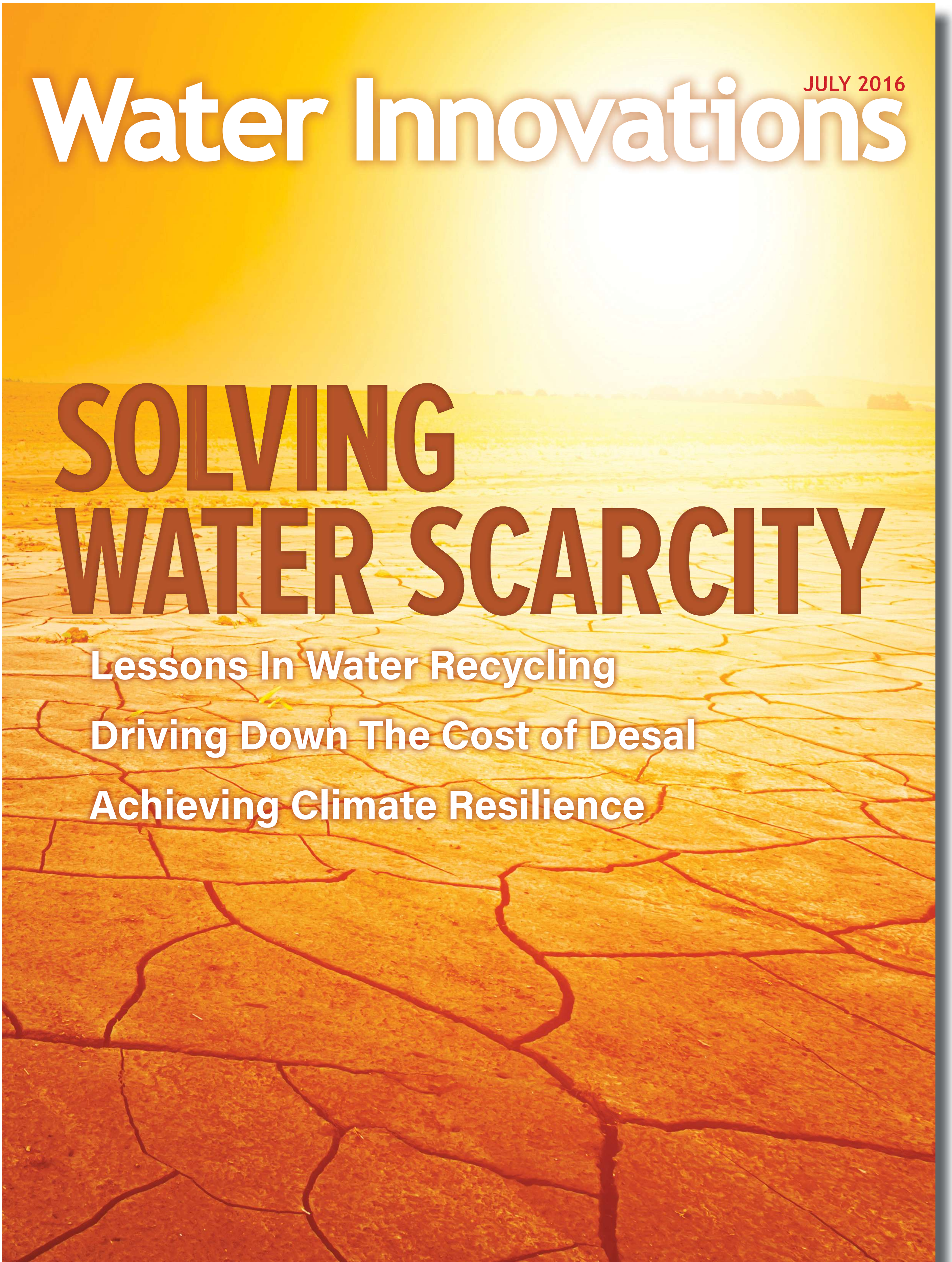
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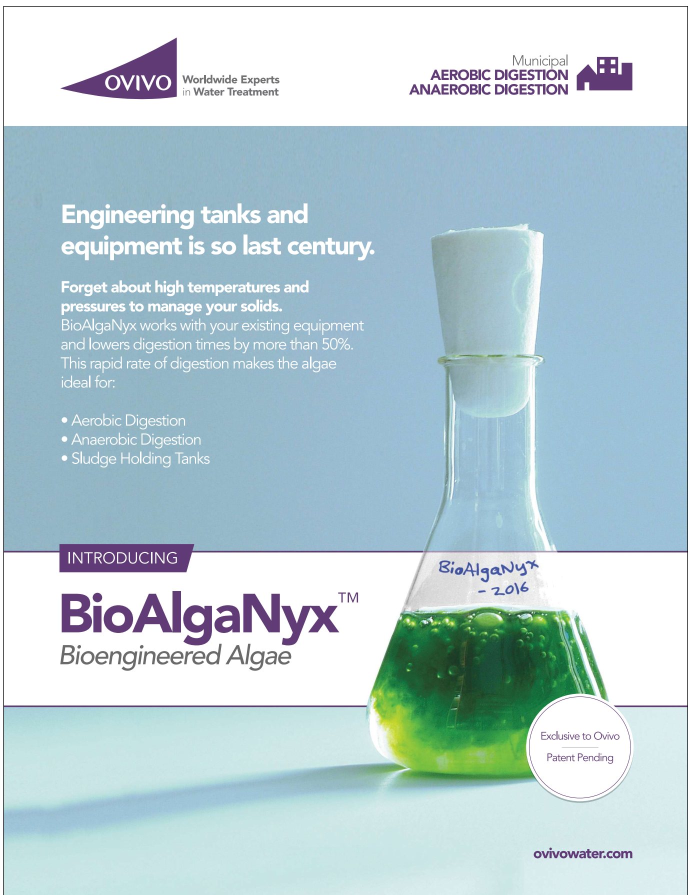


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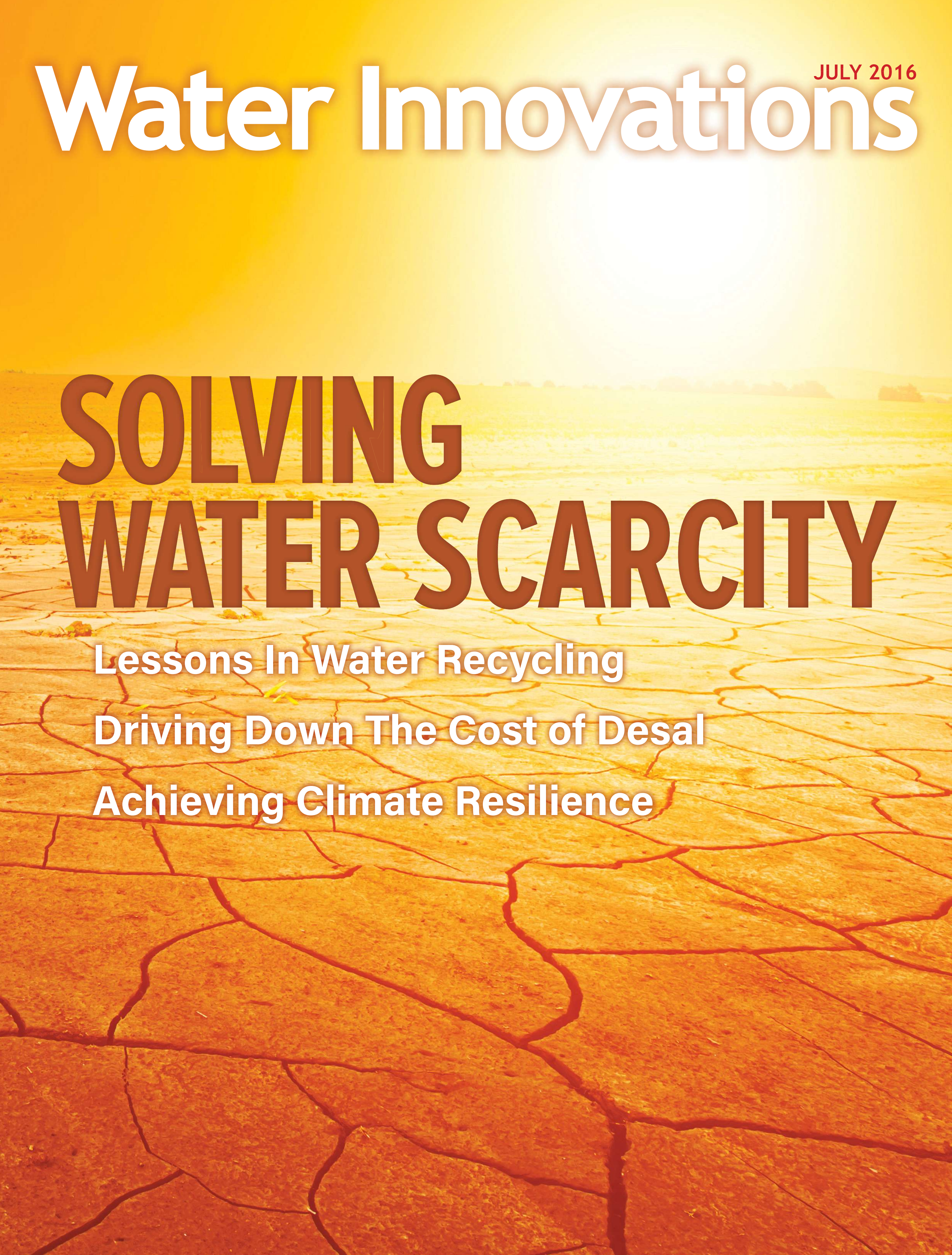

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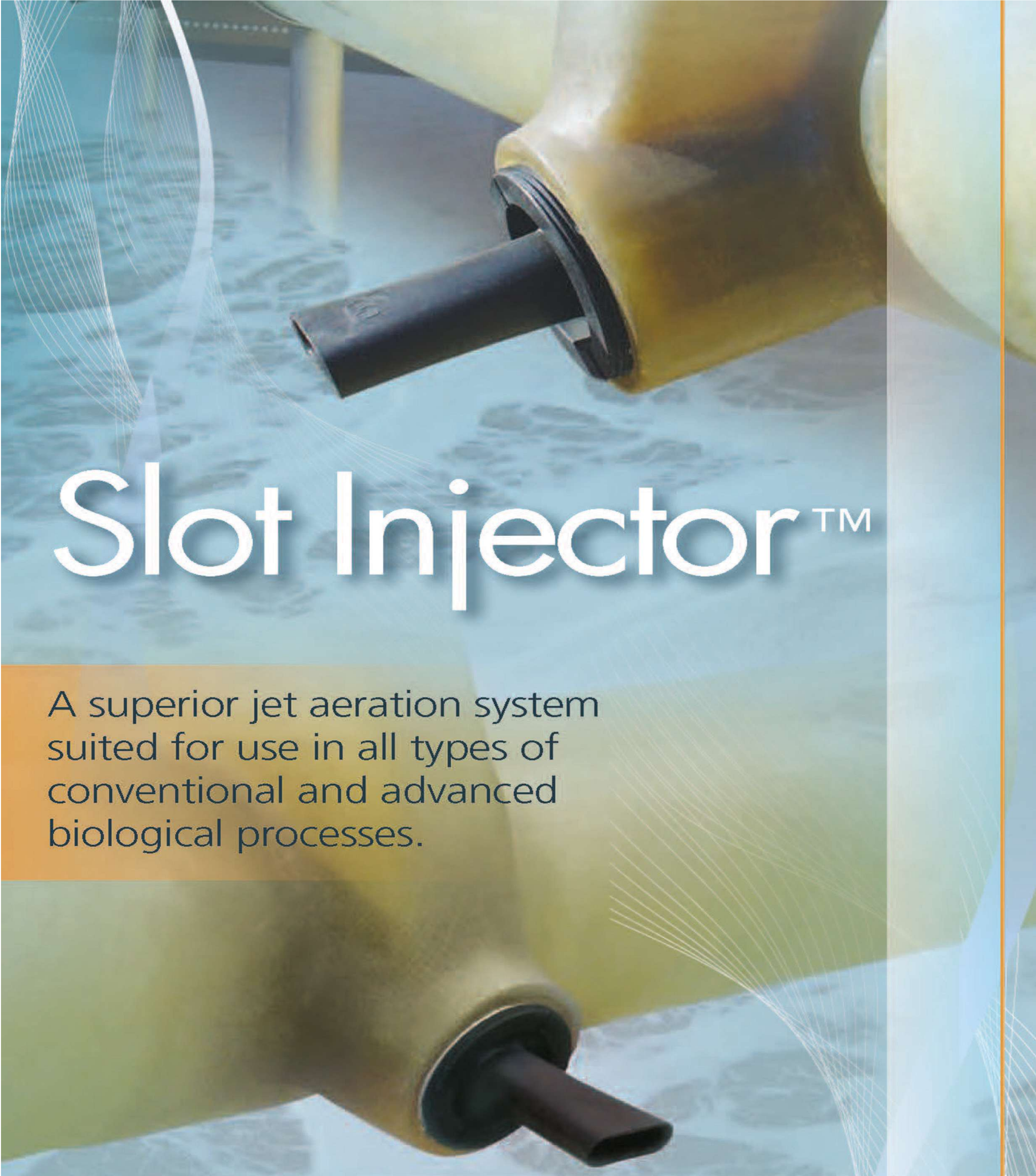

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EDITOR'S LETTER

By Kevin Westerling
Chief Editor, editor@wateronline.com

TSCA Modernization:
A Dose Of Common Sense

After 40 years, the 1976 Toxic Substances Control Act (TSCA) has finally been updated, much to the delight of most — but certainly not all.

The old rule was woefully outdated for the scores of chemicals that have proliferated in consumer goods and eventually passed through our water system and into the environment. Some chemicals, such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), even wind up in drinking water and are likely carcinogens. So who wouldn't agree on the revision, now that 65,000 or so unregulated chemicals, in addition to any new chemical concoctions, will be checked by the U.S. EPA for safety?

Bernie Sanders, for one. But that's not because he supports the big chemical manufacturers (of course not, if you're familiar with Bernie at all). Senator Sanders and Congressman Peter Welch, both of Vermont, are among the minority of legislators who have raised issue with the new law on the grounds that federal jurisdiction will ultimately preempt stricter state laws.

The dissenters may have legitimate points, but putting the EPA in charge is obviously much wiser than granting free rein to chemical manufacturers.

Hypothetically, consider again PFOA and PFOS, best known as the chemicals behind DuPont's Teflon and 3M's Scotchguard, respectively. This May, the EPA issued a new lifetime drinking water health advisory of 70 parts per trillion (ppt) for the PFOA-PFOS combo — a good bit below its previous, separate recommendations of 400 ppt for PFOA and 200 ppt for PFOS. However, Vermont set its own advisory level for PFOA at 20 ppt in 2009. Herein lies the problem: Some localities with increased incidence of certain chemical contaminants, and thus increased community concerns, would like to go beyond the guidelines and/or regulations that the EPA might set. For some states, "reasonable certainty of no harm" — the abiding safety standard of the EPA — might not be enough.

The above is hypothetical in that the bill allows state laws or rules put in place before April 22, 2016 to remain, but it points to the objection being raised in Vermont as well as Connecticut, Minnesota, New Hampshire, New York, and Washington — all with state environmental officials who have objected to the constraint. In a joint statement, the six officials said, "To be clear, there are good elements in the legislation. However, state authorities are excessively and unnecessarily preempted, in exchange for the promise of federal protection that is too meager."

But there may still be a window for wiggle room. A provision exists that allows states to act on a "high-priority" chemical if the EPA has yet to begin its own risk evaluation of the chemical. Failing that, a "regulatory pause" ensues for up to three-and-a-half years as the EPA conducts its review; the EPA's findings would then determine the course of action for all — "meager" or not.

The dissenters may have legitimate points, but putting the EPA in charge is obviously much wiser than granting free rein to chemical manufacturers. Forty years later, common sense finally won out.

Our first story in this edition of *Water Innovations* deals with a particular chemical quandary: antimicrobials persistent in water and wastewater. Turn the page to better understand the potential health crisis posed by antimicrobial resistance, and keep paging through for guidance on conventional water management concerns including sustainability, water reuse, desalination, and resiliency.

Kevin Westerling

Water Innovations

101 Gibraltar Road, Suite 100
Horsham, PA 19044
PH: (215) 675-1800
FX: (215) 675-4880
Email: info@wateronline.com
Website: www.wateronline.com

CHIEF EDITOR
Kevin Westerling
(215) 675-1800 ext. 120
kwesterling@vertmarkets.com

ASSOCIATE EDITOR
Peter Chawaga
(215) 675-1800 ext. 124
pchawaga@vertmarkets.com

PUBLISHER
Travis Kennedy
(215) 675-1800 ext. 122
tkennedy@vertmarkets.com

ASSOCIATE PUBLISHER
Patrick Gallagher
(215) 675-1800 ext. 129
pgallagher@vertmarkets.com

PRODUCT MANAGER
Bill King
(215) 675-1800 ext. 100
bking@vertmarkets.com

MANAGING EDITOR
Michael Thiemann
(814) 897-9000, ext. 340
mthiemann@vertmarkets.com

PRODUCTION DIRECTOR
Lynn Netkowicz
(814) 897-9000, ext. 205
lnetkowicz@vertmarkets.com

PRODUCTION MANAGER
Susan Day
(215) 675-1800, ext. 101
sday@vertmarkets.com

DIRECTOR OF AUDIENCE DEVELOPMENT
Martin Zapolski
(814) 897-7700, ext. 337
mzapolski@vertmarkets.com

DIRECTOR OF ONLINE DEVELOPMENT
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aglenn@vertmarkets.com

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What Lies Beneath: Antimicrobials And Antimicrobial-Resistant Bacteria In Wastewater

Antimicrobials coursing through wastewater are making bacteria stronger, a problem that could lead to 10 million deaths per year if left unchecked.

By Dearbháile Morris and Martin Cormican

Antimicrobial resistance is a worldwide public health emergency. In the last few decades, there has been widespread and increased use of antibiotics in both human and veterinary medicine. In addition, there is a huge market for antibacterial agents in personal care products (such as soap), in disinfectants, and as surface coatings on containers and appliances. As antimicrobial agents have been used more widely, microorganisms have become increasingly resistant to them. It is now commonplace for antimicrobial agents, which could be relied upon 20 years ago, to fail.

The increased use of antimicrobial agents is influenced by an increasing population, an aging population, longer survival of people with complex illnesses, changes in food production systems, and by other social and economic factors. Infection associated with antimicrobial-resistant bacteria results in significant increases in healthcare costs, morbidity, and mortality. The World Health Organization (WHO) has ranked antimicrobial resistance as a "major threat to human health."[1] The European Centre for Disease Prevention and Control (ECDC) estimates that antimicrobial resistance results in 25,000 deaths and related costs of over €1.5 billion in healthcare expenses and productivity losses in Europe annually.[2] The Review on Antimicrobial Resistance commissioned by the UK Government estimates that if appropriate action is not taken, by the year 2050, 10 million deaths each year will be due to antimicrobial-resistant organisms at a global economic cost of $100 trillion USD.[3] It is increasingly recognized that an intersectoral approach is required to mitigate the problem of antimicrobial resistance. The May 2015 World Health Assembly adopted the Global Action Plan on Antimicrobial Resistance,[1] which endorses a "One Health" approach to tackle the issue. The One Health concept recognizes that there is a relationship among human health, animal health, and the environment, and that the well-being of each sector is influenced by the others.

Antimicrobial Agents And Wastewater

Antimicrobial residues can enter the aquatic environment in effluent from industries involved in the production of antimicrobial products or following direct disposal (intentional and unintentional) into waste streams (landfill and wastewater). In addition, a significant quantity of the antimicrobial agents used therapeutically in human and veterinary medicine is shed into waste streams in urine or feces, in a form that is still biologically active. In most of Europe, hospital effluent is released into the urban wastewater system without any specific measurement of antimicrobial levels or antimicrobial-resistant bacteria and without any pretreatment. Despite European Union (EU) directives, many European countries lack appropriate policies with regard to disposal of unused pharmaceuticals including antimicrobial agents.[4]

Antimicrobial agents in water and wastewater are a potential problem in two ways: First, there is potential for direct human health effects through ingestion as chemical contaminants; second, there is potential harm if they change the microorganisms in the water. The immediate public health concern regarding the effect of antimicrobial agents in water is that microorganisms in water change to become more antimicrobial-resistant. There is also concern that antimicrobial agents may change the natural balance in the microbial ecosystem. Changes in the microbial cells and populations can last long after the antimicrobial agent has broken down or been removed. If people drink the water or swallow it during recreation, this may help to spread antimicrobial-resistant microorganisms over a large population very quickly.

The immediate public health concern regarding the effect of antimicrobial agents in water is that microorganisms in water change to become more antimicrobial-resistant.

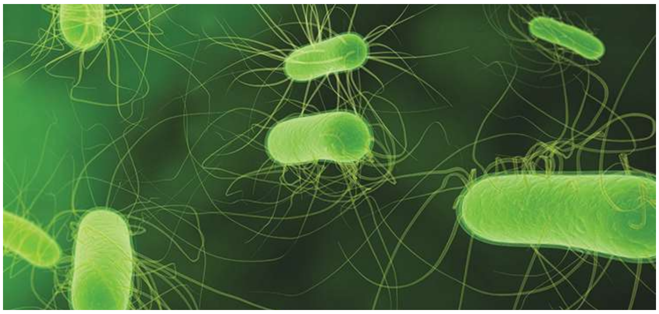
In research funded by the Irish Environmental Protection Agency (EPA), urban wastewaters and two wastewater treatment systems (one of the systems receives and treats effluent that includes effluent from a major hospital, and the other does not) were examined for the presence of antimicrobial residues and antimicrobial-resistant bacteria.[5] A computer model was developed and identified quinolones/fluoroquinolones as a group of antimicrobial agents with very high resistance formation potential and very low rates of degradation in the aquatic environment (50 percent after 100 days for fluoroquinolones, compared to 99.8 percent for penicillin after 100 days).[5,6] A separate model revealed the mean predicted concentrations of ciprofloxacin were 579 mg/m^3 — equivalent (579) in micrograms (µg)/L — in hospital effluent, compared with 0.15 mg/m^3 in seawater receiving effluent from a wastewater treatment plant (WWTP). Based on these predicted concentrations, it is highly unlikely that a swimmer in receiving waters would be exposed to levels of these antimicrobial agents that exceed the acceptable daily intake of 12 µg per kilogram of body weight (kg BW)/day.[5,7] Rodriguez-Mozaz et al. (2015) recently reported detection of fluoroquinolones at a concentration of 4.7 ± 0.1 nanograms (ng)/L upstream of a wastewater treatment plant.[8]

The presence of antimicrobial residues in the environment can be difficult to detect due to their low concentration, but this doesn't mean they are not having an adverse impact on microbial biodiversity, and potentially on human health, through resistance formation. Currently, environmental quality standards for pollutants are determined based on their direct toxicity or other effects on representative organisms. For antimicrobial agents, it would be prudent to also consider their resistance formation potential.

Antibiotic-Resistant Bacteria And Wastewater

Patients in major hospitals and residents of long-term care facilities use large amounts of antimicrobial agents and consequently may have antibiotic-resistant bacteria resident in their gut, large numbers of which are passed into the toilet every day.[9] *E. coli* is a very common gut bacteria and a very common cause of infection (common infections such as urinary tract infection and life-threatening infections such as blood stream infection) and has become increasingly resistant to antibiotics in recent decades.

In most European countries, urban wastewater is treated in WWTPs before discharge to the environment. The value of wastewater treatment in reducing antimicrobial-resistant bacteria numbers has been examined in a number of studies. Some researchers report that wastewater treatment helps to reduce the proportion of antimicrobial-resistant bacteria, while others suggest that the treatment process may increase the proportion. The differences in the findings may be because WWTPs differ in the effluent they receive and in the treatment



Escherichia coli (E. coli) bacteria

processes used, and because season and rainfall may also impact on findings. Proia et al. (2016) demonstrated that WWTP effluent favors the persistence and spread of antimicrobial resistance in aquatic microbial communities.[10] A meta-analysis of previous research in this area reveals that WWTP processing appears to increase the proportion of resistant bacteria (odds ratio of 1.60, 1.33, and 1.19 for multiple antimicrobial-resistant bacteria, single antimicrobial-resistant *E. coli*, and quinolone- or fluoroquinolone-resistant bacteria, respectively).[5, 11] This may suggest that antimicrobial-resistant bacteria are better able to survive the wastewater treatment process, although analytical data from the same study indicates unequivocally that the total number of antimicrobial-resistant *E. coli* is greatly reduced by wastewater treatment, even if the proportion is somewhat increased.[5] There is a need for further research to understand how the secondary wastewater treatment process may impact the development of antimicrobial resistance — in particular, what drives the development of resistance in effluent and what helps to maintain it.

Emerging Contaminants

In addition to antimicrobial agents and antimicrobial-resistant bacteria, other emerging contaminants of concern include microplastics and engineered nanomaterials (ENMs). Microplastics and ENMs have a wide range of potential applications, from everyday uses (such as improvements in fabrics, paints, cosmetics, packaging, etc.) to medical applications, water and soil remediation, and renewable energy production.[12] Whereas significant benefits are claimed for their use, there are concerns regarding the potential for adverse impacts on human health and the environment. Based on current available information, it is difficult to predict likely environmental discharges. There is inadequate data on persistence/transformation in the environment, and such parameters are likely to vary with the nature of the microplastic or ENM and its application. There is no consensus regarding optimal methods for detection of such contaminants in the environment; therefore it is difficult to ascertain to what extent microplastics and ENMs are distributed in aquatic and other environments, to what extent they persist or undergo transformation, and what impact wastewater treatment systems and other processes have on their removal. An ongoing project funded by the Irish EPA is currently examining some of these issues. ■

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About The Authors

Dearbháile Morris, B.Sc., PhD, is lecturer in the School of Medicine, director of the Antimicrobial Resistance and Microbial Ecology Group, and codirector of the Centre for Health from Environment at the National University of Ireland Galway. Dearbháile has over 18 years' experience in the study of antimicrobial resistance and waterborne pathogens.

Martin Cormican, MB, BCh, BAO, MD, is Chair of Bacteriology, and director of the Centre for Health from Environment at the National University of Ireland Galway; consultant microbiologist at Galway University Hospitals, director of the National Salmonella Shigella and Listeria Reference Laboratory, and director of the National Carbapenemase Producing Enterobacteriaceae Reference Laboratory. Martin has over 20 years' experience of research on antimicrobial resistance and waterborne organisms of public health concern.

Inside An Innovative Urban Water Reclamation Facility

The award-winning WaterHub at Emory University is more than a mere campus treasure – it has become a model of sustainable wastewater treatment for urban water management of the future.

By Matthew Early

The WaterHub at Emory University is a decentralized, on-site urban water reclamation and reuse facility that implements a holistic approach to modern water management. Through innovative technologies, the ecologically engineered reclamation facility treats up to 400,000 gallons daily, recycling up to two-thirds of the university's wastewater production, while reducing the campus water footprint by nearly 40 percent.

By localizing water supply through on-site reuse, Emory University has greater control over supply, water quality, and campus resiliency. Nestled among the trees and green spaces of Emory's campus resides a wastewater reclamation and reuse system that is changing the paradigm of commercial-scale water management.

A Quarter Century Of Water Stressors

Throughout history, water has remained the single thread that has brought us all together. From the aqueducts of the Romans to advances in agricultural irrigation, water remains a vital resource for every community. Recently, though, our newspapers have been topped with headlines of water-related challenges in almost every corner of the globe. No stranger to its own water-related challenges, Emory University sought to reduce its dependence on municipal water and de-risk the campus from future water challenges.

Located only 15 minutes from downtown Atlanta, Emory University lies within one of the smallest watersheds serving a metropolitan area of its size. Water is becoming increasingly limited, with scarcity exacerbated by revolving drought conditions and political stressors over water rights. In a 25-year dispute known as the "Tri-State Water Wars," Georgia, Florida, and Alabama have been vying for the allocation rights of water withdrawals from the Chattahoochee River Basin, which serves the Atlanta metro area.

Further compounding these challenges were the U.S. EPA's issuance of consent decrees against the City of Atlanta (and the surrounding counties) to improve water and wastewater management and resolve issues related to combined sewer overflows (CSOs). Due to these new federal mandates, water and wastewater utility costs skyrocketed between 2007 and 2012 and are now considered some of the highest rates in the country. Consequently, sustainable water management has become a critical challenge for the region and a specific operational focus for large water consumers in the metro Atlanta area.

Emory University has a significant water footprint, using close to 350 million gallons of water annually with over 50 percent of campus water use considered non-potable demand. The university has five major chiller plants and one steam plant that provide critical heating and air conditioning services to the campus. Together, these six utility plants consume 30 percent of the total campus water supply, or approximately 105 million gallons annually. From these challenges, Emory began to deploy water conservation campaigns beginning around 2005, successfully implementing rainwater collection and storage, installation of low-flow fixtures, urinals, and shower-heads, and capturing graywater for reuse in toilet flushing.

The university had significantly decreased total potable water use, but the magnitude of the stresses and challenges dictated a more strategic and impactful water management solution. Subsequently, Emory University found itself in a unique position to develop a water management strategy centered on wastewater reclamation and reuse.

Ecological Design For Strategic Water Management

The WaterHub is an adaptive, ecological water reclamation system designed to treat domestic sanitary sewage, mined directly out of the campus sewer system, and reclaim it for non-potable demands including heating, cooling, and toilet flushing. Commissioned in the spring of 2015, the WaterHub at Emory University is an eco-engineered treatment plant composed of innovative and proven biological treatment principles.

The 4,400-linear-foot distribution system seamlessly integrates into the campus framework while providing recycled water to the university's three largest chiller plants, the campus steam plant, and toilet flushing in residence halls. Designed to accommodate future expansion and increased non-potable demands, the WaterHub is expected to save 70 million gallons during its first year of operation, with future uses also including irrigation at major athletic fields.

The system allows flexible site integration, a compact footprint, and a natural aesthetic conducive to a dense urban setting. The WaterHub is divided into two locations: the upper site and lower site. At the upper site, performance landscaping allowed previously undevelopable space to become home to a 3,200-square-foot greenhouse, or "glasshouse," containing a hydroponic treatment system. Considered the heart of the system, the glasshouse showcases lush, tropical plant life that emerges from wastewater reactor tanks. Attached to the glasshouse is a mechanical room and a fully functional lab space where operators can monitor the system.

The lower site, located across the street, includes outdoor hydroponic reactors, a demonstration reciprocating wetland system, and a 50,000-gallon clean water storage tank. Because it's covered with native plants, nearby pedestrians may not realize this is a wastewater treatment plant, but beneath the surface is a highly engineered reclamation system.

Water Treatment: Enhancing A Natural Process

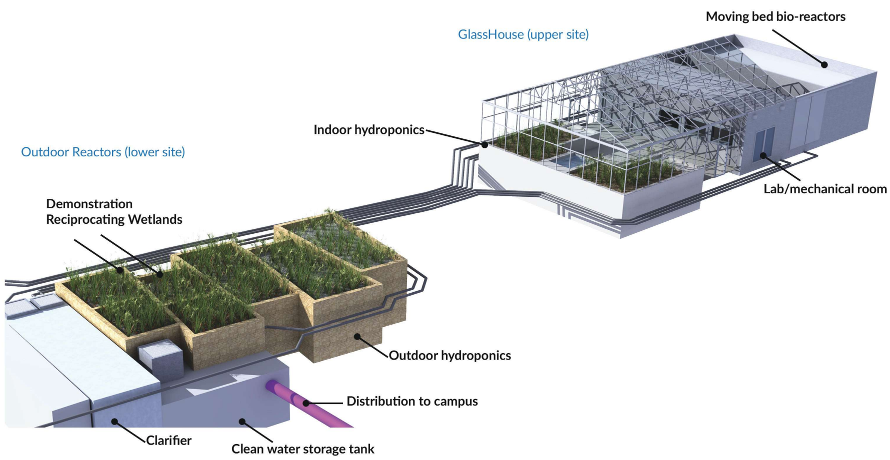
The WaterHub is a low-energy/high-efficiency, eco-engineered treatment system that utilizes a number of sustainable features, including passive heating, collection of stormwater run-off, photovoltaic panels, and efficient, condition-responsive controls. From sewer mining to reclaimed water supply at individual utility plants, the WaterHub is highly automated with a master control system integrated into all aspects of the treatment plant operations.

The WaterHub system is currently rated at a hydraulic capacity of 400,000 GPD, with expansion capabilities up to 600,000 GPD. Overall system design includes integrated fixed-film activated sludge (IFAS) hydroponic reactors in conjunction with a moving-bed bioreactor (MBBR) as primary treatment. The hybrid hydroponic-MBBR system enables the treatment of large volumes of wastewater with a relatively small physical footprint. The entire process, from wastewater extraction to distribution, requires approximately 14 hours.

A below-grade diversion manhole and pump station, at the lower site, intercepts wastewater from a municipal sewer collector. The station pumps wastewater to the glasshouse (upper site), where it passes through a rotary screen to remove any large solids or trash entrained in the wastewater. From the rotary screen, raw wastewater flows into primary treatment reactors, which include a series of MBBRs able to operate selectively as anaerobic, anoxic, or aerobic. The sealed MBBRs, with access through airtight hatches, vent all gasses through activated carbon air filters — eliminating virtually all odors from the primary treatment process.

Hydroponic reactors follow the primary MBBRs and are located within the upper site glasshouse. These reactors reduce remaining biochemical oxygen demand (BOD) to secondary levels and complete the nitrification process. The surface of the hydroponic reactors is covered with vegetation supported on plant racks. These reactors are aerated with fine bubble diffusers, which provide the oxygen required for treatment and keep the tank contents mixed. The roots of the vegetation provide ideal surface area for fixed-film growth.

By utilizing a natural treatment approach, the WaterHub has significantly reduced energy demands when compared to other biological or membrane treatment systems. Natural systems exhibit an intrinsic ability to diffuse oxygen into the systems. This helps reduce the energy required for aeration, which is typically one of the most significant energy and cost factors in a wastewater plant. These efficiencies are also



complemented by solar energy production via two large photovoltaic panels located on either side of the treatment plant.

A disc filter located between the glasshouse and MBBR tanks removes any remaining suspended solids before the final disinfection process. A dual-stage disinfection system includes UV and maintaining of oxidizing biocide residual. Online instrumentation verifies effluent turbidity and UV transmissivity.

The WaterHub was engineered to meet Georgia reclaimed water quality standards. More importantly, however, engineering and design teams directly engaged the existing water treatment company to develop a process that delivered a water quality stream conducive to utility plant operations. Ultimately, the reclaimed water system at Emory provides a stable, high-quality water source without sacrificing water efficiency at cooling towers, as well as biological, corrosion, and deposition control for the utility equipment.

Strengthening A Campus Through Water Reclamation And Reuse

In addition to its functional use as a water reclamation facility, the WaterHub is designed as a living laboratory to enhance the university's academic environment. The treatment facility fosters research in disciplines directly related to botany, microbiology, engineering, public policy, and urban planning, among others.

Emory's Rollins School of Public Health and its Center for Global Safe Water are using the WaterHub as a teaching tool for students to have hands-on training in testing the treated water at various points in the facility. The Center is conducting research to test the feasibility of using the WaterHub in areas around the globe that face issues of water insecurity and are in need of decentralized wastewater treatment or reclamation solutions.

Overall, the WaterHub at Emory provides a number of environmental, social, and economic benefits to the university and broader community. Designed to de-risk campus operations from potential water service disruptions, the WaterHub at Emory University extends the lifespan of community water-related infrastructure. Additionally, the WaterHub has generated interest from diverse market sectors representing government agencies, higher education, and Fortune 500 companies. Professionals ranging from college professors to sustainability coordinators, engineers, and executive officers have traveled to the WaterHub for tours and presentations. Moving the field of water reclamation forward, the WaterHub serves as a model for commercial-scale sustainable water management in urban areas.

Recently, the eco-engineered water reclamation facility was recognized for its sustainable technology by the US Water Alliance. On April 8, 2016, the US Water Alliance announced Emory University and its WaterHub as one of three winners awarded the prestigious 2016 US Water Prize. This award recognizes organizations and companies that execute innovative solutions toward the advancement of "one water" sustainability.

In announcing the winners, US Water Alliance CEO Radhika Fox said, "While the challenges facing the water sector are great, our capacity of innovation and positive solutions is greater. That's why the US Water Alliance created the US Water Prize — the first-of-its-kind recognition program that celebrates outstanding achievement in driving towards a sustainable water future."

In response to the US Water Prize announcement, Emory stated "Through this project, [Emory has] shown how universities can play an important role in advancing sustainability nationwide. Not only has the WaterHub had tremendous impact on how we think about water and how it is utilized on campus, it has also become a national model for those seeking innovative technology to address the global need for water conservation and sustainable solutions."

Now an 11-time award winner, the WaterHub at Emory University continues to be honored with accolades and awards including the 2015 Project Achievement Award by Construction Management Association of America South Atlantic Chapter; 2015 Innovative Project of the Year by the WateReuse Association; 2015 Atlanta E3 Award (liquid assets category) by the Metro Atlanta Chamber; 2015 Superior Environmental Performance award by Georgia Safety, Health and Environmental Conference and the Georgia Chapter of the American Society of Safety Engineers; 2015 Innovative Deal of the Year by Urban Land Institute — Virginia; 2016 Engineering Excellence Grand Award by the American Council of Engineering Companies of North Carolina; 2016 inaugural Fulcrum Award by Southface; 2016 SCUP Excellence in Landscape Architecture — General Honorable Mention Award by the Society for College and University Planning; 2016 National Engineering Excellence Grand Award by the American Council of Engineering Companies; and 2016 Effective and Innovative Practices Award by APPA. ■

About The Author

Matthew Early oversees a division of over 800 employees in departments of planning, design and construction, facilities management, finance and business operations, public safety, and customer relations and support. He is a professional civil engineer and a 1987 graduate of the U.S. Naval Academy in Annapolis, MD. He holds a Master of Science degree in Engineering, with a minor in Construction Management from the University of California-Berkeley, as well as a Master of Business Administration degree from the University of La Verne.

Down Under On Top: Lessons In Water Recycling From Australia

More than a decade before the U.S. West's historic drought, Australia had to solve an even longer, drier spell. What can we learn from their experience?

By John Radcliffe

Australia is a federation of six states and two territories, each with its own government, independent of the Australian government. Water is constitutionally a states/territories matter. In most states, water supplies are undertaken by state-owned corporations, though in regional New South Wales and in Queensland, these services are generally provided by the third tier of government — local government. Wastewater services are usually operated by water supply organizations. Stormwater systems are universally separated from wastewater systems. Over the years, the Australian Federal and state/territory governments have jointly agreed on a series of innovative water policies that have provided a firm foundation with a common understanding among governments.

National Strategy

Australia commenced developing its National Water Quality Management Strategy over 30 years ago. The strategy has resulted in the production of 24 guidelines encompassing drinking water; freshwater and marine water quality; groundwater protection; sewerage systems, including effluent management, trade wastes, and biosolids; effluents from agricultural industries (dairies, piggeries, wool scouring, tanneries, wineries, and distilleries); and water recycling (managing health and environmental risks, augmentation of drinking water supplies with recycled water, the use of stormwater, and managed aquifer recharge). All these guidelines are then able to be adopted into states/territories legislation and regulations for enforcement by Environment Protection Authorities and Public Health Departments.

Local Agreements

Uniform policies for Australia's urban and rural water resources were brought together between the Federal and states/territories governments in the Intergovernmental Agreement on the National Water Initiative in 2004. This encompasses clauses on water entitlements and the equitable sharing of water allocations in proportion to those entitlements, water markets and trading, water pricing, management of environmental water, national water accounting, urban water, and community partnerships, together with knowledge and skills. It has objectives of ensuring healthy, safe and reliable water supplies; increased domestic and commercial water use efficiency; facilitating water trading between and within the urban and rural sectors; encouraging innovation in water supply sourcing, treatment, storage and discharge; achieving improved pricing for metropolitan water and establishing a national water accounting system. As a result, there is virtually no litigation over water rights issues in Australia.

The agreement included the development of national guidelines for water-sensitive urban development in housing subdivisions and high-rise buildings, incorporating the integrated design of the urban water cycle, water supplies, wastewater, stormwater and groundwater management, urban land use design, and environmental protection.

Historic Drought

From about 1996, Australia entered a long period of below-average rainfall, known as the "millennium drought." The drought reached an apogee around 2006 when harsh water restrictions — accompanied by community awareness programs — were in place in all mainland capital cities and for most of irrigated agriculture. Most of the community responded positively to these challenges and per capita consumption has remained lower since the end of the drought. The importance of the water market was demonstrated when rice growers, rather than planting their rice, found it more profitable to sell their annual water allocations to farmers growing more valuable crops in horticulture. An established and consistent policy framework served Australia well.

Solutions That Worked

The drought encouraged widespread uptake of water recycling from urban wastewater treatment plants for use on high-value irrigated crops in Sydney, Melbourne, and Adelaide. In some cases, the recycled water was mixed with limited supplies of mains (public) water, stormwater, or groundwater to reduce the salinity of the recycled water.

Dual reticulation systems were installed in new suburbs, the first being Rouse Hill in Sydney. Similar developments followed

Figure 1. Adelaide, capital city of South Australia, was established in 1836 with a unique set of parklands around what is now the central business district. The dry Mediterranean climate meant the parklands were dry and brown in summer, and for many years were burned off annually. Recycled water from the Glenelg wastewater treatment plant is now reticulated throughout the parklands for irrigating sporting fields and gardens. (Credit: South Australian Water Corporation)

in Brisbane, Melbourne, and Adelaide, the recycled water being delivered in separately identified "purple pipes" and available for toilet flushing, car washing, garden watering, etc. Ensuring there were no cross connections between the two systems was essential and required disciplined inspections. Many high-rise office buildings and apartment buildings include wastewater recycling plants for redistribution of recycled water for reuse within the building. This contributed to such buildings achieving high "Green Star" environmental accreditation, thereby being able to secure higher rents to offset the additional capital cost of fitting the buildings with dual reticulation. The Melbourne City Council, Sydney Water, Melbourne Water, and the South Australian Water Corporation were among leaders with new buildings that were both energy- and water-efficient. Recycled water has also been returned to rivers to add to environmental flows, offsetting water removed upstream. Managed aquifer recharge began to be introduced for the storage of recycled water until needed, responding to the minimal winter/peak summer demand for irrigation water for public parks and amenities. Some systems used reverse osmosis (RO) and advanced oxidation processes (AOP), while others used ultrafiltration (UF). An interesting example was the UF system installed in Adelaide's Glenelg Wastewater Treatment plant, the recycled water being piped to Adelaide Airport and also the Parklands, which surround Adelaide's Central Business District.

Municipal Investment

In 2004, a Water Smart Australia program was announced. This provided for investment in the conservation and more effective utilization of water resources. "Diversity of supply" through the provision of alternative water sources became the new driver. The Federal government contributed financially to recycling and desalination initiatives to "accelerate the development and uptake of smart technologies and practices in water use across Australia." Within two years, 48 percent of the investment had been directed towards water recycling projects. Some projects were developed in "near emergency conditions." Ultimately, the program ran until June 2012, supporting 78 projects with total costs of AUD$5 billion, $1.5 billion of which came from the Federal government.

Following the unprecedented water restrictions having been introduced in all mainland capital cities, seawater desalination plants were urgently developed for Perth (2), Sydney, Adelaide, Queensland's Gold Coast, and Melbourne. These plants, with a total annual capacity of 530 gigaliters (GL) — roughly 120 billion gallons (BG) — involved a variety of design, funding, and technical development methods, but all were fundamentally dependent on RO. The Queensland government developed Advanced Water Recycling Plants adjacent to Brisbane Waste Water Treatment Plants at Bundamba, Luggage Point, and Gibson Island, with a capacity of 84 GL (19 BG) per year. The scheme, known as the Western Corridor Scheme, was based on the manufacture (as it was described) of purified recycled water by microfiltration (MF), RO, and AOP. The recycled water was to be pumped as "indirect potable" to the Wivenhoe Dam. A portion of the flow was to be used for cooling at two power stations which were then using 10 percent of Brisbane's daily drinking water consumption. Brisbane's water resources were linked together with the Gold Coast desalination plant to form a water grid. The whole project was completed urgently within two years and involved constructing 208 km (129 miles) of pipelines.

Figure 2. The Glenelg Wastewater Treatment Plant generates recycled water with these ultrafiltration modules followed by advanced oxidation (UV and chlorination) with the consequent saline stream piped to the much larger Bolivar plant for further treatment.

Lessons Learned

Unfortunately, most of these projects came to fruition as the drought came to an end with localized but widespread flooding in 2010. The Wivenhoe dam filled to 200 percent of water storage capacity as the "head space" served as a flood control dam. Hence, the Western Corridor Scheme has never been used for its intended purpose of supplementing Brisbane's water


FLYGT
a xylem brand

Figure 3. Melbourne Water uses these ozone generators as components for treating secondary effluent at its Eastern Treatment Plant at Carrum, using a pre-ozone/biological media filtration/postozone/UV/chlorine process train to improve discharge quality and produce water suitable for horticultural irrigation and potential third (purple) pipe domestic use.

supply, and the Advanced Water Treatment Plants are now closed. With hindsight and with secured public acceptance, it might have been much cheaper to use the product water as “direct potable” to the nearby Mount Crosby Water Treatment Plant. The Gold Coast, Sydney, and Melbourne desalination plants have never had regular use, though 50 GL (11.4 BG) of water has been ordered from the Melbourne plant for 2016. The two Perth desalination plants have been in full operation since constructed; that in Adelaide has been kept running at 10 percent capacity. The investment in alternative water sources (some would say too generously) has had an impact on the capital management and costs of water utilities. The Victorian Auditor-General observed in 2013 that interest-bearing liabilities had increased from 2009 to 2013 by 248 percent in that state, with interest representing 21 percent of total operating costs. Servicing the debt and repaying it are now major challenges for the water industry in Australia’s capital cities.

Future Focus

Towards the end of the drought, the Federal Government established the National Urban Water and Desalination Plan to “reduce reliance on rainfall dependent sources by supporting infrastructure projects and research in desalination, water recycling, and stormwater harvesting and reuse.” This program included funding of research over five years for a newly created National Centre for Excellence in Desalination (NCED) in Perth and an Australian Water Recycling Centre of Excellence (AWRCoE) in Brisbane, each supported with AUD$20 million, to which additional funding was added by co-investment from governments, research agencies, and water utilities.

The National Centre for Excellence in Desalination had objectives of leading and coordinating national research in energy-efficient desalination technology, building national capacity and capabilities in desalination, and to advance the science of desalination with specific application to Australia’s unique needs and challenges.

The Australian Water Recycling Centre of Excellence had four goals: incorporating new technologies; establishing a national validation framework for elements of water recycling; having recycled water accepted for drinking; and developing a national knowledge base for recycled water.

Industrial/Decentralized Reuse

Initially, a summary of learnings from already-introduced recycling plants across Australia showed that unexpected circumstances could change the direction of introducing water recycling. New technologies explored included the use of recycled water in the food industry. Recycled water has been promoted in the meat industry, and a pilot installation of water reuse was made in a dairy factory where limited access to additional water was precluding expansion. Elsewhere, the use of recycled water from dairy manufacturing was evaluated to support pasture irrigation to increase milk supply. Water restrictions had already induced two large Queensland breweries to turn to water recycling to maintain production.

It was recognized that the economics of business cases would ultimately determine whether recycling was adopted by industries. Modeling programs have been developed for commercial use to evaluate the economic viability of reuse proposals. Hydrogeological modeling was adopted in Perth, where limits to reticulated water availability, declining groundwater availability, and seawater intrusion were constraining industry expansion in the city’s principal heavy industry area. Accessing water from a nearby treated wastewater

Figure 4. A pilot plant was built at Luggage Point, Brisbane, to check the MF/RO technology before the full scale Advanced Water Treatment Plants were built, highlighting the need to recognize that influents to recycling and desalination plants can vary considerably.

Some projects were developed in "near emergency conditions."

marine outflow for managed aquifer recharge was established as a potentially viable longer-term investment; it would also protect the amenity value of groundwater-fed lakes and hence, the capital values in an adjacent developing suburb. As a result, governance of water resources in the area is now being reviewed.

Achieving Class A recycled water for irrigation from unfiltered secondary wastewater can be difficult, as suspended particles present in the wastewater can protect pathogens from UV and chlorination disinfection. A protocol was developed for the validation of pasteurization for wastewater recycling for use by future proponents of pasteurization technology as an alternative to UV and free chlorination.

A particular challenge was the construction and testing in Tasmania of a small, stand-alone, minimum-maintenance advanced water recycling plant for ultimate use at an Antarctic research station to preclude environmental damage from previous wastewater discharges. After a further year of testing, it is intended to be deployed at the Australian Antarctic Division's Davis Station. The operators of other nations' Antarctic bases have expressed interest in the development, as those bases also face the same environmental issues as the Davis base.

The validation project was established to minimize the necessity of the validation (confirming that the treatment technology meets the specified performance targets) of every new reuse plant where proven standard technology had been adopted. Developed in association with the National Recycled Water Regulators' Forum (comprising state/territory regulators), the research has explored validation protocols for membrane bioreactors (MBRs); RO membranes; activated sludge treatment; use of Bayesian Nets (BNs) to measure system performance, as well as producing validation conclusions through the formalized description of cause-effect relationships that define treatment process mechanisms and observational data; and methods for pathogen isolation, culture, detection, and enumeration.

Figure 5. Water from an on-farm recycled water holding basin being used to irrigate dairy pastures in Shoalhaven, New South Wales

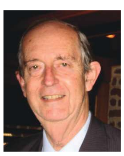
Coming To America

The goal of seeking to gain acceptance of direct potable recycling for drinking has generated many products that can be used in community awareness and participation programs. More recently, the WateReuse Research Foundation (WRRF) has joined with the Centre because of the current concern about water resources in California. Some of the short videos developed by the Centre can be found on the WRRF website at https://watereuse.org/water-reuse-101/videos/how-reuse-works/. Other products include independent reviews commissioned from the Australian Academy of Technological Sciences and Engineering, entitled *Drinking Water through Recycling* and *Wastewater, an Untapped Resource* (www.atse.org.au).

The National Knowledge Base of information contains details of the AWRCoE research outcomes. In addition, a database of climate-resilient water sources, jointly developed by the Water Recycling Centre and Desalination Centre, is managed by the Australian Bureau of Meteorology and lists 268 recycling and 92 desalination plants in the country, along with their technology and use (www.bom.gov.au/water/crews).

However, despite the very substantial investment in water recycling facilities and technologies, Australia's water resources are not currently under great pressure, resulting in government policy orientation and investment turning elsewhere. The two Centres of Excellence have effectively completed their programs and potential sources of additional funds are not evident. Australia has much to show for its adoption of water recycling over the past 30 years. Yet there is a message for the U.S. — even after it has started raining and the snowpack has returned, innovation capabilities in water recycling should continue to be nurtured, as droughts will come again, and mankind's demand for water is increasing inexorably. ■

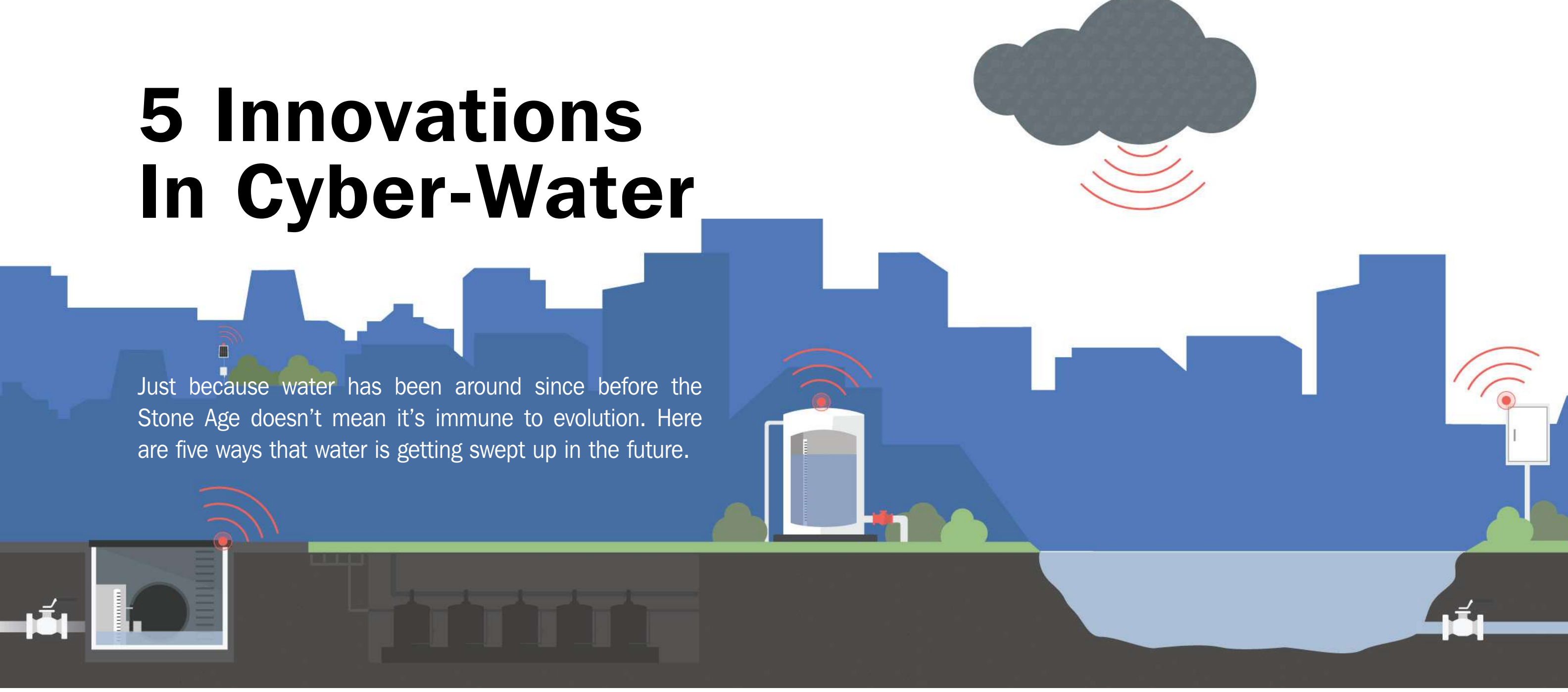
About The Author



Dr. John Radcliffe outlines his perspective of water recycling in Australia from his position as chair of the Research Advisory Committee of the Australian Water Recycling Centre of Excellence. He is an Honorary Research Fellow of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and before retirement was its Deputy Chief Executive. Earlier, he was Director-General of Agriculture in South Australia. He has been a Commissioner of Australia's National Water Commission, is a Member of the Order of Australia (AM), and Fellow of the Australian Academy of Technology and Engineering (ATSE). He has an Agricultural Science degree from the University of Adelaide and a PhD from Oregon State University.

5 Innovations In Cyber-Water

Just because water has been around since before the Stone Age doesn't mean it's immune to evolution. Here are five ways that water is getting swept up in the future.



By Peter Chawaga

Some researchers say that the Earth's water is even older than the sun, arriving on the planet as it formed by way of interstellar ice. It's the genesis for all life as we know it, central to our earliest civilizations, and still as important to our existence as it has ever been.

But despite water's consistency through time, we are always getting smarter about how we use it. Early Rome had its aqueducts, the Industrial Revolution relied on steam power, and today's innovations are creating a bright new world of digital water. Things like supervisory control and data acquisition (SCADA), modeling programs, simulation training, cybersecurity, advanced metering infrastructure (AMI), and Big Data analytics are making it easier and more efficient than ever to treat the prehistoric substance and bring it to those in need.

To explore the intersection of technology and water, what's currently possible and what we're poised to discover in the future, *Water Online* reached out to some select leaders in water technology and asked them about their most compelling projects. We've painstakingly narrowed those ventures down to our top five innovations in cyber-water.

1. WatrHub: Harvesting water data to advance the adoption of new treatment technology

Change can be difficult to predict in the treatment industry. It's often a safe bet that things won't change too quickly ... until they do. But which cities are most likely to adopt advanced metering infrastructure? Which utilities will replace their underground networks next?

Predicting where innovation will take hold seems like a lucrative power, and WatrHub has led the charge to do so. By accessing millions of capital plans, financial documents, and permits from cities and towns across the country, the company has merged a massive amount of data that it can use to forecast the future water innovation needs of a given municipality.

During a recent interview, a vice president of marketing at a large U.S.-based water technology company told WatrHub that its product was able to analyze his market blind spots and create a sales target map including cities that had a strong need for his treatment technology. "Now [with WatrHub] they had a blueprint to start a meaningful relationship in order to help upgrade the city's treatment infrastructure," said a WatrHub representative.

2. The Water Equipment And Policy Research Center: Probabilistic reliability evaluation of water distribution networks

A water system is an interconnected network of water sources, pipes, pumps, valves, regulators, tanks — everything it takes to get water to consumers quickly and safely. As a complicated network of sophisticated equipment, our water systems are prone to failures that affect public health and take a heavy financial toll.

To combat these failures and prepare for rapid response, the Water Equipment and Policy (WEP) research center developed a software tool for the probabilistic, quantitative evaluation of water systems, which accounts for a variety of indeterminate factors that might tamper with them.

"This software tool is developed based on a generic, holistic procedure for building high-confidence reliability models of water distribution systems, from which a comprehensive set of reliability indices can be calculated, indicating the probable, expected number of occurrences [that harm the system], expected frequency and duration, and expected amount of water not supplied," explained Lingfeng Wang, an associate professor at the University of Wisconsin-Milwaukee, who worked on the software with WEP.

The decision tool can evaluate the reliability of different systems and has a user-friendly interface that can be utilized by utilities, urban planners, policymakers, or anyone else who needs to make an informed asset management decision in the water sector.

3. Water Planet: AI-based software that controls water filtration systems

No longer just the preoccupation of robot-fearing movie characters, artificial intelligence (AI) has reached the point that it can be leveraged for water treatment purposes. Water Planet, a water treatment and reuse company founded in 2011, has developed its IntelliFlux software to control membrane filtration systems automatically. The system can adapt when influent conditions change, to keep everything stable and maximize water recovery, process uptime, and filter life. The software can be used to control virtually any type of filter that needs backwashing, cleaning, or regeneration. It's being used in an effort to clean produced water for agricultural reuse in Bakersfield, CA, which is looking to expand.

"Currently, we have a system on-site from Water Planet that does 500 barrels a day," Dundee Kelbel, the manager of Sweetwater Tech Resources, told local broadcasters about the project. "But, our intent is obviously to put in an industrial facility long-term ... which would handle about 25,000 barrels — a million gallons, if you will — on a daily basis."

4. OptiRTC: Stormwater infrastructure through active control and reporting

According to OptiRTC, the U.S. discharges over 900 billion gallons of raw sewage into natural bodies of water every year through combined sewer overflows. This, along with the fact that stormwater runoff carries pollutants to said bodies, inspired the two-year-old tech company to develop its platform for enhanced stormwater infrastructure.

With OptiRTC's system, rain is collected from roofs and stored in basement cisterns. When the weather forecast calls for rain, water is automatically discharged from these cisterns to accommodate the oncoming runoff. The water that's been collected can be reused for agriculture during dry periods. This system enables stormwater management facilities to increase retention times and infiltration, reduce downstream erosion, and improve water quality. The company claims that its platform is 30 to 80 percent less expensive over its lifetime than traditional retrofits. To date, it's been employed in more than 19 states.

5. Dropcountr: Smartphone connections for customers and utilities

It's clear that all of our interactions are moving to a more digital place. There is certainly still a need for traditional communication — face-to-face, through mail, and by telephone — but many consumers would prefer to interface with their water providers the way they do with everyone else: through their smartphones.

Dropcountr is an app for mobile devices that connects utilities with customers. It allows customers to see their water usage and compare it to that of their neighbors, connect to rebate offers, and stay on top of leaks or abnormalities. Utilities can use the app to send targeted messages directly to the consumers that need them, access advanced analytics, and find out who uses the most water and why. ■

About The Author

Peter Chawaga is the associate editor for ***Water Online***. He creates and manages engaging and relevant content on a variety of water and wastewater industry topics. Chawaga has worked as a reporter and editor in newsrooms throughout the country and holds a bachelor's degree in English and a minor in journalism. He can be reached at pchawaga@wateronline.com.

Simple Steps To Drive Down The Cost Of Desal

Using natural gas to power the mechanical vapor compression unit – the "heart" of conventional desalination and its most energy-intensive process – may prove to be an economic game-changer.

By Tomer Efrat and Hadar Goshen

In a time when gas prices are plummeting across the globe, traditional methods employed in many industries must be reexamined from a techno-economic standpoint. One such example is the water desalination industry, and more specifically, the mechanical vapor compression (MVC) application.

Conventionally, an MVC unit utilizes an electric motor to drive its compressor, which is the central component in this desalination method, accounting for 80 to 90 percent of the plant's overall power consumption. The compressor induces the temperature difference required for the evaporation/condensation process, in which seawater is converted to high-quality distillate.

The electric motor driving the compressor can be replaced with a gas engine, thus dramatically reducing the operation costs.

The gas engine (which is standard industrial equipment) utilizes all types of gas — from petroleum gas to natural gas — in an inner-combustion chamber, to facilitate the mechanical drive to the compressor. The waste heat from the gas engine can be further utilized in the MVC unit to reduce the heat transfer area, which in turn reduces the capital costs of the unit, making the investment all the more worthwhile.

The electric motor driving the compressor can be replaced with a gas engine, thus dramatically reducing the operation costs.

These modifications can be done in new plants or as a retrofit to existing plants. In this article, we review the economic implications and the advantages of the innovative solution of a gas-driven MVC unit.

Natural Gas In The U.S.

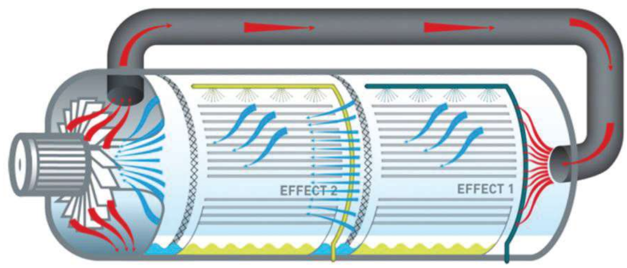
Natural gas has served a growing role in the U.S. economy in the last decade, second only to petroleum as the primary source of energy and the primary source of energy when it comes to power generation.[1] Since 2009, the U.S. has been considered the world's largest producer of natural gas, increasing the natural gas availability for local markets. As a result, the U.S. power and industrial markets benefit from some of the lowest natural gas prices in the world. These low prices, together with other benefits of using the natural gas as an energy source, such as its environmental aspects, encouraged a rapid growth in the use of natural gas for a growing number of industries. As a result, the natural gas consumption in the local U.S. market has increased by about 25 percent in the last decade,[2] during which period the U.S. natural gas reserves have climbed by 49 percent. These figures alone indicate the large potential that still exists for the growth of natural gas consumption in the U.S., encouraging developers to introduce more innovative ways to utilize natural gas.

MVC Process Description

The MVC process is an evaporation-condensation distillation process utilizing a centrifugal compressor to generate the motive energy for distillation.

The feed water enters heat exchangers where it is heated by the discharged distilled water and brine, thus recovering process heat. Next, the feed water enters an auxiliary deaerator/condenser in order to remove non-condensable gases (NCG) from it. The heated and deaerated feed water then flows to the evaporator through spray nozzles, forming continuous, thin water films over the horizontal tubes of the evaporator.

Since the suction of the compressor provides a pressure lower than the equilibrium pressure of the brine film on the tubes, part of the brine flashes into vapor. The vapor generated passes through a set of deflectors, louver demister, and mesh demister to remove droplet carryover and maintain the purity of the distillate. The vapor is then compressed by the compressor and discharged into the tubes of the evaporator at a pressure that is now slightly higher than the liquid-vapor equilibrium pressure. The vapor inside the tubes condenses, transferring its latent heat of condensation across the walls of the tubes to the brine flowing on the outside, thus providing the required heat to initially raise the temperature of the brine to its liquid-vapor equilibrium temperature, and then to evaporate part of the brine. The newly created vapor is then drawn out by the compressor. The condensed vapor from the evaporator is collected and pumped out as distillate. The brine and distillate are rejected out of the evaporator by pumps, and on the way out they



Flow scheme of MVC (mechanical vapor compression) unit

exchange heat with the incoming feed water and then flow out.

This process can be done in one effect, as well as with two or three subsequent effects.

The MVC low-temperature process is suitable for industrial uses,[3] such as boiler feed water, flue gas desulfurization (FGD) make-up water, cooling-tower make-up water, and others.

Driving The Compressor With A Natural Gas Engine

As previously mentioned, the main innovative feature of this MVC method is driving the MVC unit with a gas engine. A gas engine, as opposed to an electric motor, is an internal combustion engine where the gas is mixed with air, compressed, and burned to yield mechanical power. This power can be converted to electricity (by coupling it to an electric generator) or used as a mechanical drive (not very different from the mechanism in a natural gas vehicle). In the case of MVC, it is not necessary to convert the power into electricity and then back to a mechanical drive. As a result, the conversion/transmission-related losses are spared, as well as the equipment costs associated with them.

As the gas engine rotates at relatively low speeds (1,400 to 1,800 rpm) and the compressor usually rotates at higher speeds (2,500 to 3,600 rpm), the gas engine is connected to the compressor via a gearbox, which increases its rotation speed. The dimensions of the gas engine are fairly similar to those of an electric motor, so it can still be installed on top of the unit.

A gas infrastructure is required on-site. The required gas pressure at the inlet to the engine is between 1.5 and 50 pounds per square inch gage (psig), depending on the engine size. A pressure regulator can be an integral part of the system. The gas engine can consume natural gas, biogas, petroleum gas, coal seam gas, and other types of fuel gas.

Heat Recovery

The typical efficiency of a gas engine is about 40 percent, meaning that about 60 percent of the energy input will not be converted to mechanical energy. Instead, it will be lost as heat energy, where 40 percent is lost to the atmosphere (whether through the exhaust gases or by radiation), and the additional 20 percent is lost to the engine cooling systems (jacket water cooling or oil cooling).

Therefore, when considering the use of a gas engine, utilizing its waste heat would be a smart move.

In an MVC/gas-engine integration, there are several options for use of the waste heat:

1. *Heating the feed water* — As mentioned, the MVC incorporates two heat exchangers that recover the heat from the product and brine streams in order to preheat the feed water. In this innovative solution, the waste heat from the gas engine is utilized for the same purpose and contributes to minimizing the heat exchange areas, thus reducing cost.

   The waste heat can be recovered from the gas engine's oil cooling cycle or the jacket cooling water cycle.
2. *Producing steam* — The exhaust gases of the gas engine are released at a fairly high temperature of 400 to 500°C (750 to 930°F). This heat source can be utilized to produce steam by employing a heat recovery steam generator (HRSG). The source water for this steam would be the product water of the unit (or service water).

   The steam can be used to heat the MVC unit at startup, to assist a stripping process (if the feed water contains any constituents that should be removed prior to entry to the MVC unit), or sent to any other industrial processes, thus improving the heat rate of the plant.

Carbon Dioxide Recovery

An additional benefit from the exhaust gas stems from its chemical composition. The main emission product from natural gas combustion is carbon dioxide (CO_2), which can be harnessed to increase its value.

When the designation of the distillate from the MVC unit is drinking water (rather than high-quality process water/boiler feed water), a post-treatment stage is necessary. Usually, the post-treatment process involves the dissolution of limestone (calcium carbonate [$CaCO_3$]) into the product water to regain hardness (calcium), which in turn decreases the corrosion potential of the water (calculated by Langelier saturation index [LSI]). When looking at the carbonate system, this dissolution takes place at low pH levels, which are achieved by dosing either acid or CO_2 prior to the limestone reaction chamber.

In the case of using a gas engine, the CO_2 can be recovered from its exhaust gases and used in the post-treatment process, thus decreasing greenhouse gas (GHG) emissions, as well as reducing the operational expenses (OPEX) of the plant.

Techno-Economical Evaluation

A techno-economical evaluation was performed to assess the benefits of this system. In the presented case study, we considered an MVC-1000 unit, a fairly commonly used unit from IDE Technologies. This two-effect unit produces 1,000 m^3 (264 kgal)/day (or 264,000 gpd) of distillate, with a specific power consumption of about 11 kWh/m^3 (of which 9.6 kWh/m^3 accounts for the compressor).

The electricity price was taken as $0.1/kWh and natural gas price as $2.5/MMBtu (1 MMBtu = 1 million BTU [British thermal units]), which is a conservative value. From the

Parameter	Unit	MVC Electric	MVC Gas
Capacity	m^3/day (kgal/day)	1000 (264)	
Electricity	kW	450	55
Gas	MMBtu/m^3 (MMBtu/kgal)	-	0.085 (0.322)
OPEX	\$/m^3 (\$/kgal)	1.30 (4.9)	0.55 (2.1)
CAPEX	M$	3.7	3.9
Estimated Water Cost	\$/m^3 (\$/kgal)	2.15 (8.15)	1.40 (5.30)

MVC Electric vs. MVC Gas Comparison Chart

investment point of view, the return period is 25 years, with 6 percent interest. Under these assumptions, and without including the heat and CO_2 recovery, we have calculated the OPEX and capital expenses (CAPEX), which, when summed up, yield the water cost.

The OPEX takes into account electricity, gas, chemicals, labor, and maintenance costs. The CAPEX takes into account the cost of the MVC unit, gas engine, and the balance of plant (BoP).

As can be seen in the comparison table (above), the operational expenses are reduced by more than 55 percent and the total water cost by 35 percent. With an integrated heat recovery, the costs reduction is even higher. The ROI is approximately one year, which makes this a rewarding proposal for both new and refurbished plants.

Enumerating Value

1. *Unit efficiency and heat rate improvement*
   a. Waste heat can be recovered from the gas engine to decrease the specific cost of the MVC unit (by minimizing the heat transfer area).
   b. At the same time, the waste heat can be used for steam production, thus increasing the heat rate of the plant.
   c. CO_2 can be recovered to the post-treatment (remineralization) process, to decrease the OPEX of *the plant.*
2. *Electric infrastructure minimization* — No need for medium voltage transformer, switchgear, MCC, cables, and conduits.
3. *Easy refurbishment of existing plants* — As weight and dimensions are comparable in size, it is easy to replace the electric motor with a gas engine.

As gas prices drop, it becomes evident that integrating a gas engine instead of an electric motor in an MVC unit, in order to drive the centrifugal compressor — the "heart" of the unit — eliminates the need for most of the electricity in the plant.

While not inflicting higher costs, the gas engine variation is able to reduce operation costs by more than 55 percent, and the total water cost by a third, with an ROI of about one year. The use of heat recovery will further increase savings and improve the heat rate of the plant. This modification of installing a gas engine is possible in both new and refurbished plants, making it a promising solution for the desalination market. ■

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About The Authors

Tomer Efrat is the process engineering manager at IDE Technologies, where he is responsible for the process design of IDE Technologies' seawater desalination and industrial water treatment plants. Tomer has more than a decade of experience in desalination and treatment of seawater and industrial water. He has been with IDE for more than 10 years, first as a process engineer, and later as deputy manager and manager in the thermal process department. In these positions, Tomer has been closely involved in the commercial activities related to the process design of seawater desalination, industrial water treatment, and ice plants. In addition, he leads a team of highly skilled process engineers in the execution and implementation of the company's R&D program and supports sales and marketing and business development activities. He holds several patents and pending patents for water treatment technologies. Efrat has an MBA and a B.Sc. in mechanical engineering from Tel Aviv University.

Hadar Goshen is the thermal desalination process team leader at IDE Technologies, and has been overseeing advancements in IDE's thermal desalination since 2015. He previously served as a process engineer for five years, where he participated in project process design and worked with external suppliers. Goshen holds two patents for the water vapor deposition process and freeze desalination. Goshen has an M.Sc. in systems engineering from the Technion – the Israel Institute of Technology, and a B.Sc. in mechanical engineering from Tel Aviv University.

Energy Boost: From Biogas To Bio-Methane

A pilot project demonstrates how biogas purification yields better fuel in the form of high-purity bio-methane.

By Patrick J. Evans with Gokhan Alptekin, Ambal Jayaraman, and Michael Stevens

Food is the largest component of municipal solid waste (21 percent), and currently innovative processes are being developed that divert food waste from landfills to recover this valuable resource. Anaerobic digestion is an effective process where food wastes including pre- and postconsumer food waste, waste cooking oil, and grease trap waste can be converted to biogas. This biogas can be further purified and converted to bio-methane, which contains more than 95 percent methane. Bio-methane can then be used for transportation purposes or to generate combined heat and electricity using fuel cells. A major challenge is cost-effectively purifying biogas, while simultaneously minimizing energy requirements.

Biogas is frequently produced by anaerobic digestion at municipal wastewater treatment facilities and at wastewater treatment plants for the food and beverage industry. Biogas is the result of decomposition of organic wastes, but the methane is diluted with large amounts of carbon dioxide (greater than 30 percent), and it therefore possesses less energy per unit volume than pipeline methane (natural gas). In addition to carbon dioxide (CO_2) and methane (CH_4), the biogas generated in the digesters and fermentation units also contains moisture at saturation and various trace contaminants such as sulfur compounds (e.g., hydrogen sulfide) and siloxanes. These contaminants must be removed and CO_2 and other inerts reduced to produce a higher-quality fuel that contains more than 90 percent methane (bio-methane).

Biogas Purification Challenges

Although various adsorbents or solvent systems are available to remove hydrogen sulfide (H_2S), the most common form of sulfur in the biogas, the biogas also contains a wide range of organic sulfur compounds, from mercaptans to higher-molecular-weight disulfides. Unfortunately, the conventional desulfurization systems do very little to remove the organic sulfur compounds, particularly the disulfides. The conventional sorption systems such as iron sponge also have disadvantages with respect to safety and material handling. Another class of compounds present in biogas are siloxanes. Siloxanes are generated during anaerobic digestion of waste-activated sludge that concentrates silicone-based personal hygiene, healthcare, and industrial products. Siloxanes must be removed from biogas prior to use as an energy source.

Biogas Purification System Description

A low-cost, two-stage, complete biogas purification system has been developed by TDA Research in Wheat Ridge, Colorado, that removes various contaminants, such as inorganic sulfur, organic sulfur, siloxanes, CO_2, and moisture to produce greater than 95 percent bio-methane. The purification system was recently demonstrated in biogas derived from anaerobic digestion of food wastes at the U.S. Air Force Academy (USAFA) in Colorado Springs, Colorado, to demonstrate mono-digestion of food waste; fats, oil, and grease (FOG); solids reduction; and stable bio-methane production. Two replicate digesters were operated for nearly one year, and a mixture of food waste and canola oil was fed to the digesters at various organic loading rates.

The first stage is for sulfur removal and is based on a low-cost, high-capacity, and expendable sorbent called SulfaTrap™ that simultaneously removed sulfur and siloxane down to ppb levels. The second stage is a vacuum swing adsorption (VSA) system based on a regenerable mesoporous carbon media modified with surface functional groups to reduce the CO_2 and H_2O concentration in the biogas to pipeline specifications. Figure 1 shows the two-stage biogas purification process to bio-methane.

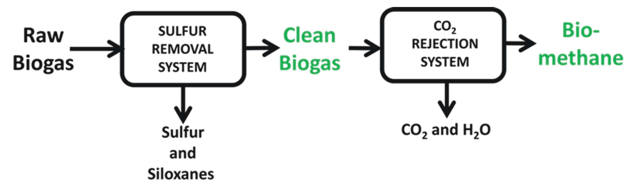

Figure 1. Two-stage biogas purification process to bio-methane

The second stage is for CO_2 and moisture rejection and is based on a VSA system that uses TDA Research's proprietary CO_2 adsorbent to reduce the CO_2 and other inerts in the biogas to less than 5 percent. The approach is similar to the pressure swing adsorption (PSA) and VSA systems that have been successfully used for years in small- to medium-scale air separation processes to produce very high-purity oxygen. A simple vacuum swing cycle consists of three steps. The adsorption of CO_2 from the biogas stream is carried out at the biogas delivery pressure (about 1.3 absolute atmospheric pressure [atm]), while the sorbent is regenerated and CO_2 recovered under vacuum (at about 0.2 absolute atm). The bed is subsequently pressurized with the feed (biogas) gas. The methane loss from the system is reduced by using intermediate pressure equalization steps between the main adsorption and regeneration portions of the cycle. The methane loss with the full vacuum swing cycle is minimal (i.e., less than 10 percent).

Bench-Scale Tests

The CO_2 sorbent's performance was demonstrated in a bench-scale, two-bed vacuum swing system (Figure 2). This system is capable of counter-current adsorption and desorption operation simulating the VSA operation expected in the full-scale system. In this system, the desired gas mixtures (CH_4 and CO_2) are directed into a bench-scale reactor that contains the sorbent. All gas flows are controlled with electronic mass flow controllers. An in-line sparger is used to introduce moisture at 100 percent relative humidity in the biogas. After mixing in a manifold, the feed gas mixture is then directed into the reactor. A valve system allows the gases to bypass the reactor and flow directly to the analytical system for accurate measurement of the feed gas composition as needed. The sorbent reactor consists of a 1.5" outside-diameter spring-loaded stainless reactor. One hundred grams of sorbent particles in the 8-20 mesh size are loaded into the reactor for testing. The reactor is spring-loaded and has a length/diameter (L/D) ratio of 8 with a bed volume of 100 milliliters (ml). The reactor has three thermocouple ports to monitor the sorbent bed temperature. A back pressure regulator is used to control the adsorption pressure. After exiting the reactor, the CO_2 and CH_4 content of the stream are monitored by an on-line NOVA multi-gas analyzer and Vaisala CO_2 and humidity probes. Continuous analysis of CO_2 allows the monitoring of breakthrough gas concentrations and measurement of total CO_2 adsorption capacity. The desorption line is equipped with a BOC Edwards scroll (oil-free) vacuum pump. The pump can easily reach vacuums of less than 1 pound per square inch absolute (psia). The apparatus is fully automated using a control system from Opto 22 Corporation and can run without an operator for long periods of time, including overnight. The control system controls the test conditions, logs the analytical data, and also safely shuts down the apparatus in case of a malfunction. A simulated biogas composition of 60 percent CH_4 and 40 percent CO_2 on a dry basis were used for the bench-scale evaluations (water content was 3 percent by volume).

Figure 2. Bench-scale, two-bed VSA system

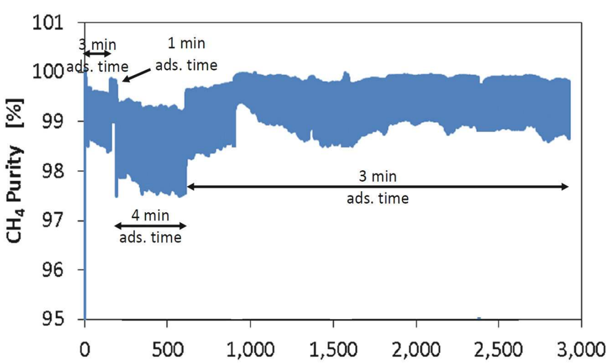

Figure 3. Bench-scale tests in a two-bed vacuum swing cycling system. CH_4 = 60 percent, CO_2 = 40 percent, (dry basis), H_2O = saturation at 22°C, space velocity = 125 $hour_{-1}$; T = ambient, parallel and distributed simulation (P_{ads}) = 19.0 psia, parallel discrete event simulation (P_{des}) = 0.2 psia, L/D = 8.

In these bench-scale tests, the life of the sorbent was demonstrated for over 2,900 cycles without any loss in performance, and the sorbent beds produced high-purity methane above 99 percent. Figure 3 shows the results from these bench-scale tests.

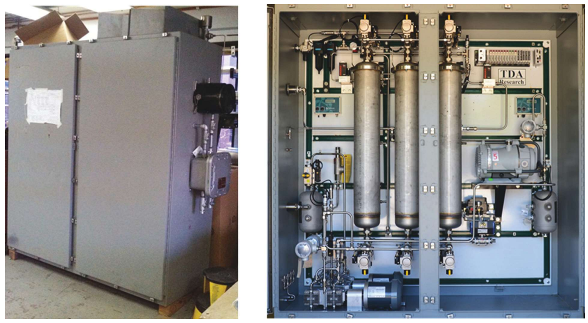

Figure 4. Picture of the pilot scale VSA system for CO_2 and moisture removal from biogas

Pilot-Scale Tests

A pilot-scale, fully automated, VSA-based carbon dioxide and moisture removal system for biogas was designed and fabricated. This system is part of the biogas purification subsystem and is installed downstream of the SulfaTrap desulfurization system and a biogas storage sphere. The storage sphere was used to store biogas and feed the carbon dioxide and moisture removal system. It can achieve greater than 95 percent methane (CH_4) purity in the product gas with greater than 90 percent methane recovery, reducing the inerts to less than 3 percent (i.e., combined nitrogen [N_2] and CO_2) in the product gas and a moisture content lower than 7 lbs/millions of standard cubic feet (MMscf).

The system was designed and fabricated for operation in a Class 1 Division 1 environment and is skid-mounted inside a NEMA 4 enclosure equipped with a purge system and is rated for installation in an outdoor environment. Figure 4 shows a picture of the system after fabrication.

The purification system was demonstrated in conjunction with a food waste anaerobic digestion study conducted at the USAFA. This particular test site was selected due to the plentiful supply of food and grease trap waste. The pilot-scale biogas purification system was installed and tested with biogas generated via anaerobic digestion of a variety of food wastes, including pre- and

Sample Date:	Raw biogas 7/16/2014	Sweetened biogas 7/16/2014	Bio-methane 7/16/2014
CH_4	64.40	61.70	96.35
CO_2	34.80	36.00	2.03
N_2	0.60	1.66	1.11
O_2/Ar	0.23	0.67	0.52

Table 1. Typical composition of raw, sweetened biogas and bio-methane from food wastes during field tests

postconsumer food waste, waste cooking oil, and grease trap waste to produce pipeline-quality bio-methane. Typical composition of the raw biogas and the bio-methane produced in the field tests are provided in Table 1. The sulfur in the raw biogas was typically around 1,000 to 1,500 ppm H_2S with trace amounts of organic sulfur compounds. SulfaTrap-R7 desulfurization sorbent removed the sulfur compounds to less than 0.25 parts per million by volume (ppmv).

Initially, breakthrough tests were carried out with the CO_2 sorbent beds in the field using desulfurized food waste-derived biogas to measure the capacity of the saturated VSA adsorbent bed, which were above 4.4 weight percent (wt%) CO_2. The VSA cycles were optimized in the field, and the optimized VSA cycle scheme was used to produce high-purity bio-methane with methane recovery greater than 90 percent. VSA cycle schemes with both feed-end and product-end pressurizations provided working capacities in excess of 2.8 wt% and the CO_2 concentration in the bio-methane product was reduced to less than 0.5 percent by volume. The dew point of the biogas was reduced from 10° to 15°C to less than -35°C, providing essentially a dry bio-methane product. Figure 5 shows the methane purity of the bio-methane as measured by an IR-based methane analyzer. The biogas purification system was operated for a total of 50 hours, purifying more than 4,000 standard cubic feet (scf) of biogas to produce bio-methane with greater than 90 percent methane recovery.

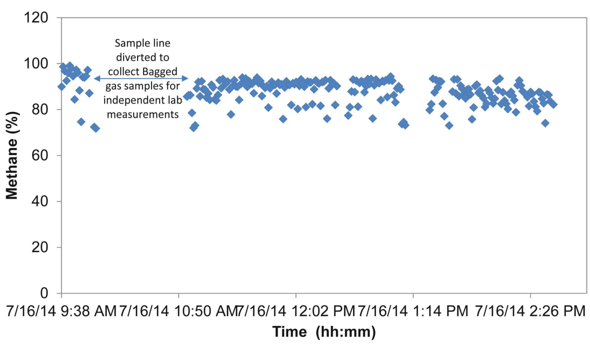

Figure 5. Biogas purification system performance under actual biogas at USAFA (Colorado Springs, CO) showing the high-purity bio-methane production

Economic Evaluation

A VSA unit was designed that is sized to process 1,000 m^3/day of biogas with a composition of 60 percent CH_4, 40 percent CO_2 (on dry basis), and saturated amount of moisture at 24°C. The vacuum power requirement was estimated to be 7.3 kilowatt-electric (kWe), the sorbent bed size to be 336 L/bed, the operating power cost was \$0.04 per m^3 CH_4 produced, and the total operating cost including the sorbent replacement cost was \$0.07 per m^3 CH_4 produced with a methane purity and recovery of 99.5 percent and 80.3 percent, respectively. The methane recovery can be further increased to 90 percent or above by relaxing the methane purity to 96+ percent.

Conclusions

Anaerobic digestion of both pre- and postconsumer food waste, waste cooking oil, and grease trap waste can be converted to biogas. This biogas can be further purified and converted to bio-methane, which contains more than 95 percent methane. Bio-methane can then be used for transportation purposes or to generate combined heat and electricity using fuel cells. A major challenge is cost-effectively purifying biogas, while simultaneously minimizing energy requirements. Several contaminants must be removed, and CO_2 and others inerts reduced, to produce a higher-quality fuel that contains more than 90 percent methane (bio-methane).

The piloting of an innovative biogas purification system at the USAFA has successfully demonstrated a very effective sorbent-based sulfur removal and VSA system for the purification of biogas streams. The pilot enabled the optimization of VSA system performance and demonstrated the sorbent performance in both bench-scale and pilot-scale vacuum swing systems operating on simulated and real biogas derived from food wastes. The pilot-scale unit processed more than 4,000 scf of actual food waste-derived biogas to produce bio-methane with greater than 90 percent methane recovery. The total operating cost for a 1,000 m^3/day bio-methane production was estimated to be \$0.07 per m^3 of bio-methane produced including the vacuum pump power and sorbent replacement cost.

Acknowledgement

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About The Author

Patrick Evans, PhD, is a VP with CDM Smith and has 30 years of experience in environmental remediation, wastewater and drinking water treatment, and renewable energy. He specializes in research, development, and demonstration of innovative technologies in these areas with a focus on chemical engineering and environmental microbiology. He received his PhD in chemical engineering from the University of Michigan and conducted a postdoctoral fellowship in environmental microbiology at the New York University Medical Center. He has served as the principal or co-principal Investigator on numerous research projects funded by the Department of Defense SERDP/ESTCP, the Air Force Civil Engineer Center, the Water Research Foundation, and the Advanced Research Projects Agency-Energy.

A Community Approach To Climate Resilience

How to accumulate and leverage social capital to achieve healthy freshwater ecosystems, green infrastructure improvements, and triple-bottom-line benefits

By Rebecca Wodder

In New Orleans, a devastated neighborhood seeks to revive their community after Hurricane Katrina. They begin by regaining access to a bayou where earlier generations hunted and fished.

In Toledo, OH, 400,000 people go without drinking water for two days, due to a toxic algal bloom brought on by water pollution and high temperatures. In response, low-income residents work together on green infrastructure projects that can reduce polluted runoff while improving property values.

In Fredericksburg, VA, a historic community comes together to protect their river from development and pollution. Working collaboratively with builders, a low-impact development ordinance is unanimously adopted and a new riverside trail becomes a place where residents connect with each other and with nature.

In Portland, OR, a watershed association unites urban, suburban, and rural neighbors in support of creek restoration projects that reduce frequent episodes of flooding and restore salmon habitat.

As these examples show, water is a ready source of common cause. Neighbors come together to defend against floods, droughts, and water pollution and to obtain the quality-of-life benefits of being near, on, or in, clean, sparkling water. There is a vital lesson here for freshwater organizations and agencies. Projects to build *natural capital* in the form of protected or restored rivers, wetlands, watersheds, and green infrastructure that mimics the natural water cycle can also build *social capital*, in the form of trust, collaborative skills, and shared values. In return, social capital can strengthen and sustain freshwater natural capital.

The synergistic role of freshwater in building natural and social capital becomes increasingly important in a changing climate. Since most of the ways in which Americans experience climate change are connected to the hydrological cycle, freshwater organizations and agencies can make important contributions to help communities and regions become more resilient to extreme weather events.

Yet, too often, freshwater conservation strategies focus solely on protecting, restoring, and replicating natural hydrological functions. But, social capital is also extremely important to community resilience. A recent report finds that "promoting social cohesion — in which a society's members cooperate to achieve shared well-being — in communities is an additional and overlooked tool for strengthening climate resilience, with particularly good outcomes in low-income communities."[1]

Restorative Power

Social capital improves freshwater plans and projects, thanks to the knowledge and support provided by engaged local residents. The resulting freshwater assets can then be monitored and maintained by involved neighbors whose collective efforts to rescue a local stream or protect a watershed reinforce social capital by delivering results that people can see, touch, and feel. Shared success builds community pride and reinforces the value of learning to work together.

In his classic book, *Bowling Alone: The Collapse and Revival of American Community*, Robert Putnam details four features of social capital that enable people to work together on a common cause. First, "social capital allows citizens to resolve collective problems more easily." Second, it "greases the wheels that allow communities to advance smoothly." Third, it "widen[s] our awareness of many ways in which our fates are linked." And fourth, social networks act "as conduits for the flow of helpful information to achieve common goals."[2] Experts distinguish between two types of social capital, bonding and bridging. Bonding social capital exists within a homogeneous community, while bridging develops between dissimilar communities. Putnam puts it memorably: "Bonding social capital constitutes a kind of sociological superglue, whereas bridging social capital provides a sociological WD-40."[3]

Communities that invest in both bonding and bridging social capital are better at solving large, complex problems like climate change.[4] Successful collective efforts require trust, shared values and norms, and social networks. Trust is most important and depends on equity and fairness.[5] But social capital is undermined by poverty, inequality, and environmental injustice.

Freshwater initiatives to benefit the most vulnerable communities should be especially careful to prioritize both natural and social capital in their design and execution. Freshwater nonprofit and government agencies are well-equipped to do so. These organizations are trusted

because of their public service mission to protect and restore the shared water resources of their community. They are also respected, thanks to technical knowledge they possess about how to sustain the hydrological commons in the face of climate change and other challenges.

Furthermore, their freshwater protection and restoration plans and projects can create engagement opportunities to bring people together across cultural divides. And these projects often deliver rapid, tangible, and comprehensible results that reinforce the good feelings that come from accomplishing something together.

Shelter From The Storm

Freshwater groups also have much to gain from engaging their community in efforts to enhance climate resilience. As community members begin to see the many economic, ecological, and social advantages of protecting and restoring their freshwater, they will be more likely to turn out for volunteer work days, support local ordinances for low-impact development, and be less likely to waste or intentionally pollute water. Small-scale, distributed green infrastructure alternatives to large, single-purpose stormwater or wastewater treatment plants are easier to build and maintain with the support of engaged neighborhoods and informed residents.

The positive feedback loop between freshwater-related natural and social capital can produce economic, technological, and social benefits for communities and regions.

Economically, ecosystem services provided by healthy hydrologic features and green infrastructure can reduce energy consumption, diminish flood damage, improve public health, and save money on treating water-borne illnesses and lost productivity, as well as reduce the construction and operating costs of water-related infrastructure.[6] This leaves more money for other community priorities — and in people's pockets.

Technologically, green infrastructure depends upon and supports social capital. These nature-mimicking infrastructure projects are generally smaller and more localized than traditional water infrastructure projects. They offer multiple benefits to their community versus serving a single, and often unseen, purpose. As Milwaukee Mayor Tom Barrett testified to Congress regarding the social benefits of natural stormwater infrastructure, "You can't hold a picnic or a tailgate party on a Deep Tunnel."[7] Green infrastructure is flexible and adaptive versus fixed and prescriptive, enabling projects to be adapted to a community's particular needs. And, these small-scale, widely distributed projects offer ongoing opportunities for involvement in establishment, maintenance, and monitoring.

Socially, time spent in nature makes us feel happier and more connected. Neurological research reveals a linkage between human well-being and natural environments, especially those with water elements. "In study after study, those who choose to spend time in nature speak about its ability to make us feel more connected to something outside of ourselves — something bigger, more transcendent, and universal … In another study, people who viewed nature scenes and imagined themselves fully immersed in nature were more concerned with prosocial goals and more willing to give to others."[8]

Rivers and lakes provide attractive, close-to-home spaces where people can gather and relax. And freshwater restoration projects are especially valuable for building a community's social cohesion. "Designing experiences where people come to know each other, where they can expect to encounter one another repeatedly, and where the quality of life is increased for all if each individual thinks of himself as a steward" increases trust and collaborative skills.[9]

That is why environmental justice activists are turning to their freshwater assets as a means of creating positive changes in their communities.[10] For example, in Toledo, OH, a task force "is exploring ways to bring green infrastructure to disadvantaged areas … to help reduce threats and damage from flooding and water pollution and build home equity. These projects help address other community priorities, including reducing crime by turning vacant lots into community gardens, beautifying neighborhoods, and improving access to waterways. Community members work together to maintain green infrastructure, which supports local project ownership and community."[11]

Freshwater initiatives to benefit the most vulnerable communities should be especially careful to prioritize both natural and social capital in their design and execution.

The City of Philadelphia's response to a problem plaguing cities across America — combined sewer overflows — illustrates the economic, technological, and social benefits of tapping natural capital. Rainstorms regularly overwhelmed the capacity of combined storm and sanitary sewers and resulted in raw sewage being discharged into the Schuylkill River. A study done for the city detailed the "triple-bottom-line benefits" — ecological, economic, and social — of green versus traditional infrastructure solutions to the problem. Ecological benefits included water quality improvements and wetland creation. Economically, green infrastructure was cheaper to build and maintain and contributed to poverty reduction by providing local green jobs and energy savings. And Philadelphians benefited from improvements in recreation opportunities, livability, heat stress reduction, and air quality.[12]

A key challenge for freshwater organizing efforts is that "smaller is better" for tapping and building social capital, while freshwater problems generally require larger-scope solutions. A watershed approach can resolve this "dilemma of size and scope."[13] Because every piece of land — whether urban, suburban, or rural — resides in a particular watershed and because a watershed is made up of nested drainage basins of smaller rivers and streams, the connectivity and scalability of freshwater hydrology can be used to link the concerns of communities upstream and downstream.

Another dilemma facing freshwater stewards is how to achieve social cohesion while prioritizing diversity and inclusivity. Ties that link dissimilar groups are harder to build, but ultimately more valuable. "Crafting cross-cutting identities is a powerful way to enable connection across perceived diversity."[14] The common identity of living in the same watershed and depending on the same water resources and hydrological functions offers important opportunities for building bridges between different groups.

Freshwater organizations are well aware of upstream-downstream conflicts and the value of creating common cause to resolve them. As

Sign of the times: Communities are highly incentivized to fight climate change.

some have observed, "What they call an 'unfunded mandate' upstream looks like raw sewage downstream."[15] Similar upstream-downstream conflicts can arise when there is too much or too little water. Increased awareness of impacts on trusted and valued neighbors downstream is an important benefit of strengthened social capital.

5 Takeaways

Whether the challenge is pollution, flooding, or drought, engaging and working effectively with diverse populations within a watershed requires the ability to recognize, tap, build, and sustain the social capital that binds people together in a common cause. Five basic principles can guide collective efforts to protect and restore freshwater resources and build a community's climate resilience:

- **Work with the most trusted members of a community.** Learn and honor their history and knowledge. Identify mutual concerns and shared values. Ensure equitable opportunities for community engagement and shared decision making. Share resources and credit.
- **Prioritize diversity and inclusiveness.** An inclusive approach can increase the depth and range of knowledge available for problem-solving. To be successful in engaging diverse participants requires attention to chronic environmental justice concerns and other community problems that compete for time and attention.
- **Identify existing strengths and adaptive mechanisms for climate resilience, in both natural and social capital.** Especially for the most vulnerable neighborhoods in a community, these resources have been tested and refined over years of serving as their own "first responders" to natural and man-made disasters.[16]
- **Build cohesion among the social networks that make up your community.** Focus on bridging diverse interests and finding common cause. Take small, tangible steps framed in terms of a larger vision, so that success will breed success. Ensure that participants are empowered to make choices and see them enacted in their communities.
- **Support visionary leaders.** Collective efforts require a special type of leader — one who has the ability to see the larger system and build a shared understanding of complex problems, to encourage reflective group dynamics that lead to appreciating each other's reality, and to shift the group's focus from reactive problem-solving to jointly creating a common future.[17]

Finally, recognize that building climate resilience requires an integrated approach for both people and nature. Avoid focusing on a single scale or single outcome. Instead, think and act at multiple scales and aim for win-win-win outcomes. Watersheds are well-suited to nested, connected solutions. Healthy freshwater ecosystems and green infrastructure are good at improving economic, ecological, social, and political outcomes. And freshwater organizations are most successful when they tap the synergy that flows between water-related natural and social capital to help communities become more resilient to climate shocks and stresses. ■

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About The Author

Rebecca Wodder is a nationally known environmental leader whose career in conservation began with the first Earth Day. As president of the national river advocacy organization, American Rivers, from 1995 to 2011, she led the development of community-based solutions to freshwater challenges. From 2011 to 2013, she served as senior advisor to Secretary of the Interior Ken Salazar. Previously, Rebecca was a vice president at The Wilderness Society, and a legislative assistant to Senator Gaylord Nelson. In 2010, she was named a Top 25 Outstanding Conservationists by *Outdoor Life Magazine*. In 2014, she received the James Compton Award from River Network. Through her River Revival Project, Rebecca explores the ways in which freshwater conservation efforts can revive social and natural capital in American communities. She serves on the boards of River Network, the Potomac Conservancy, and the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison.

California Dreaming: The Need For Homegrown Agricultural Water Technology

In drought-plagued California, the supply of water falls well short of demand – with food production hanging in the balance. The implications are felt globally, but relief can be found locally.

By Jim Lauria

Ask somebody to name five things California is great at, and chances are two of them are going to be "growing things" and "technology." The Golden State is the salad bowl of America and much of the world, and home to legendary Silicon Valley. So it would be natural for California to become the hotbed of agricultural water technology — the Silicon Valley of Ag Water, if you will.

Just look at the numbers.

In 2014, in the midst of an epic drought, California's agricultural exports totaled $21.59 billion. The state is firmly ensconced as one of the top 10 global agricultural economies in the world, ahead of Canada, Mexico, Germany, and Spain. Go to India, and you'll be served California almonds. Milk from California cows is served in China (and premium alfalfa from California farms feeds China's own dairy herd). Mexico's tacos are topped with California cheese. Golden State fruit is prized in markets from Geneva to Japan.

California's farm and agricultural-related industries employ 7.3 percent of the state's private-sector labor and generate 5.6 percent of the state's labor income. For every 100 jobs in agriculture and the food industry, 94 additional jobs are created throughout the state, according to the University of California, Davis.

So it's especially devastating to see what the lack of water can mean for California. Last year, 564,000 acres were fallowed due to drought. More than 18,000 jobs were lost, most in the hardscrabble communities of the Central Valley. Some of those communities, like East Porterville, lost their household water to falling groundwater levels; others, like the Lake Don Pedro Community Services District, scrambled for emergency funding for wells to stave off a disaster when lake levels receded beyond the reach of their intake pipes.

Agriculture's economic losses in 2015 were estimated at $2.7 billion, after $2.2 billion in losses the year before. Farmers desperate to save their crops sucked so much groundwater that NASA satellites could see the ground subsiding from space — as much as two inches per month in some locations.

As groundwater recedes along the coast, saltwater intrusion occurs. As water users drill for deeper sources of groundwater, they may encounter water that is more saline or tainted with sulfur or arsenic. That may force many communities to tap into desalination and other treatment technologies just to maintain access to traditional sources of water.

And even after an El Niño winter that helped replenish reservoirs that had fallen to record lows, the threat of another drought looms.

Always Looming

In fact, the prospect of another drought always looms in California. California is dry country in the best of years, and you don't have to have a particularly long memory to think

As California creeps out from an epic drought — and with others always on the horizon — unmetered irrigation practices will come under greater scrutiny.


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back to water restrictions and unplanted crops in the state. Worse, climate models predict wider swings in weather, with the potential for bigger storms and drier droughts. That's a huge threat in an agricultural basin that is the envy of the world for its combination of great weather, great soils, and great irrigation infrastructure.

Ironically, many farmers reacted to previous droughts by adopting more precise irrigation technologies, including drip and microsprinklers. To get a return on their investment in these expensive systems, they shifted from annual crops like cotton or melons to permanent crops like wine grapes, almonds, and fruit trees. The downside: In a drought like the most recent one, it's possible to take a one-year economic hit and just not plant cotton or melons, but it's a devastating blow to consider drying up an orchard just part-way into its productive life — maybe before it has even produced an economic return. Water-savvy farmers were faced with a kind of Sophie's Choice: kill their crops (and maybe destroy their entire business) or pump groundwater to eke by. Meanwhile, a whole generation of urban residents had already installed low-flow showerheads, low-use toilets, and xeriscapes, making it tougher to squeeze much more conservation from municipal water districts.

Of course, water issues in California go well beyond supply. Environmental issues like smog and greenhouse gas emissions are linked to agricultural water. Addressing environmental needs — an ongoing tug-of-war between farmers and fish — is a massive challenge that demands attention not just to maintaining river flows and reservoir levels, but also to safeguarding water quality. Meanwhile, Western water law discourages conservation and, often, even measurement of withdrawals. On the plus side, nurturing the soil ecosystem, which is key to productivity and sustainability, is directly tied to water.

California farmers need top-shelf agricultural water technology. They should be getting it from the inventors and innovators that have made the state famous for generations.

California farmers need top-shelf agricultural water technology. They should be getting it from the inventors and innovators that have made the state famous for generations. Instead, Israel and Singapore, among others, have emerged as the Silicon Valleys of Water. It's ironic.

The San Joaquin River, dried in long stretches by diversions and drought, epitomizes the challenges facing California.

Alternative Water Sources

The first key shift California needs to make is located directly between the ears — not in a technological, innovation-challenge sort of way, but in a change of mindset. While farmers and planners look to the hills to seek places to site new reservoirs for water capture (and environmentalists draw lines in the sand at every turn), the state must look at alternative water sources that are already right under their noses.

Throughout farm country, lagoons at dairy farms, wastewater ponds beside every vegetable processing plant, and municipal wastewater treatment aeration tanks represent millions of gallons of available water.

That wastewater has already been pumped to the surface or conveyed to the site. It's already been counted out of river flows or groundwater reserves. Rather than seeking even more water from the environment — while releasing wastewater back to the ecosystem — it makes more sense to treat effluent for reuse as irrigation water.

There's plenty of precedent. Israel, by far the world leader in water reuse, sends 90 percent of its wastewater to treatment plants; of that, a staggering 85.6 percent is reused. Think about that. For every gallon of water that comes through an Israeli tap, more than three quarts is reused. More than half of the desert nation's irrigation water is treated, recycled wastewater. Even better, a study by the Galilee Technology Center demonstrated that irrigation with treated wastewater eliminated the need to flush fields with additional water to reduce soil salinity — which is also an issue in many areas of the Central Valley.

Emerging Technologies

There are some bright spots on the horizon. The California State University and University of California systems have scores of dedicated researchers committed to improving water efficiency. Their efforts range from breeding more water-efficient crops and improving irrigation timing — the demand side of the equation — to advancing water delivery systems on the supply side.

Some especially exciting technologies focus at the intersection of our understanding of irrigation management and our growing awareness of the complexities of soil biochemistry.

In 2014, water level at Shasta Lake dipped below 30 percent of capacity — 178 feet below full.

As Leonardo da Vinci once said, "We know more about the movement of celestial bodies than about the soil underfoot." That was profound in the 16th century, and it's even more profound now that we have the tools to start unlocking the complex ecosystem in every ounce of soil. Researchers at the Center for Irrigation Technology (CIT) at California State University, Fresno, have dug deep into a fascinating connection among drip irrigation, aeration, nitrogen availability to plants, and the balance of microbial populations in the soil.

Working with colleagues from the Memorial University of Newfoundland, Dave Goorahoo and Josue Samano Monroy of the CIT found that aerating subsurface irrigation water with a Mazzei AirJection system (homegrown technology designed and manufactured in Bakersfield, CA) altered the balance of microbes in the irrigated soil, reducing the amount of DNA present that indicated the prevalence of denitrifying bacteria. In short, it means the soil microbial community in the area irrigated with oxygenated water with additional microbubbles was less likely to produce NOx — the smog-producing greenhouse gases that float into the atmosphere, taking valuable plant nutrients out of the soil — and more likely to keep the nitrogen in the soil and available to crops. Good water management can also enhance plant uptake of nutrients, reducing the odds that the nitrate would leach into groundwater. That's a win-win for farmers and the environment.

Measure And Manage

Another Mazzei system, the Tru-Blend fertilizer injection system, helps farmers deliver precise amounts of vital nutrients directly into the root zone. That maximizes plant health and minimizes the chances for runoff with rainwater or surface irrigation, preventing costly and environmentally harmful discharges into canals, rivers, and lakes. It allows farmers to maximize the chances of uptake of the products they apply and minimize the likelihood of them leaching into groundwater.

Such systems also play another vital role — as recordkeeping devices. Between federal and state regulations governing pesticides to California's special groundwater management rules, precise metering and recordkeeping is increasingly crucial to farmers.

In the near future, we may also see a need for affordable and accurate water metering instruments that fit agricultural systems. California's strategic plan for groundwater management includes water budgets and careful accounting of water going in and out of many basins. Metering water is relatively simple in municipal systems, but takes on much greater complexity at the scale, and in the systems, of commercial agriculture. Achieving sustainability, just like improving any management system, requires measurement.

California's Time In The Sun

The gauntlet has been thrown. Consider Israel the reigning champion of drought-managing water technologies. Will the Golden State step up to challenge the status quo?

With the specter of drought on the increase — both natural drought from dry weather and man-made drought from regulations parsing water among farmers, environmental needs, and a growing urban population — California's water prospects look about as dire as Israel's. And like Israel, California is graced with innovative farmers growing high-value crops, world-class universities, and some of the most creative imaginations and funding sources on the planet. Now is the time to bring the Silicon Valley of Water much, much closer to Silicon Valley. ■

About The Author

Jim Lauria is vice president of sales & marketing for Mazzei Injector Company, LLC, a fluid design company that manufactures mixing and contacting systems. He holds a Bachelor of Chemical Engineering degree from Manhattan College and has over 20 years of global water treatment experience in the agricultural, municipal, industrial, and commercial markets. Jim can be contacted at jlauria@mazzei.net.