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Potable Reuse of Water

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The potable reuse of water has occurred throughout time as communities that grew up along rivers took their supplies from the river and disposed of their waste into the same river. The natural flow of the river served as a physical and symbolic purification mechanism that made reuse acceptable to downstream communities. Increases in knowledge about water contamination led to an expanding suite of water treatment technologies, but did not change the basic relationship. Now, although potable reuse of water is not a new concept, the intentional reuse by one community of its own wastewater is new to most people. For this reason, a great deal of study and debate surrounds the issue, as water managers, policy makers, regulators, and public safety advocates face prospects for its implementation.

The United States Census Bureau estimates that the U.S. population will reach 360 million by 2030, and population shifts toward drier regions of the country will continue. By the same year Arizona's population is expected to reach 8.5 million people. This population growth is anticipated to increase stress on developed water supplies. In addition, projections of future climate indicate higher temperatures and increased likelihood of drought. According to reporters Mike Bostock and Kevin Quealy, who have been mapping the spread of drought across the United States for the New York Times, Palmer Drought Severity Index data show that drought levels in 2015 approached those of the dust bowl era, with the 10-year average increasing for nearly all of the last 20 years. The Western United States is particularly hard hit; this area is strongly influenced by drought extremes, but also continues to experience unprecedented population growth. The resulting strain on fresh water resources is prompting the people responsible for ensuring a reliable supply of water to turn to alternative sources previously considered

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undesirable. One of those alternative sources is treated wastewater for potable reuse.

What is Potable Reuse?

Potable reuse is defined as treating and purifying wastewater to potable, or drinkable, standards and delivering the purified water to the drinking water distribution system. The advanced treatment used to treat wastewater for reuse has also been employed to treat other impaired water sources, but here the focus is on wastewater. In the United States, water delivered for potable reuse must meet all federal and state drinking water standards and usually goes beyond these treatment requirements. In fact, because of its high level of treatment, water from an advanced water treatment facility is likely to be far cleaner than many raw water sources of drinking water.

Why Potable Reuse?

Utilities, both public and private, have come to appreciate wastewater as a resource rather than a waste product. Wastewater disposal involves costs, and water reuse provides a way to turn these costs into revenues. Recycling wastewater is a good strategy for meeting environmental goals and regulations as it addresses the issues of waste disposal and water supply at the same time. The benefits of recycled water have long been recognized in the western United States, with the result that non-potable reuse systems are widespread. These systems require building and maintaining distribution infrastructure that duplicates drinking water distribution systems. Although upon thorough evaluation of options many communities will continue to reuse water in this way, for others, investment in duplicate "purple pipe" systems may not be cost effective and may limit flexibility in the future use of the water. A potable reuse system may be more suitable in these instances.

Another factor driving interest in potable reuse is improvement in treatment technology. State-of-the-art water treatment systems can produce water that is of near-distilled quality. Although generally more expensive than standard drinking water treatment, the costs have been declining. At the same time, the cost of providing traditional potable water service has been increasing, and as it does, the price of treatment for potable reuse is becoming less of a barrier.

Types of Potable Reuse

There are three types of potable reuse; de facto potable reuse, indirect potable reuse (IPR), and direct potable reuse (DPR).

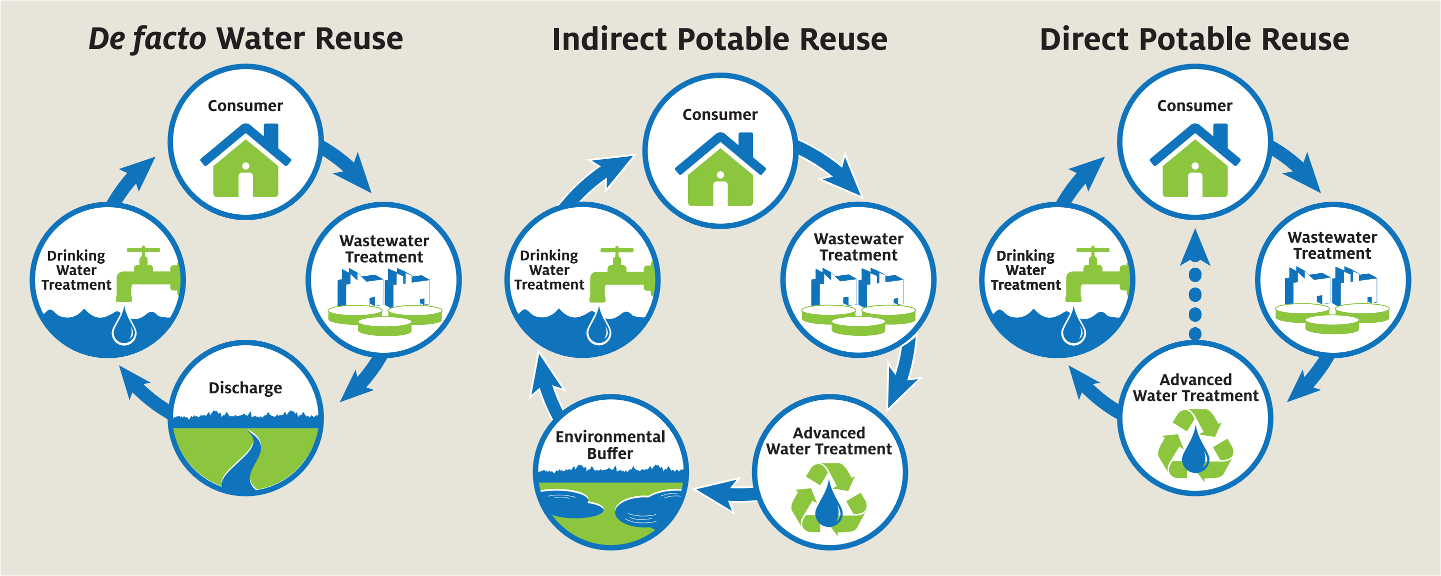
De facto reuse is the most common of these. It occurs when upstream communities release treated wastewater into large bodies of water such as rivers or reservoirs, and that water is diverted and treated by downstream communities to serve their potable water needs. De facto potable reuse is distinguished from IPR and DPR by being unplanned. As a result the upstream wastewater discharges may have undergone only conventional treatment. Typically, this process includes screening, aeration, sludge removal, scum removal, and treatment to significantly reduce the number of microorganisms. Under the federal Clean Water Act (CWA) all point sources that discharge to surface waters must meet National Pollutant Discharge Elimination System (NPDES) permit program requirements. Point sources are defined by the Environmental Protection Agency (EPA) as publicly owned treatment works, industrial facilities, and urban runoff sources. The NPDES program regulates the release of pollutants such as oil and grease, and requires monitoring of numerous water quality parameters, including biochemical oxygen demand (BOD), total suspended solids (TSS), pH, and fecal coliform concentrations.

Treated wastewater discharged upstream is often substantially diluted before being withdrawn for use, but during times of drought or in semi-arid regions, the percentage of treated wastewater in a body of water can reach as high as 100 percent. For example, during low flows in the summer, the Trinity River in Texas sometimes contains a significant fraction (half or more) of treated wastewater discharged from Dallas, Fort Worth, and other smaller cities along its banks. From Dallas it travels approximately 250 miles and empties into Lake Livingston, where it is stored before being withdrawn and treated to drinking water standards for use in Houston.

In both IPR and DPR, the reuse of treated wastewater is planned. With IPR, wastewater is treated to potable or near-potable standards and then intentionally released into an environmental buffer, where it mixes with water from other sources. Water withdrawn from the buffer is used, after additional treatment, for drinking water. For DPR there is no environmental buffer.

Lake Mead provides an example of IPR. The Southern Nevada Water Authority extracts water from Lake Mead for the City of Las Vegas' drinking water supply. The City, in turn, collects and treats its wastewater in the Flamingo Water Resource Center, which employs nutrient removal, ultrafiltration, and ozonation to reduce algal blooms in the lake and boost disinfection. From this facility, most of the 96 million gallons per day (MGD) of treated wastewater is released into the Las Vegas Wash, which feeds back into Lake Mead.

Las Vegas' treated wastewater is diluted by the vast quantity of water in the reservoir and downstream is withdrawn for potable and non-potable use in Arizona, California, and Mexico. Paul Westerhoff at Arizona State University estimates that 1 to 2 percent of Arizona's Central Arizona Project (CAP) water is treated wastewater from the Las Vegas plant. This estimate is based on flow modeling and tracer measurements in Lake Havasu and



Types of Potable Reuse. Source: Texas Water Development Board

various points along the CAP. Based on his modeling, Westerhoff estimates that wastewater could amount to 14 percent of total CAP flow during times of drought.

Major reasons for including an environmental buffer are related to the time between treatment and use. An environmental buffer provides time for monitoring, reaction time if an upset causes water to fail standards, and time for natural treatment to occur when the water is in the buffer.

When treated wastewater is allowed to percolate naturally into aquifers through spreading basins, the treated wastewater can benefit from soil-aquifer treatment (SAT). SAT relies on environmental degradation processes to remove pathogens and other contaminants. It is effective at removing pathogens from the water, including viruses and protozoa, such as Cryptosporidium.

IPR projects that use injection wells bypass the SAT benefit. The City of Phoenix has proposed an IPR in Cave Creek in the northern part of the city. Wastewater that has been highly treated, but not to potable standards, will be injected, reside in the aquifer for some specified time, then be drawn out and treated to potable standards. The rationale for this approach is that the injected water will mix with poorer quality water in the aquifer and treatment to potable standards twice would be a waste of resources.

With DPR, treated and purified wastewater is usually blended with water from other sources either upstream of a drinking water treatment plant or directly at the plant. The only operating DPR facility in the United States is located in Big Spring, Texas. Since 2013, it has been producing highly purified water for blending with other raw water sources before these are treated in drinking water treatment plants. Wastewater can conceivably be treated in a DPR system and introduced directly into the drinking water distribution system, and future systems may be designed without blending.

A higher standard is placed on water purity in DPR systems because they do not incorporate environmental buffers and therefore bypass the time before purified wastewater reaches customers' homes. Eliminating an environmental buffer may provide cost savings. On the other hand, additional treatment processes and/or monitoring may be required with DPR systems to ensure that no contaminants are passed through during treatment.

IPR and DPR Treatment Trains

According to an article by Daniel Gerrity and others published in the *Journal of Water Supply: Research and Technology*, potable reuse systems must be designed using a multiple barrier framework with three essential components: resiliency, redundancy, and robustness. Potable reuse systems are scrutinized more closely than conventional water sources and therefore must exercise the utmost care in ensuring that chemical and microbial contaminants are removed in the purification process. Designing potable reuse treatment systems for resiliency requires that systems have the ability to adjust to treatment upset. Systems designed with redundancy have backup systems in place in case of failure of the main system. Finally, addressing robustness means building systems that have the ability to address a multitude of biological and chemical contaminants. The F. Wayne Hill Water Resource Center Extension in Gwinnett County, Georgia is an example of this multiple barrier approach. It uses a variety of treatment processes that all target the same set of pollutants, ensuring high removal reliability. In addition, backup equipment and a secondary power supply provide redundancy. This wastewater treatment plant is permitted to discharge 60 MGD of recycled water

Example Treatment Trains. Source: Water Reuse Research Foundation

into Atlanta's main drinking water source, Lake Lanier, and the Chattahoochee River. According to Gwinnett County's 2030 Water and Wastewater Master Plan, it is "recognized for producing one of the highest quality effluents in the Southeast United States."

A variety of potable reuse purification processes, or treatment trains, operate throughout the world, and they differ for a number of reasons. Choices in technology may depend on regulations, challenges unique to the project site, common contaminants in the area, and the technologies available at the time the treatment plant is built. In addition, financial and sustainability issues may affect the choice of treatment technologies. There is no "one size fits all" approach to treating recycled wastewater to potable standards.

In general, however, conventional wastewater treatment (including removal of large particulates, clarification, aeration, nutrient removal, and disinfection) precedes the advanced treatment portion of the process. Advanced treatment can include any number and type of treatment processes, however, the most common treatment train used in IPR and the Big Spring DPR project consists of microfiltration (MF), reverse osmosis (RO), and a ultraviolet light-based advanced oxidation process (UVAOP), in that order.

MF removes microscopic solids using membrane technology to filter out bacteria, protozoa, and solids. Viruses and dissolved constituents are removed by RO, using semi-permeable membranes through which water and only very few other constituents are able to pass. UVAOP, which uses an oxidant (generally hydrogen peroxide) ahead of high-powered UV reactors, is used to chemically destroy many dissolved organic constituents and to inactivate a broad range of pathogens, including virus, protozoa, and bacteria. Advanced oxidation can also be achieved through the use of ozone, which can be applied upstream of RO on its own, or downstream of RO in conjunction with hydrogen peroxide.

In addition, ozone is sometimes placed upstream of MF units to reduce membrane fouling and to increase water output capacity. Treating the wastewater with ozone before it enters the RO membrane also improves the quality of the RO waste by-product, or brine stream, by reducing pathogens and organic contaminants. The West Basin Municipal Water District's Edward C. Little Water Recycling Facility in El Segundo, California and the Scottsdale Water Campus in Arizona both employ ozone as the first step in their treatment processes. They also employ UVAOP.

An important final step for RO-treated water is stabilization. In this step, chemicals such as lime and calcium hydroxide are added to the water to reduce the corrosiveness of the water and improve its taste. These additions effectively reduce the potential for substances to leach from piping and other infrastructure into the drinking water. In addition, because RO purification strips out minerals, some minerals are added during the water stabilization stage to produce the desired taste.

RO is the most energy intensive stage of the process because it takes energy to force water through the pores of the RO membranes. For this reason, research into alternative treatment methods that are equally effective is ongoing. A number of treatment trains that do not include RO were studied by the Texas Water Development Board, which concluded that such alternatives would require additional monitoring for pathogens. A promising alternative to an RO-based treatment train, however, is one centered on a combination of ozone with biologically active filtration, where the ozone provides advanced oxidation and the subsequent filter mitigates byproduct formation and degrades the organic constituents made bioavailable through ozonation. This alternative treatment approach avoids the creation of RO concentrate, but does not remove salt from the purified water.

Other Uses of Recycled Water

Most recycled water now goes to non-potable uses, such as irrigating golf courses, parks, and agricultural land. California and Florida are notable for their high usage of recycled water for agricultural purposes. Relatively little of Arizona's recycled water goes to irrigate agriculture, although a 2015 study by Cusimano and others, published by Arizona Cooperative Extension, found agricultural regions throughout the state take advantage of available high quality treated wastewater and are likely to increase their use of this supply. A study by Quay and others at Arizona State University found that for the Phoenix region, with 60 percent of Arizona's population, 82 percent of the wastewater generated was reused, with agriculture using 22 percent plus much of the "uncommitted" 18 percent largely discharged to the Gila River. The power sector accounted for an additional 22 percent, with the remainder going to recharge, environmental uses, and landscape irrigation.

The Palo Verde Nuclear Generating Station consumes about 19.5 billion gallons, or 60,000 acre feet, of recycled water each year. If treated for potable use, the volume of water consumed by the Palo Verde power plant would be enough to meet the needs of 120,000 families each year. Guy Carpenter, President of the WateReuse Association and Water Reuse Technical Practice Director at Carollo Engineers, is an advocate for tailoring water quality to its intended use. He stated that he believes everyone would agree that the power plant is a good use of recycled water. "We need to run our air conditioners, and we need water, so there are trade-offs. In Arizona, we've assigned the highest and best use of recycled water to the nuclear power plant. But, in the future, as drinking water sources become scarcer, most water providers are not going to be interested in selling off their reclaimed water for non-potable demands because they will need it to meeting drinking water needs."

Rio de Flag Riparian Area. Source: Tom Bean

Recycled water also supports artificial and natural wetland environments in Arizona. The Tres Rios Wetlands Project, a constructed wetlands project in western Phoenix, is a 1500 acre wildlife sanctuary supporting more than 150 species of birds, mammals, and other wildlife. Highly treated wastewater is supplied from Phoenix's 91st Avenue Wastewater Treatment Plant with a capacity of just over 200 MGD. A similar facility, Tucson's Sweetwater Wetlands, has been in operation since 1996. The many species of birds attracted to this constructed wetlands have made the site a major attraction for bird enthusiasts, and the facility also serves as an education center.

Treated wastewater discharged into water courses, such as the Santa Cruz River in south-central Arizona and the Rio de Flag near Flagstaff, supports riparian habitat that has become locally important for wildlife and passive recreation. Approximately 45,000 acre-feet of treated wastewater flows in the Santa Cruz River each year, making up the majority of the river's flow. The City of Flagstaff signed an agreement with the Arizona Game & Fish Department to maintain a minimum reclaimed water discharge from its two water reclamation facilities to maintain riparian habitat within the Rio de Flag and the Picture Canyon Natural and Cultural Preserve.

With all these existing uses of recycled water, is there enough to go around? According to a fact sheet published by the University of Michigan's Center for Sustainable Systems, only 2.5 percent, or one billion gallons per day, of wastewater is recycled in the United States for non-potable purposes. In Arizona, the Arizona Department of Water Resources (ADWR) estimates that only about 3 percent of the state's water demand is met with reclaimed water, although this estimate excludes environmental uses. A published Bluefield Research study estimates that reclaimed water is now 7 percent of Arizona's total water supply.

A study done for the Central Arizona Project (CAP) by the consulting firm HDR shows that 95 percent of the treated wastewater generated in south-central Arizona goes to agriculture, power production, industries, landscape irrigation, and intentional recharge, as well as wetlands and riparian habitats. If almost all of the treated wastewater generated in the most populous part of the state is being utilized, some change in use and/or future increases in effluent flow would be necessary to develop a potable supply.

Regulations

An increased urgency to find new water sources has outpaced political discourse and planning for potable reuse. Potable reuse is not defined under the Safe Drinking Water Act (SDWA) and there are currently no federal regulations in place to govern the use of recycled wastewater for potable purposes. The EPA publication, "2012 Guidelines for Water Reuse," noted that only nine states, including California, Florida, Hawaii, and Washington, have developed regulations or guidelines specifically pertaining to IPR and none has specific regulations for DPR. Texas and Virginia do not have specific IPR regulations but make case-by-case determinations. Arizona does not have IPR regulations, but IPR projects can be implemented under a set of other water regulations. States with potable reuse guidelines or regulations typically have specific requirements for treatment and monitoring.

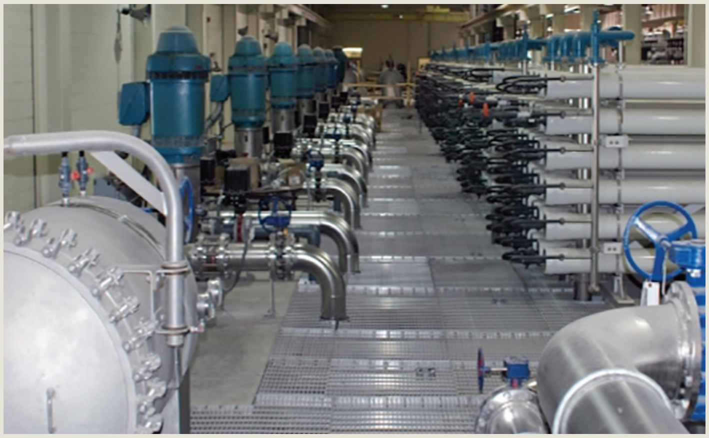
The 2012 Guidelines represent some change from the EPA's previous position. A 1999 memorandum issued by the EPA on the viability of potable reuse recommends the exploration of potable reuse as an alternative drinking water source as fresh water becomes scarcer due to prolonged drought and population growth in semi-arid areas of the country. The memorandum also notes that de facto reuse already occurs in more than two dozen major potable water treatment facilities across the country. In addition, the regulated contaminants in recycled water are already being addressed in the course of purifying the conventional drinking water supply. However, the 1999 guidelines stated that recycled wastewater should remain underground for at least one year before being withdrawn, indicating that EPA did not consider DPR an option. In its "2012 Guidelines for Water Reuse," the EPA states that, while past evaluations have found DPR to be unacceptable due to public safety concerns, advances in treatment technology and data from IPR and DPR studies may make DPR an option going forward.

California has the most developed regulatory structure for potable reuse. California's new regulations for IPR via groundwater recharge strongly emphasize use of specific technologies, rather than being performance-based. They provide detailed criteria prescribing the number and type of unit treatment processes, contaminants that must be tested for, and time recycled wastewater must be retained in the environment before it is withdrawn. Treatment must achieve at least 12-log reduction for enteric virus, 10-log reduction for Giardia cysts, and 10-log reduction for Cryptosporidium oocysts. These "log reductions" take very large numbers down to a vanishingly small numbers. Ten log reduction means the number of Giardia cysts is ten billion times smaller in the treated water than in the untreated wastewater. A minimum of three separate treatment processes are required in the treatment train, and each treatment is credited with a specified amount of pathogen reduction. Additionally, treated wastewater that remains underground for at least six months will receive full credit for Giardia and Cryptosporidium reduction, provided the other pathogen reduction requirements are met. Ongoing monitoring is required to verify the performance of each treatment process.

In Texas, the Texas Commission on Environmental Quality approves potable reuse projects on a case-by-case basis. Although Texas does not have regulations that specifically address IPR, the state regulates elements of IPR projects through existing programs and rules. These include reclaimed water rules, Texas Pollutant Discharge Elimination System discharge permits, Texas Surface Water Quality Standards, and the Texas Health and Safety Code, which incorporates Safe Drinking Water Act requirements for potable water quality.

The Arizona Administrative Code expressly prohibits the use of recycled water for human consumption, and current regulations, while not prohibiting indirect potable reuse, do not provide relevant regulatory criteria. ADEQ opened a docket on Jan 1, 2016, to begin the process of revising its reclaimed water rules, including gathering input from interested parties. Among many possible rule changes, the revision will encompass allowed end uses. Meanwhile, Arizona's water providers that wish to implement potable reuse projects are

Scottsdale Water Campus



Scottsdale Water Campus is Arizona’s first advanced water treatment plant for IPR through groundwater replenishment. Before the Water Campus was constructed, Scottsdale sent most of its wastewater to a regional treatment plant in Phoenix, where Scottsdale owns 20.3 million gallons per day (MGD) of capacity. Scottsdale’s daily wastewater flows exceeded that amount, and it had to borrow capacity at the Phoenix treatment plant to meet its wastewater disposal needs. Taking into account the projected future growth of Scottsdale’s population, potable water needs, and wastewater disposal needs, the city concluded that it would be more cost-effective to construct its own wastewater treatment plant than to continue to pay for excess capacity at the Phoenix plant.

The first phase of construction on the Water Campus was completed in 1998, and the plant has undergone three expansions since. Scottsdale’s Water Campus has a tertiary wastewater treatment plant that supplies water to 23 local golf courses. Funding generated from golf course irrigation helps support the potable reuse side of the project. The Campus’ advanced water treatment facility treats wastewater to meet EPA SDWA standards. Potable water is then injected via vadose zone wells to 180 feet below the surface, where it percolates down into the aquifer. According to Arturo Nuñez, Scottsdale’s Water Reclamation Services Director, DPR was never on the radar for Scottsdale. Much of the greater Phoenix area is, in fact, well-suited to IPR because of the great expanse and depth of its aquifers, which make perfect environmental buffers. The Water Campus’ injection wells are on-site, so transportation to a distant environmental buffer is not necessary. This helps to keep costs down.

In the mid-1990s, as part of the initial project, Scottsdale hired a public information firm to do outreach on the benefits of potable reuse to the community. According to Nuñez, the firm worked side-by-side with the city, holding meetings with homeowners’ associations and at other community forums. A year after opening, the Water Campus held a three-day open house event and invited regulators, the media, and the general public to come and view the facility. More than 500 residents attended the third day of the event, and Nuñez said that the exposure helped to strengthen the Campus’ position in the community. Since 9-11, however, perspectives on giving the public open access to utilities have changed. Nuñez said that the Water Campus had to back off of their public relations campaign because of security concerns. He acknowledged that public relations continues to be important, but said that after nearly 20 years of operation, there is less concern about the quality of the water.

In its most recent expansion in 2013, the Water Campus again upgraded its technology. Scottsdale became the first plant of its kind to use large-diameter RO technology. The new RO elements provide four to five times the surface area of standard elements and increase capacity by 30 percent. Concerns about CECs, including NDMA, drove the technology upgrade. Scottsdale hired a panel of industry experts, including scientists from the University of Arizona and Arizona State University, who identified hundreds of CECs, broke them into categories, and then broke those categories down further. When the panel went on to identify the technologies that would be effective against the maximum number of these contaminants, ozone and UV were selected. Both unit treatment processes were added during the 2013 expansion. The Campus is equipped with a cutting edge water quality testing laboratory. In addition, the plant has on-line monitors that measure water quality parameters at various stages of the treatment process.

The state-of-the-art technologies used in potable reuse systems like Scottsdale’s are challenging to implement and maintain. Identifying the right technology and understanding how the intricate process works continue to be two of the Water Campus’ biggest challenges. “Everything can look good on paper, but once the system is built, there are always kinks that have to be worked out,” Nuñez said. Hiring is another challenge, according to Nuñez. Because few people have worked on IPR systems, hiring almost always requires additional training. In addition, Scottsdale’s IPR system is so rare that Nuñez serves as a resource for other cities investigating implementation of similar projects. “Not a week goes by,” said Nuñez, “that I don’t get a call or an email from someone asking questions about what we’re doing here.”

stepping into uncharted territory. Permitting programs effectively allow IPR through aquifer recharge, but the permitting process to construct a potable reuse facility involves multiple state and county agencies, and it can be a difficult and lengthy process.

The Scottsdale Water Campus, for example, required five permits from three different agencies before the facility could commence operations. A Wastewater Reuse Permit and an Aquifer Protection Permit were required by the Arizona Department of Environmental Quality (ADEQ), and the ADWR required an Underground Storage Facility Permit. Finally, an Air Quality Emissions Permit and an Operating Permit were both required by Maricopa County. Arturo Nuñez, the City of Scottsdale’s Water Reclamation Services Director, stated that obtaining permits for the project was more time-consuming than for a traditional drinking water treatment plant. In addition to submitting plans to state and county regulators, his team brought officials from the agencies to the Scottsdale Water Campus to demonstrate the

Table 1. Examples of Safe Drinking Water Act Regulated Contaminants by Category

Contaminant	Sources of Contamination	Potential Health Effects
Microorganisms		
Cryptosporidium	Human and animal fecal waste	Gastrointestinal illness: diarrhea, vomiting, and cramps
Giardia lamblia	Human and animal fecal waste	Gastrointestinal illness: diarrhea, vomiting, and cramps
Total Coliforms (including fecal coliform and E. Coli)	Naturally present in the environment, as well as feces. Fecal coliforms and E. coli only come from human and animal fecal waste.	Not a health threat in itself, used to indicate whether other potentially harmful bacteria may be present
Viruses (enteric)	Human and animal fecal waste	Gastrointestinal illness: diarrhea, vomiting, and cramps
Organic Chemicals		
Benzene	Discharge from factories, leaching from gas storage tanks and landfills	Anemia, decrease in blood platelets, increased risk of cancer
Glyphosate	Runoff from herbicide use	Kidney problems, reproductive difficulties
Polychlorinated biphenyls (PCBs)	Runoff from landfills, discharge of waste chemicals	Skin changes, thymus gland problems, immune deficiencies, reproductive or nervous system difficulties, increased risk of cancer
Inorganic Chemicals		
Cadmium	Corrosion of galvanized pipes, erosion of natural deposits, discharge from metal refineries, runoff from waste batteries and paints	Kidney damage
Lead	Corrosion of household plumbing systems, erosion of natural deposits	Infants and children: Delays in physical or mental development, children could show deficits in attention span and learning abilities. Adults: Kidney problems, high blood pressure
Nitrate (measured as Nitrogen)	Runoff from fertilizer use, leaking from septic tanks, sewage, erosion of natural deposits	Infants below the age of six months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill or die. Symptoms include shortness of breath and blue-baby syndrome.
Selenium	Discharge from petroleum refineries, erosion of natural deposits, discharge from mines	Hair or fingernail loss, numbness in fingers or toes, circulatory problems
Disinfectants		
Chloramines	Water additive used to control microbes	Eye/nose irritation, stomach discomfort, anemia
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Disinfectant By-products		
Bromate	By-product of drinking water disinfection	Increased risk of cancer
Chlorite	By-product of drinking water disinfection	Anemia, infants and young children: nervous system effects
Radionuclides		
Radium 226 and Radium 228 (combined)	Erosion of natural deposits	Increased risk of cancer
Uranium	Erosion of natural deposits	Increased risk of cancer, kidney toxicity

effectiveness of potable reuse treatment. Once regulators understood that potable reuse systems actually produce water of higher quality than conventional water purification, Nuñez explained, safety concerns were allayed.

An ADWR report recommends the development of a comprehensive regulatory framework for IPR and states that Arizona will need to invest in DPR as water supplies become scarcer. The report, "Arizona's Next Century: A Strategic Vision for Water Supply Sustainability," (Strategic Vision) released In January of 2014, is intended to guide the state's water strategies over the next 100 years. The Strategic Vision's 10-Year Action Plan includes reviewing legal and institutional barriers to DPR in year three, to provide the lead time needed to develop the appropriate regulatory framework for safe potable reuse.

Contaminants

The original intent, and still primary benefit, of drinking water treatment is the reduction of pathogens in the water supply. Pathogens can make people sick or die soon after exposure—an acute response. Increasingly, regulations have been adopted to also reduce chemical contaminants, most of which have chronic effects at fairly low concentrations. The EPA currently regulates over 90 contaminants under the Safe Drinking Water Act (SDWA), including physical, biological, chemical, and radiological constituents. Table 1 gives specific examples of microorganisms, organic and inorganic chemicals, disinfectants and their by-products, and radionuclides in these categories.

The EPA's Unregulated Contaminant Monitoring (UCM) program was established to collect data on contaminants that are not currently regulated but are suspected to be present in drinking water. The UCM program runs on a 5-year cycle, and EPA lists no more than 30 contaminants on its Contaminant Candidate List (CCL) each cycle. By the end of each cycle, the EPA must decide whether or not to regulate at least five contaminants on the CCL. The EPA bases its regulatory determinations on each contaminant's effect on human health and the likelihood that the contaminant occurs in public water systems at levels of concern to public health. The EPA has published three CCLs and released a draft CCL4 for comment. Table 2 gives examples of contaminants listed on the CCLs.

An ill-defined group of largely unregulated contaminants receives the majority of attention in scientific studies and in the media with respect to potable reuse. These constituents are known as contaminants of emerging concern (CECs). According to the EPA, CECs are contaminants that had not been detected previously in water or that are being detected at significantly higher levels than expected. Other definitions emphasize uncertainty relating to exposure and health effects of substances in water detected with ever more sensitive devices. Studies have found that some CECs resist removal through conventional drinking water treatment processes, and some CECs may even resist removal through advanced treatment.

Relatively little is known about the risks of most CECs in the environment and to human health, but some are linked to adverse impacts on certain aquatic species. CEC studies often conclude that more research is needed to determine the true risks of these chemicals to humans and the environment. The EPA is working to improve its understanding of CECs, particularly pharmaceuticals and personal care products (PPCPs). ADEQ formed the

Table 2. Examples of Contaminants Listed on the Contaminant Candidate Lists

Chemical Candidate	Use
Benzyl chloride	Used in the production of other substances, such as plastics, dyes, lubricants, gasoline and pharmaceuticals
Estradiol (17-beta estradiol)	It is an estrogenic hormone and is used in pharmaceuticals
Formaldehyde	Used as a fungicide, may be a disinfection by-product and can occur naturally
Metolachlor	Used as an herbicide for weed control on agricultural crops
Nitroglycerin	Used in pharmaceuticals, in the production of explosives, and in rocket propellants
N-nitrosodimethylamine (NDMA)	Formerly used in the production of rocket fuels, currently used as an industrial solvent and an anti-oxidant, and also a water disinfection by-product
Microbial Candidate	**Health Effect**
Adenovirus	Virus most commonly causing respiratory illness, and occasionally gastrointestinal illness
Campylobacter jejuni	Bacterium causing mild self-limiting gastrointestinal illness
Escherichia coli (0157)	Toxin-producing bacterium causing gastrointestinal illness and kidney failure
Hepatitis A virus	Virus that causes liver disease and jaundice
Legionella pneumophila	Bacterium found in the environment including hot water systems causing lung diseases when inhaled
Salmonella enterica	Bacterium causing mild self-limiting gastrointestinal illness

Chanute, Kansas Direct Potable Reuse

Implemented in 1956, the DPR system in Chanute, Kansas is the earliest example of potable reuse in the United States. Kansas endured a severe drought from 1952-1957. The city of Chanute, Kansas sits adjacent to the Neosho River, which served as the city's exclusive water supply. As a result of the drought, Chanute experienced intermittent water shortages.

According to the Kansas Geological Survey, 1956 was Kansas' single most severe drought year on record. The Neosho River ran dry that summer, and after weighing several options, government officials decided to turn to recycled water from Chanute's secondary treatment plant as a potable water source. The secondary treatment train consisted of primary sedimentation, trickling filters, and chlorine disinfection. A National Water Research Institute White Paper prepared by James Crook states that the Neosho River was dammed below the treatment plant outlet and treated wastewater was allowed to back up into a retention pond. Treated wastewater was retained for 17 days in the pond before it was treated and distributed for potable use. The potable reuse treatment train consisted of softening, chlorination, recarbonation, sedimentation, rapid sand filtration, and disinfection via chlorination. The recycled water was reused for five months, recirculating as many as 15 times. By today's standards the treatment train would not be considered acceptable for potable reuse.

Although city officials claimed the water was safe to drink, a yellowish tint and displeasing taste and odor remained. Despite these objectionable characteristics, initial public perception of the potable reuse project was positive because it was seen as a necessary short-term emergency measure. Crook argues that the public may also have accepted the measure because they knew they were already practicing de facto potable reuse. The Neosho River, when it was flowing, contained diluted secondary-treated wastewater from seven upstream communities. Public sentiment became more unfavorable when local newspapers began running negative stories about the project. Bottled water sales flourished as concerns over the quality of Chanute's water grew. In 1957 the drought ended, the Neosho River's normal flow returned, and the DPR project was discontinued.

Advisory Panel on Emerging Contaminants (APEC) to provide advice to the department and water utilities on matters relating to CECs. APEC has been addressing unregulated chemical and microbial contaminants in open discussions and preparing guidance for minimizing risk from CECs to human health and the environment.

Testing conducted by the U.S. Geological Survey (USGS) looked at CEC levels in 74 untreated drinking water sources throughout the U.S., including rivers and aquifers, and found that despite their ability to detect substances at very low levels, many targeted contaminants, particularly pharmaceuticals, were not detected in samples collected from source water sites. This means they were either not being transported to the sources of drinking water in detectable concentrations due to natural attenuation processes and/or there is no source for these contaminants to enter the watersheds and aquifers sampled. Detections were more common in water collected from surface-water sites than from ground-water sites, probably because of differences in environmental fate and transport processes. Authors noted that concentrations of any environmental water contaminant can be expected to decrease as they are transported away from the contaminant source to downstream locations, as long as no other source of the contaminant is present in the watershed. As a caveat, however, the USGS researchers acknowledged that compounds are likely to transform as they move through the environment as a result of natural processes, and therefore testing solely for parent compounds may not be an effective method for determining contaminant levels in raw sources of drinking water.

A study conducted at the Montebello Forebay Groundwater Recharge Facility in Los Angeles County, California looked at the fate of CECs, including viruses, during SAT. It found that the majority of pharmaceuticals tested, including caffeine, ibuprofen, and naproxen, were all removed or reduced to concentrations near or below detectable limits after retention times of less than six months. A handful of the chemicals tested, including two antiepileptic drugs, were not effectively removed throughout the testing period. Authors Bonnie Laws and colleagues concluded that SAT may be an effective way to treat for most CECs, but continued monitoring is essential to ensure removal of all contaminants. A similar investigation conducted in 2007 in Australia, in which an SAT demonstration program tested the attenuation of over 400 chemicals, found that advanced treatment coupled with an environmental buffer produces a safe potable water supply. Although detection has become more sensitive since the time of these studies, SAT is still considered an effective component for some IPR projects.

While the goal of the potable water purification process is to remove contaminants from water, some contaminants, including disinfection by-products (DBPs) and lead, can be created or make their way into drinking water as a result of treatment technologies. When chlorine, a commonly used disinfectant, reacts with naturally-occurring organic materials in wastewater, harmful DBPs are formed. According to the EPA, consuming water containing these DPBs at levels higher than the maximum contaminant level (MCL) over a long period of time may lead to an increased risk of cancer. An article by Susan Richardson and others in the journal *Mutation Research/Reviews in Mutation Research* reviewed 30 years of research on DBPs in drinking water and found that some studies draw a connection between life-time exposure of chlorinated water and a higher risk of cancer, notably bladder and kidney cancer. An epidemiological study that looked at risk by route of exposure concluded, however, that much of the risk associated with bladder cancer is not from drinking chlorinated water, but rather from showering, bathing, and swimming. The SDWA regulates a variety of DBPs with standards that allow only very low concentrations in potable water supplies.

Lead, an inorganic chemical, has many adverse effects on human health, including causing neurodevelopmental problems in children. The EPA's scientific findings indicate that there is no safe level of exposure to lead; therefore the SDWA has set the MCL for lead at zero. Some potable treatment trains use chloramine, a combination of chlorine and ammonia, as a disinfectant. Using chloramine in place of chlorine can be desirable because it produces lower levels of DBPs, but it has a downside. Research conducted by chemist Jay Switzer at the University of Missouri and published in the journal *Environmental Science & Technology* revealed that when distributed into residential pipes, recycled water treated with chloramine is likely to dissolve lead scale, releasing lead into the drinking water and out the tap.

N-Nitrosodimethylamine (NDMA) is a nitrosamine, a group of semi-volatile organic chemicals, which are by-products of the ozonation and chloramination processes. NDMA is classified as a probable human carcinogen and is of particular concern because it dissolves easily in water and is very difficult to separate back out. NDMA is a CEC that is not currently regulated by the EPA but has been placed on the CCL for further monitoring and study. Due to mounting concerns over NDMA's potential health risks, many potable reuse plants are incorporating UV technology, effective in controlling NDMA, at the end stage of their treatment trains. Adding ozone before the RO process also helps to reduce NDMA formation by reducing levels of precursor substances; some potable reuse plants, such as Scottsdale Water Campus, have taken this added step to further control NDMA production.

Testing for contaminants enables control actions. Testing is costly, and it is generally not economically feasible to test for every potential contaminant. Furthermore, as contaminants move through the various treatment processes, they may degrade or transform, which makes testing for parent contaminants ineffective. Procedures to identify contaminants for testing to minimize risk make up an important part of any potable reuse project.

Because the quantity and diversity of contaminants in wastewater can vary greatly from day to day and over longer time periods, frequent testing is desirable. An article published in the *International Journal of Environmental Research and Public Health* by Clemencia Rodriguez and others argues that compliance testing alone is not enough to protect the public. The authors raise concerns that non-compliance with SDWA regulations is typically determined after contaminated water has already left the treatment plant. In addition to testing the finished product, Rodriguez called for the monitoring of critical control points along the treatment train. Proactive failure detection systems measure the performance of the treatment processes. Some potable reuse projects, such as those in Scottsdale and Windhoek, Namibia, incorporate on-line monitoring systems into their treatment trains in addition to testing the finished product. Advocates for potable reuse believe that this two-fold strategy addresses timeliness issues associated with testing, ensuring that public safety is routinely maintained.

Treatment Waste Streams

The treatment processes used to purify wastewater also produce waste by-products such as biosolids, digester gases, and brine. Biosolids and gases are products of primary and secondary wastewater treatment processes, while brine is a product of the RO process used in many advanced treatment trains for potable reuse. Brine is a highly concentrated solution of salts, organic solids, and other contaminants. Disposal of brine is a major problem in RO treatment due to its high salinity and its high concentration of contaminants, especially in inland settings like Arizona.

There are several strategies used by treatment plants to deal with brine. One strategy for brine stream disposal is surface water discharge into oceans, rivers, or reservoirs. This technique is better suited to coastal cities because oceans, with their comparatively larger size and high salinity level, can receive and dilute brine discharges more readily than inland bodies of water. Surface water dischargers must comply with state and federal regulations, including NPDES permitting under the

Bullard experimental concentrate management wetland
Source: U.S. Bureau of Reclamation

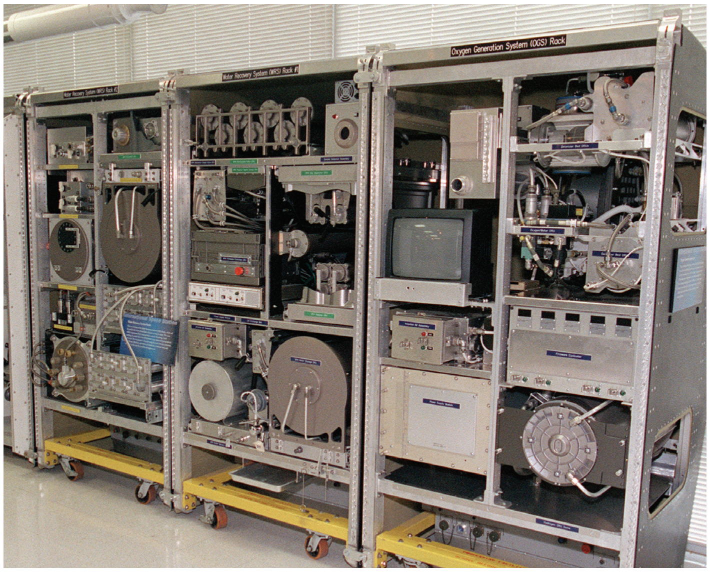
Clean Water Act. Those regulations may limit a treatment plant's ability to dispose of brine in this manner.

According to a study conducted by Thomas K. Poulson on salinity in central Arizona, the two most common forms of brine disposal in the Phoenix area are evaporative ponds and sewer disposal. Evaporative ponds collect brine in large lined, artificial impoundments, from which water evaporates leaving behind salts and other solids. This technique is often used in inland areas with no access to an ocean or other large body of water. The main drawback of evaporative ponds is the large surface area and costly liner they require, which can make this method of disposal prohibitively expensive. Scottsdale Water Campus currently disposes of brine created by its IPR system to the sewer. The brine is conveyed through the sewer system to the 91st Avenue Wastewater Treatment Plant in Phoenix. While this method is cost effective now, Poulson argues that sewer disposal of brine reduces capacity at wastewater treatment plants, and it will cease to be a feasible disposal method in the future as brine streams increase. Furthermore, wastewater containing high levels of brine may reduce the suitability or increase the cost of the reclaimed water for many end uses of the water.

Deep well injection is another technique used for brine disposal. Brine is injected into alluvial sediments or porous rock formations underground. The City of Los Angeles disposes of brine through deep well injection, reducing the impact of brine discharge on the nearby Pacific Ocean. In Arizona, deep well injection of brine is not allowed under a current interpretation of Arizona's Aquifer Protection Permit program.

An experiment conducted at Al-Quds University in Jerusalem looked at the effectiveness of a biological wastewater recycling system based on hydroponic plant cultivation. In an article published in the *International Journal of Molecular Sciences*, this new technique was shown to be effective at reducing the salt content of brine to safe disposal levels. In addition, it can be used to produce ornamental and landscape plants of high economic value. The lead author on the study, Mohannad Qurie, cautions that this technique should not be used to grow edible plants due to the toxic nature of brine.

Researchers in Arizona are experimenting with the disposal of brine stream through native salt-tolerant, or halophytic, plants. A 1-year pilot project at the Bullard Regulating Wetlands pumps brine through a series of tanks that are planted with three square rush, cattails, and salt grass. The study's goals include reducing salts and other constituents in the brine so that the end product is usable as recycled water or for discharge into the Gila River. Other work looked at quailbush irrigated over three growing seasons with brine from a RO water treatment plant in Marana, Arizona. Results showed that a halophyte crop could be grown productively on saline irrigation water with minimal excess deep percolation of salt past the root zone.



Unconventional Forms of Potable Reuse - International Space Station Environmental Control and Life Support System Water Recovery System

Many technologies in use in the water industry and throughout society today originated as innovations from space exploration. The International Space Station (ISS) was launched into orbit in 1998 and has been occupied continuously since the year 2000. According to NASA, the ISS is a reusable spacecraft intended for use through 2020 and possibly longer; therefore its life support system must function for many years to come. Water and other supplies can be ferried from Earth, but shipping upwards of 15 tons of water each year, the amount needed for a crew of three, is expensive--estimated at $10,000 per pound. Water recycling on the space station reduces these costs. A water recovery system (WRS) was delivered to the ISS in November of 2008, and the crew was given authorization to drink water purified by the system in April of 2009. The WRS allowed the crew of the ISS to expand to six members by reducing the amount of water that must be transported from Earth by 15,000 pounds per year.

The treatment train employed by the WRS relies on distillation, a technology commonly used in desalination. The WRS comprises a Urine Processor Assembly (UPA) and a Water Processor Assembly (WPA). The UPA collects and processes urine from the crew, separating water from waste through distillation. Water from the UPA process is transferred to the WPA where it is combined with wastewater from other parts of the station. The combined wastewater is rid of gasses and solids and then put through a series of filtration steps, including an ion exchange step. Finally, a high-temperature catalytic reactor is used to remove any remaining organic contaminants or microorganisms. Water is tested for purity using electrical conductivity sensors, and if it does not meet testing standards it is reprocessed. Clean water is held in a storage tank for reuse by the crew.

Financial Hurdles

High startup costs can be a significant barrier to the implementation of potable reuse projects. IPR systems include an environmental buffer and pipelines to transport water to it. Thus the initial costs of IPR projects may include environmental assessments to evaluate the potential impacts on terrestrial and aquatic habitats and species, including how the construction of water transportation pipelines will affect the surrounding habitats.

High operation and maintenance costs are another area of financial concern for potable reuse projects. Such costs include energy, ongoing maintenance, water quality testing, and training costs. IPR systems may have additional transportation requirements that can increase operating costs. San Diego's IPR system, for example, pumps purified wastewater over 20 miles to be discharged into the San Vicente Reservoir. If a suitable aquifer is nearby, however, there may be little to no added transmission cost, as is the case with Scottsdale Water Campus where the injection wells are on site. For DPR systems, costs may be driven up by the additional monitoring expectations that come with the absence of an environmental buffer. Some DPR systems may incorporate engineered buffers, and these can significantly increase the cost of the project.

Although potable reuse may have a higher price tag than conventional drinking water, some cities see it as a bargain compared to the alternatives. According to David Smith of WateReuse California, compared to alternative sources such as desalination, recycled water is much more energy efficient to produce. A white paper published in 2014 by the WateReuse Association, reported that the average cost of potable reuse water is $820-$2,000 per acre-foot compared to $1,500-$2,330 per acre-foot for desalinated water. For coastal cities that are faced with a choice between the two, potable reuse seems to be the more cost-effective option. The San Diego Coastkeeepers, a non-profit organization that protects and restores waters in San Diego County, states that in addition to being more cost-effective, potable reuse solves the problems of water scarcity and pollution while desalination only addresses the water scarcity issue.

The City of Tucson published a Recycled Water Master Plan in 2013 and has started an implementation program. Cost is one of the major factors standing in the way of developing a reuse supply of water. Tucson Water's potable water, which is a blend of CAP water and native groundwater, costs approximately $288 per acre foot before delivery to customers. This figure does not include any past capital costs. For planning purposes, price estimates for potable reuse in Tucson range from $1,500-$2,000 per acre foot, including amortized capital construction costs—a substantial increase. Tucson Water's staff point out that a potable reuse supply is not needed in the short term. When factors like stored CAP water and dropping potable demand are considered together with capital construction costs, the implementation of treatment and distribution of recycled water for potable use is easily more than 10 years away.

Guy Carpenter emphasized that the financial issues of potable reuse must be thoroughly examined to assess the true nature of benefits and costs. Carpenter stated that many cities have implemented purple pipe systems for non-potable reuse, but the systems are expensive to construct and maintain. When comparing the advantages of a purple pipe system against those of an IPR system with aquifer recharge, the IPR system typically wins the benefit-cost comparison. According to Carpenter, the purple pipe system does not afford most cities the flexibility that may be needed in the future if a shortages forces cuts in water usage for non-essential demands, such as golf course irrigation. In contrast, an IPR system's water can be used for both potable and non-potable uses.

Unconventional Forms of Potable Reuse - Pure Cycle Complete Water Recycling System

In the late 1970s and early 80s, the Pure Cycle Corporation installed about 50 single-family DPR systems in Colorado. These self-contained, complete water recycling systems cost about $15,000 installed, according to an article in the New York Times by Michael deCourcy Hinds. This cost was comparable to that of conventional septic systems at the time. Customers also paid a monthly $35 service and warranty fee, which covered repairs and maintenance to the potable reuse system.

Pure Cycle's state-of-the-art, computer operated system collected all of the home's wastewater and purified it using a 5-step process. Wastewater treatment began with anaerobic sewage digestion. The remaining steps in the treatment train were akin to what might be found in a modern potable reuse plant, and included nanometer membrane filtration (similar to MF), carbon filtration, ion exchange, and finally, UV sterilization. Robert Mankes, vice president of Pure Cycle claimed in 1981 that the system had a remarkable 99.3-percent water recovery rate, which eliminated the need to add water to the system after an initial 1,000 gallons of water were added to its reservoir.

Pure Cycle planned on expanding their operation to Arizona, New Mexico, and Wyoming, where its system had already been approved by government health officials. However, the short-lived project never made it out of Colorado. A report on DPR for the WateReuse Research Foundation and WateReuse California, states that Pure Cycle was forced to shut down due to financial issues and was subsequently unable to continue maintenance on clients' DPR systems.

Nejlah Hummer, Montgomery & Associates Summer Writing Intern at the WRRC, graduated from the University of Arizona in May 2015 with a degree in Anthropology and Environmental Studies and is enrolled in the Master of Planning Program at UA. Her interdisciplinary approach to academics reflects her belief that the best solutions to environmental issues come from the integration of multiple perspectives. Her greatest takeaway from the internship was that, like many solutions to environmental issues, potable reuse involves trade-offs. After graduating, Nejlah hopes to work with a government agency or non-profit working to solve problems of the urban environment, including water scarcity, in her hometown of Tucson or the greater Southwest.

Operations Hurdles

Once plans are approved by regulators, funding secured, and construction of a potable reuse plant completed, the day-to-day challenge of operating such an advanced water treatment facility can be formidable. Arturo Nuñez, the City of Scottsdale's Water Reclamation Services Director, stated that understanding exactly how each piece of the treatment train works and how the pieces work together can be difficult. "There's not a lot of history, not a lot of places you can turn for help," said Nuñez. He added that hiring and training can also be challenging. "There are not a lot of people who have worked on IPR systems before, so almost everyone we hire has to be taught," Nuñez said.

Nuñez's sentiments regarding staffing difficulties were echoed by Guy Carpenter, who observed that there is no certification program for non-potable reuse operators, let alone potable reuse operators, and this makes staffing for potable reuse projects daunting. To ensure that public safety is maintained, it is essential that plant operators are fully abreast of the risks associated with recycled water and what to do in case of a malfunction. At a 2010 workshop on DPR sponsored by the California Urban Water Agencies, the National Water Research Institute, and WateReuse California, participants recognized that a potable reuse operator certification program is needed in order to build confidence in potable reuse systems with regulatory agencies and the public.

Public Acceptance

While regulatory and financial obstacles may impede implementation of potable reuse projects, many industry experts agree that the single greatest hurdle is public acceptance. While potable reuse projects have been successfully implemented, public backlash against potable water reuse has torpedoed projects in Tampa, Florida, Brownwood, Texas, and South Queensland, Australia. For example, after receiving approval in December 2012 to construct a DPR plant, complete with $12 million in funding in the form of loans from the Texas Water Development Board, the City of Brownwood, Texas, was prompted by a public backlash to delay implementation in order to reassess their options. Guy Carpenter observed that "there are significant cultural and demographic differences among communities, and these differences influence the degree to which the community embraces or rejects a potable reuse project."

The complexity of public attitude formation and change defies simple formulas. Po, Kaercher, and Nancarrow, in a paper from Australia, identified multiple factors that influence public perceptions of water reuse. These included disgust and trust, as well as perceptions of risk, recycled water source, choice, environmental attitudes, environmental justice issues, cost, and socio-demographic factors. Others have identified other factors such as social norms, cultural constructs, and political contexts. Knowledge and transparency also have a role.

Research on the concept of contamination and disgust supports the hypothesis that people are reluctant to drink recycled wastewater because they regard it as unclean through association with its source. For example, psychologist Paul Rozin, a specialist in disgust and contamination psychology at the University of Pennsylvania, reasoned that even if people understand the science behind the water purification technology, they still may be unwilling to drink recycled wastewater because of its association with human waste products.

Trust in the utility and public officials is an important factor. In 2012, University of Arizona researchers Kerri Jean Ormerod and Christopher A. Scott conducted a survey of more than 250 Tucson residents on the topic of recycled water. They found that public acceptance of potable reuse was largely tied to the public's level of trust in government officials and the officials who design and implement water purification and distribution systems. Respondents were overwhelmingly supportive of using recycled water for non-potable uses such as irrigating golf courses and city parks, but when asked about drinking recycled water, support was much weaker.

In an article for *Water Policy*, authors Russell and Lux reviewed much of the literature on factors affecting

Singapore NEWater visitor center.
Source: Singapore Government

public acceptance of recycled water. Russell and Lux concluded that although attitudes "may develop over long periods of socialization and be deep-rooted," they can be changed. Accordingly, providing "an iterative process in which people can discuss, question and develop their views on recycling" can allow the public to take an informed and reasoned approach to evaluating options.

The Steering Committee on Arizona Potable Reuse (SCAPR) was formed in 2012 by the Arizona state section of the WateReuse Association. To achieve its goal of helping to break down barriers to potable reuse, SCAPR identified key actions that can lead to the successful rollout of potable reuse projects. These include implementing public relations campaigns while potable reuse projects are in their infancy and using consistent terminology that is clear and understandable to everyone. A key to building trust identified by both SCAPR and University of Arizona researchers is the influence of trusted experts such as non-profit organizations, public health officials, academic researchers, and community leaders.

The City of Flagstaff organized an advisory panel of 12 local, state, and nationally recognized researchers, scientists, and industry professionals to address questions related to the occurrence and impacts of CECs in raw, treated, and reclaimed water. Public meetings over several years improved understanding of issues and prepared the community for making future choices or policy decisions while using sound science.

SCAPR also noted that campaigns are likely to be ineffective if they simply try to convince the public that recycled wastewater is clean. A more effective strategy, according to SCAPR, is to focus on how potable reuse will benefit the community. Also, recent focus group studies show that emphasizing the multiple barrier approach significantly increases the public's acceptance.

Successful IPR projects in San Diego, California, and Singapore have visitor centers integrated into their plants. These visitor centers offer the public a behind-the-scenes view of the technical operations that would otherwise be seen only by those who work in the plants. According to an article by Steirer and Thorsen in the *Journal of the American Water Works Association*, such centers teach the public about water purification technologies and help correct inaccurate perceptions about potable reuse.

The ADWR Strategic Vision report recommends implementing a DPR public relations campaign in year four of its ten-year action plan. It concludes that by addressing public perception issues early, Arizona will ensure that DPR will be available when it is needed in the future.

Conclusion

Although some questions remain, water professionals and decision makers recognize potable reuse may be one of the best options for expanding water portfolios. A white paper prepared for the National Water Research Institute by Edward Schroeder and others states that potable reuse alone will not fill all future water requirements, but in many cases, combining potable reuse with sustainable use of local water sources may be adequate to meet future water demands. Each community that is considering potable reuse must conclude for itself what is in its best interest for future water supply. Projects employing technologies that produce water of near pristine quality are in operation today. As supply stresses inevitably increase, more jurisdictions will consider potable reuse, spurring technological innovation. Improved technologies are likely to bring costs down relative to other water sources. The public is still on the fence, but a combination of cost advantages and advances in purification may well increase public support as water stress increases. Close attention to risks posed by contaminants will remain essential and much work needs to be done to establish and maintain practices that ensure public safety. Operator training will be key, as will research on effective detection, treatment, and monitoring.

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