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Guidance Framework for Direct Potable Reuse in Arizona

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FINAL REPORT:

Guidance Framework for Direct Potable Reuse in Arizona

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Steering Committee for Arizona Potable Reuse

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Contributor

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ACRONYMS AND ABBREVIATIONS

ADEQ	Arizona Department of Environmental Quality
AOP	Advanced oxidation process
APEC	Advisory Panel on Emerging Contaminants
ATW	Advanced treated water
AWTF	Advanced water treatment facility *(Note: This term is equivalent to "Advanced Reclaimed Water Treatment Facility" in Arizona's 2017 proposed rulemaking)*
AZPDES	Arizona Pollutant Discharge Elimination System
BADCT	Best Available Demonstrated Control Technology
BAC	Biological active carbon
BAF	Biologically active filtration
BOD	Biochemical oxygen demand
CAP	Central Arizona Project
CCP	Critical control point
CEC	Constituent of emerging concern
CF	Cartridge filtration
COD	Chemical oxygen demand
DBP	Disinfection byproduct
DPR	Direct potable reuse
DWHA	Drinking Water Health Advisory
DWTF	Drinking water treatment facility
ED	Electrodialysis
FRT	Failure response time
GAC	Granular activated carbon
GWAC	Governor's Water Augmentation Council
H_2O_2	Hydrogen peroxide
IPR	Indirect potable reuse
IU	Industrial user
L	Liter
LRV	Log reduction value
LT2 ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum contaminant level

MCLG	Maximum contaminant level goal
MF	Microfiltration
mg	Milligram
mg/L	Milligram per liter
MOU	Memorandum of Understanding
NDMA	N-Nitrosodimethylamine
NF	Nanofiltration
ng	Nanogram
ng/L	Nanogram per liter
NRC	National Research Council
NWRI	National Water Research Institute
O&M	Operation and maintenance
POTW	Publicly owned treatment work
RO	Reverse osmosis
SCADA	Supervisory Control and Data Acquisition
SCAPR	Steering Committee for Arizona Potable Reuse
SDWA	Safe Drinking Water Act
SIC	Standard Industrial Code
SRP	Salt River Project
SWA	Surface water augmentation
SWTR	Surface Water Treatment Rule
TCEQ	Texas Commission on Environmental Quality
TMF	Technical, managerial, and financial
TDS	Total dissolved solids
TOC	Total organic carbon
UF	Ultrafiltration
U.S. EPA	U.S. Environmental Protection Agency
UV	Ultraviolet light
UVT	Ultraviolet light transmittance
WWTP	Wastewater treatment plant
µ	Micron
µg/L	Microgram per liter

EXECUTIVE SUMMARY

The purpose of this Guidance Framework is to provide recommendations on items that would be specifically addressed in the development of regulations in Arizona for direct potable reuse (DPR) that are protective of public health. A number of recommendations are made that would be best addressed in guidance and/or permitting language rather than as part of regulations. Based on current information and experience, it is feasible for the State of Arizona to develop regulations for DPR that would incorporate a level of public health protection as good as or better than what is provided currently by conventional drinking water supplies in the United States.

Introduction

To improve the sustainability of Arizona's water supplies, the Arizona Department of Environmental Quality (ADEQ) currently is engaged in revising the Arizona Administrative Code to expand the beneficial reuse of treated wastewater in Arizona. This revision process will rely heavily on stakeholder involvement and expertise. Two stakeholders, WateReuse Arizona and the AZ Water Association, tasked the National Water Research Institute (NWRI) – a nonprofit organization experienced with potable reuse regulations – to prepare a Guidance Framework with recommendations regarding the development of regulations for direct potable reuse (DPR) in Arizona.

DPR is an emerging strategy that involves using treated municipal wastewater to augment public water supplies. At present, Arizona does not have guidance or regulations specific to DPR. Although DPR is formally prohibited under the Arizona Administrative Code as written currently,[1] ADEQ, has prepared a draft interim regulation to remove this prohibition and allow DPR under strict regulatory oversight until a final DPR regulation can be developed and enacted. Work has already begun on the final DPR regulation. This Guidance Framework is meant to both help advance its progress and inform ADEQ's process to revise Arizona's rules governing the beneficial reuse of reclaimed water.

The DPR recommendations provided in this Guidance Framework are intended to:

- Be protective of public health based on available technical and scientific information.
- Incorporate a level of public health protection as good as or better than provided by conventional drinking water supplies (including indirect potable reuse [IPR]) in the United States.

The information and recommendations presented in this document cover various facets of DPR, including: (1) source control; (2) treatment performance; (3) pathogen control; (4) chemical control; (5) monitoring; (6) water quality; and (7) other related areas.

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[1] The Arizona Administrative Code specifies that the direct potable reuse of water specifically for human consumption is prohibited. Refer to the Arizona Administrative Code, Title 18 (Environmental Quality), Chapter 9 (Department of Environmental Quality - Water Pollution Control), Article 7 (Direct Reuse of Reclaimed Water), Section 704 (General Requirements), Subsection G [see 7 Ariz. Admin. Code § R18-9-704 (2013)]. http://apps.azsos.gov/public_services/Title_18/18-09.pdf.

Summary of Findings and Recommendations

Included in this Guidance Framework are specific findings and recommendations on various aspects of DPR. "Findings" are statements that emphasize the current knowledge or understanding of DPR. "Recommendations" are specific items that should be considered in the development and implementation of DPR in Arizona. Recommendations are categorized into two areas: (1) recommendations that should be considered in the formal regulation in Arizona (Regulatory); and (2) recommendations that can be addressed in guidance and/or permitting of projects (Guidance or Permitting). Certain components must be addressed in the regulation to ensure that DPR projects are protective of public health, but many components of a DPR system would be more appropriately addressed in guidance or permitting to allow for flexibility as experience with DPR increases over time and additional science becomes available. Recommendations are summarized in **Tables ES-1** to **ES-15** by topic. More details about these recommendations are provided in **Chapter 3**.

Table ES-1: Recommendations for Topic #1 on Terminology

No.	Recommendation	Regulation	Guidance or Permitting
1	Certain terms have to be defined in regulations.	✓	
2	Many terms may be best addressed in policy, guidance, and/or permitting, which allows for flexibility.		✓

Table ES-2: Recommendations for Topic #3 on Pathogen Control and Log Reduction Requirements

No.	Recommendation	Regulation	Guidance or Permitting
1	Pathogens should be removed or inactivated with a goal of 10^{-4} annual risk of infection. This level of risk is consistent with the rules promulgated under the Safe Drinking Water Act and with other potable reuse efforts (i.e., California and Texas).	✓	
2	A multiple barrier treatment approach should be defined and required (such as adopted by California for indirect potable reuse).	✓	
2a	Specific requirements can be provided in supporting guidance and/or permitting.		✓
3	Both the California (12/10/10 log reductions for virus, *Cryptosporidium*, and *Giardia*) and Texas (minimum 8/5.5/6 log reductions for virus, *Cryptosporidium*, and *Giardia* post wastewater treatment) pathogen log reduction criteria approaches should be offered. Allowing both approaches provides maximum flexibility for projects in Arizona.	✓	
4	The implementation of a log credit system will need to be established; however, the system can be addressed through policy or guidance. In addition, the burden can be placed on the utility to propose its approach to achieving the log reduction targets in the form of a project proposal.		✓
4a	A "project proposal report" or "design report" should be required through regulation.	✓	

No.	Recommendation	Regulation	Guidance or Permitting
4b	The requirements for the project proposal report or design report can be addressed in guidance and/or permitting.		✓
5	Using the Texas approach will require ADEQ to review the project, characterize the wastewater, and approve the treatment process.		✓

Table ES-3: Recommendations for Topic #4 on Chemical Control

No.	Recommendation	Regulation	Guidance or Permitting
1a	A three-tiered monitoring approach can be used to control chemicals for DPR and include: 1. Tier 1 – Safe Drinking Water Act (SDWA) and state requirements (including disinfection byproducts and nitrate). 2. Tier 2 – Unregulated chemicals (including constituents of emerging concern [CECs]) of interest from the standpoint of public health (such as NDMA). 3. Tier 3 – Unregulated chemicals (Including CECs) that are useful for evaluating the effectiveness of organic chemical removal by treatment trains. The three-tier monitoring approach can be required in regulations.	✓	
1b	The details for implementing the monitoring requirements can be set in guidance/permitting.		✓
2	Nitrate is regulated under the SDWA and presents a potential acute risk; as a result, it is of particular importance to DPR and should be monitored for in the advanced water treatment system.	✓	
3	Appropriately sensitive and specific analytical methods are needed.		✓
4	Conduct comprehensive analytical studies on the types and quantities of chemicals (including CECs of interest and emerging CECs) that can be present in treated wastewater. The results would help determine how much removal is needed and what CECs need to be monitored.		✓

Table ES-4: Recommendations for Topic #5 on Potable Reuse Applications in Arizona

No.	Recommendation	Regulation	Guidance or Permitting
1	DPR regulations in Arizona should address both raw water augmentation and treated drinking water augmentation.	✓	
2	DPR regulations in Arizona can cover surface water augmentation, which involves augmenting reservoirs, lakes, and water conveyance structures with advanced treated recycled water.	✓	

Table ES-5: Recommendations for Topic #6 on Utility Collaboration

No.	Recommendation	Regulation	Guidance or Permitting
1	Memoranda of Understanding (MOUs) or inter-governmental agreements are needed to define the roles and responsibilities of multiple utilities and/or jurisdictions. These agreements can describe the methods that the utilities and/or agencies would use to work together and implement a DPR project.		✓

Table ES-6: Recommendations for Topic #7 on Source Control Programs

No.	Recommendation	Regulation	Guidance or Permitting
1	A pretreatment program and source control program should be established as part of the DPR permitting process.	✓	
1a	The elements of implementing an aggressive education and source control program in conjunction with the pretreatment program can be developed for utilities pursuing DPR projects, regardless of size.		✓
2	Minimum requirements should be established for all systems (i.e., not just medium and large systems), regardless of jurisdictional issues and/or boundaries.		✓
3	A source control program for a DPR project should control chemicals from a drinking water perspective. The source control program should go beyond pretreatment regulations to manage chemicals.		✓
4	An interagency cooperation and responsiveness plan should be developed between the entities operating the wastewater treatment plant, advanced water treatment facility, and drinking water treatment facility to ensure pretreatment and source control are conducted effectively.		✓

Table ES-7: Recommendations for Topic #8 on Wastewater Treatment

No.	Recommendation	Regulation	Guidance or Permitting
1	For DPR applications, the treated wastewater effluent must meet all existing federal and state regulations.	✓	
2	For DPR applications, control of nitrate should either (1) be accomplished in the wastewater treatment plant to supply Class A+ or Class B+ for advanced water treatment or (2) properly engineered into the advanced water treatment facility.	✓	
3	Pathogen log removal credits are needed for wastewater treatment if log removal reductions are needed.	✓	
3a	Credits can be established in guidance, or utilities can propose credits based on available information or a specific study.		✓

Table ES-8: Recommendations for Topic #9 on Advanced Water Treatment Technologies

No.	Recommendation	Regulation	Guidance or Permitting
1	All potable reuse projects should include a bypass from the outlet of the advanced water treatment facility into the sewer system (if available) or recycled back to the start of the treatment process.		✓
2	Pilot testing or demonstration studies are useful for the design and operation of DPR projects.		✓
3	For DPR, allow for a Best Available Demonstrated Control Technology (BADCT) approach that employs engineering controls, processes, and operating methods or other alternatives, including site-specific characteristics (i.e., local conditions), for approving treatment technologies that control for chemicals and pathogens.		✓

Table ES-9: Recommendations for Topic #10 on Pathogen Reduction Values for Treatment Processes

No.	Recommendation	Regulation	Guidance or Permitting
1	The State of Arizona can establish or approve log reduction values for a pathogen credit system for DPR treatment technologies based on systems developed in California and Texas and based on available guidance.		✓
2	As part of the log reduction credit system approach, Arizona can allow for utilities to verify or demonstrate log reduction levels for unit processes that can be used to assign appropriate log reduction credits.		✓

Table ES-10: Recommendations for Topic #12 on Monitoring, Instrumentation, and Process Control Requirements of Direct Potable Reuse Systems

No.	Recommendation	Regulation	Guidance or Permitting
1	Startup performance monitoring should be reported to ADEQ for approval. Water quality monitoring is recommended for each major treatment process and final product water quality.	✓	
2	Appropriate process monitoring for DPR systems using rapid surrogate measures is needed to measure pathogen reduction performance and to document and review system performance.		✓
3	In the event the DPR system cannot attain target pathogen credits or another water quality excursion, a judgment needs to be made based upon all the information available as to whether the facility should be shut down or out-of-specification water bypassed or diverted to another system (i.e., the sewer).		✓

Table ES-11: Recommendations for Topic #14 on Facility Operations and Maintenance

No.	Recommendation	Regulation	Guidance or Permitting
1	The operation and maintenance (O&M) requirements for a DPR system exceed the demands of a wastewater or drinking water supply, requiring specific operator skills and experience. DPR treatment plant operators should have a Grade 4 level of certification as a water treatment plant operator.	✓	
1a	The details of the number of operators required and level/types of certification can be addressed in guidance or permitting.		✓
1b	Lead operators and the Operator of Record should be Grade 4 licensed water operators.		✓
2	An O&M plan for DPR should be required.	✓	
2a	These plans should include procedures for initial startup, annual startup, shutdown, asset management, and O&M.		✓
2b	The O&M plan must include regulatory compliance sampling and monitoring.		✓
3	For DPR projects, the following should be required: (1) start-up reporting; (2) DPR system reporting added to drinking water reporting; and (3) an annual report.	✓	
3a	The details for start-up reporting, additional monthly reporting, and the annual report can be specified in guidance or permitting.		✓
4	A response plan for off-specification water should be required.	✓	
4a	The procedures of a response plan for off-specification water can be incorporated into the O&M plan for DPR.		✓
5	Alternative sources of water should be addressed in the ADEQ-required Emergency Operation Plan and the Emergency Response Plan.		✓
6	Certified water/wastewater operators will be needed to run a DPR system. Staffing for a DPR system should be required when the facility is operational.	✓	
7	An electronic remote sensing system should be available to provide real-time data, appropriate alarms, and automatic response so that operators and other expert support personnel can be on call at all times.		✓

Table ES-12: Recommendations for Topic #15 on Technical, Managerial, and Financial Capacity

No.	Recommendation	Regulation	Guidance or Permitting
1	An assessment could be required for DPR projects involving a technical, managerial, and financial (TMF) capacity assessment or a similar assessment that does not involve the state's TMF program.	✓	
2	The capacity assessment process for evaluating the ability of a utility to implement DPR can be detailed in guidance and could be part of the utility's project proposal.		✓

Table ES-13: Recommendations for Topic #16 on Small Water System Considerations

No.	Recommendation	Regulation	Guidance or Permitting
1	An analysis of technical, managerial, and financial (TMF) capacity or a similar process for assessing the ability of the small system to implement DPR is essential.		✓

Table ES-14: Recommendations for Topic #17 on the Consideration of Alternatives to the Criteria for Direct Potable Reuse

No.	Recommendation	Regulation	Guidance or Permitting
1	The State of Arizona should include an alternative provision as part of DPR regulations. The purpose of the alternative provision would be to allow for a utility to propose an alternative approach to any of the DPR criteria or requirements. The utility would need to demonstrate that the alternative provided at least the same level of public health protection.	✓	
2	Specific requirements for implementing the alternatives provision could be addressed in guidance or permitting.		✓

Table ES-15: Recommendations for Topic #18 on Public Acceptance and Outreach

No.	Recommendation	Regulation	Guidance or Permitting
1	Utilities considering DPR should be encouraged to develop a robust public outreach program to build awareness, trust, confidence, support, and acceptance of the DPR project.		✓

CHAPTER 1: INTRODUCTION

- Brief overview of water reuse in Arizona.
- Difference between planned and unplanned potable reuse.
- Difference between indirect potable reuse and direct potable reuse (including the environmental buffer).
- Recent efforts in Arizona to increase applications of water reuse.
- Purpose and organization of this Guidance Framework.

Potable water supplies are derived from a variety of sources (e.g., local and imported surface water, groundwater, desalinated brackish water and seawater, and recycled water), but factors such as population growth, urbanization, extended droughts, and climate change are stressing these supplies in some parts of the United States, including Arizona. Consequently, alternative strategies are needed to help communities meet future water demands and develop more sustainable water supplies (Tchobanoglous et al., 2015). One such strategy is direct potable reuse (DPR), in which highly treated municipal wastewater is used to augment public water supplies. DPR is the subject of this Guidance Framework.

1.1 Overview of Water Reuse in Arizona

Potable water supplies in Arizona tend to rely on groundwater, surface water, and imported water. It is expected, however, that potable water supplies in Arizona will be stressed over the next few decades due to drought, climate change, population growth, and other factors. Water resource reliability is a growing concern, particularly in areas of the State not connected to either the Salt River Project (SRP)[2] or Central Arizona Project (CAP)[3] or where communities have not diversified their water resources portfolios. In response to these challenges, the State of Arizona is actively engaged in revising the Arizona Administrative Code to expand the beneficial reuse of treated wastewater in Arizona. As noted in a 2010 Blue Ribbon Panel report to the Governor (Mayes et al., 2010), although much recycled water is used in Arizona, significant additional opportunities exist, including potable reuse. Currently, treated wastewater in Arizona is recycled for non-potable uses, environmental uses, and groundwater replenishment.

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[2] The Salt River Project (SRP) has provided water and power services to the Phoenix metropolitan area in central Arizona for over 100 years. It is one of the largest raw-water suppliers in Arizona, delivering about 800,000 acre-feet of water annually to a 375-square-mile service area and managing a 13,000-square-mile watershed that includes an extensive system of reservoirs, wells, canals, and irrigation laterals. Refer to www.srpnet.com for more information.

[3] The Central Arizona Project (CAP) is designed to bring about 1.5-million acre-feet of water from the Colorado River to Central and Southern Arizona every year. More than 5-million people (over 80 percent of the state's population) live in Maricopa, Pima, and Pinal counties, where CAP water is delivered. It is a 336-mile long system of aqueducts, tunnels, pumping plants, and pipelines, and is the largest single resource of renewable water supplies in Arizona. Refer to www.cap-az.com for more information.

1.2 Overview of Water Reuse Applications

Brief summaries of different applications of water reuse, including non-potable and potable reuse, are provided in this section.

1.2.1 Nonpotable Reuse

"Nonpotable reuse" is a general term used for all water reuse applications except those related to potable reuse. Nonpotable applications could include agricultural and landscape irrigation, for example.

The planned use of recycled water for non-potable reuse applications has been practiced for many years in Arizona. The first rules in Arizona regarding the reuse of reclaimed water were promulgated in 1972 by the Arizona Department of Health Services. These rules established: (1) effluent quality requirement for various irrigation uses and industrial reuse; and (2) monitoring requirements for reclaimed water. The rules were revised in 1985.

The Environmental Quality Act of 1986 created the Arizona Department of Environmental Quality (ADEQ), which was given administrative responsibility of the recycled water rules in Arizona. ADEQ promulgated rules for Aquifer Protection Permits and reclaimed water programs, which became effective in 2001 (ADEQ, 2017a). The rule framework provides an approach to regulate the reuse of reclaimed water in Arizona, including permitting requirements, reclaimed water quality standards, allowable end uses, and technical standards for the conveyance of reclaimed water. Recently, ADEQ initiated a revision process for the reuse rules in which DPR will be addressed (ADEQ, 2017b); see **Section 1.5** for further discussion.

1.2.2 Unplanned (*De Facto*) Potable Reuse

De facto potable reuse (**Figure 1-1**) is the unplanned or incidental presence of treated wastewater in a downstream surface water supply source or downgradient in the case of groundwater impacted by wastewater discharge (NRC, 2012). Unplanned potable reuse involves the discharge of treated wastewater effluent from one community into a surface water body that is used as a source of drinking water supply for another community. Unplanned potable reuse is a common occurrence in a number of drinking water supplies in the United States derived from surface water sources (NRC, 2012). In Arizona, unplanned potable reuse more typically results from the recharge of treated effluent, either through constructed works or through ephemeral streambeds, into local aquifers used for potable water production.

Figure 1-1: Schematic of unplanned (*de facto*) potable reuse. Figure courtesy of Olivieri et al. (2016).

1.2.3 Planned Potable Reuse

Planned potable reuse involves the use of recycled water to augment drinking water supplies. A well-known application of potable reuse is indirect potable reuse (IPR), which has been practiced through a number of projects in the United States for over 50 years (Crook, 2010). With IPR, treated wastewater is introduced into an environmental buffer, such as a groundwater basin or surface water body (i.e., reservoir, lake, or canal),[4] before being withdrawn, treated to drinking water standards, and used as a water supply. While some environmental buffers might offer opportunities for further treatment, the main functions of the environmental buffer include providing: (1) some level of water quality equalization; and (2) time to respond to any process failures or out-of-compliance water quality monitoring results (Drewes and Khan, 2011). Longstanding experience, including numerous examples in Arizona, has demonstrated that IPR is protective of public health (NRC, 2012).

Alternatively, an emerging application is DPR, which does not involve the use of an environmental buffer or the buffer is not of sufficient size to provide a substantial equalization or response time. As shown in **Figure 1-2,** the two main types of DPR include:

- **Advanced treated water (ATW) produced in an advanced water treatment facility (AWTF)[5] is introduced into the raw water source immediately upstream of a drinking water treatment facility (DWTF), also referred to as "raw water augmentation**." In the United States, two projects using this form of DPR have been permitted, both in Texas: (1) Colorado River Municipal Water District's Big Spring Raw Water Production facility; and (2) the City of Wichita Falls DPR Project.[6]

- **Finished water produced in an AWTF that also is permitted as a DWTF is introduced directly into a drinking water distribution system, also referred to as "treated drinking water augmentation**." A long-standing DPR project in Windhoek, Namibia, is the only example of this form of DPR in operation (Tchobanoglous et al., 2015). The City of El Paso, Texas, recently completed pilot testing for this type of DPR project.

1.3 National Research Council Studies on Potable Reuse

The National Research Council (NRC, 1998, 2012) has conducted two assessments of potable reuse in the past 20 years. During these assessments, potential challenges were identified and appropriate solutions were suggested to ensure planned potable reuse is a safe practice from the perspective of public health. The 1998 study focused solely on IPR, while the 2012 study addressed both IPR and DPR. The 2012 study benefited from advances made in treatment technologies and monitoring capabilities, along with increased research. Findings from NRC (2012) with respect to chemical and microbial constituents are summarized in **Table 1-1.**

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[4] If the environmental buffer is a groundwater aquifer, recycled water can be applied by surface application (i.e., the spreading of tertiary effluent to take advantage of soil aquifer treatment) or subsurface application (i.e., direct injection of highly treated recycled water). In Arizona, groundwater recharge with recycled water is addressed under existing regulatory frameworks.

[5] The term "advanced water treatment facility" is equivalent to "Advanced Reclaimed Water Treatment Facility" in Arizona's 2017 proposed rulemaking.

[6] The Wichita Falls Direct Potable Reuse project in Texas was permitted by the Texas Commission on Environmental Quality as an emergency water supply and was operated from July 2014 to July 2015.

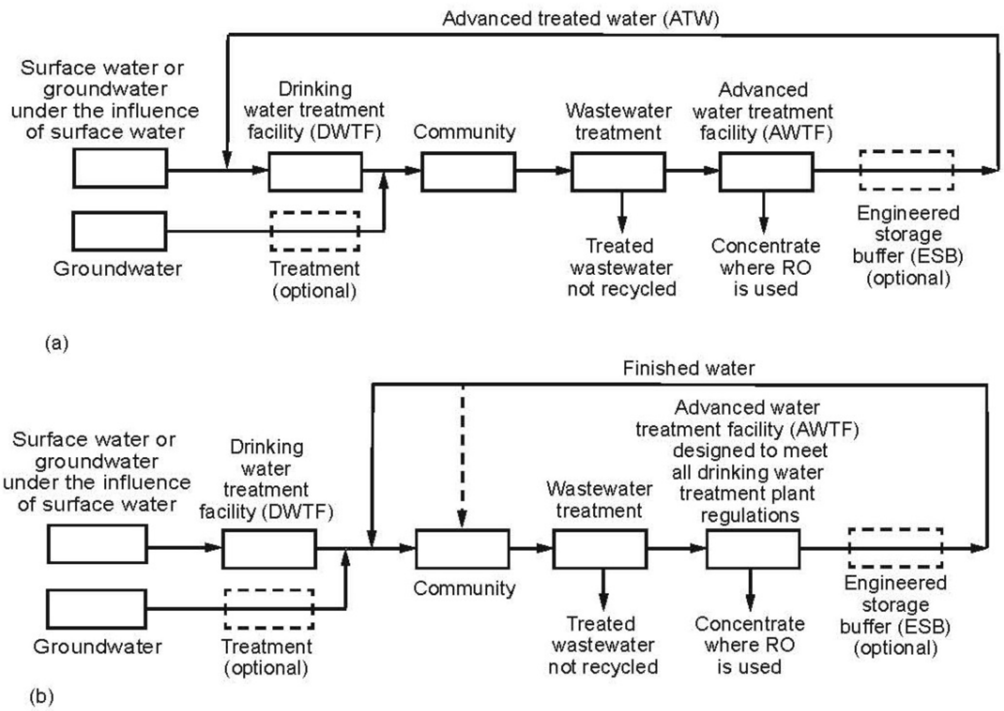

Figure 1-2: Flow diagrams for direct potable reuse: (a) with advanced treated water introduced upstream of a drinking water treatment facility (raw water augmentation); and (b) with finished water introduced into the drinking water supply distribution system downstream of a drinking water treatment facility (treated drinking water augmentation). Figure courtesy of Tchobanoglous et al. (2015).

Table 1-1: Findings from NRC (2012) as Related to Risks from Chemical and Microbial Constituents

Type of Risk	Findings
Risk from chemical constituents	Water quality is ensured through (a) source control programs, (b) treatment technologies that meet drinking water maximum contaminant levels and other limits, and (c) monitoring for constituents that present a public health risk. For advanced water treatment trains, most chemicals are not detected; those that are detected are found at levels lower than those found in conventionally treated drinking water supplies (NRC, 2012).
Risk from microbial constituents (i.e., pathogens)	The risk from pathogens in potable reuse "does not appear to be any higher, and may be orders of magnitude lower, than currently experienced in at least some current (and approved) drinking water treatment systems (i.e., *de facto* reuse)" (NRC, 2012).

Sources: NRC (2012) and Tchobanoglous et al. (2015).

1.4 Recycled Water as a Drinking Water Source

The Safe Drinking Water Act (SDWA) was established in 1974, during an era when the focus of regulatory efforts was limited to source waters from streams, rivers, lakes, and groundwater aquifers. Since then, recycled water has increasingly been used throughout the nation as a source of water supply. In addition, advanced water treatment technologies, such as advanced oxidation processes (AOPs), are becoming more routine. By building on key elements of the SDWA and using available advanced treatment processes, the water industry can use recycled water as a drinking water supply.

1.5 Changes to the Rules for the Reuse of Reclaimed Water in Arizona

In 2010, Governor Jan Brewer of Arizona created a Blue Ribbon Panel on Water Sustainability comprised of a broad group of stakeholders and water users for the purpose of finding ways to improve water sustainability in Arizona through conservation, reuse, and new technologies (AMWUA, 2016). The Blue Ribbon Panel noted in its report to the Governor (Mayes et al., 2010) that although much recycled water is used in Arizona, significant additional opportunities exist, including potable reuse. In addition, the Blue Ribbon Panel recommended that water and/or wastewater agencies be encouraged to evaluate the ability to implement a reuse program.[7]

In 2013, the Steering Committee for Arizona Potable Reuse (SCAPR) was formed to guide Arizona water interests in identifying and mitigating real or imagined impediments to potable reuse within industry standards of practice.

In 2014, the Arizona Department of Water Resources (ADWR) released *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability* (ADWR, 2014), which provided a comprehensive water supply and demand analysis for Arizona and identified key priorities, timelines, and action items needed to maintain sustainable water supplies for Arizona's future.

In 2015, Governor Douglas Ducey announced a water planning initiative for the State of Arizona. Based on the work in *Arizona's Next Century*, the "Arizona Water Initiative" was implemented with the signing of Executive Order 2015-13 (ADWR, 2017a). As part of this initiative, a Governor's Water Augmentation Council was created to investigate long-term water augmentation strategies, additional water conservation opportunities, funding, and infrastructure needs to help secure water supplies for Arizona's future. Four subcommittees were created under the Council, one of which was the Recycled Water Committee, chaired by John Kmiec (Marana Water) (ADWR, 2017b). The Recycled Water Subcommittee was formed to evaluate the progress made on the recommendations of the Blue Ribbon Panel on Water Sustainability for reclaimed water and to consider statewide opportunities for future recycled water projects (GWAC, 2017). The Subcommittee recommended that ADEQ end the prohibition on DPR (ADWR, 2017b).

In 2016, ADEQ began the process of revising Arizona's rules governing the reuse of reclaimed water and graywater (ADEQ, 2017b). Notably:

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[7] Regarding pharmaceuticals and personal care projects (also referred to as "trace organics" or "constituents of emerging concern"), the Blue Ribbon Panel stated in Chapter 4 (Section A.2) of its report that "there is a need for the public, community leaders, water treatment professionals, businesses, and industry to understand and be aware of water quality issues and how their actions, may impede the use of reclaimed water (Mayes et al., 2010).

> ADEQ last updated its reuse rules in 2001. While the rules have served the state well, Arizona has seen a striking expansion in the beneficial reuse of treated wastewater since then. During this time, research and technology have moved forward and new uses of reclaimed water have been proposed.
>
> ADEQ will rely heavily on stakeholder involvement and expertise in developing the reclaimed water rule revisions. ADEQ held initial listening sessions in Phoenix, Tucson, and Flagstaff to gather input on key needed changes. In addition, ADEQ initiated two technical work groups in early 2017. With input from stakeholders, ADEQ will develop proposed rule changes that the public can review and comment on. ADEQ will then move forward on adopting the proposed rule changes as Arizona's new rules (ADEQ, 2017b).

As part of this process, Arizona has been working on developing regulations specific to DPR. Although DPR is formally prohibited under the Arizona Administrative Code as currently written,[8] ADEQ has prepared a draft interim regulation to remove this prohibition and allow DPR under strict regulatory oversight until a final DPR regulation can be developed and enacted.

ADEQ oversees two technical committees tasked with developing final recommendations for the DPR rules:

- Water Quality Standards Work Group, chaired by Channah Rock, Ph.D. (University of Arizona).
- Reclaimed Infrastructure and Technology Work Group, chaired by Tim Thomure, P.E. (Tucson Water).

In 2017, SCAPR shifted from its original role of exploring opportunities for potable reuse in Arizona to direct involvement with ADEQ in developing a framework for the implementation of DPR.

1.6 Summary of Topics on Direct Potable Reuse for the Arizona Department of Environmental Quality

ADEQ held a series of three listening sessions across Arizona with stakeholders to hear specific concerns and questions regarding the existing reuse regulatory framework, including the development of DPR regulations. The six major topics that were discussed included:

- ***Public Health Protection***. Protection of human health is paramount.
  - An emphasis was placed on constituents of emerging concern (CECs).
  - Consideration must be given regarding how to ensure the safety of DPR across the various classes of reclaimed water (that is, A+, A, B+, B, or C).
- ***Development of Direct Potable Reuse Regulations***. The currently proposed (as of June 2017) interim reuse rules for Arizona provide a path forward for DPR. ADEQ has commenced

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[8] The Arizona Administrative Code specifies that the direct potable reuse of water specifically for human consumption is prohibited. Refer to the Arizona Administrative Code, Title 18 (Environmental Quality), Chapter 9 (Department of Environmental Quality - Water Pollution Control), Article 7 (Direct Reuse of Reclaimed Water), Section 704 (General Requirements), Subsection G [see 7 Ariz. Admin. Code § R18-9-704 (2013)]. http://apps.azsos.gov/public_services/Title_18/18-09.pdf.

stakeholder efforts to develop DPR criteria, which can be done by adoption by rule concurrently or after the rescission of the prohibition on DPR.

- ***Revision of Reclaimed Water Rules***. According to ADEQ, revisions are needed for Arizona reclaimed water regulations to:
    - Reflect new technologies, research, and processes.
    - Eliminate conflicts and clarify ambiguities.
    - Simplify processes, where possible.
    - Add new end-uses.
- ***Constituents of Emerging Concern***. Questions associated with CECs are important and are being addressed through the following:
    - Review by the Advisory Panel on Emerging Contaminants (APEC).
    - Review of current guidance on the monitoring and treatment of CECs.
- ***Concentrate Management***. Concentrate management is necessary for certain membrane-based treatment trains. A separate stakeholder process on deep well injection may be established.
- ***Small Systems***. Small systems (i.e., <1 million gallons per day) are of potential concern due to limited resources and staffing, as well as occasional difficulties in meeting SDWA compliance (as acknowledged in the 1996 SDWA Amendments).

1.7 Purpose of the Framework Guidance

As stakeholders interested in revising the reclaimed water rules, WateReuse Arizona and the AZ Water Association tasked the National Water Research Institute (NWRI) – a nonprofit organization experienced with potable reuse regulations – to prepare a Guidance Framework with recommendations regarding the development of regulations for DPR in Arizona. The DPR recommendations provided in this Guidance Framework are intended to:

- Be protective of public health based on available technical and scientific information.
- Incorporate a level of public health protection as good as or better than provided currently by conventional drinking water supplies (including IPR) in the United States.

Ultimately, the Guidance Framework will be used to both help inform ADEQ's process to revise Arizona's rules governing the reuse of reclaimed water and advance progress in developing final recommendations for the DPR rules.

1.8 Approach to Develop the Framework Guidance

NWRI developed this Framework Guidance based on work previously undertaken by SCAPR and input from WateReuse Arizona, AZ Water Association, and other stakeholders. NWRI facilitated two workshops in Arizona for the purpose of (1) presenting regulatory options and/or approaches for consideration and (2) receiving input from stakeholders. Specifically, the following two workshops facilitated by NWRI included:

- **WateReuse Arizona Board Workshop, April 6-7, 2016, Phoenix, Arizona.** The objective included developing the scope and potential topics of the Guidance Framework. Attendees included members of the Board of WateReuse Arizona and invited water reuse experts.

- **SCAPR Workshop, May 12, 2016, Glendale, Arizona.** The objective included developing material for the Guidance Framework. Attendees included Arizona water professionals who attended the AZ Water Conference and were interested in commenting on the outline of the Guidance Framework.

1.9 Scope of the Guidance Framework

The options and approaches presented in this Guidance Framework address DPR specifically; however, these recommendations and many of the key aspects presented and discussed herein also can be applied to IPR using groundwater recharge/augmentation or surface water augmentation.

The options and approaches cover various facets of DPR associated with regulations, including: (1) source control; (2) treatment performance and AWTF operations; (3) pathogen control; (4) chemical control; (5) monitoring; (6) water quality; and (7) other related areas. Notably, many aspects of DPR are addressed in permits and guidance rather than regulations. To reflect this distinction, the recommendations in this document are organized into two bins: (1) regulations and (2) permitting or guidance.

1.10 Useful Resources

Although a number of resources were used to develop this Guidance Framework and are identified in the references, the following reports were integral to the development of the recommendations listed herein:

- Mosher, J., G. Tchobanoglous, and G. Vartanian (2016). *Potable Reuse Research Compilation: Synthesis of Findings*, Water Environment & Reuse Foundation, Alexandria Va. https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportId=Reuse-15-01

- National Research Council (2012). *Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater.* National Research Council, National Academies Press: Washington, DC. http://www.nap.edu/catalog.php?record_id=13303

- National Water Research Institute (NWRI) (2013). *Examining the Criteria for Direct Potable Reuse*. Independent Advisory Panel Final Report prepared for Trussell Technologies, Inc., under WateReuse Research Foundation Project No. 11-02, National Water Research Institute: Fountain Valley, CA. https://www.watereuse.org/product/11-02-1

- Olivieri, A.W., J. Crook, M.A. Anderson, R.J. Bull, J.E. Drewes, C.N. Haas, W. Jakubowski, P.L. McCarty, K.L. Nelson, J.B. Rose, D.L. Sedlak, and T.J. Wade (2016). *Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse*. Prepared August 2016 by the National Water Research Institute for the State Water Resources Control Board, Sacramento, CA. http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/rw_dpr_criteria/app_a_ep_rpt.pdf

- SWRCB (2016). *Investigation on the Feasibility of Developing Uniform Water Recycled Criteria for Direct*

Potable Reuse, California State Water Resources Control Board, Report to the Legislature, Sacramento, CA, December 2016.
http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/rw_dpr_criteria.shtml

- Tchobanoglous, G., J. Cotruvo, J. Crook, E. McDonald, A. Olivieri, A. Salveson, and R.S. Trussell (2015). *Framework for Direct Potable Reuse*, WateReuse Association, Alexandria, VA.
http://www.nwri-usa.org/pdfs/DPR-Framework----FINAL.pdf

- Texas Water Development Board (2015). *Final Report: Direct Potable Reuse Resource Document*. Report prepared for the Texas Water Development Board by Alan Plummer Associates, Inc.: Fort Worth, TX.
http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1248321508_Vol1.pdf
http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1248321508_Vol2.pdf

WateReuse Arizona, AZ Water Association, and the Arizona Department of Environmental Quality are encouraged to use these resources when considering guidance and operational requirements for DPR.

Findings from Chapter 1

- Based on current wastewater treatment practices, the national drinking water regulatory framework, and the use of advanced treatment technologies, a sound technical basis exists for DPR that is protective of public health.
- Regulations for DPR also could be used to permit surface water augmentation Arizona.
- Recommendations can be organized into two bins: (1) regulations and (2) guidance or permitting. Many recommendations would be best addressed through guidance or permitting to allow for flexibility based on increased experience.
- A number of resources on DPR exist and should be considered by WateReuse Arizona, AZ Water Association, and the Arizona Department of Environmental Quality during the establishment of guidance and operational requirements for DPR.

References

ADEQ (2017a). *Water Quality Division: Permits*. Webpage of the Arizona Department of Water Quality.
http://legacy.azdeq.gov/environ/water/permits/index.html

ADEQ (2017b). *Water Quality Division: Permits: Reclaimed Water Rulemaking*. Webpage of the Arizona Department of Water Quality.
http://legacy.azdeq.gov/environ/water/permits/reuserulemaking.html

ADWR (2014). *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability*. Arizona Department of Water Resources, Phoenix, AZ.
http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/documents/ArizonaStrategicVisionforWaterResourcesSustainability_May2014.pdf

ADWR (2017a). *Governor Doug Ducey's Arizona Water Initiative.* Website of the Arizona Department of Water Resources, Phoenix, AZ.
https://new.azwater.gov/water-initiative

ADWR (2017b). *Governor's Water Augmentation Council.* Website of the Arizona Department of Water Resources, Phoenix, AZ. https://new.azwater.gov/water-initiative/governor-water-augmentation-council

AMWUA (2016). *ADEQ's Updating of the Water Reuse Rules*. Document of the Arizona Municipal Water Users association, dated September 27, 2016. http://www.amwua.org/pdfs/211__7a_201610_Water_Reuse_Rules_Paper.pdf.

Crook, J. (2010). *Regulatory Aspects of Direct Potable Reuse in California*, National Water Research Institute, Fountain Valley, CA.

Drewes, J., and S.J. Khan (2011). "Water Reuse for Drinking Water Augmentation." Chapter 16 in *Water Quality & Treatment*, McGraw-Hill, New York, NY.

GWAC (2017). May 22, 2017 Meeting Summary of the Recycled Water Committee of the Governor's Water Augmentation Council. http://infoshare.azwater.gov/docushare/dsweb/Get/Document-10134/Meeting%20Summary%205.22.17%20REVISED.pdf

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NRC (1998). *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water.* National Research Council, National Academy Press, Washington, D.C.

NRC (2012). *Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater*, National Research Council, National Academies Press, Washington, D.C. http://www.nap.edu/catalog.php?record_id=13303 (accessed 9/3/2015).

Olivieri, A.W., J. Crook, M.A. Anderson, R.J. Bull, J.E. Drewes, C.N. Haas, W. Jakubowski, P.L. McCarty, K.L. Nelson, J.B. Rose, D.L. Sedlak, and T.J. Wade (2016). *Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse*. Prepared August 2016 by the National Water Research Institute for the State Water Resources Control Board, Sacramento, CA.

Tchobanoglous, G., J. Cotruvo, J. Crook, E. McDonald, A. Olivieri, A. Salveson, and R.S. Trussell (2015). *Framework for Direct Potable Reuse*, WateReuse Association, Alexandria, VA.

- Pathogens of concern.
- Regulated and unregulated chemical constituents of concern.
- Regulatory mechanisms to manage potential risks from pathogens and chemical constituents.

Public health protection requires that microbial and chemical constituents in wastewater be removed to the extent practical before discharge to the environment or reuse (Tchobanoglous et al., 2015). As a result, DPR must be designed to provide continuous protection against short-term and long-term exposures to contaminants (NRC, 2012). The protection of public health is the guiding principle for implementing potable reuse (Crook, 2010).

2.1 Public Health Considerations

Treated wastewater effluents contain a wide range of naturally occurring and anthropogenic trace organic and inorganic contaminants, residual nutrients, total dissolved solids (TDS), residual heavy metals, and microorganisms (including pathogens) (Drewes and Khan, 2011). For DPR, the goal is to limit human exposure to concentrations of chemicals and pathogens that may be harmful to human health. Drinking water standards under the SDWA are established for chemicals using “maximum contaminant levels” (MCLs) and for pathogens using “log reduction values” (LRVs). Bacteria, viruses, and protozoan parasites are the most critical microbial constituents to control in reclaimed waters due to the potential human health impacts resulting from short-term exposure. Among the large number of chemical constituents that can be present in recycled water, some are of concern due to their potential adverse health effects associated with both short-term and long-term exposures (NRC, 2012). Beyond the existing regulatory requirements to meet LRVs and MCLs, unregulated chemicals also must be characterized and properly controlled. In addition, the use of wastewater as a direct source of drinking water raises aesthetic issues related to taste and odor, which can impact public acceptance of potable reuse projects (Agus et al., 2011).

2.2 Criteria for Microbial Constituents

Microbial constituents in recycled water can include bacteria, viruses, helminths, and protozoan parasites. Pathogenic (i.e., disease-causing) microorganisms present significant acute risks to consumers and are the most important design and operating concern for DPR systems.

2.2.1 Federal Regulations for Microbial Constituents in Drinking Water

Existing federal regulatory requirements for microbial already exist in which DPR – as a source of drinking water supply – would be subject. For example, for treated drinking water augmentation, the AWTF also serves as a DWTF and, therefore, would need to be approved under the SDWA as a DWTF (i.e., a Public Water Supply System [PWSS]). As a result, these facilities would need to meet federal regulations under the Surface Water Treatment Rule (SWTR) and Long Term 2 Enhanced Surface Water Treatment Rule (LT2 ESWTR).

The SWTR requires DWTFs using surface water sources and groundwater under the direct influence of surface water (GWUDI) to provide treatment that typically includes filtration and disinfection, ultimately achieving a minimum of 4-log reduction of virus and 3-log reduction of *Giardia*. There are criteria that allow exceptions to filtration in 40 CFR 141.71. The level of treatment required under the LT2 ESWTR is based primarily on the concentration of *Cryptosporidium* oocysts in the source water.

In addition, the U.S. Environmental Protection Agency (U.S. EPA) has established an MCL of <1 fecal coliform or *E. coli* organism per 100 milliliter (mL) in drinking water. Total coliforms no longer have a drinking water MCL, but monitoring and follow-up response requirements do exist.

2.2.2 Pathogen Treatment Targets for Direct Potable Reuse

Currently, there are no federal or state regulations that specifically address DPR; however, individual states (e.g., California and Texas) have undertaken efforts to develop treatment criteria for pathogens.

2.2.2.1 Approach of the Texas Commission on Environmental Quality for Direct Potable Reuse

Faced with an urgent need for additional water supplies in parts of the state, the Texas Commission on Environmental Quality (TCEQ) has approved DPR projects on a case-by-case basis in accordance with the innovative/alternative treatment clause in the Texas Administrative Code [30 TAC §290.42(g)] that allows "any treatment process that does not have specific design requirements" listed in that chapter to be considered for permitting (TAC, n.d.). According to the Texas Administrative Code, innovative/alternate treatment processes will be considered on an individual basis. Where innovative/alternate treatment systems are proposed, the licensed professional engineer must provide pilot test data or data collected at similar full-scale operations demonstrating that the system will produce water that meets all requirements.

Federal and state drinking water treatment regulations for pathogens are predicated on reducing the risk of infection to minimal levels, as defined by Trussell et al. (2013). The concentration end goals for targeted pathogens in drinking water correspond to a modeled annual risk of infection of one in 10,000 or less (Trussell et al., 2013). TCEQ's case-by-case approach to developing treatment requirements for potable reuse projects is based on determining the difference between the finished water pathogen values and the measurement of project-specific secondary effluent pathogen concentrations.

TCEQ has established baseline log reduction requirements for DPR, as shown in **Table 2-1**, using effluent from wastewater treatment plants (WWTPs) as the starting point. The reduction requirements are based on the 10^{-4} (one in 10,000) annual risk of illness level. The baseline removal requirements are a starting point for the TCEQ approval process (TWDB, 2015). The levels could be revised based on data collected to characterize the wastewater effluent. This site-specific WWTP effluent characterization is used to evaluate the need for additional log reduction requirements above the baseline targets.

Table 2-1: Microbial Reduction Criteria of the Texas Commission on Environmental Quality

Microbial Group	Criterion (Minimum Log Reduction)
Enteric Virus	8
Cryptosporidium spp.	5.5
Giardia Lamblia	6

Note: The baseline targets are for the advance treatment process only (i.e., they represent the required reduction between treated wastewater and the finished drinking water). The Texas Commission on Environmental Quality (TCEQ) sets project-specific requirements for pathogen reduction and inactivation for DPR. These minimum baseline targets may be increased based on site-specific data.

Source: TWDB (2015).

The pathogen sampling requirements are, in general, analogous to those required for *Cryptosporidium* under LT2 ESWTR, but also extend to sampling for *Giardia* and enteric virus. This process has been applied to three approved projects in Texas (i.e., the Raw Water Production Facility at Big Spring, the Wichita Falls Emergency DPR Project, and the City of Brownwood DPR Project – the latter project has been approved, but not implemented).

In awarding log reduction credits, TCEQ uses an approach based on drinking water, which means challenge testing[9] alone is not sufficient to determine inactivation credits given to common disinfection processes, such as ozonation and ultraviolet (UV) irradiation. These processes must adhere strictly to CT (concentration × time) requirements (for ozone) and the validation provisions under the U.S. EPA's *Ultraviolet Disinfection Guidance Manual* (U.S. EPA, 2006a). Membrane-based processes must pass daily integrity tests, as described in and required by the U.S. EPA's *Membrane Filtration Guidance Manual* (2005), to receive any log reduction credit; therefore, log reduction credit for reverse osmosis (RO) membranes and membrane bioreactor processes are not allowed currently under the Texas approach (which is not the case in California).

Because pathogens are removed during primary and secondary treatment, the use of wastewater effluent pathogen numbers results in lower log-reduction targets compared to other efforts (e.g., California's regulations for IPR using groundwater replenishment set the log reduction requirements from raw wastewater to drinking water).

Beyond the theoretical calculation of log reduction credits, TCEQ also requires that significant pilot testing be completed before a project can achieve final approval. This testing can be achieved from the operation of a dedicated, smaller-scale pilot unit that appropriately mimics the proposed final treatment solution, or through full-scale verification, which would occur during commissioning and start up. This second approval method allows treatment facilities to be approved for construction without completing

[9] Challenge testing is a performance and capacity test of a treatment system using a surrogate that is either conservative or has a proven correlation to the parameter of interest.

a pilot study prior to the design of the full-scale system. With a full-scale verification approach (which was the basis for the City of Wichita Falls Emergency DPR project, for example), full-scale facilities were operated in "pilot mode" to collect the data necessary for final approval while finished water was sent to disposal pending final approval by TCEQ to deliver water.

2.2.2.2 Approach of the National Water Research Institute Expert Panel for Criteria for Direct Potable Reuse

NWRI convened an expert panel to develop a set of microbial and chemical constituent criteria protective of public health to evaluate treatment technologies for DPR that might be applied throughout the United States. The panelists included former staff of the California Department of Health Services (environmental engineers James Crook and Harvey Collins) and former staff of the U.S. EPA (toxicologist Richard Bull, chemist Joseph Cotruvo, and microbiologist Walter Jakubowski). This effort was part of a WateReuse Research Foundation project on *Equivalency of Advanced Treatment Trains for Potable Reuse* (WRRF 11-02).

As shown in **Table 2-2**, the panel recommended 12-log reduction of enteric virus, 10-log reduction of *Cryptosporidium*, and 9-log reduction or inactivation of total coliform bacteria (NWRI, 2013), and concluded that these microbial log reduction criteria were conservative and actually would achieve risks of illness lower than one in 10,000 per year. The panel also concluded that a 10-log reduction of *Cryptosporidium* will ensure the same or greater removal of *Giardia* as *Giardi*a is larger and more easily disinfected than *Cryptosporidium*. These log reduction criteria include the full treatment cycle from raw wastewater to the final product water.

Table 2-2: Microbial Log Reduction Criteria Recommended by the Independent Advisory Panel of the National Water Research Institute[a]

Microbial Group	Criterion (Minimum Log Reduction)
Enteric Virus	12
Cryptosporidium spp.[b]	10
Total Coliform Bacteria[c]	9

[a] Reduction criteria for an advanced water treatment facility, including secondary treatment.

[b] Addresses *Giardia* and other protozoa as well.

[c] Addresses enteric pathogenic bacteria, such as *Salmonella* spp.

Source: Adapted from NWRI (2013).

2.2.2.3 Approach of the State of California for Indirect Potable Reuse Using Groundwater Replenishment

The regulation of IPR using groundwater replenishment in California (Trussell et al., 2013; CDPH, 2014) uses the most conservative values found in the literature for pathogen occurrence in wastewater: 12-log reduction of enteric virus, 10-log reduction of *Cryptosporidium*, and 10-log reduction of *Giardia* (see **Table 2-3**), beginning with raw sewage. A portion of these log reduction credits can be achieved during wastewater treatment. The Division of Drinking Water of the California State Water Resources Control Board has approved pathogen log reduction credits for primary and secondary treatment (WRD, 2013), as well as for advanced treatment processes (more information is provided in **Section 3.3** in **Chapter 3**).

Table 2-3: Microbial Reduction Criteria of the State of California for Indirect Potable Reuse Using Groundwater Replenishment

Microbial Group	Criterion (Minimum Log Reduction)
Enteric Virus	12
Cryptosporidium	10
Giardia	10

2.2.2.4 California Versus Texas Approaches for Microbial Reduction

The States of California and Texas regulate potable reuse by applying significant levels of conservatism in their approaches. California starts from worst-case wastewater influent pathogen concentrations and imposes additional safety factors on the total log reduction requirements that must be achieved. Texas is conservative in its approach to crediting treatment processes with microbial log reduction credits. Both approaches are considered by their respective regulatory agencies to be protective of public health from pathogen risks.

2.2.3 Potential Pathogen Criteria for Direct Potable Reuse in Arizona

One or a combination of the following three approaches could be adopted for DPR pathogen criteria in Arizona:

- Texas TCEQ approach for DPR (see **Section 2.2.2.1**)
- NWRI Expert Panel approach for DPR (see **Section 2.2.2.2**)
- State of California approach for IPR using groundwater replenishment (see **Section 2.2.2.3**)

Individually, each approach provides public health protection for pathogens. The selection of a preferred approach would depend on how it would be implemented. For instance, the Texas DPR approach starts with log reductions after wastewater treatment, whereas the California IPR approach and NWRI Panel DPR approach both use raw wastewater as the starting point. To provide flexibility, a combination of approaches could be used (for example, Arizona could allow permitting for either the Texas DPR approach or the California IPR approach, or both).

2.3 Criteria for Chemical Constituents

For DPR, chemical constituents typically represent long-term chronic health risks. They also could impact corrosion within the drinking water distribution system, as well as aesthetics (i.e., color, taste, and odor) (TWDB, 2015). Encompassing both regulated and unregulated constituents, chemical constituents could include organic and inorganic chemicals, radionuclides, disinfection byproducts (DBPs), pesticides, synthetic organic chemicals, pharmaceuticals, and consumer care products.

It is important to note that the chemical nitrate presents a potential acute health risk and, as a result, is of particular importance to DPR. Nitrate is regulated by the U.S. EPA in drinking water and occurs in wastewater that is not fully denitrified. It will need to be controlled as part of the wastewater or advanced water treatment process for DPR.

Utilities considering the implementation of DPR projects should conduct comprehensive analytical studies on the types and quantities of chemicals that can be present in influent wastewater, AWTF feedwater, and the final ATW. As discussed later in **Section 3.4**, an aggressive source control program is essential for any potable reuse project (IPR or DPR) to limit the discharge of chemical constituents into the wastewater collection system (TWDB, 2015).

2.3.1 Existing Requirements and Resources

The basic requirement for controlling chemical constituents would be to meet all U.S. EPA and State drinking water MCLs and other requirements that apply to public drinking water supplies in Arizona. Other chemicals may be identified by the State that warrant the establishment of additional water quality or performance specifications. For instance, in California, certain chemicals of public health interest – such as N-Nitrosodimethylamine (NDMA) and 1,4-dioxane – have notification levels. In addition, the U.S. EPA recently updated its public health guidance for two perfluorinated compounds. The target values for other chemicals of interest could be determined using the same principles for developing Maximum Contaminant Level Goals (MCLGs) and MCLs. If published values do not exist for these chemicals, specifications could be developed for MCLGs on an *ad hoc* basis. Authoritative sources include: U.S. EPA's Drinking Water Health Advisories (U.S. EPA, 2012, 2015a), U.S. EPA's "human health benchmarks for pesticides" in drinking water (U.S. EPA, 2015b), and the World Health Organization's *Guidelines for Drinking Water Quality* (WHO, 2011).

2.3.2 Chemical Targets for Direct Potable Reuse

Chemicals known to be detrimental to human health above certain concentrations are regulated through MCLs. Potable reuse projects should meet these requirements and other requirements set by the State of Arizona for drinking water. Because of the original source (i.e., wastewater) and because of public and practitioner concerns about chemical contaminants, potable reuse projects also should track a suite of unregulated chemicals in the wastewater source, as recommended in **Section 3.4**.

A number of efforts have examined the need to address chemical constituents in potable reuse, including:

- Research has been conducted on the concentrations of unregulated trace organic constituents (e.g., pharmaceuticals and personal care products, flame retardants) in wastewater, their attenuation through conventional WWTPs, and further breakdown during advanced treatment

(Baronti et al., 2000; Lovins et al., 2002; Schäfer et al., 2005; Sedlak and Kavanaugh, 2006; Steinle-Darling et al., 2010; Linden et al., 2012; Salveson et al., 2010, 2012; Snyder et al., 2012; Cotruvo et al., 2012; and many others). The majority of these constituents are not found in treated wastewater effluent at concentrations that have been shown to present risks to human health.

- For ATW, trace chemical constituents are controlled by various treatment technologies, including membrane-based technologies and oxidation technologies. RO has been shown to: (1) control for most chemical constituents (including trace organic chemicals) and meet low total organic carbon (TOC) limits (e.g., 0.5 milligrams per liter [mg/L] in California for IPR); and (2) control for salinity. Alternative technologies, such as nanofiltration (NF), ozone and biological active carbon (ozone/BAC), and granular active carbon (GAC), can be used with higher limits for TOC (2 to 4 mg/L) and are more suitable for inland locations where the disposal of RO concentrate is a challenge. AOPs are effective in treating for trace organic chemicals. The selection of treatment processes is determined by regulatory requirements, including: bulk organic limits (i.e., TOC, chemical oxygen demand [COD]), pathogen log reduction requirements, the use of multiple barriers to control for pathogens and chemicals (including tract organic chemicals), and finished water goals (e.g., MCLs) (Mosher et al., 2016).

- For IPR, California set requirements to limit TOC concentrations to <0.5 mg/L because TOC can be used as a bulk parameter of treatment efficacy for organic chemicals, including unregulated and unknown chemicals. The TOC level was not set based on health criteria, but instead based upon the ability of treatment schemes for groundwater recharge to meet this low TOC level (e.g., surface spreading of tertiary recycled water, direct injection of ATW). TOC levels in drinking water also are influenced by conventional source water characteristics, notably the natural organic matter present in surface water supplies. For Arizona, TOC might be more appropriately used as a monitoring parameter rather than as a regulatory limit to provide flexibility in the selection of DPR treatment technologies. The regulatory framework under development in Oklahoma adopts this approach to the use of TOC as a performance monitoring parameter (Graves, 2017).

- Both 1,4-dioxane and NDMA are difficult to treat by conventional and membrane-based treatment. NDMA is a DBP formed during water and wastewater treatment (among other sources), while 1,4-dioxane is a potential local concern related to industrial activity in the sewershed. These compounds are amenable to treatment by AOPs such as ultraviolet light-hydrogen peroxide (UV/H_2O_2) oxidation. California has established a performance expectation for UV oxidation, whereas NDMA has a low notification level (10 nanograms per liter [ng/L]). California has set the performance expectation for AOP based upon 0.5-log reduction of 1,4-dioxane, understanding that 1,4-dioxane is a conservative surrogate for the wide-range destruction of organics following RO (CDPH, 2014). Also, a source control program for chemical and pharmaceutical disposal in the wastewater system should be applied to mitigate or eliminate the occurrence of these and other compounds (see **Chapter 3**).

- Conventional DBPs, such as trihalomethanes, haloacetic acids, bromate, and chlorate, are regulated in the distribution system by the Stage 1 and Stage 2 Disinfectant and Disinfection Byproduct Rules (U.S. EPA, 1998, 2006b). The existing regulatory structure for DBPs is well defined; however, attention should be paid to the potential for DBP formation when implementing any change to the source water of a DWTF, including ATW.

- An Expert Panel for WRRF Project 11-02 examined chemical criteria for DPR and developed a list of regulated chemicals (including DBPs and nitrate), unregulated chemicals of potential health concern, and chemicals for the evaluation of treatment trains (NWRI, 2013).

Findings from Chapter 2

- For DPR, pathogens represent the greatest acute health risk and are the most significant design and operating concern for DPR systems. Chemicals also are a major concern.
- The following pathogen treatment criteria for DPR are protective of public health: (1) Texas TCEQ approach for DPR; (2) State of California approach for IPR using groundwater replenishment; or (3) NWRI Expert Panel approach for DPR. Each approach involves specific assumptions and implementation requirements that should be developed for implementation purposes. To provide flexibility, a combination of approaches can be used (that is, the State of Arizona could allow permitting for either the Texas DPR approach or the California IPR approach, or both).
- Treatment target criteria for chemical constituents should include meeting all U.S. EPA and state drinking water MCLs, as well as other requirements that apply to public drinking water supplies in Arizona. In addition, monitoring could be required for unregulated chemicals (including CECs) of interest from a public health standpoint and unregulated chemicals that are useful for evaluating treatment effectiveness.
- Utilities interested in implementing DPR should conduct studies on the types and quantities of chemicals present in their influent and effluent wastewaters. These studies could be part of the DPR project application process.
- Source control through pretreatment programs, local limits, and other measures can mitigate or eliminate the presence of many chemical constituents in the wastewater collection system and obviate monitoring and treatment for them (see **Section 3.7** in **Chapter 3**).

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CHAPTER 3: FINDINGS AND RECOMMENDATIONS

- General areas of interest and important considerations.
- Regulatory, guidance, and permitting recommendations for DPR by topic area.

In this chapter, specific findings and recommendations are provided for DPR in Arizona based on information available from states with regulations or implementing potable reuse, as well as guidelines, research summaries, and related information. "Findings" are statements that emphasize the current knowledge or understanding of DPR. "Recommendations" are specific items that should be considered in the development and implementation of DPR in Arizona. The following eight factors were considered during the development of findings and recommendations for Arizona:

- Consistency with current regulations in Arizona.
- Review of potable reuse regulations and guidance in other states.
- Use of appropriate terms and definitions, including:
    - Definitions or descriptions of potable reuse terminology.
    - Recommendations on regulatory terms and new terms.
    - Recommendations for revising current terms.
- Multiple barrier approach (i.e., a combination of multiple treatment, operational, and management processes) based on the drinking water concept for the control of pathogens and regulated and unregulated chemicals.
- Addressing the lack of an environmental buffer for DPR, including failure response time.
- The appropriate use of regulations, and what can be included in guidance or through the permitting process.
- Recommendations for regulations versus permitting or guidance.
- The use of technical, managerial, and financial (TMF) factors to assess the capacity of utilities to implement DPR.

Because DPR involves technical, managerial, and operational aspects, the recommendations provided in this document address a range of topics relevant to regulating and implementing DPR. Recommendations are categorized into two areas: (1) recommendations that should be considered in the formal regulation in Arizona (Regulatory); and (2) recommendations that can be addressed in guidance and/or permitting of projects (Guidance or Permitting).

Certain recommendations need to be addressed in regulations; however, many recommendations would be best addressed through guidance or permitting to allow for flexibility based on increased experience with DPR and advances in science.

3.1 Topic #1: Terminology

Proposed definitions for terms related to DPR are listed in **Table 3-1**. Certain terms should be specifically defined in the regulations; however, for flexibility and ease of implementation, many terms can be described in guidance and permitting.

Table 3-1: Terms and Definitions for Consideration for Arizona Direct Potable Reuse Regulations and Guidance Purposes

Term	Definition	Regulatory	Guidance and/or Permitting
Advanced treated water (ATW)	Water produced from an advanced water treatment facility for potable reuse applications.	✓	
Advanced water treatment	A general term used to describe the overall process and procedures involved in the treatment of wastewater beyond secondary treatment to produce ATW.		✓
Advanced water treatment facility (AWTF)	The treatment facility where ATW is produced. This term is equivalent to "advanced reclaimed water treatment facility" in Arizona's 2017 proposed rulemaking.		✓
Barrier	A measure implemented to control microbial or chemical constituents in ATW. A barrier can be technical, operational, or managerial in nature. Log reduction credits are assigned only for technical barriers.		✓
Concentrate	A liquid waste stream containing elevated concentrations of total dissolved solids and other constituents.		✓
Constituent	Any physical, chemical, biological, or radiological substance or matter found in water and wastewater.		✓
Constituents of emerging concern (CECs)	Chemicals or compounds not regulated in drinking water or ATW. They may be candidates for future regulation depending on their ecological toxicity, potential human health effects, public perception, and frequency of occurrence.		✓
Contaminant	Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil. The term "constituent" is used in place of "contaminant" in this Guidance Framework.		✓
Critical control point (CCP)	A point in advanced water treatment where control can be applied to an individual unit process to reduce, prevent, or eliminate process failure and where monitoring is conducted to confirm that the control point is functioning correctly. The goal is to reduce the risk from pathogen and chemical constituents.	✓	

Term	Definition	Regulatory	Guidance and/or Permitting
De facto potable reuse	The downstream use of surface water or downgradient use of wastewater-impacted groundwater as a source of drinking water that is subject to upstream wastewater discharges (also referred to as "unplanned potable reuse").		✓
Direct potable reuse (DPR)	There are two forms of direct potable reuse. In the first form, ATW is introduced into the raw water supply upstream of a drinking water treatment facility. In the second form, finished drinking water from an AWTF permitted as a drinking water treatment facility is introduced directly into a potable water supply distribution system.	✓	
Disinfection	Rendering pathogens incapable of reproducing, thereby preventing their ability to cause illness. When referring to any microorganism, also known as "Inactivation."		✓
Disinfection byproducts (DBPs)	Chemicals that are formed by the reaction of a disinfectant (e.g., chlorine or ozone) with organic or inorganic matter found in treated water or wastewater.	✓	
Drinking water	Water that is supplied to a community for potable uses, including drinking, cooking, bathing, and other household uses, that meets the standards prescribed by the U.S. Environmental Protection Agency's National Primary Drinking Water Regulations (40 CFR Part 141) and any applicable state or local regulations.	✓	
Engineered storage	A storage facility used to provide retention time—before ATW is introduced into the drinking water treatment facility or distribution system—to (1) conduct testing to evaluate water quality and (2) hold the water for a specified time in the event that it does not meet specifications.		✓
Environmental buffer	A groundwater aquifer or surface water reservoir, lake, or river into which recycled water is introduced before being withdrawn for potable reuse. In some cases, environmental buffers allow for (1) response time in the event that the recycled water does not meet specifications and (2) time for natural processes to affect water quality. Where tertiary effluent is applied by spreading (recharge) basins, the environmental buffer provides both treatment and storage.		✓
Indirect potable reuse (IPR)	The introduction of ATW into an environmental buffer, such as a groundwater aquifer or surface water body, before being withdrawn for potable purposes. Indirect potable reuse also can be		✓

Term	Definition	Regulatory	Guidance and/or Permitting
	accomplished with tertiary effluent when applied by spreading (i.e., groundwater recharge) to take advantage of soil aquifer treatment.		
Integrity testing	A pressure-based or marker-based process usually performed daily to detect breaches in a membrane system.		✓
Log reduction	Log reduction corresponds to a reduction in the concentration of a constituent or microorganism by a factor of 10. For example, a 1-log reduction would correspond to a reduction of 90 percent from the original concentration. A 2-log reduction corresponds to a reduction of 99 percent from the original concentration.		✓
Log reduction credit	The number of credits assigned to a specific treatment process (e.g., microfiltration, chlorine disinfection, or ultraviolet disinfection), expressed in log units, for the inactivation or removal of a specific microorganism or group of microorganisms. A reduction of 90 percent would correspond to 1-log credit of reduction, whereas a reduction of 99 percent would correspond to 2-log credits of reduction.	✓	
Nonpotable reuse	A general term for all water reuse applications except those related to potable reuse.	✓	
Pathogen	A microorganism (e.g., bacteria, virus, protozoa) capable of causing illness in humans.		✓
Public outreach	The process of communicating with and educating/informing the public on options and proposed plans for implementing potable reuse projects, as well as receiving input from the public, including questions and concerns that need to be addressed.		✓
Public water system	A system used to provide the public with water for human consumption through pipes or other constructed conveyances, if such system has at least 15 service connections or regularly serves at least 25 individuals; see Section 1401(4)(A) of the Safe Drinking Water Act.	✓	
Raw water augmentation	Water produced by an advanced water treatment facility that is delivered into a system of pipelines or aqueducts that deliver raw water to a drinking water treatment facility.		✓

Term	Definition	Regulatory	Guidance and/or Permitting
Redundancy	The use of multiple treatment barriers to attenuate the same type of constituent, so that if one barrier fails, performs inadequately, or is taken offline for maintenance, the overall system will still perform effectively and risk is reduced.		✓
Residuals	Waste streams and semisolids produced by wastewater treatment, advanced water treatment, and drinking water treatment processes.		✓
Resilience	The ability to adapt successfully or restore performance rapidly in the face of treatment failures and threats.		✓
Risk	In risk assessment, the probability that something will cause injury combined with the potential severity of that injury.		✓
Robustness	The use of a combination of treatment technologies to address a broad variety of constituents and changes in concentrations in source water.		✓
Source control	The elimination or control of the discharge of constituents into a wastewater collection system that can impact wastewater treatment, are difficult to treat, and can impair the final quality of the secondary effluent entering the AWTF.	✓	
Treated drinking water augmentation	Water produced by an AWTF that also meets all federal, state, and local regulatory requirements for a drinking water treatment facility and can be introduced directly into a water supply distribution system.		✓
Treatment reliability	The ability of a treatment process or treatment train to consistently achieve the desired degree of treatment, based on its inherent redundancy, robustness, and resilience.		✓
Treatment technique	According to the U.S. Environmental Protection Agency, a treatment technique is an enforceable procedure or level of technological performance which public water systems must follow to ensure the control of a contaminant.	✓	
Treatment train	A grouping of treatment technologies or processes to achieve a specific treatment or water quality goal or objective.		✓
Wastewater characteristics	General classes of wastewater constituents, such as physical, chemical, and biological constituents.		✓

Recommendations for Terminology

Regarding setting definitions or descriptions for terms related to DPR:

- Certain terms must be defined in regulations. **(Regulation)**
- Many terms may be best addressed in policy, guidance, and/or permitting, which allows for flexibility. **(Guidance/Permitting)**

3.2 Topic #2: Public Health Protection

Because DPR is a drinking water supply and the source is treated wastewater, public health protection from pathogens and chemicals is the paramount objective for DPR. As a result, the DPR system in its entirety is designed and operated to meet this objective. To do so, a number of operational controls, design elements, and various types of monitoring are employed at many stages in the DPR system. In addition, specific approaches are needed to control pathogens and chemicals (regulated and unregulated).

To meet the appropriate level of pathogen and chemical control for DPR, a number of approaches are needed, including the following:

- Identification of pathogens and chemicals (regulated and unregulated) and the level of control required (discussed further in **Sections 3.3** and **3.4**, respectively).
- Multiple barriers, including management, treatment, and operational barriers.
- Assessment of treatment performance, which involves the use of continuous and/or periodic monitoring for indicators and surrogates, defined as:
    - **Indicator compound**: An individual chemical that can be used to measure the effectiveness of a process for a family or group of compounds in the treatment process of interest (e.g., conductivity for RO).
    - **Surrogate**: A quantifiable parameter that can serve as a performance measure of treatment processes that relate to the removal of specific contaminants. Surrogate parameters provide a means of assessing water quality characteristics without conducting difficult trace contaminant analysis (e.g., UV absorbance).
- Use of critical control points (CCPs) and critical operating points (COPs) to verify treatment performance and support operations.
    - Used to inform operations, CCPs are unit processes where the reduction of risk can be demonstrated and verified by monitoring. CCPs provide information for automatic alarms and plant shutdowns based on trigger values.
    - COPs are control points focused on operational issues and are not directly related to risk reduction.
- Compliance monitoring, which involves regulatory limits.

Findings on Public Health Protection

- Collectively, DPR regulations in Arizona and supporting guidance or permitting must be protective of public health.
- For DPR, protecting public health will involve management, treatment, and operational barriers established by regulations and supporting guidance or permitting.

3.3 Topic #3: Pathogen Control and Log Reduction Requirements

A description is provided in **Chapter 2** of the types of pathogen classes and currently adopted pathogen log reduction requirements used in Texas (**Section 2.2.2.1**) and California (**Section 2.2.2.3**). The two approaches are risk-based and address enteric virus, *Cryptosporidium spp.,* and *Giardia lamblia* (also referred to as virus, *Cryptosporidium*, and *Giardia*). As implemented, both methods include significant levels of conservatism and are considered protective of public health from pathogen risks. The two approaches are discussed in more detail in **Chapter 2.2**; however, brief descriptions are provided below.

- **The TCEQ (Texas) Pathogen Reduction Criteria Approach**. In Texas, the minimum pathogen criteria are 8-log reduction of virus, 5.5-log reduction of *Cryptosporidium*, and 6-log reduction of *Giardia* for DPR applications. These log reductions are met after wastewater treatment. A site-specific WWTP effluent characterization (reviewed by TCEQ) is used to evaluate the need for increasing the minimum log reduction requirements. TCEQ also requires pilot testing (or full-scale verification) to be completed before a project can achieve final approval.

- **The State Water Resources Control Board (California) Pathogen Reduction Criteria Approach.** In California, log reduction requirements have been adopted as part of the regulations for Groundwater Recharge with Recycled Water (i.e., IPR). The requirements are 12-log reduction of virus, 10-log reduction of *Cryptosporidium*, and 10-log reduction of *Giardia*, starting with raw wastewater. A portion of these log reductions can be achieved during wastewater treatment.

A third approach discussed in **Chapter 2**, the NWRI approach, was based on a panel review (see **Section 2.2.2.2**). This effort was important in that it validated the use of the 12-log reduction of virus, 10-log reduction of *Cryptosporidium*, and 10-log reduction of *Giardia* for DPR. In addition, the NWRI panel recommended including 9-log reduction for total coliform bacteria starting with raw wastewater; however, a system to assign log reduction credits for total coliform bacteria has not been established in California or other states for most treatment technologies. As a result, it is not recommended that Arizona include this requirement as part of a regulation due to the lack of log reduction credit system for total coliform bacteria. Once information has been developed on total coliform bacteria removals, the inclusion of log reduction targets for total coliform bacteria could be considered.

Both the Texas and California approaches require a *system to assign log reduction credits based on treatment technologies*. Both Texas and California have experience with assigning log reduction credits to specific technologies; however, they differ in significant respects. California allows for log reduction credits for wastewater treatment. Texas does not allow for log reduction credits for RO because, currently, Texas requires membranes to conduct integrity testing (i.e., a pressure-based or marker-based process usually performed daily to detect breaches in a membrane system), which is not possible for RO membranes or MBR systems (though it could change in the future). In addition, California has a requirement for a minimum number of barriers and has set a maximum log reduction credit allowed for any technology (i.e., a maximum of 6-logs).

In permitting IPR projects using groundwater replenishment in California, the Division of Drinking Water of the California State Water Resources Control Board has approved log reduction credits for individual treatment process. The approved log reduction credits are reported in **Table 3-2** and represent the maximum reduction credit allowances.

Table 3-2: Approved Log Reduction Credits for Groundwater Replenishment Projects in California

Process	Pathogen Log Reduction Credits Assigned in California		
	Virus	*Cryptosporidium*	*Giardia*
Secondary activated sludge	1.9	1.2	0.8[a]
Microfiltration or ultrafiltration	0	4	4
Filtered and disinfected secondary	5	0	0
Reverse osmosis	2	2	2
Free chlorine post reverse osmosis	4	0	3
Ultraviolet/hydrogen peroxide (advanced oxidation process)[b]	6	6	6

[a] Waiting for the results of WRRF-14-02 regarding potential additional information that may support additional log reduction credits for wastewater treatment plants.

[b] 6-log reduction of virus (including adenoviruses) and 6-log reduction of protozoa, assuming the ultraviolet dose is >300 millijoules per square centimeter (mJ/cm^2) (based on advanced oxidation, typically >900 mJ/cm^2).

Source: Adapted from Olivieri et al. (2016).

Recommendations for Pathogen Control and Log Reduction Requirements

The following recommendations pertain to the setting of pathogen criteria for DPR:

- Pathogens should be removed or inactivated with a goal of 10^{-4} annual risk of infection. This level of risk is consistent with the rules promulgated under the SDWA and with other potable reuse efforts (i.e., California and Texas). **(Regulation)**
- A multiple barrier treatment approach should be defined and required (such as adopted by California for IPR). **(Regulation)**
  - Specific requirements can be provided in supporting guidance/permitting. **(Guidance/Permitting)**
- Both the California (12/10/10 log reductions for virus, *Cryptosporidium*, and *Giardia*) and Texas (minimum 8/5.5/6 log reductions for virus, *Cryptosporidium*, and *Giardia* post wastewater treatment) pathogen log reduction criteria approaches can be considered. Allowing both approaches provides maximum flexibility for projects in Arizona. **(Regulation)**
- The implementation of a log reduction credit system will need to be established; however, the system can be addressed through policy or guidance. In addition, the burden can be placed on the utility to propose its approach to achieving the log reduction targets in the form of a project proposal report. **(Guidance/Permitting)**

    - A "project proposal report" or "design report" should be required through regulation. **(Regulation)**
    - The requirements for the project proposal report or design report can be addressed in guidance/permitting. **(Guidance/Permitting)**
- Using the Texas approach requires ADEQ to review the project, characterize the wastewater, and approve the treatment process. **(Guidance/Permitting)**

3.4 Topic #4: Chemical Control Approach

The control of chemical constituents in DPR applications for public health protection is described in **Section 2.3** of **Chapter 2**. Chemicals represent a range of issues, including: chronic public health risks; corrosion within the drinking water distribution system; and aesthetics (i.e., color, taste, and odor) (TWDB, 2015). Chemical constituents include organic and inorganic chemicals, radionuclides, DBPs, pesticides, synthetic organic chemicals, pharmaceuticals, and consumer personal care products. Important considerations for chemicals in DPR include the following:

- Chemicals that need to be considered include bulk chemicals, regulated chemicals, and unregulated constituents, such as CECs.
- Nitrate presents a potential acute risk and, as a result, is of particular importance to DPR.
- Salinity management is an important consideration for the long-term sustainability of water supplies.
- Some chemicals, such as CECs, are of particular interest to the public and impact public acceptance of DPR.

Selecting chemicals for evaluating the efficacy of treatment trains should focus upon certain key factors, including the following (Trussell et al., 2013):

- Meeting MCLs, published guidelines, and health advisory levels.
- Using constituents and parameters as performance indicators that occur in the source water at sufficient concentrations to allow for evaluating treatment trains.
- Appropriately sensitive and specific analytical methods.
- An array of constituents and parameters that are broadly representative of:
  - Different types of contaminants of health concern that could be present in wastewater.
  - Different properties of contaminants that affect removal by various unit processes within a treatment train.

A utility considering the implementation of DPR projects should conduct comprehensive analytical studies on the types and quantities of chemicals that can be present in its influent wastewater, AWTF feedwater, and the final ATW. An aggressive source control program is essential for any potable reuse project to limit the discharge of chemical constituents into the wastewater collection system (TWDB, 2015).

Categories of chemicals to address in DPR applications include the following:

- Regulated chemicals, including bulk chemicals and regulated chemicals resulting from treatment. DBPs are the principal class that fall within the latter group. The nature and concentrations of the DBPs will vary with the types of disinfection used in the treatment train and applied technologies.
- If certain regulated chemicals (e.g., selected pesticides and herbicides) are observed in the wastewater source, it will be important to document their removal.

- Numerous contaminants occur frequently in wastewater, but generally at concentrations several orders of magnitude below those of health concern. These chemicals can serve as a useful tool for evaluating treatment train performance (NWRI, 2013).
- Pharmaceuticals and personal care product ingredients have been studied extensively in wastewater and drinking water, and many occur quite commonly (especially in wastewater) albeit at very low concentrations. These constituents can serve as surrogates or indicators of the performance of water treatment as it pertains to their removal.
- The frequency of monitoring should be reviewed periodically. The frequency of monitoring could be reduced over time where certain chemicals are shown to not occur or occur at very low levels.
- Additional chemicals can be monitored because they can be measured with the same methods. The inclusion of these compounds can improve the evaluation of treatment train performance.
- There are several general surrogate parameters that provide useful information on the functioning of processes and their continuing performance for removing many chemicals (and microbials). TOC is an example.

Monitoring is used to determine treatment efficiencies for alternative treatment trains and to develop a framework for determining the criteria to protect public health and demonstrate regulatory compliance. In addition, the appropriate locations in the treatment train and frequency of sampling are needed.

3.4.1 Chemical Control: Compliance Monitoring

To control chemicals in a DPR application, a tiered monitoring approach for chemical criteria can be implemented to address the range of chemicals, including regulated and unregulated chemicals. The tiers would be based on the type of monitoring (NWRI, 2013) to:

- Meet SDWA primary standards for regulated chemical constituents, including DBPs and nitrate.
- Monitor for unregulated chemical constituents that are of public health interest.
- Monitor for unregulated chemical constituents that provide information on the effectiveness of treatment.

These three compliance monitoring tiers are as follows:

- **Tier 1 – SDWA and State Requirements.** Potable reuse projects must meet all chemical primary MCL requirements under the SDWA and other requirements, if any, set by the State of Arizona for drinking water.

- **Tier 2 – Unregulated Chemicals (including CECs) of Interest from the Standpoint of Public Health.** Included in **Table 3-3** is a variety of chemicals that could occur in wastewater and are not regulated in drinking water, but should be monitored for in a potable reuse program. In addition, some DBPs with Notification Levels in California are included. If detected, some should be monitored in the AWTF product water as well (NWRI, 2013). If the levels in the ATW are above the health criterion, the treatment approach should be evaluated to ensure the levels remain below the health criterion. Another source of potential chemicals of concern is the U.S. EPA's Contaminant Candidate List (CCL), which is a list of contaminants that are not subject to current regulations, but are known or anticipated to occur in public water systems. Contaminants listed on the CCL may require future regulation under the SDWA.[10]

- **Tier 3 – Unregulated Chemicals (Including CECs) that Are Useful for Evaluating the Effectiveness of Organic Chemical Removal by Treatment Trains.** The chemicals listed in **Table 3-4** are considered useful for evaluating the effectiveness of alternative treatment trains and treatment performance. These constituents are detected frequently and at sufficiently high concentrations relative to their detection limits so as to make them useful measures of the removal of health-significant organic chemicals with a variety of structures and physical chemical properties. All these chemicals may not need to be monitored in the ATW. Rather, an approach could involve selecting specific chemicals of varying properties for evaluating treatment performance and are shown to be present in treated wastewater (NWRI, 2013). If the levels in the ATW are above the performance criterion, it may not be necessary to shut down operations; however, the treatment approach should be evaluated in collaboration with regulators to ensure that levels remain below the performance criterion.

3.4.2 Other Considerations for Chemical Control

The tiered approached in **Section 3.4.1** provides a monitoring framework for addressing regulated and unregulated chemicals, including CECs. This compliance monitoring approach would need to be augmented by treatment processes, performance monitoring (including continuous monitoring), and operational considerations to effectively control for regulated and unregulated chemicals.

3.4.2.1 Membrane Systems Based on Reverse Osmosis

Membrane systems involving RO have been shown to be capable of removing the constituents identified in the three tiers. In California, TOC of 0.5 mg/L has been used as a performance indicator for RO and as a surrogate for unregulated chemicals (including CECs), although TOC is not a measure of public health significance. If an RO-based system is employed and TOC of 0.5 mg/L is attained, control of the regulated and unregulated compounds listed in the three tiers is achievable.

In California, oxidation (UV) and AOPs are employed to address low molecular weight compounds that have been shown to pass through RO (i.e., NDMA and 1,4-dioxane, which are both listed in **Table 3-3**).

3.4.2.2 Systems Not Based on Reverse Osmosis

In the United States, full-scale potable reuse projects provide multiple barriers for chemicals; however, specific treatment technologies employed at AWTFs vary depending on local regulations and site-specific requirements. Meeting low regulatory limits for TOC (i.e., <0.5 mg/L in California) will require the use of RO. RO-based treatment trains for potable reuse can be expensive, energy intensive, and require the disposal of concentrate. RO may be needed in cases where salinity removal is a driver of water quality. In Arizona, non-RO systems are of interest due to the cost and sustainability concerns of managing the concentrate from RO (Mosher et at., 2016; Stanford et al., 2017).

[10] For more information, visit: www.epa.gov/ccl/contaminant-candidate-list-4-ccl-4-0.

Table 3-3: Examples of Unregulated Chemicals of Interest from the Standpoint of Public Health (If Present in Wastewater Effluent) (NWRI, 2013)

Chemicals	Criterion (if applicable)	Rationale	Source
N-Nitrosodimethyl-amine (NDMA)	10 ng/L	Byproduct of chloramination	Division of Drinking Water, California State Water Resources Control Board notification level
Chlorate	800 µg/L	Reflective of hypochlorite use	Division of Drinking Water, California State Water Resources Control Board notification level
Perfluorooctanoic acid	0.4 µg/L	Known to occur, frequency unknown	Provisional short-term U.S. EPA Health Advisory
Perfluorooctane sulfonate	0.2 µg/L	Known to occur, frequency unknown	Provisional short-term U.S. EPA Health Advisory
Perchlorate	15 µg/L; 6 µg/L	Of interest, same analysis as chlorate and bromate	U.S. EPA Health Advisory; California Maximum Contaminant Level
1,4-Dioxane	3 µg/L	Occurs at a relatively low frequency in wastewater, but is likely to penetrate reverse osmosis membranes	Public Health Protective Concentration of the Office of Environmental Health Hazard Assessment (OEHHA)
Steroid Hormones			
Ethinyl estradiol	None, but if established, it will approach the detection limit (low ng/L).	Should evaluate its presence in source water	Bull et al. (2011)
17-β-estradiol	None, but if established, it will approach the detection limit (low ng/L).	Should evaluate its presence in source water	Bull et al. (2011)

Notes: ng/L = Nanogram per liter. µg/L = Microgram per liter. U.S. EPA = U.S. Environmental Protection Agency.

Table 3-4: Chemicals that Could Be Useful for Evaluating the Effectiveness of Organic Chemical Removal by Treatment Trains (NWRI, 2013)

Pharmaceuticals[a]	Criterion[b] (if applicable)	Rationale	Source
Cotinine, Primidone, Phenyltoin	1 µg/L, 10 µg/L, 2 µg/L	Surrogate for low molecular weight; partially charged cyclics	Bruce et al. (2010), Bull et al. (2011)
Meprobamate, Atenolol	200 µg/L, 4 µg/L	Occur frequently at ng level	Bull et al. (2011)
Carbamazepine	10 µg/L	Unique structure	Bruce et al. (2010)
Estrone	320 ng/L	Surrogate for steroids	Based on an increased risk of stroke and deep vein thrombosis in women taking the lowest dose (0.625 mg/d) of conjugated estrogens per 1,000[a]
Other Chemicals			
Sucralose	150 mg/L[c]	Surrogate for water soluble, uncharged chemicals, moderate molecular weight	CFR Title 21, revised 4/1/12
Tris (2-Carboxyethyl) phosphine) hydrochloride	5 µg/L	Chemical of interest	Minnesota Department of Health guidance value (MDH, 2015)
N,N-diethyl-meta-toluamide	200 µg/L	Common constituent in highly treated wastewaters	Minnesota Department of Health guidance value (MDH, 2015)
Triclosan	2,100 µg/L	Chemical of interest	Risk-based action level (NRC, 2012)

[a] Conjugated estrogens (largely, estrone conjugates) administered without progestin significantly increased the risk of deep vein thrombosis and stroke in a large clinical study of postmenopausal women conducted over 5.1 years (it involved groups of >5,000 treated and 5,000 placebo subjects). Cited in RxList (2012).

[b] In the case of pharmaceuticals, the criterion is given as the drinking water equivalent concentration for the lowest therapeutic dose per 1,000. In the case of the anticonvulsant drugs, the lowest daily maintenance dose in adults per 10,000 was used in recognition of the teratogenic potential of these drugs (Primidone); however, the numbers for carbamazepine and phenyltoin are based on reported carcinogenicity.

[c] Sucralose is based upon an acceptable daily intake established by the U.S. Food and Drug Administration of 5 milligrams per kilogram (mg/kg) per day × 60 kg/2 liters (L).

Notes: CFR = Code of Federal Regulations. mg/d = Milligram per day. mg/L = Milligram per liter. ng = Nanogram. ng/L = Nanogram per liter. µg/L = Microgram per liter.

Non-RO based treatment options can provide an alternative approach for potable reuse applications. Alternative technologies, such as ozone/biological activated carbon (ozone/BAC) or GAC, can be used to control for chemicals in potable reuse applications (Stanford et al., 2017).

Although low bulk organic limits (e.g., TOC or COD) do not reflect the toxicity caused by the presence of trace organic chemicals, other states have established regulatory requirements for TOC or COD for potable reuse as a surrogate measure for the removal of trace organic chemicals that are unknown or difficult to measure. Florida's regulations for IPR limit TOC to 3 mg/L and specifically state that treatment "…shall include processes which serve as multiple barriers for control of organic compounds and pathogens" (FAC, 62-610). Virginia's Occoquan Policy, which is the regulatory policy defining requirements for the longstanding IPR project of the Upper Occoquan Service Authority, requires a COD limit of 10 mg/L (approximately 4 mg/L of TOC) (Mosher et al., 2016).

Due to the cost and difficulty of managing RO concentrate at inland locations and the energy consumption of RO, an increasing amount of research has been conducted on alternative technologies for potable reuse. In a number of studies, AOPs, ozone/BAC, and GAC have been shown to be capable of achieving significant removals of trace organic compounds. The use of AOPs, ozone/BAC, and GAC has been studied extensively for potable reuse applications (Mosher et al., 2016; Stanford et al., 2017).

In addition, NF can be used in place of RO to control for trace organic compounds and to limit TDS concentrations. El Paso Water Utilities has pilot-tested NF for a full-scale DPR project to limit the TDS concentration in the concentrate stream and allow a surface discharge (Mosher et al., 2016).

If TOC is used to confirm process performance for non-RO treatment technologies, then TOC levels would need to be established for the technologies employed. For instance, in an ozone/BAF treatment scenario, achievable TOC levels would be on the order of 3 to 5 mg/L.

3.4.2.3 Related Criteria

Appropriate chemical control in RO-based and non-RO based systems can be achieved using a holistic approach that includes a range of technical, managerial, and operational barriers and requirements. Specifically, the following factors should be considered:

- The use of continuous and periodic water quality testing for unit processes can be an effective measure of performance.
- The use of CCPs, including point of compliance monitoring/verification monitoring of each treatment step, to ensure treatment performance.
- Conducting comprehensive analytical studies on the types and quantities of chemicals (including CECs of interest and emerging CECs) that can be present in treated wastewater. The results would help determine how much removal is needed to protect public health and what CECs should be monitored.
- Chemical constituents that impact the aesthetics of the final water quality should be evaluated.
- An aggressive source control program can limit the discharge of chemical constituents into the wastewater collection system.
- Managing salinity is a long-term sustainably issue. As water is recycled in a community, chemical constituents will increase in concentration unless some form of salinity control is

employed. Salinity can be partially managed through source control by characterizing dischargers to the collection system and requiring industrial users to address TDS in their discharges. RO, NF, and/or ion-selective ion exchange membranes may be used for salinity control.

Findings on Chemical Control

The following recommendations pertain to chemical criteria for DPR:

- Chemicals to consider include regulated and unregulated constituents (e.g., CECs) and, possibly, chemicals that impact the aesthetics of the final water quality (e.g., TDS).
- Managing salinity is a long-term sustainably issue.
- Chemicals like CECs are of particular interest to the public and impact public acceptance of DPR.
- It is possible to use constituents and water quality parameters that occur in wastewater at sufficient concentrations as performance indicators to evaluate treatment unit processes.
- Diverse constituents and water quality parameters can be identified that are broadly representative of various contaminants of health concern that could be present in wastewater.
- Monitoring, including continuous monitoring, can be used to determine treatment efficiencies for alternative treatment trains, such as NF, ozone/BAC, GAC, and AOPs.
- A monitoring framework can be developed that demonstrates RO-based and non-RO based treatment trains are protective of public health.
- Appropriate locations in the treatment train and the frequency of sampling for monitoring purposes are needed.
- Augment the monitoring approach with treatment processes, performance monitoring, and operational considerations to effectively control regulated and unregulated chemicals.
- Water quality testing of indicators and surrogates can be used as effective measures of the performance of unit processes.
- CCPs, including point of compliance monitoring/verification monitoring, can be used to ensure treatment performance and the ultimate chemical safety of the ATW.
- The frequency of monitoring should be assessed periodically and modified or reduced based on a review of the results.
- An aggressive source control program can limit the discharge of chemical constituents into the wastewater collection system.

Recommendations for Chemical Control

The following recommendations pertain to the chemical criteria for DPR:

- A three-tiered monitoring approach (described in **Section 3.4.1**) can be used to control chemicals for DPR and include:

  Tier 1 – SDWA and state requirements (including DBPs and nitrate).

  Tier 2 – Unregulated chemicals (including CECs) of interest from the standpoint of public health (such as NDMA).

  Tier 3 – Unregulated chemicals (including CECs) that are useful for evaluating the effectiveness of organic chemical removal by treatment trains.

  Specifically:

  - The three-tier monitoring approach can be required in regulations. **(Regulation)**
  - The details for implementing the monitoring requirements can be set in guidance/permitting. **(Guidance/Permitting)**
- Nitrate is regulated under the SDWA and presents a potential acute risk; as a result, it is of particular importance to DPR and should be monitored for in the advanced water treatment system. **(Regulation)**
- Appropriately sensitive and specific analytical methods are needed. **(Guidance/Permitting)**
- Conduct comprehensive analytical studies on the types and quantities of chemicals (including CECs of interest and emerging CECs) that can be present in treated wastewater. The results would help determine how much removal is needed and what CECs need to be monitored. **(Guidance/Permitting)**

3.5 Topic #5: Potable Reuse Applications in Arizona

A form of IPR, groundwater augmentation can be permitted and implemented in Arizona under current regulations. The focus of the recommendations in this document addresses DPR. Specifically, the recommendations would address the following forms of DPR:

- Raw water augmentation (that is, when an existing surface water treatment plant is part of the overall treatment process).

- Treated drinking water augmentation (that is, when the AWTF and the DWTF are both sources of drinking water and the ATW is sent directly into a distribution system or blended with other drinking water before sent into a distribution system).

The recommendations presented in this document could be modified where necessary and used for the regulation of surface water augmentation, which involves augmenting reservoirs, lakes, and water conveyance structures with advanced treated recycled water. Open water conveyance and pipeline conveyance are defined in the Arizona Administrative Code R18-9-601.

Recommendations for Potable Reuse Applications in Arizona

- DPR regulations in Arizona should address both raw water augmentation and treated drinking water augmentation. **(Regulation)**
- DPR regulations in Arizona could be modified as necessary to also cover surface water augmentation, which involves augmenting reservoirs, lakes, and water conveyance structures with advanced treated recycled water. **(Regulation)**

3.6 Topic #6: Utility Collaboration

DPR projects often involve multiple water and wastewater utilities. Because of the collaboration required for DPR, inter-jurisdictional issues are important and must be addressed. It should be required to develop Memorandums of Understanding (MOUs) or an inter-governmental agreement that define roles and responsibilities and describe how different agencies will work together (e.g., joint committees).

Recommendation for Utility Collaboration

- MOUs or inter-governmental agreements are needed to define the roles and responsibilities of multiple utilities and/or jurisdictions. These agreements can describe the methods that the utilities and/or agencies would use to work together and implement a DPR project. **(Guidance/Permitting)**

3.7 Topic #7: Source Control Program

An efficient and cost-effective strategy for managing chemicals of concern is to prevent them from being discharged into the wastewater collection system through an aggressive source control program (Tchobanoglous et al., 2015). Source control programs for DPR can be implemented by augmenting federal pretreatment programs. A source control program can be designed to control, limit, or eliminate the discharge of constituents into wastewater that can be difficult to treat or impair the final quality of treated watered intended for DPR.

A source control program will require interagency cooperation between the entities operating the WWTP, AWTF, and DWTF. In addition, the program will involve coordination with the community through permitting (e.g., for industries) or voluntary action (e.g., for residents). Additional measures can include online monitoring of WWTP influent and effluent to detect illicit discharges to the sewer system.

3.7.1 Background on Pretreatment Requirements in the United States

Under the 1972 Clean Water Act (CWA), the U.S. EPA was given authority to regulate discharges of pollutants into the waters of the United States and regulate quality standards for surface waters. The CWA made it unlawful to discharge any pollutant from a point source (i.e., conveyances such as pipes or man-made ditches) into navigable waters, unless a permit was obtained. The U.S. EPA's National Pollutant Discharge Elimination System (NPDES) permit program is the federal regulatory program designed to control these discharges to surface waters (USEPA, 2017a).

The National Pretreatment Program is an integral component of the NPDES permit program. It authorizes local municipalities to perform permitting, administering, and enforcing tasks related to discharges into publicly owned treatment works (POTWs), which collect and transport wastewater to treatment facilities. The goals include: (1) protecting the infrastructure of POTWs; and (2) reducing conventional and toxic pollutant levels discharged by industries and other nondomestic wastewater sources into municipal sewer systems and into the environment (USEPA, 2017b).

Under the National Pretreatment program, industrial and commercial dischargers – referred to as industrial users (IUs) – are required to obtain permits or other control mechanisms to discharge wastewater to POTWs. The Pretreatment Program Requirements (40 CFR Part 403.8) of the National Pretreatment Program require all large POTWs (those designed to treat flows of more than 5 million gallons per day) and smaller POTWs (that accept wastewater from IUs that could affect the treatment plant or its discharges) to establish local pretreatment programs (LII, n.d.).

Pretreatment standards and requirements include: (1) general and specific prohibitions, (2) categorical pretreatment standards, and (3) local limits (U.S. EPA, 2017b).

3.7.2 Pretreatment Requirements in Arizona

Since 2002, the State of Arizona has used the Arizona Pollutant Discharge Elimination System (AZPDES) to carry out the NPDES permit program. In Arizona, pretreatment involves any biological, chemical, or physical treatment process applied to an industrial wastewater stream before it is mingled with sanitary wastewater and/or released into a sanitary sewer collection system for ultimate treatment at a centralized (publicly-owned or privately-owned) treatment works (ADEQ, 2017a).

3.7.3 Source Control Program for Direct Potable Reuse

Using a source control program to expand upon pretreatment programs is needed for DPR. Although not all POTWs are required to implement pretreatment programs, any community or utility pursuing a DPR project, regardless of size, should consider the impacts of industrial and commercial contributions on the wastewater supply and implement an aggressive source control program. A smaller utility can implement its own source control program with many of the basic elements, but may or may not have to submit the program to the State or U.S. EPA for approval as a pretreatment program. It is recommended that Arizona consider requiring a source control program as a condition of permitting a DPR system.

The following activities should be undertaken as part of a source control program:

- **Understanding the Sewershed.** Investigate what chemicals are used and disposed of by homeowners and/or commercial establishments (e.g., pesticides and cleaning products). Also, identify the potential for spills and other sources of chemicals (e.g., dry cleaners) that may enter the wastewater collection system.
- **Survey.** Conduct (1) an initial survey (i.e., source study) of discharges into the system to determine what industrial contaminants already exist and (2) sample wastewater effluent for drinking water constituents and CECs. This sampling provides important information about chemicals in the wastewater. The information then can be used to determine what advanced treatment processes and monitoring are necessary. This survey should be conducted every 5 years to monitor for new chemicals and/or sources.
- **Classification of businesses.** Compile a list of current commercial and industrial entities that discharge into the wastewater system. Use the Standard Industrial Code (SIC) approach to inventory businesses that discharge into the collection system. Source control criteria will need to be established for new industries or businesses (e.g., medical care facilities, dental clinics, photo processors, and silver jewelry manufacturers) that move into the area.
- **Residential programs.** Education and outreach programs can be used to inform the public about the proper disposal of pharmaceuticals and household products containing chemicals that may be difficult to treat.

While beneficial, pretreatment programs generally do not completely eliminate pollutant loadings from industrial sources. Hence, an important preventative approach when pursuing and planning for potable water reuse is the implementation of a source control program to eliminate or control the discharge of chemicals that might impact the DPR treatment process (Tchobanoglous et al., 2015).

3.7.4 Goals of a Source Control Program

The goals of an effective source control program (Tchobanoglous et al., 2015) include:

- Understand the sources of chemical constituents entering the sewershed from readily managed point sources (e.g., industries, health care facilities, commercial businesses, homes, and waste haulers).
- Minimize the discharge of potentially harmful or difficult-to-treat chemical constituents to the wastewater collection system.

- Improve wastewater quality and the performance of advanced water treatment processes.
- Provide the public with confidence that the wastewater collection system is being managed with potable reuse in mind.

Source control cannot eliminate all CECs; however, it is important to identify the contaminants that may be present in the sewershed, mechanisms by which they may be introduced to the wastewater collection system, and actions that can be taken to minimize their introduction into the wastewater collection system.

3.7.5 Elements of a Source Control Program

The principal elements of an effective DPR source control program are provided in **Table 3-5**. The source control program should be tailored to the individual service area. Guidance is provided in TWDB (2015) regarding source control recommendations and enhanced source control program elements to "provide an effective barrier for DPR." For instance, one recommendation includes establishing local limits to control chemicals and provisions to take action to protect the DPR project.

Table 3-5: Elements of a Source Control Program for Direct Potable Reuse

Element	Description
Regulatory Authority	• Legal authority • Discharge permits • Enforcement • Alternative control programs
Monitoring and Assessment of the Wastewater Collection System Service Area (Sewershed)	• Routine monitoring program • Constituent prioritization program • Evaluation of technically-based local limits
Source Investigations	• Industrial and commercial business inventory • Joint response plan of the wastewater treatment plant and advanced water treatment facility
Maintenance of Current Inventory of Chemicals and Constituents	• Chemical inventory program • Waste hauler monitoring program • Chemical fact sheets
Public Outreach Program	• Industrial discharges • Service area pollution prevention partnership program • Public education and outreach program
Response Plan for Identified Constituents	• Interagency collaboration • Response to water quality deviations

Sources: U.S. EPA (2011), TWDB (2015), and Tchobanoglous et al. (2015).

Findings on Source Control Programs

- An aggressive source control program can be an efficient and cost-effective approach to preventing chemicals from entering a wastewater collection system and for improving water quality for DPR.
- A source control project can build on Federal Pretreatment Standards.
- Elements of a source control program have been defined.
- If a community does not have local limits, an inventory of commercial and industrial dischargers could be developed.
- Realistic expectations are needed for a source control program; however, employing such a program can be meaningful from a public relations point-of-view.

Recommendations for Source Control Programs

- A pretreatment program and source control program should be established as part of the DPR permitting process. **(Regulation)**
  - The elements of implementing an aggressive education and source control program in conjunction with the pretreatment program can be developed for utilities pursuing DPR projects, regardless of size. **(Guidance/Permitting)**
- Minimum requirements should be established for all systems (i.e., not just medium and large systems), regardless of jurisdictional issues and/or boundaries. **(Guidance/Permitting)**
- A source control program for a DPR project should control chemicals from a drinking water perspective. The source control program should go beyond pretreatment regulations to manage chemicals. **(Guidance/Permitting)**
- An interagency cooperation and responsiveness plan should be developed between the entities operating the WWTP, AWTF, and DWTF to ensure pretreatment and source control are conducted effectively. **(Guidance/Permitting)**

3.8 Topic #8: Wastewater Treatment

For DPR projects, the goal of wastewater treatment is to remove or inactivate physical, chemical, and microbial constituents from raw wastewater so that the treated effluent can be an appropriate source for advanced treatment. The different levels of wastewater treatment (e.g., primary, secondary, and tertiary treatment) and different treatment processes (e.g., biological wastewater treatment, filtration, and disinfection) may result in treated effluent quality with a range of differences in concentrations of nutrients, metals, microorganisms, organics, and solids.

Ideally, the WWTP and AWTF should be designed as an integrated system to ensure compatibility among unit operations and provide reliable performance. Most existing WWTPs, however, were not designed for potable reuse applications. As such, enhancements can be made to existing WWTPs to improve the quality of effluent for subsequent advanced treatment (Tchobanoglous et al., 2015).

3.8.1 Wastewater Effluent for Direct Potable Reuse Applications

Some representative data for the expected effluent quality from different wastewater treatment trains are reported in **Table 3.6**. The final water quality of the effluent from these wastewater treatment processes will vary depending on the treatment steps included in the treatment trains.

Secondary treatment involves the removal of biodegradable organic matter and suspended solids. For the DPR process, the benefits of using higher-quality wastewater treatment (which may involve nutrient removal, filtration, nitrification/denitrification, disinfection, or both filtration and disinfection) include:

- Reduced contaminant load, leading to reduced demands on subsequent treatment processes.
- Improved performance of subsequent advanced treatment processes.
- Increased reliability of the overall DPR treatment train.

Nitrification and denitrification can be incorporated in most secondary treatment processes to control and remove nitrogen in wastewater. Nitrification involves converting ammonia to nitrate, while denitrification involves reducing and/or removing nitrate. For the DPR process, the benefits of nitrification and denitrification include:

- Reduced membrane fouling rates for advanced treatment (Trussell et al., 2009).
- Reduced degree of nitrate removal that must be achieved in the AWTF.
- Reduced DBP formation potential, especially for NDMA.
- Reduced level of CECs in secondary effluent (Salveson et al., 2012).

Tertiary treated water, including the use of membrane bioreactors (MBRs), is more desirable than secondary treated water because tertiary treatment usually involves additional removal of residual suspended solids by granular media filtration or membrane filtration. Disinfection and nutrient removal may be included in tertiary treatment. Tertiary treatment also can be performed at the AWTF.

Table 3-6: Effluent Quality for Various Wastewater Treatments (Tchobanoglous et al., 2015)

Parameter	Units	Untreated Wastewater	Range of Effluent Quality after Indicated Treatment					
			Conventional Activated Sludge[a]	Conventional Activated Sludge with Filtration[a,b]	Activated Sludge with BNR[b]	Activated Sludge with BNR and Filtration[c]	Membrane Bioreactor
Total suspended solids	mg/L	130–389	5–25	2–8	5–20	1–4	<1–5
Turbidity	NTU	80–150	2–15	1–5	1–5	1–5	<1–2
Biochemical oxygen demand	mg/L	133–400	5–25	<5–20	5–15	1–5	<1–5
Chemical oxygen demand	mg/L	339–1,016	40–80	30–70	20–40	20–30	<10–30
Total organic carbon	mg/L	109–328	20–40	15–30	10–20	1–5	<0.5–5
Ammonia nitrogen	mg N/L	14–41	1–10	1–6	1–3	1–2	<1–5
Nitrate nitrogen	mg N/L	0–trace	5–30	5–30	<2–8	1–8	<8[c]
Nitrite nitrogen	mg N/L	0–trace	0–trace	0–trace	0–trace	0.001–0.1	0–trace
Total nitrogen	mg N/L	23–69	15–35	15–35	3–8	2–5	<10[d]
Total phosphorus	mg P/L	3.7–11	3–10	3–8	1–2	≤1	<0.3[d]–5
Volatile organic compounds	µg/L	<100–>400	10–40	10–40	10–20	10–20	10–20
Iron and manganese	mg/L	1–2.5	1–1.5	1–1.4	1–1.5	1–1.5	trace
Surfactants	mg/L	4–10	0.5–2	0.5–1.5	0.1–1	0.1–1	0.1–0.5
Total dissolved solids	mg/L	374–1,121	374–1,121	374–1,121	374–1,121	374–1,121	374–1,121
Trace constituents[e]	µg/L	10–50	5–40	5–30	5–30	5–30	0.5–20
Total coliform	No./100 mL	10^6–10^{10}	10^4–10^5	10^3–10^5	10^4–10^5	10^4–10^5	<100
Protozoan cysts and oocysts	No./100 mL	10^1–10^5	10^1–10^2	0–10	0–10	0–1	0–1
Viruses	PFU/ 100 mL	10^1–10^8	10^1–10^4	10^1–10^3	10^1–10^3	10^1–10^3	10^0–10^3

[a] Conventional secondary is defined as activated sludge treatment with nitrification.

[b] BNR is defined as biological nutrient removal for the removal of nitrogen and phosphorus.

[c] With anoxic stage.

[d] With coagulant addition.

[e] For example, fire retardants, personal care products, and prescription and non-prescription drugs.

Notes: L = Liter. mg/L = Milligram per liter. mL= Milliliter. N = Nitrogen. NTU = Nephelometric Turbidity Unit. P = Phosphorus. PFU = Plaque-forming units. µg/L = Microgram per liter.

For the DPR process, the benefits of tertiary treatment include:

- Improved feedwater quality to the AWTF, which improves AWTF performance.
- Reduced measure of complexity and reduced effects of close-coupled processes (i.e., the performance of a process in the series can affect the selection and performance of subsequent processes) (Salveson et al., 2014).
- An additional disinfection barrier added to the subsequent advanced treatment train.

3.8.2 Modification of Wastewater Treatment Processes

Modifying existing WWTPs for use in a DPR project may require technical evaluation, innovative engineering, and possible upgrades to the wastewater management infrastructure, along with related operation and management activities. In general, WWTPs can be designed or modified to optimize overall performance, enhance reliability, and produce an effluent quality that is suitable for advanced treatment for DPR applications. Some measures that can improve performance and enhance the reliability of existing and proposed WWTPs include:

- Enhanced screening process and, possibly, fine screening.
- Influent flow and load equalization.
- Elimination (or equalization) of untreated return flows.
- Operational mode for biological treatment process to improve reliability and produce an effluent of consistent quality.
- Improved disinfection while preventing DBP formation.
- Post-treatment filtration (to reduce suspended solids).

More information about such modifications can be found in Tchobanoglous et al. (2015) and TWDB (2015).

3.8.3 Use of Membrane Bioreactors

Membrane bioreactor (MBRs) provide a number of benefits for potable reuse (Helsley, 2017; Erdal, 2017) and can be used in place of conventional wastewater treatment for potable reuse projects. MBRs produce tertiary filtered effluent, which eliminates the need for microfiltration (MF) in a potable reuse treatment train. As result, MBR effluent can be used for RO or another advanced treatment process. The advantages of MBRs include: reliable performance; pathogen removal; small footprint; and nutrient removal (Helsley, 2017; Erdal, 2017). Notably, the costs of MBRs have decreased over the past 10 years. Overall, MBRs could be a viable option for greenfield, retrofit, or decentralized/distributed projects.

As shown in **Table 3-6**, MBRs produce high-quality effluent, efficiently and effectively providing high removal rates of BOD, nutrients, and solids. MBRs can provide equal or better treatment than conventional wastewater treatment coupled with MF or ultrafiltration (UF), including 3+ log reduction of a broad range of pathogens (Helsley, 2017). MBRs also can be more effective in the removal of trace organic chemicals than some conventional activated sludge systems based upon the solids retention time (SRT) and the complete removal of suspended solids with sorbed pollutants. As a result, MBRs can provide a high-quality source water for RO or other advanced potable reuse treatments processes.

One limitation for MBRs is that there is a lack of Direct Integrity Test (DIT)[11] or other approved method to assess membrane integrity (as is commonly and effectively used to measure MF and UF membrane integrity and, thus, pathogen log removal performance). Historically, MBR manufacturers have not provided DIT components to any type of MBR, though some suppliers now are implementing this approach. DIT cannot be applied to flat sheet MBR membranes. Consequently, pathogen credits have not been given to MBRs. Recent studies in the United States and Australia (Helsley, 2017) have demonstrated the robust removal of a broad range of pathogens by MBR, even with damaged fibers that could not pass a DIT. States such as California have not yet agreed to allow pathogen removal credits for MBRs without DIT. Other projects are evaluating how DIT can be applied to MBR systems for pathogen credits (Erdal, 2017).

3.8.4 Specific Topics to Address for Arizona

There are two topics of specific relevance to Arizona: classes of reclaimed water and log removal credits for wastewater treatment.

3.8.4.1 Classes of Reclaimed Water

In Arizona, five classes of reclaimed water were established under the Reclaimed Water Quality Standards, reflecting a combination of minimum treatment requirements and a limited set of numeric reclaimed water quality criteria. Class A reclaimed water is required for reuse applications where there is a relatively high risk of human exposure to potential pathogens in the reclaimed water. For uses where the potential for human exposure is lower, Classes B and C are acceptable. The Reclaimed Water Quality Standards include two "+"categories of reclaimed water: Class A+ and Class B+. Both categories require treatment to produce reclaimed water with a total nitrogen concentration of less than 10 mg/L.[12] In Arizona, Best Available Demonstrated Control Technology (BADCT) also specifies final treatment levels for reclaimed water: for example, non-detection for *E. coli* in four of seven weekly samples and no single sample of >23 colony forming units (CFU) per 100 milliliters.

For DPR, the control of pathogens and chemicals in the wastewater is an important factor for water quality. As a result, Class A+ and Class B+ should be used for DPR applications unless full-stream RO is used for advanced water treatment.

3.8.4.2 Log Removal Credits for Wastewater Treatment

Where pathogen log removal credits are needed for wastewater treatment, utilities will need a system to assign credits for different wastewater treatment options. Pathogen log removal credits for virus, *Giardia*, and *Cryptosporidium* will be different for Class A/A+ and Class B/B+ effluents. Existing data can be used to develop specific credits. In addition, individual utilities can conduct studies to determine log removals.

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[11] A Direct Integrity Test (DIT) involves a physical test applied to a membrane unit to identify and isolate integrity breaches. Typically, DIT involves pressurizing membrane fibers from inside to approximately 12 to 20 pounds per square inch (psi) about 30 to 45 seconds. Once the pressure is stabilized, the pressure source is isolated and the decay test is started. The pressure is recorded over a 5-minute period or until the pressure decreases to the minimum permissible pressure, as required by the test resolution, whichever occurs first.

[12] http://legacy.azdeq.gov/environ/water/permits/reclaimed.html.

Findings on Wastewater Treatment

- Secondary wastewater treatment processes can vary, resulting in a range of wastewater effluent water quality.
- Higher quality wastewater effluent (e.g., tertiary treatment, nitrification/denitrification) provides water quality and operational benefits for potable reuse treatment trains.
- For DPR, future WWTPs should be designed to produce an effluent optimized for further processing by AWTFs.
- The WWTP and AWTF should be designed as an integrated system to ensure compatibility among unit operations and provide reliable performance.
- Enhancements should be considered for existing WWTPs to optimize overall performance, enhance reliability, and produce an effluent quality that is suitable as a feedwater supply for an AWTF producing ATW.

Recommendations for Wastewater Treatment

- For DPR applications, the treated wastewater effluent must meet all existing federal and state regulations. **(Regulation)**
- For DPR applications, control of nitrate should either (1) be accomplished in the WWTP to supply Class A+ or Class B+ for advanced water treatment or (2) properly engineered into the AWTF. **(Regulation)**
- Pathogen log removal credits are needed for wastewater treatment if log removal reductions are needed. **(Regulation)**
    - Credits can be established in guidance, or utilities can propose credits based on available information or a specific study. **(Guidance/Permitting)**

3.9 Topic #9: Advanced Water Treatment Technologies

In a DPR system, advanced water treatment technologies are applied to wastewater effluent to produce ATW as a source of drinking water. The ATW must meet all applicable federal, state, and local potable reuse regulations to serve as a source of water supply (Tchobanoglous et al., 2015). The treatment process must be sufficiently robust so that it will pass regulatory review and public scrutiny. Over the past decade, a number of new technologies have been developed and the performance of existing technologies has been significantly improved.

3.9.1 Treatment Technologies Used for Advanced Water Treatment

A summary is provided in **Table 3-7** of the principal advanced treatment technologies currently used to remove particulate, colloidal, and dissolved inorganic and organic constituents found in the effluent from WWTPs. The treatment technology options provided in this table include alternative membrane process (RO and NF) and non-membrane processes (ozone/BAC and AOPs). DPR treatment trains will employ a range of different treatment technologies based on specific water quality goals, operational objectives, and regulatory requirements.

Table 3-7: Summary of Technologies for Advanced Water Treatment

Treatment Option	Use	Notes
Filter screens (FS)	Remove large suspended solids in unfiltered and filtered secondary effluent.	Filter screens are needed to protect downstream membranes.
Flow equalization (FE)	Eliminate diurnal flow rate variations, reduce the size of downstream units, and reduce variations in water quality.	Constant flow with consistent water quality to the advanced treatment process reduces wear and tear on equipment (e.g., stress cracks in equipment from cycling) and results in improved performance.
Ozone followed by biologically active filtration (BAF)	Pretreatment step used before MF or UF to achieve a reduction in pathogenic microorganisms and trace organics, and to condition treated secondary effluent to enhance the performance of downstream processes like MF and UF.	It has been demonstrated that ozone/BAF ahead of MF/UF provides a greater benefit than ozone/BAF after MF/UF, but ahead of RO (Trussell et al., 2013). In some cases, the use of ozone/BAF may eliminate the need for RO for advanced water treatment, assuming TOC is used as a performance indicator and not as a regulatory compliance measure.
Granular activated carbon (GAC) adsorption	Removal of trace organic compounds.	Can be used in conjunction with other technologies for the removal of trace organic compounds.
Microfiltration (MF)	Remove residual suspended particles by mechanical sieving.	Typical membrane pore size range is 0.1 to 0.2 micrometers (μm).
Ultrafiltration (UF)	Remove residual suspended particles by mechanical sieving.	Typical membrane pore size range is 0.008 to 0.04 μm. UF is often used in place of MF.
Cartridge filtration (CF)	Remove suspended and colloidal impurities from chemicals added to prevent fouling on RO membranes.	Typical filter cartridge pore size range is 5 to 10 μm.

Treatment Option	Use	Notes
Electrodialysis (ED)	Remove salt from solution through the use of ion-exchange membranes.	ED is designed mainly for desalinate and is less effective for suspended solids, total organic carbon, or other contaminants.
Nanofiltration (NF)	Remove dissolved constituents and colloidal solids, primarily divalent ions and trace organics, be means of size exclusion and solution/diffusion.	Typical membrane pore size range is 0.001 to 0.02 μm with a molecular weight cutoff range of 200 to 1,000 Daltons. NF has been used in place of RO when only softening or partial demineralization is needed.
Pasteurization	Heat water to a specified temperature and time to kill or inactivate microorganisms.	No notes.
Reverse osmosis (RO)	Remove dissolved constituents and colloidal solids, including salts and trace organics, by means of size exclusion and solution/diffusion.	Typical membrane pore size range is 0.0001 to 0.002 μm with a molecular weight cutoff of less than 100 Daltons. RO concentrate for wastewater typically is 15 percent of the flow.
Advanced oxidation processes (AOPs)	Destroy or alter chemical constituents that are not removed completely by conventional biological treatment processes or by filtration, especially trace organics.	AOP may contain a range of processes, but most commonly uses ozone with H_2O_2 or UV with H_2O_2. More recent projects are implementing UV with sodium hypochlorite for AOP. The use of UV, ozone, and sodium hypochlorite also provides disinfection benefits.
Post-processing (when RO is used, decarbonation and stabilization are typically involved)	Decarbonation is used to remove (i.e., strip out) excess carbon dioxide from RO product water to increase pH and reduce the amount of chemicals added for stabilization. Stabilization involves the addition of a chemical (typically, lime) to the RO product water to increase hardness and alkalinity and reduce its corrosive properties.	A variety of different corrosivity indices (e.g., Aggressiveness Index, Langelier Saturation Index, calcium carbonate precipitation potential) are used to assess the stability of product water.
Engineered storage, with or without free chlorine	Store water between the AWTF and DWTF; however, engineered storage should not be a requirement.	In some cases, travel time in the pipeline from the AWTF to the DWTF may serve the same purpose.

Source: Adapted from Tchobanoglous et al. (2015).

3.9.2 Treatment Trains without Reverse Osmosis

Because of cost and logistical issues associated with managing RO concentrate (typically, 15 percent of the flow for potable reuse applications), interest exists in developing treatment trains capable of removing or converting chemical constituents without physically separating them from the product water. RO especially is problematic in arid and semi-arid regions of the United States, such as Arizona, because some feedwater (about 15 percent) is lost as concentrate that must be addressed through disposal or other means.

Treatment trains that do not include RO can use other treatment processes (e.g., ozone, BAF, UF, AOP) to meet chemical and pathogen treatment goals. The lack of TDS removal and a higher level of TOC in the effluent are the principal differences between the RO-based and non-RO based treatment trains (Tchobanoglous et al., 2015).

Pathogen control, including meeting required log removal values, can be accomplished in non-RO treatment trains through the use of disinfection treatment and alternative treatment technologies. As discussed in **Section 3.10** on pathogen reduction values for various treatments, a range of treatment technologies can be used to meet pathogen treatment needs. These technologies include conventional disinfection (e.g., chlorine) and non-RO membranes (i.e., MF, UF, and NF). In addition, AOPS are an effective barrier for pathogens and chemicals. As a result, pathogen control can be achieved through a variety of treatment technologies that support a multiple-barrier approach for potable reuse.

RO is an effective barrier to regulated and unregulated trace organics and other chemical constituents of interest for potable reuse, including nitrate, commercial and industrial chemicals, DBPs, and (of particular interest in wastewater) trace organic chemicals (including pharmaceuticals and ingredients in personal care products). Non-RO treatment trains for potable reuse must be able to control these chemicals constituents.

A number of non-RO treatment alternatives are available for potable reuse application that can treat for trace organic chemicals. NF, which operates at lower pressure than RO (i.e., uses less energy) and has a much larger recovery (i.e., minimal residual stream produced), has been shown to remove a range of trace organic chemicals. AOPs have been shown to be effective in controlling trace organic chemicals. Recently, a significant amount of research on ozone/BAC has shown that it provides effective removal of trace organic chemicals in potable reuse applications. GAC, in combination with other treatment technologies, is effective in trace organic chemical removal (Tchobanoglous et al., 2015; Mosher et al., 2016).

3.9.3 Role of Engineered Storage

The use of engineered storage is optional for DPR, but this storage can provide benefits. Some water analyses can be made during storage time, which may be several hours. This monitoring may help provide additional confirmation of water quality, ensuring the ATW will only be released to the DWTF (or finished water will only be released to the distribution system) as long as it is in full compliance with operational and regulatory parameters. Engineered storage could be sized to hold the water for the time period equivalent to the failure response time (FRT), which allows for system monitoring, verification of results, potential resampling, calibration of monitoring devices, determination of failure, and operational response. Engineered storage would be part of an integrated control system that uses online monitoring results for all advanced processes to document that each process is functioning properly and the combined processes are meeting the design targets for the removal of chemicals and pathogens.

Several configurations can be used for the design of engineered storage, such as plug-flow pipelines, lined and possibly covered reservoirs, baffled tanks, or tanks in parallel operated in a fill, store, and draw mode. Free chlorine can be added to engineered storage, resulting in additional disinfection credits in line with U.S. EPA standards.

Engineered storage may be replaced by additional or redundant treatment with appropriate and effective monitoring. The additional treatment allows for the continuous production of ATW if one of the major treatment processes is out of specification. This approach relies on the use of online monitoring systems and the ability to immediately divert flow in the event of further process failure (Tchobanoglous et al., 2015).

3.9.4 Operational Bypass

For DPR, it is critically important to verify ATW system performance during startup or when there are operational issues that require a portion of the system to be taken out of service for maintenance or repairs. All projects should include a bypass from the outlet of the system into the sewer system (if available) or recycled back to the start of the treatment process. This bypass will allow the operators to verify and document that all systems are operating in accordance with the DPR Operation and Maintenance (O&M) Plan (see **Section 3.14.4**). Further, it requires that the WWTP maintain an alternate discharge permit (e.g., AZPDES) for times when the AWTF is offline.

3.9.5 Representative Performances of Various Treatment Trains

Final water quality (i.e., solids concentrations, organics, nutrients, metals, and microorganisms) will vary depending upon the treatment technologies used in the treatment processes (Tchobanoglous et al., 2015). Some representative data are provided in **Table 3-8** of the water quality produced from different treatment combinations. The final water quality may need post-processing to stabilize the water to prevent corrosion and related issues.

3.9.6 Pilot Testing/Demonstration Studies

Pilot testing/demonstration studies can be used for the following purposes:

- Make decisions about the selection of specific AWT processes for the DPR project.
- Verify AWT performance and gain regulatory approval for the treatment train.
- Evaluate the effectiveness of different types of treatment processes or different vendors of the same treatment processes.
- Inform the design of the full-scale DPR system.

Pilot tests and/or demonstration studies should have treatment study goals guided by test plans, including a framework for monitoring (i.e., performance, CCPs, and water quality).

3.9.7 Best Available Demonstrated Control Technology (BADCT) Approach

In Arizona, the use of the BADCT approach for wastewater discharge has been successfully implemented. The approach includes the use of approved technologies or a process to demonstrate diverse treatment. BADCT's purpose is to employ engineering controls, processes, operating methods or other alternatives, including site specific-characteristics (i.e., the local conditions), to reduce the discharge of pollutants to the greatest degree achievable.

It may be useful to develop a similar type of approval approach for treatment technologies for DPR. The system could address chemical control and could incorporate the log removal credit system required for pathogen control (see **Section 3.10**).

Table 3-8: Typical Range of Effluent Quality after Various Levels of Conventional Wastewater and Advanced Water Treatment (Tchobanoglous et al. 2015)

Constituent	Unit	Untreated Wastewater	Range of Effluent Quality after Indicated Treatment			
			Conventional Activated Sludge with Filtration	Activated Sludge with Ozone/BAF	Activated Sludge with MF and RO	Activated Sludge with MF, RO, and UV-AOP
Total suspended solids	mg/L	130–389	2–8	1–2	≤1	≤1
Turbidity	NTU	80–150	1–10	≤1	≤0.1	≤0.1
Biochemical oxygen demand	mg/L	133–400	<5–20	≤1	≤1	≤1
Chemical oxygen demand	mg/L	339–1,016	30–70	≤10–30	≤2–10	≤2–10
Total organic carbon	mg/L	109–328	15–30	2–5	0.1–1	0.1–1
Ammonia nitrogen	mg N/L	14–41	1–6	≤1	≤1	≤1
Nitrate nitrogen	mg N/L	0–trace	5–30	5–30	≤1	≤1
Nitrite nitrogen	mg N/L	0–trace	0–trace	≤0.001	≤0.001	≤0.001
Total nitrogen	mg N/L	23–69	15–35	≤1	≤1	≤1
Total phosphorus	mg P/L	3.7–11	2–6	2–6	≤0.5	≤0.5
Volatile organic compounds	µg/L	<100–>400	10–40	≤1	≤1	≤1
Iron and manganese	mg/L	1–2.5	1–1.4	≤0.3	≤0.1	≤0.1
Surfactants	mg/L	4–10	0.5–1.5	≤0.5	≤0.1	≤0.1
Totals dissolved solids	mg/L	374–1,121	374–1,121	374–1,121	≤5–40	≤5–40
Trace constituents[a]	µg/L	10–50	5–30	≤0.1	≤0.1	≤0.1
Total coliform	No./100 mL	10^6–10^{10}	10^3–10^5	350	<1	<1
Protozoan cysts and oocysts	No./100 mL	10^1–10^5	0–10	≤0.002	≤0.002	≤0.002
Viruses	PFU/100 mL	10^1–10^8	10^1–10^4	≤0.03	≤0.03	≤0.03

[a] For example, fire retardants, personal care products, and prescription and nonprescription drugs.

Notes: L = Liter. mg/L = Milligram per liter. mL= Milliliter. N = Nitrogen. NTU = Nephelometric Turbidity Unit. P = Phosphorus. PFU = Plaque-forming units. µg/L = Microgram per liter.

Findings on Advanced Water Treatment Technologies

- AWTFs will employ different treatment trains using different treatment technologies, based on specific water quality goals, operational objectives, and regulatory requirements. The proposed treatment train must meet pathogen log reduction criteria and chemical criteria. No one specific treatment train is required for DPR.
- AWTF treatment trains should be designed to eliminate acute risks (i.e., pathogens) and minimize potential chronic risks (i.e., chemical constituents).
- AWTF treatment trains include RO-based options and alternative advanced treatment options that may include NF, ozone/BAC, AOPs, and GAC.
- The use of an engineering storage is not necessary for DPR, but can provide additional response time.
- Final water quality will vary depending upon the treatment technologies used in the treatment train, but all treatment processes should be used with the goal of ensuring the protection of public health.
- Research and experience in the field are continuously contributing to the enhancement of current treatment technologies and development of new ones. The consideration of alternative treatment processes for DPR should be encouraged.
- Treatment trains identified in **Table 3-8** do not represent an exhaustive list of treatment options.

Recommendations for Advanced Water Treatment Technologies

- All potable reuse projects should include a bypass from the outlet of the AWTF into the sewer system (if available) or recycled back to the start of the treatment process. **(Guidance/Permitting)**
- Pilot testing or demonstration studies are useful for the design and operation of DPR projects. **(Guidance/Permitting)**
- For DPR, allow for a BADCT approach that employs engineering controls, processes, and operating methods or other alternatives, including site specific-characteristics (i.e., local conditions), for approving treatment technologies that control for chemicals and pathogens. **(Guidance/Permitting)**

3.10 Topic #10: Pathogen Reduction Values for Treatment Processes

A wide range of information is available regarding pathogen treatment credits through either chemical inactivation (disinfection) or physical separation (removal). Available information is sufficient to design multi-barrier advanced treatment systems capable of meeting the log reduction requirements for virus, *Cryptosporidium*, and *Giardia*.

For pathogen control, a risk-based log removal approach for DPR is modeled after the SWTR. The foundation of this approach is as follows:

- Establish appropriate risk levels for exposure to pathogens (i.e., viruses, bacteria, and protozoa) consistent with public health protection.
- Understand the concentrations of pathogens in source water by specifying the log reduction values required to meet the appropriate risk levels for health protection.
- Design an integrated treatment process capable of providing the necessary log reduction values using multiple barriers that consist of treatment processes with validated treatment credits.
- Monitor the performance of both individual and integrated treatment processes to ensure their abilities to reliably provide the intended log reduction values.

Using these principles, a suitably designed, well-operated, and properly maintained integrated treatment process is capable of managing pathogen risks in a DPR scenario so that human health protection goals are met (Mosher et al., 2016).

3.10.1 Establishment of Acceptable Risk Levels for Pathogens

The SDWA establishes the minimum drinking water quality standards for public water systems in the United States. Standards set under the SDWA must be met by public water systems regardless of the original source of water. Setting standards under the SDWA is a complex process in which the U.S. EPA must balance public health benefits with the costs associated with implementing standards. The goal of the U.S. EPA is to restrict exposure to regulated contaminants to a level representing *de minimis* (or insignificant) risk to the public. During the development of the SWTR, the U.S. EPA concluded that, for pathogens, a 10^{-4} annual risk of infection represents a *de minimis* risk (NWRI, 2013). As a result, to remain consistent with the concept of *de minimis* risk, finished drinking water produced from DPR projects should risk no more than one infection in 10,000 persons per year (Mosher et al., 2016).

3.10.2 Log Reduction Credits

When designing an AWTF, the sum of validated log reduction credits for the individual treatment processes must equal or exceed the log reduction values needed to protect human health. Quantifying the log-reduction performance of treatment technologies has been the subject of considerable research. State regulatory agencies should grant or approve reduction credits based on available research and guidance. California and Texas have developed log reduction values for potable reuse applications.

3.10.2.1 Division of Drinking Water of the State Water Resources Control Board

In connection with the development of rules and regulations for IPR using groundwater replenishment, the Division of Drinking Water of the California State Water Resources Control Board developed log reduction values for individual treatment process and for water retention times above and below ground. The approved log reduction credits are shown in **Table 3-9** and represent the maximum reduction credit allowances. Based on a review of allowed the log reduction credits, an expert panel in California that assessed the feasibility of developing DPR regulations concluded: "a similar process for assigning log reduction value credits for individual unit treatment process is feasible for DPR; however, additional process monitoring is recommended to ensure reliable treatment" (Olivieri et al., 2016).

Table 3-9: Approved Log Reduction Credits for Groundwater Replenishment Projects in California

Process	Pathogen Log Reduction Credits		
	Virus	*Cryptosporidium*	*Giardia*
Secondary activated sludge	1.9	1.2	0.8
Microfiltration or ultrafiltration	0	4	4
Filtered and disinfected secondary	5	0	0
Reverse osmosis[a]	2	2	2
Free chlorine post reverse osmosis	4	0	3
Ultraviolet/hydrogen peroxide[b]	6	6	6
Surface application retention time[c]	6	10	10

[a] Log reduction values of 2 are achieved using total dissolved solids and electrical conductivity as a performance measure. Research on alternative measures may demonstrated that log reduction values of greater than 2 may be assigned.

[b] Six-log reduction of virus (including adenoviruses) and 6-log reduction of protozoa, assuming the ultraviolet dose is >300 millijoules per square centimeter (mJ/cm^2) (based on advanced oxidation, typically >900 mJ/cm^2).

[c] Based on a 6-month retention time.

Source: Adapted from Olivieri et al. (2016).

3.10.2.2 Texas Commission on Environmental Quality

The log reductions that TCEQ uses as a basis for granting credits for a particular technology are presented in **Table 3-10**. These values are compared to “upper end reductions” that have been developed based on pilot-scale and full-scale installations, as reported in WRRF-11-02 (Trussell et al., 2013). Due to the inability to directly monitor pathogen concentration in a timely manner, indirect measures are used to verify treatment performance. These measures can include methods that: (1) predict pathogen removal performance (e.g., calibrated UV sensors for UV disinfection); (2) estimate pathogen removal performance (e.g., pressure decay tests for membrane monitoring); and/or (3) evaluate overall process performance, without assessing pathogen removal performance (e.g., turbidity) (NWRI, 2013).

In several cases, the technical limitations of integrity testing and/or monitoring programs often are the controlling factors in determining log reduction credits for treatment technologies. For example, referring to **Table 3-10,** TCEQ does not recognize log reductions for RO technology, not because the technology fundamentally fails to serve as a barrier to the passage of pathogens, but because of the lack of a DIT. Improved methods for RO integrity testing and/or monitoring would allow the full pathogen removal capability of the technology to be reflected in its log reduction credit. Upper end reduction (UER) values are provided in **Table 3-10**; the UERs represent the potential high end of removal values possible by the technology.

Table 3-10: Potential Log Removal Values for Pathogens

Process/Technology	*Cryptosporidium* (log removals)		*Giardia* (log removals)		Virus (log removals)	
	TCEQ	UER	TCEQ	UER	TCEQ	UER
Microfiltration or ultrafiltration	4	4	4	4	0	0
Membrane bioreactor	0	4	0	4	0	0
Reverse osmosis	0	2	0	2	0	2
Nanofiltration	0	---	0	---	0	---
Chlorine	0	0	1	1	3	3
Ultraviolet irradiation disinfection	4	4	4	4	4	4
Ultraviolet/photolysis	4	≥4	4	≥4	4	≥4
Advanced oxidation processes	4	6	4	6	4	6
Ozone	3	3	3	3	5	5
Ozone/biological activated carbon	3	3	3	4	5	5
Stabilization	---	---	---	---	---	---
Engineered storage	---	---	---	---	---	---

Notes: TCEQ = Texas Commission on Environmental Quality. UER = Upper end reduction value.

Source: Adapted from APAI (2015). See Table 5-1 of APAI (2015) for caveats and limitations associated with these values.

3.10.3 Pathogen Removal

The expected log reduction credits for three different DPR treatment train examples are shown in **Tables 3-11** to **3-13** (Mosher et al., 2016). The log reduction credits shown do not include pathogen reduction credits for the upstream WWTP or for the downstream DWTF where the ATW is blended upstream of the DWTF. All three example treatment trains provide significant removal of pathogens.

Recent and ongoing research may impact the application of some of these treatment technologies in potable reuse schemes or require special considerations for their use, including:

- **Online Monitoring for RO Integrity:** Based on preliminary results from WRRF-12-07 and WRRF-14-10, it appears that online water quality monitoring techniques (e.g., TRASAR®) may lead to higher log reduction credits for RO, which could result in fewer treatment processes or modified operating and monitoring requirements.

- **Ozone DBPs:** Ozone has the potential to produce unwanted DBPs, such as bromate and NDMA. Mitigation techniques include the use of BAC downstream of ozone to remove NDMA to below pre-ozone levels (Gerrity, 2015), and ammonia addition or the application of ozone at sub-residual doses can control the formation of bromate.

- **MBRs:** MBRs, which have become more common for wastewater treatment, may eliminate the need for MF/UF treatment if proper membrane integrity testing can be provided by manufacturers to confirm adequate pathogen log reduction. Because integrity testing is challenging for MBR membranes, other indicators of treatment performance should be considered, such as turbidity.

- **Engineered Storage:** Engineered storage provides response time (i.e., time to sample, analyze the sample, and react to the result). Providing adequate retention time to meet the failure response time (hours or days) can be prohibitively expensive for medium- to large-sized AWTFs. Appropriate online water quality and performance monitoring, including CCPs, can eliminate the need for engineered storage.

Interim information is provided in **Table 3-14** on an ozone/BAF based treatment train that is being conducted at a facility in Florida. The DPR demonstration system has full-scale components. The data reflects information based on 6 months of operation.

Table 3-11: Pathogen Log Reduction Credits for Treatment Train #1 for Direct Potable Reuse (adapted from Mosher et al., 2016)

Pathogen	MF[a]	RO[b]	UV/AOP[c]	Storage with Cl[d,e]	Total
Virus	0	2	6	4	12-log
Cryptosporidium	4	2	6	0	12-log

[a] Four-log reduction of *Cryptosporidium* has been assumed for microfiltration (MF), based on credit commonly granted by states for membranes passing daily membrane integrity tests.

[b] Two-log reduction of viruses, *Cryptosporidium,* and *Giardia* have been assumed for reverse osmosis (RO), based on credit commonly granted by states for online monitoring of conductivity or total organic carbon.

[c] Six-log reduction of viruses and *Cryptosporidium* have been assumed for ultraviolet/advanced oxidation processes (UV/AOP), based on testing by UV manufacturers.

[d] Per the U.S. EPA Surface Water Treatment Rule, free chlorine provides 4-log virus inactivation at a CT of 6 mg/L-min at a temperature of 10° Celsius.

[e] Actually demonstrated values (Gerringer et al., 2015) or values referenced by WRRF-12-06.

Table 3-12: Pathogen Log Reduction Credits for Treatment Train #2 for Direct Potable Reuse (adapted from Mosher et al., 2016)

Pathogen	Ozone[a,b]	BAF	MF	RO	UV/AOP	Total
Virus	4	0	0	2	6	12-log
Cryptosporidium	0	0	4	2	6	12-log

[a] Per the USEPA Surface Water Treatment Rule, ozone provides 4-log virus inactivation at a CT of 1 mg/L-min at 10° Celsius.

[b] Both chlorine and ozone likely will achieve higher log reduction values than shown if higher CTs are used.

Table 3-13: Pathogen Log Reduction Credits for Treatment Train #3 (No Reverse Osmosis) for Direct Potable Reuse (adapted from Mosher et al., 2016)

Pathogen	Ozone[a,b]	BAF	UF[c]	UV/AOP[d]	Storage with Cl_2[b,e]	Total
Virus	4	0	2	6	4	16-log
Cryptosporidium	0	0	4	6	0	10-log

[a] Per the USEPA Surface Water Treatment Rule, ozone provides 4-log virus inactivation at a CT of 1 mg/L-min at 10° Celsius.

[b] Both chlorine and ozone likely will achieve higher log reduction values than shown if higher CTs are used.

[c] Two-log reduction of viruses has been assumed based on MS-2 phage challenge testing conducted by ultrafiltration (UF) module manufacturers under National Science Foundation (NSF) Environmental Technology Verification and California Title 22 Certification Programs.

[d] Six-log reduction of viruses and *Cryptosporidium* have been assumed for ultraviolet/advanced oxidation processes (UV/AOP), based on testing by UV manufacturers.

[e] Per the U.S. EPA Surface Water Treatment Rule, free chlorine provides 4-log virus inactivation at a CT of 6 mg/L-min at a temperature of 10° Celsius.

Table 3-14: Pathogen Log Reduction Credits for an Ozone/Biologically Active Filtration Based Treatment Train for Direct Potable Reuse

Unit Process	Virus	*Giardia*	*Crypto*	Notes
Ozone	5-log	-	-	• Ozone operated at sub-residual dose to minimize disinfection byproducts and not impact biofiltration. • Research demonstrates 5-log virus at ozone-to-TOC ratios of 0.6:1.0.
Biologically active filtration	+	+	+	• Protozoa and virus removal possible due to the reduction of total suspended solids • Requires demonstration testing.
Ultrafiltration	+	4-log	4-log	• Protozoa removals based upon proven U.S. EPA Membrane Filtration Guidance Manual concepts. • Virus removal expected, but needs demonstration testing to prove performance.
Granular activated carbon	-	-	-	• No removal anticipated.
UV/AOP (high-dose)	6-log	6-log	6-log	• High dose UV (900+ mJ/cm^2). • 235+ mJ/cm^2 necessary for 6-log of all known pathogens.
Engineered Storage with Chlorine	4-log	3-log	-	• Free chlorine disinfection based upon U.S. EPA CT criteria.
Total	**15-log**	**13-log**	**10-log**	• Health standards met without engineered storage. • Additional credit from engineered storage can be obtained.

Notes: "+" indicates some removal expected. "-" indicates no removal anticipated. *Crypto* = *Cryptosporidium*. mJ/cm^2 = Millijoules per square centimeter. TOC = Total organic carbon. UV/AOP = Ultraviolet/advanced oxidation process.

Findings on Pathogen Reduction Values for Treatment Processes

- The U.S. EPA concluded that for pathogens, a 10^{-4} annual risk of infection represents a *de minimis* risk (NWRI, 2013). As a result, to remain consistent with the concept of *de minimis* risk, finished drinking water produced from DPR projects should meet the level of one infection in 10,000 persons per year (i.e., 10^{-4} annual risk of infection).
- The sum of validated log reduction credit for the individual treatment processes (i.e., wastewater treatment, advanced water treatment, and drinking water treatment) in a DPR system must equal or exceed the log reduction values needed to protect human health. Quantifying the log-reduction performance of treatment technologies must be approved by State regulatory agencies, which grant or approve reduction credits based on available research and guidance.
- California and Texas regulators have instituted log reduction values for pathogen credit systems for potable reuse. These systems can serve as an example for Arizona.
- Other considerations include the following:
  - For RO, log reduction credits of 2 can be demonstrated for virus, *Cryptosporidium*, and *Giardia* based on online TOC and electrical conductivity before and after RO. It may be possible to demonstration higher than 2-log reduction credits for RO based on new monitoring methods that are currently being research (e.g., Trasar®).
  - Log reduction credits have been assigned in California for wastewater involving activated sludge treatment; however, additional research is underway to review other approaches involving pathogen data collection.
  - MBRs are a promising technology for potable reuse; however, currently integrity testing cannot be tested on MBRs. Research is underway to evaluate the possibility of assigned log reduction credits based on online water quality parameters.

Recommendations for Pathogen Reduction Credits for Treatment Processes

- Arizona can establish or approve a log reduction credit system for pathogen reductions for DPR treatment technologies based on systems developed in California and Texas and based on available guidance and treatment studies. **(Guidance/Permitting)**
- As part of the log reduction credit system approach, Arizona can allow for utilities to verify or demonstrate log reduction levels for unit processes that can be used to assign appropriate log reduction credits. **(Guidance/Permitting)**

3.11 Topic #11: Potential Water Quality Impacts of Blending

Existing DWTFs or the distribution system may be impacted positively or negatively when ATW is blended upstream of the DWTF or in the distribution system. The potential effects of blending ATW from an RO-based DPR facility in a surface water treatment plant could be based on differences in alkalinity or turbidity. The blended water also could affect treatment kinetics and aesthetic acceptance. The potential effects of blending ATW from a non-RO based system such as ozone/BAF could be based on differences in the organic content of blended water. The specific effects will vary based on the blending ratio and chemical characteristics of the waters to be blended. A summary of the potential impacts is provided in **Table 3-15.**

Table 3-15: Potential Water Quality Impacts from Blending before a Drinking Water Treatment Facility and Distribution System

Issue	Potential Impacts[a]	
	Reverse Osmosis-Based Treatment Train	**Ozone/Biologically Active Filtration-Based Treatment Train**
Organic material	Contribution of advanced treated water (ATW) will decrease organic content of the resulting blend, which may result in improvements in efficiency of conventional water treatment.	Depending on the efficiency of wastewater treatment process and type of surface water, the ATW could increase or decrease the organic content of the resulting blend.
Inorganics	Naturally occurring minerals (i.e., total dissolved solids [TDS]) and metal concentrations will be reduced. Alkalinity may be reduced.	Naturally occurring minerals (i.e., TDS) and metal concentrations might be increased in the blended water.
Trace-level constituents (e.g., constituents of emerging concern, trace organic chemicals)	The ATW will reduce the concentration and composition of trace chemical constituents in surface water.	The ATW will reduce the concentration and composition of trace chemical constituents in surface water.
Disinfectant stability and disinfection byproducts	ATW is likely to provide a more stable disinfectant residual and decrease the formation of total trihalomethanes and haloacetic acids.	Because of different precursors being introduced and depending upon the efficiency of advanced treatment process and total organic carbon, disinfection byproducts may form in greater or lesser concentrations and different compositions.
Corrosion and chemical stability[b]	Corrosiveness of the ATW must be addressed by increase in pH, TDS, hardness, and alkalinity. Dosages for conditioning may potentially be reduced through blending.	Depending on the blending ratio, the potential corrosiveness of blended water will stay the same or decrease.
Aesthetics	Adding ATW may improve aesthetic characteristics of blended water.	
Pathogens	Concentrations of pathogens will be reduced in the blended water.	

[a] Potential impacts depend on the blending ratio (i.e., the ratio of the volume of advanced treated water and the volume of other untreated source waters) and composition of the advanced treated water and other source waters.

[b] When assessing the water quality resulting from blending, mass balance calculations may apply for some of the parameters responsible for corrosion and chemical stability; however, the complexity of the corrosion phenomenon warrants that each water blend should be examined individually (Tang et al., 2006).

Findings on Potential Water Quality Impacts of Blending

- Existing DWTFs or the distribution system may be impacted positively or negatively when ATW is blended upstream of the DWTF or in the distribution system.

3.12 Topic #12: Monitoring, Instrumentation, and Process Control Requirements

Process monitoring for DPR systems involves the following two key components: (1) documentation and review of system performance in accordance with design intent and manufacturer recommendations to ensure water-quality specifications are met; and (2) the ability of the control system to accurately measure operational indicators of chemical and pathogen reduction performance to meet specified criteria.

3.12.1 System Control through Critical Control Points

CCPs are points in advanced water treatment where control can be applied to individual unit processes to reduce, prevent, or eliminate risk from pathogens and chemicals and where monitoring is conducted to confirm proper performance (Walker et al., 2016). The CCP approach also requires the development of specific actions and/or investigations in response to monitoring controls.

For each CCP (i.e., a unit treatment process), surrogates(s) are monitored to assess whether the treatment process is functioning as expected or has been compromised based on the measured data. These surrogate measures need to be continuous. To support response actions by operators and other follow-up actions, the CCP approach should be coupled with a set of alarms, alerts, and critical limits (Walker et al., 2016).

The application of the CCP approach can be used to ensure appropriate operating conditions are maintained. This concept is illustrated in **Figure 3-1 and Table 3-16** for an example RO-based AWTF treatment train. This example includes the unit processes that are CCPs and the monitoring controls required to demonstrate performance. The application of the CCP concept for an example ozone/BAF-based AWTF treatment train is illustrated in **Figure 3-2** and **Table 3-17**.

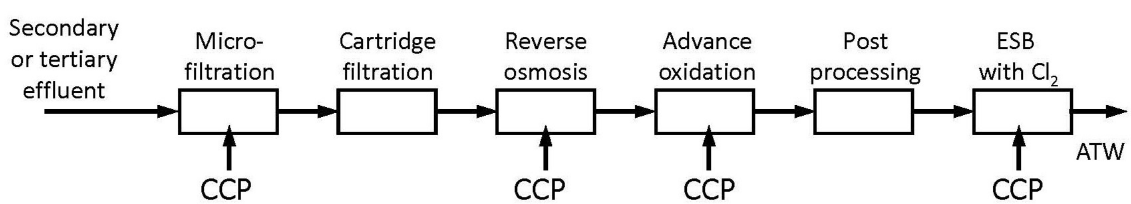

Figure 3-1: Example of an advanced water treatment facility process flow diagram with critical control points identified for the individual treatment processes for both process control and establishing log reduction credits. Figure courtesy of Tchobanoglous et al. (2015).

Table 3-16: Example of the Critical Control Point Monitoring Scheme Shown in Figure 3-1 (Tchobanoglous et al., 2015)

Process	Critical Control Point Monitoring
Secondary treatment	At present, the science is insufficient, but developing. WE&RF Project 14-16 includes promising work correlating secondary effluent quality (e.g., total organic carbon, bacteria counts, etc.) with pathogen concentrations. Similar investigations have been completed by WERF (CEC4R08) correlating secondary treatment process performance with the destruction of trace organic chemical pollutants.
Microfiltration or ultrafiltration	Daily Pressure Decay Test following the U.S. EPA Membrane Filtration Guidance Manual.
Reverse osmosis	Online electrical conductivity (feed and permeate) and total organic carbon.[a]
Ultraviolet/advanced oxidation processes	Intensity sensors, ultraviolet transmittance, and flow rate.
Storage with free chlorine, CL_2, residual ($\geq$0.4 mg/L)	Online Cl_2.

[a] Other methods are under development.

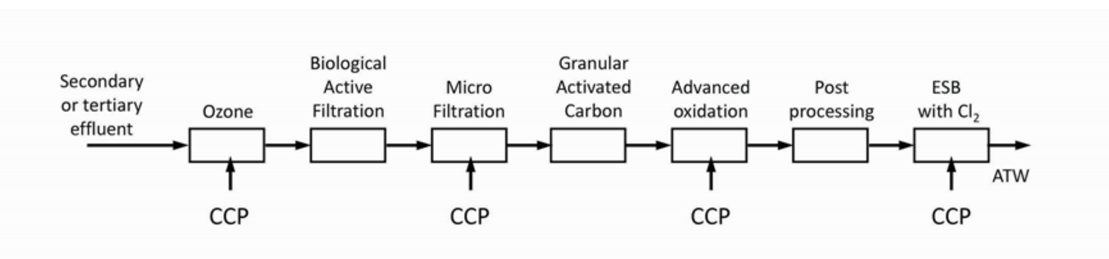

Figure 3-2: Example of an ozone/biologically active filtration-based treatment train process flow diagram with critical control points identified for the individual treatment processes for both process control and establishing log reduction credits.

Table 3-17: Example of the Critical Control Point Monitoring Scheme Shown in Figure 3-2

Process	Critical Control Point Monitoring	Reference Projects/Notes
Secondary treatment	At present, the science is insufficient, but developing. WE&RF Project 14-16 includes promising work correlating secondary effluent quality (e.g., TOC, bacteria count, etc.) with pathogen concentrations. Similar investigations have been completed by WERF (CEC4R08) correlating secondary treatment process performance with the destruction of trace organic chemical pollutants.	• WERF CEC4R08. • WE&RF 14-16.
Ozone	The ozone/TOC ratio demonstrates a clear correlation to virus kill (WE&RF 11-02) and the destruction of trace organic chemical pollutants.	• WE&RF 11-02. • Chemical pollutant destruction work led by Dan Gerrity at the University of Nevada Las Vegas.
Biological active filtration (BAF)	Pertaining to TOC removal, biofiltration performance is monitored online using calibrated TOC meters at the ozone feed location and post BAF. Pertaining to pathogen removal, studies are planned, but not completed, to correlate turbidity reduction through BAF with virus and protozoa reduction.	
Microfiltration or ultrafiltration	Daily Pressure Decay Test for protozoa removal only.	• Following U.S. EPA Membrane Filtration Guidance Manual.
Granular activated carbon	Online TOC and ultraviolet transmittance (UVT) monitoring demonstrates the transition from adsorption to a second stage biofiltration system (documented in WE&RF 14-16).	
Ultraviolet/ advanced oxidation processes	Intensity sensors, UVT used for real-time dose monitoring for pathogen kill. Use of an oxidant weighted dose proven to correlate with the destruction of trace organic chemical pollutants.	• Pathogen kill follows the U.S. EPA Ultraviolet Disinfection Guidance Manual. • Oxidant weighted dose first demonstrated at the City of Los Angeles' Terminal Island potable water reuse system.
Engineered storage with free chlorine, CL_2, residual ($\geq$0.4 mg/L)	Online Cl_2 used to monitor virus kill and *Giardia* kill in real time based upon CT measurements, also flow rate.	• Follows U.S. EPA tables. • Engineered storage not installed at the Altamonte Springs Demonstration Facility.

Note: Based upon correspondence with Andrew Salveson, Carollo Engineers, Inc., dated 6/19/2017, regarding the Altamonte Springs Florida Direct Potable Water Reuse Demonstration Facility.

3.12.2 Automated System Control – Direct Potable Reuse Treatment Train

The treatment process control system (i.e., the controls programming, Supervisory Control and Data Acquisition [SCADA] system, and human-machine [HMI] configuration) would provide rapid and appropriate operational response. In addition, it should continuously record the CCP data. The control system would allow operators to: (1) proactively review performance to anticipate problems before they occur; (2) respond effectively to alarms and shutdown conditions; (3) provide a thorough investigation of why the problem occurred and transfer lessons learned to improve future operations; and (4) return systems safely and effectively to service in a timely manner (Walker et al., 2016).

The control system also allows for the calculation the total pathogen log reduction credits in real time, with automated warning systems and, if needed, system shutdown and diversion. Similar alarms could be set based upon the anticipated removal of salts, TOC, and other parameters, depending upon the treatment processes and their respective treatment performance.

3.12.3 Flow Diversion

In the event the entire treatment train cannot attain target pathogen goals, effluent from the AWTF may need to be diverted (through means of a discharge permit) or the system may need to be shut down until targets are met.

3.12.4 Start-Up/Documentation of Baseline Performance

At startup and prior to system operation, water quality monitoring is recommended for each major treatment process and for final product water quality (an example of startup testing is provided in **Table 3-18** for one example treatment train). A Start-Up Performance Plan should be required, similar to existing procedures for Approval of Construction. This monitoring is intended to: (1) document that system performance results in a finished water protective of public health; (2) provide a baseline of system performance for future comparison and analysis; and (3) validate the effectiveness of CCP selection and monitoring. Ideally, this baseline performance would establish a normal distribution of performance and monitoring data. Future deviations from the normal distribution would be flagged for a more detailed evaluation and, potentially, equipment repair.

Recommended sampling for compounds with MCLs and secondary MCLs, as well as specific compounds with Drinking Water Health Advisory (DWHA) values, can be found in U.S. EPA (2012).

At start up, monitoring should be conducted to assess chemicals control, as discussed in **Section 3.4** for both unregulated and regulated constituents, including CECs.

3.12.5 Performance Monitoring

Performance monitoring can include CCPs and COPs, which focused specifically on operational issues. This monitoring, which can include continuous or periodic sampling, is intended to demonstrate the continuous production of high-quality water protective of public health. Specifically:

- Recommended continuous online sampling for all feasible control parameters and periodic bench-top calibration of online meters are summarized in **Table 3-19** for one example treatment train.

- In lieu of online monitoring, frequent grab samples should be required if online systems are not available.
- Recommended periodic sampling for water quality monitoring (using grab samples) is summarized in **Table 3-20** for one example treatment train. The sampling frequency can be reduced over time based on whether sampling shows non-detects for a reasonable time period.

Table 3-18: Example Startup Testing for the Advanced Water Treatment Facility Flow Diagram Shown in Figure 3-1 (Tchobanoglous et al., 2015)

Process	Test	Sample Type and Frequency	Notes
Secondary effluent	Effluent turbidity, biochemical oxygen demand (BOD), and total suspended solids (TSS) microbial indicators	Online (continuous) and grab (daily) for 30 days	Sets baseline water quality.
	Effluent MCLs, secondary MCLs, and health advisory values	Two grab samples over 30 days	Provides a preliminary understanding of trace constituents ahead of advanced treatment.
MF or UF	Pressure Decay Test; Turbidity	Offline testing (daily)	Provides an assessment of performance.
RO	Influent and effluent TOC	Online (continuous) and grab (daily) for 30 days	TOC reduction to <0.5 mg/L is expected with well-functioning RO membranes.
	Influent and effluent EC	Online (continuous) and grab (daily) for 30 days	EC monitoring is required for long-term operation.
	Influent and effluent CECs	Two grab samples over 30 days	Demonstrates removal by key process for CEC reduction (RO).
UV/AOP	Influent and effluent NDMA and 1,4-dioxane (if present in source water)	Two grab samples over 30 days	Demonstrates UV and oxidant doses and removal of indicator constituents difficult to remove by other techniques. 1,4-dioxane is primarily removed by AOP; NDMA by UV photolysis.
	UV sensors	Online (continuous) and verification (weekly) monitoring	Comparisons to anticipated values from manufacturers required.
	Influent ultraviolet light transmittance (UVT)	Online (continuous) and grab (daily) monitoring	Provides as assessment of performance.
	Effluent *E. coli* and total coliform	Grab (weekly) for 1 month	Total coliform is not an MCL, but a general bacteria performance check.
	Effluent MCLs, secondary MCLs, unregulated CECs	Two grab samples over 30 days	Demonstrates quality of advanced treated water ahead of blending.
	Influent and effluent chloramine	Grab (daily) for 30 days	UV/AOP performance correlates with chloramine destruction.
Storage with free chlorination	Effluent free chlorine residual	Online (continuous) and grab (daily) for 30 days	Demonstrates the ability to maintain minimum target residual and minimum CT.

Table 3-19: Performance Monitoring: Example Online and Calibration Sampling for the Flow Diagram Shown in Figure 3-1 (Tchobanoglous et al., 2015)

Process	Test	Type and Frequency of Sampling during Operation
Secondary effluent	Turbidity and microbial indicators	Turbidity: online (continuous) and grab (weekly). Microbial: grab (weekly)
	Ammonia, total suspended solids, and biochemical oxygen demand	Grab (weekly)
Microfiltration or ultrafiltration	Pressure decay test	Offline testing (daily)
	Turbidity	Online (continuous) and grab (weekly)
Reverse osmosis	Influent and effluent electrical conductivity and total organic carbon	Online (continuous) and grab (weekly)
Ultraviolet/advanced oxidation process	Ultraviolet sensors	Online (continuous) and verification (weekly)
	Influent ultraviolet transmittance	Online (continuous) and grab (weekly)
	Influent and effluent chloramine	Online (continuous) and grab (weekly)
Storage with free chlorination	Effluent free chlorine residual	Online (continuous) and grab (weekly)

Table 3-20: Recommended Periodic Sampling for Water Quality Monitoring (Using Grab Samples) (Tchobanoglous et al., 2015)

Monitoring Parameters	Sample Locations	Regulatory Monitoring	Process Monitoring	Frequency
Total organic carbon, electrical conductivity	ROF, ROP		✓	Monthly
Maximum contaminant levels (MCLs), secondary MCLs	ATW	✓		Quarterly or as mandated by State
Constituents of emerging concern (CECs) and unregulated	UV/AOP		✓	Quarterly (initially)
Total coliform, *E. coli*	UV/AOP	✓		As mandated by State
NDMA	UV/AOP		✓	Quarterly

Notes: ROF = Reverse osmosis feed; ROP = Reverse osmosis permeate. ATW = Advanced treated water. UV/AOP = Ultraviolet/advanced oxidation process.

Findings on Monitoring, Instrumentation, and Process Control Requirements of DPR Systems

- Having redundant monitoring processes (e.g., TOC and EC for RO monitoring) and active CCPs may allow for some process or monitoring excursions, while still producing water that is protective of public health.
- Automated system control (e.g., turbidity and disinfectant residuals) for the DPR system will provide continuously recorded CCP data and calculate total pathogen log reduction credits in real time. Automated water systems can provide system shutdown and diversion. Pathogen credit alarms and system shutdown values should be established.
- The use of engineered storage can allow for time to make such decisions.
- Process monitoring, including continuous online sampling and periodic sampling, is needed to demonstrate the continued production of high-quality water.
- Periodic calibration of online meters is needed.

Recommendations for Monitoring, Instrumentation, and Process Control Requirements of DPR Systems

- Startup performance monitoring must be reported to ADEQ for approval. Water quality monitoring is recommended for each major treatment process and final product water quality. **(Regulation)**
- Appropriate process monitoring for DPR systems using rapid surrogate measures is needed to measure pathogen reduction performance and to document and review system performance. (**Guidance/Permitting**)
- In the event the DPR system cannot attain target pathogen credits or another water quality excursion, a judgment needs to be made based upon all the information available as to whether the facility should be shut down or out-of-specification water bypassed or diverted to another system (i.e., the sewer). **(Guidance/Permitting)**

3.13 Topic #13: Management Options for Reverse Osmosis Concentrate

For DPR treatment trains using RO, the management of the RO concentrate is a major cost consideration for inland communities. Inland communities do not have the ability to discharge concentrate through ocean outfalls.

RO concentrate disposal options currently in use in inland areas are listed in **Table 3-21**. For inland locations, the first five options listed in **Table 3-21**, arranged in order of use, comprise the vast majority of the disposal options applied currently.

Because the cost of RO concentrate disposal for inland locations can be considerable, regional solutions may be a feasible alternative (Raucher and Tchobanoglous, 2014). Nontraditional uses of concentrate are considered in Jordahl (2006).

Zero liquid discharge (ZLD) processes can be used to reduce the volume of concentrates and brines. ZLD processes are "high-recovery process where either the final brine is disposed of within the plant boundary (such as in an evaporation pond) or the process produces solids for disposal" (Mickley, 2008). A variety of ZLD treatment processes are available, and many others are under development, to reduce or eliminate the volume of RO concentrate that must be managed; however, the options can be costly. Over time, ZLD processes may become more attractive if costs can be reduced (Mickley, 2008).

Table 3-21: Summary of Reverse Osmosis Concentrate Disposal Options for Inland Areas

Disposal Option	Use/Description
Surface water discharge	A common method of disposal is discharge of reverse osmosis (RO) concentrate to surface waters, including lakes, reservoirs, or rivers, where sufficient dilution capacity is available. Membrane concentrate disposal in surface waters is regulated by the Clean Water Act and would require a permit under the Arizona Pollutant Discharge Elimination System (AZPDES).
Discharge to the wastewater collection system	Suitable for relatively small discharges in which the increase in total dissolved solids is not significant [e.g., typically <20 to 50 milligrams per liter (mg/L)] and that otherwise comply with sewer ordinance local discharge limits.
Deep well injection	Depends on the availability of a geologically suitable subsurface aquifer that is brackish or otherwise unsuitable for domestic uses. An applicable regulatory framework currently is lacking in Arizona.
Evaporation ponds (with or without a greenhouse)	Involves the discharge of RO concentrate to shallow, lined ponds. A large surface area is required in most regions, with the exception of some southern and western states. Required surface area can be reduced using greenhouses. Solidified constituents may or may not need to be disposed of in industrial waste landfills based on testing.
Land application	Used for some low-concentration RO concentrate solutions, though this option generally is not available. Some RO concentrate solutions can be disposed of in industrial waste landfills.
Zero liquid discharge	Involves the use of evaporators (e.g., vapor compression), brine concentrators, and crystallizers or spray dryers to convert RO concentrate to brine, a semisolid product, or a dry product suitable for landfill disposal. The recovery of useful salts may be possible.

Source: Adapted from Tchobanoglous et al., 2015.

Current ZLD processing schemes for treating wastewater brine have included the following processes:

- Reverse osmosis.
- Lime softening.
- Thermal brine concentrators.
- Thermal crystallizers.
- Spray dryers.

Capital and operation costs for these processes vary based on conditions such as water quality and volumes. Solids from lime softening and crystallization would need to be disposed in landfills or reused (Mickley, 2008).

Newer commercial technologies are being studied and piloted for municipal applications and benchmarked against current approaches. These new technologies include: SAL-PROC (Geo-Processors); HEEPM (EET Corporation); VSEP (New Logic); and ARROW (O'Brian and Gere) (Mickley, 2008).

High-recovery and ZLD processes are technically feasible, but generally are not economically feasible for municipal applications. Economic feasibility for municipal applications requires cost reductions. High costs are associated with energy and chemical needs, the evaporative process steps, and final disposal septs, such as evaporation ponds and landfill (Mickley, 2008).

Findings on Management Options for Reverse Osmosis Concentrate

- If RO is used in a DPR treatment train, the management of the RO concentrate is a major consideration for inland communities. A number of RO concentrate disposal options are currently in use in inland areas; however, in Arizona, several inland concentrate management options are uncertain from a regulatory context, and the cost implications are significant.

3.14 Topic #14: Facility Operations and Maintenance

A DPR system involves the use of a number of treatment and monitoring processes. Appropriate O&M is necessary to ensure that the DPR system meets all public health objectives and operates consistently and reliably. O&M activities begin with the design and construction of the DPR system and continue throughout its lifetime (Walker et al., 2017; Tchobanoglous et al., 2015).

3.14.1 Initial Startup Plan

Initial startup and system performance testing (commissioning) will demonstrate that the DPR system works properly. An initial startup plan will identify the steps necessary to complete performance testing of equipment for water treatment, monitoring, and pumping.

3.14.2 Annual or Seasonal Startup Plan

An annual startup plan may be needed for systems that are operated intermittently or seasonally. The annual startup plan should include:

- Information identified in the initial startup plan.
- Information on periodic maintenance or cleaning and equipment rehabilitation or replacement.
- A checklist of tasks for each treatment process and the system as a whole, as performed by certified operators who have been trained on the overall operation of the DPR system.
- A schedule for completing these tasks.

3.14.3 Shutdown Plan

The shutdown plan should provide the same level of detail as the startup plan, including provisions to drain piping and tanks where freezing or stagnant non-compliant water exists. After shutdown, some systems may need to stay "wet"; therefore, handling this stagnant water during the preparation for startup needs to be addressed.

3.14.4 Operation and Maintenance Plan

An O&M plan demonstrates system performance of the various treatment processes to provide the public and regulators assurance that the DPR system is performing as designed. The O&M plan must also include regulatory compliance sampling and monitoring, as well as performance monitoring. In Arizona, existing emergency preparedness and response efforts under the SDWA will inform and support the O&M plan (see http://legacy.azdeq.gov/environ/water/dw/ep.html). Specifically:

- In Arizona, an **Emergency Operations Plan** is required for drinking water systems. Per A.A.C. R18-4-204, all community water systems, regardless of size, are required to develop and maintain an Emergency Operations Plan that details physical and technical aspects of water systems operation, such as maintaining proper water pressure, the collapse of a major structure, or loss of mechanical components like pumps or valves. The Emergency Operations Plan also addresses public notice and alternate water supplies.

- The federal Bioterrorism Preparedness and Response Act requires every community water system that serves a population of greater than 3,300 people to conduct a **vulnerability assessment** to identify areas and processes within a water system that could be vulnerable to attack, sabotage, or disruption. Vulnerability assessments are voluntary for systems serving 3,300 or less people; however, ADEQ encourages all water systems to use this document to review their vulnerabilities.
- Community water systems that serve more than 3,300 people must use their vulnerability assessments to compile an **Emergency Response Plan**. This plan should contain all the information required in an Emergency Operations Plan, but provide greater detail regarding the potential problems the water system may face. The Emergency Response Plan includes information about other agencies that must be notified, including law enforcement, public health officials, and firefighters.
- An **O&M Manual** is a baseline tool for a facility that describes: (1) system characteristics; (2) distribution system (including maintenance and sampling); (3) start-up procedures; and (4) Emergency Operations Plans. This tool gives facility operators and managers instructions, log sheet samples, and technical information for the efficient and safe operation of a facility during normal operations or during an unplanned or emergency situation. An O&M Manual also may be used by emergency responders for reference regarding such items as chemical storage and fire flow capabilities.

The ADEQ-required O&M Manual can be augmented to include an O&M plan. Components of an O&M plan for DPR are listed in **Table 3-22.**

3.14.5 Response to Off-Specification Water

Because of the limited response time, a response plan is needed in the event of off-specification water at a DPR facility. The plan should include: (1) the process to identify and address problems; and (2) the amount of time needed to react and the use of automated systems with triggers and alarms, such as through the use of SCADA. The response plan procedures can be included in the O&M Plan (see **Section 3.14.4**).

3.14.6 Alternative Source of Water

If possible, communities that pursue DPR should have an alternative source of water in case the DPR facility is not operational. In Arizona, this could be addressed by an alternative source of water or through the Emergency Operations Plan (which is required by ADEQ for all drinking water systems) and the Emergency Response Plan (which is required for community water systems that serve more than 3,300 people). See **Section 3.14.4** for more information on these two plans.

Table 3-22: Components of an Operations and Maintenance Plan for a Direct Potable Reuse System

Component	Description
Staffing (i.e., for daily operations and emergencies)	• Appropriately trained staff will be needed to ensure the direct potable reuse (DPR) plant is operated properly and routine periodic maintenance is performed. • Licensed drinking water operators (e.g., Grade 3 or 4) are needed to manage day-to-day plant operations, allowing for continued operation in the event of illness or vacation. It is recommended that drinking water operators have wastewater certification or that some operators could be wastewater-certified operators. Other options to consider include: (1) the development of an advanced water operator certification program or (2) specific advanced treatment endorsements on existing certifications (Walker et al., 2017). • A wide range of skills and experience are required to operate the plant; therefore, it may be difficult to hire the required personnel. An alternative would be to use a contracted turnkey service provider to operate the plant with appropriately trained personnel. • Remote monitoring and control capability is necessary to provide 24/7 surveillance. These systems should be demonstrated during startup and commissioning to confirm compliance. • A summary of the various tasks to be performed, along with corresponding hours, can provide insight into the number of operators that would be needed to perform all the required maintenance, sampling, and monitoring.
Operator training and certification	• The lead operators of a DPR system will need the highest level of certification (Water Level 4). It would be useful if operators had both water and wastewater certifications. • Operators must be trained in and demonstrate an understanding of advanced treatment system operations for potable reuse. • The Arizona Department of Environmental Quality (ADEQ) should create a training program for each specific advanced treatment technology to be used for potable water reuse, as well as a general training program to define the broader picture of public health protection, pathogen and pollutant targets, and other issues. The training program could require a minimum of 16 hours per year to maintain a pool of higher level operators and advance the knowledge of advanced treatment systems in the State. • A separate DPR (advanced treatment) certification program could be developed, or an “endorsement” for DPR (advanced treatment) could be applied to a water certificate.
Checklists for operations procedures (daily, weekly, and monthly)	• Use the checklists developed with information provided by manufacturers to ensure routine procedures and duties are performed. • Checklists should include water quality sampling and monitoring to document treatment performance. • Incorporate monthly or other water quality sampling for compliance with ADEQ requirements.
Routine maintenance of equipment	• An important aspect of operations is periodic maintenance of equipment and monitoring systems. • Identify routine maintenance as recommended by equipment manufacturers, and verify that online meters are properly integrated for each critical control point. • Determine the number of hours and type of work needed to perform periodic maintenance, and incorporate this information into the annual startup and shutdown plans. • Regularly perform the monitoring and calibration of online instruments to ensure they function properly.
Critical spare parts and failure training	• Identify a list of critical spare parts needed onsite in the event of system failure. • Recommend periodic "failure" drills to verify that staff is trained and parts are available to make rapid repairs to equipment.
Control system (e.g., SCADA,	• Operators need to be connected to the Supervisory Control and Data Acquisition (SCADA) system to constantly monitor system operations. • Program the SCADA system to alert operators when the system is not operating properly and

Component	Description
shutdown procedures, and alarms)	to shut down the system if performance is compromised. • A phone, internet, or cloud-based messaging system could be used to notify operators during non-working hours if an alarm goes off. • The types of alarms that would generate these phone calls need to be determined to ensure operators respond swiftly to the situation. • System shutdown criteria need to be developed to automatically stop the system from allowing out-of-specification water to enter into the distribution system. These systems should be checked at least once per year.
Process monitoring and control	• Operators must know proper procedures for the calibration of online instruments, sampling and testing, and sensor testing. • Additional spare units may be needed to allow for easy change out if the instrument fails or calibration requires that the system be shut down for extended periods of time. • Develop process control during initial startup and verify with vendors, contractors, and operations staff.
Regulatory compliance	• Address regulatory compliance monitoring, including online instruments, daily sampling, monthly compliance sampling and testing, and others. • ADEQ will need to determine the number and types of sampling required with online monitoring. • ADEQ will need to determine the type and frequency of monitoring used to demonstrate compliance.
Frequency of monitoring	• Process monitoring is needed to monitor the performance of individual equipment or a collection of equipment. • Process monitoring should be based on manufacturer recommendations to ensure the proper operation and performance of equipment. • Process monitoring should involve a combination of online instruments and water quality sampling. • Use the initial startup period to familiarize operators with equipment and various methods of process monitoring. • Employ the SCADA system as a means of monitoring online instruments and processes during non-working hours. • ADEQ will need to determine the frequency and types of monitoring used to demonstrate the protection of public health.
Distribution System	• Include periodic sampling of the distribution system during initial startup to determine chemical compatibility between existing drinking water supplies and the advanced treated water. • Implement these tests prior to bringing the DPR project online and on a regular basis during operation. • Consider simple water quality testing comparing existing supplies to the advanced treated water (or blend of the two), including pH, hardness, alkalinity, total ions, and cations. • Ensure that the advanced treated water is conditioned to be compatible with the distribution system corrosion control plan, if one exists, and modify the corrosion control plan as necessary to accommodate the new water supply. Develop a corrosion control plan if one does not yet exist.
Response time to treatment failures or non-compliant water quality	• Operators should be required to be present during facility operation. Remote monitoring and control capabilities are necessary to provide surveillance.

3.14.7 Operator Training and Certification

AWTFs are complex systems that must be operated and maintained by well-trained, highly skilled operations staff. These operators must be able to effectively respond to any issues or challenges that arise at the AWTF, as well as receive ongoing training and certification as new processes and techniques become available. Training could be provided by utilities, national or state water and wastewater associations, commercial training programs, and community college training classes. Efforts are underway in the State of California to determine what is needed for DPR operator training and certification. The California Urban Water Agencies led an effort to develop a framework for potable reuse operator training and certification (CUWA, 2016). Certification could take the form of "endorsements" to existing operator certification that cover advanced treatment or specific unit process. In addition, for DPR facilities, a new additional category of certification, such as Advanced Treatment Technologies Operator, could be developed (Walker et al., 2017).

For DPR applications in Arizona, the following scenarios could be used:

- In a DPR facility that is <u>not</u> certified as a DWTF: The use of licensed drinking water certified operators is required; however, a licensed wastewater with advanced water treatment endorsement also is possible if an endorsement system is established. An Operator of Record who is drinking water certified must be designated.

- In a DPR facility that is <u>permitted</u> as a DWTF: The use of licensed drinking water operators is required. An Operator of Record who is drinking water certified must be designated.

3.14.8 Reporting

Once a DPR system is operational, reporting will be an important component of documenting the performance of the system. Reporting associated with a DPR system could involve the following:

- Start-up monitoring should be reported.
- Performance and compliance monitoring should be reported consistent with State drinking water program reporting requirements.
- An annual report for DPR projects should be required. The report should detail trends in water quality and treatment over the year and list any significant operational or technical challenges. It also should verify that the required maintenance was performed for various systems.

Findings on Facility Operations and Maintenance

- Highly trained and certified operators are critical to the safe, successful functioning of DPR systems. Operators should be trained and certified specifically for operating the DPR system.
- For DPR facilities, the following will need to be determined: (1) the number and types of sampling required with online monitoring; (2) the type and frequency of monitoring used to demonstrate compliance; and (3) the frequency and types of monitoring used to demonstrate the protection of public health.
- ADEQ staff will need to acquire the necessary knowledge to provide oversight for DPR systems.

Recommendations for Facility Operations and Maintenance

- The O&M requirements for a DPR system exceed the demands of a wastewater or drinking water supply, requiring specific operator skills and experience. DPR treatment plant operators should have a Grade 4 level of certification as a water treatment plant operator. (**Regulation**)
  - The details of the number of operators required and level/types of certification can be addressed in guidance or permitting. **(Guidance/Permitting)**
  - Lead operators and the Operator of Record should be Grade 4 licensed water treatment operators. **(Guidance/Permitting)**
- An O&M plan for DPR should be required. **(Regulation)**
  - These plans should include procedures for initial startup, annual startup, shutdown, asset management, and O&M. **(Guidance/Permitting)**
  - The O&M plan must include regulatory compliance sampling and monitoring. **(Guidance/Permitting)**
- For DPR projects, the following should be required: (1) start-up reporting; (2) DPR system reporting added to drinking water reporting; and (3) an annual report. **(Regulation)**
  - The details for start-up reporting, additional monthly reporting, and the annual report can be specified in guidance or permitting. **(Guidance/Permitting)**
- A response plan for off-specification water should be required. **(Regulation)**
  - The procedures of a response plan for off-specification water can be incorporated into the O&M plan for DPR. **(Guidance/Permitting).**
- Alternative sources of water should be addressed in the ADEQ-required Emergency Operation Plan and the Emergency Response Plan. **(Guidance/Permitting)**
- Certified water treatment plant operators will be needed to run a DPR system. Staffing for a DPR system should be required when the facility is operational. **(Regulation)**
- An electronic remote sensing system should be available to provide real-time data, appropriate alarms, and automatic response so that operators and other expert support personnel can be on call at all times. **(Guidance/Permitting)**

3.15 Topic #15: Technical, Managerial, and Financial Capacity

TMF capacity is the ability of a water utility to provide safe and dependable water to its customers. In general, it includes forms of financial support or assistance (i.e., recurring revenues, grants, and loans), regulatory enforcement, and operator certification activities, among others. Arizona has an existing capacity development program for public drinking water systems, per requirements in the 1996 SDWA, to assess the TMF capacities of water systems and assist those in need of developing or improving TMF capacity. This existing program can be modified or expanded upon to address DPR.

3.15.1 Background on Technical, Managerial, and Financial Capacity

The 1996 SDWA requires states to incorporate TMF capacity into public water system operations. This requirement helps ensure that public water systems – including small drinking water systems – have long-term sustainability and are able to maintain compliance with all applicable drinking water laws and regulations. In particular, the Capacity Development Program was created under the SDWA Amendments of 1996 and includes the following three major components (U.S. EPA, 2017c):

- **Section 1420(a) New Systems**: States must have a program established to "ensure that all new community water systems and non-transient, non-community water systems commencing operations after October 1, 1999, demonstrate TMF capacity with respect to each national primary drinking water regulation in effect, or likely to be in effect, on the date of commencement of operations."

- **Section 1420(c) State Capacity Development Strategies**: States must develop and implement a "strategy to assist public water systems in acquiring and maintaining TMF capacity."

- **Section 1452(a)(3) Assessment of Capacity**: States may not provide Drinking Water State Revolving Fund (DWSRF) loan assistance to systems that lack the TMF capability to ensure compliance, or if the system is in significant noncompliance with any drinking water standard or variance; however, States may provide assistance if the use of such assistance will ensure compliance and the system has agreed to make the necessary changes in operation to ensure that it has the TMF capacity to comply over the long-term.

3.15.2 Technical, Managerial, and Financial Capacity for Direct Potable Reuse

A TMF assessment for DPR can be used to determine the capacity of a utility to:

- Build, operate, manage, and sustain a DPR system for the long-term.
- Plan, achieve, and maintain regulatory compliance.
- Provide effective public health and environmental protection.
- Make efficient use of public funds and sustainable public investments.

Because wastewater is used as the source water, DPR should require a higher level of accountability by the utilities undertaking these projects; therefore, TMF capacity could also address issues such as the quality of the source water, advanced treatment technologies in use at the AWTF, ability to take corrective action for a problem or failure within a shorter response time, and efforts to build and maintain public trust and confidence.

3.15.3 Assessment of Technical, Managerial, and Financial Capacity

A list is included in **Table 3-23** of possible areas to assess when evaluating the TMF capacity for a DPR project. The ultimate goal of a TMF capacity assessment should be to help utility administrators, employees, and operators identify potential or existing weaknesses and improve the utility's ability to safely operate a DPR system on a long-term basis.

Table 3-23: Potential Areas to Assess for the Technical, Managerial, and Financial Capacity of a Direct Potable Reuse Project

Capacity	Description	Potential Areas to Assess
Technical	Deals with the performance and operation of the advanced water treatment facility (AWTF).	• Feasibility of consolidation. • Existing water sources (sufficient sources, source control, etc.). • Water system treatment capacity. • Monitoring. • Number of trained certified operators. • Operations and maintenance (O&M) plan. • Treatment, storage, and distribution facilities. • Compliance records, violations of federal and state compliance standards, and plans to correct these violations.
Managerial	Deals with governance (e.g., administrators must understand the responsibilities of overseeing the AWTF; employees and contractors must understand their roles; adequate time is needed to conduct all required tasks).	• Ownership. • Management. • Water rights. • Operations (including training and technical competency, and the O&M plan). • Organization. • Master planning (including an inventory of equipment and infrastructure). • Emergency response planning. • System policies. • Customer service.
Financial	Deals with the financial ability to operate and maintain existing infrastructure and financial planning for future needs. Assessed through budget statements, asset management, and financial audits.	• Capital costs. • Lifecycle costs. • Budgeting (and budget control). • User fees. • Financial audits/bond rating. • Rate studies. • Financial planning and management. • Capital improvement plan.

3.15.4 Examples of Technical, Managerial, and Financial Capacity Development Components

Specific components to consider as part of a TMF capacity development program for DPR may include:

- Adequate infrastructure.
- Asset management.
- Business plan or capital improvement plan.
- Communication/outreach.
- Construction.
- Distribution.
- Emergency response.
- Energy efficiency and management.
- Financing, revenue, and water rates.
- Funding for small water systems.
- Management.
- Monitoring.
- O&M.
- Regulations.
- Reserve fund.
- Source control.
- Source water quality.
- Technical knowledge and implementation.
- Training.
- Treatment reliability.
- Water security.

Recommendations for Technical, Managerial, and Financial Capacity

- An assessment could be required for DPR projects involving a TMF capacity assessment or a similar assessment that does not involve the state's TMF program. **(Regulation)**
- The capacity assessment process for evaluating the ability of a utility to implement DPR can be detailed in guidance and could be part of the utility's project proposal. **(Guidance/Permitting)**

3.16 Topic #16: Considerations for Small Water Systems

A review involving TMF capacity may be appropriate for utilities and/or communities interested in implementing DPR. Notably:

- A structure exists in Arizona and possibly can be modified to include DPR.
- DPR standards will be the same for both large and small water systems, but this process exists to help small systems determine and achieve TMF.
- The Water Infrastructure Finance Authority of Arizona (WIFA) is available to help small systems fund projects and ensures small systems pay back loans on projects (e.g., through appropriate rate setting). It is important to note that the AWTF should be defined as part of the drinking water program, considering private wastewater facilities are ineligible for WIFA funding.

Small water systems, which can be defined as serving less than 10,000 people, are of special interest because small systems:

- Tend to have limited resources and a limited number of operators and other staff with technical expertise.
- Are often located in rural communities and low-income areas.
- Face the greatest challenges with SDWA compliance (for this reason, the 1996 SDWA Amendments include provisions that allow for additional flexibility in regulatory implementation and monitoring requirements for small water systems).

The applicability of these DPR recommendations for small systems are as follows:

- **Water Quality Criteria.** The water quality criteria should be the same for all system sizes. That is, the pathogen and chemical criteria for DPR should apply equally to all utilities.
- **Source Control.** Small systems often are exempt from federal pretreatment programs; however, small systems considering DPR should adopt pretreatment and source control programs.
- **Wastewater Treatment.** Wastewater treatment for small systems can be enhanced for DPR.
- **Advanced Water Treatment Technologies.** Advanced water treatment technologies exist on a small-scale and are available to small systems, often in package plants that facilitate O&M.
- **Process Control and Monitoring.** Consistent with the 1996 SDWA Amendments provisions that allow for additional flexibility in regulatory implementation, modified monitoring requirements for small water systems proposing DPR may be possible. These modifications could be considered on a case-by-case basis; however, the protection of public health still needs to be ensured.

- **O&M.** Appropriate O&M is necessary because AWTFs are complex systems that must be operated and maintained by well-trained, highly skilled operations staff. It is critical that small system operators receive ongoing training and certification. The appropriate level of O&M needed for small systems interested in implementing DPR must be established.
- **TMF Capacity.** Arizona's TMF program under the SWDA should provide strategies for small systems to develop the capacity needed for DPR. This process may be essential for assessing small systems.
- **Public Acceptance and Outreach.** It is important for small systems to conduct public outreach to gain public acceptance of and confidence in a DPR project.

Findings on Small Water System Considerations

- Small water systems interested in implementing DPR will present unique challenges; however, small systems will need to comply with all DPR regulations.

Recommendation for Small Water System Considerations

- An analysis of TMF capacity or a similar process for assessing the ability of the small system to implement DPR is essential. **(Guidance/Permitting)**

3.17 Topic #17: Consideration of Alternatives to the Criteria for Direct Potable Reuse

As part of the State of Arizona regulations on DPR, a provision should be considered that allows a utility to propose an alternative to any of the DPR criteria, related criteria, or requirements. The utility would need to demonstrate that the proposed alternative provides at least the same level of protection to public health. The State of Arizona would need to review and approve the proposed alternative prior to implementation. This type of provision gives utilities the flexibility to propose innovative approaches for potable reuse. California has a similar provision in its regulations for Groundwater Replenishment Using Recycled Water (CCR, 2015).

Recommendation for the Consideration of Alternatives to the Criteria for Direct Potable Reuse

- The State of Arizona should include an alternative provision as part of DPR regulations. The purpose of the alternative provision would be to allow a utility to propose an alternative approach to any of the DPR criteria or requirements. The utility would need to demonstrate that the alternative provides at least the same level of public health protection. **(Regulation)**
- Specific requirements for implementing the alternatives provision could be addressed in guidance or permitting. **(Guidance/Permitting)**

3.18 Topic #18: Public Acceptance and Outreach

Public confidence, acceptance, and support is necessary for the successful implementation of potable reuse projects and will be essential for DPR. Notably, public acceptance is equally as important as technical merit (TWDB, 2015; Macpherson and Slovic, 2011). The public needs to trust that the use of recycled water as a source of municipal water supply is protective of public health. For example, one concern could be the health risks associated with chemical constituents, such as CECs, in the water supply. Proponents of DPR (i.e., utilities and communities) should develop and launch public outreach programs within their service areas to address public concerns, build public confidence, and garner public acceptance of potable reuse.

Utilities should develop a communication plan that documents an organized and robust outreach approach. The WateReuse Foundation published a study, titled *Model Communication Plans for Increasing Awareness and Fostering Acceptance of Direct Potable Reuse,* that provides extensive information on developing a communications plan and describes the specific activities that should be conducted as part of an outreach program (Millan et al., 2014). Specifically, the following activities are important in developing an outreach program (Millan et al., 2014; Tchobanoglous et al., 2015; TWDB, 2015):

- Designing the outreach program to be strategic, transparent, and thorough.
- Starting outreach early and continuously engaging the public throughout the lifetime of the project (i.e., planning and design, construction, operation, expansion, etc.).
- Using proven techniques and tools to listen to and communicate with the community, engage the media, and address public concerns.
- Providing useful, accurate information that builds awareness of potable reuse and builds confidence in the quality of recycled water.
- Developing consistent messages to communicate to the entire community, including different audiences in the community.
- Building relationships with opinion leaders, educators, and other influential community members.
- Creating transparency in all aspects of the project, including costs, water quality, and safety.
- Preparing for tough questions and addressing misinformation.

It is not the role of the State of Arizona to perform outreach for individual DPR projects or to provide guidance to utilities on DPR outreach strategies; however, the State should be aware of how it can impact the public's perception of potable reuse and develop a strategy for communicating about DPR in general. For example:

- The State of Arizona should consider adopting a general outreach program on DPR, especially during the initial years of DPR rule adoption and implementation of the first few DPR projects in Arizona. Guidance on a statewide approach for potable reuse communications and outreach is available in Millan et al. (2014).

- The State may need to engage in activities that impact public perception of potable reuse. To that end, the State should be prepared to communicate openly and candidly with the public about the safety and challenges associated with implementing DPR.
- The State can take the lead on setting appropriate terminology that can be used when discussing potable reuse to the public. Currently, efforts are being undertaken to develop consistent terminology for potable reuse within the water industry (Brown et al., 2016). The same is needed for the public (Tchobanoglous et al., 2015).

Findings on Public Acceptance and Outreach

- Utilities should develop a communication plan that documents an organized and robust outreach approach. The following are some important activities for an effective outreach program: (1) developing a strategic, transparent, and thorough program; (2) starting outreach early and continuing to engage the public throughout the lifetime of the project; (3) using proven techniques and tools to engage stakeholders; (4) providing useful, accurate information on potable reuse; (5) developing consistent messages; and (6) building relationships with community leaders.
- It is not the role of the State of Arizona to perform outreach for individual DPR projects or provide guidance to utilities on DPR outreach strategies; however, the State should develop a strategy for communicating to the public about DPR in general.

Recommendations for Public Acceptance and Outreach

- Utilities considering DPR should develop and launch public outreach programs within their service areas to address public concerns, build public confidence, and garner public acceptance of potable reuse. **(Guidance/Permitting)**

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CHAPTER 4: OTHER CONSIDERATIONS

- System Reliability
- Antibiotic Resistant Bacteria and Antibiotic Resistance Genes
- Research Advances

Implementing DPR that is protective of public health is feasible, and regulations for DPR can be developed. At the same time, the water industry has been engaged in research to address information that will support the implementation and operations of potable reuse facilities. With increasing experience and the continuation of applied research, additional information will be generated that may help to: (1) reduce the potential for overly conservative designs inherent in the early implementation of potable reuse; and (2) increase the knowledge base for facility operations. Three examples of areas that will benefit from experience and research are discussed in this chapter. They include system reliability, antibiotic resistance and antibiotic resistance genes, and research advances.

4.1 System Reliability

Current projects practicing IPR, either using groundwater recharge or surface water augmentation, all include an environmental buffer. The functions provided by the environmental buffer can be achieved by other means (e.g., the reliability of mechanical systems and treatment plant performance), thereby ensuring the delivery of a water quality that is protective of human health. To do this, DPR practices need to provide appropriate reliability and performance. These features can be considered in the design and implementation of projects.

The DPR system must be reliable. Reliability is achieved by: (1) providing multiple independent treatment barriers; (2) incorporating the frequent monitoring of surrogate parameters at each step to ensure treatment processes are performing properly; and (3) developing and implementing rigorous response protocols (such as CCPs). Other key attributes that promote reliability include:

- Using a treatment train with multiple, independent treatment barriers (i.e., redundancy) that meet performance criteria.

- Ensuring the independent treatment barriers represent a diverse set of processes (i.e., robustness) in the treatment train that are capable of removing particular types of contaminants by different mechanisms. This diversity better ensures that if a currently unrecognized chemical or microbial contaminant is identified in the future, there is a greater degree of likelihood it will be removed effectively by the treatment train.

- Using parallel independent treatment trains (i.e., resilience and redundancy) and providing sufficient replacement parts, along with trained personnel, to carry out the most frequently needed repairs.

4.2 Antibiotic Resistant Bacteria and Antibiotic Resistance Genes

The development of antibiotic resistance is a worldwide public health problem. The level of concern is evidenced by the issuance of global and national action plans for dealing with antibiotic resistance. Antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARG) are known to be in wastewater. The advanced water treatment processes used to produce ATW are expected to remove all detectable bacteria, including those that might be antibiotic resistant. A concern might be the efficacy of treatment to remove ARG. Areas of additional study include the following:

- Assemble and evaluate available data on the occurrence of ARB and ARG.
- Determine the effectiveness of wastewater and drinking water treatment processes for reducing and/or inactivating ARB and ARG.
- The determination of ARB and ARG concentrations in water can be helpful in assessing treatment process efficiencies to remove antibiotic resistance determinants.
- Identify significant data gaps and research needs (e.g., risks associated with ARB and ARG).

4.3 Research Advances

Although the pace of technological developments in the field of potable reuse in the past 10 years has been dramatic, experience and information related to ensuring the safety of the ATW or finished water is still needed. As a result, research will help inform the implementation and operation of DPR systems. Two examples of areas of research interest include the following:

- **Access to more real-time monitoring tools**. It is not practical to use the direct measurements of some contaminants to assess treatment processes and identify failure events when ATW is used for DPR. Indicators, surrogates, and treatment process parameters are used to estimate the removal of many pathogens and CECs. Some monitoring techniques require extensive time periods to obtain results. Research is needed to further develop indicators, surrogates, and other parameters that can reliably monitor ATW quality and individual treatment processes in real or near-real time.
- **Reviewing facility operation and performance data.** As more potable reuse projects come online, available information covering topics such as treatment plant design, process performance, operation practices, and mechanical reliability should be compiled in a consistent format and made accessible. Then such data can be used to assess current practices, as well as inform new designs.

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