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# ADVANCES in WATER RESEARCH

A Publication of The Water Research Foundation

## INFRASTRUCTURE

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Emerging DBPs

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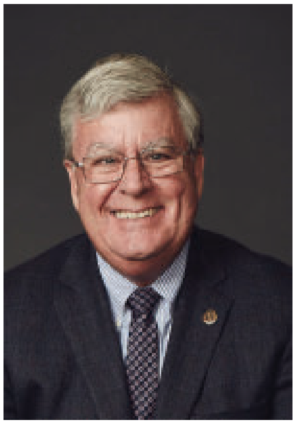
# VIEWPOINT

# Research of Enduring Value

**The Water Research Foundation (WRF) has been** delivering subscriber-driven water research for over 50 years. While there have been many changes in the water sector throughout that time, previous WRF research projects are still popular resources for our community, and WRF continues to develop timely solutions for our subscribers. How do we make certain that the value of our research endures over time? We strike a careful balance between long-term strategic thinking and responsiveness to emerging issues, ensure the right stakeholders are involved at every level of our research programming, focus on actionable research that supports innovation across the water sector, and leverage resources to energize the commitment to continuous improvement that is demonstrated throughout our subscriber community.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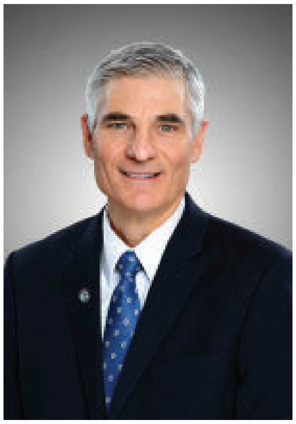
Peter Grevatt

Our five research programs provide flexible funding opportunities with a focus on applied, practical research that promotes innovation across the sector. Each program has unique goals, allowing us to meet a wide range of research needs. Collectively, our research programs enable us to address broadly relevant water sector issues; support utility-specific needs; conduct time-critical research on emergent, high-priority challenges; fund novel projects that take existing research to the next level; and assist utilities in conducting their own independent research projects. Each of our programs provides numerous opportunities for a diversity of stakeholders to be involved.

WRF's collaborative research approach relies on the expertise of our extensive network of subscribers, partners, researchers, and volunteers, ensuring we obtain feedback from the people out in the field in service of communities. Including stakeholders in every aspect of our research enables WRF to deliver the integrated, high-quality One Water research that our subscribers rely on. In addition, our approach allows us to draw on the remarkable expertise of public and private utilities, consultants, manufacturers, nonprofits, universities, and government agencies from across the globe to deliver trusted, timely, and transformative water research.

In this issue of *Advances in Water Research*, you will read about an exciting new approach to take our research programming to the next level, as well as overviews of past research projects that continue to have enduring value today. WRF research projects produce actionable solutions that build on past knowledge and set the foundation for addressing future challenges. That's how we ensure that we continue to deliver research of enduring value.

Michael R. Markus, PE
Chair, Board of Directors

Peter Grevatt, PhD
Chief Executive Officer

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# CONTENTS

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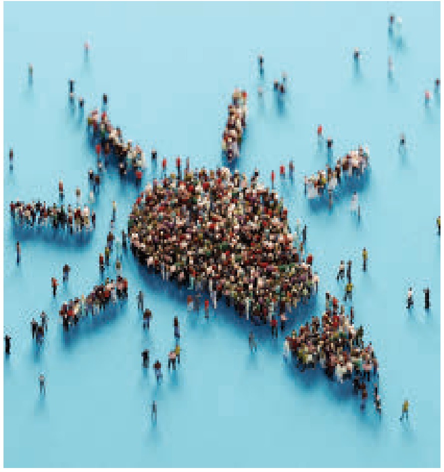
THE Water Research FOUNDATION® The Water Research Foundation (WRF) is the leading research organization advancing the science of all water to meet the evolving needs of its subscribers and the water sector. WRF is a nonprofit, educational organization that funds, manages, and publishes research on the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



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## BY THE NUMBERS

# Water Infrastructure

**This installment of By the Numbers provides statistics on water infrastructure. For more on this subject, see the article, Management of Drinking Water Pipelines.**

**Water infrastructure assets are the core building blocks of water services. Understanding the condition and value of their water infrastructure can help utilities better assess, maintain, and ensure the resilience of the services they provide to their communities. Every four years, the American Society of Civil Engineers develops a "report card" for America's infrastructure. The 2021 report card addresses 17 categories of infrastructure, including drinking water, stormwater, and wastewater. The statistics below are from the 2021 report card.**

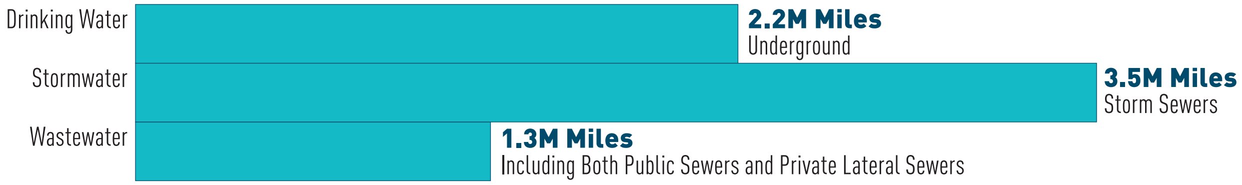
Water infrastructure includes not only water resource recovery facilities and drinking water treatment plants, but pipelines, storm drains, and much more.

### Water Assets in the United States

| Type of System | Number of Systems |
|---|---|
| Drinking Water | >148,000 active systems |
| Stormwater | 270 million storm drains<br>2.5 million stormwater treatment assets (e.g., sewers, rain gardens, etc.) |
| Wastewater | >16,000 publicly owned wastewater treatment systems |

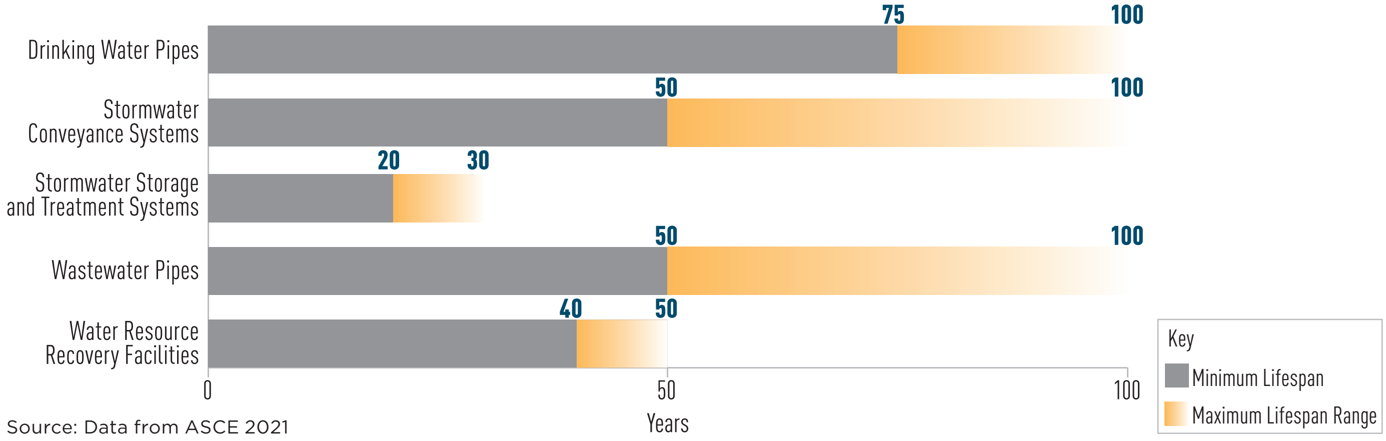
Source: Data from ASCE 2021

### Water Pipeline Assets in the United States



Source: Data from ASCE 2021

### Average Asset Lifespan



Source: Data from ASCE 2021

Many utilities have demonstrated that taking proactive action to assess the extent and condition of their infrastructure can better prepare them for the future.

**33%**

Drinking water utilities with robust asset management programs in place in 2019

**45 Years**

Average age of drinking water and wastewater pipes in the United States

**1–4.8%**

Replacement rate of drinking water pipelines per year as of 2019

There is a gap between the amount of funding available for water infrastructure work and the amount needed to ensure regulatory compliance and resilient infrastructure.

**37%**

Water infrastructure capital needs met in 2019 in the United States

**$1.045 Trillion**

Infrastructure investment needed from 2020–2029 for drinking water, stormwater, and wastewater combined

**$434 Billion**

Estimated infrastructure investment gap from 2020–2029 for drinking water, stormwater, and wastewater combined

### Federal Funding Mechanisms for Water Infrastructure

| Funding Source | Managing Agency | Water Infrastructure Supported |
|---|---|---|
| Clean Water State Revolving Fund Loan Program | U.S. Environmental Protection Agency | Drinking water, stormwater, and wastewater |
| Community Development Block Grants | U.S. Department of Housing and Urban Development | Drinking water, stormwater, and wastewater |
| Drinking Water State Revolving Fund Program | U.S. Environmental Protection Agency | Drinking water |
| Rural Utilities Service | U.S. Department of Agriculture | Drinking water, stormwater, and wastewater, with a focus on communities with populations ≤10,000 |
| Water Infrastructure Finance and Innovation Act Program | U.S. Environmental Protection Agency | Drinking water, stormwater, and wastewater |

Source: Data from ASCE 2021

## Reference

ASCE (American Society of Civil Engineers). 2021. *2021 Report Card for America's Infrastructure*. Reston, VA: American Society of Civil Engineers. Accessed September 29, 2021. https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.

WRF has built an extraordinary body of asset management research, providing the water sector with leading practices, tools, and knowledge. This research takes a One Water approach to asset management, looking at a unified collection of water systems that have traditionally been divided by service type. To learn more about WRF's research in this area, visit www.waterrf.org/sites/default/files/file/2020-07/4949-AssetManagement.pdf.

# Interview with Haydee De Clippeleir

## Partial Denitrification Anammox

**In 2020, The Water Research** Foundation (WRF) and partners received a $1 million grant from the U.S. Environmental Protection Agency (EPA) to further the prevention and control of cyanobacterial harmful algal blooms by improving full-scale applications of shortcut nitrogen removal processes at water resource recovery facilities (WRRFs), with a specific focus on partial denitrification anammox (PdNA). The project partners include WRF, Columbia University, DC Water, George Washington University, HRSD (Hampton Roads Sanitation District), and Northwestern University. WRF spoke with Haydee De Clippeleir, Acting Director of Clean Water and Technology at DC Water, to learn more about DC Water's involvement in the project.

**How did you get started in the water sector?** I studied bioengineering in Belgium, with a focus on environmental technologies. I had an enthusiastic professor who was teaching us about wastewater treatment and got me interested in the environmental aspects of this. I focused my master's thesis work on nutrient removal and anammox (anaerobic ammonium oxidizing bacteria) applications for wastewater. I then got my PhD in anammox research, during which I collaborated with people in the field, including Sudhir Murthy at DC Water. That led me to come to the United States and eventually work for DC Water.

**How long have you been with DC Water, and what is your role?** During my post doc with Columbia University, I was based at DC Water's Blue Plains facility leading anammox-related work. That evolved into a position at DC Water. I became a DC Water employee in 2015 as a program manager for research, then became the R&D manager, and I'm currently the Acting Director of Clean Water and Technology. In this role, I lead the research, the pre-treatment program, and the main laboratory.

**The EPA-funded project is focused on PdNA. Can you provide a brief explanation of this process?** PdNA aims to provide a shortcut in the nitrogen (N) cycle. Typically, conventional nitrification and denitrification processes are used in treatment plants—we oxidize ammonium to nitrite and eventually to nitrate using air and energy. Then we use carbon to reduce the nitrate to nitrite and then to nitrogen gas. In this process, we have two stops at nitrite. We have a stop at nitrite when we are oxidizing ammonium, and we have a stop at nitrite when we are reducing nitrate. PdNA can leverage the nitrite that is formed during denitrification. We are trying to only denitrify nitrate to nitrite and stop the process there. Then if you have anammox, you can remove the nitrite and the available ammonium and directly convert them to nitrogen gas. That last reaction does not require any oxygen or carbon. In that case, you only have to oxidize about half of your ammonium with air—the rest you can channel through the anammox—and you need about 80% less carbon.

**Why did DC Water get involved in the project, and what is your role?** DC Water has been interested in leveraging anammox-based technologies that show good potential and have clear business cases for sidestream treatment, and understanding how to use these technologies for mainstream treatment. Sidestream treatment only treats about 20% of the nutrients. If you could do the same process—low energy, low carbon, small footprint, very sustainable process—for 80% or 100% of your nutrients, that would be a game changer. We've been looking at taking the principles of sidestream treatment and using them in the mainstream. This involves shortcut N removal that relates to nitrite oxidizing bacteria out-selection. We found that it works, but it's very complex and needs stringent control. This was not the most practical application. On the other hand, we saw that we needed to bleed through some ammonium to get it to work, so we realized that we needed some post-treatment. That's when we thought about the PdNA option. We started working on that in terms of post-polishing, and found out that it was an easier path of selection and nitrite production than the first approach was. That led us to reconsider the shortcut N approach. Why not use this approach that we thought was just a post-treatment as the main route for shortcut N removal?

We've collaborated a lot with HRSD to understand the fundamentals and the principles first. Now that we have that understanding, we're focusing on determining what our implementation options are and what we need to learn to bring this to the next level. We believe that this is going to change nutrient removal practice as we know it. We're ready to push this forward; we just need to understand how we can implement it, start it up, and move it over that edge into practice. This project with EPA is about accomplishing that.

I'm a co-principal investigator on the project, and we are doing some of the pilot testing at our facility. We have two utilities involved: HRSD and DC Water. In our case, we collaborate very closely with George Washington University. Some of the grant funds support graduate students to help with this work; they come to our facility to perform the research. The utilities are leading the technology configurations and testing. The university partners are helping to answer the more fundamental questions and extrapolate some of the technology to phosphorus removal so we can figure out combinations of both nitrogen and phosphorus removal for this system.

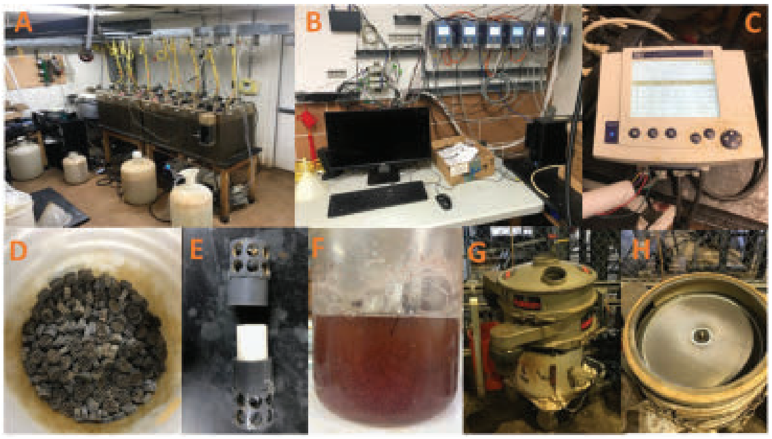
**How is the project going so far?** It was a bit challenging with the COVID-19 pandemic. We needed to recruit a graduate student from George Washington University to help, but with school being online and people not necessarily being here in the city, it was quite challenging. We already had one graduate student on the project, and we recruited some undergraduate students to do the first part of the project. Hopefully, as we get out of the pandemic, we can bring another graduate student onboard. We only had a few months' delay, because we needed to figure out how to optimize our work to have distancing and make sure we created a safe environment. We have since made good progress and have some of the first runs completed.

The project is bringing people together. We were able to form a bigger team and leverage collaboration to accelerate new technologies into practice. We can also test configurations that may not be directly applicable to us, but that can serve the water industry, that we could not test without this funding. This helps us provide the broadest set of options to help us better understand and justify these applications.

**How will you use the project results?** We are working toward a business case for Blue Plains. We have very stringent nutrient limits because of the Chesapeake Bay, and we spend a lot of money on nutrient removal. This technology could reduce our methanol costs and create increased capacity in our existing infrastructure. We don't yet know how much savings we could have, what our business case is, or what modifications we would need to make to implement this. We are testing different approaches so we can quantify the benefits and determine what is easy to operate and what provides safety in terms of effluent quality and meeting our permits. Once we identify the best way of implementing this, and what the potential performance parameters are, we can build a business case and move this forward toward final implementation.

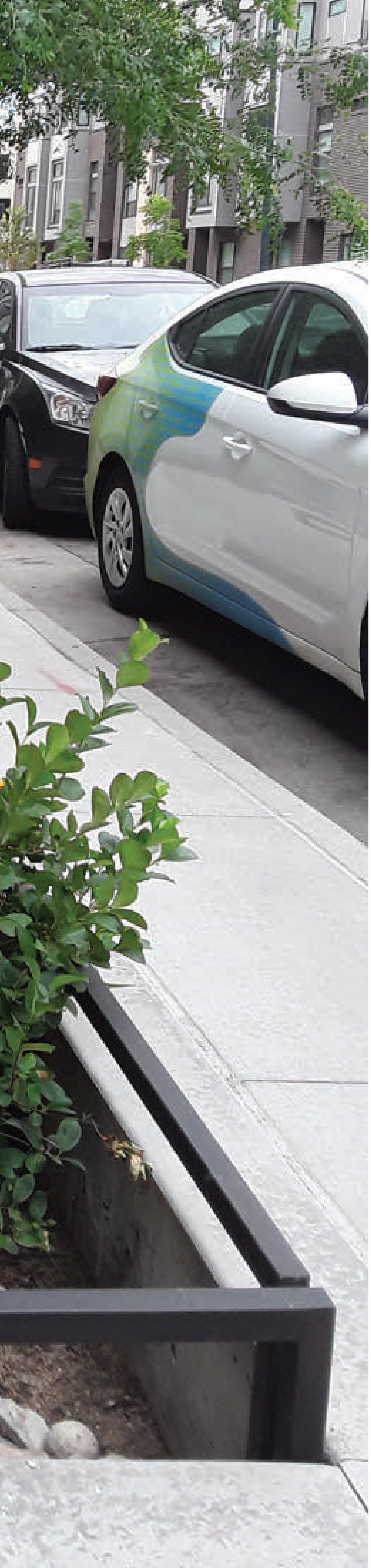
**How will this project be applicable to other WRRFs?** The project will outline different configurations and ways this technology can be implemented. We are also improving our process models so that we can extrapolate that information to other locations. WRRFs that have similar configurations to what we tested can obtain direct information. There will also be tools available for process simulation that can be used at different facilities to evaluate the potential of this technology.

We've always tried to be pioneers and help the water industry move forward. What we can do as a big facility can help smaller facilities as well. It's about serving the community, not just our facility. That's our mission here.



**Mainstream N pilot components. A. Pilot setup, B. DO sensor setup, C. N probes control box, D. IFAS carriers, E. Screens used to restrict movement of IFAS carriers within the pilot, F. An AOB seed bioaugmented into pilot, G. Wasting screens, H. Closer look at wasting screens used for bioaugmentation runs**

# CLASIC Advances Stormwater Management



# A holistic stormwater management approach takes a comprehensive view of stormwater throughout the full hydrologic cycle, from its source all the way to the receiving water.

By Harry X. Zhang, The Water Research Foundation; Sybil Sharvelle and Tyler Dell, Colorado State University; Jennifer Egan and Jennifer Cotting, University of Maryland, Environmental Finance Center; Tonya Bronleewe, Wichita State University, Environmental Finance Center; Christine Pomeroy, University of Utah; Mazdak Arabi, Colorado State University; Jane Clary, Wright Water Engineers; Marc Leisenring, Geosyntec Consultants; Janet Clements, Corona Environmental Consulting; and Barry Liner, Water Environment Federation

R**eframing the traditional view** of stormwater from problem to valuable resource is a growing trend, for example through stormwater harvesting and use (Zhang 2018). A holistic stormwater management approach has three key elements necessary for stormwater management decision making: infrastructure option performance, life cycle costs, and co-benefits.

As communities assess deteriorating water infrastructure systems, ratepayer expectations, the need to maintain healthy waterways, and an interest in sustainable and livable communities, many are implementing, or considering the use of, green infrastructure (GI) along with more traditional gray infrastructure. GI has the potential to assist communities with stormwater challenges and reduce the overall costs of stormwater management while offering benefits additional to runoff and pollution reduction (co-benefits). The increased interest in GI calls for tools that enable communities in varying climate regions to proactively implement comprehensive solutions using both green and gray infrastructure at the community scale.

## CLASIC Decision Support System

TO ADVANCE HOLISTIC stormwater management, a decision support system (DSS) entitled Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) was funded through a U.S. Environmental Protection Agency (EPA) National Priorities Life Cycle Costs of Water Infrastructure Alternatives grant in 2016. Over the course of five years, a multidisciplinary team and national partners, including American Society of Civil Engineers, American Rivers, and Water Environment Federation, collaborated to develop the CLASIC tool, which was released in April 2021 (WRF 2021a). The tool development team consisted of Colorado State University, the University of Utah, two of EPA's regional Environmental Finance Centers (hosted at University of Maryland and Wichita State University), and the University of Georgia.

The CLASIC tool utilizes a life cycle cost framework to support feasibility assessment and planning for stormwater infrastructure. CLASIC helps stormwater professionals, community planners, and local decision makers understand and weigh the estimated costs, reductions in runoff and pollutant loads, and co-benefits of various planning scenarios as they consider stormwater management projects. The CLASIC tool is applicable to a variety of users, including managers and operators of regulated stormwater

CLASIC allows users to build and compare stormwater infrastructure options

systems (e.g., municipalities, counties, and utilities), consultants, academics, and others interested in integrated water management.

The tool builds on existing efforts and leverages capabilities in the International Stormwater Best Management Practice (BMP) Database (WRF 2020), EPA's National Stormwater Calculator (EPA 2019), and other research, such as *Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure* (Clements et al. 2021).

The CLASIC tool can assess green and gray infrastructure scenarios to inform robust decision making based on preferences to estimate capital and maintenance costs over time. The EPA's Environmental Finance Centers and the University of Utah developed a rigorous life cycle cost framework to assist users with regulatory objectives, funding and financing strategies, and programmatic objectives.

The system is hosted on a cloud-based modeling platform, is geographic information systems (GIS)-based, and includes interaction with national databases (Dell et al. 2021). Users have the option to automatically upload data from national databases (e.g., U.S. census boundaries, the National Land Cover Database, climate databases, and soil databases) or to upload their own data sets with more site-specific or higher-resolution information.

The three main components in the tool outputs are as follows (also see Table 1):

- Performance
  - Hydrologic performance, such as runoff volume reduction
  - Water quality performance, such as pollutant load reduction
- Life cycle costs
- Triple bottom line (TBL) benefits
  - Relative score of co-benefits (e.g., environmental, social, and financial) based on performance and select characteristics of GI

Users can select from a variety of green and/or gray stormwater management practices (Table 2). The practices/technologies in the CLASIC tool are categorized according to implementation strategy and primary technology function (WRF 2021b):

1. Volume-based filtration technologies (e.g., rain gardens, infiltration trenches, sand filters, and grass swales/bioswales)
2. Volume-based detention technologies (e.g., extended detention basins and wet ponds)

**Table 1. Summary of CLASIC tool functionality**

| Output | Included in CLASIC Life Cycle Cost Tool |
|---|---|
| Pollutant Load Reduction | • Total suspended solids<br>• Total nitrogen<br>• Total phosphorus<br>• Fecal indicator bacteria |
| Hydrologic Performance | • Runoff volume<br>• Volume infiltrated<br>• Volume evapotranspired<br>• Number of runoff events |
| Life Cycle Cost | • Net present value<br>– Construction<br>– Maintenance<br>– Replacement<br>• Average annual cost over design life<br>• Unit cost for scenario comparison |
| Co-benefits | • Score of economic, environmental, and social benefits based on user-selected importance factors |

Source: WRF 2021a

**Table 2. Green and gray stormwater management practices included in CLASIC tool**

| | | |
|---|---|---|
| Rain Garden / Bioretention | Extended Detention Basin | Green Roof |
| Sand Filter | Wet Pond | Permeable Pavement |
| Infiltration Trench | Stormwater Harvesting | Rooftop Disconnection |
| Grass Swale | Storage Vault/Tunnel | |

Some cities have programs that provide incentives to developers and property owners who implement GSI projects

3. Volume-based reclamation/storage technologies (e.g., stormwater harvesting and storage vaults/tunnels)
4. Area-based volume reduction or filtration technologies (e.g., green roofs and permeable pavement)

The CLASIC DSS allows users to build and compare multiple stormwater infrastructure options and enables simulation of various climate scenarios. Specifically, the CLASIC tool has incorporated a multivariate adaptive constructed analog method for simulating climate scenarios.

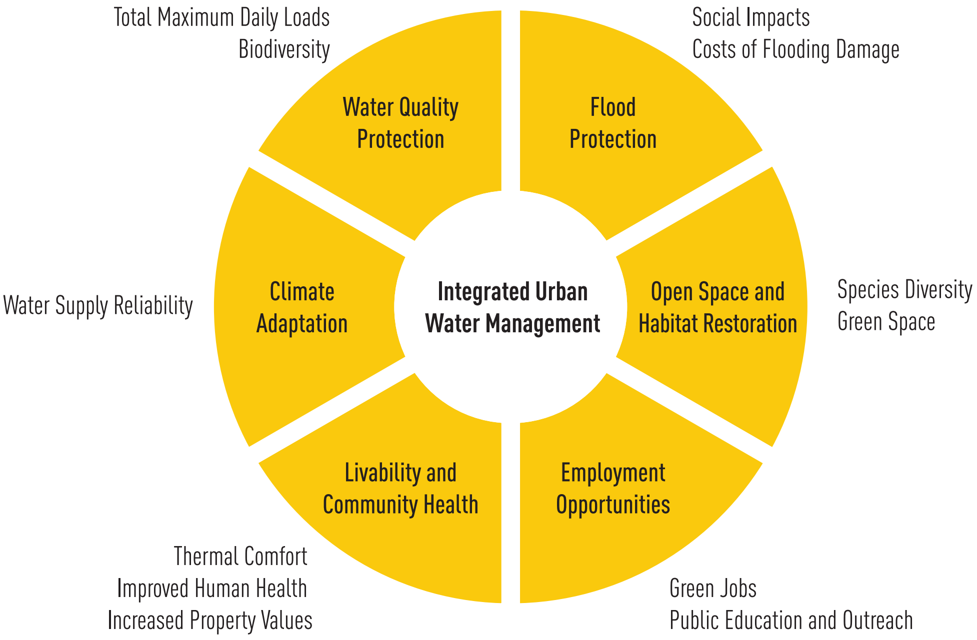
The TBL analysis assigns co-benefit scores from environmental, social, and financial aspects (Figure 1). The user assigns weights according to a multi-criteria decision analysis process. This analysis process provides quantitative outputs to compare co-benefits across scenarios of technology selection. Outputs also provide the performance of scenarios in terms of hydrology (e.g., runoff volume reduction) and pollutant load reduction. Figure 2 shows an example of the CLASIC output dashboard.

Stakeholder input and user-based design are core components of the CLASIC system. The goal is to produce a publicly accessible tool that can be readily used to meet the varying needs of stormwater communities of different scales (e.g., large, medium, and small) around the United States. It is worth noting that the CLASIC tool does not provide site-specific designs for green or gray infrastructure or optimization of design.

Case study applications have been included on the tool's main page to showcase the variety of ways that the CLASIC tool can assist communities with stormwater project planning and decision making. Ten CLASIC case studies provided to date cover communities of different sizes, all climate regions in the United States, and climate scenario simulations. CLASIC outputs are displayed in an immersive set of charts, graphs, and tables that can be analyzed, printed, and shared. These case studies represent the variety of hydrologic, performance, cost, and co-benefit comparisons along with climate scenarios that the CLASIC tool can provide to communities to help them make informed decisions about future stormwater projects.

The CLASIC DSS seeks to create increased confidence for decision makers and regulators when comparing life cycle costs and multiple benefits of using GI to support holistic stormwater management. This integrated tool enables communities to analyze risk tolerance for stormwater services and consider associated costs while also addressing climate resilience. The resulting data and DSS work at the municipal scale and foster innovation and collaboration.

In summary, the CLASIC DSS has three integrated components and outputs: (a) hydrologic and water quality performance, (b) life cycle costs, and (c) TBL benefits. The life cycle costs will inform considerations of green and gray infrastructure scenarios selected by the user. The TBL analysis is



Source: WRF 2021a

**Figure 1. Categorizing green infrastructure co-benefits in the CLASIC tool**

informed via multi-criteria decision analysis, which provides quantitative outputs to compare co-benefits across scenarios of technology selection. The TBL analysis can be used along with a companion tool developed by the WRF research team (Clements et al. 2021). The three outputs from the CLASIC tool work synergistically to inform decisions on scenarios for holistic stormwater management at the community level.

To assist users, an online video library of CLASIC tool demos and instructions is available (WSU 2021). The CLASIC tool is officially included in the EPA Green Infrastructure Modeling Toolkit (EPA 2021).

## TBL Benefit Tool

IN ADDITION TO PROVEN WATER quality benefits, green stormwater infrastructure (GSI) can provide many important co-benefits, including flood risk reduction, improved air quality and related health benefits, energy savings, climate resilience, enhanced community livability, and more. In addition, the costs of pursuing GSI strategies may compare favorably to expanding or upgrading conventional stormwater treatment and conveyance facilities or other typical gray infrastructure solutions. Recognizing these benefits, many municipalities are looking to enhance their GSI programs, encourage developers to implement GSI (and go beyond minimum requirements), and promote the installation of GSI retrofits at existing private development sites. Some cities have implemented programs that provide financial or market-oriented incentives to developers and private property owners who implement GSI projects.

WRF's GSI TBL Benefit Tool (Clements et al. 2021) is a companion to the CLASIC tool that allows stormwater practitioners to quantify and monetize the TBL benefits of GSI including (a) financial benefits such as avoided gray infrastructure costs; (b) environmental benefits such as improved water quality and associated habitat improvements, terrestrial ecosystem benefits, and carbon reduction and decreased greenhouse gas emissions; and (c) social benefits such as the public health benefits associated with reduced urban heat stress and improved air quality, flood risk reduction, increased water supply through stormwater capture and harvesting, and improved urban aesthetics and community livability.

The rigorous quantification methodology for GSI co-benefits is analyzed in conjunction with a life cycle cost analysis of stormwater infrastructure to enable better decision making at the community level. Results of the

Choose Scenario: Baseline
Study Period: 30 years
Annual Discount Rate: 0 %

Choose Scenario: Developed Area
Study Period: 30 years
Annual Discount Rate: 0 %

Choose Scenario: Developed Area - Rain Garden
Study Period: 30 years
Annual Discount Rate: 0 %

Source: WRF 2021a

Figure 2. Example interface of CLASIC decision support system

TBL benefit analysis can help communities identify stormwater management alternatives that maximize community value, compete for scarce funding, leverage private capital and alternative funding sources, support alternative project delivery models, and gain community support. With a connection to the CLASIC tool, the outcome of this study facilitates use of the GI co-benefits framework and tool through a national network of utilities and municipalities.

## International Stormwater BMP Database

UTILITIES AND MUNICIPALITIES that implement integrated stormwater management programs rely on water quality data to support modeling efforts and decision making. The International Stormwater BMP Database provides performance monitoring data for stormwater BMPs (WRF 2020). The long-term BMP Database project has benefited from more than two decades of collaboration among many partners, such as EPA, Federal Highway Administration, and Environmental and Water Resources Institute (EWRI). With over 700 BMP studies, the BMP Database project provides categorical BMP performance summaries, tools for extracting BMP performance data, monitoring guidance, and other study-related publications that can be used by stormwater managers, consultants, researchers, and many others to assess the statistical performance of BMPs in the field. Approximately 400,000 stormwater quality records are also now accessible in the BMP Database. Additionally, the project website provides access to the National Stormwater Quality Database, which is an urban stormwater runoff characterization database. The latest version of the National Stormwater Quality Database contains data from more than 9,000 events from approximately 200 municipalities throughout the United States, serving as an important resource for municipal stormwater managers and researchers seeking urban runoff characterization data.

Recently, the BMP Database project expanded its focus to collect BMP cost data, not limited to BMPs with performance monitoring data. Improved tracking of BMP operations and maintenance (O&M) activities and costs, particularly GI practices, is a significant need of local

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governments. To help meet this need, and in connection with the CLASIC tool development effort, the Municipal Water Infrastructure Council of EWRI collaborated with WRF on the development of O&M activity and cost reporting protocols (Clary et. al. 2018). The long-term objective of this effort is to improve the basis for recommended BMP maintenance activities and frequencies, as well as support whole life cycle cost estimation. The reporting protocols describe the recommended O&M parameters to track for stormwater BMPs, including both activities and cost data. Through development of a standardized set of parameters forming a reporting protocol, practitioners will have a common basis for cost estimation and maintenance activity planning. A new urban BMP O&M cost database module was developed to coincide with the completion of the CLASIC tool (BMPDB 2021). Users of the data spreadsheets and/or database are encouraged to submit their data to the BMP Database to advance the state of the practice regarding the costs of maintaining stormwater BMPs across communities.

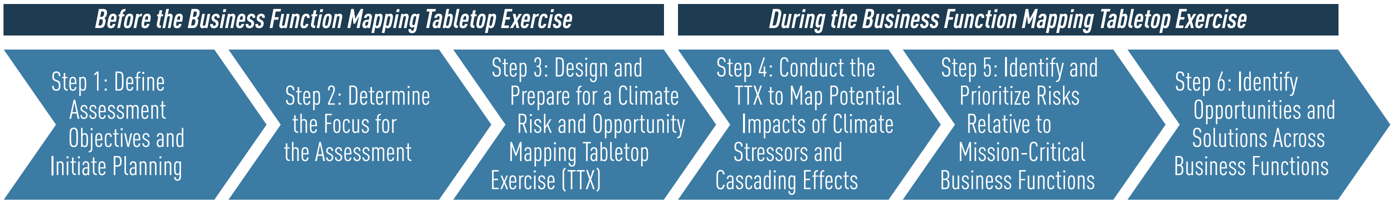
### Looking into the Future

AT A U.S. NATIONAL LEVEL, EPA promotes comprehensive, community-wide approaches for managing stormwater and wet weather flows. EPA's integrated planning framework will assist municipalities on their paths toward achieving the human health and water quality objectives of the Clean Water Act. The integrated planning framework can also facilitate the use of sustainable and comprehensive solutions (e.g., GI) that protect human health, improve water quality, manage stormwater as a resource, and support other economic benefits at the community level. For example, stormwater harvesting and use have become more common in recent years. Stormwater harvesting can expand local water sources while providing additional benefits such as reduced water pollutant loads and a more sustainable water supply.

With a holistic stormwater management principle in mind, WRF has spearheaded the development of a next-generation DSS for integrated solutions to stormwater management and wet weather challenges. Collectively, the CLASIC DSS and its affiliated tools enable communities to analyze risk tolerance for stormwater services and build resilience to risks from extreme events and their associated life cycle costs (Zhang 2018). The related TBL approach holistically evaluates co-benefits to determine the most appropriate strategies that consider both costs and benefits. With WRF's forward-looking vision, the holistic stormwater management approach will help create innovative solutions for addressing evolving wet weather challenges and thriving in the new era of One Water in the years to come.

# Climate Change (5056)

**In 2020, WRF published** *Mapping Climate Exposure and Climate Information Needs to Water Utility Business Functions* (4729). As a follow-up to that project, *An Enhanced Climate-Related Risks and Opportunities Framework and Guidebook for Water Utilities Preparing for a Changing Climate* conducted tabletop exercises with two utilities in order to test, update, and refine the 4729 framework. The updated framework and guidebook will help utilities understand and assess the risks and opportunities associated with climate change, evaluate how climate considerations intersect with specific business functions, and identify opportunities to incorporate climate considerations and resilience into utility management.



Source: Courtesy of Water Utility Climate Alliance

**Steps in the business function mapping framework**

# Empowering Innovation through Activation

**The Water Research Foundation (WRF) generates** new knowledge by conducting applied research on topics identified as high priorities by its subscribers. The evaluation and application of new research and knowledge empower the water sector to be innovative with its operations and enhance services to communities. The WRF website and communication networks provide tools that assist the water sector in actively implementing research outcomes.

Engagement in research and pilot projects facilitates information sharing and enhances knowledge uptake across the water sector. A great example of this is the soon-to-be-completed project, *Leading Water and Wastewater Utility Innovation* (4907). This project, led by Arcadis and Means Consulting, includes a team of 76 utility partners and other collaborators from around the world. An *Innovation Leader's Resource* was developed to provide specific tools and tactics for utilities of any size to support innovation as a core business practice. This resource is broken into three distinct modules:

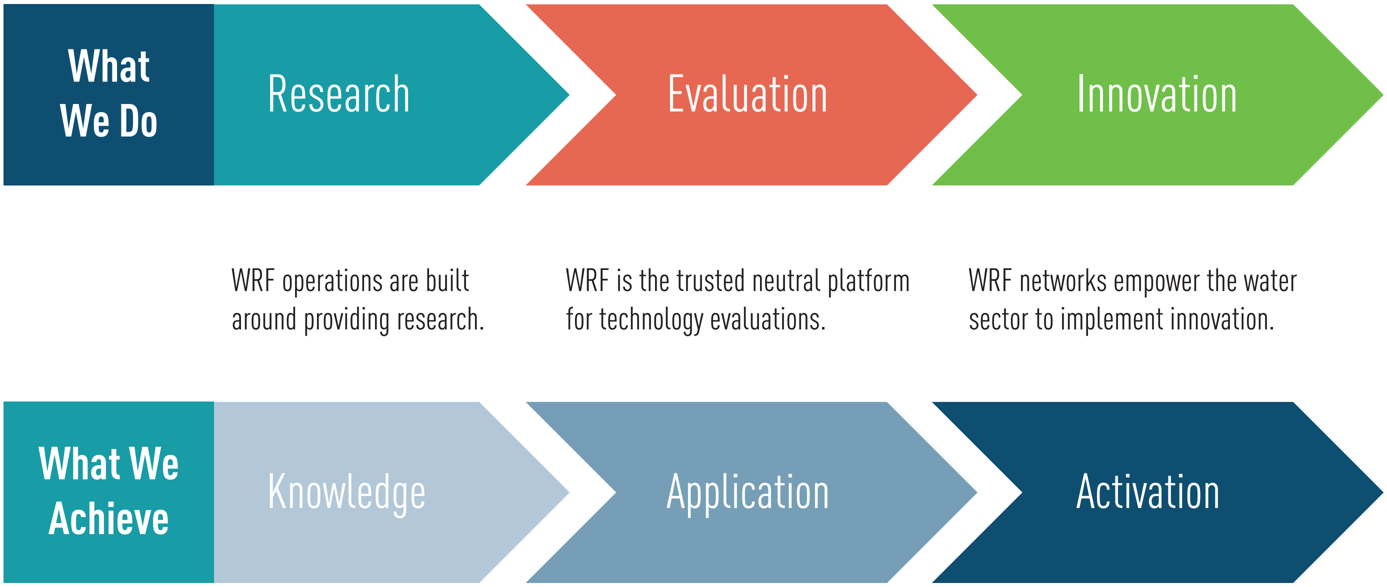
- Module 1: Building an Innovation Strategy
- Module 2: Engaging the Workforce to Power Innovation
- Module 3: Refreshing Your Innovation Partnerships

A separate report, *Executive's Brief: Tactics for Executive Innovation Champions*, was developed as part of this project to guide utility executives in cultivating innovation management as a business practice. This report focuses on critical functions of the executive champion, creating a meaningful innovation strategy, and launching and sustaining an innovation program.

In addition, a web-based planning tool was developed to provide an easy-to-use assessment of an organization's current innovation maturity level, as well as a method for selecting a target maturity level. It also provides insight on the common practices implemented by utilities with programs at varying degrees of maturity. Activation and support of this innovation community will continue at WRF through further integration of WRF's online innovation resources and networking opportunities.

Existing WRF tools to accelerate the uptake of innovation in the water sector include the Fast Water Network, the Scholarship Exchange Experience for Innovation & Technology (SEE IT), technology scans, pilot projects, and the Tech Trends Tool. These products and programs currently stand alone as individual resources. WRF intends to integrate these tools to enable subscribers to quickly connect with their peers, new technologies, shared knowledge, and research and pilot facilities, enabling activation of innovation through shared knowledge of research and technologies.

To learn more about WRF's Innovation Program, and how you can get involved, visit www.waterrf.org/innovation.



What We Do

Research

Evaluation

Innovation

WRF operations are built around providing research.

WRF is the trusted neutral platform for technology evaluations.

WRF networks empower the water sector to implement innovation.

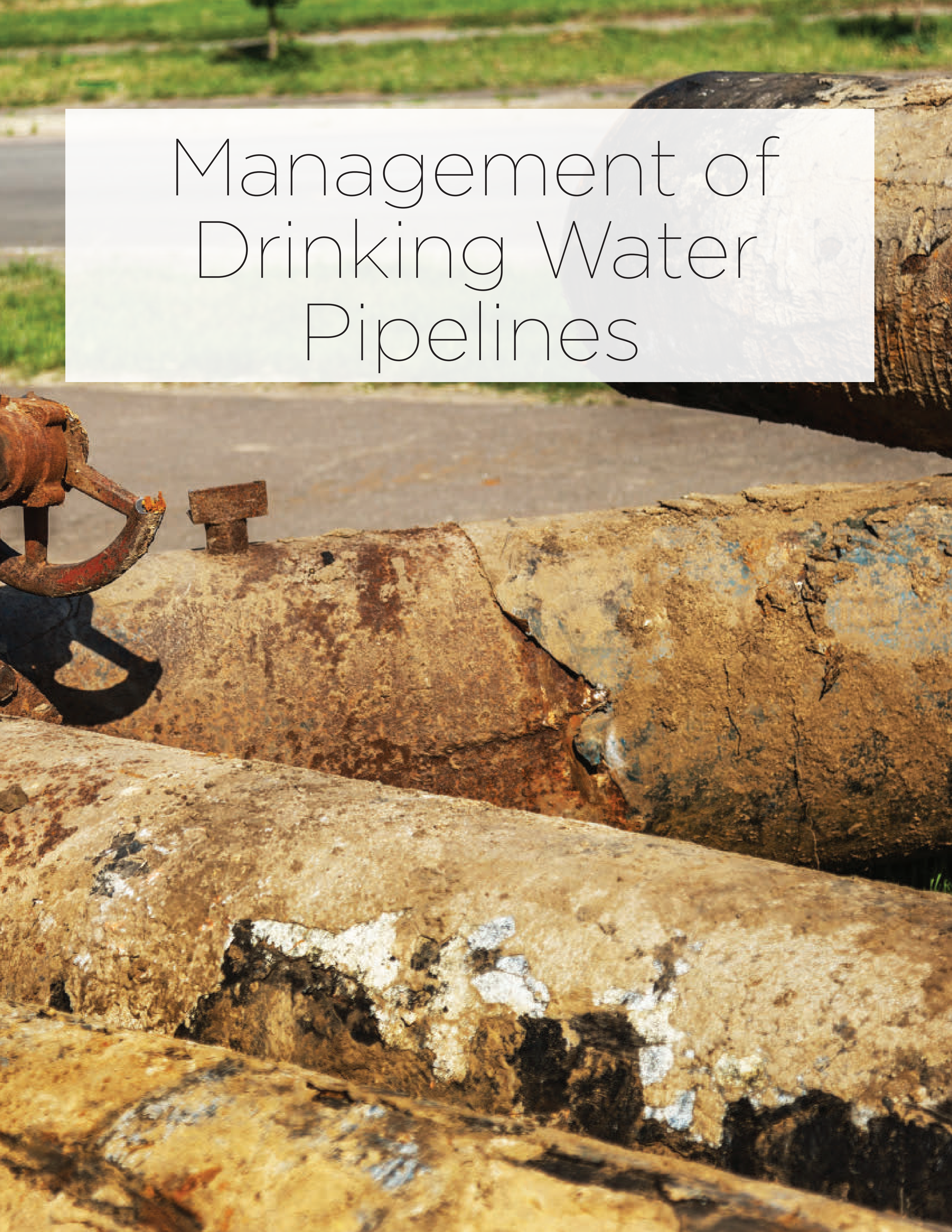
What We Achieve

Knowledge

Application

Activation

# Management of Drinking Water Pipelines

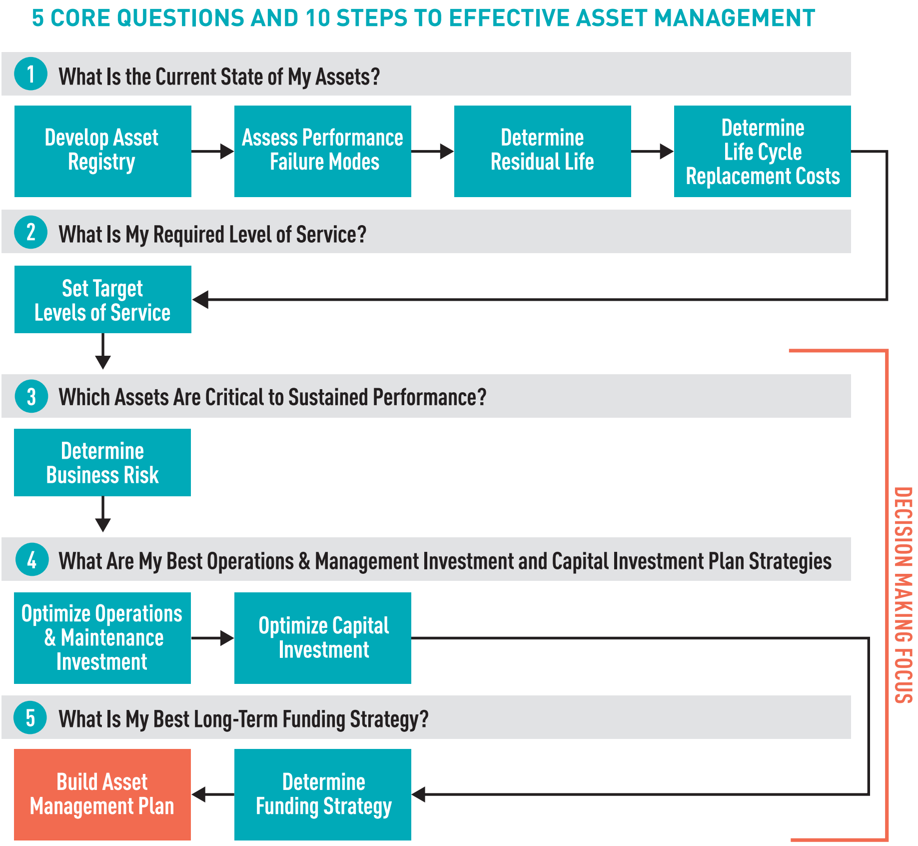


# Aging infrastructure and asset management continue to be chief concerns for water utilities.

By Megan Karklins, The Water Research Foundation

High-quality water services depend on having infrastructure that meets the requirements of customers, utilities, and regulators. Because water services are asset intensive, utilities are constantly working to maintain their pipes, pumps, tanks, and systems, while also controlling costs and reducing risks. With deteriorating infrastructure, limited budgets, restricted flexibility in rates, and increasing expectations, utilities are on a continual quest to implement the most appropriate practices to meet these competing demands.

The Water Research Foundation (WRF) has built a solid foundation of asset management research, providing the water sector with more than 300 projects resulting in leading practices, tools, and knowledge, such as the asset management framework shown in Figure 1. This article highlights a selection of past, but still relevant, WRF research on long-term pipe performance, corrosion, and condition assessment. Although this article focuses primarily on drinking water assets, WRF also has research available on wastewater and stormwater asset management,



Source: WRF 2020

**Figure 1. Asset management framework**

as well as other complementary topics (e.g., water loss control and main breaks).

## Long-Term Pipe Performance

WATER UTILITIES HAVE USED A variety of pipe materials for buried assets, and these materials have varying characteristics. The different specifications and manufacturing techniques for pipes can impact the likelihood and types of failures, as well as overall pipe lifespan; however, installation errors can also impact pipe lifespan. WRF's research in this area helps water utilities better understand pipe performance, thereby improving pipe failure prediction and prevention.

Since the 1970s, plastic pipes have been increasingly installed in new distribution systems and used to replace legacy pipes made of cast iron and steel. The primary materials include polyvinyl chloride (PVC) and polyethylene (PE), and WRF research can help utilities better understand the performance of PVC and PE pipes.

*Long-Term Performance Prediction for PVC Pipes* (Burn et al. 2005) outlined approaches for estimating PVC pipe in-service lifetimes, assessing the likelihood of chemical, fatigue, and physical failures. Choosing an appropriate approach for estimating long-term performance depends on the type(s) of PVC pipe a utility has in its system. The research team compared unplasticized PVC (PVC-U), modified PVC (PVC-M), and oriented PVC (PVC-O). PVC-U tends to be more brittle, whereas PVC-M and PVC-O tend to be more ductile. Despite these differences, the research found that PVC pipe failure is most often due to installation errors, rather than manufacturing errors.

*Long-Term Performance Prediction for PE Pipes* (Davis et al. 2007) gathered historical PE pipe failure data from water utilities across the United States, Australia, and the United Kingdom. This data, as well as anecdotal evidence, showed that PE pipes are more prone to failure if surface preparation, installation, and jointing practices are poor (e.g., differential soil settlement resulting in excessive bending and point load impingement in stony soils). In older PE pipes, slow crack growth failures can occur after damage during pipe transport and installation.

Key failure mechanisms for buried steel pipes are largely associated with corrosion processes within soils

Steel is the most widely used material for large-diameter water transmission pipelines transferring water from large reservoir/water supply sources to storage for distribution. Although these transmission pipelines represent a small length of an overall water system, they are critical components that need ongoing and focused management to avoid catastrophic failure and network downtime. In terms of asset value, it is likely that these steel transmission pipelines would account for >20% of the entire network. *Long-Term Performance Prediction of Steel Pipelines* (Davis et al. 2016) found that key failure mechanisms for buried steel pipes are largely associated with corrosion processes within soils. Older steel pipes with bitumen external coatings tend to have less external corrosion protection, whereas newer steel pipes with fusion-bonded epoxy or polyolefin coatings showed better adhesion strength, less water permeability, and improved hardness and impact strength.

In addition to research on plastic and steel pipes, WRF has published research on long-term performance of ductile iron, prestressed concrete cylinder, and asbestos cement pipes; as well as on the life expectancy of elastomeric components, epoxy linings, cement-mortar linings, and polyethylene wrap materials.

## Corrosion

CORROSION IS OF PARTICULAR interest in buried infrastructure management. Many buried pipes are made of metal or contain metal components, and corrosion of that metal, especially external corrosion, can lead to pipe failure. For buried metallic pipelines, corrosion is the result of the formation of anodic (corroding) and cathodic (non-corroding) areas of electrically continuous materials in a common electrolyte (soil). The resulting corrosion damage at the anodic area of the pipe can be similar in appearance for different causes, thus it is often misdiagnosed (Romer et al. 2004).

*External Corrosion and Corrosion Control of Buried Water Mains* (Romer

continued on page 18

# Failure Prediction of Critical Cast Iron Pipes

IN 2011, A CONSORTIUM OF AUSTRALIAN WATER utilities led by Sydney Water joined forces with WRF and UK Water Industry Research to initiate a five-year research program, *Advanced Condition Assessment and Failure Prediction Technologies for Optimal Management of Critical Water Supply Pipes* (Kodikara 2018). This project provided important findings on cast iron pipe corrosion, main breaks, and condition assessment.

The project team investigated corrosion in three main categories—uniform corrosion, pit or patch corrosion, and corrosion clusters. Using 3D finite element modeling, a new stress analysis tool was developed to analyze these corrosion configurations and to determine the remaining life of pipes. It was found that a substantially large corrosion patch with extensive corrosion (as much as 80% of wall thickness) is normally required to cause longitudinal failures in the pipe barrel. It was also found that the first failure is most likely to occur as a fracture in the corroded patch, which may lead to water leakage. In many instances, this fracture may not be large enough to cause pipe burst in the first occurrence. Therefore, the concept of "leak before burst" was developed for cast iron water pipes, where a generated fracture could grow with transient loadings and corrosion until fast fracture occurs (Figure 2). It was approximated that the first failure leading to leakage was controlled by a pipe material's tensile strength, whereas the subsequent burst was controlled by a pipe material's fracture toughness. This demonstrates important connections between the timing of an initial fracture and an eventual burst, substantially improving failure prediction techniques, and saving the industry roughly $1 billion per year.

Prior to this study, little was known about the possible contribution of traffic loads to water main breaks. To learn more, the research team instrumented a pipe and the soils and pavement in a street. After extensive monitoring using weighted trucks and normal traffic, it was found that traffic loading did not exert significant strains/stresses on the pipe even under simulated truck braking, cornering, and going over a speed bump. In contrast, 660 kPa (95.7 psi) of water pressure exerted as much as seven times the strain on the pipe, highlighting the relative importance of internal water pressure in contrast to traffic loads.

The team also analyzed raw data of various condition assessment technologies (magnetic flux leakage, broadband electromagnetics [also known as pulsed eddy currents], remote field eddy currents, and in-pipe acoustic waveforms) using machine learning and artificial intelligence to try to advance these technologies beyond current capabilities. Several case studies and trials were conducted to verify the value of different condition assessment technologies that were available at the time, and numerous follow-up research needs were identified for these technologies.

Source: Kodikara et al. 2016

Figure 2. (a) Project pipe burst facility, (b) three test pipe sections, (c) failed lab pipe

et al. 2004) developed a draft Corrosion Control Master Plan (CCMP), which covers a broad range of technical topics affecting the integrity of water transmission and distribution pipeline systems. The four sections of the CCMP are as follows:

1. **Management:** Provides for implementation and coordination of the corrosion mitigation/monitoring/control program. Coordination is critical to the success of the program.
2. **Cathodically Protected Pipelines:** Addresses care and feeding of existing corrosion control systems and recommended modernization of cathodic protection systems, including interference effects.
3. **Unprotected Pipelines:** Provides for the collection and tabulation of engineering and operational data for risk assessment of the corrosion threat and prioritization of corrosion mitigation activities. Only fragmented corrosion control data typically exist for unprotected pipelines (e.g., pipelines without cathodic protection and with either no coating or a passive coating system). Existing information on these pipelines should be identified. The utility should then identify gaps in the data and institute data collection to fill the gaps so that useful risk assessments can be prepared.
4. **New Construction, Modification, and Repair:** Provides for the establishment of engineering design methods, methodology and standard details, and specifications for the application of construction materials and techniques to minimize corrosion problems; assessment of the probability of corrosion damage and consequences; and avoidance of corrosion problems before they begin.

Utilities can tailor the sample CCMP to fit their unique needs and experience.

> To avoid the enormous capital cost of replacing an entire pipeline, it is increasingly important to conduct pipeline inspections and perform selective maintenance

*Retrofit and Management of Metallic Pipe with Cathodic Protection* (Bell et al. 2018) focused on how to cost-effectively minimize corrosion using cathodic protection (CP). The basic concept behind a CP system is that by feeding electrons or current to a metallic compound, the metallic ions' tendency to be separated from the metal (usually in forms of oxides) is reduced, resulting in less metal loss. In other words, cathodic protection connects the metal at risk (the metallic pipe material) to a "sacrificial" metal that corrodes in lieu of the metal at risk (EonCoat 2017). This study found that the most successful CP techniques for existing water pipelines are hot spot protection and anode retrofit programs. Hot spot CP is the practice of opportunistically installing a protective galvanic anode at the location of a pipe repair. These anodes are typically installed without any monitoring and stay in the ground until total depletion, usually without replacement. Anode retrofit programs, also called retrofit cathodic protection, entail adding CP to existing pipes to provide galvanic protection. For example, if a pipe is electrically discontinuous, then an anode is attached to each pipe segment (e.g., through excavation at every other joint), as opposed to going through the tedious process of making the pipeline electrically continuous.

## Condition Assessment

INSTEAD OF DIRECTLY determining the condition of water mains, utilities typically make renewal decisions using less direct data: repair records, pipe age, pipe type, and soil data. This may result in functional pipes being discarded because they are presumed to be in poor condition. To avoid the enormous capital cost of replacing an entire pipeline, it is increasingly important to conduct pipeline inspections and perform selective maintenance. Pipeline inspection is an integral component of any risk management program, and nondestructive examination (NDE) methods to evaluate the integrity of infrastructure are becoming more essential.

*Electromagnetic Inspection of Prestressed Concrete Pressure Pipe* (Mergelas and Kong 2001) helped establish the foundation upon which electromagnetic inspection of prestressed concrete cylinder pipe (PCCP) is based. PCCP consists of a thin steel cylinder that is wrapped with a winding of steel prestressing wire. Depending on the pipe diameter and the operating pressure, a concrete core may be present outside the steel cylinder and beneath the external windings. This project investigated and advanced the understanding of remote field eddy current/transformer coupling (RFEC/TC), a transmit/receive geometry approach that can detect broken prestressing wires and predict the number of broken wires in PCCP. The RFEC/TC tool was able to detect broken wires anywhere along the length of the pipe. The size of an RFEC/TC signal shows a strong and direct relationship with the number of broken wires, which means that distressed pipes can be ranked in order of severity.

In the past, many utilities avoided using NDE technologies because of the expense and uncertainties associated with them; however, advances in NDE methods are being made that may address these challenges. *Leveraging Data from Non-Destructive Examinations to Help Select Ferrous Water Mains for Renewal* (Ellison et al. 2018) found that NDE can be used cost-effectively on some mains, and the results used to infer the condition of similar mains. By applying NDE where it is relatively easy, and on mains that are in questionable condition, money saved through better infrastructure renewal decisions can cover the costs of the NDE inspections. A routine and proactive NDE inspection program focused on easily accessible (e.g., fire hydrant access) small-diameter metallic pipe would almost certainly be cost-effective for a larger utility, where economies of scale can be produced, and where metallic pipe corrosion is the primary cause of breaks and pipe renewal. For smaller utilities where corrosion is prevalent, but economies of scale are not, it may be appropriate in the near term to focus NDE on “tough decisions” (e.g., where a

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street project or other concurrent work is planned). Eventually, large and small utilities should realize increased value as NDE sees broader application. A rapid growth in value should occur with better information provided and a lower cost.

### What's Next

PRESSURE HAS BEEN IMPLICATED in pipe failure in several studies. In those studies, pressure reductions apparently correlated with reductions in both pipe leakage and breaks. In addition, major pressure surges in a distribution system could be followed by a series of pipe breaks. Lowering pressure, consistent with water quality protection, may be able to provide significant reductions in pipe breaks, leakage, and energy costs. Certain smart water technologies are applicable for measuring and managing pressure with the direct result of reduced water loss and less stress on pipes. *Utilizing Smart Water Networks to Manage Pressure and Flow for Reduction of Water Loss and Pipe Breaks* (Karl et al., forthcoming) will use network solutions to help water utilities better manage pressures and flows in distribution networks to extend the life of pipes and reduce water loss.

The management of pipelines and other infrastructure has a strong connection to utility and water sector resilience, and WRF anticipates an increased emphasis on infrastructure resilience research in the future.

# Stream Restoration (5075)

**Stream restoration provides a multitude of** benefits to ecosystems and communities. Restoration projects may also provide pollutant trading and mitigation opportunities. *Stream Restoration as a BMP: Crediting Guidance* provides a technical framework for quantifying the water quality benefits of a specific suite of stream restoration practices, focusing on sediment, nutrients, and temperature. The practices addressed in this guidance include stream stabilization, riparian buffers, in-stream enhancements, and floodplain reconnection. The general technical considerations and challenges for developing stream restoration credits are discussed, along with guidance for credit development. Information related to the verification and monitoring of stream restoration projects is also provided.

**Minimum recommended water quality–related monitoring parameters for stream restoration projects**

| Field Parameters (Can Be Monitored Using Field Probes) | |
|---|---|
| Temperature | Specific Conductivity |
| pH | Turbidity |
| Dissolved Oxygen | Flow Rate and Depth |
| **Laboratory Parameters (for Nutrient[1] and Sediment Objectives)** | |
| Alkalinity | Nitrate/Nitrite |
| Total Suspended Solids<br>(or Suspended Sediment Concentration) | Total Kjeldahl Nitrogen |
| Total Dissolved Solids | Ammonia |
| Total Phosphorus | Particle Size Distribution[2] |
| Orthophosphate | Chlorophyll *a*<br>(or Other Biological Monitoring) |
| Total Organic Carbon | |

Note: Certain metals (e.g., iron, selenium) may also be of interest on a site-specific basis.

[1] Nitrogen-related parameters can be used to calculate total nitrogen and total inorganic nitrogen.

[2] Particle size distribution should ideally be monitored for several pre-restoration and post-restoration events under varying flow conditions, even if it is not evaluated for every monitoring event.

# Research on Emerging Disinfection Byproducts

## Chronic exposure to disinfection byproducts can pose various risks, and water managers are seeking ways to better understand and manage these risks.

By Katie Spahr, The Water Research Foundation

**The goal of disinfection of public** water supplies is the elimination of the pathogens responsible for waterborne diseases. However, the oxidants used to protect against pathogens may react with natural organic matter, bromide, and iodide to form disinfection byproducts (DBPs). While inactivation of pathogens removes an acute public health risk, chronic exposure to DBPs in drinking water can lead to higher occurrences of bladder cancer (Li and Mitch 2018). To help mitigate the risks associated with chronic exposure to DBPs, the U.S. Environmental Protection Agency (EPA) has regulated 11 different DBPs found in drinking water. With advances in detection equipment and methods, researchers have been able to identify over 600 DBPs in water matrices. Emerging DBPs may be more geno- and cytotoxic than their regulated counterparts (Li and Mitch 2018). Water managers are tasked with finding the right balance between complying with current DBP regulations and remaining agile enough to mitigate risks associated with emerging DBPs.

> Changes in treatment to address one DBP may result in the formation of more toxic DBPs

From a One Water perspective, emerging DBP research is focused on minimizing exposure via human consumptive end uses and is thus most important in drinking water and direct potable reuse applications. One Water management can impact the types of anthropogenic and natural organic materials found in source waters and influence which species of DBPs are present in treated water. In addition, climate change and drought can lead to higher fractions of effluent in waterbodies, resulting in higher DBP loads for drinking water treatment plants (Richardson and Plewa 2020).

Addressing emerging DBPs is a moving target for water managers. Regulated DBPs were originally thought to be proxies for total DBP concentrations, but this is not always the case (Li and Mitch 2018). Changes in treatment to address one DBP may result in the formation of more toxic, emerging DBPs. These changes often manifest in a shift in the way utilities disinfect, which, depending on the oxidant and source water matrix, may result in more and/or different DBPs in treated water (Richardson and Plewa 2020). Holistic management of DBPs may be driven by toxicological data to evaluate and mitigate the total risk associated with the full suite of DBPs present in treated water.

## Emerging DBP Research Area

IN 2017, WRF ESTABLISHED THE Emerging Disinfection Byproducts in Drinking Water: Occurrence, Toxicological Relevance, and Control Strategies research area within its Research Priority Program. Under the guidance of a team of DBP experts, WRF has funded five projects through this research area to better understand the factors that impact emerging DBP formation and control; minimize the formation of regulated and emerging DBPs; identify sources of, and develop removal strategies for, emerging DBP precursors; and leverage this research to provide guidance to utilities seeking to comply with regulations while minimizing unintended consequences (Table 1). This research area was built upon WRF's robust portfolio of DBP-related work, including a previous research area focused on control and treatment of N-nitrosodimethylamine and other nitrosamines, which was completed in 2016.

The first project funded by the Emerging DBPs research area, *Occurrence Survey of Bromide and Iodide in Water Supplies* (Westerhoff et al., forthcoming), characterized the spatio-temporal trends in bromide and iodide concentrations in drinking water sources. Some of the project's key findings are highlighted below. The second project funded in this research area (5140) builds on a previous study (Stanford et al. 2019) to investigate the toxicological and DBP speciation implications of pre-chlorinating before granular activated carbon (GAC) treatment. Additional projects funded by this research area explore the formation and fate of haloacetonitriles and assess the impacts of the regulatory shift from five to nine haloacetic acids (HAA) (projects 5083 and 5085, respectively). The final project in this research area (5122) is shifting focus away from unit processes to investigate the control of brominated and iodinated DBPs throughout the water system, from source water acquisition to distribution system management.

## Occurrence Survey of Bromide and Iodide in Water Supplies

WESTERHOFF ET AL. (forthcoming) builds on Amy et al. (1994), which characterized bromide levels at 100 water utilities across the United States and analyzed the seasonal variation of bromide at 50 utilities. This project expanded the scope of Amy et al. (1994) to include iodide, and aimed to (i) determine the role of bromide and iodide in the formation of regulated and emerging DBPs; and (ii) develop a better understanding of how seasonal changes in watersheds, regional geochemistry, and other factors impact bromide and iodide concentrations in source waters. To expand the number of

**Table 1. Projects funded through the emerging DBP research area**

| Project Title | Project Goal |
|---|---|
| Impact of a Haloacetic Acid MCL Revision on DBP Exposure and Health Risk Reduction (5085) | To support the regulatory process of developing a revised DBP rule by focusing on understanding and communicating the implications of a shift from the regulation of five haloacetic acids (HAA5) to a regulation focused on the nine chlorinated and brominated haloacetic acids (HAA9). |
| The Impact of Pre-chlorination and GAC Treatment on DBP Formation and Overall Toxicity in Drinking Water (5140) | To investigate the impact of GAC, with and without pre-chlorination, on DBP formation and the resulting toxicity of drinking water using appropriate bioassays. |
| Occurrence Survey of Bromide and Iodide in Water Supplies (4711) | To investigate the source factors influencing the temporal and spatial occurrence of bromide ions and total organic bromine or chlorine in drinking waters, and identify treatment strategies to control bromide and iodide. |
| Precursors and Control of Halogenated Acetonitriles (5053) | To conduct a comprehensive and systematic study to investigate and characterize precursors in varying water sources, as well as their control in water treatment. |
| Technologies and Approaches to Minimize Brominated and Iodinated DBPs in Distribution Systems (5122) | To develop creative and novel techniques and approaches to minimize the formation of currently unregulated brominated and iodinated DBPs in the distribution system, considering practical applicability and economic feasibility in the operation of existing treatment systems. |

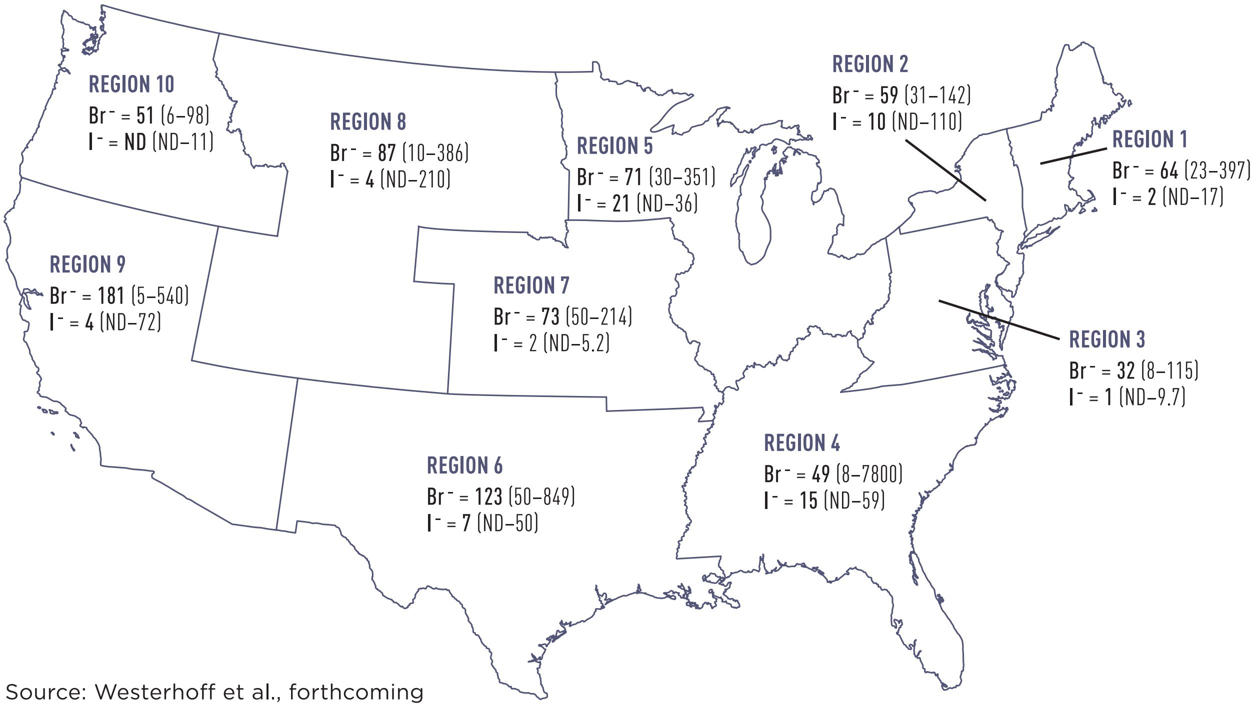
source waters sampled, the research team leveraged historic datasets supplemented with field sampling to enable a spatial occurrence analysis at regional and national scales. The researchers also performed bench- and pilot-scale testing of technologies to remove bromide and iodide from source waters to reduce DBP formation potential.

The researchers found that bromide levels were not increasing nationally and that bromide levels can have weekly or monthly variations in some water sources. Figure 1 shows the distribution of bromide and iodide from approximately 700 samples aggregated by EPA region. Bromide concentrations were found to be higher in groundwaters than in surface waters. EPA Regions 9 and 6, which span the Southwest, were found to have the highest median bromide levels (181 and 123 µg/L, respectively), while Region 3 in the Northeast had the lowest median level nationally (32 µg/L).

**For 20 years, much of WRF's disinfection** byproduct research was managed by Dr. Djanette Khiari, who passed away in 2020. Djanette also brought valued expertise in cyanobacteria, taste & odor, and more to WRF. She embodied WRF's mission of advancing the science of water, and we are grateful for her service to WRF and the water community. She is greatly missed, not only as a coworker, but also as a friend. This article is dedicated to her memory.

While most of the utilities sampled in this project had bromide present in their source waters, fewer utilities had iodide present. Again, groundwater was found to have more iodide than surface water, with 64% of groundwater sources testing above the detection limit (1 µg/L), compared to 46% of surface water sources. Nationally, median iodide concentrations were highest in EPA Region 5 (21 µg/L), which spans the Great Lakes, and lowest in Region 10 in the Pacific Northwest, where the median concentration was non-detect (ND). Source waters from coastal regions and those influenced by wastewater discharges had higher bromide and iodide concentrations.

To remove bromide and iodide from source waters, the research team tested silver-impregnated adsorbents, silver-amended coagulation processes, and ion exchange processes. These technologies worked well for low conductivity and waters with



Source: Westerhoff et al., forthcoming

**Figure 1. Median bromide ($Br^-$) and iodide ($I^-$) occurrence and the range in samples from 228 utility drinking water sources by EPA region**

low chloride. Cost-effective bromide removal via silver-amended coagulation was dependent on chloride to bromide ratios, with higher ratios yielding lower bromide removal rates. Higher bromide levels were linked to increased silver consumption and, thus, increased chemical costs.

WRF looks forward to updating its subscribers on the results of all of these important emerging DBP projects over the next couple of years.

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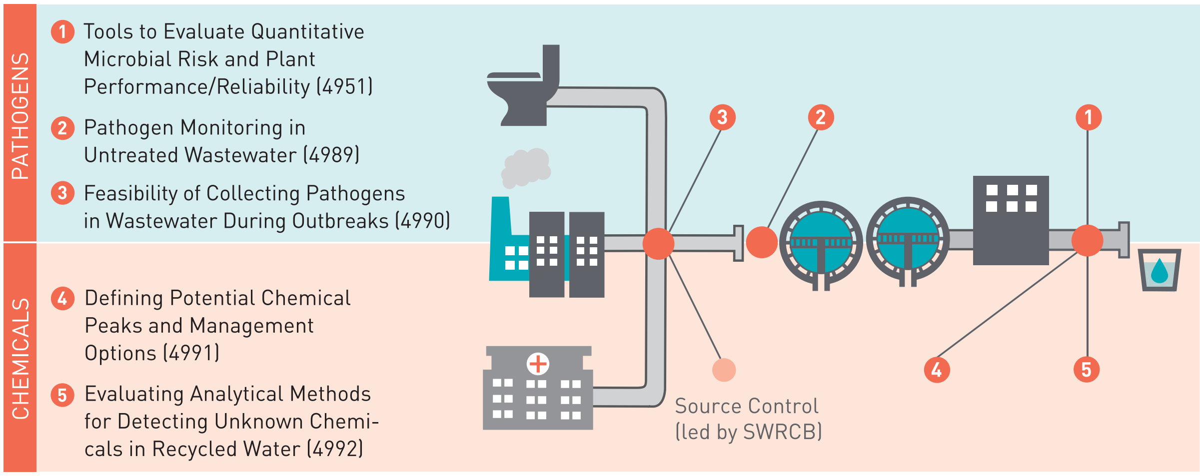
# Direct Potable Reuse

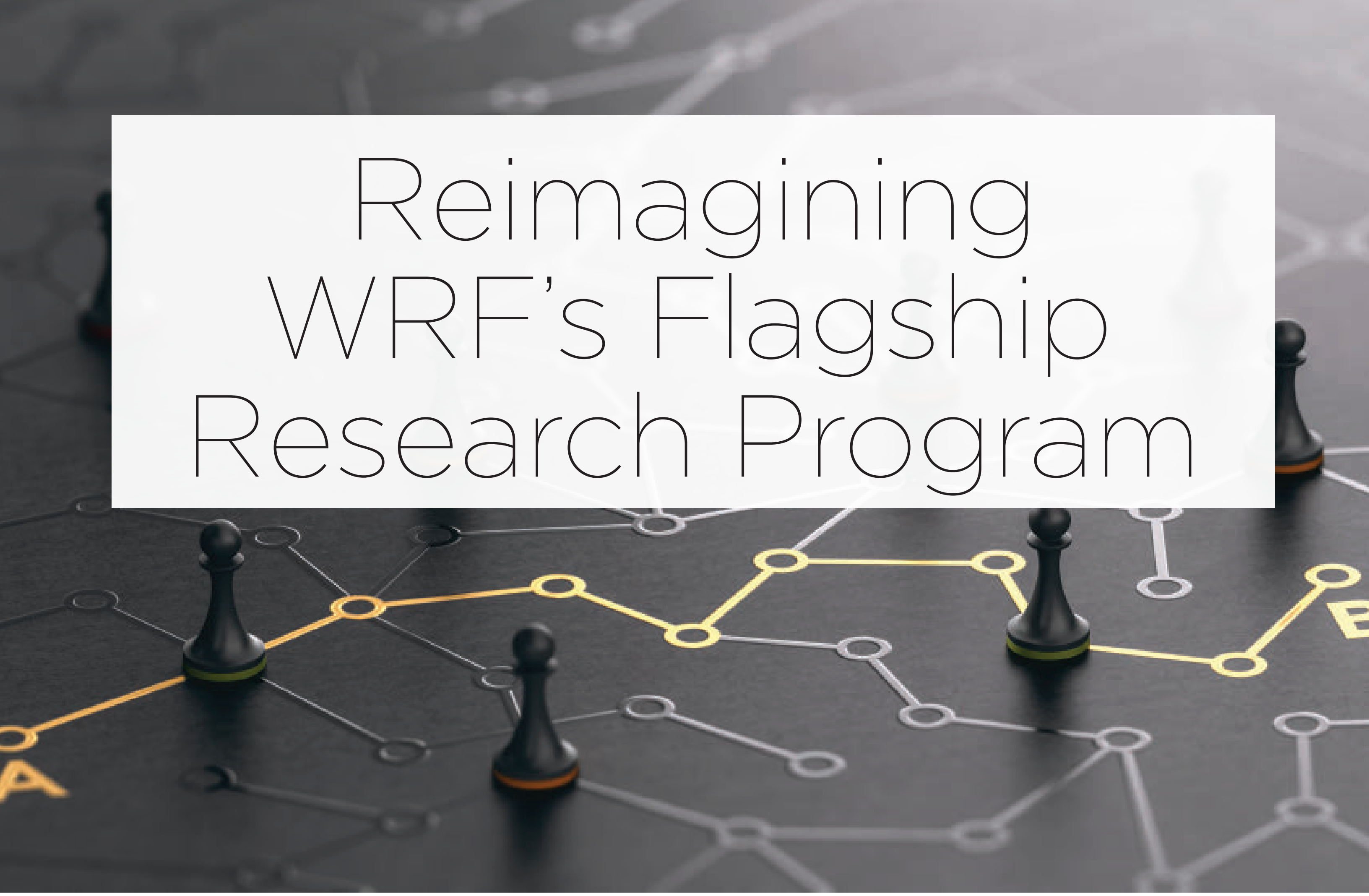
## (4951, 4989, 4990, 4991, 4992)

**In 2018, WRF received** two grants, totaling $4.5 million, from the California State Water Resources Control Board (SWRCB) to support non-potable and potable reuse research. This funding was leveraged by WRF and other key partners, including Metropolitan Water District of Southern California, to fund WRF reuse research. The first grant funded five projects related to the feasibility of developing criteria for direct potable reuse (DPR), and the second grant is funding 20 projects addressing both potable and non-potable reuse. All five of the first grant's DPR projects have now been completed. The findings from these projects will be used by the SWRCB to develop regulations for DPR.

PROJECTS TO INFORM THE DEVELOPMENT OF DPR REGULATIONS



# Reimagining WRF's Flagship Research Program



**The Water Research Foundation (WRF) recently embarked on a journey to yield even greater impact through its flagship research program, the Research Priority Program.**

By John Albert and Alyse Greenberg, The Water Research Foundation; and Yvonne Forest, City of Houston

**The Research Priority Program** (RPP) is part of a 50+ year effort by WRF to engage the best researchers around the globe to strategically address broadly relevant water sector challenges and opportunities. The RPP is the cornerstone of WRF's research efforts.

WRF and our Research Advisory Council (RAC), which oversees the RPP, embarked on a process to accelerate the delivery of research products while maintaining the highest quality and integrity of the research. This effort aligns with WRF's strategic plan goal of being the trusted source in One Water research by empowering and enabling subscribers and the water sector to unlock opportunities and solve problems through sound science.

In addition to advancing the strategic plan, drivers for changing the RPP process include (1) expediting the delivery of research while maintaining the input of experts and the integrity of the process, (2) increasing the program's ability to adapt and respond to changes in the water sector, (3) continuing to deliver research to address the highest-priority needs of subscribers, (4) better defining the water sector's greatest needs and the research needed to address them, and (5) ensuring the effective use of staff and volunteer time.

WRF staff and the RAC launched an effort in October 2020 to develop an updated framework for the RPP process. The framework was approved by the RAC in spring 2021, and was subsequently provided to WRF's Board of Directors for review. This article provides a snapshot of the proposed approach to the research planning process for the RPP. Specific details may change as the process evolves.

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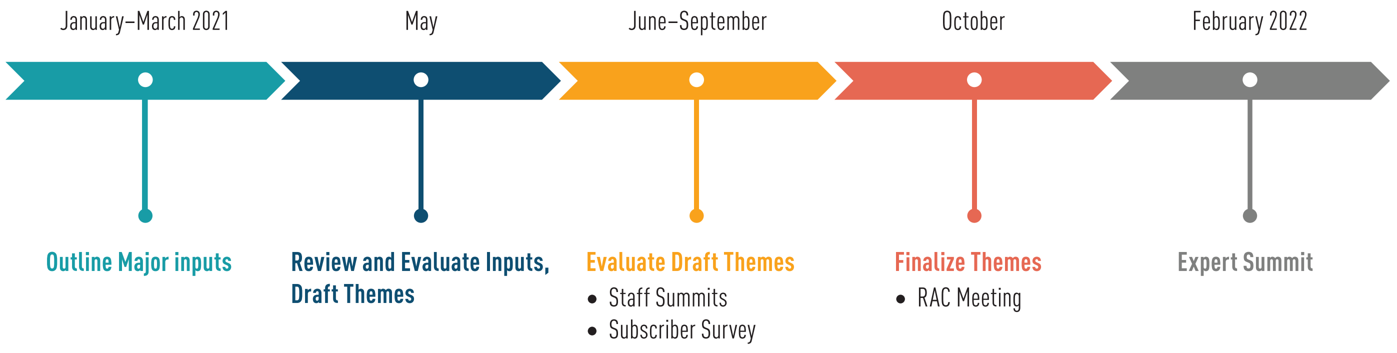


**Figure 1. Theme development process**

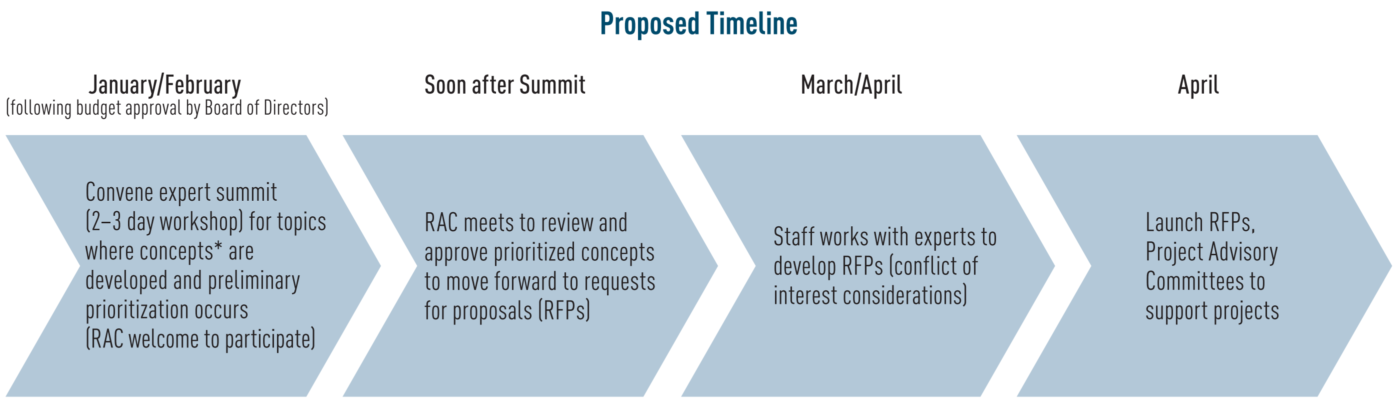
The first step in the new process is to identify high-level research themes that are responsive to the key needs of the water sector. Figure 1 shows the theme development process. A variety of inputs were used to gather key information for theme development, including the results of WRF's 2021 Upstream Strategies: Future Water Research and Innovation Solutions gathering; conversations with WRF subscribers, partners, volunteers, and other stakeholders; water sector surveys; and water sector reports. For example, the Upstream Strategies participants identified the most significant challenges the water sector is likely to face over the next 10–20 years, along with research topics with the greatest potential to overcome these challenges.

It is anticipated that four to seven themes will be identified. The themes will be broad, high-level ideas that are anticipated to be integral to the water sector over the long term. They will serve as the strategic framework supporting RPP planning moving forward. Each theme will fit within WRF's One Water approach, having the ability to include all types of water. Five draft themes have been proposed by WRF and are currently undergoing RAC review:

- Healthy Communities and Environment
- Resilient Infrastructure
- Energy Efficiency and Resource Recovery
- Innovative Treatment
- Utility Operations and Management

A survey of WRF subscribers will be conducted to gain additional input on the draft themes. The final themes will be approved by the RAC this fall, then presented to the WRF Board of Directors. A challenge statement or aspirational goal will be developed for each theme, explaining the importance of the theme to the water sector and the drivers for the research.

Once the themes and their aspirational goals are finalized, key topics within each theme will be outlined. While the themes are intended to carry forward from year to year, the topics in support of the themes will



*Concepts would include a title, needs statement, objective, and budget

**Figure 2. Draft project concept development process**

be revisited periodically. Having high-level themes with topics that will be updated over time will allow the RPP to maintain its strategic vision while also being flexible and adapting to the changing needs of the sector.

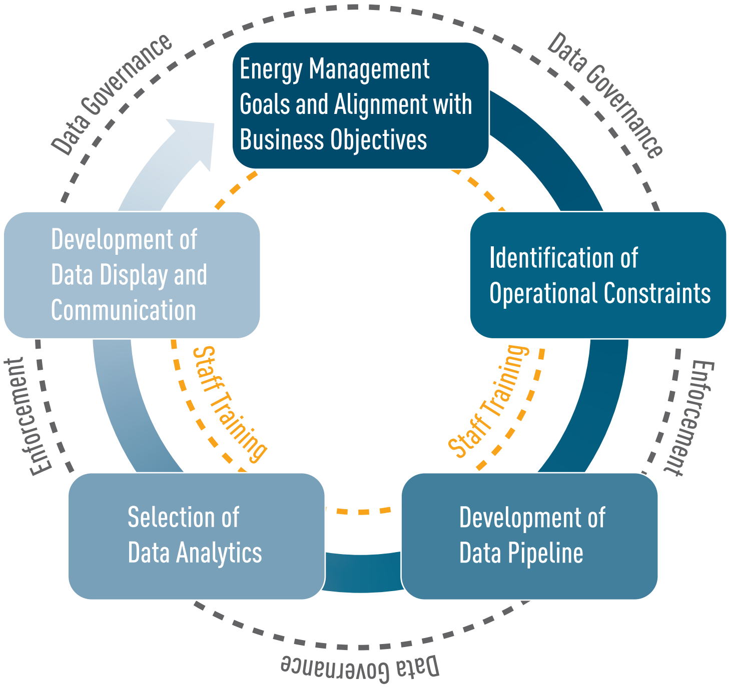
Each year, project concepts will be developed under the topics (Figure 2). WRF anticipates holding an expert summit, likely in January or February, to bring together a broad set of experts on each topic. The summit will include a breakout group for each topic, which will be tasked with identifying and prioritizing specific research needs. Research project concepts to address each topic area will be developed, including a title, needs statement, objective, and a suggested budget. The concepts will be prioritized, and the RAC will then meet to review the concepts and make funding recommendations. Requests for Proposals for the funded project concepts will be released in April, accelerating the RPP planning process by 4–5 months, thereby moving key research projects forward faster.

Expert summits will likely take place annually, providing an ongoing opportunity for WRF subscribers to help steer the RPP and inform the final research prioritization decisions made by the RAC.

Over the years, the structure of WRF's research programs has changed to address the needs of the water sector. WRF envisions this new process as striking the right balance between strategically addressing the water sector's near-term and long-term challenges.

# Energy Use (4978)

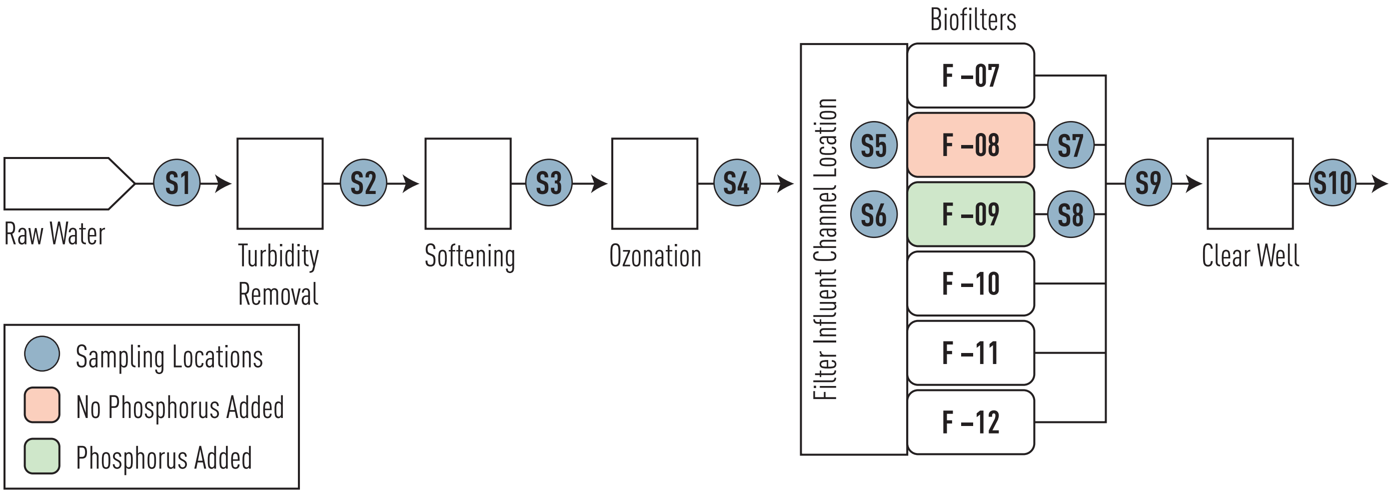
**There are increasing concerns within the water sector related to energy** use, rising costs, energy security, and energy reliability. Utilities are increasingly implementing innovative data management solutions and approaches based on big data to attain operational sustainability, target cost/energy savings, and strive toward a net-zero energy balance at their facilities. Despite the technological and analytical improvements made around the management, accessibility, interpretation, and visualization of energy data, the application of big data concepts for energy management is still in its infancy. *Application of Big Data for Energy Management in Water Utilities* addresses these gaps by providing utilities with knowledge on advanced big data analytics for automated data collection and achieving energy-efficient, cost-effective operations. This research also provides an approach for the development of a comprehensive data management and analytics strategy at a reference utility, which can become a model for future pilot studies.



Concepts addressed by the data pilot plan

# Optimizing Biofiltration (4731)

**Holistic biofiltration** optimization is designed to shift a plant's total organic carbon removal to the biofiltration step to reduce overall treatment costs without compromising overall plant performance. *Optimizing Biofiltration and Integrating Biofiltration into Existing Treatment* aimed to demonstrate extensive full-scale biofiltration optimization and integration into the overall treatment train. Holistic biofiltration optimization was performed at two full-scale facilities to enhance biofilter performance and to understand how biofiltration can be most efficiently integrated with upstream processes. Biofiltration and upstream process optimization tests were performed, and an automated data management system was used for managing, analyzing, and interpreting the data.



**Schematic Representation of Biofilter Testing at Hap Cremean Water Plant**

# Long-Term Vulnerability Assessment (4703)

**Climate change, water quality, regulatory changes,** growth, and economic cycles are among the many factors that create uncertainty and vulnerability for water systems and impact their ability to meet the needs of their communities. Therefore, utilities must consider these factors when planning for the future. *Long Term Vulnerability Assessment and Adaptation Plan for the San Francisco Public Utilities Commission Water Enterprise - Phase I* developed a long-term vulnerability assessment (LTVA) of the San Francisco Public Utilities Commission's Regional Water System (RWS). The goal of the LTVA is to help quantitatively and qualitatively assess to what extent climate change will be a threat to the RWS in comparison to, or in combination with, other external drivers of change over the next 50 years. The LTVA was performed using an innovative decision scaling approach whereby vulnerabilities were first identified and used as a basis for assessing risks. The analysis includes a multi-dimensional quantitative stress test and qualitative scenarios in which sources of vulnerability are revealed through testing against changing conditions. This research provides a detailed case study of the decision scaling methodology, providing a systematic approach for addressing climate change concerns while also incorporating non-climate considerations. The findings will also serve as the basis for future work to explore adaptation pathways and identify investments and long-term options to increase resilience of the RWS infrastructure.

# CALENDAR

January–March

**January 10-12, 2022**
**WEF Forum 2022: Particles and Colloids**
Fort Lauderdale, FL
www.wef.org/forum

**January 23–26, 2022**
**NEWEA Annual Conference**
Boston, MA
annualconference.newea.org

**January 31–February 3, 2022**
**NACWA Winter Conference**
Scottsdale, AZ
www.nacwa.org/conferences-events/2022-winter-conference

**February 1–3, 2022**
**Pacific Water Conference (AWWA/HWEA 8th Annual Joint Conference)**
Virtual
pacificwaterconference.com

**February 13–16, 2022**
**NARUC Winter Policy Summit**
Washington, DC
www.naruc.org/meetings-and-events/naruc-winter-policy-summits/2022-winter-policy-summit

**February 21–25, 2022**
**AWWA/AMTA Membrane Technology Conference**
Las Vegas, NV
www.awwa.org/Events-Education/Membrane-Technology

**February 22–24, 2022**
**WEF/AWWA Utility Management Conference**
Orlando, FL
www.wef.org/events/conferences/upcoming-conferences/Utilitymanagement2021/utilitymanagement2022

**February 22–23, 2022**
**World Water-Tech Innovation Summit**
London
worldwatertechinnovation.com

**February 23–25, 2022**
**MSSC Salinity Summit**
Las Vegas, NV
www.multi-statesalinitycoalition.com

**March 6–9, 2022**
**37th Annual WateReuse Symposium**
San Antonio, TX
watereuse.org/news-events/conferences/37th-annual-watereuse-symposium

**March 21–24, 2022**
**WEF Public Health and Water Conference & Wastewater Disease Surveillance Summit**
Cincinnati, OH
www.wef.org/PublicHealth

**March 27–April 2, 2022**
**IWA Leading Edge Conference on Water and Wastewater Technologies**
Reno, NV
iwa-let.org