CAROLLO ENGINEERS VOLUME 4 2022 ANNUAL CRG EDITION

currents

CAROLLO RESEARCH GROUP

25 YEAR ANNIVERSARY

FEATURING

- 25 Years of CRG
- UV Disinfection
- Water Reuse
- Desalination
- Membrane Filtration
- Biological Treatment
- Blue Plan-it®
- Wastewater and Biosolids
- Water ARC®
- Emergency Response
- Contaminants of Emerging Concern

ORIGINS AND EVOLUTION OF THE CAROLLO RESEARCH GROUP: 25 YEARS OF APPLIED RESEARCH BY DESIGN

JESS BROWN, PhD, PE (jbrown@carollo.com); **GIL CROZES, PhD, PE** (gcrozes@carollo.com)

ORIGINS

In the late 1980s and 1990s, the number of contaminants regulated under the USEPA's Safe Drinking Water Act (SDWA) almost quadrupled relative to the original 1974 regulations. In parallel, a new trend in proprietary technology development was observable in the water industry; often technologies brought in from around the world by way of industry consolidation and globalization. Consequently, Carollo began to recognize that technical innovation needed to be integrated with sound engineering to address the increasingly complex challenges and opportunities facing our clients.

This recognition was the driving force that launched the Carollo Research Group (CRG) in 1997. Established as a centralized team of drinking water researchers and engineers in our Boise, Idaho office, the group embraced the technical specialization of its members who have since become leading technologists in several areas such as UV, advanced oxidation processes, membrane filtration, desalination, biological drinking water treatment, and emerging contaminants.

The group completed stand-alone applied R&D projects for national water agencies, but also began working closely with internal project managers to help municipalities "bridge the gap" between good technical ideas and practical full-scale solutions. The group also established a laboratory, equipped with jar testers, media columns, flow-through ozone demand/decay equipment, UV collimated beam, bench-scale membrane and dissolved air floatation systems, wet chemistry testing, total organic carbon analyzer, and a small fleet of pilot testing equipment.

> The needs and challenges facing our clients and the water industry will continue to direct the focus, energy, and resources of the Carollo Research Group for the next 25 years and beyond."
>
> – Jess Brown, CRG Director

EVOLUTION

Since CRG's founding, challenges facing the water industry have grown in number, complexity, and urgency... aging infrastructure, increasingly stringent water quality and discharge limits, public demand for sustainability, emerging contaminants, and variable water supplies to name a few Carollo's geographic reach has also grown, expanding from 13 offices in 8 states in 1997 to over 50 offices in 24 states and one Canadian Province today. In response to these internal and external dynamics, CRG evolved from a small group in Boise to a decentralized group of over 30 staff with eight Regional R&D Leads across the country, thereby more directly connecting R&D initiatives/resources with our clients' needs. CRG's focus areas expanded to include wastewater, reuse, stormwater, industrial water, decision support, digital water, and a growing portfolio of emerging contaminants. Additionally, CRG's laboratory- and field-based testing capabilities have grown to meet an exploding demand, culminating in our Water ARC® program that features an 8,900-square foot treatability testing center along with full-service support for field, pilot, and demonstration studies.

LOOKING AHEAD

The last 25 years have seen rapid change across the water industry, and while CRG's team of in-house engineers, scientists, planners, modelers, and researchers has grown and diversified as a result, what hasn't changed is our commitment to working toward reliable solutions and tools for our clients. A few examples are called out on the opposite page, discussed in this Annual CRG Edition of *Currents*, and featured in past editions. Looking ahead, as we see change as a constant in the water industry, the needs and challenges facing our clients will continue to direct the focus, energy, and resources of the Carollo Research Group for the next 25 years and beyond.

2022 CRG BROCHURE | *CURRENTS* 2019 VOL. 2 | *CURRENTS* 2021 VOL. 1

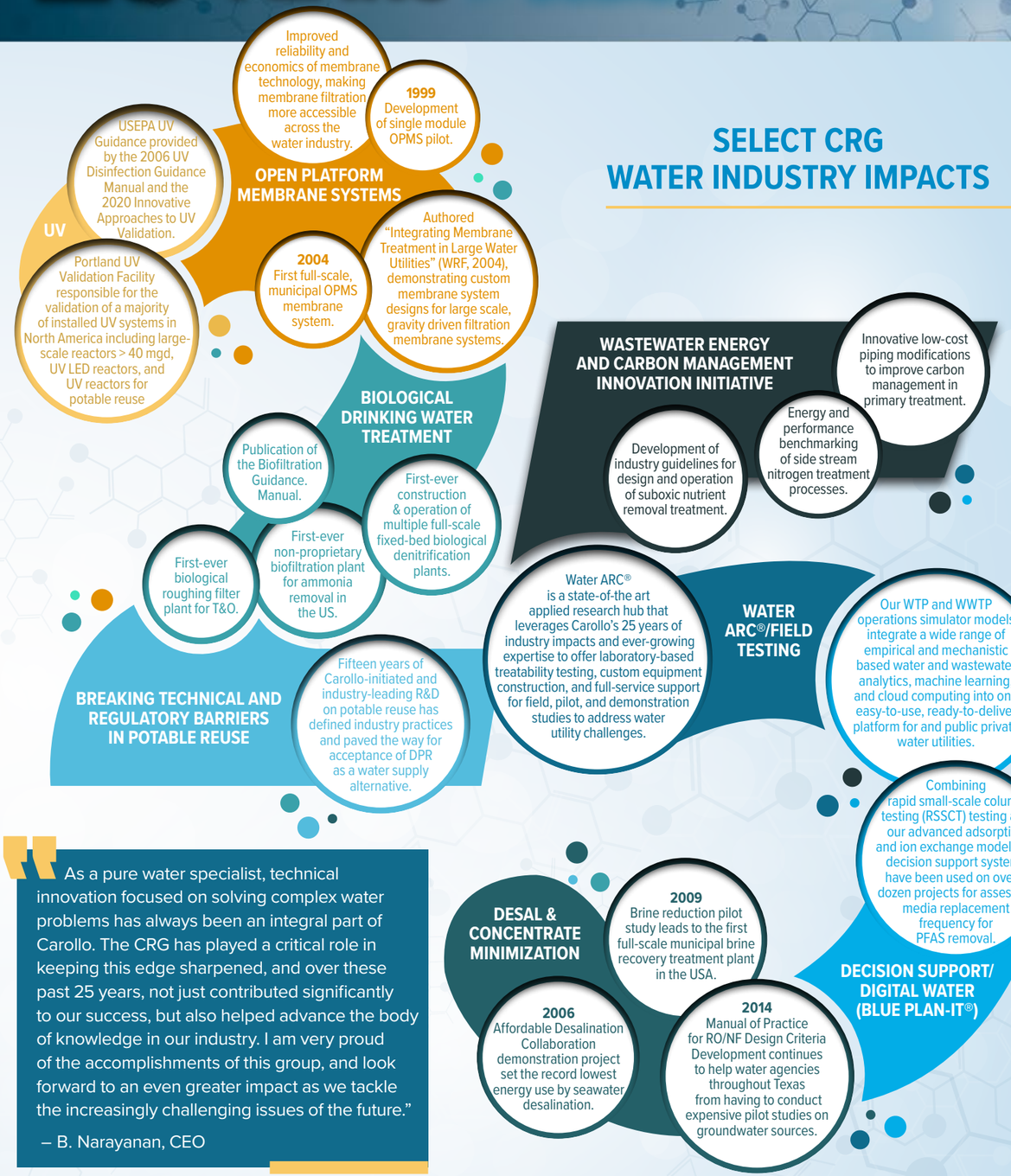
carollo

TECHNICAL EDITOR: Jess Brown, 714-593-5100 | jbrown@carollo.com

CONTENT EDITOR: Nick Webber

DESIGN AND PRODUCTION: Silvia Backlund, Laura Corrington, Matthew Parrott

SELECT CRG WATER INDUSTRY IMPACTS



> As a pure water specialist, technical innovation focused on solving complex water problems has always been an integral part of Carollo. The CRG has played a critical role in keeping this edge sharpened, and over these past 25 years, not just contributed significantly to our success, but also helped advance the body of knowledge in our industry. I am very proud of the accomplishments of this group, and look forward to an even greater impact as we tackle the increasingly challenging issues of the future."
>
> – B. Narayanan, CEO

Advancing **UV Technologies** for the **Drinking Water Industry**

HAROLD WRIGHT (hwright@carollo.com),
MARK HEATH, **TRACI BROOKS**

Twenty years ago, ultraviolet (UV) technologies were primarily used in North America for the disinfection of wastewater effluents. Today, UV technologies provide drinking water disinfection at flows up to 2,000 mgd, advanced oxidation of taste and odor compounds, destruction of *N*-Nitrosodimethylamine (NDMA) and other nitrosamines in ground water, and disinfection and advanced oxidation with potable reuse. This expanded application of UV technologies has been driven by new regulations and guidance promulgated by the US Environmental Protection Agency (USEPA), UV projects funded by the Water Research Foundation (WRF) and other agencies, and technology advances and validation by UV system manufacturers. The Carollo Research Group (CRG) has been active in each of these areas and has provided leadership in promoting UV technology applications.

DEVELOPING THE UV VALIDATION TESTING FACILITY

In 2001, USEPA contracted with Carollo to develop the UV Disinfection Guidance Manual (UVDGM) for the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). At that time, there was very limited experience with drinking water UV disinfection, especially in the area of UV dose monitoring and validation. In response, Carollo worked with UV system manufacturers to develop the Portland UV validation test facility, located in Portland, OR. The facility opened in 2003 and has since conducted UV validation testing on over 80 commercial UV reactor products at flows ranging from 5 gallons per minute (gpm) to 70 million gallons per day (mgd) per reactor. The UV dose monitoring algorithms developed at the Portland test facility not only provided a foundation for the UV monitoring requirements specified in the LT2ESWTR and the validation test protocol provided in the UVDGM, both published in 2006, but have also promoted confidence in UV technologies with utilities and their regulators.

Figure 1 - Calgon 48" Chevron reactor installed at the Portland UV Validation Test Facility.

RAISING THE BAR FOR UV PERFORMANCE

Since 2006, CRG has been the Principal Investigator (PI) or Co-PI for 11 UV projects funded by WRF. These projects have defined the state-of-the-art UV technologies resulting in better public health protection with lower capital and operation and maintenance costs. For example, WRF Project 2977 developed design and performance guidelines for UV sensor systems and UV dose monitoring. Prior to WRF 2977, UV dose algorithms provided indirect predictions of pathogen log inactivation based on UV validation conducted using a single surrogate, such as MS2 Phage. With indirect predictions of pathogen log inactivation, the UVDGM specified application of a reduction equivalent dose (RED) bias factor to account for prediction uncertainty. This factor was based on a "worst case" commercial reactor, and hence was highly conservative with many UV technologies. To address this issue, WRF Project 2977 defined UV dose algorithms based on validation conducted using multiple surrogates. These algorithms include a kinetic term for the microbe, which allows direct prediction of pathogen inactivation thereby eliminating the RED bias uncertainty. Since WRF 2977 was finalized, all of the major UV system manufacturers have adopted these algorithms for UV dose monitoring.

In 2020, USEPA published the document entitled "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems" (EPA/600/R-20/094). Authored by CRG, the Innovative Approaches document acts as a compendium of new approaches for UV dose monitoring, validation, and implementation developed since the publication of the 2006 UVDGM. For UV dose algorithms that provide direct predictions of pathogen log inactivation, the document provides criteria for developing a robust validation test matrix, monitoring algorithm goodness of fit and quality assurance/quality control requirements, and standardized approaches for defining the validated range of UV reactors. To simplify UV system operation, the document provides approaches for UV dose monitoring algorithms that do not require an online UV transmittance monitor. The document also provides UV dose values for 6-log inactivation of *Cryptosporidium*, *Giardia*, and adenovirus that can be applied with UV technologies used for potable reuse.

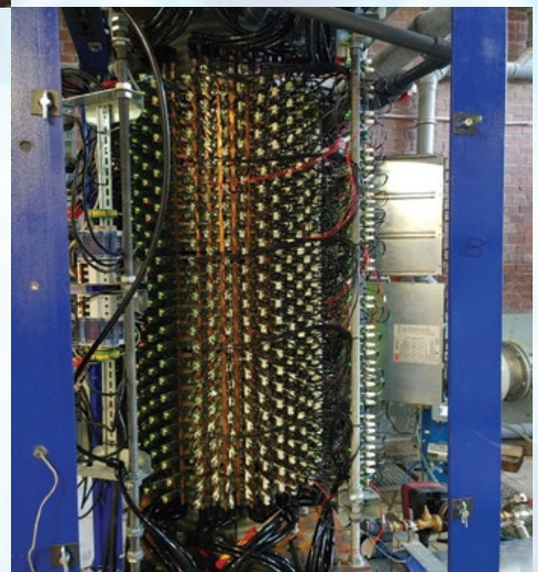


Figure 2 - UV technology advances developed through UV projects funded by the Water Research Foundation and other agencies are the foundation of the USEPA's "Innovative Approaches" document.

Carollo's work on advancing UV technologies continues to this day. In 2021, Carollo completed validation of a UV LED reactor for drinking water disinfection at flows up to 3.2 mgd, all in accordance with the USEPA UVDGM and Innovative Approaches document. UV LEDs provide a mercury-free alternate to low-pressure high-output (LPHO) and medium-pressure (MP) UV lamps used with many UV reactors. In 2022, based on UV dose models developed through WRF Project 4764, Carollo developed a UV dose calculator tool based on computational fluid dynamics (CFD) that quantifies the impact of lamp failures on UV dose delivery and public health protection with installed wastewater UV systems. The tool enables plant staff to develop strategies for addressing lamp failure with their system. These two examples show that new and exciting work is still going on in the world of UV.

Figure 3 - 3.2-mgd UV LED reactor validated per USEPA guidance for drinking water applications.

Reuse Innovation Program
Innovation is at our Core

EVA STEINLE-DARLING, PhD, PE (esd@carollo.com);
ANDREW SALVESON, PE (asalveson@carollo.com); **ROSA YU** (ryu@carollo.com)

The recent development of water reuse as an intentional, engineered practice is built on decades of innovation that persist well into our projects today. Carollo is at the forefront of water reuse innovation, from concept to realization, as illustrated by our implementation of potable reuse projects across the entire US and more recently globally **(Figure 1)**.

While the field has matured significantly over the last decade, globally operating projects can be counted on several hands; potable reuse is still inherently an innovative practice and will be for some time. Many of our client's projects reflect this innovation, from pilot and demonstration testing to the exploration of alternative treatment approaches and better sensing, monitoring, and data management solutions. Our innovation also takes us far afield, with clients around the world requesting our expertise as they develop innovative approaches to potable reuse in their geographies (Japan, Israel, Australia)!

ALTERNATIVE ADVANCED TREATMENT APPROACHES: NOT JUST OZONE/BAC!

For approaches to advanced treatment for potable reuse, past conventional wisdom (and some regulations) dictated that an approach built around reverse osmosis (RO) was the only defensible path. Our focus has shifted significantly to a wider range of treatment processes and combinations over the last few years. Carollo has been a leading force behind the development of a carbon-based advanced treatment (CBAT) alternative approach that relies much more heavily on our industry's wisdom and experience in traditional drinking water treatment processes, such as ozone and biofiltration. Our team, in partnership with many utility and academic partners, has developed no less than seven CBAT pilot or demonstration facilities for direct potable reuse (DPR) in four states over the last five years, with more to come (see Figure 2). Increasingly, these various "firsts" have also garnered attention—even among those for whom water is not a day-to-day preoccupation. And we're not resting on our laurels: a new collaboration with our drinking water treatment experts has developed a new treatment concept, affectionately called XBAT, that provides a potential solution to the Achilles Heel of both RO-based treatment and CBAT: salinity management. Stay tuned for more information about this exciting concept!

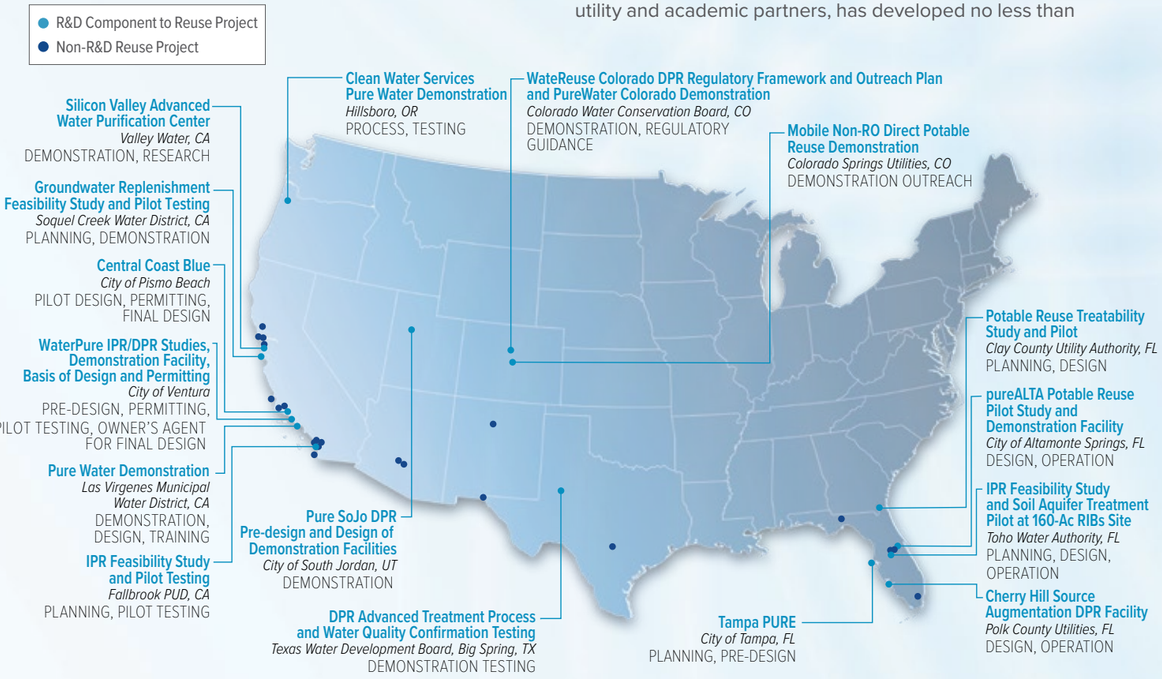


Figure 1 - Carollo's potable reuse projects range from feasibility study to full-scale design and beyond. They include design of the first direct-to-distribution DPR facility in the US for El Paso Water and program management/engineering support for the City of Los Angeles's 272-mgd potable reuse program.

Figure 2 - One of Carollo's CBAT demonstration projects, the City of South Jordan's Pure SoJo DPR project encapsulates the progress we have made in potable reuse: It's the first DPR project in the state of Utah, forms the basis of that state's regulatory approach to DPR, and has garnered the attention of Utah Senator Mitt Romney. During his visit in October 2022, he noted, "This is the kind of solution that could be adopted around the State."

SYSTEMS-LEVEL THINKING REQUIRES BETTER SENSING, MONITORING, AND DATA MANAGEMENT CAPABILITIES

In our previous column (Volume 2 2019), we explored system-level thinking with projects like The Water Research Foundation (WRF) Project #4833, which examines the interplay between wastewater treatment and advanced treatment for potable reuse holistically as one integrated treatment system. With that project now nearing completion, some of the biggest take-aways are that without other drivers it is almost always most cost-effective to address treatment "gaps" at the advanced treatment level. But, more importantly, the project clearly illustrates that in order to advance our capacity for analysis and optimization, we need better sensing, monitoring, and data management tools.

Not one to shy away from a challenge, Carollo has embarked on a new comprehensive focus on **gathering better data**. This doesn't start with machine learning (ML) algorithms or "digital twins," but with the fundamentals. Asking questions like: What should we measure? Can we develop better sensors? How do we move data around efficiently and securely? Once those questions are answered, and good defensible datasets are available, the application of ML for analysis or system control applications is comparatively straightforward and opens up a whole new realm of opportunity for both individual process and system-wide optimization.

2014 Clean Water Services, Oregon. First Beer from Recycled Water.

2017 Arizona RO-based Trailer. First Beer Brewing Competition.

2021 Colorado Carbon-based Trailer. Beer, wine and other beverages made from recycled water.

2022 Las Virgenes-Triunfo Demonstration Facility. Gelato made with purified water!

A little bit of levity is one important ingredient in a successful public outreach approach. Lest you think we take ourselves too seriously, here is a great example of how our outreach efforts connect with the community at a more lighthearted level—can you think of more good things to make with purified recycled water?

THE FUTURE IS NOW

Desalination and Concentrate Minimization are Changing the Face of Water Supply and Management

ABHISEK MANIKONDA, PhD (amanikonda@carollo.com);
TOM SEACORD, PE (tseacord@carollo.com); **BRANDON YALLALY, PE** (byallaly@carollo.com)

Rapid urban growth, climate change, as well as supply challenges due to limited amounts of freshwater and salinity buildup have been key drivers for communities and industries across the US in adopting desalination as a means of diversifying their water supply. Some examples include: (1) Use of more saline waters once considered expensive to treat (e.g., seawater), (2) Advanced treatment to recycle both fabrication waste from semiconductor manufacturing and cooling tower blowdown water from data centers, and (3) Potable reuse. Although, desalination has recently become more efficient and cost-competitive, managing waste products like reverse osmosis (RO) concentrate remains a challenge. Strict environmental regulation, a need for higher water recovery, and/or extraction of valuable minerals are leading to global growth of RO concentrate volume minimization and zero liquid discharge (ZLD) technologies. During the last decade, there has been a significant development of concentrate minimization and ZLD systems, particularly in the US, with the market for ZLD construction projected to reach $8.1 billion by 2023.

The Carollo Research Group (CRG) has been instrumental in securing Carollo's position as the national leader in this growing and challenging field...bringing ideas from scientific concepts to practical solutions. This is showcased by the projects completed by Carollo over the past 25 years as shown on the timeline.

THE CRG HAS HELPED CAROLLO SECURE MARKET LEADERSHIP IN THE MANAGEMENT OF DESALINATION CONCENTRATE AND VOLUME REDUCTION

Leveraging funds from the Water Research Foundation (WRF), the WateReuse Association, and the US Bureau of Reclamation, the CRG has contributed groundbreaking work that focuses on concentrate management technology, regional decision making, and permitting. Carollo has taken these concepts and invested our own resources for the improvement of the water/desalination industry as a whole by sharing these advancements and contributing to industry standard publications, like the AWWA Manual of Practice for Inland Desalination and Concentrate Management (M69).

CRG'S PELLET SOFTENING PILOT

Characteristically, RO concentrate is supersaturated with salt. One way to maximize the water recovery from a desalination process and reduce the volume of concentrate that requires disposal is to remove these salts from RO concentrate by precipitative softening. Although pellet-softening treatment processes have been used throughout Europe for decades, it was not practiced in the US until 2008. That year, recognizing the potential of pellet-softening with the added benefit of making high-purity calcium carbonate pellets, CRG pilot-tested pellet softening at the Arlington Desalter in Riverside County, CA **(Figure 1)**. The pilot demonstrated that pellet softening could be used to maximize RO recovery and reduce the maintenance required in the Inland Empire Brine Pipeline (IEBL), where these salts would precipitate and plug the pipeline. CRG's successful testing at the Arlington Desalter led to the world's first full-scale concentrate treatment plant at the Chino II Desalter using this technology.

CHINO CONCENTRATE REDUCTION FACILITY

The Chino Concentrate Reduction Facility (CRF) best demonstrates how the CRG laid the groundwork to make Carollo the industry leader in concentrate management and treatment. The CRF uses pelletized softening, solids contact softening, media filtration, and RO to remove hardness and silica to allow for additional water recovery and a reduction in concentrate disposal. The heart of the CRF design is the high-rate pellet softening and solids contact clarifier system to remove the limiting foulants (specifically calcium and silica) from the primary RO concentrate. Seeded calcium carbonate precipitation occurs in the fluidized pellet reactors, where hard and durable pellets are generated, as shown in **Figure 2**. The produced pellets are a value-added product that can be used in a variety of industrial applications, thus converting a waste stream of the Chino process into a usable commodity.

Due to the turbid nature of the pellet reactor effluent solids, contact clarification is required to remove magnesium solids that are formed in the pellet reactors and carry over due to their lower density. After the fouling compounds are reduced in the pellet reactor and the clarifier, the softened primary RO concentrate is polished with dual media filters. The filtered effluent is sent as feed to a secondary RO (SRO) system where the concentrate volume is further reduced. SRO treated water is blended with the primary RO permeate from the Chino II Desalter, and SRO concentrate is disposed to the IEBL. Using this approach, total water recovery from the RO system at the Chino II Desalter is increased from 83.5 to 95 percent, substantially reducing the volume of concentrate disposed, while increasing permeate production.

LOW ENERGY RECORD FOR SEAWATER DESALINATION

CRG's work with the Affordable Desalination Collaboration (ADC) demonstrated that, with a combination of proven technologies, seawater RO (SWRO) can be used to produce water at an affordable cost compared to other supply alternatives. In March 2006, ADC's demonstration-scale SWRO plant completed over 6 months of testing at the US Navy's Seawater Desalination Test Facility in Port Hueneme, CA. The results of this study drew attention from all over the world and helped establish Carollo as a US leader and innovator in seawater desalination. The concepts demonstrated through the ADC's testing were applied in our recent design of the Florida Keys Aqueduct Authority's (FKAA) Stock Island Seawater RO Treatment Plant.

Figure 1 - RO Concentrate Treatment Pilot Study at Arlington Desalter.

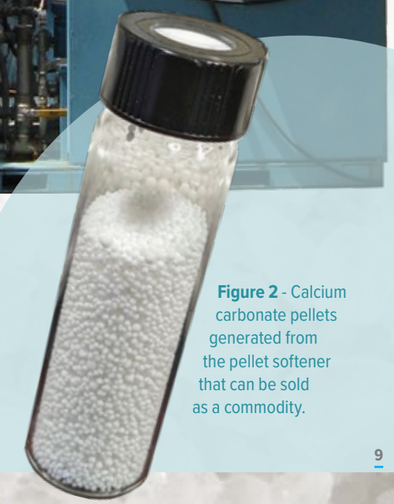


Figure 2 - Calcium carbonate pellets generated from the pellet softener that can be sold as a commodity.

COMMITTED TO INNOVATION

Two Decades of Demonstrating Big Ideas in Membrane Technology

DAN HUGABOOM, PE (dhugaboom@carollo.com)

Microfiltration and ultrafiltration membrane filtration technologies (MF/UF) rapidly commercialized in the late 1990s as a means of removing chlorine-resistant pathogens. This class of pathogens were the focus of developing regulations, promoted by the 1993 *Cryptosporidium* outbreak in Milwaukee, WI. In 1999, Carollo Research Group (CRG) invested in a custom membrane pilot plant to investigate membrane technology applications imagined by CRG and Carollo's design teams.

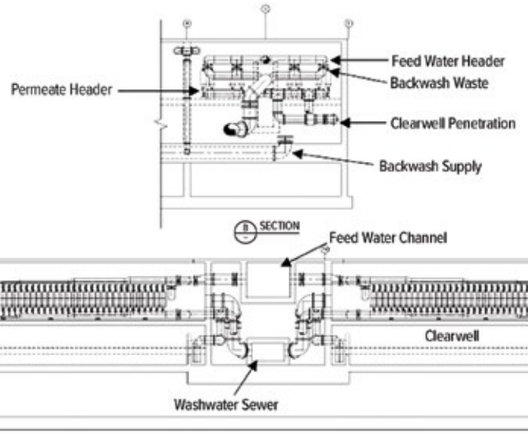
GRAVITY-DRIVEN MEMBRANE DESIGNS

One of the first concepts tested was a gravity-driven (pumpless) membrane process that could be retrofitted into traditional media filter cells. Successful pre-trials at United Water Idaho's Marden Water Treatment Plant (WTP), using CRG's pilot plant, led to funded research through the Water Research Foundation in association with Kansas City, MO (2004) and the Energy Center of Wisconsin (2002). The approach used short, high-surface-area, high-permeability membrane modules located within the hydraulic gradeline of conventional WTPs between the clarifier and clearwells. The approach was found to be viable with high-quality feed waters that resulted in low membrane fouling rates, including lime softened (or coagulated) settled waters.

The lessons learned in that funded research were applied to media filter retrofits at Two Rivers, WI (2004), Clifton, CO (2015), and Manatee County, FL (2022). The Manatee County project built on the gravity concepts by using a siphon arrangement in the permeate piping to operate within the plant's shallow hydraulic profile, reducing energy costs by 75%.

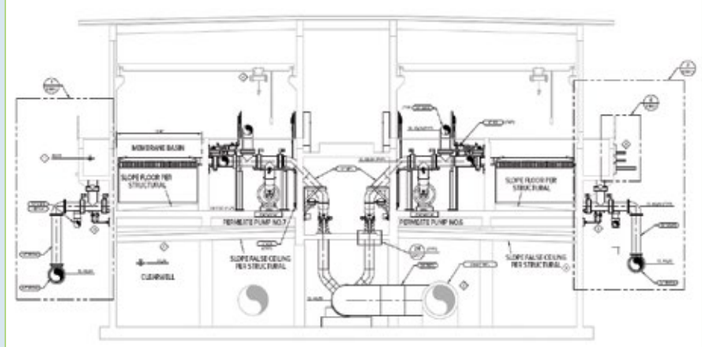
KANSAS CITY GRAVITY MEMBRANE RETROFIT CONCEPT

2004



MANATEE COUNTY GRAVITY MEMBRANE RETROFIT CONCEPT

2018



OPEN PLATFORM MEMBRANE SYSTEMS (OPMS)

Early adoption of membrane systems for municipal treatment occurred in the early 1990s. Membrane modules were offered as a component of a single element proprietary system (SEPS). These systems operated modules with unique membrane fiber chemistries, modules sizes, and system hydraulic requirements. As the installation base grew in the 2000s, the range of materials, module sizes, and systems designs converged. Carollo recognized the potential of this convergence in membrane product offerings to change the way systems were delivered to address some of the concerns our clients had with large-scale proprietary technology: replacement module availability, cost, and access to innovation.

The concept was to design membrane systems to operate membrane modules other than those provided by the original equipment supplier. This system would need to remove mechanical and controls-based barriers to interchangeability inherent in proprietary systems to allow changes in module providers without complex system configurations or wholesale system replacements.

Using its MF/UF pilot plant, CRG investigated the feasibility of this concept on the pilot-scale at the Marden WTP in Boise, ID. That work showed that a narrow range of operational protocols could, in fact, support efficient operation of a wide range of membrane modules. This meant that a set of feed pumps, backwash pump, blowers, compressors and CIP systems could be selected to operate different modules.

With this experience, and close collaboration with membrane system manufacturers, Carollo specified OPMS systems beginning in 2004 (Two Rivers, WI). That concept was later used to integrate OPMS design concepts into a UF membrane plant rehabilitation project near Sandpoint, ID (Oden Water Association) in 2009. Those systems are designed to operate modules using "inside to outside" flow membrane modules.

In the 2010s, there was significant growth in the number of modules with "outside to inside" flow configurations utilizing polyvinylidene fluoride (PVDF) polymer membrane fibers. These modules were being used in challenging surface water and widely studied for reuse/recycling applications due to their demonstrated ability to operate with high solids feed waters. Additionally, these modules offered high lifetime chlorine exposure, desirable for applications that required pre-chlorination/pre-chloramination and highly chlorinated chemical cleaning solutions. Carollo was a leader in OPMS designed for this style of module, designing what was, at the time, North America's largest such system for the Clifton Water District, CO (2015).

Carollo's newest MF/UF pilot plant simultaneously tests three outside to inside, PVDF membrane modules. This allows for cost-efficient, comparative pilot studies to support module performance evaluations and module procurement for interchangeable membrane module systems.

2015

Carollo's OPMS pilot which is used to compare module performance and interchangeability.

2004

2016

The Two Rivers, WI, membrane system (2004) was designed to facilitate inside to outside membrane interchangeability through specific considerations in the manifold design and the use of non-proprietary controls software (top). Shown after module replacement in 2016 (bottom).

CRG has advanced innovation in membrane technology applications for over two decades. These efforts have fostered improved reliability and improved economics of membrane technology, making it more accessible for our clients that need it to meet their treatment challenges.

BIOLOGICAL DRINKING WATER TREATMENT

Leveraging Nature for Robust, Sustainable Removal of Multiple Challenging Contaminants

JESS BROWN, PhD, PE (jbrown@carollo.com); **GIRIDHAR UPADHYAYA, PhD, PE**; **JENNIFER NYFENNEGGER, PhD, PE**; **GREG POPE, PhD, PE**; **STETSON BASSETT, PE**

The use of naturally-occurring biological activity to remove contaminants from drinking water has been well documented since the early 1800s. However, the biological treatment of drinking water has been more limited in the US and, only in recent years, has it expanded to include the treatment of a wide variety of organic and inorganic contaminants from both surface water and groundwater. Why consider biotreatment? There are many drivers, but at the top of the list is that naturally-occurring bacteria concentrated in an engineered treatment system can convert multiple contaminants to innocuous end-products efficiently without generating a concentrated waste stream. The Carollo Research Group (CRG) launched our Biological Drinking Water Treatment Initiative back in 2002. Over the past two decades, we have led the industry in drinking water biotreatment innovation and R&D, testing and scale-up, and full-scale design, implementation, and operation… covering surface water and groundwater in both aerobic and anoxic applications.

SURFACE WATER BIOFILTRATION

Historically, biofiltration has largely been operated as a passive process in the water treatment industry. As part of our Biological Drinking Water Treatment Initiative, CRG has been developing design and operational strategies for enhancing the performance of standard biofiltration processes by improving microbial health—an approach known as "Engineered Biofiltration" and a concept that we first published on in 2011.

Since 2011, Carollo has served as Principal Investigator (PI) or co-PI on nine Water Research Foundation (WRF) biofiltration projects that have: **(1)** Helped document the state of the North American biofiltration practice, **(2)** Developed and applied Engineered Biofiltration strategies, and **(3)** Provided industry guidance on the planning, testing, design, and operation of biofiltration facilities. Further, we have been involved in the design of over 1.1 billion gallons per day (bgd) of surface water biofiltration plants in the last five years alone.

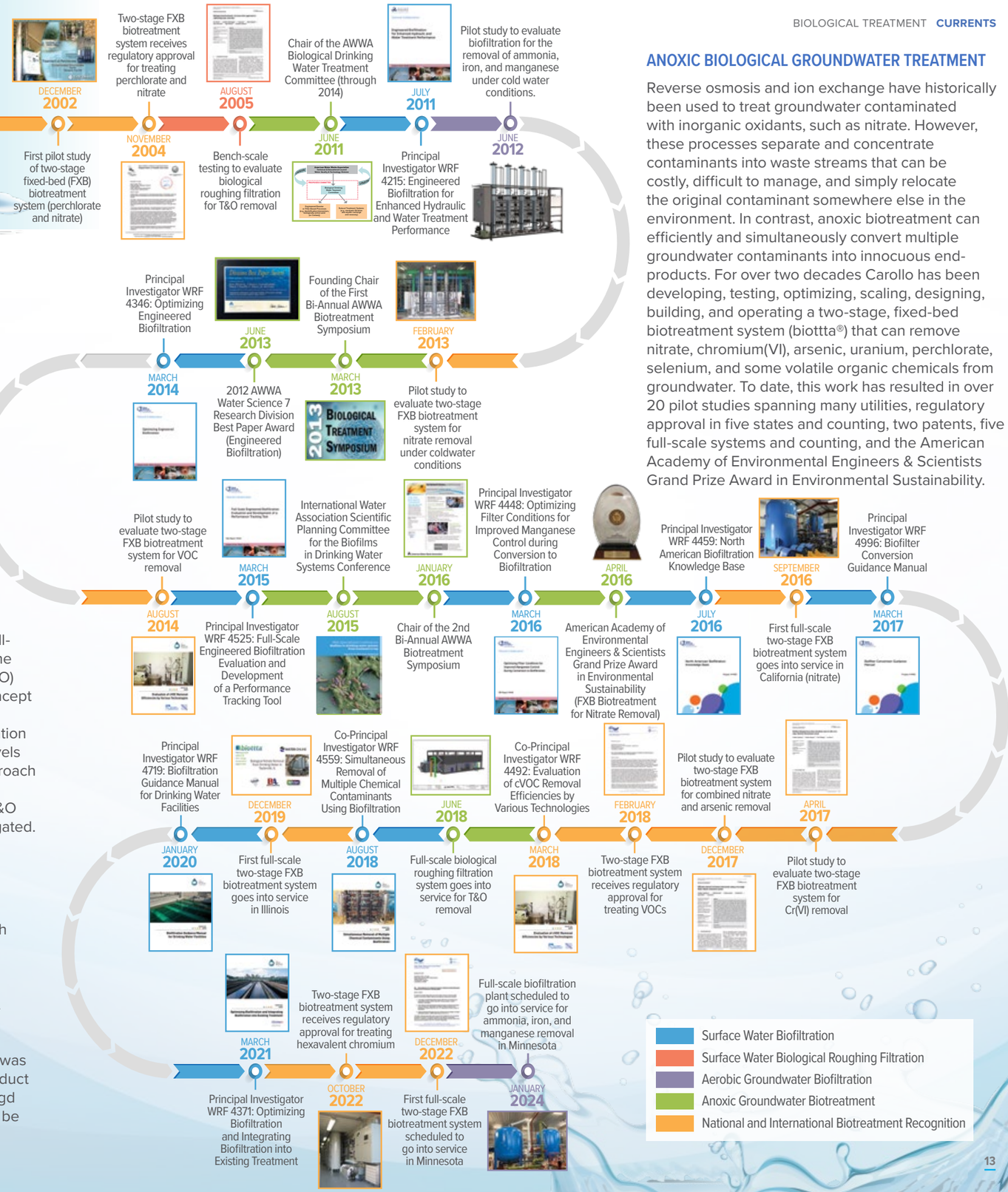
R&D has helped produce definitive water industry resources for biofiltration design and operation, which allow utilities leverage intentional biofiltration, mitigate unintended consequences, and improve overall biofilter performance.

SURFACE WATER BIOLOGICAL ROUGHING FILTRATION

Carollo's biotreatment work also led to the first-ever full-scale biological roughing filter (i.e., biofilter placed at the head of a water treatment plant) for taste and odor (T&O) removal. We conceptualized and bench-tested this concept at Manatee County, FL. Along with the County's pilot testing, this work showed that biological roughing filtration can effectively treat a wide range of raw water T&O levels using short contact times. The main benefit of this approach is that by degrading T&O compounds biologically, the O&M demands and costs associated with traditional T&O treatment (chemical oxidation, adsorption) can be mitigated.

AEROBIC BIOLOGICAL GROUNDWATER TREATMENT

Many groundwater systems across the Midwest deal with inorganic contaminants like iron, manganese, and ammonia, which can be complicated to remove through conventional approaches (e.g., chemically intensive, produce unwanted byproducts). CRG developed, pilot tested, and optimized a biofiltration process to simultaneously remove biodegradable organic carbon, iron, manganese, and ammonia (4 mg/L) from a 10°C groundwater in Minnesota. In addition to complete contaminant removal, testing showed that the effluent was biologically stable and had very low disinfection byproduct formation potential. Design for the approximately 12-mgd groundwater biotreatment system is complete and will be built in 2023.



ANOXIC BIOLOGICAL GROUNDWATER TREATMENT

Reverse osmosis and ion exchange have historically been used to treat groundwater contaminated with inorganic oxidants, such as nitrate. However, these processes separate and concentrate contaminants into waste streams that can be costly, difficult to manage, and simply relocate the original contaminant somewhere else in the environment. In contrast, anoxic biotreatment can efficiently and simultaneously convert multiple groundwater contaminants into innocuous end-products. For over two decades Carollo has been developing, testing, optimizing, scaling, designing, building, and operating a two-stage, fixed-bed biotreatment system (biottta®) that can remove nitrate, chromium(VI), arsenic, uranium, perchlorate, selenium, and some volatile organic chemicals from groundwater. To date, this work has resulted in over 20 pilot studies spanning many utilities, regulatory approval in five states and counting, two patents, five full-scale systems and counting, and the American Academy of Environmental Engineers & Scientists Grand Prize Award in Environmental Sustainability.

BLUE PLAN-IT® UPDATES

New Trends for Decision Support Systems

CHARLIE HE, PE (che@carollo.com)

Invented in 2007, Blue Plan-it® (BPI) Decision Support System has grown from a drag-and-link mass balance model into a mature simulation and optimization platform that combines leading edge data management, data analytics, data integration, and data visualization technologies. In 2020, our BPI team successfully completed a major pivot by migrating from ExtendSim® to our current new platform, BPI 365, using a mainstream Microsoft C#. NET framework and SQL database. This strategic move opened endless opportunities to bring BPI onto a steep growth trajectory, outpacing our competition in leading the digital transformation of the water industry. Here are some highlights of this exciting development, focusing on water and wastewater treatment. Development related to water resources planning for an uncertain future will be presented separately.

WATER AND WASTEWATER DIGITAL TWIN

One fast-growing trend of the water industry is the rising popularity of digital twin technology. Using BPI, Carollo offers a unique "process and/or operation twin" to assist engineers, utility managers, and operators in experimenting with their own facilities. Our BPI Digital Twin offers a virtual replica of the physical water and wastewater treatment plants (WTP and WWTP), capable of tracking flow and mass balance, predicting water quality, estimating solids production and chemical usage, simulating truck traffic for chemical delivery and solids hauling, and assessing power consumption. Moreover, this revolution of treatment plant modeling distills Carollo's 90 years of water and wastewater engineering expertise into a strong set of process analytics. A few examples of our unique WTP analytics include empirical and mechanism-based disinfectant and disinfection byproducts (DBPs) models for chlorine, chloramine, chlorine dioxide and ozone; corrosion and stability assessment using over 15 water quality indices including lead and copper solubility; advanced adsorption and ion exchange modeling for per- and polyfluoroalkyl substances (PFAS) removal evaluation by granular activated carbon (GAC) and ion exchange; membrane performance projection; solids handling and dewatering simulation; and flocculation sedimentation and softening process modeling. Our WWTP Digital Twin integrates GPS-X biological process modeling seamlessly using cutting edge Application Programming Interface (API) technologies.

Other built-in analytics include advanced digestion modeling, biosolids management and biogas utilization modeling, greenhouse gas emission modeling, and more.

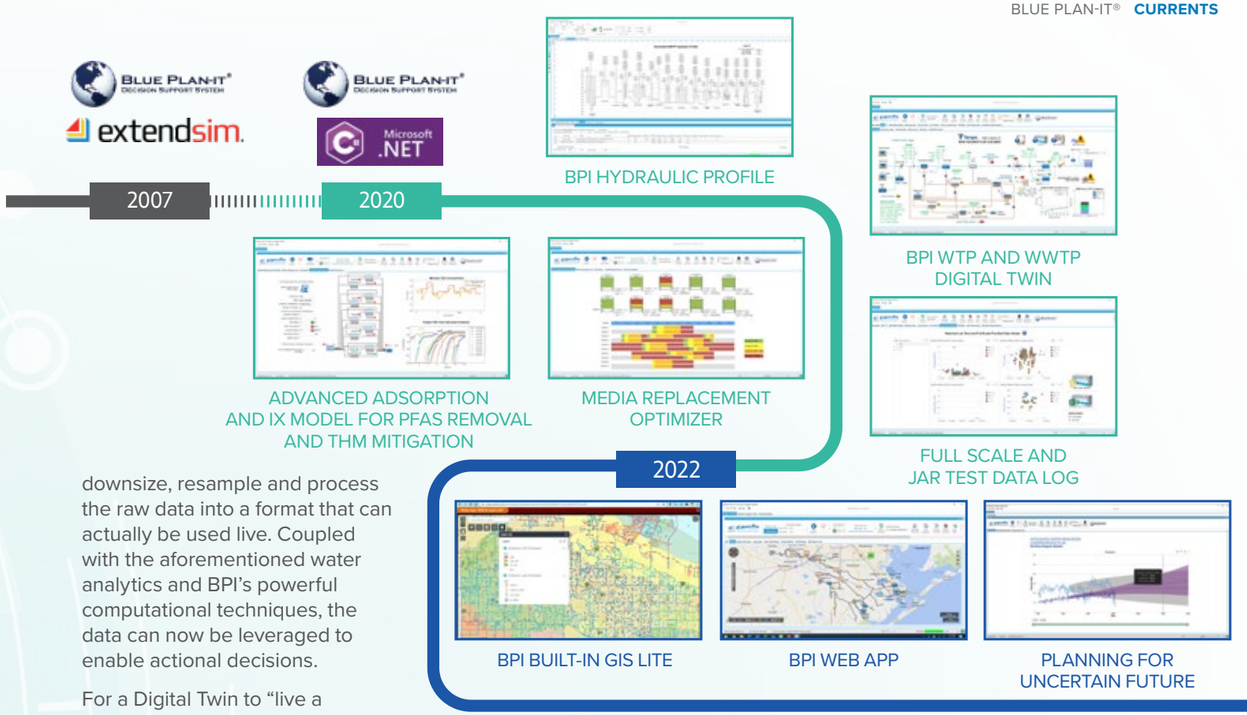
MACHINE LEARNING EMPOWERED WATER ANALYTICS

In recent years, artificial intelligence and machine learning technologies have gained increased attention and applications in the water industry. With machine learning integrated into the BPI platform, our engineers can easily leverage built-in algorithms, such as random forest regressor or K-neighbors regressor, to enable data-driven decision making. As part of the BPI full-plant digital twin, these data-driven models are consolidated with our conventional analytics based on empirical and mechanism-based approaches. This hybrid approach significantly improved the flexibility, capability, and accuracy of process modeling.

In the previous issue of *Currents*, we shared a success story on how our machine learning-empowered Digital Twin accurately predicted settled water turbidity and TOC based on raw water quality and a given chemical dosing scheme used for the flocculation/sedimentation process. Machine learning can also be leveraged on a wide range of water and wastewater applications. Machine learning models, which constantly receive and process real-time data and frequently get retrained in an automated manner, could offer enormous efficiency, accuracy, sustainability, and safety benefits to water utilities.

DATA CONNECTIVITY AND VISUALIZATION

For a Digital Twin to be live, it needs to be fed with real-time static and dynamic data. Often times, the issue is not a lack of data, but a lack of an established approach to turn the data into knowledge and power. Raw data is not always available in a compatible and ready-to-use format. To cope with this challenge, Carollo is working with utilities to establish a data pipeline for pulling in data semi or fully automatically from various sources (SCADA, Lab Information Management Systems [LIMS], data loggers, USGS website, etc.) to feed our Digital Twins and dashboards. A strong data processing module is being integrated into BPI to scrub, downsize, resample and process the raw data into a format that can actually be used live. Coupled with the aforementioned water analytics and BPI's powerful computational techniques, the data can now be leveraged to enable actional decisions.



For a Digital Twin to "live a meaningful life," data visualization is the key to translating the data and modeling results into useful information, decisions, and optimized solutions. The upgrade of Blue Plan-it® to BPI 365 enabled seamless connectivity with powerful tools like ArcGIS, Power BI dashboards, web apps, mobile apps, hydraulic models, Computational Fluid Dynamic Models, Building Information System Model (BIM), etc. Combining these tools, we are excited to deliver a 4-D or 5-D decision support experience to support utilities manage their water and wastewater systems. This makes planning for the future dynamic, transparent, accessible and fun; and design and operation decision-making easy, reliable, defensible and interactive.

BPI BUILDING INFORMATION MODEL WITH INTEGRATED CFD (UNDER DEVELOPMENT)

RESILIENCE ANALYSIS

How exciting it is to maximize the value of our Digital Twin technology for utilities through combining the power of Monte Carlo simulation, machine learning, and cloud computing! In a recent case study, the resilience of a water production system was assessed using a calibrated full-plant operations model. Several main risk contributing factors were modeled, including water quality excursions (high solids, high TOC, low temperature [which impacts CT compliance], and more), preventative maintenance, and unexpected shutdowns. Historical water quality data were statistically analyzed to establish the basis for the Monte Carlo simulation. The unexpected shutdowns for major processes were modeled as uniform distribution using frequencies expressed in hours per year per unit estimated based on the engineer's inputs, survey results, and literature data. The preventative maintenance for each unit process scheduled for low-demand seasons was optimized based on the resilience modeling results. This approach was instrumental in identifying major risk contributors and process bottlenecks, optimizing the facility redundancy levels, and evaluating risk mitigation alternatives.

When conducting such a full-plant Monte Carlo Simulation and multi-objective optimization, simulation speed becomes increasingly important. Our team successfully implemented parallelization and cloud computing techniques in conjunction with improvements on user interface refresh management, memory access acceleration, and miscellaneous computational optimization. This improved the BPI's simulation speed by over 15 times, reducing the run hours of a 20-year daily Monte Carlo simulation from 20 hours to less than 1.5 hours.

At Carollo, we are committed to helping water utilities improve operational effectiveness and enable better decision making. With our data-smart Blue Plan-it® Decision Support System, we are ready to partner with you in this exciting age of digital transformation.

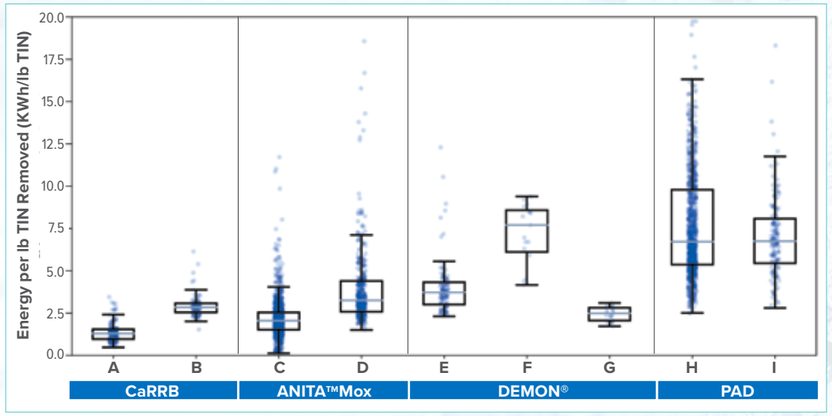
A STRATEGIC VISION FOR Wastewater AND Biosolids Treatment

TANJA RAUCH-WILLIAMS, PhD, PE (trauch-williams@carollo.com)

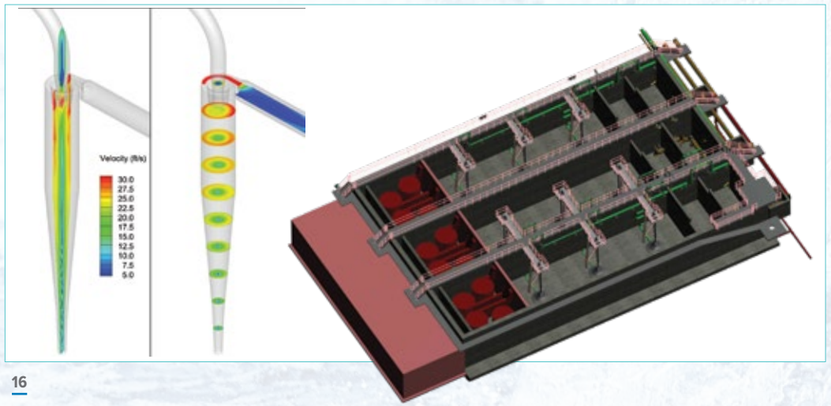
In 2016, Carollo started a new program under the Carollo Research Group (CRG): Carollo's Strategic Wastewater Innovation Leadership Initiatives. Following an extensive reconnaissance supported by utilities and industry experts, we defined seven specific technology fields that warrant the strategic focus and investment of our company in coming years. These initiatives listed in **Figure 1** have a growing and lasting relevance for many utilities. Important scientific, engineering, or operational knowledge gaps remain that CRG and our technical practices are committed to help fill.

Over the past six years, many of our utility clients have partnered with Carollo on wastewater innovation and research projects related to these leadership initiatives. Together, we have completed research projects, pilot, bench, and full-scale tests at your facilities with notable impact. Below are a few recent highlights.

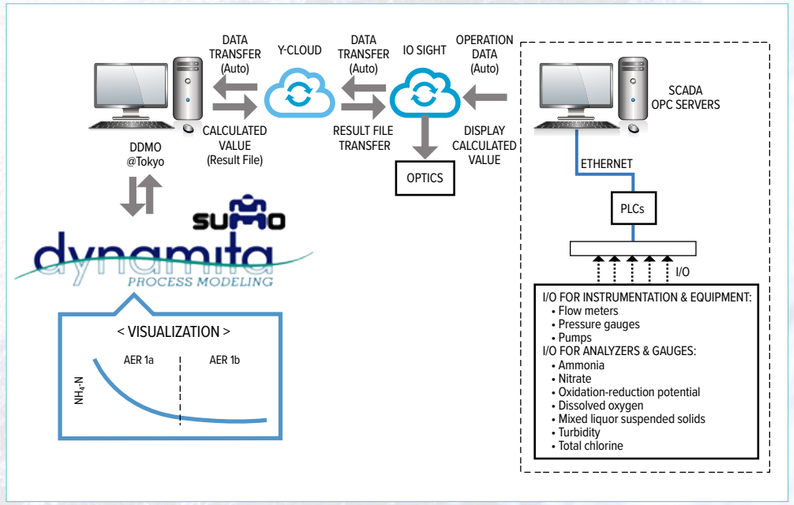
Figure 1 - Carollo's Strategic Wastewater Innovation Initiatives.



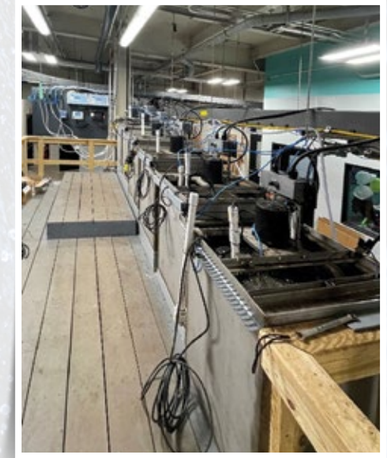
CARBON AND ENERGY MANAGEMENT – The Energy and Carbon Management Initiative is helping shape the industry's practices on driving toward energy-efficient, net zero, and ultra-low-nutrient water treatment facilities. Here are the results of long-term energy demand of common side stream treatment processes that Carollo compiled and benchmarked based on long-term, full-scale facility data in 2022.



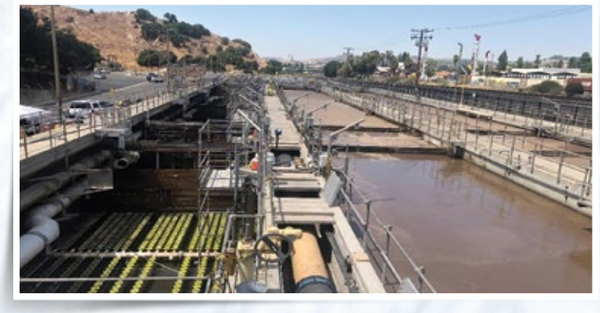
GRANULAR ACTIVATED SLUDGE – Our team is working with vendors and utility partners to creatively combine existing technologies into new technology solutions to advanced flow-through granular activated sludge treatment and better understand existing densified sludge selectors.



ADVANCED PROCESS CONTROL (APC) – Carollo has advanced our clients' capabilities and solutions in the rapidly growing field of data-driven APC aiming for reduced energy, improved process performance, and lower operation and maintenance costs. In partnership with Carollo and Yokogawa Electric Corporation, and funded by the US Bureau of Reclamation and the Japanese Ministry of Economy, Trade, and Industry, Carollo is validating artificial intelligence and machine learning (AI/ML) solutions at the Las Virgenes Municipal Water District – Triunfo Joint Powers Authority, CA.



ANAEROBIC AND SUBOXIC TREATMENT – Carollo's research helps develop guidelines for the design, operation, and control of activated sludge aeration systems to allow nutrient removing facilities to operate safely under conditions of low to no dissolved oxygen (DO), achieve ultra-low nitrogen removal without chemical addition and save as much as 50% of aeration energy. We are currently partnering with the Hampton Roads Sanitation District, VA, and Los Angeles County Sanitation District, CA, along with other collaborators in a Department of Energy funded project consisting of a pilot on a full-scale demonstration of suboxic nitrogen removal technology.



Carollo's wastewater innovation program has brought benefits beyond new technical solutions. We hope our program experience motivates utilities to broaden their engagement in innovation and R&D and help them achieve similar benefits!

- Acquisition of new talent interested in innovation and learning.
- Interdisciplinary collaboration throughout Carollo to creatively solve key challenges.
- A broad network of national and international partners to share resources and knowledge in advancing innovative solutions.

HOW DO YOU CATALYZE A GAME CHANGER for the Water Industry?

JUSTIN SUTHERLAND, PhD, PE (jsutherland@carollo.com)

This edition of *Currents* is a testament to the innovations that Carollo has brought to the water industry over the last 25 years. This article has a slightly different twist. Instead of looking back at the great things we've done, this one highlights how Carollo is prepared to catalyze the next game changer in the water industry...through Carollo's Water Applied Research Center (Water ARC®).

Nearly 15 years ago, a colleague asked me to find a cutting-edge technology to remove chlorides from a drinking water source for a project proposal. That is, something other than reverse osmosis. As you may imagine, my options were limited. However, I did come across a technology that used bicarbonate regeneration with a commercially available ion exchange resin. The concept would work for chloride removal. Unfortunately, the technology was not mature enough. The information I had found was academic research, and there were no known vendors or installations. For an engineering proposal, this is typically a non-starter since there was no industry experience and cost model with which to do your due diligence. Nevertheless, the concept had merit, and I placed it on a growing list of innovative technologies in the back of my mind that I was interested in exploring and testing further in the future. *But how?*

Long-story-short, over the next several years I continued to work on various bench and pilot studies, eventually leading to a series of events that resulted in the development of Water ARC®. This center is the culmination of Carollo's culture to provide innovative solutions. In this case, through applied research with laboratory-based testing, pilot and field testing, and equipment construction services. One of the goals of Water ARC® is to help catalyze the type of innovative ideas that had been growing on my mental list. The difference is that now we have a set of services, synergistically working together to bring ideas to life and solve issues our clients may experience.

Interestingly, earlier this year, a couple of colleagues at Carollo proposed testing a familiar idea, a bicarbonate regeneration system for ion exchange, at Water ARC®. I smiled and offered my story of connection to the technology. I knew I wouldn't be intimately involved in the development of it, but was excited that Water ARC® provided the ideal space to advance the technology. In any case, I would be able to check it off my mental list of potential innovative technologies. With the brain power and hard work of many other people at Carollo, my colleagues were able to prove the concept and develop the initial process application data to carry them to the next step: pilot testing. We are now constructing the prototype pilot system to be tested in the near future. On a separate track, our lab services are engaged in developing a protocol to accurately and efficiently test bicarbonate regeneration at the bench-scale, a service that will be available soon to all of Carollo's clients.

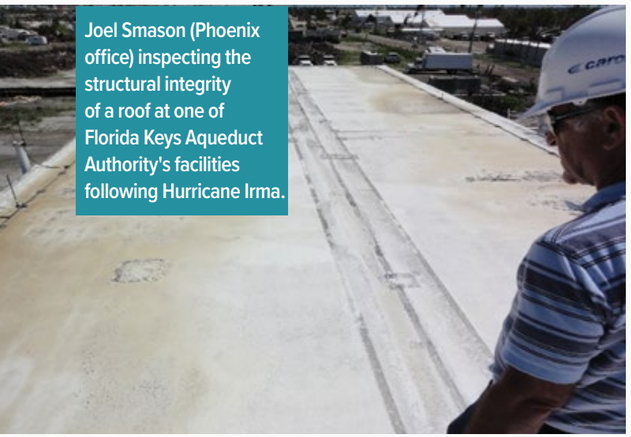
The time from technology concept to pilot application and beyond has been a few months. This short turnaround time to achieve such a goal is a feat that would have been more challenging to realize without Water ARC®. And it sets the stage for the next innovative idea. In other words: It's applied research by design - *how Carollo catalyzes a game changer!*

EMERGENCY RESPONSE SUPPORT: Helping Keep the Water Running When the Lights Have Gone Out

CAROLINE RUSSELL, PhD, PE, BCEE (crussell@carollo.com);
GREG POPE, PhD, PE (gpope@carollo.com)

INTRODUCTION

Water systems are increasingly faced with extreme weather events, source water impairments such as harmful algal blooms (HABs), and potential supply chain disruptions that strain operators' abilities to continue to produce treated water that meets drinking water standards. Coupled with loss of institutional knowledge from a retiring workforce, these events place a heavy burden on water system staff. Helping our clients navigate emergency events is one of the ways we shine as a company, with our staff often working around the clock, side-by-side with operators to keep the water flowing .



Joel Smason (Phoenix office) inspecting the structural integrity of a roof at one of Florida Keys Aqueduct Authority's facilities following Hurricane Irma.

FROM FLOOD EVENTS IN TEXAS...

In 2018, the City of Austin experienced an unprecedented flood event that drastically changed the raw water quality at the City's water treatment plants (WTPs). Turbidity increased 100-fold, alkalinity and hardness dropped to half the historical values, and the total organic carbon (TOC) concentration doubled. These water quality differences lasted for more than a week, creating a major operational challenge for the City's lime softening plants that are designed to treat lower turbidity, high hardness water. Carollo's staff with WTP staff during the flood to identify the optimal approach to treat the water within the operational bounds of the existing facilities (e.g., flocculation mixing speed, residuals handling capacity, target finished water pH). After the event, Carollo helped the City identify and design a low-cost treatment solution to aid in future flood response.

Carollo's response in Austin benefited from experience helping other Texas utilities respond to major rain events, for example using zeta potential measurements to dial in coagulant doses to optimize turbidity removal.

...TO WILDFIRES IN THE WESTERN US

Following the August 2020 Grizzly Creek Fire that burned more than 32,000 acres in Colorado's Glenwood Canyon, concerns about water quality impacts from the burn scar prompted the City of Glenwood Springs to take immediate action. The City hired Carollo to design and implement the Grizzly Creek Water System Improvements project. This effort involved constructing a new pre-sedimentation system to capture and remove bulky debris and sediment from water before it is conveyed to the main WTP, where Carollo also led extensive upgrade efforts. This project was an emergency fast-tracked design in response to the Grizzly Creek wildfire event of 2020.

Watch a short video on the Grizzly Creek Fire Water System Improvements.

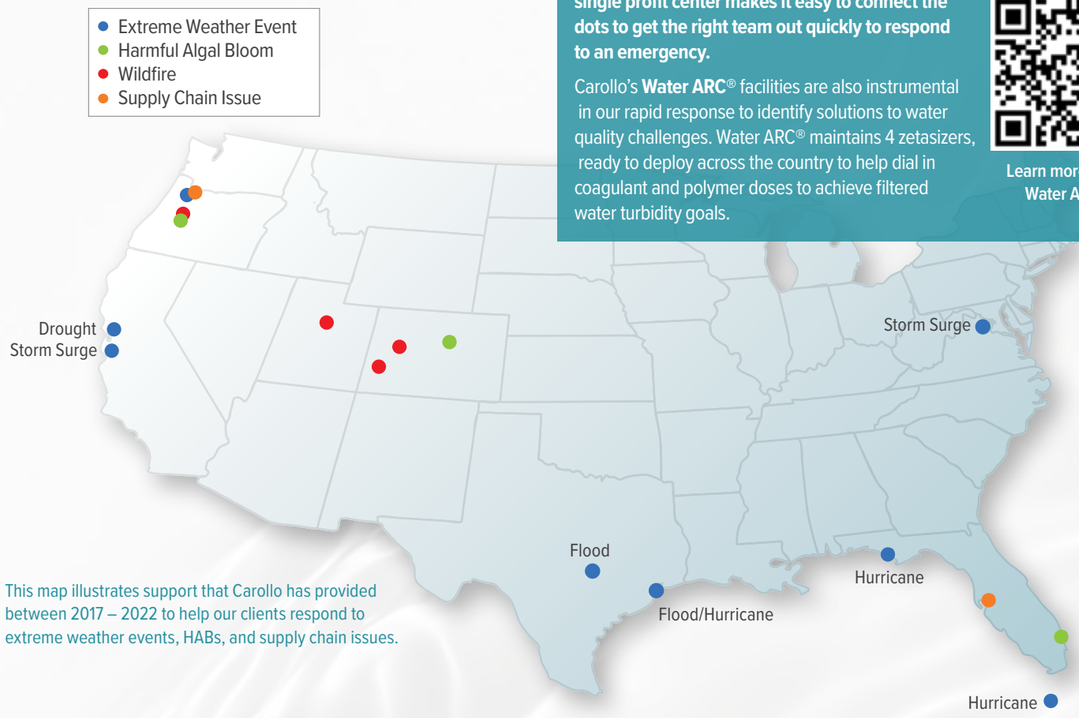
...TO HURRICANE RESPONSE IN FLORIDA

With debris from Hurricane Irma still littering the roads, Carollo staff meticulously inspected each of the Florida Keys Aqueduct Authority (FKAA) facilities from Key West all the way up to Florida City, identifying and documenting damage for FEMA funding. A year later, Carollo applied the same tools for Bay County in response to Hurricane Michael.

SOURCE WATER IMPAIRMENTS: HABS

From Florida to the Pacific Northwest, Carollo staff have helped water utilities respond to cyanotoxin events and lift "do not drink" (DND) advisories. Bob Cushing (Sarasota office) led the expert panel that guided West Palm Beach, FL, through a 2021 HAB. The panel worked with the utility to relocate chlorine addition, providing more contact time for cyanotoxin oxidation to meet finished water targets. Following the initial emergency response, the panel developed a monitoring plan and a report outlining near- and long-term response strategies. In 2018, Carollo staff helped the City of Salem, OR, respond to an HAB event, completing testing within a week of mobilization that set the path forward for the strategy that enabled the City to lift the DND advisory.

Read more about the City of Salem's HAB response from Volume 4 2019.



This map illustrates support that Carollo has provided between 2017 – 2022 to help our clients respond to extreme weather events, HABs, and supply chain issues.

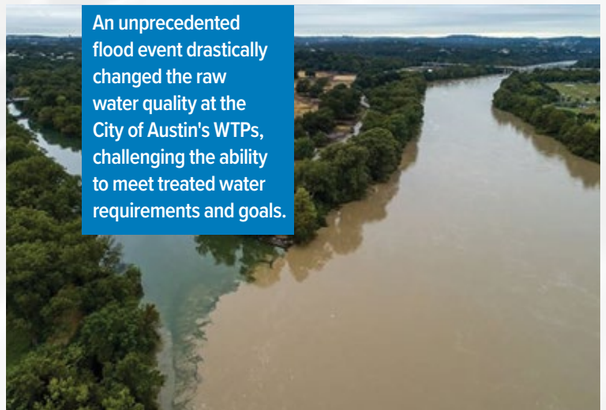
Carollo's culture of collaboration along with a single profit center makes it easy to connect the dots to get the right team out quickly to respond to an emergency.

Carollo's **Water ARC®** facilities are also instrumental in our rapid response to identify solutions to water quality challenges. Water ARC® maintains 4 zetasizers, ready to deploy across the country to help dial in coagulant and polymer doses to achieve filtered water turbidity goals.

Learn more about Water ARC®.

SUPPLY CHAIN CHALLENGES

Carollo has also helped water utilities respond to and plan for supply chain issues. In 2020, the City of Tampa's liquid oxygen (LOX) supply was interrupted by a 'force majeure' event related to the COVID-19 pandemic and the need for oxygen at hospitals. Carollo staff developed recommendations to achieve treatment objectives while lowering oxygen consumption to reduce dependence on LOX. To provide resiliency for future LOX supply challenges, Carollo evaluated and provided recommendations for facilities to concentrate oxygen on-site.



An unprecedented flood event drastically changed the raw water quality at the City of Austin's WTPs, challenging the ability to meet treated water requirements and goals.

During a regional chlorine supply disruption in 2021, Jude Grounds (Portland office) facilitated communication and collaboration between numerous drinking water systems and state agencies throughout Washington and Oregon, which helped the utilities coordinate resources critical to drinking water treatment. His commitment to clients, utilities, and the communities they serve did not go unnoticed; Jude was nominated by his colleagues for the Washington State Department of Health's 2022 Drinking Water Week "Most Innovative" Award.

> "It's really unusual for a member of the consulting community to be nominated for a Drinking Water Week award. It's usually operators and utility managers. The fact that you were recognized for this, speaks to not only the work that you do but the heart that you have to get involved in whatever needs to be done."
>
> – Derek Pell, Engineer with the Washington Department of Health

NAVIGATING CONTAMINANTS of EMERGING CONCERN

KYLE THOMPSON, PhD, PE (kthompson@carollo.com)

HISTORICAL PERSPECTIVE

In the US, over 2,000 new chemicals are introduced each year. Unfortunately, some of these chemicals have been detected in water systems and are determined to be toxic. For example, one study found over 120 pharmaceuticals in wastewater effluent and a meta-analysis counted over 70 per- and polyfluoroalkyl substances (PFAS) in wastewater effluent. (See QR Code). The combination of detection in water and toxicity evidence leads to new guidelines and enforceable standards.

Read more about PFAS trends in municipal WWTPs.

These chemicals are commonly known as contaminants of emerging concern (CECs). As new CECs are discovered, and as they attract more media attention, this increases public awareness and concern about these chemicals, especially in the realm of potable reuse. Water utilities may need guidance on how to manage or remove chemicals with new or upcoming standards, and to know what new CECs are likely to receive scientific, public, and regulatory scrutiny.

The water industry has done significant research on the toxicity, measurement, and removal of chemicals. **Carollo has long been at the forefront of this research,** with projects dating back more than a decade **(Figure 1)**. Recurring themes in this research have included: **(1)** chemical removal in wastewater or reuse, **(2)** PFAS, and **(3)** narrowing the numerous chemicals to key indicators or monitoring priorities. Two recent projects are highlighted in this article.

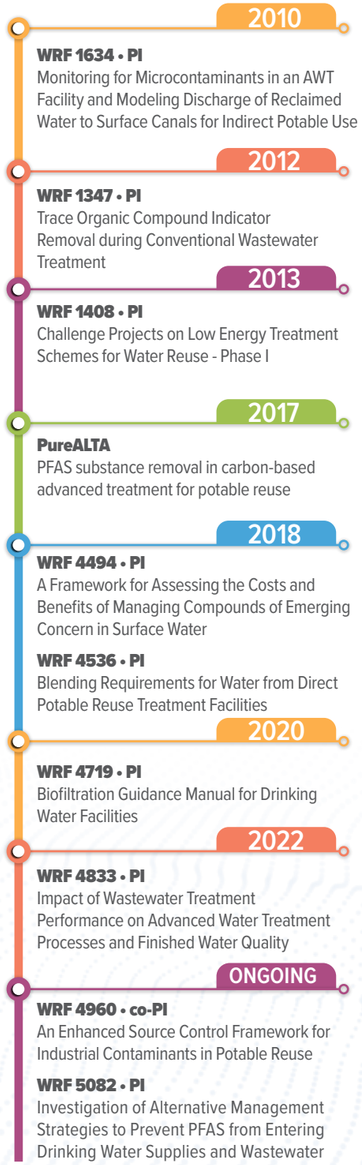


Figure 1 - Timeline of CEC research projects.

PROJECT HIGHLIGHT #1:

WRF 4960: An Enhanced Source Control Framework for Industrial Contaminants in Potable Reuse

Many CECs enter wastewater from industrial discharges and are challenging to remove, toxic, or have the potential to interfere with treatment processes. Enhancing source control programs could be more cost-effective, reliable, and environmentally just than adding further treatment barriers at reuse facilities. Much research had been done on chemical removal by the advanced processes applied for reuse. However, a comprehensive review considering reuse treatment trains as a whole was needed to assess full-scale pass-through potential. As part of Water Research Foundation (WRF) 4960, around 300 industrial chemicals were selected for review. These chemicals were reviewed for their toxicity and their removal in wastewater treatment plants, conventional drinking water treatment, and three reuse treatment trains:

- **Train A:** Reverse osmosis (RO) and ultraviolet (UV) advanced oxidation process (AOP) with peroxide (H_2O_2) addition.
- **Train B:** Ozonation, biofiltration, granular activated carbon (GAC), and UV disinfection.
- **Train C:** Ozonation, biofiltration, RO, and UV/AOP with H_2O_2.

Then Industrial Contaminant Screening Scores were calculated based on toxicity and whole-train removal. Chemicals that ranked highly were recommended for monitoring at planned reuse sites as the first step towards enhanced source control **(Table 1)**.

Rank	Train A	Train B	Train C
1	NDMA	NDMA	NDMA
2	PFOA	PFOA	PFOA
3	PFOS	NMOR	PFOS
4	NMOR	PFOS	NMOR
5	1,4-Dioxane	Cobalt	Cobalt
6	Cobalt	PFBS	PFBS
7	PFBS	PFBA	Uranium
8	Uranium	Mercury	PFBA
9	PFBA	Arsenic	Mercury
10	Mercury	Chromium	Arsenic
11	Arsenic	Uranium	Chromium
12	Chromium	Cadmium	1,4-Dioxane
13	Cyanide	1,4-Dioxane	Cadmium
14	2,4,6-Trichlorophenol	Nickel	TCEP
15	1,2,4-Trichlorobenzene	TCEP	TDCPP
16	Atrazine	Selenium	Nickel
17	Cadmium	Fluoride	Atrazine
18	TCEP	Iodide	Carbon Tetrachloride
19	1,2-Dichloroethane	Copper	Selenium
20	TDCPP	Carbon Tetrachloride	Fluoride

Table 1 - Recommended chemical monitoring lists based on WRF 4960.

Benefitting a Large Reuse Project

This project was co-funded by the California Water Boards and these monitoring lists have already been implemented at Los Angeles Sanitation and Environment's Hyperion Membrane Bioreactor Pilot. This pilot is a step of the Hyperion 2035 Program, which will culminate in the largest reuse system in the world. This monitoring at Hyperion based on WRF 4960 even included the "further research recommended" version of the list, which assumed poor removal of understudied toxic chemicals.

PROJECT HIGHLIGHT #2:

WRF 5082: Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater

PFAS are a family of chemicals notorious for their persistence, bioaccumulation, and toxicity. Two well-known PFAS are perfluorooctanoic acid (PFOA) and perfluorosulfonic acid (PFOS). Based on the third Unregulated Contaminant Monitoring Rule (UCMR3) (2013-2015), 66 water systems had PFOA and PFOS above the Environmental Protection Agency's (EPA) 2016 health advisory level (HAL) of 70 ng/L combined. And even more systems will have detectable PFOA or PFOS in the upcoming UCMR5 (2023-2025), which will use more precise methods. Any detectable PFOA or PFOS would be above the new EPA HALs for these compounds: 0.004 ng/L and 0.02 ng/L, respectively.

The EPA is planning to finalize an enforceable drinking water rule for PFOA and PFOS in 2023.

The effective PFAS removal technologies are expensive, which motivates more research on preventing PFAS from entering the water supply. The goal of WRF 5082 was to develop actionable strategies for utilities for effective PFAS source management. The first step was surveys about utilities' experiences in monitoring, tracking, and mitigating PFAS. The project then filled data gaps about the relative importance of different PFAS sources across wastewater, surface water, and groundwater. Investigations of two watersheds concluded that PFAS were entering primarily via wastewater treatment plants, not direct industrial discharges. A groundwater investigation found that PFAS was emanating from an airport. In four wastewater collection systems, the majority of PFAS came from residential areas, not point sources. Lessons learned while conducting these investigations are informing step-by-step guidance for tracking PFAS **(Figure 2)**.

Figure 2 - Step-by-step guidance for source tracking of PFAS.

Innovation driven by you

The Carollo Research Group's in-house team of innovators is dedicated to tackling water's most challenging issues. We pioneer technologies, best practices, and need-based solutions that seek to change the world by first changing how each of us sees and works with water. By putting you at the center of everything we do, we build on what we know, envision what could be, and minimize the risks and costs that come with charting new territories.

See how far you'll go with Carollo.

carollo.com

carollo