currents

MACHINE LEARNING

Soft Sensors Enable More Adaptive Treatment

EDITORIAL

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This quarter, our cover story explores a promising development in water quality monitoring: machine learning. We examine how soft sensors—intelligent algorithms rather than physical devices—are transforming water quality prediction and management, with two fascinating case studies from Carollo's work in potable water reuse systems. We also bring you insights on how utilities can leverage AWIA recertification to boost their long-term resilience strategies, and we spotlight Tucson's forward-thinking One Water Plan, which maps out water reliability through 2100.

Our article on San Diego showcases a variety of community engagement strategies to inspire future water engineers, while Carollo's Corrosion Group tackles the persistent challenge of asset preservation. And don't miss our Water Applied Research Center news on I-FLOAT, an innovative portable off-gas testing technology that's making it easier to assess energy efficiency and reduce emissions in aeration systems.

From cutting-edge AI to long-term planning, this issue captures our industry's dynamic spirit. We hope it sparks fresh ideas in your work.

IN THIS ISSUE

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AWIA RECERTIFICATION
A Springboard for Water System Emergency Preparedness

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Water utilities across the United States are facing an important deadline. Under America's Water Infrastructure Act (AWIA), drinking water providers serving over 3,300 customers must recertify their Risk and Resilience Assessments (RRAs) and Emergency Response Plans (ERPs) every five years.

With the inaugural assessments completed in 2020 and 2021, the time is ripe for utilities to not only meet compliance requirements but also build a robust culture of preparedness.

BEYOND COMPLIANCE:
BUILDING A RESILIENCE STRATEGY

While meeting AWIA's baseline requirements is an important first step, many utilities are seizing this opportunity to implement strategic, action-oriented initiatives that transcend mere compliance. Here's how your utility can move from resilience in theory to resilience in practice.

Enhance Standard Risk Assessments

The American Water Works Association (AWWA) J100 process is a seven-step framework that guides utilities in characterizing critical assets, assessing and prioritizing risks, and developing strategies to reduce risk and increase resilience. All seven steps of this approach not only help utilities fulfill AWIA requirements, but also translate risk information into actionable projects that enhance resilience.

Develop Implementation Plans for Resilience Projects

While not required under AWIA, implementation plans in RRAs can help prioritize projects like improving fencing around critical assets or building redundant pipelines. By identifying risk mitigation solutions, estimating the costs of implementation, and performing cost-benefit analyses, these plans can provide measurable and fiscally-responsible resilience improvement recommendations, supported by data on long-term cost savings and risk reduction.
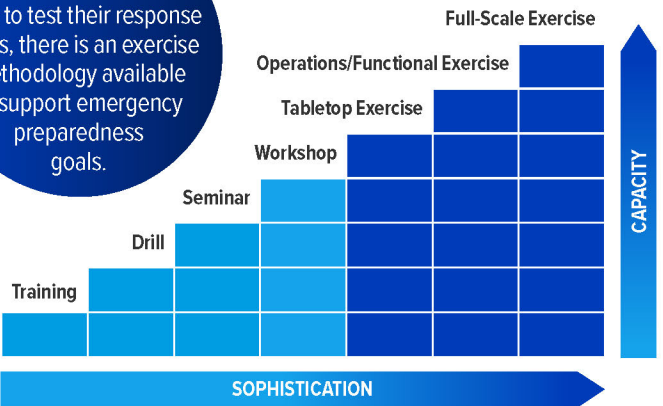
Coordinate Emergency Response Plans

Utilities should share their ERPs with local emergency responders to support response coordination in advance of an emergency. This helps to build relationships within the community, and can promote more effective and collaborative responses to disasters.

Conduct Regular Simulation Exercises

Utilities can test and evaluate their ERPs through tabletop discussions, functional exercises, and full-scale simulated responses. Exercises allow staff to explore assumptions about response procedures and timelines, test the effectiveness of mitigation measures, and validate recovery strategies before emergencies arise. Utilities can start with basic training and drills, strategically building capacity for more complex exercises.

Implement a Security Strategy

This can include a security master plan that encompasses physical security measures, cybersecurity protocols, and evolving policies and procedures. Conducting cybersecurity evaluations and implementing robust training programs also helps protect against digital threats.

Plan for Business Continuity

Developing and regularly updating Business Continuity and Continuity of Operations Plans can help your utility maintain essential functions during and after an emergency, identify critical business functions, and establish alternate operating procedures.

Cultivate a Culture of Resilience

Embed preparedness into your organization by providing regular training, integrating security into all decision-making processes, and encouraging staff at all levels to contribute to resilience efforts.

Whether a utility has two hours or two days to test their response plans, there is an exercise methodology available to support emergency preparedness goals.

Full-Scale Exercise
Operations/Functional Exercise
Tabletop Exercise
Workshop
Seminar
Drill
Training

CAPACITY

SOPHISTICATION

AWWA J100 STANDARD

Asset Characterization
+
Threat Characterization
+
Consequence Analysis
+
Vulnerability Analysis
+
Threat Analysis
+
Risk/Resilience Analysis
+
Risk/Resilience Management

BASELINE AWIA INFORMATION

It is recommended that utilities complete all seven steps within the AWWA J100 framework to reduce their vulnerabilities to natural, man-made, and technological hazards.

PROGRAM DEVELOPMENT · CONTINUOUS IMPROVEMENT · STAKEHOLDER ENGAGEMENT · CROSS-FUNCTIONAL COLLABORATION · RISK MANAGEMENT · ACTION MANAGEMENT

MITIGATION & PREVENTION | PREPAREDNESS
RECOVERY | RESPONSE

ACTION OVER INTENTION

When it comes to emergency response planning, action is more valuable than intention and theory. By taking these proactive steps, your utility can move beyond compliance to true preparedness, protect assets and customers from hazards, improve your emergency response, and narrow your recovery timelines.

CELEBRATING PROGRESS

Tucson's One Water Plan in Action

The CAVSARP facility reduces reliance on local groundwater by blending it with Colorado River water from the CAP that Tucson Water recharges and recovers in Avra Valley, west of Tucson.

WARREN GRECO (wgreco@carollo.com)
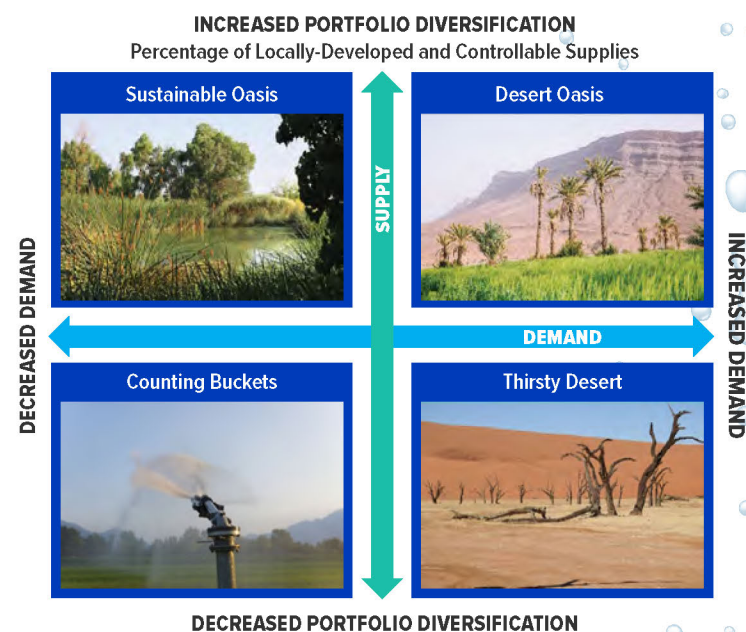**NATALIE DeROOCK** – City of Tucson

In a significant step towards sustainable water management, the City of Tucson has made remarkable strides with its One Water Plan, a comprehensive long-range water resource management strategy designed to protect the reliability and quality of Tucson's water supply through the year 2100. Approved by Tucson's mayor and council in the fall of 2023, this plan represents a collaborative effort involving extensive community engagement and public meetings to confirm diverse voices were heard.

BUILDING A SUSTAINABLE OASIS

Tucson's One Water approach centers on four essential water types: surface water, groundwater, recycled water, and stormwater. It features 16 strategies and 68 actionable items aimed at safeguarding Tucson's water supply in the face of a changing environment by emphasizing a holistic and unified approach that prioritizes sustainability and equity.

Its core principles recognize that all water has value and advocate for using the right water for the right purpose. Crucial aspects of this approach are demand management and conservation, which are essential to maintaining water availability and quality.

As 2023 marks the first reporting year for the One Water Plan, Tucson Water is excited to share its progress and the steps taken toward implementing its strategies. Through innovative scenario planning, Tucson is working to mitigate the risks of a "thirsty desert future" while fostering conditions that support a sustainable oasis.

INCREASED PORTFOLIO DIVERSIFICATION
Percentage of Locally-Developed and Controllable Supplies

FUNDING TO ENHANCE TUCSON'S WATER RESOURCES

Major financial milestones in 2023 secured essential funding for Tucson's water initiatives.

The Lower Colorado System Conservation and Efficiency Program Implementation Agreement with the U.S. Bureau of Reclamation	**$44 million** over a three-year period
Grants and low-interest loans with some forgivable principal from agencies such as the Water Infrastructure Finance Authority of Arizona (WIFA) and the Arizona Department of Environmental Quality (ADEQ)	**$50 million**
Contributions from other sources for infrastructure improvements	**$28 million**

THE POWER OF COLLABORATION IN WATER STEWARDSHIP

The tremendous success of the One Water Plan was further highlighted during the 1W2100 summit held in Tucson in November 2023. This event brought together community members and agencies, showcasing the power of collaboration and engagement in water stewardship. The City of Tucson remains committed to delivering a reliable and sustainable water future for all of its residents through continued public participation and proactive planning.

SCAN THIS QR CODE TO LEARN MORE ABOUT TUCSON'S ONE WATER 2100 PLAN

Tucson's One Water Plan development was led by a team of professionals at **Tucson Water** and **Carollo Engineers**, with contributions from Brown and Caldwell, HDR, Jacobs, Katz & Associates, Gordley Group, Galardi Rothstein Group, Raucher LLC, and WaterDM.

SIGNIFICANT DEVELOPMENTS

Surface Water Initiatives

■ **Safeguarding Deliveries:** Designs for upgrades to Tucson Water's Central Avra Valley Storage and Recovery Project (CAVSARP) have been finalized. As the older of two major aquifer recharge and recovery facilities using Central Arizona Project (CAP) water, CAVSARP's enhancements will support the delivery of **98,670 acre-feet** of Colorado River water.

Groundwater Projects

■ **Restoring Local Supplies:** The Tucson Airport Remediation Project (TARP) has made strides by connecting to the Santa Cruz River and the reclaimed water distribution system, delivering up to **7,000 acre-feet** of treated groundwater for multiple uses.

■ **Implementing PFAS Treatment:** The TARP per-and polyfluoroalkyl substances (PFAS) ion exchange treatment facility design is complete, and construction is getting underway. In addition, the Central Tucson PFAS project treated **308 acre-feet** of groundwater in 2023.

Reclaimed Water Advancements

■ **Increasing Beneficial Use:** Tucson is planning a demonstration-scale advanced water purification project and will collaborate with ADEQ on rule-making processes, while the Northwest Reclaimed System Augmentation Project will enhance supply by adding reclaimed water from Pima County's Tres Rios Water Reclamation Facility to Tucson Water's reclaimed water distribution system for the first time.

Stormwater Management

■ **Mitigating Local Flooding:** New stormwater parks, such as El Vado Stormwater Park, with a **402,511-gallon** capacity, have been established, along with other projects to improve local infrastructure.
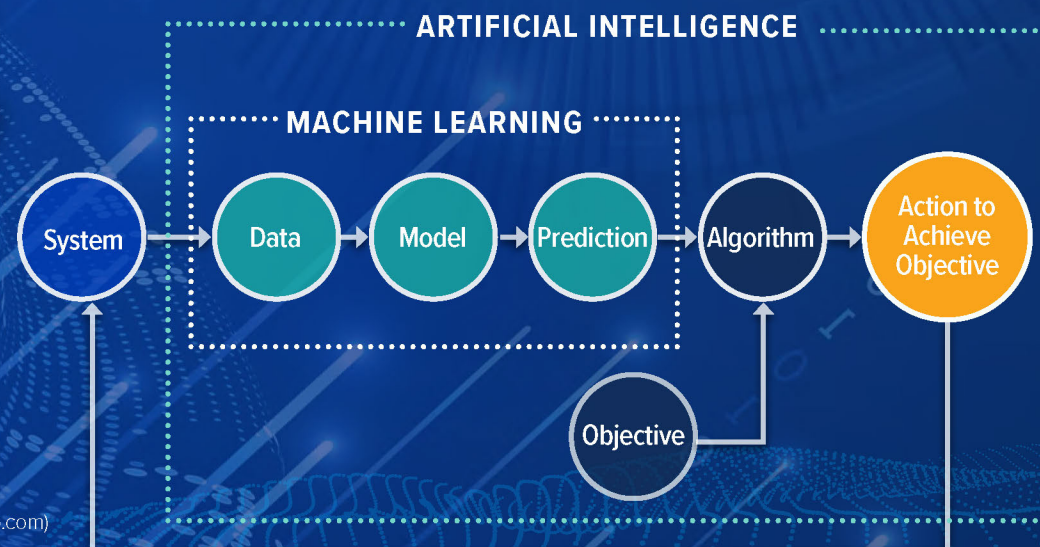
Demand Management Efforts

■ **Advancing Water Stewardship:** Initiatives such as advanced metering infrastructure for leak detection and turf replacement rebate programs are promoting conservation and equity among Tucson residents.

MACHINE LEARNING

The Future of Water Quality Monitoring

ARTIFICIAL INTELLIGENCE

MACHINE LEARNING

System → Data → Model → Prediction → Algorithm → Action to Achieve Objective

Objective

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Machine learning (ML), a branch of artificial intelligence, is transforming how we monitor and manage water quality. At the forefront of this innovation are "soft sensors"—not physical devices, but intelligent algorithms that predict slow or expensive-to-measure water quality variables using readily-available data. This breakthrough is reducing monitoring costs and enabling more adaptive treatment processes.

Carollo is pioneering the application of these technologies in water treatment facilities across North America. In this article, we explore two case studies that showcase how ML is reshaping water quality monitoring in potable water reuse systems.

PREDICTING TOTAL ORGANIC CARBON IN VIRGINIA

Imagine being able to predict water quality faster than traditional methods allow. That's exactly what the Hampton Roads Sanitation District (HRSD) has achieved at the SWIFT Research Center in Virginia.

Total organic carbon (TOC) is a critical parameter for controlling ozone dosing in carbon-based reuse systems. Typically, TOC is measured less frequently than ozone levels, which could lead to less responsive control. Our solution? An ML-powered soft sensor for TOC.

Using three months of historical data from HRSD's SWIFT Research Center, a 1-mgd carbon-based reuse demonstration facility, Carollo developed a model that predicts TOC levels with remarkable accuracy. A boosted trees (bstTree) model outperformed the last-known value—a linear model with a root mean square error (RMSE) of 0.709 mg/L—by achieving a RMSE of 0.349 mg/L.

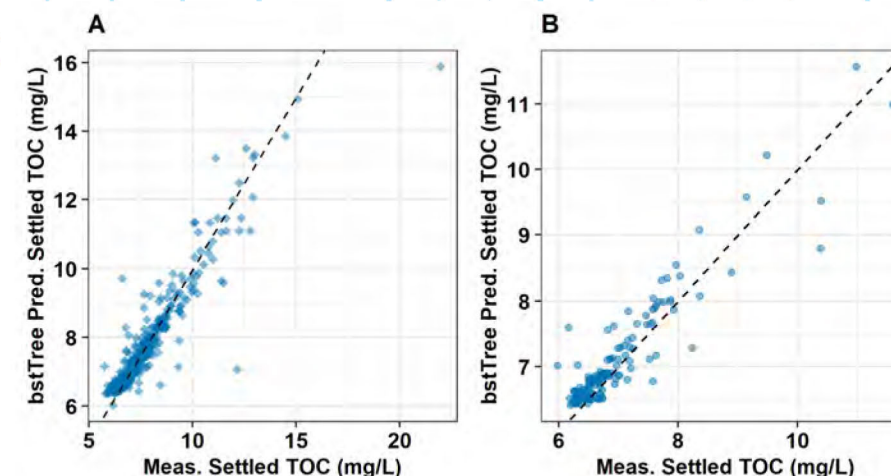> Machine learning is revolutionizing water quality monitoring, enabling real-time predictions.

The model's success was based on a comprehensive dataset that included measurements at five-minute intervals for 37 water quality and operational variables. Our team extracted 749 TOC measurements and paired them with predictive features such as UV transmittance, pH, and ammonia.

This translates to more precise and responsive ozone dosing, which could lead to significant energy savings and more effective water treatment.

TACKLING NDMA IN CALIFORNIA

Our second case study highlights Las Virgenes Municipal Water District's (LVMWD's) Pure Water Demonstration Facility, where Carollo faced a different challenge: monitoring N-nitrosodimethylamine (NDMA), a critical disinfection byproduct in potable reuse systems.

NDMA levels can drive UV dosage requirements in advanced oxidation processes downstream of reverse osmosis (RO). Without real-time NDMA sensors, UV doses are typically set conservatively, based on maximum historical concentrations. This leads to unnecessarily high energy use; therefore, Carollo developed an ML-based soft sensor for NDMA.

Using a dataset of 162 NDMA measurements from Orange County Water District's (OCWD) Groundwater Replenishment System, our collaborator, Dr. Kathryn Newhart of Oregon State University, created a random forest model that predicts NDMA concentrations with an RMSE of 3 ng/L using measurements recorded every three hours over three weeks. Predictive features included ammonia, pH, turbidity, total chlorine, and pressure.

Predicted versus measured values of settled TOC for HRSD's SWIFT Research Center bstTree ML model, showing the accuracy for the (A) training set and (B) testing set.

As with HRSD, our team developed the ML models using open-source R programming, a powerful tool for statistical computing and data visualization. Implementing UV dosage adjustments based on the predicted NDMA concentrations could reduce UV energy consumption by 26 percent. Incorporating safety factors based on model uncertainty could still achieve a 13 percent energy savings.
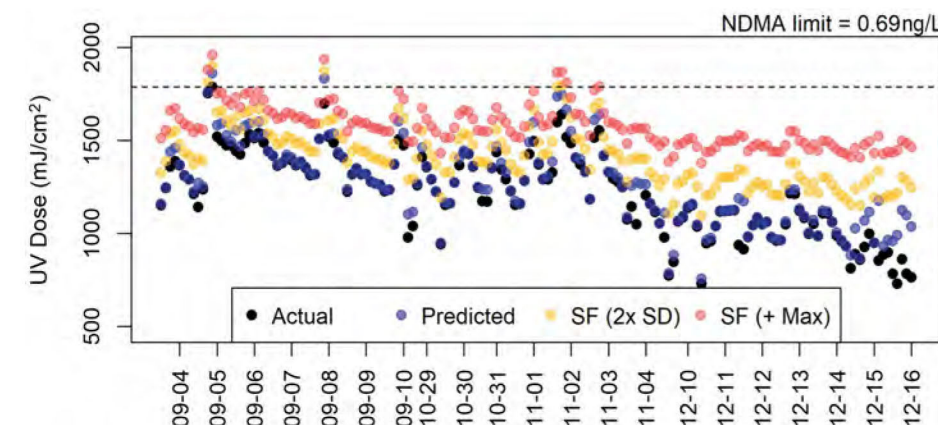
Carollo is transferring this model to LVMWD's demonstration facility and collecting extensive new data to enhance the model's efficacy.

This includes a comprehensive data collection effort spanning April 2024 to January 2025, and using approximately 200 NDMA samples from RO permeate, with daily sampling at random times to capture daily and seasonal variations. This dataset will further refine and validate the NDMA ML model, which could lead to even greater energy savings and treatment efficiency.

A comparison of predicted UV dose requirements for NDMA treatment for the Las Virgenes-Triunfo Pure Water Facility showcases the potential for 13 percent energy savings with safety factors.

LOOKING AHEAD

These advancements highlight the transformative potential of machine learning and real-time sensor technology in optimizing water treatment processes. By harnessing the power of AI, we're creating smarter, more efficient, and more sustainable water systems for the communities we serve.

Carollo is currently exploring another frontier: real-time NDMA sensors. We are collaborating with Hyperion Analytical, LLC to test a prototype NDMA sensor that could one day automate UV control in water treatment.

In San Diego, where water resource management is crucial, Carollo is committed to more than just engineering. Our San Diego office has implemented a comprehensive outreach program that extends into schools, community centers, and public spaces. The goal is to educate and inspire the next generation about water science and engineering.

Giving Back
IN SAN DIEGO

Community Initiatives Throughout the Region Motivate Future Leaders

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DANA FUDURICH – Fudurich Consulting

Through our Carollo Cares program, we expose young people to science, technology, engineering, art, and mathematics (STEAM). Our goal is to give participants first-hand experiences with how these disciplines shape our world.

IGNITING AN INTEREST IN STEAM WITH SAN DIEGO YOUTH

Pure Water San Diego's "Near-to-Peer" Program

Pure Water San Diego is a pioneering water recycling project that will provide nearly half of San Diego's water supply by the end of 2035. As the design engineer, Carollo has partnered with the City of San Diego to host several "Near-to-Peer" workshops, which offer hands-on learning experiences at the North County Water Reclamation Plant and Pure Water Demonstration Facility. These workshops give middle and high school students the chance to interact with Carollo's young engineers, who share their career journeys, passion for water, and contributions to critical projects. The goal is to educate the next generation on the importance of engineering and the strategic role these treatment facilities play in San Diego's future.

EMPOWERING WOMEN IN WATER SCIENCES

Carollo has initiated several programs to encourage young women to consider careers in water sciences.

Workshops and Plant Tours at San Elijo Water Campus

Carollo partners with the San Elijo Joint Powers Authority to host an annual workshop and tour of this facility. The event is a continuation of our partnership with the Fleet Science Center's Better Education for Women in Sciences (BeWise) program for seventh to twelfth grade girls across San Diego.

Carollo-led tours at the San Elijo Water Campus help students visualize and understand the inter-workings of the treatment process.

Enthusiasm is contagious. A hands-on experience building a filter is good training for the engineers of tomorrow.

Women Who Inspire Conference

Each year on International Women's Day, Carollo highlights women in STEAM careers to students from under-resourced high schools. The goal is to convey an inclusive message to young women, broaden students' perspectives on potential careers, and recognize their career-relevant STEAM skills.

BRINGING STEAM TO UNDERSERVED COMMUNITIES

Making STEAM education accessible to all communities in San Diego, regardless of socioeconomic factors, is a key priority.

Barrio Logan STEAM Block Party

San Diego's Barrio Logan has been designated as one of 14 California Cultural Districts. Produced in partnership with the Barrio Logan Science & Art Expo, Carollo participates in this annual event that combines culture, science, and art to provide a valuable learning experience through a mix of student competitions, interactive exhibits, and STEAM-related activities.

WOMEN WHO Inspire

> *Carollo Engineers has been an invaluable partner to Generation STEAM for several years. Whether through hands-on exploration at our San Diego Festival of Science and Engineering, or through Day-in-the-Life workshops at our Women Who Inspire Conference for high school girls, Carollo shows up for our community, and for our students, without fail. We are fortunate to have this partnership and to benefit from Carollo's support—and the community is better off for it."*
>
> *—Silvana DelPiccolo, Community Relations Director, Generation STEAM | Biocom California*

CULTIVATING THE NEXT GENERATION OF WATER LEADERS

Carollo's outreach extends to various public events and educational institutions:

Engineering Day at the Mall

This annual event, hosted by the San Diego chapter of the American Society of Civil Engineers Younger Member Forum is part of Engineers Week. It features a Carollo interactive water filter building activity to spark interest for young students of various ages and backgrounds.

Festival of Science and Engineering

Carollo is an active participant in the largest STEAM festival in Southern California. A collective effort between industry, school districts, community organizations, and government, this event features interactive activities, stimulating demonstrations, and all types of STEAM entertainment to help excite minds of all ages!

Evening of Professional Development

Each year, Carollo participates in the Evening of Professional Development, hosted by the Society of Women Engineers' San Diego State University chapter. This networking event provides San Diego State University engineering students with the opportunity to explore internship and post-graduate career options and includes a career fair to connect companies with potential future employees.

INTRODUCING CAROLLO'S
CORROSION GROUP

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Unchecked corrosion can rapidly compromise critical infrastructure. According to the National Association of Corrosion Engineers' Impact Study, the annual cost of corrosion as of 2013 was $451.3 billion for the U.S. alone. Essential services, which includes the water industry, accounts for $146 billion of annual corrosion costs.

Carollo's Corrosion Group is responding to this pervasive challenge by implementing strategies that protect and preserve clients' assets. Whether during design, construction, or ongoing maintenance, our team has the expertise to identify and mitigate our clients' corrosion risks and enhance the long-term viability of their investments.

THE ESSENTIAL ROLE OF MATERIALS SELECTION

An effective corrosion strategy requires a thorough evaluation of material options, particularly in aggressive environments. Our Corrosion Group's experience spans corrosion-resistant alloys and non-metallic alternatives, as well as failure analysis and rehabilitation methods.

COATINGS ARE THE FIRST LINE OF DEFENSE

Customized protective coatings are essential to withstand the environmental challenges faced by metallic, composite, and concrete structures. Our services include the selection, specification, and inspection of coatings for immersion, burial, atmospheric, and other challenging conditions.

USING ELECTROCHEMICAL TECHNIQUES TO PROTECT BURIED OR IMMERSED STRUCTURES

Cathodic protection (CP) is an electrochemical method to protect underground and submerged structures from corrosion. We design, test, and implement CP systems that safeguard storage tanks, pipelines, concrete structures, immersed gates, and other underground wastewater and water treatment facility components in diverse environments.

FIELD TESTING AND INSPECTION

Effective corrosion and CP mitigation requires systems to be maintained and regularly checked. Carollo's corrosion and construction management teams work together to provide coatings inspection and CP testing to save our clients time and money by preventing corrosion failures before they occur.

Below is a small sample of municipal and industrial clients whose corrosion challenges Carollo has helped solve.

Client	Services
City of Tampa, FL	Design of distributed galvanic CP system for buried ductile iron pipe at the David L. Tippin Water Treatment Facility.
Confidential Client, CA	Design and in-service installation of an impressed current CP system in the interior of an industrial wastewater tank.
Mesa Water District, CA	Field testing of the water district's CP systems.
Confidential Client, PA	Wastewater system tank coating inspection/recommendations.
Metro Water Recovery, CO	Composite foul air ductwork coating inspection and rehabilitation recommendations at the Northern Treatment Plant.

OFF-GAS TESTING USING I-FLOAT
Real-time Monitoring to Optimize Aeration and Measure Greenhouse Gases

SAM REIFSNYDER, PhD (sreifsnyder@carollo.com)

OPTIMIZING AERATION PERFORMANCE

Aeration is the beating heart of any water resource recovery facility (WRRF). It breathes life into biological treatment by supplying oxygen for the mineralization of organic substances and the conversion of nutrients. However, the energy-intensive equipment used for aeration, such as blowers, can account for over half of a facility's total energy consumption.

Depending on the aeration system, only a fraction of the supplied oxygen (8 to 12 percent) is dissolved in the wastewater, where it is available to the microbial biomass. It's like filling up your car's gas tank but only being able to use a tenth of the fuel and wasting the rest. Beyond this inefficiency, aeration basins also become hotspots for greenhouse gas (GHG) emissions like methane and nitrous oxide.

The actual efficiency of aeration and the direct emissions are often estimated based on literature values, but these can vary significantly between facilities and fluctuate over time due to changes in incoming loads and treatment operations. This variability underscores the importance of monitoring and optimizing each system's performance to benchmark the energy use and environmental impact.

THE BENEFITS OF OFF-GAS TESTING

Imagine standing by an aeration basin and watching the bubbles rise to the surface. These bubbles reveal more than just the tank's activity—they hold clues about the facility's energy use and environmental impact. Off-gas testing captures these gases to reveal the hidden efficiency of diffuser systems and the presence of GHGs like methane and nitrous oxide.

This isn't just about numbers. It's about making informed decisions that can save money, optimize operations, and reduce a facility's carbon footprint.

Picture a plant manager who can fine-tune blower settings, schedule diffuser cleanings for optimal efficiency, and address GHG emissions—all based on real-time data.

And the story doesn't end with data collection. Traditionally, off-gas testing has faced challenges in gathering data efficiently without disrupting daily operations. Conventional off-gas hoods are heavy and cumbersome, requiring laborious pre-assembly and often needing multiple people or lifting machinery for setup—UNTIL NOW.

ENTER I-FLOAT

Carollo has recognized the logistical and cost challenges of off-gas testing and decided to rewrite the script. I-FLOAT stands for **I**nflatable, **F**ast, **L**ightweight **O**ff-gas **A**nalysis **T**echnology. This innovative solution, developed at Carollo's Water Applied Research Center (Water ARC®), is a portable off-gas testing solution that can be easily deployed by any trained professional. Once on-site, it inflates and uses a unique water ballast system to stabilize the hood, even in turbulent conditions. No pre-assembly, no heavy machinery, no crane—just smart engineering that makes off-gas testing more accessible and labor-efficient than ever before.

EVERY BUBBLE COUNTS

This isn't just a technical breakthrough; it's a tool that empowers WRRFs to gain a deeper understanding of their aeration basin performance and expand sustainable practices. I-FLOAT helps facilities benchmark their aeration energy efficiency and understand their emissions—enabling steps towards their reduction.

So, what's the next chapter? With I-FLOAT, Carollo continues to strive to make off-gas testing more convenient and impactful, thereby expanding off-gas monitoring practices at facilities large and small. Our aim is to help facilities turn every bubble rising to the surface into a step toward a greener future.

I-FLOAT features a hood that deflates, fits into a suitcase, and can be carried to the testing site by a single person.

I-FLOAT

Real-time monitoring to optimize aeration and measure greenhouse gases?

That's Carollo innovation.

Introducing I-FLOAT, Carollo's Inflatable Fast and Lightweight Off-gas Analysis Technology. Developed at Carollo's Water Applied Research Center (Water ARC®), I-FLOAT is portable, easy to install, and covers a large surface area for accurate results. Plus, it delivers real-time data on greenhouse gases like methane and nitrous oxide — enabling decision-making that aligns with your sustainability goals. With I-FLOAT, you can monitor readings remotely and optimize aeration like never before.

800.523.5826 / carollo.com

carollo® **I-FLOAT**