IMPLEMENTATION OF DIRECT POTABLE REUSE

A GUIDE FOR CALIFORNIA WATER UTILITIES

FINAL | MARCH 2021

VENTURA WATER

Valley Water

LA DWP Los Angeles Department of Water & Power

San Francisco Water Power Sewer

SEAL OF THE CITY OF SANTA BARBARA CALIFORNIA

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Preface

This document represents the collective effort of the National Water Research Institute (NWRI), contributing authors, the Los Angeles Department of Water and Power (LADWP), the San Francisco Public Utilities Commission (SFPUC), the City of Santa Barbara, Valley Water, and Ventura Water. This document aims to fill an existing information gap in how to plan and implement direct potable reuse (DPR) in California. For perspective, potential DPR options for the five contributing utilities are presented in the following table and described in more detail in an appendix to this guide. These types of projects are explored throughout this document.

Utility Leadership Team Project Goals

TEAM MEMBER	PRODUCTION GOALS	PROJECT TIMELINE	NOTES
Los Angeles Department of Water and Power	>200 mgd	By 2035	LADWP is considering how best to reuse 100 percent of the effluent generated from four of the City of Los Angeles' water reclamation plants. Success with this effort requires a combination of potable reuse projects using groundwater recharge, raw water augmentation, and treated drinking water augmentation.
San Francisco Public Utilities Commission	To be determined	To be determined	SFPUC is examining a range of regional and local potable reuse projects that may utilize groundwater recharge and/or reservoir water augmentation. SFPUC is also examining the potential for treated drinking water augmentation projects.
City of Santa Barbara	Up to 6.4 mgd	To be determined	Santa Barbara, depending on surface water supply challenges they face, may implement a reservoir water augmentation project. However, noting that their reservoir is small and will not meet the requirements for reservoir water augmentation, the project would be a raw water augmentation potable reuse project.
Valley Water	~21.4 mgd (24,000 AFY)	2028	As part of their county-wide water reuse master plan, Valley Water is evaluating a range of potable reuse projects, which include groundwater recharge, raw water augmentation, and treated drinking water augmentation. Finalization of the master plan in 2020 will help identify the optimum potable reuse projects for the agency.
Ventura Water	~4 mgd (Phase 1a) with expansion to ~6 mgd (Phase 1b)	2025 (Phase 1a) 2030 (Phase 1b)	Ventura Water's Phase 1a is a conventional groundwater recharge potable reuse project. Phase 1b expands the project's capacity and, provided regulations are ready, upgrades it to a treated drinking water augmentation project.

Introduction

NWRI, in collaboration with Carollo Engineers, Inc. (Carollo), developed this Guide for California Water Utilities (Guide) to assist agencies and their facilities in implementing DPR projects in and across the State of California. NWRI sponsored this project along with five utilities operating in California—Ventura Water, LADWP, SFPUC, City of Santa Barbara, and Valley Water—who are interested in DPR as a water supply alternative.

This Guide was developed using existing federal and state resources on potable reuse including DPR, experience gathered through current indirect potable reuse (IPR) projects, and the results of published and ongoing research including studies sponsored by industry foundations such as the Water Research Foundation (WRF). These pages provide best practices and recommendations on the technical, operational, managerial, and regulatory issues that pertain to the implementation of potable reuse projects with a particular focus on DPR but also with useful information on IPR.

USING THIS GUIDE

This Guide can be used by utilities, consulting engineers, and regulators to support potable reuse efforts:

- **Utilities.** Implementing potable reuse is a challenging effort whose various components require substantial time and resources to plan and implement. This document summarizes the necessary components for a successful project, which utility staff can use to cross-check their own efforts for potable reuse and develop tailored implementation plans and schedules.
- **Consultants.** This Guide provides various reference materials for many key challenges associated with potable reuse's implementation as well as important context as to why each item is either useful or necessary.
- **Regulators.** IPR projects have a long record of success in California and, as such, IPR regulations are in place for groundwater recharge and reservoir water augmentation; however, regulations for DPR in California have not been developed. This Guide summarizes the many diverse aspects of a successful potable reuse project and bolsters regulators with a reference document that can be used to support the development of DPR regulations and permitting of DPR projects.

This Guide can be used from the early stages of a project's development all the way to the permitting and startup of a potable reuse facility. Efforts on individual items must be tracked by utilities as progress is made.

PROJECT TEAM

This Guide was developed by a group of utility leaders and technical specialists under the direction of NWRI, as follows:

NWRI TEAM

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UTILITY LEADERSHIP TEAM

- Ventura Water
- Los Angeles Department of Water and Power
- San Francisco Public Utilities Commission
- City of Santa Barbara
- Valley Water

ACKNOWLEDGMENTS

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13 KEY COMPONENTS TO IMPLEMENT POTABLE REUSE PROJECTS

1. Project Definition
2. Technical, Managerial, and Financial Capability
3. Interagency Agreements
4. Outreach and Education
5. Wastewater Source Control
6. Wastewater Treatment
7. Multiple Treatment Barriers
8. Pathogen Control and Monitoring
9. Chemical Control and Monitoring
10. Operations
11. Water Quality Management
12. Emerging Issues
13. Collaboration to Spur Innovation

DPR PLANNING CASE STUDIES
Potential DPR projects that are being evaluated by utilities in California can be found at the end of this Guide.

Overview

Different types of potable reuse projects are being executed and considered for implementation internationally, nationally, and within the State of California. These projects include groundwater recharge and reservoir water augmentation, which are typically thought of as forms of IPR, and raw water and treated drinking water augmentation, which are forms of DPR. Certain hybrid projects have a mixture of characteristics, such as a groundwater recharge project that has a short time (<2 months) underground before extraction.

In California, regulations for groundwater recharge and reservoir water augmentation are clearly described within Title 22's Water Recycling Criteria (Title 22). However, much uncertainty remains on how the State will implement DPR with only a "framework" in place (SWRCB, 2019b) and a legislative requirement for regulations to be established by the end of 2023. In the absence of regulations, this Guide delivers both broad-level and focused guidance for potable reuse projects that do not qualify as groundwater recharge or reservoir water augmentation.

With a focus on raw and treated drinking water augmentation projects, this Guide's multi-topic approach first summarizes definitions, relevant publications, and existing regulations for potable reuse in California, followed by 13 key components that comprise the broad-level effort required to implement potable reuse projects that protect public health. Engineers, decision-makers, and regulators may use this Guide to develop and track the progress of potable reuse projects.

Potable reuse projects represent some of the most complex and, in some cases, challenging water supply projects in our industry. These endeavors require engineering rigor, intense regulatory oversight, and public scrutiny. The development of a potable reuse program, including its planning, pilot testing, permitting, design, construction, and operation, must be a deliberate, measured process that takes planning and time.
The full implementation of a potable reuse program has been shown to take from 5 years to more than 10 years.

Definitions

Terminology related to potable reuse has evolved from initial classifications of IPR and DPR defined in the report Framework for Direct Potable Reuse (NWRI, 2015) to more specific definitions established by California Assembly Bill 574 (2017). In addition to establishing regulations, this legislation required the State Water Resources Control Board (SWRCB) to develop a framework for regulating DPR that encourages the development of potable reuse but also mitigates the impact of long-term drought and climate change.

The term "potable reuse" covers all types of projects through which recycled wastewater is incorporated into drinking water supplies in a way that is protective of public health. In this Guide, "potable reuse" refers to the practice of using purified water derived from raw wastewater or a wastewater treatment plant's (WWTP) effluent to supplement drinking water supplies.

The following definitions were compiled from the Framework for Direct Potable Reuse (SWRCB 2019b) and language from Assembly Bill 574, to reflect recent changes in terminology:

The Environmental Buffer

Groundwater recharge and reservoir water augmentation have the benefit of an environmental buffer, which may either be a groundwater basin or a surface water reservoir. These buffers offer a measure of dilution and, in some cases, treatment. Most importantly, they provide response retention time (RRT), which is the time used to monitor water quality and respond to identified concerns. As our industry develops raw water augmentation and treated drinking water augmentation projects, we must understand and replace the value of these environmental buffers prudently.

Recycled water is water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource (Water Code §13050(n)).

Purified water is highly treated recycled water that has been treated at a WWTP and an advanced water treatment facility (AWTF), and has been verified through monitoring to be suitable for augmenting drinking water supplies.

Potable reuse includes raw water augmentation, treated drinking water augmentation, groundwater recharge, and reservoir water augmentation.

Groundwater recharge is the use of recycled water to replenish a groundwater basin or an aquifer that has been designated as a source of domestic drinking water supply for a public water system.

Reservoir wateraugmentation is the placement of recycled water into a raw surface water reservoir used as a source of domestic drinking water supply for a public water system or into a constructed system that conveys water to such a reservoir.

Indirect potable reuse (IPR) is the introduction of advanced treated water into an environmental buffer such as a groundwater aquifer or surface water body before it is withdrawn for potable purposes.

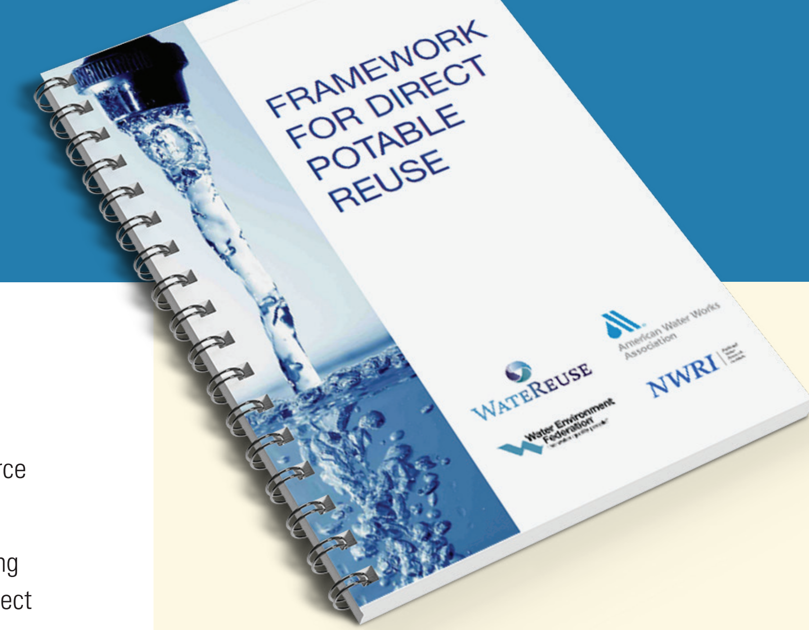
Direct potable reuse (DPR) is the planned introduction of recycled water either directly into a public water system or a raw water supply immediately upstream of a water treatment plant (WTP).

Raw water augmentation is the planned placement of recycled water into a system of pipelines or aqueducts that deliver raw water to a drinking WTP that provides water to a public water system. A reservoir water augmentation project that does not meet the regulatory criteria for RRT or dilution may be classified as a raw water augmentation project.

Treated drinking water augmentation is the planned placement of recycled water directly into a finished water distribution system of a public water system. A groundwater recharge project that does not meet the regulatory criteria for RRT may be classified as a treated drinking water augmentation project.

Acronyms

AOP	advanced oxidation process
AWT	advanced water treatment
AWTF	advanced water treatment facility
AWTO	advanced water treatment operator
AWWA	American Water Works Association
BAF	biologically active carbon filtration
CBAT	carbon based advanced treatment
CCP	Critical Control Point
CECs	constituents of emerging concern
CT	concentration multiplied by contact time
CWEA	California Water Environment Association
DBP	disinfection byproduct
DDW	Division of Drinking Water
DPR	direct potable reuse
EC	electrical conductivity
ESCP	enhanced source control program
FPA	flavor profile analysis
GAC	granular activated carbon
GWRS	Groundwater Replenishment System
HACCP	Hazard Analysis Critical Control Point
IPR	indirect potable reuse
LRV	log reduction value
MCL	maximum contaminant level
MF	microfiltration
mg/L	milligrams per liter
MPN/L	most probable number per liter
MTL	monitoring trigger level
NDEA	N-nitrosodiethylamine
NDMA	N-nitrosodimethylamine
NDPA	N-nitrosodi-n-proplylamine
ng/L	nanogram per liter
NL	notification level
NMOR	N-nitrosomorpholine
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NTA	non-target analysis
NTU	Nephelometric Turbidity Units
NWRI	National Water Research Institute
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
OOP	operations optimization plan
PFAS	per- and polyfluoroalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
POTW	publicly owned treatment works
QMRA	quantitative microbial risk assessment
qPCR	quantitative polymerase chain reaction
RO	reverse osmosis
RRT	response retention time
RWQCB	Regional Water Quality Control Board
SAT	soil aquifer treatment
SCADA	supervisory control and data acquisition
SCCWRP	Southern California Coastal Water Research Project
SDWA	Safe Drinking Water Act
SM	Standard Methods
SWMOA	Southwest Membrane Operators Assocation
SWRCB	State Water Resources Control Board
T&O	taste and odor
TMF	technical, managerial, and financial
TOC	total organic carbon
TWDB	Texas Water Development Board
μm	micrometer, micron
UF	ultrafiltration
UV	ultraviolet light
WRF	Water Research Foundation
WTP	water treatment plant
WWTP	wastewater treatment plant



Existing Guidance

Extensive work has been completed at national and state levels to define the challenges associated with implementing DPR in the United States and develop effective solutions. Many of these efforts have been completed by panels of experts and include the following:

- Framework for Direct Potable Reuse (NWRI, 2015).
- Direct Potable Reuse Resource Document (TWDB, 2015).
- Development of DPR Regulations in Colorado (WateReuse Colorado, 2018a).
- Communications and Outreach Plan for DPR in Colorado (WateReuse Colorado, 2018b).
- Guidance Framework for Direct Potable Reuse in Arizona (NWRI, 2018).
- Recommended DPR General Guidelines and Operational Requirements for New Mexico (NWRI, 2016).
- Model Communications Plans for Increasing Awareness and Fostering Acceptance of Direct Potable Reuse (Millan, et al., 2015).
- Advancing Potable Reuse in Florida: A Regulatory Framework (Florida Potable Reuse Commission, 2020).

In California, the following important resource documents pertain to IPR and DPR:

- Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse (SWRCB, 2016).
- Title 22 Water Recycling Criteria related to IPR [Title 22 of the California Code of Regulations (Title 22)].
- Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water (SCCWRP, 2018).
- Policy for Water Quality Control for Recycled Water (SWRCB, 2019a).
- A Proposed Framework for Regulating Direct Potable Reuse in California, Second Edition (SWRCB, 2019b).

These documents provide important information on all aspects of potable reuse, relevant to both IPR and DPR. However, these documents tend to offer an ***overabundance of technical information***, meaning they contain too much information to reasonably assimilate into a project. To resolve this challenge, this Guide presents a practical framework for the consistent implementation of a range of DPR applications in California while also providing valuable information for IPR projects. In particular, this document provides guidance on public health protection (e.g., pathogen and chemical control) for potable reuse projects.

SWRCB has determined that "it is feasible to develop uniform criteria for DPR that adequately protects public health". They also identified six areas of research that will inform those developing regulations and influence how DPR is implemented in California.

Managed by WRF, the first five research projects are as follows:

1. Tools to quantify microbial risk and evaluate plant performance/reliability.
2. Determination of standard methodology to measure pathogens in wastewater.
3. Collecting pathogens in wastewater during outbreaks.
4. Defining potential chemical peaks and management options.
5. Evaluating analytical methods for detecting unknown chemicals in recycled water.

Additional information on these five research projects can be found online at https://www.waterrf.org/california-state-water-board-grant.

6. The sixth project, Enhanced Source Control, was managed by NWRI and DDW staff (Olivieri, Crook, and Trussel, 2020).

Existing Regulations for Potable Reuse in California

Important points of reference for any type of potable reuse project are the core regulatory requirements assigned to groundwater recharge and reservoir water augmentation by the State of California.

GROUNDWATER RECHARGE REGULATIONS

In 2014, SWRCB's Division of Drinking Water (DDW) finalized regulations for groundwater recharge—also referred to as groundwater replenishment—projects in Title 22. Two types of groundwater recharge projects exist:

- **Surface application projects.** Often referred to as spreading projects, these efforts require lower levels of engineered treatment, higher levels of blending with other water supplies, the use of soil aquifer treatment (SAT), and more than two months of travel time. This Guide does not cover surface application projects.
- **Subsurface injection projects.** These efforts require full advanced treatment which Title 22 defines as the use of reverse osmosis (RO) and an advanced oxidation process (AOP) that achieves at least 0.5-log reduction of 1,4-dioxane or equivalent treatment. Additionally, a minimum of two months of subsurface travel time, during which RRT is provided, is required before water can be extracted for potable use.

Regulations allow for the use of alternatives to any of these requirements, provided that the project sponsor demonstrates at least the same level of public health protection. Figure 1 presents a schematic of a groundwater recharge project with subsurface application while Table 1 summarizes the general requirements for groundwater recharge.

Figure 1. Groundwater Recharge Project Schematic Process Flow Diagram

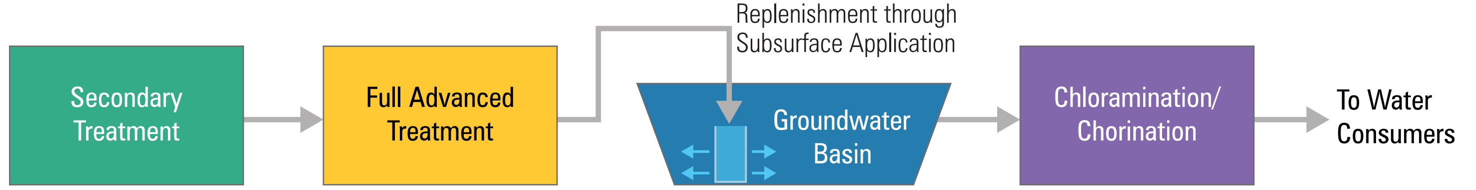


Table 1. Title 22 Groundwater Recharge via Subsurface Application (Injection) Requirements for Potable Reuse

PARAMETER	CRITERIA[3]
Enteric Viruses	12-log Reduction[1]
Giardia Cysts	10-log Reduction[1]
Cryptosporidium oocysts	10-log Reduction[1]
Total Organic Carbon (TOC)	• Maximum 0.25 mg/L in 95% of samples within first 20 weeks • Maximum 0.5 mg/L in 20-week running average
Full Advanced Treatment	RO and an AOP that achieves 0.5-log reduction of 1,4-dioxane
Total Nitrogen	10 mg/L as N
Inorganic Chemicals in Table 64431-A	≤ Maximum contaminant levels (MCLs)
Radionuclide Chemicals in Tables 64442 and 64443	≤ MCLs
Organic Chemicals in 64444-A	≤ MCLs
Disinfection Byproducts in Table 64533-A	≤ MCLs
Lead and Copper	≤ Action Levels
Priority Toxic Pollutants in 40 CFR Section 131.38	≤ WQOs
DDW-specified chemicals with Notification Levels (NLs)	≤NLs[2]
Other DDW-specified chemicals	Not Applicable
Basin Plan Water Quality Objectives (WQOs)	≤WQOs
Minimum Subsurface RRT	2 months
Recycled Water Policy Parameters[4]	
Health	Monitoring Trigger Levels (MTLs)
Performance	None
Surrogate	None
Bioanalytical Screnning Tools	None

NOTES:

1. Log reductions are calculated from the point of raw wastewater to the point of finished water for public consumption.
2. Notable chemicals that currently have NLs include NDMA (10 ng/L), PFOA (5.1 ng/L) and PFOS (6.5 ng/L).
3. Regulations allow for the use of alternatives to a requirement, provided that the project sponsor demonstrates at least the same level of public health protection.
4. In addition to the monitoring requirements found in Title 22, SWRCB revises its CEC monitoring requirements every five years as part of its Recycled Water Policy update (SWRCB 2019a). Refer to Section 9 for more details.

RESERVOIR WATER AUGMENTATION REGULATIONS

In 2018, DDW adopted reservoir water augmentation regulations. Reservoir water augmentation projects use a reservoir as an environmental buffer between the AWPF and the WTP. The advanced treated water augments the reservoir that contains water from other sources. Figure 2 shows a process flow diagram for reservoir water augmentation while Table 2 summarizes key requirements for reservoir water augmentation projects.

Unlike groundwater recharge projects, reservoir water augmentation projects do not have the benefit of receiving log-removal credit from the retention time underground. However, they can use treatment credits from the WTP downstream of the reservoir. Promulgated by the United States Environmental Protection Agency (USEPA) (USEPA 1989), the Surface Water Treatment Rule requires the WTP to provide treatment to remove 4-log virus, 3-log *Giardia*, and 2-log *Cryptosporidium*. Adding the minimum pathogen log reduction requirements (i.e., 8-log virus, 7-log *Giardia*, and 8-log *Cryptosporidium*) required by DDW for the AWPF to those required for a conventional surface WTP (i.e., 4-log virus, 3-log *Giardia*, and 2-log *Cryptosporidium*) yields the same total required by groundwater recharge regulations: 12-log virus, 10-log *Giardia*, and 10-log *Cryptosporidium*.

Reservoir water augmentation projects are also subject to a minimum theoretical retention time in the reservoir of 6 months and a 24-hour average dilution ratio of 1:100 advanced treated water to surface water. Requirements for retention time and dilution ratio can be eased with additional pathogen treatment barriers, as described in Table 3.

As with the groundwater recharge regulations, purified water for reservoir water augmentation must meet all current drinking water regulatory standards. Full advanced treatment systems typically produce product water that is well below any current regulatory limits; however, the Regional Water Quality Control Board (RWQCB) may require more stringent limits for environmental reasons or to meet basin plan requirements, such as those for nutrients.

Figure 2. Reservoir Water Augmentation Project Schematic Process Flow Diagram

Table 2. Title 22 Reservoir Water Augmentation Requirements for Potable Reuse

PARAMETER	CRITERIA[2]
Pathogens	Refer to Table 3
Full Advanced Treatment	RO and an AOP that achieves 0.5-log reduction of 1,4-dioxane
Inorganic Chemicals in Table 64431-A	≤ MCLs
Radionuclide Chemicals in Tables 64442 and 64443	≤ MCLs
Organic Chemicals in 64444-A	≤ MCLs
Disinfection Byproducts in Table 64533-A	≤ MCLs
Lead and Copper	≤ Action Levels
Priority Toxic Pollutants in 40 CFR Section 131.38	≤ WQOs
DDW-specified chemicals with Notification Levels (NLs)	≤ NLs[1]
Other DDW-specified chemicals	Not Applicable
Basin Plan Water Quality Objectives (WQOs)	≤ WQOs
Minimum Dilution of any 24-hour input of Recycled Water	• 100:1 with no additional pathogen log reduction • 10:1 with 1-log additional pathogen reduction
Minimum theoretical retention time in the reservoir	• 6 months with no additional pathogen log reduction • 2 to 6 months requires written approval from DDW • 2 to 4 months with 1-log additional pathogen reduction
Recycled Water Policy Parameters[3] Health Performance Surrogate Bioanalytical Screnning Tools	 Monitoring Trigger Levels (MTLs) None None None

Table 3. Summary of Treatment, Dilution, and Theoretical Retention Time Criteria for Reservoir Water Augmentation

DILUTION RATIO	RESERVOIR RETENTION TIME: VOLUME / FLOW (DAYS)	LOG REDUCTION REQUIRED (Virus/*Giardia*/*Cryptosporidium*)	
		THROUGH BOTH WWTP/AWTF	TOTAL
100:1	≥ 180	8/7/8	12/10/10
	< 180 – 120[1]		
	< 120 – 60[1]	≥ 9/8/9	≥ 13/11/11
10:1	≥ 180	9/8/9	13/11/11
	< 180 – 120[1]	9/8/9	13/11/11
	< 120 – 60[1]	≥ 10/9/10	≥ 14/12/12

1. If reservoir retention time is less than 180 days, SWRCB approval is required.

NOTES:

1. Notable chemicals include NDMA (10 ng/L), PFOA (5.1 ng/L) and PFOS (6.5 ng/L).
2. Regulations allow for the use of alternatives to a requirement, provided that the project sponsor demonstrates at least the same level of public health protection.
3. In addition to the monitoring requirements found in Title 22, SWRCB revises its CEC monitoring requirements every five years as part of its Recycled Water Policy update (SWRCB 2019a). Refer to Section 9 for more details.

1 Project Definition

With key definitions and regulations in mind, the first step to developing a potable reuse program is to understand the constraints and benefits that accompany your project.

Several categories of projects can be considered a DPR project.

Questions to consider when defining a DPR project:

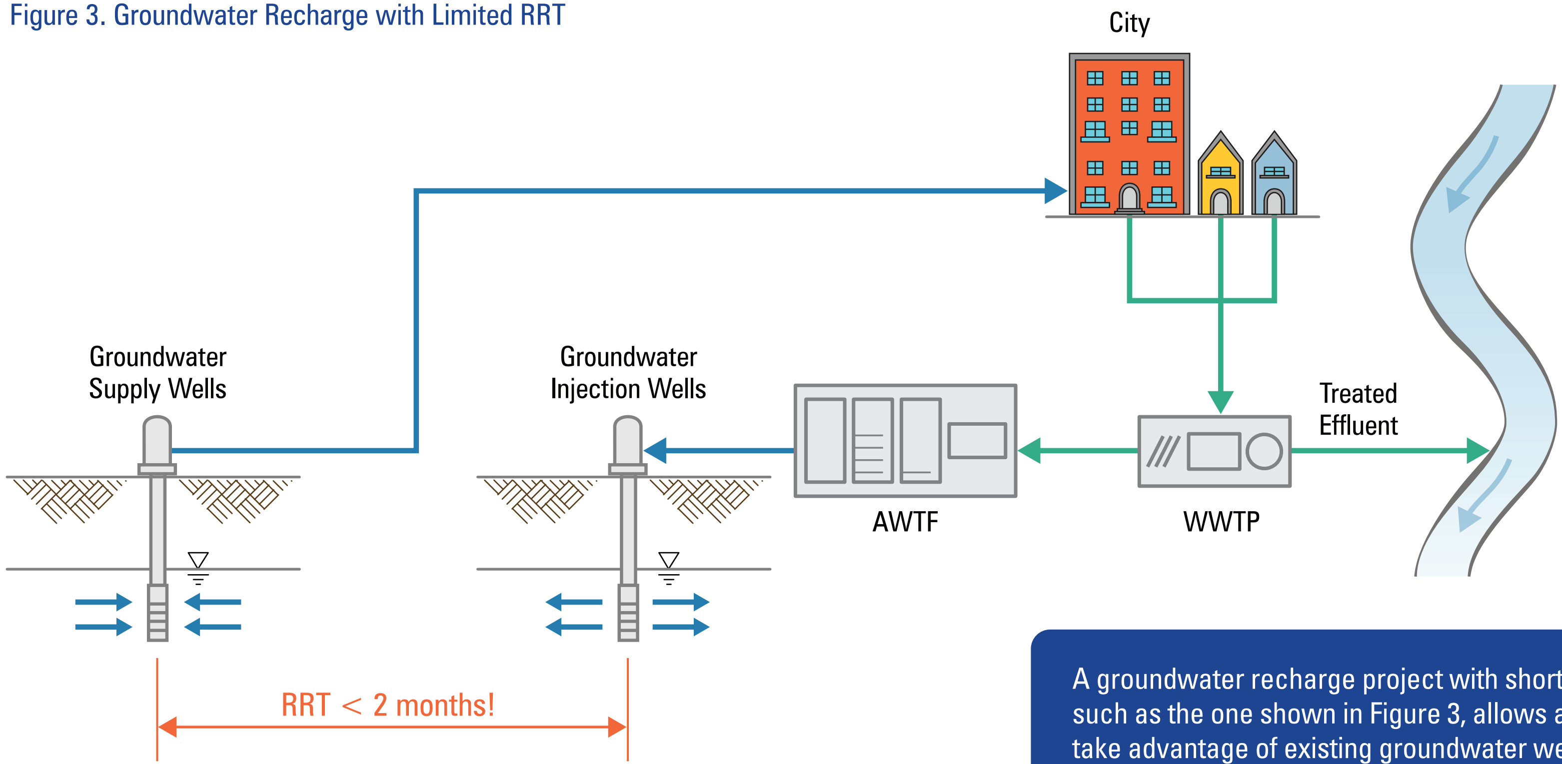
- Is there any type of environmental buffer?
- Is there a groundwater buffer with limited storage time (i.e. RRT)?
- Is there limited dilution in the surface water reservoir?

The following pages explore four example DPR projects:

1. A groundwater recharge project with limited RRT
2. A reservoir water augmentation project with limited dilution
3. A raw water augmentation project
4. A treated drinking water augmentation project

Regulatory concerns and potential mitigation measures associated with each type of project are also discussed.

Figure 3. Groundwater Recharge with Limited RRT

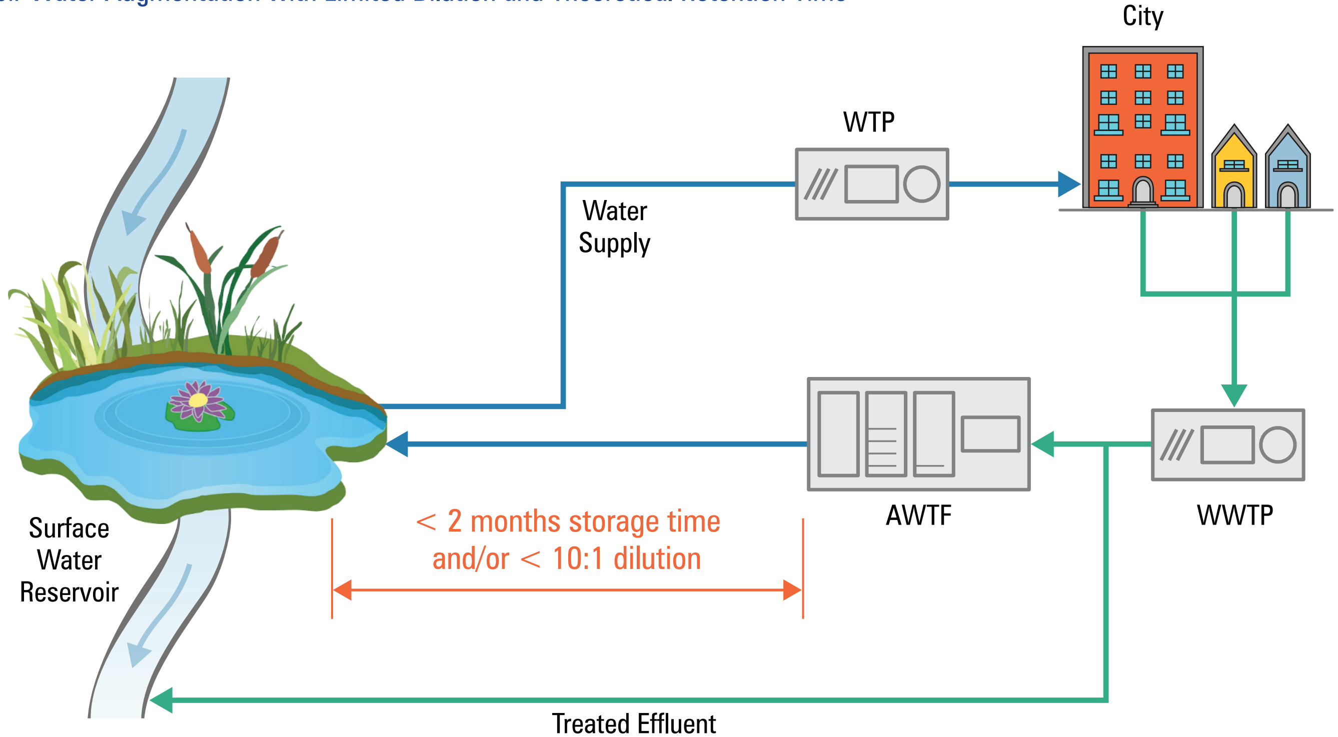


A groundwater recharge project with short RRT, such as the one shown in Figure 3, allows a utility to take advantage of existing groundwater wells and infrastructure even if it does not meet the requirements for an IPR groundwater recharge project.

Table 4. Regulatory Concerns and Potential Mitigation Strategies for Groundwater Recharge with Limited RRT

REGULATORY CONCERN	MITIGATION	EXAMPLES
Short RRT results in less virus reduction.	Add additional virus reduction barriers for redundancy.	Use free chlorination as part of ultraviolet (UV) AOP and carry a residual to gain virus credits.
Short RRT results in insufficient time to detect and respond to chemical breakthrough.	• Provide for additional online monitoring of chemicals. • Add additional treatment barriers for chemicals.	• Add online monitoring for TOC coupled with engineered storage and diversion. • Add ozone and biologically active carbon filtration (BAF) to address a broad range of chemicals. • Install real-time monitors in the wastewater collection system, focused on the detection of contamination events that could affect the purified water quality.

Figure 4. Reservoir Water Augmentation with Limited Dilution and Theoretical Retention Time

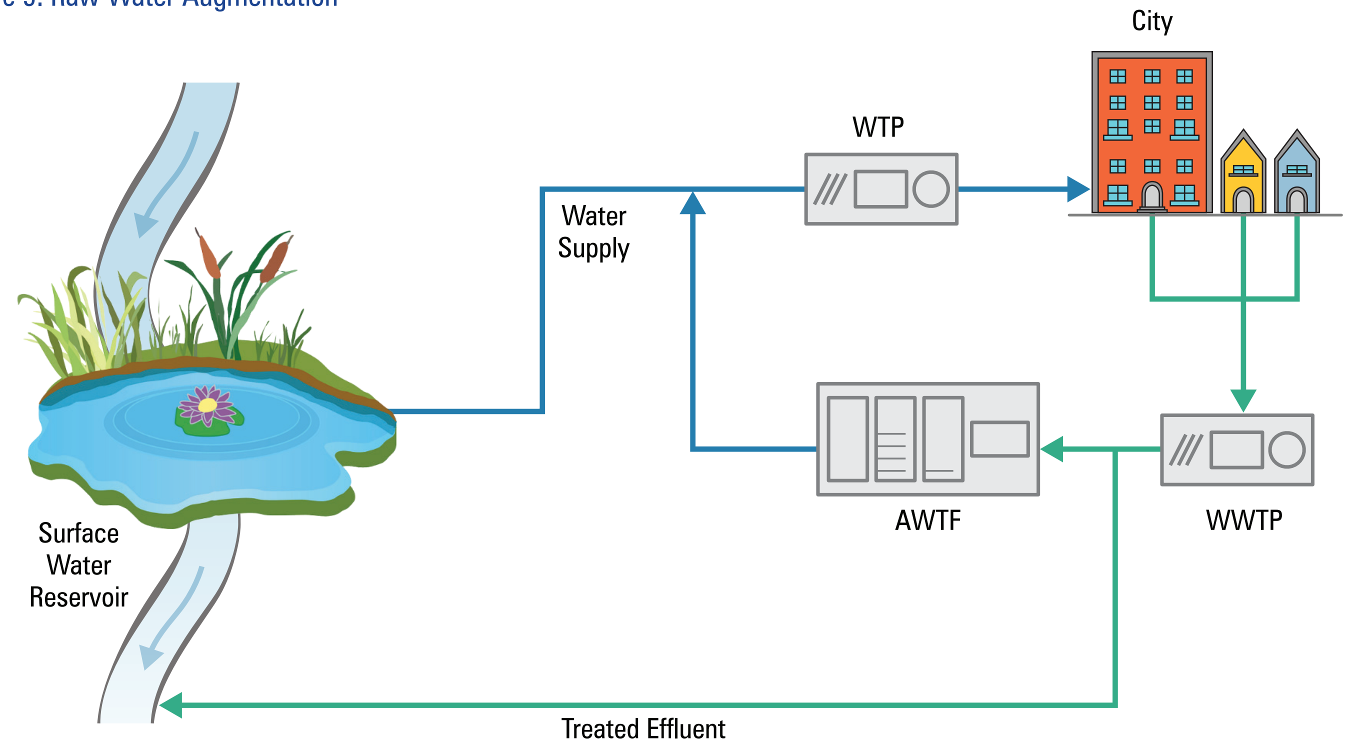


A reservoir water augmentation project with a short theoretical retention time, such as the one shown in Figure 4, allows a utility to take advantage of surface water resources and infrastructure even if it does not meet the requirements for a reservoir water augmentation project.

Table 5. Water Quality Concerns for Reservoir Water Augmentation with Limited Dilution and RRT

REGULATORY CONCERN	MITIGATION	EXAMPLES
• Short theoretical retention time and/or reduced dilution raises concerns regarding time to respond to chemicals. • Reduced dilution results in less opportunity to reduce chemicals in the purified water source.	• Provide for additional online monitoring of chemicals. • Add additional treatment barrier for chemicals.	• Add online monitoring for TOC coupled with engineered storage and diversion. • Add ozone and BAF to address a broad range of chemicals. • Consider installing real-time monitors in the wastewater collection system focused on the detection of contamination events that could affect the purified water quality.
Reduced time in the reservoir means less time for natural treatment, such as sunlight for oxidation and disinfection, or biodegradation and sorption of chemicals to sediment.	• Add additional treatment barrier for chemicals. • For pathogens, add redundancy of treatment barriers, and additional online monitoring and feedback to operators.	• Add ozone and BAF to address a broad range of chemicals. • Use risk-analysis tools, such as QMRA, to define the need for additional virus and/or protozoa treatment and then implement those barriers.

Figure 5. Raw Water Augmentation



A raw water augmentation project directs advanced treated water to the raw water supply just upstream of a WTP, as depicted in Figure 5. This configuration can be favorable for utilities that would like to make use of existing WTPs but lack a large raw water supply reservoir.

Table 6. Regulatory Concerns and Potential Mitigation Strategies for Raw Water Augmentation

REGULATORY CONCERN	MITIGATION	EXAMPLES
Without RRT from an environmental buffer, the existing water supply is at risk if the water is non-compliant.	Implement advanced online monitoring coupled with engineered storage and diversion.	• Add online monitoring of all key processes for chemical and pathogen removal, closely linked with a critical control point (CCP) system. • Add an engineered storage buffer designed to capture off-spec flow prior to release for potable supply. Divert off-spec water automatically if a risk to the water supply is detected.
Complete loss of the chemical and pathogen removal value derived from the environmental buffer.	• Install additional treatment systems for both chemical and pathogen control. • Install additional online monitoring.	• Add ozone with BAF for improved chemical control. • Use risk-analysis tools, such as QMRA, to define the need for additional virus and/or protozoa treatment and then implement those barriers.

A treated drinking water augmentation project adds purified water to the drinking water distribution system, downstream of the treatment processes for other water supplies, as shown in Figure 6. This configuration allows utilities to maintain capacity in existing WTPs for their other water supplies, and to tailor advanced processes in the AWTF for recycled water.

Figure 6. Treated Drinking Water Augmentation

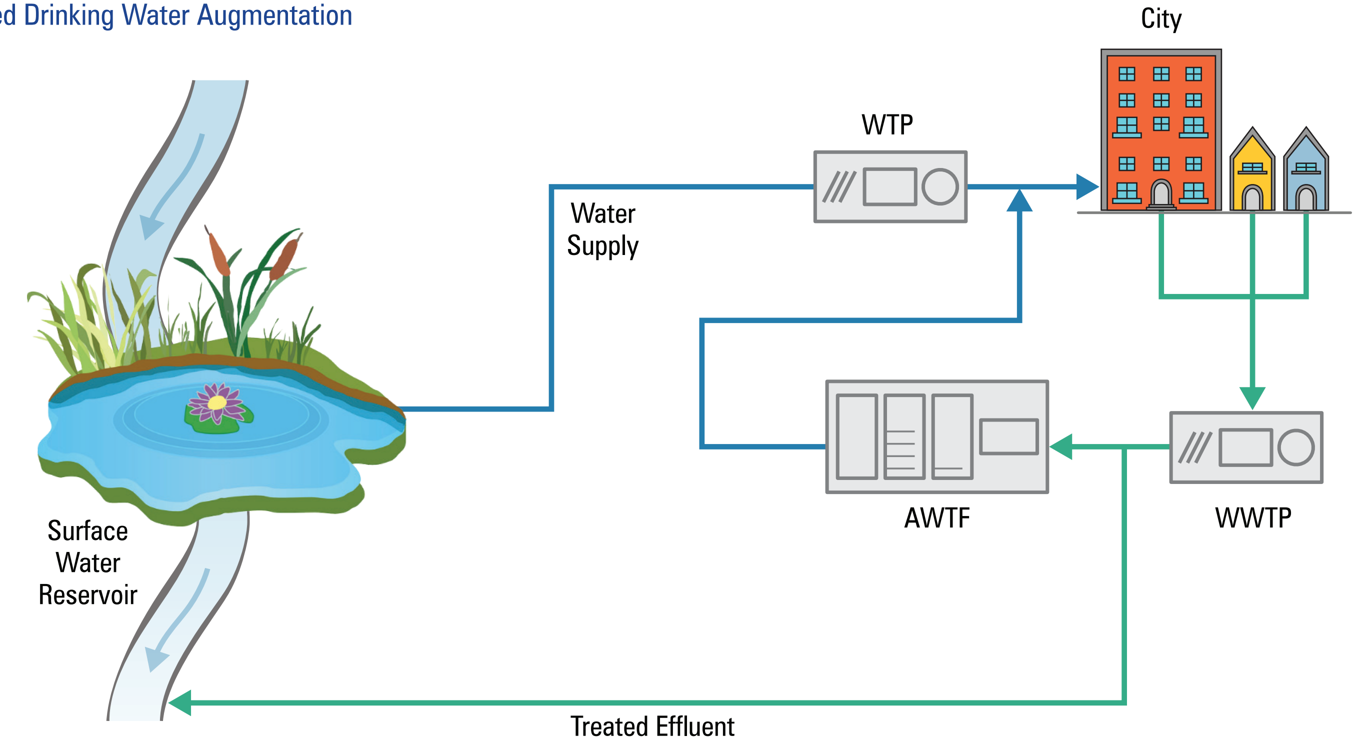


Table 7. Regulatory Concerns and Potential Mitigation Strategies for Treated Drinking Water Augmentation

REGULATORY CONCERN	MITIGATION	EXAMPLES
Without RRT from an environmental buffer, the existing water supply is at risk if the water is non-compliant.	Implement advanced online monitoring coupled with engineered storage and diversion.	• Add online monitoring of all key processes for chemical and pathogen removal, closely linked with a CCP system. • Add an engineered storage buffer designed to capture 30 minutes (or more) of flow prior to release for potable supply. Divert off-spec water automatically if a risk to the water supply is detected.
Complete loss of the chemical and pathogen removal value derived from an environmental buffer.	Install additional treatment systems for both chemical and pathogen control at AWTF.	• Add ozone with BAF for improved chemical control. • Use risk analysis tools, such as QMRA, to define the need for additional virus and/or protozoa treatment and then implement those barriers.
Loss of additional treatment barriers within the WTP.	Replace the value of WTP processes by using equivalent or additional process barriers within the DPR facility.	Define the value of the WTP (e.g., conventional filtration and chlorine disinfection) and replace those treatment barriers, as needed, with similar value barriers within the AWTF.

2 Technical, Managerial, and Financial Capability

Utilities must demonstrate an appropriate level of technical, managerial, and financial (TMF) capability to ensure their compliance with regulations and to successfully implement and manage a DPR project [NWRI (2016), SWRCB (2019b)].

As a part of this process, utilities must identify specific needs and capacity gaps and, in doing so, complete the following:

- Build, operate, manage, and sustain a potable reuse program 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.

Safe Drinking Water Act (SDWA) Provision on TMF Capacity for Drinking Water Systems

The concept of demonstrating TMF capabilities for potable reuse projects is based, in part, on a provision of the 1996 SDWA Amendments that address TMF capacity for public water systems. TMF capacity helps ensure that drinking water systems, especially small ones, are able to maintain compliance with regulations and have the long-term organizational sustainability to provide to their customers with water that is protective of public health. This provision is implemented by the USEPA through state primacy agencies.

Current California Title 22 Regulations Related to TMF Capability

Regulations for groundwater recharge and reservoir water augmentation include provisions related to utilities demonstrating TMF capabilities. Specifically, the following provisions are included in Title 22 and relate to IPR projects:

- Prior to operating a groundwater recharge project, utilities must demonstrate that they "possess adequate managerial and technical capability to assure compliance" §60320.124 (f).
- Prior to designing and operating a reservoir water augmentation project, utilities must demonstrate that they possess "adequate financial, managerial, and technical capability to assure compliance…" §60320.301 (b).

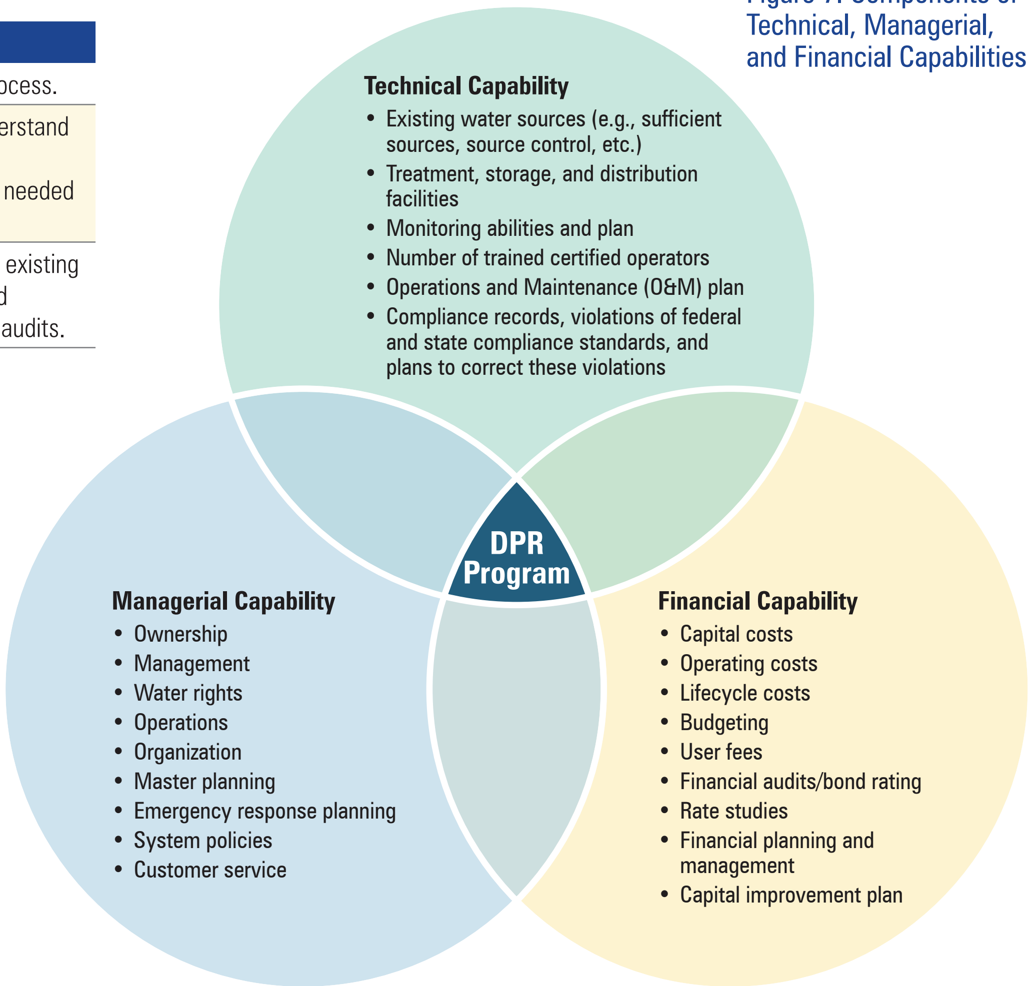
Table 8 provides definitions for technical, managerial, and financial capability, and Figure 7 lists the components of each capability.

Table 8. TMF Definitions

CAPABILITY	DESCRIPTION
Technical	Addresses the performance and operation of the treatment process.
Managerial	Addresses governance. For instance, administrators must understand the responsibilities of overseeing the AWTF; employees and contractors must understand their roles; and adequate time is needed to conduct all required tasks.
Financial	Addresses the utility's financial ability to operate and maintain existing infrastructure and financial planning for future needs. Assessed through budget statements, asset management, and financial audits.

Source: Adapted from NWRI, 2016.

Figure 7. Components of Technical, Managerial, and Financial Capabilities



Source: Adapted from NWRI, 2016.

3 Interagency Agreements

Potable reuse projects require strong interagency cooperation and responsiveness when different agencies operate the WWTP, AWTF, and/or drinking water treatment facility.

An interagency agreement or memorandum of understanding between agencies is critical for institutional, planning, management, regulatory, and technical collaboration as well as cost-sharing. These agreements define the roles and responsibilities of multiple utilities, agencies, and/or jurisdictions and describe the methods they must use to collaboratively plan and implement the potable reuse project.

In general, these agreements can include the following areas:

- Institutional
  - Separate or different jurisdictions.
  - Cost sharing.
  - Responsibility for risk and liability.
  - Capital improvement programs.
  - Project messaging.
- Integrated Planning
  - Management responsibilities for water resources.
  - Cooperative planning and feasibility studies.
- Technical and Operational
  - Quantity and quality of the source.
  - Operational responsibilities and requirements.
  - Response to system failure and/or interruption.
  - Meeting regulatory requirements.

FORMING A FOUNDATION FOR SUCCESS

Potable reuse projects are complex and can result in public challenges, including no-growth concerns, rate impacts, and uncertainty or outright alarm surrounding the concept of potable reuse. All of these concerns present political challenges, especially for projects with multiple agencies and jurisdictions. A robust project must be built on top of the foundational commitment of all participating agencies.

The following specific topics related to potable reuse can be addressed through interagency cooperation:

- Water rights associated with wastewater effluent.
- Appropriate WWTP effluent water quality and quantity.
- An enhanced source control program and pretreatment to manage constituents in wastewater collection systems.
- Development of response plans between the entities operating the WWTP, AWTF, and the drinking water treatment facility to ensure effective planning, communication, and collaboration on technical, engineering, operational, and management topics.
- Assignment of funding for capital and operational expenses.
- Cooperation on addressing regulatory questions.
- Submission of joint grant proposals for project funding.
- Cooperation on public outreach and engagement efforts.

INTERAGENCY COLLABORATION EXAMPLE: SOURCE CONTROL

The success of a source control program depends on strong interagency cooperation and responsiveness between the WWTP and AWTF. For potable reuse projects that receive industrial waste from outside assigned service areas, the agreement to accept the discharge must be consistent with the source control program's requirements. For a project whose agency that administers the source control program differs from the agency that operates the AWTF, entering a memorandum of understanding or other contractual agreement may be required, so that appropriate source control actions can be taken, as necessary, to protect water quality.

INTERAGENCY COLLABORATION CASE STUDY: GWRS

A joint project of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD), the Groundwater Replenishment System (GWRS) is the world's largest AWTF for potable reuse and has become an essential element of a local water supply that provides enough new water for nearly 850,000 residents. OCSD treats wastewater and produces water that is clean enough to undergo purification at the GWRS instead of being discharged into the Pacific Ocean.

Both agencies shared the cost of constructing the first phase of the GWRS, which was $481 million. OCSD supplied OCWD with stringently controlled, secondary treated wastewater at no charge and invested resources to build a pump station to maximize wastewater flows to the GWRS. OCWD, in turn, agreed to manage and fund GWRS operations. Through this collaboration, the GWRS has emerged as one of the most celebrated civil engineering and water reuse projects in the world.

Together, the two agencies also developed and implemented an aggressive educational outreach program to build upon the public's trust and earn overwhelming support for this unprecedented water-recycling project. Furthermore, they successfully secured $92 million in state, federal, and local grants to help fund their project.

Cooperation between OCWD and OCSD was essential in designing and building the GWRS, which ensures that Orange County's water supplies remain reliable and protective of public health. The two agencies continue to work together to make history in the world of water.

The project involved the use of a memorandum of understanding that addresses the specific roles and responsibilities of the two agencies. The GWRS Steering Committee, a joint committee consisting of both OCWD and OCSD staff, was formed in 1997 and has since met on a quarterly basis to manage and plan the development of the GWRS. Today, the GWRS Steering Committee continues to manage and plan the GWRS's expansion and continued operation, discussing collaborative issues such as flow availability from the OCSD plant, operational challenges, plant expansion, source control, and water quality.

OCSD and OCWD also partner on outreach activities. At its first meeting in March 1997, the GWRS Steering Committee identified public engagement as a high priority and, thus, produced a proactive outreach campaign that has helped the project avoid active public opposition. These outreach activities continue to remain high priorities for both OCSD and OCWD whose ongoing goal is to maintain community support for the GWRS by educating the next generation of local citizens and community leaders about its process, benefits, and impact.

Another example of partnership success is the source control program that OCSD established and manages to benefit the GWRS. As part of its National Pollutant Discharge Elimination System (NPDES) permit, OCSD manages a source control program that strives to limit pollution from drugs, medications, and industrial chemicals, such as 1,4-dioxane, that can impact the water quality in the collection system and, ultimately, the GWRS. In addition to their source control program, OCSD has implemented additional programs such as educational outreach programs, toxics inventory, and a pollutant-ranking system in response to permit criteria set by DDW.

4 Outreach and Education

Public outreach and engagement are critical components of successful potable reuse projects.

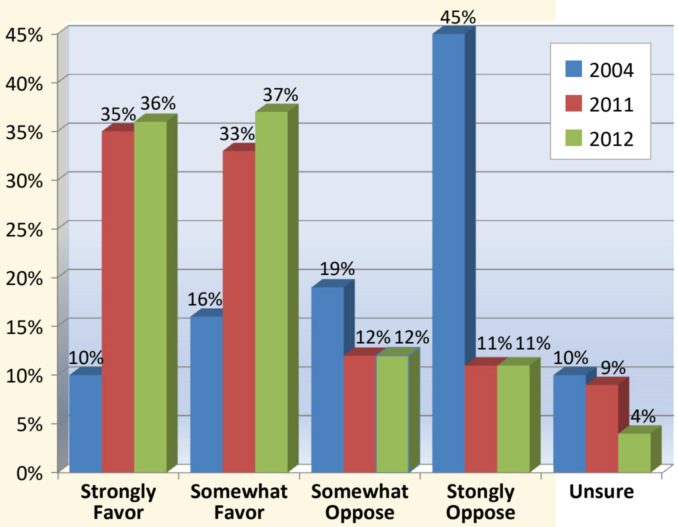
As a utility implements a potable reuse project, community confidence, understanding, acceptance, and support, as well as stakeholder involvement, become essential. However, members of the general public often lack knowledge about their water sources, the systems in place to bring drinking water to their business and homes, and the mechanisms employed to ensure that the quality of their finished water is protective of public health. Questions frequently raised about potable reuse projects often concern water quality, such as constituents of emerging concern (CECs), and finances associated with cost and benefits.

Proactive, appropriate, and consistent public outreach programs for potable reuse projects can significantly help facilitate contributions from stakeholders, build public confidence and acceptance, and allay real and perceived concerns. Past project experience has proven this, and effective resources are available to help agencies develop tailored outreach and communication strategies for water projects (NWRI [2015], TWDB [2015], Millan et al. [2015]). Recent work in Colorado (WateReuse Colorado, 2018b) focused on a regional approach to communications and outreach whose early-phase efforts identified who key audiences are, what priority should be given to them, and their specific roles on the project, as shown in Table 9.

A utility planning a DPR project should develop and launch public outreach programs within their service area once their project's early vision is in place. Local factors, such as demographics, are important to consider when developing a utility-specific approach to communications.

Figure 8 depicts the growth of support for San Diego's potable reuse project as a result of its outreach and education program.

Figure 8. Public Opinion About Pure Water San Diego Before and After Its Outreach Program



An extensive outreach and education program was developed to garner public support in San Diego. Data on public acceptance from 2004, 2011, and 2012 exemplify the success of this program (graphic from Pure Water San Diego).

Table 9. Key Audiences for DPR Outreach (Adapted from WateReuse Colorado, 2018b)

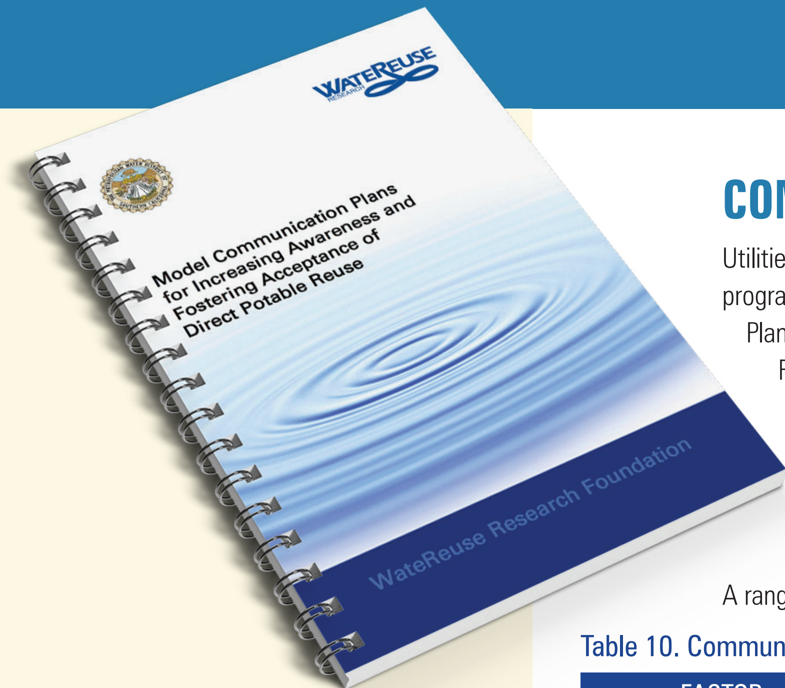
GROUP OR ORGANIZATION	PRIORITY[1]	CATEGORY
Local elected officials	High	Influencer
Press/media	High	Influencer
Town councils and boards	High	Implementer
Community organizations	High	Influencer
Local health department	High	Influencer
Managers/executives	High	Influencer and Implementer
Community leaders	High	User
State of California RWQCB/DDW	High	Regulator/Agency
Industries (food and beverage, manufacturing, etc.)	High	User
Environmental groups	High	Influencer
State legislators	Medium	Influencer
Water associations and organizations (CWEA, Cal-Nevada AWWA, WateReuse California)	Medium	Influencer
Groundwater basin roundtables	Medium	Influencer
Schools (K-12)	Medium	Influencer
Secondary education academic staff	Medium	Influencer
Water provider leadership	Medium	Influencer
Water provider operations staff	Medium	Implementer
Water resources staff	Medium	Implementer
Agricultural and downstream users	Medium	Users
Medical professionals	Low	Influencer
Other state elected officials	Low	Influencer
Development community	Low	Influencer

NOTES:
1. Audiences are prioritized based on initial impact on DPR project implementation.

BEST PRACTICES IN A POTABLE REUSE OUTREACH PROGRAM

- Proactively and strategically design the outreach program.
- Be accurate, transparent, and consistent.
- Develop relationships with opinion leaders, educators, university professors and researchers, and other influential community members.
- Prepare to address tough questions and misinformation.

Sources: Millan et al., 2015; NWRI, 2015; TWDB, 2015.



COMMUNICATION PLAN

Utilities are recommended to develop a communication plan that documents an organized and robust outreach program. One useful resource for developing a potable reuse-focused communication plan is Model Communications Plans for Increasing Awareness and Fostering Acceptance of Direct Potable Reuse, published by the WateReuse Research Foundation, now known as WRF (Millan et al., 2015).

The written communication plan should contain a detailed set of strategies used to communicate information about the project to the public, elected officials, and others. The plan should be comprehensive and include messaging, outreach tools, and communication strategies while also being flexible enough to adapt to the needs of specific locations and situations (NWRI, 2015; Millan et al., 2015).

A range of factors listed in Table 10 should be considered in developing a communication plan.

Table 10. Communication Plan Success Factors and Significance

FACTOR	SIGNIFICANCE
Schedule and Duration	Communication should start early in the process and continue throughout design, construction, startup, and lifetime operation of the AWTF.
Purpose of Communication	Communication activities should have a clearly stated purpose that is then used to support decisions.
Messages	Messages should provide a framework for understanding the project's need, including a narrative to engage the public, raise awareness, and gain acceptance. The messages should also reinforce the higher quality of the purified water and the treatment and monitoring efforts utilized by the agency.
Terminology	Accessible terms like "purified water" are more effective with the public than industry jargon like "potable reuse" and "IPR." Technical terms not understood by the public may not resonate well even when explained.
Problem Solving	A clearly articulated problem helps the public better understand and support the need for potable reuse; therefore, define the water supply condition that will be resolved by the project.
Anticipated Outcomes	The benefits and outcomes of the outreach program should be broad and include: public consensus that wastewater is a resource, community trust in the agency to implement the project, and a public commitment by the agency to be transparent and seek public input.
Costs and Benefits	Financial considerations may be the primary project concern for some communities. Clear and transparent explanation of the costs and benefits is necessary to gain public confidence.
Demographics and Environmental Justice	Attention should be given to effectively communicate with and solicit feedback from a range of demographic groups, and to provide water that is equally protective of public health for all users.

Sources: NWRI, 2015, Millan et al. (2015) and Ruetten (2004).

ROLE OF PUBLIC OPINION RESEARCH

Public opinion research, including focus groups, phone and online surveys, and one-on-one interviews with stakeholders, can provide critical information on the public's view of a DPR project:

Phone/Online Surveys. Through phone surveys, trained interviewers collect data from community members. Phone surveys can be supplemented with online surveys. The information collected is quantitative, which provides utilities with the ability to conduct statistical analyses and present their findings according to a wide range of demographic metrics.

Focus Groups. Focus groups allow members of a selected group to interact through open and honest discussion. Groups are moderated and can be general or specific to different demographics (i.e., gender, race, geographic location). Focus groups produce qualitative research results that identify feelings, perceptions, and thoughts on a given topic.

One-on-One Interviews. In-depth interviews with stakeholders produce qualitative market research and allow individuals to give more detailed and thoughtful responses to questions.

Outcomes of the qualitative and quantitative research are used to develop targeted messages and outreach activities that speak to the unique needs and priorities of a given community.

OUTREACH STRATEGIES

A utility can consider a range of outreach strategies and tactics and outline them in a communication plan to engage their community:

- Public opinion research.
- Audience identification.
- Internal communications.
- Outreach to opinion leaders.
- Outreach to community leaders.
- Written materials.
- Personal interaction.
- Identification of supporters and champions.
- Messaging plan.
- Letters of support.
- Common questions and answers.
- Discussion and resolution of difficult issues.
- Technology demonstrations.
- Tours.

EXISTING ESCP REGULATORY REQUIREMENTS FOR POTABLE REUSE

Existing regulatory requirements for wastewater source control for potable reuse are defined in Sections 60320.106 and 60320.206 of Title 22. Enhanced source control programs (ESCPs) should include the following minimum requirements:

1. An assessment of the fate of chemicals and contaminants that are specified by DDW and the local RWQCB.
2. Chemical and contaminant source investigations and monitoring that focuses on DDW- and RWQCB-specified chemicals.
3. An outreach program to industrial, commercial, and residential communities within the service area who contribute flows into a POTW that will subsequently supply the potable reuse project. This program should focus on managing and minimizing the discharge of chemicals at the source.
4. A current inventory of chemicals, including chemicals resulting from new sources or changes to existing sources, that may be discharged into the wastewater collection system.
5. Compliance with the effluent limits established in the NPDES permit.

5 Wastewater Source Control

The U.S. EPA's National Pretreatment Program (NPP) was established as part of the Clean Water Act to control and regulate the discharge of pollutants from commercial and industrial dischargers of wastewater to collection systems and WWTPs, collectively referred to as publicly owned treatment works (POTWs).

The NPP's general pretreatment regulations are contained in the Code of Federal Regulations, 40 CFR 403. These regulations establish the responsibilities of federal, state, and local governments, as well as industrial dischargers, in implementing pretreatment standards to control pollutants discharged from non-domestic sources.

Since its inception, the NPP has been notably successful in reducing the discharge of pollutants into POTWs nationwide. The program has the following objectives:

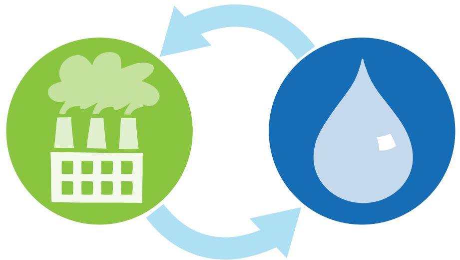
- Prevent the introduction of pollutants into a POTW that will interfere with the operation of the POTW, including interference with use or disposal of municipal biosolids.
- Prevent the introduction of pollutants into a POTW that will pass through a treatment facility and exit the POTW, resulting in effluent or biosolids permit violations.
- Improve opportunities to recycle and reclaim municipal and industrial wastewaters and biosolids.

The NPP **was not intended to complete the following:**

- Protect POTWs from chemicals that may pass through conventional treatment and represent a public health concern for potable water consumption.
- Apply to small POTWs of <5 mgd (unless they accept wastewater from industrial users that could affect their treatment plant or discharges), given that they have a reduced potential for industrial impacts, which does not offset the cost burden to implement a rigorous pretreatment program.

WHO COMES FIRST – BUSINESS OR WATER?

Potable reuse requires a "water first" mentality. However, maintaining industrial sectors is not only important to a community, but unavoidable within the sewersheds of potable reuse projects. An effective source control program should, therefore, strive to avoid negatively affecting industries while also aggressively engaging them to fully understand the waste streams they discharge and how those streams can be best handled while reliably producing purified recycled water.



SWRCB'S ESCP EXPERT PANEL RECOMMENDATIONS

SWRCB convened an expert panel on ESCPs for DPR whose insights can be used to support utilities in maximizing public health protection for DPR projects (NWRI 2020). Table 11 summarizes key recommendations from the panel report.

Table 11. Key Elements of Enhanced Source Control for Direct Potable Reuse in California Recommended by the SWRCB-Convened Panel

KEY PROGRAM ELEMENTS	RECOMMENDATIONS / ENHANCEMENTS
Federal National Pretreatment Program	• The NPP is a solid foundation for enhanced source control for a DPR program. • Pretreatment programs should be required for all DPR systems with significant industrial users, regardless of size. This should be enforced through permits. • Source should be a component of an integrated water supply program. • The RWQCB and DDW should have a consistent, programmatic approach to enhanced source control for DPR.
Enhanced Local Limits	• Local limits must be designed to protect water quality for potable reuse. • Quantitative risk assessments should be conducted to design local limits and identify constituents of concern.
Enhanced Discharger Evaluation	• Risk assessments should be used to screen business applications and permits for constituents of concern. • Risk assessments should evaluate the discharge of concentrated waste into the DPR program. • Utilities should be required to maintain permit databases and annually update GIS maps of industrial users.
Enhance Collection System Monitoring	• Utilities should be required to evaluate the potential of establishing a sensor/software monitoring system in the collection system or at the WWTP to provide early warning of source control issues such as illegal or accidental discharges.
Enhance Education/Outreach	• Public education and outreach programs should be established regarding the control and disposal of hazardous constituents for industrial, commercial, and domestic dischargers.
Technical/ Managerial/ Financial Capacity	• DPR programs should be required to implement a continuous improvement plan as part of their ESCPs. • DPR programs should form and maintain a source control steering committee. • DPR programs should maintain a staffing plan and budget.

CAN SMALL POTWS SKIP THE ESCP?

The short answer is "NO." Title 22 requires potable reuse projects to source wastewater from a wastewater management agency that administers an industrial pretreatment and pollutant source control program as well as implements and maintains a source control program.

While all potable reuse project proponents must administer a DDW-approved ESCP, they are not necessarily all required to administer a federally approved pretreatment program. Small POTWs (<5 mgd) that don't handle waste from certain types of industries typically do not have a federally approved pretreatment program nor will they necessarily need one. Instead, smaller POTWs are recommended to carefully evaluate the industrial waste that is discharged to their collection system and consider voluntarily including elements of a federally-approved pretreatment program, such as industrial discharge permits, a sewer use ordinance, and the adoption of Local Limits for pollutants of concern.

The elements of a source control program for a small POTW should be selected according to a robust understanding of source waters and an assessment of risk.

THE FUTURE OF ENHANCED SOURCE CONTROL

For ESCPs, the future may be right around the corner. WRF has completed the first phase of research (WRF 4908) with three utilities in Oregon, California, and Texas to trial real-time monitoring and response within their collection systems (Steinle-Darling et al., 2019). Under these projects, installed probes track water quality at key nodes in the collection system and look for statistical perturbations that signal a contamination or dumping event. The current response to those events is to sample at the affected node and examine the water quality for a range of chemicals to then use that information to enforce action.

In the future, this configuration could be tuned to directly notify POTWs or AWTFs of a pending slug of poor quality feed water. The next phase of this work, WRF 5048, will evaluate monitoring systems while working through implementation and data collection challenges.

> An ESCP includes an aggressive sampling plan of the collection system, extending beyond local limits and industry-specific monitoring to include regulated and unregulated chemical testing across the AWTF, across the WWTP, and across the collection system.

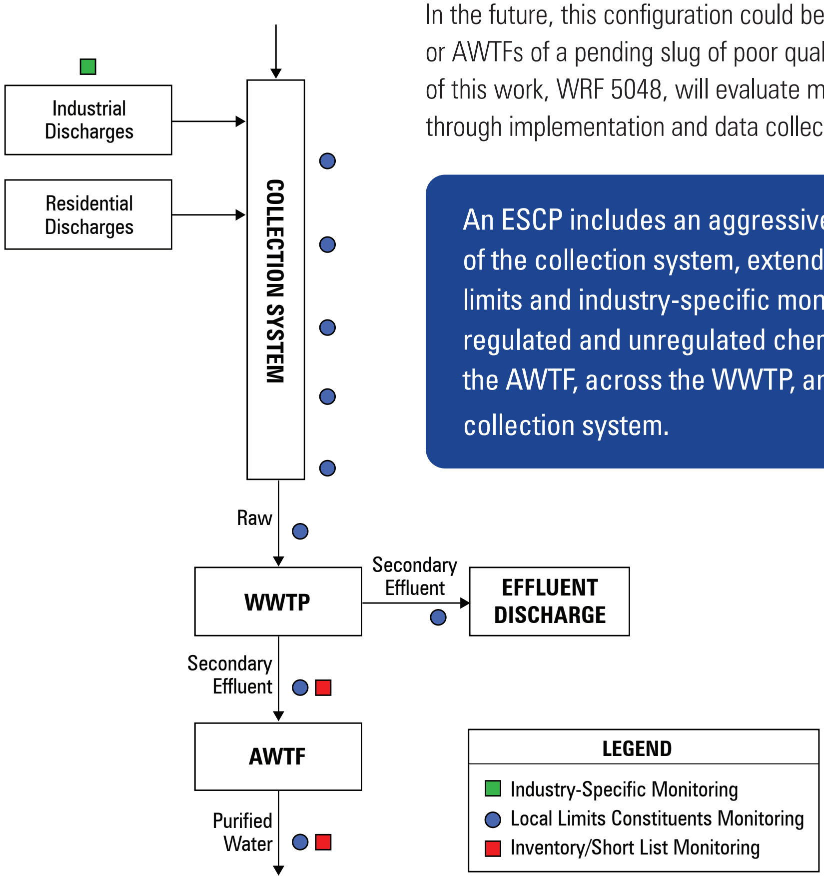


Figure 9. A Schematic of ESCP Monitoring Locations

Figure 9 depicts sampling locations within the collection system and treatment facilities typical for an ESCP monitoring program.

6 Wastewater Treatment

NWRI (2015) places importance on the role of the WWTP within the overall scheme of potable reuse. More specifically, the WWTP must produce reliable, high-quality effluent to foster the predictable performance of advanced treatment processes. This emphasis on water quality is a paradigm shift for WWTPs since their core function has traditionally been the bulk removal of solids and organics and, in some cases, nutrient removal or the treatment of pathogens for discharge.

The ideal WWTP provides the following factors:

- A water quality that is both consistent and low in:
  - Total suspended solids (TSS) and turbidity.
  - Total organic carbon (TOC).
  - Nutrients (e.g., nitrogen).
- Lack of or limited return streams that are treated and/or equalized.
- Equalized flow.

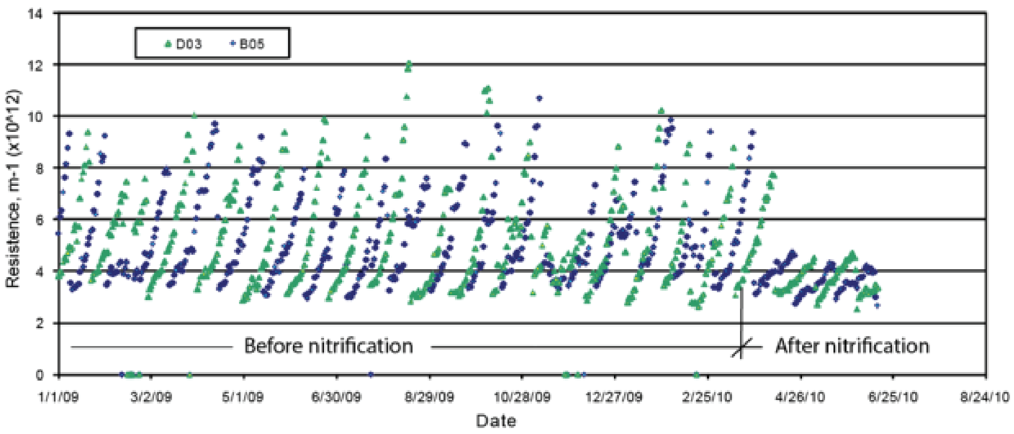
With such water quality and treatment, advanced treatment systems downstream will run more efficiently and produce fewer disinfection byproducts (DBPs). These systems will also run more smoothly with less cycling of pumps and valves due to equalized flow. As an example of the impacts of source water on advanced treatment processes, Figure 10 depicts the degrees of membrane fouling using both a non-nitrified and a nitrified secondary effluent as the influent waters to the membrane system.

Table 12 shows how different WWTP operations affect subsequent advanced treatment systems. Note that the "ideal" WWTP is not needed for potable reuse and, so long as the challenges associated with a particular facility's effluent are known, the advanced treatment process can be designed to maintain production and protect public health.

Table 12. Characterization of Impacts of WWTP Performance on Downstream Advanced Treatment

WWTP CHARACTERISTICS	EXAMPLES	IMPACTS ON DOWNSTREAM ADVANCED TREATMENT
TSS and Turbidity	• Secondary clarifier performance in wet weather. • Poor mixed liquor settleability. • Mixed liquor deflocculation. • Indication of a more significant biological treatment upset.	TSS and turbidity can impact membrane operation, granular media filter run time and maintenance requirements, filtered water turbidity, pathogen loading, ozone demand, and disinfection efficacy.
TOC	Indicator of biological process upset or existence of refractory TOC in raw wastewater.	Elevated TOC affects ozone demand, granular activated carbon (GAC) utilization, and membrane fouling.
Nutrients	High effluent nitrate concentrations.	Nitrate or total nitrogen concentrations violate finished water quality goals.
Return Streams	High nitrogen loads from centrate return.	Variable feed water quality affects biological treatment performance, which has subsequent impacts on downstream oxidation and filtration steps.
Peak Flows and Loads	Flow and/or load equalization.	Cost savings to reduce peak flow capacity can result in improved performance due to constant operation and water quality.

Figure 10. Observed Reduced Membrane Fouling for Two Different Effluent Qualities



Graphic courtesy of OCWD.

Tertiary treatment can also be beneficial. Tertiary processes use a broad range of technologies, some robust and some limited, that often help produce non-potable recycled water or provide a higher quality effluent for discharge. Table 13 highlights the benefits and challenges of these technologies.

Table 13. Characterization of Impacts of Tertiary Treatment on Downstream Advanced Treatment

TERTIARY PROCESSES	WATER QUALITY IMPACTS
Tertiary Filtration to Meet 2 NTU Turbidity	Direct filtration (ozone/BAC) could be considered for membrane pretreatment.
Tertiary Filtration to Meet <0.3 NTU Turbidity	Resistance to membrane fouling is facilitated.
Chloramine Disinfection	Higher NDMA load.
Free Chlorine Disinfection	DBPs will be present; decreased ozone demand.
UV Disinfection	Reduced pathogen load
Ozone Disinfection	Ready for biofiltration; good from a UF membrane performance standpoint
Nitrate or Phosphorus Polishing	Improved resistance to membrane fouling.

7 Multiple Treatment Barriers

Using multiple barriers has been known to be important for potable reuse (Sakaji et al., 1998) since it allows potable reuse systems to be redundant, resilient, and reliable (Pecson et al., 2015).

Title 22 includes the multiple barrier concept, requiring a minimum of three treatment barriers for each pathogen and a minimum of 1-log reduction by each process. The removal of pathogens and chemicals can be efficiently achieved with a blend of technologies that provides sufficient performance overlap, as shown in Table 15.

Acute and Chronic Risk

With respect to public health protection, the goal of advanced water treatement (AWT) is to minimize risk through the destruction and removal of specific chemical constituents and pathogens. To meet this goal, AWTF treatment trains should be designed to eliminate acute risks, such as pathogens, and minimize potential chronic risks such as chemical constituents (Salveson et al., 2014).

Table 14. Reliability as Defined by Redundancy, Robustness, and Resiliency

TERM	DEFINITION AS PERTAINING TO DPR	NOTES
Redundancy	The use of multiple unit processes to attenuate the same type of constituent.	More unit processes in series, even with reduced individual performance, can result in improved overall performance.
Robustness	The combination of technologies that address a broad variety of constituents.	Broad spectrum treatment is required because wastewater is the source water.
Resiliency	The ability to adapt successfully or restore performance rapidly in the face of treatment failures and threats.	This includes the ability to correct single- or multiple-process performance failures.

Source: Adapted from Pecson et al., 2015.

Table 15. A Blend of Technologies Provides Overlap for the Removal of Constituents of Concern

TARGET CONSTITUENT	MANAGEMENT BARRIER[1]	SECONDARY TREATMENT	O_3	BAC	UF	GAC	UV
Regulated Chemicals	⦿	⦿	⦿	⦿		⦿	⦿
Viruses		⦿	⦿	⦿	⦿[2]		⦿
Protozoa		⦿	⦿	⦿	⦿		⦿
Other Chemicals of Interest[3]	⦿	⦿	⦿	⦿		⦿	⦿

NOTES:

1. For example, TMF, ESCP.
2. UF removes virus, but is not currently credited.
3. For example, per- and poly-fluoroalkyl substances (PFASs), pharmaceuticals.

FAILURE ANALYSIS THROUGH QMRA

Properly designed potable reuse treatment trains have been proven to protect public health. With that being said, treatment and monitoring systems can fail, which can affect water quality and pose health risks (Salveson et al., 2018a, Soller et al., 2018). Quantitative microbial risk assessments (QMRAs) can be used to optimize the treatment and monitoring systems for potable reuse and answer these key questions:

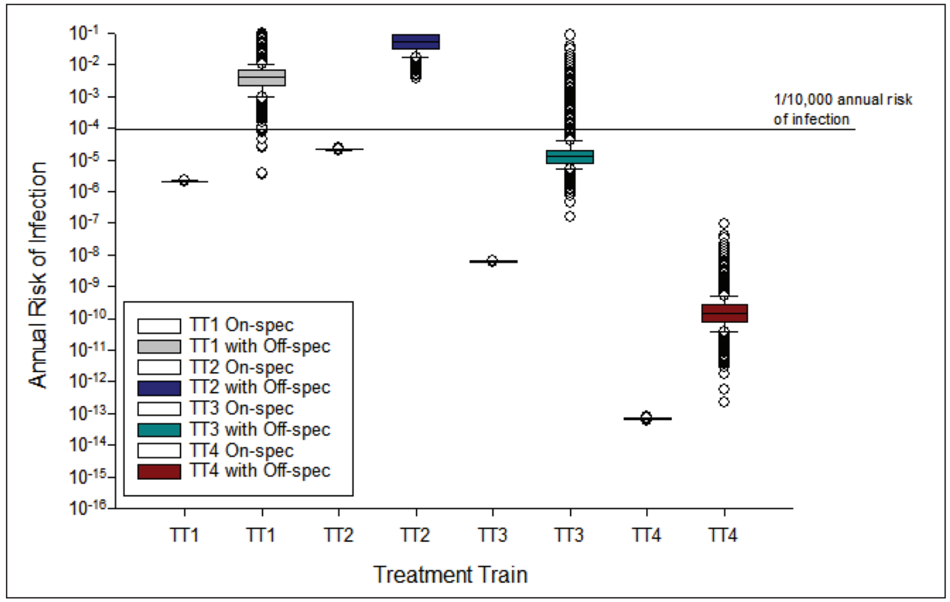
- What levels of treatment and monitoring system redundancy are needed for potable reuse (including IPR and DPR)?
- When should diversion be used to stop water production and distribution?
- How can concepts such as engineered storage (Salveson et al., 2016) be used to limit (or eliminate) off-specification water distribution?

The value of the multiple-barrier approach is well demonstrated in the literature through QMRA studies (e.g., Amoueyon et al., 2019, Salveson et al., 2018a, Soller et al., 2018, 2017a,b). These barriers substantially reduce chronic and acute risks from chemicals and pathogens such as those presented in Table 16. Specifically for pathogens, QMRA results can be used to demonstrate the reliability of different treatment trains to meet pathogen risk goals, as shown in Figure 11.

Table 16. Chemical and Pathogen Risk

PARAMETER	CHRONIC RISK	ACUTE RISK
Chemicals	The vast majority of regulated chemicals pose a chronic risk based upon lifetime exposure.	A short list of chemicals pose an acute risk based upon short term exposure (e.g., nitrate, perchlorate).
Pathogens	Limited concern.	Pathogens pose an acute risk.

Figure 11. Example Results from a QMRA



Risk assessments can be used to demonstrate the value of multiple barriers in reducing pathogen risk. Source: Salveson et al., 2018a.

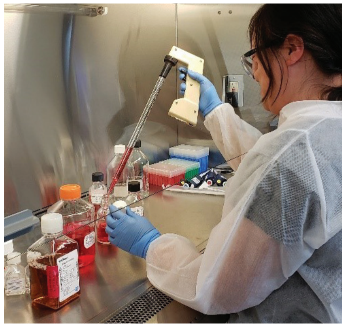
8 Pathogen Control and Monitoring

The primary acute risk associated with potable reuse is pathogens.

Wastewater contains high concentrations of pathogens, including human enteric viruses (e.g., norovirus, adenovirus), protozoa (e.g., *Giardia, Cryptosporidium*), and bacteria (e.g., E. coli). As one example, WRF Project 4767 (Salveson et al., 2018a) compiled data on raw wastewater pathogens from a number of studies and documented virus concentrations of 107 to 109 gene copies per liter for qPCR-based analyses, virus concentrations of 3 to 1,300 per liter for culture-based analyses, and protozoa concentrations of 6 to 17,000 per liter for enumeration-based analyses.

While different approaches to permitting potable reuse projects exist nationally, fundamental potable water end-goals for pathogens focus on minimizing pathogen risk to 1 or fewer infections per 10,000 people per year for each examined pathogen group (Regli et al., 1991). This goal was also considered for the control of *Cryptosporidium* oocysts as part of Long Term 2 Enhanced Surface Water Treatment Rule (USEPA, 2006).

Table 18 lists the pathogen concentration goals for drinking water to meet the 1-in-10,000 risk goal. For DPR, DDW may consider regulating pathogen control according to a daily risk level derived from the annual goal.



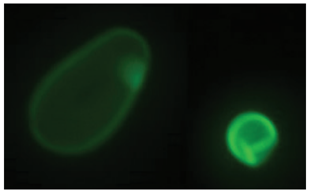


Figure 12.
Laboratory Analysis

Photos courtesy of the Metropolitan Water District.

Precise and accurate laboratory results for protozoan and viral pathogens remain challenging to obtain, especially in raw wastewater or primary effluent. Prudent data collection requires dozens of sample replicates and the use of methods with repeatable and measurable seeded pathogen recovery.

A variety of pathogens are found in wastewater, all with different sizes, susceptibilities to disinfection, and health impacts. Table 17 describes some such notable pathogens.

Table 17. Pathogen Examples

PATHOGEN	SIZE[1]	EXAMPLE TREATMENT METHODS	EXAMPLE SYMPTOMS
Giardia	5-10 μm	UV, MF, UF, RO	Severe diarrhea
Cryptosporidium	3-6 μm	UV, MF, UF, RO	Severe diarrhea
Norovirus	0.030 – 0.040 μm	Free chlorine, Ozone, UV, UF[2], RO	Gastroenteritis
Adenovirus	0.070 – 0.140 μm	Free chlorine, Ozone, UV, UF[2], RO	Upper respiratory tract infections
E. coli	0.5 μm by 1.0 μm	Free chlorine, Ozone, UV, MF, UF, RO	Gastroenteritis

NOTES:

1. For size comparison, a human hair has a diameter of 40 to 250 μm.
2. Low pressure membrane systems have different pore sizes, which impact pathogen removal efficiency. For example, some ultrafiltration (UF) membranes have a nominal pore size of 0.03 μm, whereas some microfiltration (MF) membranes have a nominal pore size of ~0.1 μm. UF systems will be challenged to remove small viruses while MF systems will be challenged to remove any viruses. However, viruses that are attached to solids can be readily removed by both MF and UF systems.

Table 18. Drinking Water Pathogen Goal Concentrations

PATHOGEN	DRINKING WATER GOAL[1]	REFERENCE
Giardia	< 6.8 x 10^{-6} cysts/L	Regli et al. (1991)
Cryptosporidium	< 3.0 x 10^{-5} oocysts/L <1 x 10^{-6} oocysts/L (*estimate*)	Haas et al. (1996) USEPA (2006)
Enteric viruses	< 2.2 x 10^{-7} MPN/L[2]	Regli et al. (1991)

NOTES:

1. Drinking water goals are identified for DPR research and as implied by California regulations and cited by Trussell et al. (2013).
2. MPN/L = most probable number per liter. The 10^{-4} risk level concentrations of a number of enteric viruses are provided by Regli et al. (1991). The most conservative value listed in Table 2 of Regli et al. (1991) is for rotavirus (at 2.22 x 10^{-7} MPN/L). Note, this target concentration is for culturable viruses, not viruses detected by qPCR.

To address human health risks associated with pathogens in wastewater, DDW reviewed the literature and used the maximum concentration of pathogens in raw wastewater to establish "12/10/10" log reduction goals for viruses, *Giardia*, and *Cryptosporidium*, respectively. A minimum of three treatment processes must be in place for each pathogen, providing for at least 1-log reduction (i.e., 90 percent) of the target pathogen. With these pathogen concentrations and goals known, engineering teams can design treatment trains that meet potable reuse standards, as exemplified in Table 19.

Note three items regarding the pathogen log reduction values (LRVs) in Table 19: First, the table shows pathogen reduction through engineered processes only and does not include pathogen reduction through an environmental buffer such as a groundwater basin. Second, similar levels of pathogen reduction can be attained with non-RO-based treatment trains, as documented in Salveson et al. (2018a). Third, the pathogen-reduction "credits" approved by regulators are conservative; in some cases, treatment processes may provide substantially higher removal of pathogens but be limited in credits due to the lack of precise and accurate monitoring systems.

Table 19. Example Pathogen LRVs for UF, RO, and UV AOP Treatment Train

TARGET	WWTP	UF	RO	UV AOP	FREE CHLORINATION	TOTAL LRV
Protozoa	Variable - For example, 1.2 LRV *Cryptosporidium*[1] 0.8 LRV *Giardia*[1]	4+[2]	1.4 to >2[4]	6[4]	1.0 LRV *Giardia*[5]	10+
Virus	Variable - For example, 1.9 LRV[1]	0[3]	1.4 to >2[4]	6[4]	4[5]	13+

NOTES:

1. Pathogen reduction by primary and secondary treatment processes is proven, but the level of reduction is variable. Additional research in this area is needed. Pathogen reduction at six WWTPs was evaluated by Rose et al. (2004); with the lower 10th percentile removal values from that data set are shown here.
2. Salveson et al. (2018a), Oxnard (2018), Los Angeles (2018a).
3. UF membranes can reject viruses depending upon the pore size and integrity of the membrane. However, no current monitoring method has demonstrated sufficient membrane integrity to allow for confidence in performance.
4. Oxnard (2018) and Los Angeles (2018a).
5. In this example, free chlorination is provided for a concentration multiplied by time (CT) of 12 mg-min/L. The credits shown are based upon USEPA (1991) for a CT of 12 at a temperature of 0.5ºC and pH of 6-9.

Table 20. Impact of Advanced Treatment on Water Quality and WTP Operations

TREATMENT PROCESS	WATER QUALITY (MINERALS)	WATER QUALITY (ORGANICS)	POTENTIAL IMPACT ON PATHOGEN REMOVAL BY WTP
RO Based Treatment	Low TDS (<50 mg/L) water requires stabilization prior to blending with raw water.	No detectable TSS, turbidity of <0.01 NTU, and TOC of <0.3 mg/L.	At high relative percentages of purified water, lack of organics and solids may affect WTP operations and, thus, LRVs. WTP processes that cannot provide or measure the treatment of RO permeate may not be credited for potable reuse LRVs.
Ozone/BAF Based Treatment	Ambient or somewhat elevated TDS compared to the raw water supply. No water quality adjustments necessary.	No detectable TSS, turbidity of <0.15 NTU, TOC in the range of 2 to 4 mg/L.	No anticipated WTP challenges at this time.

Blending purified reclaimed water with a conventional raw water supply ahead of an existing WTP presents several potential challenges for pathogen removal and regulatory credit.

Supernumerary Challenges

Pathogens can be reduced to DDW standards using existing IPR treatment trains and, to respond to concerns raised about DPR implementation, additional treatment can be implemented to result in "supernumerary" credit. However, adding on treatment processes for extra LRV credit also increases the cost and complexity of a system. A better approach is to have sufficient treatment with a reasonable safety factor while properly monitoring and maintaining treatment performance.

For DPR, DDW considers processes within an existing WTP as part of the DPR treatment train (SWRCB 2019b). WTP processes must be validated in the same manner that other unit processes in the train are validated. However, because existing WTPs have been designed to treat natural surface water rather than RO-permeate quality water, treatability studies are required to prove pathogen log reductions in the WTP influent, whether it is reuse water or a blend of reuse and existing source waters. Table 20 summarizes water quality challenges and their potential impacts on pathogen removal and monitoring of that removal through the WTP.

An efficient advanced treatment system for potable reuse strikes a balance between robust treatment and accurate and precise monitoring systems. Too much reliance on superfluous treatment processes results in a system that is costly to install and operate. However, too much reliance on monitoring systems presents a health risk since monitoring systems can drift and fail.

CRITICAL CONTROL POINTS

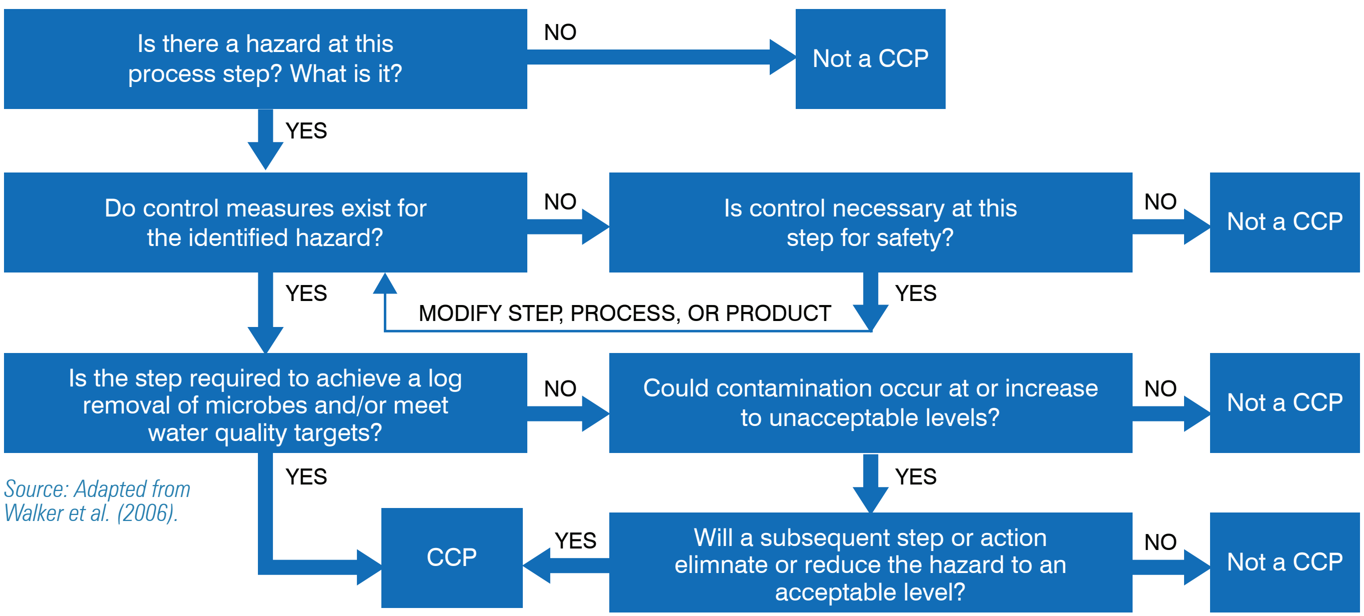
The long-term operational success of a potable reuse facility relies on coupling robust treatment systems with precise and accurate process monitoring. In particular, the application of critical control points (CCPs) to potable reuse monitoring is critical, as described in detail by Walker et al. (2016).

NWRI (2015) defines a CCP as "a point in AWT 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." CCPs apply to both chemical and microbiological risk. Figure 13 depicts the process to determine what is and isn't a CCP. Figure 14 shows CCPs in an example treatment train.

The CCP concept begins with a broader hazard analysis critical control point (HACCP) analysis, which requires the following steps:

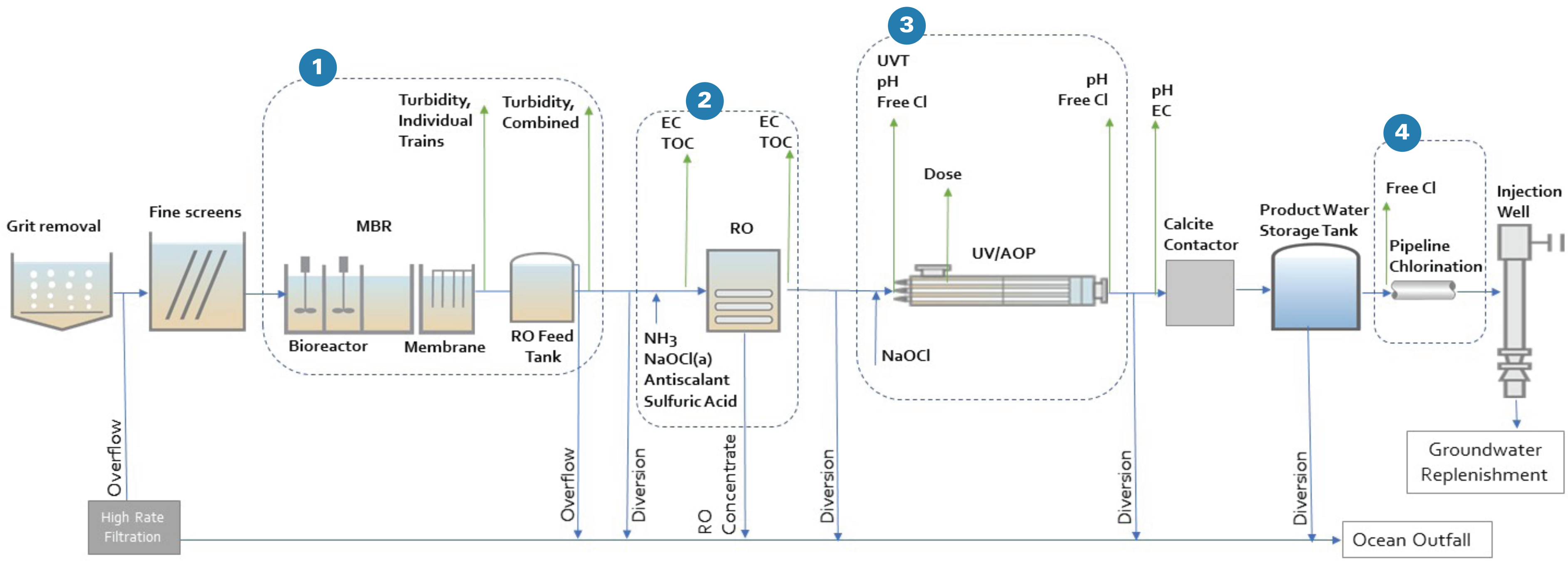
- A risk assessment or hazard analysis is carried out to determine water quality risks or hazards in a process train. Hazards can be both chemical and biological.
- The process unit or combined group of processes where risks are controlled are determined as CCPs, which serve as process barriers.
- For each CCP, surrogate constituents are selected to be continuously monitored to verify the efficacy of the treatment process. Monitoring systems and analyzers are required to monitor treatment surrogates and confirm that the process barrier is intact.
- Critical limits for each treatment surrogate are established. An alert level is set to provide early indications of possible degradations in treatment efficacy. A critical alarm level is a level that triggers a response, such as a diversion, when it is exceeded.
- Once the plant is operational:
    - The CCP system function is verified.
    - If a CCP control fails, a control action/response is initiated. The corrective action could be an automated response or operator response.
    - Documentation procedures are established to report and document failure events and lessons learned.

Figure 13. Steps to Determine What Is and Isn't a CCP



Source: Adapted from Walker et al. (2006).

Figure 14. Example AWPF showing CCPs and Surrogates for Monitoring each CCP



Example CCP	Example surrogate for monitoring the CCP
1 MBR	Effluent turbidity
2 RO	Influent and effluent electrical conductivity (EC)
3 UV AOP	UV dose
4 Free chlorination	CT

This graphic shows an MBR, RO, UV AOP treatment train with four CCPs for a combination of chemical and pathogen control.

9 Chemical Control and Monitoring

THE CHALLENGE

Today, we can detect a broad range of chemicals at the nanogram per liter (ng/L) level. These include both regulated chemicals with maximum contaminant levels (MCLs) as well as CECs such as pharmaceuticals, personal care products, consumer chemicals, flame retardants, and others. ***At sufficiently high concentrations,*** some of these CECs have potential endocrine-disrupting, carcinogenic effects and/or other potentially harmful endpoints.

In addition to the literature compiled on chemical and radiological constituents explicitly regulated through MCLs, a wealth of research has been conducted on CECs in wastewater, their attenuation through conventional WWTPs, and their further removal by RO and breakdown during advanced oxidation treatment (Baronti et al., 2000; Lovins et al., 2002; Schäfer et al., 2005; Sedlak et al., 2006; Steinle-Darling et al., 2010; Linden et al., 2012; Salveson et al., 2010; Salveson et al., 2012, Salveson et al., 2014, Snyder et al., 2012, and many others). Furthermore, various research projects document the ability of an AWTF to meet stringent water quality standards (Trussell et al., 2013, Salveson et al., 2010, Salveson et al., 2014, Linden et al., 2012).

The question is not if chemicals should be treated through a series of multiple barriers but, instead, how much treatment is necessary and what type of treatment is the most effective.

ON ONE HAND…

The detection of chemicals does not infer human health significance. A number of research studies have found that secondary or tertiary effluents meet most, if not all, MCLs without further treatment (Trussell et al., 2013). In other words, CECs are detected in wastewater effluent, but most are present at levels that are not of concern for human health (Trussell et al., 2013).

ON THE OTHER HAND…

The fact that MCLs are met and CECs are measured at low or non-detect levels does not mean that additional treatment is not warranted for chemical constituents. Such detections of CECs continuously drive the industry to look closer at water quality and remain vigilant about public health protection. Furthermore, due to the broad occurrence of CECs in wastewater and some help from media interest, CECs are often the primary public concern for potable reuse projects.

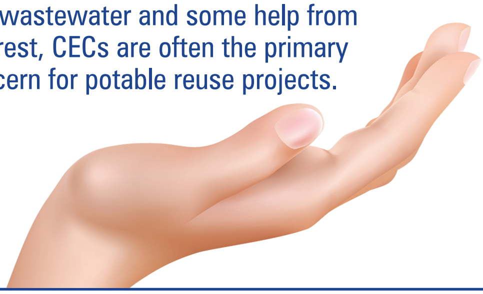


Table 21. AWTF Performance Using UF, RO, and UV AOP

PARAMETER	WASTEWATER SOURCE CONTROL	BIOLOGICAL TREATMENT (SECONDARY)	ULTRA-FILTRATION	REVERSE OSMOSIS	UV ADVANCED OXIDATION
Many Regulated MCLs	⦿	⦿	–	⦿	⦿
Select DBPs	⦿	–	–	⦿	⦿
Total dissolved solids	⦿	–	–	⦿	
Unregulated CECs	Case-by-case	⦿	–	⦿	⦿

DDW has detailed engineering requirements along with specific water quality targets for regulated and unregulated chemicals. Regarding the engineering requirements, groundwater recharge using injection and reservoir water augmentation ***both require the following:***

- RO to achieve broad-spectrum reduction of TOC to <0.5 mg/L: In reality, a properly operated and maintained RO system results in an RO permeate with TOC of <0.1 mg/L (Los Angeles, 2018a). Removal to this level coincides with the removal of most detectable regulated and unregulated chemicals.

- UV AOP that achieves a minimum of 0.5-log reduction of 1,4-dioxane, a chemical that has a CA NL and also serves as a conservative surrogate for the oxidation of trace-level (ng/L) chemicals with low molecular weights that may be found in RO permeate.

The reduction targets for TOC by RO and for 1,4-dioxane by UV AOP are process-validation metrics. If RO is reducing TOC by >99 percent, then this process is performing to specification. If UV AOP is reducing 1,4-dioxane by 0.5-log (~68 percent), then this process is performing to specification.

Because both RO and AOP are required for specific types of potable reuse in California and anticipated to be required for DPR, attaining ultra-low TOC (e.g., 0.1 mg/L) and advanced oxidation of 1,4-dioxane are assumed to be necessary for public health protection. However, other states have successful and protective potable reuse projects that do not rely on TOC or 1,4-dioxane requirements.

Chemical monitoring programs involve a significant investment of time and resources. Whether through third-party contracting or on-site laboratory work, a successful project and regulatory approval hinge on the collection, analysis, and timely reporting of large datasets. A majority of the sampling and analysis is either monthly or quarterly with select daily efforts. Sampling efforts cover MCLs, secondary MCLs, CECs, priority toxic pollutants, nutrients, regulator specified chemicals, and NPDES discharge requirements.

The following sites can be used as sample locations:

- The feed to the WWTP.
- The WWTP effluent (i.e., feed to the AWTF).
- Within the AWTF treatment train.
- The final effluent (i.e., finished water).
- Within the environment (e.g., for IPR projects within a groundwater basin).

Costs are variable and site-specific, but Table 22 offers several examples.

Table 22. Example Annual Laboratory Costs for Potable Reuse Projects

ITEM	ANNUAL LABORATORY COST
Raw Wastewater and WWTP Monitoring	Depending on utility size, from $50,000 (small utility) to >$100,000 (larger utilities).
AWTF Monitoring	$50,000 to $100,000, depending on regulatory requirements.
Groundwater or Surface Water Monitoring	>$25,000, depending on the extent or size of the project (i.e., number of environmental monitoring locations).

Table 23. Nitrosamines of Concern for Potable Reuse

CONSTITUENT	REGULATORY TYPE	LEVEL (ng/L)
N-Nitrosodiethylamine (NDEA)	NL	10
N-Nitrosodi-n-propylamine (NDPA)	NL	10
N-Nitrosodimethylamine (NDMA)	NL	10
	MTL – health and performance indicator	10
(N-nitrosomorpholine) NMOR	MTL – health indicator	12

NOTES:

NL: Notification level: Most recent update to NL list February 6, 2020 (SWRCB, 2020).

MTL: Monitoring trigger level: Included as part of the amended Recycled Water Policy as one of the monitoring requirements for CECs (SWRCB, 2019a).

Table 24. Health and Performance-Based CEC Monitoring and Bioanalytical Screening[4] (SWRCB 2019a)

CONSTITUENT	RELEVANCE[1,2]	MTL (ng/L)
1,4-dioxane	Health	1,000
NDMA	Health and Performance Indicator	10
NMOR	Health	12
PFOS	Health	13[3]
PFOA	Health	14[3]
Sulfamethoxazole	Performance Indicator	–
Sucralose	Performance Indicator	–
Dissolved Organic Carbon	Performance Surrogate	–
UV Absorbance	Performance Surrogate	–
EC	Performance Surrogate	–
Estrogen receptor-alpha bioassay	Bioanalytical Screening	3.5 ng/L
Aryl hydrocarbon bioassay	Bioanalytical Screening	0.5 ng/L

NOTES:

1. Health-based CECs and bioanalytical screening to be monitored following treatment.
2. Performance indicator CECs and surrogates to be monitored before RO and after treatment.
3. PFOS and PFOA also have NLs of 6.5 and 5.1 ng/L.
4. Monitoring requirements for reservoir water augmentation and groundwater injection projects.

Regarding numeric limits and monitoring requirements, Title 22 and SWRCB's Recycled Water Policy set acceptable limits for chemical constituents (e.g. MCLs, NLs, and other constituents specified by DDW) ***and require monitoring for CECs.*** Tables 23 and 24 highlight monitoring requirements for nitrosamines and CECs, respectively, in California.

In total, chemical control focuses on minimizing chronic risk, lowering chemical levels well below levels with known human health impacts, and providing real-time and periodic monitoring to protect public health. With that being said, chemical control also addresses acute risk (e.g., nitrate is a chemical that poses an acute risk) and must consider public perception.

The CCP process, reviewed previously under Topic 8, applies equally to chemical control. Each process required for chemical removal must include methods to monitor and control performance according to specific target water quality goals. One example is the control of TOC by RO, which is anticipated to continuously provide > 99% reduction.

CEC-REMOVAL CASE STUDY:
ALTAMONTE SPRINGS FLORIDA

For the past several years, the City of Altamonte Springs in Florida has been developing a treated drinking water augmentation DPR program called PureALTA. As part of this effort, the city researched non-RO purification processes referred to as carbon-based advanced treatment (CBAT). While it is anticipated that the State of California will require RO for DPR projects, the PureALTA project demonstrated its ability to produce high-quality water that exceeds treatment and pathogen goals for potable reuse and received awards from both the WateReuse Association and the International Water Association for Innovation.

Altamonte Springs' (2018) 12-month demonstration project treated filtered secondary effluent using ozone, BAC, UF, GAC, and high dose UV. It achieved compliance with all regulated chemicals and researched the occurrence and removal of CECs, for example, Meprobamate (Figure 15). Furthermore, the percentage of CECs that were detected in the purified water was much lower than that in the secondary effluent, as shown in Figure 16.

Altamonte Springs also used bioassays, as described in Section 12, which address broad groups of chemicals to demonstrate a more comprehensive level of chemical removal.

Figure 15. Meprobamate Levels Throughout the Treatment Train

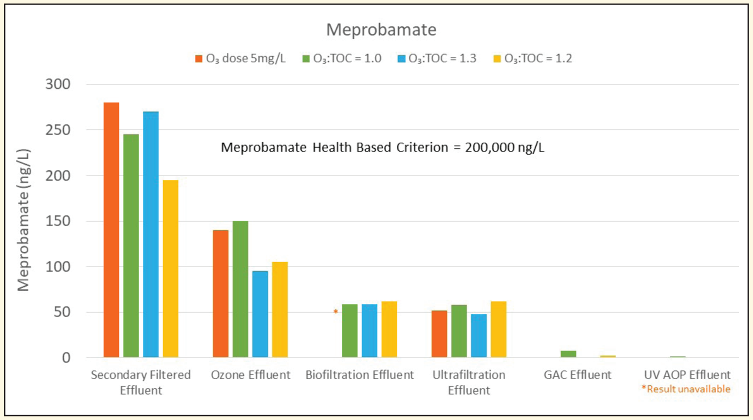
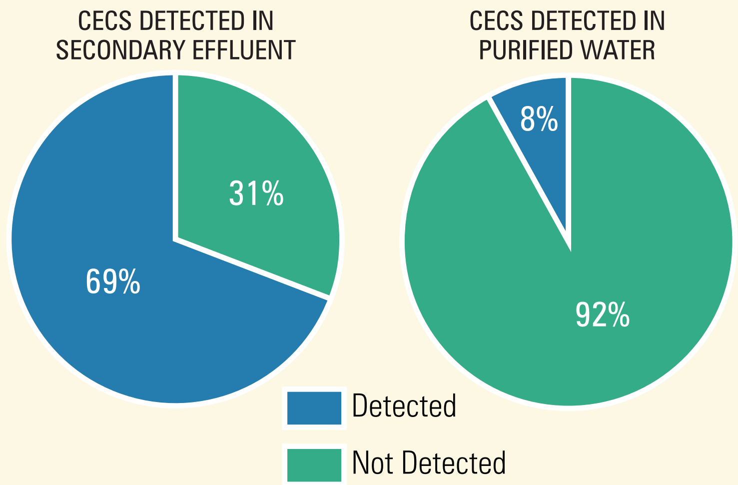


Figure 16. Detections of CECs in Secondary Effluent and Purified Water



Detailed testing of CECs through treatment shows limited detections in the secondary effluent and, at ng/L levels, in purified water.

10 Operations

The AWT Operator (AWTO) Certification program was developed to train and certify drinking water and wastewater operators for potable reuse operations.

The AWTO Certification program was created by a group of dedicated volunteers from across the industry with support from the California/Nevada American Water Works Association (CA/NV AWWA) and the California Water Environment Association (CWEA). The AWTO program is meant to supplement, not replace, existing wastewater and drinking water operator certification programs. Detailed information can be found at https://www.awtoperator.org/.

Table 25. Progress Toward the First AWTO Certification

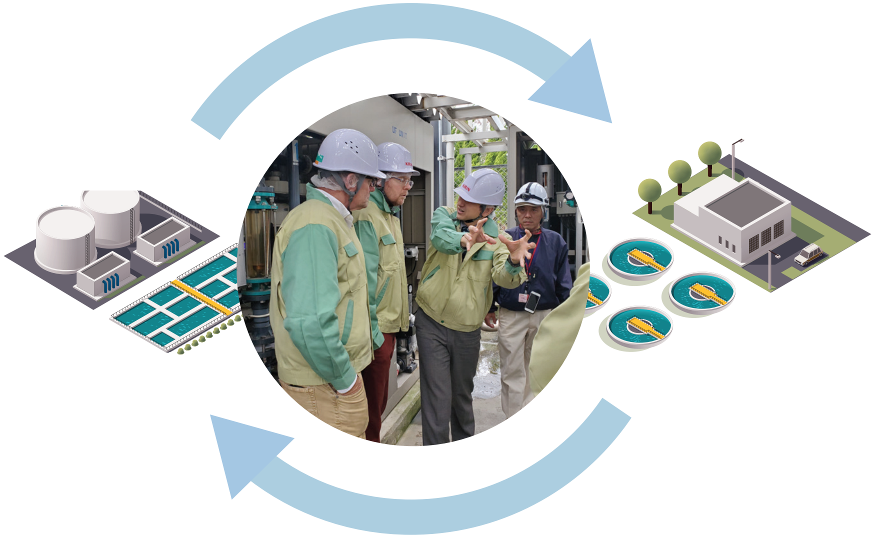
PROGRESS TOWARD AWTO SUCCESS	REFERENCE DOCUMENTS/NOTES
Job requirements developed	Job Analysis Report (CA/NV AWWA, 2017).
Training materials developed	Walker et al., 2018.
Test exams developed	Grades 3-5 AWTO exams complete.
AWTO exam administration	Exam administration began in 2019 and is available for Grades 3-5.

Well-trained AWTO staff are necessary for the continued success of potable reuse facilities. The AWTO program is available for Grades 3 through 5. As adapted from CA/NV AWWA's *Job Analysis Report* (2017), a Grade 3 AWTO possesses the following skills and knowledge:

- Understands AWT processes and the impact of feed water quality on production and finished water quality.
- Operates, monitors, and maintains AWT processes such as membrane systems and AOP.
- Has a basic understanding of AWT-related terminology, process-related calculations and chemicals used in individual AWT processes.
- Understands and executes operational and safety procedures and chemical-handling practices.
- Maintains and follows regulations pertinent to the end uses of treated water, such as recycled water, potable water, and potable reuse.
- Understands how instrumentation and analyzers function, as well as basic maintenance, calibration, and verification.
- Has a basic understanding of the control strategy of plant systems.
- Has a basic understanding of supervisory control and data acquisition (SCADA) systems and data-trending with a particular focus upon CCPs and a secondary focus on operational control points.
- Has a basic understanding of incident response and investigation.
- Follows a HACCP systems approach, including its CCPs, critical levels, key health risks, and operational response procedures.
- Has a general understanding of engineering plans and specifications as well as sampling analysis procedures.

Who Qualifies for AWTO?

All California and Nevada wastewater and drinking water treatment operators with a Grade 3 or above start the AWTO certification program as a Grade 3 AWTO after passing the first test.



Potable reuse is the intersection of wastewater and drinking water treatment and requires continuous cross training between certified wastewater operators and certified drinking water operators.

WRF has prepared extensive training materials for AWTOs (Walker et al., 2018), which can be supplemented by existing training materials, such as those available through the Southwest Membrane Operators Association (SWMOA, https://www.swmoa.org/).

Walker et al. (2018) provides detailed training materials on the following topics:

1. Introduction to DPR operator training.
2. Microfiltration and ultrafiltration membranes.
3. RO membranes.
4. Ozonation.
5. Granular activated carbon (GAC) adsorption.
6. Biofiltration.
7. UV disinfection and advanced oxidation.
8. Corrosion control.

In permits for potable reuse, DDW is now requiring AWT operators to obtain AWTO certification. Furthermore, California's regulations require utilities to develop operations optimization plans (OOPs), which are detailed, site-specific manuals for AWTFs that include information on their treatment technologies, chemical feed systems, control systems, CCPs, O&M staffing plans, and sampling and monitoring requirements. An example OOP is provided here for reference (Los Angeles 2018b).

11 Water Quality Management

When introducing a new potable reuse supply, its impact on delivered water quality, distribution system stability, and blending location within the WTP must be carefully considered.

DDW advocates for the feasibility and importance of evaluating an existing drinking WTP as a train of separate treatment processes; that is, processes within the WTP must be validated in the same manner as other individual processes (SWRCB 2019). In particular, treatability studies are required to demonstrate the drinking WTP's ability to effectively treat RO permeate-quality water or a blend of RO permeate and other waters.

This is because integrating a new potable reuse supply upstream of an existing WTP can affect treatability and plant operations, including the optimal coagulant type and dose, settled water quality, filter run times, residuals handling, and disinfectant dose and contact time requirements. Jar testing, for instance, can be conducted to assess how blending influences coagulation and disinfection requirements. WRF Project 4536 (Salveson et al., 2018b) outlines methods for conducting jar tests to evaluate the effects of blending reuse supplies in drinking WTPs.

Regardless of the blending location, introducing a new potable reuse supply can affect the aesthetic quality of the delivered water, disinfectant residuals, DBP speciation and concentrations, and distribution system stability. While characteristics such as taste and odor (T&O) and color do not pose public health concerns, experience has shown that public trust in a new water supply can be eroded by an adverse change in the aesthetics of water, which results in major cost and public relations repercussions to the water system.

Figure 17. Flavor Profile Analysis Tasting

Flavor profile analysis (FPA) and consumer panels can be powerful tools that identify and plan for potential changes in the T&O characteristics following the introduction of a new DPR supply.

Flavor profile analyses (FPAs) (Standard Methods [SM] 2170) and other methods of characterizing the T&O of blended water can be used to identify and plan for any changes in the delivered water's aesthetic quality following the introduction of a new potable reuse supply. Disinfectant demand and simulated distribution system bench tests (SM 5710C, APHA, WEF, and WEF, 2005; Koch et al., 1991) can also be conducted to plan for changes in disinfectant dose and DBP formation in blended water.

DISTRIBUTION SYSTEM STABILITY

The USEPA's Lead and Copper Rule recognizes the potential impacts that introducing any new source water can have on distribution system stability and, therefore, requires systems to notify the primacy agency (i.e., SWRCB) prior to introducing a new source or any long-term change in water treatment. SWRCB reviews and approves the addition of the new supply before it is implemented by the utility.

Corrosion control models can be used to predict the scaling characteristics of the potable reuse blend and simulate how pH, alkalinity, and/or calcium adjustments can stabilize the water according to anticipated blends. The impact of adding a phosphate- or silica-based corrosion inhibitor cannot be modeled; instead, pipe loops or coupon testing using pipes harvested from a given distribution system is required to evaluate these inhibitors' effects on pipe scale stability and metal solubility. Additional guidance documents to help plan for and mitigate unwanted impacts on distribution system stability are offered by the USEPA (2016), AWWA (2017), AWWA (2011), and Brown et al. (2013).

The stabilization strategy depends on the percent blend. For small amounts of new supply (on a percent basis), pH adjustment alone can achieve target values for the calcium carbonate precipitation potential, which is a measure of the scaling tendency of water in a new potable reuse supply. However, both pH and alkalinity adjustments are likely needed if the new supply is a substantial component of the total water blend. Figure 18 depicts an approach to determine a stabilization method.

Figure 18. Steps to Determine Optimal Stabilization Option

A step-wise approach to planning for and mitigating any changes in pipe scale stability and metal solubility in the distribution system and premise plumbing.

12 Emerging Issues

Properly engineered and regulated potable reuse projects produce a high quality water that is protective of public health (NRC, 2012).

Potable reuse projects require the following barriers and verification steps to reliably produce potable water:

- Wastewater source control.
- Multiple barrier treatment systems.
- Monitoring and control following the CCP methodology.
- Extensive and repeated sampling of finished water for regulated chemicals.
- Exploratory sampling for unregulated chemicals.

What about Unknowns?

Analytical chemists continue to lower detection levels to the ng/L and lower even as more chemicals are used and enter our wastewater. This is why engineers, regulators, and the public continue to raise concerns about unknowns, asking: What are we not detecting and might there be a health risk associated with unknown chemicals?

Table 26. Emerging Chemicals and the Industry Response

EMERGING CHEMICAL	TIME FRAME	WATER REUSE INDUSTRY RESPONSE	NOTES
NDMA	Late 1990s	Added high dose UV for photolysis of NDMA.	Chronic health risk.
1,4-dioxane	Early 2000s	Added advanced oxidation for organic chemical destruction.	Chronic health risk.
Hormones, Pharmaceuticals, and Personal Care Products	2000s and 2010s	Existing RO-based and ozone/BAF-based systems perform well. Polishing treatment often used to meet public concerns.	Public perception challenge; health risks not documented for ng/L concentrations of known chemicals in these chemical groups.
PFAS	2010s	Implementation of ion exchange, GAC, or RO treatment.	Chronic health risk at ng/L levels.
MERS-CoV and SARS-CoV-2 (COVID-19)	2010s and 2020s	Verified current treatment effectiveness and researched wastewater as a surveillance tool.	Robust pathogen barriers with appropriate safety factors can address emerging pathogens.

New chemicals and pathogens will emerge through the lifespan of any project. Examples are listed in Table 26, with notes on how the industry has adjusted treatment and monitoring systems according to these developments. Key to maintaining high water quality is having a resilient and robust treatment system that can handle a broad range of pathogens and chemicals, both known and unknown.

In response to regulatory and public concern for unknown chemicals, the water reuse industry continues to drive forward with leading-edge research. As targeted studies and national experience with potable reuse increases, the information generated will help reduce the potential for overly conservative designs while also enhancing regulatory and public confidence.

BIOANALYTICAL TOOLS FOR ASSESSING CHEMICALS

Bioanalytical tools assess water quality by quantifying its impact on living cells or tissues and, as such, detect chemicals not by their structure but by their biological activity. More specifically, these tools use cells or proteins of a targeted organism—human cells, in the case of drinking water and potable reuse—as surrogates for specific human systems and health endpoints (PRC, 2019).

The vast majority of chemicals, including emerging constituents, are not regulated. Traditional targeted analytical methods exist for all regulated chemicals but for only a fraction of unregulated chemicals and transformation byproducts. As a result, additional tools are needed to better characterize water quality for potable reuse. The use of bioanalytical tools can supplement these targeted analyses including those that assess emerging constituents (Snyder and Leusch, 2018).

Bioanalytical tools can be used in numerous ways to support potable reuse:

- As an additional measure of water quality during the initial assessment of a new water source.
- As a measure of treatment effectiveness during validation or verification of a treatment process or train.
- As a routine water-quality-monitoring tool to identify changes in water characteristics that may trigger further investigation.
- To help build public support by providing more comprehensive screening of unknown water constituents with endpoints based on human health relevance (Drewes, 2018; Snyder and Leusch, 2018).

As part of its update to the Recycled Water Policy, SWRCB added two bioanalytical tools—estrogen receptor-alpha bioassay and aryl hydrocarbon bioassay—to its list of monitoring requirements for CECs in recycled water as performance indicators to be monitored before RO and after treatment. These two bioassays assess estrogenic and dioxin-like biological activities, respectively, in recycled water. Additional bioassays could be considered as part of a pilot or demonstration testing plan.

EMERGING CHEMICALS AND PATHOGENS

Emerging chemicals and pathogens will always be a concern for potable reuse since new chemicals are introduced into water systems every year. In response, novel analytical methods are developed to identify these chemicals and to drive down the detection limits of existing methods.

Emerging pathogens are also of interest. Recent works have investigated the efficacy of current treatment practices and regulations on controlling pathogens, such as norovirus, not traditionally considered under the current regulatory approaches. In addition, advanced techniques, including molecular methods, are being used to assess microbial water quality and operations, although there are challenges to using this information for regulatory purposes.

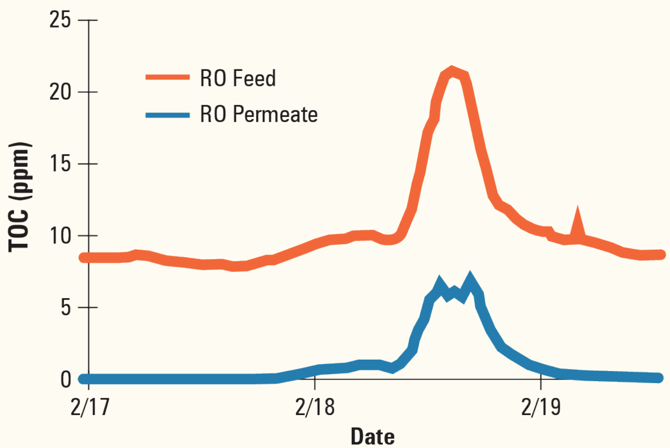
Utilities must track ongoing research and coordinate with regulators regarding chemicals and pathogens of concern.

PEAK REDUCTION RESEARCH

SWRCB sponsors research on options to identify and reduce potential chemical peaks that might persist through advanced treatment processes, and then proposes management options using the results.

Water quality excursions (e.g., acetone) have been observed at AWTFs and, for DPR, controlling these excursions will become more important. Established laboratory and quality control techniques, such as online TOC, have the ability to identify "peaks," as shown in Figure 19. However, specific strategies must be developed to control chemical peaks. Source control may provide some value as may additional sewershed monitoring, which can catch early warnings of such peaks. Additional measures, including blending, source control, monitoring, and treatment, must be considered and researched further (Debroux et al., 2019).

Figure 19. TOC Spikes in RO Feed and Permeate



LOW MOLECULAR WEIGHT RESEARCH

SWRCB sponsored a research project to evaluate the analytical methods available to detect and determine the chemical structure of unknown chemicals in recycled water (Maruya and Wong 2020). Existing methods for semi-targeted and non-targeted analyses require extensive capital and labor costs and, thus, are not recommended for routine monitoring at this time. Instead, Maruya and Wong 2020 proposes a three-tiered screening approach:

1. Focus efforts first on using multiple methods to screen for surrogates (e.g. pH, conductivity, TOC).
2. Use targeted methods to analyze samples for known constituents and compounds that can be efficiently analyzed.
3. If warranted, employ semi-targeted and non-targeted analysis to identify problematic trace constituents using a suite of more advanced diagnostic methods.

THE PUBLIC HEALTH PROTECTION CULTURE

In the *Proposed Framework for Regulating DPR in California*, SCRWB describes an expectation of an organizational "public health protection culture" that is not easily addressed in regulation but critical in ensuring the safety of DPR (2019b).

The concept of "culture" deserves more attention. Effective wastewater treatment programs and their operators deal with a highly impacted water supply and must focus on the removal of biological oxygen demand, nutrients, TSS, turbidity, and bacteria, and typically operate with limited safety factors. Conversely, WTPs and their operators start with a moderate- to high-quality feed water and operate with large safety factors.

The mentality shift and educational burden placed on staff are substantial for potable reuse treatment facilities whose source water is especially impacted. Safety factors must be maintained. The AWTO program is one of several key steps to bridge the gap between wastewater and water mentalities and build the right culture for potable reuse.

OUTBREAK MONITORING

SWRCB sponsors a research project to investigate the feasibility of collecting concentration data of raw wastewater pathogens that have been associated with community outbreaks of disease.

According to the California DPR expert panel (SWRCB, 2016), flow volumes in larger community wastewater systems are likely to dampen pathogen loads from localized outbreaks.

The planned SWRCB research project on outbreak monitoring will help utilities understand whether or not additional outbreak monitoring is warranted.

PUBLIC HEALTH SURVEILLANCE

In their *Proposed Framework for Regulating DPR in California*, SWRCB noted that public health surveillance accomplishes the following:

- Establishes partnership, engagement, and communication between water utilities and public health partners.
- Identifies sources of data to characterize baseline public health considerations and track trends.
- Helps determine if transient treatment failures and contamination events lead to adverse health outcomes.

Current regulations require reporting of waterborne microbial disease and other events that have the potential for adverse effects on human health due to short-term exposure. For DPR, SWRCB may decide where additional strategies are demanded. For example, projects may be required to perform wastewater monitoring during community outbreaks to characterize baseline public health conditions.

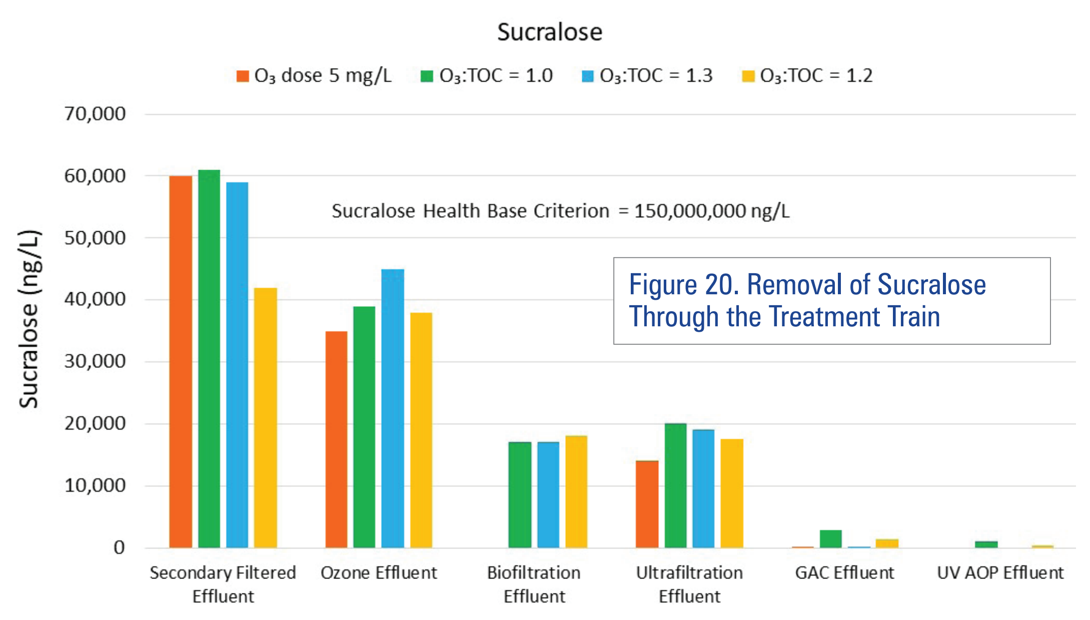


Figure 20. Removal of Sucralose Through the Treatment Train

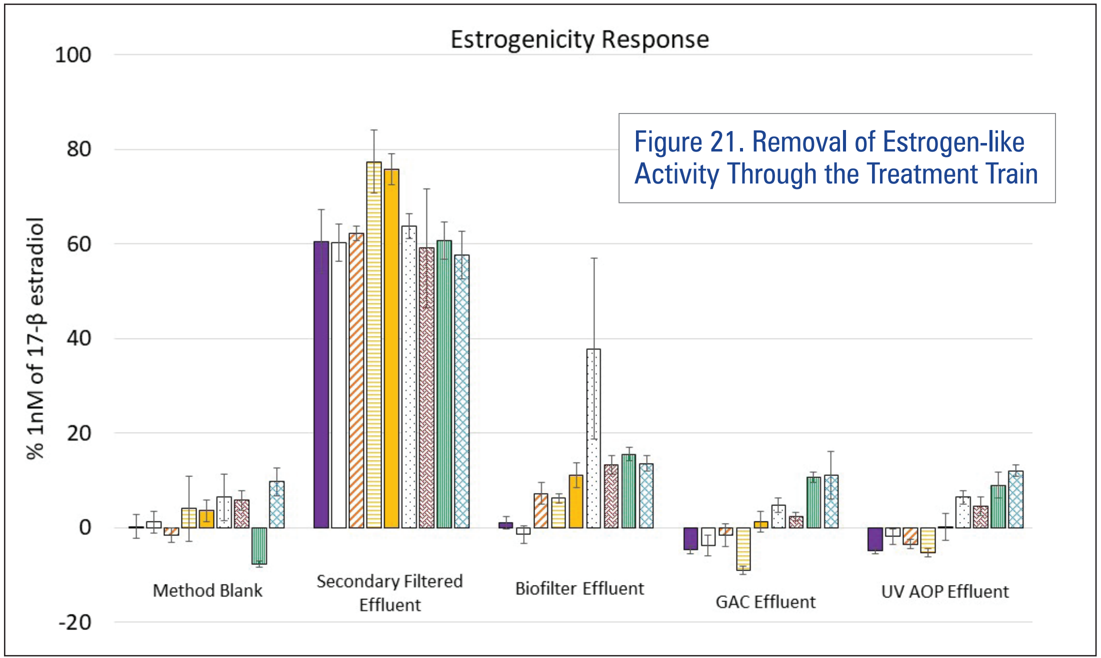


Figure 21. Removal of Estrogen-like Activity Through the Treatment Train

CASE STUDY: SEARCHING FOR THE UNKNOWNS IN FLORIDA

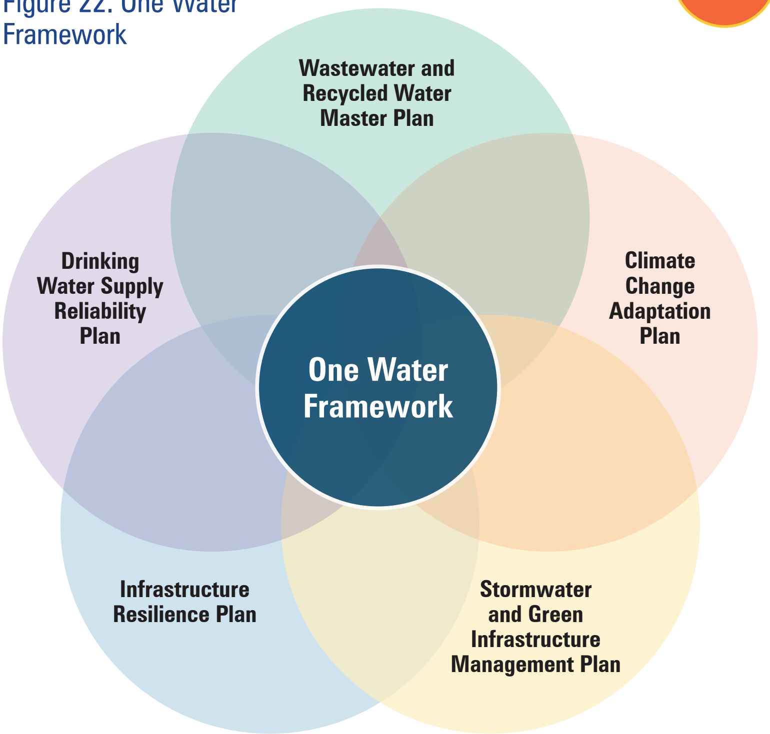
For an example of leading-edge research of emerging issues, we return again to Altamonte Springs (2018), a city that used traditional targeted chemicals analytical methods for a range of unregulated chemicals in addition to using six bioassay tests to assess the removal of unknown chemicals in its water. For this award-winning work, Altamonte Springs will continue garnering regulatory and public support.

Testing for individual chemicals in the feed water and in the finished (i.e., treated) water only reveals a small portion of the purification process and its effectiveness (Figure 20). The use of bioassays allows for a broader level of understanding of how large chemical groups are removed (Figure 21).

The six bioassays that Altamonte Springs used measured estrogen-like chemicals, glucocorticoid/progesterone-like chemicals, androgen-like chemicals, dioxin-like chemicals, genotoxicity, and cytotoxicity by comparing the sample's estrogen response to a known concentration of an estrogen molecule, 1 nanomolar (nM) of 17-β estradiol. For instance, a water sample could produce 40 percent of the response that a water mixture containing 1 nM of 17-β estradiol does.

13 Collaboration to Spur Innovation

Figure 22. One Water Framework



Source: Water Research Foundation, 2017.

Utilities are embracing the concepts of integrated planning and One Water to better manage water resources as they are faced with increasing challenges associated with population growth, water scarcity, competition for limited supplies, water pollution, and climate change.

These key concepts involve new approaches that recognize not only the value of all water but also the reality that cities must strive and are striving to be as sustainable as possible by breaking down traditional water, wastewater, and stormwater silos; engaging the community; protecting public health and the environment; and working with stakeholders (WRF, 2017; U.S. Water Alliance, 2016). Similarly, new and innovative strategies, such as potable reuse, will benefit from the experience of existing projects and collaboration between other utilities, experts in the field, and stakeholders.

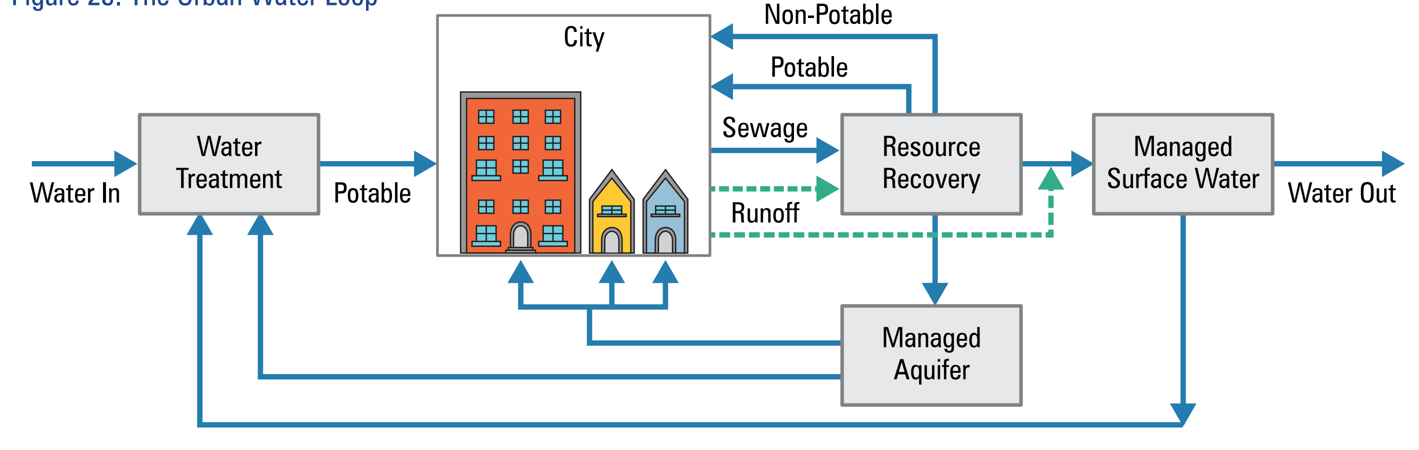
Improving the urban water cycle underscores how water resources are managed by water agencies. For instance, by sustainably managing wastewater, utilities can treat wastewater flows for beneficial uses while continuing to improve water quality in receiving waters. This is why water reuse for non-potable and potable applications is becoming more widespread even in non-arid regions of the country. Sedlak (2014) described this progression as the "Fourth Water Revolution," through which our communities have begun closing the urban water loop by reusing our wastewater and turning it into recycled water as well as capturing stormwater that falls in our cities and converting it into a viable water supply. This urban water loop is illustrated in Figure 23.

A collaborative approach is required to achieve sustainable, reliable, and resilient water systems. To this end, utilities must adopt tactical steps and guidance, including those for DPR.

The following approaches provide opportunities for collaboration on potable reuse efforts:

- Learning from other utility potable reuse projects and the use of case studies that describe how utilities have implemented innovative approaches, including the methods they employed to overcome potential barriers and obstacles
- Extensive use of stakeholder involvement and community engagement as addressed under Topic 4.
- Use of technical and scientific advisory panels to provide independent, expert advice on technical and regulatory topics, which will guide implementation.

Figure 23. The Urban Water Loop



Source: Adapted from Sedlak, 2014.

Consider pilot testing and research. Demonstrate the effectiveness of advanced treatment technologies to your community, regulators, operators, and engineering staff, and look for efficiency and innovations to best meet your water quality goals.

COLLABORATION WITH UTILITIES ON PROJECTS

Over the years, the potable reuse community has benefited from sharing information, experiences, and lessons learned. Because potable reuse is an emerging practice regulated only on the state level, utilities around the county are allowed to investigate and evaluate a range of innovative approaches.

Utilities interested in pursuing potable reuse can effectively collaborate with other utilities in the following areas:

- **Governance.** Because potable reuse typically involves multiple agencies and/or jurisdictions, governance becomes an important factor in planning and implementing projects.
- **Treatment Technologies.** Touring existing full-scale treatment facilities and pilot and demonstration projects provides first-hand experience to observe treatment processes and engage experienced operators.
- **Water Quality.** Understanding and addressing existing and emerging water quality issues is important in operating a potable reuse facility, addressing regulator questions, and providing confidence to the public.
- **Operations.** Operations, including appropriately trained and certified operators, is a critical element in the production of purified water that is protective of public health.
- **Complying with Regulations.** Utilities with potable reuse projects have broad experience working with regulators, complying with regulations, and negotiating permits.
- **Development and Use of Frameworks and Case Studies.** Using published guidance frameworks and case studies such as the USEPA's *2017 Potable Reuse Compendium* (2018).

FURTHER COLLABORATION OPPORTUNITIES

- Attend annual national and state water reuse conferences, including the WateReuse Symposium and the California WateReuse Conference.
- Participate in formal or informal tours at existing potable reuse facilities including full-scale, pilot, and demonstration facilities. Examples of projects with formal tour programs include the GWRS in Orange County, CA, and Valley Water's Silicon Valley Advanced Purification Center in San Jose, CA.
- Collaborate on potable reuse research projects with other utilities through WRF's Tailored Collaboration Program (see www.waterrf.org).
- Join the WateReuse Association and WateReuse California, which are utility-based industry organizations. The WateReuse Association provides networking opportunities with other utilities as well as technical and outreach resources. Meanwhile, WateReuse California has a track record of advocating for utilities on the state level through sponsoring and advancing legislation and by interacting with state agencies on state policies, including with SWRCB. Other California associations engaged in advocacy on water reuse include the California Association of Sanitation Agencies and the Association of California Water Agencies.

USE OF EXPERT PANELS

Expert panels, or technical advisory panels, can provide important validation of potable projects for regulators and utilities alike. Panels, which are understood as credible and independent, can review and oversee projects, assess public health protection, and address questions posed by the public, especially in regions where experience with potable reuse is limited. A science-based independent panel can also provide advice on the design and implementation of projects. Each of these benefits can bolster a utility's case in pursuing potable reuse efforts.

These panels can be comprised of leading water professionals, including academics, former regulators, and independent consultants who have expertise in areas relevant to the project. Panel reports generated by these professionals can be used to guide further studies and as background documents to inform elected officials, regulators, and the public.

A number of utilities have successfully used expert panels for their projects, including the GWRS, San Diego PureWater, and the Silicon Valley Advanced Purification Center. Many of those panels were administered by NWRI.

SWRCB includes the requirement for an "independent scientific advisory panel" for certain potable reuse projects where the project sponsor proposes an alternative to a specific requirement (Title 22, Section 60320.130 Alternatives). For these proposed alternatives, formal SWRCB approval is needed, and a utility must demonstrate that the proposed alternative assures at least the same level of protection to public health. As such, unless specified otherwise by DDW, the proposed alternative must be reviewed by an independent scientific advisory panel that includes a specified range of scientific and engineering experts.

References

Altamonte Springs (2018). Potable Reuse Demonstration Pilot Project Report. Revision 1. A report prepared by Carollo Engineers, Inc. for the City of Altamonte Springs Florida.

Amoueyan, E., Ahmad, S., Eisenberg, J.N.S., and Gerrity, D. (2019). Equivalency of indirect and direct potable reuse paradigms based on a quantitative microbial risk assessment framework. Microbial Risk Analysis 12, 60-75.

APHA, AWWA, and WEF (American Public Health Association, American Water Works Association, and Water Environment Federation). 2005. Standard Methods for the Examination of Water and Wastewater, 21st ed. Washington, D.C.: APHA.

AWWA (2011). AWWA Manual of Practice M58 Internal Corrosion Control in Water Distribution Systems. American Water Works Association. Denver Colorado.

AWWA (2017). AWWA Manual of Practice M68 Water Quality in Distribution Systems. American Water Works Association. Denver Colorado.

Baronti, C., R. Curini, G. D'Ascenzo, A. DiCoricia, A. Gentili, and R. Samper (2000). Monitoring Natural and Synthetic Estrogens at Activated Sludge Sewage Treatment Plants and in a Receiving River Water. Environmental Science and Technology, 34(24): 5059-5066.

Brown, R., McTigue, N., and Cornwell, D. (2013). Strategies for assessing optimized corrosion control treatment of lead and copper, JAWWA, 105:5:62

CA/NV AWWA (2017). Job Analysis Report, California-Nevada Section of the American Water Works Association, Advanced Water Treatment Operator (AWT). Prepared by PSI Services LLC for CA/NV AWWA.

Debroux, J., S. Trussell, and M. Plumlee (2018). Treatment for Averaging Potential Chemical Peaks. Presentation at the 2019 WateReuse California Conference, Garden Grove, CA. March 18, 2019.

Haas, C., Crockett, C., Rose, J., Gerba, C., and Fazil, A. (1996). Assessing the risk posed by oocysts in drinking water. Journal AWWA, September 1996.

Koch, B., S.W. Krasner, M.J. Sclimenti, W.K. Schimpff. 1991. Predicting the Formation of DBPs by the Simulated Distribution System, JAWWA 83:10:62.

Linden, K., A. Salveson, and J. Thurston (2012). Innovative Treatment Technologies for Reclaimed Water, WateReuse Research Foundation Project 02-009 Final Report, Alexandria, VA.

Los Angeles (2018a). Demonstration of Water Quality for Potable Reuse Report Terminal Island Advanced Water Purification Facility Expansion: Dominguez Gap Barrier Project. March 2018. A report prepared by Carollo Engineers, Inc. and Walsh Construction for the Los Angeles Bureau of Sanitation.

Los Angeles (2018b). Los Angeles Sanitation Terminal Island Water Reclamation Plant Advanced Water Purification Facility Operation Optimization Plan. Prepared by Carollo Engineers, Inc. and Walsh Construction.

Lovins, III, W., J. Taylor, and S. Hong (2002). Microorganism Rejection by Membrane Systems. Environ. Eng. Sci., 19(2): 453-465.

Maruya, K. and Wong, C. (2020). Evaluating Analytical Methods for Detecting Unknown Chemicals in Recycled Water. Report prepared for the Water Research Foundation and CA SWRCB.

Millan, M., Tennyson, P., Snyder, S. (2015). Model Communications Plans for Increasing Awareness and Fostering Acceptance of Direct Potable Reuse. Report prepared for the WateReuse Research Foundation. Alexandria, Virginia.

NWRI (2015). Framework for Direct Potable Reuse. A publication by the National Water Research Institute in collaboration with the WateReuse Association, The American Water Works Association, and the Water Environment Federation. Alexandria, Virginia.

NWRI (2016). Final Report of an NWRI Independent Advisory Panel: Recommended DPR General Guidelines and Operational Requirements for New Mexico. Prepared by NWRI for the New Mexico Environment Department.

NWRI (2018). Guidance Framework for Direct Potable Reuse in Arizona. Prepared by NWRI for WateReuse Arizona, the AZ Water Association, and the Steering Committee for Arizona Potable Reuse.

NWRI (2020). Enhanced Source Control Recommendations for Direct Potable Reuse in California. Prepared for: California SWRCB DDW. Sacramento, CA. March 31, 2020.

NRC (2012). Water Reuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater. National Academies Press, Washington, D.C.

Oxnard (2018). Engineering Report for Groundwater Replenishment Reuse Project. December 2018. Prepared for the City of Oxnard. A report by Carollo Engineers, Inc.

Pecson, B.M., Trussell, R.S. , Pisarenko, A.N. and Trussell, R.R. (2015) Achieving Reliability in Potable Reuse: The Four Rs. Journal AWWA. 107:3.

PRC (2020). Advancing Potable Reuse in Florida: A Regulatory Framework. Prepared by the Florida Potable Reuse Commission. Published by the WateReuse Association, Alexandria, VA.

Regli, S., J.B. Rose, C.N. Haas, and C.P. Gerba (1991). Modeling the Risk from Giardia and Viruses in Drinking Water. JAWWA, November 1991, 76-84.

Rose J.B., S.R. Farrah, V.J. Harwood A.D. Levine, J. Kukasik, P. Menendez, and T.M., Scott T.M. (2004). Reduction of Pathogens, Indicator Bacteria, and Alternative Indicators by Wastewater Treatment and Reclamation Processes. Report for Water Environment Research Foundation, Alexandria, VA.

Ruetten, J. (2004). Best Practices for Developing Indirect Potable Reuse Projects: Phase 1 Report. Published by the WateReuse Foundation, Alexandria, VA.

Sakaji, R., Hultquist, R., Olivieri, A., Soller, J., Trussell, R., and Crook, J. (1998). Whither the Multiple Treatment Barrier? Proc.. Water Reuse 98, 95-108.

Salveson, A., J. Brown, Z. Zhou, and J. Lopez (2010). Monitoring for Microconstituents in an Advanced Wastewater Treatment Facility and Modeling Discharge of Reclaimed Water to Surface Canals for Indirect Potable Reuse, WateReuse Research Foundation Project 06-019, Final Report, Alexandria, VA.

Salveson, A., T. Rauch-Williams, E. Dickenson, J. Drewes, D. Drury, D. McAvoy, and S. Snyder (2012). A Proposed Suite of Indicators for Assessing the Efficiency of Secondary Treatment for the Removal of Organic Trace Compounds, Water Environment Research Foundation Project CEC4R08 Final Report.

Salveson, A., Mackey, E., Salveson, M., Flynn, M. (2014). Application of Risk Reduction Principles to Direct Potable Reuse, Final Report for WateReuse Research Foundation Project No. 11-10, Alexandria VA.

Salveson, A., Steinle-Darling, E., Trussell, S., Pecson, B., Macpherson, L. (2016). Guidelines for Engineered Storage for Direct Potable Reuse. Reuse-12-06. Alexandria, Virginia.

Salveson, A., Dickenson, E., Soller, J., Angelotti, B., and Parker, A (2018a). Pathogen Risk Evaluation of Treatment and Monitoring System Performance for Potable Reuse. Water Research Foundation Project 14-16/4767. Denver, Colorado.

Salveson, A, Sutherland, J., Garvey, E., Charbonnet, E., Steinle-Darling, E., Edwards, M., Pruden, A., Garner, E., Parks, J., Dickenson, E., Glover, C., Imyang, M., Grimaldi, A., Trusssell, S., Trussell, B., Monroy, I., Baribeau, H. (2018b). Blending Requirements for Water from Direct Potable Reuse Treatment Facilities. Water Research Foundation Project 4536. Denver, Colorado.

SCCWRP (2018). Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water. Prepared by the Southern California Coastal Water Research Project for the State of California Water Resources Control Board.

Schäfer, A.I., A.G. Fane, and T.D. Waite, Eds. (2005). Nanofiltration, Principles and Applications, Elsevier.

Sedlak, D.L., and M. Kavanaugh (2006). Removal and Destruction of NDMA and NDMA Precursors during Wastewater Treatment, Final Report for WateReuse Research Foundation Project 01-002, Alexandria, VA.

Sedlak, 2014. Water 4.0: The Past, Present, and Future of the World's Most Vital Resource. Published by Yale University Press.

Snyder, S., G. Korshin, D. Gerrity, and E. Wert (2012). Use of UV and Fluorescence Spectra as Surrogate Measures for contaminant Oxidation and Disinfection in the Ozone/H2O2 Advanced Oxidation Process, WateReuse Research Foundation Project 09-10 Final Report, Alexandria, VA.

Soller, J., Eftim, SE, and Nappier, SP (2017a). Direct potable water reuse microbial risk assessment methodology: Sensitivity analysis and application to State log credit allocations. Water Res, 2018. 128: 286-292.

Soller, J., Eftim, SE, Warren, I, and Nappier (2017b). SP, Evaluation of microbiological risks associated with direct potable water reuse. Microb Risk Anal, 2017. 5: 3-14.

Soller, J., Parker, A., Salveson, A. (2018). Public Health Implications for Short Duration, Off-Specification Conditions at Potable Water Reuse Water Treatment Facilties. Environ.Sci.Technol. Lett. 2018, 5, 675-680.

Steinle-Darling, E., E. Litwiller, and M. Reinhard (2010). Effects of Sorption on the Rejection of Trace Organic Contaminants during Nanofiltration. Environmental Science and Technology, 44(7): 2,592-2,598.

Steinle-Darling, E., Carlo, P., Salveson, A., Nye, N., and Dorrington, G. (2019). Demonstrating Real-Time Collection System Monitoring for Potable Reuse. Water Research Foundation Project: Reuse-17-30. Project in progress.

SWRCB (2016). Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. Prepared by NWRI for the State (of California) Water Resources Control Board.

SWRCB (2019a). Water Quality Control Policy for Recycled Water. Adopted December 11, 2018. Effective April 8, 2019. SWRCB California EPA. https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2018/121118_7_final_amendment_oal.pdf

SWRCB (2019b). A Proposed Framework for Regulating Direct Potable Reuse in California, Second Edition. Prepared by the State of California Water Resources Control Board Division of Drinking Water, August 2019.

SWRCB (2020). Drinking Water Notification Levels and Response Levels: An Overview. Updated February 6, 2020. SWRCB – DDW. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/notificationlevels/notification_levels_response_levels_overview.pdf

Texas Water Development Board (TWDB, 2015). Direct Potable Reuse Resource Document. Final Report. Prepared by Alan Plummer Associations, Inc. for the Texas Water Development Board.

Trussell, R.R., A. Salveson, S.A. Snyder, R.S. Trussell, D.Gerrity, and B.M. Pecson B.M. (2013) Potable Reuse: State of the Science Report and Equivalency Criteria for Treatment Trains. WateReuse Research Foundation, Alexandria, VA.

USEPA (1991). Surface Water Treatment Rule Guidance Manual. EPA 68-01-6989, Cincinnati OH.

USEPA (2006). Long Term 2 Enhanced Surface Water Treatment Rule. 71 CFR page 654, Federal Register, January 5.

USEPA (2016). Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems. Office of Water (4606M). EPA 816-B-16-003. March 2016.

US Water Alliance (2016). One Water for America Policy Framework - Executive Summary. Published by the U.S. Water Alliance, Washington DC.

Walker, T., Stanford, B., Khan, S., Robillot, C., Snyder, S., Valerdi, R., Dwivedi, S., Vickers, J. (2016). Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of Direct Potable Reuse Scheme. WateReuse Research Foundation Projecvt 13-03. Alexandria, Virginia

Walker, T., Stanford, B., Salveson, A., and Cheung, A. (2018). Curriculum and Content for Potable Reuse Operator Training. Water Research Foundation Project 15-05/4772. Denver Colorado.

WateReuse Colorado (2018a). Technical Memorandum 1: Development of DPR Regulations in Colorado. Prepared by Carollo Engineers, Inc. for WateReuse Colorado.

WateReuse Colorado (2018b). Technical Memorandum 2: Communications and Outreach Plan for DPR in Colorado. Prepared by Carollo Engineers, Inc. for WateReuse Colorado.

Water Research Foundation (2017). Blueprint for One Water. Prepared for the Water Research Foundation. Project Number 4660. Denver, CO.

WSAA (2012). Australian Sewage Quality Management Guidelines. Water Services Association of Australia. June, 2012.

POTENTIAL DIRECT POTABLE REUSE PROJECTS:

CASE STUDIES FROM CALIFORNIA UTILITIES

Valley Water

DIRECT POTABLE REUSE EXAMPLE PROJECTS

Valley Water is evaluating a number of potable reuse projects that span groundwater recharge, raw water augmentation, and treated drinking water augmentation. Several DPR options are included in Valley Water's 2020 Draft Countywide Water Reuse Master Plan, each with a goal to produce up to 24 mgd via potable reuse by 2028.

POTENTIAL RAW WATER AUGMENTATION PROJECT

Valley Water's Penitencia WTP currently sources water primarily from the South Bay Aqueduct. Penitencia WTP is designed to treat 42 mgd, but the average daily flow rate is 19.2 mgd (2003-2019).

A raw water augmentation project would source up to 24 mgd of effluent from the SJ/SC RWF for purification at a new Advanced Water Purification Facility (AWPF). The purified water would be piped to the Penitencia WTP where it would be blended with the other sources upstream of Penitencia's processes which include ozonation, flocculation, sedimentation, sand-anthracite filtration, and chlorine disinfection.

One of the challenges for this project would be to understand how the varying feed water qualities would impact WTP operations, including finished water corrosion control and pathogen reduction credits. The project would also benefit from a clear understanding of treatment and monitoring requirements from DDW.

POTENTIAL TREATED WATER AUGMENTATION PROJECT

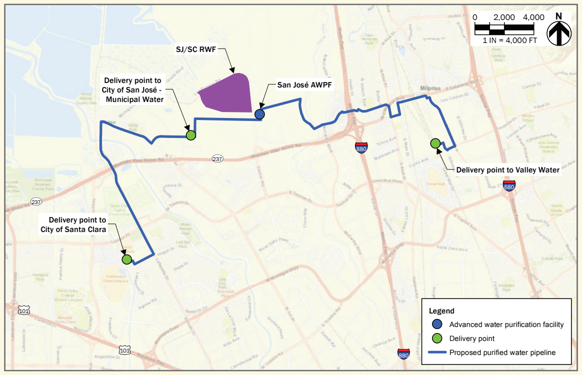
Treating water to augment the drinking water distribution system (DWDS) would enable Valley Water to provide a more direct and efficient new supply to their customers, enabling potable reuse of up to 24 mgd through this approach. Advanced treatment of SJ/SC RWF effluent would occur with a new and robust AWPF. The finished purified water (compliant with strict upcoming TWA level of treatment regulations) would be piped to:

- Up to 4 mgd to the City of Santa Clara and City of San Jose, where it would blend with their other potable water supplies before going out to the distribution system.
- Up to 20 mgd to Valley Water's distribution system via 36-inch pipe to either Valley Water's Milpitas Pipeline or a new dedicated pipe to PWTP's potable water pipe.

The planning of this project could benefit from understanding the level of treatment and monitoring that will be required by DDW under the pending DPR regulations.

Valley Water

Raw Water Augmentation to Penitencia WTP.



Treated Water Augmentation.

Ventura Water

VENTURA WATER

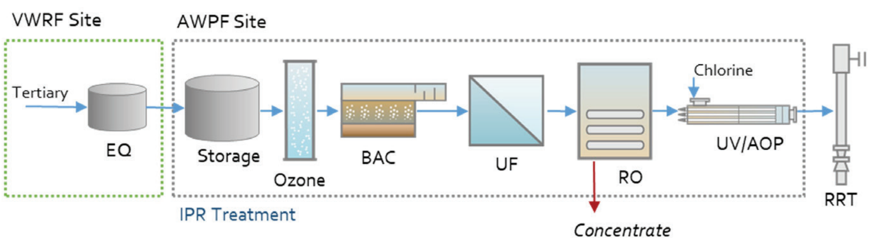
Ventura Water is planning VenturaWaterPure–an IPR project with the potential for expansion to a DPR project. The IPR project would deliver advanced treated water to the groundwater basin for "groundwater augmentation", whereas the DPR project would deliver purified water either to a water treatment plant for raw water augmentation or, after sufficient treatment, directly to the public for treated drinking water augmentation.

VenturaWaterPure will be broken down into two phases:

- Phase 1a: IPR, up to 3.2 mgd
- Phase 1b: Expansion of IPR, up to 4.8 mgd with a potential to add DPR facilities in addition to IPR for purified water distribution.

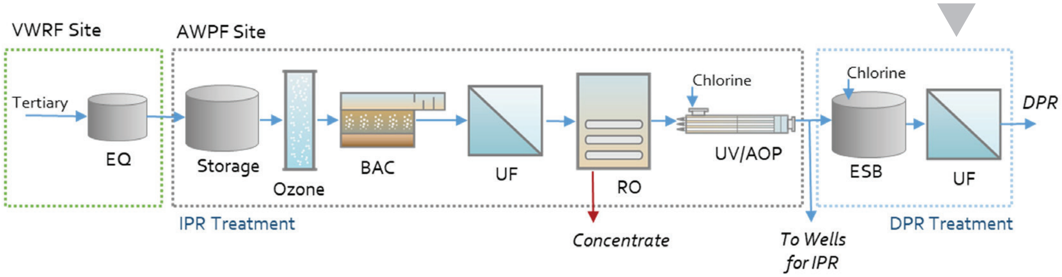
The initial IPR project will treat effluent from the Ventura Water Reclamation Facility (VWRF) through a new AWPF with a treatment train that is expected to be suitable for DPR under the forthcoming regulations (see treatment train schematics). For Phase 1a, the advanced treated water will be injected into a nearby aquifer for subsequent withdrawal and blending within the drinking water distribution system. The AWPF will be design to accommodate expansion of future flows for Phase 1b.

Phase 1b will expand the treatment capacity and will also either expand the IPR project, with the addition of new wells, or will allow for advanced treated water to be blended directly into the drinking water distribution system. Having both IPR and DPR options available would allow for greater operational flexibility.

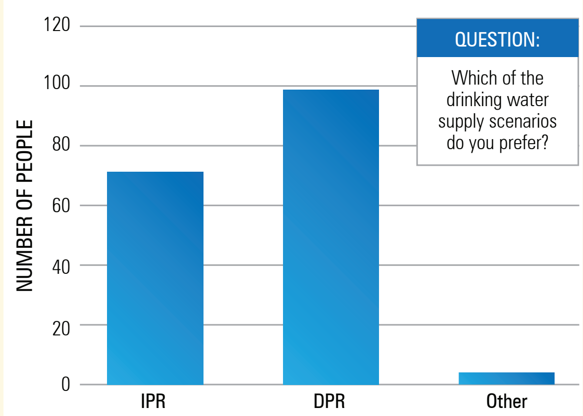


IPR treatment train

Potential future IPR/ DPR treatment train



Ventura Water operated a temporary DPR demonstration facility which raised public awareness and support for a future potable reuse project. Ventura Water is now installing a permanent DPR demonstration facility.



Survey results show positive support for potable reuse following a tour of the DPR demonstration facility,

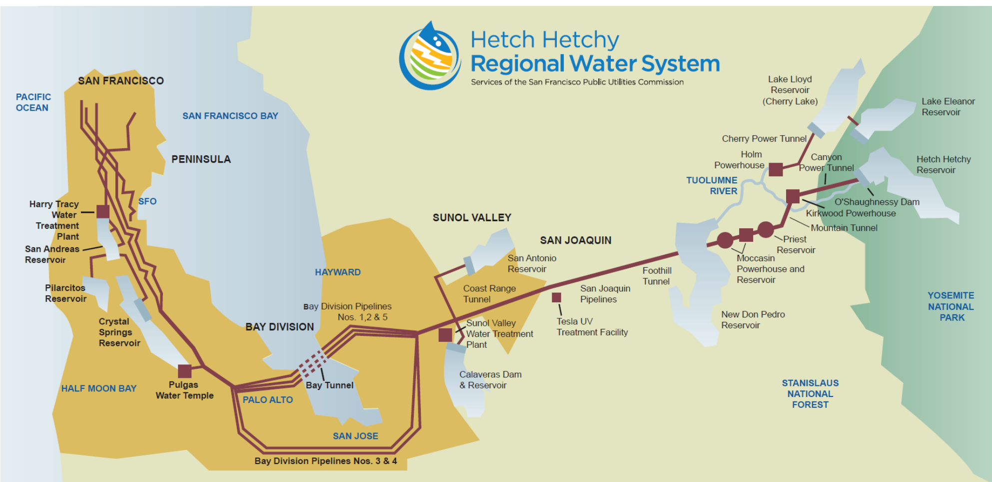
SFPUC

San Francisco Public Utilities Commission (SFPUC) serves 2.7 million customers within the San Francisco Bay Area, including both retail customers within the City of San Francisco and wholesale customers located throughout the region. SFPUC relies primarily on a blend of surface water supplies from both the Tuolumne and Bay Area watersheds.

SFPUC is currently investigating the feasibility of several potable reuse projects within its service area that would augment its water portfolio during drought-time shortages. The potential regional potable reuse projects make use of reservoirs and groundwater basins as environmental buffers that also provide storage. The City of San Francisco, however, is a densely populated, 7x7 square mile city with steep topography and no large reservoirs or surface water treatment plants—there is no clear IPR project option within the City.

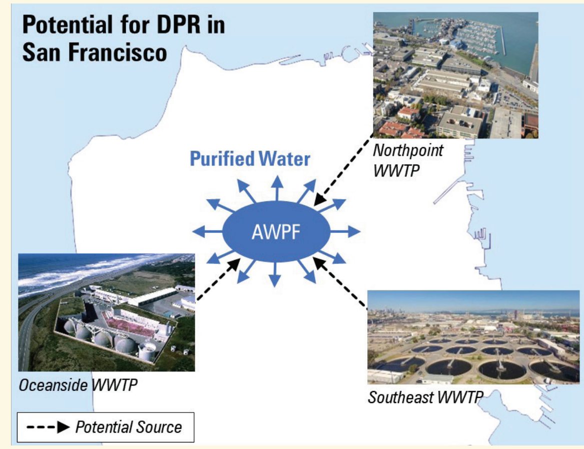
SFPUC is investigating treated drinking water augmentation within the City of San Francisco. Possible project details are as follows:

- SFPUC has a combined sewer system. One or more advanced treatment facilities could source wastewater effluent from one of SFPUC's two all-weather WWTPs or its wet-weather WWTP.
- Water from the advanced treatment facilities would be blended into the City's drinking water distribution system via one or more of the City's existing drinking water reservoirs.
- SFPUC is conducting a study to characterize the potential for DPR in San Francisco.

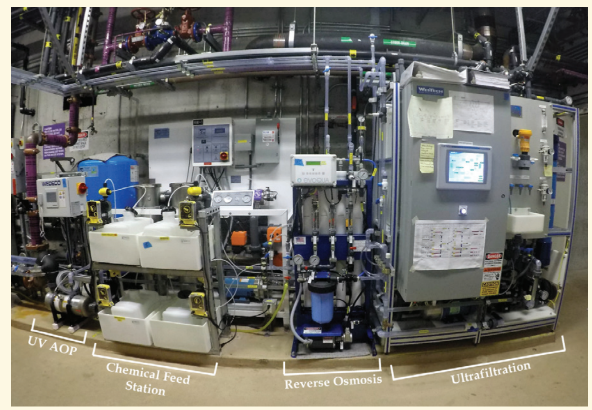


SFPUC's regional water system is complex and relies on bringing surface water supplies from across a wide region. Potable water reuse offers a local, reliable supply option.

San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission



DPR treatment facilities for treated drinking water augmentation could source water from any of San Francisco's three wastewater treatment plants.



An image of the 1 gallon per minute PureWaterSF DPR pilot project that was used to research decentralized DPR and provide public tours.

Santa Barbara

City of SANTA BARBARA

The City of Santa Barbara has a diverse water supply portfolio to meet the annual demand in the range of 11,000 to 12,000 acre-feet per year (AFY). This includes the following water supply used in 2020[1]:

- Local water supplies from Lake Cachuma (1,901 AF), Lake Gibraltar (4,335 AF), which flows through the Lauro Canyon Reservoir prior to treatment at the Cater Water Treatment Plant (WTP);
- Local groundwater (1,076 AF from Mission Tunnel, 22 AF from other groundwater);
- State Water that can be delivered into Lak Cachuma (none used in 2020);
- Desalinated water (2,749 AF), with a permitted capacity of 10,000 AFY; and
- Non-potable recycled water (1,024 AF).

The City currently has more than sufficient supply to meet the current demand, with approximately 24,000 AFY of total combined supply from the sources listed above.

The City has evaluated a range of potable reuse options to provide an additional ~6,000 AFY of future supply. Options include conventional groundwater recharge projects, augmentation of Lake Cachuma, and augmentation of Lauro Canyon Reservoir. Of these options, infrastructure and pumping costs determine that the Lauro Canyon Reservoir option is the most feasible due to the close proximity of the Reservoir (within City Limits adjacent to the Cater WTP). However, the augmentation of Lauro Canyon Reservoir will not meet the retention time requirements for indirect potable reuse via raw water augmentation and is thus a direct potable reuse project.

Central to the project is the use of the very small Lauro Canyon Reservoir (640 AF of total storage) and the use of the robust Cater WTP, which utilizes pre-ozonation, flocculation/sedimentation, dual media filtration, and free chlorine disinfection. Properly integrating in this purified water source, understanding blending impacts on the Cater WTP process operations, and understanding regulatory impacts to pathogen credits for the Cater WTP are central concerns.

The City is experienced with recycled water and advanced membrane treatment, through the successful implementation of non-potable reuse and seawater desalination (shown here).

Charles E. Meyer Desalination Plant in Santa Barbara.

1. City of Santa Barbara Water Supply Management Report, Draft, December 17, 2020.

LADWP

The Los Angeles Department of Water and Power (LADWP) is committed to maximizing the use of recycled water to address the need for a new resilient and independent water supply. LADWP is developing plans to recycle 100% of Los Angeles's wastewater for beneficial reuse, including potable reuse through raw water augmentation and treated water augmentation.

OPERATION NEXT WATER SUPPLY PROGRAM

The Operation NEXT Water Supply Program is a major initiative aimed at maximizing production of purified recycled water from the Hyperion Water Reclamation Plant for groundwater replenishment and raw water augmentation. Hyperion will be retrofitted with advanced treatment facilities to produce up to 217 MGD of purified recycled water, which will be used to replenish underlying aquifers in the San Fernando, Central, and West Coast Groundwater Basins and potentially connect to the Los Angeles Aqueduct Filtration Plant as well as MWD's Regional Recycled Water Program's Backbone System. Ongoing efforts include preparation of various planning, feasibility, route studies, interagency coordination, institutional agreements, and the development of a Programmatic Environmental Impact Report.

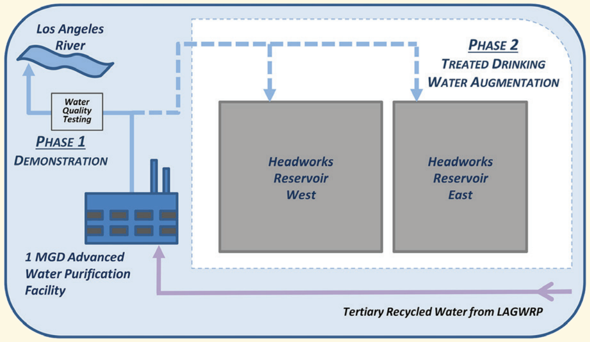
HEADWORKS DIRECT POTABLE REUSE DEMONSTRATION PROJECT

The Headworks Direct Potable Reuse Demonstration Project will guide future implementation of direct potable reuse projects at LADWP. The project will be implemented in three phases and will utilize water from the Los Angeles-Glendale Water Reclamation Plant (LAGWRP) to establish treated water augmentation at the Headworks Reservoir Complex near Griffith Park.

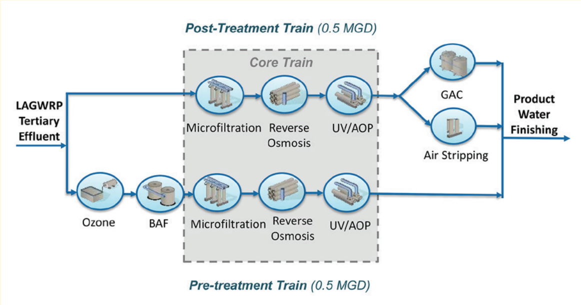
- Phase 1. Demonstration: a proof of concept platform to pilot emerging technology, establish control systems, and demonstrate LADWP's ability to produce safe, high quality drinking water. Multiple treatment trains will be operated simultaneously and evaluated for reliability and efficiency.
- Phase 2. Treated Water Augmentation: use the optimal treatment train to produce 1 MGD of purified water for blending with potable system water through the Headworks Reservoir Complex.
- Phase 3. Full-Scale: upgrade to a full-scale treated water augmentation facility.

This project is currently in the planning stage; ongoing efforts include the preparation of various feasibility studies.

Los Angeles Department of Water & Power



Phase 1 of the Headworks DPR Project will demonstrate LADWP's ability to safely produce purified recycled water. Phase 2 will implement treated water augmentation at the Headworks Reservoir Complex.



The Headworks DPR Project will run parallel treatment trains to measure the incremental benefit of adding unit processes to the core treatment.

IMPLEMENTATION OF DIRECT POTABLE REUSE

A GUIDE FOR CALIFORNIA WATER UTILITIES

FINAL | MARCH 2021

PREPARED FOR

- Los Angeles Department of Water and Power
- San Francisco Public Utilities Commission
- City of Santa Barbara – Public Works Department, Water Resources Division
- Valley Water
- City of Ventura – Ventura Water

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