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ADVANCES in WATER RESEARCH

A Publication of The Water Research Foundation

Intelligent Water Systems

also in this issue

Future Research

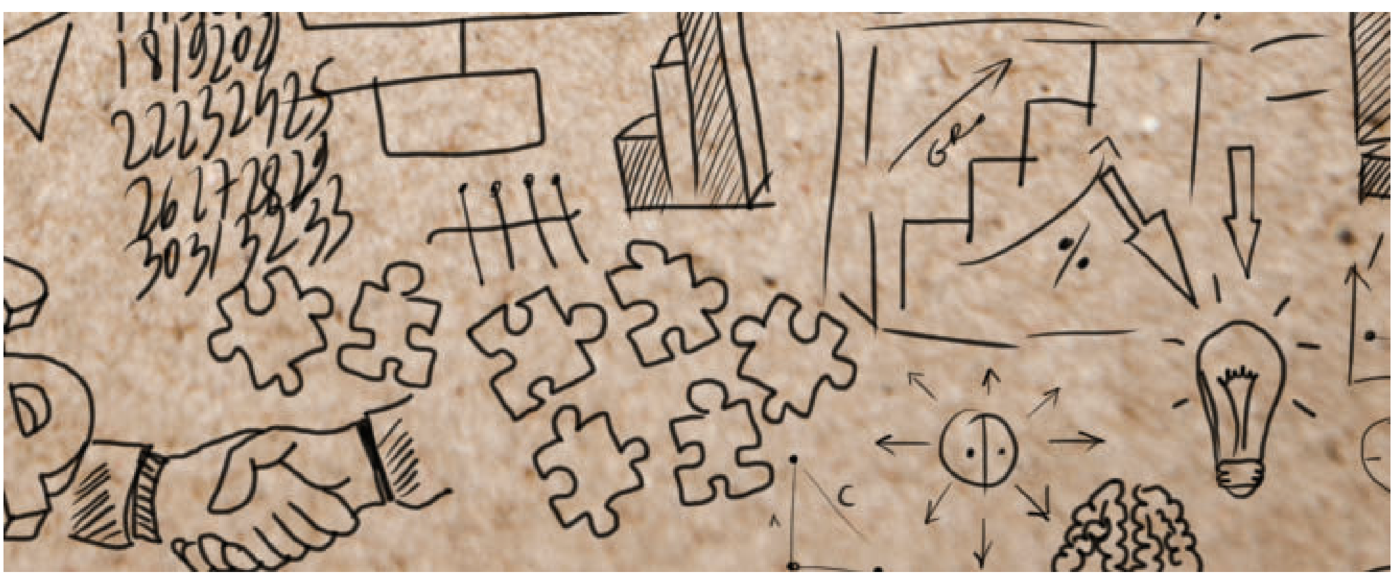
Aesthetics Top Ten

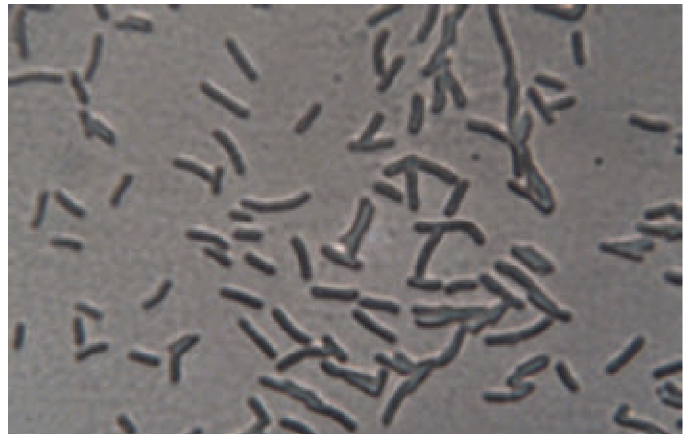
Water Loss Control

CONTENTS

THE Water Research FOUNDATION®

The Water Research Foundation (WRF) is the leading not-for-profit research organization advancing the science of all water. WRF funds, manages, and publishes research on drinking water, wastewater, reuse, and stormwater—all in pursuit of protection of public health and the environment.





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Leading One Water Research and Innovation

Peter Grevatt and Dennis Doll

On September 24 at WEFTEC, The Water Research Foundation (WRF) hosted its annual Subscriber Appreciation Luncheon, the high point of which was the announcement of Dr. Ameet Pinto, Assistant Professor of Civil and Environmental Engineering at Northeastern University, as the winner of the 2019 Paul L. Busch Award. Since 2001, the Award has recognized up-and-coming researchers who are making major breakthroughs in the water quality industry. The theme of this year's Luncheon, "Leading One Water Research and Innovation," was especially fitting considering Dr. Pinto's research on microbial and microbiome science in the world of drinking water.

Managing microbial communities is essential for maintaining the safety of drinking water supplies, the reliability of biological drinking and wastewater treatment, and the sustainability of resource recovery efforts. Current approaches for monitoring microbial communities are time-consuming, and require advanced expertise and expensive instrumentation. While cost and expertise requirements can limit user access to microbial characterization methods, the time gap between sample collection and data acquisition eliminates the possibility of timely interventions informed by microbial data. Overcoming these limitations would revolutionize microbial community monitoring, management, and biotechnology development in the water industry. With the $100,000 prize, Dr. Pinto seeks to develop a modular platform for low-cost and real-time characterization of microbial communities across the engineered water cycle. This platform would advance miniaturized microscopy; portable, real-time DNA sequencing technologies; and the integration of data from these two technologies using deep learning approaches.

Lisa and Jordan Busch were on hand to present this award, given in honor of their late father. Dr. Paul L. Busch led the development of water quality technology for more than 40 years as an environmental engineer. He embodied the spirit of creativity, visionary thinking, and practical application of scientific research. He also believed passionately in the importance of education, devoting much of his time to mentoring the next generation of environmental engineers. From 1994 to 1995, Dr. Busch served as chairman of the Board of Directors of the Water Environment Research Foundation (WERF), and then served as emeritus chairman until his death in 1999. He supported WERF's mission with the same passion with which he had encouraged countless rising engineers and scientists.

The Award is made possible by the Endowment for Innovation in Applied Water Quality Research. The Endowment has provided more than $1.6 million in funding to push ideas on the brink of discovery forward.

Dennis W. Doll
Chair, Board of Directors

Peter Grevatt, PhD
Chief Executive Officer

January 26–29, 2020
NEWEA 2020 Annual Conference & Exhibit
Boston, MA
annualconference.newea.org/

February 3–4, 2020
LIFT Strategic Planning Meeting
San Antonio, TX
(by invitation only)

February 4–7, 2020
NACWA Winter Conference
Atlanta, GA
www.nacwa.org/conferences-events/event-at-a-glance/2020/02/04/nacwa-events/winter-conference

February 10–11, 2020
International Symposium on Potable Reuse
Atlanta, GA
www.awwa.org/Events-Education/Potable-Reuse

February 12–13, 2020
International Symposium on Biological Treatment
Atlanta, GA
www.awwa.org/Events-Education/Biological-Treatment

February 25–27, 2020
ACWA DC2020 – Annual Washington D.C. Conference
Washington, DC
www.acwa.com/events/dc2020/

February 25–28, 2020
WEF/AWWA Utility Management Conference
Anaheim, CA
www.wef.org/Utilitymanagement
OR
www.awwa.org/Events-Education/utility-management

February 4–6, 2020
Pacific Water Conference: AWWA/HWEA 7th Annual Joint Conference
Honolulu, HI
pacificwaterconference.com

March 15–17, 2020
WateReuse California Annual Conference
San Francisco, CA
watereuse.org/event/2020-watereuse-california-annual-conference/

March 15–17, 2020
WEF National Stormwater Symposium
Cincinnati, OH
www.wef.org/events/conferences/upcoming-conferences/nationalstormwater/

March 15–18, 2020
WEF Odors and Air Pollutants Conference
Cincinnati, OH
www.wef.org/events/conferences/upcoming-conferences/odors-and-air-pollutants-conference-2020/

March 15–18, 2020
South Carolina Environmental Conference (SCEC)
Myrtle Beach, SC
www.scwaters.org/page/SCECAbout

March 16–20, 2020
AWWA Membrane Technology Conference
Phoenix, AZ
www.awwa.org/Events-Education/Membrane-Technology

March 29–April 1, 2020
AWWA Sustainable Water Management Conference
Minneapolis, MN
www.awwa.org/Events-Education/Sustainable-Water-Management

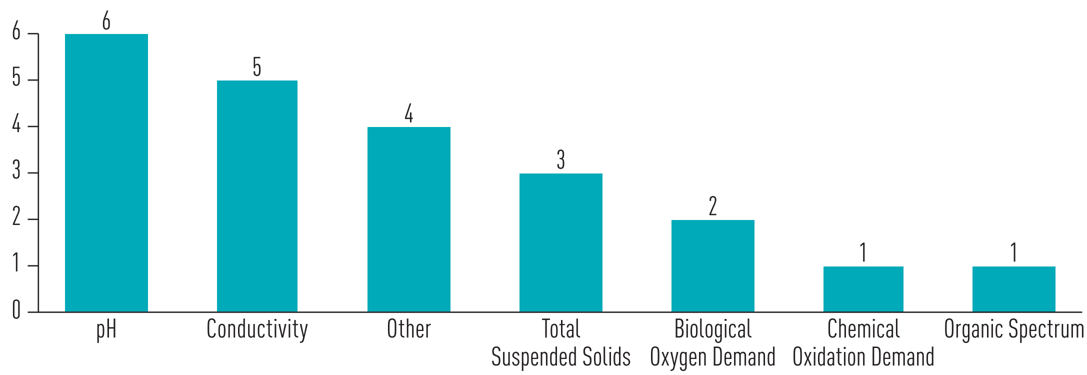
March 31–April 3, 2020
WEF Residuals and Biosolids Conference
Minneapolis, MN
www.wef.org/events/conferences/upcoming-conferences/ResidualsBiosolids/

BY THE NUMBERS

This installment of By the Numbers provides statistics on intelligent water system trends. For more information on this subject, see the article, A Journey into Smart(er) Waters.

As regulatory requirements increase and potential water system disruptions take on greater importance, more utilities are deploying sensors and meters to optimize treatment and offset potential system risks. A survey of 20 wastewater utilities and 20 technology providers elucidated the current state of advanced sensor networks in sewersheds.

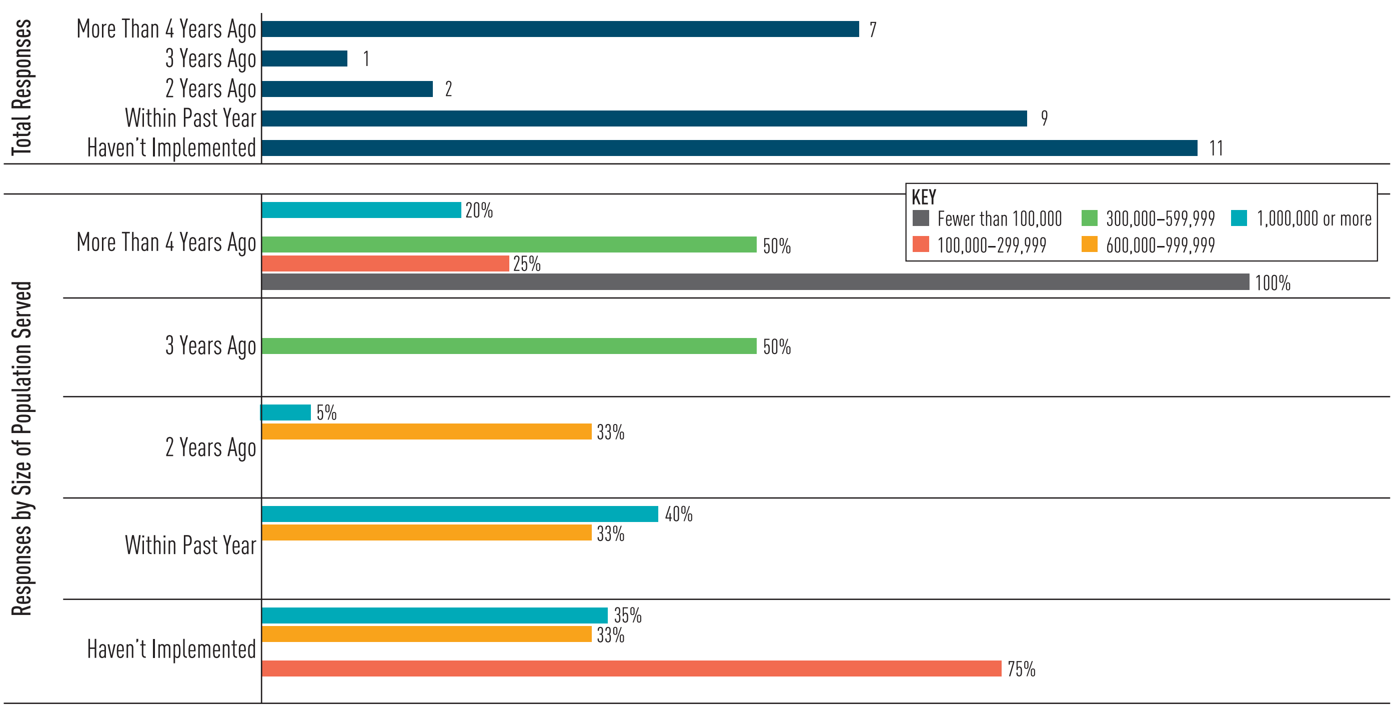
Parameters that surveyed utilities measure using online water quality sensors



Source: Liggett et al. 2018

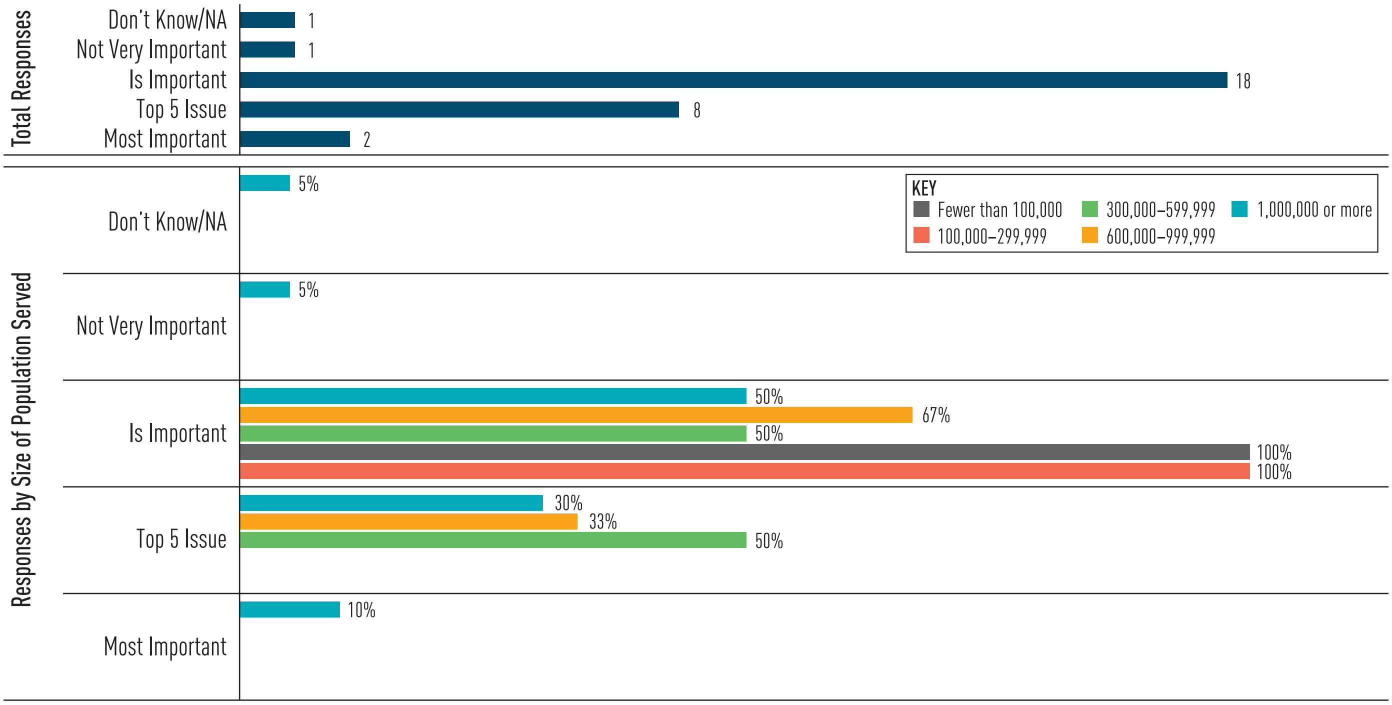
Once a utility has sensors and meters in place, the data starts rolling in. How is this data being managed by utilities? Another survey of 30 utilities gathered information on their capabilities for storage and processing of Big Data (very large volumes of data).

Utilities are implementing components to store and process Big Data on different timelines



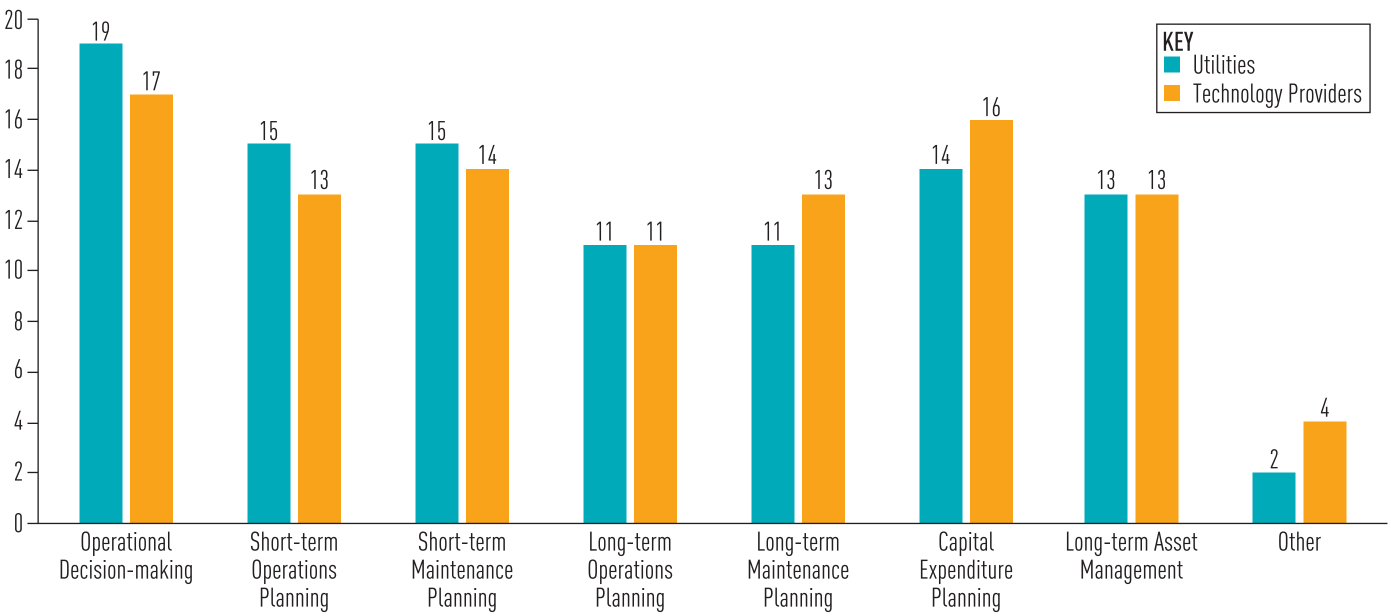
Source: Kadiyala and Macintosh 2018

Importance of Big Data analysis to utilities



Source: Kadivala and Macintosh 2018

Uses of Big Data include operations planning, capital expenditure planning, and more



Source: Liggett et al. 2018

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LIGGETT, J., C. Macintosh, and K. Thompson. 2018. *Designing Sensor Networks and Locations on an Urban Sewershed Scale*. Project SENG6R16/4835. Alexandria, Va.: The Water Research Foundation.

Interview with WRF's Outstanding Subscribers

Leading Utilities Making a Difference in the Sector

At WRF's annual awards breakfast, three utilities were named as WRF's 2019 Outstanding Subscriber Award recipients: Southern Nevada Water Authority (SNWA), San Francisco Public Utilities Commission (SFPUC), and Tampa Bay Water (TBW). This Award honors subscribing utilities that have made notable improvements to their treatment, delivery, and/or management processes through the successful application of WRF research. All three of this year's award winners have been subscribers of The Water Research Foundation for 20 to 30 years, underscoring their long-term dedication and leadership in supporting WRF. Since that time, the winning utilities have participated in over 200 WRF projects in every capacity, including as participating utilities, Project Advisory Committee members, research partners, and Principal Investigators.

WRF interviewed leaders from each of these utilities to learn more about their dedication to applied research.

Southern Nevada Water Authority

Dave Rexing, Water Quality R&D Manager; Eric Wert, Project Manager – Applied Water Quality Research; Eric Dickenson, Water Quality R&D Project Manager

What does winning WRF's Outstanding Subscriber Award mean to SNWA? Rexing: To be singled out among 1,200 utility subscribers is a privilege, and it recognizes the quality of our current and past research projects.

Wert: I think it recognizes years of strong support across multiple levels of the organization. From the general manager and board down to the research team. That support has enabled us to do what we do with respect to applied research.

Can you speak to any of the current WRF projects that you're involved in? Rexing: We're particularly interested in cyanotoxins right now. We're working with Metropolitan Water District on *Refinement and Standardization of Cyanotoxin Analytical Techniques for Drinking Water* (4716). Another important project is *Developing Guidance to Control HABs in Source Water* (4912). We've had a couple of algal blooms in Lake Mead, but luckily for us, we have ozone in place at our plants, which is one of the most effective agents to use against algal toxins.

What other WRF projects have had a large impact for SNWA? Rexing: When you use ozone, if there is any bromide in your raw water supply you can produce bromate, which is regulated at a low level, 10 micrograms per liter. *Effect of Ozone Dissolution on Bromate Formation, Disinfection Credit, and Operating Cost* (4588) investigated this issue and led us to develop a bromate mitigation strategy that we and other treatment plants use to this day.

Dickenson: SNWA has been one of the pioneers in measuring trace organic chemicals, particularly pharmaceuticals, endocrine disrupting compounds, and perfluorinated chemicals, in drinking water and reuse water systems. We have been one of the pioneers in developing those methods, and going out and measuring those levels in drinking water and potable reuse.

Wert: Another interesting one is the Tailored Collaboration project, *Localized Treatment for Disinfection Byproducts* (3103). As a result of that project, we investigated air stripping technologies for trihalomethane removal.

Following the completion of that work, we installed full-scale air stripping facilities in several of our reservoirs. That project had a direct impact to our system.

You've mentioned cyanotoxins. What are some of the other big issues that SNWA is facing where you need more research? Rexing: One that comes to mind is PFAS. It's a critical issue for the water industry because it appears that regulatory limits will be set very low for PFAS. We're investigating, from an analytical standpoint, how you get down to the detection levels necessary to monitor a very low regulatory limit.

Wert: Emerging pathogens are another area of future research for us here at SNWA. We've recently dedicated new research laboratory space so that we can better address issues related to things like *Legionella*, free-living amoebae, antibiotic resistance, and more.

Why do you think research is such a strong part of SNWA's utility culture? Rexing: Our research culture and being on the cutting edge originates with John Entsminger, our general manager, all the way at the top. Unless you have that support, you really can't go anywhere with research.

Wert: Performing applied research allows us to continuously assess our treatment and distribution system capabilities in order to prepare for changing water quality concerns or meeting current or future regulations.

Dickenson: Research helps us address public inquiries about emerging topics. When we get questions from the public, we can address them appropriately as far as state of the science knowledge on that topic.

Thinking more about the direction that the water sector is heading right now, this move toward One Water, what do you see as the future of the water sector? Rexing: I see improved public perception of the water sector. Research brings about discoveries of low-level contaminants, etc., but if you aggressively find solutions, that raises the public's perception of us. The public is beginning to understand that we can turn wastewater into potable water without concern for contaminants long-term, and that has a positive effect on public perception.

San Francisco Public Utilities Commission

Michael Carlin, Deputy General Manager and Chief Operating Officer

San Francisco Water Power Sewer

What does winning the WRF Outstanding Subscriber Award mean to SFPUC? It's nice to be recognized by our colleagues, that we have been out there on the cutting-edge of research with WRF. For my colleagues who have been working on these projects over the years, it means a lot to know their projects are of importance and are adding value to the total knowledge base.

Are there any current projects that you are working on with us that you are particularly proud of or excited about? *Long-term Vulnerability Assessment and Adaptation Plan for SPFUC* (4703) focuses on climate resiliency and its impacts on our water supply. It's going to have repercussions for anybody who depends upon snowpack for water supply. *Building-Scale Treatment for Direct Potable Water Reuse* (4691) is looking at implementing direct potable reuse in our building as a way to stretch our water supply.

What are some of the biggest issues that SFPUC is facing, or will face in the future, where more research is needed? We are always facing the issue of emerging contaminants. PFAS and things of that nature are starting to play on everybody's mind. What are their sources, how do we control them? As we get into the future there will be more and more water scarcity, and there will be more water reuse, more efficiency quotas placed on the use of water. I believe that at some point in the future there will be two pipes in every dwelling unit, one serving reuse water and one serving drinking water.

Let's not forget the environment. We always talk about water for people and reuse water, but we need to have water in the environment to maintain our ecosystems and keep them healthy.

Can you speak a little bit about this trend in the water sector to move in the direction of One Water, to treat all water holistically, and how SFPUC sees that trend? We've embraced the One Water philosophy. SFPUC has a water enterprise, a wastewater enterprise, and a power enterprise. You look at it holistically: Are we putting our resources to the best use? When you consider reuse water in a building, is that a wastewater project or a water project? It's both, and you bring both parties to the table.

How has SFPUC used WRF research to further its goals over the years? WRF research is helping us stay on the cutting edge, and it brings real science to bear on some of these issues. Whether they're pure science issues, social issues, or economic issues, all of them break down to people needing to have information to believe the utility is doing the right thing and moving in the right direction.

Are there any past projects that stick out in your mind as particularly impactful for SFPUC? *Advancing and Optimizing Forested Watershed Protection* (4595) was very helpful. We have a watershed up in the Sierra Nevada Mountains that belongs to the federal government. We had a devastating forest fire in 2013, and we learned a lot from that research, which is also being utilized by our natural resources division.

We already spoke briefly about the direction of One Water. Do you have any other big-picture ideas about where you see the water sector going in the future? One of the issues I'm involved in right now is the access to clean, safe drinking water. It's a big issue here in the State of California. How can we ensure that everybody in the United States has access to safe, clean, affordable drinking water? There's got to be some innovation that we can do, like small-scale treatment plants, there's got to be something with consolidation. We need to address that issue, because we have a population that's very vulnerable to exposure to chemicals that they have no ability to control or treat. I think that's just a tragedy.

Tampa Bay Water

Ken Herd, Chief Science and Technical Officer

What does winning the Outstanding Subscriber Award for Applied Research mean to Tampa Bay Water? It is an honor to be recognized. Our Board of Directors is committed to using applied research to make data-driven decisions. This award recognizes Tampa Bay Water staff for their involvement in research projects and initiatives, which is important to attracting and retaining talent in our industry.

Are there any past WRF projects that TBW has been involved with that had a large impact? The most notable are the Tailored Collaboration projects that helped us implement our master water plan and successfully develop the new types of water supplies needed to meet the regional demands that created Tampa Bay Water 20 years ago. Examples include *Effects of Blending on Distribution System Water Quality and Control of Distribution System Water Quality Using Inhibitors* (2702) and *Decision Process and Trade-Off Analysis Model for Supply Rotation and Planning* (3003). This research provided science-based assurance to our region that new water sources (surface water and desalinated water) could be successfully integrated into our system. We were able to blend groundwater, surface water, and desalinated water into a high-quality product that we deliver our customers.

Are you involved in any current WRF projects? TBW is involved in *Multi-Objective Evolutionary Algorithm Application Guidance for Utility Planning* (4941), which is developing a decision support tool that assesses complex system tradeoffs for integrated water supply planning. It helps the user consider climate change, infrastructure vulnerabilities, demand uncertainty, and changing social values. We are also participating in two other WRF projects: *Risk Management Frameworks and Tools for Managing Source Water Risks* (4748) and *Decision Support Framework for Water Treatment Plants* (4920). These multi-utility projects are developing and testing approaches to help drinking water utilities address short- and long-term changes to source water quality including treatment and protection challenges.

When you talked about past projects, you mentioned diversifying your water sources. Are there other ways that TBW has used WRF research to further your goals? We've had several projects in the past related to demand management and water use efficiency, and there's been a lot of critical research that was done. Looking at tools that utilities can use to track and improve water efficiency has grown for us into a demand management program that's pretty impressive. That's a critical side of water: not only treating and providing clean, safe water, but also reducing demand for water where you can. We have also participated in and used WRF research to address specific water quality treatment and communication challenges. And that involves all different levels of research activities with The Water Research Foundation.

Do you have any thoughts on the water sector moving in the direction of One Water and integrated water resources overall? Yes, we're strongly supportive of that. We've got to effectively manage these resources today. All of our water resources must be looked at collectively if we're going to manage water in the most efficient and effective way possible. Tampa Bay Water is a good example of regional cooperation that can be a model for other communities throughout the country. We're looking at multiple sources of water for our drinking water supply, so we have a very diverse portfolio of water supply options.

Do you have any additional thoughts about the future of sector? The industry needs to figure out how to attract new talent. We're facing this challenge of aging—not only aging infrastructure, but aging employees. How do we attract talented scientists and engineers? TBW believes that offering not only direct application of science and technology, but the opportunity to be involved in research and cutting-edge projects, is a good way for us to attract new employees. That's one of the most critical future challenges most utilities are facing—how do we sustain our human resources moving forward?

Are you currently implementing any efforts toward that end? We have several internships. We are also developing career ladders through our human resources department so we can challenge employees throughout the agency to continue to improve themselves and strive to enhance their qualifications. We are also looking at ways to steer employees who want to be on a management track versus a technical science track. If you're a good scientist or engineer, there's a career here for you at Tampa Bay Water. You don't have to be a manager to be successful. You can be a successful chief scientist or a chief engineer.

A Journey into Smart(er) Waters: The Great Lakes Water Authority's Experience and Approach to Smart Water Systems

The phrases "smart water," "intelligent water," and "digital twin" are being increasingly mentioned in the water sector.

By John W. Norton, Jr., Bryon Wood, Biren Saparia, Steven Jin, and Laura Radtke
Great Lakes Water Authority

Some early adopters of smart water technologies have invested a lot of money and effort into these systems without gaining much added value. However, when properly applied and implemented to meet utility goals and needs, smart water systems can provide useful information, analysis, and decision-making guidance for utility management and operations.

The Great Lakes Water Authority (GLWA) provides drinking water to nearly 40 percent of Michigan's population, and wastewater services to nearly 30 percent of the state, approximately 4 million and 3 million people, respectively. GLWA has experienced the entire range of potential outcomes with our smart water system efforts. Our experiences, suggestions, and recommendations can help improve outcomes for other utilities as they chart their courses into the future of smart water systems. This is our smart(er) water story.

Smart Water Systems

SMART WATER SYSTEMS aggregate and analyze disparate data to provide guidance that may otherwise be missed or hidden. Essentially, they convert water-related data into information, and that information into decision-making wisdom.

Typical data sources are the assets, sensors, meters, control settings, and costs inherent in utility operations. These data sources cover essentially the entire range of data types encountered by water professionals. Other sources of data can include state and federal weather agencies, local power companies, satellites, local and regional government agencies, and water utility customers and rate payers. Considerations for data collection include complexity, frequency of collection, cost of measurement, and value obtained. Another important parameter is the granularity of the data in both time and space.

These data are aggregated, verified, and analyzed to provide guidance to managers and operators. There are many uses for smart water technologies, including power monitoring, pressure sensors, and spatial data.

Power Monitoring

UTILITIES CAN SUBMETER THEIR electrical systems to gain insight into cost and performance issues. Very precise power meters are more expensive, and can be used to detect and diagnose power quality issues. Less precise power meters are not useful for power quality monitoring, but are helpful for energy management strategies and assessment of electrical motor efficiency. Least granular of all, instead of submetering their systems, utilities can utilize energy use data from electrical providers to assess and reduce energy costs via peak shifting and peak shaving. GLWA is currently upgrading all of our electrical meters to "power quality" measurement capability.

Pressure Sensors

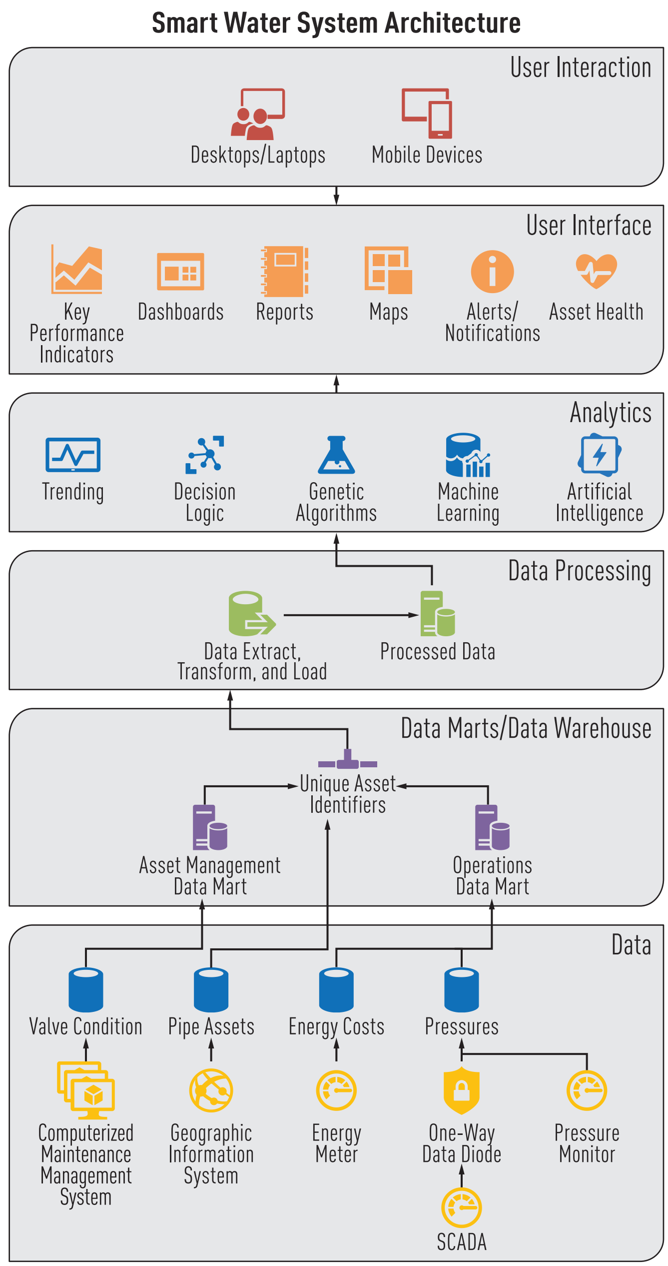
PRESSURE SENSORS RANGE IN capability and measuring frequency. GLWA is installing advanced sensors and associated data recording systems to detect and measure pressure transients. We are also actively participating in the WRF project, *Utilizing Smart Water Networks to Manage Pressure and Flow for Reduction of Water Loss and Pipe Breaks* (Karl, forthcoming). We plan to use data on transients to reduce pipe failures resulting from short-duration surges in water pressure.

Spatial Data

MAPS AND DATA TOGETHER TELL strong stories. Displaying spatial data, especially combined with near-real time operations information, can quickly inform both internal and external stakeholders of the status of a water network. GLWA's geographic information system (GIS) data has improved greatly in recent years, and GLWA has begun building map-driven smart applications with the combined power of GIS and operations data. For example, mapping of GLWA's sewer conveyance system combined with supervisory control and data acquisition (SCADA) systems and precipitation radar data provides operators with a system-wide view of potential capacity issues, allowing them to strategically direct flow during wet-weather events.

GLWA's Experience with Smart Water Systems

GLWA'S APPROACH TO SMART water systems is to first determine what key decisions and guidance we need to improve service levels and efficiencies. We then assess the available data, the benefits that could be achieved through smart water systems, and how technology might be able to support our decisions. If we start with the technology itself,



Courtesy GLWA

Figure 1. GLWA's smart water system architecture

we can lose sight of the original goal or issue we are trying to support. The benefits and challenges GLWA has experienced thus far in our journey into smart water systems is shaping our pioneering, yet grounded, approach towards delivering real value to our organization and our partners.

GLWA's Smart Water System Architecture

IT IS KEY TO FIRST ESTABLISH THE architecture needed to support a smart water system, building a foundation to support data collection, processing, and analysis. GLWA's ideal architecture, which is in the process of being established, is shown in Figure 1.

A key step in architecture development is determining what data are needed to support decision-making. These data likely reside in disparate databases.

Loading this data into a data mart or data warehouse framework allows for streamlined access by the smart water system. GLWA prefers a data mart framework with multiple databases built-for-purpose for reporting and smart water system use. For instance, a unique data mart is established for all asset maintenance and condition data, while another one is developed for the asset operations data. This approach allows increased flexibility for schema changes and data application, as well as tailoring to data types (e.g., spatial, finance, time-series, etc.).

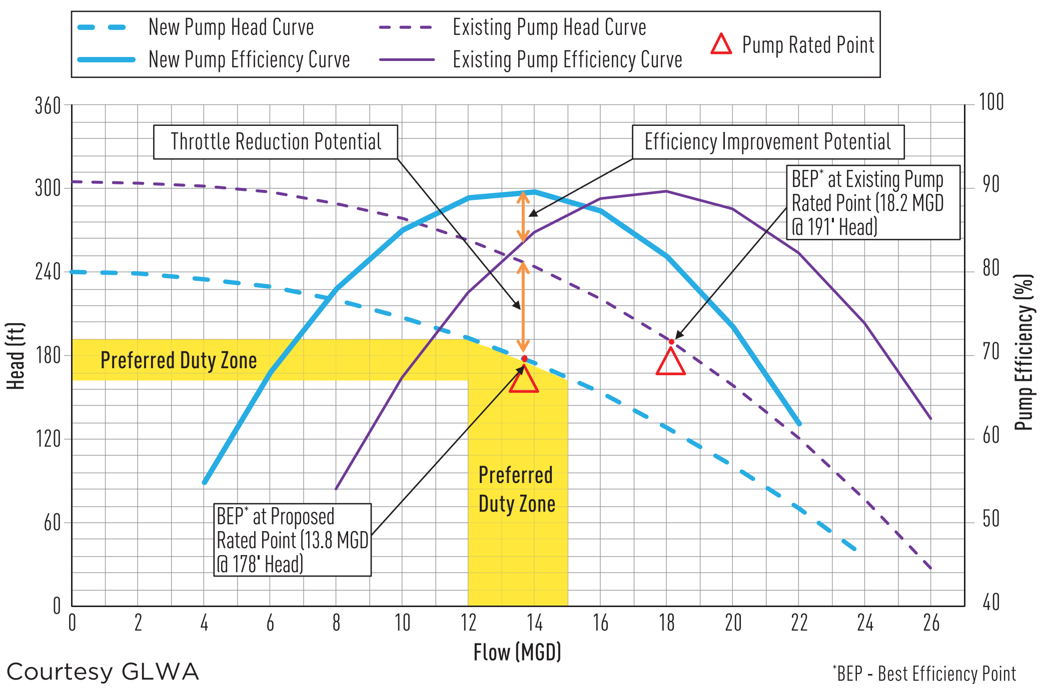
Once the data are in a data mart format, an analytical layer is prepared. Having an analytical layer between the data and the user interface can help address challenges such as imperfect data due to sensor anomalies or data gaps from communication outages. The analytical layer is divided into two phases: data processing and analytics. Data processing provides data transformation, smoothing, and gap handling (e.g., averaging pressure values across short data gaps) to prepare the data for better results during the analytics phase. During the analytics phase, data are converted into information to support decision making. Common analytics in the water sector include decision logic, trending, genetic algorithms, and machine learning.

Finally, an interactive user interface consisting of performance indicators, reports, dashboards, and/or mapping can be developed to summarize, alert, and advise on the processed data. Without all of the previous layers, the information and knowledge gleaned from the system may be misrepresented. Having a solid foundation of data and information that can be counted on allows for valuable and trustworthy insight and communication to stakeholders.

Real-Time Efficiency Evaluation for Pump Stations

GLWA IS PUTTING CONSIDERABLE focus on improving pumping energy efficiency. GLWA pays about $25 million per year for electrical energy used within our potable water treatment and distribution systems. More than 90% of that energy is used for pumping. To improve pumping efficiency, GLWA developed the real-time efficiency evaluation for pumping stations (REEPS) project. As part of REEPS, GLWA will evaluate real-time efficiency for each of the 120 pumps in our 19 water booster stations. REEPS is currently being implemented at two pump stations, Adams Road Station and Franklin Station, each of which contains 6 booster pumps.

The REEPS project installs smart meters at the stations, including a



Courtesy GLWA

Figure 2. Original Adams Road Station Pump L4 curve vs resized pump curve

station flow meter, a power monitoring meter, and a differential pressure meter for each pump. Real-time pump efficiency is a value of pump output energy (hydro energy) as a function of input energy (electrical energy), also known as wire-to-water efficiency. To assess real-time pump efficiency, real-time pump flow rate is required to compute pump output energy.

A differential pressure meter, which records real-time pressure differentials between the system sections upstream and downstream of the pump, and the calibrated pump head characteristic curve were used to compute values of real-time pump output energy. The pump station flow meter was used to calibrate the pump head characteristic curve for each pump when only that pump was on duty.

For each station, a dashboard was developed to display real-time pump efficiencies. Based on historical pump efficiency values over a 6-month period, an optimal-efficiency line is shown on the dashboard as an operational reference for the operators.

The Adams Road Station's 2018 real-time pump efficiency values were used to assess the performance of pumps. Pump L1, the only variable frequency drive pump in the station, was overused to reduce line pump discharge valve throttling. Pump L1 ran about 75% of the run-time of all the line pumps. Due to changing demand conditions in the system, the three other line pumps are over-capable and throttled at the pump discharge valves. It was found that Pump L4 had the lowest pump efficiency.

To improve pump efficiency, Pump L4 was resized to its best efficiency point. Figure 2 shows the pump head characteristic curve change resulting from the resizing. The refurbished pump has increased pump efficiency by 12% (from 68% to 80%) and reduced run time of the overused Pump L1 by 50%. Moving pump operations closer to the optimal efficiency point and reducing pump degradation conditions resulted in an annual energy savings of about 7%.

GLWA's RPO program is expected to reduce electricity use by 3% to 8%

Real-Time Pumping Optimization Program

PUMPING WATER IN GLWA'S drinking water system consumes over 200,000 megawatt hours (MWh) of electrical energy annually. This costs about $23 million, and is one of the largest controllable costs for operating GLWA's system.

GLWA's real-time pumping optimization (RPO) efforts for the system can be tracked back over 10 years. An RPO feasibility study was completed in 2007 through the Detroit Water and Sewer Department's (DWSD's) energy management plan. The feasibility study suggested RPO will optimize pumping scheduling in the following ways:

- Reduce energy costs related to DTE Energy's tariff
- Reduce electricity peak demands by improving pump efficiency and optimizing use of stored energy
- Optimize water transmission paths to reduce pumping requirements

The initial RPO program development efforts were based on feasibility studies that used a genetic algorithm (GA) optimization engine. GA is an evolutionary algorithm that can take a long time to search for the optimum solution. Due to the size of DWSD's system, the GA optimization engine took over a day to generate an optimal pumping schedule. This performance was not practical for RPO, and the efforts were put on hold.

In early 2019, GLWA resumed the RPO program by introducing two new critical smart water technologies, which: (1) improved the calculation time of the optimization engine to get very fast (fewer than 15 minutes) near-optimal pump scheduling; and (2) used an improved water model, which included very detailed water demand, pipe flow, and pressure values for the system.

GLWA is attempting to use cloud-based parallel computing technology to allow the GA calculation to be completed in a short enough time to be used for real-time operations. GLWA is also appraising another real-time feasible optimization engine that uses linear programming combined with non-linear programming. Unlike the GA optimization engine, a linear programming engine requires a feasible pumping schedule as a starting point to complete final pumping optimization.

GLWA's RPO program is expected to reduce electricity use by 3% to 8%. Assuming a 5.5% electricity saving, this corresponds to 13,200 MWh of electricity. Using an average greenhouse gas value of 0.5425 short tons of CO_2 per MWh of electricity production assessed by U.S. Department of

Energy (DOE 2016), over 7,000 tons of CO_2 emission could be eliminated if GLWA implements the RPO program.

Pressure Transient Monitoring

TO MONITOR AND REDUCE pressure transients in GLWA's water transmission system, GLWA has installed 26 Telog PR-32i insertion pressure recorders in our water transmission system to capture transient data. Twenty-four of them are installed in 11 pumping stations; the other two devices are installed in valve pits. Each pumping station has two PR-32i devices installed, one at the suction side and the other at the discharge side. Some stations have two discharge headers; therefore, three monitoring devices were installed in these stations in order to have a device at each discharge header.

The PR-32i devices record a pressure transient event when the pressure difference (either increasing or decreasing) reaches 15 pounds per square inch or more in one second. The pressure impulse data sampled by PR-32i devices is wirelessly downloaded to Telog's host computer server. To ease evaluation of pressure transient conditions, GLWA developed a custom application program interface (API) to pull the pressure impulse data from Telog's host server and push the data to GLWA's SCADA database. GLWA is planning to implement a web-based application to display and alert on the downloaded transient monitoring results in real-time.

Over 25,000 pressure transient events have been recorded to date. After investigating the pressure transient monitoring records, GLWA found that the major causes of pressure transients include power quality issues, pump trips, fast pump closing, and valve operations. By changing some operational procedures, GLWA has reduced the frequency of pressure transient events in specific pumping stations that had high transient frequency. GLWA plans to install additional pressure transient recorders to more thoroughly monitor pressure transients throughout the entire transmission system.

> The quality of the data drives the quality of the solutions

Principles for Using Smart Water Systems

TO ENSURE EFFECTIVE USE OF resources, it is imperative to identify distinct utility issues, define a specific purpose, and develop a clear business case prior to pursuing smart water technologies. Distinguish where the system issues or conditions (e.g., energy quality, transient pressures, water quality, pump and valve operations, etc.) have correlations and relationships that would benefit from a single smart water system to find trends and opportunities to solve the issues. This approach reduces the number of technology systems that need to be supported and maintained.

The quality of the data drives the quality of the solutions. Vendors might be willing to scrub a utility's data, but each vendor will use different methods and algorithms, and results may vary between vendor offerings. Utility managers should predefine data needs, sources, and quality, and use predefined data processing methods to prepare a standard data set for evaluation and comparison. Understanding and preparing the data ahead of time will pay dividends when a utility implements its next smart water system.

Where possible, smart water system pilot and feasibility studies should not be solely vendor-led. Instead, they should be partnerships, with the utility providing strong business cases and data validation, and the vendor providing analytical engines and user interfaces. Utility champions should lead the way in setting up the systems and data architecture in a way that allows vendor software to be built on top of this foundation.

Smart water solutions cannot replace key human qualities such as intuition, perception, and decision-making abilities. However, smart water technologies will be part of most utilities' futures, allowing utility decision makers to have new insights and awareness.

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RESEARCH
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Guiding Our Future Research Agenda

In April 2019, The Water Research Foundation conducted a survey of our subscribers and research partners to gather input on priority research needs to help guide our future research agenda.

By Katie Henderson, Jeff Moeller, and Brenley McKenna, The Water Research Foundation

W**RF's Research Needs** Survey is a key information source that we will use to shape our research priorities over the next few years. Responses were segmented into three categories: utility subscribers, consultant subscribers, and research partners. Research partners included academics; federal, state, and local government agencies; water sector organizations; foundations; and more.

We designed the survey so that respondents could distinguish between near-term, mid-term, and long-term research needs. The survey included a few demographic questions (e.g., location, position, organization type). We then asked respondents to consider 25 research topics, and indicate whether there is a research need for each topic in the near-, mid-, and/or long-term. Each utility respondent was asked to indicate the need for research for both their individual utility and for the water sector as a whole, while the consultants and research partners were asked to consider only the water sector. All three groups were also able to write in suggestions of research topics for WRF to consider for the future.

Quantitative Results

RESPONDENTS WERE GIVEN THREE weeks to fill out the survey, and 451 surveys were completed. Two hundred and sixty five responses were from utilities, 110 were from research partners, and 76 were from consultants. Of the utility respondents, the majority reported that they provide drinking water and/or wastewater services, although a number of utilities also provide other services, including water reuse

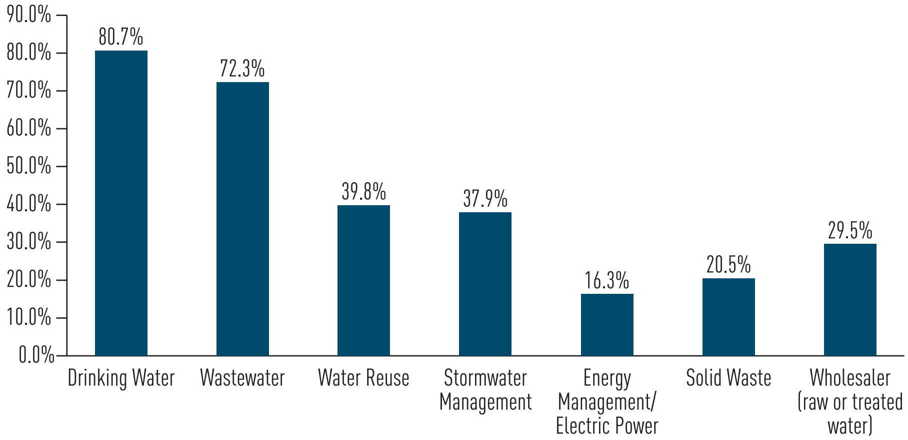

Figure 1. Types of service provided by utility respondents

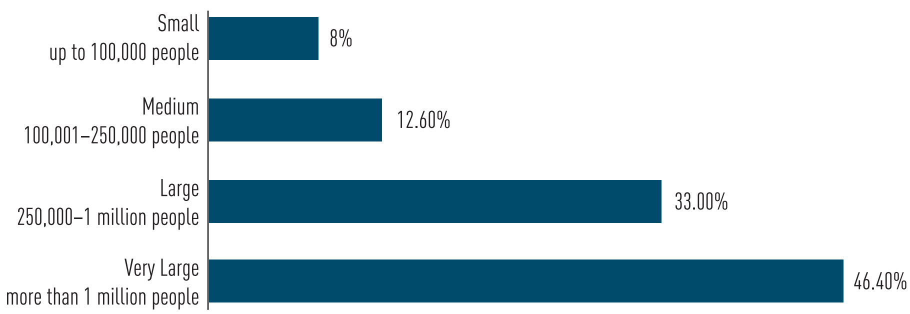

Figure 2. Utility respondents by population served

(Figure 1). Note that utility respondents may provide more than one type of service.

While a large majority of respondents were from the United States, we also received responses from Canada (10%) and Australia (5%). There was one respondent each from Denmark, New Zealand, South Africa, and the United Kingdom.

Utilities were grouped into four size categories based on the size of the population they serve: small (up to 100,000 people), medium (100,001–250,000 people), large (250,000–1 million people), and very large (more than 1 million people). Over half of the utility respondents were from utilities serving over 500,000 people (Figure 2).

There was some variation in perspectives based on respondent types (utility, consultant, research partner) and utility type (drinking water, wastewater, reuse, etc.); however, there was broad consensus on the top near-term research needs: asset management, climate change and resilience, deteriorating infrastructure, harmful algal blooms/cyanotoxins, lead and copper management, per- and polyfluoroalkyl substances, and workforce planning (Table 1).

Overall, utilities identified similar near-term research needs independent of size category. Asset management, climate change and resilience, deteriorating infrastructure, and workforce planning were identified as the most important near-term research needs. However, medium utilities identified asset management as a need only at the utility level; while small, large, and very large utilities felt it was a need for the entire water sector as well. Very large utilities identified climate change and resilience as a primary need for both the utility and the water sector; while small, medium, and large utilities felt it was a need for the water sector only.

There was little overlap between the top mid- and long-term utility-level needs and water sector needs. The top mid-term utility-level research needs identified were

Table 1. Top-rated near-term research needs by respondent type

Research Need	Utilities (utility issues) n=265	Utilities (water sector issues) n=265	Research Partners (water sector issues) n=110	Consultants (water sector issues) n=76
Asset Management	59.3%	59.8%	28.9%	56.9%
Climate Change and Resilience	43.3%	58.8%	56.6%	63.0%
Deteriorating Infrastructure (e.g., Collection/Distribution Systems)	58.8%	69.6%	57.6%	66.3%
Harmful Algal Blooms/Cyanotoxins	35.2%	50.9%	54.4%	58.3%
Lead and Copper Management	31.1%	52.1%	51.5%	42.9%
Per- and Polyfluoroalkyl Substances (PFAS)	36.8%	53.9%	44.3%	62.0%
Workforce Planning	55.6%	56.1%	25.8%	40.8%

energy management, water efficiency, disinfection byproducts, and intelligent water systems & smart water networks; whereas, the mid-term sector needs identified were watershed management and stream restoration, resource recovery, and water efficiency. Potable reuse and CECs/trace organics were the highest scoring long-term needs at the utility-level, with desalination and source separated organics as the highest scoring needs at the sector-level.

Write-in Results

RESPONDENTS HAD THE opportunity to write in additional priority research topics that they think WRF should address in the next few years. The responses were analyzed using thematic analysis and deductive coding. The steps of this kind of analysis are:

1. Becoming familiar with the data: reviewing all of the responses
2. Coding: identifying topics that could be used to group responses together
3. Identifying themes: counting the responses related to each code to determine which codes had significant numbers of responses
4. Analyzing results and writing the narrative

Table 2 lists the topics that were used to code the individual write-in responses.

We received write-in responses from 28% of the consultants, 34% of the research partners, and 40% of utilities. Many, if not most, of the respondents included more than one topic in their responses. In order to capture all of the distinct suggestions, individual responses that included multiple topics were split into separate answers for coding and analysis. After splitting the answers, a total of 189 priority research topics were identified from utilities, along with 51 from research partners, and 34 from consultants.

Priority Write-in Research Needs

FOR THE WRITE-IN QUESTION, there was more variation in responses

Table 2. Write-in response codes

Affordability/Social Equity	Lead and Copper Management
Asset Management	Microplastics
Biosolids	Nutrient Management
CECs/Trace Organics	Odor Control
Climate Change	Per- and Polyfluoroalkyl Substances (PFAS)
Communication	Resource Recovery
Data Management	Source Separated Organics (i.e., Co-digestion with Food Waste)
Deteriorating Infrastructure	Stormwater and Flood Management
Digestion/Dewatering	Technology/Innovation
Disinfection	Treatment Process/Optimization
Disinfection Byproducts	Utility Finance and Management
Distribution & Collection System Management and Water Quality	Water Demand Management and Forecasting
Ecosystem Services/Sustainability	Water Loss Control
Emergency Preparedness	Water Quality
Energy Management	Water Reuse
General Wastewater and Drinking Water	Water Supply Planning
Groundwater Management	Waterborne Pathogens in Distribution and Premise Plumbing Systems
Harmful Algal Blooms/Cyanotoxins	Watershed Management
Integrated Planning/One Water	Workforce Planning
Intelligent Water Systems & Smart Water Networks	

based on respondent type than there was for the quantitative questions. For example, research partners provided more reuse-related responses than the other two groups. Utility finance and management was a top response category for utilities and consultants, but not research partners. All three groups listed topics related to compounds of emerging concern (CECs), technology/innovation, treatment process/optimization, and climate change as top response categories. Other common topics included watershed management, communication, and distribution/collection system management.

Certain topics could potentially be grouped together, and if they were, they would represent a much larger share of the results. For example, per- and polyfluoroalkyl substances (PFAS) and microplastics were coded separately from CECs/trace organics. If they were combined into a single category, they would be the highest response category among utility responses. The same pattern would occur if watershed management and stormwater/flood management were combined; or if utility finance and management, communication, and affordability/equity were combined. This is to say that these rankings based on count should be viewed with care; the way the data are grouped influences how important certain topics appear. presents the count of responses for each topic.

Figure 3 shows the number of write-in responses for each research topic, based on respondent type.

Table 3. Count of responses for each research topic (all respondent types)

Topics	Count
Technology/Innovation	24
Treatment Process/Optimization	24
Communication	20
CECs/Trace Organics	20
Watershed Management	19
Asset Management	17
Water Reuse	17
Climate Change	13
Utility Finance and Management	12
Per- and Polyfluoroalkyl Substances (PFAS)	11
Distribution & Collection System Management and Water Quality	8
Stormwater and Flood Management	7
Water Demand Management and Forecasting	6
Intelligent Water Systems & Smart Water Networks	6
Lead and Copper Management	6
Emergency Preparedness	5
Ecosystem Services/Sustainability	5
Resource Recovery	5
Integrated Planning/One Water	5
Affordability/Social Equity	5
Water Loss Control	4
Waterborne Pathogens in Distribution and Premise Plumbing Systems	4
Energy Management	4
Workforce Planning	4
Biosolids	4
Data Management	2
Nutrient Management	2
Water Quality	2
General Wastewater and Drinking Water	1
Microplastics	1
Disinfection Byproducts	1
Water Supply Planning	1
Grand Total	265

Conclusions

ONE STRIKING OBSERVATION about these data is that overall, the top priority research topics in both the quantitative and the write-in survey results seem to reflect our current research portfolio well. For example, we have existing Research Areas on PFAS, cyanotoxins, water reuse, and lead and copper management. Technology/innovation was a top issue in the write-in data, and our Leaders Innovation Forum for Technology

(LIFT) is specifically designed to identify, evaluate, and advance the uptake of innovative technologies and processes.

However, other highly rated topics, such as asset management, communication, watershed management, utility finance/management, workforce, and climate change will be considered as future research areas based on this feedback. Additionally, past research that WRF has conducted on these topics will be compiled, and subscribers and partners will be informed of this existing research.

The survey results, along with other inputs such as perspectives from our Research Advisory Council, Public Council for Water Research, and Academic Council, will help shape our research priorities moving forward. WRF is dedicated to advancing the science of water to support the entire water sector, and we depend on the feedback and support of our research partners and subscribers. We want to thank everyone who participated in this survey, and invite you to contact us if you have any questions about the survey or future research needs.

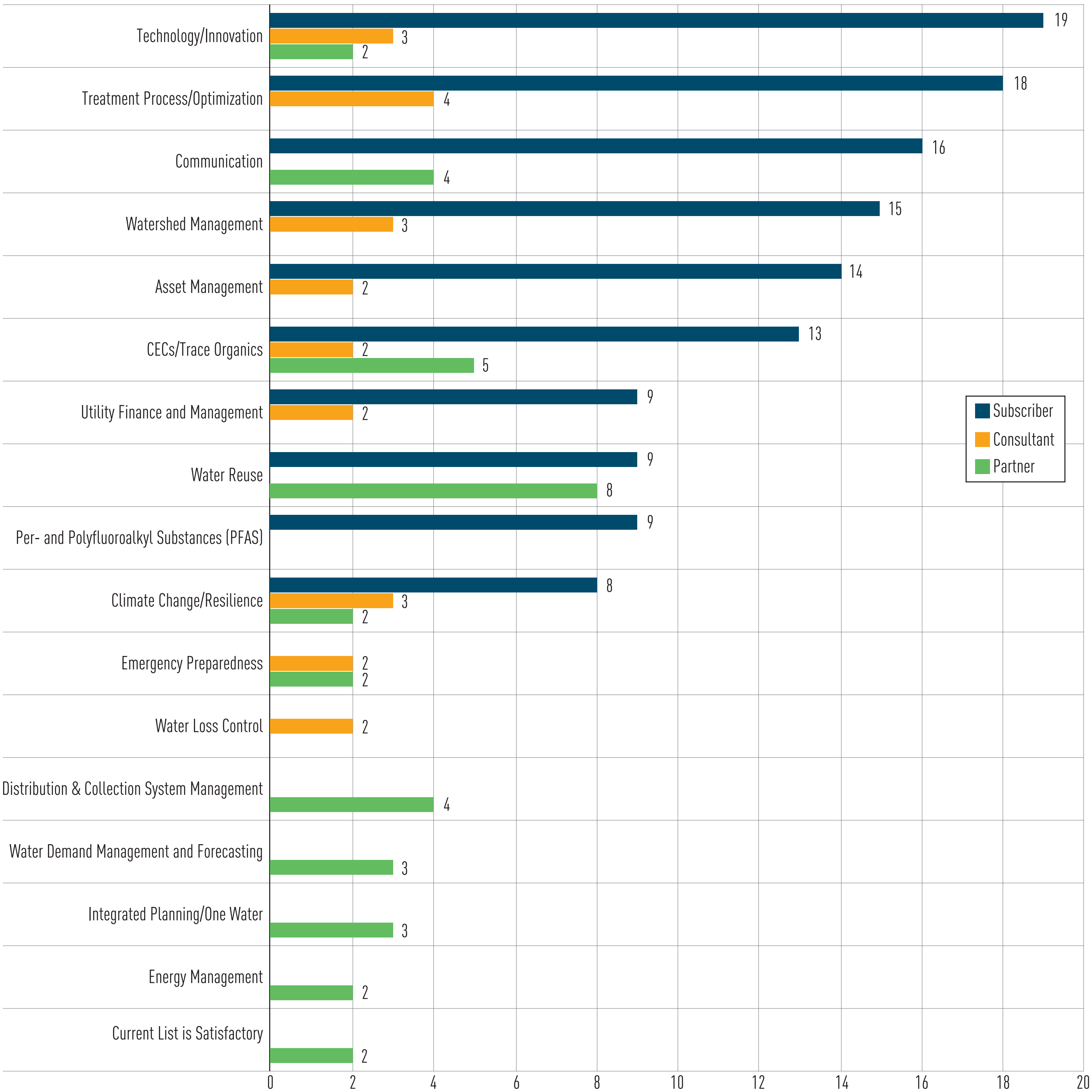

Figure 3. Top write-in priority research topics

Aesthetics Top Ten

There are ten key reasons why every utility should pay attention to tap water aesthetics, and focus on consumer satisfaction with water quality at the tap.

By Gary A. Burlingame, Philadelphia Water Department; Andrea M. Dietrich, Virginia Tech; and Djanette Khiari, The Water Research Foundation

The Water Research Foundation provides utilities with a wide range of resources, such as reports, web tools, and webcasts, for improving the taste and odor (T&O) quality, and overall aesthetics, of drinking water. This work dates back to the 1980s when the U.S. Environmental Protection Agency (EPA) set Secondary Maximum Contaminant Levels for inorganic or physical parameters, such as iron, copper, manganese, pH, and total dissolved solids, that can affect tap water's aesthetics (EPA n.d., Dietrich 2015). The chlorine residual in tap water was already known to affect water's flavor. However, while blooms of cyanobacteria and algae in surface waters had long been a nuisance, the organic chemicals released by cyanobacteria and algae that caused odors and made drinking water aesthetics objectionable were a mystery. The integration of modern chemical, biological, and sensory analytical techniques provided an opportunity to study the volatile organic chemicals, including algal and cyanobacterial metabolites, that gave tap water an unacceptable smell. Two prominent odorants that were discovered in water are geosmin and 2-methylisoborneol (2-MIB). These naturally occurring chemicals were found to be leading causes of earthy/musty odors in all types of surface waters, worldwide, at low ng/L levels. Figure 1 shows the full range of distinct tastes and odors.

Aesthetic issues, along with years of openly polluting the nation's waterways, the heavy dosing of chlorine to compensate for contaminated source waters, and a lack of strong national regulations, led to a distrust in tap water's safety and palatability. Since the 1980's bottled water marketing and sales skyrocketed in the United States as tap water quality was questioned. Water utility managers needed to understand the aesthetic quality of water and how to manage it. Many water utilities tend to be more reactive in their approaches to addressing aesthetics and related consumer concerns.

After several decades of research, the aesthetics of drinking water are better understood and remain very important. However, more work is needed to understand consumer perceptions and concerns, especially given contemporary challenges of increased water shortages, flooding, boil water notices, and publicized chemical and microbial contamination events.

Here are 10 reasons why utilities need to proactively manage the aesthetic quality of drinking water:

1. **Water Reuse:** While wastewater can be processed to meet drinking water safety requirements, it may not meet the taste or odor characteristics desired by customers. Trace organic chemicals with odors but

no known health effects, even at very low concentrations, can lead customers to perceive water as unacceptable for drinking, especially if it is recycled water. Standards for water reuse may focus more on public health contaminants than aesthetics. Aesthetic quality is important for utilities to address as they develop and promote water reuse programs.

2. Desalination and Other Emerging Technologies: An ultrapure water is neither healthy nor good tasting. Therefore, desalinated water is typically re-mineralized, in part to balance the taste. As desalination has become more affordable and more accessible worldwide, researchers have been paying attention to the aesthetic quality of the water both following treatment and after its interaction with the distribution system infrastructure.

3. Public Mistrust: Local and national news outlets often cover stories of tap water problems, such as discolored water (e.g., brown, black, pink, or yellow), salty taste, or algal odors. Water utilities can no longer pass these off as benign problems. The water quality problems of Flint, Michigan, still affect how the public views discolored water. Such water can create an uproar, especially if it comes out of taps in schools. These water quality issues need to be attended to before utilities lose their customers' trust.

4. Movement Away from Bottled Water and Toward Sustainability: Schools, universities, and recreation centers are installing bottle refill stations to encourage the use of refillable bottles rather than single-use plastic bottles. Plastic and microplastic pollution are big issues. Plastic water bottles account for a good amount of litter along streets and in waterways. Yet some people may prefer bottled water because they dislike the flavor of their tap water. Educating the public on the flavor of tap water (particularly the reason that chlorine is in it) and the value of tap water is necessary to encourage the use of tap water.

5. Geographic and Cultural Diversity of Customers/Consumers: Wherever they are from, people carry with them their historical water use perspectives and habits when they move to other areas. For example, if customers lived in locations where they could not trust the quality of their tap water, they may continue to boil their tap water or use bottled water

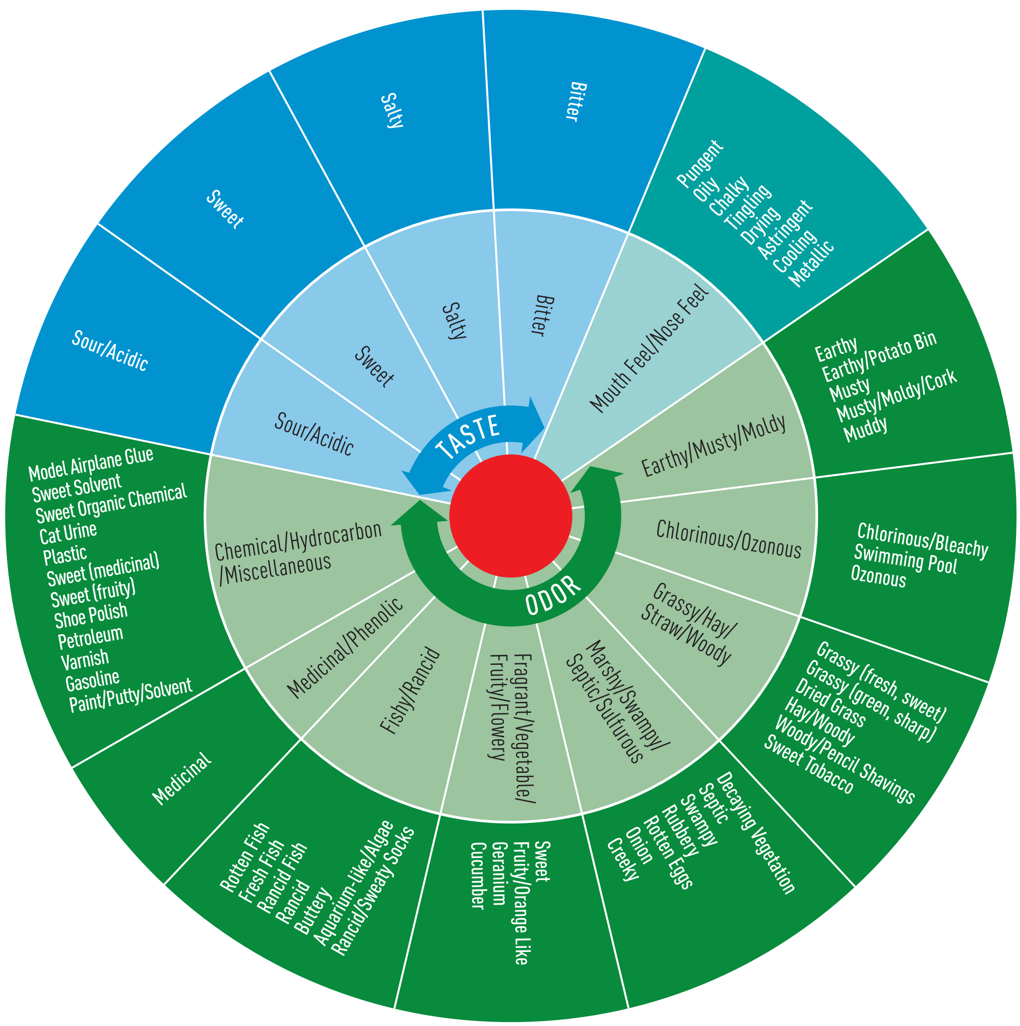

Figure 1. T&O wheel showing the distinct tastes and odors

for drinking and cooking even if the tap water in their current location is safe to cook with and drink. Aesthetics continue to play an important role when assuring customers that water is safe to drink straight from the tap.

6. Nutrition and Health: A variety of nutrition and health programs aim to redirect children away from less healthy beverages, especially high-calorie sugary beverages, and turn them on to healthier options such as highly hydrating tap water. This change in beverage preferences is also important for elderly people; maintaining adequate hydration can be critical for them. The aesthetics of tap water can help or hinder the valuable programs that work to encourage people to make healthier beverage choices.

7. Cost: Tap water is an inexpensive beverage, usually costing much less than other options. The savings that result from using tap water can make other healthy choices, such as eating fresh fruits and vegetables, more accessible.

8. Water Security: Water consumers are a first line of defense against contamination of the water supply. Consumers may notice an unusual color or smell to their water that could indicate that something has contaminated the water. By maintaining a background of low taste and odor, changes in water quality will be readily noticed and reported by consumers, thereby increasing water security. It is imperative that consumers communicate directly with their utilities when they notice such changes.

9. Water Scarcity: Whether scarcity is addressed by securing new water sources or by changing the way water is treated from existing sources, public support and education are important. The public has been known to reject better source waters, or water treatment alternatives, because of aesthetic quality.

10. Deteriorating Infrastructure: Support for improving drinking water infrastructure can be boosted by supporting aesthetically good drinking water. Replacing old cast iron mains or galvanized service lines can reduce iron

WRF's research on tastes and odors covers a wide range of topics, including:

- Identifying the sources of common tastes and odors in drinking water
- Adapting sensory techniques from the food and beverage industries to identify drinking water tastes and odors
- Correlating sensory methods of identifying tastes and odors with results from analytical instruments
- Refining T&O data collection methods and terminology, enabling water professionals across the globe to share their knowledge
- Comparing T&O changes in response to various control strategies applied in supply sources, during treatment, and in distribution systems
- Creating a T&O wheel delineating eight distinctive types of odors and four tastes
- Evaluating methods to control chlorine dioxide byproduct residuals
- Elucidating the role of various algal species in producing tastes and odors
- Investigating consumer attitudes about tap water, bottled water, and point-of-use filtration devices
- Producing a self-assessment tool to help utilities evaluate their preparedness to deal with T&O episodes
- Providing guidance for communicating with utility staff and the public during and after T&O events
- Creating a decision-making tool to help utilities develop reasonable and defensible treatment goals for managing geosmin and 2-MIB events
- Developing early warning strategies to avert or minimize the impact of T&O episodes in surface waters

In August, WRF published the report, *Sources and Fate of Taste and Odor Causing Compounds in the Missouri River* (Ghosh et al. 2019). This project describes an approach for developing, implementing, and maintaining an early warning system for source water challenges related to taste and odor compounds. The research resulted in near- and long-term recommendations for utilities located along the lower Missouri River, and general recommendations for utilities that experience T&O challenges in source waters.

Among WRF's T&O projects, *A Decision Tool for Earthy/Musty Taste and Odor Control* (Mackey et al. 2013), stands out as a one of the most impactful. This project established a decision-making tool to integrate the factors for controlling earthy/musty T&O compounds (geosmin and 2-MIB) into a reasonable and defensible treatment goal. The Earthy/Musty Taste & Odor Decision Tool helps utilities characterize their earthy/musty T&O problems, identify reasonable goals for geosmin and 2-MIB control, and develop alternative scenarios for meeting these goals.

sediment, colored-water events, and metallic-tasting water. Upgrading infrastructure can provide customers with high-quality drinking water at a lower cost than other alternatives.

With these 10 reasons, and more, in mind, WRF will continue to think creatively and be progressive in its approach to help utilities manage and communicate with consumers about the aesthetic quality of water.

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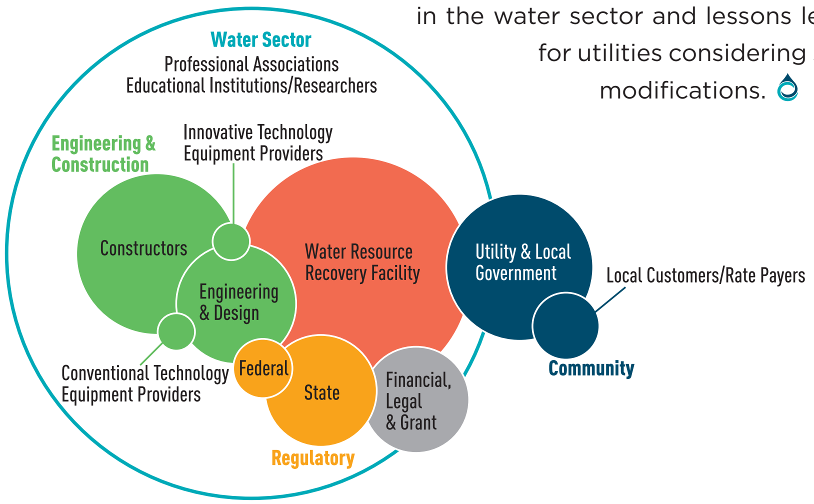
Microbial Inactivation Efficiency (4701)

***Verification of the Effect of pH on the Microbial Inactivation** Efficiency of Free Chlorine* was designed to validate the use of a chlorine speciation model, a chemical-based mechanistic model representing free chlorine as two disinfectants, to reliably describe chlorine inactivation efficiency as a function of pH. Bench-scale chlorine inactivation testing was carried out using a model organism, *B. subtilis*, to understand the behavior of free chlorine inactivation of microorganisms in water. The modeling results indicated that the chlorine speciation model satisfactorily described the observed chlorine inactivation data with *B. subtilis* spores at all pH levels tested. The results from the study suggest that CT (concentration in mg/L, times contact time in minutes) values at pH >9 are only slightly higher than those at pH 9, which benefits water utilities that operate chlorine inactivation processes at a pH ≥9.

Putting Innovation into Practice (ENER11R13a/1399)

***Case Study on Barriers and Solutions for Putting Innovation into** Practice* identifies and examines the real-time barriers to innovation faced by Bath Electric, Gas & Water Systems (BEGWS) in New York State. Several categories of barriers were identified and explored: technical, regulatory, institutional, financial, and public/community-related. BEGWS sought to incorporate innovative technology for carbon management into their plant upgrade; however, they encountered several challenges that were significant enough to derail the resource recovery portion of the project. The case study details this experience and examines challenges to pursuing innovation in the water sector and lessons learned for utilities considering similar modifications.



General categories of stakeholders in water sector innovation: types, magnitudes, and inter-relationships

Water Loss Control

Water utilities are increasingly implementing water loss control efforts to ensure wise use of water resources, enhance water supply reliability, increase revenue generation, and accurately account for water usage.

By Alyse Greenberg, The Water Research Foundation

Clean and safe water resources are becoming more and more stressed due to factors such as drought, increased populations, and water pollution. Water loss control strategies can help water utilities mitigate the effects of these stresses. Through water loss control, utilities audit their water supplies and implement strategies to minimize system losses (AWWA n.d.). As utilities enhance their water loss control programs, they can move through a series of key tactical steps (Figure 1) to address water losses. Water losses may include real losses (physical losses of water, such as leaks) and apparent losses (nonphysical losses such as meter or data handling errors). Once water losses are identified, utilities can address them through best management practices for water accountability and efficiency, such as enhancing meter accuracy, improving record accuracy, optimizing pressure management, performing leak detection surveys, and repairing or replacing infrastructure. By implementing water loss control practices, utilities can proactively increase efficiency, reduce both real and apparent water losses, and increase revenue recovery.

There are a variety of reasons utilities engage in water loss control. For many utilities, regulations are the primary driver. In the United States, 27 states and territories had some form of water loss control regulation as of January 2018, ranging from rudimentary water loss reporting to system-specific, volume-based performance benchmarking. California and Georgia had the most stringent regulations, requiring annual water loss reporting with American Water Works Association (AWWA) standard terminology, annual use of the AWWA Free Water Audit Software, validation of water loss audit data, and volume-based performance benchmarking (NRDC 2018).

There are also many non-regulatory drivers for water loss control, including water scarcity, financial incentives, asset management, improved customer experience, sustainability, and more. These drivers vary depending on region- and utility-specific conditions, and may change over time.

As a result of these drivers, many utilities are looking to initiate or expand water loss control efforts. To assist these utilities, WRF partnered with the Minnesota Section of AWWA and the New York City Department of Environmental Protection to co-host water loss control workshops earlier this year. These workshops introduced attendees to water loss control; informed attendees about water loss management strategies; provided information on resources, such as WRF research; and facilitated peer-to-peer information sharing.

Key findings from these workshops are as follows:

- There is much diversity in the reasons utilities pursue water loss control initiatives; regulations are not the only drivers.
- Water loss control is recognized and conducted in a variety of ways across the United States. Many utilities follow the best practices outlined by AWWA; however, variability in practices may result from regulatory requirements and site-specific methods for implementing improvements.

WRF interviewed four utilities that presented at these workshops to learn more about their experiences with water loss control and the unique drivers that led their utilities to pursue water loss control efforts.

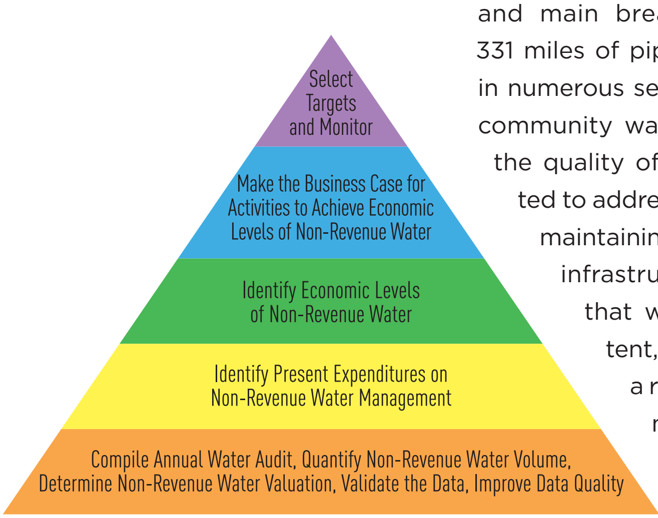
A California Case Study

IN 2015, CALIFORNIA PROMULGATED Senate Bill No. 555 (SB 555, 2015), requiring urban retail water suppliers to submit completed and validated water loss audit reports annually. The audits must be compiled in accordance with the method outlined in *M36: Water Audits and Loss Control Programs* (AWWA 2016) and in the Free Water Audit Software (AWWA 2014). However, these state requirements are not the only drivers for water loss control.

Prior to the development of the CA water loss control regulations, the California Urban Water Conservation Council (CUWCC) developed a list of 14 voluntary best management practices for water conservation, including one on controlling water losses in the distribution system. As a signatory of CUWCC, Sweetwater Authority, a publicly-owned water agency in southern California, conducted annual water loss audits as recommended by CUWCC, and implemented several recognized water loss control practices.

The primary drivers for Sweetwater were to address the high costs of water, follow best management practices, and enhance public trust. For example, according to Sue Mosburg, Program Manager at Sweetwater, Sweetwater worked to better manage its distribution system pressures, replace aging cast iron water mains, and proactively exercise valves not specifically because these activities were part of a water loss program, but "because it seemed like the right thing to do. When we were created over 40 years ago, we had nearly 200 leaks and main breaks per year in our 331 miles of pipeline, which resulted in numerous service disruptions. The community was a little outraged at the quality of service. We committed to addressing these issues and maintaining our system and our infrastructure in such a way that we can deliver consistent, high-quality water. As a result of our aggressive main replacement program, all 95 miles of cast iron pipeline initially part of the acquired system have been replaced. Sweetwater now maintains over 400 miles of pipeline, and experiences fewer than 10 leaks per year. When main breaks or hydrant knock-offs do occur, trained operators quickly respond to isolate the area and initiate repairs. Accurate system maps and a supervisory control and data acquisition (SCADA) system monitoring pressure in real-time, coupled with the confidence that valves will operate when needed, minimize real water loss and limit the number of customers without water during emergency shutdowns."

While Senate Bill No. 555 was not be the primary reason Sweetwater engaged in water loss control, it did have an impact on how Sweetwater conducted these efforts. "We've been doing a lot of things over the course of time, but now we're looking at them through a new lens, and getting a team of staff members together," said Mosburg. "Agencies don't always have a collaborative way to look at their data; activities tend to be in silos. At Sweetwater, when the rule came into effect, we pulled together a cross-functional team and started to share that data, talk about it, and learn from each other."



Source: Trachtman et al. 2019

Figure 1. Key tactical water loss control steps

The Minnesota Experience

WHILE MINNESOTA DOES NOT HAVE regulations specific to water loss control, many utilities are engaging in these efforts voluntarily. Key drivers in MN include enhancing water supply sustainability and ensuring good business practices. Jon Eaton, Utility Superintendent at the City of Eagan, MN, emphasized that water utilities are businesses; they "have a product, and our product is water. We're trying to minimize the loss of our product and maximize our revenue." MN utilities are also working to ensure that their water supplies are sustainable into the future, increase knowledge of water systems, and obtain more detailed data to apply in decision-making.

Whatever the driver for an individual utility getting started with water loss control, and whatever the level of expertise, valuable information can be gained from initial, simpler, water loss control efforts. Eaton; Tom Jauquet, Project Engineer at Saint Paul Regional Water Services; and Brett Anderson, Business Operations Manager for the City of Minneapolis, all recommend that utilities get started at any level, and not be intimidated by the complexities of water loss control. Utilities can begin with more general information, and enhance their work over time, gaining more in-depth data and experience each step of the way. In addition, Jauquet suggests that utilities start with the best available data. When Saint Paul Regional Water Services began its water loss work, the finished water meters were not as well calibrated as the utility would have liked, which made it challenging to compare results year to year. "If you don't have good confidence in your starting number, it's hard to have good confidence in your ending number. If we had tackled that right away, then we could have looked back at our numbers and seen how they compared, and had a little more confidence in the calculations," stated Jauquet.

Water loss control efforts in MN appear to be successful. In 2018, the Minnesota Department of Natural Resources (DNR) gathered data from over 300 water suppliers that serve more than 1,000 customers, in order to assess the success of water conservation efforts across the state. The data indicate that, as a state, MN is meeting the DNR's recommendation of no more than 10% water loss (Nelson and Steidel 2018). One factor in this success is the presence of resources for MN utilities. For example, the Minnesota Section of AWWA works to increase utilities' ability to implement effective water loss control activities through its Water Loss Control Committee. Anderson, a member of the Committee, stated that the Committee serves as "an underlying, non-regulatory force working to improve water loss control efforts and promote the audit process across the state." The Committee provides support, training, and other resources for utilities interested in engaging in water loss control.

Research and Resources

IN ADDITION TO WORKSHOPS SUCH as the ones WRF co-hosted, there are

Table 1. WRF water loss control projects

Title	Purpose	WRF Project Number
Guidance on Implementing an Effective Water Loss Control Plan	This project created a Guidance Manual and Decision Framework to help North American water utilities develop actionable, cost-effective, and defensible water loss reduction and control plans. The research will allow utilities to develop plans that align with their strategic goals, water resource management concerns, financial concerns, and local circumstances.	4695
Leakage Management Technologies	Assesses the practicality of applying UK proactive leakage management techniques to North American utilities. Provides guidance to water utilities on how to practically apply promising leakage management technologies.	2928
Level 1 Water Audit Validation	This project defines and guides water utilities and regulatory entities in understanding what makes an accurate and reliable water audit. Clear guidance and a standardized methodology for validation of water audit data are provided.	4639
Pressure Management: Industry Practices and Monitoring Procedures	This project provides a better understanding of pressure management practices under both baseline and optimized conditions in drinking water utilities in the United States. The research presents case studies from small, medium, and large water utilities both before and after implementing the pressure management and monitoring criteria outlined in *Criteria for Optimized Distribution Systems* (4109). The project also makes recommendations for modifications to these criteria.	4321
Water Audits and Real Loss Component Analysis	This project provides guidance on designing efficient and sustainable leakage control programs. *Real Loss Component Analysis: A Tool for Economic Water Loss Control* provides water utilities with an analysis tool to better understand the sources of their real water losses and a means of analyzing their economic intervention strategies. *Water Audits in the United States: A Review of Water Losses and Data Validity* provides a snapshot of water loss reporting in the United States, including an assessment of water audit validity and median results for key performance indicators.	4372

many resources available on water loss control. AWWA's M36 and Free Water Audit Software are two of the primary water loss control resources used by utilities. In addition, over the last 20 years, WRF has published more than 50 reports, manuals, and tools focused on water use and efficiency, including water loss control. *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (Sturm et al. 2014) guides utilities in analyzing their real losses in detail. *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, offering material that complements AWWA M36. Table 1 provides a sampling of WRF projects specific to water loss control programs.

Whether a utility is in the initial stages of water loss control or has been working on these efforts for many years, there are resources that will help the utility define and meet its goals.

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Demonstration of the Water Footprint Concept (4652)

A **footprint is an indicator, or** a profile of indicators, that reflects the impact of human activities on an aspect of the environment. The overall objective of *Pilot-Scale Demonstration of the Water Footprint Concept for Sustainable Decision Making* was to demonstrate the application of the water footprint concept for water utilities through a pilot study in water-stressed areas of the United Kingdom. This study developed a methodology that was used to determine the impact of an activity on a specific waterbody, as well as on the water environment of the entire resource zone. The team concluded that the water footprint assessment methodology can be tailored for water utility operations. However, this can require a significant allocation of resources and active engagement from external stakeholders. Therefore, it is imperative to understand the drivers and benefits of conducting a water footprint to achieve a desirable return on investment. This project includes a Water Footprint Assessment Tool that can be used as a guide for conducting a water footprint assessment. An additional workbook provides an example of how the water footprint assessment can be calculated and tailored by a water utility using the tool.

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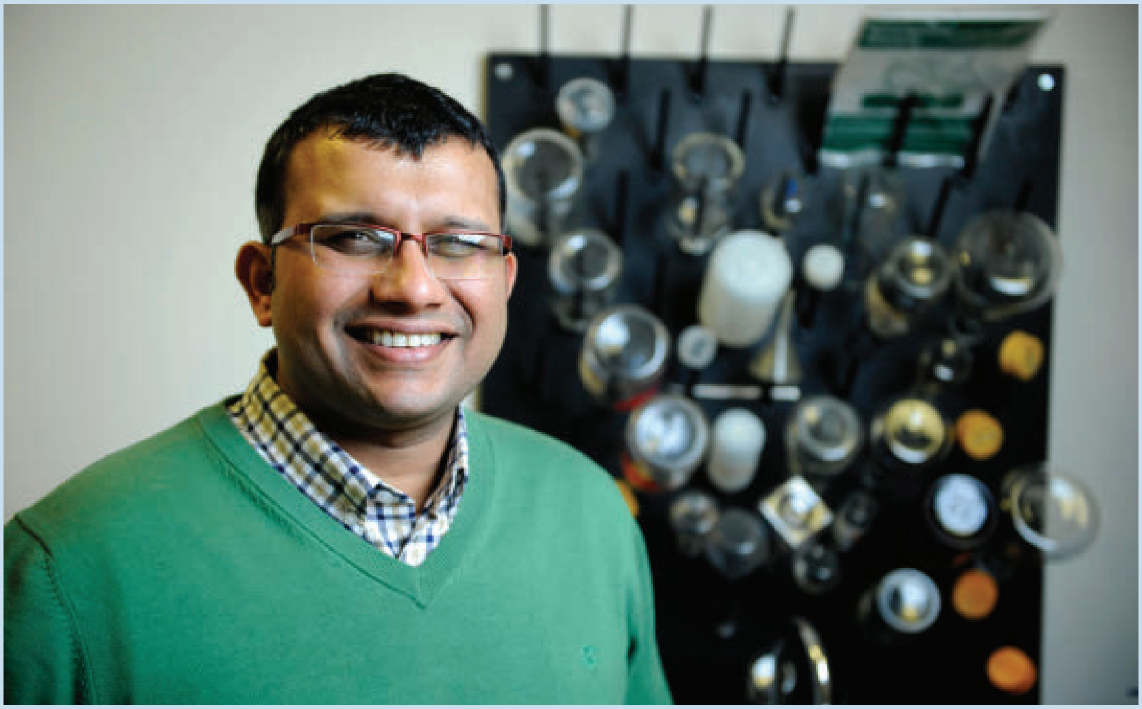

With the $100,000 prize, Dr. Pinto seeks to develop a modular platform for low-cost and real-time characterization of microbial communities across the engineered water cycle.

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