CAROLLO ENGINEERS | VOL 2 2019 **ANNUAL CRG EDITION**

currents

Innovation to IMPACT

PLUS —

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IN THIS ISSUE

Innovation to IMPACT

JESS BROWN, PhD, PE (jbrown@carollo.com)

This *Currents* issue is the first Annual CRG Edition, and it provides a few recent examples of how Carollo is leveraging the Innovation to Impact model to help our clients and the water industry solve new and complex water challenges.

WHEN YOU THINK ABOUT INNOVATION, WHAT COMES TO MIND? A light bulb suddenly glowing above someone's head? Perhaps Dr. Emmett Brown slipping while hanging a clock, hitting his head on the sink, and seeing the flux capacitor? While these discrete "Eureka" moments may happen occasionally, more often, innovation is derived from an extended, deliberate process, and it almost always begins with **creativity.**

Arthur Koestler, a Hungarian-British author and journalist, described creativity not as an act of inventing something new from scratch, but rather as an act of recognizing how existing facts, ideas, faculties, and skills can be shuffled, combined, and assembled differently to make a striking new whole … a deliberate search for new patterns, derived from elements that already exist. The more familiar the elements, the more powerful the resulting pattern, the new whole. Innovation, then, is the multi-step implementation of creativity, and it includes:

1. Assessing which of these new patterns/ideas have merit.
2. Performing research and development to establish operating and design criteria.
3. Applying the ideas in the field. **Innovation to Impact!**

We face many challenges across the water industry, like aging infrastructure, increasingly stringent water quality and discharge limits, the need for sustainability, the introduction and detection of new contaminants, climate change and variable water supplies. As these challenges grow, so must systems and programs that foster Innovation to Impact in our field. As Albert Einstein stated, "The significant problems we face cannot be solved at the same level of thinking we were at when we created them."

The Carollo Research Group (CRG), a diverse team of engineers, scientists, planners, modelers, and researchers located throughout the country, was established 25 years ago through the Innovation to Impact lens. Originally a small centralized group located in Boise, Idaho, CRG now includes over 30 staff (although in reality all Carollo engineers are critical members of CRG), involves seven Regional R&D Leads across the United States, and also features five Innovation Managers covering Water, Wastewater, Reuse, Decision Support, and Laboratory/Field Testing.

CRG MISSION: BRIDGING THE GAP BETWEEN GOOD IDEAS AND PRACTICAL, INNOVATIVE, AND RELIABLE SOLUTIONS.

This ***Currents*** issue is the first annual CRG special edition, and it provides a few recent examples of how Carollo is leveraging the Innovation to Impact model to help our clients and the water industry solve new and complex water challenges. I hope you enjoy this edition! Please don't hesitate to contact me or the other authors if you have questions about a particular article, want to learn more about CRG, or just generally want to discuss Innovation to Impact in the water industry.

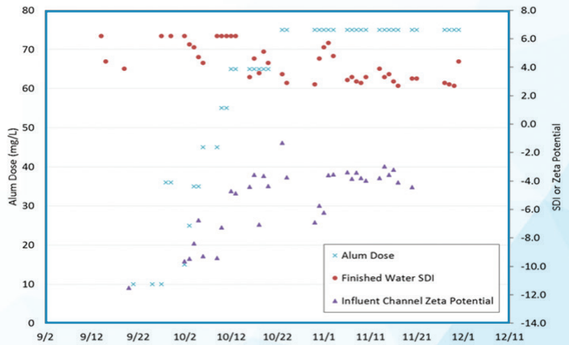
CUTTING-EDGE DRINKING WATER TECHNOLOGIES

CAROLINE RUSSELL, PhD, PE, BCEE (crussell@carollo.com)

From creatively applying tools and knowledge to pushing the industry to think about new ways to design membrane filtration, UV disinfection and advanced oxidation processes (AOP), and biofiltration systems, Carollo's engineers are continuously advancing the field of drinking water. Throughout 2017 and 2018, our engineers have applied a number of innovative ideas to the drinking water sector.

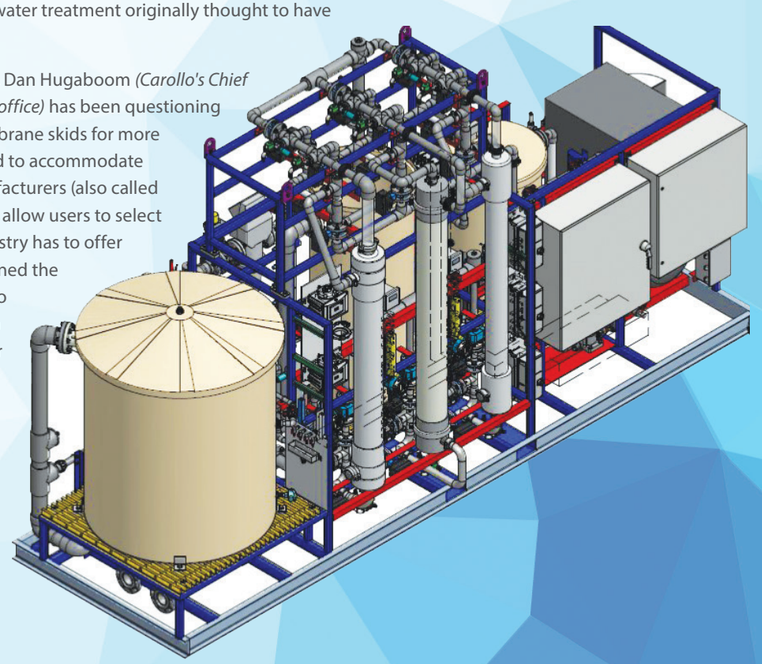
Use of Zeta Potential to Optimize Plant Operations. Vincent Hart *(Carollo's Senior Project Manager, Denver office)* has embraced zeta potential as a key part of identifying optimal coagulation conditions for water treatment facilities, assisting operations staff with coagulant targets, which resulted in better settled and filtered water turbidity as well as chemical optimization. Through Carollo's partnership with multiple utilities that are using zeta potential for coagulation control, we have developed a better understanding of the "right" zeta target, depending on which coagulant is used and whether there is a preoxidant. In addition, Carollo has identified up to a 30-fold difference in the charge of different coagulant aid polymers (PolyDADMAC polymers), giving utilities a science-based method of bidding coagulant aid polymers, resulting in significant cost savings and reductions in solids. Recently, Carollo has worked with zeta at softening facilities with promising results in a field of water treatment originally thought to have limited zeta applications.

> "Discovery consists of seeing what everybody has seen and thinking what nobody has thought."
>
> — Albert von Szent-Gyorgy



Carollo Engineers used zeta potential to identify the alum dose corresponding to a reduction in finished water silt density index (SDI), translating to improved performance of an RO membrane system.

Open Platform Membrane System (OPMS). Dan Hugaboom *(Carollo's Chief Technologist, Low Pressure Membranes, Boise office)* has been questioning the use of single-element, proprietary membrane skids for more than a decade. Membrane systems designed to accommodate membrane modules from competing manufacturers (also called Open Platform Membrane System or OPMS) allow users to select from the best available technology the industry has to offer and get better pricing. In 2013, Carollo designed the first OPMS in the United States as a retrofit to an existing membrane plant in Idaho, and in 2015 applied the concept to a larger plant for a Colorado client. In 2018, Carollo invested in a pilot-scale OPMS skid, facilitating simultaneous pilot testing of different membrane modules on the same skid. Carollo worked with H_2O Innovation, a water and wastewater original equipment manufacturer, to modify its OPMS pilot skid design to facilitate testing of both polymeric and ceramic membranes.



UV Disinfection. Harold Wright *(Carollo's Chief Technologist, UV Disinfection, Boise office)* and the Portland UV Validation team, working for the USEPA, developed new guidelines for drinking water UV disinfection. Titled, "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems," this document presents new approaches and procedures for UV monitoring and validation that will lower costs and improve the design and operation of UV systems for water utilities nationwide.

Biological Filtration. With fundamental and applied research providing critical process and design direction, Carollo continues to expand the boundaries and effectiveness of biological drinking water treatment applications. The following are some examples:

1. Serving as lead author of the Water Research Foundation Biofiltration Guidance Manual.
2. Demonstrating the effectiveness of fixed-bed biotreatment for simultaneously treating multiple groundwater contaminants (e.g., nitrate, perchlorate, VOCs, chromium 6, arsenic, uranium, and selenium).
3. Implementing the first full-scale two-stage, fixed-bed biotreatment plants treating nitrate, perchlorate, and VOCs.
4. Expanding the application and power of Proformance, an automated data management and biotreatment performance monitoring tool.
5. Designing a full-scale biological groundwater plant for removing iron, manganese, and ammonia at low temperatures.

Blue Plan-it®. In the last year or so, Charlie He *(Carollo's Chief Technologist, Phoenix office)* and his team have added to the capabilities of Carollo's Blue Plan-it® model by integrating advanced computing techniques to help analyze risk in potable reuse projects, sizing water treatment processes, and assessing water supply system resilience. Additional details on Blue Plan-it® are provided in the article on pages 10-11 of this issue.

FINDING SOLUTIONS TO ADDRESS EMERGING ISSUES

Some of the work highlighted above reflects multi-year efforts that began by identifying an opportunity to develop a better tool or design and then developing, testing, and validating the proposed solution. From 2017 to 2018, Carollo also applied creative solutions to help clients quickly address emerging issues, such as identifying treatment techniques to reduce concentrations of perfluorinated compounds (PFCs) like PFOS and PFOA in contaminated water supplies and leading the City of Salem, Oregon, out of a water advisory stemming from a harmful algal bloom. For Salem, Carollo tested the use of powdered activated carbon (PAC) as a near-term solution and ozonation as a longer term solution to remove cyanotoxins during harmful algal events. Having the capability to conduct tests at the Water ARC® (Carollo's Water Applied Research Center in Boise, Idaho), facilitated a rapid response to help the City safely treat the water and lift the advisory.

Carollo continued working on drinking water-related Water Research Foundation (WRF) projects summarized in the table to the right. Carollo's engineers are also serving as Project Advisory Committee members for several projects, including those involving the treatment of perfluorinated compounds, manganese removal through biofiltration, and bromide occurrence in drinking water supplies.

WRF ONGOING AND RECENTLY WON PROJECTS	CAROLLO'S INVOLVEMENT	UTILITIES PARTNERING IN ONE OR MORE OF THE PROJECTS AT LEFT
Impact of Prechlorination and GAC Treatment on DBP Formation and Toxicity in Water (Recently Won) #4916	Caroline Russell, Greg Pope (co-PIs)	Sacramento County Environmental Services Department (Vineyard WTP), CA City of Phoenix, AZ Palmdale Water District, CA City of Altamonte Springs, FL Seminole County Environmental Services Dept, FL City of Columbus, OH Central Utah Water Conservancy District, UT Southern Nevada Water Authority, NV Dallas Water Utilities, TX Greater Cincinnati Water Works, OH Greenville Utilities Commission, NC Gwinnett County Dept. of Water Resources, GA Halifax Water, CAN Metropolitan Water District of So Cal, CA Toronto Water, CAN Alameda County Water District, CA Arlington Water Utilities, TX City of Ann Arbor, MI Aurora Water, CO City of Denton, TX Minneapolis Public Works, MN Mohawk Valley Water Authority, NY Newport News Waterworks Department, VA Santa Clara Valley Water District, CA St. Paul Regional Water Services, MN Region of Waterloo, CAN
Biofiltration Optimization and Holistic Integration #4731	Jess Brown (PI), Giridhar Upadhyaya (PM/co-PI), Jen Nyfennegger, Greg Pope (co-PIs)	
A Biofiltration Guidance Manual for Rapid-Rate Filtration Facilities #4719	Jess Brown (PI), Giridhar Upadhyaya, Jen Nyfennegger, Greg Pope, Stetson Bassett (co-PIs)	
Biological Filtration: NDMA Control or Source of Precursors #4669	Caroline Russell (co-PI)	

REUSE INNOVATION PROGRAM AT CAROLLO

EVA STEINLE-DARLING, PhD, PE
(esd@carollo.com)

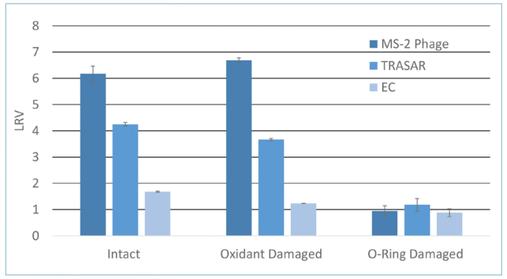
Some might say that water reuse is already a pretty innovative practice – and they'd be right! In fact, many of our clients' current major reuse projects were borne from research conducted by Carollo over the last two decades. For example, we performed the first research project on Direct Potable Reuse (DPR), funded by the WateReuse Research Foundation (now the Water Research Foundation, or WRF), almost a decade ago. Shortly thereafter, we evaluated the water quality and operation of the nation's first operating municipal DPR project as part of research funded by the Texas Water Development Board and other organizations. And we haven't looked back.

Currently, we are working on potable reuse design projects in six states and are supporting efforts to develop regulatory pathways for potable reuse for at least that many states across the country. None of this would have been possible without a strong program in reuse research.

In the spirit of maintaining that capacity and reputation for innovation in reuse, our current Reuse Innovation Program focuses on three major areas: next-generation disinfection, advanced purification, and systems-level thinking. That isn't to say that our work in other reuse areas related to reuse isn't as strong; simply that we've structured our program to focus on those three areas. And at each level, we are incorporating advances in data management to produce repeatable, definable, and technically sound results.

NEXT-GENERATION DISINFECTION

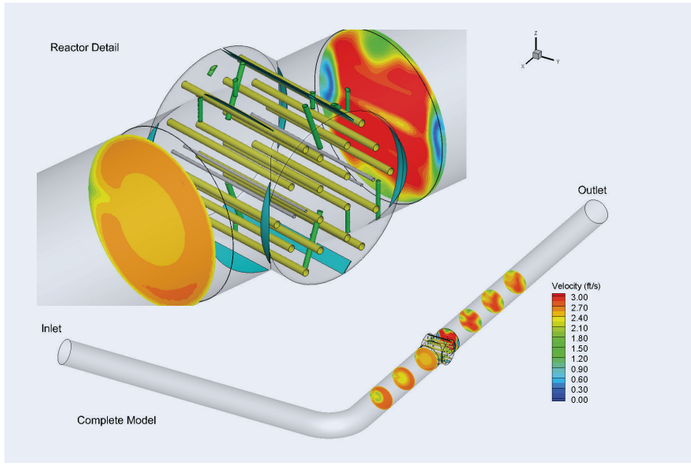
This research area includes evaluating novel disinfectants, such as peracetic acid and a variety of other oxidants for their ability to disinfect pathogens of interest—bacteria as well as virus and protozoa. This area of research also includes efforts to establish the pathogen log removal value (LRV) capacity of various membrane-based technologies. These technologies range from establishing a new "system level" paradigm for LRV assignment on membrane bioreactors (rather than focusing on integrity testing), to testing and demonstrating a variety of approaches, to increasing the LRV credit given to reverse osmosis (RO) membranes, including molecular markers and many others. This area of research also involves pilot- and demonstration-scale efforts to recognize an alternative approach to defining ozone disinfection using the ozone-to-TOC ratio. Unlike the traditional "contact time" approach, using this ratio not only exhibits a linear dose response, but also provides the capacity for substantial virus disinfection at ozone doses at which no residual can be measured. With lower doses, less chemical is used, which also helps minimize disinfection byproduct formation.



Demonstrating continuous 4-log removal of a fluorescent molecular marker (Trasar) through RO membranes in Ventura, CA, takes a big bite out of total disinfection requirements for potable reuse!

ADVANCED PURIFICATION

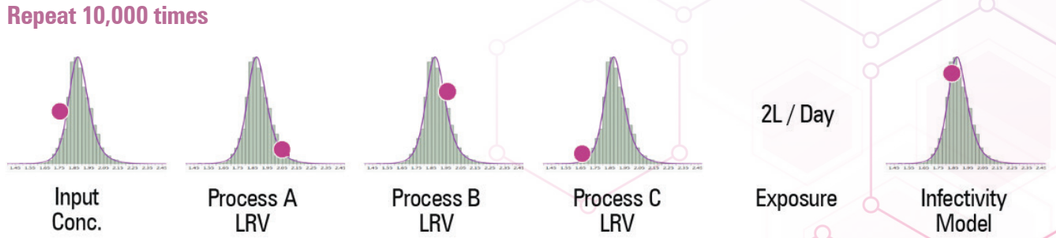
Most treatment processes used in advanced purification for potable reuse are no longer considered novel—membrane filters, RO, ozone, and UV disinfection are all "tried and true." However, these processes still have room for innovation, which Carollo is pursuing through our many pilot and demonstration projects. For example, in partnership with IDE Technologies, we are demonstrating the use of RO for potable reuse without membrane pretreatment. In partnership with Evoqua, we are demonstrating the use of electrodes rather than traditional oxidants to generate hydroxyl radicals for UV AOP, and we are predicting complex UV AOP reactions using mechanistic models that also account for the fluid dynamics within UV reactors. Add to those the many practical innovations needed to adapt designs to potable reuse requirements, and our "tried and true" processes are undergoing quite an innovation revolution!



SYSTEMS-LEVEL THINKING

Produced from wastewater and used for many purposes, including drinking water, reuse sits at the nexus of the human water cycle. Thus, a reuse innovation program must also consider the whole system in which water reuse occurs.

For example, we spend a lot of time thinking about public health risk. Why? In traditional water and wastewater processes, regulations have determined what constitutes acceptable risk and what treatment must be provided to mitigate that risk. However, for reuse, particularly potable reuse, the regulatory frameworks are just catching up with our capacity to develop projects. As a result, defining "sufficient" treatment often becomes the engineer's responsibility. In this context, Carollo has developed the capability to perform quantitative microbial risk assessments (QMRA), which gives us a uniform method for evaluating proposed potable reuse concepts across state lines and various regulatory approaches.



Carollo's QMRAs combine a powerful multi-step Monte Carlo simulation with large datasets from real advanced treatment facilities to confirm the protection of public health from microbial risks.

Other systems-level research and innovations include project WRF 17-30, where we demonstrate the capacity to monitor collection system water quality in real time with our partners at Kando, who use predictive analytics to pinpoint the source of unwanted discharges. Together, we are assessing this monitoring system's potential to protect downstream potable reuse projects.

Finally, with a number of research partners, we are about to kick off a large, multi-faceted effort funded through the Water Research Foundation (#4833) that will examine the interplay between wastewater treatment practices and advanced treatment for potable reuse on the basis of large amounts of operating data, taking the entire treatment train under one unified umbrella.

By understanding the positive impact our prior track record in innovation has had on our clients' reuse projects, it is imperative that we continue to focus on reuse. Through these targeted efforts in our Reuse Innovation Program, we fully expect to remain at the forefront of both potable and non-potable reuse research, technology development, regulation, and ultimately design for many decades to come.

HELPING WASTEWATER TREATMENT TO THE NEXT LEVEL

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

Carollo's top wastewater engineers have started to focus our creative thinking and R&D investment toward four areas of wastewater where research innovation and impacts are necessary and achievable:

1. Advanced Energy and Carbon Management
2. Low Dissolved Oxygen (DO) and Anaerobic Mainstream Treatment
3. Big Data Management and Smart Water Process, Automation and Control
4. Ballasted Activated Sludge

The 2018 Special Edition of ***Currents***, titled "Wastewater Systems Intensification - Big Opportunity in Small Packages" described specific project and research examples related to Carollo's four focus areas of wastewater innovation leadership. In that issue, we discussed activities in the field of ballasted activated sludge research. Below are summaries of the challenges and potential for the other three focus areas.

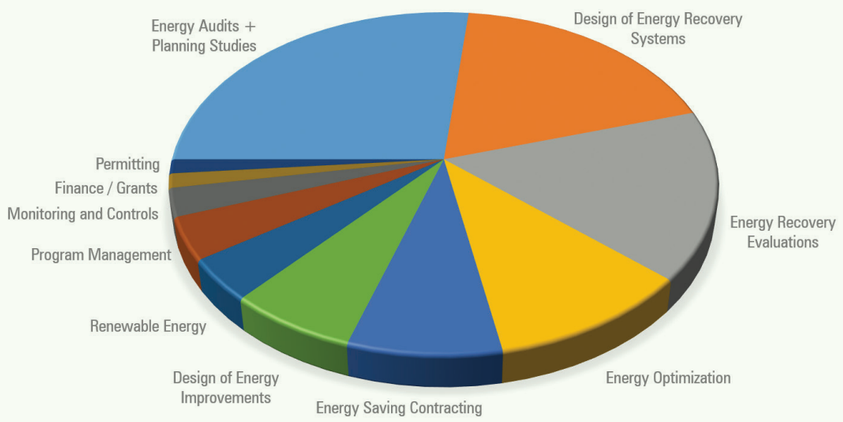
ADVANCED ENERGY AND CARBON MANAGEMENT

What drives utilities across the country to better manage energy demands inside and outside the fence differs widely. This is not simply a function of regional electricity costs. Political drivers, leadership values, and customer expectations can also be strong. However, utilities that have systematically reduced energy demand and increased production over the years have shown core benefits common to all utility organizations:

- Overall higher treatment efficiencies and effluent quality.
- Better educated and a more satisfied workforce.
- Superior management of taxpayer expenses.

Recognizing these benefits, the question for us is this: How can we best support utilities on this pathway in all of Carollo's service areas?

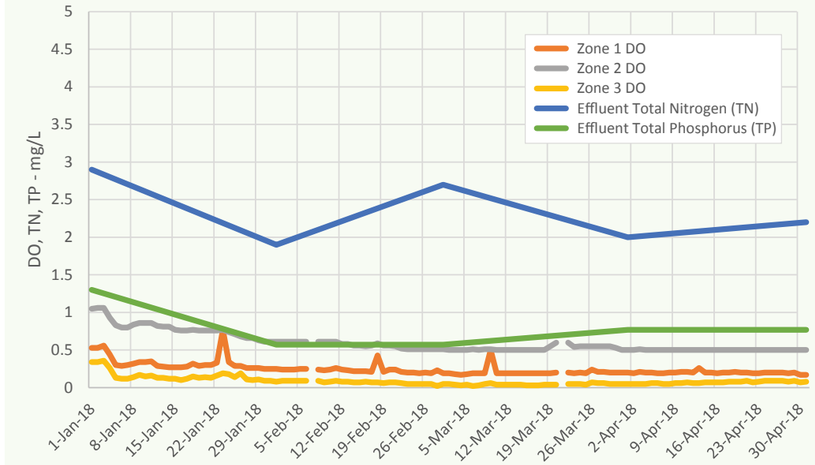
Beginning with master planning, business case evaluations, conceptual and final design developments, metering and instrumentation, and SCADA screen designs, Carollo is helping utilities track kilowatt hours and BTUs with the same rigor we dedicated to biological oxygen demand (BOD) and nitrogen. The number of utilities for which we saved operating costs by utilizing wastewater internal carbon in smarter ways, without big capital investments, is growing each year!



THE SERVICES UTILITIES HAVE REQUESTED FROM CAROLLO OVER THE PAST YEARS REFLECT THE DIVERSE NEEDS AND OPPORTUNITIES TO IMPROVE ENERGY MANAGEMENT IN OUR INDUSTRY.

LOW DO AND ANAEROBIC MAINSTREAM TREATMENT

A lot of today's efforts are directed toward reducing the amount of air supplied for treatment. The most common treatment processes for BOD, total suspended solids, nitrogen, and phosphorus removal require oxygen, but we are far from operating efficiently. How can facilities achieve effluent total inorganic nitrogen levels below 3 mg/L with DOs not exceeding 0.5 mg/L using traditional infrastructure? And how can we design robust mainstream anaerobic treatment processes in areas with harsh winters? Carollo has partnered with facility operators to test how processes and aeration energy can be reduced without compromising treatment. Today, we have many examples where we reduced air and improved treatment.



This domestic oxidation ditch facility achieves very low effluent total nitrogen and phosphorus concentrations in cold weather (50° to 59°F during the data range shown) without chemical addition at unprecedented low DO concentrations. Understanding design, process, and microbial community distribution helps us design other facilities to achieve comparable performance.

BIG DATA MANAGEMENT AND SMART WATER PROCESS, AUTOMATION AND CONTROL

We all acknowledge the enormous treatment improvements through better use of online data, automation, and controls. Using traditional means of operation severely limits our abilities. Here are a few examples:

- We are largely blind to early fault detection or erroneous data generation.
- We have difficulty matching operation optimally to diurnal treatment dynamics.
- We can't accurately predict exact treatment requirements over the next 24 to 48 hours, which would help us plan ahead for energy demand and production to satisfy treatment needs.

New software solutions rely on algorithms and statistical tools that quickly exceed today's understanding of most utility operators and engineers. In a joint effort with utilities and industry partners, Carollo has been actively exploring opportunities for fail-safe implementation, tuning, and testing of new automation tools to overcome current limitations and help build trust and acceptance.

If your utility is interested in learning more about opportunities in any of our four WW innovation focus areas, or if you would like to discuss and participate in collaboration and R&D opportunities to help advance your practices, please talk to our engineers or contact Carollo's Wastewater Innovation Lead Tanja Rauch-Williams.

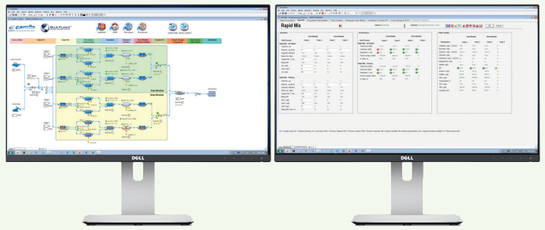
UPDATES ON BLUE PLAN-IT® DECISION SUPPORT SYSTEM

CHARLIE HE, PE (che@carollo.com) and CHAO-AN CHIU, PhD, PE

Our Blue Plan-it® (BPI) Decision Support System team continues to work wonders with this fully customizable integrated simulation and optimization platform of Carollo's own creation. Among the many recent exciting achievements, we'd like to highlight five quick updates.

1 User-Friendly Dashboard Tools Allow Transfer of Complex Models in Easier Ways

Carollo developed a BPI Design and Operations Model for the City of Houston, Texas, Northeast Water Purification Plant (NEWPP) Expansion Project. The tool was first used in a decision-support workshop to allow the City to virtually experiment with their 320-mgd future water treatment facility and understand the impacts of design decisions before implementing them. The City was very pleased with the outcome and requested it to be further developed into an operations tool for both the future and existing plants. The new model consisted of several process flow diagrams and summary charts (e.g., overview, liquid stream, solids stream, solids mass balance sheet) and more than 20 organized dashboards (e.g., water quality, operation, capital and O&M costs, individual processes, etc.). Now operators use BPI's new dashboard function and built-in scenario manager to better manage a wide range of raw water turbidity and TOC conditions (e.g., average, maximum month, peak) and evaluate optimal design and operation strategies (e.g., one train offline, chemical dose adjustment, thickening and dewatering facility run mode and time).



Blue Plan-it® Dashboard Tool for the City of Houston NEWPP Expansion Project

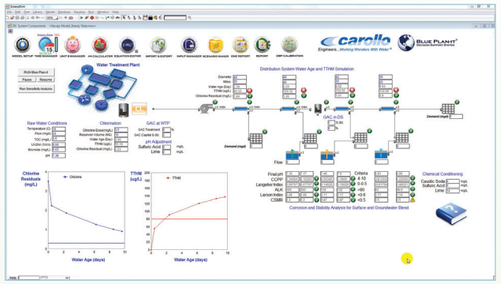
The new dashboard tool is a big leap forward toward BPI's new generation of user-friendly tools. Typical users can learn how to operate it in less than an hour with minimal training.

2 Enhancing Our Water Treatment Process Modeling Expertise

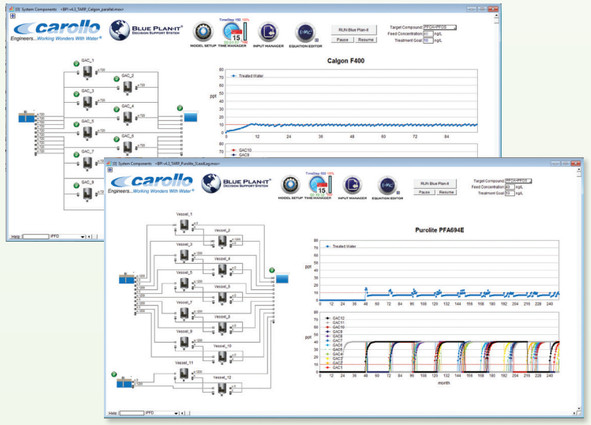
Carollo's BPI team is dedicated to strengthening our water treatment process modeling leadership in all areas of surface and groundwater treatment, water treatment, desalination, and concentrate management, as well as advanced water treatment. Building on the recent success of modeling solids mass balance and organics removal for surface water treatment plants, the model is particularly good at modeling conventional and high rate coagulation/sedimentation process, granular media and membrane filtration, and various disinfection processes. It has been widely used for guiding contact time compliance and disinfection by-products mitigation in distribution systems using blending, aeration, and GAC. It has also helped identify solutions for controlling corrosion and scaling for both treatment plants and distribution systems.

The most recent advancement is the dynamic adsorption and ion exchange operation model, which can be used to optimize the operation strategies and design configurations (replacement or regeneration frequency, lead lag series, staged parallel, etc.) of different media to achieve a list of different water quality goals, especially when calibrated using bench-scale rapid small-scale column test (RSSCT) results.

BPI has been used to simulate and optimize operations of PFAS treatment processes for over 15 different water sources and blends, which resulted in a PFAS breakthrough database with over 40 sets of RSSCT results with PFAS concentrations ranging from 0 to 3,000 ng/L.



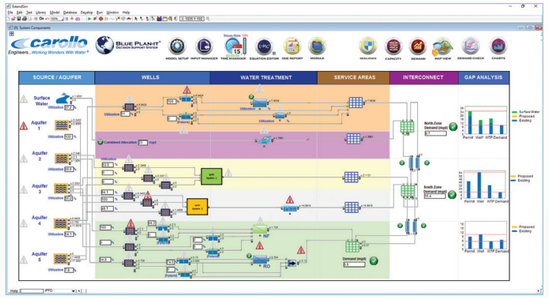
Water Treatment Process Modeling for DBP and Corrosion Stability



Dynamic Adsorption and Ion Exchange Process Operation Tool

3 Water Supply Prioritization and Resilience Tool

Using a state-of-the-art statistical approach, such as Monte Carlo simulation, and Resilience Centered Design principles programmed in BPI, quantitative analysis computer simulations can now assist regulators, utilities, and design engineers make better decisions to enhance water system reliability. Although still a developing feature of BPI, the reliability assessment module has gained a lot of attention recently, adding applications such as qualitative microbial risk assessment (QMRA) for direct potable reuse, as well as the ability to study water infrastructure resilience to better prepare for earthquakes, hurricanes, or other climate change impacts. On a recent Florida project, Carollo used this tool to identify bottlenecks in the water systems, which helped support the utility's infrastructure improvement and treatment facility expansion decisions. In the Pacific Northwest, BPI has helped utilities make critical planning and design decisions to maximize the value of their investments on new treatment and conveyance systems based on quantifiable cost-to-resilience-improvement ratios.



Water Supply Resilience Dashboard

4 Blue Plan-it® Optimization Achieved Capital and O&M Savings for Carollo Clients

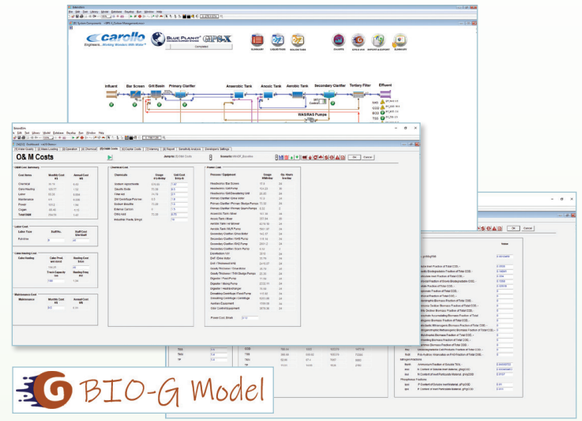
Offered exclusively by Carollo, Blue Plan-it® uses proven algorithms and cutting-edge computational technologies, such as Scenario Manager, Genetic Algorithm Optimizer, Full Factorial Solver, Monte Carlo Simulation, Multi-Objective Optimization, and Artificial Neural Network, to optimize the solutions we deliver to our clients. As shown in the table below, these technologies helped capture significant savings, especially by helping utilities solve challenges to their complex water systems.

	Conventional Approach	Blue Plan-it® Solution	Estimated Savings	Computation Technology Leveraged
Data Center Cooling Tower Make-up Water Treatment*	~$56.5 M	~$10.6 M	~$45.9 M	Genetic Algorithm
City of Odessa RO Facility	~$77 M	~$65 M	~$12 M	Monte Carlo Simulation
Industrial Reuse System*	~$10 M	~<$5 M	$5 M	Full Factorial Solver, Multi-objective Optimization
Southwest Region Well Field PFAS Treatment*	~$11.4 M	~$3.8 M	~$7.6 M	Combined Testing and Modeling Approach

Confidential client.

5 BPI and GPS-X Integration

Finally, our most influential breakthrough in 2018 was the successful connection of BPI and GPS-X, a wastewater modeling and simulation software, resulting in one of the most advanced dynamic wastewater treatment plant simulators available. Built on the creditable biological process modeling expertise of GPS-X, the BPI and GPS-X combination offers a great platform for integrating and consistently applying Carollo's 86-year wastewater treatment and design experience to projects across the country. This past March, Carollo's Wastewater Process Group began using this new integrated wastewater decision support model as one of our standard tools, helping our clients find better, smarter, and more reliable ways to reduce operating costs, energy use, waste, and carbon footprint associated with wastewater treatment.



Bio-G (Blue Plan-it® GPS-X Combo) for Wastewater Process and Operations Modeling

For further information and more updates, check out the Blue Plan-it® Decision Support System website using the QR code at www.carollo.com/blueplan-it. Together, we can connect the dots faster and easier and can help your utility be the best it can be.

Do You Know Your TREATMENT SOLUTION?

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Bench treatability testing may be used to economically and efficiently compare technologies, gain confidence in a selected process, optimize or troubleshoot pilot- and full-scale performance, and confirm a proof-of-concept. In other words, it is a great way to know your treatment solution. This is the service that Carollo's Water Applied Research Center (Water ARC®) provides our public and private sector water, wastewater, and reuse clients.

Water ARC® is a nationwide service that integrates and enhances Carollo's capabilities for laboratory-based treatability testing and field analytical, pilot, and demonstration testing. Our treatability lab provides a controlled environment for testing and brings together our laboratory and technical expertise to help solve our clients' treatment challenges. We manage and support a multi-million dollar inventory of custom-made, pilot- and demonstration-scale equipment.

In the last year, Water ARC® was involved in a broad range of projects, including emergency response to long-range planning, single process to multi-process treatment trains, and routine to chemically/biologically complex. The technologies and contaminants involved in these projects are summarized in the word cloud. For each of these projects, success in the field began in our Water ARC® lab.

DO YOU KNOW WHAT WATER ARC® HAS BEEN UP TO IN THE LAST YEAR?

HERE ARE SOME OF THE HIGHLIGHTS:

- **20** Treatment process technologies tested to support public- and private-sector water, wastewater, and reuse projects
- **1** Emergency response to evaluate treatment alternatives for algal toxin removal
- **3** Evaluations of the impacts of watershed/source changes (for example, wildfires and seawater intrusion) on existing treatment performance
- **3** Innovative technologies/applications validated before pilot- or full-scale implementation
- **4** New bench test process capabilities added – dissolved air flotation, ballasted flocculation, ozone, and MF/UF
- **3** New pilots added – open platform MF/UF, MF/UF membrane pretreatment unit, and ozone unit