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Understanding the increased use and practicality of water reuse will help operators when reuse is implemented in their system.

BY KEISUKE IKEHATA, HUNTER ADAMS, MARK SOUTHARD, STEVE ASH, DANIEL K. NIX, EVA STEINLE-DARLING, AND CHRISTINA MONTOYA-HALTER

OPERATORS NEED TO KNOW WATER REUSE

WATER REUSE is the future of water resource management. Its use by utilities will be determined by how it's reclaimed, how it's intended for use, and if it's intended for public contact and/or consumption. For these reasons, operators should be knowledgeable about reuse and how it may affect their community. This article continues the "Operators Need to Know" series and discusses the various types of water reuse, their treatment requirements, regulations, and public health considerations and perception. For more information on types of advanced treatment processes and how reuse water compares to other water sources, see "Operators Need to Know Advanced Treatment Processes," which appeared in *Opflow*'s April 2022 issue, and "Operators Need to Know Source Water Basics," which appeared in *Opflow*'s November 2022 issue.

Water reuse, also known as water recycling, refers to the process of treating and purifying wastewater for various nonpotable (nondrinking) purposes, such as urban and agricultural irrigation, industrial processes, toilet flushing, and environmental restoration, as well as for potable purposes (drinking, cooking, hygiene). Treated wastewater, also called reclaimed water, can be safely reused for those purposes if it's treated to specific standards. Water reuse helps conserve conventional freshwater resources, such as surface water and groundwater, by reducing the demand from those sources for potable water.

Water reuse is becoming increasingly important worldwide because of growing water scarcity, population growth, and the need for sustainable water management practices.

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Water Reuse

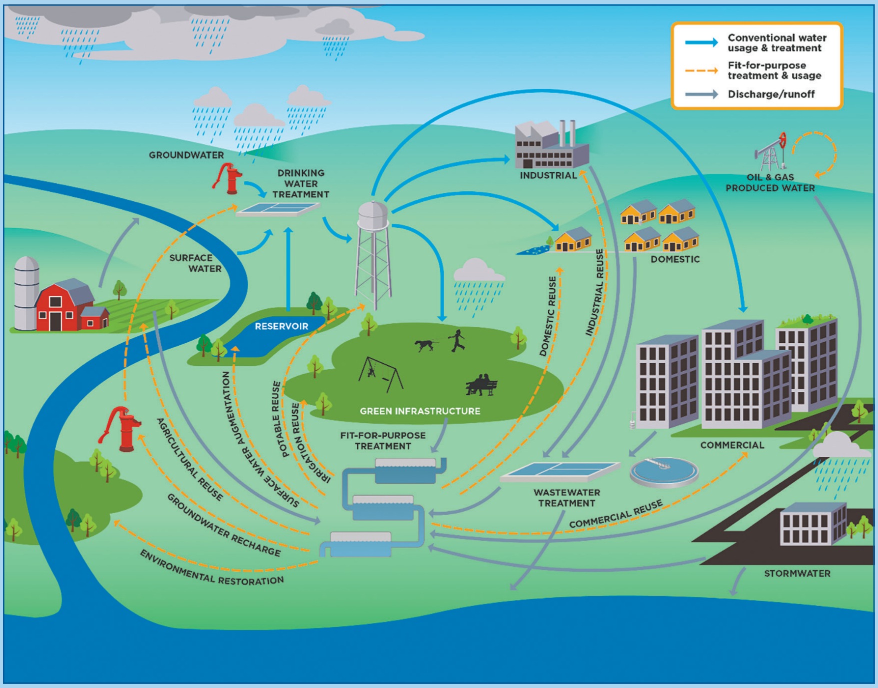
WHY WATER REUSE?

Water reuse is becoming increasingly important worldwide, including in the United States and Canada, because of growing water scarcity, population growth, and the need for sustainable water management practices. In fact, reclaimed water is a drought-resistant water source that's locally available even during a prolonged drought. As the saying goes, "It rains every day at a wastewater plant." Reusing reclaimed water within communities recovers a resource that would otherwise be discharged to a receiving stream for someone downstream to use for drinking water. Reuse keeps the resource locally available. It also can provide significant cost savings for utilities and consumers when/where the traditional water sources become limited and more expensive. Moreover, water reuse diversifies a community's water resource portfolio and enhances its resilience in times of water crises, including drought, contamination incidents, and infrastructure failures. It also leads to more sustainable water resources management.

At the same time, inherent resistance and misconceptions remain among the public toward water reuse. Such hesitation comes from a lack of understanding about wastewater treatment processes and water quality as well as the "yuck factor" associated with wastewater and its odor. We have all been taught from an early age that wastewater was "dirty" and "bad." This perception clouds the reality of the value of wastewater as a resource that can be successfully treated to benefit the environment and public health. These perceptions are particularly significant and persistent when discussing potable reuse. Also, the cost of advanced water purification, such as microfiltration (MF)/ultrafiltration (UF), reverse osmosis (RO), ozone (O_3), and the ultraviolet (UV) advanced oxidation process (AOP) for potable reuse, as well as dual plumbing systems (i.e., purple pipe) for nonpotable reuse, could be a major obstacle for some communities. Such advanced water purification processes may require higher-level operator training or certification. The seasonal and climate dependence of nonpotable water demand (e.g., irrigation) is another important factor.

Figure 1. Water Reuse Cycle

Potable reuse water will ultimately be ingested by humans and therefore must meet the same quality standards as drinking water.



Source: US Environmental Protection Agency, 2023

POTABLE VERSUS NONPOTABLE REUSE

Nonpotable reuse water isn't meant for consumption or physical contact by humans. It's widely used for irrigation and industrial applications, such as in cooling towers or washdown processes. For this reason, quality standards for nonpotable reuse are less stringent than they are for potable reuse. Potable reuse water will ultimately be ingested by humans and therefore must meet the same quality standards as drinking water (Figure 1).

Water that's destined for drinking may be discharged from a wastewater treatment plant (WWTP) into a natural buffer, such as a lake, river, or natural aquifer, before being treated to drinking water standards in a surface water treatment plant. This practice, known as indirect potable reuse (IPR), has become more feasible due to treatment advances. If the WWTP effluent undergoes advanced treatment and is directly blended with surface water or groundwater before final treatment at a water facility, skipping the natural buffer, this is known as direct potable reuse (DPR). There's even a form of DPR that involves only a single advanced purification facility taking in treated wastewater effluent, providing advanced purification processes, and producing finished water ready for distribution.

TYPES OF NONPOTABLE REUSE

Irrigation is the major application of

When water managers and operators understand how their system is likely to be affected by reuse in the future, they can begin to plan how it may be implemented in their systems.

reclaimed water for nonpotable reuse. Reclaimed water can be used to irrigate urban landscapes, such as parks, community gardens and sidewalks, streets, highway medians, and golf courses. It can also be used for agricultural irrigation for food crops and nonfood crops if the customers (e.g., farms, wineries, ranches, nurseries) are present within or adjacent to the municipality in which reclaimed water is produced. Industrial applications, such as cooling towers for power plants and factories, cleaning, dust control, and process water, are also common if industrial users are nearby. Toilet flushing can be a nonpotable application of reclaimed water and is often practiced in small-scale (e.g., buildings) decentralized reuse projects. Another important application is a make-up water for man-made lakes that aren't used as a drinking water supply. Several reservoirs in Southern California are used to store reclaimed water for irrigation and other nonpotable applications.

It's important to know the desired water quality (e.g., salinity, hardness, color, nutrients) of each reuse application or customer in the area and to ensure the reclaimed water meets those water quality requirements. Usually, tertiary treated wastewater is readily reusable for nonpotable purposes, such as dust control for construction sites, urban and agricultural irrigation, and man-made lakes. Certain nonpotable reuse may require additional treatment, such as partial desalination and gypsum addition, to lessen the impacts of sodium and dissolved solids on salt-sensitive crops like avocados and turf grass. Boiler feedwater for oil refineries also requires extensive demineralization by two-pass RO (e.g., as seen at the Edward C. Little Water Recycling Facility, West Basin Municipal Water District, El Segundo, Calif.). Nutrient removal must be carefully controlled to prevent excessive algal growth leading to eutrophication in man-made lakes and reservoirs receiving reclaimed water.

Nutrients also may be purposely left to provide phosphorus and nitrogen for crop irrigation, as detailed in the accompanying case study "Agricultural Reuse Abounds in Israel." Color removal is desirable for toilet flushing. To prevent waterborne diseases, proper disinfection is important for all nonpotable applications in which reclaimed water may come in contact with the users, the edible portions of food crops that aren't cleaned before consumption (e.g., lettuce, radishes, carrots), and the public. Dechlorination may be required before discharging effluent to a reclaimed water reservoir.

POTABLE REUSE

Potable reuse is much more common than most people think. Most surface water systems are involved in de facto reuse in which utilities draw water from a source that typically contains a small percentage of wastewater effluent. Almost everybody lives downstream of some other system that's discharging its treated wastewater into its neighbors' drinking water source. The effluent can increase occurrence of *Giardia* cysts and *Cryptosporidium* oocysts; result in algal blooms that cause filter clogging, taste and odor issues, and cyanotoxins; and bring with it the stigma of emerging contaminants. As illustrated through initial Fifth Unregulated Contaminant Monitoring Rule sampling data and recent literature (https://doi.org/10.1021/acs.estlett.3c00185), the widespread presence of per- and polyfluoroalkyl substances (PFAS) in surface waters can be attributed to de facto reuse. One or more additional treatment processes, such as ozonation, biofiltration, powdered or granular activated carbon (PAC or GAC), and membrane filtration (MF or UF), may be required at such surface water treatment plants when heavily affected by de facto reuse.

Because of ongoing drought and population growth, an increasing number of US utilities and states such as California, Colorado, Texas, Utah, and Virginia are implementing planned potable reuse systems. Planned reuse includes IPR and DPR. IPR can further be divided into groundwater replenishment and surface water augmentation. Although IPR uses an environmental buffer (a large reservoir or aquifer), which provides dilution, response time, and additional natural treatment, DPR lacks such a buffer (Figure 2). Thus, water will be recycled faster in DPR (on the order of hours to days) compared with IPR (on the order

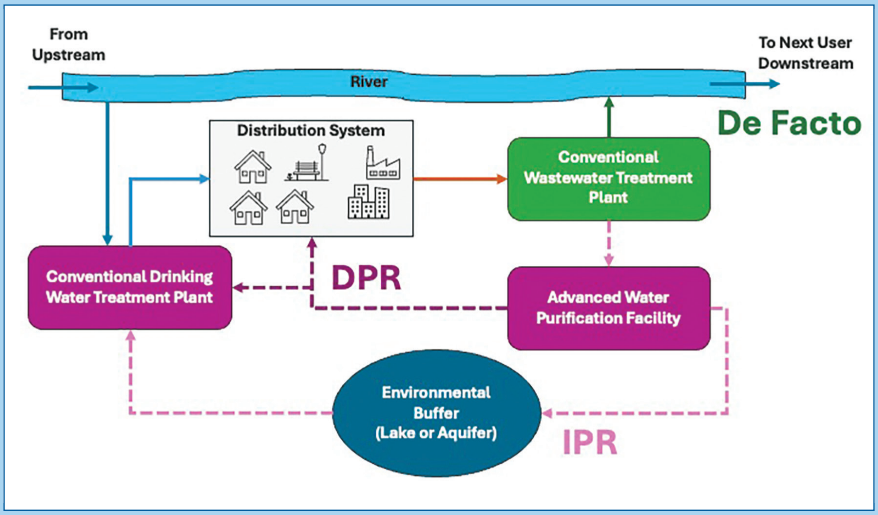
CASE STUDY

AGRICULTURAL REUSE ABOUNDS IN ISRAEL

Israel is an international leader in water reuse to augment its limited freshwater resources. The nation diversifies its resources for water supply by desalinating water from the Mediterranean Sea and building an infrastructure framework prioritizing agricultural reuse, recycling approximately 90% of residential and commercial wastewater. Because Israel's Water Authority intentionally plans for agricultural reuse, it collaborates with water suppliers and agricultural stakeholders to ensure regulations are appropriate and attainable for food production and environmental protection. As part of this intentional planning, Israel doesn't require nutrient removal in wastewater effluent to the same degree that's required in the United States; the nutrients are intentionally maintained at levels adequate to act as fertilizer for the agricultural industry. By tailoring wastewater treatment regulations for end users, a national fit-for-purpose system has been implemented, creating an oasis in the deserts of the Middle East. For more information, see "Learning from Water Reuse in Israel," which appeared in *Journal AWWA*'s May 2023 issue.

Figure 2. Indirect and Direct Potable Reuse

Indirect potable reuse uses an environmental buffer to provide dilution, response time, and additional natural treatment, whereas direct potable reuse lacks such a buffer.



of weeks to months). In all cases, secondary or tertiary treated wastewater is purified at advanced water purification facilities (AWPFs) to further remove pathogens and chemicals and to minimize public health risks. DPR also requires more redundant treatment processes as part of a multibarrier approach and/or more frequent and robust water quality monitoring than IPR. Except for direct-to-distribution (i.e., pipe to pipe) DPR, a conventional drinking water treatment plant treats the purified water retrieved from the environmental buffer (IPR) or storage reservoir (raw water production DPR) before distribution.

The most common treatment train used in AWPFs is MF or UF, RO, and UV AOP, which is also known as RO-based advanced treatment (RBAT). Additionally, hydrogen peroxide (H_2O_2) is often used in UV AOP, and UV/free chlorine (Cl_2) AOP is becoming popular. The latter option requires fully nitrified secondary/tertiary effluent with minimal ammonia-N because any residual ammonia reacts with Cl_2 to form chloramines. The UV/chloramine AOP is far less effective than UV/Cl_2 AOP in terms of trace organics (e.g., 1,4-dioxane) abatement. Breakpoint chlorination is required to destroy any chloramines, thereby increasing chlorine demand. Thus, the UV/H_2O_2 AOP should be used in the RBAT train to treat partially nitrified effluent.

Carbon-based advanced treatment (CBAT) is an alternative to the RBAT approach. This AWPF approach centers on core processes of O_3 and biological activated carbon filtration (BAC or BAF). Almost always, additional organics removal and disinfection will be required by GAC and UV, respectively, to complete water purification. The CBAT train doesn't have RO, which is expensive to build and operate, and it doesn't require concentrate management and disposal, unlike RO. Thus, this type of AWPF is more suitable for inland potable reuse projects. However, the CBAT doesn't remove total dissolved solids (TDS) and isn't suitable for reclaimed water with high TDS.

It's been demonstrated that either RBAT or CBAT alone can be sufficient to achieve sufficient water quality for IPR and DPR. A combination of ozone and/or BAC and RO-based trains for IPR is also common (e.g., Scottsdale Water Campus AWPF, Scottsdale, Ariz.). Ozonation helps reduce membrane organic fouling by oxidizing organic matter. However, it also increases the concentration of total organic carbon in RO permeate. Ozone also provides additional virus and protozoa inactivation credits that are sometimes required to achieve a log reduction value for DPR.

Both RBAT and CBAT approaches also provide robust barriers for PFAS. Thus, potable reuse projects already have a PFAS solution "built in." However, AWPF operators will be faced with the same disposal challenges faced by conventional treatment facilities: what to do with the PFAS-containing waste brine or media, respectively?

NOTABLE POTABLE REUSE SYSTEMS

DPR is less common than IPR because DPR lacks an environmental buffer and sends highly treated wastewater effluent "directly" from the wastewater treatment facility to the drinking water treatment facility or to the distribution system. Because of this unconventional route, only five US cities have been approved for DPR (Table 1).

Wichita Falls' DPR system is no longer in operation, leaving Big Spring as the sole operating US municipal DPR system. However, as several state regulatory agencies are setting rules and guidelines on DPR, more US water utilities are exploring DPR as a viable water supply option.

IPR has a longer history of use and is more widely accepted by the public and regulatory agencies than DPR. This is because IPR uses an environmental buffer to mix the purified water with surface water or groundwater that's used as a source of drinking water. Approximately 20 US public water systems are currently operating IPR systems. Other countries, such as Singapore and Australia, also operate several IPR systems. One

All water is reused at some point, so it's only natural that the water industry continues to promote the development of reuse guidance, regulations, and public education.

of the most notable US examples of an IPR system is Orange County Water District's Groundwater Replenishment System (GWRS) in Fountain Valley, Calif. (www.ocwd.com/gwrs). The GWRS treats secondary effluent from two conventional wastewater treatment plants of the Orange County Sanitation District and produces up to 130 mgd of purified water using an RBAT train (UF, RO, and UV/H_2O_2 AOP). Purified water has been used for seawater intrusion barriers as well as for recharging local groundwater basins since January 2008. In fact, the GWRS was constructed at the site of its predecessor, Water Factory 21, an original 20-mgd AWPF for IPR that used GAC and RO in parallel and was operational over three decades between 1976 and 2004.

Another marked example of advanced water purification for potable reuse is the City of Wichita Falls' emergency DPR project in 2014–2015. In response to a historic drought, the city planned and implemented a DPR system by using an existing brackish surface water desalination facility (Cypress Water Treatment Plant) that already had MF and RO. By constructing a 12.3-mile pipeline from the River Road Wastewater Treatment Plant, 7.5-mgd tertiary effluent was brought into Cypress Water Treatment Plant as a source water, where reclaimed water was treated by conventional coagulation, flocculation, sedimentation, MF, and RO. After six months of operation, UV was also added to the treatment train, following RO. The highly purified reclaimed water was then sent to an adjacent conventional surface water treatment plant, blended with raw surface water at a 1:1 ratio, and treated conventionally to produce drinking water for just over 12 months, treating more than 2 billion gallons for public consumption. However, the emergency DPR project effectively cut off one of the surface water supplies. Ultimately moving to IPR allowed Wichita Falls to bring that surface water source back online and realize the benefit of treated effluent by adding it back to another of its surface water reservoirs. For additional details, see the March 2021 *Opflow* article "Tracking Wichita Falls' Path from DPR to IPR."

REUSE REGULATIONS

Nonpotable regulations typically focus on standard wastewater-type parameters, such as biochemical or chemical oxygen demand, turbidity, and bacteria counts. Generally speaking, it's a routine process in many states to obtain a permit or authorization to reuse water for nonpotable applications.

Potable reuse regulations typically require compliance with a much wider range of parameters, including drinking water pathogens (viruses, *Giardia*, *Cryptosporidium*), and regulated contaminants—i.e., those with maximum contaminant levels (MCLs) and secondary MCLs (SMCLs). Most regulatory approaches to potable reuse also require some additional "programmatic" components to ensure water quality, such as enhanced source control and better monitoring; however, some, but not all, require monitoring for and control of chemicals that aren't otherwise regulated in drinking water. Overall, obtaining a permit or authorization for potable reuse is a complex, multiyear, and multistep undertaking that needs to be coordinated carefully and collaboratively with a utility's regulatory agencies (Figure 3).

PUBLIC PERCEPTION

Aesthetic issues generally aren't considered health-related, but public water systems (PWSs) must take aesthetic quality into account when planning for potable reuse. For example, the SMCL for odor is indicated by a threshold odor number of >3, which can be quite odorous, depending on the type of compound present. Also, the SMCL for iron is 0.3 mg/L, and consumers won't understand the difference between discolored water caused by iron when a potable reuse system is in use; they'll likely jump to conclusions and believe the reuse system has failed.

Although potable reuse systems have demonstrated that they can meet and exceed all National Primary Drinking Water Standards and National Secondary Drinking Water Standards, the public perception of reuse can be a deciding factor in the PWS's acceptance and support. To overcome this, systems exploring reuse to augment their water supply should employ proactive outreach and education programs.

El Paso Water, which serves the city of El Paso, Texas, made outreach and education a crucial part of its future AWPF project for direct-to-distribution DPR from the beginning. In 2013, the utility surveyed the community to determine the public's initial perception of this project.

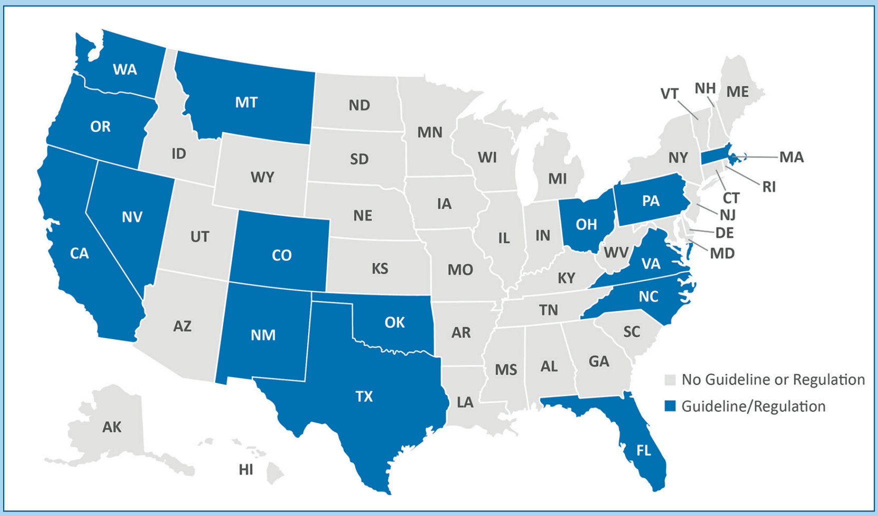
Table 1. US Potable Reuse Systems

Only five US cities have been approved for direct potable reuse.

Facility	Location	Max Flow	Type	Notes
Colorado River Municipal Water District	Big Spring, Texas	2 mgd	Raw water production	Operational since 2012
City of Wichita Falls	Wichita Falls, Texas	10 mgd	Emergency raw water production	Operated 2014-2015
City of El Paso	El Paso, Texas	10 mgd	Direct-to-distribution	Under construction in 2025
Village of Cloudcroft	Cloudcroft, N.M.	0.05 mgd	Raw water production	Construction started in 2005, halted in 2007, recently resumed
City of Brownwood	Brownwood, Texas	N/A	N/A	Approved in 2012 but not constructed

Figure 3. States With Potable Water Reuse Regulations or Guidelines

Obtaining a permit or authorization for potable reuse is a complex, multiyear, and multistep undertaking.



Results showed that 84% of El Pasoans were in favor of cleaning wastewater for drinking water and sending it directly to consumers. The survey also revealed that the more information people received about the advanced water purification processes, the greater the approval rating, jumping to 95%. The communications team used the survey results to create a public education program for the AWPF. A major goal of the program was to increase awareness and acceptance of the project by informing the community of the following key messages: The utility has been practicing water reuse successfully for decades, there's a need for drought-proof and sustainable sources of water, and technology makes purified water safe to drink.

El Paso Water has maintained an ongoing education program since 2013. The first phase included briefings for media and elected officials. An employee Speakers Bureau visited several utility departments and community organizations. The utility engaged a public relations consultant to assist with focus groups and roundtable meetings that yielded terminology recommendations that were incorporated into outreach materials and public tours of the AWPF Pilot Facility. Later phases of the program included videos featuring health experts testifying about the safety of the AWPF, social media campaigns, and even a partnership with the University of Texas at El Paso that included classroom instruction and engineering projects. Currently, the utility is partnering with the University of Texas at Houston School of Public Health on outreach with the local medical community about the safety of water reuse and, in particular, the AWPF. The utility also included a large-scale educational exhibit in the AWPF that's expected to start construction in 2025. Education will be an ongoing priority for the utility even after the facility goes online in 2027.

The City of Wichita Falls, Texas, also produced an aggressive reuse public relations campaign, engaging local leaders, including academics, and medical professionals. The general public was overwhelmingly in favor of the reuse system because they were educated and received updated information through the campaign. During operation, the city received zero water quality complaints related to the reuse system, and many consumers even stated that the DPR system produced a better tasting water than the conventionally treated surface water system had produced. This is a clear indicator that a positive rapport with the public must be proactively maintained.

DPR AESTHETICS RESEARCH

Recent research conducted at Texas State University on DPR aesthetics continues to prove that DPR produces high-quality water that is safe and pleasant to drink. A 1.5-gpm pilot-scale DPR system consisting of O_3, BAC, MF/UF, RO, and UV H_2O_2 AOP was operated for more than 18 months. Each unit process was monitored using sensory and instrumental analysis for taste and odor compounds and other appearance-related parameters. The pilot DPR system consistently produced water below SMCLs and odor thresholds.

REUSE IS THE FUTURE

When water managers and operators understand how their system is likely to be affected by reuse in the future, they can begin to plan how it may be implemented in their systems. All water is reused at some point, so it's only natural that the water industry continues to promote the development of reuse guidance, regulations, and public education. For a more comprehensive look at this topic, refer to AWWA's collection of reuse-related resources, including AWWA's Manual of Water Supply Practices M24, *Planning for the Distribution of Reclaimed Water*, M62, *Membrane Applications for Water Reuse*, AWWA's technical guidance document Potable Reuse 101, and ANSI/AWWA Standards G485-18, *Direct Potable Reuse Program Operation and Management*, and G481-14, *Reclaimed Water Program Operation and Management*, along with other excellent resources in the association's online store (www.awwa.org/store).