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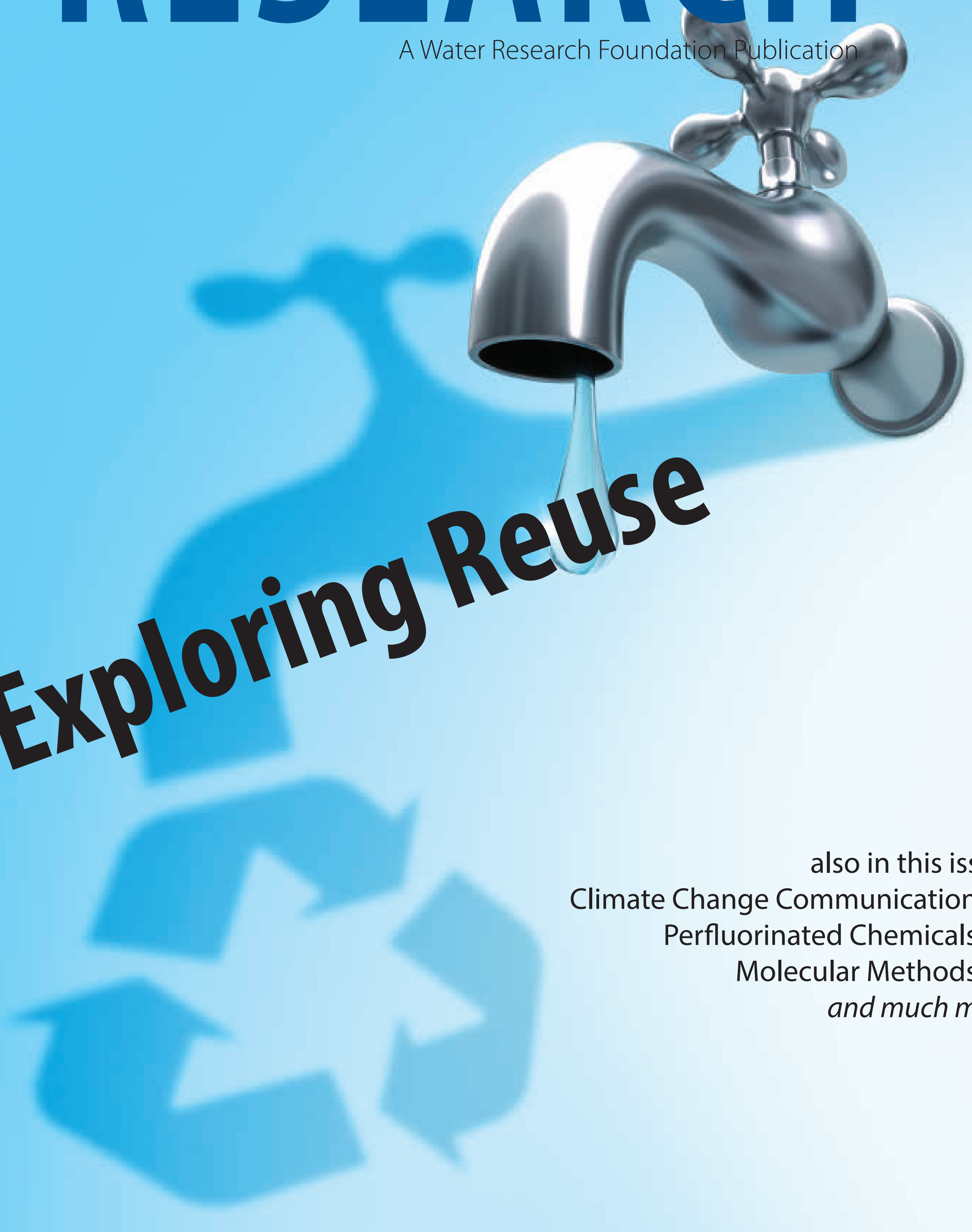
ADVANCES in WATER RESEARCH

A Water Research Foundation Publication



Exploring Reuse

also in this issue:

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ADVANCES in WATER RESEARCH

FEATURES

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In Honor of Dr. Pankaj Parekh

AT THE WATER Research Foundation's Annual Subscriber Appreciation Breakfast held on June 9 in conjunction with ACE14 in Boston, I was given the honor of announcing the new name of WRF's Research Innovation Award.

Per the Board of Trustees' approval, the Foundation renamed the award, the **Dr. Pankaj Parekh Research Innovation Award**. Dr. Parekh was a passionate and dedicated supporter of the Foundation—contributing his knowledge and expertise to numerous research planning and project development efforts through his work on advisory committees as well as guiding the Foundation at an organizational level through service on the Board of Trustees.

But Dr. Parekh's influence extended well beyond the Foundation—he was a tireless, life-long advocate for ensuring safe drinking water to protect public health on an international scale. Dr. Parekh dedicated 28 years to the Los Angeles Department of Water and Power (LADWP), serving in various roles including the Manager of Water Quality Regulatory Affairs for 10 years and the Director of Water Quality for 14 years. Prior to his service with the LADWP, Dr. Parekh spent 13 years working to improve public health by addressing a variety of environmental and drinking water challenges in Africa.

In 2011, Dr. Parekh was badly injured in a motorcycle accident on his way to work at LADWP. He fought with incredible determination to overcome his injuries and was eventually able to return to work; however, in January of 2014, he succumbed to injuries sustained in the motorcycle accident and passed away.

I was lucky to know Dr. Parekh as our professional paths often crossed in California and because we served as WRF Trustees together. When I first met Dr. Parekh over 20 years ago, he helped me navigate the significant challenges of delivering safe, clean water every day to our communities. He was a mentor and a friend, and he was a vibrant example of the dedicated civil servant many of us in the water community aspire to be.

Dr. Parekh was passionate about credible research and active collaboration. He believed, like I do, that only by working together to advance the science of water, can we overcome the challenges facing us today and into the future.

It is the Water Research Foundation's intention that the **Dr. Pankaj Parekh Research Innovation Award** will serve as a reminder of the limitless possibilities and important work we can accomplish by working collectively.

Together, we are one water.

Denise Kruger

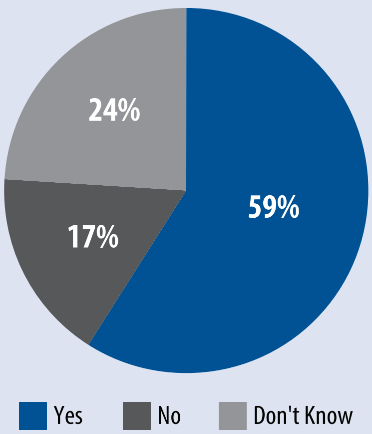
Denise Kruger
Chair, Board of Trustees

THE 2014 DR. Pankaj Parekh Research Innovation Award, which honors researchers and research teams who have made significant contributions to advancing the science of water through Foundation-sponsored research, was presented to Issam N. Najm, PhD, PE, President, Water Quality & Treatment Solutions, Inc. Congratulations to Dr. Najm.

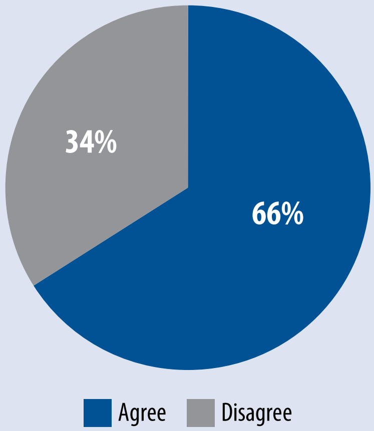
BY THE NUMBERS

This installment of "By the numbers" features survey results on Americans' beliefs and policy preferences regarding climate change, extreme weather events, and water supplies. The graphs are derived from the soon-to-be-published WRF report, "Effective Climate Change Communication to Water Utility Stakeholders" (project #4381). As part of this research, a national survey was conducted in April 2013, with 1,021 surveys completed. More information can be found in the article on this project in this issue of *Advances in Water Research*.

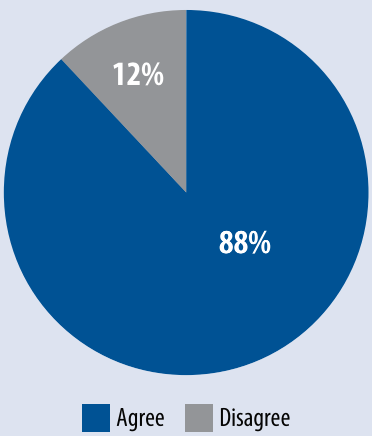
Do you think that global warming is happening?



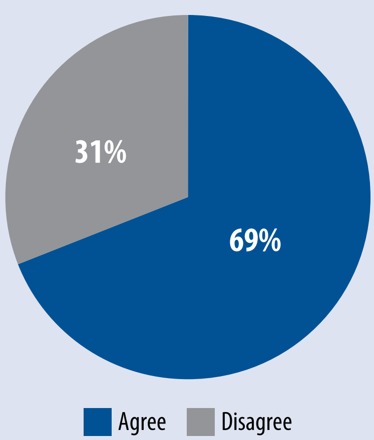
The impact of climate change on the water cycle will make it more difficult for water utilities to meet community water needs in the next 10–40 years.



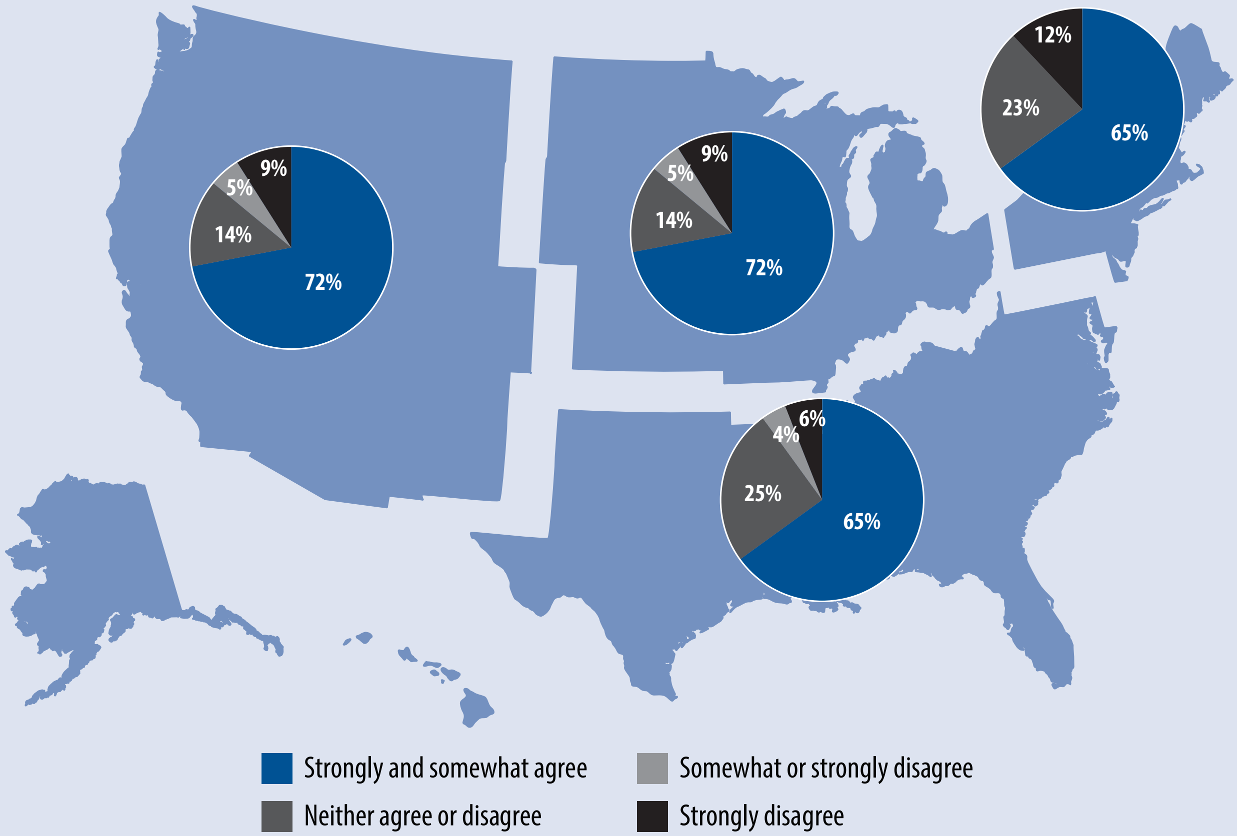
My water utility should plan—and take the necessary steps—to ensure that our community has safe, adequate supplies of water for the next 10–40 years.



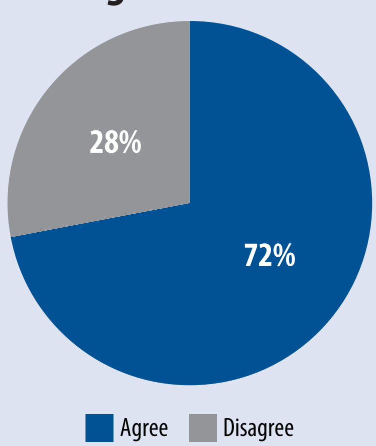
Assuming the money is needed, and would be spent wisely and efficiently, would you be willing to pay extra each month to ensure that your community has access to abundant, safe water for the next 10–40 years?



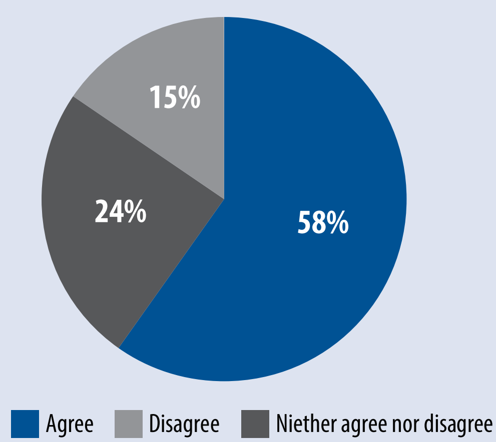
Climate change will have a significant impact on extreme weather events, causing changes in the severity of droughts, hurricanes, rainstorms, and heat waves.



How concerned are you that future extreme weather events will negatively impact your community water provider's ability to provide safe, healthy drinking water?



Assuming the money is needed, and would be spent wisely and efficiently, I am willing to pay more to ensure that my water utility is prepared for future extreme weather events.



Q&A with Marsi Steirer

Deputy Director, Long-Range Planning and Water Resources at City of San Diego Public Utilities Department

San Diego's implementation of a Potable Reuse Program

The Water Research Foundation (WRF) has recently expanded its focus to include potable reuse, which may become a valuable strategy for communities as they continue to look for ways to grow their water supplies. Marsi Steirer, Deputy Director, Long-Range Planning and Water Resources at the City of San Diego Public Utilities Department, recently visited with WRF to discuss her role in implementing potable reuse in San Diego and the challenges the utility is facing in activating its new programs.

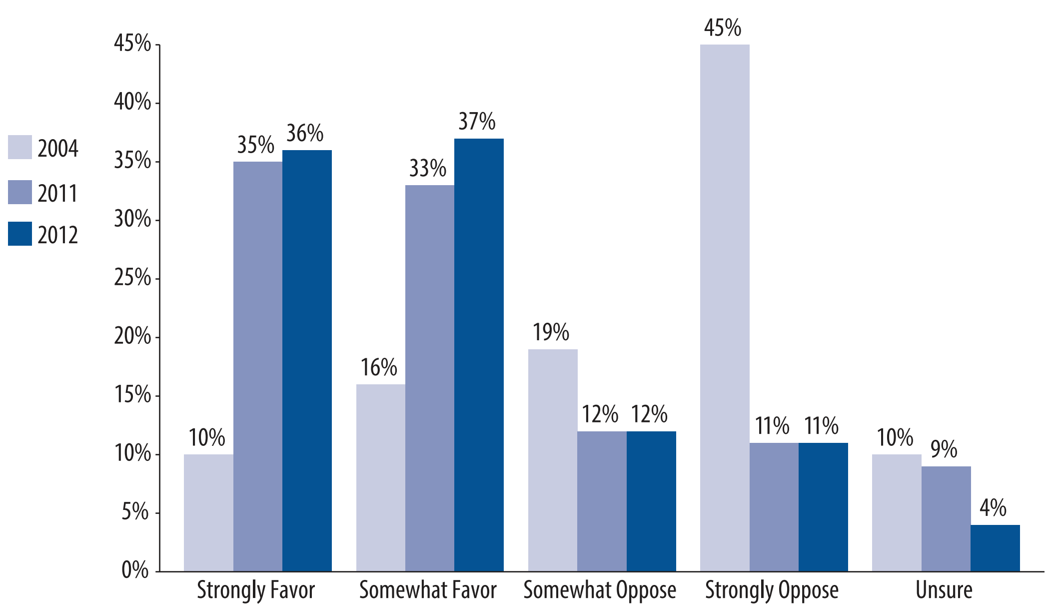
Water Research Foundation: What are the biggest challenges San Diego Public Utilities faces in implementing potable reuse?

Marsi Steirer: How we are pursuing this is different than other utilities. For example, Orange County, California, has had a facility that has been operational for about five years and their purified water goes into a groundwater basin. We do not have large groundwater basins in our service area, so our water goes into a reservoir. Currently, there are no regulations for reservoir augmentation. Part of moving forward is trying to ensure that what we propose to do will fit into the future reservoir augmentation regulations, which are supposed to be completed at the end of 2016. California is also supposed to determine if direct potable reuse is feasible at that same point in time. There is an advisory committee associated with this effort, of which I am a member, of people from throughout the state.

How has public acceptance of potable reuse evolved in San Diego?

We started doing telephone surveys of our customers in 2004 and have been asking the same questions every time we do them. The continuity facilitates the tracking of responses from year to year. In 2004, public acceptance of potable reuse was 26% and in 2012, it was 73%. We had a comprehensive outreach effort going on during that time which included an active tour program. In 2011 we began offering tours of the demonstration project, where people could come and actually see the treatment process and the water. The tours continue to be very popular and aid the public in overcoming the "yuck factor" by seeing the science of potable reuse first hand. We have also made a lot of informational materials and a virtual tour video available on our Website, purewatersd.org.

San Diego Public Opinion Poll:
Use Advanced Treated Recycled Water as an Addition to Drinking Water Supply



For the last year or so, we have been working on a program geared towards younger audiences between the ages of 6 and 18. We think it is really important for them to understand the water situation, as they are the future.

What are some research issues that will help expand the implementation of potable reuse?

There are a couple of areas which will be helpful: research on public outreach as well as public acceptance, research that is associated with the feasibility of direct potable reuse, and research about regulatory acceptance.

How is San Diego Public Utilities distinguishing between indirect and direct potable reuse?

For indirect, the purified water is treated and then goes to a very large reservoir where it mixes with runoff from rain as well as imported water. It then goes to a water treatment plant before going to our customers' homes and businesses. Direct basically skips the reservoir step and takes the water directly to a water treatment plant.

We actually have some research underway presently in San Diego on two additional treatment steps that could replace the environmental buffer, which is the reservoir, so we are doing some direct potable reuse testing.

How do you balance potable reuse with other supply alternatives?

In terms of pursuing potable reuse, what we would really like to do is reduce the total amount of water that we import, which is about 85%, and be a little bit more water independent. That really resonates with local officials as well as the general population. Right now, it is a bit of a precarious situation in California with all of the cutbacks. We have no control over that, so the idea of creating your own local water supply is very appealing.

How our system works, and the commitment that we have made in the past, is that the majority of the water we buy is untreated, or raw, water because we have three water treatment plants. There are a lot of other water agencies in the region that buy treated water. We also have a desalinization plant that is coming on line. We have a small portion of our service territory that is not connected with our treated water system, so the desalinated water basically will be the treated water for that area. We are estimating that this represents about 3% of our total water supply; the rest of our service territory is served by our three water treatment plants. So it is kind of an easy decision to make, we just buy enough of the desalinated water to equal our treated water needs.

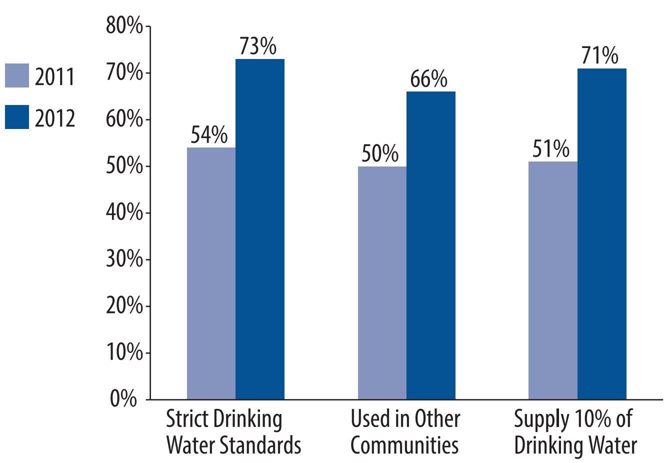
How do you balance developing new supplies with demand management activities?

We are at the end of an imported water pipeline so we have been pretty aggressive at pursuing demand management over the course of the last 20 years. For example, our water sales are the same amount as they were 30 years ago. We attribute that to water conservation. We have had population growth of about 400,000 people and we are selling the same amount of water. What we are pursuing is working.

If the current drought subsides in the next year or two, how will that impact your planning?

It wouldn't. We would still be pursuing exactly what we are currently pursuing. We do long-range water resource supply planning; we update our planning document every five to 10 years and most recently completed it in December of last year. Since we import 85% of our water, we are very keen on water conservation. At the end, in 2035, we could be creating enough water supply to equal about 30%. We recognize, because of the situation where we are in Southern California, and because we are at the end of an imported water pipeline, that there is no one magic solution; we need all of it.

San Diego Public Opinion Poll:
Accepting of Recycled Water to Supplement Drinking Water if Respondent Learned ...



Exploring Potable Reuse to Diversify Water Supplies

John Whitler, Water Research Foundation

Water utilities globally are faced with increasing water supply pressures due to factors such as population growth, increased hydrologic and climate variability and uncertainty, decreasing availability of high quality water sources, decreasing quality of existing sources, and increasing water demands from other sectors like energy and agriculture.

While challenges to existing supplies have been managed successfully in many locations through demand management efforts including water conservation, other challenges are leading to a tipping point of action where new supplies will need to be developed.

Potable reuse is one component of a more integrated approach to water management that many utilities are interested in implementing. As part of the Water Research Foundation's (WRF's) efforts to support "one water" we are working on a variety of efforts by utilities to support a more sustainable and integrated approach to water management. This article reviews the different types of reuse, the types of research needed to further reuse implementation, WRF efforts to support this research, and where reuse is currently being implemented.

What is Driving Utilities Towards Potable Reuse?

SOURCES OF POTABLE water supplies are very geographically and locally dependent. Whereas some utilities have the benefit of switching between sources when they have quality or quantity issues with one of their sources, many utilities do not have a diversified portfolio of water supply options. This challenges utilities to look beyond traditional surface and groundwater sources to new sources of water supply. Increasing interest is focused on several non-traditional water supply options to help water utilities diversify their water supplies. In addition to options such as desalination and aquifer storage and recovery (injecting water underground for future use), potable water reuse is becoming an increasingly popular option for utilities to explore.

What are the Different Types of Reuse?

NON-POTABLE REUSE—Non-potable reuse refers to water that is not treated or intended to be a part of the potable supply, so there is no human consumption. Non-potable water may be treated to a specific quality depending on its purpose. For example, for agricultural or landscape irrigation, nutrients would not be removed because of the benefits they provide, unless there is a problem with nutrient pollution in the area.

WRF "ONE water" definition

THE CONCEPT THAT water from all sources must be managed holistically and cooperatively to meet economic, social, and environmental needs.

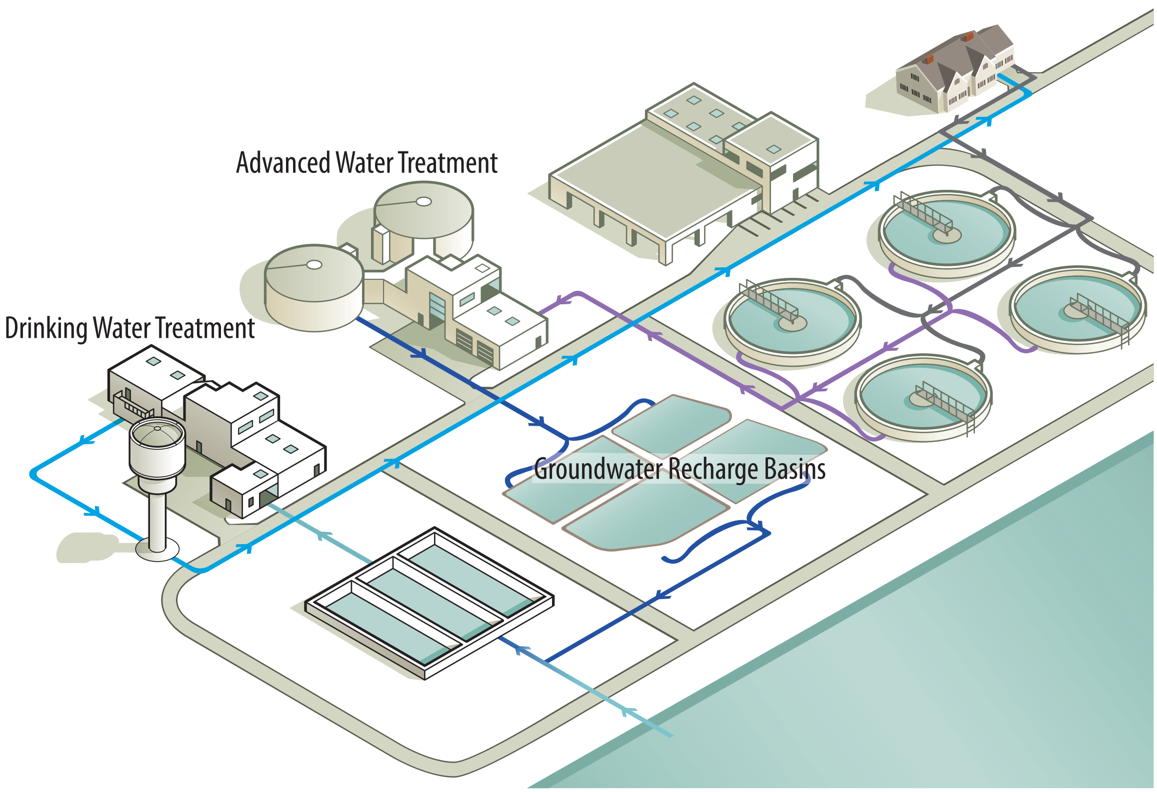


Figure 1. Scenario depicting indirect potable reuse.

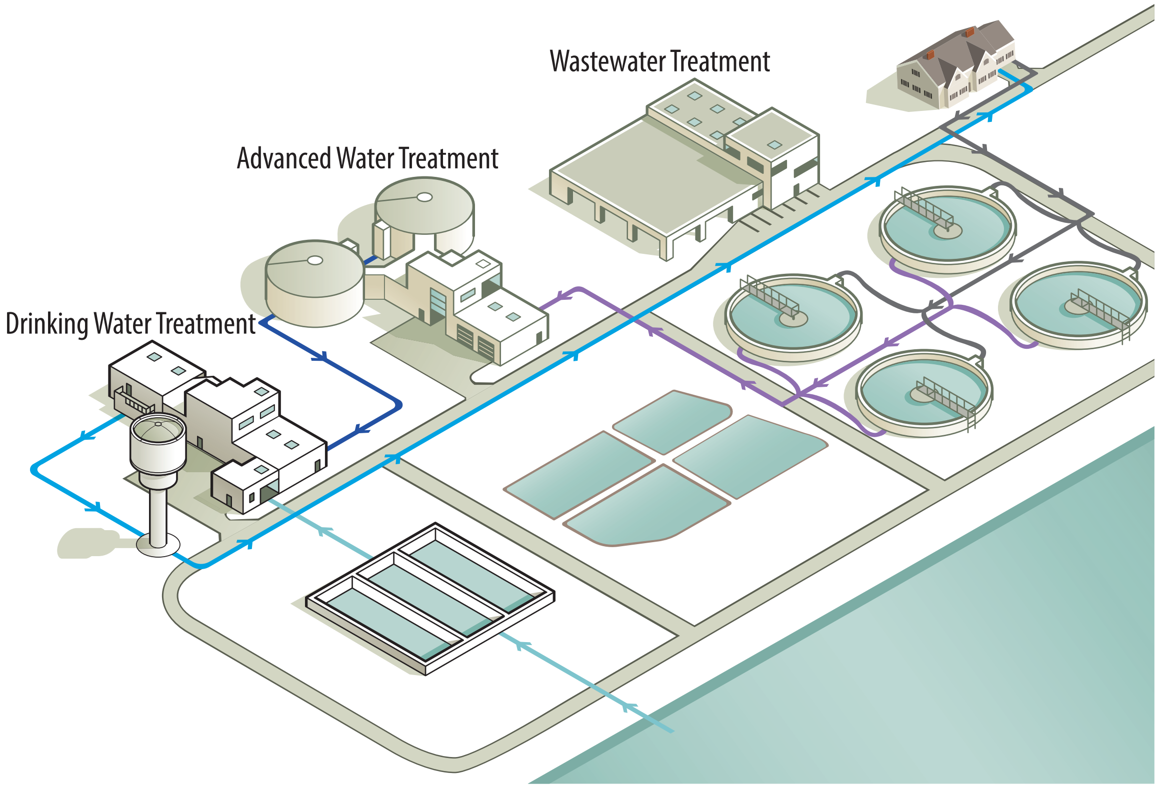


Figure 2. Scenario depicting direct potable reuse.

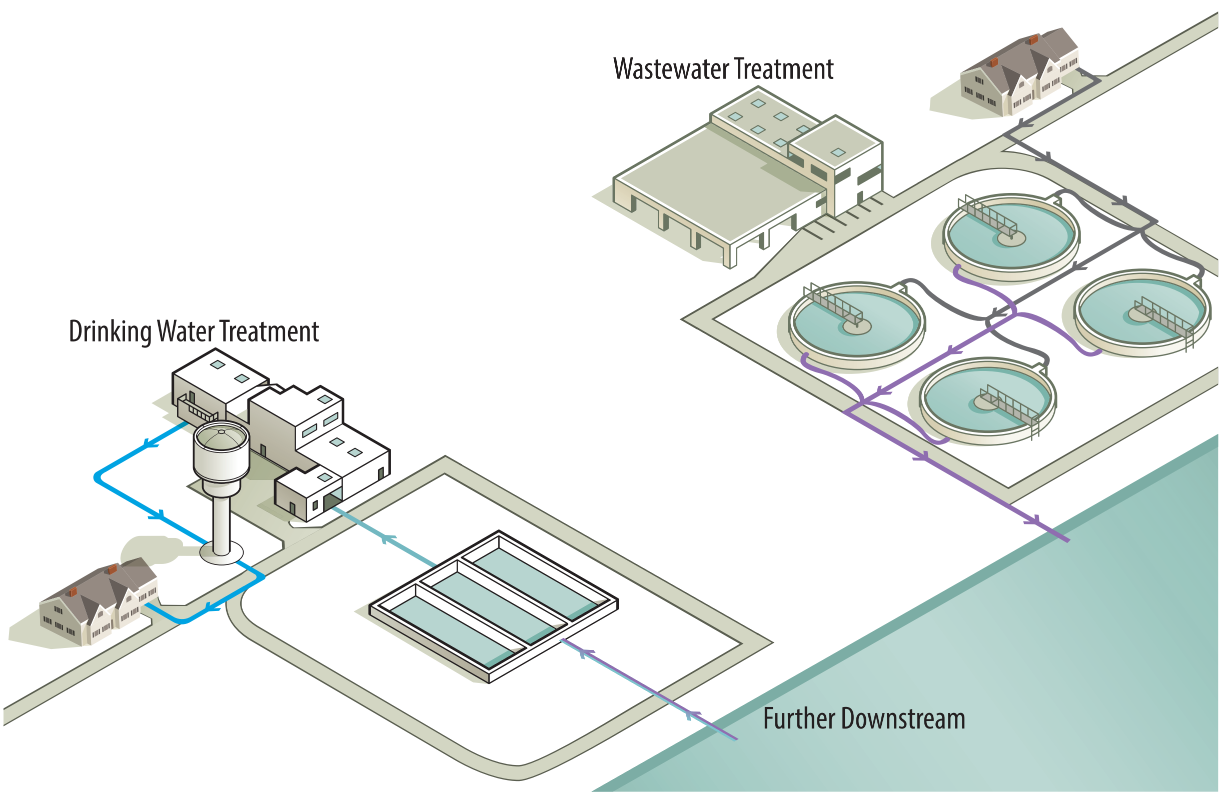


Figure 3. Scenario depicting de-facto potable reuse.

Non-potable reuse water may also be provided to industrial operations that do not require high quality water. An example of this would be the use of reuse water for industrial cooling towers at a power plant or large industrial operation. While non-potable reuse systems reduce demand on potable water supplies and require less treatment than potable reuse operations, these systems can be cost prohibitive to develop and maintain due to the need for a separate distribution system.

POTABLE REUSE projects are not just limited to California or the Southwest

Indirect potable reuse—Indirect potable reuse means that after extensive treatment the water spends time in an environmental buffer. This environmental buffer may be a surface reservoir or the water may be infiltrated or injected underground. The water is then pumped back to the surface and may undergo additional treatment before entering the potable distribution system (see Figure 1).

Direct potable reuse—Direct potable reuse (DPR) eliminates the environmental buffer, relying on more robust and redundant treatment that eliminates the time delay of the environmental buffer. While regulations for direct potable reuse do not currently exist on the national level, there are some states, such as California, that are actively working to develop direct potable reuse regulations. In absence of federal and state regulations, different direct potable reuse systems are being explored, often driven by the individual utility circumstances. The most aggressive approach would be for a utility to blend water from an advanced wastewater treatment facility with potable water in the distribution system. A more conservative approach would be to take highly treated wastewater and blend the water somewhere before or within a drinking water treatment system (see Figure 2).

De-facto reuse—Often overlooked in the conversation about reuse is that water is already being used many times over in many places. De-facto (unintentional) reuse occurs when a community downstream from another community withdraws its drinking water from the same surface water where the upstream community discharges its treated wastewater (see Figure 3). There has not been a comprehensive study of the contribution of wastewater to downstream water treatment plants in the United States; however, one study was conducted in 2013 to review and update a 1980 study that focused on 25 cities. The results of this updated study showed an increase in the amount of sewage discharged from these 25 cities and, in most cases, an increased contribution of wastewater to downstream drinking water facilities. While in most cases there is a distance between the discharge point and intake creating an environmental buffer where there may be some natural attenuation of contaminants, in some parts of the United States at certain times of the year, these rivers and streams are dominated by the effluent from the upstream community. (Rice 2013)

What are the Sources of Water for Reuse?

THERE ARE MANY sources of water that utilities may look to reuse as part of their water supply portfolio. Wastewater effluent is one source that gets a lot of attention. Rather than discharging highly treated wastewater back into a stream, river, estuary, or ocean, one option is to close the loop and reuse this wastewater as part of the water supply. Many communities are struggling with management of stormwater, which left untreated or mismanaged can cause water quality problems where it is discharged. Some utilities may be able to capture and reuse stormwater as part of their water supply. While potentially most effective on a smaller scale, reuse of graywater (water from laundry and non-kitchen sinks) from domestic or commercial buildings or at a community scale, may offer utilities another supply option. WRF is a funding partner to a National Research Council (NRC) study on graywater and stormwater, titled, "Beneficial Use of Graywater and Stormwater: An Assessment of Risks, Costs, and Benefits." (NRC 2014)

LOCAL NEWS coverage of this project also highlighted some of the challenges with public perception with potable reuse

Where is Potable Reuse Currently Occurring?

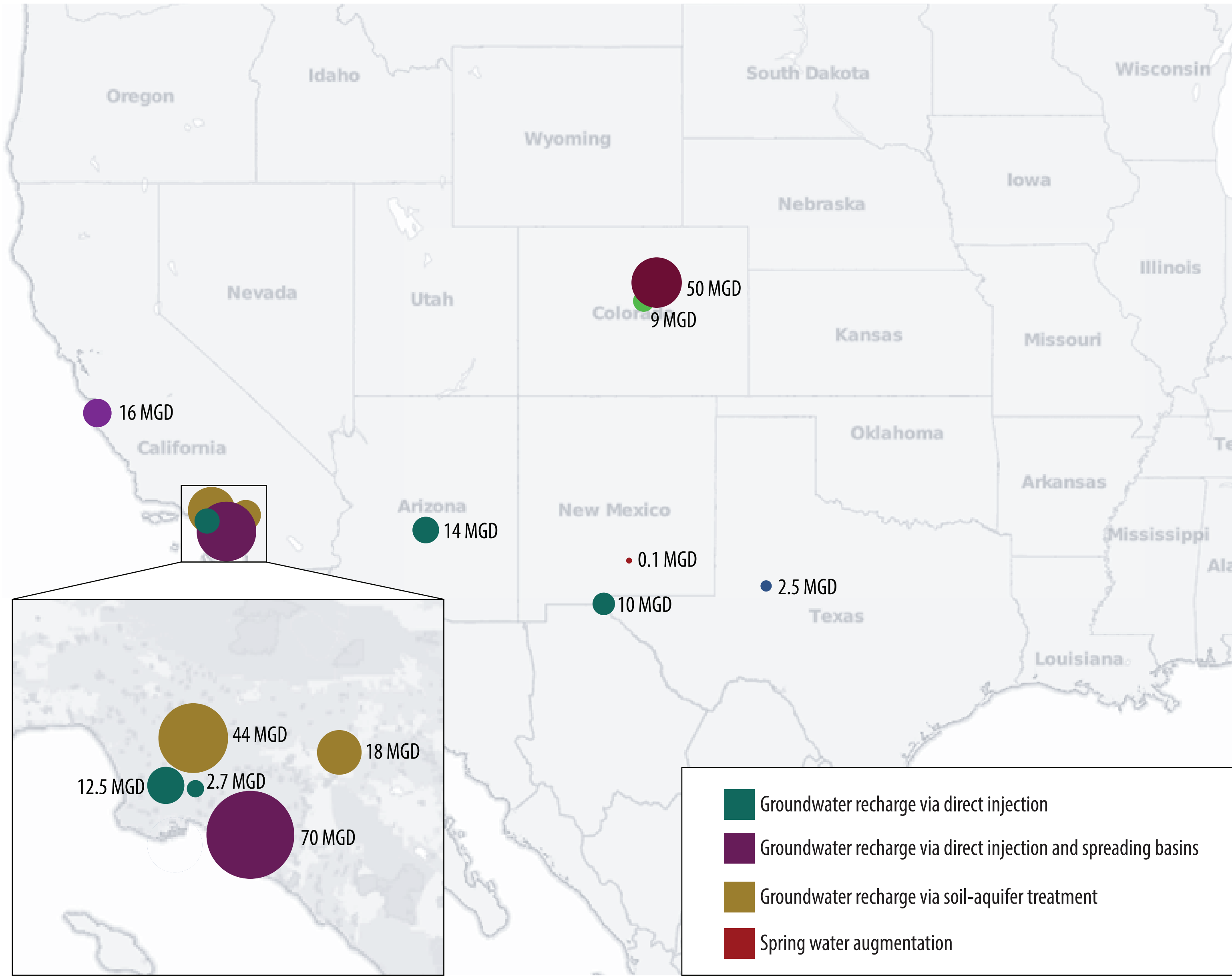
IN ORDER TO provide more context and a better understanding of how reuse has been implemented across the United States, a few examples provide an interesting perspective.

The Montebello Forebay Spreading Grounds in Los Angeles is one of the oldest reuse projects in the United States. Since the late 1930s, they have been recharging the groundwater basins with stormwater runoff. Imported water was added in the 1950s and recycled water in the 1960s to supplement this natural source, because storm water amounts are insufficient for the total replenishment needs. This operation began using recycled water in 1962 and has a capacity of 44 mgd. This project was started in order to prevent seawater intrusion into drinking water aquifers that were over pumped. Through groundwater recharge, this project utilizes soil aquifer treatment, media filtration, and chlorination. These operations are intensely monitored to ensure that when the water is utilized for drinking water supply, it meets all applicable regulations (Johnson 2008).

Potable reuse projects are not just limited to California or the Southwest. The Upper Occoquan Service Authority was created in the early 1970s and oversees a surface water augmentation project. Prior to its creation, there were many small wastewater treatment plants along the reservoir, and there were nitrogen and phosphorous contamination problems. The new treatment facility was not conceived as a reuse facility, but rather as an effort to simply improve water quality in the reservoir. This simplified the permitting and public perception issues. After discharging highly treated wastewater into the Occoquan Reservoir, Fairfax County Water uses that reservoir as part of their water supply (NRC 2012, Rice 2013, UOSA 2014).

Another example of potable reuse in the eastern part of the United States occurs in Gwinnett County, Georgia. This is another surface water augmentation project. Gwinnett County returns highly treated wastewater back into Lake Lanier, which is also their water supply source. The challenge they face is how to account for this water that goes back into the lake in order to factor that into their net withdrawal. The use of Lake Lanier water for water supply is currently undergoing evaluation by the U.S. Army Corps of Engineers, and its allocation may be impacted (Gwinnett County 2012, NRC 2012).

Growing populations and limited water resources in the eastern half of Colorado have led to a large potable reuse project in Aurora, Colorado called the Prairie Waters Project. Installed just a few years



Data from: NRC 2012

Figure 4. Selected examples of potable reuse in the United States.

ago, up to 50 mgd of water is reused through groundwater recharge utilizing riverbank filtration along the South Platte River. This project could potentially be expanded in the future, and the surplus water could serve additional Denver metro communities through a partnership with Aurora Water (ASCE 2011). Water rights issues can present challenges to reuse in many Western states. In the case of the Prairie Waters Project, Aurora has the proper type of water right to allow reuse of this water. (NRC 2012)

THERE ARE no federal regulations for reuse in the United States

One of the most recent potable reuse projects was just completed in Big Springs, Texas. About 2.5 mgd of reused water is utilized in this system where highly treated wastewater is blended with a raw surface water supply before going to a drinking water treatment plant. This example illustrates some of the terminology issues with potable reuse as some people call this direct, and others call it indirect. Some local news coverage of this project also highlighted some of the challenges with public perception with potable reuse. Surprisingly, many residents did not drink the tap water previously being provided due to taste issues. Many are hopeful this new project will make the water more palatable. Other reuse projects in Texas are currently in development, including one in Wichita Falls (NRC 2012, Trojan UV 2012, Weissman 2014).

While direct potable reuse in the United States has just started to gain in popularity, there are several international examples of direct potable reuse including Namibia and Singapore. In Singapore, they utilize advanced treatment to distribute reuse water to non-potable customers and to blend reuse water in reservoirs with rain water and imported water. Referred to as "NEWater," this project is necessary due to the small geographic area, high population density, and low rainfall amounts. Because most of the produced water from the NEWater facilities goes directly to industry it makes up less than 2% of the volume in the reservoirs that are used for potable supply (NRC 2012).

The other well-known international example of potable reuse is in Windhoek, Namibia. Representing between 35–50% of their potable water supply, treated wastewater is blended with other potable sources. This reuse project has been in place since the 1960s with changes taking place over time, and with upgrades in 2002 that represent its current configuration (NRC 2012).

What are the Key Issues that Need to be Addressed to Expand the Amount of Potable Reuse?

SEVERAL KEY ISSUES must be addressed in order to successfully implement a water reuse project. The first and perhaps most important issue to consider is the regulatory context for the type of reuse the utility chooses in order to be protective of public health. While the Clean Water Act and Safe Drinking Water Act serve as the foundation of how wastewater needs to be treated and the quality of drinking water provided, respectively, there are no federal regulations for reuse in the United States. So in order to implement reuse projects, utilities rely on state regulations. This patchwork system of regulations specific to each state has left differences in what types of reuse can be done in different states. In California, indirect potable reuse has been around for decades and boasts one of the largest and most famous indirect potable reuse projects, the Orange County Groundwater Replenishment System. California is also leading the charge for developing direct potable reuse regulations, as required by the governor as part of SB 918 and SB 322 (CDPH 2014).

IN CALIFORNIA, indirect potable reuse has been around for decades

What are the Research Needs Related to Potable Reuse?

EXTENSIVE AMOUNTS OF research are occurring in support of more widespread adoption of direct potable reuse. The 2012 NRC report, *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*, identifies 14 research needs to support the expansion of potable reuse. The issues identified in the report include treatment requirements, residuals and concentrate management, post-treatment issues such as blending with other supplies, monitoring requirements, source control, public acceptance, and issues with emerging contaminants.

Health, Social, and Environmental Issues

1. Quantify the extent of de facto (or unplanned) potable reuse in the United States.
2. Address critical gaps in the understanding of health impacts of human exposure to constituents in reclaimed water.
3. Enhance methods for assessing the human health effects of chemical mixtures and unknowns.
4. Strengthen waterborne disease surveillance, investigation methods, governmental response infrastructure, and epidemiological research tools and capacity.
5. Assess the potential impacts of environmental applications of reclaimed water in sensitive ecological communities.
6. Quantify the nonmonetized costs and benefits of potable and nonpotable water reuse compared with other water supply sources to enhance water management decision making.
7. Examine the public acceptability of engineered multiple barriers compared with environmental buffers for potable reuse.

Treatment Efficiency and Quality Assurance

1. Develop a better understanding of contaminant attenuation in environmental buffers.
2. Develop a better understanding of the formation of hazardous transformation products during water treatment for reuse and ways to minimize or remove them.
3. Develop a better understanding of pathogen removal efficiencies and the variability of performance in various unit processes and multibarrier treatment and develop ways to optimize these processes.
4. Quantify the relationships between polymerase chain reaction (PCR) detections and viable organisms in samples at intermediate and final stages.
5. Develop improved techniques and data to consider hazardous events or system failures in risk assessment of water reuse.
6. Identify better indicators and surrogates that can be used to monitor process performance in reuse scenarios and develop online real-time or near real-time analytical monitoring techniques for their measurement.
7. Analyze the need for new reuse approaches and technology in future water management.

REUSE IS not a one size fits all approach

How is WRF Supporting Potable Reuse?

ALTHOUGH NOT ALWAYS recognized for its role in potable reuse, WRF has a long history of research that supports it. Past projects at WRF have focused on aquifer storage and recovery, membranes, and brine or concentrate disposal.

In January 2014 the WRF Board of Trustees approved a new Focus Area Program called Integrated Water Management: Planning for Future Water Supplies. During 2014, with guidance and support provided by a multi-disciplinary advisory team, a planning workshop will be held to develop objectives and a research agenda for this new Focus Area.

A knowledge portal will be established on the WRF Website that organizes our water supply resources in one place. Some of the topics that will be included in this knowledge portal include potable reuse, desalination, and managed underground storage.

More recently, WRF has funded two direct potable reuse projects in collaboration with six funding partners: Alameda County Water Agency, Contra Costa Water District, East Bay Municipal Water District, Los Angeles Department of Water & Power, San Francisco Public Utilities Commission, and Zone 7 Water Agency. These projects were awarded this spring and results should be completed by the end of 2015. These projects are being coordinated with the California Direct Potable Reuse Initiative led by WateReuse California and the WateReuse Research Foundation.

Project #4536, "Blending Requirements for Water From Direct Potable Reuse Treatment Facilities"

THIS PROJECT WILL examine the impact of adding distinctly different levels of reclaimed water quality and purified water quality at various locations within the water supply chain. Several locations will be examined at different blending ratios and include the following: prior to water treatment, into a raw water reservoir prior to water treatment, within a treatment plant, and by direct injection into the distribution system. The project will also evaluate additional benefits of an engineered storage buffer. The research team will examine the water quality of these treatment and blending scenarios at bench, pilot, and full-scale for team member utilities, including Southern Nevada Water Authority, the Santa Clara Valley Water District, and Ventura Water. The final product will include a guide on conditioning strategies for the DPR water.

Project #4508, "Assessment of Techniques to Evaluate and Demonstrate the Safety of Water from Direct Potable Reuse Treatment Facilities"

THIS PROPOSED PROJECT will produce a DPR guidance framework that water utilities and regulators can use to evaluate the safety of existing or potential future DPR scenarios and help facilitate a proactive DPR monitoring process that is protective of public health. This framework will include practical guidance for selecting and implementing monitoring and control tools for DPR. The project objectives will be achieved through the execution of three tasks: (1) conducting a thorough literature review and identifying key criteria to assess the safety of DPR systems with respect to both microbial and chemical compounds of public health concern; (2) conducting two expert panel workshops to identify existing and emerging analytical methods used to evaluate the safety of water from DPR systems; and (3) evaluating the effectiveness of identified methods to characterize water quality from a variety of treatment processes on the prevalence and safety of DPR systems compared to benchmark scenarios throughout the country.

Conclusion

THESE EXAMPLES DEMONSTRATE that potable reuse is happening today, and in many different parts of the country (see Figure 4). The approach to potable reuse does differ between locations, and in almost all cases some sort of environmental buffer exists. The distinction between types of reuse is closing, partially because we are starting to recognize the actual incidence and widespread nature of de-facto reuse in many surface water supplies. Solutions, including advanced treatment technologies and engineered buffers, may demonstrate capabilities to enable removing the environmental buffer, but public acceptance will remain a challenge in some locations.

Reuse is not a one size fits all approach. It must be tailored to the specific location where it is being implemented. In some cases this may mean additional research questions arise as reuse is attempted in new places with new circumstances.

With several organizations leading reuse efforts, the challenge for utilities is going to be finding all the different puzzle pieces. WRF is actively coordinating with many of these organizations to ensure our subscribers have access to the most up-to-date and relevant information.

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Effective Climate Change Communication to Water Utility Stakeholders

Karen Raucher and Robert Raucher, Stratus Consulting

As a community water provider you should be proud of the trust you have earned and recognize the responsibility this trust engenders; as one of the only identified trusted sources for information about local climate change impacts, your community is relying upon your support in preparing for the local implications of climate change.

This knowledge was gained from the survey findings from project #4381, "Effective Climate Change Communication for Water Utilities." This article includes the primary survey findings from the project as well as a brief summary of how this research is being used by water agencies.

As a first step in understanding the issues utilities face when communicating about climate change, 12 utilities were asked,: "Who do you need to talk to about climate change and what do you see as the primary barriers to communication?" All 12 utilities agreed, "We need to talk to internal staff and Governing Board members first; after all, if we can't talk about climate change internally, we have nothing to say to external audiences." The surveyed utilities also agreed on the primary communication barriers, saying, "When we talk about climate change, it often results in someone being dismissive of the issue, and frequently someone becomes angry. Talking about climate change stops the conversation and no progress is made on planning for the future." All 12 utilities felt that the primary ongoing barrier to talking about climate change is the perception that everyone in their utility and customer service area dismisses climate change, and therefore talking about climate change does not increase support.

Based on this identification of the problem, the project team developed four tools water agencies can use as they begin the process of developing effective climate change communication strategies:

1. **A survey to identify what Americans really think about community water and climate change:** A nationally representative survey was developed to identify how Americans really feel about climate change when the concept of community water is added. A summary of the data is presented below.
2. **A template for talking to climate deniers:** Risk-based communication strategies were applied to help industry professionals address climate deniers and keep the conversation moving. A complete description of how to use this tool, with examples, is provided in the full report.
3. **A worksheet for developing a long-term climate communication strategy:** A message mapping worksheet was developed that can assist agencies in developing strong, long-term communication plans—similar to those developed as part of a water conservation campaign—to use communication as a tool to build support over time.
4. **An informational series for increasing the knowledge base of internal audiences:** A series of narrated PowerPoint presentations were developed that provide users with the information they need to be knowledgeable about climate change and community water.

THIS RESEARCH found that most Americans want their community water provider to be a leader in preparing their community for climate change.

What Do Americans Think about Community Water and Climate Change?

AS PART OF the research, the project team conducted a national survey to assess Americans' beliefs, attitudes, behaviors, and policy preferences regarding climate change and community water. The research team developed the survey with the guidance of team member Dr. Anthony Leiserowitz, from the Yale Project on Climate Change Communication. The target population was American adults age 18 or over who receive their water from a community water system. Knowledge Networks, which is part of the GfK Group, sampled households using its online probability-based KnowledgePanel; the panel participants are selected to be representative of the U.S. population. In total, the panel

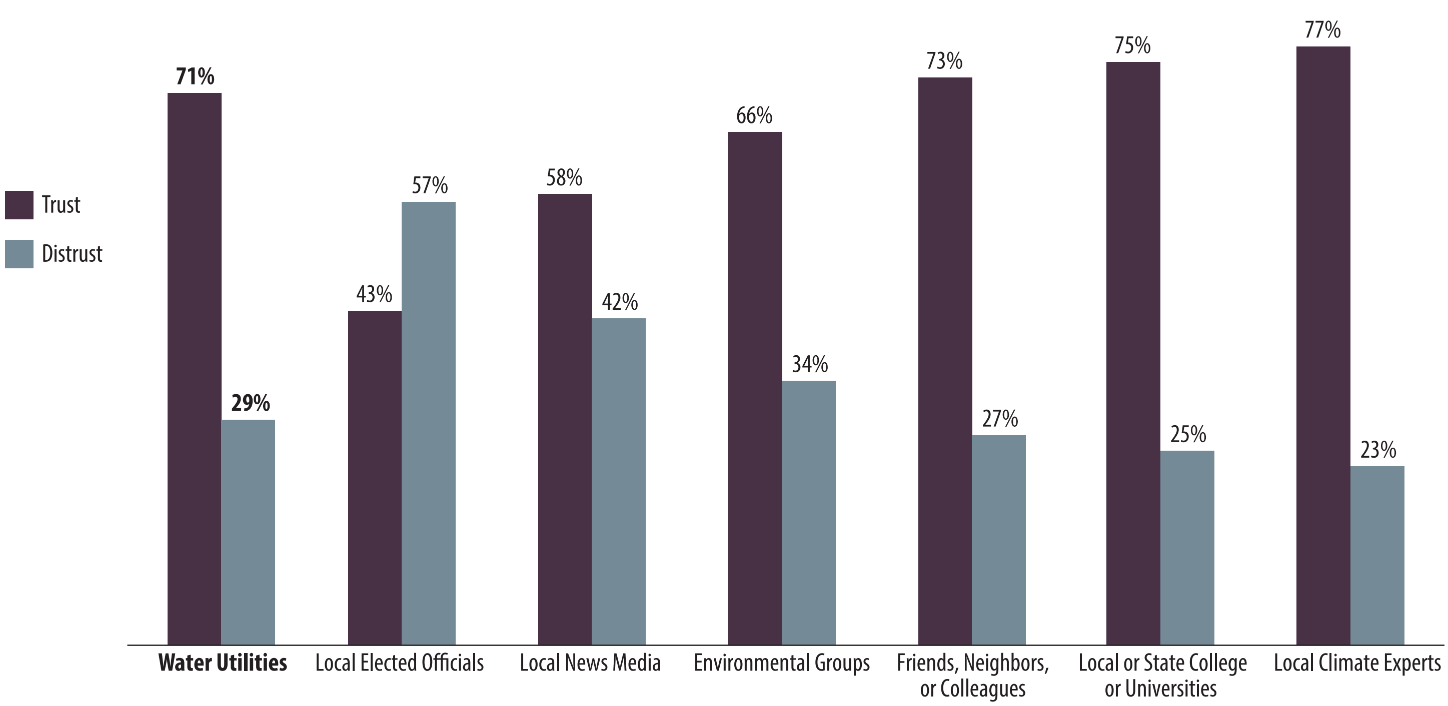


Figure 1. People trust their utilities for information about climate change impacts on local water systems.

participants completed 1,021 surveys. The samples were weighted to correspond with U.S. Census Bureau parameters for the United States. The margin of error is plus or minus 3%.

The findings of the survey tell us that utilities have done a great job of cultivating trust. In fact, Americans trust their community water provider to:

- Provide enough water at all times (90%)
- Provide safe, healthy water (88%)
- Provide timely information about water (78%)
- Provide water at a reasonable cost (77%)

Americans also trust their community water supplier as a source of information about climate change (Figure 1). Research indicates that friends, neighbors, and colleagues are almost always the most trusted source for information. It is significant that water utilities are as trusted a source of information about climate change as friends and local experts. It is also interesting to note that utilities are a far more trusted source of information than local elected officials or the local news media.

The survey also found that 88% of Americans support their utility in planning for the future and 75% of them believe that utilities should pay attention to climate change as they develop plans for the future. However, only 39% of Americans know if their utility has a plan for the future. This represents a great communication opportunity to tell your audience that you are already doing something they want you to do.

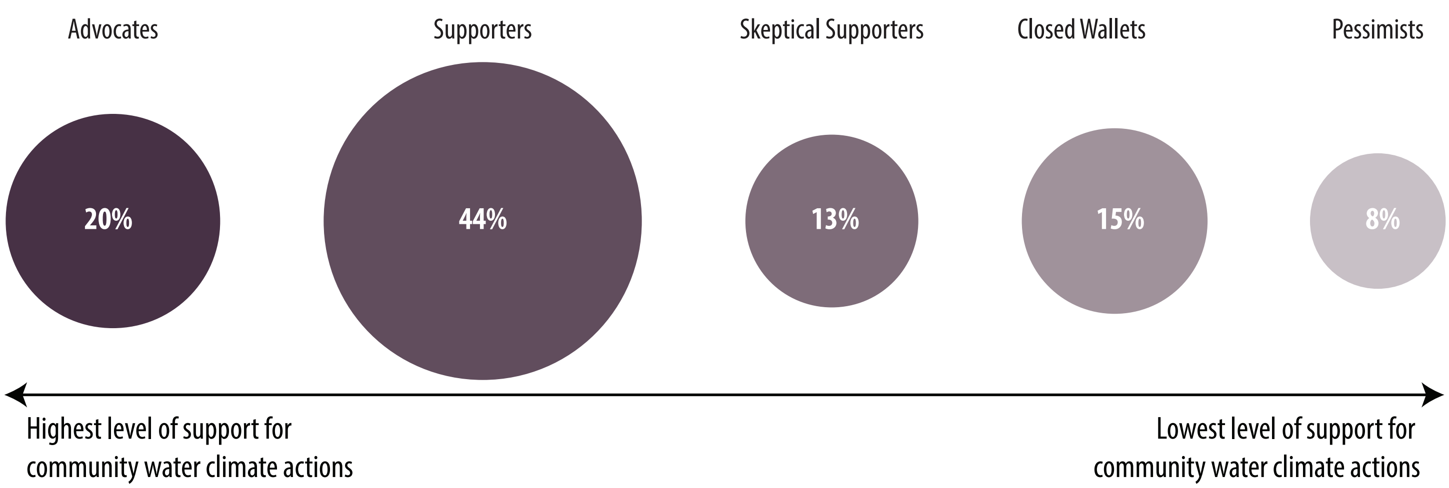
Seventy-two percent of Americans are also concerned that extreme weather events will negatively affect their community water providers' ability to provide safe, healthy drinking water; 86% of Americans want their water utility to prepare, and keep updated, a plan for dealing with extreme weather. Sixty-two percent of Americans also agree that the impact of climate change on extreme weather events will make it more difficult for their community water provider. And perhaps most importantly, almost 3/4 of Americans are willing to pay extra, each month to ensure their community has access to abundant, safe water for the next 10–40 years.

In summary, the survey found that 92% of Americans are not dismissive of climate change. They want their community water provider to be a leader in preparing their community for climate change. As a community water provider you should be proud of the trust you have earned and recognize the responsibility this trust engenders; as one of the only identified trusted sources for information about local climate change impacts, your community is relying upon your support in preparing for the local implications of climate change.

The Five Americas for Community Water and Climate Change

THE SINGLE MOST important aspect of communication is understanding your audience. So, the project team also used the survey findings to develop an audience segmentation analysis. The audience segmentation analysis sorted survey answers, identifying and grouping together Americans who have similar attitudes, beliefs, actions, and policy choices about community water and climate change. Figure 2 illustrates the "Five Americas for Community Water and Climate Change." These five audience segments represent primary audience groups for messages concerning community water and climate change; you can use these groups to develop effective messaging for your stakeholders.

Twenty percent of America, the **Advocates** segment, are strong climate change believers and are very confident that utilities should take action today,



This figure illustrates the proportion of Americans that have similar attitudes, actions, beliefs, and policy choices concerning community water and climate change.

Figure 2. Five Americas for Community Water and Climate Change.

even if it costs money. This group is your choir—ask them for support and they will give it gladly.

The **Supporters** segment, 44% of Americans, hold many of the same views as Advocates—they believe in climate change and in supporting their local water agency's planning actions—just a little less adamantly.

The **Skeptical Supporters** segment, 13% of Americans, are less certain about climate change than either Advocates or Supporters, but are still very strong supporters of water utility actions that prepare for climate change.

The **Closed Wallets** segment, 15% of Americans, has a common unwillingness to pay more for any water utility action, whether related to climate or not.

The remaining 8% of America were identified as **Pessimists**. The Pessimists segment is extremely sure that climate change is not happening and are, unsurprisingly, unwilling to pay for their water utility to be prepared. Unfortunately, this is the segment most likely to attend a water meeting or call a utility about an issue other than billing.

In summary, the segmentation analysis illustrates that a large majority of Americans (77% of respondents—Advocates [20%], Supporters [44%], and Skeptical Supporters [13%]) support their community water suppliers and their climate-related actions.

Only 23% of respondents (Closed Wallets [15%] and Pessimists [8%]) do not demonstrate a willingness to pay for water utility climate preparation actions. Although the Closed Wallets group is the only group unwilling to *pay* for any water utility action, the Pessimists group is the only one that is *totally unsupportive* of climate-related actions.

Messaging Increases Support

THE SURVEY ALSO tested three community water and climate change messages to examine how messages increase support for water utility climate-related actions. The messages were tested by randomly assigning each of the three messages to survey participants and then comparing both overall changes in support and how individual respondents' responses changed after reading the message.

Water cycle message

MANY SCIENTISTS SAY that climate change will have a significant impact on the water cycle, causing changes in rainfall, snowfall, and evaporation patterns. These changes will make it more difficult for water utilities to provide enough water to meet community needs. It will also make it more difficult to provide adequate purification capacity to ensure that water is always safe for drinking, and the necessary storage capacity for community needs in the next 10–40 years.

Extreme weather event message

MANY SCIENTISTS SAY that climate change will have a significant impact on extreme weather events, causing changes in the severity of droughts, hurricanes, rainstorms, and heat waves. These changes will make it more difficult for water utilities to provide enough water to meet community needs, adequate purification capacity to ensure that water is always safe for drinking, and the necessary storage capacity for community needs during and immediately after extreme weather events.

Separation message

MANY SCIENTISTS SAY that our climate is changing. This fact can be separated from the rest of the debate, for example, whether climate change is caused by human activities or natural cycles. The fact that our climate is changing makes it more difficult for water utilities to provide enough water for community needs. It will also make it more difficult to provide adequate purification capacity to ensure that water is always safe for drinking, and the necessary storage capacity for community needs in the next 10–40 years.

All three messages provide significant increases in support for utility climate related actions, as illustrated in Figure 3. However, the extent of the change in support varies by audience segmentation (Figure 4). Because 66% of Americans are either Advocates or Supporters, these large groups are the ones you are most likely to target with communications. However, if you want to increase the willingness of Closed Wallets and/or Pessimists to pay, use the separation message.

Applying the Tools—An Example from Denver Water

ALTHOUGH THIS ARTICLE focuses on the survey findings, several of the participating utilities are already applying the tools developed in this project as they begin a long-term investment in climate change communication.

Denver Water explains why they are using the project tools to develop a long-term climate change communication strategy: "In 5–10 years, when we need to ask our customer base to support a potentially unpopular action we need to take to prepare for climate change—for example, increasing the size of a reservoir—we want

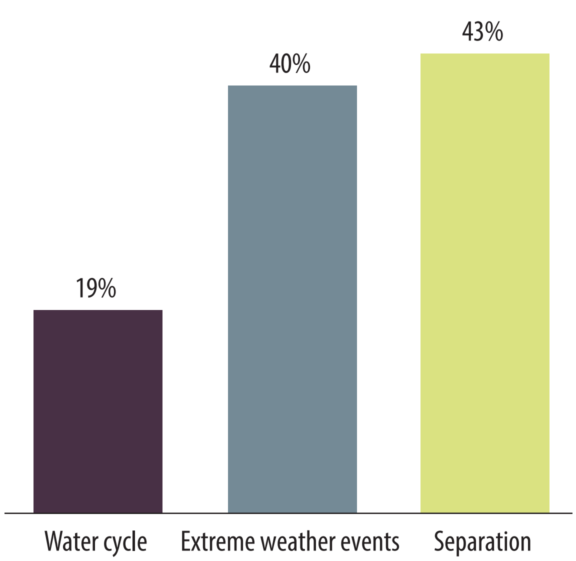


Figure 3. Net change in support for water utility spending as a response to message test.

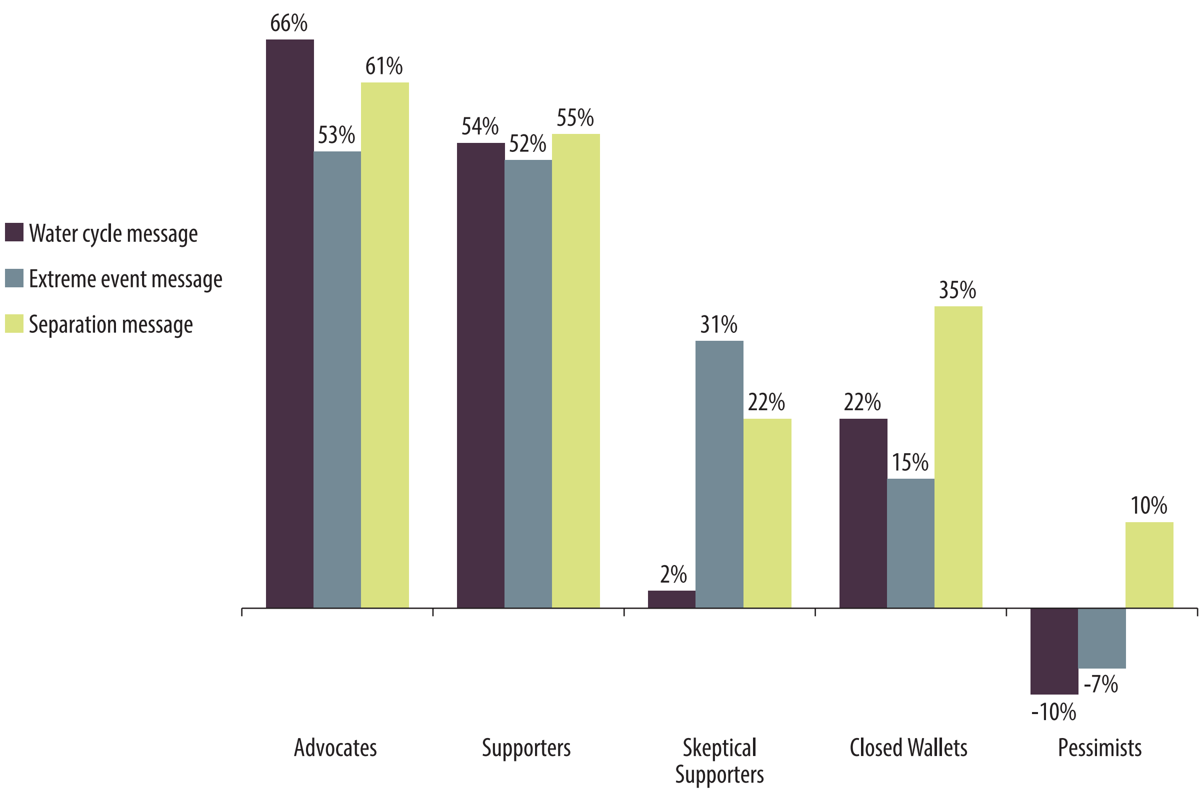


Figure 4. Net change in support as a response to climate change by audience segment.

our public to say, "Although this is not what we would choose, we understand why climate change is forcing this action and we support you!"

Denver Water is using three of the project tools:

1. **The Survey:** Denver Water will use a subset of the national survey questions to identify local attitudes, beliefs, and actions concerning community water and climate change. The utility will use this data-based information to open the door to talking about climate change by removing one of the fundamental barriers identified in the beginning of the project: that all internal staff and customers dismiss climate change. If Denver Water's local survey confirms the national finding that 92% of their customers want the utility to play a leadership role in preparing the Denver area for climate change, then clearly not all of the utility's customers dismiss climate change. A survey will also allow Denver Water to test location-specific messages.
2. **The Information Series:** Denver Water is also using the "Community Water and Climate Change Information Series," five narrated PowerPoint slides, as an internal educational opportunity regarding the fundamental principles of water and climate change. As part of their internal educational program, Denver Water will also present findings from their local service area survey. Together these presentations will help Denver Water's internal audiences understand the issues while also sending a strong internal message that the utility is preparing for climate change.
3. **Message-Mapping Tools:** Denver Water is also developing a long-term communication strategy. They are using the message mapping worksheet to develop a strategy that will begin building support today for the climate change actions they may need in the future.

Research Conclusions

THE SURVEY SHOWS that the perception that the majority of Americans are dismissive or angry when the topic of climate change arises is not actually real. Unfortunately, the small group of Americans (8%) who are angry and dismissive of climate change are the most likely group to show up at a water utility meeting (see project #4381, "Effective Climate Change Communication for Water Utilities," for details).

Instead, a vast majority of Americans trust their water utilities. In fact, 92% of Americans support their community water provider in leading their community as they prepare for climate change. This is a big responsibility. This research provides you with the tools you need to develop effective communication about climate change for your community.

Research Update on Perfluorinated Chemicals

Alice Fulmer, Water Research Foundation

Poly- and perfluoroalkyl substances (PFASs), more commonly referred to as poly- and perfluorinated chemicals or compounds (PFCs), have been found worldwide in the environment, animals, and humans. They are surfactants used in firefighting foams and stain repellants such as Scotchgard as well as in the manufacture of nonstick coatings such as Teflon and water repellent fabrics like GoreTex.

The two most commonly studied PFCs are perfluorooctanoic acid (PFOA or C8) and perfluorooctane sulfonate (also known as perfluorooctane sulfonic acid or PFOS), but many others have been found in water.

PFCs persist in the environment and bioaccumulate in animals and humans. They have been found at low levels in the blood of the general population. Long-chain PFCs, including PFOA and PFOS, have eight or more carbons and are considered a human health concern due to their long half-lives in the human body and reproductive, developmental, and systemic effects found in laboratory animal tests. The U.S. Environmental Protection Agency (EPA) has stated that they are "likely to be carcinogenic to humans." Due to this concern, and because drinking water is an important exposure route for PFCs, the EPA issued a drinking water Provisional Health Advisory (PHA) for PFOA and PFOS of 0.4 and 0.2 μ g/L, respectively. These two compounds are also on the

Contaminant Candidate List 3 (CCL3) for regulatory consideration, and some states, including Minnesota, New Jersey, and North Carolina, have already established drinking water guidelines for one or both of them.

IN THE United States, a number of PFCs have been detected in surface waters including lakes, rivers, and tributaries as well as in ground waters

As part of the research needed to support the regulatory determination process, the EPA is currently collecting occurrence information for six PFCs in U.S. drinking waters through the Third Unregulated Contaminant Monitoring Rule (UCMR3)—perfluoroheptanoic acid (PFHpA or C7), perfluorononanoic acid (PFNA or C9), perfluorobutane sulfonic acid (PFBS), and perfluorohexane sulfonic acid (PFHxS) in addition to PFOA and PFOS. While UCMR3 monitoring will continue through December 2015, preliminary results are available. As of January 2014, 7,411 results were available from 1,470 public water systems (PWSs). Table 1 summarizes this data and provides a list of PFCs included in the research presented in this article.

Of the 7,411 samples, there were only 44 detections of PFOS, 55 of PFOA, and fewer of the other PFASs. However, it should be noted that the minimum reporting levels (MRLs) for these compounds are considered to be relatively high. Maximum concentrations to date were 0.93 µg/L for PFOS, 0.14 µg/L for PFOA, 0.44 µg/L for PFHxS, and 0.07 µg/L for PFHpA. Four of the 44 PFOS detections, from three PWSs, were above the health reference level (HRL) of 0.2 µg/L. Therefore only 0.2% of PWSs have results exceeding the HRL thus far. In a recent Chemical & Engineering News (C&EN) webinar, Eurofins Eaton Analytical showed the distribution of PFCs from the UCMR3 database, with occurrence in 20 states, detections in both groundwater and surface water, and 30 sites with multiple PFCs. Figure 1 shows a map of the United States with locations of these detections, including two of the sites that exceeded the HRL for PFOS.

Prior to UCMR3, WRF funded project #4322, "Treatment Mitigation Strategies for Poly- and Perfluorinated Chemicals," led by Eric Dickenson of Southern Nevada Water Authority and Chris Higgins of Colorado School of Mines. This project began by conducting a literature review of the occurrence of PFCs in the environment, focusing mainly on aqueous occurrence, the fate of PFCs in conventional and advanced drinking water treatment systems, and potential toxicological hazards associated with these compounds. The complete literature review will be available in the project's final report, which is expected to be published later this year.

In short, the literature review found reports of PFCs in all types of waters throughout the world including surface, ground, tap and bottled waters, wastewater influents and effluents, industrial

Table 1. List of PFCs included in WRF projects, UCMR3, and CCL3.

Poly- and Perfluorinated Chemicals (PFCs)	WRF #4322	WRF #4344	UCMR3	CCL3	EPA PHA (µg/L)	UCMR3 MRL (µg/L)	# Results >MRL*	# Results >PHA*	# PWSs >MRL*	# PWSs >PHA*
perfluorobutanoic acid (PFBA, C4)	✓	✓								
perfluoropentanoic acid (PFPeA, C5)	✓	✓								
perfluorohexanoic acid (PFHxA, C6)	✓	✓								
perfluoroheptanoic acid (PFHpA, C7)	✓	✓	✓			0.01	31		17	
perfluorooctanoic acid (PFOA, C8)	✓	✓	✓	✓	0.4	0.02	55	0	24	0
perfluorononanoic acid (PFNA, C9)	✓	✓	✓			0.02	5		4	
perfluorodecanoic acid (PFDA, C10)	✓	✓								
perfluorobutane sulfonic acid (PFBS)	✓	✓	✓			0.09	1		1	
perfluorohexane sulfonic acid (PFHxS)	✓	✓	✓			0.03	29		14	
perfluorooctane sulfonic acid (PFOS)	✓	✓	✓	✓	0.2	0.04	44	4	24	3
perfluorooctane sulfonamide (FOSA)	✓									
N-methyl perfluorooctane sulfonamidoacetic acid (*N*-MeFOSAA)	✓									
N-ethyl perfluorooctane sulfonamidoacetic acid (*N*-EtFOSAA)	✓									

*Results are from UCMR3 as of January 2014, at which time 7,411 results were available from 1,470 PWSs

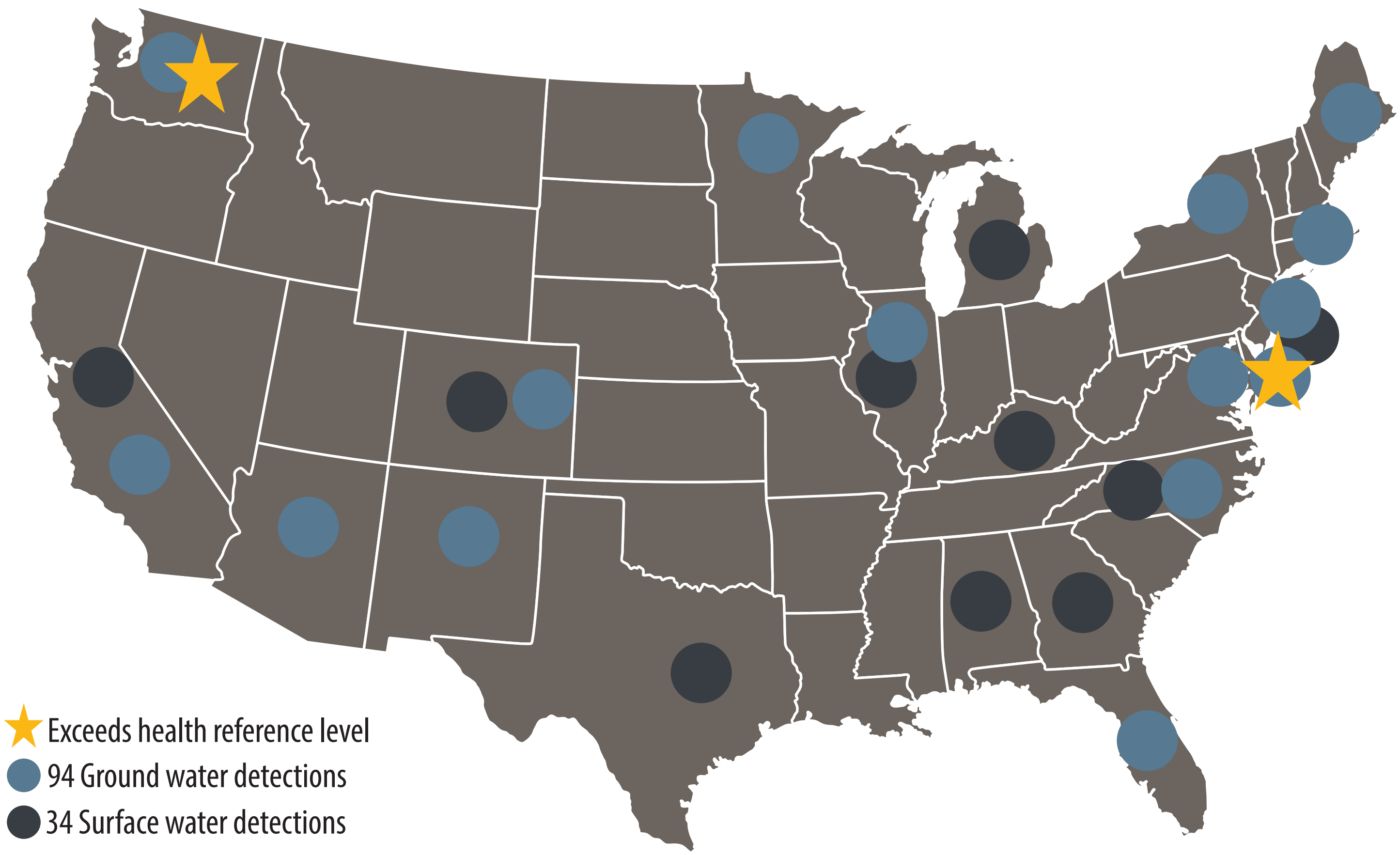


Figure 1. Map of PFC detections in UCMR3 data.

waste influents and effluents, and rivers, lakes, and tributaries in the United States, Germany, Canada, South Korea, China, Brazil, United Kingdom, France, Italy, and Spain with concentrations ranging from below detection limits to µg/L in some cases. One study found levels of up to 3.04 µg/L of perfluorohexanoic acid (PFHxA or C6), 33.9 µg/L of PFOA, 1.45 µg/L of PFBS, and 5.9 µg/L of PFOS in the Moehne River in Germany. In the United States, a number of PFCs have been detected in the ng/L range or lower in surface waters including lakes, rivers, and tributaries as well as in ground waters.

Such detections in the United States and the (at the time) upcoming UCMR3 were the drivers for the primary objective of "Treatment Mitigation Strategies for Poly- and Perfluorinated Chemicals"—to evaluate the removal of PFCs by conventional and advanced drinking water treatment processes. This evaluation first involved collecting available PFC data or measuring PFC levels in source waters from full-scale drinking water treatment systems across the United States before assessing removal at various steps along their treatment trains. Several PFCs were frequently detected in source waters for many of the utilities sampled in this study, the three most commonly detected being PFOS (84%), PFHxA (79%), and PFHxS (79%) (n = 39). Other chemicals that were frequently detected included perfluoropentanoic acid (PFPeA, 74%), PFHpA (74%), PFOA (74%), PFNA (66%), and PFBS (74%).

To assess the removal of PFCs, samples were collected during multiple sampling events for 15 full-scale water treatment systems throughout the United States, including two potable reuse treatment systems. These systems included a wide range of conventional and advanced technologies, such as ferric and alum coagulation, granular/micro-/ultrafiltration, aeration, oxidation (i.e., permanganate, ultraviolet/advanced oxidation with hydrogen peroxide), disinfection (i.e., ozonation, chlorine dioxide, chlorination, and chloramination), granular activated carbon (GAC), anion exchange (AIX), reverse osmosis (RO), dissolved air flotation, and riverbank filtration. Laboratory-scale testing was performed for select treatment technologies where the treatment of PFASs was unknown or not well understood (i.e., nanofiltration [NF] and GAC).

Table 2 summarizes the general removals (<10%, 10–90%, >90%) of those PFCs

Table 2. Summary of PFC removals for various treatment processes.

Removal <10% | Removal 10-90% | Removal > 90%

Compound	Molecular weight (g/mol)	Aeration	Coagulation/ Dissolved Air Flotation	Coagulation/ Flocculation/ Sedimentation/ Granular or Microfiltration	Anion Exchange	Granular Activated Carbon Filtration	Nanofiltration	Reverse Osmosis	Potassium Permanganate ($KMnO_4$), Ozone, Chlorine Dioxide, Hypocholorous/ Hypocholorite (Cl_2), Chloramination, Ultraviolet (UV) Photolysis, UV Photolysis with Advanced Oxidation
PFBA	214	assumed	assumed						
PFPeA	264								
PFHxA	314								
PFHpA	364								
PFOA	414								
PFNA	464		unknown		assumed	assumed			
PFDA	514		unknown		assumed	assumed			
PFBS	300								
PFHxS	400								
PFOS	500								
FOSA	499	unknown	unknown		unknown	assumed	unknown	assumed	unknown
N-MeFOSAA	571	assumed	unknown		assumed	assumed	assumed		unknown
N-EtFOSAA	585		unknown		assumed	assumed	assumed		unknown*

*<10% removal by Cl_2 and $KMnO_4$

"assumed": treatment performance is assumed based on the perfluoroalkyl acid size/charge and/or known removal data of shorter or longer chain homologues

that were frequently detected in source waters. As suggested by the few studies found in the literature review on the effectiveness of various treatment methods for PFC removal (especially at full-scale), common conventional treatments, such as coagulation followed by physical separation processes, and chemical oxidation, aeration, and disinfection, failed to remove PFCs. Only alternative treatment technologies, including AIX, GAC, NF, and RO, proved effective for PFC removal.

Full-scale AIX and GAC column treatments were effective at removing longer-chain PFCs. GAC rapid small-scale column tests (RSSCTs) demonstrated that natural organic matter (NOM) competition can affect the ability of GAC to adsorb PFCs. Therefore, it is important to understand the type and quantity of NOM that could have an impact on the degree of PFC removal. This finding suggests that GAC maybe be more effective for removal of PFCs from groundwaters, which have less NOM than surface waters. Full-scale RO demonstrated significant removal for all the PFCs, including the smallest PFC, perfluorobutanoic acid (PFBA). In laboratory testing, NF also rejected almost all of the PFCs by 90% or higher, including PFBA, which is promising. However, this finding needs to be further investigated at pilot- and full-scale.

ONLY ALTERNATIVE treatment technologies proved effective for PFC removal

A second WRF project has also been investigating treatment of PFCs—project #4344, "Removal of Perfluorinated Compounds by PAC Adsorption and Anion Exchange," led by Detlef Knappe of North Carolina State University. Since previous research had indicated activated carbon adsorption, AIX, NF, and RO to be the most promising treatment technologies for PFC removal, the objective of this research was to assess the effectiveness of two of those processes—powdered activated carbon (PAC) adsorption and AIX—more thoroughly. Specific objectives included assessing PFC removal with a wide range of commercially available PACs, determining whether superfine PAC (S-PAC) could enhance PFC removal as a result of faster adsorption kinetics and/or a larger adsorption capacity, evaluating the effects of resin type and dose as well as background water quality on PFC removal by AIX, identifying regeneration conditions that restore the PFC removal capacity of AIX resins, and measuring the PFC removal effectiveness of an AIX resin over multiple loading/regeneration cycles.

The PFCs included in this research are shown in Table 1. Overall, they proved to be difficult to remove by (S-)PAC adsorption and AIX. PFC removal with both PAC and a polyacrylic strong base anion (SBA) exchange resin increased with increasing perfluorinated carbon chain length, and for a given chain length, sulfonates (e.g., PFOS) were more adsorbable than carboxlates (e.g., PFOA). Results showed that more than 50 mg/L of the most effective as-received PAC, a thermally activated wood-based carbon, would be required to achieve 90% removal of any of the tested PFCs. With the superfine version of the same carbon, doses between 40 and 50 mg/L would be required to reach 90% removal of PFNA, PFDA, and PFOS. Thus, if adsorption equilibrium is not obtained, as is the case for most conventional surface water treatment plants, 90% PFC removal by both as-received and superfine PACs requires adsorbent doses that are prohibitively high. If contact times are sufficiently long to approach adsorption equilibrium, 90% removal of PFOA, PFNA, PFDA, PFHS, and PFOS could be possible with carbon doses of 17–23 mg/L or lower based on the two waters tested. For situations in which 50% PFC removal is sufficient, the use of (S-)PAC could become more attractive. At the non-equilibrium conditions evaluated in jar tests, 28 mg/L of thermally activated wood-based PAC in as-received form or <15 mg/L in superfine form would suffice to achieve 50% removal of PFOA, PFNA, PFDA, PFHS, and PFOS. At adsorption equilibrium, 50% removal also starts becoming feasible for PFHxA, PFHpA, and PFBS. However, 50% removal of PFBA and PFHeA cannot be readily achieved by (S-)PAC adsorption.

AIX processes showed greater promise for PFC removal, provided that resins are regenerated in a manner that restores, at least periodically, the PFC removal capacity. Among the tested resins, the polyacrylic SBA resin exhibited the fastest PFC uptake rates, while the polystyrene-based SBA resins were the only ones that permitted >90% removal of PFBA, PFHeA, and PFHxA at reasonable resin use rates (5 mL/L or 200 bed volumes). Regeneration with a 50/50 water/methanol mixture containing NaCl was at least periodically required to restore the PFC uptake capacity of the polyacrylic SBA resin. More detailed results will be provided in the final report, which is expected to be published later this year.

IT'S CLEAR based on these research efforts that removal of PFCs will be a challenge for utilities that have them in their source water, should they be regulated

It's clear based on these research efforts that removal of PFCs will be a challenge for utilities that have them in their source water, should they be regulated. The most effective treatment alternatives are costly. While U.S. production of PFOS and PFHxS by their major manufacturer ended in 2002 and the worldwide use of PFOA and long chain PFCs is currently being phased out by major manufacturers, environmental and human exposure is expected to continue for the foreseeable future due to their persistence, formation from precursor compounds, and continued production by other manufacturers. Alternative compounds, including shorter chain PFCs, have been introduced to replace the longer chain PFCs, and though they are generally less toxic, they are still highly persistent, so this challenge will remain an important research need.

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Molecular Methods in the Water Industry

Grace Jang, Water Research Foundation

Molecular methods have been used successfully in clinical and food industry applications. However, the full potential of molecular methods in environmental applications, especially for drinking water supply purposes, has not been realized.

Even though molecular methods such as polymerase chain reaction (PCR) and quantitative PCR (qPCR) offer the means to rapidly monitor and quantify regulated and emerging pathogens and indicators, the use of molecular techniques is limited by the lack of standardization of PCR and a direct comparison of its performance to culture-based methods that are currently approved by the U.S. Environmental Protection Agency (EPA).

In 2012, the EPA released EPA Method 1611 (EPA 2012), which listed recreational water quality criteria (RWQC) recommendations and adopted the qPCR technique for the detection of enterococci in recreational water. Figure 1 illustrates how PCR can be used to improve analytical response time to protect public health in a recreational situation. For this trend to be transferred to drinking water there is a need to understand if molecular methods can correlate to, or even surpass, current culture-based techniques.

According to a survey conducted by Water Research Foundation (WRF), project #3110, *Synthesis Document on Molecular Techniques for the Drinking Water Industry*, 65% (n = 37) of respondents indicated molecular methods would be beneficial to water utilities and nearly 57% (n = 37) of respondents had a very positive or positive attitude towards implementation of new analytical techniques in the utility/laboratory (Nocker et al. 2009). The number one expectation of any new method is "shorter time demand for analysis" (Figure 1). WRF project #3108, *Sample Preparation Methods for Molecular Techniques for Drinking Water*, showed similar survey results about molecular techniques. Thus, many water utility professionals feel that molecular techniques will be a part of water analysis in the near future and that there is a need for technical guidance to facilitate that increased implementation of molecular testing by utilities for water quality monitoring.

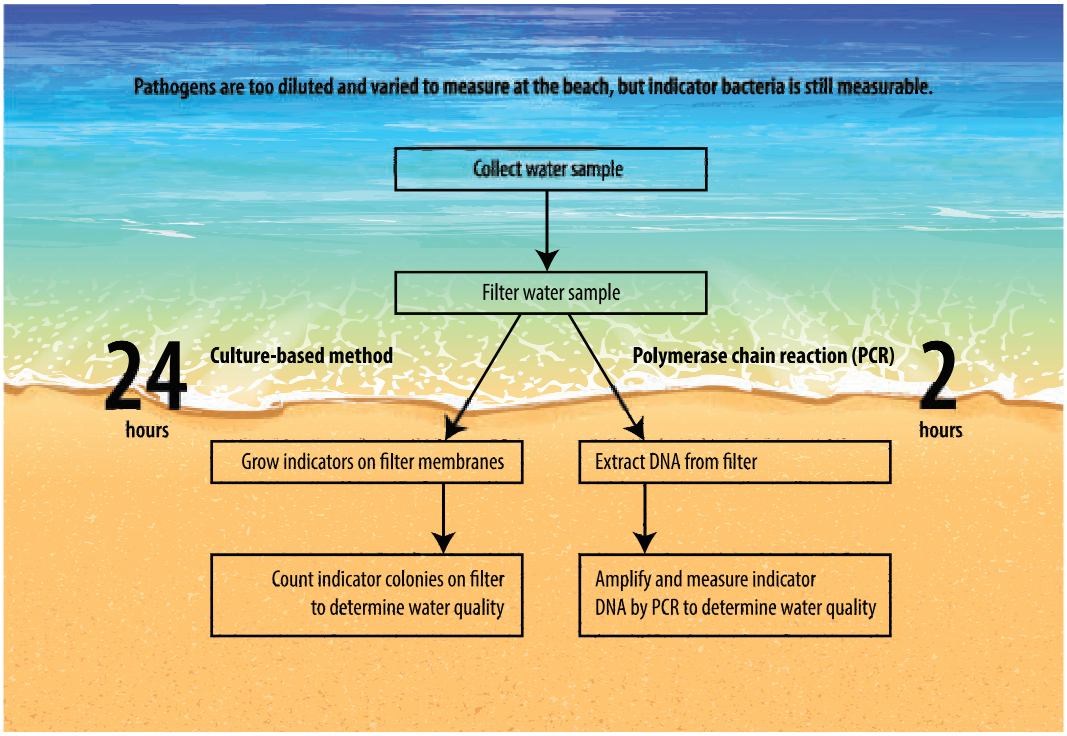
As shown in Figure 2, several main expectations of new molecular methods are 1) fast detection time, 2) higher detection sensitivity/specificity, 3) lower false positive rate, and 4) reduced costs. WRF and the Centers for Disease Control (CDC) recently completed project #4238, *Enhancing the Value of Molecular Methods to the Water Industry: an* E. coli *Case Study* (Hill et al. 2014). The report evaluated how molecular testing can be a valuable tool for drinking water quality monitoring, with a specific focus on detection of *E. coli* in source and finished drinking water. The project developed a detailed protocol for a sampling process, optimized molecular assay methods, compared the optimized molecular method with EPA-approved culture methods, and conducted an interlaboratory study.

Developing qPCR Assay for *E. coli*

TO DEVELOP A qPCR assay for *E. coli*, 117 bacterial isolates were selected and 18 molecular assays were evaluated. Each assay calculated the specificity, diagnostic sensitivity, false negative rate, and false positive rate. Data from this project indicate that there are multiple sources of potential *E. coli* false-positive results, including the presence of *E. coli* DNA in molecular reagents (especially enzyme stocks) and the potential cross-reactivity with non-*E. coli* bacteria. Therefore, utility laboratories should carefully choose molecular assays to monitor drinking water for *E. coli*. This project also demonstrates that no single qPCR assay could be used to reliably detect low levels of *E. coli* in drinking water. The duplex TaqMan PCR assay that was developed by this project was found to be effective in minimizing potential false-positive results and increasing confidence.

Rapid-Culture PCR (RC-PCR: culture-dependent method) and Propidium Monoazide PCR (PMA-PCR: culture-independent method)

A CULTURE-DEPENDENT METHOD (RC-PCR) that was developed by project #4238 is a combination of a short-term culture of *E. coli* (5-hour incubation in modified Colitag broth) and qPCR, and it allows detection of viable *E. coli* within one working day (7~8 hours). During the development, RC-PCR was compared with two EPA-approved methods (MI agar culture and Colilert-18 broth culture) for its performance evaluation. The research data indicated that the RC-PCR method could be an effective alternative to traditional culture- and enzymatic-based detection methods for viable *E. coli* in water. However, it may not be comparable with traditional culture methods for quantification.



Adapted from: EPA 2009

Figure 1. Diagram of culture vs. molecular methods to determine beach water quality

A culture-independent molecular technique is desirable because this has the potential for generating test results in the shortest turnaround time. In this project, the culture-independent method (PMA-PCR) was developed and evaluated for its effectiveness. Although this method can be completed (5 hours) in less time than a traditional culture method (18~24 hours) or RC-PCR method (7~8 hours) and differentiate between viable and non-viable

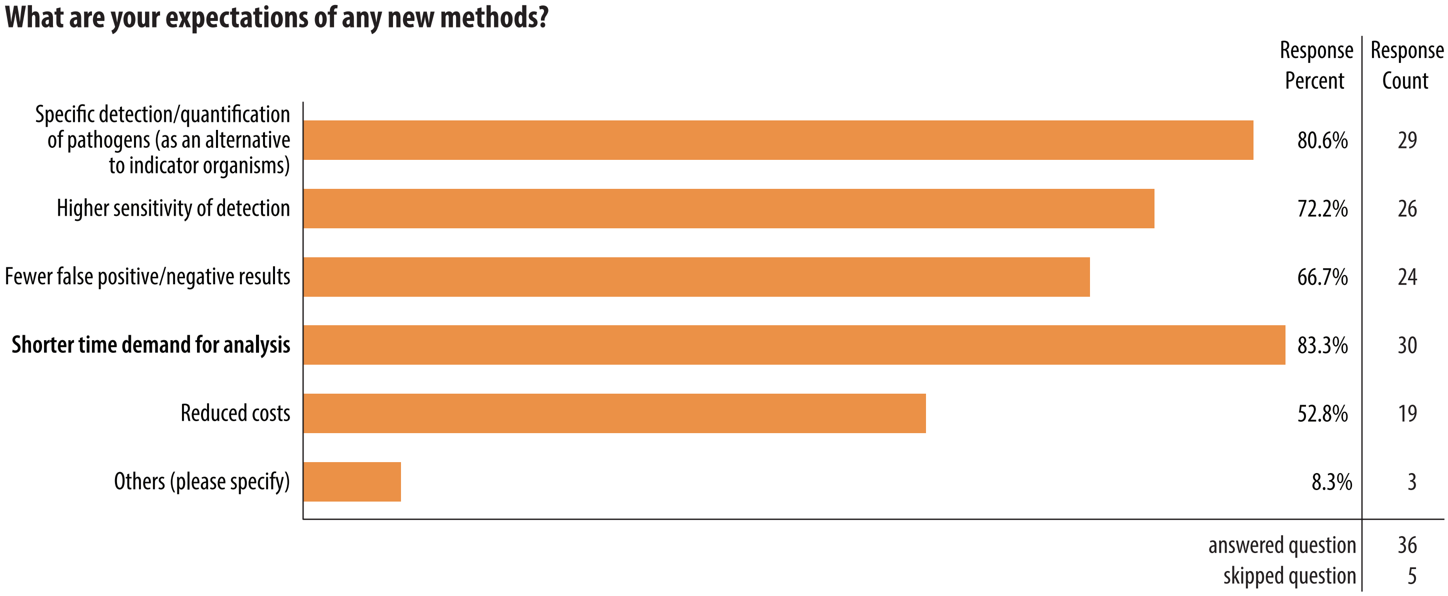


Figure 2. Expectations for molecular methods from water utilities

E. coli in conjunction with common inactivation processes (e.g., heat, free chlorine, and starvation), the detection sensitivity of this method is high (50 CFU/100 mL for a reagent-grade PBS control; detection limits were an order of magnitude higher for 1 L tap water samples). To achieve method detection limits comparable to the current regulatory standard for *E. coli* (1 CFU/100 mL), it requires filtration of a large sample volume.

Inter-laboratory Validation Study

THE PROJECT #4238 team collaborated with seven utility partners to conduct a six month inter-laboratory validation study. During the validation study, the developed RC-PCR method and EPA-approved culture methods currently used by each utility were tested in parallel. The RC-PCR method performed comparably to the lab culture method for source water samples. Detection rates in finished and distribution system water could not be compared because there were no *E. coli* detections using the lab culture method during the validation study.

At the end of the inter-laboratory validation study, participating utilities provided feedback about the RC-PCR method. The summarized comments are:

- possible to complete the RC-PCR method in one day (if samples were available for testing early in the morning),
- useful for emergency response, in which contamination was known or suspected,
- more labor intensive, and
- data could not be used within the current regulatory framework.

Project #4238 also provided a cost comparison of RC-PCR vs. commercial culture-based methods (Table 1).

Table 1. Cost comparison of two methods

Method	RC-PCR (per sample)	Culture methods (per sample)
Cost	$13.00* ~ 17.50	$ 8.00 ~10.00

*If a 50-ml pipette is not used and if a commercial internal control is not used. Note: All of these estimates could vary based on lab-specific supply choices and different brands or vendors.

Molecular methods hold much potential for monitoring microbiological water quality, but the application of this technology is challenging with environmental samples. Project #4238 showed that molecular methods can be a useful tool to confirm whether *E. coli* are present in a drinking water sample and to respond to emergency activities when known or suspected contamination is present. However, the techniques need to be more mature before it is implemented.

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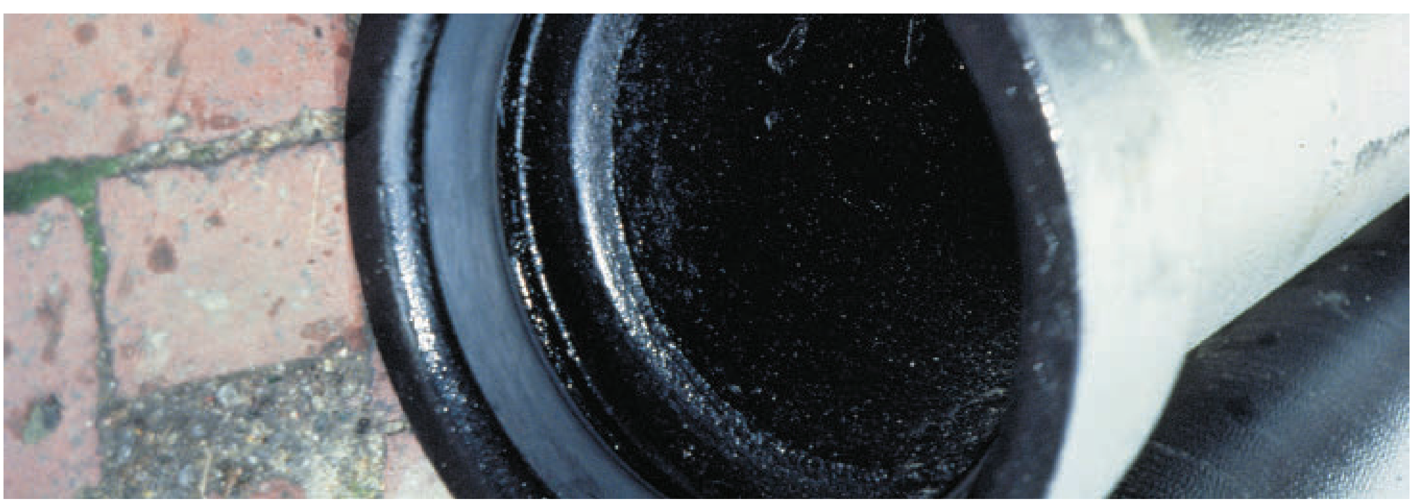
Pipe Location and Leakage Management for Small Water Systems (project #4144)

THE GOAL OF this project was to create guidance material to assist small system operators in the essential functions of locating their buried infrastructure and identifying and pinpointing leaks. The primary output of the project is four PowerPoint presentations that include speaker notes to assist trainers in educating small system operators.

Photo courtesy New Jersey American Water

Non-Destructive Condition Assessment for Small Diameter Cast and Ductile Iron Pipe (project #4230)

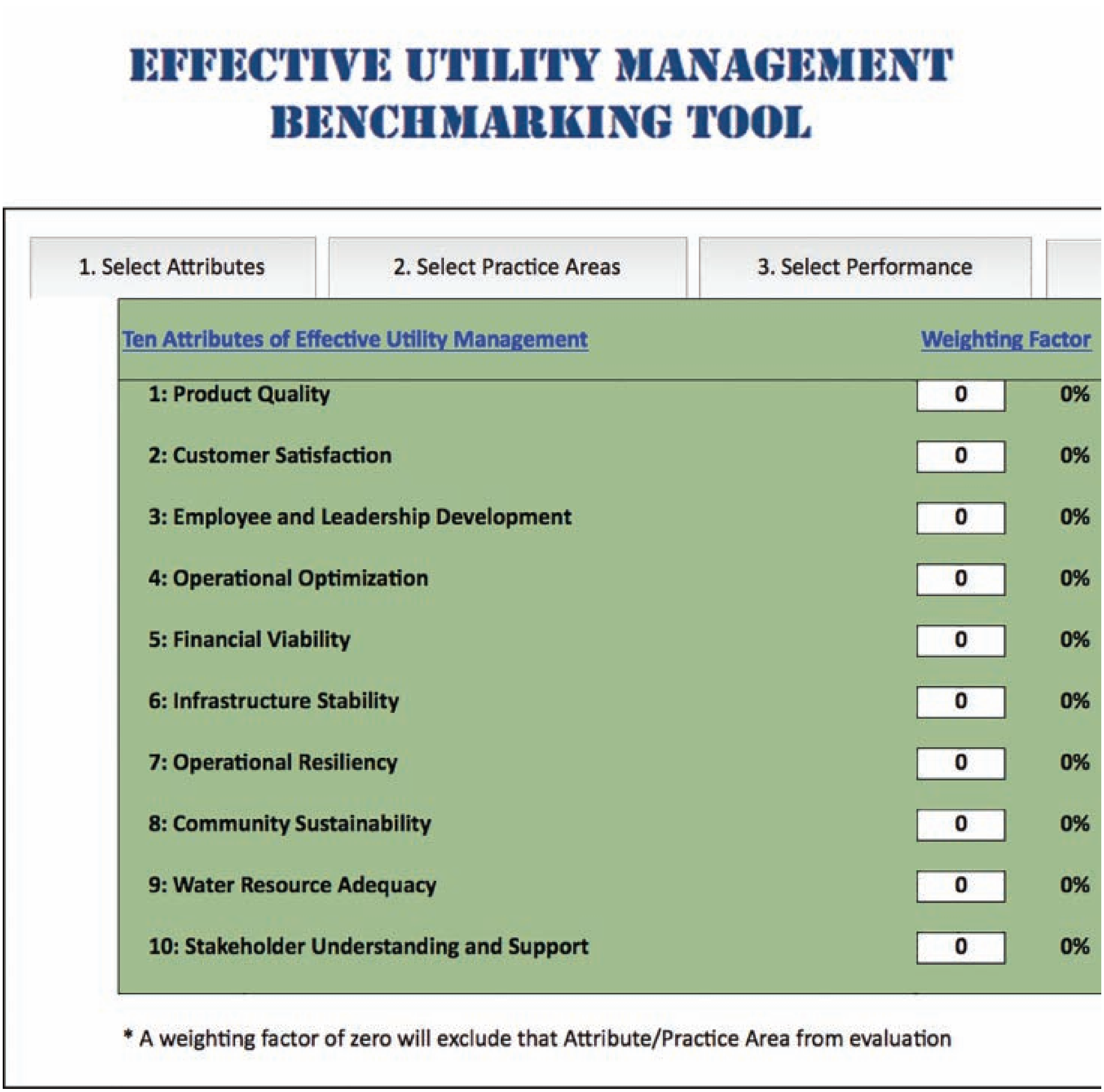
FOR LARGE DIAMETER strategic pipelines the benefits of improved understanding of pipe condition and early intervention justify the cost of condition assessment (CA), which is usually significantly less than the direct and indirect costs incurred from pipeline failure. This project evaluated technologies that can be applied to non-interruptive, non-destructive CA of small diameter (less than 16 inch or approximately 400 mm) cast iron and ductile iron pipe (CIP and DIP), with a focus on technologies that can estimate the amount of remaining structural metal in the pipe wall compared to the amount of non-structural material, or as close to that as possible, for both unlined and cement mortar-lined CIP and DIP of small diameter.



Performance Benchmarking for Effectively Managed Water Utilities (project #4313)

THIS PROJECT WAS sponsored to help utilities develop and implement the 10 key attributes for Effective Utility Management (EUM). The project builds on recommendations presented in *Effective Utility Management: A Primer for Water and Wastewater Utilities* (EPA, AMWA, APWA, AWWA, NACWA, NAWC, WEF, 2008).

A practical tool was developed for water and wastewater utilities to conduct assessments and strategically develop key organizational attributes to meet specific goals. The resources include the Excel-based tracking tool, user guide for the tool, guidance document, and research report.

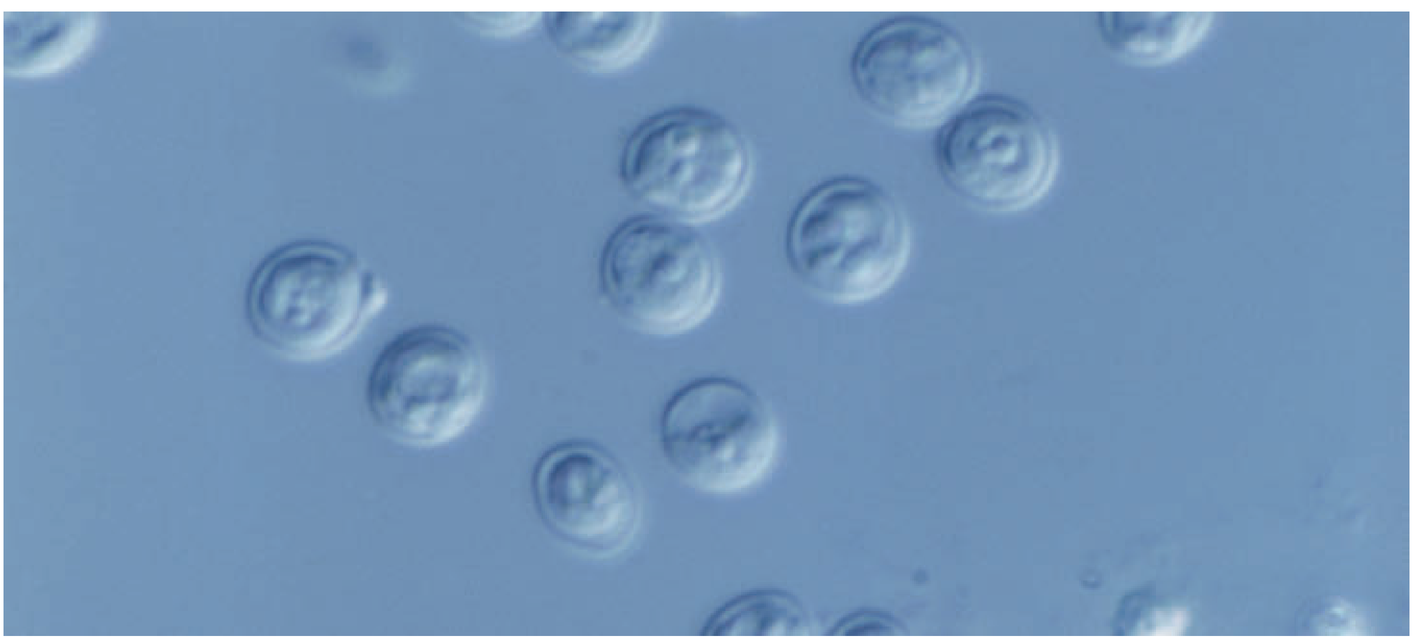


Water Quality Impacts of Extreme Weather-Related Events (project #4324)

WHETHER IT'S SEVERE drought or a polar vortex, extreme weather can cause havoc on drinking water supplies. Results from this project include a description of water quality impacts, from source to tap, of extreme weather-related events and dozens of case studies documenting the lessons learned from such events. The project deliverables include a research report, the case studies, and an Excel tool that organizes the case studies by extreme event type.

Matrix Effects on *Cryptosporidium* Oocyst Recovery (project #4348)

AN INTENSIVE *CRYPTOSPORIDIUM* monitoring program, conducted by Portland Water Bureau (PWB) in source water from the Bull Run watershed, identified a period of very low *Cryptosporidium* oocyst recovery from matrix spike samples analyzed using EPA Method 1623. To address this problem, in 2010, PWB partnered with the Water Research Foundation as part of project #4348. Through extensive statistical and laboratory analyses, this research found a set of likely causes of seasonally poor oocyst recovery in source water from the Bull Run watershed—ions, metals, algae, and organic matter. The team further studied a previously developed modification to Method 1623, the Precoat Method, which improved oocyst recovery for PWB, and demonstrated an approach using historical water quality data in combination with ultraviolet-visible (UV-Vis) spectral data for generating predictive models for oocyst recovery.



Defining a Resilient Business Model for Water Utilities (project #4366)

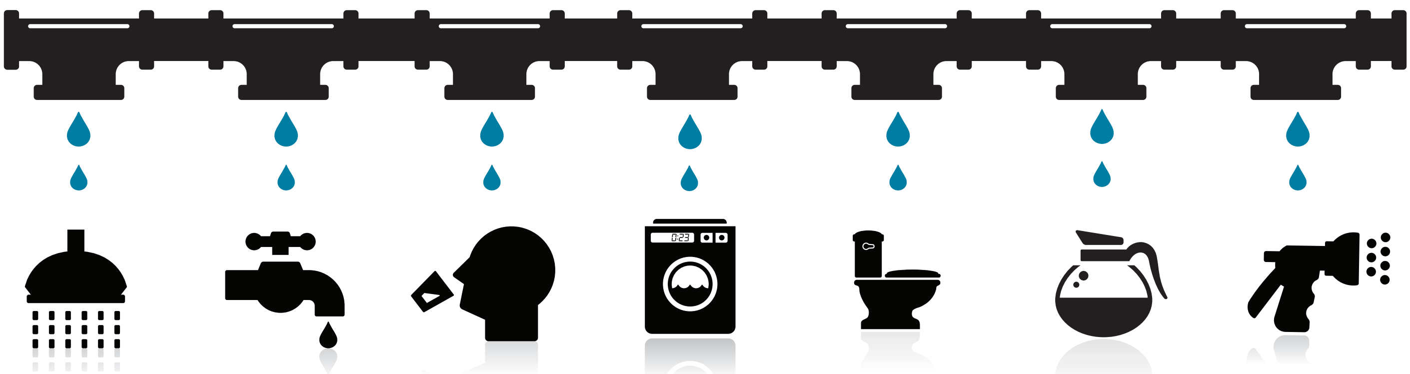
THIS RESEARCH PROVIDES an assessment of the financial condition and revenue model of water utilities in North America and the factors influencing financial performance. While it seems most research and high-profile policy papers today focus on the "cost" side of the financial balance utilities must navigate, this project primarily addresses the revenue and rates side of the equation. The analysis clearly shows that there is not one generalizable "new normal" or inevitable pre-ordained financial outcome for the industry. There are clearly differences between regions, states, and utilities. The project also provides practices that have the potential to improve the financial resiliency of the water utility industry, with examples of current, emerging, and "out of the box" strategies available to utilities to build a resilient business model. In addition to the research report and a two part archived Webcast, the project produced two spreadsheet tools: a Revenue Risk Assessment Tool and Customer Assistance Program Cost Estimation Tool.

Best Practices for Water Utility Legal Protection and Claims Management from Infrastructure Failure Events (project #4369)

THIS PROJECT PROVIDES an industry guide for drinking water utilities on legal protection and claims management issues before, during, and after infrastructure failure events. The guide provides background information on the legal principles governing this area of the law and effective measures utilities can employ both to defend themselves from the claims of those asserting damages from a break and to prosecute their own claims when breaks are not caused by either the utility's actions or failure to act. It includes checklists of recommended practices before, during, and after failure events. This project also developed three brief training videos that highlight the recommended practices.

Water Footprint: A New Concept for Sustainable Water Utilities (project #4378)

THE WATER FOOTPRINT concept has been used by agricultural, commercial, and industrial water users to measure and report their water consumption, assess the magnitude of environmental impact(s) arising from this consumption, and identify opportunities for risk mitigation strategies that promote sustainable water use. However, water utilities have not studied and documented the application of this concept in the same manner that other industries have. This research presents (1) the growing body of information on the water footprint concept, (2) opportunities for integrating the water footprint concept into water utility planning efforts as a broader means of achieving and maintaining sustainable communities, and (3) guidance that water utilities can follow for implementing this concept within their organizations.

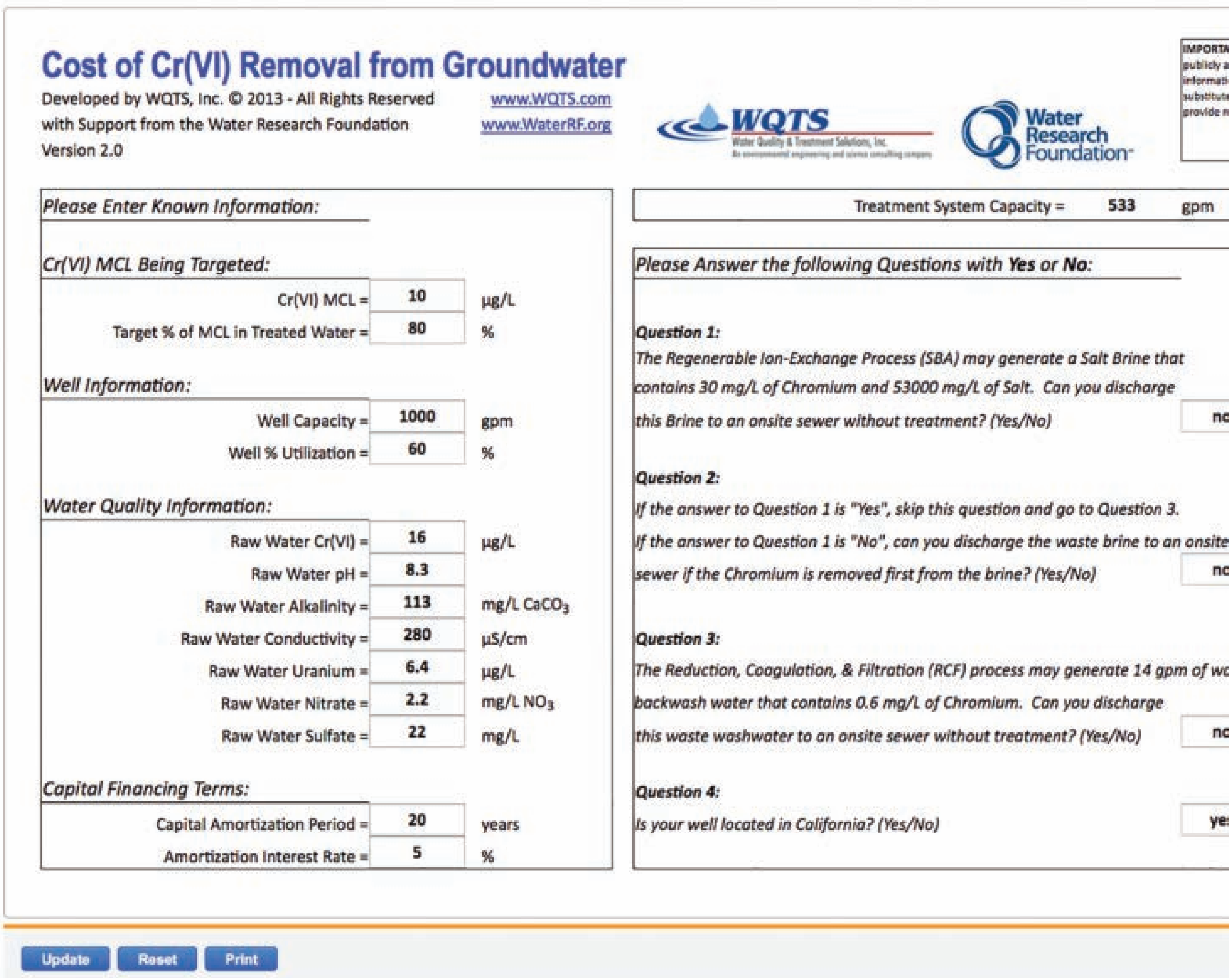


Identifying the Gaps in Understanding the Benefits and Costs of Boil Water Advisories (project #4385)

THE RESULTS FROM this project include a strategic roadmap for future data gathering, analysis, and research aimed at increasing the benefits and reducing the costs of boil water advisories (BWAs), and a systematic review of the practices and results of boil water and other types of advisories (such as do not drink and do not use). One of the key findings to be explored is how to better target precautionary BWAs so that they focus on the situations where health risks are relatively more likely to be evident (and, conversely, minimize the use of BWAs in instances where there is very low likelihood of a public health risk reduction). This includes developing risk-based criteria that utilities and regulatory/public health officials can quickly apply to target BWAs.

Impact of Water Quality on Hexavalent Chromium Removal Efficiency and Cost (project #4450)

THE CALIFORNIA DEPARTMENT of Public Health (CDPH) recently adopted the nation's first-ever drinking water standard for hexavalent chromium, at 10 parts per billion. Meanwhile, The EPA is working on a Cr(VI) toxicology review, with a draft expected to be ready for public comment by September 2015. To help the water community prepare for these regulatory actions, the Water Research Foundation (WRF) funded project #4450 to evaluate the removal of Cr(VI) from 10 groundwater sources in an effort to understand the impact of different water quality parameters on the performance and cost of three Cr(VI) treatment technologies: Weak-Base Anion resin, Strong-Base Anion resin, and Reduction-Coagulation-Filtration. Based on the treatment performance, capital and annual Operations & Maintenance cost estimates were developed for each treatment technology. The project also developed defensible capital and annual operations and maintenance cost estimates for implementing treatment systems of various sizes that can comply with a range of potential drinking water contaminant levels. Additionally, in 2013, this project produced the online Cost Estimation Tool for Cr(VI) Removal From Groundwater to help drinking water systems estimate a range of potential costs to remove Cr(VI) from their water based on system-specific information about the impacted well, water quality, residuals handling, and different treatment options.



National Dialogue on Contaminants of Emerging Concern and Public Health (project #4463)

INTER-DISCIPLINARY COMMUNICATION ON the potential human health risks of contaminants of emerging concern (CECs) in drinking water is currently lacking. Water utilities would benefit from partnerships with public health professionals who could provide information on the safety and quality of water supplies. To address this need, WRF hosted an inter-disciplinary workshop as part of project #4463 to broaden the national dialogue on this topic in July 2013. The research report resulting from the workshop presents the key findings, and provides the water community with a first-hand opportunity to better understand the public health perspective on CECs in drinking water. In addition to the report, six overview documents on CECs were created that summarize topics presented at the workshop.

Pressure Management: Industry Practices and Monitoring Procedures (project #4321)

MOST SYSTEMS TEND to operate at much higher pressure than needed, resulting in increased energy use, increased non-revenue water loss, and excessive main breaks. Project #4321 developed guidance on best practices and cost/benefits of implementing an optimized pressure management program. The project included an analysis of a year-long pressure monitoring program from 22 utilities. The report includes a survey of pressure management practices, examination of case study examples, and recommendations to improve pressure management in drinking water distribution systems.

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