CAROLLO ENGINEERS VOLUME 1 2021 / ANNUAL CRG EDITION

currents

INNOVATION TO IMPACT

PLUS —

THIS ISSUE'S Contributors

DR. JESS BROWN is Director of Carollo's Research and Development Practice and leads Carollo's Drinking Water Biotreatment Initiative. He has 23 years of experience, specializing in drinking water process, applied research, and water quality testing methods.

ED WICKLEIN has 23 years of experience in design and analysis of hydraulic facilities using numerical models. He has conducted many CFD studies of municipal facilities, including pump intake modeling, as well as detailed modeling of most of the major water and wastewater treatment components and processes.

CHARLIE HE has 21 years of experience in the water industry. He leads Carollo's integrated decision support system team and the research and development of Blue Plan-it®, an advanced water and wastewater system simulation and optimization tool to manage distribution system water quality.

HAROLD WRIGHT has 32 years of experience with UV technologies for disinfection and advanced oxidation processes. He was the primary author for the USEPA's *UV Disinfection Guidance Manual*. He was Principal Investigator (PI) or Co-PI on nine Water Research Foundation UV Projects, and founded Carollo's UV validation facility located in Portland, OR.

IN THIS ISSUE

carollo
Engineers...Working Wonders With Water®

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

CONTENT EDITOR: Nick Webber

COPY EDITOR: Karen Leonard

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

CFD

GETTING THE MOST OUT OF YOUR PUMP STATION

ED WICKLEIN, PE (ewicklein@carollo.com)

Carollo has developed computational fluid dynamics (CFD) modeling approaches and methods to evaluate and optimize pump intake hydraulics. CFD modeling is used for smaller facilities that cannot be physically modeled and for optimizing designs prior to physical modeling. Using CFD modeling minimizes costs while allowing Carollo to verify complex designs.

The Hydraulic Institute, a consortium of pump manufacturers, engineering designers, and end users, has agreed on generally acceptable flow conditions that the system needs to deliver, and has provided guidance on facility layout and hydraulic conditions. Traditionally, scale physical models have been used to verify or optimize the hydraulics of larger facilities (pump systems starting at 10,000 gpm or higher depending on system geometry). However, these models have limitations, including the time it takes to build them, high production costs, and space constraints.

Many Carollo projects involve dynamic pumps, which move large volumes of water by converting input kinetic energy to liquid flow.

The equipment is certified by the manufacturers to deliver a specified flow and head before it is incorporated into designs. The pump's rated pump flow and head are based on fairly optimal flow conditions. With that in mind, it is imperative to deliver water to the pump with balanced velocity and minimal rotation, turbulence, and vortex activity for reliable operation.

CASE STUDY 1 Self-Cleaning Headworks Pump Station

The recently constructed City of San Leandro, CA, influent pump station is a 27-mgd facility that uses submersible pumps in parallel, self-cleaning trench-style wet wells. CFD modeling evaluated and optimized the system hydraulics by testing a range of flows and pump operating conditions. The model showed a uniform velocity entering the pumps, but high swirl and turbulence (almost 2 times and 1.3 times greater than recommended, respectively) and excessive vortex formation, which can be seen in Figure 1. The model was used to test geometric modifications such as fillets and a center flow splitter. Wet well modifications reduced the maximum swirl by 75%, lowered the turbulence levels, and reduced vortex formation.

Additionally, the model was used to simulate a self-cleaning cycle to evaluate the performance, as shown in Figure 2. The results showed that the upstream portion of the wet well scoured, while the hydraulic jump entrained lighter material, maintaining sufficient submergence on the downstream pump.

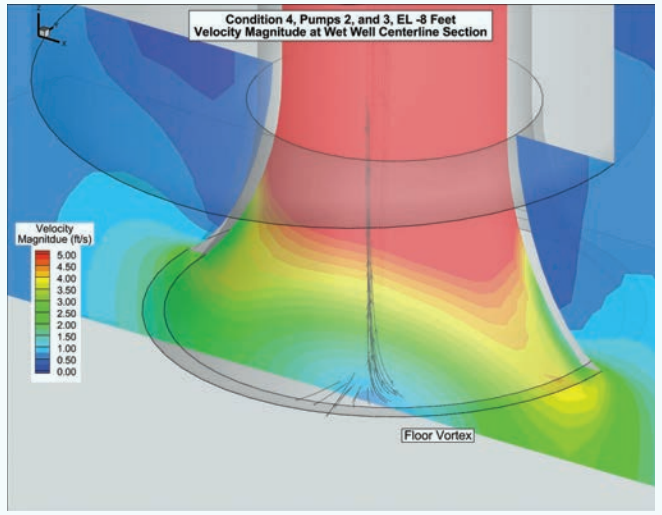


Figure 1. *The model, created for the City of San Leandro, CA, Influent Pump Station System, was used to identify vortices that could reduce pump performance.*

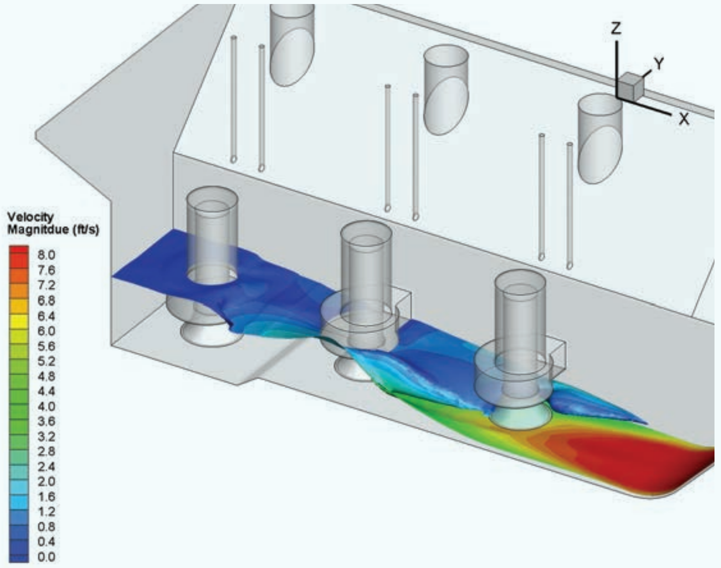


Figure 2. *The model simulated a self-cleaning cycle on the downstream pump.*

CASE STUDY 2 Custom Pump Retrofit Saves Time and Money Replacing 48 pumps

Process improvements at the Sacramento Regional County Sanitation District (SRCSD), CA, treatment plant required changes to the return activated sludge (RAS) pumping, including both higher flow and head. As highlighted in Figure 3, the RAS pumps were in open bottom cans adjacent to the secondary clarifiers. Since the piping was in place for the 24 existing clarifiers, the design goal was to reuse the existing cans, thereby saving significant construction effort.

A CFD model was used early in the design process to identify likely hydraulic conditions in the open bottom can pumping system. Overall, the CFD model showed that the intake hydraulics were acceptable with the proposed larger pumps in the existing cans. The velocity distribution on the system centerline plane is shown in Figure 4. Although flow separation was observed entering the can, the velocity was mostly uniform when it reached the pumps. Figure 5 shows a possible vortex that may develop near the pump inlet. The CFD model also found slightly elevated turbulence levels entering the pumps.

Given the overall size and complexity of the project, a scale physical model was prepared to verify the CFD model results. The physical model verified the hydraulic conditions identified in the CFD model, such as higher but acceptable turbulence and intermittent vortex formation from the can wall, shown in Figure 6. Based on the results of the CFD modeling and physical modeling, the facility was upgraded with new pumps that are currently installed and in operation.

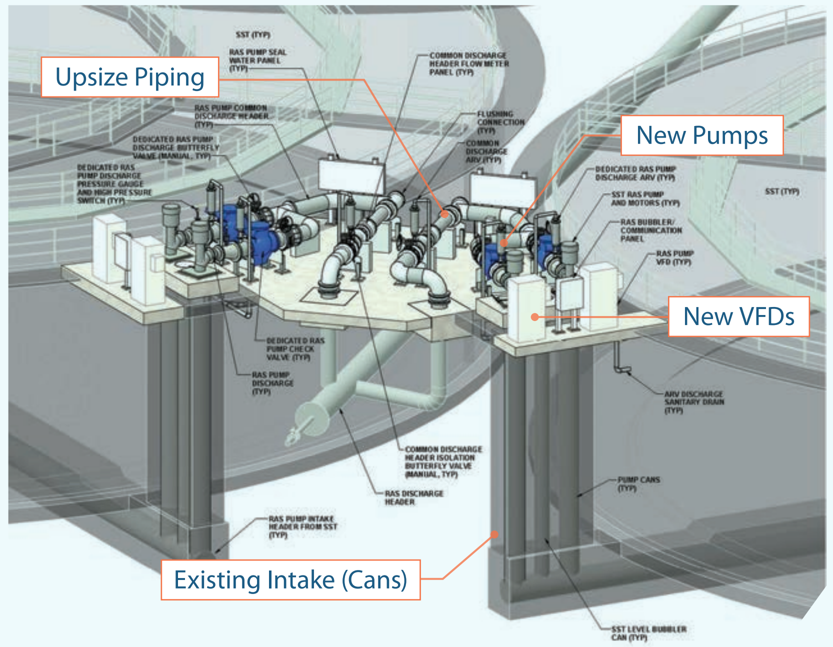


Figure 3. *SRCSD, CA, RAS Pump Station arrangement.*

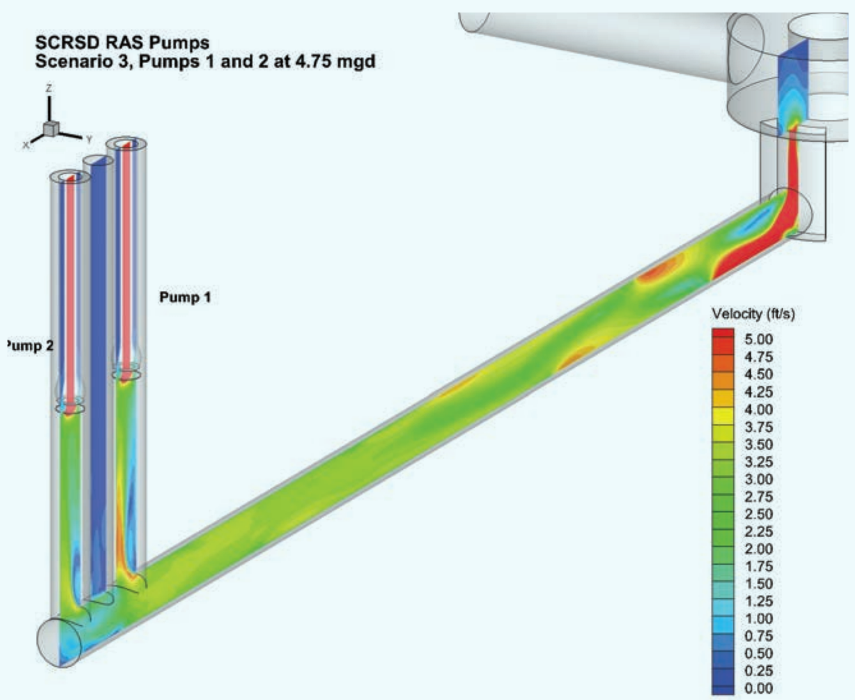


Figure 4. *Velocity distribution through pump suction piping.*

Summary and Conclusions

CFD modeling is frequently used to evaluate and improve the layout and geometry of new and retrofit pump stations. Carollo has successfully used this tool for verification and/or improvement of many pump stations, enhancing our understanding of both the modeling approach as well as the analysis of results.

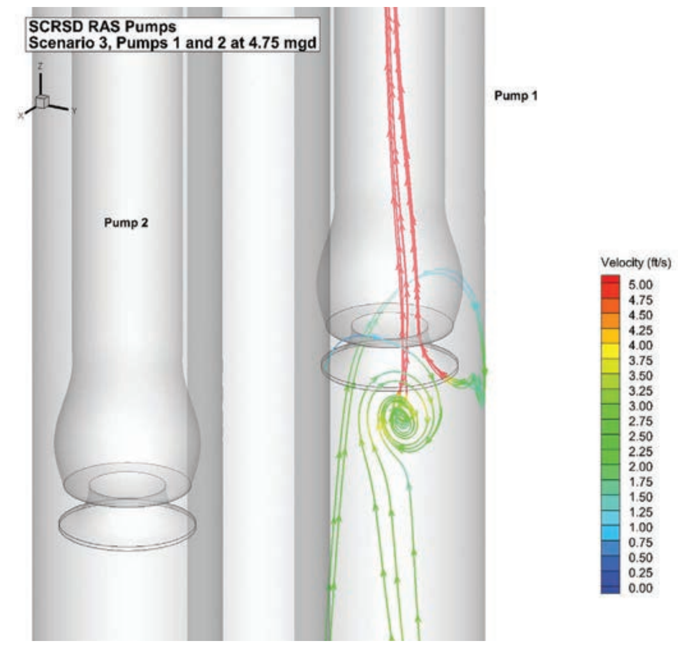


Figure 5. *Vortex entering the upstream pump in the CFD model.*

Figure 6. *Potential vortex entering the pump in the physical model.*

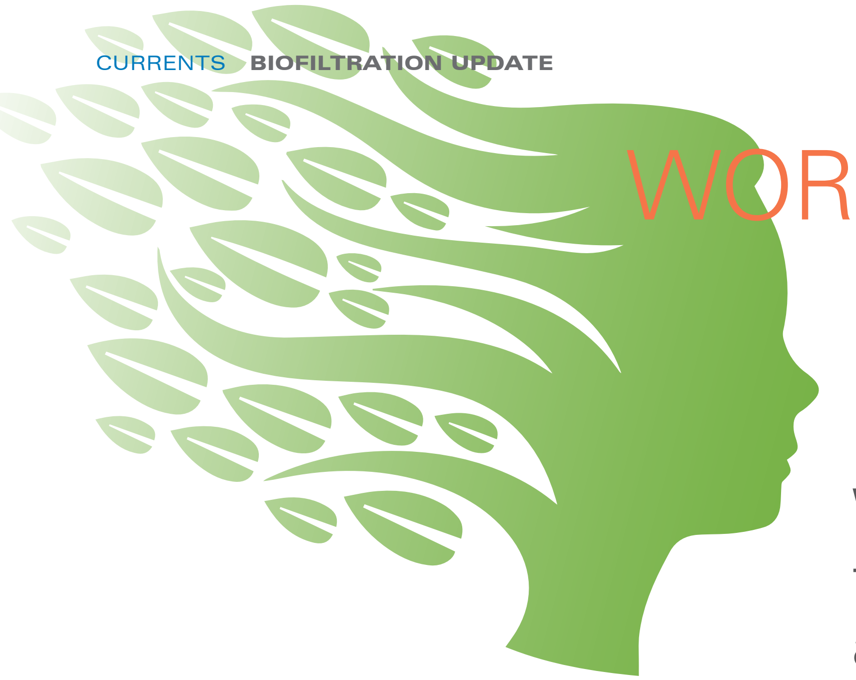
2020 ASCE STATE-OF-THE-ART OF CIVIL ENGINEERING AWARD

JieZhang

Carollo's own **Jie Zhang** and his team were awarded the 2020 American Society of Civil Engineers (ASCE) State-of-the-Art of Civil Engineering Award in May 2020, and presented virtually to Jie in October 2020, for the book titled *Computational Fluid Dynamics: Applications in Water, Wastewater, and Stormwater Treatment* (EWRI, June 2019).

Jie Zhang is an engineer with expertise in numerical modeling. He earned his PhD degree in Civil Engineering at the University of South Florida in 2014. He served as the founding chair of the ASCE EWRI Task Committee on Computational Fluid Dynamics from 2015 to 2017 and the lead guest editor of the *Journal of Environmental Engineering* special collection on CFD in 2018.

Congratulations, Jie!

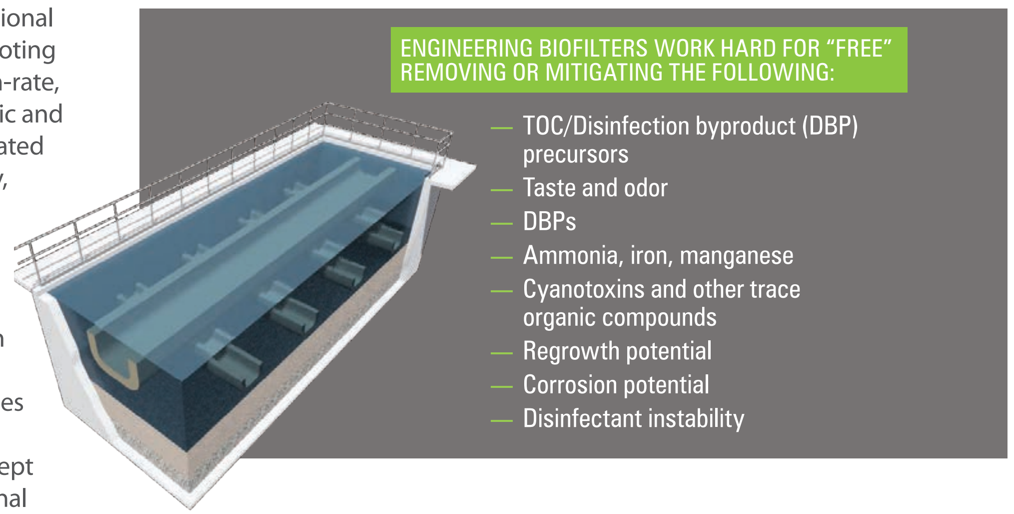


WORKING WITH Mother Nature:

How R&D Helped Produce Essential Water Industry Tools for Biofilter Design and Operation

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

Biological filtration (biofiltration) is the operational practice of managing, maintaining, and promoting biological activity on granular media in a high-rate, gravity filter to enhance the removal of organic and inorganic constituents before introducing treated water into the distribution system. Historically, biofiltration has largely been operated as a passive process in the water treatment industry. As part of our Biological Drinking Water Treatment Initiative over the last 15+ years, Carollo 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 (WRF 4215 Final Report, see details below).



Since 2011, Carollo has served as Principal Investigator (PI) or co-Principal Investigator on 9 Water Research Foundation biofiltration projects that have: **1) helped document the state of 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.**

BASELINING NORTH AMERICAN BIOFILTRATION PRACTICE

- ***PI, North American Biofiltration Knowledge Base (WRF 4459).*** Catalogued and summarized the design, operation, and monitoring of 43 full-scale biofiltration facilities in North America, and documented the observed benefits of biofiltration, established lessons learned on mitigating negative impacts, and identified knowledge gaps and needs for future research. The resulting *Biofiltration Knowledge Base* is the most comprehensive biofiltration facility catalog in the water industry to date.

DEVELOPING AND APPLYING ENGINEERED BIOFILTRATION STRATEGIES

- ***PI, Engineered Biofiltration for Enhanced Hydraulic and Water Treatment Performance (WRF 4215).*** Introduced the concept of engineered biofiltration and demonstrated how both water quality and hydraulic improvements can be realized through various biofiltration enhancement strategies.
- ***PI, Optimizing Engineered Biofiltration (WRF 4346).*** Further optimized engineered biofiltration strategies through pilot testing on two different source waters. Introduced the concept of holistic optimization, showing how overall total organic carbon (TOC) removal goals might be met across a water treatment plant using half the typical coagulant dose.
- ***PI, Optimizing Filter Conditions for Improved Manganese Control during Conversion to Biofiltration (WRF 4448).*** Explored and optimized biofiltration enhancement strategies with a specific focus on accelerating biological acclimation to manganese (Mn) removal while preventing legacy Mn from desorption and release during biofiltration conversion.

- ***PI, Full-Scale Engineered Biofiltration Evaluation and Development of a Performance Tracking Tool (WRF 4525).*** Performed full-scale evaluation of hydrogen peroxide dosing as a tailored biomass control tool and developed *Proformance*, a customizable biofiltration tracking tool that automates large-volume data management and performance output graphics. *Proformance* efficiently allows plant operations staff to assess biofilter health and detect any concerns before they become major operational challenges.
- ***PI, Optimizing Biofiltration and Integrating BAF into Existing Treatment (WRF 4731).*** At full-scale, evaluated various engineered biofiltration strategies, including phosphorus supplementation, prechlorination, and biofilter shutdown maintenance optimization. Performed full-scale holistic optimization to understand how biofiltration can be most efficiently integrated with upstream processes without compromising finished water quality. Resulting reductions in chemical doses and residuals volumes translated to an annual O&M savings greater than $500,000.

PROVIDING INDUSTRY GUIDANCE

- ***PI, Biofilter Conversion Guidance Manual (WRF 4496).*** Surveyed, catalogued, and summarized biofilter conversion knowledge and experience in the water industry, focusing on planning, evaluation, and conversion implementation. Developed a Biofilter Conversion Assessment Tool and Guidance Manual to assist utilities improve their conventional filtration to biofiltration conversion experience.
- ***Co-PI, Simultaneous Removal of Multiple Chemical Contaminants Using Biofiltration (WRF 4559).*** Identified design and operating criteria that maximize the simultaneous removal of multiple chemical contaminants through biofiltration while mitigating unintended consequences. The deliverables included a multi-contaminant removal matrix designed to set appropriate expectations of percent contaminant removal through biofiltration as a function of key design and operational parameters, including media type, temperature, and other biofilter influent water characteristics, pre-oxidation, and empty bed contact time.
- ***PI, Biofiltration Guidance Manual for Drinking Water Facilities (WRF 4719).*** Combined decades of fundamental and applied research with extensive biofilter design and operating experience across the water industry to develop the first and only consolidated set of guidelines for the design, operation, maintenance, and monitoring of biofilters. In addition to providing biofiltration guidance for operators, engineers, regulators, manufacturers, and researchers, the manual also provides access to a host of practical biofiltration-related tools, as summarized in Figure 1.

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

Figure 1. Practical biofiltration-related tools.

4-D DECISION SUPPORT: DISTRIBUTION SYSTEM WATER QUALITY MODELING Part I: Disinfection Byproduct Modeling

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

The Blue Plan-it® decision support system is now offering a unique, 4-D decision support experience for managing your distribution system water quality. Recent advancements in computer simulation, optimization, and visualization techniques, and the unique integration of water quality modeling, hydraulic modeling, and water treatment plant (WTP) operation simulation, converge into one seamless platform.

ADVANCED DBP SIMULATION ALGORITHMS

Many empirical and mechanism-based kinetic models have been developed to simulate disinfection byproducts (DBPs). For example, empirical models expressed as nonlinear power functions were used for the Environmental Protection Agency (EPA) WTP Model versions 1.5 through 2.0 (1992-2001). In this model, trihalomethanes (THMs) formed during chloramination were estimated roughly as a percentage of the THMs formed during chlorination. Sophisticated kinetic models that describe the fast and slow THM formation pathways were used in EPA WTP Model versions 2.1 through 3.0 (2002 - 2016). EPA also released several chlorine and chloramine web apps in recent years.

In short, empirical models are easy to employ, but work only for the conditions to which they were calibrated. Kinetic models are far more complex to use, but once calibrated, they are often more applicable. Most of these available tools are stand-alone, typically designed for chlorine or chloramines. Similar tools for chlorine dioxide or ozone are often less developed. The user interface of these models is fixed, which provides limited or no options for users to adjust the built-in algorithms. They cannot meet the modeling needs when the treatment process or the distribution system conditions change from the default program setup.

The Blue Plan-it® Decision Support System includes ready-to-use empirical and kinetic algorithms to simulate disinfectant decay and DBP formation. Our kinetic DBP models include over 45 chemical reactions associated with ozone, chlorine dioxide, chlorine, and chloramines, simulating not only the impacts of bromide, pH, temperature, etc., but also considering the impact of the co-presence of multiple disinfectants, the sequence of chemical dosing, and the length of free chlorine contact time. These models are validated using bench and pilot testing data from several projects and compared with results generated using EPA WTP models and web apps.

With improved overall performance in both accuracy and speed, the way our newest Blue Plan-it® 365 simulator applies these advanced DBP algorithms goes way beyond a single steady-state simulation. Users can leverage more advanced functions, including sensitivity analysis (see Figure 1), scenario manager, extended time simulation, Monte Carlo simulation, and multi-objective optimization. This allows engineers and utilities to simulate water quality in a large distribution system under a wide range of conditions, solve complex problems quicker and more accurately, and find solutions that optimize the WTP and distribution system operation.

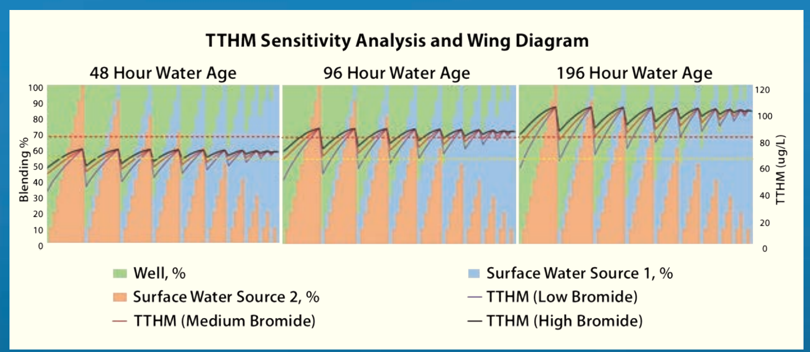


Figure 1. *An innovative visual, referred to as Wing Diagram, presents the results of a sensitivity analysis where three sources are being blended from 0 to 100% for each source, with a 10% interval, at three water ages and three different bromide levels for the well water. This results in a total of 1,782 scenarios in one diagram.*

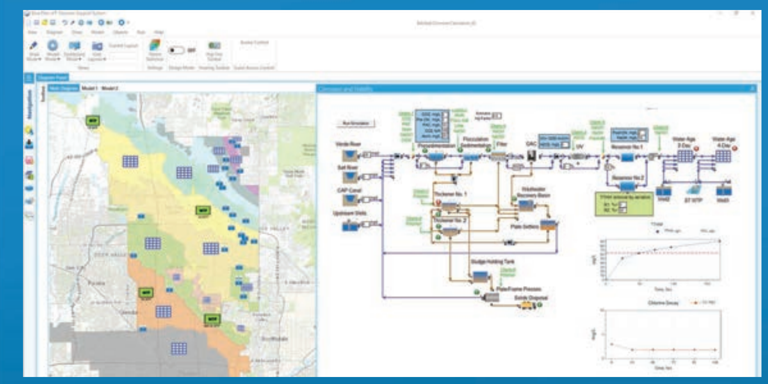


Figure 2: *Combining water quality modeling with the WTP Operations Simulator Model (www.carollo.com/blueplan-it) and Distribution System Hydraulic Model, Blue Plan-it® offers an integrated system-wide approach for managing distribution system water quality.*

AN INTEGRATED MODELING APPROACH

Although some hydraulic models have built-in water quality modeling capabilities, such as Multi-Species Extension (MSX), these plug-ins often have limited functionalities. The typical MSX set-up includes simple equations for chlorine and chloramines, but does not consider the impacts of pH, bromide, UV254, or different formation pathways. Even when THM, chlorine residuals, and other water quality data are collected from the distribution system, it is very difficult to calibrate such a model. On one hand, this would require a large amount of relevant data besides the water quality, including: chlorine and ammonia dose at chemical injection points, production rates of each plant and wells, demands at each junction, and SCADA data on tank levels, etc. On the other hand, even when such data become available through data acquisition technologies, the MSX hydraulic model could take many hours to run a single scenario. Since a calibration would typically take several rounds of adjustment, this process could be very time consuming.

Integrating empirical or kinetic DBP models with hydraulic models offers a much faster alternative to MSX. Blue Plan-it® offers a built-in, easy-to-use calibration tool, so the user could adjust any kinetic parameters to quickly match multiple sets of modeled versus measured data at the same time. When tested for the City of Phoenix Water Quality and Hydraulic Study, our integrated model simulated total THM (TTHM) within -10% to +14% accuracy compared to historical data collected from the distribution system.

Integrated with the hydraulic model and our WTP Operation Simulator models, operators and managers can now explore their DBP mitigation strategies virtually. This approach is not just to predict the performance of a single disinfection process, but also considers how changes at a treatment facility could impact the DBPs leaving the plants and in the distribution system. Operators can assess ways to meet CT (concentration x time) credits using chlorine dioxide or free chlorine when the ozone system is down. Managers can explore how changing coagulant dose or adding aeration and granular activated carbon can impact the finished water quality and the DBP levels in the distribution system.

A 4-D DECISION SUPPORT EXPERIENCE

With the built-in GIS-lite and time lapse features in Blue Plan-it® 365, the modeled water quality results (e.g., TTHM, chlorine, water age, and corrosion indices) can be presented geographically over time. What a cool 4-D visualization technique for managing your distribution system water quality! The combination of cutting-edge simulation and optimization with state-of-the-art visualization technologies, all managed through one customizable and user-friendly platform, makes Blue Plan-it® 365 not just a new tool, but a new way of engineering distribution system water quality.

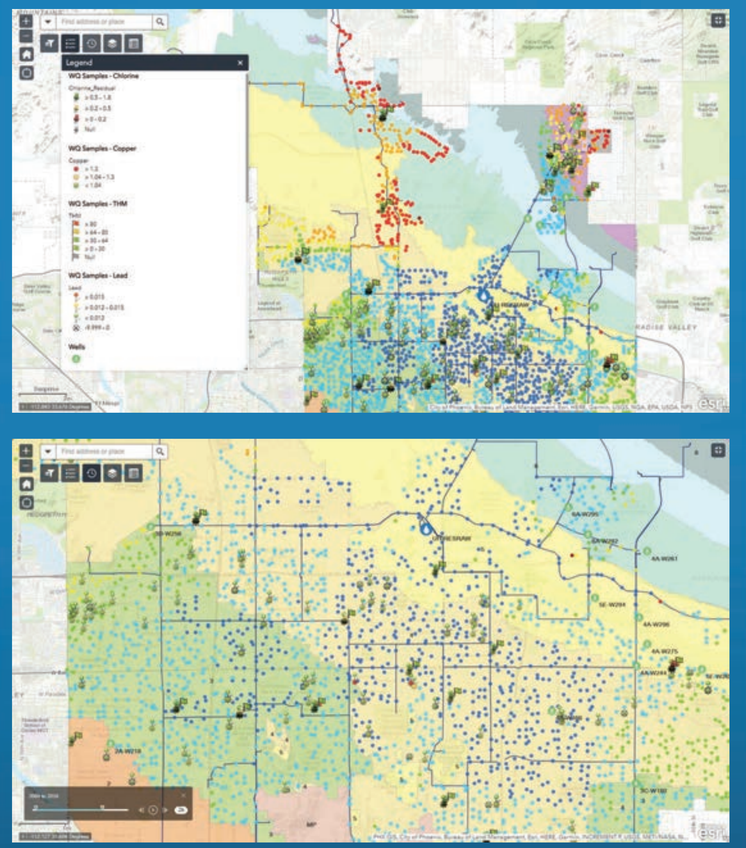


Figure 3: *With the pan and zoom functions on the map and the time lapse tool bar, users can easily access the measured and modeled distribution system water quality for a wide range of hydraulic conditions to see temporal water quality variations for the entire system or any point of interest.*

UV 20 YEARS OF CHANGING THE PARADIGM

HAROLD WRIGHT (hwright@carollo.com) // TRACI BROOKS, PE // MARK HEATH, PE // ED WICKLEIN, PE

Twenty years ago, the Environment Protection Agency (EPA) was developing new regulations to address public health concerns associated with *Cryptosporidium* in water supplies. At that time, various researchers reported that *Cryptosporidium* oocysts and *Giardia* cysts were easily inactivated by ultraviolet (UV) light at low UV doses. In response, EPA developed the Long Term 2 Enhanced Surface Water Treatment Rule and the *UV Disinfection Guidance Manual* (UVDGM), published in 2006, that provided UV dose requirements for pathogen inactivation and recommendations for UV system validation, design, and operation. At that time, UV was recognized as the best available technology for addressing *Cryptosporidium*.

The development of the UVDGM drew from experience applying UV for drinking water applications in Europe and applying UV for non-potable reuse applications in the United States. However, there were knowledge gaps, particularly in the area of UV dose monitoring and validation.

With UV reactors, performance monitoring is based on online measurements of flow through the UV reactor, UV output of the lamps measured by UV intensity sensors, and, in many cases, the ultraviolet transmittance (UVT) at 254-nm wavelength of the water passing through the reactor. Because of the complexity of the dependence of UV dose delivery on flow, UV sensor readings, and UVT, regulations and guidance for UV disinfection specified that utilities use UV reactors with UV dose monitoring algorithms developed and proven through UV validation testing.

Figure 1. *Validation of a Calgon Carbon 48-inch Sentinel Reactor at Carollo's Portland, OR, UV Validation Facility. We developed the facility in 2003 to provide UV validation testing in North America at flows up to 70 mgd per reactor.*

Advancing Implementation Through Research

With UV validation, a manufacturer installs a UV reactor representative of a product line into a test train. The reactor is operated over a range of flow rates, water UVTs, and lamp power settings. At each test condition, a challenge microorganism is injected into the flow upstream of the reactor, and the log inactivation of that challenge microorganism by the reactor is measured. In parallel, the UV dose-response of the challenge microorganism is measured using a collimated beam apparatus. The UV dose response is then used to relate the log inactivation of the challenge microorganism to a UV dose value, referred to as the reduction equivalent dose (RED). The resulting dataset is then analyzed to define a UV reactor's monitoring algorithm, which is programmed into the UV reactor's PLC.

To address knowledge gaps and improve implementation of UV, the Water Research Foundation (WRF) funded multiple projects after the UVDGM was published, many led by the Carollo Research Group. The project "Optimization of UV Disinfection" (2007) identified new test microbes and analytical methods for validating UV reactors for *Cryptosporidium* and *Giardia* inactivation credit. The project "Design and Performance Guidelines for UV Sensor Systems" (2009), a collaboration with the National Institute of Standards and Technologies (NIST), addressed knowledge gaps with UV dose monitoring resulting in new UV sensor standards and better UV dose monitoring algorithms. The project "Computational Fluid Dynamics Based Models for Assessing UV Reactor Design and Installation," a collaboration with Sandia National Laboratories, developed approaches for using computational fluid dynamics (CFD) to understand and optimize UV system design hydraulics. These and other projects defined the state of the art for implementation of UV.

Real-World Impacts of UV Development

Recognizing these advances in UV disinfection, the EPA worked with Carollo to develop and publish the document entitled, *Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems* (EPA/600/R-20/094 April 2020). (https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=349759&Lab=CESER)

This publication is the result of a 4-year project, funded by the EPA, to document new approaches for UV dose monitoring and validation. Detailed information is presented for defining, validating, and implementing four new UV dose monitoring algorithms that provide utilities a more cost-effective, robust, and simplified implementation of UV disinfection. The document includes quality assurance and quality control criteria for UV validation, checklists, and validation report outlines to help regulators approve UV systems with confidence. Prior to publication, the document completed a 2-year stakeholder review led by the International UV Association, including regulators, academia, consultants, and UV system manufacturers.

The new document is already seeing application. Based on the document, the City of Shelby, MT, recently obtained approval to implement UV disinfection for full primary disinfection, including 4-log adenovirus inactivation. Utilities implementing potable reuse are also using the document to define UV dose requirements and monitoring for 6-log pathogen inactivation and UV dose monitoring for NDMA photolysis and advanced oxidation. While there is still more work to be done advancing the role of UV technologies for water treatment, the new EPA document provides a new paradigm for best UV practice.

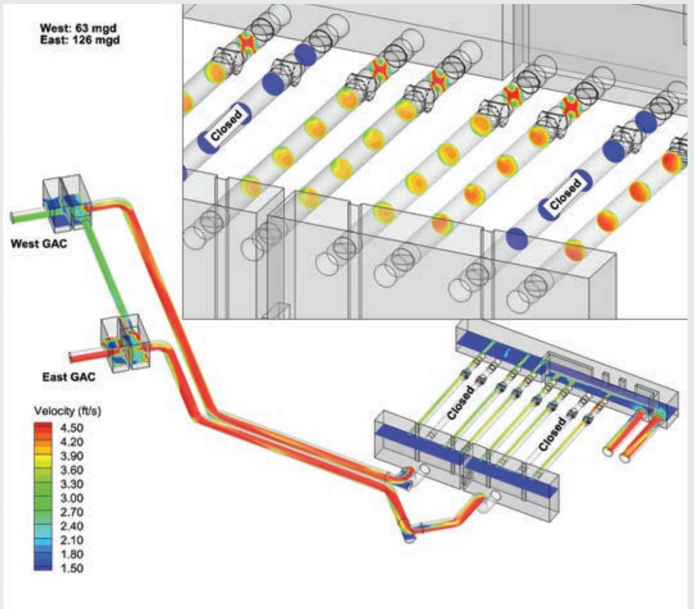


Figure 2. *Carollo used CFD modeling to optimize UV system hydraulics and UV dose delivery for Greater Cincinnati Water Works' 240-mgd Richard Miller Treatment Plant.*

Figure 3. *EPA's Innovative Approaches document presents the latest in UV implementation and serves as a supplement to the UVDGM.*