecson 2020) and *Understanding the Factors That Affect the Detection and Variability of SARS-CoV-2 in Wastewater* (Jiang et al., forthcoming). The rapid development of this field of research and its implementation to support improved health outcomes is unprecedented.



Source: Vitasovic et al. 2022

**Figure 1. Improvement methodology cycle**

Embracing the "i" can be easier because continuous improvement is part of the culture of the water sector. However, the variety of possible approaches can be daunting. *Utility Analysis and Improvement Methodology* (UAIM, Vitasovic et al. 2022) addresses this challenge. The goal of this project was to provide water sector utilities with a well-defined, structured, and value-based improvement methodology, captured in Figure 1.

UAIM efforts provide utilities with practical and actionable steps to add value through:

- Documenting business processes so that they can be analyzed and improved.
- The Water Sector Value Model: A mechanism for utility partners to share business process models with partners.
- A platform for utility partners to share asset management plans, risk matrices, capital improvement program methods, and improvement case studies.
- Collaboration with a network of peers and development of business process models, maturity models, assessment methods, and best practices for specific areas of utility management.

To build resilient utilities that meet the evolving needs of their communities, the water sector must embrace each type of innovation. WRF is committed to working with utilities to help them innovate, with both the big "I" and the little "i."

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# Water Loss Control

## It is crucial for drinking water utilities to be able to measure the efficiency of their distribution systems to fully capture sales and reduce non-revenue water.

This article was adapted from *Water Loss Control*, a synthesis report from The Water Research Foundation (WRF 2022).

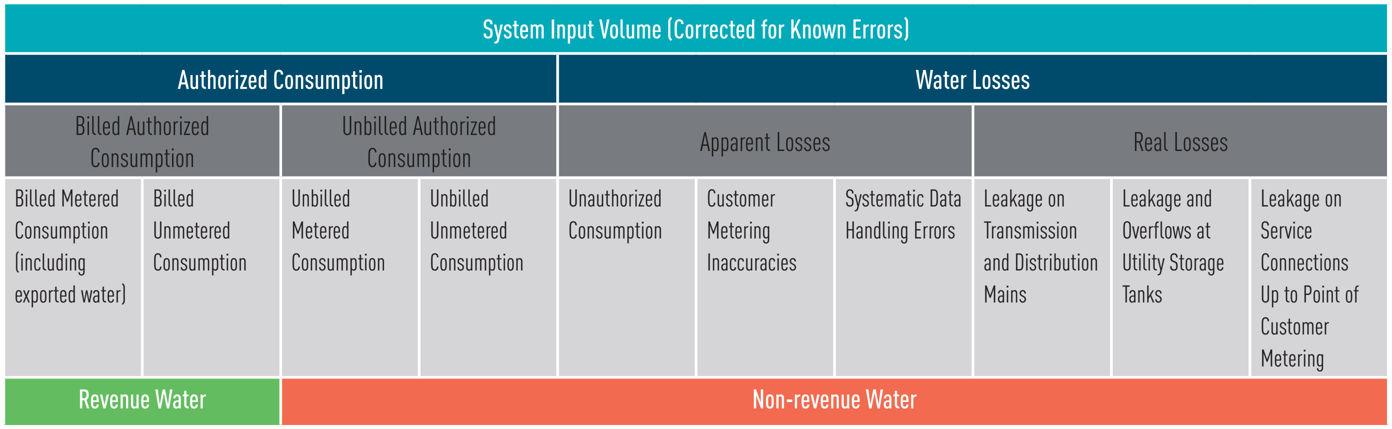
**Non-revenue water includes real** losses (leaks), apparent losses (unauthorized uses, metering inaccuracies, or systematic data handling errors), and unbilled authorized consumption. Water utilities are increasingly engaging in water loss control efforts to enhance water supply reliability, increase revenue generation, and accurately account for water usage. Whether a utility is in the initial stages of a water loss control program or has been working on these efforts for many years, The Water Research Foundation (WRF) has resources that will help the utility define and meet its water loss control goals.

Since the 1980s, WRF has undertaken nearly 30 research projects on water loss control. Much of this research has been conducted in partnership with other organizations, such as the American Water Works Association (AWWA) Water Loss Control Committee, helping to further advance the field through collaboration. This article highlights some of WRF's key water loss control research projects.

### Water Audits

AN INITIAL AND PROACTIVE STEP for improving distribution system efficiency is conducting a water audit—a thorough examination of a water utility's data, records, accounts, and procedures regarding the volumes of water that are moved from system input through the distribution system to the customer (i.e., a "top-down" water audit, Figure 1). Water audits are essential for assessing the efficiency of a water utility's resources and operational and financial impacts. In 2015, WRF released *Water Audits in the United States: A Review of Water Losses and Data Validity* (Sturm et al. 2015), one of the first analyses of a large batch of water audits. The research team analyzed more than 4,500 water audits, and found that 21% of the water audits did not pass basic checks of plausibility, underscoring the importance of education, training, and data validation for improving the quality of a water audit.

Some of these challenges can be addressed through water audit validation, which is the process of examining water audit inputs to improve the audit's accuracy and document the uncertainty associated with water audit data. There are three levels of water audit validation. WRF has developed a manual to guide utilities in Level 1 validation. The first edition of *Level 1 Water Audit Validation Guidance Manual* (Andrews et al. 2016) provides North American water utilities and regulatory entities with a standardized methodology for validating water audit data when using AWWA's Free Water Audit Software version 5 (AWWA 2014). The second edition of the manual was published in 2021 (Sturm et al. 2021) for use with AWWA Software version 6 (Jernigan et al. 2020). Level 1 water audit validation confirms that the AWWA water audit methodology was correctly applied to a utility's specific situation, identifies



| System Input Volume (Corrected for Known Errors) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Authorized Consumption | | | | Water Losses | | | | | |
| Billed Authorized Consumption | | Unbilled Authorized Consumption | | Apparent Losses | | | Real Losses | | |
| Billed Metered Consumption (including exported water) | Billed Unmetered Consumption | Unbilled Metered Consumption | Unbilled Unmetered Consumption | Unauthorized Consumption | Customer Metering Inaccuracies | Systematic Data Handling Errors | Leakage on Transmission and Distribution Mains | Leakage and Overflows at Utility Storage Tanks | Leakage on Service Connections Up to Point of Customer Metering |
| Revenue Water | | Non-revenue Water | | | | | | | |

Source: Data from AWWA 2016

**Figure 1. Calculating a top-down water audit**

inaccuracies in summary water audit data, and verifies that data validity grades accurately reflect utility practices. While some uncertainty may persist, the audit is more reliable after Level 1 validation.

## Apparent Losses

IT IS RECOMMENDED THAT METER data be double-checked after completing a water audit. Apparent water losses are caused by revenue meter under-registration, water theft, and billing errors. It is not so much that water is being "lost," but rather that utilities are losing potential revenue. Utilities may be able to cut down on apparent losses by ensuring that water meters are sized appropriately and collecting accurate measurements.

*Accuracy of In-Service Water Meters at Low and High Flow Rates* (Barfuss et al. 2011) tested meters for accuracy and endurance. Many meter types were evaluated in this study, including fluidic oscillator, nutating disc, piston, multi-jet, and single-jet meters. The results illustrated that a larger-than-expected number of new meters did not meet the AWWA flow registry standard applicable to that meter type. In addition, some meter types passed the AWWA registry standard tests more consistently than other meter types. Test results illustrate that some meter types were capable of accurately measuring flow at flow rates well below and well above the AWWA standard flow rates, while other meter types were not capable of measuring these same flows.

WRF research has also addressed oversized water meters, which are a common problem for utilities, especially considering increased water conservation and more efficient plumbing fixtures. When meters are oversized, they cannot accurately capture low flows. The project, *Assessing Water Demand Patterns to Improve Sizing of Water Meters and Service Lines* (Mayer et al. 2020), improved understanding of correct meter sizing and performance to help prevent inaccurate meter registration at low flow regimes and under-reporting of delivered water. This was accomplished through the exploration of water meter

## Solutions in the Field:

### California Water Audit Validator Training

**In 2017, after facing its worst drought on record, the State of California** began requiring urban retail water suppliers to submit validated distribution system water audits each year—a first step in understanding and preventing water loss. To help utility personnel prepare for, and comply with, this development, the California-Nevada Section of AWWA sponsored a training series. The Water Audit Validator course is a two-day program designed to qualify individuals to perform Level 1 water audit validations in California. Water audit validators examine water loss audit inputs to consider the water audit's accuracy and document sources of uncertainty. The training materials for this course drew heavily on Andrews et al. (2016). The use of this research furthered the project goals—providing clear guidance and standard methods for water audit validation to water utilities and regulatory entities. It is likely that *Level 1 Water Audit Validation Guidance Manual, Second Edition* (Sturm et al. 2021) will be utilized for future training efforts.

and service line sizing practices in three utility service areas.

A growing number of water utilities are implementing advanced metering infrastructure (AMI) to capture detailed information from customer meters; however, most utilities have not realized the full potential of AMI data. By effectively using AMI data, utilities can better address customer needs (see Figure 2), enforce policies for water usage, and better quantify (and ultimately reduce) the level of non-revenue water in their distribution systems. *AMI Meter Data Analytics* (Brueck et al. 2020) improved understanding of the benefits of correct meter sizing and meter performance. The research identified strategies for AMI data analyses and used case studies to demonstrate the value of using AMI data. The research resulted in a meter performance index, which allows utilities with AMI data to define their meter maintenance and replacement strategies based on actual meter performance.

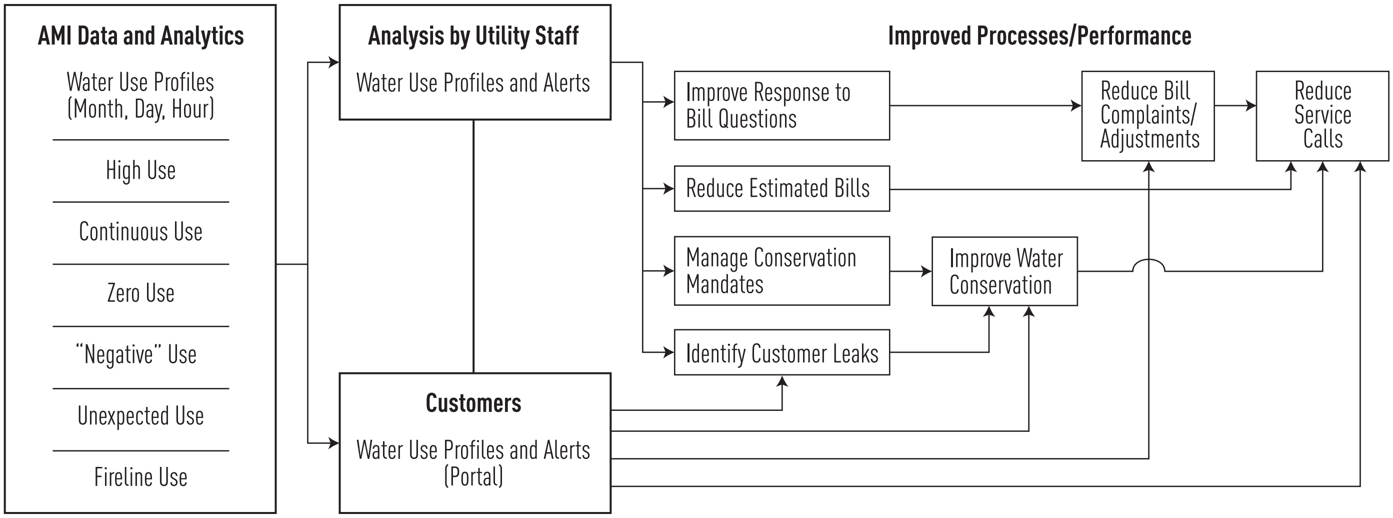
## Real Losses

EFFORTS TO CONTROL non-revenue water frequently focus on identifying and efficiently minimizing water distribution leakage (real losses). WRF has published a range of projects to help utilities identify leaks. *Continuous System Leak Monitoring: From Start to Repair* (Hughes et al. 2011) found that continuous acoustic monitoring (CAM) systems could detect about 65% of leaks earlier (prior to leaks surfacing), thereby reducing real losses. Leaks that were not detected by the CAM system were likely not "heard" because of the inability of leak noise to travel through certain pipe materials (i.e., acoustic noise sensors can more easily detect leak sounds from metal/ferrous pipes than plastic pipes).

To prevent real losses, water utilities must also manage pressure within the distribution system. Persistent pressure fluctuations may contribute to long-term weakening of distribution system piping. *Criteria for Optimized Distribution Systems* (Friedman et al. 2010) sought to identify the key optimization criteria for distribution system performance. The three primary criteria identified were chlorine residual, main breaks, and pressure management. Pressure management was found to be a critical barrier in maintaining distribution system integrity because it directly influences so many other operational parameters.

To help address pressure management challenges, *Pressure Management: Industry Practices and Monitoring Procedures* (LeChevallier et al. 2014) developed best practices for continuous pressure improvement programs. Proactive pressure monitoring is recommended, and collecting pressure readings every hour was found to be inadequate—accelerated monitoring, known as "impulse recording," is recommended where sensors automatically record data when significant changes in pressure occur. For best results, utilities must consider pressure management optimization along with other distribution system performance indicators, such as leakage, breaks, and energy usage.

Another approach to calculating real losses is to perform a real loss component analysis or leak component analysis, which requires detailed annual leak and repair data as well as a top-down water audit. *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (Sturm et al. 2014) developed the Leakage Component Analysis Model—a utility-tested, user-friendly tool to help utilities better



Source: Brueck et al. 2020

**Figure 2. Illustration of how AMI data and analytics can improve customer interactions**

understand the sources of their real losses (subcategorized as reported, unreported, or background), identify the appropriate intervention strategies, and analyze the economics of the intervention strategies. The need to provide clear guidance on failure data collection and documentation was addressed through the development of a Leak Repair Data Collection Guide, an open-source MS Excel spreadsheet.

## Water Loss Control Plans

MORE RECENTLY, WRF RESEARCH has focused on strategically integrating water loss control activities and plans with broader institutional goals, objectives, and spending programs. Published in 2019, *Guidance on Implementing an Effective Water Loss Control Plan* (Trachtman et al. 2019) provides advice on how to analyze more than three years of water audits to set performance targets and offers material that complements AWWA's *Manual 36: Water Audits and Loss Control Programs* (AWWA 2016). This project created a guidance manual and decision framework to help water utilities develop actionable, cost-effective, and defensible water loss reduction and control plans. Figure 3 shows the key steps involved in water loss control program planning and implementation.

## Looking Forward

DETERIORATING INFRASTRUCTURE is a top concern among utilities, and pressure has been implicated in pipe failure in several studies. In many case studies, pressure reductions apparently correlated with reduced pipe breaks. Lowering pressure, consistent with water quality protection, may provide significant reductions in pipe breaks, leakage, and energy costs—and certain smart water technologies are available for measuring and managing pressure with the direct result of reduced stress on pipes and water loss. Ongoing WRF research is already exploring this concept. For example, *Utilizing Smart Water Networks to Manage Pressure and Flow for Reduction of Water Loss and Pipe Breaks* (Karl et al., forthcoming) is using network solutions to help water utilities better manage pressure and flows in their water distribution networks to extend the life of pipes and reduce water loss.

Source: Adapted from Trachtman et al. 2019

**Figure 3. Water loss control program planning**

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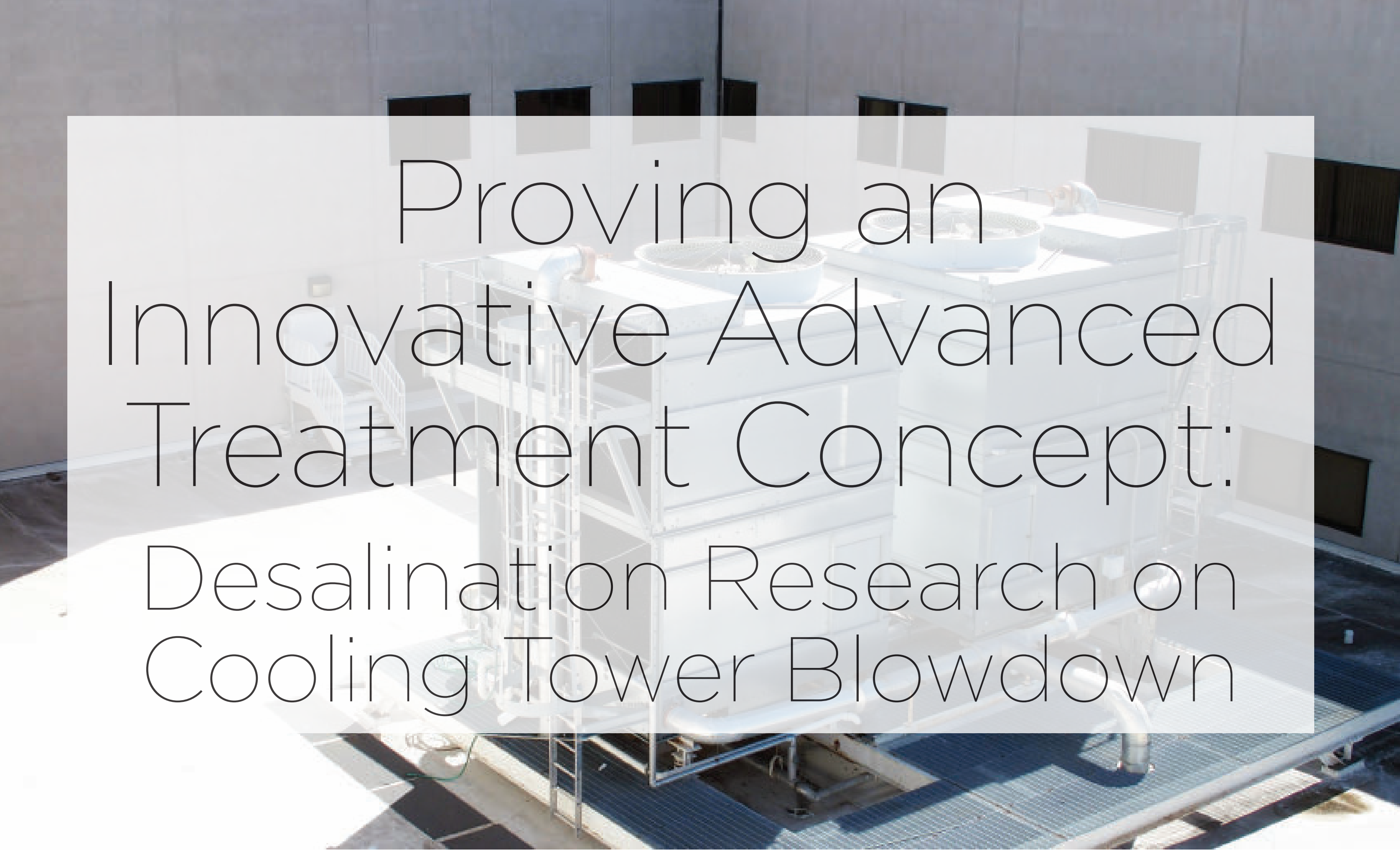
# Earthquake Impacts on Pipes (4752)

Do major stress events such as strong ground shaking due to earthquakes significantly reduce the remaining service life of buried water distribution pipes? *Effect of Major Stress Events on Buried Pipe Service Life* sought to answer this question by employing a statistical approach informed by mechanics of materials and using data from five major cities. The dataset included 16,000 miles of buried water distribution pipes that required more than 64,000 repairs over varying periods (depending on utility) from 1975 to 2017. Multivariate statistical analysis was applied to this dataset to develop measures of buried pipe service life as a function of covariates of pipe diameter, material, age, soil and slope, and earthquake activity. The research found that pipes subjected to higher ground motions have a lower probability of survival than those not subjected to high ground motions, demonstrating that earthquakes can cause substantial long-term losses to water utility buried pipe networks, reducing the useful life of these pipes by a significant amount. These findings may have significant implications for disaster aid policy and claims for disaster assistance.



# Proving an Innovative Advanced Treatment Concept:

## Desalination Research on Cooling Tower Blowdown

**Contaminating our precious water supplies with salt water can be easy, but removing the salt is not.**

By Eric Dole, Garver

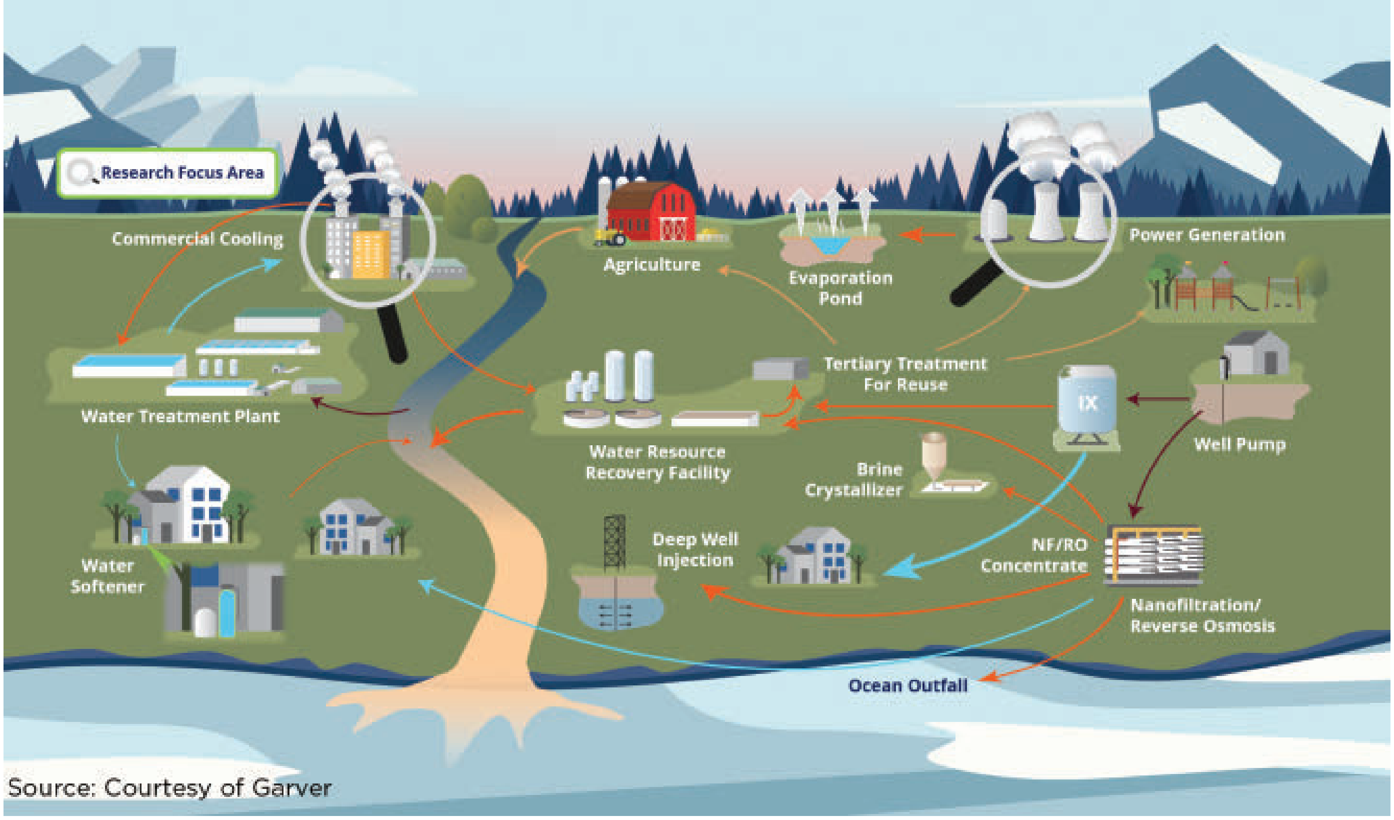
**Salt can enter the watershed** from a variety of sources (Figure 1). Understanding the salt loading sources sets the stage for salinity management. Cooling towers (CTs) can be major contributors to salt loading in the local watershed. The CT water that does not evaporate in the evaporative cooling process cascades down the CT internals into the supply tank, while the fresh water evaporates. This causes minerals and salts to "upcycle" in the CT supply water. The upcycling of minerals, especially hardness and silica, causes scaling of the heat exchanger surfaces and a significant decrease in cooling efficiency. To maintain the proper water chemistry in the supply water, some of the water must be discharged to the sewer and replenished with fresh water from the potable water supply, which also serves as make-up water (replacement for water lost to evaporation). The saline water discharged to the sewer is known as blowdown. The high-salinity blowdown may present treatment challenges for water resource recovery facilities and ultimately increase the salt loading to receiving waterbodies. The majority of industrial and commercial cooling systems utilize evaporative CTs, especially in arid regions. According to the *Central Arizona Salinity Study*, "a study performed by the Phoenix water conservation department concluded that 15 percent of all water produced goes to cooling towers… The water is discharged to the sewer system when the salt concentration gets too high and starts impacting the cooling process. Standard practice calls for concentrating brine 3 to 5 times before discharging to the sewer" (BOR 2003).

Best management practices around CTs (and other salt pollution sources like water softeners) can be implemented to reduce desalination treatment intensity. In 2019, Garver received a $150,000 Pitch to Pilot grant from the U.S. Bureau of Reclamation's (BOR) Desalination and Water Purification Research Program to study an innovative process train to recover the saline blowdown from commercial and industrial CTs. Garver collaborated with several entities on this project, including Red Rocks Community College (RRCC), Dr. Mike Mickley, and other industry partners[1], who collectively donated over $480,000 of in-kind equipment, instrumentation, and labor.

> "We are excited to partner with Garver and the U.S. Bureau of Reclamation in support of the community and our adult learners here at Red Rocks Community College. Many of our students are adults seeking certifications or degrees to assist in career transitions and obtaining better job opportunities to support their families and communities. They are not often provided the opportunity to contribute directly to cutting edge research, so we are optimistic our partnership with Garver will provide such opportunities to all students who participate."
>
> —DR. BEVERLY CLARK III, VICE PRESIDENT FOR ACADEMIC AFFAIRS, RRCC

## The Solution

THE PILOT STUDY'S ZERO-LIQUID discharge (ZLD) blowdown treatment train was designed by Garver and constructed at RRCC in Lakewood, CO. The train is sized to provide 1.5 gpm of treatment for the CT blowdown through electro-coagulation (EC),



Source: Courtesy of Garver

Figure 1. Watershed salt loading

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[1] Additional partners included Blue-White Industries, Ltd.; Colorado Analytical Laboratories, Inc.; Endress+Hauser; Flowrox; Garney; Harrington; Lyons Filter Company; Powell Water; Rockwell Automation; Sundine Enterprises; and The Salt Miner.

ultrafiltration (UF), granular activated carbon (GAC), and reverse osmosis (RO), with vacuum-assisted electrodistillation (VAED) concentrate treatment. The CT in this study discharged approximately 1,500 gallons per day of 2,200 mg/L total dissolved solids (TDS) blowdown to the sewer, so the 1.5 gpm capacity could be considered full-scale for this application if true ZLD could be achieved. The treatment train separates the blowdown into concentrate/salt and permeate water. If successful, this approach will prevent high-salinity wastewater from entering the sewer system and eliminate the potable water demand to augment the blowdown water. Potable water augmentation will still be needed to replenish the water evaporated. Figure 2 presents a process flow schematic of the treatment train and how it was integrated into the existing CT system.

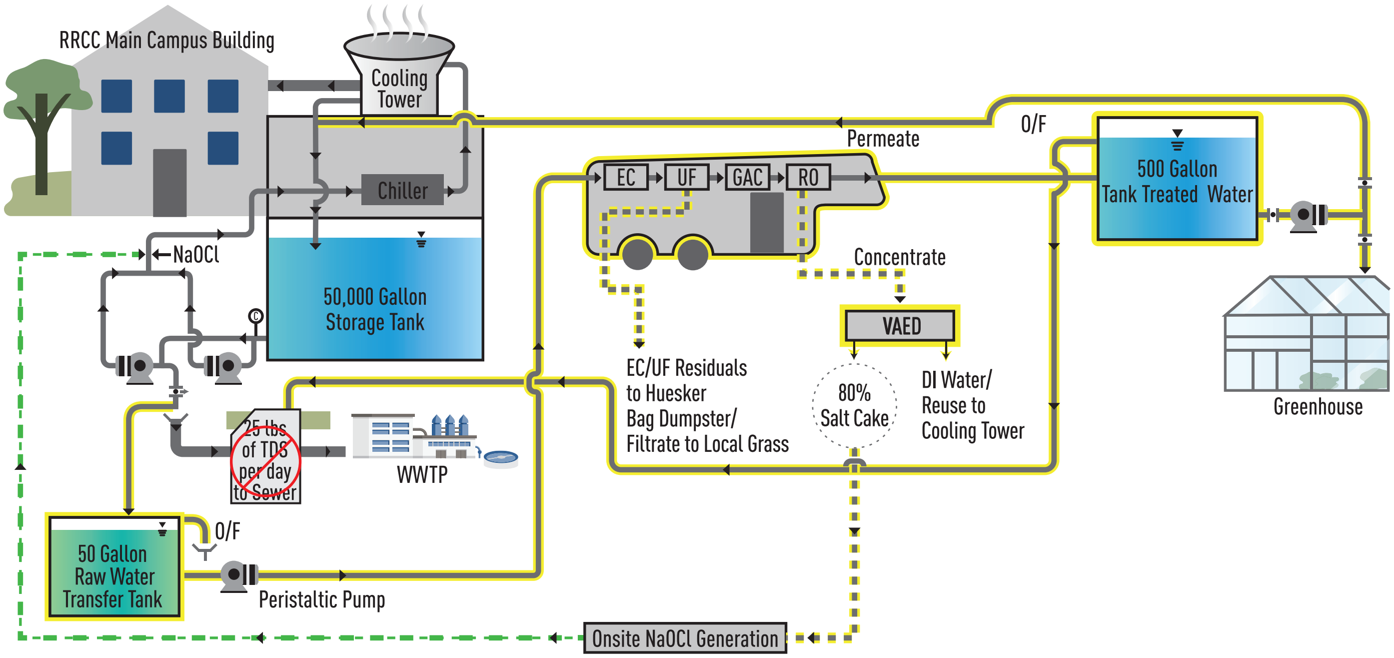
The goal of this project is to prove that an EC/UF/GAC/RO/VAED treatment system can be effective in treating the high TDS commercial CT blowdown from the 600-ton evaporative cooling system located at RRCC. The water quality of the treated permeate and distillate was analyzed to determine if it can be re-purposed for CT make-up water.

## The Research

THE PURPOSE OF EC IS TO precipitate the constituents present in the blowdown that can foul the CT and the RO membranes used to treat the blowdown. EC is an alternative method of adding a metal coagulant without adding a salt counter-ion by using a direct current and metal electrodes submerged in the water. Under a direct current, the metal anode dissolves into the water, adding the metal coagulant, while hydroxide is generated at the cathode. A ferric hydroxide or aluminum hydroxide “sweep” floc is formed depending on what blades are used. The 0.2-micron UF system removes the pin-floc (particles that are not heavy enough to settle in the clarifier) from the EC supernatant. The purpose of the GAC is to remove total organic carbon (TOC) or any free chlorine prior to RO. If the pre-treatment train is effective at removing the common foulants prior to RO, the membranes should theoretically perform at a higher permeate flux and specific flux without damaging the membranes.

The concentrate from RO is sent to a holding tank where the VAED system treats the 2,200–4,100 mg/L TDS in 8-gallon batches. The VAED system is a patented distillation process for spent brine treatment from water softeners that combines ohmic heating and vacuum distillation into one unit process. It flashes high TDS waters and condenses the steam into low TDS condensate, leaving an 80% (by weight) salt slurry.

Rockwell Automation power quality monitors and Endress Hauser picomag meters and in-line water quality analyzers are installed throughout the process to measure kW, kWh, total flow, instantaneous flow, conductivity, pH, oxidation reduction potential (ORP), and temperature. Together, this instrumentation allows the team to trend kWh consumed per kgal treated and the treatment efficacy in a real-time environment.



Source: Courtesy of Garver

**Figure 2. Garver’s process flow diagram**

## The Results

PRELIMINARY FINDINGS ARE currently available. The BOR final report, due in June 2022, will reveal the difference between the various testing parameters and confirm the validity of the preliminary findings. The report will be available on the BOR's website (BOR 2021).

Throughout the field testing, various parameters were adjusted in the EC process train, such as hydraulic residence time, electrode material, electrode jumping configuration, amperage density, pre-treatment chemistry for pH adjustment, and downstream filtration micron removal size. RO permeate flux and specific flux were challenged based on the various EC configurations and the fact that the three-stage RO only had one element in each stage, due to budget constraints. Typically, three-stage RO has multiple parallel elements in the first stage, and the number of parallel elements decreases as the number of stages increases, due to less flow leaving the final stages. Electrode configuration, amperage density, re-seeding of salt slurry, and condensation energy adjustments were made to the VAED system throughout testing.

The main treatment train consistently met water quality goals and resulted in high TDS removal efficacy without fouling the RO membranes (Table 1). The main treatment train was operated for three to five hours a day for three days a week from August to December 2021. After each RO run, the membranes were forward flushed with 8–10 gallons (< 2% of processed flow) of 10 mg/L TDS permeate until the concentrate conductivity was within 20% of the permeate feed flush conductivity.

Since the VAED system utilizes ohmic heating, it operates more efficiently the higher the conductivity or TDS; therefore, the lower TDS concentrate was initially spiked with rock salt to bring the TDS from ~4,000 mg/L to ~56,000 mg/L. The salt slurry remaining after each 8-gallon batch was processed was left in the flash chamber to re-seed the incoming lower TDS concentrate.

Notable trends include:

1. The sweep floc formed by the EC unit was significantly diminished

**Table 1. Water quality data**

| TARGET CONSTITUENT | 10th Percentile | | | Average | | | 90th Percentile | | |
|---|---|---|---|---|---|---|---|---|---|
| | Raw Water | Filtered EC Supernatant | Permeate | Raw Water | Filtered EC Supernatant | Permeate | Raw Water | Filtered EC Supernatant | Permeate |
| Total Hardness as $CaCO_3$ (mg/L) | 699.74 | 174.28 | 0.1 | 743.38 | 428.68 | 1.38 | 810.44 | 723.42 | 4.86 |
| pH | 8.1 | 7.9 | 7.1 | 8.3 | 8.8 | 8.8 | 8.7 | 9.3 | 9.9 |
| TDS (mg/L) | 1683.3 | 1515 | 5.0 | 2848.7 | 1686.2 | 11.4 | 1991.8 | 1966.2 | 21.2 |
| Silica (mg/L) | 15.613 | 0.30 | 0.3 | 17.7 | 1.39 | 0.3 | 19.4 | 3.24 | 0.3 |
| Total Suspended Solids (mg/L) | 5.0 | 5.0 | 5.0 | 5.3 | 12.5 | 5.0 | 5.3 | 17.8 | 5.0 |
| Total Phosphate (mg/L) | 0.11 | 0.05 | 0.05 | 0.16 | 0.06 | 0.05 | 0.19 | 0.05 | 0.05 |
| TOC (mg/L) | 5.79 | 4.84 | 0.5 | 6.38 | 5.18 | 0.51 | 7.34 | 5.46 | 0.5 |
| ORP* (mV) | 180.0 | -141.8 | -182.9 | 194.00 | -112.40 | -124.60 | 211.0 | -70.0 | -61.2 |
| Temperature* (°C) | 15.86 | 13.19 | 12.86 | 18.09 | 16.99 | 16.96 | 19.94 | 21.23 | 21.33 |
| Total Coli (mpn/100 mL) | 1.0 | 1.0 | 1.0 | 1.18 | 1.67 | 1.0 | 1.0 | 1.0 | 1.0 |
| OPERATING PARAMETER | 10th Percentile | | | Average | | | 90th Percentile | | |
| Energy Intensity (kWh/kgal) | 39.6 | | | 44.9 | | | 51.4 | | |
| Pressure (psi) | 312.0 | | | 346.0 | | | 386.0 | | |
| Permeate Flow (gpm) | 0.72 | | | 0.80 | | | 0.86 | | |
| Permeate Flux (gfd) | 11.9 | | | 13.2 | | | 14.3 | | |
| Concentrate Flow (gpm) | 0.80 | | | 0.88 | | | 0.97 | | |
| % Recovery 3-stage RO | 43% | | | 48% | | | 52% | | |
| % Recovery Overall** | 49% | | | 54% | | | 59% | | |

*As trended through in-line analyzers
**@ 400 ppm TDS w/ Blend

Source: Courtesy of Garver

> This demo is an excellent opportunity to see the sort of small-scale, distributed desal system NAWI seeks to develop and advance with both its pilot program and our overall baselining and road mapping."
>
> —PETER FISKE, NATIONAL ALLIANCE FOR WATER INNOVATION

after 4–6 hours due to scaling of the electrodes, and required a clean-in-place with 34% hydrochloric acid (HCl).

2. The HCL was reused 8–13 times to clean the blades before it lost its cleaning efficacy and was processed through the EC unit.
3. Increasing the pH with sodium hydroxide from 8.6 to between 9.7 and 10 resulted in total hardness removal efficacy between 72% and 95% after the EC.
4. Regardless of pH or residence time, the EC unit removed 67%–98% of silica.
5. EC consistently depressed the average ORP in the raw water from 194 mV to -113 mV, indicating a reducing condition and the absence of oxidizers that would harm the membrane.
6. The VAED proof of concept system removed 98%–99% of the TDS for three lab analysis dates where the raw TDS was between 100,000 mg/L and 186,000 mg/L.

## Conclusions

THE TREATMENT TRAIN consistently achieved high removal efficacy of target RO foulants. EC was a successful alternative mechanism for foulant precipitation and created ideal water quality for RO membranes without the use of anti-scalents or pH depression. RO fouling was not noticed if a brief permeate flush was implemented. The custom clarifier and UF system used to settle the EC floc met the treatment goals. However, the GAC system did not provide TOC removal and was not a benefit to the process train.

With automation, enhanced RO recovery and increased cooling efficiency of the VAED system, the EC/UF/RO with VAED treatment train has the potential to achieve ZLD treatment for the blowdown from the 600-ton CT at RRCC; however, due to some limitations, minimum liquid discharge was achieved. More research into the removal mechanisms, optimization of full-scale design constraints, capital costs, and operational costs would be beneficial to the advancement of this technology as a solution to manage the salt loading from CTs or brackish water desalination applications.

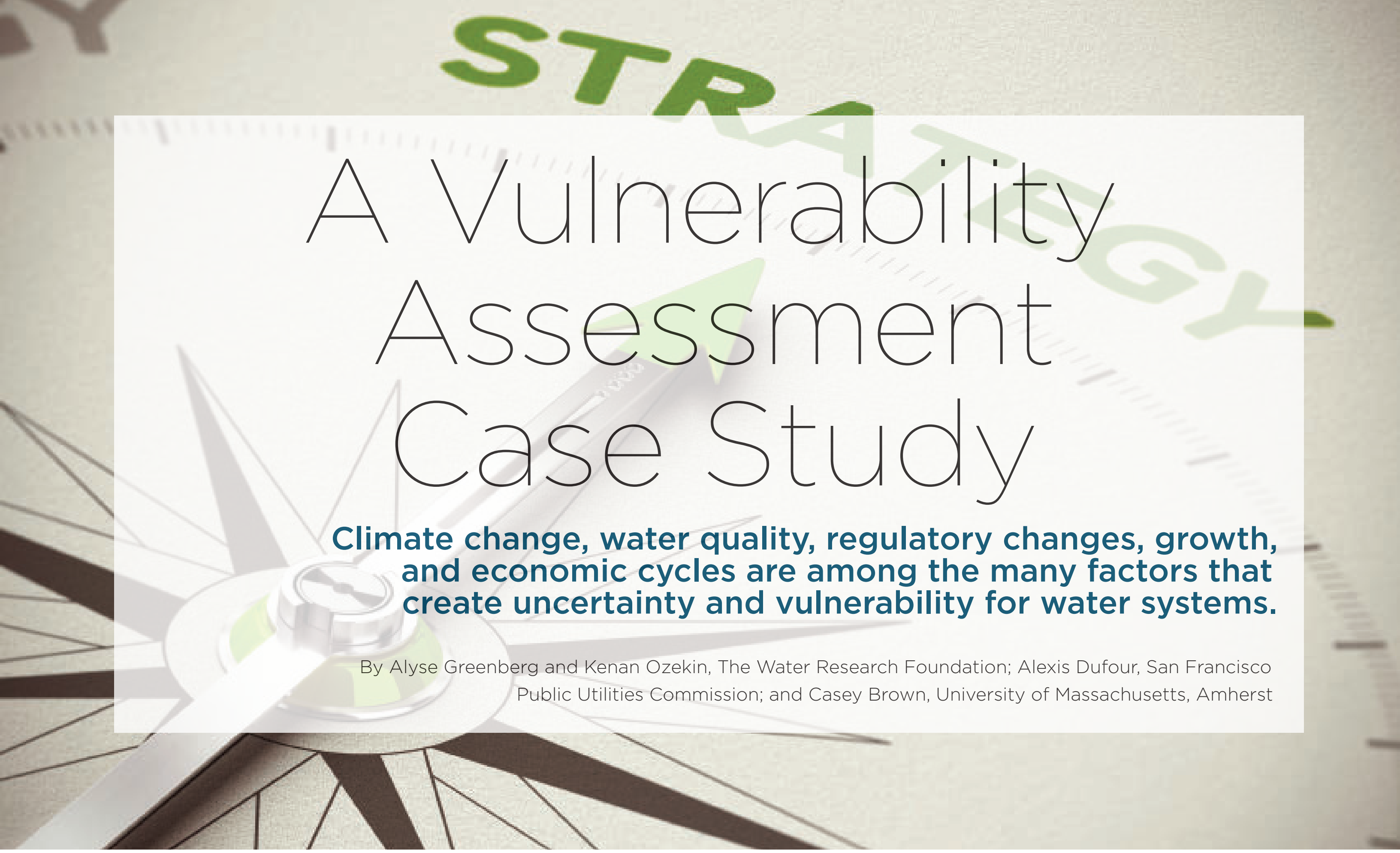
### References

BOR (U.S. Bureau of Reclamation). 2003. *Central Arizona Salinity Study: Phase I Report*. BOR.

———. 2021. "DWPR Pitch to Pilot Research Projects." Accessed March 3, 2022. https://www.usbr.gov/research/dwpr/P2P_Reports.html.

# Membrane Filtration Pilot (4906)

**Microfiltration systems have** long been developed as proprietary systems where interchangeability between membrane modules was not possible. Utilities are often left with installed systems that may no longer produce the desired capacity, treat challenging feedwater quality, or meet more stringent water quality goals. To address these challenges, West Basin Municipal Water District is exploring the use of a custom engineered membrane filtration system. Through the project, *West Basin Municipal Water District Custom Engineered Membrane Filtration Pilot: Evaluation of Fouling Characteristics and Cleaning Efficacy*, polyvinylidene difluoride (PVDF) membrane modules were evaluated for performance treating ozonated secondary effluent water. Pilot testing for seven PVDF membranes was conducted over the course of 18 months. Five of these membranes were qualified for use at the West Basin Municipal Water District facility. The results of this pilot test were used to develop design conditions for each of the qualified modules in a future full-scale custom engineered membrane filtration system. The research results can be applied by other facilities that also have a challenging feedwater or an ozonated secondary effluent feedwater.

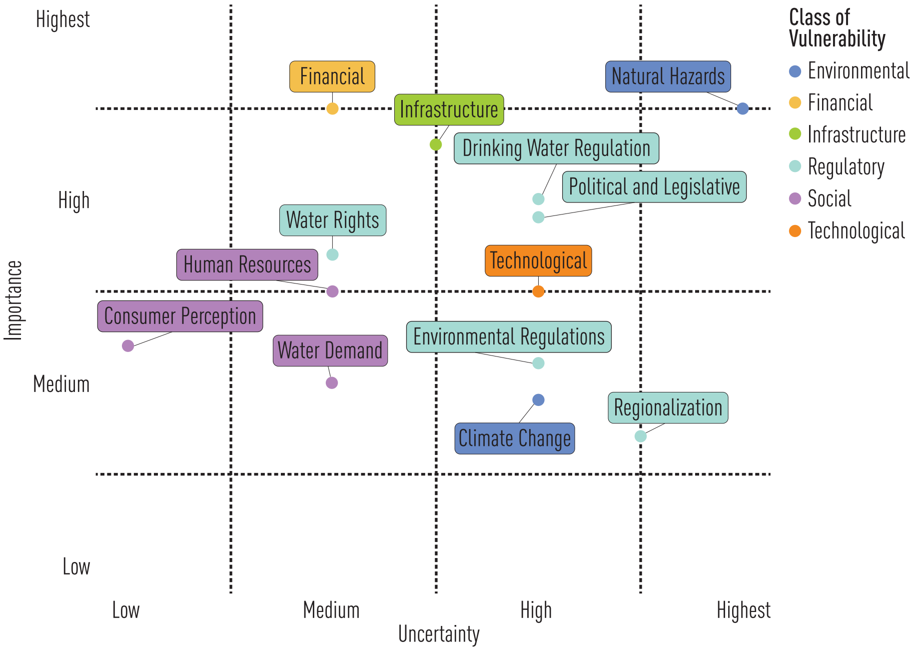


# A Vulnerability Assessment Case Study

## Climate change, water quality, regulatory changes, growth, and economic cycles are among the many factors that create uncertainty and vulnerability for water systems.

By Alyse Greenberg and Kenan Ozekin, The Water Research Foundation; Alexis Dufour, San Francisco Public Utilities Commission; and Casey Brown, University of Massachusetts, Amherst

**Water utilities must consider** the uncertainties they face and how those factors may impact their ability to meet the needs of their communities. To better understand the potential vulnerabilities of its regional water system (RWS) to uncertain future conditions, the San Francisco Public Utilities Commission (SFPUC) partnered with The Water Research Foundation (WRF) and University of Massachusetts' Hydrosystems Research Group to develop a long-term vulnerability assessment (LTVA) of the RWS. The goal of *Long Term Vulnerability Assessment and Adaptation Plan for the San Francisco Public Utilities Commission Water Enterprise - Phase I* (François et al. 2021) was to quantitatively and qualitatively assess the extent that climate change will be a threat to the RWS in comparison to, or in combination with, other drivers of change over the next 50 years (2020–2070). Figure 1 shows the relative uncertainty and importance of the vulnerability sources SFPUC initially found in the scoping phase of the study. The sources of vulnerability considered were climate, demand, regulatory changes (i.e., change in instream flow requirements), raw water quality, finance, and infrastructure failures. Overall, the LTVA was conducted to determine (1) under what conditions and when the RWS will no longer



Source: François et al. 2021

**Figure 1. Importance and uncertainty associated with sources of vulnerability identified by SFPUC**

meet system performance criteria, and (2) whether climate change is the most important driver of vulnerability for the RWS. While climate change is the driver that triggered this study, the intent was to understand the effects of climate change in the context of effects from other drivers of change on the RWS.

## Project Approach

THE LTVA WAS PERFORMED USING a decision scaling approach where vulnerabilities were first identified and used as the basis for assessing risks. The analysis included a multidimensional quantitative stress test and qualitative scenarios in which sources of vulnerability were revealed through testing against changing conditions. A suite of computer models of the RWS was created, calibrated, and used to estimate system performance under a range of future and/or unexpected conditions. Models simulated changes in climate and weather, hydrology of the contributing watersheds, operations of the RWS, long-term demand, raw water quality, and finance. Figure 2 shows the inputs and outputs of the modeling system. Narratives or qualitative scenarios were designed to investigate the effects of instream flow requirements and failures of key infrastructure components. A series of performance metrics and targets was used to reveal vulnerabilities of the RWS water supply.

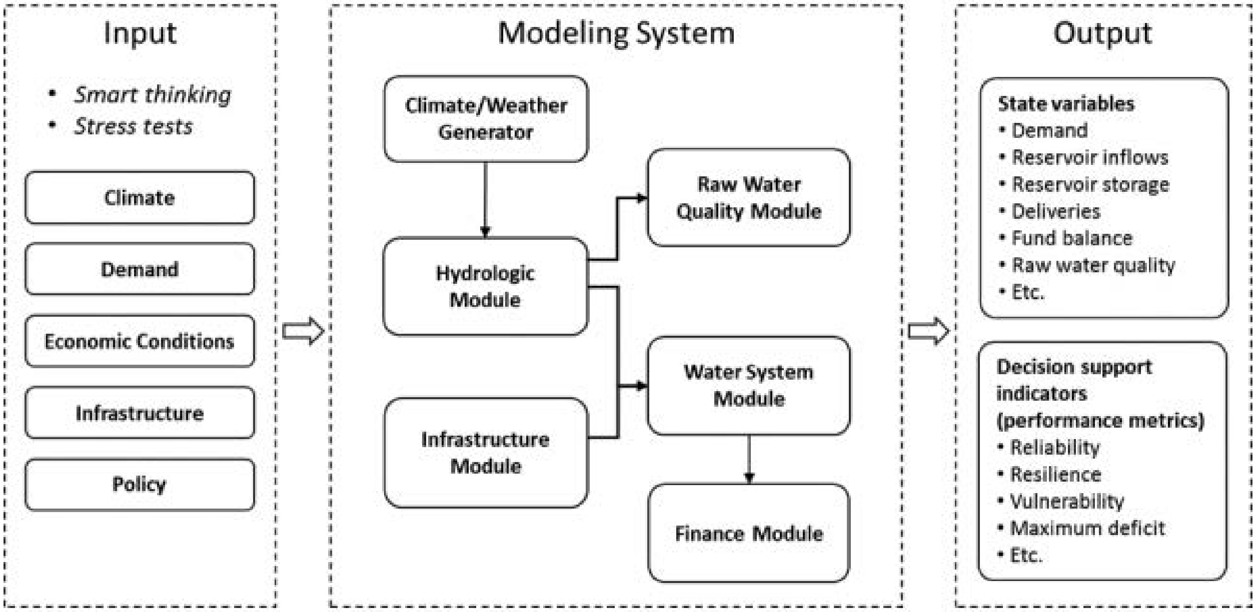
Boundaries of temperature and precipitation changes were determined for the stress test by reviewing climate projections and findings from a workshop with climate science experts. Temperature changes of up to +7°C above historical baseline and precipitation changes from -40% to +40% of historical baseline were examined. A range of demand changes above baseline was also evaluated. The qualitative scenarios developed included five new instream flow requirements and four critical infrastructure outages.

## Results

THE STRESS TEST WAS APPLIED to three regions—Upcountry, East Bay, and Peninsula—for the years 2021–2070. Changes in temperature ranged from no change to +7°C. Changes in precipitation ranged from -40% to +40%. Overall, at 227 mgd baseline water demand, the RWS could sustain up to a +4°C temperature change and a -5% precipitation change before failing to meet targets for delivery reliability, storage reliability, and frequency and duration of water rationing.

The study results indicate that precipitation change is an important driver for RWS performance. A precipitation decrease of 10% or more will cause RWS targets to be missed. The climate projections and expert input show that such a change in precipitation is possible, but unlikely, by 2040. However, the likelihood of this degree of change increases closer to 2070.

Changes in hydrology due to climate change are likely to affect the RWS's ability to meet water supply targets. The primary reason for change in water delivery reliability was shown to be the reduction in inflow to RWS reservoirs due to decreased



Source: François et al. 2021

Figure 2. Conceptual diagram of the modeling system developed for the LTVA

precipitation. In the Upcountry region, warming is anticipated to have a small effect on annual volume of inflow into the reservoirs, but will influence the timing of spring runoff and the variability of SFPUC water available for diversion under existing water allocation agreements. In the East Bay and Peninsula regions, warming would reduce annual inflow volumes due to evapotranspiration.

With regard to change in water demand, an increase of 15% (265 mgd) will lead to failure to meet rationing frequency targets under current climate conditions. However, if there is also an increase in precipitation of 10%, the rationing frequency targets would be met. If demand increases by 30%, the rationing target cannot be met even if precipitation increases by 40%.

Regulatory requirements for instream flows were also considered. Additional instream flow requirements in the East Bay and Peninsula regions will have small effects on RWS performance in comparison to new instream flow requirements in the Upcountry region. Specifically, the new instream flow requirement below Don Pedro Dam of 40% of full natural flow from February to July represents a significant reduction in the amount of water available for the RWS. At a demand of 227 mgd, rationing occurs 1 out of 20 years on average; with this new instream flow requirement, it becomes 1 out of 6 years on average. An equivalent increase in frequency of rationing is observed with a decrease of 15% in mean annual precipitation from severe climate change.

## Applications

BOTH THE PUBLIC AND WATER professionals are concerned about the potential impacts climate change will have on water supplies. Yet, drinking water utilities are struggling to characterize the effects of future climate change on water supply systems and to incorporate climate change considerations into their long-term planning. François et al. (2021) provides a detailed case study of a systematic approach for addressing climate change concerns while also incorporating non-climate considerations. The resulting vulnerability assessment reveals clear thresholds of climate change that are problematic, while using climate projections to inform rather than drive the analysis. The report demonstrates the use of climate stress testing and qualitative scenarios of demand change, new regulations, and infrastructure failure to reveal vulnerabilities singly and in combination. Furthermore, the study provides an example of how climate change projections and input from climate experts can be used to assess the level of concern associated with various vulnerabilities.

A webcast on this project was held in January 2022, and is available for on-demand viewing on the WRF website.

### References

FRANÇOIS, B., A. Bruce, K. Nguyen, D. K. Park, D. Rheinheimer, U. Taner, S. Wi, H. Khan, A. Dufour, D. Behar, D. Yates, C. Ammann, M. Haasnoot, and C. Brown. 2021. *Long Term Vulnerability Assessment and Adaptation Plan for the San Francisco Public Utilities Commission Water Enterprise - Phase I*. Project 4703. Denver, CO: The Water Research Foundation.

# Cyanotoxin Monitoring (4716)

**The overall objective of** *Refinement and Standardization of Cyanotoxin Analytical Techniques for Drinking Water* was to refine and standardize analytical techniques for cyanotoxins in water by streamlining and unifying procedures for sample collection, preservation, cell lysis, and analysis. This project provides an approach for standardizing cyanotoxin detection and quantification methods so that water resource managers can more reliably and confidently assess cyanobacterial blooms and make informed operational decisions. The findings of this study will help water utilities address challenges with cyanotoxin monitoring, data interpretation, and responsiveness to regulatory health advisory levels.

# Bromide and Iodide (4711)

***Occurrence Survey of** Bromide and Iodide in Water Supplies* sought to determine the occurrence of bromide ($Br^-$) and iodide ($I^-$) in drinking water sources; determine their role in the formation of regulated and emerging disinfection byproducts (DBPs); and develop a better understanding of how seasonal changes in watersheds, regional geochemistry, and other factors impact these key inorganic DBP precursors. The project approach involved data mining of historic $Br^-$, $I^-$, and DBP levels; field sampling to enable geo-statistical analysis of bromide and iodide occurrence data; and bench- and pilot-scale testing of technologies to remove these halides from water and reduce DBP formation potential.

**Figure 1. On-site bromide sensor installation at Nevada water treatment plant (left) and Arizona water treatment plant (right)**

# Stormwater BMPs (4968)

**To complement existing resources related to the** International Stormwater Best Management Practices (BMP) Database, two new fact sheets have been published. The *International Stormwater BMP Database* fact sheet provides a detailed overview of the database, along with related projects and research needs. *Advancing Stormwater Management: International Stormwater BMP Database* provides examples of how the BMP Database has been used to address challenges such as BMP design criteria and regulatory requirements.

| **BMPs in 2020 release of the database** | |
|---|---|
| Bioretention | Manufactured Treatment Device |
| Composite (Treatment Train) | Media Filter |
| Detention Basin | Percolation Trench/Well |
| Grass Strip | Permeable Pavement |
| Grass Swale | Permeable Friction Course |
| Green Roof | Rainwater Harvesting |
| Infiltration Basin | Retention Pond |
| Low Impact Development | Wetland Basin |
| Maintenance Practice | Wetland Channel |

# CALENDAR

## JULY–SEPTEMBER

**July 17-20, 2022**

### NARUC Summer Policy Summit

San Diego, CA
www.naruc.org/meetings-and-events/naruc-summer-policy-summits/2022-summer-policy-summit/

**July 24-27, 2022**

### NACWA Utility Leadership Conference & Annual Meeting

Seattle, WA
www.nacwa.org/conferences-events/2022-utility-leadership-conference

**August 1-3, 2022**

### AWWA Transformative Issues Symposium

Cincinnati, OH
www.awwa.org/Events-Education/Embracing-Our-Differences

**August 15-18, 2022**

### IOA-PAG Conference

Las Vegas, NV
ioa-pag.org/2022-IOA-PAG-Conference-Vegas

**August 23-September 1, 2022**

### World Water Week

Stockholm, Sweden
www.worldwaterweek.org/

**August 29-31, 2022**

### Smart Water Summit

San Antonio, TX
www.smartwatersummit.com/2022

**September 11-15, 2022**

### IWA World Water Congress & Exhibition

Copenhagen, Denmark
worldwatercongress.org/

**September 11-14, 2022**

### AWWA Water Infrastructure Conference

Portland, OR
www.awwa.org/Events-Education/Water-Infrastructure

**September 11-13, 2022**

### WateReuse California Annual Conference

San Francisco, CA
watereuse.org/event/2022-watereuse-california-annual-conference

**September 12-14, 2022**

### PNCWA Annual Conference & Exhibition

Spokane, WA
conference.pncwa.org/

**September 12-15, 2022**

### WaterJAM 2022

Virginia Beach, VA
pheedloop.com/EVEHOTYDWGEOJ/site/home/

**September 13-15, 2022**

### One Water Summit

Milwaukee, WI
uswateralliance.org/events/summit2022

**September 13-16, 2022**

### Michigan AWWA Section Annual Conference and Exhibits

Traverse City, MI
www.mi-water.org/page/MIACE

**September 18-21, 2022**

### Rocky Mountain Water Conference

Keystone, CO
www.rmwea.org/rmwc.php

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