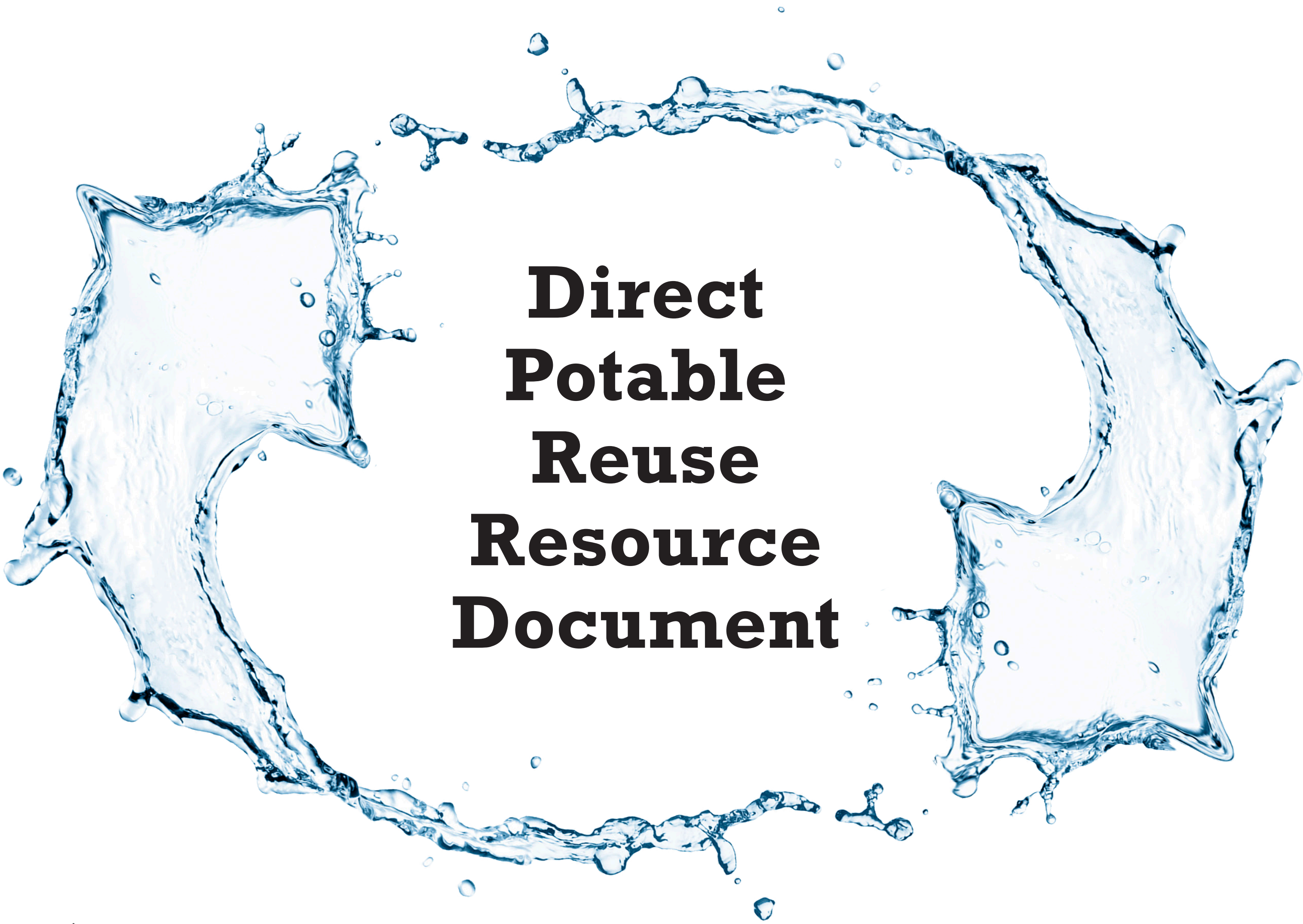
Texas Water Development Board
1700 North Congress Avenue
Austin, Texas 78711

FINAL REPORT



Direct Potable Reuse Resource Document

April 2015

TBPE Firm Registration No. F-13

ALAN PLUMMER ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERS AND SCIENTISTS

TWDB Contract No. 1248321508
Volume 1 of 2

In conjunction with:

EOA, Inc. • Lloyd Gosselink Attorneys at Law • Nellor Environmental Associates, Inc. • Separation Processes, Inc. • Soller Environmental, LLC • Trussell Technologies, Inc. • Dr. Jörg Drewes, Technical University of Munich • Dr. Steven Duranceau, University of Central Florida • Dr. Desmond Lawler, University of Texas at Austin • Dr. Shane Snyder, University of Arizona • Dr. George Tchobanoglous, University of California at Davis

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Austin, Texas 78711

FINAL REPORT

Direct Potable Reuse Resource Document

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ACKNOWLEDGMENTS

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Texas Water Development Board (lead sponsor agency)

Dr. Sanjeev Kalaswad
Dr. Robert Mace
Erika Mancha

Sponsors

City of College Station/ Brazos Valley Groundwater Conservation District
El Paso Water Utilities
City of Houston
City of Irving
City of Lewisville
City of Lubbock
San Antonio Water System
Upper Trinity Water Quality Compact

- City of Dallas
- City of Fort Worth
- North Texas Municipal Water District
- Trinity River Authority

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TABLE OF CONTENTS

Appendices (Volume 2)

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ACU	Apparent Color Units
ADIs	Acceptable Daily Intakes
AOC	Assimilable Organic Carbon
AOP	Advanced Oxidation Processes
AWT	Advanced Water Treatment
AWTF	Advanced Water Treatment Facility
BAC	Biological Activated Carbon
BDCM	Bromodichloromethane
BDOC	Biodegradable Dissolved Organic Carbon
BEG	Bureau of Economic Geology
BMPs	Best Management Practices
CCL3	Contaminant Candidate List 3 (US EPA)
CCPP	Calcium Carbonate Precipitation Potential
CDBM	Chlorodibromomethane
CFR	Code of Federal Regulations
CIUs	Categorical Industrial Users
COCs	Contaminants of Concern
CDC	The Centers for Disease Control
CECs	Constituents of Emerging Concern
CPCs	Constituents of Potential Concern
CRMWD	Colorado River Municipal Water District
CWA	Clean Water Act
DBPs	Disinfection By-Products
DBPR	Disinfection By-Products Rule
DDW	Division of Drinking Water (California)
DEET	N,N-diethyl-meta-toluamide
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DPR	Direct Potable Reuse
DWEL	Drinking Water Equivalent Level
EBCT	Empty Bed Contact Time

EDCs	Endocrine Disrupting Compounds
EEM	Excitation-Emission Matrix
EfOM	Effluent Organic Matter
EPA	United States Environmental Protection Agency
ERP	Enforcement Response Plan
ETEC	Enterotoxigenic *Escherichia coli*
GAC	Granular Activated Carbon
GC	Gas Chromatography
gpm	gallons per minute
HAA5	Haloacetic Acids
HI	Hazard Index
HRT	Hydraulic Loading Rate
gpd	gallons per day
IPR	Indirect Potable Reuse
IUs	Industrial Users
L	Liter
LC-MS/MS	Liquid Chromatography with Mass Spectrometric Detection
LCR	Lead and Copper Rule
LOAEL	Lowest Observed Adverse Effect Level
LSI	Langelier Saturation Index
MBR	Membrane Bioreactor
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
MEC	Measured Environmental Concentration
MF	Microfiltration
MGD	Million Gallons per Day
mg/L	milligrams per Liter
MOS	Margin of Safety
MRL	Method Reporting Limit
MTTs	Monitoring Trigger Thresholds
N	Nitrogen
NDMA	N- nitrosodimethylamine
NF	Nanofiltration

ηg/L	nanogram per Liter
NOAEL	No Observed Adverse Effect Level
NOM	Natural Organic Matter
NRC	National Research Council
NSAID	Non-Steroidal Anti-Inflammatory Drug
NSF	National Sanitation Foundation International
O&M	Operation and Maintenance
PAC	Powdered Activated Carbon
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
POTW	Publicly Owned Treatment Works
PPCPs	Pharmaceuticals and Personal Care Products
PNEC	Predicted No Effect Concentration
PWS	Public Water System
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QMRA	Quantitative Microbial Risk Assessment
qPCR	quantitative Polymerase Chain Reaction
QRRA	Quantitative Relative Risk Assessment
RBAL	Risk-Based Action Level
RfD	Reference Dose
RO	Reverse Osmosis
RSI	Ryznar Stability Index
RTCR	Revised Total Coliform Rule
SCL	Secondary Constituent Level
SDWA	Safe Drinking Water Act
SF	Slope Factor
SIU	Significant Industrial User
SMCL	Secondary Maximum Contaminant Level
SRT	Solids Retention Time
STEC	Shiga Toxin producing *Escherichia coli*
SWRCB	State Water Resources Control Board (California)
SWQMS	Surface Water Quality Monitoring System

SWTR	Surface Water Treatment Rule
TAC	Texas Administrative Code
TCA	Trichloroacetic Acid
TCDPP	Tris (1,3-dichloro-2-propyl) phosphate
TCEP	Tris-(2-Carboxyethyl)phosphine
TCEQ	Texas Commission on Environmental Quality
TCPP	Tris (1-chloro-2-propyl) phosphate
TDIs	Tolerable Daily Intakes
TDS	Total Dissolved Solids
THM	Trihalomethanes
THSC	Texas Health and Safety Code
TOC	Total Organic Carbon
TON	Threshold Odor Number
TPDES	Texas Pollutant Discharge Elimination System
TRI	Toxics Release Inventory
TSWQS	Texas Surface Water Quality Standards
TSS	Total Suspended Solids
TWDB	Texas Water Development Board
UCMR	Unregulated Contaminant Monitoring Rule
UER	Upper End Reduction
UF	Ultrafiltration
US	United States
UV	Ultraviolet Irradiation
WBMWD	West Basin Municipal Water District
WHO	World Health Organization
WRF	Water Research Foundation
WRP	Water Reclamation Plant
WRRF	WateReuse Research Foundation
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

1 Introduction

Road Map

In This Chapter

- » Project background and drivers for direct potable reuse in Texas
- » Purpose of the resource document
- » Structure of the resource document

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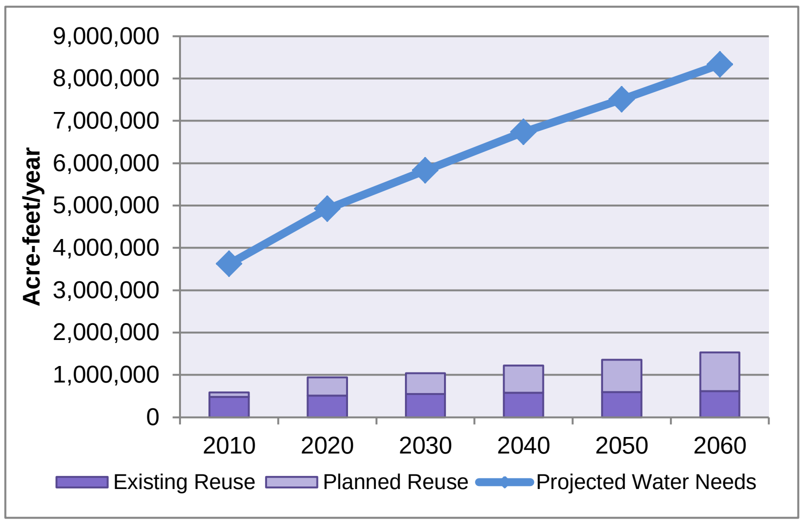
1.1 Background on Water Reuse in Texas

Texas law defines the beneficial use of reclaimed water to be the economic use of domestic or municipal wastewater that has been treated to a suitable quality for a specific use and takes the place of potable and/or raw water that would otherwise be needed from another source.[1] Water reuse has been identified as an important component of the future water supply portfolio for Texas to support population growth and continued economic development. Planned water reuse has been practiced in Texas since the late 1800s. While initial uses were primarily for irrigation of agriculture, today reclaimed water is used for a wide range of beneficial purposes, including power plant cooling water, commercial and municipal irrigation, river and stream flow enhancement, natural gas exploration activities, and augmentation of drinking water supplies (potable reuse).

According to the 2012 State Water Plan water reuse will provide approximately 1.53 million acre-feet per year of water supply statewide by the year 2060 and will meet approximately 18% of the projected water needs (TWDB, 2012). However, there is significantly more potential for development of water reuse as a water management strategy than is currently included in the state water plan. Much of this potential is likely to be realized through the development of potable reuse projects, particularly as progress is made in communicating the advantages, benefits and safety of potable reuse to the public.



Source: TWDB, 2012

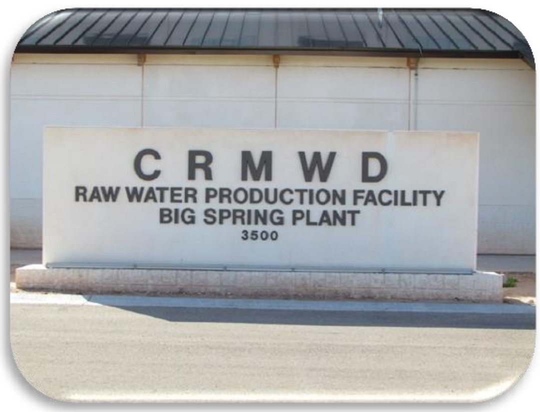
Figure 1-1: Role of water reuse by decade in 2012 State Water Plan

Through various funding programs, the Texas Water Development Board (TWDB) has provided financial support for efforts to develop information and perform research that will help to advance the implementation of water reuse in Texas. In 2011, as part of a TWDB-funded project called *Advancing Water Reuse in Texas*, the TWDB published a series of documents that address public awareness, technical issues, and research needs associated with water reuse in Texas. One of these documents, titled *Water Reuse Research Agenda* (APAI, 2011), presented

[1] See Texas Administrative Code, Title 30, Section 210.3.

a prioritized list of research projects that, if performed, would help advance the implementation of water reuse water management strategies in the state.

For purposes of this document, direct potable reuse (DPR) is defined as: the introduction of advanced-treated reclaimed water either directly into the potable water system or into the raw water supply entering a drinking water treatment plant (WTP).



At the time of publication of this document, two DPR projects were in operation in Texas and a significant portion of the state was experiencing unprecedented drought conditions. Both of these projects were planned and implemented without the benefit of any comprehensive guidance resources specifically addressing issues associated with DPR. As a result of the drought, as well as recognition that DPR was being implemented and accepted within some Texas communities, the TWDB identified a need for a technical resource document that could be used by water utilities, consultants and other stakeholders involved in the planning and implementation of DPR projects. Through funding from the TWDB and 13 utility/agency sponsors, this resource document has been developed to meet that need.

Potable Reuse Definitions (also see Figure 1-2)

De facto Water Reuse:

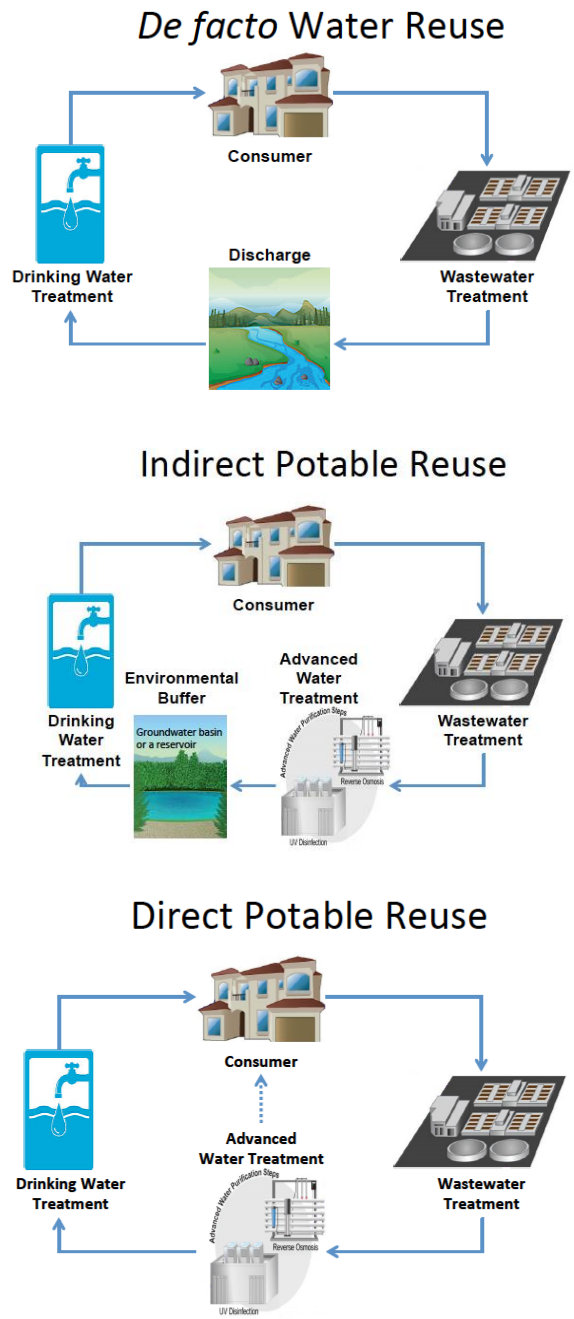
A drinking water supply that contains a significant fraction of treated wastewater, typically from wastewater discharges, although the water supply has not been permitted as a water reuse project.

Indirect Potable Reuse (IPR):

The use of reclaimed water for potable purposes by discharging to a water supply source, such as a surface water or groundwater. The mixed reclaimed and natural waters then receive additional treatment at a water treatment plant before entering the drinking water distribution system.

Direct Potable Reuse (DPR):

The introduction of advanced-treated reclaimed water either directly into the potable water system or into the raw water supply entering a water treatment plant.



Source: Courtesy of WateReuse Research Foundation, 2015

Figure 1-2: Types of potable reuse.

1.2 Purpose of the Direct Potable Reuse Resource Document

The TWDB allocated priority research funding to support the development of a resource document that will provide scientific and technical information related to the implementation of direct potable reuse (DPR) projects in Texas. The TWDB is coordinating closely with the Texas Commission on Environmental Quality (TCEQ) in the development of this resource document.

> **This document…**
>
> - ***IS*** *a technical resource*
> - ***IS NOT*** *a regulatory document*

The document is intended to be a technical resource for utilities, consultants, planners, academicians, and other parties interested in evaluating the feasibility of implementing DPR or for utilities that have determined that DPR is feasible and are entering the planning phase of a project. The topics covered are intended to provide a foundation on which to build. A significant amount of research is ongoing on a number of topics related to DPR, so while the document is representative of the current state of knowledge, it is not intended to be completely comprehensive and would benefit from periodic updates as new or updated information is developed.

It should be emphasized that while technical staff from TCEQ participated in the project and provided feedback on its content, this is not a regulatory document. It is a resource and reference document. It is strongly recommended that any public water system interested in pursuing DPR meet with the TCEQ Water Supply Division and Water Quality Division early in the pre-planning phase of the project to ensure that regulatory requirements will be adequately addressed.

Although the focus of this document is on DPR, a review of the significance of environmental buffers (such as surface water reservoirs or groundwater aquifers) with respect to indirect potable reuse (IPR) projects was performed as part of this project (see Appendix A). Environmental buffers, when available, can provide benefits and any decision to pursue a potable reuse project should consider all options available (both IPR and DPR) and the advantages and disadvantages of each.

1.3 Structure of Document

For most of the technical topics addressed in each of the following chapters, a detailed technical memorandum was developed during the course of the project. The chapter text is essentially an executive summary of the information contained in each technical memorandum. The complete technical memoranda are provided as appendices. Therefore, if additional detail is desired on a particular topic, it can be found by referencing these appendices. In addition, throughout the document numerous references have been cited that also provide valuable resources for those interested in delving into more detail.

1.4 Document Development

The document and issue-specific TMs were prepared by a consultant team under the leadership of Alan Plummer Associates, Inc. Other team members included:

- EOA, Inc.
- Lloyd Gosselink Attorneys at Law
- Nellor Environmental Associates, Inc.
- Separation Processes, Inc.
- Soller Environmental, LLC
- Trussell Technologies, Inc.
- Dr. Jörg Drewes, Technical University of Munich
- Dr. Steven Duranceau, University of Central Florida
- Dr. Desmond Lawler, University of Texas at Austin
- Dr. Shane Snyder, University of Arizona
- Dr. George Tchobanoglous, University of California at Davis

Project sponsors included the TWDB, WateReuse Texas, and the following Texas utilities:

- City of College Station/ Brazos Valley Groundwater Conservation District
- El Paso Water Utilities
- City of Houston
- City of Irving
- City of Lewisville
- City of Lubbock
- San Antonio Water System
- Upper Trinity Water Quality Compact:
  - City of Dallas
  - City of Fort Worth
  - North Texas Municipal Water District
  - Trinity River Authority

Two stakeholder meetings were held during the course of the project with key members of the technical team, TCEQ, and project sponsors to obtain feedback on the key issues to be addressed in the document.

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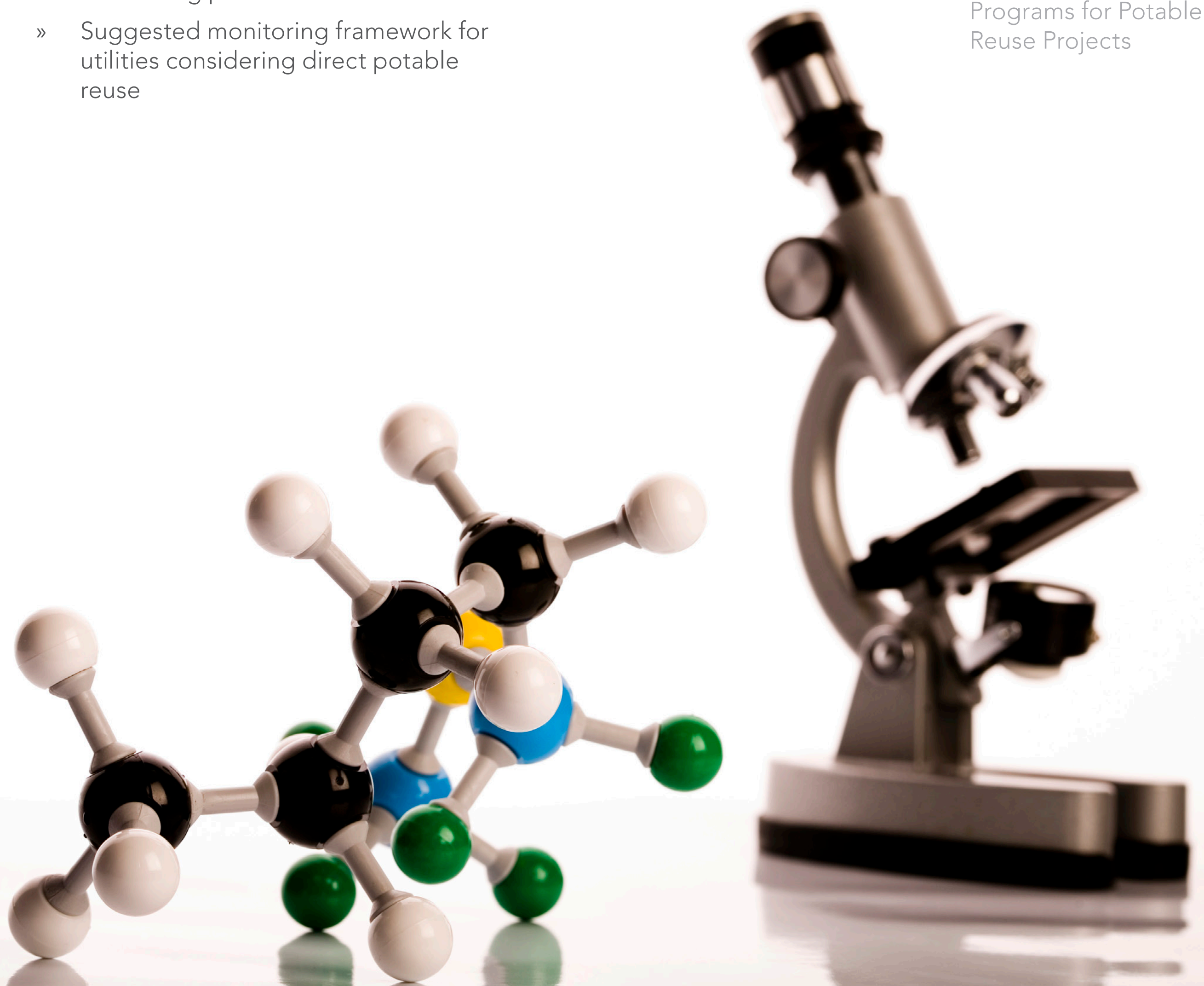
2 Relevance of Chemical Contaminants of Concern in Texas

In This Chapter

- Statewide water quality trends in surface water and groundwater
- Key water quality data from national studies
- Review of analytical technology for monitoring potable reuse
- Suggested monitoring framework for utilities considering direct potable reuse

Road Map



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2.1 Introduction

Water quality and the safety of drinking water is a primary focus for any direct potable reuse (DPR) project. For this document, a number of terms are used to discuss water quality, including chemical, compound, contaminant, and constituent, which are defined in the glossary. Two terms will primarily be used throughout the document: (1) constituent, which is used to describe a chemical or compound, and (2) contaminant, which is any physical, chemical, biological, or radiological substance that has an adverse effect on air, water, or soil substance (often also called pollutants).

When considering DPR projects, pathogens, contaminants of concern (COCs) and constituents of emerging concern (CECs) present in the originating wastewater (source water for DPR treatment schemes) and treated reclaimed water should be evaluated.[2] The objective would be to determine if and what treatment or management strategies may be required to produce a raw source water for further treatment at a water

What are COCs and CECs?

Contaminants of Concern (COCs) are:

- *Any substance that has an adverse effect on human health that is regulated in drinking water or under consideration for regulation in Texas or at the national level.*
- *A substance that may not pose a health risk, but that can inform treatment process effectiveness and maintenance.*

Constituents of Emerging Concern (CECs) are:

- *Chemicals or compounds not regulated in drinking water or reclaimed water and /or not routinely monitored. They may be candidates for future regulation depending on their ecological toxicity, potential human health effects, public perception, and frequency of occurrence in environmental media (Lazorchak and others, 2008).*
- *Constituents that have been present in the environment for a long time, but for which analytical or health data have only recently become available (NRC, 2012).*

[2] In Chapter 6, as part of the Quantitative Relative Risk Assessment (QRRA), COCs and CECs are further differentiated. Contaminants of Concern that (1) are detected in the waters used for the example QRRAs, (2) are regulated or are currently under consider for regulation, and (3) have published toxicity information are referred to as Constituents of Potential Concern (CPCs). For the example QRRAs, CECs are defined as unregulated detected constituents with published toxicity information to evaluate their health significance.

treatment plant or a finished drinking water. In all cases, the final drinking water must meet the TCEQ standards for a drinking water supply.

It should be noted that pathogens represent the most immediate, acute health concern for DPR. Information on pathogens is provided in Chapter 3. Information provided in Chapter 2 focuses on chemical COCs and CECs for DPR.

With current and future analytical methods, it will be possible to detect nearly any constituent in drinking water, reclaimed water, and/or wastewater at trace levels. Detection of COCs and CECs is not the pinnacle issue. The critical issue is their health and environmental relevance and their utility in evaluating treatment performance.

Some examples of CECs include pharmaceuticals and ingredients in personal care products (PPCPs), endocrine disrupting compounds (EDCs), pesticides, and components of household products.

The primary goals of this chapter are to:

- Provide an overview of available water quality data for chemical COCs and CECs relevant to potable reuse in Texas;
- Identify information gaps;
- Summarize challenges with water quality monitoring; and
- Provide a recommended chemical monitoring framework for DPR projects.

2.2 Summary of Chemical Contaminants of Concern and Constituents of Emerging Concern in Texas

A summary of the available chemical COC and CEC data in Texas is provided in this section. Water quality information summarized in this section includes information from Texas Water Development Board (TWDB) reports, data provided by participating project sponsors, and data from a literature review of published studies conducted for Texas waters.

2.2.1 Statewide Raw Water Quality Trends

The state of Texas spans a territory of 268,820 square miles. Geological conditions and land use across the State vary widely, affecting chemical and aesthetic groundwater and surface water qualities, and thus can also affect the chemical and aesthetic quality of reclaimed water. Information on surface water quality in Texas is available from TCEQ. Groundwater quality information is maintained by the TWDB.

2.2.1.1 Groundwater

Groundwater Information Resources

The TWDB's Groundwater Resources Division is responsible for all aspects of groundwater studies in the state. They monitor groundwater levels and groundwater quality in 9 major and 21 minor aquifers, conduct regional-scale groundwater modeling, and house and maintain water well records.

For more information, visit:

http://www.twdb.state.tx.us/groundwater/index.asp

Maps previously developed by the TWDB illustrating the concentrations of regulated COCs present in groundwater are a useful resource for depicting raw water quality trends (Reedy and others, 2011). Maps are available for the following regulated COCs:

Antimony	Mercury	Aluminum
Arsenic	Nitrate-N	Chloride
Barium	Nitrite-N	Iron
Beryllium	Selenium	Manganese
Cadmium	Thallium	Silver
Chromium	Gross alpha-radiation activity	Sulfate
Copper	Gross beta-radiation activity	pH
Fluoride	Combined radium radiation	Silica
Lead	Uranium	Total dissolved solids (TDS)

As an example, a map for TDS is shown in Figure 2-1[3]. Similar maps for the other regulated COCs are included in Appendix B. Across the State, a number of constituents with primary drinking water standards [arsenic, gross alpha-radiation, combined radium, and nitrate-as nitrogen (N)] were detected in groundwater at concentrations greater than their allowable drinking water maximum contaminant levels (MCLs) in more than 5% of groundwater samples

[3] Maps were developed based on groundwater analysis from the TWDB water quality database from 1988-2010.

analyzed. When examining constituents with secondary drinking water standards, concentrations of TDS, sulfate, manganese, iron, fluoride, and chloride were greater than the allowable federal secondary MCL (SMCL) in more than 10% of groundwater samples analyzed. Texas has recognized that naturally-occurring sources of dissolved salts result in higher concentrations of some constituents in parts of the State. As a result, the TCEQ has established secondary constituent levels (SCLs) for TDS, sulfate and chloride that are higher than the SMCLs (Table 2-1)[4].

Table 2-1: Comparison of Federal and Texas secondary levels of interest

Constituent	SMCL (mg/L)	SCL (mg/L)
Aluminum	0.05 to 0.2	0.05 to 0.2
Chloride	250	**300**
Copper	1.0	1.0
Fluoride	2.0	2.0
Iron	0.3	0.3
Manganese	0.05	0.05
Silver	0.1	0.1
Sulfate	250	**300**
TDS	500	**1,000**
Zinc	5	5.0

SMCL = secondary maximum contaminant level (refers to EPA secondary standard)
SCL = secondary constituent level (refers to TCEQ secondary standard)
mg/L = milligrams per liter. Bold numbers indicate higher SCL than SMCL.

[4] When referring to secondary drinking water standards, the term for the federal (EPA) standard is 'secondary maximum contaminant level' (SMCL). The EPA SMCLs are not enforceable. The TCEQ term for secondary drinking water standards is 'secondary constituent level' (SCL). In Texas, the SCLs are enforceable.

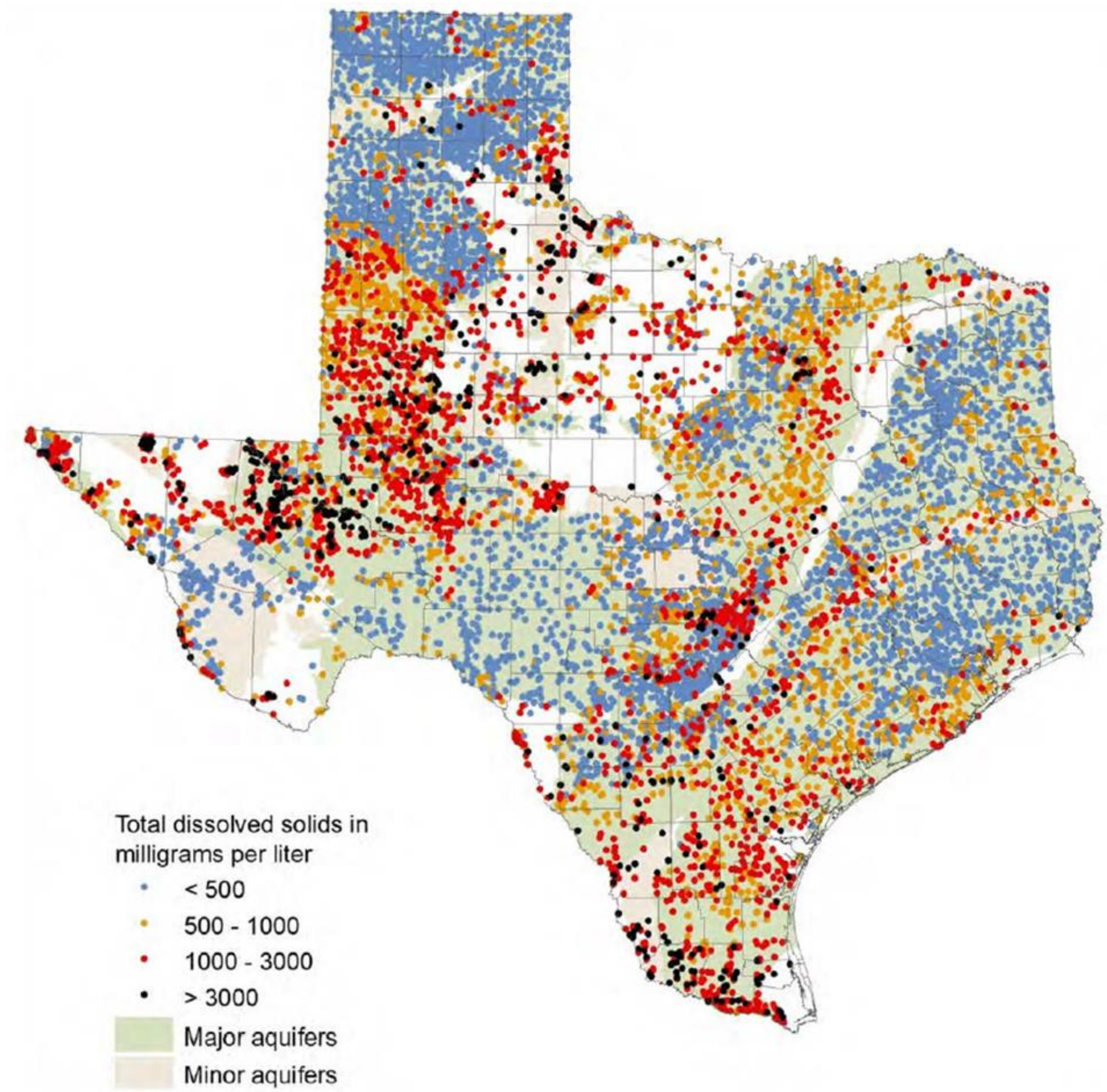


Figure 2-1: Total dissolved solids concentrations in Texas groundwater[5].

[5] Prepared by Bureau of Economic Geology (BEG for TWDB Contract #1004831125, with data from TWDB (Reedy and others, 2011). Maps for additional constituents, as well as maps of the major and minor aquifers of Texas, are shown in Appendix B.

2.2.1.2 Surface Water

Similar maps were developed for surface water based upon the Texas Surface Water Quality Standards (TSWQS) established by TCEQ, and data obtained from the Texas Surface Water Quality Monitoring System database (SWQMS)[6]. The TSWQS include designated uses for surface waters, such as drinking and agricultural use, and numeric and narrative water quality criteria to protect those uses as part of the TSWQS. For protection of human health for drinking water uses, the criteria do not consider cost or feasibility per the Clean Water Act (CWA). The CWA approach differs in comparison to how drinking water standards are established under the Safe Drinking Water Act (SDWA) in that the SDWA takes into consideration technical feasibility and cost. In addition, not all surface waters are designated as sources of drinking water in Texas. For TDS, chloride and sulfate, the TSWQS water quality criteria are typically based on historical concentrations in each stream segment; therefore, the criteria for these constituents provide a general indication of expected concentration levels. As an example, the range of TDS in surface water statewide based on the TSWQS is shown in Figure 2-2. Maps for other constituents (alkalinity, total suspended solids (TSS), total organic carbon (TOC), hardness, and turbidity) were developed using average values of the last 10 years of historical data obtained from the SWQMS database (see Appendix B).

TCEQ Surface Water Quality Monitoring

- *The TCEQ Surface Water Quality Monitoring (SWQM) program monitors and evaluates physical, chemical, and biological characteristics of aquatic systems.*
- *The SWQM program coordinates the collection of physical, chemical, and biological samples from more than 1,800 surface water sites statewide.*
- *For more information, visit http://www.tceq.texas.gov/waterquality/monitoring/index.html*

[6] The Texas Surface Water Quality Monitoring System is maintained by TCEQ.

Secondary Drinking Water Standards		
Constituent	SMCL	SCL
TDS (mg/L)	500	1000

SMCL = secondary maximum contaminant level (EPA)

SCL = secondary contaminant level (Texas)

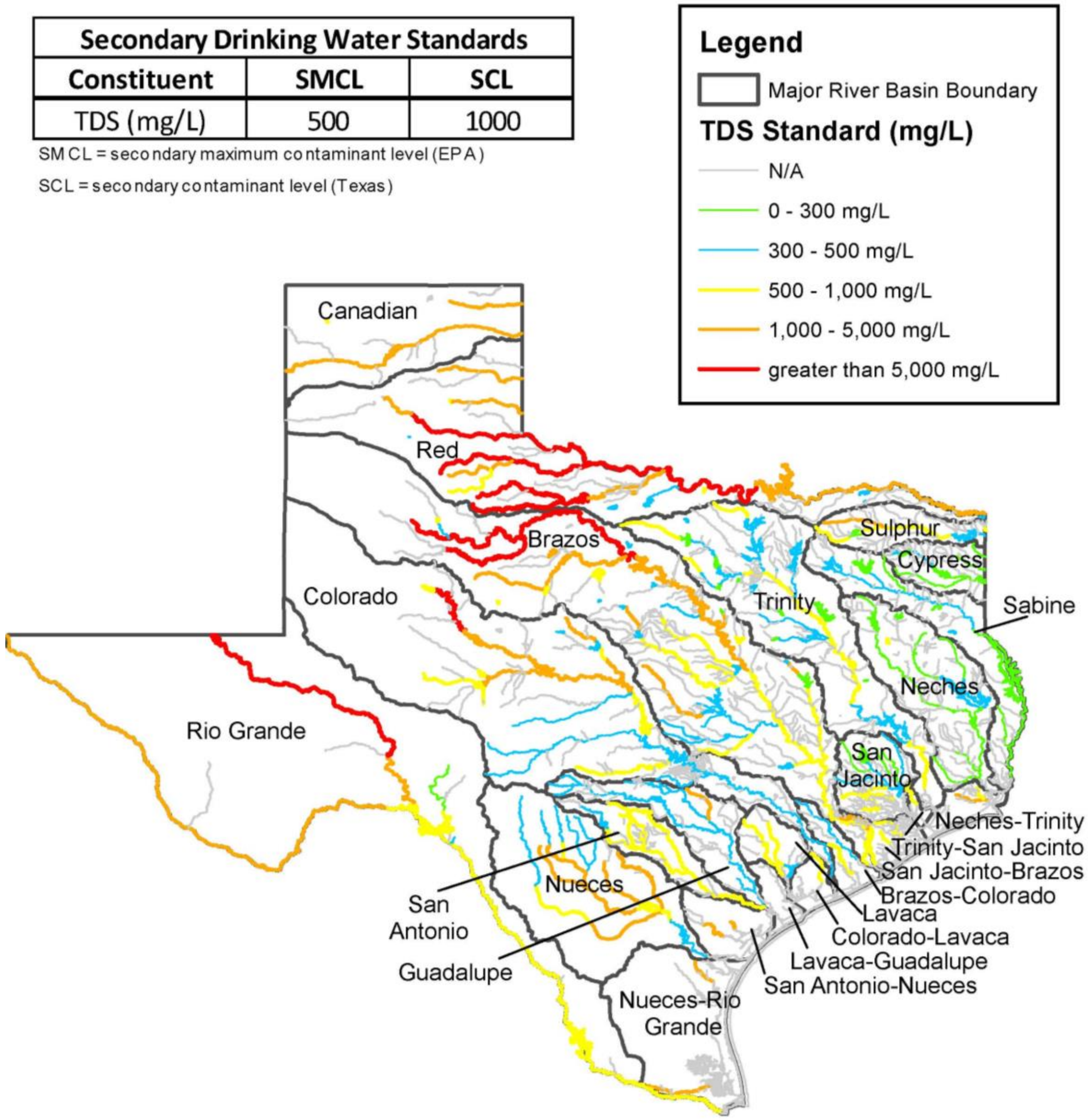


Figure 2-2: Texas total dissolved solids (TDS) surface water quality standards and secondary drinking water standards[7].

[7] Maps for additional constituents are shown in Appendix B.

Information was also obtained from the 2006 State regional water plans[8] and used to summarize water quality "concerns" identified by each of the regional water planning groups and is presented in Figure 2-3. The intent of identifying the concerns was to identify potential water quality issues that might impact the sustainability of existing water supplies or the development of future water supplies in each of the planning regions. Water quality concerns were not strictly defined in the regional plans, and concerns may have been interpreted differently among the regions. However, the constituents shown in Figure 2-3 do give some indication of COCs that may be of interest in planning for future water supplies in the given region. A public water system (PWS) considering DPR will need to have a comprehensive understanding of local water quality conditions as well as the site-specific monitoring and water quality requirements applied by the TCEQ's Water Supply Division during the approval process.

2.2.2 Stakeholder Data

A total of 12 municipal utility stakeholders participated in the TWDB DPR project. At the request of the technical team, each stakeholder provided three years of water quality data for both raw source water (groundwater or surface water, depending on the utility) and treated wastewater[9]. The data were comprised of both regulated and unregulated constituents (if available). In general, for the raw source water, the reported data for the regulated constituents (where data were provided) were at levels below the MCLs and often below detection limits. For treated wastewater, very little data were available for MCL constituents since sampling at these facilities has primarily focused on Priority Pollutants[10] and other TSWQS and CWA requirements.

[8] The TWDB has implemented a regional water planning process that is updated every 5 years. Regional water planning groups in each of the 16 regions shown in Figure 3 are responsible for compiling relevant data and presenting a water supply plan. In the 2006 plans, the regional water planning groups were tasked with identifying potential water quality concerns in their regions. This information was summarized in each of the regional plans. This information was not provided in the 2011 regional plans.

[9] Stakeholder wastewater treatment generally included conventional activated sludge with disinfection at a minimum. Most facilities include sand or media filters and many currently have nutrient removal or plan to add nutrient removal in the near future.

[10] The 126 chemical pollutants regulated by the U.S. Environmental Protection Agency. The current list of chemicals can be found in Appendix A to Section 40 of the Code of Federal Regulations, Part 423.

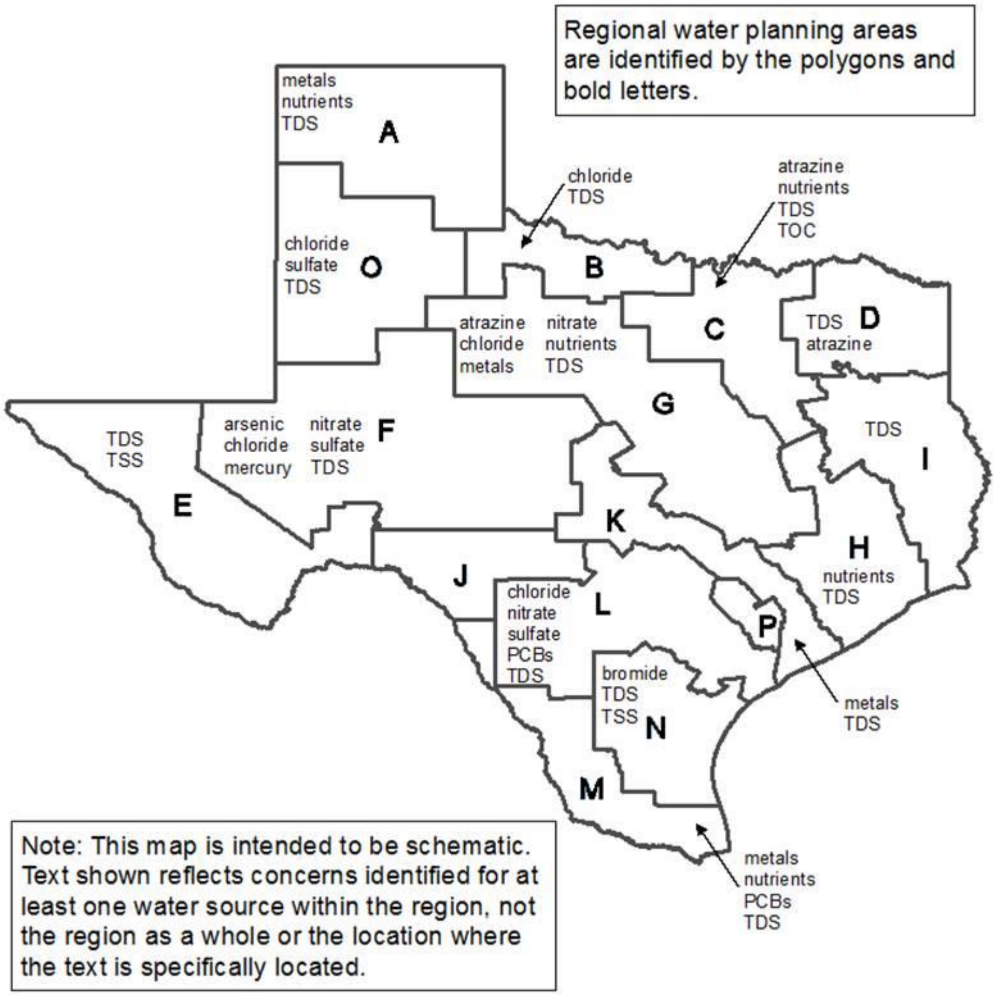


Figure 2-3: Summary of water quality concerns for chemicals identified in the 2006 Regional Water Plans

It was also of interest to evaluate the extent to which contaminants currently on the EPA's Contaminant Candidate List 3 (CCL 3) are being monitored and measured. A complete data set for CCL 3 constituents was not provided; however some data for some CCL 3 constituents were available. The availability of the data is attributed primarily to monitoring that occurred through the Unregulated Contaminant Monitoring Rule (UCMR) program (for raw source water) or constituents that are also Priority Pollutants sampled in wastewater. A summary of stakeholder raw source water and treated wastewater quality data, including CCL 3 contaminants sampled, is provided in Appendix B.

What is the Contaminant Candidate List 3?

The Contaminant Candidate List 3 (CCL 3) is a list of contaminants that are currently not subject to any proposed or promulgated national primary drinking water regulations, that are known or anticipated to occur in public water systems, and which may require regulation under the Safe Drinking Water Act. The list includes, among others, pesticides, disinfection byproducts, chemicals used in commerce, waterborne pathogens, pharmaceuticals, and biological toxins. The final CCL 3 includes 104 chemicals or chemical groups and 12 microbiological contaminants.

The United States Environmental Protection Agency is currently requesting nominations for a fourth Contaminant Candidate List, CCL 4.

For more information, visit:

http://water.epa.gov/scitech/drinkingwater/dws/ccl/index.cfm

2.2.3 Data from Other Studies

A literature review of published studies in Texas involving CECs was performed. The studies focused on different areas of the State, different CECs, and different sampling targets (surface water in some cases and wastewater in others). A summary of the studies is provided in Table 2-2. A summary of contaminants sampled, together with measured concentrations (where available) is provided in Appendix B. As seen from Table 2-2, a limited number of published studies were identified. Concentrations of CECs observed in the studies were at very low levels (nanograms per liter or ng/L) and generally were consistent with concentrations observed in treated wastewater or wastewater

How much is a nanogram/Liter?

A nanogram (ng) is a unit of mass that is one billionth (10^{-9}) of a gram. A concentration of 1 ng/L is equivalent to less than one drop of water in an Olympic sized swimming pool.

effluent-dominated surface waters elsewhere in the United States (U.S.) (Anderson et al., 2010; NRC, 2012).

Table 2-2: Summary of published studies investigating constituents of emerging concern in Texas

Reference	CECs	Study Scope
Barnes and others, 1999	21 antibiotic compounds, 40 organic wastewater compounds, 14 steroid and hormone compounds	Sampled the Trinity River below Dallas as part of nationwide study of U.S. streams
Fono and others, 2006	Wastewater derived compounds, pharmaceuticals	Examined attenuation in effluent-dominated rivers; sampled 5 locations along the Trinity River beginning south of the Dallas/ Fort Worth Metroplex and ending near Houston, northwest of Lake Livingston
Ging and others, 2009	277 organic compounds tested, 103 detected, including pesticides, solvents, gasoline hydrocarbons, and personal care products	Examined the Elm Fork of the Trinity River (near Carrollton) from 2002 to 2005
Foster, 2007	23 known or suspected EDCs	Investigated removal efficiency throughout the San Marcos Wastewater Treatment Plant
Karnjanapiboonwong and Anderson, 2010	6 PPCPs	Examined occurrence at the Lubbock Water Reclamation Plant and land application site (including soil and groundwater receiving the treated wastewater)
Battaglin and others, 2008	Pesticides	Streams near the towns of Electra, DeLeon, and Tilden were examined for runoff from peanut fields

CEC: Constituent of Emerging Concern

2.3 Relevant Data from Outside Texas Related to Direct Potable Reuse

The National Research Council (NRC, 2012) noted that low concentrations of a variety of organic constituents can be present in wastewater as shown in Table 2-3. A comprehensive evaluation of COC and CEC data outside of Texas is beyond the scope of this project. However, one relevant example is the data assembled to identify a list of CECs for monitoring reclaimed water for indirect potable reuse (specifically indirect potable reuse through groundwater replenishment using reclaimed water) as part work conducted by an Expert Panel for the California State Water Resources Control Board (SWRCB) pursuant to its Recycled Water Policy (Anderson and others, 2010). The Panel developed a survey that considered sampling locations, analytical methods used for quantification, frequencies, and treatment processes for the water reuse practices within the state of California and of interest to the State Water Resources Control Board (SWRCB).

Table 2-3: Categories of constituents of concern and constituents of emerging concern (natural and synthetic) detectable in reclaimed water

Category	Examples
Disinfection byproducts	Bromoform, Chloroform, N-Nitrosodimethylamine (NDMA), Trihalomethanes
Household products and food additives	Alkylphenol polyethoxylates, Bisphenol A, Dibutyl phthalate, Flame retardants, Perfluorooctanoic acid, Perfluorooctane sulfonate, Sucralose
Industrial	1,4-Dioxane, Methyl tert-butyl ether, Perflurooctanoic acid, Tetrachloroethane
Naturally occurring	2-Methylisoborneol, Geosmin, Hormones (17β -estradiol), Phytoestrogens,
Personal care product ingredients	Fragrances, Pigments, Triclosan, Sunscreen ingredients
Pesticides	Atrazine, Diuron, Fipronil, Lindane,
Pharmaceuticals and metabolites	Analgesics (Acetominophen, Ibuprofen), Antibacterials (Sulfamethoxazole), Antibiotics (Azithromycin), Antiepileptics (Phenytoin, Carbamazepine), Beta-blockers (Atenolol), Oral contraceptives (Ethinyl estradiol)

Source: Table 3-3 (NRC, 2012)

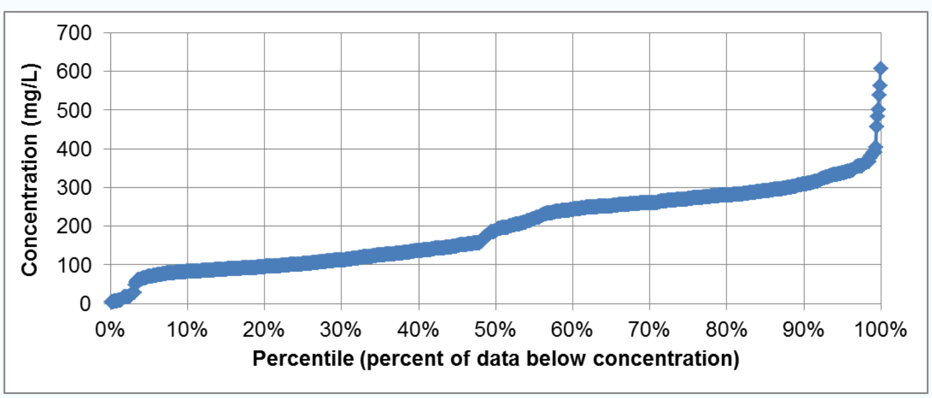
The survey was provided to stakeholders in California and CEC monitoring data were requested for the time period 2007 and 2009. The Panel received survey responses from water and wastewater utilities in California, the WateReuse Association of California, commercial laboratories, and research laboratories that were engaged in monitoring efforts for CECs in recycled water projects in California. The Panel screened these databases and summarized the occurrence of CECs in these reuse applications in California. The CECs included CCL 3 and non-CCL 3 constituents. As a conservative approach, only the measured environmental concentrations (MECs) representing secondary or tertiary[11] effluent qualities and not advanced water treatment were compiled to represent the final MEC for the purposes of selecting CECs for monitoring groundwater replenishment projects. The combined effluent qualities represent a conservative estimate of MECs for groundwater replenishment projects since treatment credit was not included for additional advanced water treatment processes, dilution in groundwater, and/or incidental treatment in the soil-aquifer system after surface application of reclaimed water.

The 90th percentile MECs of CCL 3 CECs (only eight were identified) and the 90th percentile non-CCL 3 CECs (43 were identified) for California are presented in Table 2-4 and Table 2-5, respectively. In Table 2-4, the 90th percentile concentration of estrone is shown as 73 ng/L, which means that 90% of the other measured data values were less than 73 ng/L. Only 10% of the data values were reported at concentrations greater than 73 ng/L.

The next update of California CEC monitoring by a SWRCB expert panel will occur in 2015.

Data presented as percentiles - what does it mean?

Multiple data samples for individual constituents are often statistically summarized in terms of percentiles. The nth percentile is a place in a data set that lists concentrations from lowest to highest. For example, if a concentration of a contaminant is reported as a 90th percentile value, 90% of the data values in the data set for that contaminant are below this value and 10% are above this value.



[11] Tertiary treatment is defined as standard secondary treatment with filters and disinfection.

Table 2-4: 90th percentile measured environmental concentrations of Contaminant Candidate List 3 constituents of emerging concern in California secondary and tertiary[12] effluent

CCL3 CECs	Category	Occurrence in Recycled Water Secondary/Tertiary Treated (ng/L) (90th percentile)
17α-estradiol	Hormone	1
17β-estradiol	Hormone	8.4
Erythromycin	Antibiotic	113
Estrone	Hormone	73
Ethinyl estradiol	Hormone	1
PFOA	Manufacture of Non-stick polymer	28
PFOS	Manufacture of Non-stick polymer	90
NDMA	Disinfection byproduct	68

Source: Table 5.1 (Anderson and others, 2010)
CCL3 = Contaminant Candidate List 3, CEC = Constituent of emerging concern, NDMA = N-nitrosodimethlyamine, PFOA = Perfluorooctanoic acid, PFOS = Perfluorooctane sulfonate

Table 2-5: 90th percentile measured environmental concentrations of non-contaminant Candidate List 3 constituents of emerging concern in California secondary and tertiary effluent

CCL 3 CECs	Category	Occurrence in Recycled Water Secondary/Tertiary Treated (ng/L)
4-Nonylphenol	Surfactant degradant	161
Atorvastatin (Lipitor)	Cholesterol medication	79
Diclofenac	NSAID	230
Epitestosterone (cis-Testosterone)	Hormone	10
Ketoprofen	NSAID	43
Metoprolol	Beta blocker medication	246
o-Hydroxy atorvastatin	Cholesterol medication degradant	10

[12] Tertiary treatment is defined as standard secondary treatment with filters and disinfection.

CCL 3 CECs	Category	Occurrence in Recycled Water Secondary/Tertiary Treated (ng/L)
Propanolol	Beta blocker medication	25
Simvastatin hydroxyacid (Zocor)	Cholesterol medication	25
Sucralose	Artificial sweetener	26,390
Acetaminophen	Analgesic	550
Bisphenol A	Used in polycarbonate plastics	286
Dilantin	Anticonvulsant	217
TCEP	Flame retardant	688
4-Octylphenol	Surfactant degradant	207
Atenolol	Beta blocker	1,780
Azithromycin	Antibiotic	1,200
Caffeine	Stimulant	900
Carbamazepine	Anti-epileptic	400
Ciprofloxacin	Antibiotic	100
Clofibric acid	Metabolite of various lipid regulators	820
DEET	Insecticide	1,520
Diethylstilbestrol	Hormone	10
Fluoxetine (Prozac)	Antidepressant	31
Furosemide	Diuretic	38
Gemfibrozil	Cholesterol medication	3,550
Ibuprofen	NSAID	500
Iopromide	Radiographic contrast agent	2,174
Meprobamate	Tranquilizer	430
Methylisothio-cyanate	Pesticide	114
Musk ketone	Synthetic fragrance	25
Naproxen	NSAID	851
Primidone	Anti-epileptic	264
Progesterone	Hormone	18
Salicylic acid	NSAID; used in personal care products	110
Sulfamethoxazole	Antibiotic	1,400
TCDPP	Flame retardant	296
TCPP	Flame retardant	5,920
Testosterone (trans-Testosterone)	Hormone	37
Triclocarban	Anti-bacterial	223

CCL 3 CECs	Category	Occurrence in Recycled Water Secondary/Tertiary Treated (ng/L)
Triclosan	Anti-bacterial	485
Trimethoprim	Anti-bacterial	112
Warfarin	Anticoagulant	16

Source: Table 5.2 (Anderson and others, 2010)
CCL3 = Contaminant Candidate List 3, CEC = Constituent of emerging concern
DEET = N,N- diethyl-meta-toluamide
NSAID = Non-steroidal anti-inflammatory drug
TCDPP = Tris (1,3-dichloro-2-propyl) phosphate
TCEP = Tris (2-chloroethyl) phosphate
TCPP = Tris (1-chloro-2-propyl) phosphate.

2.4 Comparison of Contaminants of Concern in Available Data to Regulatory Standards and Guidance/Advisory Levels

In the following sections, water quality issues unique to Texas for groundwater and surface water are discussed based upon the maps and data presented in the previous section. In locations where naturally occurring constituents are approaching concentrations close to their specific MCLs, attention should be paid to monitor these COCs more frequently[13].

2.4.1 Groundwater Quality Comparison

Based on state-wide occurrence data, Table 2-6 presents a summary of constituents present in groundwater supplies across Texas that occasionally exceed current MCLs. Based on this analysis, it appears that major aquifers in Terry County exhibit co-occurrence of elevated concentrations of arsenic, selenium, and fluoride. Major aquifers in western central and south Texas exhibit elevated TDS concentrations (including chloride and sulfate).

While not regulated, silica occurrence in major aquifers in northwest and southeast Texas can exceed 30 mg/L, which is potentially problematic where high-pressure membranes (such as nanofiltration (NF) or reverse osmosis (RO)) are used for treatment. Silica causes irreversible scale formation and impacts the volume of water recovered after treatment. For example, silica present at a concentration of 30 mg/L can limit recovery to no more than 80%. The higher the silica concentration, the less water recovered.

[13] It is recommended that a PWS pursuing DPR work with the TCEQ Water Supply Division and Water Quality Division to ensure that any TCEQ-required sampling is included in the DPR piloting and monitoring plans.

Table 2-6: Constituents occurring in Texas groundwater supplies

Constituent	SMCL & SCL [SCL only]	Region	Occurrence Level
Antimony	6 µg/L	One hot spot, western TX, Reeves County	6-12 µg/L
Arsenic	10 µg/L	Large occurrence in Western TX, Terry County; southern Texas along the Gulf coast; El Paso County	>20 µg/L
Bromide*	N/A	Groundwater supplies, unspecified	180 mg/L
Chloride	250 mg/L** [300 mg/L**]	Western central and southern TX	>600 mg/L
Fluoride	4 mg/L	Large occurrence in Western TX, Terry County; some excursions in San Antonio-Austin-Waco corridor	4-8 mg/L
Nitrate	10 mg/L	Hot spots in northwest TX, in particular in Lubbock County	>20 mg/L
Selenium	50 µg/L	Large occurrence in Western TX, centered in Terry County	50-100 µg/L
Sulfate	250 mg/L ** [300 mg/L **]	Western central and southern TX	>600 mg/L
TDS	500 mg/L ** [1,000 mg/L **]	Western central and southern TX	>1,000 mg/L
Gross Alpha radiation	15 pCi/L	Western central part of the state; southern TX, south of San Antonio	15-30 pCi/L >30 pCi/L
Combined radium radiation	5 pCi/L	Widespread in western central TX and southeast TX	>10 pCi/L
Uranium	30 µg/L	Central Texas, Tom Green County	30-60 µg/L

* Can form bromate during disinfection and ozonation;
**SMCL and [SCL]: SMCL= secondary maximum contaminant level (EPA standard) and SCL= secondary constituent level (TCEQ standard)
pCi/L = pico curies per liter

2.4.2 Surface Water Quality Comparison

Constituents present in surface water that are exceeding various levels of interest in Texas are summarized in Table 2-7.

Table 2-7: Constituents of interest occurring in major Texas rivers

Constituent	SMCL & SCL [SCL only]	Region	Occurrence level
Bromide**	none	Surface water, Coastal Bend Region	100-900 mg/L
Chloride	250 mg/L* [300 mg/L *]	Elevated levels in upper parts of Red River, Brazos River and Pecos River	>5,000 mg/L
Sulfate	250 mg/L * [300 mg/L *]	Elevated levels in upper parts of Red River, Brazos River and Pecos River	1,000-5,000 mg/L
Total dissolved solids	500 mg/L * [1,000 mg/L *]	Elevated levels in upper parts of Red River, Brazos River and Pecos River	>5,000 mg/L

*SMCL and [SCL]: SMCL= secondary maximum contaminant level (EPA standard) and SCL= secondary constituent level (TCEQ standard);
** can form bromate during disinfection and ozonation

In addition to the COCs listed, hardness is elevated in many rivers in Texas with occurrence levels greater than 180 mg/L, representing very hard water.

2.4.3 Treated Wastewater Quality

As discussed in Section 2.2.2, several stakeholders shared effluent water quality data from their wastewater treatment facilities. Treated wastewater quality in Texas is well characterized regarding the 126 Priority Pollutants, which are primarily of industrial origin.[14] As expected, for those Priority Pollutants that also have MCLs, the concentrations in treated wastewater are usually below MCLs and in many cases below analytical method reporting limits (MRLs) and/or method detection limits (MDLs).

[14] See 40 Code of Federal Regulations at 401.15.

Method Reporting Limits versus Method Detection Limits

*The method reporting limit (**MRL)** represents an estimate of the lowest concentration of a compound that can be detected in a sample for which the concentration can be quantified and reported with a reasonable degree of accuracy and precision.*

*The method detection limit (**MDL)** is the lowest concentration at which a compound can be detected in a sample (it can be distinguished from a blank with 99% certainty). It is a statistically calculated concentration where the compound is qualitatively expected to be identified.*

A result between the MRL and greater than the MDL means the compound is likely present, but cannot be quantified.

Most of the remaining Priority Pollutants are below detection limits. No data were available for other COCs or CECs. This situation is typical for most wastewater facilities and illustrates that utilities considering wastewater as a potential raw water source will need to collect additional data on wastewater quality.

Of the constituents that have occasionally been observed at levels above primary MCLs in drinking water supplies and based on the limited number of samples available for treated wastewater, concentrations in wastewater for antimony, arsenic and selenium remained consistently below the MCLs of 6, 10 and 50 µg/L, respectively. For stakeholders that use groundwater and surface water with elevated TDS concentrations, the treated wastewater frequently exhibited effluent concentrations for chloride and TDS in excess of the Texas SCLs.

2.5 Review of the State of Analytical Technology

Monitoring in potable reuse systems can be challenging and requires additional precautions as compared to typical drinking water monitoring with regard to the water matrix, reliability of analytical methods, quality assurance plans and reporting levels. Development of a monitoring program for DPR should be done in close coordination with the TCEQ. TCEQ ‘s review and approval of the monitoring plan will be required before the data can be used to evaluate or demonstrate the efficacy of the DPR treatment process.

2.5.1 Water Matrix

In potable water reuse, the starting matrix is often secondary or tertiary treated municipal wastewater, which presents challenges for the analytical determination of COCs and in particular CECs, often due to lack of standardized methods. Thus, analytical methods that are to be applied for performance monitoring, before and after a given treatment process or series of processes (and the laboratories that perform them) must be capable of addressing this more challenging matrix as well as a cleaner matrix after advanced treatment.

What is Advanced Treatment?

Treatment technologies used to remove dissolved solids, contaminants of concern, constituents of emerging concern, or other constituents for specific reuse applications.

- *Advanced treatment may include membranes, oxidation, disinfection, adsorption, ion exchange and other processes as discussed in Chapter 5.*
- *Advanced treatment is a necessary component of a DPR treatment scheme.*

In addition, the monitoring of organic constituents is often conducted at trace levels (ng/L), which is uniquely challenging within a wastewater matrix. These challenges can be addressed through isotope dilution methods. It is also important to address potential sample contamination issues that can occur when samples are collected in the field or analyzed in the laboratory. Potential sample contamination issues should be addressed through the collection of laboratory and field blanks.

2.5.2 Analysis of CECs

Analysis of CECs present challenges based on the lack of standardized methods, their varying physicochemical properties, the possibility for sample contamination, and their low concentrations in the environment. As a result, there is uncertainty in whether results generated by a given method accurately depict the true concentration of each CEC in a sample (for example there can be false positive results, false negative results, and differences in results between laboratories). Vanderford and others (2012) suggested that the reliability of CEC data is tied to quality assurance/quality control (QA/QC) as defined by accuracy, precision, the use of laboratory and sample blanks, and establishing appropriate MRLs. Gas chromatography with mass spectrometric detection (GC-MS) and liquid chromatography with tandem mass spectrometric detection (LC-MS/MS) analytical technologies are used for many semi-volatile/non-volatile CECs along with the use of isotopically-labeled surrogates and spiking of the target CEC to determine if the results are accurate.

Tandem mass spectrometry greatly reduces the chances of a false positive due to a chemical interference. With either LC-MS/MS or gas chromatography with tandem mass spectrometric detection (GC-MS/MS), a peak found on the chromatograph should not be assigned as the targeted compound unless the retention time and mass transitions are within a range that has been defined for the compound. However, despite these safeguards, it is still possible for an organic substance to yield a false positive as a chemical mimic[15]. Recently, chemical mimics for DEET, NDMA, and perchlorate have been discovered. Thus, great care must be taken to ensure that within an extremely complex mixture, such as wastewater effluent, that numerous QA/QC checks be rigorously followed to ensure accuracy and precision in trace organic compound measurement. To help ensure that appropriate QA/QC protocols are followed, it is recommended that a quality assurance project plan (QAPP) be developed before initiating any environmental sampling. A detailed discussion of quality control and assurance is provided in Appendix B.

2.5.3 Considerations for Developing a Monitoring Program

In addition to having a detailed QAPP, the design of a monitoring program should focus on capturing representative samples, including spatial and temporal variability. For instance, in a large reservoir, a monitoring program with a single collection depth would not likely portray the actual environmental conditions within the reservoir. Similarly, in a recent publication it was reported that time of day can greatly impact the concentration of certain CECs in wastewater treatment plant (WWTP) effluent (Nelson, Do and others, 2011). Based on this and other publications, different days of the week, months, seasons, weather patterns, and even holidays can

Key Questions to Ask When Developing a Monitoring Program

- *Has TCEQ approved the monitoring program?*
- *Is sample size large enough to provide adequate statistical relevance?*
- *Does program properly capture spatial and temporal variability?*
- *Are grab or composite samples more appropriate?*

[15] A chemical mimic is a substance that has a chemical resemblance to the actual chemical in question.

impact the loading of trace organic compounds from WWTPs (Huerta-Fontela, Galceran and others, 2008; Ort, Lawrence and others, 2010; Delgado-Moreno, Lin and others 2011; Gerrity, Trenholm and others, 2011). Providing adequate statistical power is also an important consideration, but needs to be balanced with practical considerations such as cost (the greater the number of samples the higher the cost). In addition, the type of sample collected (grab versus composite) may be a function of the compound, analytical method, and sampling constraints.

Sample preservation, storage, and transport are additional key aspects of ensuring quality monitoring data. Vanderford, Mawhinney and others (2011) describe many of the key considerations in sample containers, preservation, and holding times for some trace organic chemicals. However, specific sample handling conditions should be verified and validated for all compounds targeted for monitoring. Field blanks and matrix spikes are a critical QA/QC component that can identify false positives from contamination and false negatives from sample loss (such as degradation during sample transport to the laboratory). Holding times should be established for all analytical methods and sample matrices.

2.5.4 Method Reporting Limits

Method reporting limits are critical to consider in environmental monitoring. The MRL is the lowest concentration that can be reliably achieved within specified limits of accuracy and precision during routine laboratory operating conditions. A result below the MRL is considered to be an estimated value that does not satisfy quality control objectives.

Analytical methods with appropriate MRLs should be selected based on the desired concentration goal and not based on trying to achieve the lowest concentration possible. Most commercial analytical laboratories seek to develop the most sensitive method feasible with the instruments available. Often, MRLs below the ng/L level can be developed. However, for many trace organic compounds, such low MRLs are not needed and can increase the probability of erroneous results. Thus, it is strongly recommended that MRLs be established that are no less than one-tenth of the applicable health or performance goals (see Section 2.6). By not forcing unnecessarily low MRLs, it is possible to conduct analyses using available and reliable laboratory methods that may provide greater analytical reliability. In some cases lower MRLs also require collecting larger volumes of water.

TCEQ Analytical Methods Requirements

The TCEQ's site-specific conditions for direct potable reuse evaluation and implementation will include the methods and type of laboratory that may be used. When drinking water methods are required, the methods and minimum detection levels adopted by EPA under the Safe Drinking Water Act must be used. For most methods, TCEQ will require that laboratories accredited by the TCEQ be used.

2.5.5 Bio-analytical Methods

Bioassays are tests performed using live cell cultures or mixtures of cellular components in which the potency of a chemical or water concentrate is tested based on its effect on a measurable constituent, such as inhibition or the induction of a response (including carcinogenicity and mutagenicity). For unknown chemicals that may be present in the environment, and for which there are currently no known methods for their quantification, biological monitoring could be used to quantify mixture potencies for both known and unknown chemical compositions (Anderson, Denslow and others, 2010; Snyder, 2014). The main advantage of bioassays is that they can be used to detect the presence of chemicals based on their bioactivity rather than on their detection by analytical chemistry. An added benefit of bioassays is that they can be used to measure synergistic, additive, and antagonistic interactions between compounds that may be present in a mixture. Both *in vivo* and *in vitro* assays have been developed, which can also be linked with analytical chemical methods to identify potential toxicants; *in vivo* bioassays are conducted using whole organisms while *in vitro* bioassays are conducted at the cellular level. Research is being conducted to further develop *in vivo* and *in vitro* bioassays that can be used to rapidly and selectively screen water for possible physiological effects (NRC, 2012; Snyder, 2014). The primary weakness of bioassays is the uncertainty surrounding the potential for quantifying adverse effects in humans with a positive response (Anderson et al., 2010 and others). Although in vitro assays are useful for identifying specific bioactivity and chemical modes of action, the NRC concluded that at this time they are not likely to be used in isolation for the determination of human health risk (NRC 2012).

2.6 Suggested Monitoring Framework for Utilities Interested in Pursuing Direct Potable Reuse

As public water systems begin exploring DPR projects, it is important that they begin considering what COCs and CECs should be monitored[16]. Monitoring of regulated constituents should focus on COCs included in the primary and secondary drinking water standards. For unregulated constituents, determining which compounds to monitor and providing a justification for selection of these compounds can be a significant challenge. Because it would be infeasible to monitor all possible unregulated constituents, small subsets must be selected that are representative of particular constituent groups and/or that can be used to evaluate performance of specific treatment processes. These subset groups are called indicators and surrogates.

Why Monitor for Unregulated Constituents?

Although it may not be required, monitoring for unregulated constituents, when planned well and done properly, can provide valuable information for:

- *Proactively addressing the safety of reclaimed water. Some constituents of emerging concern (CECs) have health advisories or are likely to become regulated compounds in the future.*
- *Communicating to the public about project health impacts and treatment effectiveness - the public is interested in what is being monitored and how often, will ask about these constituents and will want to know that they are not a concern.*
- *Selecting treatment processes for direct potable reuse projects.*
- *Evaluating treatment performance for a wide range of constituent classes.*
- *Providing credibility based on expertise with monitoring and addressing CECs particularly as analytical detection methods become more sensitive and more CECs are detected.*

[16] Any PWS considering a DPR project should meet with the TCEQ Water Supply and Water Quality Divisions prior to developing a monitoring program. The TCEQ's review and approval will be needed before the data can be used to evaluate or demonstrate the efficacy of the DPR treatment process.

2.6.1 Indicator and Surrogate Concept

In the indicator and surrogate approach, a combination of indicator compounds and specific surrogate constituents are used to monitor the removal efficiency of specific types of contaminants through individual unit processes. An indicator compound is an individual constituent that is a COC or a CEC and represents certain physicochemical and biodegradable characteristics of a family of constituents. The indicator compounds are important in terms of human health and/or are relevant to fate and transport of broader classes of chemicals and provide a conservative assessment of removal during treatment. A surrogate is a bulk constituent for which a quantifiable change can be measured to evaluate the performance of individual treatment processes (often in real-time, including failure) or operations in removing trace organic compounds and/or assuring disinfection efficacy. Indicator chemicals of toxicological relevance to human health are referred to as "health-based indicators". Indicator compounds determined not to have human health relevance, but useful for monitoring treatment process effectiveness, are referred to as "performance indicators".

The Difference between Indicators and Surrogates

- ***Indicators*** *are* *individual* *constituents that represent specific physicochemical and biodegradable characteristics of a family of constituents. Examples: caffeine, sucralose, N,N-Diethyl-meta-toluamide (DEET)*
- ***Surrogates*** *are* *bulk* *constituents used to evaluate the performance of individual treatment processes. Examples: total organic carbon, ultraviolet irradiation (UV)*

It is recommended that monitoring programs for DPR projects include monitoring for: (1) human health-based indicators; (2) performance indicators; and (3) surrogates.

Recommendations for health-based and performance indicator constituents to be monitored along with their respective MRLs are provided in Table 2-8. The indicators and surrogates selected are based on relevance (human health)[17] and suitability as performance indicators. Additional background information for each compound is provided in the references listed in the last column in the table. The MRLs listed are for clean matrices, which are appropriate for the quality of water to be used for DPR in Texas.

[17] Indicators are selected using a risk based approach that considers the concentration of a CEC in reclaimed water compared to Monitoring Trigger Levels.

Monitoring Trigger Thresholds (MTTs)

Because many constituents of emerging concern (CECs) do not have established drinking water standards or advisory levels, researchers have developed a method to describe an estimate of the amount of a substance in drinking water, expressed on a body-weight basis (usually in milligrams of the substance per kilograms of body weight per day), that can be ingested daily over a lifetime without appreciable risk. The procedure to derive this estimated "safe" amount involves collecting all relevant toxicity data, ascertaining the completeness of the data, determining the most sensitive toxicity outcome (taking into account sensitive population groups such as infants, children, pregnant women, and those with compromised health), and applying appropriate safety factors. Health outcomes include:

- *Therapeutic dose of medications;*
- *The "no observed adverse effect level" (NOAEL)*
- *The "lowest observed adverse effect level (LOAEL)*
- *Carcinogenicity*

Depending on the researcher conducting the study, these estimated safe amounts are called different names: Tolerable Daily Intakes (TDIs), Acceptable Daily Intakes (ADIs), or Predicted No Effect Concentrations (PNEC) (Schwab and others, 2005, Environment Protection and Heritage Council and others, 2008, Anderson and others, 2010, Bruce and others 2010a,b).

To compare the estimated safe amounts to concentrations of chemicals in recycled water or drinking water, researchers calculate a Drinking Water Equivalent Level (DWEL). The DWEL represents the concentration of a chemical in drinking water that would be equivalent to the TDI/ADI/PNEC, assuming a 150-pound person (70 kilograms or kg) consumes 2 liters (L) of water per day (about 8½ cups) using the following equation.

$$DWEL\ (\mu g/L) = \frac{TDI\ (\mu g/kg\text{-}day) \times 70\ kg}{2\ L/day}$$

The MTTs in Table 2-8 *are equivalent to the lowest MCL, advisory level, or DWEL established for each indicator.*

Table 2-8: Suggested indicator chemicals to be included in direct potable reuse monitoring program[1]

Constituent	Rationale	MTT (ng/L)[2]	Reporting limit (ng/L)	Reference
THMs	Health	80,000	1,000	MCL
HAA5	Health	60,000	1,000	MCL
NDMA	Health	10	2[3]	DDW Notification Level[4]
PFOA	Health	400	10	Provisional Short-term EPA Health Advisory
PFOS	Health	200	10	Provisional Short-term EPA Health Advisory
Bromate	Health	10,000	1,000	MCL / WHO guideline
Perchlorate	Health	15,000	1,000	EPA Health Advisory
1,4-Dioxane	Health	1,000	100	DDW Notification Level
17□-Estradiol	Health	<1	0.9	Drewes and others 2013
Atenolol	Health/ Performance	4,000	100	Bull and others 2011
TCEP	Health/ Performance	5,000	100	Minnesota Dept. of Health (2011) Guidance Value
Caffeine	Performance	--[5]	50	Drewes and others 2013
Gemfibrozil	Performance	800,000	10	Schwab 2005
Iopromide	Performance	750,000	50	Environment Protection and Heritage Council and others 2008
Meprobamate	Health/ Performance	200,000	100	Bull and others, 2011
DEET	Performance	200,000	50	Minnesota Dept. of Health (2011) Guidance Value
Primidone	Performance	10,000	10	Bruce and others 2010
Sucralose	Performance	150,000,000	100	CFR Title 21
Triclosan	Performance	2,100,000	50	Drewes and others 2013

CFR = Code of Federal Regulations
DDW = California Division of Drinking Water
EPA = U.S. Environmental Protection Agency
HAA5 = Haloacetic acids
THMs = Trihalomethanes
PFOA = Perfluorooctanoic acid
PFOS = Perfluorooctane sulfonate
DEET = N,N-diethyl-meta-toluamide
WHO = World Health Organization

1. The TCEQ will set site-specific monitoring requirements that may or may not include an analyte on this table.
2. MTT values are based on “safe” levels in the drinking water (see information box on previous page). For DBPs, additional formation can occur following treatment and should be taken into account when evaluating water quality.
3. The reported MRL value is significantly lower than the level used for EPA Method 1625, which is approved per 40 CFR Part 136 with a detection level of 50 µg/L; NDMA is part of the Priority Pollutant scan.
4. California has established Notification Levels for chemicals in drinking water without MCLs. If a chemical concentration is greater than its Notification Level in drinking water, the public water system must inform its customers and consumers about the presence of the chemical, and about health concerns associated with exposure to it.
5. The lowest MTT for caffeine is 350 ng/L based on the Threshold of Toxicological Concern, which is a predictive model (Environment Protection and Heritage Council and others, 2008). Intertox (2009) developed a toxicity-based DWEL of 8.75E+6 ηg/L. Because of the wide range in the two MMT values, a value is not included in the table. Caffeine is commonly found in wastewater and thus is an appropriate indicator to use for evaluating treatment performance.

Surrogates that should be considered for monitoring treatment of reclaimed water using various advanced water treatment processes as part of a DPR scheme are listed in Table 2-9. Other surrogates not listed in Table 2-9 may also be considered, depending on the specific situation. Where applicable, surrogates may be measured using on-line or hand-held instruments, provided that instrument calibration procedures are implemented in accordance with the manufacturer's specifications and that calibration is documented. To be accepted by the TCEQ, calibration must also comply with the requirements of 30 TAC 290.46 and the site-specific requirements put in place by the TCEQ.

*See **Chapter 5** for a detailed discussion of treatment for direct potable reuse projects.*

Table 2-9: Suggested surrogates for advanced water treatment processes to be included in direct potable reuse monitoring program

Surrogate	Unit processes
Total organic carbon (TOC) or dissolved organic carbon (DOC)	RO, NF, GAC, PAC, ozone, AOP
UV absorbance (254 nm)	RO, NF, GAC, PAC, ozone, AOP
Fluorescence indices/ratios	RO, NF, GAC, PAC, ozone, AOP
Total dissolved solids (TDS)/electrical conductivity	RO, NF
Boron (surrogate for NDMA)[1]	RO, NF
Aesthetics	
Temperature	RO, NF, GAC, PAC, ozone, AOP
Color (436 nm)	RO, NF, GAC, PAC, ozone, AOP
Odor	RO, NF, GAC, PAC, ozone, AOP
Hardness	RO, NF

AOP = Advanced oxidation processes
GAC = Granular activated carbon
NF = Nanofiltration
nm = nanometer
PAC = Powdered activated carbon
RO = Reverse osmosis
UV = Ultraviolet irradiation
1. Tu and others 2013.

In addition to the surrogates suggested for advanced water treatment processes in Table 2-9, turbidity is a valuable surrogate for evaluating wastewater treatment ahead of the advanced water treatment processes. It is likely that the TCEQ will require some turbidity monitoring as part of the DPR monitoring program.

2.6.2 Phased Monitoring Program

The purpose of phased monitoring is to allow monitoring requirements for health-based indicators, performance indicators and surrogates to be refined based on the monitoring results and findings of the previous phase. Monitoring is divided into three phases (Figure 2-4). The first phase involves monitoring that would be initiated prior to and during piloting and/or project start-up and continue through the early years of project operation. The second phase would represent baseline operations following start-up. The third phase is the standard operating phase. In any case, the program should comply with the site-specific requirements imposed by the TCEQ throughout every phase.

*See **Appendix B2** for specific monitoring recommendations provided by the TCEQ.*

All chosen indicator compounds should be monitored during the initial assessment phase. Based on monitoring results and findings, the list of performance indicators required for monitoring may be refined for the baseline assessment; information collected during the baseline assessment will be used to inform the standard operating monitoring program. Quality assurance and quality control measures should be used for both collection of samples and laboratory analyses as previously discussed. Each project should develop a QAPP that includes the appropriate number of field blanks, laboratory blanks, replicate samples, and matrix spikes (see Section 2.5).

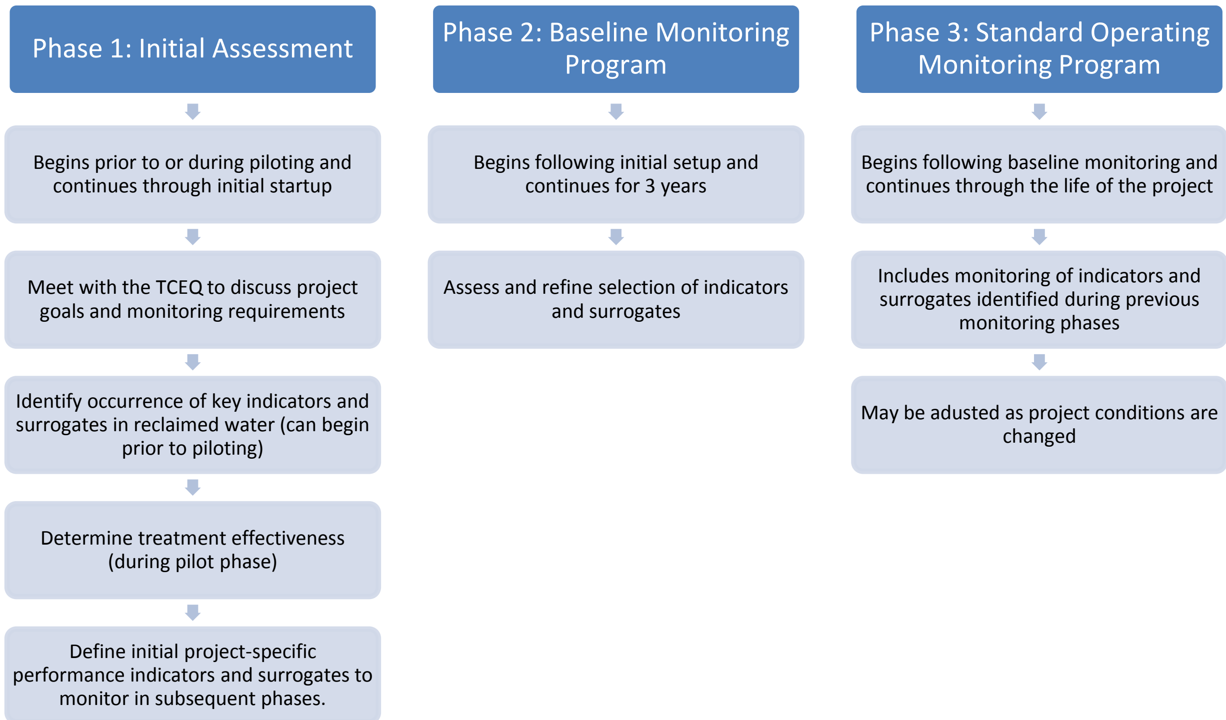


Figure 2-4: Recommended phased monitoring program

2.6.2.1 Initial Assessment Monitoring Phase

The goals of the initial assessment phase are to: (1) identify the occurrence of health-based indicators, performance indicators, and surrogates in reclaimed water; (2) determine treatment effectiveness; (3) define the project-specific performance indicators and surrogates to monitor during the baseline phase; and (4) specify the expected removal percentages for performance indicators and surrogates. The initial assessment monitoring phase should be conducted for a period of at least one year to evaluate seasonal variability.

During the initial assessment monitoring phase, each of the health-based and performance indicators (Table 2-8) and appropriate surrogates (Table 2-9) should be monitored. Surrogates should be selected to monitor individual unit processes or combinations of unit processes that remove constituents of concern. Performance indicator and surrogate monitoring results that are used to demonstrate measurable removal for a given unit process are candidates for use in the monitoring programs for the baseline and standard operation phases.

2.6.2.2 Baseline Monitoring Program

Based on the findings of the initial assessment monitoring phase, project-specific performance indicators and surrogates should be selected for monitoring during the baseline monitoring phase. The purpose of the baseline monitoring phase is to assess and refine which health-based and performance indicators and surrogates are appropriate to monitor the removal of COCs and CECs and treatment system performance for the standard operation of a facility. Performance indicators and surrogates that exhibited reduction by unit processes and/or provided an indication of operational performance should be selected for monitoring during the baseline monitoring phase. The baseline monitoring phase should be conducted for a period of three years following the initial assessment monitoring phase. Following the baseline operation monitoring phase, monitoring requirements should be re-evaluated and subsequent requirements for the standard operation of a project should be determined on a project-specific basis.

2.6.2.3 Standard Operating Monitoring

Based on the findings of the baseline monitoring phase, monitoring requirements for health-based and performance indicators and surrogates may be refined to establish project-specific requirements for monitoring the standard operating conditions of a DPR project.

2.6.3 Assessment of Performance

Monitoring results for performance indicators and surrogates should be used to evaluate the operational performance of a treatment process and the effectiveness of a treatment process in removing COCs and CECs. The effectiveness of a treatment process in removing COCs and CECs should be evaluated by determining the removal percentages for performance indicator chemicals and surrogates.

Calculation of Removal Percentage

The removal percentage is the difference in the concentration of a compound in reclaimed water prior to and after a treatment process, divided by the concentration prior to the treatment process, multiplied by 100.

$$\text{Removal Percentage} = ([X_{in} - X_{out}]/X_{in})\ (100)$$

X_{in} - *Concentration in reclaimed water prior to a treatment process*

X_{out} - *Concentration in reclaimed water after a treatment process*

During the initial assessment, the DPR project proponent should monitor performance to determine removal percentages for performance indicator COCs, CECs and surrogates. The removal percentages should be confirmed during the baseline monitoring phase.

Based on the results of the baseline and/or standard monitoring, response programs should be developed. For monitoring results that exceed the MTTs, actions could include collection of additional samples and/or implementation of corrective actions (for example if the ratio of the measured concentration and MTT is > 1,000). For monitoring results that are below detection or a fraction of the MTT (for example 10%), consideration should be given to discontinuing monitoring for that particular indicator compound.

2.6.4 Re-evaluation of Indicators and Surrogates

It will be important to periodically re-evaluate indicators to use for DPR monitoring programs based on occurrence in wastewater and advanced treated reclaimed water, and health information on MTTs. Suggestions include:

- Conducting periodic occurrence studies to evaluate concentrations of CECs in wastewater and reclaimed water (for example every five years); and
- Checking MTTs to determine if they have been updated or new MTTs are available.

WateReuse Research Foundation Direct Potable Reuse Research - Monitoring

- ***Project 11-01***: *Monitoring for Reliability and Process Control of Potable Reuse Applications*
- ***Project 12-07***: *Methods for Integrity Testing of NF and RO Membranes*
- ***Project 14-01***: *Integrated Management of Sensor Data for Real Time Decision Making and Response*
- ***Project 14-10***: *Enhanced Pathogen and Pollutant Monitoring of the Colorado River Municipal Water District Raw Water Production Facility at Big Spring, TX*
- ***Project 14-12*** *Demonstrating Redundancy and Monitoring to Achieve Reliable Potable Reuse*

For more information: https://www.watereuse.org/foundation

3 Water Quality Performance Targets for Direct Potable Reuse

Road Map

In This Chapter

» Overview of microbial and chemical contaminants

» Recommended targets for pathogens, chemicals, and aesthetics

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3.1 Introduction

Direct potable reuse (DPR) projects can differ from indirect potable reuse (IPR) projects or conventional drinking water treatment projects as discussed below:

- **Reduced response times to address potential treatment failures or other impacts to water quality**. In contrast, IPR projects include storage in a reservoir or in groundwater that may range from several months to several years or more. This storage time allows operators to identify and respond to operational problems or other situations that may compromise water quality. The storage components of IPR projects can also provide contaminant reduction through natural degradation processes.

- **Differences in the quality characteristics of reclaimed source water as compared to traditional surface water or groundwater drinking water sources**. For both DPR and IPR projects, advanced treated reclaimed water can have significantly different characteristics from traditional source waters. While the quality of any reclaimed water will be closely tied to its originating drinking water source, the introduction of additional microbial and chemical constituents through municipal and industrial use of the water could distinctly change its quality characteristics. In addition, if membrane treatment is included, the aesthetic characteristics of the treated reclaimed water may differ significantly from the existing water supply and become a factor in how a project sponsor integrates reclaimed water into its overall supply.

- **Public acceptance of DPR.** Although recent research has shown that the public is becoming more accepting of drinking reclaimed water (Macpherson and Snyder, 20, this is only true if it can be demonstrated that the DPR system will consistently produce high quality purified water (Macpherson and Snyder, 2013). The use of performance targets as presented in this chapter, in association with public education efforts, will aid in the public acceptance of DPR projects.

*See **Chapter 9** for more information related to public outreach.*

To address these factors, it is advisable to incorporate water quality performance targets beyond those established under the Safe Drinking Water Act (SDWA) into a DPR project[18]. Because protection of public health is the primary consideration, recommended performance targets include regulated pathogens and chemicals. However, additional performance targets are suggested for unregulated constituents that may have potential human health impacts or

[18] The TCEQ addresses these factors by reviewing DPR projects on a case-by-case basis and incorporating site-specific water quality targets.

serve as treatment performance indicators and aesthetic indicators. These targets are important because they can be used to guide decisions regarding treatment and performance and assist with public acceptance of a DPR project.

The recommended targets do not relate specifically to the type of DPR scheme to be implemented - whether the advanced treated reclaimed water is delivered directly to the drinking water distribution system or is blended with raw source water and processed through a water treatment plant prior to delivery to the drinking water distribution system. However, use of the recommended performance targets, together with a focus on reliability (see box below), will help to minimize risk.

The 4 R's – Reliability, Redundancy, Robustness, Resilience

Reliability: *The overarching goal for DPR treatment- to consistently achieve the desired water quality. A reliable system is redundant, robust and resilient.*

- ***Redundancy:*** *The use of multiple barriers for the same contaminant, so that risks can be properly managed even in the event of an upset or failure in a unit process.*
- ***Robustness:*** *The use of a combination of treatment technologies to address a broad variety of contaminants and changes in concentration in source water.*
- ***Resilience:*** *Protocols and strategies to address failures and bring systems back on-line.*

3.2 Constituents of Concern for Direct Potable Reuse

Constituents of concern for DPR include both microbial and chemical contaminants. Water quality can be impacted directly through the presence of COCs, or indirectly through impacts to aesthetic qualities such as color or odor. In addition, the presence of certain COCs can impact the stability of the drinking water and, if not properly considered, may result in corrosion within the distribution system. Additional information related to COCs for DPR is provided in this section.

3.2.1 Microbial Contaminants

Microbial contaminants in reclaimed water can include bacteria, viruses, helminths and protozoan parasites. Pathogenic microorganisms (microorganisms that can cause disease in a host) are widely acknowledged as the most critical element with respect to potential acute impacts on human health in public water supplies, such as diarrhea, vomiting, cramps, and pneumonia. The presence and concentration of pathogens in raw wastewater varies depending on infection patterns in the community tributary to the wastewater management system and in treated wastewater will vary depending on the type and performance of wastewater treatment processes utilized. A summary of the fifteen most common illness-causing pathogens in the United States are provided in Table 3-1 and whether they are associated with waterborne infections (Asano and others, 2007; CDC, 2009; Garcia, 2011; CDC, 2012). Although Table 3-1 represents all cases in the United States (food, personal contact, drinking water, contact with recreational water, fomite[19], etc.), this information does provide a general indication of the pathogens that are most likely to be present in raw wastewater.

The ability to routinely measure specific pathogens in water is a function of the concentration present in the water source. For example, it may be easier to measure pathogens in raw wastewater since the numbers are typically high. Measurement becomes more difficult as the water is purified. Pathogen measurement is also limited by the availability of reliable and sensitive analytical methods. Consequently, little specific pathogen data are available for advanced treated reclaimed water. For wastewater treatment there is very limited data on removal of pathogens through treatment processes because very few studies have been conducted. However, attention on potable reuse has resulted in new interest in evaluating pathogen removal through wastewater treatment plants. Surrogates, such as coliforms[20], must still be used to characterize desired treatment levels for some pathogens. However, coliforms are not good predictors for removal of viruses. Operational parameters, such as disinfection dose or contact time are also used to characterize treatment. The increased interest in advancing DPR has drawn attention to the need for greater capability for monitoring pathogens and for real-time monitoring of surrogates; research in this area is ongoing.

Most bacteria associated with waterborne diseases are relatively susceptible to chemical disinfection practices such as chlorination and chloramination, or ultraviolet radiation and advanced oxidation. Viruses typically are more resistant to environmental stresses than bacteria. Numerous studies have used viruses as model organisms to determine the fate of microorganisms because viruses can be more resistant to disinfection than bacteria and are smaller in size.

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[19] Any inanimate object or substance capable of carrying infectious organisms and hence transferring them from one individual to another.

[20] Coliforms are bacteria that are naturally present in the environment and used as an indicator that other, potentially harmful, bacteria may be present. Coliforms found in more samples than allowed is a warning of potential problems.

Table 3-1: Fifteen pathogens causing the highest level of illness in the United States annually[1]

Rank	Pathogen	Type	Episodes	Hospitalizations[2]	Deaths[2]	Water-borne Infections[3]
1	*Norovirus*	V	20,796,079	55,825	569	Yes
2	*Giardia intestinalis*	PP	1,121,864	3,289	31	Yes
3	*Salmonella* species (non-	B	1,095,079	20,608	403	Yes
4	*Campylobacter species*	B	1,058,387	10,599	95	Yes
5	*Clostridium perfringens*	B	966,120	438	26	[4]
6	*Cryptosporidium* species	PP	678,828	2,438	42	Yes
7	*Shigella* species	B	421,048	4,672	32	Yes
8	*Staphylococcus aureus*	B	241,188	1,063	6	Yes[5]
9	*Toxoplasma gondii*	PP	173,415	8,859	654	[6]
10	*STEC* non–O157	B	138,063	331	0	Yes
11	*Yersinia enterocolitica*	B	108,490	592	32	Yes
12	*STEC* O157	B	93,094	3,152	30	Yes
13	*Bacillus cereus*	B	63,411	20	0	[4]
14	*Vibrio parahaemolyticus*	B	40,309	116	4	[4]
15	Diarrheagenic *Escherichia coli* other than STEC and ETEC	B	39,739	26	0	Yes

B = bacterium
ETEC = Enterotoxigenic *Escherichia coli*
PP = protozoan parasite
STEC = Shiga Toxin producing *Escherichia coli*
V = virus

1. Source: Trussell, and others, 2013, Table 1.9 (Based on Scallan and others, 2011). The Centers for Disease Control (CDC) compiled these data as part of a foodborne illness study based on data mostly from 2000–2008, and all estimates were based on the US population in 2006; estimates were possible for 31 pathogens. Three additional viral pathogens (astrovirus, rotavirus, and sapovirus) were measured, but not included in this table due to CDC's assumption that they are only relevant for children under 5 years of age.
2. Based on foodborne illnesses.
3. Related to wastewater.
4. Primarily a foodborne infectious agent.
5. Via exposure to water via bathing or cooking food.
6. Water contaminated with cat feces.

Cryptosporidium and *Giardia* are the most common enteric protozoan parasites associated with reported waterborne disease outbreaks. In water and wastewater, protozoa may produce cysts or oocysts that aid in their survival. Consequently, these organisms can be highly resistant to chlorine disinfection and must generally be controlled by other means, such as filtration, ultraviolet radiation, or ozone oxidation (APAI, 2011).

3.2.2 Chemical Contaminants

Chemical contaminants can be of concern for both acute and chronic exposure effects. In addition, the chemical makeup of the water can impact corrosion within the drinking water distribution system. The composition of chemical contaminants is unique for every reclaimed water source at any given time. Factors such as industry volume and type, land use, source control programs, and treatment play an important role in the types and concentrations of chemical contaminants present in reclaimed water. Additionally, naturally occurring inorganic chemicals and salts that are present in source water and the addition of water and wastewater treatment chemicals impact the quality of reclaimed water sources. Categories of chemical contaminants are summarized in Table 3-2.

Monitoring the concentrations and toxicities of thousands of potential organic compounds in a reclaimed water source is not feasible. Total organic carbon (TOC) has been cited as a potential surrogate that could be used to evaluate removal of organic contaminants for potable reuse applications. TOC also has been used for many purposes to gauge the risk from unregulated and unidentified organic compounds. Since 1998, when the U.S. Environmental Protection Agency (EPA) promulgated the Stage 1 Disinfectants and Disinfection Byproducts Rule, TOC has also been used to indicate the potential for disinfection byproduct formation.

The use of TOC as a surrogate for trace organic chemicals presents some challenges. TOC is often present in source water in a wide range of concentrations. The unidentified bulk of residual TOC in reclaimed water, also called effluent organic matter (EfOM), is comprised largely of humic and fulvic acids, soluble microbial products created during the wastewater treatment process, and natural organic matter (NOM) contributed by drinking water sources (Drewes and others, 2003, 2006; Fox and others, 2001, 2006). The TOC test cannot distinguish between volatile and non-volatile organics, NOM and EfOM.

Table 3-2: Chemical contaminant categories[1]

Category	Description
Nutrients	Discharge to receiving waters can cause algal blooms and eutrophication (not applicable for direct potable reuse). Some nutrients, such a nitrates, do have drinking water standards.
TDS	The TDS of reclaimed water sources is generally higher than the potable water source in the region. Without treatment to remove dissolved salts, the TDS concentrations in a reclaimed water source could be significant (the secondary maximum contaminant level for TDS in Texas is 1,000 mg/L). In a closed-loop, DPR system, the TDS will become more concentrated over time if none of the dissolved solids are removed as a separate waste stream in the treatment process.
Metals	A number of metals are designated as Priority Pollutants and subject to control via Clean Water Act industrial pretreatment programs and TPDES permits. Naturally occurring metals can also be a concern, as well as in distribution systems with significant quantities of lead pipe.
Nanomaterials	Nanomaterials have been described as having at least one dimension on the order of approximately 1 to 100 nanometers and often have unique or novel properties that arise from their small size. An example includes nanoscale titanium dioxide that is used as an active ingredient in topical sunscreen. The increased use of nanomaterials for a wide range of applications in recent years has introduced these contaminants into reclaimed water supplies. Information on the potential risk of nanomaterials in potable reuse applications is limited at this time.
Trace Organic Chemicals	The trace organic chemical category includes compounds that are naturally occurring, synthetically produced, or are formed as a result of chemical reactions and transformations (such as disinfection byproducts). Trace organic chemicals are known to occur in drinking water and reclaimed water sources, but generally occur at a greater frequency in reclaimed water. However, even at the concentrations typical of secondary wastewater effluent, many trace organic chemicals pose no risk to human health due to the tremendous volume of water that would have to consumed before any adverse or therapeutic effects would be observed (Snyder and others, 2014). Critical contaminants for potable reuse include those that are already regulated through the drinking water standards as well as some unregulated constituents of emerging concern. Indicator compounds and surrogates can be used to evaluate treatment effectiveness on groups of unregulated compounds with similar structure or reactive properties.

mg/L = milligrams per liter
TDS = total dissolved solids
TPDES = Texas Pollutant Discharge Elimination System
1. Information adapted from Trussell and others, (2013) and TWDB (2011).

3.2.3 Aesthetics

In addition to public health protection, the aesthetic quality of potable reuse water can be very important, particularly as it relates to public perception. Some metrics and indicators that have recently been identified by regulatory agencies or in the literature related to aesthetics are included in Table 3-3. Establishing targets for aesthetic indicators may be desirable or necessary to obtain public acceptance for a DPR project as well as evaluate treatment options and performance.

Table 3-3: Potential metrics and indicators for direct potable reuse aesthetics[1]

Metrics	Indicators
Organic Matter Concentration	Total Organic Carbon, Dissolved Organic Carbon
Color	Color
Absorbance	UV 254 Absorbance, Specific UV Absorbance
Fluorescence	Total Fluorescence, Fluorescence Indices/Ratios
Solids Concentration	Total Suspended Solids, Turbidity
Odor	Odor
Mineralization/Salinity	Total Dissolved Solids, Conductivity, Chloride, Hardness

UV = ultraviolet irradiation
1. Source: Trussell and others (2013).

3.3 Direct Potable Reuse Performance Targets

3.3.1 Targets for Microorganisms

Two sets of performance targets for microorganisms are discussed in this chapter:

- Targets that were developed based on the general approach presented in *Potable Reuse: State of the Science Report and Equivalency Criteria for Treatment Trains* (State of the Science Report) prepared as part of WateReuse Research Foundation Project 11-02 (WRRF Project 11-02)[21]. The *State of the Science Report* developed microbial, chemical, and aesthetic criteria for determining the equivalency of advanced treatment schemes for DPR. The criteria were developed as part of a multi-step process that

[21] This approach is presented to illustrate the thought process behind WRRF Project 11-02 and is not a requirement for Texas public water systems.

included extensive review of existing potable reuse projects and guidelines, the development of an initial set of "strawman" criteria, and the refinement of the criteria by a panel of public health experts.

- TCEQ baseline targets that apply to the inactivation and removal of pathogens from wastewater by innovative treatment processes, all of which fall under the authority of the SDWA, Texas State Health Code, and Texas Administrative Code.

In many cases, a selected treatment scheme will meet the requirements of both sets of targets. To obtain project approval, the TCEQ targets (as discussed in Section 3.3.1.2) must be achieved. However, a PWS may want to confirm that the WRRF 11-02 targets can also be achieved to help provide additional justification to the public or stakeholders that the project meets recommendations developed by a national team of experts in potable water reuse.

3.3.1.1 WateReuse Foundation Project 11-02 Target Approach

The approach used for WRRF Project 11-02 established pathogen $\log_{10}$ reduction requirements for target pathogens in reclaimed water (from raw wastewater to final reclaimed water intended for drinking). The approach used available raw wastewater quality data obtained from the literature and established drinking water concentrations needed to meet a goal based on the EPA Surface Water Treatment Rule (SWTR), developed as a component of the SDWA. For the SWTR, a risk of 1 infection per 10,000 people per year was taken as a reasonable and acceptable health goal based on mean water quality (Macler and Regli 1993). There is a difference between infection and disease. Infection, often the first step, occurs when a pathogen enters a body and begins to multiply. Disease occurs when the cells in the body are damaged as a result of the infection and signs and symptoms of an illness appear.

The justification for this risk level was that the finished drinking water derived from potable reuse projects must meet or exceed the goal/standard applied to national/local conventional drinking water.

The steps for developing pathogen removal goals identified as part of WRRF 11-02 are:

Step 1: The recommended target pathogens are *Cryptosporidium*, *Giardia*, and virus; the target bacteria surrogate is total coliform. These organisms have been selected due to consistency with the EPA's approach in developing drinking water standards under the SDWA and public water system (PWS) familiarity and confidence with sampling and analytical methods.

Step 2: The maximum concentrations of organisms in raw wastewater were used for Step 2 because the quality and quantity of pathogen data were not sufficient to rely on a statistical approach at this time. As an alternative, and as a more robust pathogen database is developed, it may be possible to use the 90^{th} or 95th percentile value (where 90% or 95% of the observations are below this value). A percentile approach may provide a more suitable value to use for purposes of establishing treatment goals. However, use of the percentile approach must be sufficiently protective to account for cases where a population is shedding pathogens at higher densities as a result of a waterborne outbreak.

Step 3: Based on the 10^{-4} annual risk of infection as the goal, the methods of quantitative microbial risk assessment (QMRA) were used to determine the calculation of acceptable pathogen concentrations in water.

Step 4: The treatment requirements were determined by calculating the difference in the concentrations in the raw wastewater (Step 2) and the finished drinking water (Step 3) according to the following formula:

$$Log\ removal = \log\left(\frac{[Pathogens]_{sewage}}{[Pathogens]_{potable}}\right)$$

where $[Pathogens]_{sewage}$ and $[Pathogens]_{potable}$ are the concentrations of pathogens in the raw wastewater and potable drinking water, respectively.

The proposed pathogen removal targets using the WRRF 11-02 approach are summarized in Table 3-4. They take into consideration the effects of waterborne outbreaks that could increase pathogen concentrations coming into wastewater treatment plants. Additional information on the approach used for developing the pathogen removal targets, including consideration of the effects of waterborne outbreaks, is presented in Appendix C. Potential treatment strategies that can be used to meet these targets are presented in subsequent chapters. However, it is assumed that, if technically justified and properly controlled, credit could be given for any treatment process between the wastewater treatment plant headworks and the drinking water distribution system.

Table 3-4: Proposed direct potable reuse pathogen $\log_{10}$ removal targets based on WateReuse Research Foundation Project 11-02 approach

	Cryptosporidium	*Giardia*	Virus	Total Coliform[2]
Suggested $\log_{10}$ removal[1]	10	10	12	9

1. Target removals represent the reduction between raw wastewater and finished drinking water and may include credit for any treatment process between the wastewater treatment plant headworks and the drinking water distribution system.
2. Used as a surrogate for bacteria

3.3.1.2 Texas Commission on Environmental Quality Baseline Targets

The TCEQ has established minimum (or baseline) log removal and/or inactivation targets for *Cryptosporidium*, *Giardia* and virus (Table 3-5). The TCEQ baseline targets are based on the 10^{-4} risk level and finished water pathogen concentrations discussed in Section 3.3.1.1, and used in the SWTR. The baseline log removal targets are considered a starting point for the TCEQ approval process and may be revised based on data collected from the wastewater effluent in question. The primary difference between the WRRF 11-02 and TCEQ approach is the starting point for counting log reductions. The TCEQ approach uses wastewater treatment plant effluent as the starting point, whereas the WRRF 11-02 approach uses the raw wastewater as the starting point. Additionally, TCEQ uses site-specific wastewater treatment plant effluent concentrations to evaluate the need for additional log removal requirements above the baseline targets and does not consider a specific log removal target for total coliform[22].

Table 3-5: Baseline Texas Commission on Environmental Quality baseline direct potable reuse pathogen $\log_{10}$ removal targets

	Cryptosporidium	*Giardia*	Virus
Log_{10} removal[1]	5.5	6	8

1. The baseline targets are for the advanced treatment process only, i.e. they represent the reduction between treated wastewater and finished drinking water. The TCEQ sets project specific requirements for pathogen reduction and inactivation for DPR. Thus, these baseline targets may be increased based on site-specific data.

3.3.1.3 Norovirus

As shown in Table 3-1, Norovirus is the leading cause of illness and outbreaks from contaminated food in the U.S. (CDC, 2009). Infections can occur from eating food or drinking liquids that are contaminated with norovirus, touching surfaces or objects contaminated with norovirus and then putting fingers in the mouth, or having contact with someone who is infected with norovirus. Because it has a potential waterborne route of exposure, it is an important pathogen to consider for DPR. The fact that no method of culturing is available (only quantitative polymerase chain reaction or qPCR) currently presents challenges for evaluating infectivity and inactivation of the virus since this method does not provide information on whether the organism is alive or infective. As methods are developed to address this issue and as new data are collected through research, the need for developing a norovirus target or a virus target that incorporates norovirus should be reevaluated.

3.3.2 Targets for Chemicals

Recommended water quality targets for chemicals include, at a minimum, compliance with the primary and secondary drinking water maximum contaminant levels (MCLs). In addition to

[22] TCEQ considers regulation of total coliform in the distribution system. The regulatory concentration of bacteria (using total coliform as a surrogate) in the drinking water system is zero. This concentration must be demonstrated to gain approval for a DPR project.

ensuring compliance with the MCLs, it is recommended that utilities pursuing implementation of DPR projects develop a monitoring program using indicators and surrogates as described in Chapter 2.

3.3.3 Targets for Aesthetics

After advanced treatment, reclaimed water may look, smell, and taste different than local drinking water. Appearance and taste are key attributes that influence how the public makes decisions on whether a water supply is acceptable or not and thus represent a key issue for DPR.

As part of WRRF Project 11-02, aesthetic targets were developed for both the uninformed and informed water consumer with the overarching goal that the reclaimed water should be free of wastewater properties obvious to the consumer. For the uninformed consumer, the targets are based on meeting secondary MCLs for aesthetic properties related to appearance, odor, and taste as shown in Table 3-6.

3.3.4 Targets for Corrosion Control

Stabilization to prevent corrosion within the drinking water distribution system is achieved by dosing with an alkaline source and a calcium source (see Chapter 5 for additional information). The product water is typically stabilized to adjust the Langelier Saturation Index to around 0 and the pH to a range of 7-9.

Table 3-6: Aesthetic targets for potable reuse

Constituent	Requirements
Aesthetic targets for uninformed consumer	
Color, Apparent color units (ACU)	≤ 15[1]
Odor • Threshold odor number (TON) • Flavor profile	 ≤ 3[1] No off-flavors
Mineralization	TDS and hardness similar to local supplies[2]
Aesthetic targets for informed consumer	
Free of dissolved organic matter (DOM[23])	
• Total organic carbon (TOC), mg/L *Or* • Effluent organic matter	≤ 0.5 Transformed into a DOM that is more NOM-like based on 90% reduction in excitation-emission matrix (EEM) total fluorescence[3]
Trace organic chemicals have been reduced to acceptable levels	
Performance- and health-based chemical indicators	See Chapter 2 (Table 2-8)

Source: Trussell and others 2013.
1. This is the state secondary constituent level (SCL).
2. In some instances, potable reuse projects may achieve lower total dissolved solides and/or hardness levels than local supplies with the goal of improving the water quality of the blended project water.
3. It is not possible to select an absolute EEM profile for all waters. Instead a 90% reduction is recommended through the treatment train, even if the TOC is greater than 0.5 mg/L.

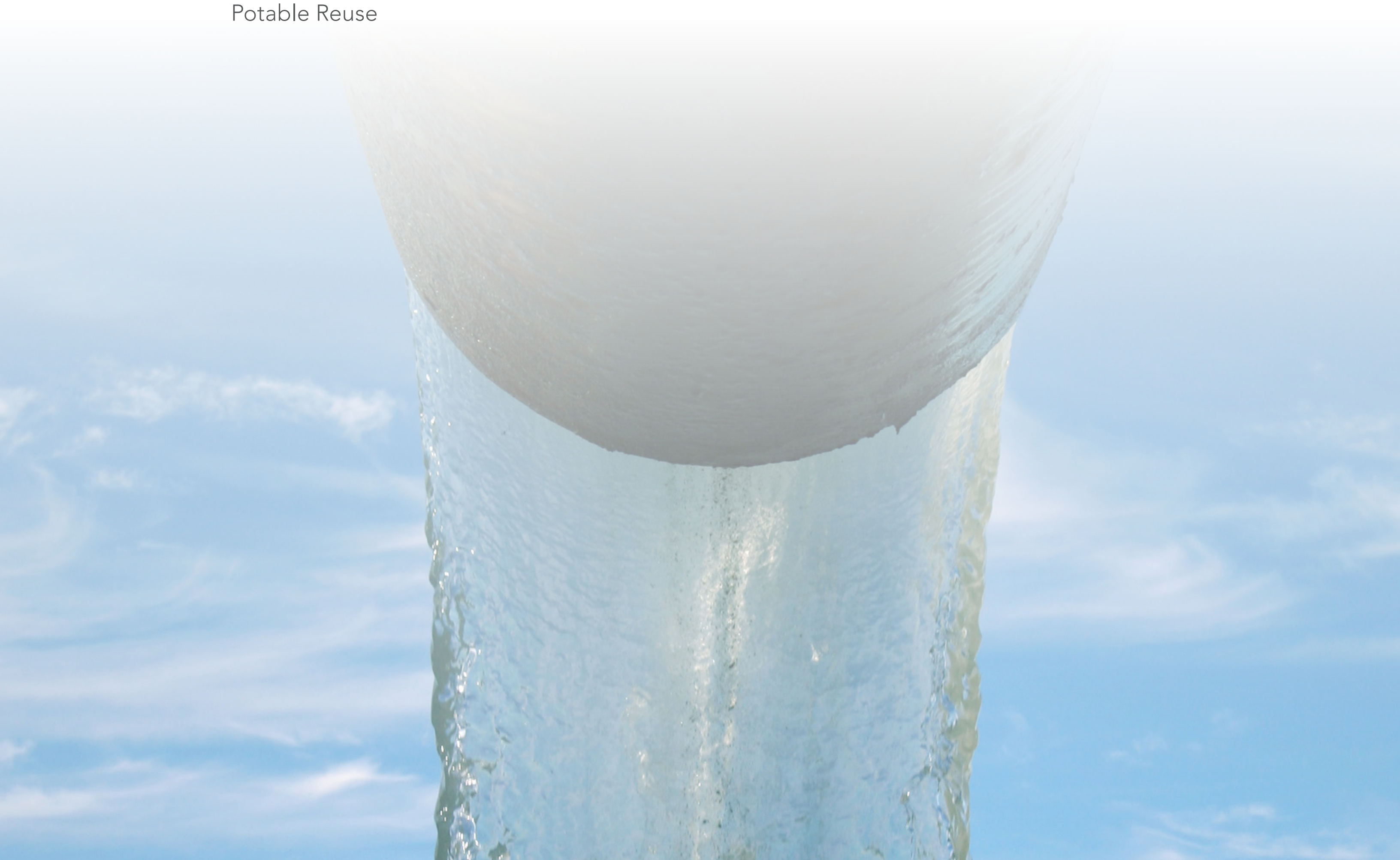
[23] To demonstrate that purified reclaimed water has lost its wastewater identity.

4 Enhanced Source Control for Direct Potable Reuse

In This Chapter

- Description of the Federal Pretreatment Program
  - National Program Elements
  - Federal Pretreatment Standards
- Characteristics of Effective Source Control Programs
- Source Control Recommendations for Potable Reuse

Road Map



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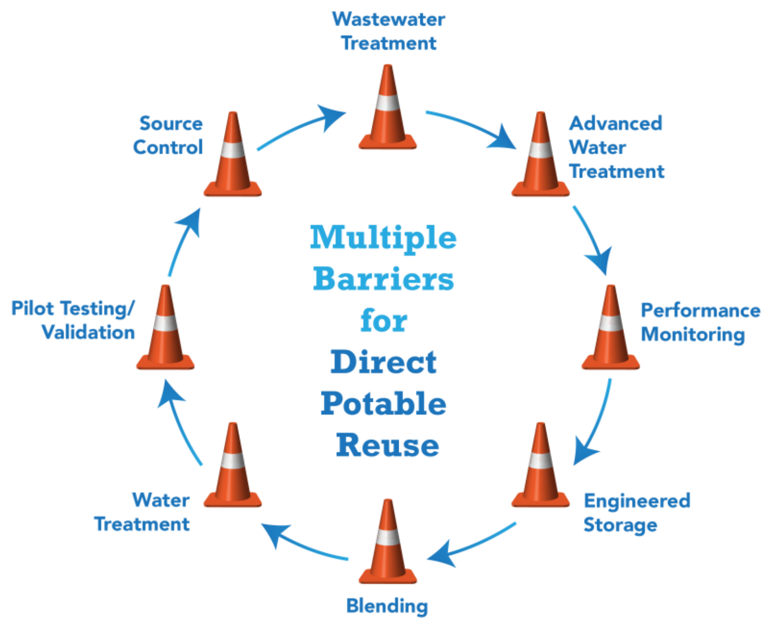
4.1 Pretreatment and Source Control Overview



The first important preventative barrier to consider when pursuing and planning for direct potable reuse (DPR) is the implementation of a source control program that limits the discharge of toxic contaminants to the wastewater collection system from industries, commercial businesses, and homes, thereby keeping them out of the reclaimed water supply. For agencies with pretreatment programs subject to the National Pretreatment Program, those requirements would be part of the source control program along with other specific program elements to address potable reuse. Agencies that operate potable reuse programs typically expand or enhance their source control programs to protect reclaimed water quality from industrial, commercial, and residential discharges.

4.2 Federal Pretreatment Program

*See **Appendix D** for more information related to source control.*

Because publicly owned treatment works (POTWs; also known as wastewater treatment plants) are not designed to treat toxic contaminants from industries or commercial businesses, the National Pretreatment Program was created as part of the Clean Water Act (CWA) to address the discharge of toxics from non-domestic sources. Even if a POTW can remove toxics, many will end up in biosolids or other residuals making them unsuitable for beneficial reuse or disposal. In the National Pretreatment Regulations, industrial and commercial dischargers (non-domestic dischargers) are defined as industrial users (IUs). The CWA only provided POTWs with the authority to control discharges from industrial and commercial sources, and not residential sources. The U.S. Environmental Protection Agency (EPA) has established General Pretreatment Regulations (40 Code of Federal Regulations (CFR) Section 403) that establish responsibilities for federal, state, and local government, and industries to achieve specific objectives.

In Texas, the National Pretreatment Program is administered by the Texas Commission on Environmental Quality (TCEQ) as part of the Texas Pollutant Discharge Elimination System

(TPDES) program. As per 30 Texas Administrative Code (TAC) Chapter 315, TPDES permits, which contain pretreatment requirements to develop and administer an approved pretreatment program, are issued to POTWs that discharge to Texas surface waters.

The objectives of the National Pretreatment Program are to prevent the introduction of contaminants into a POTW that interfere with treatment operations or that pass through treatment into receiving waters causing a violation of any requirement in a TPDES permit; and to improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

Some TPDES permits or Texas Land Application Permits may not require a POTW to implement an approved TPDES pretreatment program. However, an agency that intends to operate a DPR project should develop a source control program as the first barrier to protect reclaimed water quality even if it is not a discharge permit requirement.

4.3 National Pretreatment Program Elements

4.3.1 Legal Authority

The POTW must have the legal authority to apply and enforce any pretreatment requirements, including the following:

- Deny or condition discharges to the POTW;
- Require compliance with pretreatment standards and requirements;
- Control industrial discharges through permits or orders;
- Require compliance schedules;
- Inspect and monitor industries;
- Obtain remedies for industrial noncompliance; and
- Enter into multijurisdictional agreements with entities that discharge to a POTW, but are outside the POTW's legal jurisdiction to ensure that the entity and its IUs meet the POTW's pretreatment program requirements.

Federal Pretreatment Program Elements

- *Legal authority (ordinances, rules, agreements).*
- *Procedures, forms, checklists.*
- *Funding for resources and personnel.*
- *Technically-based local industrial discharge limits (local limits).*
- *Enforcement Response Plans.*
- *Industrial inventory.*

4.3.2 Procedures

The POTW must develop and implement procedures to ensure compliance with pretreatment requirements, including:

- Identifying and locating all industries;
- Identifying the character and volume of pollutants contributed by industries;
- Receiving and analyzing reports from industries;
- Sampling and analyzing industrial discharges;
- Evaluating the need for control plans for spills; and
- Investigating instances of noncompliance.

4.3.3 Funding

The POTW (and multijurisdictional entities) must have sufficient resources and qualified personnel to carry out the authorities and procedures specified in its approved pretreatment program.

4.3.4 Local Limits

POTWs must develop technically-based local limits to regulate the discharge of pollutants or constituents of concern (COCs) from IUs to address the specific needs and concerns of a POTW[24]. Local limits are applicable at the *end-of-pipe* discharge from an IU's facility. Some POTWs establish the legal authority to develop local limits for categories of industries, individual industries, or on a case-by-case basis. If authorized by TCEQ in their approved TPDES pretreatment programs POTWs can develop and impose best management practices (BMPs) for IUs, and for enforcement purposes these BMPs are considered to be local limits/pretreatment standards.

Examples of BMPs

- *Schedules of activities*
- *Prohibition of practices*
- *Maintenance procedures*
- *Management practices*
- *Treatment requirements*
- *Operating procedures*

[24] For POTWs with TPDES permits, the COCs must address constituents listed in the Texas Surface Water Quality Standards (30 Texas Administrative Code Chapter 307).

4.3.5 Enforcement Response Plan

The POTW must develop and implement an enforcement response plan (ERP) that contains detailed procedures indicating how the POTW will investigate and respond to instances of industrial noncompliance. It should include an enforcement response guide, which is a matrix that describes the types of violations and the POTW's range of appropriate enforcement options.

4.3.6 List of Industrial Users

The POTW must maintain a list of all IUs and identify them by their appropriate classification: significant industrial users (SIUs), categorical industrial users (CIUs), and non-significant IUs. CIUs are subject to EPA's categorical pretreatment standards. An SIU includes CIUs; IUs that discharge 25,000 gallons per day (gpd) or more of process waste; IUs that contribute substantially to the design or organic treatment capacity of the POTW; or any IU that is designated by the POTW as an SIU based on the reasonable potential for adversely affecting the treatment plant operation or violating any pretreatment standard.

4.4 Federal Pretreatment Standards

The POTW must enforce both general prohibitions and specific prohibitions in the pretreatment regulations. The general prohibitions disallow an IU from discharging a pollutant or pollutants that cause pass through or

Federal Pretreatment Standards

- ***General prohibitions-*** *disallow an IU from discharging a pollutant or pollutants that cause pass through or interference*
- ***Specific prohibitions-*** *list of specific restrictions on pollutant discharges*
- ***Categorical pretreatment standards-*** *technology-based numeric limits on pollutant discharges*

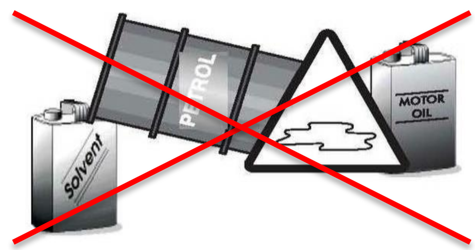
Definitions: Pass Through and Interference

- ***Pass through*** *is a discharge that exits the POTW into waters of the United States in quantities or concentrations, which, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any requirement in a POTW's TPDES permit.*
- ***Interference*** *is a discharge which alone or in combination with a discharge or discharges from other sources (1) inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, uses or disposal, and (2) is therefore a cause of a violation of any requirement in a POTW's TPDES permit.*

interference.

The specific discharge prohibitions exclude the discharge of:

- Pollutants that may create a fire or explosion hazard in the sewer system or at the POTW;
- Pollutants that are corrosive, including any discharge with a pH of less than five;
- Solid or viscous pollutants in sufficient amounts that will cause obstruction or blockage of flow;
- Any pollutants discharged in sufficient quantity to interfere with the operation of the POTW;
- Heat in such quantities that the temperature at the POTW Treatment Plant exceeds 104 °F or is hot enough to interfere with biological treatment processes;
- Petroleum oil, non-biodegradable cutting oil, or other products of mineral oil origin in amounts sufficient to cause interference or pass through;
- Pollutants that result in the presence of toxic gases, vapors, or fumes at the POTW in sufficient amounts that may cause acute worker health and safety problems; and



- Any trucked or hauled pollutants, except at discharge points designated by the POTW.

Categorical pretreatment standards are technology-based numeric limits that have been developed in accordance with section 307 of the CWA to limit the pollutant discharges to POTWs from specific process wastewaters from IUs. These national technology-based standards apply to an IU regardless of whether or not the POTW has an approved pretreatment program or the IU has been issued a control mechanism or permit. The standards are established based on the list of Priority Pollutants.

4.5 Source Control Monitoring and Notifications

Industrial Users are subject to monitoring conducted by the POTW or are required to perform self-monitoring that takes into consideration the type of IU (SIU, CIU, or non-SIU) and applicable limits and potential COCs. In addition, the pretreatment regulations require IUs to notify the POTW, EPA, and TCEQ in writing of the discharge into a POTW of a substance, which, if otherwise disposed of, would be a hazardous waste as defined by federal regulations. POTWs with approved pretreatment programs may need to monitor influent and effluent for toxic or hazardous pollutants if, based upon information available to the POTW, there is reason to suspect they may be present. Information on some hazardous chemicals manufactured, processed, or otherwise used by industries in specific sectors and discharged to POTWs is available from the EPA's Toxics Release Inventory (TRI). The TRI Program currently covers 683 chemicals and chemical categories including many, but not all, hazardous chemicals as well as non-hazardous chemicals.

4.6 Source Control Effectiveness

It is important to note that expectations regarding source control effectiveness must be realistic. Source control programs will be successful in achieving reductions under the following conditions:

- The pollutant can be found at measurable levels in the wastewater influent and/or collection system. If a pollutant is only found sporadically it is very difficult in most cases to identify the source.
- A single source or group of similar sources accounting for most of the influent loading can be identified, such as the source's relative contributions to the mass loading and concentration of a contaminant or contaminants. The portion of the total influent source that is identified and considered controllable must be greater than the reduction in contaminant levels needed. Contaminants that are ubiquitous are typically infeasible to control, such as quinoline from automobile exhaust or copper from brake pad linings. Substances such as banned pesticides that homeowners may stockpile and occasionally flush down the drain are difficult to control, but potentially can be addressed through hazardous waste collection programs and/or public outreach.
- The sources are within the jurisdiction of the wastewater management agency to control (or significant outside support/resources are available). For example, industrial sources are more easily controlled because industries are regulated and required to meet sewer use permit requirements, while residential sources are not within the legal jurisdiction of wastewater agencies and, therefore, voluntary behavioral changes must be accomplished. If a pollutant source is a commercial product, such as mercury thermometers or lindane head lice remedies, it may not be within the local agency's power to ban or restrict the use of the product. To be effective, the use of a product must be restricted on a local, regional, statewide, or national basis. One example of a successful statewide effort is the California statutory ban placed on lindane in head lice products, which was accomplished based on the combined efforts of wastewater agencies, a state legislator, and the National Pediculosis Association.

4.7 Source Control Recommendations for Potable Reuse

A key factor for creating an effective source control program for potable reuse is the recognition that the program is a critical sentinel in creating a safe water supply and no longer is focused on just wastewater compliance. The following recommendations provide guidance on how to structure a source control program to provide an effective barrier for DPR. The program elements listed are voluntary and are not intended to be part of approved pretreatment programs. These recommendations could impact source control program resources and budgets in terms of staffing, technical skills, and operating procedures.

> **Enhanced Source Control Program Elements**
>
> - *Targets wastewater and drinking water quality and compliance.*
> - *Proactive tailored program.*
> - *Sufficient flexible legal authority.*
> - *Local limits address wastewater and drinking water contaminants of concern (COCs).*
> - *Comprehensive industry inventory along with their COCs.*
> - *Assist industries in identifying substitutes for COCs.*
> - *Ensure permits and monitoring programs address COCs.*
> - *ERPs that can rapidly identify and respond to COC discharges.*
> - *Memorandum of understanding for source control if the agency producing the reclaimed water does not manage the source control program.*
> - *Outreach to industries and the public on COCs.*
> - *Communication between source control, wastewater operations, and advanced water treatment staffs to rapidly respond to and address problems.*

- Implement a proactive source control program tailored to your service area's industrial and commercial business inventory and wastewater treatment system.

- Ensure that a source control program's legal authority has sufficient power to develop and implement source control measures to protect reclaimed water quality and the ability of the treatment facility to produce reclaimed water; including establishing local limits to control both drinking water and wastewater COCs and provisions to take actions as necessary to protect a DPR project.

- Develop and maintain a frequently updated comprehensive inventory of industries and businesses, which may use products or chemicals that contain COCs or that could generate intermediate compounds of concern.

- Assist and encourage industries and businesses, which use chemicals that contain COCs, to identify source control options, such as chemical substitution.
- For development of local limits, consider including a broader spectrum of COCs, including regulated and non-regulated constituents that are relevant for DPR, such as drinking water contaminants, or constituents of emerging concern.
- Ensure that IU discharge permits and other control mechanisms can effectively regulate and reduce the discharge of COCs for DPR, and permits are reviewed and revised to adapt to any changing conditions, as needed.
- Consider alternative control mechanisms, such as BMPs or self-certification for zero discharge of pollutants for classes of industries or commercial businesses.
- Ensure that monitoring programs conducted by the POTW and IUs address COCs for DPR.
- Ensure that the enforcement response program can rapidly identify and respond to discharges of COCs for DPR, taking into consideration water quality and performance data at the wastewater treatment plant and the advanced water treatment facility.
- For projects with multiple agency involvement (in particular when a separate agency treats the wastewater supplied to the agency that produces the reclaimed water used for DPR), consider entering into a memorandum of understanding or other contractual agreement so that appropriate source control actions can be taken, if necessary to protect reclaimed water quality.
- Provide outreach information on DPR to industries, source control practices and compliance assistance, and permit assistance to support the DPR program.

See ***Appendix D*** *for examples of national and local voluntary source control efforts related to potable reuse.*

- Develop environmental stewardship programs with local industries and businesses for support of the DPR program.
- Provide outreach to the public regarding proper disposal of pharmaceuticals and household products that contain chemicals that may be COCs; consider developing household hazardous waste collection programs; and consider developing school education programs that addresses potable reuse.
- As part of public outreach efforts for the DPR program, provide information on the source control program and how it works.

- Ensure that there is communication between the source control staff, wastewater treatment operations staff, and advanced water treatment operations staff to address situations in which there may be impacts to water quality or the effectiveness of treatment performance. There should be a plan that guides rapid responses and corrective actions.

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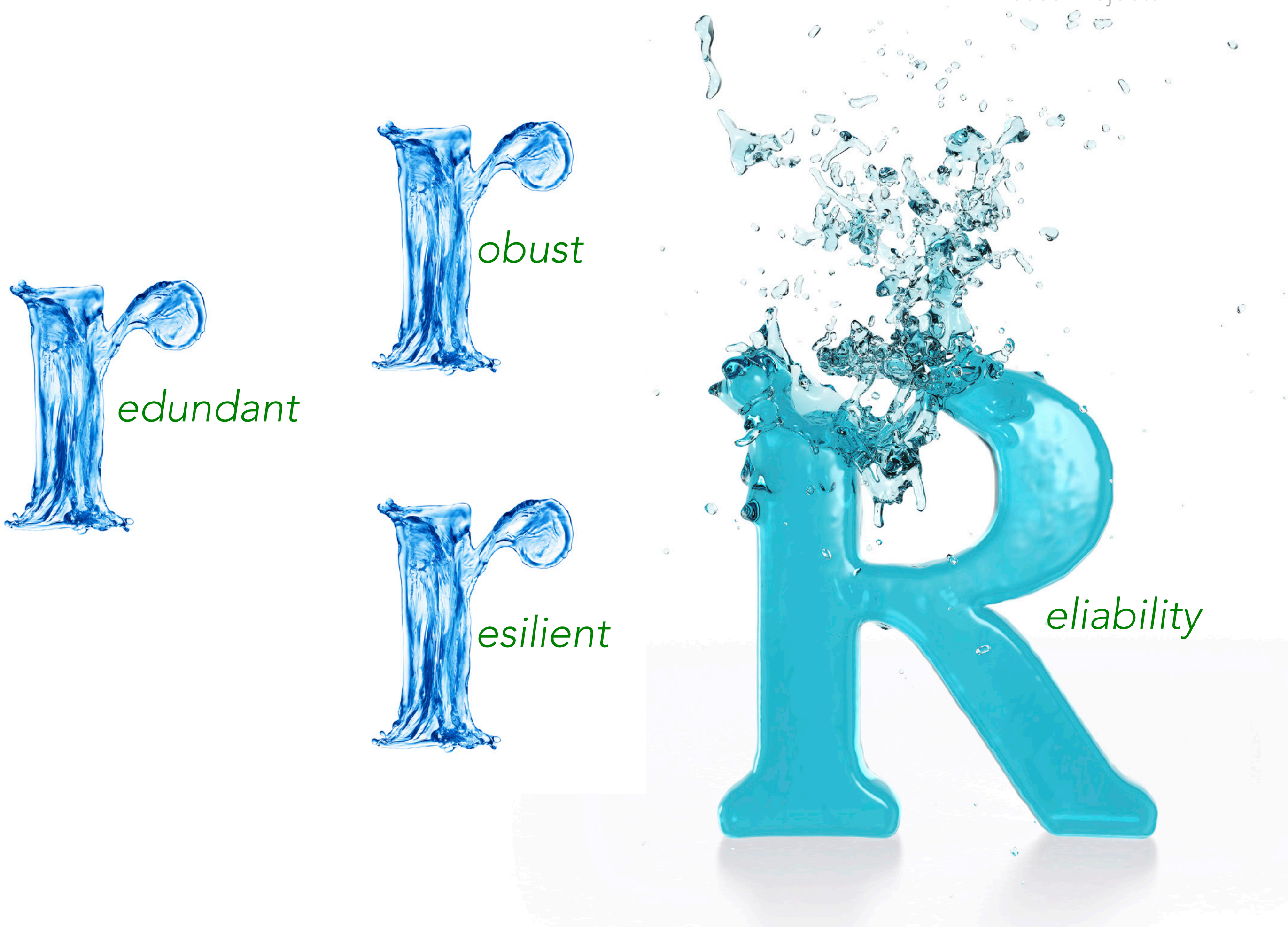
5 Treatment Strategies for Direct Potable Reuse

Road Map

In This Chapter

- Focus on the 4-R's: reliable, redundant, robust, resilient
- The importance of secondary/tertiary treatment
- Advanced treatment options for Direct Potable Reuse
- Suggested treatment schemes
- Advanced treatment costs



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5.1 Introduction

A multi-barrier treatment system capable of reliably achieving the desired water quality goals is an integral component of direct potable reuse (DPR). The treatment system must be: redundant (composed of multiple systems for the same contaminant so that if one fails or must be taken out of service for maintenance the system still effectively performs); robust (composed of a combination of treatment technologies to address a broad range of contaminants of concern (COCs) including both regulated and unregulated pathogens and chemicals, and changes in source water quality); and resilient (protocols and strategies are in place to address failures and bring systems back on-line). Other components of the DPR treatment strategy include the managerial and technical capability of the project sponsor to operate a DPR system, financial considerations (both capital and operational costs), treatment process residuals management, regulatory permitting, stabilization of the final product water, operation and maintenance plans, and contingency plans.

5.2 Treatment Options

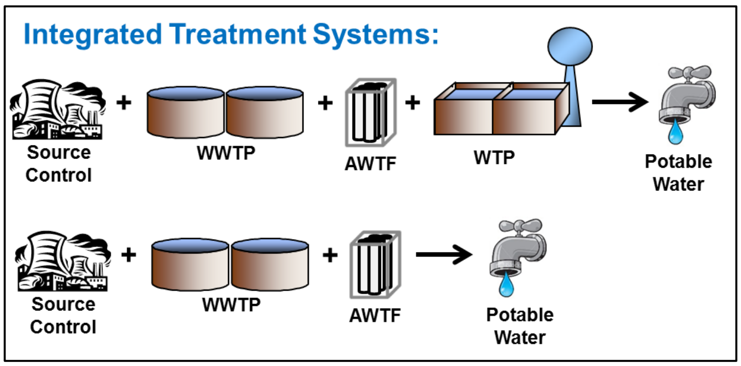
*See **Appendix E** for more information on AWT options for direct potable reuse.*

A variety of advanced water treatment (AWT) technologies are available to treat secondary or tertiary wastewater for potable reuse. Many of these technologies have been employed in full-scale applications to generate reclaimed water for non-potable use or for indirect potable reuse (IPR). Other AWT technologies have either limited full scale applications or have not resulted in efficient or effective treatment for producing reclaimed water. Site- and project-specific attributes can be a factor in selecting the appropriate treatment process for a reuse project.

5.2.1 Secondary/Tertiary Wastewater Treatment

The feed water for an advanced water treatment facility (AWTF) that supplies source water for advanced treatment is either secondary or tertiary effluent from a wastewater treatment plant (WWTP) or water reclamation plant (WRP), which may or may not be disinfected. Wastewater treatment typically includes primary clarification and a secondary biological process followed by secondary clarifiers. Secondary treatment can include aerated lagoons, rotating biological contactors, trickling filters, or conventional activated sludge processes (with or without nutrient removal). Some facilities may also provide filtration (tertiary treatment) utilizing granular media filtration (sand, anthracite or multi-media filters) or cloth-media filtration. Prior to discharge or direct non-potable reuse, the effluent is disinfected. Project sponsors may elect to use wastewater effluent that is not disinfected to reduce formation of disinfection by-products (DBPs) in the feed water to the AWTF.

A crucial consideration for DPR projects is quality of the feed water to the AWTF. The original focus of operating WWTPs or WRPs was to meet discharge or non-potable reuse requirements. A higher quality feed water can improve the quality of the final DPR product water and the operations of the AWTF. Therefore a shift in thinking about the function of the WWTP or WRP is important as it now is part of an integrated treatment system to produce a potable drinking water supply. A number of process modifications can be implemented at existing WWTPs or WRPs to improve the final effluent quality, including (1) influent wastewater flow equalization; (2) improved primary treatment performance via chemical addition[25] such as alum or polymers; (3) improved secondary treatment performance via increased solids retention times (SRTs), and the use of microbial selectors[26] to achieve nitrification, denitrification, and/or biological phosphorus removal; (4) enhanced secondary particle settling or phosphorus removal with chemical addition such as alum or polymers; (5) the use of deeper secondary clarifiers,



[25] National Sanitation Foundation International (NSF) approved chemicals may be needed.

[26] In biological wastewater treatment, special groups of microorganisms responsible for the treatment process can be "selected" (or encouraged to grow) through consideration of plant design and operating conditions. Use is made of the physiological and physical properties of the microorganisms to create what are known as primary and secondary selection pressure conditions. Secondary selection is achieved with special techniques ("microbial selectors") based on characteristics such as cell settlement properties and size, and occurs only in continuous and semi-continuous systems. Each combination of primary and secondary selection conditions creates a unique population of microorganisms.

especially in warmer areas; and (6) alternative management of return flows from solids processing facilities including flow equalization, treatment, and/or elimination. Nitrogen removal is an essential part of the overall transformation from wastewater to drinking water based on acute health effects related to nitrate and nitrite in drinking water. Thus, the use of de-nitrifying filters for both nitrogen and pathogen removal should be considered as an important barrier in the integrated treatment system. The decision to include the filter as part of the WWTP or the AWTF would be a function of meeting Texas Commission on Environmental Quality (TCEQ) criteria for DPR projects. For any systems change, such as chemical addition using polymers, consideration should be given to the type of polymer used since it could contain precursors for formation of DBPs, such as N-nitrosodimethlyamine (NDMA).

Changing the Paradigm for Wastewater Treatment

Historically, the goals of wastewater treatment have focused on meeting water quality limits associated with discharge permit requirements. For potable reuse projects, the wastewater treatment plant is part of the overall integrated treatment system and treatment goals should focus on providing a water quality that will benefit the downstream advanced water treatment processes. Potential process modifications include:

- *Flow equalization*
- *Improved primary treatment*
- *Improved secondary treatment*
  - *Increased solids retention times*
  - *Nitrification/denitrification*
  - *Nutrient removal*
- *Alternate management of return flows from solids processing*

Secondary effluent and tertiary effluent are typically disinfected using free chlorine, chloramine, ozone, and/or ultraviolet irradiation (UV). Selection of disinfected or un-disinfected secondary or tertiary effluent prior to AWT should be considered in light of factors such as pathogen reduction targets or requirements, maintenance of the distribution system from the WWTP or WRP to the AWTF, and formation of DBPs for treatment at the AWTF.

It should be noted that the TCEQ has not specifically assigned pathogen removal or chemical constituent removal credit for treatment prior to AWT for a DPR project. However, thorough characterization of the proposed wastewater effluent source is required by the TCEQ prior to project approval to establish treatment requirements between the wastewater discharge and the entry point to the potable water distribution system. Ongoing water quality monitoring of the wastewater effluent is also required during the operation of a DPR project to validate the treatment requirements.

Although the TCEQ sets treatment requirements and assigns treatment credits for DPR starting after a WWTP, the wastewater treatment processes that remove pathogens and chemical constituents from the raw wastewater provide important barriers for the multi-barrier treatment framework and the 4-Rs by reducing the pathogen and chemical loads in the wastewater effluent.

As discussed in Chapter 3, for the pathogen removal targets recommended in WRRF 11-02, integrated treatment schemes were assembled assuming that both pathogen and chemical constituent removal credits would be allowed for the WWTP. For un-disinfected secondary/tertiary treatment, the following pathogen $\log_{10}$ reductions were assumed (Trussell, R. and others (2013)):

- *Cryptosporidium* 2 logs;
- *Giardia* 2 logs; and
- Viruses 1 log.

For total coliform, a 2 log reduction for un-disinfected secondary/tertiary was assumed (see Appendix E).

5.2.2 Pathogen Removal for Advanced Treatment Processes

The different types of DPR advanced water treatment processes and assumed pathogen removals and maximum credits currently allowed by the TCEQ are summarized in Table 5-1. The assumed “upper end reductions” shown are based on available data from various pilot- and full-scale installations that were summarized in Trussell and others (2013). These reductions represent the upper range of removal that could be achieved for specific treatment technologies; several operational and water quality factors associated with individual technologies affect actual performance as more fully discussed in Appendix E. Actual log removal credits will be subject to TCEQ approval and may need to be adjusted for specific DPR projects.

5.2.3 Chemical Removal for Advanced Treatment Processes

Similar to pathogens, the various advanced treatment processes have varied performance with respect to the chemical Water Quality Performance Targets. Approximate removal percentages were acquired from a literature review and discussed in more detail in Section 5.5 for each of the treatment strategies.

Table 5-1: Potential log reductions for pathogens and total coliform for advanced treatment processes

Process	Purpose	Pathogen and Total Coliform Log Reduction[1]							
		Crypto-sporidium		*Giardia*		Virus		Total Coliform	
		TCEQ	UER	TCEQ	UER	TCEQ	UER	TCEQ	UER
Microfiltration (MF) or Ultrafiltration (UF)	– Removes suspended and colloidal solids and pathogens. – Typically functions as pretreatment for subsequent membranes to prevent fouling.	4	4	4	4	0	0[2]	NA	3
Membrane Bioreactors (MBR)	– Combines wastewater treatment plant (WWTP) biological treatment with MF or UF in one unit process and replaces WWTP secondary clarifiers and tertiary filters. – Removes biochemical oxygen demand, ammonia, turbidity, and pathogens. – Helps minimize fouling of subsequent membrane processes.	0	4	0	4	0	0[2]	NA	3
Reverse Osmosis (RO)	– Pressure driven membrane process that separates and removes dissolved solids, bulk organics, nitrate, pesticides, constituents of emerging concern (CECs), and pathogens. – Produces permeate (the water that permeates through the membranes) and concentrate or brine (impurities that are rejected by the membrane and concentrated). – Recovery of feed water ranges from 75% to 85% or up to 90% if a third stage is added. – Disposal of concentrate can be challenging and costly.	0[3]	2	0[3]	2	0[3]	2	NA	4
Nanofiltration (NF)	– Similar to RO and removes trace organics, viruses, natural organic matter, and divalent ions that comprise hard water; less effective at removing dissolved salts and nitrate compared to RO. – Produces permeate and concentrate, but at lower pressure and operating costs than RO. – Treatment or disposal of NF concentrate is less problematic than for RO due to lower volumes of concentrate produced.	0	---[4]	0	---[4]	0	---[4]	NA	---[4]

Process	Purpose	Pathogen and Total Coliform Log Reduction[1]							
		Crypto-sporidium		*Giardia*		Virus		Total Coliform	
		TCEQ	UER	TCEQ	UER	TCEQ	UER	TCEQ	UER
Chlorine	– Commonly used disinfectant that inactivates pathogens. – For most WWTP, ammonia is present that creates chloramines. – Free chlorine is a more effective disinfectant than chloramine. – For RO systems, use of chloramine prevents fouling. However, free chlorine is not tolerated by RO membranes. – Creates disinfection byproducts (DBPs).	0	0	1	1	3[5]	3	NA	3
Ultraviolet Irradiation (UV) Disinfection	– Effectiveness depends on the water quality (lower suspended solids improves efficacy), UV intensity, exposure time, and reactor configuration.	4[6]	4	4[6]	4	4[6]	4	NA	5
UV/Photolysis	– The UV disinfection system can be utilized to photolyze chemicals such as N-nitrosodimethylamine (NDMA) by using a UV dose much higher than the dose required for disinfection.	4[6]	≥4	4[6]	≥4	4[6]	≥4	NA	≥5
Advanced Oxidation Processes (AOP)	– Chemical process that generates hydroxyl radicals to oxidize organic compounds such as NDMA, 1,4-dioxane, and other CECs. – There are different types of AOP systems: UV/peroxide, ozone/peroxide, UV/ozone, UV/chlorine. – AOP also inactivates pathogens.	4[6]	6[7]	4[6]	6[7]	4[6]	6[7]	NA	6[7]
Ozone	– Strong oxidant of organics and a strong disinfectant. – Creates DBPs, such as bromate and NDMA	3[8]	3	3[8]	3	5[8]	5	NA	3
Ozone/ Biological Activated Carbon (BAC)	– Strong oxidant of organics and a strong disinfectant. – Since ozone is consumed quickly, it must be contacted uniformly in a contactor; however any remaining ozone must be quenched. – BAC helps to remove chemical by-products of ozonation, such as NDMA and assimilable organic carbon.	3[9]	3	3[9]	4	5[9]	5	NA	4
Stabilization	– Chemical stabilization via decarbonation and dosing with an alkaline source to address the corrosive character of RO permeate (low level of total dissolved solids, calcium, magnesium, alkalinity, and pH).	---[10]	---[10]	---[10]	---[10]	---[10]	---[10]	NA	---[10]

Process	Purpose	Pathogen and Total Coliform Log Reduction[1]							
		Crypto-sporidium		*Giardia*		Virus		Total Coliform	
		TCEQ	UER	TCEQ	UER	TCEQ	UER	TCEQ	UER
Engineered Storage	– Well-defined constructed storage facility. – Provides a safety factor in the form of response time to address acute risks from pathogens should a treatment system fail or operate below desired performance targets. – A multi-barrier treatment scheme with process control points could avert the need for a separate storage barrier.	---[10]	---[10]	---[10]	---[10]	---[10]	---[10]	NA	---[10]
WTP	– The proposed schemes use a conventional WTP with processes including flocculation, sedimentation, media filtration, and chlorination.	3	3	3	3	4	4	NA	5

Source: Trussell, R. and others (2013); TCEQ Water Supply Division, personal communication, April 2015.

NA= not applicable

1. TCEQ = maximum reduction credit currently granted by the TCEQ; UER = Assumed upper end reductions (see Appendix E)
2. MBR and MF/UF can achieve virus removal. However, no removal is assigned due to concerns with integrity testing verification.
3. Currently, TCEQ does not allow pathogen removal credits for RO. However, credits could be granted if appropriate direct integrity testing was demonstrated.
4. NF may be a viable treatment option, but was not included in any of the AWT schemes due to limited full-scale application, and thus pathogen credits are not included.
5. TCEQ does not have a maximum inactivation limit for chlorine, but does cap the maximum chlorine residual allowed at 4.0 mg/L and requires multiple barriers for pathogen inactivation/removal. The values shown are the same as those assumed for UER. Higher values could be approved on a site-specific basis.
6. The TCEQ does not have a maximum inactivation limit for UV. However, the TCEQ does require multiple barriers for pathogen inactivation/removal. The TCEQ cannot currently grant additional pathogen inactivation for UV/Photolysis or UV/AOP. The inactivation values in each of these rows have been set to 4.
7. These credits are for UV/AOP.
8. TCEQ does not have a maximum inactivation limit for ozone. However, the TCEQ does require multiple barriers for pathogen inactivation/removal. The values shown are the same as those assumed for UER. Higher values could be approved on a site-specific basis.
9. The TCEQ cannot currently grant additional removal for BAC above that which can be granted for ozone alone.
10. No credits.

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5.3 Potential Direct Potable Reuse Treatment Schemes

Six potential ("straw men") DPR treatment schemes were developed to serve as possible options and as a basis for further consideration by entities interested in pursuing a DPR project. Some, but not all of the technology options have proven effectiveness based on a limited number of active DPR and IPR projects. The individual unit processes have shown promise from full-scale and/or pilot studies to achieve the water quality performance targets defined in Chapter 3 if included in an AWTF treatment train. Each scheme represents the entire DPR process from the WWTP to the AWTF and WTP (if applicable) to the potable water distribution system. For some treatment schemes, a conventional WTP (flocculation-sedimentation, media filtration, and chlorination) was included to meet the pathogen and coliform log removal targets, while for others it is shown as an optional component because the log removal targets could be met without the WTP. Engineered storage is also shown as a potential element of several of the treatment schemes. Although engineered storage does not provide treatment, the need for storage should be evaluated as part of the entire integrated treatment system and can be used as an additional barrier to provide response time in the event of a treatment failure or upset. The use of engineered storage is especially important where the DPR treatment facility is located adjacent to the point of injection into the water distribution system or to the intake of the water treatment plant.

Potential Direct Potable Reuse Treatment Schemes

The specific treatment scheme selected for any direct potable reuse (DPR) project should be based on site-specific conditions that take into account:

- *Specific water quality characteristics*
- *Experience and sophistication of the public water system and operators*
- *Amount and frequency of monitoring*
- *Extent of fail-safe systems and protocols*
- *Type of DPR system (delivery directly to the distribution system versus delivery to the raw water source for a water treatment plant)*

The treatment schemes presented have been selected based on their predicted ability to achieve the water quality performance targets discussed in Chapter 3. However, supplemental processes may be needed to provide additional barriers and/or address site-specific water quality issues.

Project specific evaluations should be considered regarding issues such as:

- Nitrogen removal at the WWTP;
- Disinfectant byproduct formation;

- The need for additional processes such as activated carbon or ion exchange to address site-specific contaminants;
- The addition of other AWT components to provide additional barriers;
- The use of engineered storage; the addition of other treatment processes at the WTP to provide additional barriers;
- Compatibility with other drinking water supplies;
- Potential drinking water distribution system corrosion or stability issues;
- Post disinfection of product water to prevent regrowth in the drinking water distribution system; and
- If information is available on the design, operation, and maintenance from a full-scale facility or substantive pilot studies for the treatment scheme being considered.

The order of the DPR treatment schemes presented does not imply the ranking of a specific scheme. More information on AWT options for DPR is presented in Appendix E. If a full-scale facility resembling a treatment scheme is currently in operation, it is noted as part of the treatment scheme discussion.

5.3.1 Treatment Scheme No. 1

Treatment Scheme No.1, shown in Figure 5-1, includes ozonation prior to the MF/UF-RO-UV/AOP process sequence.[27] For this treatment scheme, disinfected secondary or tertiary effluent from a WWTP would be dosed with ozone for pathogen removal and to oxidize the organics in the wastewater effluent. Ozonation can result in formation of undesirable chemical by-products such as NDMA and bromate that may be difficult to remove with downstream AWT treatment processes. The ozone dose/contact time should be designed to accomplish the desired disinfection and oxidation with a minimum formation of these undesirable chemical by-products. The production of assimilable organic carbon (AOC) from ozonation may contribute to biofouling of downstream membranes if chloramination is not maintained.[28] After the ozone pretreatment, the water is treated with MF/UF, RO, and UV/AOP (using hydrogen peroxide prior to UV). The final treatment step is post-treatment or stabilization. Engineered Storage and a WTP are shown as optional components as this scheme meets the Water Quality Performance

[27] Treatment Scheme No. 1 is similar to the West Basin Municipal Water District's (WBMWD) Edward C. Little Water Recycling Facility in El Segundo, CA.

[28] Chloramine for control of fouling of the RO is required as a part of the treatment when using RO.

Targets without these components. Major residuals from this treatment scheme include MF/UF backwash, cleaning chemicals, and RO concentrate (or brine). Depending on the capacity of the DPR facility relative to that of the WWTP, these residual streams (except RO concentrate) may be recycled back to the WWTP. Otherwise, concentrate disposal options must be pursued.

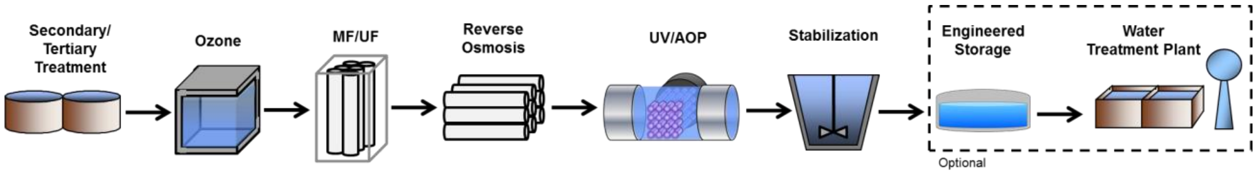

Figure 5-1: Treatment Scheme No. 1

5.3.2 Treatment Scheme No. 2

Treatment Scheme No. 2, shown in Figure 5-2, includes the MF/UF-RO-UV/AOP process sequence.[29] This treatment scheme is similar to Treatment Scheme No. 1 without the ozone pretreatment and with the addition of Engineered Storage and a WTP. At the heart of this scheme is the MF-RO-UV/AOP process sequence.[30] After stabilization, as described for Treatment Scheme No. 1, the water is conveyed to Engineered Storage and then to a WTP for additional treatment before distribution. The WTP is needed to assist with achieving pathogen reduction targets. Major residuals from this treatment scheme include MF/UF backwash, cleaning chemicals, and RO concentrate. Depending on the capacity of the DPR facility, these residual streams (except RO concentrate) may be recycled back to the WWTP. Otherwise, concentrate disposal options must be pursued.

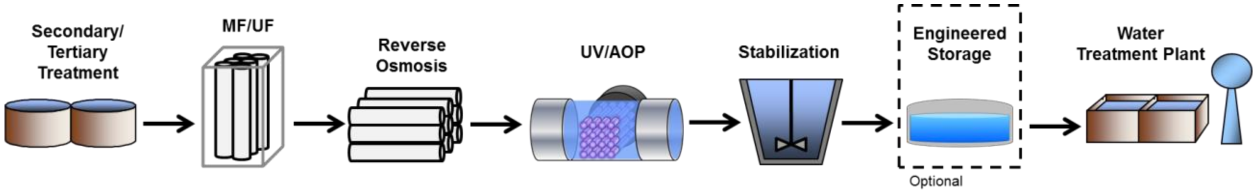

Figure 5-2: Treatment Scheme No. 2

[29] Treatment Scheme No. 2 shares some characteristics with the Colorado River Municipal Water District Project at Big Spring, TX, which treats disinfected tertiary effluent with the MF/UF-RO-UV/AOP process sequence. The reclaimed water is then blended with raw surface water and treated at a conventional WTP. It is also similar to the treatment scheme used at Wichita Falls, TX which treats disinfected tertiary effluent with MF/RO/UV prior to blending with raw surface water and treatment at a conventional WTP. This treatment scheme also is employed worldwide for IPR projects.

[30] Chloramine for control of fouling of the RO is required as a part of the treatment when using RO.

5.3.3 Treatment Scheme No. 3

Treatment Scheme No. 3, presented in Figure 5-3, includes an MBR instead of the more conventional secondary/tertiary treatment at a WWTP ahead of the RO-UV/AOP process sequence.[31]

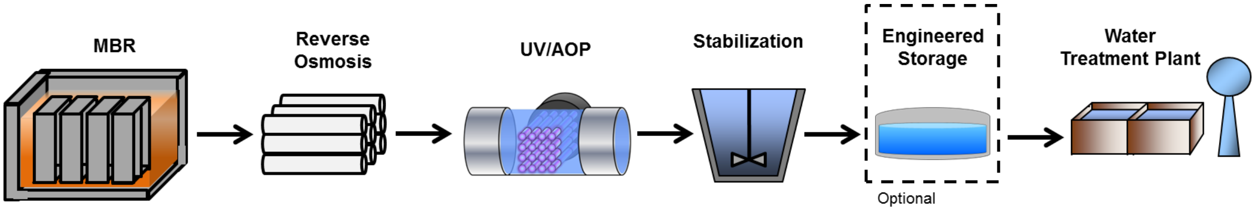

Figure 5-3: Treatment Scheme No. 3

The first step in this scheme is treatment of primary-treated wastewater with an MBR operated with full nitrification. MBR filtrate would be dosed with chloramines and then flow to a filtrate tank before being pumped to the downstream RO and UV/AOP processes. The RO[32], UV/AOP and stabilization processes would be as described for Treatment Scheme No. 1. Similar to Treatment Scheme No. 2, Engineered Storage and a WTP would comprise the final processes before distribution. The WTP is needed to assist with achieving pathogen reduction targets. Residuals from the process include wasted sludge, MBR membrane cleaning waste, and RO concentrate. The waste sludge would be processed in a typical WWTP solids handling facility. The MBR cleaning wastes would be neutralized and slowly fed back into the head of the MBR treatment plant. RO concentrate would need to be addressed as described in Treatment Scheme No. 1.

5.3.4 Treatment Scheme No. 4

Treatment Scheme No. 4, presented in Figure 5-4, includes ozone and BAC before MF/UF, followed by UV and free chlorine disinfection. Treatment Scheme No. 4 eliminates RO from the treatment process train, which would help alleviate RO concentrate disposal issues as well as the need to produce a larger flow of RO feed water. Major residuals from this treatment scheme include BAC backwash and MF/UF backwash and cleaning chemicals. The BAC backwash would be clarified and the decant stream recycled back to the head of the treatment plant or sent to the WWTP. The MF/UF residual streams may be recycled back to the WWTP.

[31] MBRs are a traditional wastewater process. The TCEQ has not implemented rules for granting pathogen removal credits for MBRs.

[32] Chloramine for control of fouling of the RO is required as a part of the treatment when using RO.

Depending on the ozone dose used, Engineered Storage and a WTP may not need to be an integral part of Treatment Scheme No. 4 to meet the Water Quality Performance Targets. However, these processes are shown as optional and would provide additional barriers, if desired. Since Treatment Schemes 4, 5 and 6 do not include RO, it is extremely important that nitrogen removal be performed as part of the secondary/tertiary treatment ahead of the advanced treatment in these schemes. The advanced treatment in these schemes will not provide appreciable removal of nitrate or nitrite.

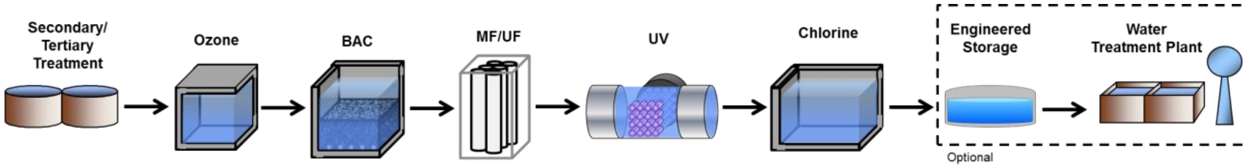

Figure 5-4: Treatment Scheme No. 4

5.3.5 Treatment Scheme No. 5

Treatment Scheme No. 5 is presented in Figure 5-5. This treatment scheme reverses the order of MF/UF and Ozone/BAC treatment compared to Treatment Scheme No. 4, and does not use UV. Disinfected secondary or tertiary effluent would be treated with MF/UF followed by Ozone/BAC. Ozone/BAC would serve the purpose of removing organic constituents from the MF/UF filtrate. The BAC effluent would be dosed with free chlorine to achieve additional virus removal. A WTP is a required component of Treatment Scheme No. 5 to assist with achieving pathogen reduction targets. Engineered storage is provided as an option. For this treatment scheme, it would be important to assess the ozone by-product formation via bench or pilot studies before proceeding with design. Major residuals from this treatment scheme are similar to those for Treatment Scheme No. 4.

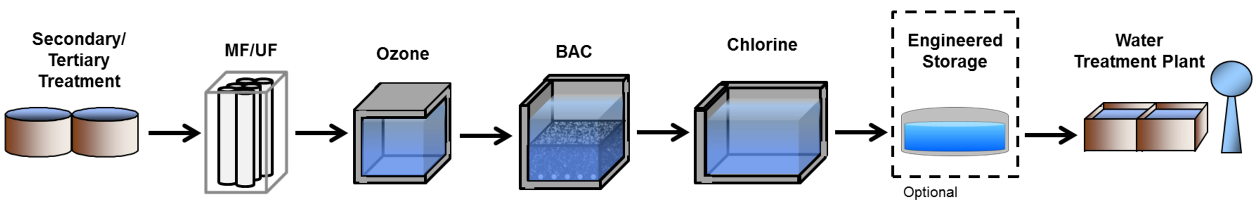

Figure 5-5: Treatment Scheme No. 5

5.3.6 Treatment Scheme No. 6

Treatment Scheme No.6.[33] ,presented in Figure 5-6, does not employ membranes as part of the treatment process. Disinfected secondary or tertiary effluent would be treated by Ozone/BAC followed by UV. Because this DPR treatment process does not use a filtration process other than BAC it would be most applicable to well-clarified wastewater. The BAC effluent would be treated with UV-AOP. This treatment scheme includes Engineered Storage and a WTP. The major residual would be BAC backwash which would be clarified and the decant stream recycled back to the head of the treatment plant or sent to the WWTP.

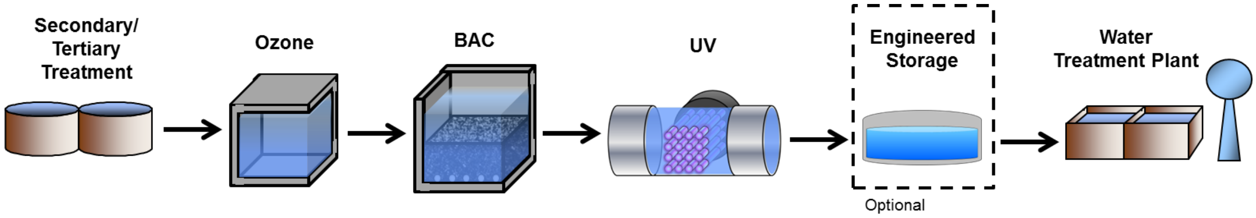

Figure 5-6: Treatment Scheme No. 6

5.3.7 Additional Treatment Considerations

The six treatment schemes presented above focus on achieving the pathogen removal targets and on providing a diversity of treatment processes that address a broad range of chemical constituents. However, there are additional treatment processes that should be considered that can address chemicals including adsorptive processes, such as granular activated carbon (GAC), physical/chemical processes such as electrodialysis and ion exchange, or other forms of oxidation, such as UV-chlorine or ozone-peroxide. The addition of these processes to any of the above treatment schemes would increase the level of robustness of the treatment strategy and may be desirable under some circumstances.

Nitrogen removal should be a primary consideration when developing the integrated treatment system. If RO is not part of the treatment scheme, it is extremely important that nitrogen removal be performed at the WWTP or through specialized processes such as ion exchange.

As mentioned earlier, the formation of DBPs is an important consideration in the selection of treatment strategies and will be dependent on site-specific water quality conditions. Pilot and/or

[33] This treatment scheme is similar to the Landsborough, Queensland, Australia indirect potable reuse process.

bench-scale testing should be performed to evaluate DBP formation and identify necessary mitigation strategies.

Impacts of introducing DPR product water to the distribution system should also be evaluated carefully. Stabilization of the treated water is sometimes needed to prevent corrosion of downstream treatment or distribution facilities. Stabilization is typically employed in the AWT component of a reuse project that utilizes reverse osmosis because the RO permeate typically has a low pH (typically about 5.5) and very low levels of TDS, corresponding to low levels of calcium, magnesium, and alkalinity. This water matrix results in low Langelier Saturation Index (LSI) values and can be very corrosive. Stabilization can be performed using a packed tower decarbonator to remove most of the carbon dioxide, followed by dosing with an alkaline source (sodium hydroxide or sodium carbonate) and a calcium source (lime, calcium chloride) for hardness and alkalinity. The alkaline source assists with adding alkalinity back into the water and adjusting the pH, while the calcium source assists with adding hardness and/or alkalinity back into the water. The product water is typically stabilized to adjust the LSI to around 0 and pH to a range of 7-9. Stabilization should also ensure that drinking water standards for lead and copper are met. These standards include corrosion control requirements if action levels for lead or copper are exceeded in a potable water system.

Related Research

Blending Requirements for Water from Direct Potable Reuse Treatment Facilities – Water Research Foundation Project 4536.

This project will develop recommendations and guidance for the appropriate use of blending as part of a DPR project, including evaluations of treatment, impact of different water qualities and blending locations, summary of corrosion issues, and the impact on engineered storage design.

5.4 Pathogen Performance for the Advanced Treatment Schemes

The assumed upper end reduction values and TCEQ credits for the individual processes shown in Table 5-1 were used to generate estimated log reduction totals for each of the treatment schemes. A summary of the anticipated log reduction for each of the treatment schemes in comparison to the targets defined in Chapter 3 is presented in Table 5-2. All of the treatment schemes are capable of meeting or exceeding the log reduction targets, assuming the upper end removals can be achieved. Some schemes are close to the log reduction targets, particularly for viruses. However, it should be emphasized that actual removals achieved and credits granted by the TCEQ will depend on the specific project conditions and the values in this table should only be used as a general guide.

Table 5-2: Treatment scheme log reduction (see Table 5-1)

Treatment Scheme		Pathogen and Total Coliform Log Reduction[1]							
		Crypto		*Giardia*		Viruses		Total Coliform	
		TCEQ	UER	TCEQ	UER	TCEQ	UER	TCEQ	UER
1	Secondary/Tertiary	NA	2	NA	2	NA	1	NA	2
	Ozone	3	3	3	3	5	5	NA	3
	MF/UF	4	4	4	4	0	0	NA	3
	RO	0	2	0	2	0	2	NA	4
	UV/AOP	4	6	4	6	4	6	NA	6
	Stabilization	--	--	--	--	--	--	NA	--
	Total	**11**	**17**	**11**	**17**	**9**	**14**	NA	**18**
2	Secondary/Tertiary	NA	2	NA	2	NA	1	NA	2
	MF/UF	4	4	4	4	0	0	NA	3
	RO	0	2	0	2	0	2	NA	4
	UV/AOP	4	6	4	6	4	6	NA	6
	Stabilization	--	--	--	--	--	--	NA	--
	Engineered Storage	--	--	--	--	--	--	NA	--
	WTP	3	3	3	3	4	4	NA	5
	Total	**11**	**17**	**11**	**17**	**8**	**13**	NA	**20**
3	MBR	0	4	0	4	0	0	NA	3
	RO	0	2	0	2	0	2	NA	4
	UV/AOP	4	6	4	6	4	6	NA	6
	Stabilization	--	--	--	--	--	--	NA	--
	Engineered Storage	--	--	--	--	--	--	NA	--
	WTP	3	3	3	3	4	4	NA	5
	Total	**7**	**15**	**7**	**15**	**8**	**12**	NA	**18**
4	Secondary/Tertiary	NA	2	NA	2	NA	1	NA	2
	Ozone	3	3	3	4	5	5	NA	4
	BAC								
	MF/UF	4	4	4	4	0	0	NA	3
	UV	4	4	4	4	4	4	NA	5
	Chlorine	0	0	1	1	3	3	NA	3
	Total	**11**	**13**	**12**	**15**	**12**	**13**	NA	**17**
5	Secondary/Tertiary	NA	2	NA	2	NA	1	NA	2
	MF/UF	4	4	4	4	0	0	NA	3
	Ozone	3	3	3	4	5	5	NA	4
	BAC								
	Chlorine	0	0	1	1	3	3	NA	3
	Engineered Storage	--	--	--	--	--	--	NA	--
	WTP	3	3	3	3	4	4	NA	5
	Total	**10**	**12**	**11**	**14**	**12**	**13**	NA	**17**
6	Secondary/Tertiary	NA	2	NA	2	NA	1	NA	2
	Ozone	3	3	3	4	5	5	NA	4
	BAC								
	UV	4	4	4	4	4	4	NA	5
	Engineered Storage	--	--	--	--	--	--	NA	--
	WTP	3	3	3	3	4	4	NA	5
	Total	**10**	**12**	**10**	**13**	**13**	**14**	NA	**16**
Target (TCEQ or *11-02*)		**5.5**	***10***	**6**	***10***	**8**	***12***	**NA**	***9***

1. TCEQ = maximum reduction credit currently granted by the TCEQ; UER = assumed upper end reductions (see Table 5-1)

Although all treatment schemes need a robust monitoring system, the schemes with fewer barriers (for example Treatment Schemes No. 5 and 6) may need additional monitoring and control provisions in order to ensure that water that does not meet the established water quality targets is not introduced into the drinking water distribution system.

5.5 Chemical Performance for the Advanced Treatment Schemes

The treatment processes considered for the treatment schemes have varied performance with respect to the chemical water quality performance targets. Each treatment process was evaluated for removal of target chemical constituents. The treatment processes were also evaluated for removal of secondary constituents categorized as "Particles and Aesthetics". Table 5-3 presents the results of this evaluation. Approximate removal percentages based on a literature review are shown for each constituent for each treatment process.

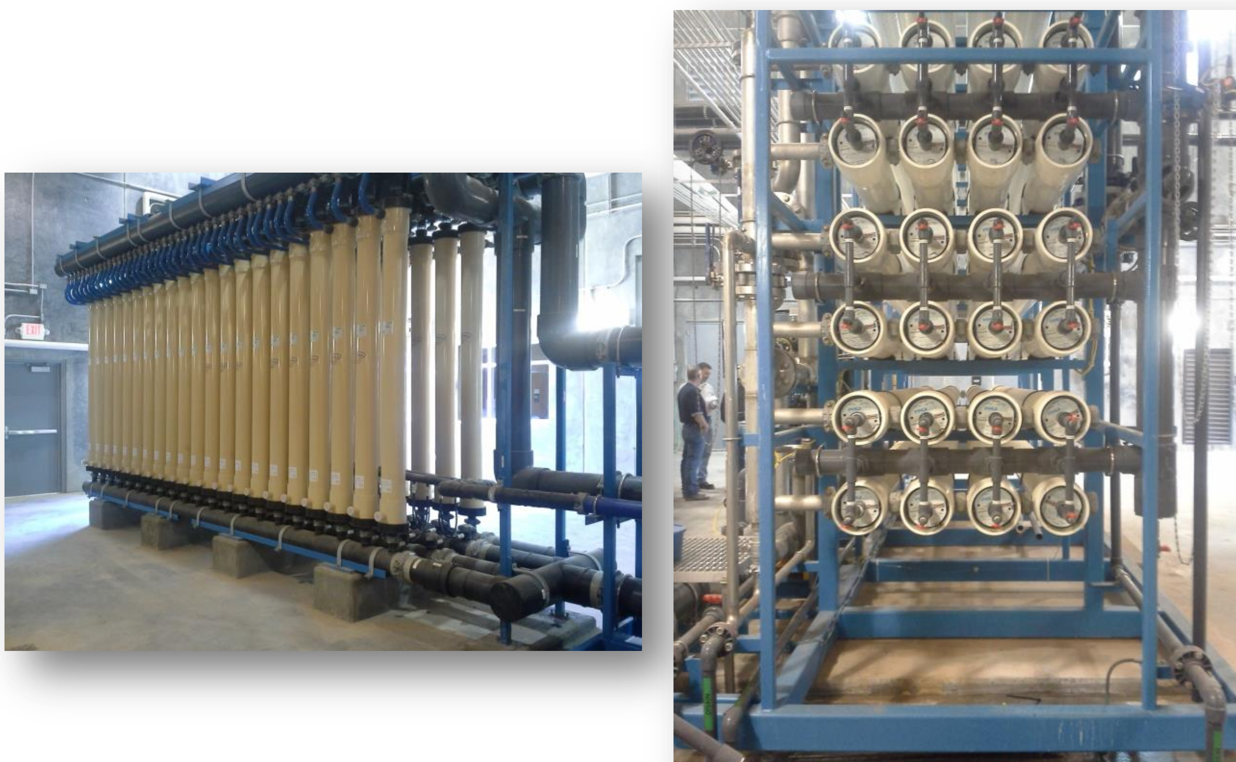

Figure 5-7: Microfiltration and reverse osmosis treatment units at Colorado River Municipal Water District Raw Water Production Facility, Big Spring, Texas

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Table 5-3: Treatment scheme qualitative chemical removal efficiency

Treatment Scheme		Chemicals Removal Efficiency[1]																			
		THM	HAA5	NDMA	PFOS	Bromate	Perchlorate	1,4-Dioxane	17ß-Estradiol	Atenolol	TCEP	Caffeine	Gemfibrozil	Iopromide	Mepro-bamate	DEET	Primidone	Sucralose	Triclosan	Particles	Aesthetics
1	Secondary/Tertiary	P	P	P	P	P	P	P	E	L	L	E	L	L	L	F	L	L	L	L	P
	Ozone	P	P	L	P	P	P	L	G	E	P	E	E	F	F	G	P	P	E	P	G
	MF/UF	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	E	P
	RO	G	G	L	E	E	E	L	E	E	E	E	E	E	E	E	E	E	E	G	F
	UV/AOP	P	P	E	L	P	P	G	G	F	L	G	E	E	G	G	L	L	E	P	F
	Stabilization	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L
2	Secondary/Tertiary	P	P	P	P	P	P	P	E	L	L	E	L	L	L	F	L	L	L	L	P
	MF/UF	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	E	P
	RO	G	G	L	E	E	E	L	E	E	E	E	E	E	E	E	E	E	E	G	F
	UV/AOP	P	P	E	L	P	P	G	G	F	L	G	E	E	G	G	L	L	E	P	F
	Stabilization	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L
	Engineered Storage	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	WTP	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	G	G	L
3	MBR	P	P	P	P	P	P	P	G	G	L	E	E	L	G	L	F	L	G	E	P
	RO	G	G	L	E	E	E	L	E	E	E	E	E	E	E	E	E	E	E	G	F
	UV/AOP	P	P	E	L	P	P	G	G	F	L	G	E	E	G	G	L	L	E	P	F
	Stabilization	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L
	Engineered Storage	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	WTP	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	G	G	L
4	Secondary/Tertiary	P	P	P	P	P	P	P	E	L	L	E	L	L	L	F	L	L	L	L	P
	Ozone BAC	E	G	G	P	P	P	G	E	E	L	E	E	F	F	F	L	L	E	G	G
	MF/UF	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	E	P
	UV	P	P	E	P	P	P	L	L	P	P	P	L	F	L	L	P	P	G	P	P
	Chlorine	P	P	P	P	P	P	P	G	L	P	P	F	P	P	P	P	L	G	P	P
5	Secondary/Tertiary	P	P	P	P	P	P	P	E	L	L	E	L	L	L	F	L	L	L	L	P
	MF/UF	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	E	P
	Ozone BAC	E	G	G	P	P	P	G	E	E	L	E	E	F	F	F	L	L	E	G	G
	Chlorine	P	P	P	P	P	P	P	G	L	P	P	F	P	P	P	P	L	G	P	P
	Engineered Storage	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	WTP	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	G	G	L
6	Secondary/Tertiary	P	P	P	P	P	P	P	E	L	L	E	L	L	L	F	L	L	L	L	P
	Ozone BAC	E	G	G	P	P	P	G	E	E	L	E	E	F	F	F	L	L	E	G	G
	UV	P	P	E	P	P	P	L	L	P	P	P	L	F	L	L	P	P	G	P	P
	Engineered Storage	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	WTP	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	G	G	L

THM = Trihalomethanes, HAA5 = Haloacetic acids, NDMA = N-nitrosodimethylamine, PFOS = Perfluorooctane sulfonate, TCEP = Tris-(2-Carboxyethyl)phosphine, DEET = N,N-diethyl-meta-toluamide

1. E = Excellent = > 90%; G = Good = 70-90%; F = Fair = 40-70%; L = Low = 20-40%; P = Poor = < 20%
2. Sources: Aga, D. (2008); Carollo Engineers (2011); Johnson, B. and others (2009); Lee, C. and others (2010); Mofidi, A. and others (2002); Munakata, N. and others (2011); MWH (2009); Rojas, M. and others (2012); Stanford, B. and others (2012b); Sundaram, V. (2011); Trussell, R. and others (2013); U.S. Department of the Interior Bureau of Reclamation (2009).

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Overall, each of the treatment schemes could provide sufficient treatment to meet the recommended water quality performance targets. However, the treatment schemes that do not employ RO (Treatment Schemes No. 4-6) will not be as effective at removing CECs that are difficult to oxidize and are not aerobically biodegradable, such as PFOS, bromate and perchlorate. For chemical constituents, robustness (diversity in treatment) is considered a key factor in reliability. Similar to pathogen control, for chemical control it is thus important to provide sufficient monitoring and controls for each treatment process to ensure reliable treatment.

5.6 Treatment Costs

Conceptual level capital and operation and maintenance (O&M) costs were summarized for each of the treatment schemes. Cost curves for estimating both capital and O&M costs (Stanford, B. and others, 2012a) were used as a basis for developing the conceptual level estimates. The curves were adjusted based on cost information from recent studies and full scale facility costs.

The costs only include the core DPR treatment processes and do not include secondary/tertiary treatment, engineered storage, transmission pipelines, residual/concentrate disposal, and water treatment plant components. The costs also do not include contractor's overhead and profit or a project contingency, as the percentages used for these items are typically site specific. A summary of the estimated capital and O&M costs expressed as million gallons per day (mgd) is presented in Table 5-4.

WRRF White Paper on Economics of Direct Potable Reuse

The Opportunities and Economics of Direct Potable Reuse – WRRF Project 14-08 (Raucher and Tchobanoglous, 2014).

- Focuses on California.
- Cost varies based on site-specific factors.
- Low-end estimate is $820/acre-foot, with 85% cost based on advanced treatment and the rest on conveyance.
- Upper-end estimate is $2,000/acre-foot and includes treatment, extensive conveyance, and concentrate management.
- Potable reuse is less expensive or comparable to the cost of new alternative water supplies, such as desalination.

Both the capital and O&M costs are generally a function of the number of treatment processes in the scheme, with the larger number of treatment processes resulting in higher costs, and lower costs as the capacity increases due to economy of scale.[34]

[34] Economies of scale do not apply beyond 100 MGD.

The treatment schemes that do not employ RO had lower capital and O&M costs compared with those using RO. Treatment schemes that employ RO have higher energy usage due to the pumping energy for the RO process. Furthermore, because RO recovery for reclaimed water production is typically 75-85% depending upon water quality, pretreatment processes, such as MF or UF, must treat a larger flow to provide adequate feed water for the RO process.

Table 5-4: Treatment scheme general comparative costs[1]

Capacity (MGD)	Treatment Scheme[2]	Capital Cost ($M/MGD)	O&M Cost ($M/MGD)
1	1	$ 9.43	$ 1.000
	2	$ 7.54	$ 0.992
	3	$ 7.89	$ 1.048
	4	$ 7.18	$ 0.537
	5	$ 6.93	$ 0.499
	6	$ 4.75	$ 0.153
5	1	$ 6.27	$ 0.778
	2	$ 5.38	$ 0.771
	3	$ 5.63	$ 0.810
	4	$ 4.04	$ 0.398
	5	$ 3.81	$ 0.362
	6	$ 2.32	$ 0.125
10	1	$ 5.30	$ 0.700
	2	$ 4.66	$ 0.693
	3	$ 4.88	$ 0.727
	4	$ 3.21	$ 0.350
	5	$ 2.98	$ 0.315
	6	$ 1.72	$ 0.115
25	1	$ 5.13	$ 0.610
	2	$ 4.63	$ 0.603
	3	$ 4.84	$ 0.631
	4	$ 2.89	$ 0.297
	5	$ 2.63	$ 0.263
	6	$ 1.42	$ 0.103

$M = million dollars, O&M = operations and maintenance, MGD = million gallons per day
Source: Stanford, B. and others (2012a).

1. Costs only include the core direct potable reuse treatment processes and do not include Secondary/Tertiary Treatment, Engineered Storage, residual/brine disposal, and water treatment plant components.
2. Treatment schemes are defined in Section 5.3.

It should be noted that entities considering a DPR project must consider each component of the DPR treatment strategy including pathogen removal, chemical constituent removal (including nitrate and nitrite), operational complexity, treatment process residuals management, public acceptance and regulatory permitting as well as costs, before selecting a DPR treatment strategy to move forward with. The lowest cost option may not be the most viable or appropriate strategy to pursue.

5.7 Operations, Maintenance, Monitoring and Process Control for Treatment Systems

Operations, maintenance, monitoring and process control are extremely critical to successful implementation of a DPR project. Detailed operational plans should be developed on a site-specific basis and should include consideration of:

- Blending impacts and blending operations;
- Plans for disposal of water that does not meet water quality requirements;
- Appropriate training for operators;
- Communication plans;
- Standard operating procedures;
- Monitoring and process control plans; and
- Other operations and maintenance considerations specific to the treatment technologies being used.

There is currently a significant amount of ongoing research focusing on these issues, as summarized below.

Sample of Ongoing Research Related to Operations, Maintenance, Monitoring and Process Control

- *Monitoring for Reliability and Process Control of Potable Reuse Applications, WRRF Project 11-01*
- *Guidelines for Engineered Storage for Direct Potable Reuse, WRRF Project 12-06*
- *Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of Direct Potable Reuse Scheme, WRRF Project 13-03*
- *Development of Operation and Maintenance Plan and Training and Certification Framework for Direct Potable Reuse Systems, WRRF Project 13-13*
- *Blending Requirements for Water from Direct Potable Reuse Treatment Facilities, Water Research Foundation (WRF) Project 4536*

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6 Chemical Quantitative Relative Risk Assessment Examples

Road Map

In This Chapter

- Why conduct a risk assessment?
- What is a risk assessment?
- Two case study examples
- Treatment and management implications of risk assessment results
- Practical applications of risk assessments

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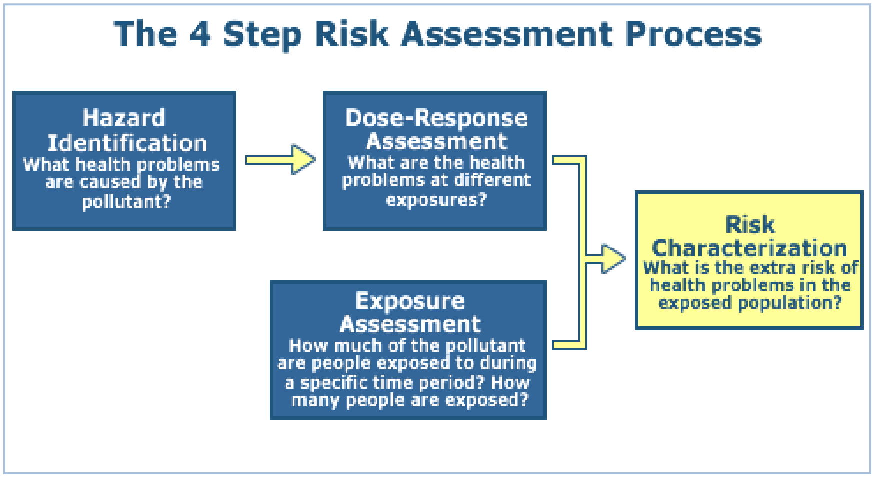
6.1 Introduction

Risk assessments are conducted to characterize the nature and magnitude of health risks to humans from chemical contaminants and other stressors that may be present in the environment. Risk managers use the resulting information to help them decide how to protect humans and the environment from stressors or contaminants.

For DPR projects, risk assessments can be used to inform decisions related to source control, wastewater treatment, water treatment and advanced water treatment. Specific examples are included in Section 6.5.

Risk assessment is a scientific process used to characterize the risk to human health from exposure to a chemical or microbe. For drinking water reuse projects, exposure to chemicals is very difficult to estimate precisely. However, it is possible to modify a traditional risk assessment approach by using a hypothetical, standardized exposure. This approach is called a Quantitative Relative Risk Assessment or QRRA. The QRRA used in this research project is a more health protective approach than traditional risk assessments because observed concentrations of chemicals in water are used for developing exposure and the assumed exposures are greater than those that would actually occur.



Source: U.S. Environmental Protection Agency, July 31, 2012, http://www.epa.gov/risk_assessment/risk-characterization.htmhttp://www.epa.gov/risk_assessment/risk-characterization.htm

Example QRRAs were conducted for two direct potable reuse (DPR) case studies. This analysis focused on chemical rather than pathogen risk since the Texas Commission on Environmental Quality (TCEQ) currently applies a set of guidelines for pathogen reduction for DPR applications. Pathogen risk evaluation could follow a similar approach as that described in this chapter and Appendix F. Each case study compared a No Project Alternative (raw surface water that has undergone drinking water treatment) with a potential DPR Alternative (treated wastewater that has undergone advanced water treatment and drinking water treatment). Consistent with the explanation about exposure above, neither DPR scenario accounts for blending with raw source water prior to drinking water treatment, blending after drinking water treatment in the distribution system, or directly distributing the purified reclaimed water into a drinking water distribution system.

The QRRA focuses on chemical constituents that are currently regulated and constituents that are not yet regulated but are of broad interest such as pharmaceuticals and personal care products.

A QRRA does not evaluate the absolute risk from ingestion of water “at the tap”, but rather a relative comparison based on an assumed quantity of water ingested and its estimated water quality. This approach eliminates difficulties in quantifying specific exposure to contaminants that occur as a result of population mobility, where tap water is consumed (home versus work), bottled water consumption, and other factors. Thus, actual exposures to drinking water are likely to be different from those assumed for the QRRA; however, the difficulties with assessing absolute exposure highlight the benefits of the relative risk approach.

6.2 Case Studies

The two case studies were selected to illustrate real situations that could occur in Texas in terms of water treatment, wastewater treatment, and advanced water treatment to produce purified reclaimed water for DPR. For water treatment, additional treatment processes (ozone and biologically activated carbon (BAC)[35]) were deliberately included at the water treatment plant (WTP) for one of the case studies to represent a treatment scheme that addresses taste and odor, iron and manganese, and/or the need to reduce disinfection byproduct (DBP) formation, common issues in parts of the State. For advanced water treatment for DPR, an advanced water treatment facility (AWTF) with reverse osmosis (RO) was used for one of the case studies and an AWTF without RO was used for the other case study. As discussed in earlier chapters, it is of significant interest to identify and evaluate treatment schemes that do not include RO due to the difficulty and costs associated with disposal of brine concentrate, particularly in inland areas of the State.

Case Study 1 (Non-RO AWTF/Enhanced WTP):

- No Project Alternative: Raw source water is treated by an enhanced WTP, consisting of ozone, BAC, flocculation-sedimentation, media filtration, and chlorination with free chlorine.

[35] While in some parts of Texas ozone and BAC are commonly used drinking water treatment processes, we have used the term “enhanced WTP” to distinguish the water treatment scheme from what is considered conventional drinking water treatment (flocculation-sedimentation, media filtration, and chlorination).

- DPR Project Alternative[36]: Secondary/tertiary wastewater treatment plant (WWTP) effluent is the feed water to an AWTF that consists of microfiltration (MF) or ultrafiltration (UF), ozone, BAC, and chlorination (Figure 6-1). This product water is then treated by the enhanced WTP consisting of ozone, BAC, flocculation-sedimentation, media filtration, and chlorination.

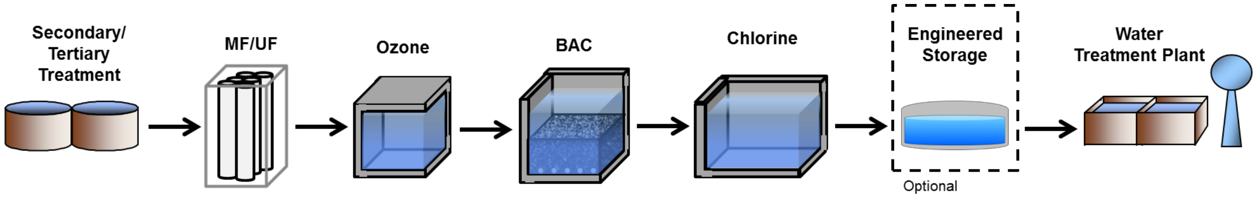


Figure 6-1: Case study 1 advanced water treatment facility

Case Study 2 (Membrane AWTF/Conventional WTP):

- No Project Alternative: Raw source water is treated by a conventional WTP consisting of flocculation-sedimentation, media filtration, and chlorination with free chlorine.

- DPR Project Alternative[37]: Secondary/tertiary WWTP effluent is the feed water to an AWTF that consists of UF, RO, and advanced oxidation (ultraviolet (UV) irradiation and hydrogen peroxide) (Figure 6-2). This product water is then treated by a WTP consisting of flocculation-sedimentation, media filtration, and chlorination.

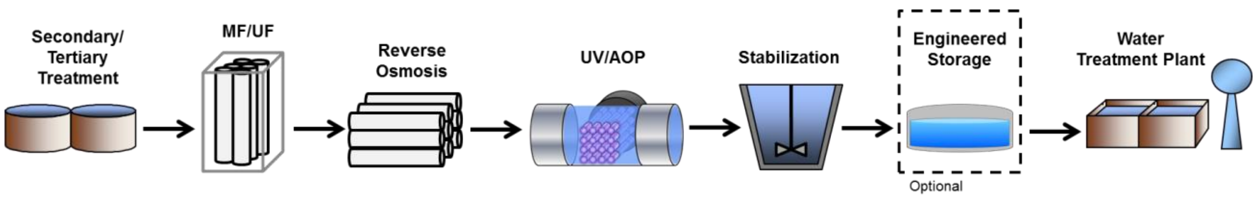


Figure 6-2: Case study 2 advanced water treatment facility

[36] This alternative is based on Treatment Scheme No. 5 as discussed in Chapter 5.

[37] This alternative corresponds to Treatment Scheme No. 2 as discussed in Chapter 5.

6.3 Risk Assessment

6.3.1 Data Collection and Estimates

To simulate the case studies for the QRRA, monthly samples were collected from two Texas raw source waters and disinfected filtered secondary effluent (tertiary effluent) from two WWTPs for the period December 2013 through May 2014. Samples were analyzed for regulated constituents (Priority Pollutants, constituents with maximum contaminant levels (MCLs), constituents with other regulatory recommendations or guidelines), and unregulated constituents (for example, prescription drugs, over-the-counter drugs, and personal care products). For the QRRA, “detected compounds” are those that were found in at least one sample at or above the compound-specific Method Reporting Limit (MRL). The MRL represents an estimate of the lowest concentration of a compound that can be quantitatively measured. For each constituent, if the concentration in at least one sample was at or above the MRL, it was deemed to be “detected”. If the other sample concentrations were reported to be below the MRL, for calculation of the average concentration for the QRRA, the constituent was assumed to be present at the MRL. This averaging approach is likely to overestimate the concentration of any observation reported below the MRL and provides an added layer of conservatism to the risk assessment.

Key Risk Results for CPCs and CECs

- *A properly designed and operated DPR system provides protection from CPCs and CECs comparable to conventional drinking water supplies*
- *All CPCs meet MCLs and health advisory levels*
- *Only one CEC was present that approached a risk-based action level - it could be addressed by including photolysis or RO as part of the AWTF or potentially via source control*
- *A higher quality secondary effluent (such as removal of nitrogen at the WWTP) could reduce risk*
- *RO and AOP technologies play an important role in reducing risk*

Detected constituents were divided into two categories:

- Constituents of Potential Concern (CPCs) are detected compounds that are regulated or currently under consideration for regulation and had associated health-based criteria that could be used to quantify the estimated relative potential health risk.
- Constituents of Emerging Concern (CECs) are detected compounds that are unregulated with published toxicity information to evaluate their health significance. The Eurofins Eaton Analytical method was used for analysis because it is capable of reliably testing for more than 90 CECs in a single method at low levels (nanogram per liter or ηg/L).

For the No Project Alternatives, estimated WTP removal efficiencies were applied to the CPCs and CECs in the raw source waters to estimate drinking water concentrations. For the DPR Alternatives, estimated AWTF and WTP removal efficiencies were applied to the CPCs and CECs in the tertiary wastewaters to estimate drinking water concentrations. This assessment accounts for DBPs already present in the water samples, but did not account for formation of DBPs, such as trihalomethanes (THMs) or N-nitrosodimethylamine (NDMA) through the various water treatment processes.

6.3.2 Quantitative Relative Risk Assessment Results for Constituents of Potential Concern

For CPCs, QRRAs were conducted for noncarcinogenic and carcinogenic risk. The results showed that a properly designed and operated DPR treatment system can provide protection from CPCs that is comparable to the No Project Alternatives.

For noncarcinogenic risk, the QRRA evaluated the cumulative hazard index (the sum of hazard quotients for each CPC) for each case study alternative. A hazard quotient is the ratio of the CPC and its applicable reference dose (the toxicity value used to evaluate its health effect). A hazard index less than 1 would indicate that the person's dose of each CPC is below its respective "safe dose" or reference dose (the RfD), and that the additive potential does not exceed a “total safe dose.” The EPA considers a hazard index less than 1 to indicate that there is no increased health risk. In other words, a hazard index less than 1 indicates that all the CPCs are present at concentrations below those that could cause effects in humans, even if the chemicals have additive effects. As shown in Table 6-1, for each No Project Alternative and DPR Alternative, the cumulative hazard index was less than 1. For the Case Study 1 DPR Alternative (the non-RO AWTF), the cumulative hazard index was close to 1, but none of the CPCs were detected at levels that exceeded MCLs for any of the alternatives. The higher cumulative hazard index for the Case Study 1 DPR Alternative in comparison to the Case Study 2 DPR Alternative illustrates the role of RO membranes in removing CPCs and their risk contributions. As discussed in more detail in Appendix F, nitrate was one of the key parameters contributing to the higher hazard index for the Case Study 1 DPR Alternative. Although the concentration was not above the MCL, this result suggests that better removal of nitrogen at the WWTP or an added nitrogen barrier as part of the AWTF would reduce risk when using this treatment scheme.

Table 6-1: Summary of noncarcinogenic risk assessment

	Case Study 1		Case Study 2	
	No Project Alternative	**DPR Alternative**	**No Project Alternative**	**DPR Alternative**
Hazard Index (HI)	0.13	**0.89**	0.20	0.05
# CPCs present with RfD	16	27	9	22
Any Single Constituent with HI > 1	No	No	No	No
Any Constituent > MCLs	No	No	No	No

CPC = constituent of potential concern; RfD = reference dose; MCL = maximum contaminant level

Carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen based on its cancer slope factor (SF). Cancer SFs are based on experimental animal data and limited epidemiological studies, when available. If a CPC has a SF, there is a known basis for estimating cancer risk. If there is no SF, either it is known that the pollutant is not carcinogenic (based on available information) or there is not sufficient information to estimate the relative carcinogenicity. The model generally used by the U.S. Environmental Protection Agency (EPA) to calculate numerical cancer potency values overpredicts risk in comparison to average population risk (EPA, 2007).

The results of the carcinogenic QRRA are shown in Table 6-2. Similar to the noncarcinogenic risk assessment, concentrations of CPCs were below MCLs and health advisory levels. The carcinogenic risks for the Case Study 1 No Project Alternative, Case Study 1 DPR Alternative, and Case Study 2 No Project Alternative were in approximately the same range. The carcinogenic risk for the Case Study 2 DPR Alternative (the AWTF with RO), however, is about an order of magnitude lower. For each alternative, arsenic and DBPs are the major contributors to risk. For the Case Study 2 DPR Alternative, RO and UV/AOP play an important role in reducing risk through removal of these CPCs. These results highlight the need to consider prevention of DBP formation or removal of DBPs as part of a DPR treatment scheme (beginning with the WWTP through AWTF and the WTP).

Table 6-2: Summary of carcinogenic risk assessment

	Case Study 1		Case Study 2	
	No Project Alternative	DPR Alternative	No Project Alternative	DPR Alternative
Drinking Water Risk Estimate[1]	1.3E-06	3.9E-06	7.0E-06	7.3E-07
# CPCs with SF[2]	4	8	4	3
Any Constituent present at a concentration > MCLs or Advisory Levels	No	No	No	No

CPC = constituent of potential concern; MCL = maximum contaminant level

1. This is the most conservative estimate of risk.
2. The slope factor (SF) is used to estimate the upper-bound probability of an individual developing cancer over a lifetime of exposure to a potential carcinogen at a particular level. If a CPC has a slope factor, there is a known basis for estimating cancer risk. If there is no slope factor, either it is known that the CPC is not a carcinogen or there is not information to estimate the relative carcinogenicity.

6.3.3 Risk Exemplar Results for Constituents of Emerging Concern

For CECs, the 2012 National Research Council (NRC) risk exemplar approach was utilized to assess risk (NRC, 2012). Based on the reported results, it is clear that a properly designed and operated DPR treatment system can provide protection from CECs that is comparable to the No Project Alternatives.

The risk exemplar approach relies on estimates of the amount of a substance in drinking water that can be ingested daily over a lifetime without appreciable risk. These “safe” levels are called Drinking Water Equivalent Levels, Predicted No Effect Concentrations, or Drinking Water Guidelines. For each of the detected CECs, potential lifetime health risks were assessed by calculating margins of safety (MOSs). A MOS is the ratio of a risk-based action level (RBAL) based on a Drinking Water Equivalent Levels, Predicted No Effect Concentration, or Drinking Water Guideline or other available heath benchmark, to the estimated concentration of the constituent in water. In using the risk exemplar approach, the NRC opined that an MOS lower than 1 for a specific CEC posed a potential concern from that CEC. This interpretation was made in light of the multiple safety factors, such as the application of uncertainty factors, included in the derivation of the RBAL.

A summary of the CEC risk for both case studies is presented in Table 6-3. With one exception, for all of the alternatives, all of the CECs have MOSs greater than 1. The exception is quinolone, with an MOS in the range of 1 for the Case Study 1 No Project Alternative and DPR Alternative. For Case Study 2, quinoline was not found in the No Project Alternative raw source water, but was found in the secondary wastewater for the DPR Alternative, and is removed by RO.

Table 6-3: Summary of constituents of emerging concern risk exemplar

	Case Study 1		Case Study 2	
	No Project Alternative	DPR Alternative	No Project Alternative	DPR Alternative
# CECs present > MRL	32	46	5	53
MOS Range	1.6 - 10,500,000,000	0.9 - 59,000,000,000	3,600 - 16,000,000	13 - 6,000,000,000
# CECs with MOS 1-10	1	1	0	0
CECs with MOS 1-10	Quinoline	Quinoline	---	0

CEC = constituent of emerging concern

MOS = margin of safety, calculated as the ratio of a risk-based action level (RBAL) and the estimated concentration in the water.

The RBAL for quinoline, a probable human carcinogen, is based on EPA's Predicted No Effect Concentration of 10 ηg/L. Quinoline has specific industrial sources (it is used in the production of dyes, paints, pharmaceuticals, and fragrances), but also has ubiquitous sources including automobile exhaust. Quinoline is biodegradable, removed by RO, and can be photolyzed. Thus, if the Case Study 1 DPR Alternative utilized photolysis or RO, it is likely that the concentration would have been further reduced and the MOS greater than 1.

For CEC assessments it is important to acknowledge that over time new and updated RBALs are likely to be developed that would further inform risk evaluations, as well as additional information on advanced treatment process performance from research, piloting, or full-scale operations.

6.4 Treatment and Management Considerations for Direct Potable Reuse Applications

Source control is the first important preventative barrier for DPR, and source control programs have been very successful in limiting the discharge of toxic contaminants from industries and commercial businesses, thereby keeping them out of the reclaimed water supply. However, expectations regarding source control effectiveness must be realistic in terms of what constituents can be directly controlled versus those that cannot.

*See **Chapter 4** for more detail related to source control.*

As discussed in Chapter 5, an important consideration for DPR projects is quality of the treated wastewater that undergoes advanced treatment. The current focus of operating WWTPs is to meet discharge or non-potable reuse requirements for discharge to the environment. Because a higher quality wastewater can improve the quality of the final DPR product water and the operations of the AWTF, a shift in thinking about the function of the WWTP is worthwhile as it now is part of an integrated treatment system to produce a potable drinking water supply. A number of process modifications can be implemented at existing WWTPs to improve the final effluent quality prior to advanced treatment. The overarching goal for an integrated DPR treatment system is to reliably achieve the desired water quality. Reliability is a function of redundancy, robustness, and resilience as discussed in Chapter 5. Reliability also depends on a project sponsor having the managerial and technical capability to operate and maintain the integrated system, including providing certified operators, training, and emergency response.

6.5 Practical Applications

Based on the results of this investigation, a QRRA analysis can be used to inform decisions that are made with respect to source control, wastewater treatment, water treatment, and advanced treatment for DPR. Information from a QRRA can be used to:

- Assist with decisions on the need for bench scale and/or pilot testing of advanced treatment technologies, potentially including evaluation of CPCs (for example DBP removal efficiency and DBP formation during water/wastewater treatment) or CECs.
- Assist with decisions on the components to include in a DPR treatment scheme based on relative risk. The assessment could use predicted concentrations similar to the approach used for this QRRA or as a site-specific study based on the results of bench scale or pilot testing.
- Modify or tailor monitoring programs to ensure that data for the most relevant contaminants are collected rather than compounds that have little impact on evaluating

overall risk. This approach is complimentary to the indicator surrogate framework described in Chapter 2.

- Focus on specific source control and/or treatment options in cases where the relative risk may increase over time or reach a level of potential concern.
- Inform the public about the safety of DPR by using the results of a QRRA for public outreach efforts – use of QRRA findings will become more important over time as analytical methodology becomes more sensitive and more constituents are found in water even after advanced treatment.
- Assess the risks and benefits of using DPR as a short-term drought mitigation measure as opposed to a long-term water supply solution by comparing acute and chronic health risks.

7 Pilot- and Bench-Scale Testing for Direct Potable Reuse Treatment Studies

Road Map

In This Chapter

- Key considerations for Direct Potable Reuse treatment studies
- Steps for developing testing protocols
- Pilot- and bench-scale testing protocol outlines
- Example test protocols
- Preliminary assessment of probable test study costs

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7.1 Introduction

Pilot and bench scale studies can be used to help make decisions about the selection of specific advanced water treatment (AWT) processes or schemes for a direct potable reuse (DPR) project. In addition, pilot and bench scale testing can be used to both verify AWT performance and gain Texas Commission on Environmental Quality (TCEQ) approval for the treatment scheme**.** It is recommended that a treatment study be carried out to evaluate the performance of AWT processes at the pilot- and/or bench-scale. [38]

DPR treatment studies have a number of benefits and can serve multiple purposes. Treatment study goals can be classified into five categories, as shown in Figure 7-1. Depending on the specific project conditions, different levels of priority may be placed on each category or individual study goal.

There are currently no specific regulations addressing DPR in Texas. DPR treatment and testing requirements are being determined by the TCEQ on a case-by-case basis. While specific DPR rules are not in place, the TCEQ does rely on existing rules governing public water systems to regulate DPR

*See **Chapter 8** for a detailed discussion of regulatory issues.*

What are pilot- and bench-scale treatment studies?

- ***Pilot-scale treatment studies*** *typically use treatment units that are significantly smaller than needed for full-scale operation, but that are large enough to accurately represent treatment behavior at full-scale. Pilot-scale studies often use portable treatment units that can be located near the source of water to be tested and can be operated continuously over several weeks or months. They can be used to evaluate the effectiveness of different types of treatment processes or different vendors of the same treatment process.*
- *As the name implies,* ***bench-scale treatment studies*** *are typically performed in a laboratory and are used to evaluate performance characteristics of treatment processes that can be represented adequately at a laboratory scale. For bench-scale studies, discrete samples of the water to be treated are typically transported to the laboratory for testing.*
- *See Appendix G for additional information.*

[38] In emergency drought situations for which a treatment study is infeasible, a public water system may consider a full-scale verification strategy whereby an AWT system is first constructed and then verified using an intensive data collection protocol. However, the full-scale verification approach includes regulatory, financial, and equipment performance-related risks to the public water system should the system not perform as expected. Pilot testing can meaningfully reduce this risk.

projects. Accordingly, TCEQ drinking water rules and guidance should be accounted for and incorporated into DPR pilot- and/or bench-scale study plans.

Regulatory

- Satisfy state and federal pilot- and bench-scale testing requirements

Design

- Establish design criteria and operating procedures
- Evaluate equipment performance
- Optimize treatment
- Determine the influence of a unit process on downstream unit processes
- Evaluate opportunities to reduce operation and maintenance costs
- Provide input to utility's source control program to identify contaminants that are not effectively treated or that negatively impact treatment performance

Treatment Efficiency

- Assess treatment performance relative to established water quality goals

Procurement

- Obtain test data on multiple manufacturers and/or process variations for the equipment selection and bid phases of the full-scale project

Other

- Provide hands-on training to plant operators and staff
- Provide an opportunity for research and development
- Provide an opportunity for public outreach to demonstrate the technology

Figure 7-1: Typical direct potable reuse treatment study goals

The discussion of pilot- and bench-scale testing plans presented in this chapter is intended to provide an overview of general considerations and common steps for treatment testing. It is not intended as a comprehensive guide to DPR project implementation nor does it provide all-encompassing protocols suitable to every DPR application. The determination of suitable treatment schemes and appropriate testing for a given water quality and situation requires site-specific knowledge and coordination with the TCEQ.

7.2 Pilot- and Bench-Scale Testing Plans for Direct Potable Reuse Treatment Studies

A DPR treatment study involves replicating a full-scale treatment scheme and coordinating testing activities to obtain process performance and water quality data. When designing a treatment study, a variety of factors should be considered including wastewater treatment plant (WWTP) effluent water quality and site constraints. Wastewater effluent quality varies in response to diurnal flows, seasonal changes, and domestic, commercial, and industrial discharges into the collection system. Moreover, the effluent quality for each public water system is unique, adding a layer of complexity that limits the ability to apply "cookie-cutter" testing approaches to DPR projects. Regardless of the treatment scheme selected for a particular application, a DPR treatment study test plan should be developed to satisfy regulatory requirements, establish design criteria, evaluate treatment efficiency and operations, evaluate monitoring systems, prepare for the equipment procurement process, and/or achieve other project-specific goals.

Test plans should be tailored to the project-specific requirements that are unique to each DPR project and submitted to the TCEQ for review and approval. A critical aspect of test plan development is determining which AWT unit processes to test and the scale at which each process should be tested. The treatment schemes identified in Chapter 5 are assembled from combinations of the following AWT processes: chlorine disinfection, membrane bioreactor (MBR), microfiltration (MF)/ultrafiltration (UF), ozone, ozone coupled with a biological activated carbon (BAC) contactor or filter, reverse osmosis (RO), stabilization, ultraviolet (UV) irradiation disinfection, and UV coupled with an advanced oxidation process (AOP). Examples of relevant testing considerations for each AWT process are provided in Table 7-1

In Table 7-2 , example test plans for the six treatment schemes presented in Chapter 5 are provided. The bench- and pilot-scale test plans are based on anticipated regulatory requirements, typical drinking water industry design practices, procurement planning, and other considerations such as familiarizing operations staff with new equipment. Treatment studies should consider testing AWT unit processes in series to simulate the full-scale AWT system where practical and feasible. Pilot-scale testing is typically well suited to series operation; however, testing processes in series at the bench-scale poses logistical challenges and may be impractical due to concerns such as process scalability, sample holding time, and sample contamination.

Table 7-1: Technology-specific testing considerations

AWT Process	Example Testing Considerations
Biological Activated Carbon[1]	hydraulic loading rate (HRT), empty bed contact time (EBCT), carbon and nutrient requirements, media properties, treatment efficiency, backwash parameters
Chlorine[2]	chlorine demand, chemical usage, and disinfection byproduct (DBP) formation potential
Membrane Bioreactors[3]	treatment efficiency, membrane selection and performance, operating flux (without significant permeability loss), chemical cleaning regime and frequency, chemical consumption, and energy usage
Ozone[4]	ozone demand, bromide concentration, ozone dose and residual decay relationships, treatment efficiency, byproducts formation including bromate, N-nitrosodimethylamine (NDMA), and biodegradable dissolved organic carbon (BDOC)
Reverse Osmosis	pretreatment requirements, treatment efficiency, membrane selection and performance, operating flux (without significant permeability loss), process recovery, chemical cleaning regime and frequency, chemical consumption, and energy usage
Stabilization[5]	pH, temperature, alkalinity, turbidity, chemical doses, Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), and Calcium Carbonate Precipitation Potential (CCPP)
Microfiltration/ Ultrafiltration[6]	pretreatment requirements, treatment efficiency, membrane selection and performance, operating flux (without significant permeability loss), process recovery, chemical cleaning regime and frequency, chemical consumption, and energy usage
Ultraviolet Irradiation /Advanced Oxidation[7]	treatment efficiency, BDOC formation, chemical interferences, UV lamp sleeve fouling

1. Prior to testing, it is important to exhaust the adsorptive capacity of granular activated carbon (GAC) media and allow sufficient time for a naturally occurring biological community to acclimate. If previously exhausted GAC is used, the exhausted GAC should not be contaminated in such a way as to influence testing results.
2. Consider evaluating disinfectant dose and contact time values sufficient to achieve pathogen log reduction targets and comply with TCEQ drinking water disinfection rules.
3. The TCEQ has not presently established criteria for granting pathogen log reduction credits to MBRs. If pathogen removal credit is requested for and MBR process, extensive pilot-testing would likely be required along with approvals for membrane integrity testing procedures and microbial challenge test results. Membrane integrity testing for hollow fiber MBR systems is not standard practice for wastewater treatment, and flat sheet MBR systems do not currently have a method for in-place membrane integrity verification.
4. Consider evaluating ozone dose and contact time values sufficient to achieve pathogen log reduction targets (if ozone is used for pathogen removal) and/or achieve chemical reduction goals.
5. Consider estimating chemical requirements using testing and water quality modeling (if applicable).
6. Current integrity testing methods do not allow for verification to receive virus removal credit; however, MF and UF processes are capable of removing viruses (particularly UF).

UV reactor validation studies are typically available from UV equipment manufacturers and define the needed UV dose to achieve pathogen log removal credit for Cryptosporidium, Giardia, and viruses. Consider sending water samples to potential UV equipment manufacturers to establish equipment design criteria.

Table 7-2: Example advanced water treatment testing plans

Treatment Scheme No.	AWT Process	Example Test Plan	Feed Source	Typical Testing Considerations[1]
1	Secondary/Tertiary	---[2]	---	---
	Ozone	Pilot-Scale	Secondary/Tertiary	R,D,T
	MF/UF	Pilot-Scale	Ozone	R,D,T,P,O
	RO	Pilot-Scale	MF/UF	R,D,T,P,O
	UV/AOP	Bench-Scale	RO	D,T,P
	Stabilization	Bench-Scale	RO	D
2	Secondary/Tertiary	---	---	---
	MF/UF	Pilot-Scale	Secondary/Tertiary	R,D,T,P,O
	RO	Pilot-Scale	MF/UF	R,D,T,P,O
	UV/AOP	Bench-Scale	RO	D,T,P
	Stabilization	Bench-Scale	RO	D
	WTP	---	---	---
3	MBR	Pilot-Scale	---	R,D,T,P,O
	RO	Pilot-Scale	MBR	R,D,T,P,O
	UV/AOP	Bench-Scale	RO	D,T,P
	Stabilization	Bench-Scale	RO	D
	WTP	---	---	---
4	Secondary/Tertiary	---	---	---
	Ozone	Pilot-Scale	Secondary/Tertiary	R,D,T
	BAC[3]	Pilot-Scale	Ozone	R,D,T
	MF/UF	Pilot-Scale	BAC	R,D,T,P,O
	UV	Bench-Scale	MF/UF	D,T,P
	Chlorine[4]	Bench-Scale	MF/UF	D,T
5	Secondary/Tertiary	---	---	---
	MF/UF	Pilot-Scale	Secondary/Tertiary	R,D,T,P,O
	Ozone	Pilot-Scale	MF/UF	R,D,T,O
	BAC[3]	Pilot-Scale	Ozone	R,D,T,O
	Chlorine[4]	Bench-Scale	BAC	D,T
	WTP	---	---	---
6	Secondary/Tertiary	---	---	---
	Ozone	Pilot-Scale	Secondary/Tertiary	R,D,T,O
	BAC[3]	Pilot-Scale	Ozone	R,D,T,O
	UV	Bench-Scale	BAC	D,T,P
	WTP	---	---	---

R = Regulatory; D = Design; T = Treatment Efficiency; O = Other

1. Regulatory considerations for the unit processes are based on anticipated TCEQ requirements for pilot- and/or bench-scale testing. The TCEQ will consider testing requirements on a case-by-case basis and additional regulatory considerations may apply. TCEQ drinking water rules currently classify MF, UF, ozone, RO, and UV technologies as innovative/alternative treatment processes requiring either a pilot-scale study or data from a similar full-scale facility (or a reactor validation study in the case of UV). It is anticipated that pilot testing will be required for both membrane processes and upstream processes that influence membrane feed water quality.
2. This does not reflect the need to conduct water quality testing of the feedwater to the AWT system, or testing improvements to the secondary treatment system.
3. Options for incorporating BAC include BAC contactors or BAC filters depending on project-specific goals.
4. Assumes free chlorine disinfection.

7.3 Treatment Study Tasks

The general tasks that are typically included as part of bench- and pilot-scale studies are provided in Figure 7-2. Detailed descriptions of each task are provided in Appendix G.

Protocol Development

- Establish study budget
- Develop resource and labor allocation plans
- Select a suitable test site to meet project specific goals and requirements
- Define project objectives, equipment requirements, division of responsibilities, treatment capacity, performance criteria, test plan, test schedule, data collectoin and management plant, quality control plan

Protocol Review

- TCEQ review of protocol (allow 3-6 months)
- Protocol revisions to address TCEQ comments (if necessary)

Equipment Procurement

- Select vendors and negotiate equipment rental and support services agreements
- Procure ancillary equipment such as pretreatment systems, chemical systesm, tanks, pumps, piping, instruments, safety equipment

Installation, Startup and Training

- Determine space and shelter requirements
- Define division of responsibilities for installation, startup and training
- Determine personnel and tool/machinery requirements to unload and install equipment
- Perform instrument calibration

Testing

- Process data collection and system monitoring
- Water quality sampling and testing
- Recalibrate instrumentation, as necessary
- Pilot study progress reports and meetings
- System Operation

Decommissioning of Test Equipment

- Disconnect vendor equipment and remove from test site

Final Report Development and Delivery

- Document study data, analysis, results and conclusions

Figure 7-2: Pilot-scale study tasks

7.4 Pilot-Scale and Bench-Scale Testing Protocol Outlines

Figure 7-3 and Figure 7-4 provide general outlines for pilot- and bench-scale testing protocols. Descriptions of the sections within each outline are provided in Appendix G. Protocol modification may be required to suit project and public water system needs on a case-by-case basis. Consultation with the TCEQ is recommended to verify that testing protocols are acceptable for the proposed DPR project.

- Introduction
- Background
- Objectives
- Site Description
- Equipment Requirements
- Division of Responsibilities
- Performance Requirements
- Test Stages
- Test Schedule
- Data Collection
- Quality Assurance/Quality Control
- Progress Updates, Meetings, and Reports

Figure 7-3: Pilot testing protocol outline

- Introduction
- Background
- Objectives
- Equipment and Methods
- Division of Responsibilities
- Test Plan
- Sample Plan
- Quality Assurance/Quality Control
- Final Report

Figure 7-4: Bench-scale testing protocol outline

7.5 Example Scenarios

Two example scenarios have been prepared to demonstrate the conceptual implementation of DPR treatment schemes.[39] For both example scenarios, treatment schemes have been selected from the six treatment schemes discussed in Chapter 5. Example Scenario I incorporates Treatment Scheme No. 5 with pilot-scale UF, pilot-scale ozone, pilot-scale BAC filter, and bench-scale chlorine study example protocols. Example Scenario II incorporates Treatment Scheme No. 2 with pilot scale RO, bench-scale UV/AOP, and bench-scale stabilization example protocols with reference to the pilot-scale UF protocol presented in Example Scenario I. For both example scenarios, it is assumed that robust sampling to identify relevant project-specific contaminants has been performed and that the selected treatment schemes are applicable for treatment of the source waters.

*See **Appendix G** for samples of detailed testing protocols for two example treatment schemes.*

7.6 Probable Costs for Pilot- and Bench-Scale Testing

Treatment study costs are a significant factor to consider when planning for DPR projects. Typical cost items include site preparation, equipment shipping, equipment rental, vendor services, engineering fees, water quality sampling costs, and internal operating costs. Importantly, treatment study costs are increased if multiple vendors are evaluated for design and procurement purposes. Membrane technologies, in particular, benefit from multi-vendor pilot studies for design and procurement purposes. Since membrane pilot studies are anticipated to be a regulatory requirement, it is important to consider these costs for budgetary planning.

Typical Treatment Study Cost Items

- *Site preparation*
- *Equipment shipping*
- *Equipment rental*
- *Vendor services*
- *Engineering fees*
- *Water quality sampling*
- *Internal operating costs*

[39] The sample plans in Example Scenarios I and II are intended to provide a starting point for sample plan development. The TCEQ may require additional sampling during their case-by-case evaluation of a proposed treatment scheme. The scope of sampling will likely depend on the conservatism of the treatment scheme with respect to pathogen and contaminant treatment for the site-specific source water quality. An example of a sample plan that may be proposed by the TCEQ is provided in Appendix G.

Conceptual total costs for conducting AWT bench- and pilot-scale studies are provided in Table 7-3. The listed costs are intended for preliminary budgetary planning purposes only. Actual costs may be more or less than the preliminary budgetary planning costs shown. Treatment study costs are dependent on a variety of factors that include, but are not limited to, the variability of site conditions, site preparation requirements, vendor services requirements, internal operating costs, sampling and testing requirements and costs, study duration, project specific goals, pretreatment requirements, and engineering fees. The preliminary budgetary costs provided in Table 7-3 assume stand-alone studies. It may be possible to realize cost savings when multiple unit processes are incorporated into an overall AWT study test plan. However, as treatment study plans and requirements become more complex, costs may increase significantly.

Water Quality Sampling

Water quality sampling and testing activities may include both ***process evaluation sampling*** *and* ***regulatory compliance sampling****.*

- ***Process evaluation sampling*** *refers to sampling performed to monitor and assess treatment process performance.*
- ***Regulatory compliance sampling*** *refers to sampling that may be required by the TCEQ to demonstrate that treatment process(es) meet drinking water standards.*

Table 7-3: Preliminary budgetary planning costs for stand-alone pilot- and bench-scale testing

Process	Test Scale	Minimum Test Duration[1]	Assumed No. of Vendors/OEMs	Preliminary Budgetary Planning Cost[2]
BAC	Pilot-scale[3]	3 months (plus acclimation)	---	$100,000 - $150,000
MBR	Pilot-scale	3 months	3	$400,000 - $550,000[4]
MF/UF	Pilot-scale	3 months	3	$350,000 - $500,000
Ozone	Pilot-scale[5]	3 months	1	$150,000 - $250,000
RO	Pilot-scale	3 months	3	$400,000 - $550,000
UV	Bench-scale	Single study	---	$25,000 - $45,000
UV/AOP	Bench-scale	Single study	---	$25,000 - $45,000

OEM = Original Equipment Manufacturer

1. The listed minimum test durations are based on the typical minimum pilot study duration required by the TCEQ for membrane pilot studies. Longer study durations should be considered to evaluate the effects of factors such as seasonal water quality variability on treatment process(es) and treated water quality.
2. Preliminary budgetary costs are based on the listed minimum test durations and do not include internal operating costs for the public water system. Regulatory compliance sampling costs (i.e. primary and secondary drinking water contaminants including pathogens) are also not included as these requirements will be determined by the TCEQ on a case-by-case basis.
3. Assumes a 1 gallon per minute (gpm) BAC pilot system. The assumed 3 month test duration does not include acclimation time for exhausting media or establishing biological activity.
4. Preliminary budgetary planning costs for MBR do not include costs for additional testing that the TCEQ may require prior to approval of MBR in DPR applications.
5. Assumes a 36 gpm ozone system.

7.7 Full-Scale Verification Without Pilot- or Bench-Scale Studies

In emergency water shortage situations, utilities may consider approaching the TCEQ about implementing a full-scale verification study in lieu of pilot- and/or bench-scale testing. Full-scale verification involves risks for the public water system that include the risk that the constructed advanced water treatment facility (AWTF) fails to receive approval from the TCEQ, the risk that treatment process(es) fail to perform adequately, and the risk that treated water quality goals and/or requirements are not achieved. These risks, and others, create the potential for significant financial and water supply related consequences for the public water system. To reduce the risk of unsuccessful performance, a conservative design approach will likely be necessary, resulting in the potential for oversized equipment and infrastructure that could increase capital and operating costs for the AWT system.

Disadvantages of Full-Scale Verification

- *Significant financial investment prior to:*
  - *verification of treatment process performance*
  - *compliance with water quality goals*
- *May require conservative design approach with increased redundancy, resulting in higher capital and operational costs*
- *Large volumes of water will be produced during testing that cannot be introduced to the drinking water system. A plan (and regulatory approval, as needed) must be in place to discharge this water or return it to the wastewater system.*

Requests for full-scale verification approval will likely be handled by the TCEQ on a case-by-case basis, because an official approval process has not been established. For past projects in Texas, the first step has been to obtain temporary, conditional approvals for the treatment of WWTP effluent and the use of innovative/alternate treatment technologies. Next, design plans and specifications (along with CT studies) have been submitted for review and approval. If approved, the full-scale facility construction could begin and a full-scale verification protocol submitted to the TCEQ for review and approval. Full-scale verification requires extensive process data collection and water quality sampling during which time treated effluent cannot be used for DPR. If, upon review of the final full-scale verification report, the TCEQ approves the temporary, conditional exceptions on a long-term basis, the AWTF could begin operation with increased monitoring requirements relative to traditional WTPs. Due to the risks associated with a full-scale verification approach, this option should be considered only in an emergency situation.

7.8 Additional Pilot- and Bench-Scale Testing Considerations

Direct potable reuse directly influences the public water supply, and DPR treatment schemes should be designed and implemented using best available practices to maintain or improve potable water quality. Accordingly, consideration should be given to the impact of AWT process streams on downstream WTPs and/or the potable water distribution system. For example:

- the introduction of BDOC into the distribution system could result in biological regrowth and depletion of disinfectant residuals;
- inadequate stabilization could cause corrosion issues;
- an increase in disinfection byproduct (DBP) precursors could result in increased DBP formation; and
- variable water quality resulting from insufficient blending or other mechanism(s) could negatively influence consumer confidence.

Direct potable reuse pilot- and bench-scale testing studies provide a mechanism for investigating the viability of DPR treatment schemes from the perspective of drinking water regulatory compliance as well as the treatment of specific contaminants of concern. Drinking water regulations to consider include, but are not necessarily limited to primary and secondary drinking water regulations, the Revised Total Coliform Rule (RTCR), the Lead and Copper Rule (LCR), and the Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules (Stage 1 DBPR and Stage 2 DBPR).

In addition to regulatory and water quality considerations, pilot-scale studies provide an excellent opportunity to familiarize personnel with new technologies and equipment. The majority of AWT processes are traditionally water treatment processes; whereas, MBR is traditionally a wastewater treatment process. Accordingly, consideration should be given to which personnel will be operating the AWT system, the familiarity of personnel with the AWT technologies, and whether the AWT system will be integrated into a WWTP, WTP, or located on an independent site. Sufficient time and resources should be dedicated to training personnel and establishing protocols for coordination between WWTP and WTP staff.

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8 Regulatory and Legal Considerations for Direct Potable Reuse in Texas

In This Chapter

- Existing Direct Potable Reuse regulations or guidelines
- Current regulatory framework for Direct Potable Reuse in Texas
- Recommended process for seeking regulatory approval for Direct Potable Reuse in Texas

Road Map

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8.1 Existing Direct Potable Reuse Regulations and Guidelines

> **Difference between regulations and guidelines**
>
> - *Regulations (or criteria) refer to enforceable rules adopted by federal agencies or states*
> - *Guidelines (or guidance) refer to non-enforceable advice or recommended actions by federal agencies or states*

Currently, water reuse in the United States is governed by individual state regulations, as there are no national regulations in place that directly address water reuse. Direct potable reuse (DPR) is not defined in statute or rule, either at the federal or State level in Texas.[40]

The U.S. Environmental Protection Agency (EPA) published water reuse guidelines in 1992, 2004 and 2012 (EPA, 2012). The *EPA 2012 Guidelines* include a definition of DPR and a brief discussion of planning considerations and research needs. The document is intended to be solely informational and does not impose legally-binding requirements on the EPA, states, local or tribal governments, or members of the public. Other than this brief reference in the EPA guidelines, no other federal or state guidelines specifically addressing DPR have yet been published. The WateReuse Association, in cooperation with the National Water Research Institute, Water Environment Federation and American Water Works Association, is currently funding a project to develop a framework by a National Water Research Institute expert panel. The framework will be available in 2015.

> **EPA 2012 Guidelines for Water Reuse**
>
> *The EPA Guidelines for Water Reuse is a comprehensive reference resource addressing many types and aspects of water reuse.*
>
> *To download the guidelines, visit:*
>
> *http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf*

[40] The State of California has defined DPR in statute and is currently evaluating the feasibility of developing DPR regulations.

8.2 Current Regulatory Framework for Direct Potable Reuse in Texas

As discussed in earlier chapters, for the purpose of this document DPR is defined as "the introduction of reclaimed water either directly into the potable water system downstream of a water treatment plant or into the raw water supply immediately upstream of a water treatment plant". By definition, it is assumed that the reclaimed water will not be discharged to waters of the State prior to use and, therefore, will not be subject to requirements of the Clean Water Act (CWA) [41]. However, it should be noted that for indirect potable reuse (IPR) applications where there is a discharge to a water course and subsequent diversion of this water for potable water supply immediately downstream, many of the technical principles discussed in this document would be relevant. Although not discussed in detail here, the CWA (addressing discharge permitting), as well as Chapter 11 of the Texas Water Code (addressing water rights), would also apply in these cases.

8.2.1 Safe Drinking Water Act Provisions

All potable reuse projects must meet drinking water standards adopted under the Safe Drinking Water Act (SDWA). The SDWA includes provisions to evaluate a source water prior to authorizing it for treatment and potable consumption. Specifically, Section 1435 of the SDWA includes the following language:

> *The review under this section shall also include a review of the methods and means by which alternative supplies of drinking water could be provided in the event of the destruction, impairment or contamination of public water systems.*

The EPA, and subsequently the Texas Commission on Environmental Quality (TCEQ), relies on the above language as the authorization to regulate each new source of water. Each new source that will be treated and ultimately consumed as potable water must be evaluated and authorized pursuant to the SDWA. Texas has explicitly included the requirements of the SDWA in Sections 341.031-0315 of the Texas Health and Safety Code (THSC). The THSC is the statutory basis for TCEQ's authority to review and approve any new sources of water prior to it being used for potable consumption. Given that DPR is a nontraditional source of water, the review and approval process involves a number of regulatory provisions promulgated by TCEQ.

[41] Public water systems interested in a DPR project are encouraged to speak with staff in TCEQ's Water Availability Division to confirm that the reclaimed water to be used as a source is not subject to any water rights restrictions.

Chapter 290 of Title 30 of the Texas Administrative Code (TAC) provides the regulatory framework for TCEQ to implement the SDWA and THSC provisions applicable to DPR. Specifically, Section 290.41(e)(1) includes the following language:

> **For More Information**
>
> *All TCEQ rules can be viewed or downloaded from the TCEQ's website at:*
>
> *http://www.tceq.state.tx.us/rules/current.html*

To determine the degree of pollution from all sources within the watershed, an evaluation shall be made of the surface water source in the area of diversion and its tributary streams. The area where surface water sources are diverted for drinking water use shall be evaluated and protected from sources of contamination.

While the origin of the reclaimed water may, or may not, have been surface water, because the DPR source is akin to surface water (and clearly not produced from a groundwater well) it is evaluated for suitability as a source water. Most notably, it is evaluated because, as noted in TAC Section 290.41(e)(1)(A), it is "…subject to continuous contamination by municipal … effluent." The entirety of the "raw water reaching the treatment plant," absent some blending with another source, is treated effluent.

The provisions of TAC Section 290.41(e) further go on to require additional data on a potential source water. Texas Administrative Code Section 290.41(e)(1)(F) provides for the following:

Before approval of a new surface water source, the system shall provide the executive director with information regarding specific water quality parameters of the potential source water. These parameters are pH, total coliform, Escherichia coli, turbidity, alkalinity, hardness, bromide, total organic carbon, temperature, color, taste and odor, regulated volatile organic compounds, regulated synthetic organic compounds, regulated inorganic compounds, and possible sources of contamination. If data on the incidence of Giardia cysts and Cryptosporidium oocysts has been collected, the information shall be provided to the executive director. This data shall be provided to the executive director as part of the approval process for a new surface water source.

Therefore, a detailed source water quality assessment must be provided and approved by TCEQ prior to implementing a DPR project.

TCEQ relies on at least two other regulatory provisions to perform its source water and treatability review. Texas Administrative Code Sections 290.39(l) and 290.42(g) involve exceptions to the limited types of treatment technology approved in rule, and the use of what is considered innovative technology to treat water for potable consumption; TAC Section 290.42(g) includes the following language:

Innovative/alternate treatment processes will be considered on an individual basis, in accordance with §290.39(l) of this title.

Texas Administrative Code Section 290.39(l) states:

Requests for exceptions to one or more of the requirements in this subchapter shall be considered on an individual basis. Any water system which requests an exception must demonstrate to the satisfaction of the executive director that the exception will not compromise the public health or result in a degradation of service or water quality.

Because a DPR project will require advanced treatment, the conventional water treatment provisions of TAC Chapter 290, Subchapter D are not sufficient. TCEQ must evaluate each DPR project on a case-by-case basis, and evaluate the types of treatment technology needed to ensure there are no "adverse effects" pursuant to TAC Section 290.41(e)(1)(F) as noted above.

At this time, there are no additional adopted regulations regarding the process for review of a DPR project as related to the SDWA. However, TCEQ does have a fairly extensive set of documents, including final approval letters for at least three DPR projects at this time[42]. The final approval letters can be used as some form of guidance as to how TCEQ implements TAC Sections 290.39(l) and 290.42(g) for DPR projects. These letters can be obtained from the TCEQ through the public information request process.

8.2.2 Authorization Under 30 Texas Administrative Code Chapter 210

One additional provision of a DPR project that should be considered is whether the project requires approval pursuant to 30 TAC Chapter 210. If there is no ultimate disposal of the reclaimed water, pursuant to Section 26 of the Texas Water Code, then arguably it is being repurposed and reused, which is the regulatory intent of Chapter 210. Texas Administrative Code Section 210.2(a) and 210.5(a) state as follows:

210.2(a) The purpose of this chapter is to establish general requirements, quality criteria, design, and operational requirements for the beneficial use of reclaimed water which may be substituted for potable water and/or raw water. As defined and specified in this chapter, the requirements must be met by producers, providers, and/or users of reclaimed water. Specific use categories are defined with corresponding reclaimed water quality requirements. These criteria are intended to allow the safe utilization of reclaimed water for conservation of surface and ground water; to ensure the protection of public

[42] Colorado River Municipal Water District Project at Big Spring, the City of Wichita Falls Project, and the proposed City of Brownwood Project.

health; to protect ground and surface waters; and to help ensure an adequate supply of water resources for present and future needs.

210.5(a) Prior to discharging any reclaimed water to the waters in the state, the provider or user shall obtain a permit from the commission in accordance with the requirements of Chapter 305 of this title (relating to Consolidated Permits) except as provided for by §210.22(e) of this title (relating to General Requirements).

While it is clear that reclaimed water is not to be utilized for human consumption pursuant to Section 210.22, there is a means for authorizing an alternative system. Texas Administrative Code Sections 210.42 and 210.43 state as follows:

210.42(a) If a reclaimed water provider or user proposes to design, construct, or operate a reclaimed water system or to utilize reclaimed water in a manner other than authorized in these rules, the provider or user shall file a request with the executive director, in addition to the notification filed pursuant to §210.4 of this title (relating to Notification), identifying the alternative proposal and requesting approval by the executive director.

210.42(b) The request shall be in writing and shall include information necessary or useful in assisting the executive director in acting on the request for approval of the alternate reclaimed water proposal.

210.43 The executive director shall review an alternate reclaimed water proposal filed under §210.42 of this title (relating to Request to Executive Director). Within 60 days, the executive director shall identify in writing to the requestor any additional information necessary for the executive director to act on the request, and provide the requestor sufficient time to provide such information. Following the receipt of such information, the executive director shall act on the request, either granting or denying the proposal, in whole or in part. If no additional information is requested, the executive director shall act on the request within 60 days, either granting or denying the proposal, in whole or in part.

These provisions allow TCEQ to authorize a reclaimed water system, which may include subsequent potable water treatment technology, prior to the ultimate beneficial use. In essence, as part of the review described above pursuant to TAC Section 290.41, TCEQ may review and approve a DPR project, which will include an ultimate end beneficial use, as part of the provisions of Subchapter D of Chapter 210.

8.3 Recommended Process for Seeking Regulatory Approval of a Direct Potable Reuse Project

As discussed earlier, it is strongly recommended that any entity wishing to pursue the planning and implementation of a DPR project meet with the TCEQ Water Supply, Water Quality and Water Availability Division staff early in the process, while potential alternatives are still in the conceptual phase. Early meetings will allow the TCEQ to advise the PWS and make recommendations that can help avoid delays and clarify the regulatory approval process. The general regulatory steps that should be considered when pursuing approval for a DPR project are summarized in Figure 8-1.

However, since approval of DPR projects is carried out on a case-by-case basis, the steps outlined in Figure 8-1 should only be used as an example and should not be considered comprehensive. Specific requirements should be clarified and defined through individual meetings with the TCEQ.

When planning a project, sufficient time should be allocated to allow for review by the TCEQ and public notice, when required. While the time needed for each step can vary and will depend on the specific project, a minimum of 2-3 years should be set aside to receive construction approval, following the time that conceptual alternatives are initially presented to the TCEQ.

Initial meeting with TCEQ (Water Supply, Water Quality and Water Availability Divisions)

- Discuss conceptual alternatives
- Obtain information about subsequent regulatory process
- Define anticipated pilot-testing and monitoring requirements

Residuals management (Water Quality Division or Office of Waste)

- Evaluate disposal requirements for treatment residuals
- Submit application for discharge permit, deep well injection, or alternative disposal methodology to TCEQ (as needed)
- TCEQ reviews application and requests additional information (as needed)
- TCEQ issues draft permit and public notice (as needed)
- TCEQ issues final permit

Chapter 210 reclaimed water authorization (Water Quality Division)

- Submit application for authorization to TCEQ (as needed)
- TCEQ reviews application and requests additional information (as needed)
- TCEQ issues reclaimed water authorization

Exception request (Water Supply Division)

- Submit exception request to TCEQ
- TCEQ reviews application and requests additional information (as needed)
- TCEQ establishes specific conditions pertaining to sampling, treatment, public notice and other activities associated with the request.
- TCEQ issues approval of the exception.

Pilot testing (Water Supply Division)

- Develop pilot/bench testing plan
- Submit testing plan to TCEQ
- TCEQ reviews plan and requests additional information (as needed)
- TCEQ issues approval of testing plan
- Perform testing
- Coordinate with TCEQ on approval of testing results and selection of treatment elements

Construction approval (Water Supply Division)

- Public water system to submit plans and specifications prepared by a registered professional engineer
- TCEQ reviews submittal and requests additional information (as needed)
- TCEQ issues construction approval

Startup approval (Water Supply Division)

- Perform required testing at full scale facility and submit to TCEQ
- TCEQ reviews submittal and requests additional information (as needed)
- TCEQ issues approval to begin operation

Figure 8-1: Suggested steps for obtaining regulatory approval of a direct potable reuse project

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9 Public Outreach Programs for Potable Reuse Projects

In This Chapter

- Lessons learned from indirect potable reuse projects
- Key conclusions of potable reuse research related to public outreach
- Tips for public outreach and participation

Road Map

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9.1 Introduction

Because the public has often been reluctant to accept potable reuse as a safe, feasible solution, a public information program is an essential element of a direct potable reuse (DPR) project. An overview of programs for potable reuse, building on the lessons learned from the two operational DPR projects in Texas, indirect potable reuse (IPR) projects, and research conducted for improving public outreach and perception for water reuse are considered in this chapter.

A public information program includes both outreach and participation, which serve different functions (Asano and others, 2007). Outreach is a way of disseminating or collecting information to educate the public; participation implies a means for stakeholders to actively engage in and influence a plan. There are a number of techniques that can be used for outreach and participation, including (Asano and others, 2007; Millan (2007):

- One-on-one communications
- Community relationship management
- Databases
- In depth interviews
- Surveys
- Open house meetings
- Workshops
- Advisory committees/task forces
- Email broadcasts
- Social media
- Consistent proactive notifications
- Call centers
- Project portals
- Tours of treatment facilities

9.2 Lessons Learned from Texas Direct Potable Reuse Projects

Gaining community support for the Colorado River Municipal Water District (CRMWD) project at Big Spring and the City of Wichita Falls project was not as difficult as expected, with both communities mostly supportive from the beginning as a result of the drought.[43] CRMWD held public meetings, provided news releases, provided information using television and radio, and gave presentations to civic clubs. In general, the level of concern was alleviated once information was provided on the project.

> *The Wichita Falls video can be viewed at:*
>
> *https://www.youtube.com/watch?v=_MKrU1yi5Yc*

Wichita Falls believes that education was the key factor in the public accepting the project. The utility created a video about the DPR project, which features utility representatives, doctors, and experts from local universities talking about the disinfection process and the safety of drinking reclaimed water. The utility also brought the media into the fold very early in the process and provided information on every step involved with implementing the project. The public feedback since the project started has been that the water tastes better than the lake water traditionally supplied.

9.3 Lessons Learned from Indirect Potable Reuse Projects

Lessons learned regarding public acceptance and the role of outreach from IPR projects, such as groundwater replenishment and reservoir augmentation projects, are relevant for DPR. Successful IPR projects have a number of characteristics in common:

- They are designed to improve water quality;
- They augment water supplies or prevent sea water intrusion versus being designed to dispose of wastewater;
- They maintain a historical water quality database and conduct research to support success;
- They are managed by agencies with established experience and that have gained the confidence of regulatory authorities.

The WateReuse Research Foundation (WRRF) sponsored a study to examine how people perceive the value of IPR, including groundwater replenishment, and how the messages and management practices of the sponsoring utility affect these perceptions (Resource Trends, 2004). A second phase of the project developed a set of internet-based tools to help utilities

[43] Source: http://www.wateronline.com/doc/texas-leads-the-way-with-first-direct-potable-reuse-facilities-in-u-s-0001.

better understand public perceptions of IPR, develop a set of best practices, and improve the community dialogue.[44] This body of work identifies 25 best practices, the most "critical" of which are shown in Table 9-1.

Table 9-1: Critical best practices for indirect potable reuse

Practice Number	Practice
1	Create and communicate improvement
2	Clearly articulate the problem
4	Evaluate alternatives to potable reuse
7	Understand and avoid environmental justice issues
11	Establish the public water system as the source of quality
12	Rename the water
13	Communication = collaboration about value
15	Practice good leadership
17	Identify and collaborate with key audiences
18	Embrace potential conflict and opposition
21	Establish relationships with the media

Source: Resource Trends, 2004

The key characteristics of unsuccessful IPR projects were also identified:

- Inability to address concerns about water quality and health;
- Concerns about a commercial product image;
- The project facilitated growth;
- The project created a political rallying point;
- Concerns regarding environmental justice;
- Cost; and
- Insufficient public input/outreach.

In some cases, the true underlying issue of public concern was not raised (such as growth), but another issue was primarily used as the means to rally public and political opposition (such as health concerns).

[44] See http://www.watereuse.org/water-replenish/index.html.

9.4 Potable Reuse Research Regarding Public Outreach and Perception

The WRRF has also sponsored research related to communications and public perception of potable reuse.

The first is *Talking about Water – Vocabulary and Images that Support Informed Decisions about Water Recycling and Desalination* (Macpherson and Slovic, 2011). This project investigated how words, images and concepts used to communicate with the public influence public acceptance of reclaimed water. The project defined issues related to the acceptance of water reuse; reviewed published materials related to the acceptance of water reuse; and conducted surveys and focus groups. The research team developed an interactive, web-based, visual glossary.[45] Key recommendations included:

- Provide information that is interesting and engaging and simple enough to understand but technical enough to trust. Avoid using technical jargon, acronyms, and negative terms.
- Focus public educations efforts on the whole water cycle.
- Recognize that public acceptance is equally important as technical merit.
- Develop dynamic communication programs and strategies.
- Proactively work with the media, educational institutions, and others to broaden understanding about water.
- Describe water by its quality and the uses for which is it suitable, rather than by its history of use or level of treatment received.
- Present information about chemical concentrations in a risk management context.

Potable Reuse Research Findings for Outreach Materials

- *Provide compelling and accurate information on the water cycle*
- *Do not use technical jargon*
- *Do not use outdated materials*
- *Materials and terminology must be consistent*
- *Guidance documents need to focus on how to create trust, communicate in charged or fear-based atmospheres, overcome negative reactions, and explain water quality*

[45] See http://www.athirstyplanet.com.

The second project is *Downstream: Context, Understanding, Acceptance - Effect of Prior Knowledge of Unplanned Potable Reuse on the Acceptance of Planned Potable Reuse* (Macpherson and Snyder, 2013). Often communities considering the use of reclaimed water for potable reuse are unaware of other common water reuse occurrences such as unplanned or incidental reuse that may enhance their familiarity with water reuse. This project explored the hypothesis that a different approach could overcome issues related to stigma and disgust that are created when describing a scenario beginning where the water was most recently in a wastewater treatment plant. The project used images and approaches to measure people's responses to drinking water reuse using focus groups and surveys. Four different hypothetical drinking water reuse scenarios were considered, including one DPR situation. One goal of the project was to determine if communities considering the use of reclaimed water for potable reuse would be more accepting of water reuse if they had prior knowledge and understanding of "unplanned" water reuse via discharges of treated wastewater into water supply sources. This involved explaining urban water as part of a system of use and reuse, including a slideshow presentation called *Downstream*. The presentation explained some of the treatment technologies used for drinking water and wastewater, and those that could be used to make wastewater suitable for drinking water. The information was presented factually, without technical jargon, and did not conceal that wastewater forms part of the world's drinking water supply. This strategy contrasts with other approaches of describing potable reuse with the stigmatizing term "treated wastewater" and asking the public to imagine drinking this water (Macpherson and Slovic, 2011).

The key findings of Macpherson and Snyder (2013) were:

- Understanding the context of the urban water cycle increased acceptance of potable reuse, and acceptance was enhanced by positive terminology, including DPR.
- The *Downstream* slideshow was effective in explaining the concepts of urban water management, the removal of contaminants from water, and the commonness of unplanned potable reuse.
- The public appears to be willing to accept potable reuse, but many want assurances about monitoring processes to know that the water delivered to the tap is always safe.
- Water described as meeting or exceeding all appropriate drinking water standards and regulations helped to ensure confidence in drinking water.

Thus outreach programs for potable reuse should be initiated early in the planning process to create familiarity with the urban water cycle of use and reuse. It is important to provide information on the financial and long-term sustainability implications of all sources of water supply so that the public can understand the broader context of a proposed solution, such as DPR. Public outreach programs should address water quality standards, regulated substances, background information on regulatory development, and how water is monitored and tested to ensure safety.

9.5 Potable Reuse Public Outreach and Participation Tools

In addition to the glossary developed by Macpherson and Slovic (2011) and the *Downstream* slide show (and video[46]) developed by Macpherson and Snyder (2013), there are other tools that are helpful for development of public information programs. The WRRF has compiled a Public Acceptance Clearinghouse that is available to Foundation subscribers. Kennedy and others (2012) developed a communications toolkit for explaining the risks of pharmaceuticals and personal care products.[47] Additional information can be obtained from utilities engaged in IPR, including:

- El Paso Water Utilities (http://www.epwu.org/)
- North Texas Municipal Water District (http://www.wetlandcenter.com/index.html)
- Tarrant Regional Water District (http://www.trwd.com/)
- Orange County Water District (http://www.gwrsystem.com)
- West Basin Municipal Water District (http://www.westbasin.org/)

Additional Tips for Public Outreach and Participation

- *Translate materials into appropriate languages for a public water system's service area*
- *Expand outreach to industrial and commercial dischargers*
- *Develop an approach that brands businesses as environmental stewards going "above and beyond" basic source control*
- *Address proper disposal of drugs, pesticides, and other products*
- *Develop a list of community supporters, governmental agencies and industries*
- *Identify which members of the community are most trusted by the public (for example, healthcare professionals and academics in science and engineering)*
- *Secure public support in written format and/or as video testimonials*
- *Conduct surveys and/or focus groups to gauge public perception*
- *Develop a communication strategy for agency staff in dealing with the public, policy makers, and media*
- *Conduct tours of facilities that would include tasting the direct potable reuse product water*

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[46] See www.athirstyplanet.com/your_h20/**downstream**.

[47] See http://athirstyplanet.com/real_life/valuable_research/reuse_safe.

- Singapore Public Utilities Board (http://www.pub.gov.sg/water/Pages/singaporewaterstory.aspx)
- Clayton County Water Authority (http://www.ccwa.us/newman-wetlands-center)

The WRRF has funded the first phase of a three-phase program to facilitate DPR outreach. Public outreach experts believe that in order to ensure that DPR can be viewed and widely accepted by communities as a viable water supply source, a model strategic communication plan and associated pilot implementation plan must be developed. The WRRF project establishes a framework strategic communication plan for DPR outreach and uses the State of California as the location for a pilot program.

Model Public Communication Plan for Advancing Direct Potable Reuse Acceptance (WateReuse Research Foundation Project 13-02)

Phase I – develop a strategic communication plan (available in 2015)

- *Identify communication goals and objectives*
- *Identify key messages*
- *Identify audiences*
- *Develop the model plan with strategies and tactics, including resources, rapid response plans, materials*
- *Develop a method for evaluating the plan's effectiveness*
- *Build two model plans (one for a single community and one for community leaders)*

Phase II – develop messaging materials and methods (not yet funded)

Phase III – implement, evaluate, and refine plan (not yet funded)

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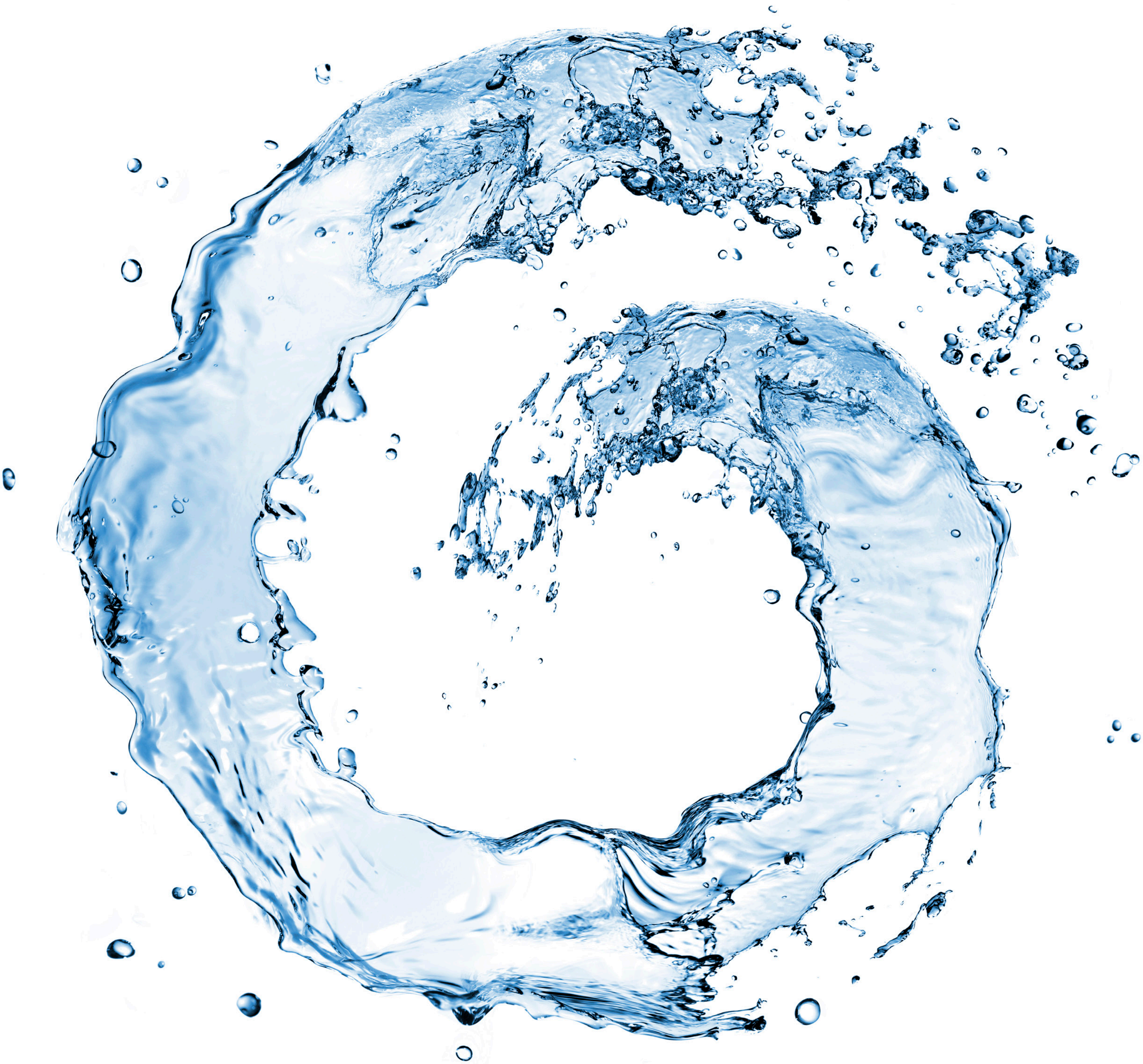

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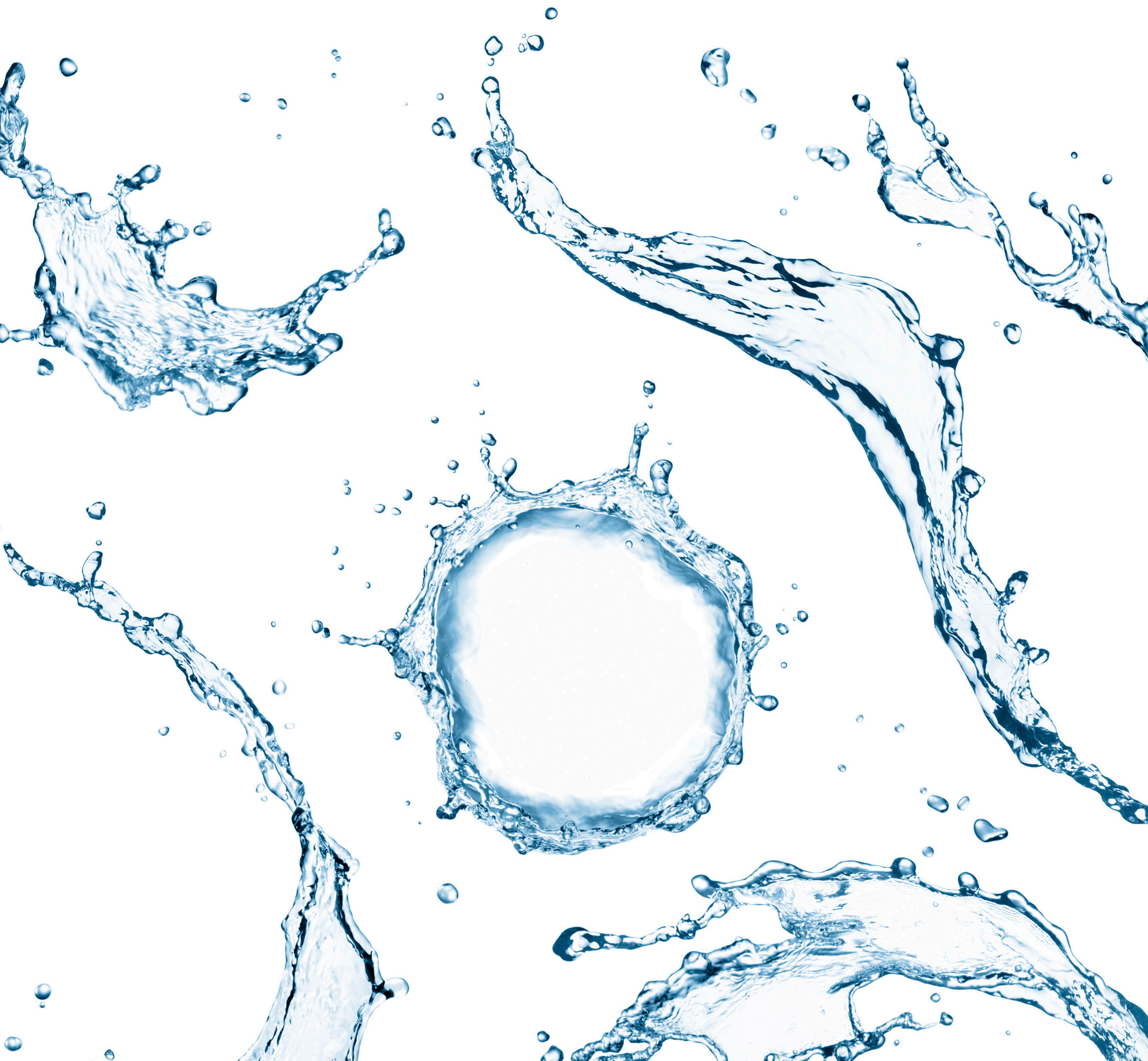
Glossary



GLOSSARY

Acute Health Effect: Health effects that usually occur rapidly, as a result of short-term exposure to a contaminant.

Advanced Oxidation: A chemical oxidation process that relies on the hydroxyl radical for the destruction of trace organic constituents found in water.

Advanced Water Treatment: Treatment used to remove total dissolved solids and or trace constituents and contaminants for specific reuse applications.

Alkalinity: The acid neutralizing capacity of solutes in a water sample, reported in mill equivalents per liter.

Assimilable Organic Carbon: Part of the dissolved organic carbon in water that can be assimilated by bacteria, and is used to predict the potential for bacterial regrowth.

Attenuation: Physical, chemical, or biological processes that, under favorable conditions, act to reduce the mass, toxicity, mobility, volume, or concentration of constituents.

Bench-scale Treatment Studies: Studies typically performed in a laboratory and are used to evaluate performance characteristics of treatment processes that can be represented adequately at a laboratory scale.

Beneficial Use of Reclaimed Water: The use of domestic or municipal wastewater that has been treated to a suitable quality for a specific use and takes the place of potable and/or raw water that would otherwise be needed from another source. Examples of beneficial uses include irrigation, industrial uses, toilet and urinal flushing, and drinking water.

Best Management Practices: Practices that are defined in industrial discharge permits used in place of or in conjunction with numeric effluent limitations to prevent or control the discharge of contaminants. Best management practices may include a schedule of activities, prohibition of practices, maintenance procedure, or other management practice.

Bioassays: Tests performed using live cell cultures or mixtures of cellular components in which the potency of a chemical or water concentrate is tested based on its effect on a measurable constituent, such as inhibition or the induction of a response (including carcinogenicity, mutagenicity, reproduction).

Biodegradation: Transformation of a substance into new compounds through biochemical reactions or the actions of microorganisms such as bacteria.

Biologically Activated Filtration: Biological filters that remove contaminants by three main mechanisms: biodegradation, adsorption, and filtration of suspended solids.

Brine: Waste stream from reverse osmosis treatment containing elevated concentrations of total dissolved solids (also called concentrate).

Bulk Organics: Classes or organic constituents characterized by surrogates such as dissolved organic carbon, UV absorbance, and specific UV absorbance.

Carcinogens: Contaminants that cause cancer.

Chemical: A substance that appears homogeneous or the same throughout its structure.

Categorical Pretreatment Standards: Technology-based numeric limits that have been developed by the U.S. Environmental Protection Agency in accordance with section 307 of the Clean Water Act to limit the pollutant discharges to publicly owned treatment works from specific process wastewaters from specific categories of industries.

Chapter 210 Authorization: Authorization issued by the Texas Commission on Environmental Quality, which allows a wastewater producer to reuse water for specific non-potable purposes.

Chemical of Emerging Concern: Constituents that have been identified in water that include pharmaceuticals, personal care products, and endocrine disrupting chemicals. Many of these constituents are not currently regulated.

Chlorine, Combined: The reaction product of chlorine with ammonia or other pollutants; also known as chloramines.

Chlorine, Free: Chlorine available to kill bacteria or algae. Chlorine that has not combined with other substances in water.

Chronic Health Effect: An adverse health effect resulting from long-term exposure to a contaminant.

Chronic Toxicity: Adverse chronic effects resulting from repeated doses of or exposures to a contaminant over a relatively prolonged period of time.

Clean Water Act: Federal law that is the cornerstone of surface water quality protection in the United States. The statute employs a variety of regulatory and non-regulatory tools to reduce direct discharges of contaminants into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff.

Coliform: Bacteria that originate in soil or vegetation and in the intestinal tracts of warm-blooded animals. This group of bacteria is used as an indicator of water contamination and the presence of pathogens.

Compound: A substance formed when two or more chemical elements are chemically bonded together.

Concentrate: The portion of a feed stream that retains the ions, organics and suspended particles that were rejected during reverse osmosis treatment.

Contaminant: Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

Contaminant of Concern: Any substance that has an adverse effect on human health that is regulated in drinking water or under consideration for regulation in Texas or at the national level. Also, a constituent that may not pose a health risk, but that can inform treatment process effectiveness and maintenance.

Contaminant Candidate List 3: A list of contaminants developed by the U.S. Environmental Protection Agency that are currently not subject to any proposed or promulgated national primary drinking water regulations, that are known or anticipated to occur in public water systems, and which may require regulation under the Safe Drinking Water Act. The list includes, among others, pesticides, disinfection byproducts, chemicals used in commerce, waterborne pathogens, pharmaceuticals, and biological toxins.

Cost-Effectiveness Analysis: The least expensive way of achieving a given water quality target, or the way of achieving the greatest improvement in some water target for a given expenditure of resources.

Constituent: A term used to describe either a chemical or compound.

Constituents of Emerging Concern: Chemicals or compounds not regulated in drinking water or reclaimed water. They may be candidates for future regulation depending on their ecological toxicity, potential human health effects, public perception, and frequency of occurrence in environmental media.

Constituents of Potential Concern: For the quantitative relative risk assessment case studies conducted for the resource document, these are contaminants that (1) were detected in the waters used for the example quantitative relative risk assessments, (2) are regulated or are currently under consider for regulation, and (3) have published toxicity information.

De facto Water Reuse: A drinking water supply that contains a significant fraction of treated wastewater, typically from wastewater discharges, although the water supply has not been permitted as a water reuse project.

Direct Potable Reuse: The introduction of advanced treated reclaimed water either directly into the potable water system or into the raw water supply entering a drinking water treatment plant.

Disinfection By-products: Chemicals that are formed with the residual matter found in treated reclaimed water as a result of the addition of a strong oxidant, such as chlorine or ozone, for the purpose of disinfection.

Drinking Water Standards: Regulations set by the U.S. Environmental Protection Agency to control the level of contaminants in the nation’s drinking water. They are enforceable standards include Maximum Contaminant Levels and treatment techniques. Drinking water standards apply to all public water systems

Drinking Water Equivalent Level: The concentration of a chemical in drinking water that would be equivalent to the Tolerable Daily Intake assuming a 150-pound person (70 kilograms) consumes 2 liters of water per day.

Effluent Dominated Waters: Surface waters that consist primarily of discharges of treated wastewater and runoff from urban and agricultural areas.

Effluent Organic Matter: Microbial products, refractory constituents, residual substrate, intermediates and end products present in secondary treated wastewater effluent.

Endocrine Disrupting Chemicals: Synthetic and natural compounds that mimic, block, stimulate or inhibit natural hormones in the endocrine systems of animals, humans, and aquatic life.

Enforcement Response Plan: A document that must be prepared as part of an agency's pretreatment program that outlines the procedures followed by pretreatment program staff to identify, document, and respond to pretreatment violations.

Engineered Storage: A constructed storage facility that provides a safety factor in the form of response time to address acute risks from pathogens should a treatment system fail or operate below desired performance targets.

Exposure: For humans, the amount of a chemical, physical, or biological contaminant at the outer boundary of the body available for exchange or intake via inhalation, ingestion, or skin or eye contact.

Filtration: The removal of particulate matter suspended in liquid by passing the liquid through a granular medium such as sand.

Granular Activated Carbon: A material made from raw organic materials (such as coconut shells or coal) that are high in carbon. Heat, in the absence of oxygen, is used to increase (activate) the surface area of the carbon. The activated carbon removes certain chemicals that are dissolved in water passing through a filter (adsorbing) the chemical in the activated carbon.

Guidelines: Refer to non-enforceable advice or recommended actions by federal agencies or states (also called guidance).

Hazard Index: The method was used for assessing the overall potential for noncarcinogenic effects posed by contaminants. In this approach, it is assumed that exposures to multiple contaminants, some of which may be below a no-effect threshold (subthreshold exposure), could result in an adverse health effect. A simplifying and health-protective assumption is made that the magnitude of that adverse health effect will be the sum of the ratios of the subthreshold exposures to acceptable exposure limits. In this assessment, the hazard index is defined as that sum.

Hormone: A chemical substance produced in the body that controls and regulates the activity of certain cells or organs.

Indicator: An individual constituent that represent specific physicochemical and biodegradable characteristics of a family of constituents.

Indirect Potable Reuse: The use of reclaimed water for potable purposes by discharging to a water supply source, such as a surface water or groundwater.

Integrated Treatment System: A combination of management, treatment and operational components for a direct potable project, including source control, the wastewater treatment plant, the advanced water treatment facility, and in some cases the water treatment plant with goal of producing drinking water that is safe for public consumption.

Interference: An industrial discharge which alone or in combination with a discharge or discharges from other sources (1) inhibits or disrupts the publicly owned treatment works, its treatment processes or operations, or its sludge processes, uses or disposal, and (2) is therefore a cause of a violation of any requirement in a public owned treatment works Texas Pollution Discharge Elimination System permit.

***In vitro*:** Biological studies that take place in isolation from a living organism, such as a test tube or Petri dish.

***In vivo*:** Biological studies that take place within a living organism.

Local Limits: Limitations that apply to commercial and industrial facilities that discharge to a publicly owned treatment works. Local limits are developed to meet the pretreatment program objectives and site-specific needs of the local publicly owned treatment works and the receiving stream.

Lowest Observed adverse Effect Level: The lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group.

Langelier Saturation Index: A mathematically derived factor obtained from the values of calcium hardness, total alkalinity, and pH at a given temperature. A Langelier Index of zero indicates perfect water balance (neither corroding nor scaling).

Maximum Contaminant Level: Enforceable numeric drinking water standards applicable to public water supplies. They represent the highest level of a contaminant that the U.S. Environmental Protection Agency allows in drinking water and are set at levels that are economically and technologically feasible.

Membrane: A device usually made of organic polymer that allows the passage of water and certain constituents, but rejects others above a certain physical size or molecular weight.

Membrane Bioreactor: A treatment process that combined wastewater biological treatment with membrane filtration of ultrafiltration in one unit process and replaces wastewater secondary clarifies and tertiary filters.

Microfiltration: A treatment system that passes liquid through semipermeable membranes to exclude particles ranging in size from 0.005-2.0 micrometers. Microfiltration cannot remove dissolved substances.

Method Detection Limit: The lowest concentration at which a compound can be detected in a sample (it can be distinguished from a blank with 99% certainty). It is a statistically calculated concentration where the compound is qualitatively expected to be identified.

Minimum Reporting Level: An estimate of the lowest concentration of a compound that can be detected in a sample for which the concentration can be quantified and reported with a reasonable degree of accuracy and precision.

Microgram per Liter: A unit of the concentration of a constituent in water. It represents 0.000001 gram of a constituent in 1 liter of water. Also called parts per billion.

Milligram per Liter: A unit of the concentration of a constituent in water or wastewater. It represents 0.001 gram of a constituent in 1 liter of water. Also called parts per million.

Nanofiltration: A filter with a pore size around 0.001 micron. Nanofiltration removes most of the larger organic molecules, sugars, and multivalent ions, with only monovalent ions and water being able to pass through. It does not remove nitrate.

Nanogram per Liter: A unit of the concentration of a constituent in water. It represents 0.000000001 gram of a constituent in 1 liter of water. Also called parts per trillion.

Nanomaterials: Materials having at least one dimension on the order of approximately 1 to 100 nanometers and often have unique or novel properties that arise from their small size.

Natural Organic Matter: The organic material present in water, and includes both humic and non-humic fractions. The dissolved fraction of natural organic matter may not be fully removed using conventional water treatment practices and have been shown to produce disinfection by-products such as trihalomethane during disinfection.

Nitrification/Denitrification: A biological treatment process used for nitrogen removal that converts ammonia to nitrate, and nitrate to nitrogen gas.

No Observed Adverse Effect Level: The highest exposure level at which there are no biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control.

Ozonation: A chemical oxidation treatment process that uses ozone to react with contaminants in water. It is also used for disinfection.

Pass Through: An industrial discharge that exits the publicly owned treatment works into waters of the United States in quantities or concentrations, which, alone or in conjunction with a discharge or discharges from other sources, is a cause of a violation of any requirement in a publicly owned treatment works' Texas Pollutant Discharge Elimination System permit.

Pathogens: Microorganisms including bacteria, protozoa, helminthes, and viruses capable of causing disease in animals and humans.

Permeate: The liquid stream that passes through a membrane.

Personal Care Products: Products such as shampoos, hair conditioner, suntan lotion, deodorants, and body lotions.

pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity.

Pilot-scale Treatment Studies: Studies that typically use treatment units that are significantly smaller than needed for full-scale operation, but that are large enough to accurately represent treatment behavior at full-scale. They can be used to evaluate the effectiveness of different types of treatment processes or different vendors of the same treatment process.

Primary Maximum Contaminant Levels: The maximum allowable amount of a contaminant in drinking water that is delivered to the consumer. The Texas primary maximum contaminant levels are set at the same level as the federal maximum contaminant levels.

Primary Wastewater Treatment: The first state of wastewater treatment that removes suspended solid materials.

Priority Pollutants: The 126 chemical pollutants regulated by the U.S. Environmental Protection Agency. The current list chemicals can be found in Appendix A to Section 40 of the Code of Federal Regulations, Part 423.

Publicly Owned Treatment Works: A publicly owned treatment works is a sewage treatment plant that is owned, and usually operated by local government. They are designed to treat domestic sewage, not industrial waste.

Quantitative Relative Risk Assessment: A traditional risk assessment approach that uses a hypothetical, standardized exposure.

Reclaimed Water: Domestic or municipal wastewater which has been treated to a quality suitable for a beneficial use.

Redundancy: The use of multiple barriers for the same contaminant, so that risks can be properly managed even in the event of an upset or failure in a unit process.

Reference Dose: An estimate of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Regulations (or Criteria): Refer to enforceable rules adopted by federal agencies or states.

Reliability: For direct potable reuse, to consistently achieve the desired water quality. A reliable system is redundant, robust and resilient.

Resilience: Protocols and strategies to address treatment failures and bring systems back on-line.

Reverse Osmosis: A treatment process where pressure greater than the osmotic pressure is applied to water to drive the more concentrated solution to the other side of the membrane and the membrane acts as a barrier to contaminants, such as salts. The permeate (product) water passes through the membrane and has reduced contaminant concentration. A reject flow stream (also often called "concentrate" or "brine") is produced that contains salts and other constituents rejected by the membrane process.

Risk: The probability that an organism exposed to a specified hazard will have an adverse response.

Robustness: The use of a combination of treatment technologies to address a broad variety of contaminants and changes in concentration in source water.

Safe Drinking Water Act: The main federal law that ensures the quality of United States drinking water.

Salinity: A parameter referring to the presence of soluble salts in waters, or in soils, usually measured as electrical conductivity.

Salts: Ionic compounds containing the cations sodium, boron, calcium, magnesium, and potassium, and the anions bicarbonate, carbonate, chloride, nitrate, phosphate, sulfate, and fluoride.

Secondary Maximum Contaminant Levels: Established by the U.S. Environmental Protection Agency as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color and odor. In Texas, in most instances, the secondary maximum contaminant levels are equivalent to the federal s maximum contaminant levels.

Secondary Wastewater Treatment: A biological wastewater treatment process used for the removal of soluble organic matter and particulates using microorganisms. The microorganisms form flocculant particles that are separated from the water using sedimentation (settling), and the settled material is returned to the biological process or wasted.

Slope Factor: An upper bound, approximating a 95% confidence limit, on the increased cancer risk from a lifetime exposure to an agent. This estimate, usually expressed in units of proportion (of a population) affected per milligram per kilogram per day.

Surface Water Treatment Rule: The drinking water regulation established by the U.S. Environmental Protection Agency to prevent waterborne diseases caused by viruses, Legionella, and Giardia. The rule requires that water systems filter and disinfect water from surface water sources to reduce the occurrence of unsafe levels of these microbes.

Surrogate: Bulk constituents, such as total organic carbon, total dissolved solids, conductivity, and coliform, used to evaluate the performance of individual treatment processes.

Tertiary Treatment: A treatment process where wastewater that has undergone secondary treatment is processed using granular media or carbon filters and then disinfected.

Tolerable Daily Intake: The amount of a constituent in drinking water, expressed on a body-weight basis (usually in milligrams of the substance per kilograms of body weight per day), that can be ingested daily over a lifetime without appreciable risk (also called Acceptable Daily Intake or Predicted no Effect Concentration).

Total Dissolved Solids: An overall measure of the minerals in water.

Total Organic Carbon: The concentration of organic carbon present in water.

Treatment: Any process that changes the physical, chemical, or biological character of a water or wastewater.

Treatment Scheme (or Treatment Train): A combination of treatment operations and processes used to produce water meeting specific water quality levels.

Ultrafiltration: A microfiltration filter with a pore size around 0.1 microns that can remove particulate matter and microorganisms. It cannot remove dissolved substances.

Uncertainty Factor: Safety factors used for risk assessments to account for variation in susceptibility among the members of the human population, uncertainty in extrapolating animal data to humans, uncertainty in extrapolating from data obtained in a study with less-than-lifetime exposure, and uncertainty associated with extrapolation when the database is incomplete.

Unregulated Contaminant Monitoring Rule: Program used by the U.S. Environmental Protection Agency to collect data for contaminants suspected to be present in drinking water, but that do not have health-based standards set under the Safe Drinking Water Act.

UV Radiation: The process by which chemical bonds of the contaminants are broken by the energy associated with UV light (photolysis). UV also has germicidal properties and is used for disinfection.

Water Quality: A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water Quality Standards: Standards required under the Clean Water Act to be developed by states define the goals for a water body by designating its uses (such as recreation, aquatic life, drinking), setting water quality criteria to protect those uses (both numeric and narrative requirements), an anti-degradation policy to maintain and protect existing uses and high quality waters, and general policies addressing implementation issues (such as variances, mixing zones, and low flows).

Water Right: Authorization issued by the Texas Commission on Environmental Quality allowing an entity to transfer, divert and use a specified quantity of water from a surface water source, such as a lake or stream.

Water Treatment Plant: Facilities that treat and produce potable water for public consumption using processes including flocculation, sedimentation, media filtration, and chlorination.

Waters of the United States: Navigable waters, including streams, rivers, lakes, creeks, and natural wetlands, as defined in the Clean Water Act.

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