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Considering the Implementation of Direct Potable Reuse in Colorado

WHITE PAPER

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CONSIDERING THE IMPLEMENTATION OF DIRECT POTABLE REUSE IN COLORADO

by:
Philip Brandhuber, PhD
Sarah Craig, PE
Timothy Thomure, PE
HDR, Inc.

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For more information, contact:
Water Environment Research Foundation
635 Slaters Lane, Suite G-110
Alexandria, VA 22314-1177
Tel: (571) 384-2100
Fax: (703) 299-0742
www.werf.org
werf@werf.org

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ACKNOWLEDGMENTS

Research Team

Principal Investigator:
Philip Brandhuber, Ph.D.
HDR, Inc. – Denver

Project Team:
Sarah Craig, PE.
HDR, Inc. – Denver

Timothy Thomure, P.E.
HDR, Inc. – Phoenix

WERF Project Subcommittee

Laura Belanger
Western Resource Advocates

Ron Falco
Colorado Department of Public Health and Environment[1]

Damian Higham
Denver Water

Tyson Ingels
Colorado Department of Public Health and Environment[1]

Sean Lieske
Aurora Water

John Rehring
Carollo Engineers

Water Environment Research Foundation Staff

Director of Research: Amit Pramanik, Ph.D., BCEEM
Program Director: Theresa Connor, P.E.

[1] Participation in Project Subcommittee does not imply concurrence with this report *in toto*.

ABSTRACT AND BENEFITS

Abstract:

This white paper investigates the potential challenges that Colorado utilities could face in implementing direct potable reuse (DPR) as a means to supplement drinking water supplies with purified recycled water. The paper concludes that the State of Colorado could facilitate the use of DPR as a water supply alternative by:

- Taking advantage of the considerable amount of research which has been completed through the California Direct Potable Reuse Initiative and from the experiences of Arizona, New Mexico, Texas and other states in considering or implementing DPR.
- Educating public officials and the general public regarding the potential benefits and safety of DPR.
- Developing more cost effective methods for the beneficial reuse or disposal of reverse osmosis (RO) membrane concentrate from water treatment processes.
- Supporting the development of non-RO based treatment trains capable of producing water suitable for DPR.
- Pursue an appropriate level of regulatory and policy development consistent with the level of interest of water providers in developing DPR projects.

Benefits:

- Offers conclusions that are valid for water-scarce western states, even though this white paper focuses on Colorado.
- Provides information to arid inland states considering using direct potable reuse as a drinking water supply alternative.

Keywords: Direct potable reuse, drinking water supply alternatives.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AOP	Advanced Oxidation Process
AWTF	Advanced Water Treatment Facility
AWWA	American Water Works Association
BAC	Biologically Activated Carbon
CDPH	California Department of Environmental Health
CDPHE	Colorado Department of Health and Environment
CWCB	Colorado Water Conservation Board
Cl_2	Chlorine
CWA	Clean Water Act
DEET	*N*,*N*-Diethyl-*meta*-toluamide
DPB	Disinfection Byproduct
DPR	Direct Potable Reuse
DDW	Division of Drinking Water (California)
EfOM	Effluent Organic Matter
FAT	Full Advanced Treatment
GAC	Granular Activated Carbon
H_2O_2	Hydrogen Peroxide
HAA	Haloacetic Acid
HACCP	Hazard Analysis and Critical Control Points
IPR	Indirect Potable Reuse
MCL	Maximum Contaminant Limit
MF	Microfiltration
MGD	Million Gallons per Day
NDMA	N-nitrosodimethylamine
NF	Nanofiltration
NOM	Natural Organic Matter
NWRI	National Water Research Institute
O_3	Ozone
PAC	Powered Activated Carbon

PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
RO	Reverse Osmosis
SCAPR	Steering Committee for Arizona Potable Reuse
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Limit
SWTR	Surface Water Treatment Rule
TCEP	Tris (2-Carboxyethyl) phosphine hydrochloride
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TTHM	Total Trihalomethane
UCMR3	Unregulated Contaminants Monitoring Rule
UV	Ultraviolet
U.S. EPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WQCC	Water Quality Control Commission
WRRF	WateReuse Research Foundation
WRRF	Water Resource Recovery Facility (Wastewater Treatment Plant)
WTP	Water Treatment Plant

EXECUTIVE SUMMARY

ES.1 Background

Sustained growth for the State of Colorado requires water. Colorado's population continues to grow and finding alternative sources of drinking water will become imperative in order to sustain that growth. Water reuse has been identified in Colorado's draft Water Plan as an important tool in closing the future supply-demand gap. Direct potable reuse (DPR), a technique which directly uses purified reuse water as a drinking water supply, is a potential method for supplementing Colorado drinking water sources in the future.

ES.2 Objective

The objective of this white paper is to investigate the potential challenges that Colorado utilities will face in implementing DPR and to propose actions that the state could take to facilitate the use of DPR as a water supply alternative. This paper focuses on four areas critical for the implementation of DPR in Colorado:

- Regulatory implementation.
- Technical considerations related to the design of DPR systems.
- Operational considerations related to the operation of DPR systems.
- Public acceptance of DPR.

This paper assumes that the implementation of DPR in Colorado must occur in the context of existing Colorado water law which specifies the water supplies that are legally reusable. Also, this paper does not include an estimate of the costs of DPR or an evaluation of the potential economic or societal value of its implementation.

ES.3 Conclusions

Direct potable reuse is a technically feasible method for supplementing drinking water supplies. In order to pave the way for the implementation of DPR, the State of Colorado should focus its efforts on:

- Taking advantage of the considerable amount of research which has been completed through the California Direct Potable Reuse Initiative and from the experiences of Arizona, New Mexico, and Texas in considering or implementing DPR.
- Educating public officials and the general public regarding the potential benefits and safety of DPR.
- Developing more cost-effective methods for the disposal of reverse osmosis (RO) membrane concentrate from water treatment processes.
- Supporting the development of non-RO based treatment trains capable of producing water suitable for DPR.
- Pursue an appropriate level of regulatory and policy development consistent with the level of interest of water providers in developing DPR projects.

ES.4 Recommendations

The Colorado Water Conservation Board (CWCB) and other state agencies should facilitate the potential for DPR in Colorado by:

- Bringing together a broad range of experts and interested parties to develop a better understanding of the benefits of DPR in Colorado and produce a roadmap for the State of Colorado to follow in developing DPR as an increasingly important and viable strategy in bridging Colorado's future water supply gap.
- Developing a program to educate the public, elected officials and water utilities about the benefits and safety of DPR.
- Partnering in research projects that advance knowledge related to technical challenges identified by this white paper. These include support for continued development of more cost-effective and environmentally acceptable RO concentrate management techniques and the evaluation of non-RO based treatment trains capable of producing water suitable for DPR.
- Working to develop specific potable reuse regulations, policies, and guidance, drawing on the results of California's ongoing Direct Potable Reuse Initiative and experience gained by New Mexico, Texas, and other states in implementing DPR projects.

CHAPTER 1.0

OVERVIEW

1.1 Introduction

When finalized, the 2014 draft of Colorado's Water Plan will provide a roadmap to close the gap between future water supply and future demand. Water reuse is identified by the plan as an important tool in closing the future supply-demand gap. Water reuse falls into two major categories, nonpotable and potable. Nonpotable reuse includes nondrinking water applications such as industrial use, landscape irrigation or agricultural activities. As the name implies, potable reuse involves the use of highly treated recycled (reclaimed) water for drinking water purposes. Direct potable reuse (DPR) – the introduction of purified recycled water directly into a potable water system - is a technologically feasible and potentially cost effective water reuse technique which is gaining wide acceptance in arid areas of the nation

1.2 Objective of This White Paper

The objective of this paper is to investigate the potential challenges that utilities will face in implementing DPR in Colorado and to propose actions that the State could take to facilitate the use of DPR as a water supply alternative. This paper recognizes that the implementation of DPR in Colorado must occur in the context of existing Colorado water law which specifies the water supplies that are legally reusable.

DPR is a complex challenge and touches on a broad range of issues – technical, legal, political, societal, and economic. An assessment of all these issues is not the intent of this paper. Instead, this paper focuses on four areas critical to the implementation of DPR in Colorado:

- Regulatory implementation.
- Technical considerations related to the design of DPR systems.
- Operational considerations related to the operation of DPR systems.
- Public acceptance of DPR.

1.3 Classification of Potable Reuse

Potable reuse can be divided into three categories as illustrated in Figure 1-1 and discussed in the following sections:

Direct potable reuse is the process of providing purified recycled (reclaimed) water to drinking water systems for human consumption and other drinking water uses. The DPR process involves a direct connection between the effluent of an advanced water treatment facility (AWTF) and the supply of a drinking water treatment plant (WTP). This connection may be blended with other drinking water sources. Taken together, the integrated treatment capabilities of the AWTF and WTP are designed to produce drinking water that is fully protective of public health.

Indirect potable reuse (IPR) intentionally places an environmental buffer, such as a lake, stream, aquifer, or reservoir between the AWTF and the WTP. For the IPR process, water treated by the AWTF is blended with a natural water source prior to treatment by the WTP. In theory, the environmental buffer reduces the concentration of any contaminants passing through the AWTF, either through dilution with natural water or by degradation during the time spent in the environmental buffer. In practice, because of the excellent water quality produced by the AWTF, blending or degradation of contaminants in the recycled water may not be necessary for the WTF using the buffer as a source to produce potable water. Until recently, environmental buffers were considered mandatory when implementing potable reuse.

De facto potable reuse is the recognition that many WTPs divert and treat water, a portion of which includes effluent from an upstream water resource recovery facility (WRRF). Ideally, by the time the downstream WTP diverts and treats the water, contaminants have had a chance to naturally degrade or be diluted by other water sources. The degree to which this occurs depends on the quality of the WRRF effluent, travel time and the presence of other water sources. In some circumstances, drought for example, the effluent of the WRRF may be a large proportion of the overall flow diverted by the WTP for treatment. Current regulatory practice in Colorado takes de facto potable reuse into consideration by identifying water supply as a designated use for waterbodies, setting stream standards based on the water supply designated use, and then requiring WRRFs to meet the stream standards through the discharge permit process.

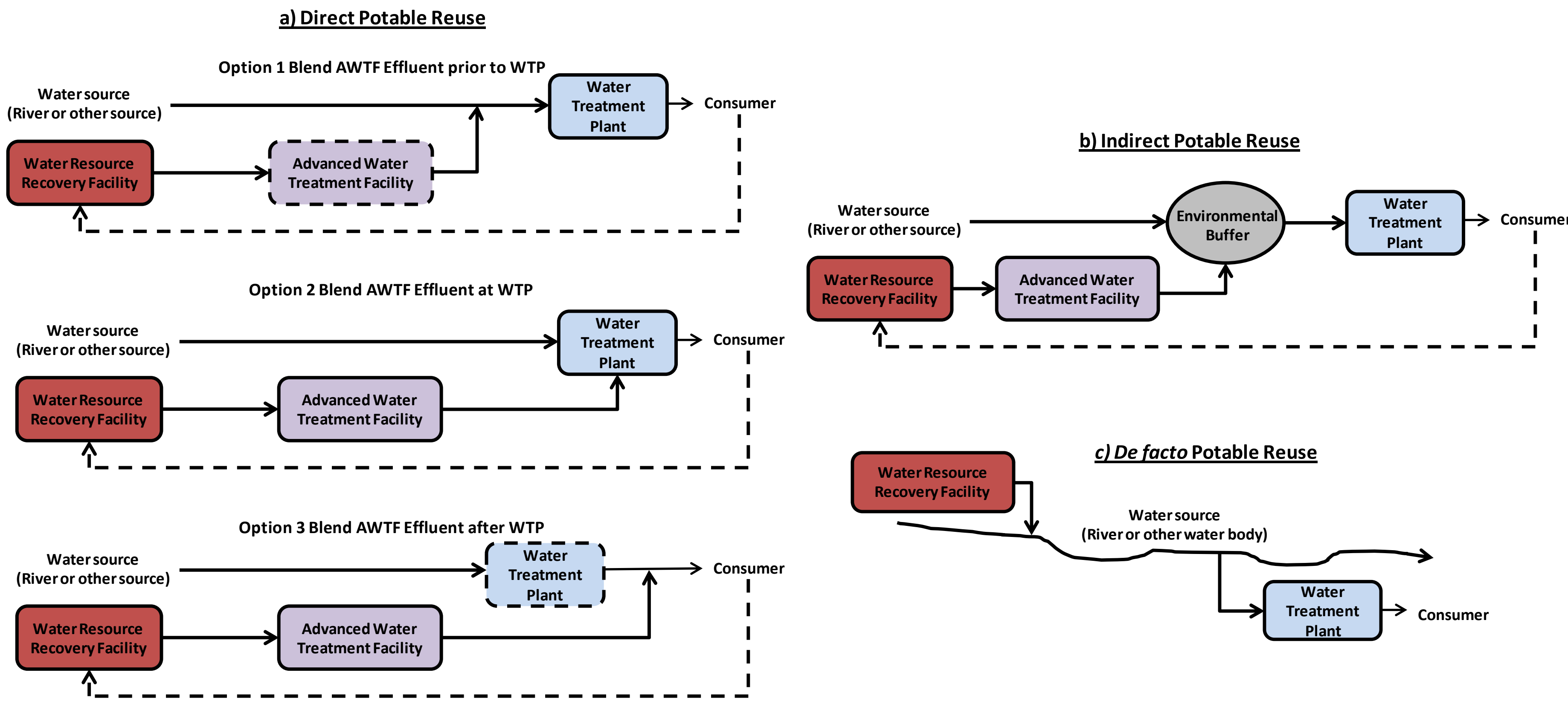

Figure 1-1. Simplified Comparison of (a) Direct, (b) Indirect and (c) *De facto* Potable Reuse.

1.4 Potable Reuse in Colorado

De facto potable reuse is a common situation in Colorado and in other states. Many of the major rivers in Colorado, such as the South Platte, Arkansas, Colorado, and their tributaries have WTPs located downstream from the outfall of WRRFs. Water treatment plants on these river systems practice *de facto* reuse to varying degrees. Projects like Aurora's Prairie Waters Project and the City of Parker's augmentation of Rueter-Hess Reservoir involve aspects of IPR. Hence, issues regarding IPR are not new to Colorado. Direct potable reuse was extensively researched by Denver Water during the 1980s and 90s, but Denver Water's current reuse program only involves nonpotable reuse. At present, no DPR projects are planned or in operation in Colorado, although a great deal of interest exists in the process as a method for supplementing water sources. Historically, DPR projects have not been implemented for many reasons including unresolved health concerns, uncertain regulatory environment, possible high costs, and a potential lack of public acceptance.

1.5 The Changing Environment for DPR

Many advances in technology have occurred since the evaluation of DPR by Denver Water, including improvements in the performance and reduction in costs of membrane systems and advanced oxidation processes. Nationally, two reports published in 2012 redefined the scientific and regulatory environment for DPR. The National Research Council Report *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater* (NRC, 2012) concluded that there was no inherent advantage of environmental buffers over engineered treatment of recycled water, opening the way for broader acceptance of DPR. The second report authored by U.S. EPA, *Guidelines for Water Reuse* (U.S. EPA, 2012) reflects a dramatic change in the agency's attitude toward DPR. While the prior version of *Guidelines* discouraged DPR, the U.S. EPA has now concluded DPR is "…a reasonable option based on (the) significant advances in treatment technology and monitoring methodology of the last decade…" These reports represent important changes in the thinking of scientific and regulatory agencies with respect to DPR.

In anticipation of the changing attitude to DPR and the need to develop additional water supplies, in 2010 the State of California passed Senate Bill 918 which directed the California Department of Public Health to provide a report on developing uniform criteria on DPR in California by 2016. In support of this effort in 2012, the WateReuse Research Foundation (WRRF), in association with a number of interested public and private parties, kicked-off the California Direct Potable Reuse Initiative. This initiative has raised over $6 million to investigate 22 priority projects related to DPR. Basic and applied research into DPR funded by this initiative is ongoing. While much of this work is California based, the findings from the initiative are applicable in arid states like Colorado.

Recent research has made a compelling case for DPR as a more efficient approach to potable reuse than IPR (Raucher et al., 2014; Schroeder et al., 2012). These studies indicate that when compared to IPR, DPR has the potential for:

- Lower capital cost.
- Lower operational cost and energy consumption.
- Smaller footprint.
- Greater treatment flexibility /operational control.

- Reduced vulnerability to environmental upset.
- Better human health protection.

1.6 Existing DPR Projects

There are several DPR projects in operation or under construction nationally and internationally. A brief summary of several of these projects are listed below:

1.6.1 Goreangab Water Reclamation Plant, Windhoek, Namibia

The Goreangab project has used highly treated wastewater since 1968 to supplement groundwater and ephemeral surface water as a drinking water source. The facility has a capacity of approximately 5.6 MGD and provides approximately 35% of the total water supply for the City of Windhoek. Secondary wastewater effluent is blended with raw water prior to the following treatment train: ozonation, powder activated carbon (as needed), coagulation and flocculation, dissolved air flotation, rapid sand filtration, additional ozonation, biological activated carbon, granular activated carbon, and ultrafiltration followed by chlorination and chemical stabilization. The highly treated water is directly blended with the potable water in the pipeline that feeds the potable water distribution system.

1.6.2 Village of Cloudcroft, NM

The Village of Cloudcroft, NM is building a DPR system which is scheduled to begin operation in 2015. The facility will provide an additional 0.1 MGD capacity to meet the highly variable potable water demands resulting from Cloudcroft being a seasonal tourist destination. The treatment facility is planned to include the following treatment processes: membrane bioreactor, chloramination, RO, and advanced oxidation using UV and hydrogen peroxide. The water will be blended with spring/well water, prior to additional treatment which includes: ultrafiltration, UV, and chlorination prior to distribution.

1.6.3 Big Spring, TX

Since 2013 the Colorado River Municipal Water District, located in Big Spring, TX has augmented approximately 2.0 MGD of its water supply with reclaimed wastewater. Disinfected tertiary effluent is treated with the following components: microfiltration, RO, and advanced oxidation using UV and hydrogen peroxide. The water is then blended with raw surface water prior to additional treatment consisting of coagulation, flocculation, sedimentation, granular media filtration and chlorination.

1.6.4 Wichita Falls, TX

In response to emergency conditions caused by extended drought, the City of Wichita Falls, TX started practicing DPR in 2014 as an interim solution until a planned IPR project is constructed. Approximately 5.0 MGD of disinfected wastewater effluent is treated using the following treatment components: coagulation, microfiltration and RO. The treated water is then blended with raw surface water. The blended water is then treated with: chlorine dioxide, coagulation, softening, flocculation, sedimentation, chemical re-stabilization and fluoridation prior to distribution.

Table 1-1. Partial List of DPR Projects in Operation or Under Construction.

Country	City, State	DPR Capacity	Facility Began Operation
USA	Cloudcroft, NM	0.1 MGD	2015 (expected)
USA	Wichita Falls, TX	5 MGD	2014
USA	Big Spring, TX	2 MGD	2013
Namibia	Windhoek	5.6 MGD	1968

1.6.5 San Diego, CA

While still in the planning phase, another prominent DPR project is for the city of San Diego, CA. Since 2004, San Diego has conducted a water reuse study, a recycled water study, a water purification demonstration project, and is currently undergoing a project titled Pure Water San Diego. An initial 15 MGD IPR facility is planned to be in operation by 2023, with conversion to DPR in the future. The long-term goal is to produce 83 MGD, or one third of the city's supply by 2035.

CHAPTER 2.0

REGULATORY IMPLEMENTATION

2.1 Challenges in Developing a Regulatory Pathway for DPR

There are no regulations in Colorado prohibiting a utility's pursuit of a DPR project, but conversely there is not a specific regulatory pathway defined for DPR in Colorado. At present the State of Colorado could work through and approve a proposed DPR project. But a more certain pathway for obtaining state approval of DPR systems will increase the attractiveness of pursuing DPR projects. The implementation of DPR on a widespread basis may create regulatory challenges for the State of Colorado. Therefore, Colorado should consider the appropriate level of regulatory and policy development in keeping with the level of interest of utilities in pursuing DPR projects. Regulatory standards and guidance involving water quality, treatment technology validation, performance monitoring, operator certifications, and reporting will need to be addressed during the design review process of approving a DPR system. Each of these areas is important, but for the purposes of this paper, the focus will be on water quality and its relationship to the protection of human health.

2.1.1 Water Quality

Current regulation of drinking water, as set by the Safe Drinking Water Act (SDWA) and Colorado regulations, conservatively assumes moderately impaired source waters are being treated. In the case of DPR, the source water, prior to the treatment by the WRRF and AWTF, is municipal wastewater whose characteristics, in terms of the presence of pathogens and levels of anthropogenic (manmade) contamination, is far more impaired than typical drinking water sources. Hence it is critical that the DPR regulatory pathway (meaning the combination of regulations, policies, and guidance), starting at the WRRF and ending at the WTP is adequately formulated and appropriately integrated to fully protect human health.

Some of the factors to consider when developing a DPR regulatory pathway include:

- The DPR regulatory pathway must assume that high concentrations of pathogenic organisms are present in the wastewater source.
- The DPR regulatory pathway must consider the likely presence of a broader range of contaminants than are typically present in drinking water sources that may threaten human health, including many that are anthropogenic in nature.
- The DPR regulatory pathway should recognize that many of the trace organic compounds currently being researched are not presently regulated under the SDWA. These contaminants often occur at trace (nanogram/liter) concentrations.
- The DPR regulatory pathway should take into consideration the impact wastewater treatment practices have on the character of organic matter and the potential implication these differences have on the formation of disinfection byproducts (DBPs).

- ♦ The DPR regulatory pathway should take into consideration that advanced oxidation technologies used for DPR may form a broader range of unregulated DPBs than traditional treatment processes.

In developing a regulatory pathway for DPR, certain factors should be kept in mind. First, per state statue C.R.S 25-1-1.5-202, the Colorado Department of Public Health and Environment (CDPHE) cannot establish, without considerable effort, standards that are more stringent than established by the SDWA. Secondly, by its nature, the regulatory development process can be contentious and arduous, often due to differences in opinion on how to perform risk assessments and interpret the available science. Hence sufficient resources must be available for this process to be carried out.

Table 2-1 identifies four major areas of regulatory focus for the implementation of DPR relative to water quality.

Table 2-1. Area of Water Quality Regulatory Focus for DPR.

Category	Subcategory	Examples	Concern	Addressed by SDWA
Microbial pathogens	Virus	Enterovirus, adenovirus, rotavirus, others	Acute infection	Yes
	Protozoa	*Cryptosporidium*, *Giardia*	Acute infection	Yes
Chemical	Nutrients	Nitrate, phosphorus Ammonia	Toxicity, Aquatic eutrophication* Disinfectant demand	Yes (nitrate) No No
	Metals	Arsenic, chromium, selenium, uranium others	Toxicity Carcinogenicity	Yes
	Trace organics	Personal care products, pharmaceuticals, flame retardants, degradation products, others	Endocrine disruption Carcinogenicity	No
Organic matter	Natural organic matter (NOM)	Humic acids, fluvic acids	Precursor for disinfection byproduct formation	Yes
	Wastewater derived (Effluent organic Matter – EfOM)	Soluble microbial products, products from NOM degradation, others	Precursor for disinfection byproduct formation	No
Disinfection byproducts	Currently regulated	TTHM, HAA, bromate	Carcinogenicity	Yes
	Currently unregulated	N-nitrosodimethylamine (NDMA) Chlorate	Carcinogenicity Toxicity	No

* Concern for IPR: limited concern for DPR.

2.1.2 Other Issues

In addition to establishing water quality and monitoring requirements, process design standards, process redundancy, and attention to operational issues such as establishing DPR specific operator certification requirements may be needed. Furthermore, for any regulatory approach, implementation and resource considerations to take into account include:

- Defining specific sampling requirements including exact location(s), analytical methods and frequencies.
- Defining reporting requirements.
- Defining compliance requirements, i.e., what constitutes a violation?
- Defining recordkeeping requirements for the utility and CDPHE.
- Constructing a database to house compliance data and outputs for compliance and other reporting.
- Public notice for violations including the required language to be included in public notice.

2.2 Colorado Regulatory Environment

Both the SDWA and the Clean Water Act (CWA) include provisions for the states to obtain authority to administer, so long as the regulations are at least as stringent as those set in the federal laws. Colorado has established Colorado Primary Drinking Water Regulations and the Colorado Water Quality Control Act to locally enforce requirements of the SDWA and CWA. Both of these Colorado statutes are enforced by the Water Quality Control Division of CDPHE. Their regulations most pertinent to drinking water and reclaimed water are summarized in Table 2-2.

Colorado has not established regulations or guidance regarding DPR. As described in the table above, Regulation No. 11 specifies requirements established by the Colorado Primary Drinking Water Regulations. These regulations are specific to traditional water supplies. Regulations No. 22 and 31 are used to implement the Colorado Water Quality Control Act, which is for the express purpose of protecting surface water quality. The Colorado Water Quality Control Act does not include provisions specific to protecting public health if the wastewater discharge is used in a DPR application and does not apply unless the discharge is to waters of the state. Regulation No. 84 is specifically written for non-potable reclaimed water. The criteria are based on low human exposure and explicitly exclude any recycled application for irrigation of food crops, let alone any sort of potable reuse application.

In 2013 Colorado House Bill 13-1044 directed the Colorado Water Quality Control Commission (WQCC) to establish standards for ‘graywater’ reuse. Regulation 86 establishes these standards. Rulemaking for Regulation 86 was completed in April, 2015.

Table 2-2. CDPHE Regulations Pertinent to Drinking Water and Reclaimed Water.

Regulation No.	Title	Stated Purpose
11	Colorado Primary Drinking Water Regulations	Assures safety of public drinking water supplies and enables the state of Colorado to assume responsibility for enforcing the standards established by the federal Safe Drinking Water Act.
22	Site Location and Design Approval Regulations for Domestic Wastewater Treatment Works	Applies to construction of domestic wastewater treatment works as a means to implement the Colorado Water Quality Control Act.
31	The Basic Standards and Methodologies for Surface Water	Establishes anti-degradation standards and an implementation process for classifying Colorado surface waters to protect Colorado's waters for beneficial uses (which include public water supplies, domestic, agricultural, industrial and recreational uses and the protection and propagation of terrestrial and aquatic life), as prescribed by the Colorado Water Quality Control Act.
41	The Basic Standards for Ground Water	Establishes statewide standards and a system for classifying ground water and adopting water quality standards for such classifications to protect existing and potential beneficial uses of ground waters.
84	Reclaimed Water Control Regulation	Establishes standards for the use of reclaimed water for non-potable use. Current allowable uses are for landscape irrigation, agricultural irrigation, fire protection, industrial, and commercial uses.

2.3 Regulatory Efforts Related to DPR

This section describes current regulatory efforts relating to DPR.

2.3.1 U.S. EPA

No national regulatory framework for DPR has been promulgated by U.S. EPA. Given the highly site specific nature of DPR, it is unlikely the U.S. EPA will develop national DPR regulations. In the absence of national regulation, states intending to practice DPR, including Colorado, will need to develop a DPR regulatory pathway compatible with existing regulations derived from the SDWA and CWA. At the time of writing, jointly, the National Water Research Institute (NWRI), WateReuse Association, Water Environment Federation (WEF), and American Water Works Association (AWWA) are developing a DPR Framework Document[2]. This document will summarize national experience and provide perspective on DPR regulation and implementation.

[2] The Draft Framework Document is scheduled to be published in summer, 2015.

2.3.2 California

California has taken important steps regarding the regulation of potable reuse water. In 2010, the California State Senate directed CDPH to:

1. Adopt uniform (statewide) criteria for potable reuse via groundwater recharge by December 31, 2013.
2. Adopt uniform criteria for potable reuse via surface water augmentation by December 31, 2016.
3. Report on the feasibility of developing uniform criteria for DPR by December 31, 2016.

An expert panel of water treatment and public health officials was formed by CDPH to facilitate this effort. Subsequent to the formation of the expert panel, oversight of recycled water in California was transferred from the CDPH to the State Water Resources Control Board – Division of Drinking Water (DDW). While focused on California issues, the work of DDW and its expert panel are doing much to establish a comprehensive regulatory framework for potable reuse. It should be emphasized that at present DDW's charge from the legislature with respect to DPR is only to report on the *feasibility* of developing a uniform criteria for DPR, not establishing the *actual* DPR criteria itself.

Nonetheless, the regulations for potable reuse via groundwater recharge (Item 1 listed above) and promulgated by California in 2014 provide some insight into the minimum set of water quality requirements that Colorado consider. Table 2-3 presents the water quality criteria for recycled water injected into an aquifer from which water intended for potable use is extracted. Although this is an IPR scenario, it indicates California's view of the level that wastewater must be treated to be suitable for use as a supply for subsequent potable reuse. It is likely that DPR regulations would require the same or higher levels of treatment and water quality, plus requirements for design, redundancy, advanced monitoring, and training.

Table 2-3. California Water Quality Parameters for Potable Reuse via Groundwater Recharge.

Parameter	Criterion[3]
Virus	≥ 12 $\log_{10}$ reduction
Giardia	≥ 10 $\log_{10}$ reduction
Cryptosporidium	≥ 10 $\log_{10}$ reduction
SDWA contaminants	Meet all Maximum Contaminant Levels (MCLs)
Total nitrogen	≤ 10 mg/L- N
Total organic carbon	≤ 0.5 mg/L - C

[3] A $\log_{10}$ reduction is a 10 fold reduction in the level of pathogens. Twelve log reduction means that 99.9999999999% of the microbial pathogens are removed or inactivated.

In addition to meeting the performance requirements of Table 2-3, California requires that a 'multi-barrier' approach be used when treating potable reuse water. The multi-barrier approach is an integrated treatment scenario engineered to have more than one opportunity for contaminants to be removed or inactivated. In a multi-barrier approach, no single step in the treatment process is wholly responsible for treating a contaminant or meeting a treatment objective. In this way the consequences of inadequate performance or failure of one portion of the process can be offset by other steps in the treatment process. The multi-barrier approach is not unique to DPR applications, and is common practice in the design of water treatment plants. Any regulatory pathway for DPR in Colorado will need to be predicated on a multi-barrier approach.

When injecting treated wastewater directly into an aquifer, a multi-barrier approach, which is commonly referred to in the literature as Full Advanced Treatment (FAT), of the WRRF effluent is mandated by California and has been used in Texas. Full Advanced Treatment consists of microfiltration, RO, and advanced oxidation. This treatment train, integrating low-pressure (microfiltration) and high-pressure (reverse osmosis) membranes, along with advanced oxidation, is capable of meeting all probable potable reuse treatment requirements. But its dependence on RO technology limits this treatment train's suitability for inland applications, due to the cost and complexity of concentrate disposal. More information about treatment trains is presented in Chapter 3.0.

2.3.3 Texas

Texas does not have statewide DPR regulations in place. However, due to a severe ongoing drought in Texas, the Texas Commission on Environmental Quality (TCEQ) has been approving DPR projects on a case-by-case basis. The TCEQ regulates DPR as a special type of raw water source, primarily under existing drinking water regulations.

TCEQ applies water quality regulations beginning with the treated effluent rather than the raw sewage as proposed by California. The specific characteristics of the treated effluent are considered in each permitted DPR facility. TCEQ requires that DPR systems demonstrate that they will achieve finished water quality goals that correspond to a one-in-10,000 per capita risk of infection; the finished water pathogen concentrations are too small to be directly measurable, thus the log removal value concept is applied to DPR the same way it is applied under existing surface water treatment regulations. However, rather than assuming an incoming raw water quality, TCEQ evaluates the log removal value requirement for a specific project, using an evaluation of the pathogen loads in the specific wastewater effluent that is proposed for DPR (Steinle-Darling, 2015).

In addition to setting log removal requirements for each DPR facility, TCEQ also encourages monitoring for unregulated constituents. It is recognized in the state that the individualized treatment requirements for each approved system may change over time, if warranted by ongoing monitoring programs. Each DPR facility has site-specific goals and may use a variety of treatment processes to achieve each water quality goal. Specific treatment processes are credited with log removal credits for their ability to remove viruses, *Giardia* and *Cryptosporidium*.

2.4 WateReuse Research Foundation (WRRF) Recommendations

A comprehensive set of treatment performance recommendations for DPR has been developed as part of the WateReuse Research Foundation project WRRF 11-02, *Equivalency of Advanced Treatment Trains for Potable Reuse*. The intent of these recommendations is to provide a benchmark against which the performance of DPR treatment technologies can be evaluated. These recommendations were not developed as a substitute for a publically developed DPR regulatory framework. However, the WRRF recommendations have been reviewed by an independent advisory panel of public health experts (WRRF/NWRI, 2013) and represent a comprehensive approach for specifying what constitutes DPR water that is safe and aesthetically acceptable for human consumption. The WRRF recommendations may be a logical point of departure for developing a regulatory pathway for DPR in Colorado. Table 2-4 summarizes the WRRF recommendation for DPR water quality.

Table 2-4. WRRF Recommendations for DPR Water Quality.

Contaminant Group	Members	Criterion	SDWA Requirement
Microbial pathogens[1]	• Enteric virus • *Cryptosporidium* • *Giardia* • Total coliform bacteria	12 $\log_{10}$ removal/inactivation 10 $\log_{10}$ removal/inactivation 10 $\log_{10}$ removal/inactivation 9 $\log_{10}$ removal/inactivation	Less stringent[2] Less stringent[2] Less stringent[2] Less stringent[2]
Disinfection byproducts	• Total trihalomethanes (TTHM) • Haloacetic acids (HAA5) • Bromate • *N*-Nitrosodimethylamine (NDMA) • Chlorate	80 µg/L 60 µg/L 10 µg/L 10 ng/L 800 µg/L	Same Same Same Not regulated Not regulated
Non-regulated chemicals of interest to public health	• Perfluorooctanoic acid (PFOA) • Perfluorooctanesulfonic acid (PFOS) • Perchlorate • 1,4-Dioxane	0.4 µg/L 0.2 µg/L 15 µg/L 1 µg/L	Not regulated Not regulated Not regulated Not regulated
Pharmaceuticals	• Cotinine • Primidone • Meprobanate • Atenolol • Carbamazepine	1 µg/L 10 µg/L 2 µg/L 200 µg/L 4 µg/L	Not regulated Not regulated Not regulated Not regulated Not regulated
Steroidal hormones	• Ethinyl Estradiol • 17-β-Estradiol	None detected None detected	Not regulated Not regulated
Recalcitrant chemicals Indictors of presence of wastewater	• Sucralose • Tris (2-Carboxyethyl) phosphine hydrochloride (TCEP) • *N*,*N*-Diethyl-*meta*-toluamide (DEET) • Triclosan	150 µg/L 5 µg/L 200 µg/L 2,100 µg/L	Not regulated Not regulated Not regulated Not regulated
Aesthetic	• Color • Odor • Total dissolved solids (TDS) • Total Organic Carbon (TOC) • Effluent organic matter (EfOM)	< 5 Apparent color unit ≤ 3 Total odor number Similar to local supply ≤ 0.5 mg/L-C 90% reduction fluorescence	Not regulated[3] Not regulated[3] Not regulated[3] Not regulated Not regulated

[1] Measured from raw wastewater to point of compliance for WTP.
[2] SDWA requirements only consider inactivation obtained in the WTP.
[3] Not regulated by primary MCL, but secondary MCL exists.

The water quality criteria in Table 2-4 provide a high level of protection from microbial pathogens, which are present in untreated wastewater. Yet some contaminants, like perchlorate whose occurrence is more probable in California than Colorado (Brandhuber et al., 2009) may not be of regulatory concerns for Colorado. This illustrates the need for an assessment of DPR water quality criteria based on both national experience and local conditions. It should also be noted that Table 2-4 contains contaminants that are typically concentrated in wastewater but not currently regulated by the SDWA. As mentioned in Section 2.1.1, CDPHE cannot establish, without considerable effort, standards that are more stringent than established by the SDWA.

A predictable regulatory pathway will be an important consideration for utilities when deciding to undertake a DPR project. Determining the regulatory pathway for DPR will be an important factor in promoting DPR in Colorado.

CHAPTER 3.0

TECHNICAL CONSIDERATIONS

3.1 Treatment Considerations to Implement DPR

In order to implement DPR in Colorado, additional treatment will be required to bridge the gap between the capabilities of existing WRRFs and WTPs. Conceptually, this role would be filled by an AWTF. The AWTF is designed to supplement the combined treatment capabilities of the WRRF and WTP. Physically the AWTF could be co-located with the WRRF, the WTP, or in a separate location (Figure 1-1). The need for public health protection and public acceptance of DPR dictate that treatment processes in the AWTF must be (Pecson et al., 2015):

- Resilient – capable of responding to upsets.
- Redundant – include back-up capabilities.
- Robust – contain processes that treat multiple contaminants.
- Reliable – consistently meet performance specifications.

When combined with the capabilities of the WTP, the AWTF must achieve all potable water treatment objectives while providing multi-barriers to microbial pathogens and chemical contaminants. Like any water treatment facility designed to produce water for potable use, the AWTF must meet four fundamental objectives (Australian Academy of Tecnological Sciences and Engineering, 2013):

The **first objective** is to reduce the concentration of the non-settleable suspended solids that carry over from conventional wastewater treatment processes. Suspended solids include colloidal material fine particles and microorganisms such as protozoan cysts and oocysts, bacteria and viruses. Removing suspended solids improves the performance and efficiency of subsequent treatment processes used to remove dissolved chemicals and remove or provide disinfection of pathogenic microorganisms.

The **second objective** is to reduce the concentration of dissolved substances, including inorganic salts, metals, natural and effluent organic matter, trace organic contaminants, and nutrients.

The **third objective** is to provide adequate disinfection. This includes meeting specified treatment targets for pathogenic microorganisms while controlling the formation of disinfection and disinfectant byproducts to acceptable levels.

The **final objective** is to stabilize or blend the water in order to reduce the corrosion potential of highly purified water towards material in the distribution system and to produce water that is aesthetically acceptable to the consumer.

A number of technologies can be used to fulfill the treatment objectives of an AWTF. The treatment objectives, treatment technologies (unit processes) capable of meeting the treatment objective and the relative prevalence of the treatment technology's use in Colorado are summarized in Table 3-1.

This table presents various technologies that can be linked together in a treatment train to meet DPR treatment requirements. It is important to emphasize that the technologies that would be used in an AWTF currently exist and, in varying degrees, are already being used in Colorado. From a treatment perspective, the unique challenge of DPR is not that it requires new technology, but in the inherent complexity of the treatment trains that, by necessity, use several advanced treatment technologies to provide multi-barrier protection. Advanced technologies in an AWTF may also require greater skill and training to operate than typical treatment plants. This may create additional training and certification requirements.

Table 3-1. Advanced Water Treatment Facility Objectives.

Treatment Objective	Primary Purpose	Possible Methods of Treatment	Effective for	Current Use in Colorado
Objective 1	Removal of suspended solids	Coagulation, flocculation, clarification	• Solids removal • Removal of microbial pathogens • Metals removal • Phosphate removal • Removal of natural and effluent organic matter	Widely practiced
		Media Filtration		Widely practiced
		Microfiltration (MF)		Practiced
		Ultrafiltration (UF)		Practiced
Objective 2	Removal of dissolved chemicals	Reverse Osmosis (RO)	• Removal of microbial pathogens • Metals removal • Phosphate removal • Nitrate removal • Removal of natural and effluent organic matter • Salinity reduction	Limited practice
		Nanofiltration (NF)		Limited practice
		Activated carbon (GAC and PAC)	• Removal of natural and effluent organic matter • Removal of trace organics	GAC limited PAC widely
		Biologically activated carbon (BAC)	• Reduction of natural and effluent organic matter • Removal of trace organics	Very limited
		Advanced oxidation processes (AOPs: $O_3+H_2O_2$, $UV+O_3$, $UV+H_2O_2$)	• Reduction of natural and effluent organic matter • Removal of trace organics • Inactivation of microbial pathogens • Reduction of DBPs (NDMA)	Very limited
Objective 3	Disinfection	Chlorination (Cl_2)	• Inactivation of microbial pathogens	Widely practiced
		Ozonation (O_3)	• Inactivation of microbial pathogens • Removal of trace organics	Limited practice
		Ultraviolet light (UV)	• Inactivation of microbial pathogens	Limited practice
Objective 4	Stabilization/ Blending	Chemical addition	• Corrosion control	Practiced
		Blending with other waters	• Corrosion control • Salinity reduction • Nitrate reduction	Practiced

3.2 DPR Treatment Trains for Colorado

A treatment train consisting of microfiltration/reverse osmosis/advanced oxidation (Figure 3-1) is the only treatment train approved by the State of California for direct injection of recycled water into aquifers used for potable water sources. This train is capable of removing natural and effluent organic matter, metals and nutrients, as well as removing or destroying trace organic contaminants. In addition, this train provides an almost absolute barrier to microbial pathogens along with substantial reduction of salinity (Gerrity et al., 2015).

The technologies used in this train are mature, and its operational performance is well documented. An AWTP using a microfiltration/reverse osmosis/advanced oxidation treatment train is likely to meet any treatment goal specified for DPR in the future.

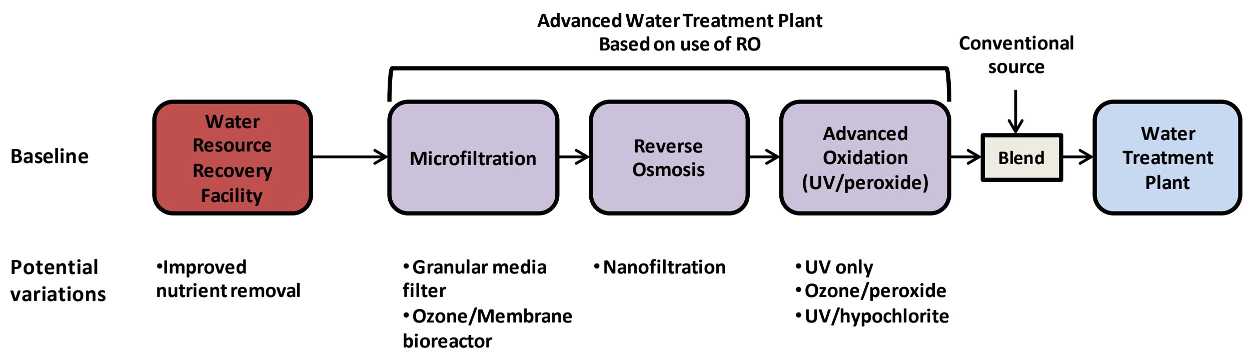

Figure 3-1. DPR Treatment Scenarios Based on Reverse Osmosis Technology.

The primary limitation of this train's suitability for use in Colorado is its dependence on RO technology. While RO is to a large degree responsible for the train's superior performance, the disposal of concentrate (waste stream) from the RO process is a significant limitation to its use in Colorado. The potential for the disposal of untreated RO concentrate to surface water bodies in Colorado is highly site specific and practically nonexistent for other than the smallest treatment plant. Deep well injection is currently the only practical disposal option for new municipal plants. Extensive progress has been made in reducing the volume of concentrate produced by RO technology. The East Cherry Creek Valley Water and Sanitation District Northern Water Treatment Facility, which uses deep well injection for concentrate disposal, is capable of obtaining over 90% recovery. In a pilot project sponsored by the State of Colorado, 98% recovery from an integrated electrodialysis/RO process capable of producing water meeting SDWA requirements was demonstrated (Brandhuber et al., 2014). But additional development of the technology would be required prior to reliable implementation at full-scale.

Alternative treatment trains, built around ozone and biological treatment processes are a possible alternative to RO based trains. Figure 3-2 presents three trains in which ozone, biological treatment or GAC are used in place of RO. These integrated trains would most likely meet microbial pathogen removal/inactivation requirements required for DPR but would be less effective in removing organic matter and trace organic contaminants than trains including RO. In addition, these treatment trains do not reduce salinity[4]. Substantial blending with low (and

[4] Typically measured as total dissolved solids (TDS).

possibly unavailable) salinity water may be needed to produce treated water consumers would find palatable. However, if these alternative treatment technologies are proven to provide an acceptable level of public health protection, in place of RO/NF, the RO/NF could be used on part of the DPR flow in a split-stream treatment approach to manage the salinity of the complete system.

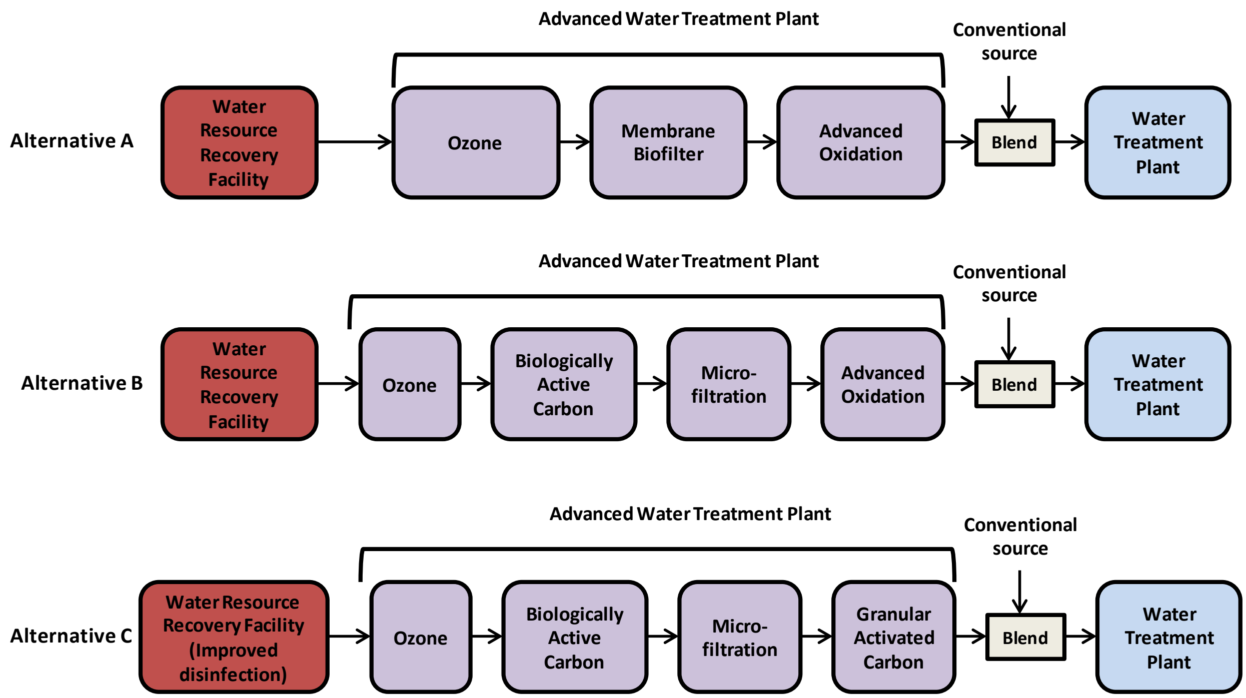

Figure 3-2. Potential DPR Treatment Scenarios Which Avoid RO.

Overall, technology currently exists which is capable of treating DPR water to levels safe for human consumption. However, the use of treatment trains based on RO technology may be cost prohibitive in Colorado without the development of more cost efficient, practical and environmentally responsible methods for concentrate treatment and disposal. This is a likely obstacle to the implementation of DPR in Colorado. Alternative treatment trains, such as those based on ozone and biological treatment in place of RO, may be able to provide a DPR treatment scenario protective of public health, while avoiding issues of concentrate management and disposal.

CHAPTER 4.0

OPERATIONAL CONSIDERATIONS

4.1 Operability of DPR System

The current state of water treatment engineering is sufficiently advanced that appropriately designed treatment trains, built around existing membrane technologies are capable of treating recycled water to standards suitable for DPR. Although additional evaluation is needed, non-membrane based treatment trains, built around ozone and/or biological treatment are likely to be suitable for DPR as well. While membrane concentrate disposal may constrain the economic feasibility of membrane based treatment trains in Colorado, it does not change the fact that these trains are capable of producing water of potable quality from recycled sources.

For the purposes of public health protection and public acceptance, DPR treatment not only needs to be *effective*, but the treatment trains must also be *operable*. Operability implies that on a day-to-day basis, the AWTF must consistently and reliably meet treatment standards without placing excessive demands on the skills of a trained operating staff. An ongoing WRRF project, *Operation and Maintenance Plan and Training and Certification Framework for DPR Systems* is, in part, developing a DPR training and certification framework to assist in regulatory development in California.

But operability is not merely a matter of staff training; it must be inherent in the design of the DPR system. A number of objectives need to be considered in designing an operable DPR system. These include:

- **Integrated operational control**. In a DPR scenario, the operations of the WRRF, AWTF and WTP are interrelated. While the individual plants may operate separately, DPR depends on the combined performance of all plants. The management of all aspects of DPR treatment must be integrated.
- **Consistent performance**. Each step in the DPR process depends on the performance of the prior step. Each plant must consistently meet its treatment objective and minimize the impacts of upsets on downstream treatment processes.
- **Monitoring capabilities**. Integrated monitoring of performance, ideally in real time, is needed to provide timely indications of failure to produce specified water quality.
- **Response to upsets or failures**. Sufficient flexibility must be built into the design of the DPR system to permit a response to upsets or failures without exposing the public to off-specification water.

The final two objectives, monitoring capabilities and response to upsets and failures, are interrelated. The failure of any critical process within the AWTF needs to be detected and resolved in ample time to prevent unsafe or improperly treated water from reaching the consumer. One approach for protecting the public from failures or upsets in the AWTF is to include in its design an engineered buffer, with residence time greater than the time it takes to verify the safety of the water prior to its distribution to customers. However, consideration should be given to advances in operational technology, such as real-time monitoring, which speed the response to failures or upsets and allow for protection equivalent to that of an engineered buffer. Several projects sponsored by the California Direct Potable Reuse Initiative are investigating improved monitoring technologies. Colorado should keep abreast of these developments.

4.2 Tools for Risk Assessment

Successful implementation of DPR should incorporate formalized tools to systematically minimize hazards during the production of potable water from recycled sources. The use of Hazard Analysis and Critical Control Points (HACCP) during the design and operation of AWTF may be a suitable approach to reduce risk and improve operability of a DPR system.

HACCP is a process control system that involves identifying and prioritizing hazards and risks to the quality of food or drinking water, and controlling processes to reliably maintain the desired level of quality. The application of HACCP in a systematic manner helps the water utility control water quality risks as close to their sources as possible (Martel et al. 2006). Although HACCP was initially developed for food safety, it also can be applied to potable water production. Seven principles in the application of HACCP are recognized in ISO 22000. These include:

- Conduct hazard analysis.
- Identify critical control points.
- Establish limits at each critical control point.
- Establish monitoring at each critical control point.
- Establish corrective action when limits at critical control points are exceeded.
- Establish system to monitor that corrective action is taking place.
- Maintain records of documenting compliance with above.

Utilities in Colorado should consider whether the use of risk assessment tools, like HACCP, would be beneficial in improving the safety and public acceptability of DPR.

4.3 Need for Validation of Pathogen Removal

Exposure to pathogens is a primary concern for potable reuse; yet real-time pathogen detection is currently not possible. Pathogen monitoring tends to be time consuming and expensive. Ideally, pathogen monitoring should be performed between each treatment process so that a breakthrough could easily be identified and remedied. But this is not possible, so the industry is moving away from endpoint monitoring toward system validations.

Technologies are tested for pathogen removal under a range of conditions, and are validated for specific levels of removal under defined conditions. Subsequently, the systems receive pathogen removal credits if they demonstrate that the process is operating under the validated conditions. This is the same process that has been used to develop pathogen reduction criteria in the Surface Water Treatment Rule (SWTR). In this way, time-consuming measurements of pathogens themselves are replaced with the continuous monitoring of surrogate parameters and more easily measured indicators of pathogen removal (Trussell et al., 2013).

However, in the context of DPR, there is no nationally recognized standard for validating process performance. This represents a challenge for all states, including Colorado, which may need to review or establish new treatment credits for technologies used at the AWTF.

4.4 Improved Source Control

Source control of inputs to the collection system of the WRRF is more critical for potable reuse than a non-potable reuse scenario. Unauthorized or illegal inputs to the WRRF collection system from industrial, commercial, or domestic sources which unintentionally pass through the WRRF could impact the performance of the AWTF. Similarly, infiltration into collection systems during storm events may cause unacceptable variations in the performance of the WRRF. This illustrates the importance of designing systems that are, as discussed in Section 3.1, resilient, redundant, robust, and reliable. At the same time a greater degree of understanding of the impacts of WRRF sources under conditions unique to Colorado should be developed prior to implementation of DPR. At present, Colorado does not have delegated authority from U.S. EPA to fully implement regulatory oversight for pretreatment.

CHAPTER 5.0

PUBLIC ACCEPTANCE

5.1 Public Acceptance of DPR

The successful implementation of DPR is dependent upon the public's acceptance of the practice. A common perception of potable reuse is captured in a cartoon which ran in a San Diego newspaper. A dog and its master stand facing a toilet. The caption reads, "Move over Rover, I got'a get a drink."[5] This cartoon is a humorous illustration of what is called the yuck factor. The 'yuck factor' is a deep-seated negative response to a practice which is obviously harmful. The 'yuck factor' should not be considered silly or irrational; consuming improperly treated water *is* hazardous to human health. Instead, the 'yuck factor' is a not too surprising response of a public who has not been provided with enough information to understand that, when treated to the appropriate standards, consuming potable reuse water *is not* hazardous to human health. The 'yuck factor' also ignores the extent to which *de facto* reuse occurs in arid states like Colorado.

Research indicates (Macpherson and Solvic, 2011; Macpherson and Snyder, 2013) that the 'yuck factor' can be overcome. The public will support DPR if adequate factual information about the process is provided to the public and they are introduced to the basics of the technology. A better understanding of the water cycle in general, and the fact that *de facto* reuse commonly occurs appear to promote the acceptance of potable reuse.

An Advisory Panel convened by the WateReuse Arizona in July 2013 explored public acceptance issues related to potable reuse in support of the ongoing Steering Committee for Arizona Potable Reuse (SCAPR). Public communications practitioners from across the globe discussed their past experiences, both good and bad, in implementing potable reuse. The workshop identified a series of best practices for consideration, when building public support for potable reuse:

- Build community trust in the implementing utility, which means communicating early and often with the customers.
- Establish a structure and a timeline for decisions to ensure that the investments made in gaining the support of community decision makers is leveraged in a timely manner.
- Use clear and consistent terminology in all communications.
- Make a compelling case for investment – focus the campaign on the benefits of the project to the community, not on trying to "convince" the public.
- Engage trusted experts such as public health officials and local university researchers.
- Cultivate trusted community champions (beyond the utility) to be vocal in supporting the project.

[5] Another cartoon, supportive of potable reuse, depicted a dog looking at a toilet thinking, "Ten million dogs can't be wrong."

5.2 Acceptance of DPR by the Public Officials

The support of public officials is also critical to the implementation of potable reuse projects. As part of a WRRF study (Millan et al. 2014), 34 California State legislators were interviewed regarding their perceptions and attitudes toward potable reuse. While the political environments in California and Colorado are different, both states face a similar problem in that future water demands exceed planned supplies. The report identifies the types of concerns public officials have when dealing with potable reuse issues. The report also reinforces the importance of informing public officials about potable reuse issues. Observations made by the report include:

- Public officials are reluctant to support potable reuse without clear assurances relative to safety, costs, needs and benefits.
- Public officials are reluctant to back potable reuse projects without evidence of public support.
- Uncertainty in the regulatory environment and the permitting process inhibits public official support for potable reuse projects.
- Public officials believe distrust of government by the public is a concern when implementing potable reuse projects. Any potable reuse project must be carefully planned, well explained, and transparent to the public.
- Public officials also believe perceptions of environmental justice are important. Officials point out that some segments of the public may find it unfair to drink water from a DPR system while others members of the community do not. In essence the displeased group feels it is being forced to carry the environmental burdens caused by privileged members of the community.

Colorado has the advantage of learning from the experience of other states in implementing potable reuse. A consistent theme, from the experience of other states, is the need to educate both the public and public officials on the potential benefits and safety of potable reuse. A potable reuse project is unlikely to succeed, unless the public and its officials, are well informed and supportive.

CHAPTER 6.0

ADVANCING DPR IN COLORADO

The fundamental goal of DPR is to provide drinking water that is protective of public health at an acceptable cost in an environmentally responsible manner while complying with Colorado water law. To be protective of public health and accepted by the public, water from DPR projects must reduce the presence of:

- Microbial pathogens to levels that protect human health from possible acute health risks.
- Chemical contaminants to levels that protect human health from possible acute and chronic health risks.

At the same time, the water that is produced by DPR must be aesthetically acceptable. The water should be free from colors, tastes, or odors that consumers find objectionable. Lastly, because of the unique nature of DPR, customers must overcome what is termed the yuck factor, a visceral and natural (but unwarranted) reaction to the realization that the water they are drinking at one time contained wastewater. Producing water that is microbiologically and chemically safe while aesthetically acceptable is accomplished through a combination of regulatory standards, treatment process design and operational performance. Overcoming the 'yuck factor' is a matter of public education and informing public leaders.

Creating an environment where DPR projects in Colorado can succeed will only occur through the interactions of many interested parties. As illustrated in Figure 6-1, meeting the goal of providing the safe DPR water will only come about through the interaction of state and public officials, utilities and water professionals, academia, and researchers. Each group provides unique insights and contributions to the process. State and public officials provide the regulatory pathway, policy determination, and water law that utilities must conform to. Utilities and water professionals need to provide treatment technologies that meet regulatory requirements while producing water acceptable to consumers in a sustainable fashion. Universities and researchers assist both state officials and utilities in providing the science needed to set acceptable treatment standards and designing technologies capable of meeting those standards. Advocacy groups can also contribute to the public acceptance of DPR.

The State of Colorado should facilitate the interchange of information between these groups in order to assess the practicality of DPR projects in Colorado and build public confidence in the concept of potable reuse.

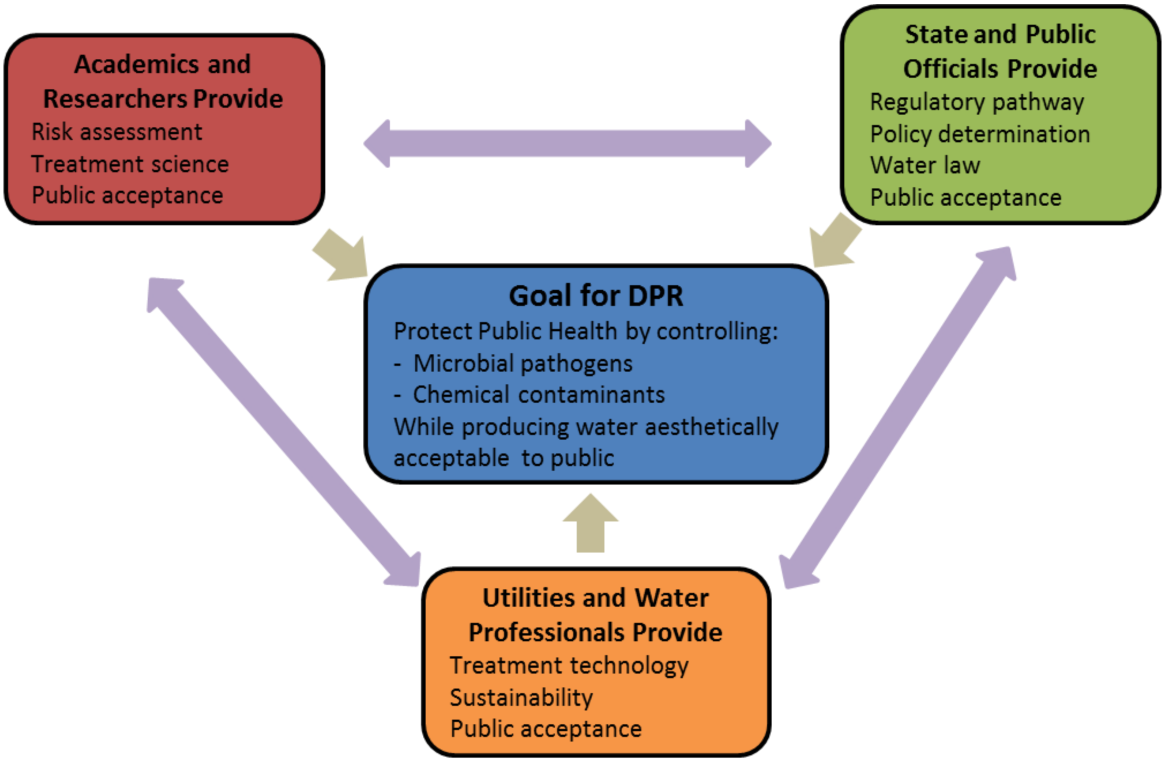

Figure 6-1. Roles in Advancing DPR in Colorado.

CHAPTER 7.0

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Direct potable reuse is a technically feasible method for supplementing drinking water supplies. In order to pave the way for the implementation of DPR, Colorado should focus its efforts on:

- Taking advantage of the considerable amount of research which has been completed through the California Direct Potable Reuse Initiative and from the experiences of Arizona, New Mexico, and Texas in considering or implementing DPR.
- Educating public officials and the general public regarding the potential benefits and safety of DPR.
- Developing more cost-effective methods for the disposal of RO membrane concentrate from water treatment processes.
- Supporting the development of non-RO based treatment trains capable of producing water suitable for DPR.
- Pursue an appropriate level of regulatory and policy development consistent with the level of interest of water providers in developing DPR projects.

7.2 Recommendations

The CWCB and other state agencies should facilitate the potential for DPR in Colorado by:

- Bringing together a broad range of experts and interested parties to develop a better understanding of the benefits of DPR in Colorado and produce a roadmap for the State of Colorado to follow in developing DPR as an increasingly important and viable strategy in bridging Colorado's future water supply gap.
- Developing a program to educate the public, elected officials, and water utilities about the benefits and safety of DPR.
- Partnering in research projects that advance knowledge related to technical challenges identified by this white paper. These include support for continued development of more cost-effective and environmentally acceptable RO concentrate management techniques and the evaluation of non-RO based treatment trains capable of producing water suitable for DPR.
- Working to develop specific potable reuse regulations, policies and guidance, drawing on the results of California's ongoing Direct Potable Reuse Initiative, and experience gained by New Mexico, Texas, and other states in implementing DPR projects.

APPENDIX A

WORKSHOP AGENDA

Colorado Direct Potable Reuse Workshop

May 27, 2015

AWWA Lynn Laskey Center
6666 West Quincy Avenue, Denver, CO, 80235

Agenda

Objectives and Goals

1. Review and discuss DPR issues for Colorado using the CO DPR White Paper
2. Identify short and long-term actions for DPR implementation in Colorado, including the recommendations provided in the CO DPR White Paper

8:30-9:00 - Registration and Breakfast (provided)

9:00-9:45 – Introductions and Opening Remarks – Cynthia Lane (AWWA)

- Colorado Water Conservation Board – Kevin Reidy
- WERF – Theresa Connor
- WRF – Frank Blaha
- WRCO – Dave Takeda

9:45-10:15 - CO DPR White Paper Overview – Phil Brandhuber (HDR)

10:15-10:30 - Break

10:30-12:00 – Technical Issues Related to DPR (Introductory presentation on each issue, followed by utility experiences, and group discussion) - John Rehring and Andy Salveson (Carollo)

- Discussion Topics
    - Treatment Technology
    - Brine Disposal
    - Utility Operations (utility operator qualifications and certifications)
    - Water Quality Monitoring
    - Updates to the white paper

12:00 – 1:00 – Lunch (provided)

12:25 – 12:30 – Overview of WRRF DPR Research – Julie Minton

12:30 – 1:00 – The Wichita Falls DPR Experience – Daniel Nix

1:00 - 2:30 - DPR Regulatory Issues

- Current Regulatory Frameworks
  - o Individual Project Basis
    - ▪ Marlo Berg (TCEQ)
    - ▪ Daniel Nix (Wichita Falls, TX)
  - o Statewide Regulations
    - ▪ Andy Salveson - Perspective on the New Mexico Approach
- DPR Framework for State (WEF/AWWA/WRRF/NWRI) – Jeff Mosher (NWRI)
- Colorado DPR Regulatory Approach – Ron Falco (CDPHE)

- Discussion Topics
  - o DPR Approach in Colorado
    - ▪ Would utilities implement DPR if there was a regulatory framework?
    - ▪ Could DPR be implemented in a severe drought situation in the future?
    - ▪ What lessons learned have been experienced in other areas that could apply to Colorado?
    - ▪ Updates to white paper

2:30-2:45 – Break

2:45-4:00 – DPR Public Perception Issues

- Introductory Presentations
    - ▪ The San Diego Experience and WRRF DPR Communication Toolbox – Patsy Tennyson

- Discussion Topics
  - o What concerns do we expect from the general public in Colorado?
  - o How will utilities need to engage public officials?
  - o Will individual utilities be responsible for all public outreach, or will there be a collaborative approach amongst utilities and possibly the state?
  - o Updates to white paper

4:00 – 4:30 – Recommendations and Wrap Up

- What are the next steps for DPR in Colorado?
- Did the discussions today identify issues that need immediate or short-term follow up?

APPENDIX B

WORKSHOP MINUTES

Meeting Minutes

Project:	CONSIDERING THE IMPLEMENTATION OF DIRECT POTABLE REUSE IN COLORADO
Subject:	Workshop Minutes
Date:	Wednesday, May 27, 2015
Location:	AWWA Lynn Laskey Center – 6666 West Quincy Avenue, Denver, CO 80235

1. Introductions and Opening Remarks

Colorado Water Conservation Board – Kevin Reidy
WERF – Theresa Connor
WRF – Frank Blaha
WRCO – Dave Takeda

2. CO DPR White Paper Overview

Presented by HDR – Phil Brandhuber, PhD
Reference PowerPoint presentation #1

A. Questions for Today's Workshop

1. Is DPR a viable water supply alternative for drinking water utilities in Colorado?
2. Is Colorado ready to implement DPR?
    a. Water quality/regulatory
    b. Technology/operations
    c. Public acceptance
3. What steps should CWCB take to facilitate the implementation of DPR?

B. Updated White Paper Conclusions/Recommendations

1. Conclusions made in paper prior to workshop
    a. DPR is technically feasible
    b. An extensive amount of research completed in the field
    c. Colorado should draw from experience in Texas, California, New Mexico, Arizona
2. Recommendations made in paper prior to workshop
    a. Develop roadmap for DPR in Colorado
    b. Survey utilities/water agencies to gauge level of interest in DPR
    c. Develop public education program
    d. Partner in projects
        i. To reduce the costs of RO concentrate disposal
        ii. Investigate non-RO based treatment trains
    e. Mature a regulatory environment for DPR

3. Technical Issues Related to DPR

Presented by Carollo - John Rehning, Andy Sulveson
Reference PowerPoint presentation #2

A. Treatment Technology

B. Brine Disposal

C. Utility Operations (utility operator qualifications and certifications)

D. Water Quality Monitoring

4. Presentation on Wichita Falls, OK

Presented by City of Wichita Falls – Daniel Nix
Reference PowerPoint presentation #3

Summary:

- Publically gained support of medical doctors and academic PhD's
- Created a professional educational video
- Some businesses in Wichita Falls were afraid of losing business
- Local shops now sell T-shirts poking fun at reuse project
- Wichita Falls made modifications at their WWTP to improve influent water quality to AWTP
- They add copper sulfate in their holding lagoon to kill algae
- They removed phosphate in clarifier with chloramines and ferric sulfate addition
- The WTP was previously a lime softening plant prior to DPR
- AWRP is a 10 MGD plant with 10 MG storage (24 hour storage)
- ~ 1 week for virus/microbial test results
- Implemented new SOPs to get WW and W operators to communicate
- UV at AWTP is tuned for cryptosporidium destruction to provide treatment redundancy

5. DPR Regulatory Issues

A. Current Regulatory Framework

a. Texas

Presented by TCEQ - Marlo Berg

Summary:

- The CA criteria of 10:10:12 removal is very expensive and the cost may not be justified
- Texas is permitting facilities on a case by case basis using the treated wastewater effluent quality as a starting point, rather than the raw WW quality approach taken by CA
- Reporting frequency and TCEQ visits need to be considered
- El Paso will use nano not RO
- DPR project a Big Spring, TX is permanent
- Can require control points but cannot require UCMR3 – includes some CECs (hormones) Wichita Falls reports that they are removed to the public

b. New Mexico

Presented by Carollo - Andy Sulveson

Reference PowerPoint presentation #4

Summary:

- o NMED, Cloudcroft, NM, 100,000 gpd capacity
- o AWTP is not yet in operation
- o The capitol cost was funded by NMED, but the community cannot pay to operate and maintain the facility. Additionally, there is a lack of operational staff that can effectively operate the plant.
- o A cost/capacity analysis will be done on small system in the future prior to giving money.
- o Note that removal credits for treatment are given if you coagulate and remove particles

c. Colorado

Presented by CDPHE – Ron Falco

Summary:

- o CDPHE currently has no permit mechanism to approve or reject a DPR project
- o CDPHE would likely focus on minimizing acute risk as a first priority, similar to TX
- o CDPHE does not have funding capacity to generate guidance
- o The service they can provide is in line with their level of authority for a requested service.
- o CDPHE recently updated their regulations and did not have any requests to address DPR.
- o No funding could probably get through on case by case but would be tough
- o Recently updated requirements and they had no requests for DPR consideration
- o CDPHE can not create new MCLs that are more strict than SDWA, but could potentially regulate surrogate parameters
- o “Mature” is not the right word in regard to CDPHE regulations in CO.
- o Mention residuals more broadly in paper.
- o In generating regulations or guidance, the following would need to be considered:
  - Where to sample
  - How frequent
  - How much for compliance?
  - A new data base would be needed to manage systems
  - New health language for new parameters would be needed to notify the public if a violation occurred
  - What would enforcement and penalties look like?
  - Public perceives that CDPHE is only working if they are enforcing against violations
  - There are many consequences to creating regulations. Creating regulations without all the considerations worked out, may provide a false sense of security.
    - Need to control public expectations
- o CDPHE could support, but not lead public outreach. They would be a voice at panel.
- o Guidance and policy would be more feasible than a regulation.
- o Assess willingness to fund a work group first – will people pay to generate this?
- o Consider taking a health advisory approach for unregulated contaminants instead of trying to determine new MCLs
- o Regulation 11could open door for policy changes; conditions can be assigned to permit approvals

- Regulation 84 is not a place to add DPR because it is fundamentally based on the Clean Water Act, anything regulating DPR would need to be fundamentally derived from Safe Drinking Water Act

6. DPR Public Perception Issues

Presented by Katz and Associates – Patricia Tennyson
Reference PowerPoint presentation #5

Summary:

- It is not the technology that stops a project – there is no project without high level support
- Some elected officials have previously asked, "Does the science work here?"
- Water is judged by its history
- Do not distinguish between DPR and IPR just PR
- IPR is more accepted than DPR
- Public attention span is 8 seconds now and was 12 sec in 2000
- What worked in Orange Co. did not work in San Diego
- Competing water supplies can derail a project
- You need leadership at all levels
- Define purpose/need
- Identify range of community interest in your community – in writing
- Outreach must be consistent
    - "Safe, Reliable Local Water Supply" was successful in San Diego
    - Increases water independence
- Advanced water purification tours in San Diego, CA
    - Women between 30-40 were most skeptical
- WERF 13-02 Provides Guidance for a Communication Plan
- Treatment sounds like a disease
    - "Purified water" and "advanced purification" terms were popular
- People were impressed by the names and photos of treatment equipment and that it is tested and regulated by health department and environmental benefits local.
- Water agency should be lead
- In educational material emphasize the urban water cycle
- Go to your audience, they will not likely come to the utility
- Utility needs to first demonstrate that they are trustworthy – make community aware of you
- Media or parties that are against the project can try to make something that is false become truth through repetition – watch out for this
- Can't just do one thing, have to market at all levels and in all mediums
- Perform an initial survey of the public before you begin a DPR/IPR campaign so you have a baseline of understanding and can measure progress
- You want to know what your community cares about
- Good to educate your public because then they are more likely to support
- Good for public to know where their water comes from and importance of diverse water supplies.
- Give public tours of your WTP and WWTPs
- Elected officials need lots of frequent updates so they know why it is good for the community
- Find advocates and use them
- Generate a reuse roadmap

7. Workshop Conclusions/Recommendations

1. Conclusions made following workshop
    a. DPR is technically feasible
    b. An extensive amount of research completed in the field
    c. Colorado should draw from experience in Texas, California, New Mexico, Arizona, North Carolina and Florida
2. Recommendations made in paper prior to workshop
    a. Develop roadmap for DPR in Colorado
    b. Survey utilities/water agencies to gauge level of interest in DPR
    c. Develop public education program before the immediate need for DPR need is present
    d. Partner in projects
        i. To reduce the costs of RO concentrate disposal
        ii. Investigate non-RO based treatment trains
    e. Develop guidance for DPR in CO
    f. Do not distinguish between DPR and IPR just PR
    g. Perform an initial survey of the public before you begin a DPR/IPR campaign so you have a baseline of understanding and can measure progress

8. Additional Presentations

WateReuse DPR Initiative Julie Minton
Reference PowerPoint presentation #6

Framework for Direct Potable Water Reuse – Jeff Mosher
Reference PowerPoint presentation #7

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July 2015

2015 Colorado Direct Potable Reuse Workshop

Colorado Direct Potable Reuse White Paper – An Overview

Phil Brandhuber PhD
Sarah Craig PE
Tim Thomure PE

HDR WERF

Presentation Agenda

- Introduction
- Water Quality/Regulation
- Technology/Operability
- Public Acceptance
- Conclusions
- Acknowledgements

Questions for Today's Workshop

- Is DPR a viable water supply alternative for drinking water utilities in Colorado?

- Is Colorado ready to implement DPR?
  - Water quality/regulatory
  - Technology/operations
  - Public acceptance

- What steps should CWCB take to facilitate the implementation of DPR as a water supply alternative?

White Paper Process

Draft White Paper

WERF
Project Subcommittee

Updated White Paper

Final White Paper

Recommendations to CWCB

Updated White Paper Conclusions/Recommendations

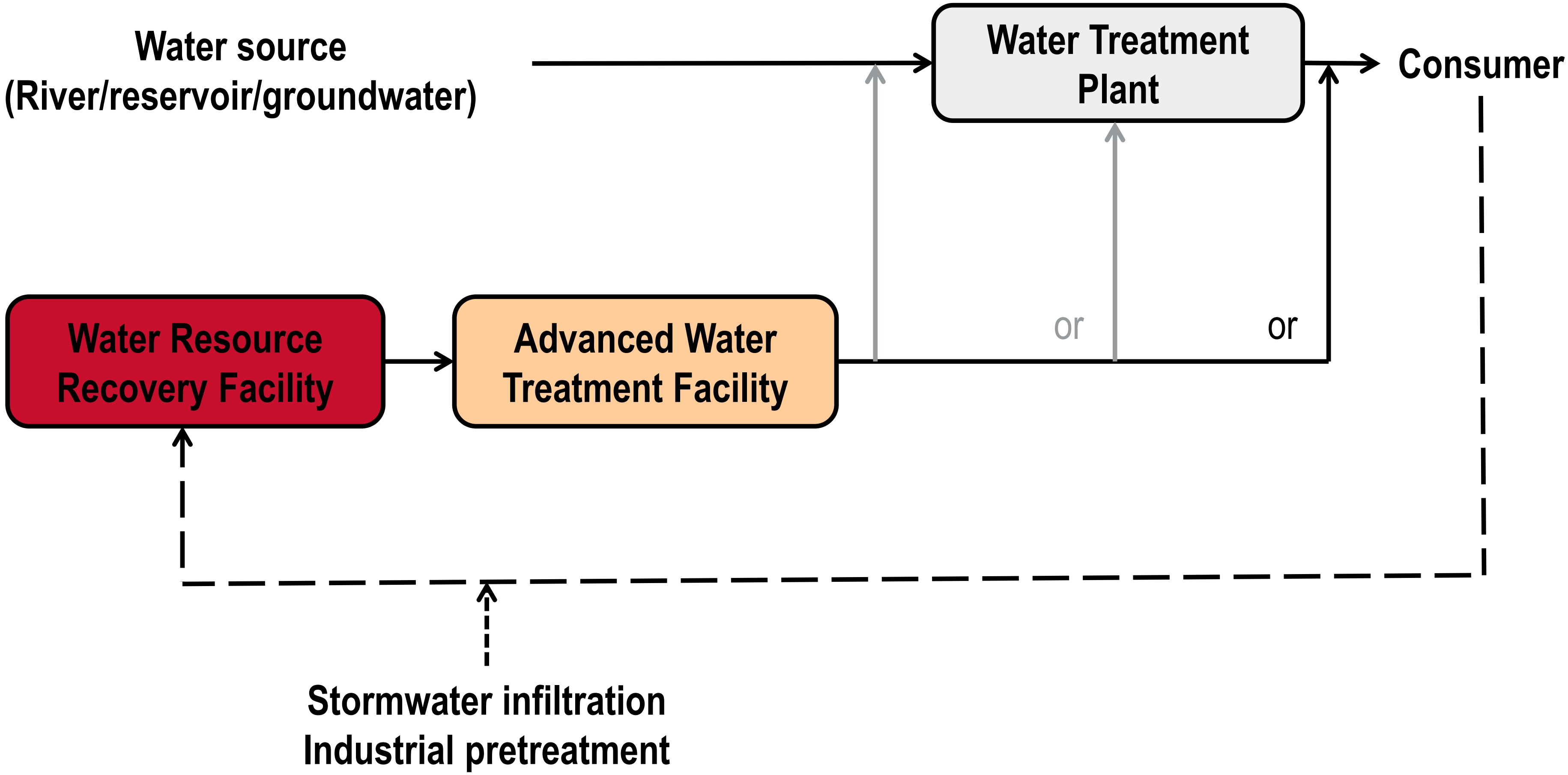
Conclusions

1. DPR technically feasible
2. Extensive amount of research completed
3. Experience in Texas, California, New Mexico, Arizona

Recommendations

1. Develop roadmap for DPR in Colorado
2. Survey utilities/water agencies to gauge level of interest in DPR
3. Develop public education program
4. Partner in projects
   a) Reducing the costs of RO concentrate disposal
   b) Investigating non-RO based treatment trains
5. Mature a regulatory environment for DPR

DPR Outlined



What's Different Compared to a Drinking Water Source?

- Known presence of pathogens in wastewater source
- Broader range of anthropogenic contaminants than in typical drinking water source
  - Presence of trace organics not currently regulated under SDWA
- Character of organic matter altered by wastewater treatment
  - Impact on formation of DBPs
- Formation of unregulated DPBs related to use of AOP

Protection from Pathogens is Critical

- SDWA acceptable risk of infection
  - 1:10,000 per capita (10^{-4} risk)

Protection from Pathogens is Critical

- SDWA acceptable risk of infection
  - 1:10,000 per capita (10^{-4} risk)
- Different approaches to setting log removal/inactivation requirements

	Uniform Standard		**Site Specific Standard**	
Pathogen	California	WRRF	Big Springs, TX	Wichita Falls, TX
Enteric Virus	≥ 12 log	≥ 12 log	≥ 8 log	≥ 9 log
Giardia	≥ 10 log	≥ 10 log	≥ 6 log	≥ 7 log
Cryptosporidium	≥ 10 log	≥ 10 log	≥ 5.5 log	≥ 5.5 log

WRRF Study as Comprehensive Regulatory Framework for Colorado?

Contaminant Group	Members	SDWA Requirement
Disinfection byproducts	• Total trihalomethanes (TTHM) • Haloacetic acids (HAA5) • Bromate • *N*-Nitrosodimethylamine (NDMA) • Chlorate	Same Same Same Not regulated Not regulated
Non-regulated chemicals of interest to public health	• Perfluorooctanoic acid (PFOA) • Perfluorooctanesulfonic acid (PFOS) • Perchlorate • 1,4-Dioxane	Not regulated Not regulated Not regulated Not regulated
Pharmaceuticals	• Cotinine • Primidone • Meprobanate • Atenolol • Carbamazepine	Not regulated Not regulated Not regulated Not regulated Not regulated
Steroidal hormones	• Ethinyl Estradiol • 17-β-Estradiol	Not regulated Not regulated
Recalcitrant chemicals Indictors of presence of wastewater	• Sucralose • Tris (2-Carboxyethyl) phosphine hydrochloride (TCEP) • *N*,*N*-Diethyl-*meta*-toluamide (DEET) • Triclosan	Not regulated Not regulated Not regulated Not regulated
Aesthetic	• Color • Odor • Total dissolved solids (TDS) • Total Organic Carbon (TOC) • Effluent organic matter (EfOM)	Not regulated Not regulated Not regulated Not regulated Not regulated

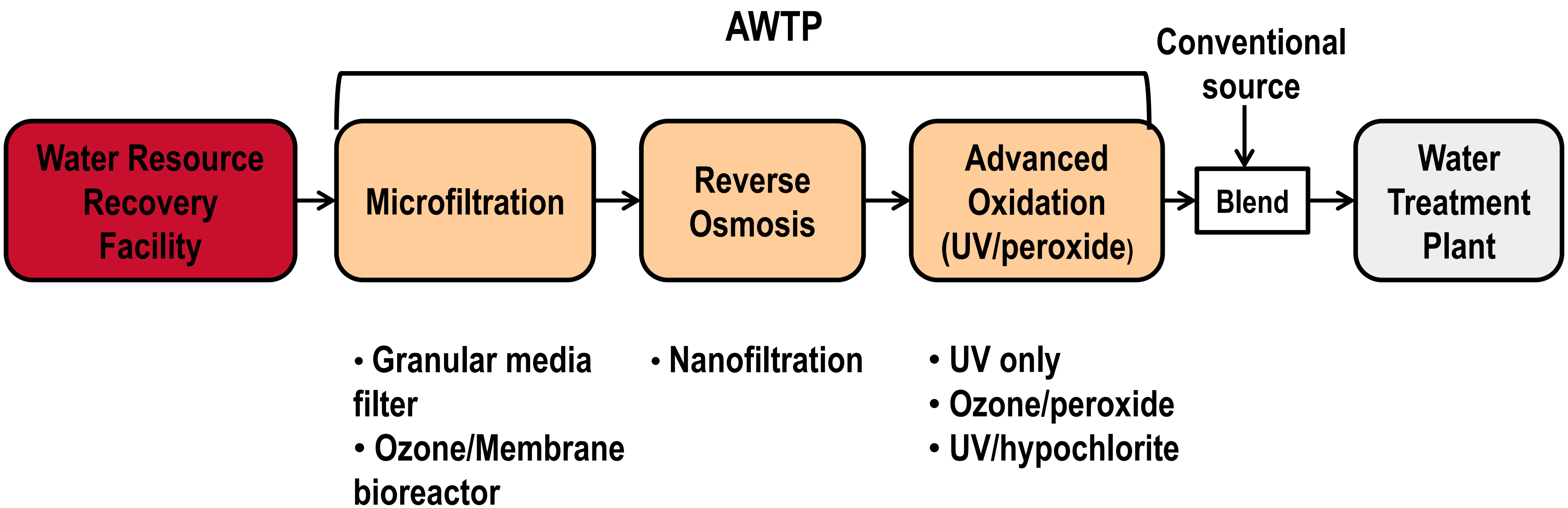
Discussion Topics

- Is having an ‘in place’ DPR regulatory framework a prerequisite for utilities to pursue DPR?

- Could DPR be implemented under a drought situation under existing regulatory framework?

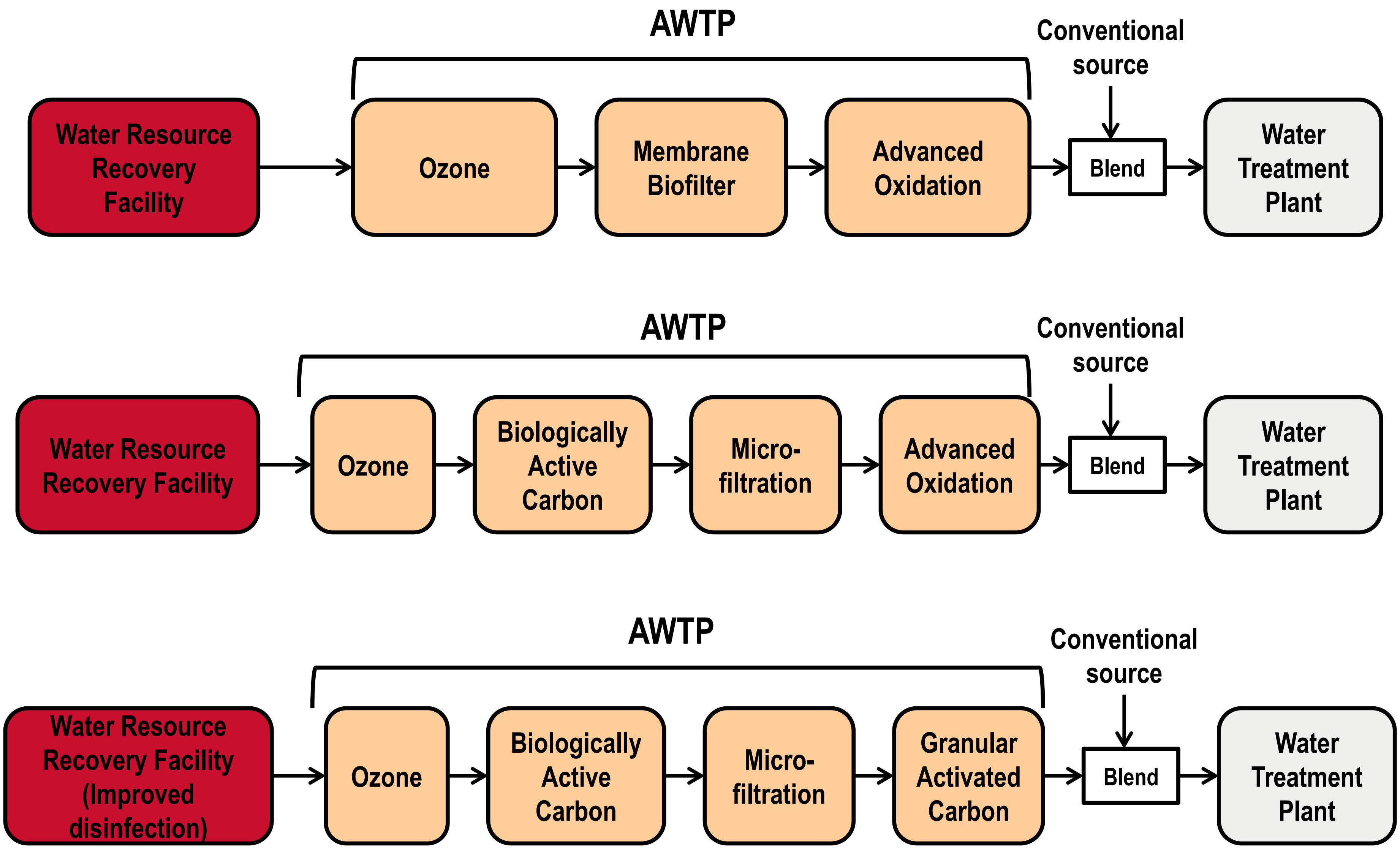
- What are the ‘lessons learned’ from Texas, New Mexico and California that can be applied to Colorado?

Advanced Water Treatment Plant: RO Based



Concentrate (brine) disposal from RO system is a significant cost challenge

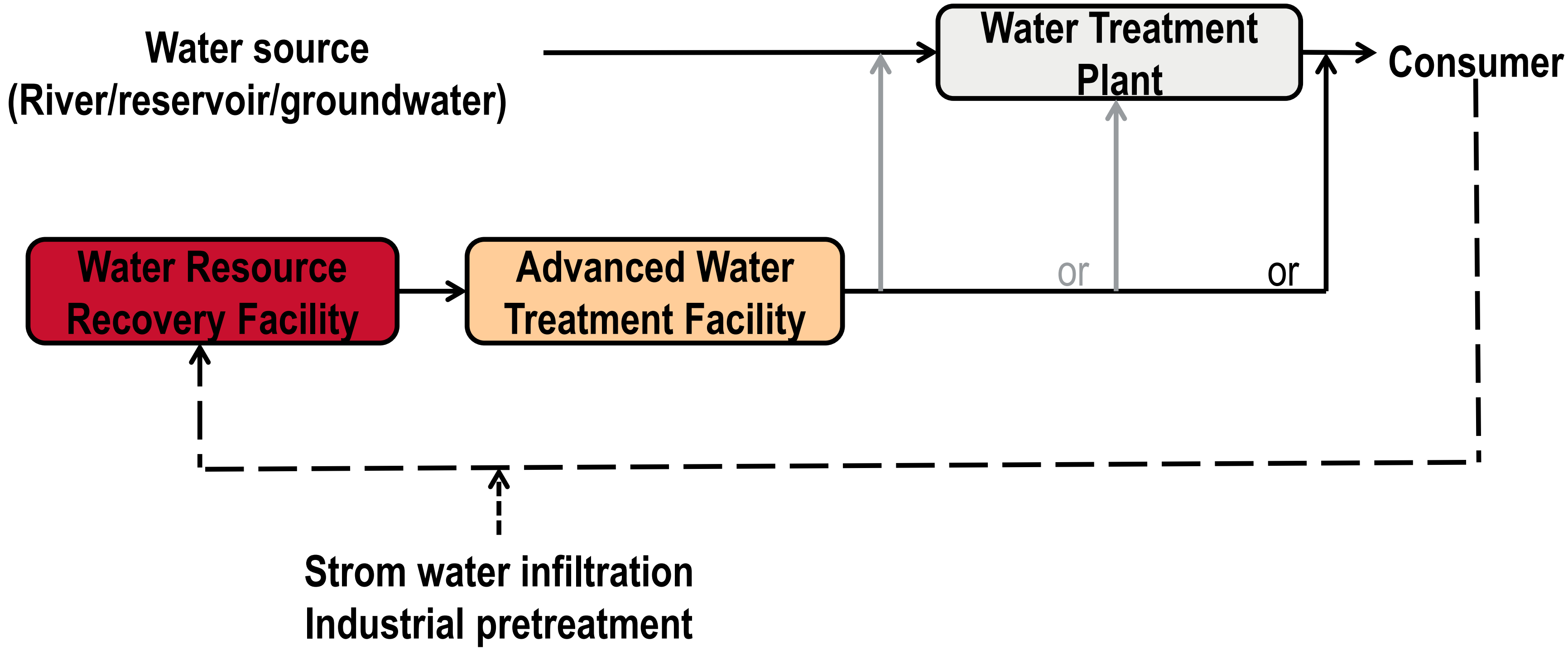
Advanced Water Treatment Plant: Non-RO



Discussion Topics

- Can public health be adequately protected when using a treatment train that does not include RO?

Operational Considerations



Characteristic

- Serial process
- Direct measurement of performance difficult
- Cannot serve off-spec product

Consideration

- Integrated operational oversight
- Consistent performance at each plant
- Monitor process integrity
- Response time to upsets and failures

AWTF Certification and Training Needs

MF

RO

AOP

Concentrate minimization

Deep well injection

Complex Technologies

- Training needs?
- Certification requirements?
- Operator availability?

Discussion Topics

- What features are required for a DPR system to operate with sufficient reliability to protect public health?
- Are there unique training and certification requirements for DPR?

Public Acceptance

A Perception Problem?

Acceptance by community

- Trust in utility
- Clear communications
- Emphasize benefits
- Engage trusted experts

Acceptance by public officials

- Measurable benefits
- Evidence of public support
- Not “big government”
- Environmental justice

Discussion Topics

- What concerns about DPR can be expected from general public?
- How should utilities engage public officials?
- Best approach for outreach?
  - Individual utilities
  - Collaborative effort

Updated White Paper Conclusions/Recommendations

Conclusions

1. DPR technically feasible
2. Extensive amount of research completed
3. Experience in Texas, California, New Mexico, Arizona

Recommendations

1. Develop roadmap for DPR in Colorado
2. Survey utilities/water agencies to gauge level of interest in DPR
3. Develop public education program
4. Partner in projects
    a) Reducing the costs of RO concentrate disposal
    b) Investigating non-RO based treatment trains
5. Mature a regulatory environment for DPR

Acknowledgements

Water Environment Research Foundation

- Program Director:
  - Theresa Connor
- Project Subcommittee:
  - Laura Belanger
  - Ron Falco
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  - Tyson Ingels
  - Sean Lieske
  - John Rehring

Water Research Foundation

- John Whitler

WateReuse Colorado

- Dave Takeda

National Water Research Institute

- Jeff Mosher

Technical Issues Related to DPR

Andy Salveson, P.E.

John Rehring, P.E.

carollo
Engineers...Working Wonders With Water®

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Technical Issues: Discussion Topics

Treatment Technology :25

Brine Disposal :15

Utility Operations :15

Water Quality Monitoring :20

White Paper Updates :15

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Direct Potable Reuse Success Depends Upon Many Factors

- Source Control Programs
- Wastewater Treatment
- Advanced Water Treatment
- Purified and Finished Water Management
- Process Monitoring and Control
- Residuals Management
- Facility Operation
- Public Outreach

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Direct Potable Reuse Success Depends Upon Many Factors

- Source Control Programs
- **Wastewater Treatment**
- **Advanced Water Treatment**
- Purified and Finished Water Management
- **Process Monitoring and Control**
- Residuals Management
- Facility Operation
- Public Outreach

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Secondary Treatment must be viewed as an integral component of a potable reuse treatment train

- Pathogen Concentrations
- Water Quality
- Process Capacity

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Higher SRT with Better Solids Capture Means Less Pollutants

Faster transformation during secondary treatment →

↓ Higher sorption during secondary treatment

		Biotransformation (K_b, L/g-d)		
		Recalcitrant <0.1	**Moderate Slow 0.1-10**	**Rapid >10**
Sorption (log K_d)	**Low <2.5**	Carbamazepine Meprobamate Primidone TCEP Sucralose	DEET Sulfamethoxazole Gemfibrozil Iopromide	Acetaminophen Caffeine Naproxen Ibuprofen Atenolol
Sorption (log K_d)	**Sorptive 2.5-3**	TCPP	Cimetidine Trimethoprim	Benzophenone Diphenhydramine Bisphenol A
Sorption (log K_d)	**Effective >3**	Triclocarban		Triclosan Fluoxetine

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The Level of Treatment Necessary to Protect Public Health is Defined

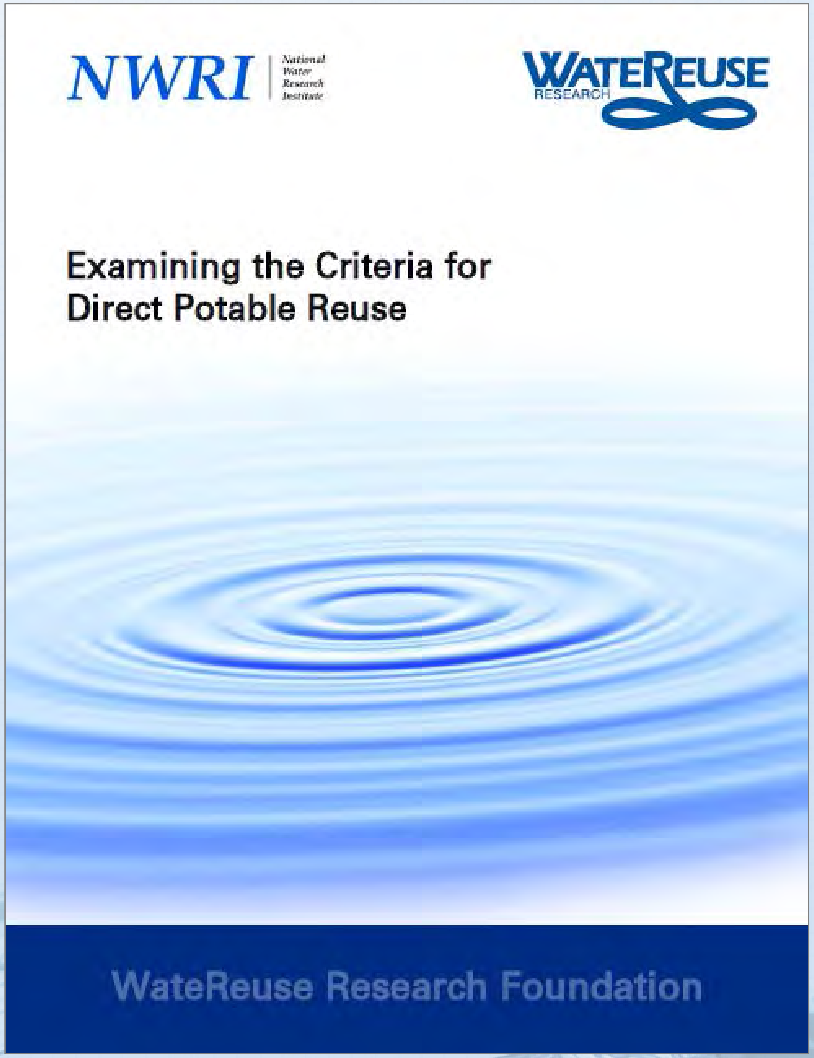
DBPs	Criterion
THMs	80 µg/L
HAA5	60 µg/L
NDMA	10 ng/L
Bromate	10 µg/L
Chlorate	800 µg/L

Chemicals Relevant to Public Health	Criterion/ If Applicable
PFOA	0.4 µg/L
PFOS	0.2 µg/L
Perchlorate	15 µg/L 6 µg/L
1,4-Dioxane	1 µg/L

Pharmaceuticals	Criterion[a]/If Applicable
Cotinine/Primidone/ Phenyltoin	1/10/2 µg/L
Meprobamate/Atenolol	200/4 µg/L
Carbamazepine	10 µg/L
Estrone	320 ng/L

Steroid Hormones	Criterion/ If Applicable
Ethinyl Estradiol	None, but if established, it will approach detection limit (low ng/L).
17-β-Estradiol	None, but if established, it will approach detection limit (low ng/L).

Other Chemicals	
Sucralose	150 mg/L[c]
TCEP	5 µg/L
DEET	200 µg/L
Triclosan	2,100 µg/L



Pathogen Goals: 12/10/9 "Virus/Protozoa/Bacteria"

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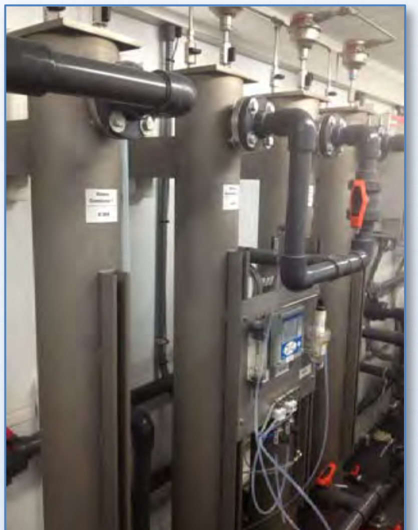
The Ability of Advanced Treatment Trains to Produce High Quality Water Has Been Demonstrated



WRRF 11-02 & Others

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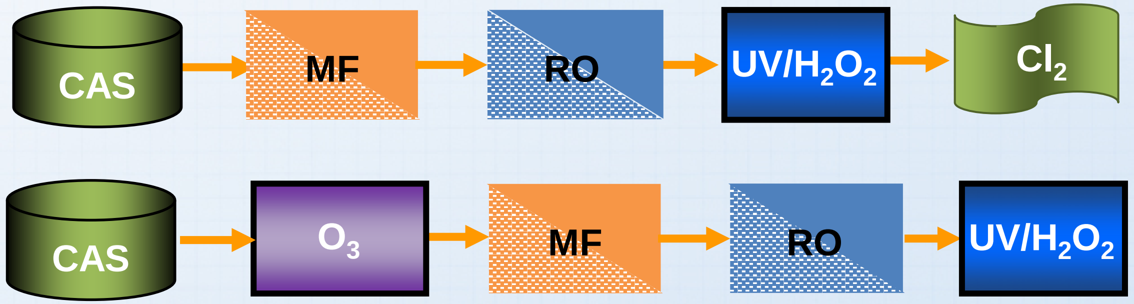
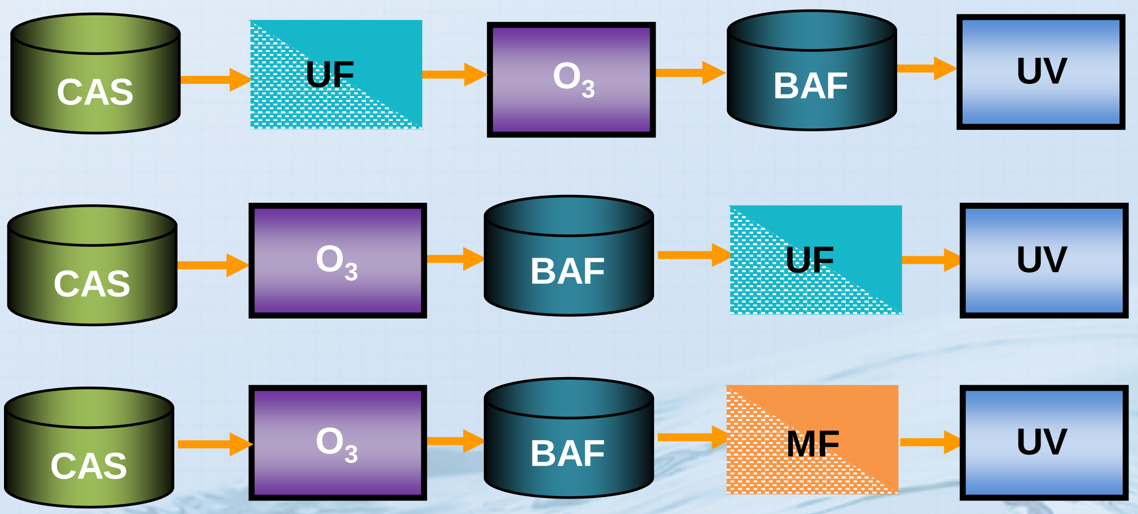
The Ability of Advanced Treatment Trains to Produce High Quality Water Has Been Demonstrated

- RO:



- O3/BAF:



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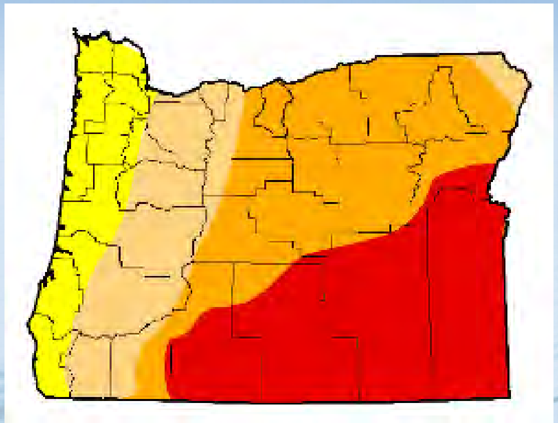
Clean Water Services Oregon



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Pilot Scale Treatment Train Using the State of the Art Treatment Technologies

Ultrafiltration

Reverse Osmosis

UV/H_2O_2 Advanced Oxidation

- Evoqua (Siemens) – Let us borrow UF and RO units
- Trojan – UV AOP

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Demonstration Testing Also Baselines Surrogate Performance Parameters

Process	Target	Demonstration	Surrogate
UF	Pathogens	Virus reduction	Particle reduction Turbidity
RO	Pathogens CECs	Virus reduction	Electrical conductivity (EC) reduction Total organic carbon (TOC) reduction
AOP	Pathogens CECs	UV Dose	NDMA Reduction
Whole System		Finished Water Quality	Finished Water Quality

Pathogen Log Removal Performance

	UF	RO	AOP	Total	Proposed Standard
Virus	4.7	4.3	6	**15**	**12**
Protozoa	4.7	4.3	6	**15**	**10**
Bacteria	4.7	4.3	6	**15**	**9**

Exceeds proposed pathogen reduction standards

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CEC* Removal Performance

DBPs	Criterion	Result
THMs	80 ug/L	ND
HAA5		
NDMA		
Bromate		
Chlorate		

Pharmaceuticals	Criterion	Result
Cotine	1 ug/L	ND
Primidone		
Meprobama		
Atenolol		
Carbamaze		
Estrone		

Chemicals Relevant to Public Health	Criterion	Result
PFOA	0.4 ug/L	ND
PFOS	0.2 ug/L	ND
Perchlor		
1,4-Diox		

Steriodal Hormones	Criterion	Result
Ethinyl Estradiol		ND
17-β-Estrad		

Other Chemicals	Criterion	Result
Sucralose	150 mg/L	ND
TCEP	5 ug/L	ND
DEET	200 ug/L	ND
Triclosan	2,100 ug/L	ND

+ Meets all drinking water standards

* CEC – compound of emerging concern

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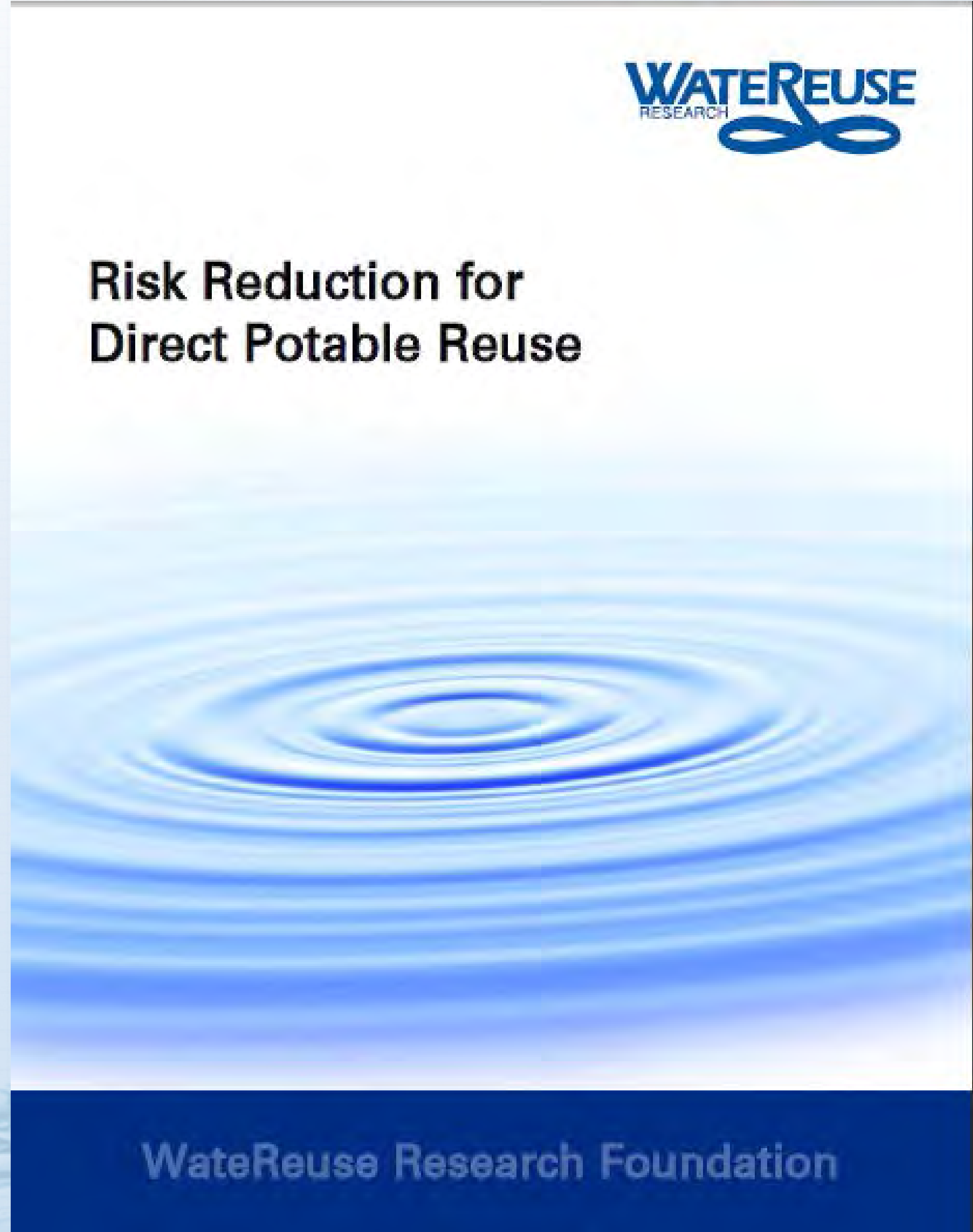
WRRF 11-10 is the first step into how to safely implement DPR



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Uncoupling Treatment Performance is the Key Engineering Challenge

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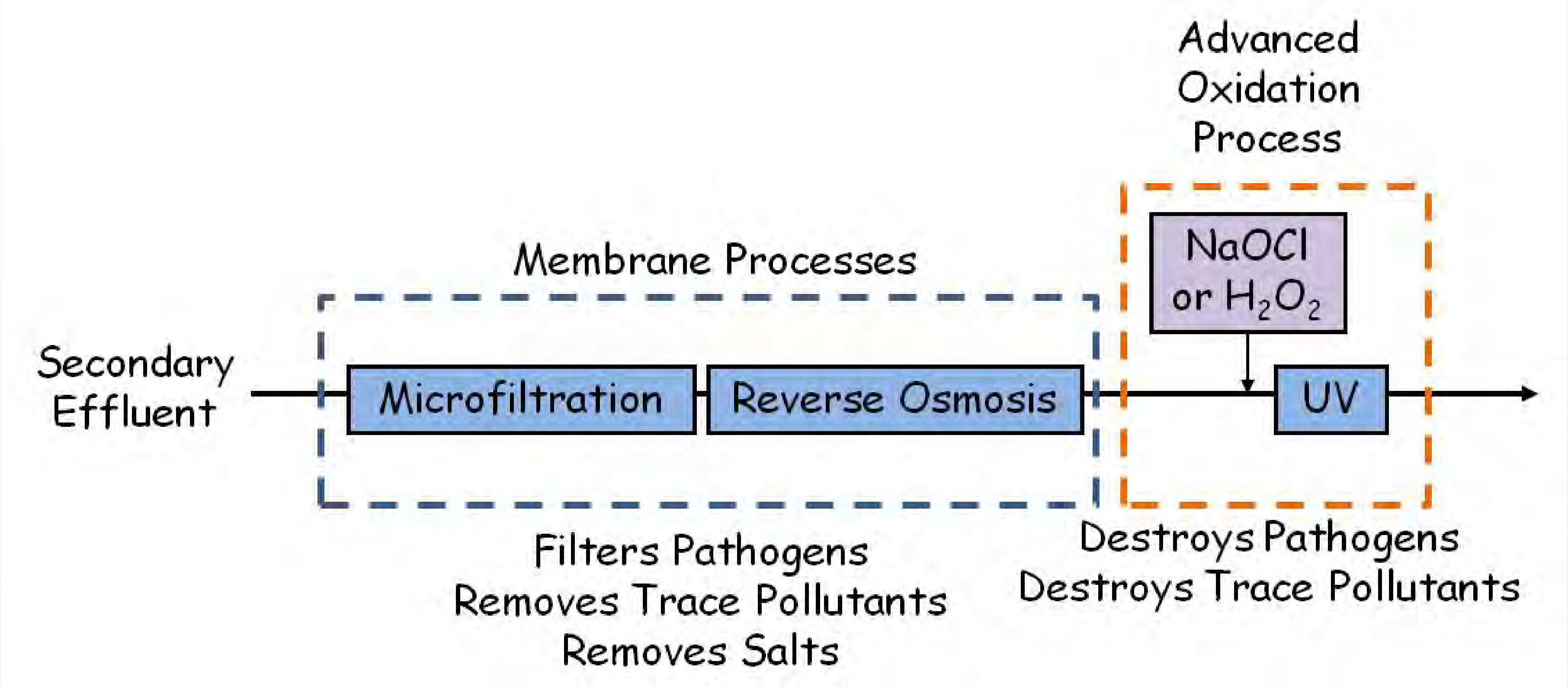
Uncoupling Treatment Performance is the Key Engineering Challenge



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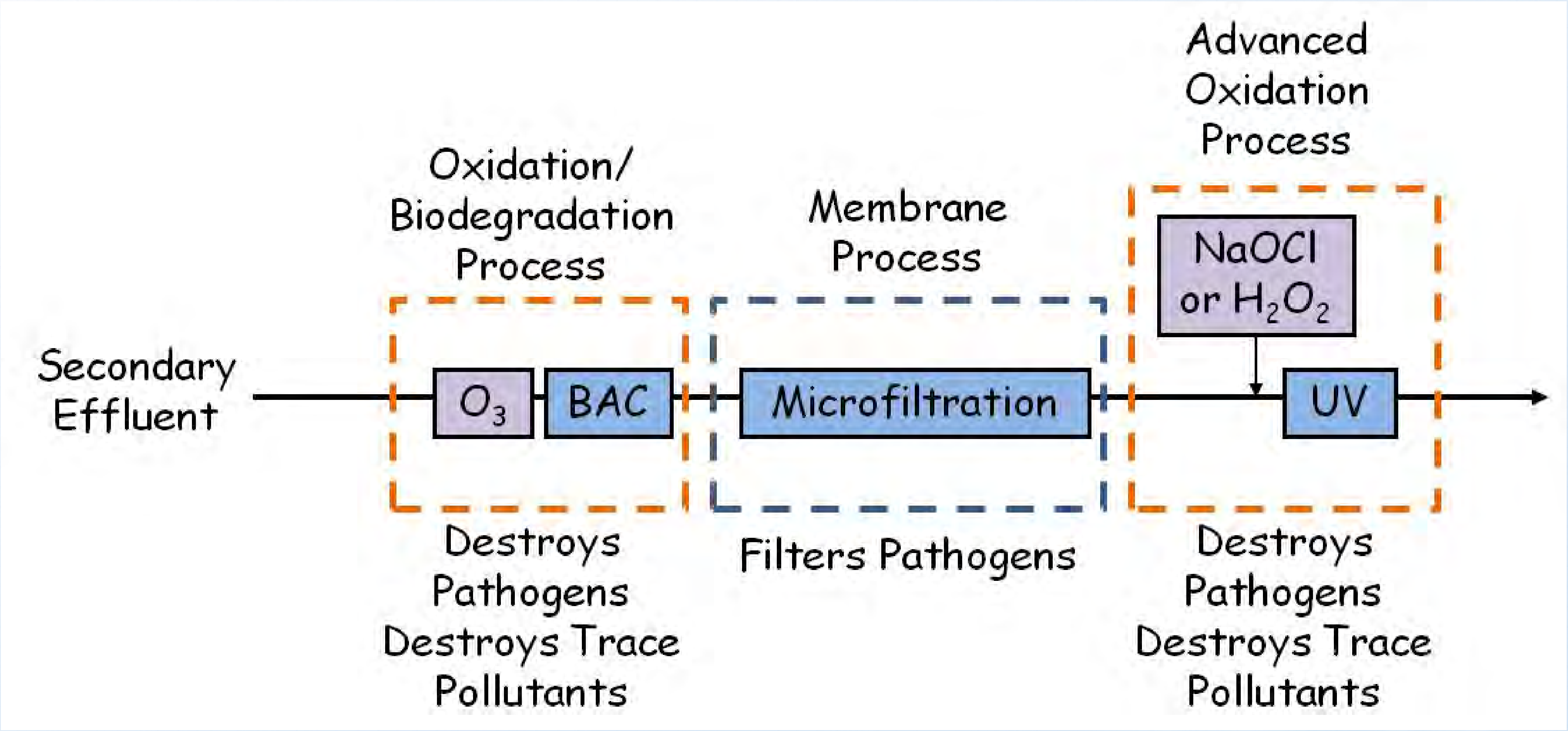
Uncoupling Treatment Performance is the Key Engineering Challenge



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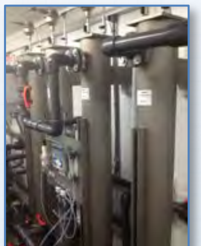
Uncoupling Treatment Performance is the Key Engineering Challenge



VERSUS

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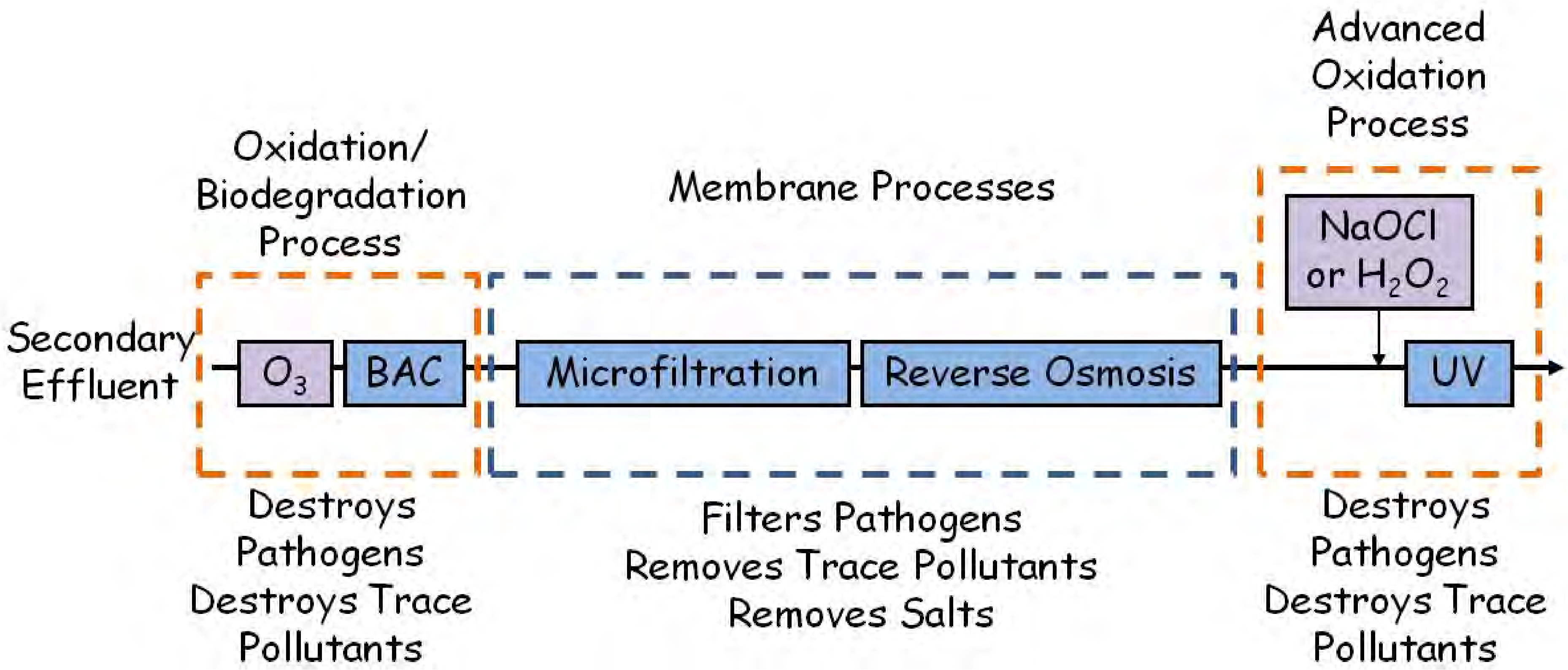
Additional Barriers Allow Complete Processes Failure Without Water Quality Failure



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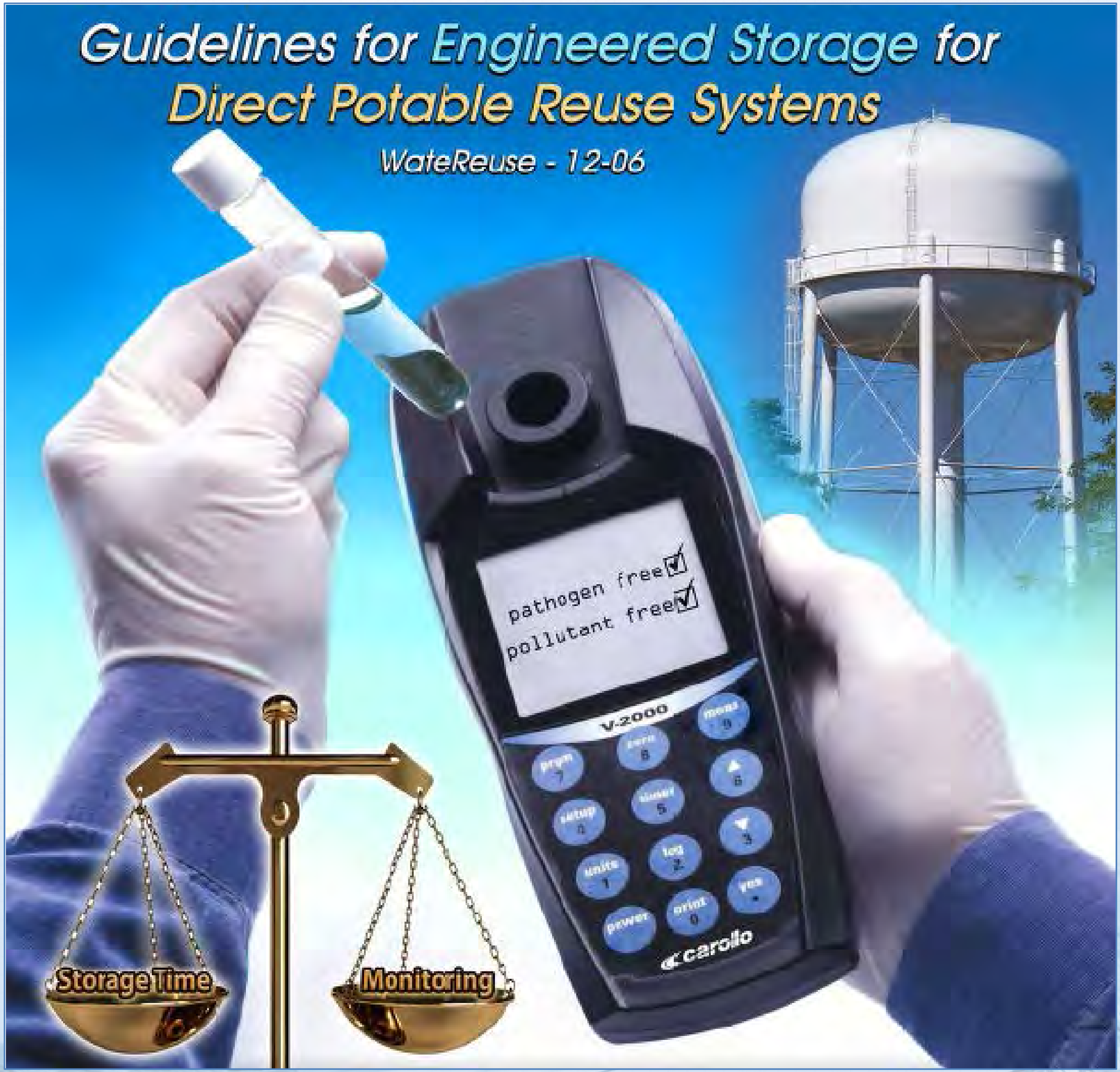
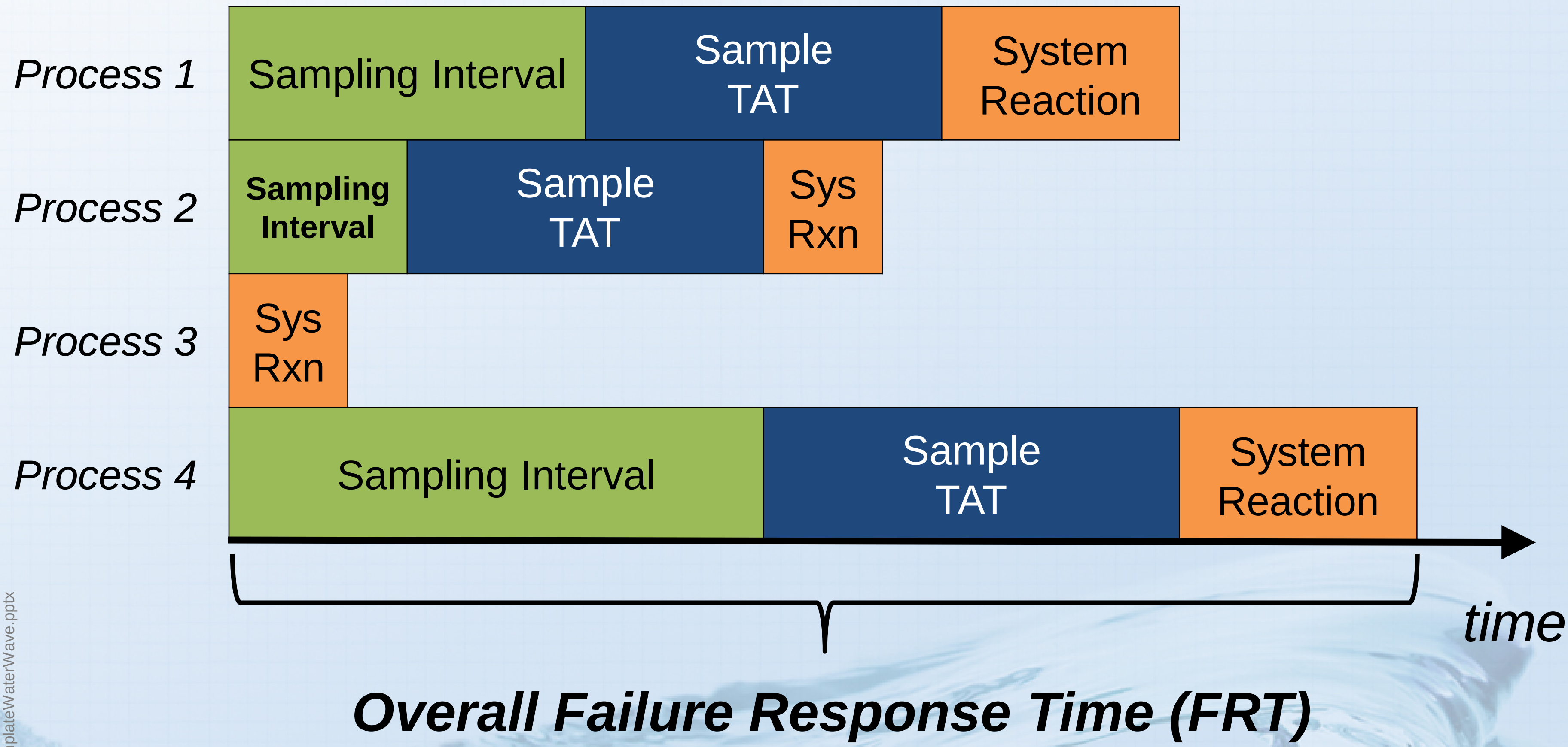

Guidelines for Engineered Storage for
Direct Potable Reuse Systems
WateReuse - 12-06
pathogen free
pollutant free
V-2000
carollo
Storage Time
Monitoring

Engineered Storage Time Based Upon Failure and Response Time



Treatment Technology: Utility Experience and Discussion

- What will we know in 5 years that we don't know now?
- What were the takeaways from the Denver Water 1980s potable reuse demonstration? Are they still applicable today?
- How can we manage salinity if we don't use NF/RO?
- How will ongoing research address the challenges we see today?
- What additional research is needed?

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Brine Disposal

Approach to Brine Management

1

Minimize generation

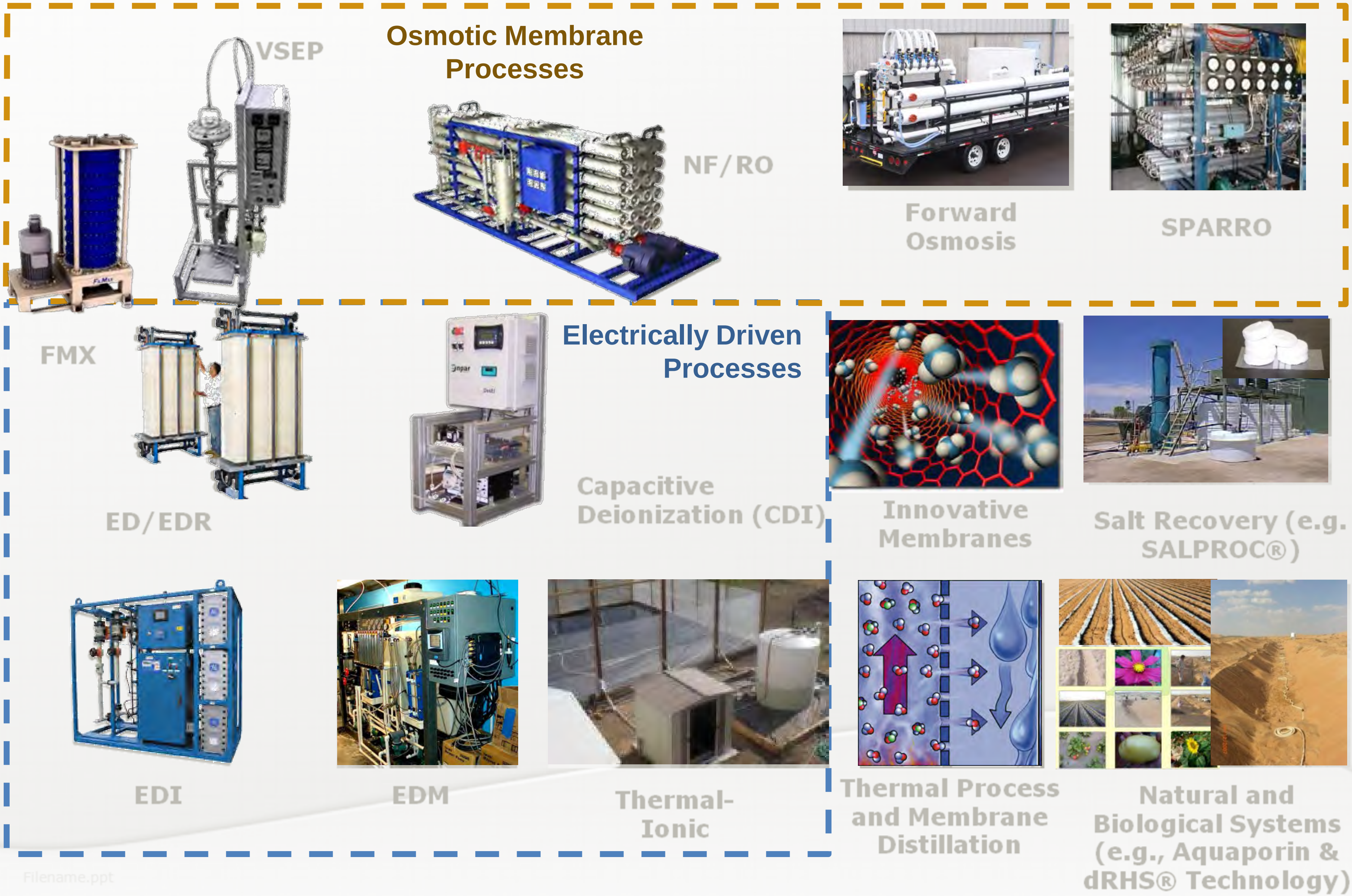
2

Cost-effective disposal

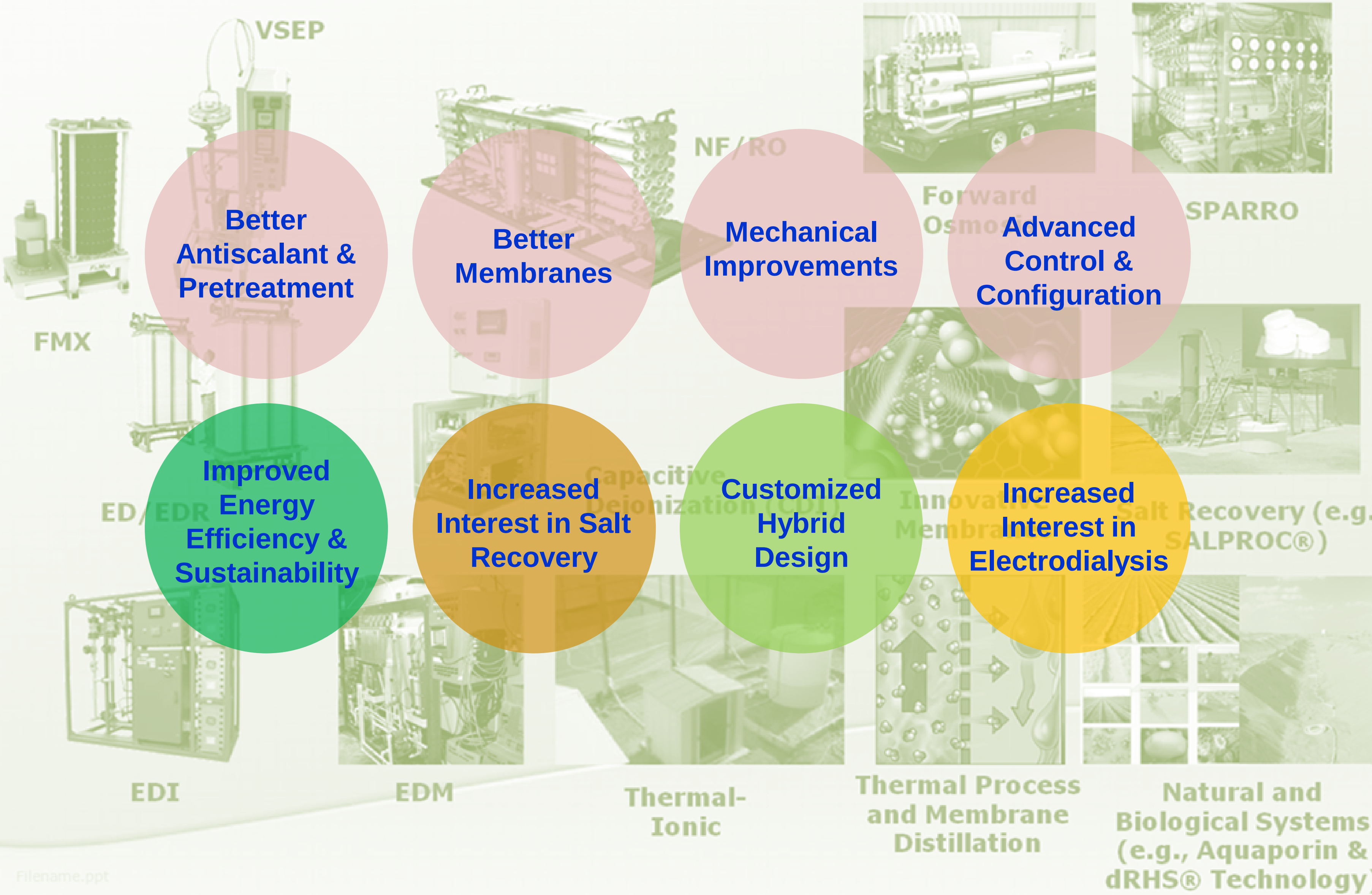
Concentrate Technologies Can Be Categorized into Several Groups

CarolloTemplateWaterWave.pptx

Concentrate Technologies Can Be Categorized into Several Groups



Several Industry Trends Are Evident



- Better Antiscalant & Pretreatment
- Better Membranes
- Mechanical Improvements
- Advanced Control & Configuration
- Improved Energy Efficiency & Sustainability
- Increased Interest in Salt Recovery
- Customized Hybrid Design
- Increased Interest in Electrodialysis

Research Efforts are Seeking Energy-Efficient and Cost-Effective Solutions for Brine Minimization and Disposal

Salinity & Brine Management

Project Number	Project Title	P.I. & Affiliation	Publication Date
WRRF-01-005	Characterizing Salinity in Sewer Contributions in Sewer Collection and Reclaimed Water Distribution Systems (AwwaRF Project)	Ken Thompson, CH2M Hill	May-06
WRRF-02-006b	Beneficial and Non-Traditional uses of Concentrate	Jim Jordahl, CH2M Hill	Sep-06
WRRF-02-006d	Regional Solutions for Concentrate Management	Erin Mackey, Carollo Engineers	Aug-08
WRRF-03-012	Salt Management Guide (TC with Central Basin WMD)	Jennifer Bender, Central Basin MWD	Aug-08
WRRF-06-010e	Development of Selective Recovery Methods for Desalination Concentrate Salts	Kerry Howe, University of New Mexico	Sep-13
WRRF-07-02	Development of a Knowledge Base on Concentrate and Salt Management Practices	Mike Mickley, Mickley & Associates	Feb-13
WRRF-09-12	Continuous Flow Seawater RO System for Recovery of Silica Saturated RO Concentrate	John Balliew, Mike Fahy EPWU	Jun-13
WRRF-10-09	Guidance for Selection of Salt, Metal, Radionuclide, and other Valuable Metal Recovery Strategies	Chris Bellona, Clarkson University	Expected Jun-15
WRRF-11-09	Desalination Concentrate Management Policy Analysis for the Arid West	Ed Archuleta, El Paso Water Utitilies	Expected May-15
WRRF-12-10	Demonstrating an Innovative Combination of Ion Exchange Pretreatment and Electrodialysis Reversal for Reclaimed Water RO Concentrate Minimization	Charlie He, Carollo	Feb-14
WRRF-13-07	Database of Permitting Practices for Seawater Concentrate Disposal	Mike Mickley, Mickley & Associates	Expected Mar-16

Studies Define Options and Approaches

Examples of Nontraditional Uses
Oil Well Field Injection
Solar Ponds
Land Application/Irrigation
Aquaculture
Wetland Creation/Restoration
Constructed Wetland Treatment
Salt Separation

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Brine Disposal Options in Colorado

[No ocean]

Stream discharge

Deep well injection

Drying beds /
thermal drying

Sanitary sewer

Land Application

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Brine Minimization and Disposal: Discussion

- What did we learn from the WERF/CWCB Colorado Brine Minimization Study?
- Is there a limit to the recovery we can get with RO?
- What are the most feasible disposal options? Why?
- What would make discharge more feasible?
- What has national research found?
- What additional research is needed?

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Utility Operations: Colorado Certification for Water and Wastewater Operators

Class D
- No direct experience
- Pass exam

Class C
- 2 years experience or equivalent
- Pass exam

Class B
- 3 years experience or equivalent
- Pass exam

Class A
- 4 years experience or equivalent
- Pass exam

WTP: Surface water >10 mgd, Filtration >2 mgd

WWTP: >4 mgd Trickling Filter and “above”

Utility Operations:
Ongoing Research to Define Frameworks

WRRF 13-13

- Standard O&M plan for DPR treatment processes (secondary through advanced treatment)
- DPR training and certification framework

Defined knowledge gaps

1. *Membranes*
2. *Advanced Oxidation*
3. *Critical Control Point Monitoring*
4. *Potable Reuse Risk*

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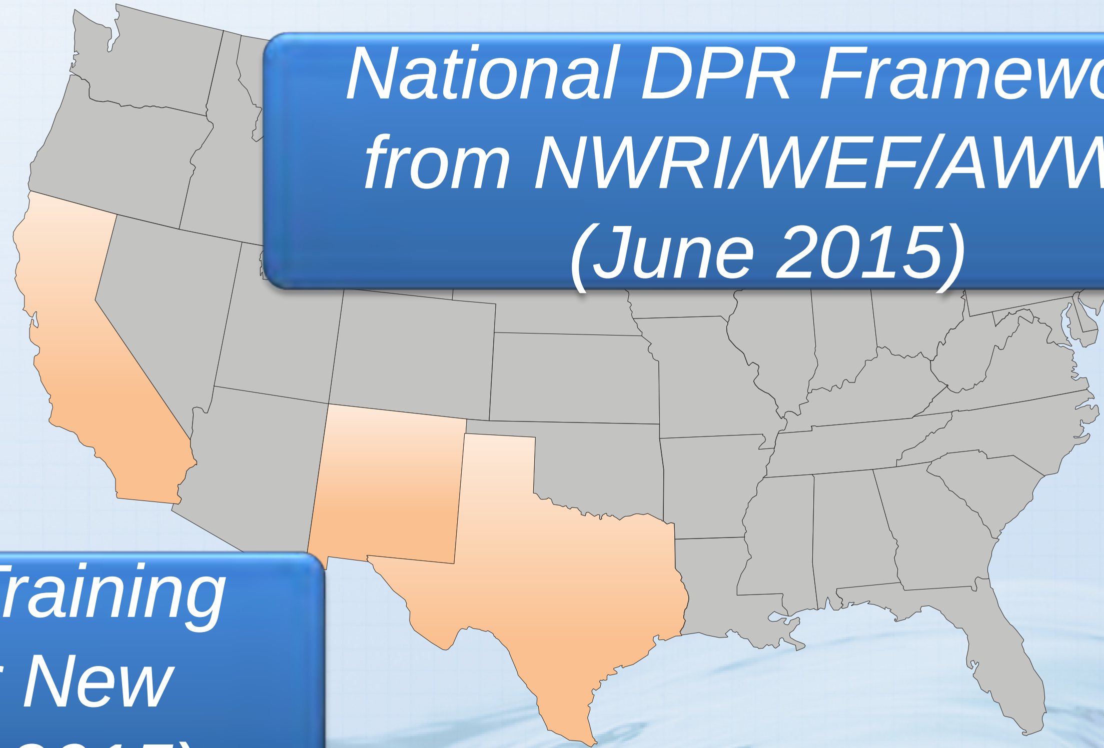
Utility Operations: Experiences from DPR Project in Operation or Under Development



National DPR Framework from NWRI/WEF/AWWA (June 2015)

Operational Training Manuals for New Mexico (Fall 2015)

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Utility Operations: Discussion

- Should there be a separate certification for potable reuse operators? Why? If not, is DPR "water" or "wastewater"?
- Can (and how can) guidelines or standard operating procedures be shared between facilities?
- What credentials or training would make an operator qualified to run a DPR system?
- What is the role of engineers in an operating DPR facility? – **Operations, Maintenance, Monitoring, and Regulatory Understanding All Key.**
- What are some best practices when the WW utility is a different entity than the Water utility?

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Critical Control Point Monitoring is Key to Water Quality Confidence

Precision & ~~Accuracy~~

Conservatism

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Award Treatment Credits Based Upon Conservative and Precise Measurements

	Standard	"Advanced"
1. Process	Microfiltration	
2. Pathogen	Protozoa (*Cryptosporidium*)	
3. Monitoring Approach	Pressure Decay	???
Log Removal Credit	4-log protozoa	
Monitoring Interval	**24 hours**	**???**
Sample TAT	minutes	**???**
Response time (valve & pumps)	minutes	**???**
Failure Response Time	**24+ hours**	**???**

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Award Treatment Credits Based Upon Conservative and Precise Measurements

	Standard	"Advanced"
1. Process	Reverse Osmosis	
2. Pathogen	Virus/Protozoa	
3. Monitoring Approach	EC monitoring	Trasar®
Log Removal Credit	**< 2-log**	**4 to 6-log**
Monitoring Interval	instant	instant
Sample TAT	instant	instant
Response time (valve & pumps)	minutes	minutes
Failure Response Time	minutes	minutes

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Critical Control Point Monitoring is Key to Water Quality Confidence

Process	Critical Control Points
Primary and secondary treatment	**No currently defined CCP.** WRRF Project 14-02 & 14-16 may address this issue through correlations of pathogens to indicator bacteria concentrations.
MF	
RO	
UV AOP	
Engineered storage buffer	

Critical Control Point Monitoring is Key to Water Quality Confidence

Process	Critical Control Points
Primary and secondary treatment	
MF	**Daily Pressure Decay Testing**. Typical values <0.3 psi/min to demonstrate membrane integrity
RO	
UV AOP	
Engineered storage buffer	

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Critical Control Point Monitoring is Key to Water Quality Confidence

Process	Critical Control Points
Primary and secondary treatment	
MF	
RO	**Online EC or Online TOC.** Log removal of EC or TOC across the RO process to demonstrates a minimum level of pathogen removal.
UV AOP	
Engineered storage buffer	

CarolloTemplateWaterWave.pptx

Critical Control Point Monitoring is Key to Water Quality Confidence

Process	Critical Control Points
Primary and secondary treatment	
MF	
RO	
UV AOP	**Intensity sensors.** Following U.S. EPA (2006) or other methods, online intensity monitoring demonstrates disinfection dose delivery.
Engineered storage buffer	

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Critical Control Point Monitoring is Key to Water Quality Confidence

Process	Critical Control Points
Primary and secondary treatment	
MF	
RO	
UV AOP	
Engineered storage buffer	**Online Cl_2.** Online residual to document CT value and disinfection in accordance with U.S. EPA (1990).

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MF	**Daily Pressure Decay Testing**. Typical values <0.3 psi/min to demonstrate membrane integrity
RO	**Online EC or Online TOC.** Log removal of EC or TOC across the RO process to demonstrates a minimum level of pathogen removal.
UV AOP	**Intensity sensors.** Following U.S. EPA (2006) or other methods, online intensity monitoring demonstrates disinfection dose delivery.
Engineered storage buffer	**Online Cl_2.** Online residual to document CT value and disinfection in accordance with U.S. EPA (1990).

Don't Forget About SCADA!

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Water Quality Monitoring: Discussion

- What is the right balance between treatment redundancy and monitoring?
- How robust are today's technologies?
  Are they robust enough to rely on?
- How does IPR process monitoring differ from DPR monitoring?
- Are drinking water monitoring approaches applicable to DPR?

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White Paper Updates: Discussion

- Based on our discussions, what changes should be made to the draft White Paper?


WERF5T10b

CONSIDERING THE IMPLEMENTATION OF DIRECT POTABLE REUSE IN COLORADO

DRAFT

by:
Philip Brandhuber, PhD
Sarah Craig, PE
Timothy Thomure, PE
HDR

2015

WERF

Treatment Technology

Brine Disposal

Utility Operations

Water Quality Monitoring

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City of Wichita Falls Emergency Direct Potable Reuse

RESPONDING TO THE
2011 – 2014 DROUGHT

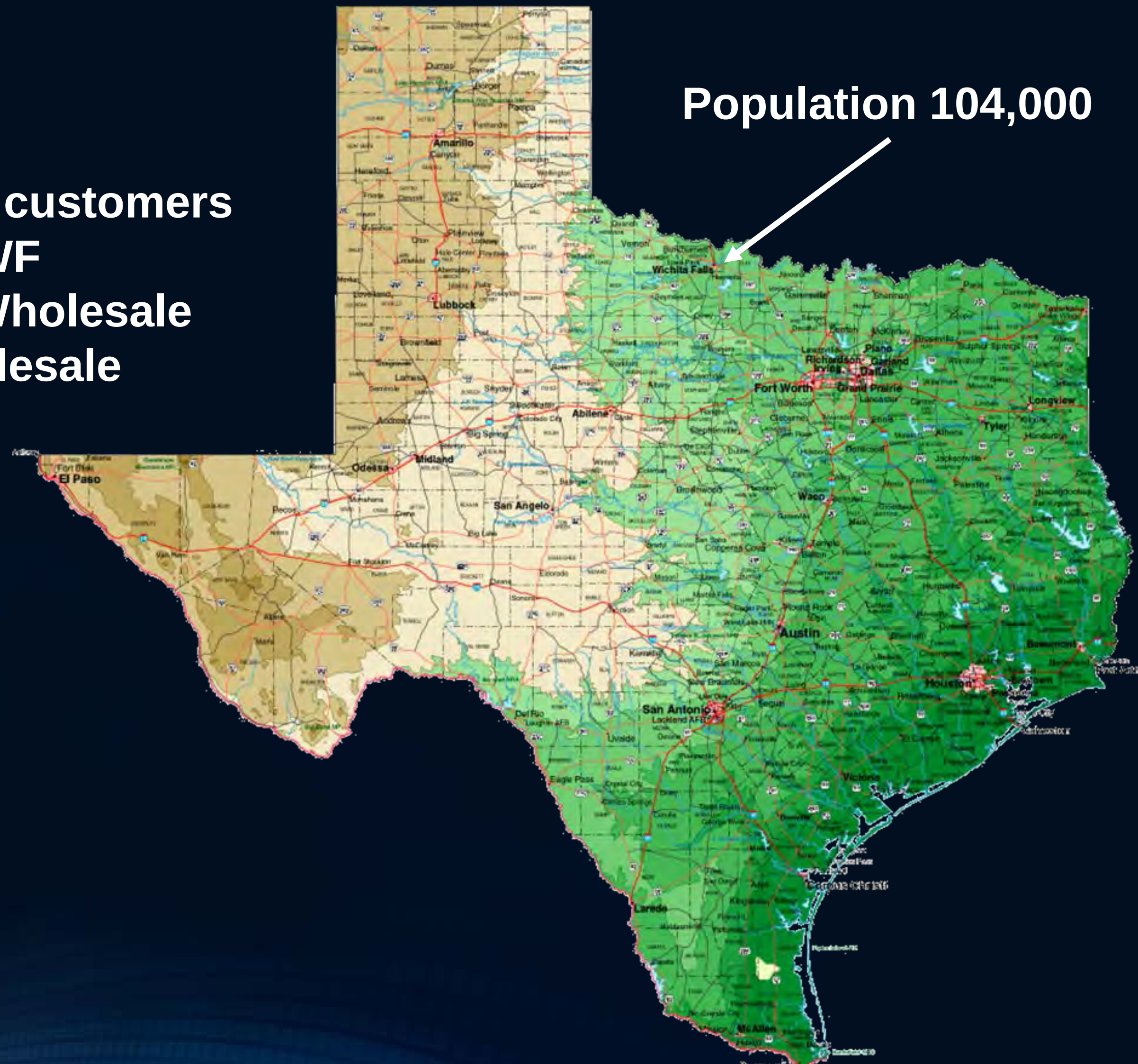
Wichita Falls

Overview

Serves Total 150,000 customers

- **104,000 City of WF**
- **36,000 Potable Wholesale**
- **10,000 Raw Wholesale**

Population 104,000



The Last Drought (late 90's)

Lessons Learned

- City constructed Reverse Osmosis Plant.
- Activated Lake Kemp Source.
- Raised the drought restriction triggers by 10%, to start conserving sooner.
- Began investigating the potential of Wastewater Reuse.

The Current Problem

Loss of Rainfall

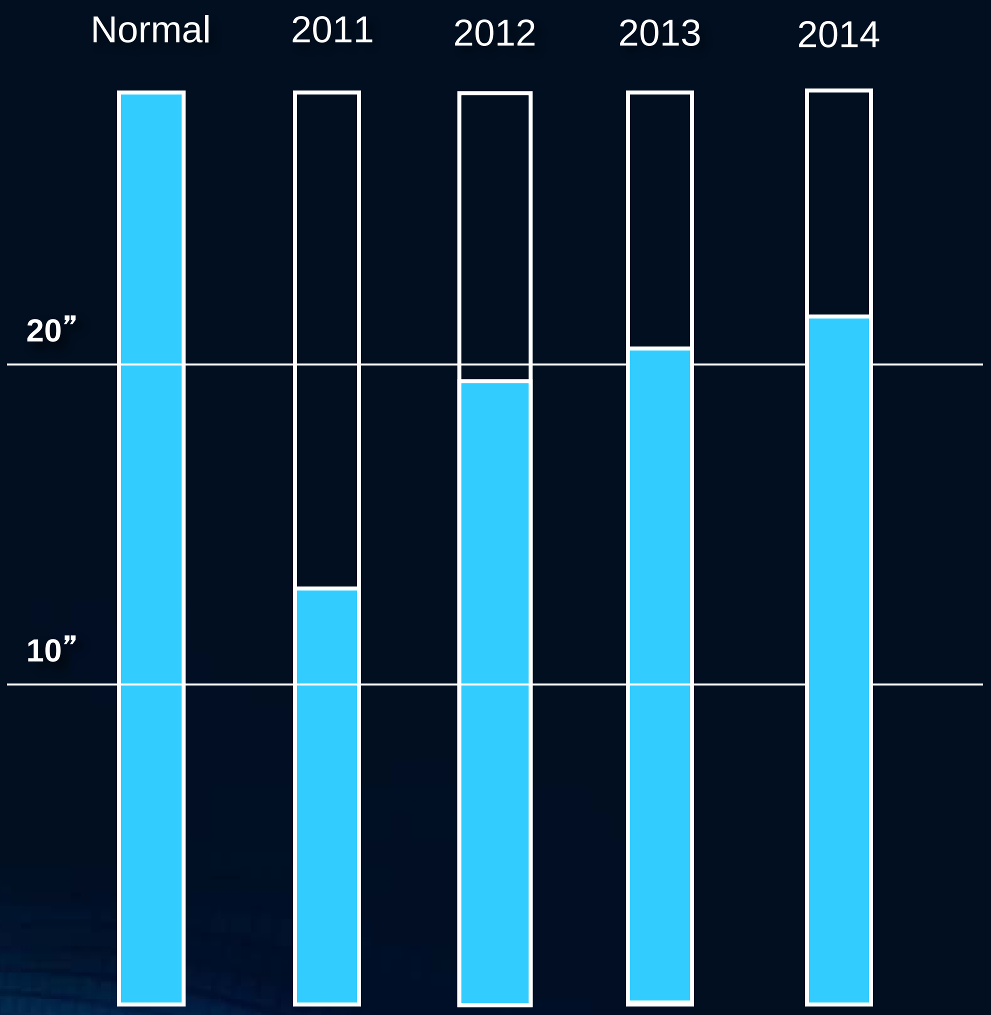
The annual average rainfall for the Wichita Falls area is 28.5 inches.

In 2011 we were 15.5 inches below normal.

In 2012 we were 8.75 inches below normal.

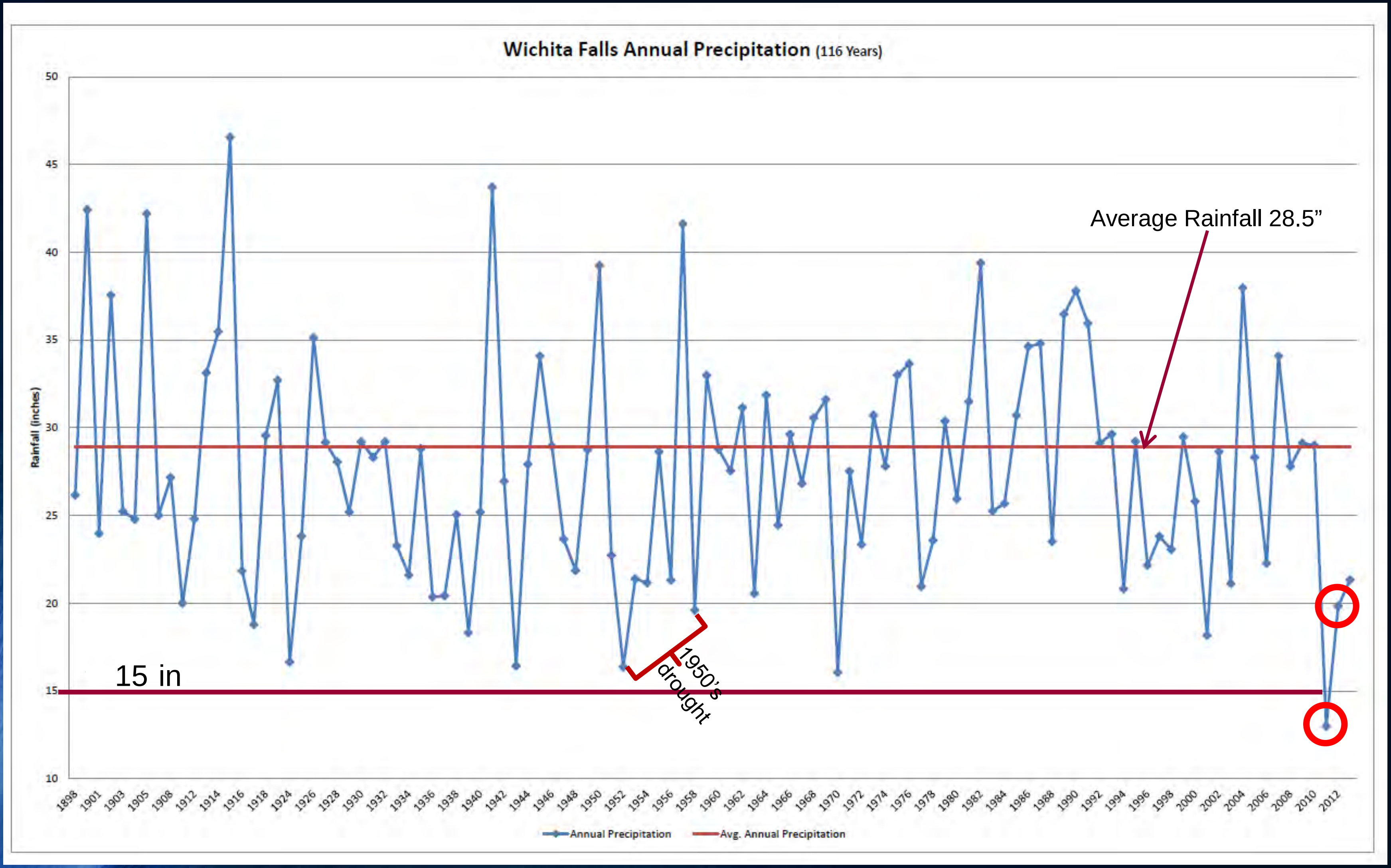
In 2013 we were 7.24 inches below normal.

So far, in 2014, we are 6.3 inches below normal



The Current Problem

Loss of Rainfall



The Current Problem

Record Temperatures

Wichita Falls typically averages 28 days over 100 degrees

In 2011 we had 100 days.

The Weather Channel ranked Wichita Falls the #1 Worst Summer anywhere in the U.S. for 2011.

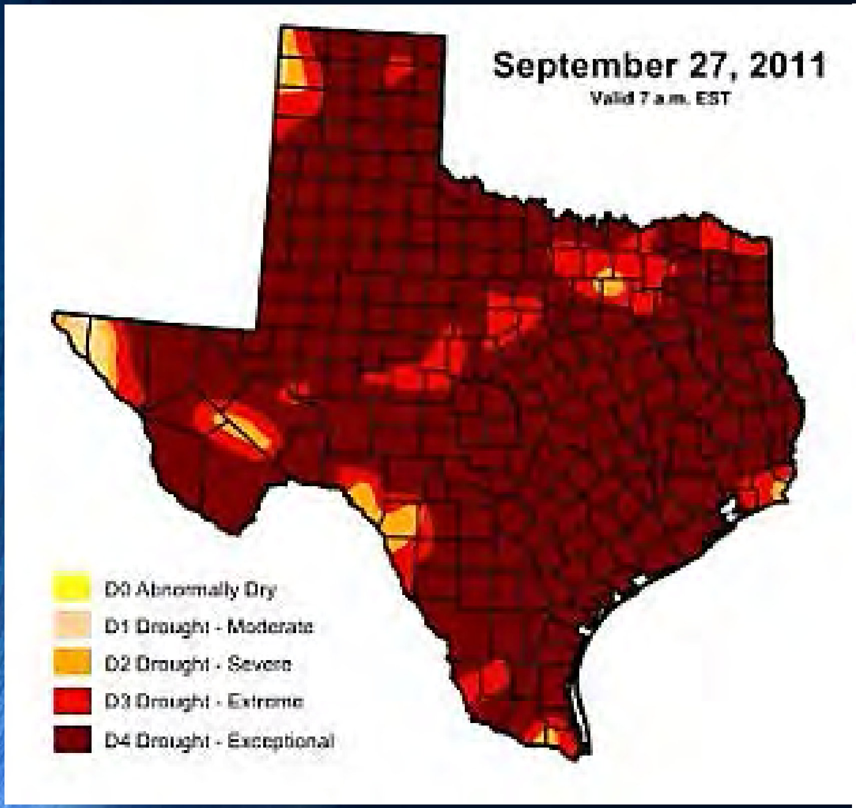
In 2012 we had 50 days.

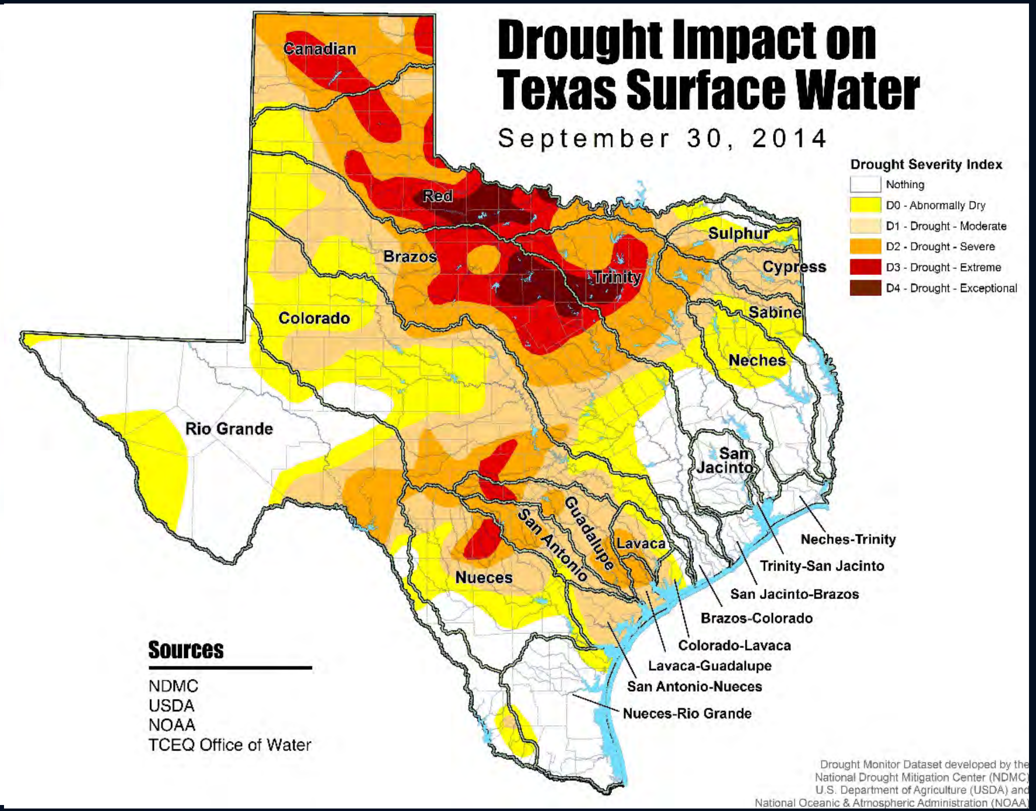
In 2013 we had 32 days.

In 2014 we had 21 days.

The Current Problem

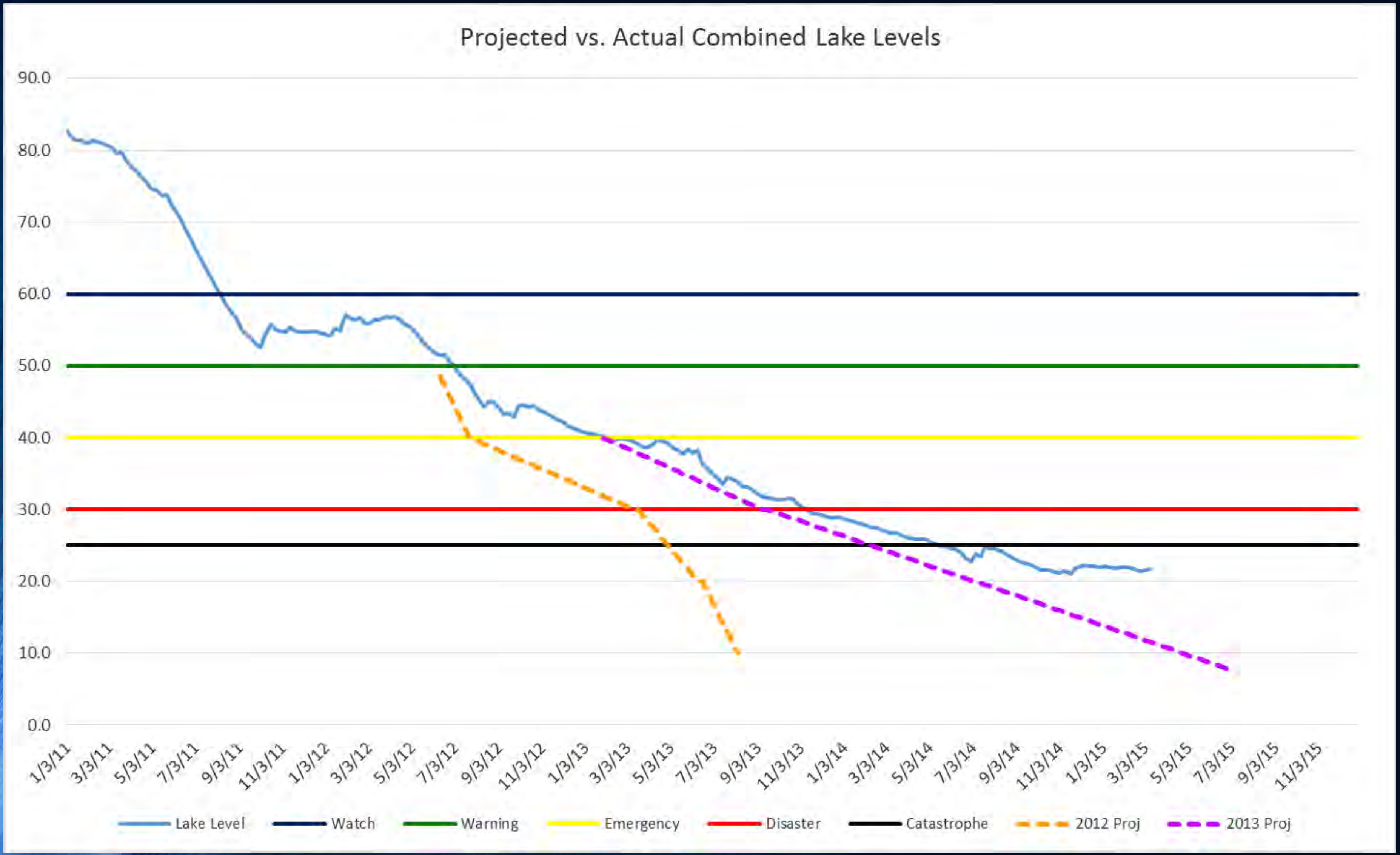
Continued Drought





The Current Problem

Lake Level Decline

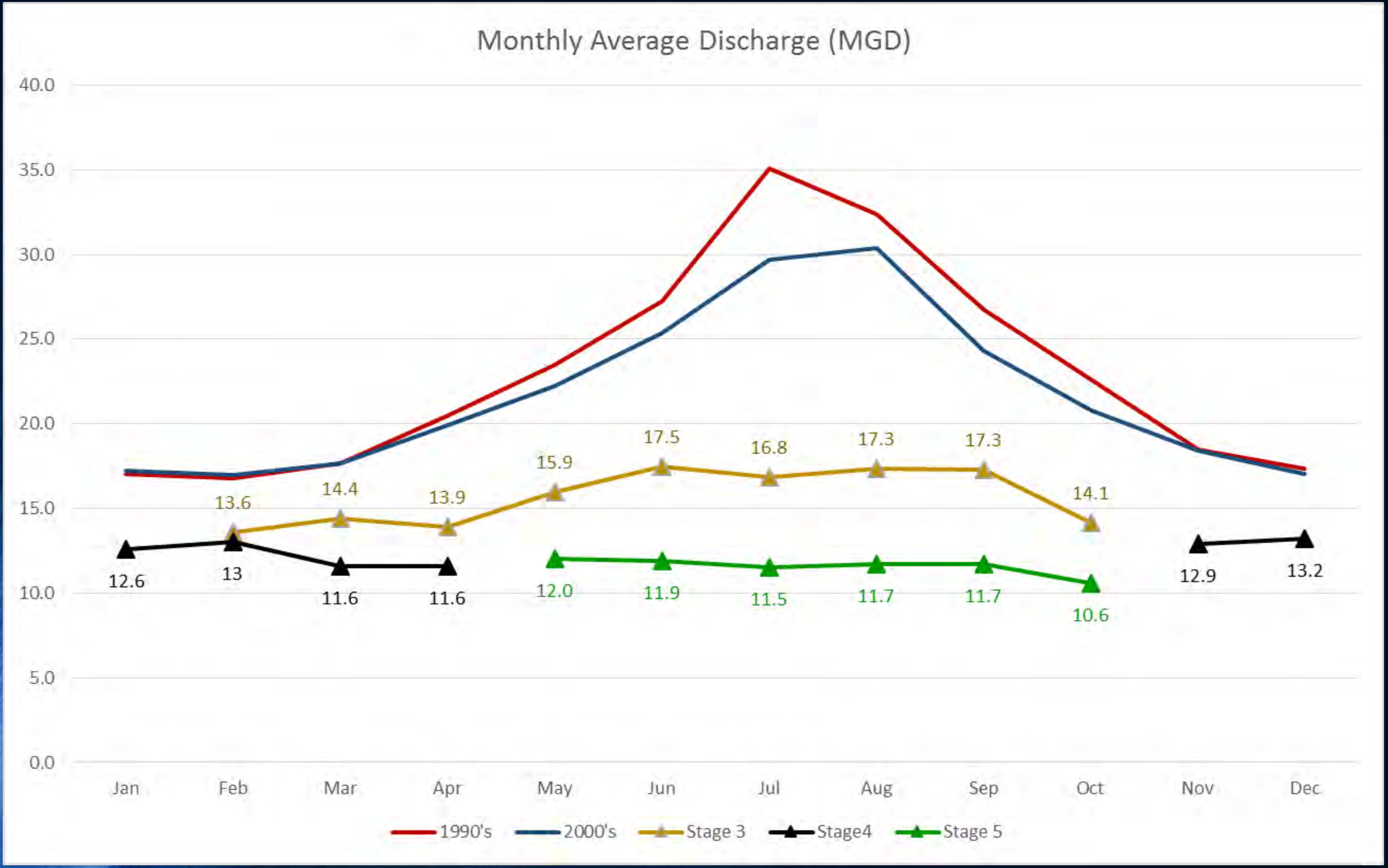


Water Conservation
Results

- Stage 1 – August 2011
- Stage 2 – July 2012 (saved 500 MG)
- Stage 3 – February 2013 (saved 2 BG)
- Stage 4 – November 2013 (saved 975 MG)
- Stage 5 – May 2014 (saved 2.6 BG, so far)

Total Savings with Restrictions 6.1 BG

The Solution
Drought Restrictions



Water Conservation
The Answer?

Unfortunately, we can not conserve our way out of this drought.

So, what's the Plan??

What's the Plan

EMERGENCY DIRECT POTABLE REUSE

Wastewater Effluent

Quantity?

- The River Road WWTP averages 12 MGD discharge to the Big Wichita River.
- Drought reductions have lowered that to 7.5 MGD.
- Using the Reverse Osmosis would generate 5 MGD of source water.
- Blended with 5 MGD water from Lakes would produce 10 MGD water for health and sanitation needs.

Wastewater Effluent

Quality?

- The River Road WWTP effluent has been tested for the last 16 months for numerous regulated and non-regulated compounds.

- Wastewater Effluent currently meets all 97 drinking water standards, with the exception of:
  - Nitrate
  - Trihalomethanes
  - Microbials

Wastewater Effluent

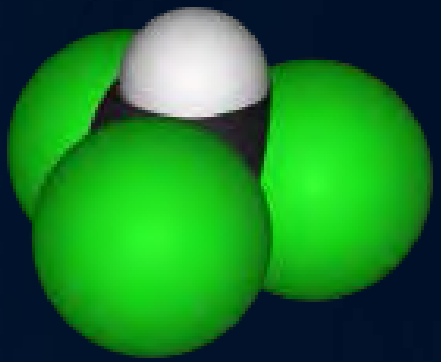
Quality?

- Nitrate – estimated 80% removal through Reverse Osmosis.
    - Effluent = 18 ppm
    - RO Permeate = 3.6 ppm
    - Blend with Raw Surface Water = 1.8 ppm

Wastewater Effluent

Quality?

- Trihalomethanes – estimated 40% removal through Reverse Osmosis with an addition of 15 ppm from Conventional Treatment.
    - Effluent = 106 ppb
    - RO Permeate = 63.6 ppb
    - Blend with Raw Surface Water = 31.8 ppb
    - Conventional Treatment = 46.8 ppb (MCL 80 ppb, WF Avg 15ppb)
- Reduced Trihalomethanes in Wastewater Effluent by using Chloramines.
    - Effluent = 10 ppb
    - RO Permeate = 6 ppb
    - Blend with Raw Surface Water = 3 ppb
    - Conventional Treatment = 18 ppb



Wastewater Effluent

Quality?

- Microbes – log removal credits:
  - Virus – 8 log Removal using Disinfection and Physical Processes
  - Giardia – 6 log Removal using Disinfection and Physical Processes
  - Cryptosporidium – 5.5 log Removal using Physical Processes

Direct Potable Reuse

Concept Paper

The City had confirmed that all required Treatment Processes were already on-site.
Just had to connect them with a pipeline.

The City developed a Concept Paper detailing:

- Processes to be Utilized
- Removal Efficiencies for Various Contaminants
- Operational Guidelines

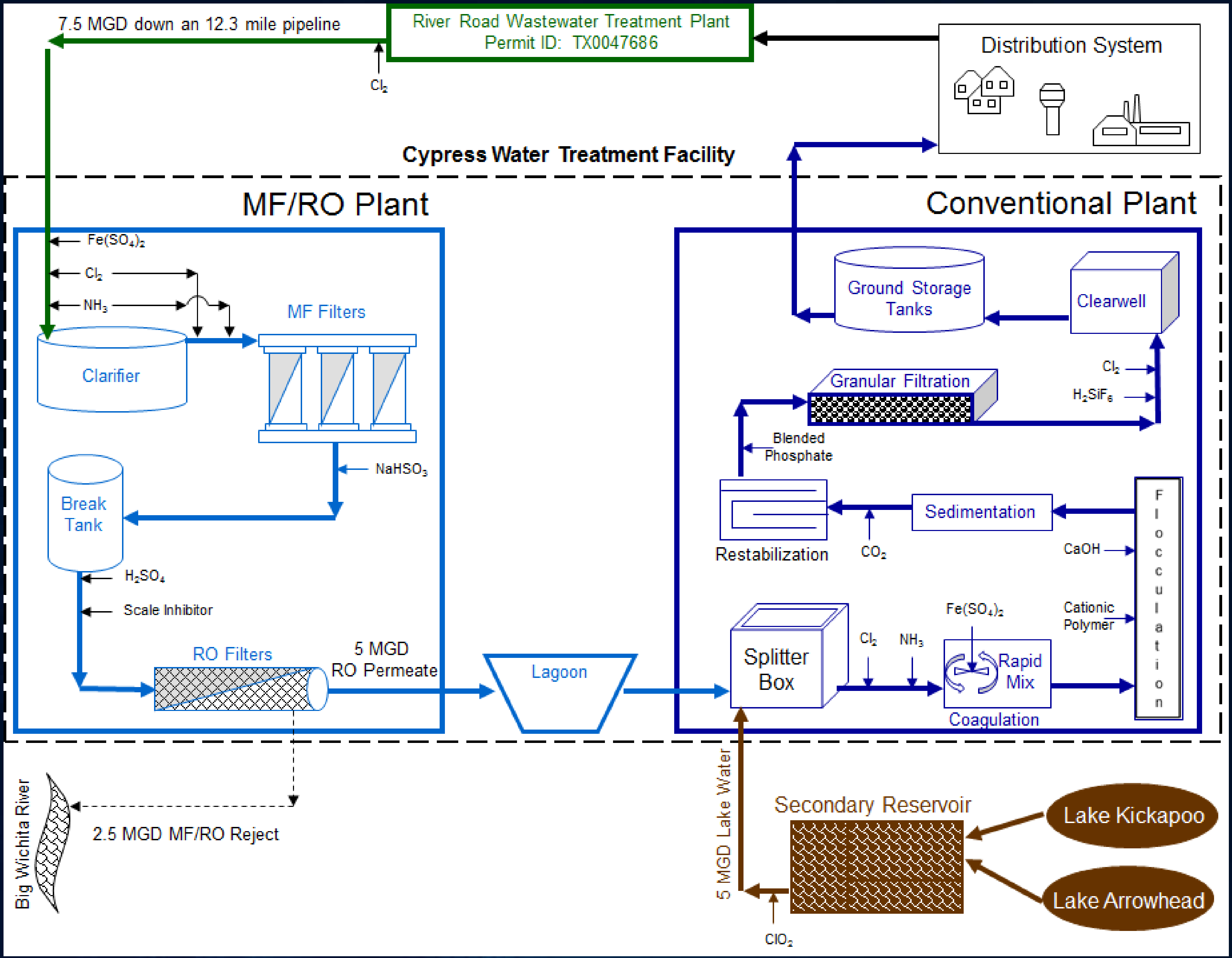
Submitted in November 2012.

TCEQ Acceptance February 2013.

Wastewater Effluent

Treatable with Existing Water Treatment Plant?

- Viruses
  - TCEQ changed from 8 log to 9 log (99.9999999 %) based on Pre-formed Chloramines.
  - No more than 2.22 X 10^{-7} copies / L in drinking water.
- Giardia
  - TCEQ changed from 6 log to 8 log (99.999999 %) based on Max Cysts.
  - No more than 7.000 X 10^{-6} cysts / L in drinking water.
- Cryptosporidium.
  - TCEQ is requiring 5.5 log (99.999684 %) removal.
  - No more than 2.99 X 10^{-5} oocysts / L in drinking water



7.5 MGD down an 12.3 mile pipeline
River Road Wastewater Treatment Plant
Permit ID: TX0047686
Cl_2
Distribution System
Cypress Water Treatment Facility
MF/RO Plant
Conventional Plant
$Fe(SO_4)_2$
Cl_2
NH_3
MF Filters
Clarifier
$NaHSO_3$
Break Tank
H_2SO_4
Scale Inhibitor
RO Filters
5 MGD RO Permeate
Lagoon
Ground Storage Tanks
Clearwell
Granular Filtration
Cl_2
H_2SiF_6
Blended Phosphate
Restabilization
CO_2
Sedimentation
CaOH
Flocculation
Cationic Polymer
$Fe(SO_4)_2$
Splitter Box
Cl_2
NH_3
Rapid Mix
Coagulation
Big Wichita River
2.5 MGD MF/RO Reject
5 MGD Lake Water
Secondary Reservoir
Lake Kickapoo
Lake Arrowhead
ClO_2

Direct Potable Reuse

Public Acceptance

The City worked from day 1 to educate the public on the processes and get them comfortable with DPR.

Utilized the Media at every step.

Brought together Medical Doctors and Academic PhD's.

Created an educational video.

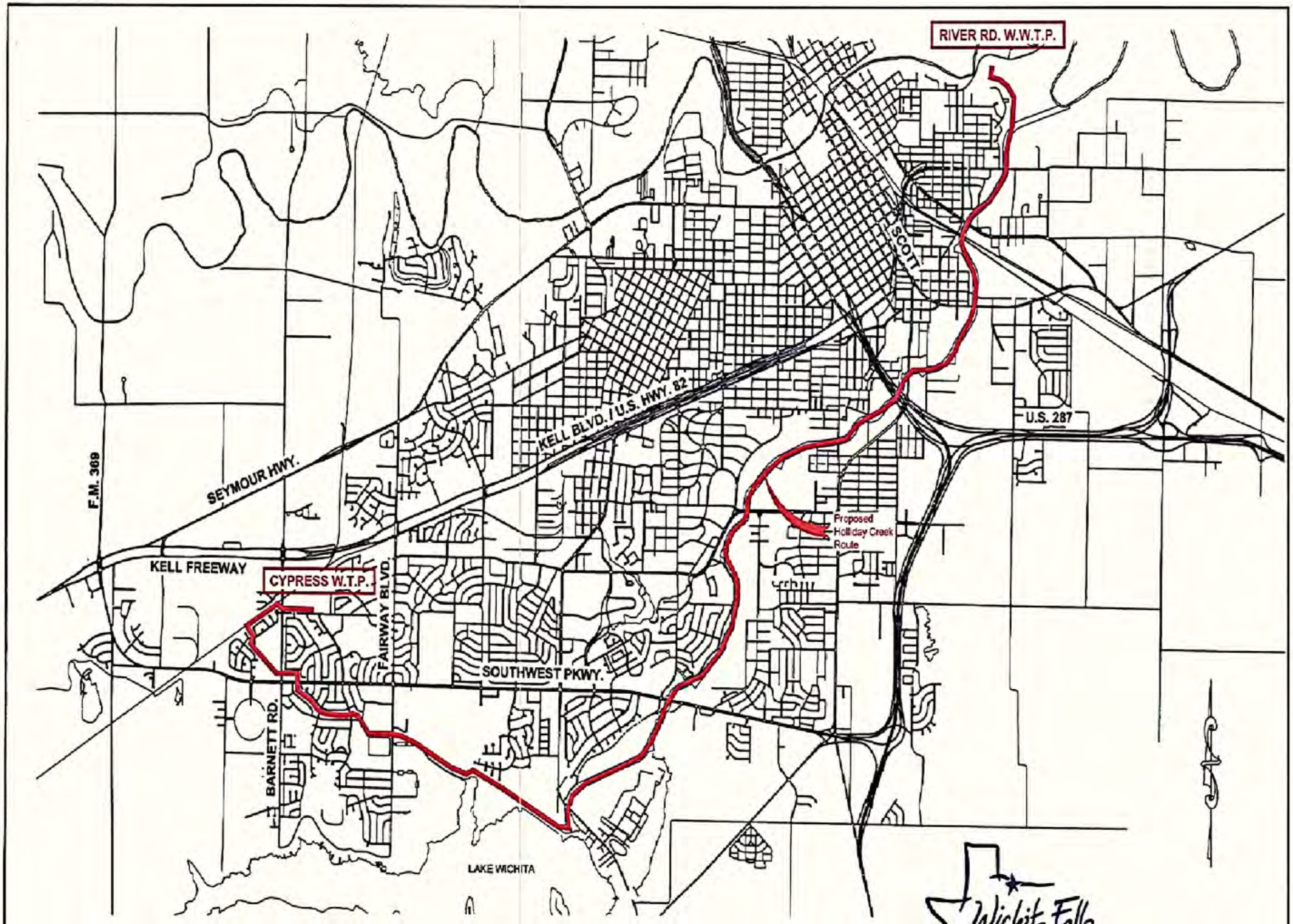
Direct Potable Reuse

Preliminary Engineering Report

The City hired Biggs & Matthews, Inc. to develop the Preliminary Engineering Report

Submitted in May 2013.

TCEQ Acceptance September 2013 to construct pipeline and conduct a 45-day Full Scale Verification test.



LOCATION MAP

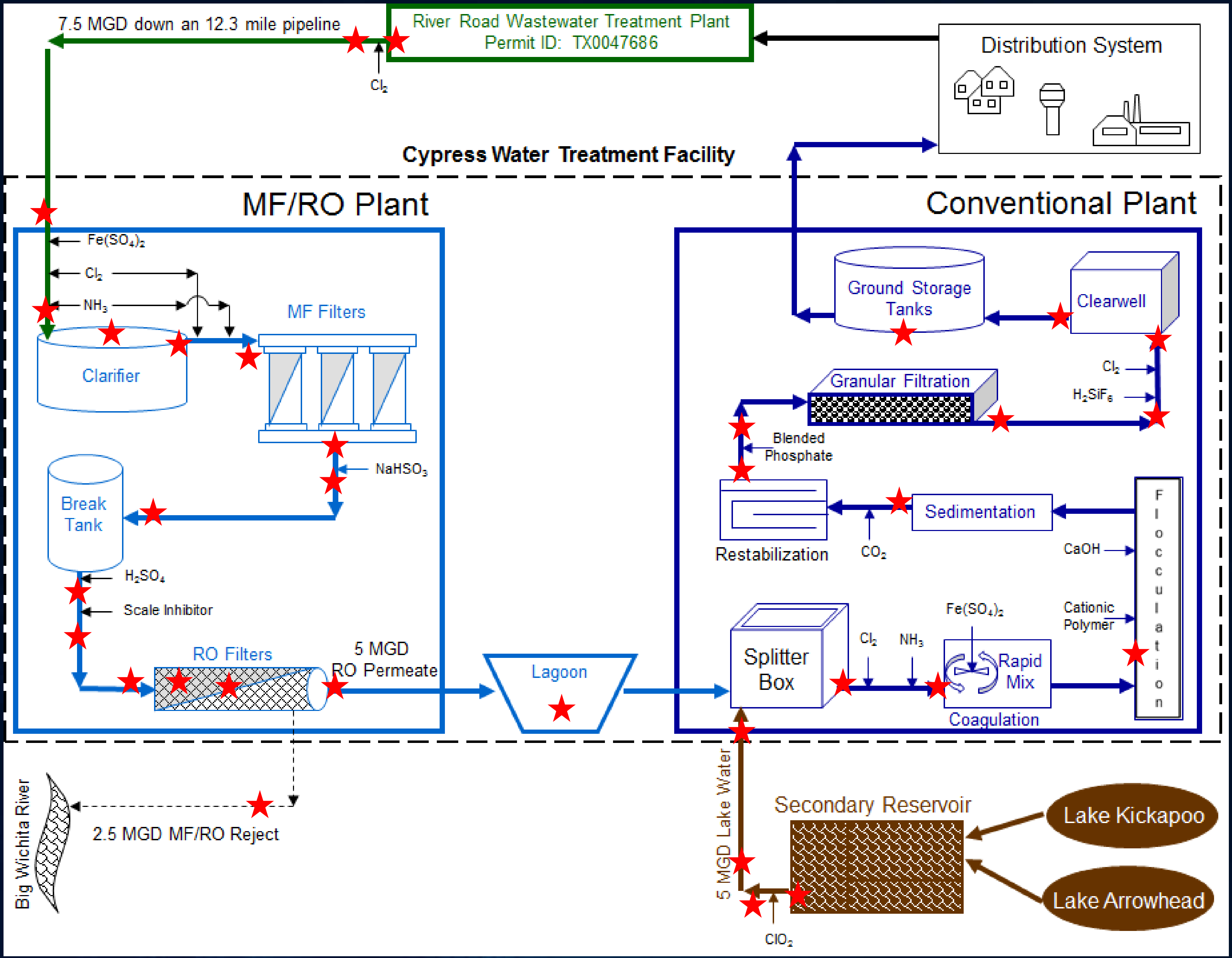

ISCO


W #28
9/3

Direct Potable Reuse

Full Scale Verification and Operations

- City started the TCEQ Mandated 45-day Verification Test on January 27, 2014.
- Second Verification was conducted in May/June 2014.
- The FSV Protocol has sampling locations at 42 different location throughout the DPR Plant.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Coagulation
Cationic Polymer
Big Wichita River
2.5 MGD MF/RO Reject
5 MGD Lake Water
Secondary Reservoir
Lake Kickapoo
Lake Arrowhead
ClO_2

Direct Potable Reuse
Full Scale Verification and Operations

- Full Scale Operation July 8, 2014.
  (27 months after initial TCEQ meeting)

Direct Potable Reuse

Effluent Pump Station

Chloramines formed prior to CCB to begin Disinfection process on Virus and Giardia.

Direct Potable Reuse

Pipeline

Chloramine residual maintained down pipeline.
Typical loss is in residual concentration is 2 ppm.

Direct Potable Reuse

MF/RO Clarifier

Chloramines boosted at Clarifier.

Ferric Sulfate added for Coagulation.

0.5 log Removal Credit for Virus, Giardia and Crypto given for Coagulation, Flocculation and Sedimentation processes.

Direct Potable Reuse

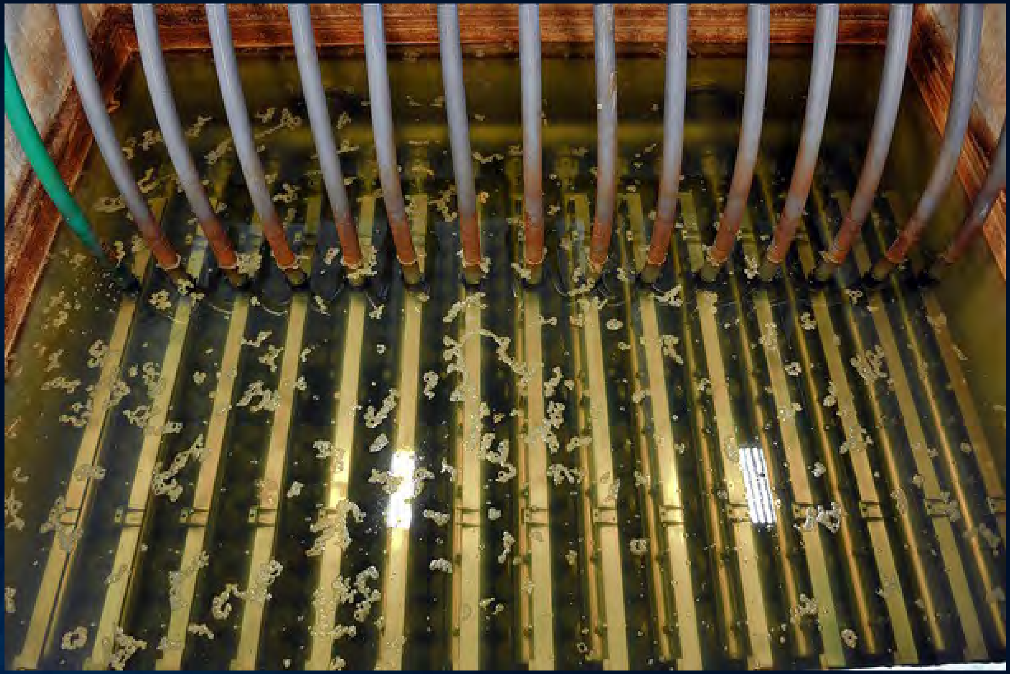
Microfiltration

Chloramines residual carried through Microfilters.

1.5 log Removal Credit given for Virus.

2.8 log Removal Credit for Giardia and Crypto

Daily Integrity Tests every 24 hours.
(not 24 hours of run time)



Direct Potable Reuse

Reverse Osmosis

Chloramines removed prior to Reverse Osmosis.

Zero log Removal Credit for any Microbial Contaminants.

Nitrates removed by 92%.

TDS tests every 8 hours.

Direct Potable Reuse

RO Permeate Lagoon

Direct Potable Reuse
Conventional Plant

Chloramine Disinfection restarted.

Ferric Sulfate and Lime added for Coagulation and pH adjustment.

0.5 log Removal Credit for Virus, Giardia and Crypto given for Coagulation, Flocculation and Sedimentation processes.

Direct Potable Reuse

Conventional Filtration

1.5 log Removal Credit given for Virus.

2.5 log Removal Credit for Giardia and Crypto

An additional 1.0 log to 0.5 log Removal Credit awarded for Filter Effluent Quality.

Direct Potable Reuse

Estimated Values vs. Actual Values

	WW Effluent	WW Effluent	RO Permeate	RO Permeate	50/50 Blend	50/50 Blend	End Plant	End Plant
	Estimated	Actual	Estimated	Actual	Estimate	Actual	Estimate	Actual
Nitrate	18	18	3.6	1.5	0.75	0.25	0.75	0.25
Trihalomethane	10	9.3	6	4.55	3	6.5	18	12.2

	WW Effluent	End Pipeline	MF Permeate	RO Permeate	Secondary Reservoir	50/50 Blend	End Plant
E. coli	>200.5	<1.0	<1.0	<1.0	29.0	<1.0	<1.0
Giardia	11	21.4	<0.07	<0.07	<0.07	<0.05	<0.07
Cryptosporidium	<0.01	0.13	<0.07	<0.07	<0.07	<0.05	<0.07
Total Culturable Virus	<0.017	<0.017	<0.01	<0.01	<0.025	<0.025	<0.002

Calculating Log Removal

Add in the Disinfection

Process Receiving TCEQ Approved Log Removal Credits	Virus	Giardia	Cryptosporidium
Pipeline between RRWWTP and CWTP (DZ 1)	8.73	3.94	0.00
MF/RO Coagulation/Flocculation/Clarification	0.50	0.50	0.50
MF/RO Clarifier Disinfection (DZ 2)	2.25	1.00	0.00
MF Filtration	1.50	2.80	2.80
MF Disinfection (DZ 3)	0.11	0.05	0.00
RO Filtration	0.00	0.00	0.00
2010 SWTP Coagulation/Flocculation/Clarification	0.50	0.50	0.50
2010 SWTP Filtration	1.50	2.50	2.50
Individual Filter Effluent Credit	0.00	1.00	1.00
Combined Filter Effluent Credit	0.00	0.00	0.00
2010 SWTP Disinfection (DZ 4)	2.49	1.13	0.00
2010 Clearwell/Ground Storage Tank Disinfection (DZ 5)	7.49	3.24	0.00
Total	**25.07**	**16.66**	**7.3**
Log Removal Required	**9**	**8**	**5.5**

Ensuring Safety
Bells and Whistles

Developed new SOP’s specific to the DPR.

Alarm & Shutdown Triggers

(50+ pages, Some Automated)

Water Quality Task Force with Health Department

The End Results

Making a Difference

Restrictions reduced July/August demand from Average of 35 MGD to 12 MGD. (65%)

Reuse further reduced July/August lake demand from 12 MGD to 7 MGD. (80%)

Current Average Potable GPCD for Wichita Falls is 52 gal / capita / day.

Estimated that Restrictions and Reuse have extended lake supply to between July 2017 and July 2018.

Reuse Humor

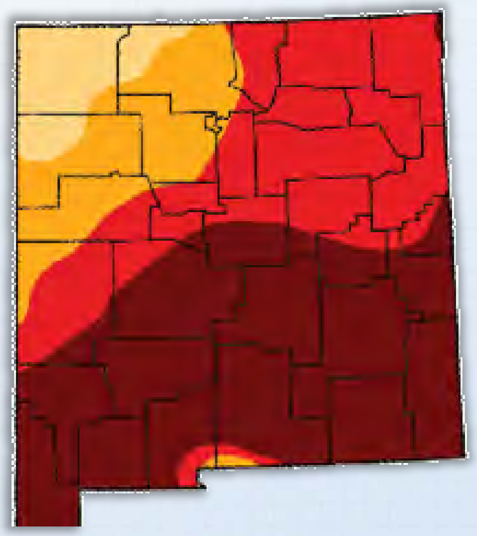
It never gets old.

Thank You

Questions??????

Daniel K. Nix
940-691-1153
Daniel.Nix@WichitaFallsTx.gov

Regulating DPR in New Mexico



Andy Salveson, P.E.
...on behalf of Joe Savage and NMED

Engineers...Working Wonders With Water®

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Critical Water Supply Shortage in the Village of Cloudcroft NM

- Water Supply is Low and DPR is the Answer
- Small Community has Limited Resources
- Operations Staff is Good, but Advanced Treatment is Beyond Current Training
- **Regulations Under Development**

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Notes from the Field, Cloudcroft NM

- System is Not Operational
  - 80% Constructed
  - Online Spring 2015
- Highly Advanced and Redundant Processes

Wastewater Purification

Membrane Bioreactor → Reverse Osmosis → UV/AOP → Chlorine Disinfection

→ 1 MG Storage (10 days) ← ~50% Blending with Raw Water

→ Ultrafiltration → UV → GAC → Chlorine Disinfection

Water Treatment

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Critical Issues Remain to Be Addressed in Cloudcroft

- New Mexico Environment Department Needs Answers
  - What level of treatment meets public health standards?
  - Is the existing treatment scheme sufficient? What about process monitoring?
  - How will a small community properly operate an advanced facility?
    - Existing WWTP is a trickling filter, is current staff and training sufficient?
  - What type of state-wide guidance is needed for big and small DPR projects?

NWRI Hired by NMED to Answer Key Questions

- Independent Advisory Panel (IAP)
  - Jeff Mosher, Supreme Leader
  - Jim Crook, Chair
  - Joe Cotruvo, Panelist
  - Andrew Salveson, Panelist
  - Bruce Thompson, Panelist
  - John Stomp, Panelist
  - Assistance From:
    - Village Trustees
    - Eddie Livingston
    - NMED

The Village Also Presents Other Challenges to the IAP

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NWRI IAP Preliminary Conclusions

- Treatment Process is Robust and Sufficient
- Additional Critical Control Point Monitoring Required
  - RO
  - UV AOP
  - Chlorine Ct
- Better Use of Engineered Storage

Critical Control Point Monitoring Ensures High Water Quality

Process	CCP Monitoring	Log reduction		
		V	G	C
MBR	Filtrate turbidity	2.7	2.7	2.7
RO	Online EC Online TOC	1.5	1.5	1.5
UV AOP	Intensity sensors, total chlorine reduction	6	6	6
ESB with free chlorination, free residual $\geq$ 0.4 mg/L	Online Cl_2	3	0	0
UF	Daily pressure decay testing (MIT)	1.0	4.0	4.0
UV	Intensity sensors	0.5	4.0	4.0
GAC	Online effluent TOC	0.0	0.0	0.0
ESB with free chlorination	Online Cl_2	3	0	0
Total		16.2	16.7	16.7

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Potable Reuse Treatment Should Be Robust, Redundant, Resilient, and in the end, Reliable

Process	Treatment performance					Robust?	Redundant?	Resilient?	Reliable ?
	Bacteria	Virus	Gia.	Crypto	Chem				
MBR	X	X	X	X	Partial	Yes	Yes	Mod.	
RO	X	X	X	X	X	Yes	Yes	Mod.	
UV AOP	X	X	X	X	X	Yes	Yes	No	
Storage and Chlor	X	X	X	-	Partial	Yes	Yes	Yes	
UF[4]	X	-	X	X	-	Mod.	Yes	Mod.	
UV[4]	X	-	X	X	-	Mod.	Yes		
GAC	-	-	-	-	X	No	Mod.		
Chlor	X	X	X	-	Partial	Yes	Yes	Yes	
Entire System						Yes	Yes	Yes	Yes

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NWRI IAP Preliminary Conclusions

- O&M issues are Key!
  - Training
  - Retraining
  - Staff Redundancy (small community!)
  - Budgeting, this will be a large increase in O&M costs.
- Outreach & Education ASAP

Communicating about Potable Reuse: Tools and Lessons Learned

By Patricia Tennyson

KATZ & Associates

Today's Agenda

- Introduction to potable reuse issues/perceptions
- Pure Water San Diego
  - o History and Progress
- WateReuse - WRRF Project 13-02
  - o Communication toolbox
- Public outreach lessons from the trenches

Potable Reuse Issues

- Technology has never kept a project from proceeding – it is always public/political issues
- “Does the science work here?”
- Water should not be judged by its history – and yet it is…
- Trust

Impediments to Acceptance

- Safety/health/quality concerns
- Engaging busy public, leaders, elected officials
- Making complex issues understandable: terminology, lay language, messages
- Misinformation
- Media sensationalism

Opposition Happens

- Opposition CAN'T be totally controlled
- Opposition CAN develop at any time
- Opposition may not be able to be neutralized

You need a good "insurance policy" – an effective outreach program.

Potable Reuse Challenges

Orange County's Model

Orange County's GWRS was a model for San Diego

- Leadership at board and staff level
- Research-based messages
- Effective multi-cultural outreach
- Frequent briefings: policy makers/media
- Comprehensive, sustained outreach program

"We talked to anyone who would listen to us!"

Three Key Guidelines

- Define purpose/need
- Identify range of community interests, understand concerns and issues, seek broad support *in writing*
- Outreach must be consistent and sustained

Potable Reuse History SD

- 1993: Water Repurification Project proposed
- 1999: Project cancelled by city council
- 2002 – 2004: Settlement with environmental groups
- 2004 – 2005: Water Reuse Study recommends reservoir augmentation
- 2007 – 2009: Demonstration project approved, temporary rate increase to fund it approved, project approved
- 2010 – 2013: Water Purification Demonstration Project conducted; report accepted by council April, 2013

- BIOCOM
- Building Industry Association
- Building Owners and Managers Association
  San Diego Chapter
- Citizens Coordinate for Century 3
- Coastal Environmental Rights Foundation
- Endangered Habitats League
- Environmental Health Coalition
- Friends of Infrastructure
- Industrial Environmental Association
- National Association of Industrial and Office Properties
  San Diego Chapter
- San Diego and Imperial Counties Labor Council
- San Diego Audubon Society
- San Diego Coastkeeper
- San Diego County Taxpayers Association
- San Diego Regional Chamber of Commerce
- San Diego Regional Economic Development Corporation
- San Diego River Parks Foundation
- Surfrider Foundation, San Diego Chapter
- Sustainability Alliance of Southern California
- Utility Consumers' Action Network

Pure Water San Diego

Pure Water San Diego is a 20-year program to develop a safe, reliable and LOCAL drinking water supply

- Provides a cost-effective and drought-proof water supply
- Uses proven purification technology
- Is environmentally friendly
- Diversifies San Diego's water supply sources and increases the city's water independence

Key Outreach Activities

- Informational materials
- Speakers bureau, community events
- Advanced Water Purification Facility tours
- Pure News, e-blasts, media, social media:
  - Pure Water San Diego
  - @PureWaterSD
  - purewatersd

Pure Water Working Group

- Diverse group, 25 members representing San Diego organizations
- Meeting topics: San Diego’s water portfolio, program details and costs, regulations, outreach
- Recommendations to city council

USD Partnership

- Student teams developed community education ideas
- Conducted surveys, developed videos and infographics, recommended strategies
  - 300 surveys with women between ages of 30 – 40, men/women between ages of 18 – 26
  - Informative videos now on YouTube
  - Creative infographics, hashtags

Sample Media Coverage

WateReuse DPR Research

- Project 13-02 conducted in 2014
- Focus on direct potable reuse
- California-centric research
- Broad application of communication plans


2014
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Literature Review
Agency IDIs
Legislator IDIs
Health Professionals IDIs
Special Interest Groups
Focus Groups
Public Surveys
State Level Comm Plan
Community Level Comm Plan
Listen
Learn
Retool
Engage

WRRF 13-02: Agency Feedback

- Addressing health and safety concerns (water quality, PPCPs/CECs, exposure to diseases)
- Costs to ratepayers
- “Yuck” factor/toilet-to-tap
- Building trust with community members
- Regulations/regulators
- Inconsistent language

WRRF 13-02: Special Interest Groups

- More environmentally responsible
- Familiarity results in support/less fear
- With little knowledge: casually supportive or strongly opposed
- Brine disposal is an area of great concern
- Other concerns: safety and cost

WRRF 13-02: Research Findings

- Majority support IPR (62%)
- Initially most oppose DPR – but support goes to 56% with information about safety
- Treatment steps alone build support
- Testing/monitoring influence support
- Environmental message next most effective

WRRF 13-02: Key Messages

- Potable reuse provides a safe, reliable and sustainable drinking water supply.
- Using advanced purified water is good for the environment.
- Potable reuse provides a locally controlled, drought-proof water supply.

Model Communication Plans

- Basic approach: Listen, Learn, Adapt
- Local Community Level
  - Customize to meet ***your*** specific needs
  - Tailor questions to ***your*** demographics
- State Level
  - Aimed at legislators/staff

Community Level Communication Plan

- Public acceptance primary challenge
- Build awareness: need, benefits, safety, high quality water
- Messaging, terminology
- Audience-driven; opinion leader focus
- Targets, strategies, activities, measurable objectives

Sample of tools being made available

WATEREUSE

Potable Reuse Summary

Commonly Referred to as Purified Water

Multiple Benefits of Purified Water

Safe, reliable water supply
Potable reuse uses proven technology to purify recycled water to provide a safe water source. Multiple treatment methods separate pollutants, producing water that is cleaner than most bottled water.

Sustainable water supply option
Potable reuse provides a sustainable and cost-competitive water supply option using less energy than many other options.

Environmental benefits
Potable reuse allows us to leave more water in rivers, lakes and streams for fish, plants and wildlife, while reducing discharges to these water bodies and the ocean.

Drought proof
Potable reuse is a drought-proof water supply. It can help ensure safe, sustainable water now and into the future.

Responsive to weather variability
Potable reuse is part of a diversified water portfolio and is independent of climate or weather.

Understanding Potable Reuse — A Key Part of Our Water Supply Solutions

Numerous regions of the world are experiencing drought and resulting lack of water supplies. While using purified water for drinking is not new, innovative projects in Australia, Texas, California and elsewhere are living examples of advanced purification practices being used to increase scarce water supplies.

Water Reuse Happens Naturally

The term "potable" water means "suitable for drinking." Water reuse, including potable reuse, happens naturally all over our planet — on rivers and water bodies everywhere. If your community is downstream from another, chances are you are reusing its water and likewise communities downstream from you are most likely reusing your water.

Reused or recycled water is water used more than one time before it passes back into the natural water cycle. It is wastewater, including sewage, which has been treated or purified to a level that allows for reuse for beneficial purposes.

Potable Reuse — Direct and Indirect

Potable reuse refers to water meeting all federal and state drinking water standards and is safe for human consumption. Potable reuse may be created by indirect potable reuse (IPR) or direct potable reuse (DPR).

To Learn More

WateReuse is a nonprofit organization wh
and efficient uses of high-quality, locally p
the betterment of society and the environ
and outreach, research, and membership.
communities are facing water supply chall
drought, depletion and contamination of
single source of supply. To learn more, visi

WATEREUSE

Draft Your Message Plan

— ESSENTIAL —

Water Terminology for Potable Reuse

The messages here introduce new terminology for potable reuse — namely, **"advanced purified water"** or, **"purified water."** This reflects the preferred terminology from the focus groups and telephone surveys conducted in the WRRF-13-02 project. **The research clearly demonstrates that "potable reuse" and "direct potable reuse" are not understood by the mainstream population and that, even when explained, they do not resonate well.**

We reference direct potable reuse (DPR) and indirect potable reuse (IPR) as "potable reuse." This is fine when talking among those in your agency and industry, but the public neither recognizes nor understands the term — we will substitute with "purified water" from here forward.

Get Ready for Public Engagement

Carefully craft your community's project story

At a minimum, answer the following questions about potable reuse:

1. What is potable reuse?
2. Where does it fit in our water supply portfolio?
3. Why is the potable reuse project needed?
4. What purpose will it serve?
5. How safe is the water?
6. How will it be monitored to ensure safety?
7. How much will it cost?
8. When will it be implemented?

Messaging Tips

Develop key messages in terms understandable to a non-technical audience and avoid jargon.

can help improve technological literacy.

Effective messaging is not enough. According to by Dr. Paul Slovic in *The Feeling of Risk: New Perspectives on Risk Perception*, 2010, information must also convey emotion or feeling to be meaningful.

Goals of Messaging

The goal of messages included here is to provide coordinated, consistent, effective communication ideas about the role and importance of potable reuse that can be uniformly used with a variety of stakeholders, from children to parents and health professionals to business interests. There are three basic objectives:

- to identify messages that help to create public understanding of water use, treatment, and potable reuse in a water cycle context;
- establish messages in the context of your water agency's mission;

WATEREUSE

Key Messages

Top Three Key Messages

Potable reuse provides a safe, reliable and sustainable drinking water supply.

Using advanced purified water is good for the environment.

Potable reuse provides a locally controlled, drought-proof water supply.

Key Messages Explained

Potable reuse, or purified water as described below, uses advanced, multi-stage treatment to provide a safe, reliable and sustainable drinking water supply.

Here are some tested and useful message bullets :

- Proven engineered treatment processes are used to purify water to a level that is safe to drink
- Purifying water is a "multi-barrier process" designed to separate water from pollutants.
- There are various treatment processes to accomplish this objective.
- Purified water is tested, in real-time, with online sensors and will be strictly monitored by the Department of Health.
- Purified water will comply with or exceed strict state and federal drinking water standards.
- The purification process produces water that is more pure than most bottled waters.
- Purified water is currently used to supplement drinking water in many communities in the United States and around the world. There have been no problems from using purified water to augment drinking water supplies.

At times it may be advantageous to include a more detailed description of the advanced technological processes used to purify recycled water. In such instances, the following language is an example of how to describe the microfiltration/reverse osmosis/ultraviolet light treatment train:

- The water first goes through microfiltration, a pretreatment process, where water is pumped through tubes filled with tiny membranes. Each membrane is made up of hollow fibers, perforated with holes 1/300th the width of a human hair! As the water moves through the tubes, solids and bacteria are caught in the fibers.
- The water then goes through reverse osmosis where it's forced through membranes that remove salt and microorganisms, including viruses, bacteria and most chemicals of emerging concern.
- Now the water is very clean, but one more step ensures its safety: exposing the water to ultraviolet light to cause any remaining organic molecules to break down.

Using advanced purified water is good for the environment.

The more recycled water we use for whatever purpose we use it, the less we have to take out

WATEREUSE

Communication and Outreach Tools

Building Trust — Why Tools are Needed

Since public acceptance of potable reuse is one of the primary challenges facing this source of water supply, developing clear and informative tools will help gain acceptance and build trust in your community for your project.

Develop Informational Materials

The following are strategies for developing informational materials:

- Make available easy-to-understand materials highlighting key messages appropriate for target audiences and provide them in print and electronic formats; consider using QR codes and social media platform strategies;
- Develop materials tailored to the interests of specific audiences;
- Ensure all materials are responsive to multicultural, multiethnic, and age-specific audiences; translate key items into other languages as needed;
- Consistently update all materials (both electronic and print) to make sure designated audiences, including agency employees, have timely and accurate materials;
- Link to other places that provide information about purified water projects.

Menu of Informational Materials and Tools

Collaterals

- Purified water fact sheet
- Purified water FAQ
- Pocket brochure
- Bill inserts
- Posters and banners
- Materials for children
- White papers
- Template articles

Web and Digital

- Website
- Presentations
- E-newsletter
- Program DVD
- Quarterly videos

Libraries and Databases

- Graphics "catalog"
- Quote/Cite bank
- Mailing list
- Centralized internal information station

Other

- Learning/visitor's center at the advanced water treatment facility
- Key messages card
- Supporter/comment cards

Speakers Bureau

- Detailed information on *Strategies & Activities for Creating Your Speakers Bureau* are available at www.waterreuse.

For more detailed and helpful information on each of these bulleted items see section 5.10 of the WRRF 13-02 report.

Sample Timeline on reverse

Spring 2015 – Water Reuse Solutions

WATEREUSE

Understanding Potable Reuse

A Key Part of Our Water Supply Solutions

Potable Reuse Education — Sharing Solutions to Water Supply Challenges

Numerous regions of the world are experiencing drought and resulting lack of water supplies. While using purified water for drinking is not new, innovative projects in Australia, Texas, California and elsewhere are currently providing advanced water purification to increase water supplies. These projects can serve as models for other states and municipalities.

WateReuse provides countries, states, municipalities and water districts with information and tools that can lead to establishment of Direct Potable Reuse (DPR) or Indirect Potable Reuse (IPR) projects that are both sustainable and protective of public health. As new water supply options, DPR projects treat wastewater, including sewer water, that has been cleaned for return to the environment and actually further clean or purify it to meet all drinking water standards. This purified water is regulated by water quality and health officials and implemented by water utilities in a safe, cost-effective and environmentally responsible manner. Uses may include purifying water to distilled quality for industrial processes, as well as for drinking. IPR projects add the step of passing the highly treated water through an environmental buffer, such as a groundwater aquifer or surface water reservoir.

Since 2012, two Texas cities (see page 3) have been operating the nation's first DPR plants. Likewise, in 2012, California has embarked on an awareness effort to help establish DPR as a water supply option. The ongoing effort is to address the regulatory, scientific, technical, and attitudinal issues surrounding potable reuse projects. This is being accomplished through funding of independent and rigorous scientific research and communicating findings and data through public outreach and awareness programs.

WateReuse is sharing solutions and best practices from 26 independent research projects, made with investments of over $11.5 million, to evaluate and demonstrate the feasibility of DPR. The research revolves around developing a robust monitoring and redundant water purification system. These projects will help inform other communities and governments moving forward when considering a range of potable reuse projects.

Wichita Falls' DPR Project went online July 9, 2014 following extensive testing by the City of Wichita Falls and the Texas Commission on Environmental Quality (TCEQ). Shown here is one of their clarifiers.

What is Potable Reuse?

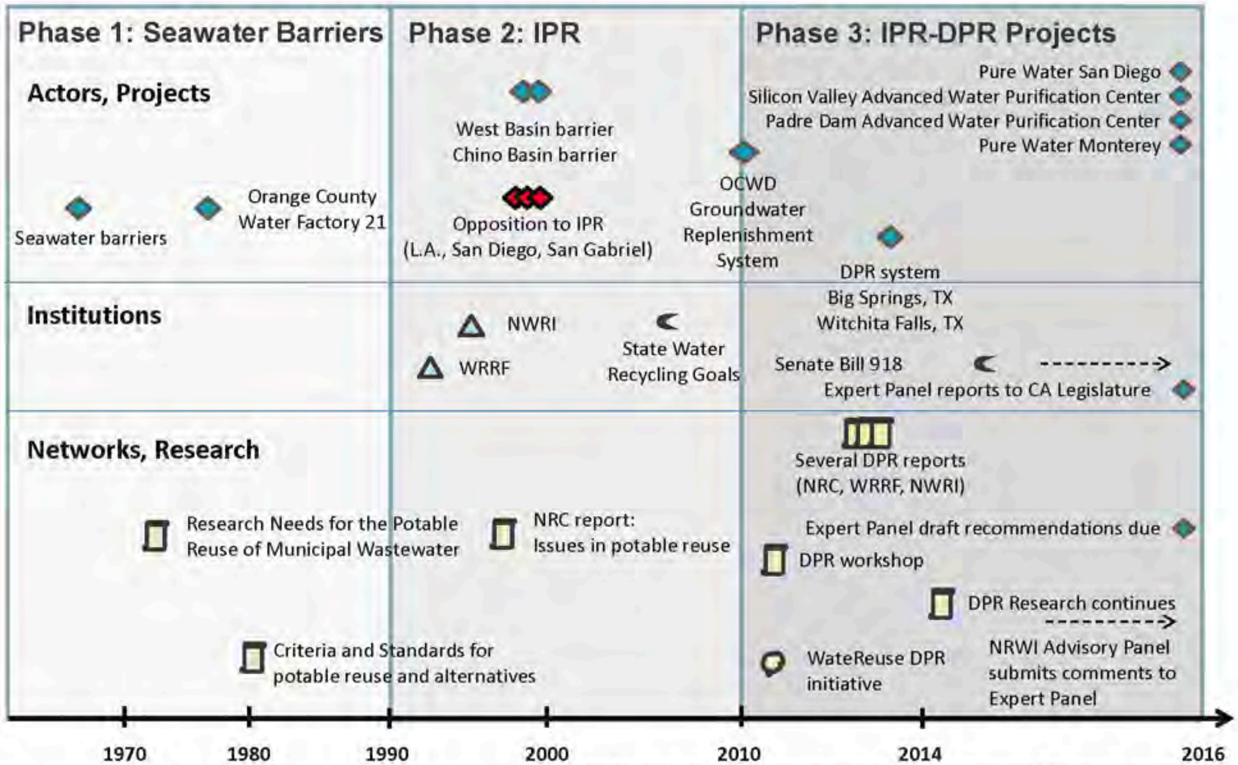
Potable reuse refers to purified water you can drink. It's highly treated to meet or exceed federal and state drinking water standards and is safe for human consumption. How potable reused water is delivered determines if it is called Indirect Potable Reuse (IPR) or Direct Potable Reuse (DPR).

Indirect Potable Reuse means the water is delivered to you indirectly. After it is purified, the reused water blends with other supplies and/or sits a while in some sort of man-made or natural storage before it gets delivered to a pipeline that leads to a drinking water plant or distribution system. That storage could be a groundwater basin or a surface water reservoir.

Direct Potable Reuse means the purified water is put directly into pipelines that go to a drinking water plant or distribution system. Direct potable reuse may occur with or without "engineered storage" such as underground or above ground tanks.

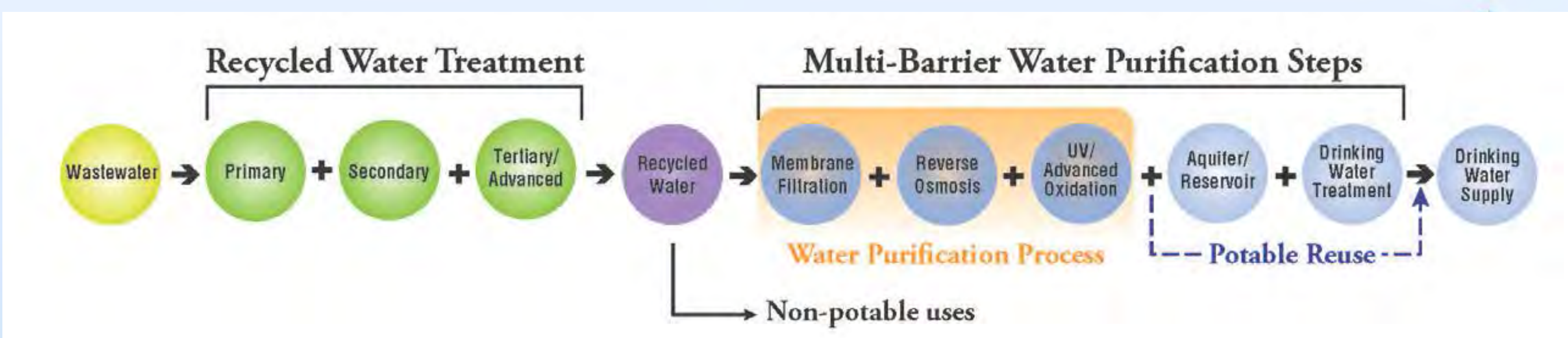
WATEREUSE

History of Potable Reuse in California



NWRI = National Water Research Institute, WRRF = WateReuse Research Foundation
IPE = Indirect Potable Reuse, DPR = Direct Potable Reuse

Based on chart created by Christian Bain/eawag. Modified by WRRF 2015



Key Plan Element Prioritization and Timeline

An example of a timeline you can adapt for your own public outreach planning.

ACTIVITY	MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Review existing communication materials (internal and external)																		
Review the literature																		
Develop draft key messages for testing																		
Identify key stakeholders						*Ongoing*												
Build mailing list/contact database							*Ongoing*											
Conduct in-depth interviews								*Ongoing as needed*										
Conduct focus groups and baseline survey																		
Finalize key messages																		
Develop or modify Community-Level Communication Plan												*Ongoing as needed*						
Create communication tools																		
• info materials														*Ongoing*				
• speakers bureau and training														*Ongoing*				
• media training														*Ongoing*				
• webpages and social media														*Ongoing*				
• IAP																		
Create a Rapid Response Plan																		
• identify a core team			*Ongoing as needed*															
• conduct spokesperson training			*Initial*								*Key messages*			*Ongoing as needed*				
• create template articles for media			*Initial*								*Key messages*			*Ongoing as needed*				

Opinion Leader Outreach

Goals of Opinion Leader Outreach

- establish or enhance the relationship between the opinion leader and the agency;
- build awareness, trust, and confidence in purified water treatment technology processes;
- inform leaders of water supply demands and shortages and how purified water can meet demands;
- listen to these stakeholders and be responsive to concerns related to purified water project implementation;
- secure written support of purified water projects from strategic community and opinion leaders.

Opinion leaders influence attitudes, beliefs, motivations, and behaviors of others. They influence opinions by raising awareness, persuading others, establishing or reinforcing norms, and leveraging resources. They usually have high visibility and a defined constituency. Opinion leader outreach builds strong relationships and garners third-party involvement in disseminating information to a broader network.

Identifying Opinion Leaders

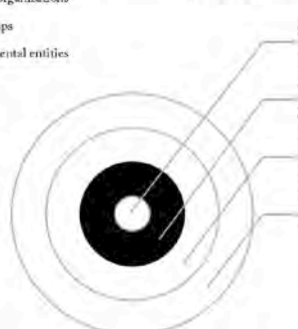
Each community will have its own unique set of influencers, which will likely change and grow as the project progresses. Keeping an accurate database of opinion leaders, contact information, preferred communication methods, and other pertinent notes is imperative to a successful outreach program.

It's important to identify the leaders and their staff. Characteristics include: t appointed or elected position, values and traits, competence or expertise, and social position. Opinion leaders can include, but are not limited to, the following (in alphabetical order):

- academic/education leaders
- business organizations
- civic groups
- environmental entities
- media
- medical, public health, and water quality experts
- multicultural and faith-based leaders and groups these leaders/groups may be found within the other audiences listed)
- state and local elected officials and their staff

Relationship of opinion leaders to other target audiences

The graphic below illustrates the opinion leaders in relation to other community members. As a core group, from which information spreads to other community members, opinion leaders must be made aware of the need to increase water supply sources and should be knowledgeable about purified water as an option.



Rapid Response Plan

When unexpected events occur, the agency must be prepared to respond quickly. During emergency and unplanned events, it is the project team's responsibility to communicate promptly, effectively, and efficiently with affected internal and external stakeholder groups. If the team is prepared and executes the plan appropriately, consistently, and often, vital information will be provided and lasting effects on the organization's reputation and credibility will be positive.

This Rapid Response Plan is intended to be a living document that provides guidelines and recommendations for how the agency should work to provide a consistent and prompt communication response.

Strategy

The strategy behind the Rapid

Rapid Response Plan Activities

Rapid Response Team
Identify a core team within the agency that is designated as the rapid response team. This team should include the board chair, the CEO, legal counsel, operations staff, communication staff, and customer service staff. This group should meet periodically to review potential scenarios and strategize responses. When a crisis occurs, convene the team immediately to develop a specific response.

Message Development
Develop three key messages in response to the situation or event and share those with key staff and board members. These are the three messages that should be included in all written and verbal communication about the event.

Employee Communication
Employees are one of the most important stakeholders in a crisis or rapid response situation, and they are often forgotten because of other pressing issues, such as responding to media inquiries and ensuring the safety of the agency's customers. An all-employee e-mail should be developed and distributed with the details of the event and the agency's response. This communication should also include the contact information for someone at the agency who can answer employee questions. This needs to be the assigned responsibility of a

"Dark" web pages and Public Notices
Create web pages and public notices for potential crisis situations and keep them ready to upload/print in the event of an actual crisis.

Phone Lists
Keep up-to-date phone lists (both hard and electronic versions) with home and cell phone numbers of board members, agency management and elected officials, and top staff from other local agencies.

Op-eds and Letters to the Editor
Address inaccurate news coverage by writing letters to the editor and submitting op-ed articles stating the agency's position. Always include appropriate agency messages to leverage any opportunity for providing correct information about potable reuse.

Media Outreach
Identify one spokesperson or select spokespeople for the agency staff (the board members will likely be contacted and speak for themselves) and ensure that all employees know to direct any inquiries to that designated person or persons. The identified spokesperson/people should be aware of the key messages developed and should incorporate them as they respond to media questions.

Social Media

Outreach Lessons Learned

- Ensure water agency is project lead
- Emphasize importance/need for **<u>all</u>** local water supply sources
- Correct inaccuracies immediately
- Conduct repeated policy maker briefings
- Identify/work with strong third-party allies

More Outreach Lessons

- Emphasize the ***urban*** water cycle!
- Terminology matters
- Know your community
- Tours/tasting opportunities
- Media outreach/social media
- “Go to them” vs. “Come to us”

Communicating about Potable Reuse: Tools and Lessons Learned

Questions?

ptennyson@katzandassociates.com

KATZ & Associates

Supporting Points

- The purification process produces water that is more pure than most bottled water.
- There have been no problems from this use of purified water

Additional Points

- Purified Water:
  - will comply or exceed strict state and federal drinking water standards.
  - will be tested, in real-time, with online sensors and be strictly monitored by the department of health.
  - currently used to supplement drinking water in many communities in the U.S. and around the world.

What’s Worked Well

- Plant tours
- Direct face-to-face contact
- Working closely with community leaders
- Community-based advisory group
- Keeping regulators informed
- Media: establish relationships and engage them early

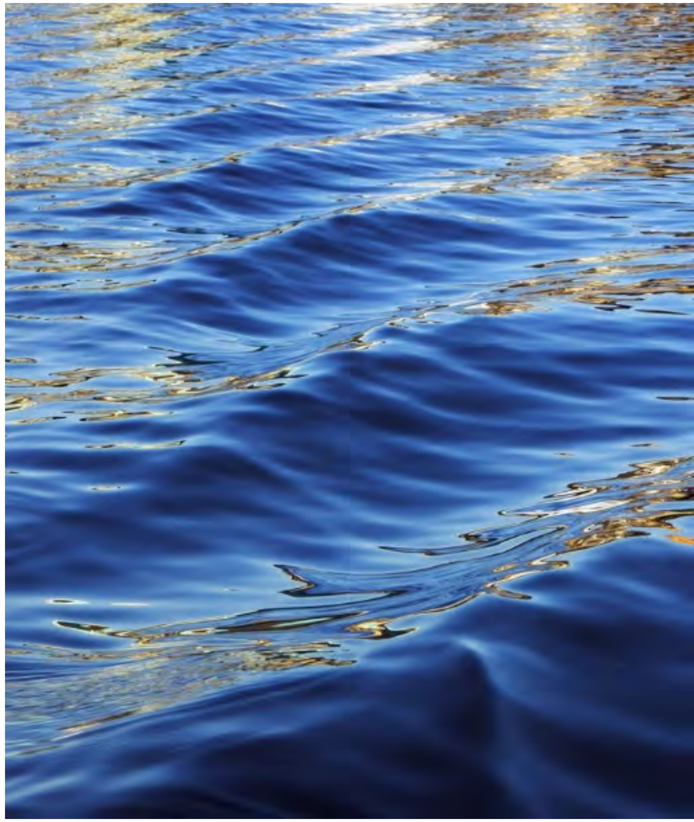
What's Worked Well, cont'd

- School outreach
- Frequent notices of water supply levels
- Speakers' bureau
- Getting written support
- Website, videos, radio interviews, social media

WateReuse DPR Initiative

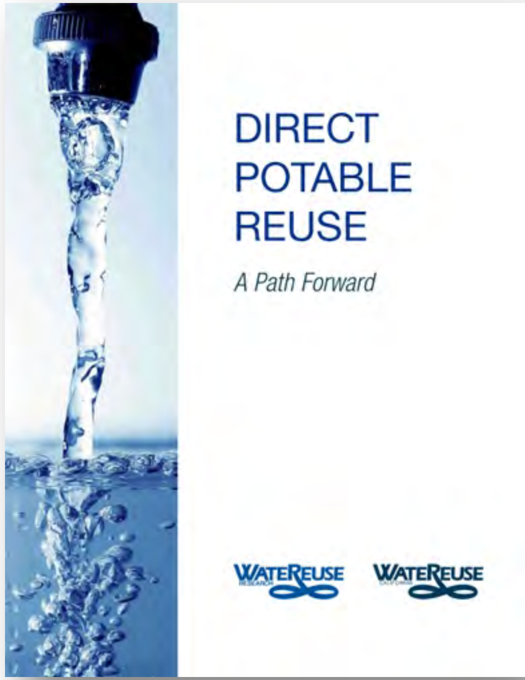
CO DPR Workshop
May 27, 2014
Julie Minton
WRRF Research Director

WATEREUSE



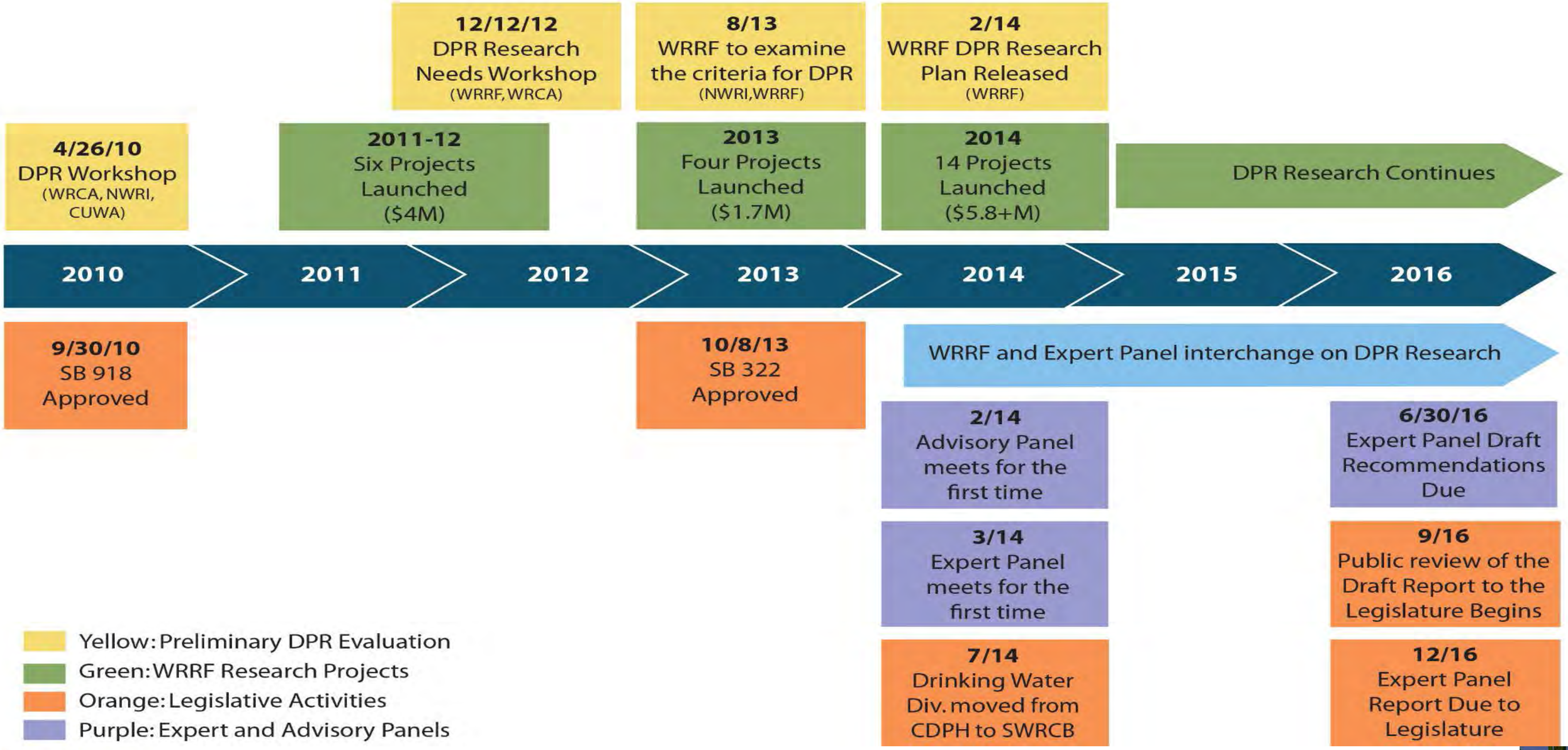
DPR Initiative

- **Partnership of WRRF and WRCA**
- **Goals**
  - Rigorous research (WRRF)
  - Stakeholder awareness & acceptance (WRCA)
  - Regulations for DPR (SWRCB DDW)
- **US $6 million raised from almost 70 entities**
- **Research priorities center around potable reuse as a supply solution to water scarcity/availability across the US -- CA, TX, NM, AZ, CO, GA, etc.**



WATEREUSE

DPR Initiative Timeline



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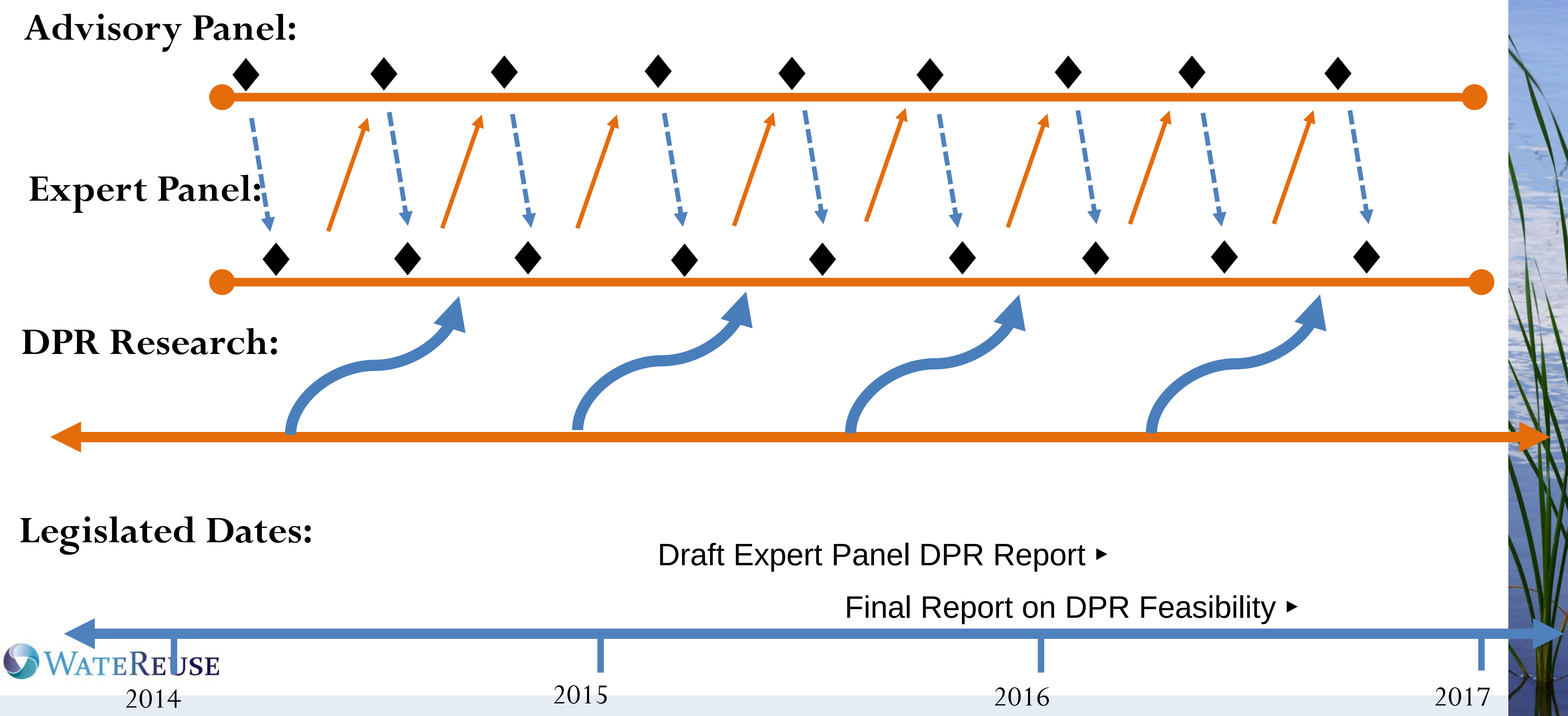
DPR Interactions

◆ = Meeting
▸ = Deadline



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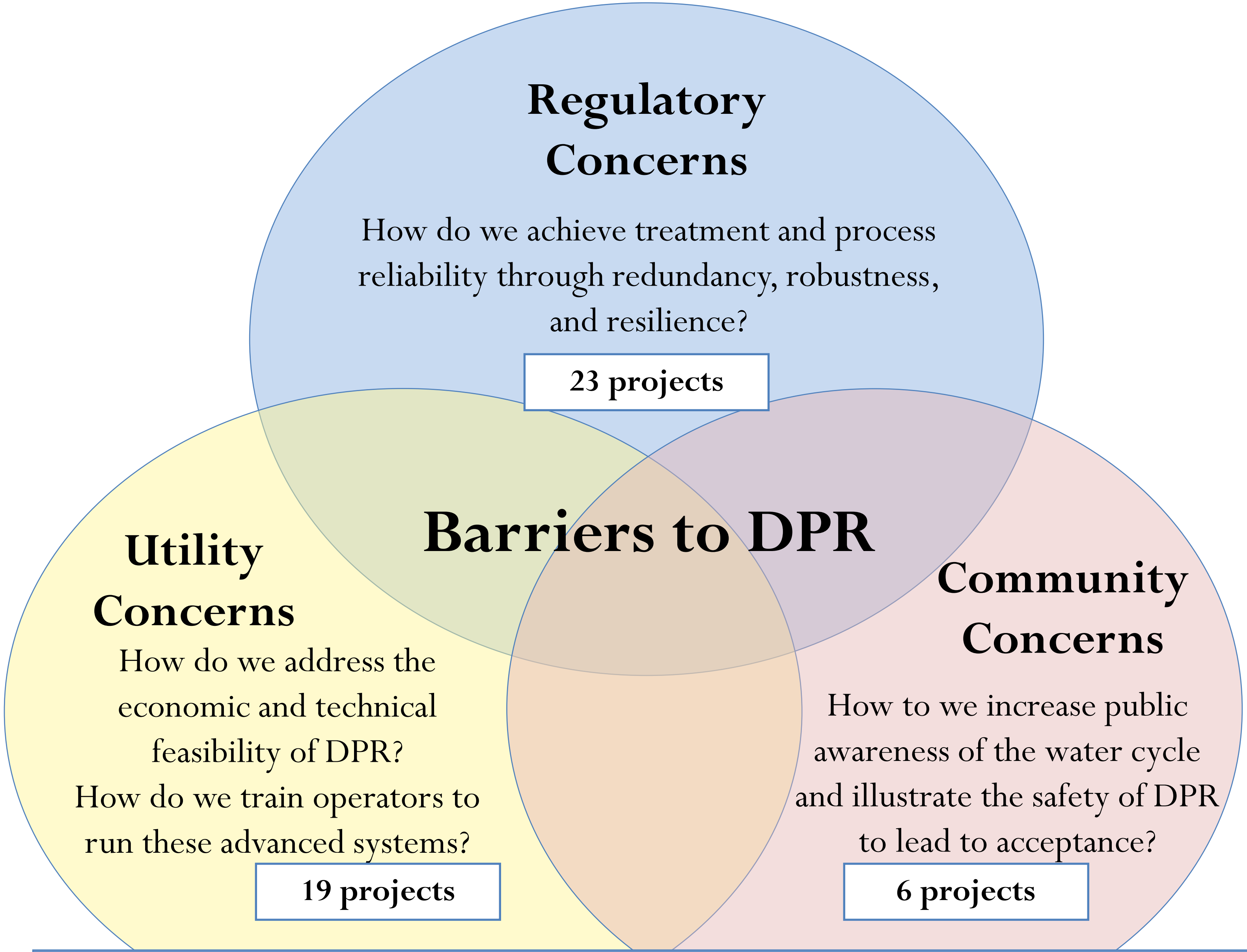
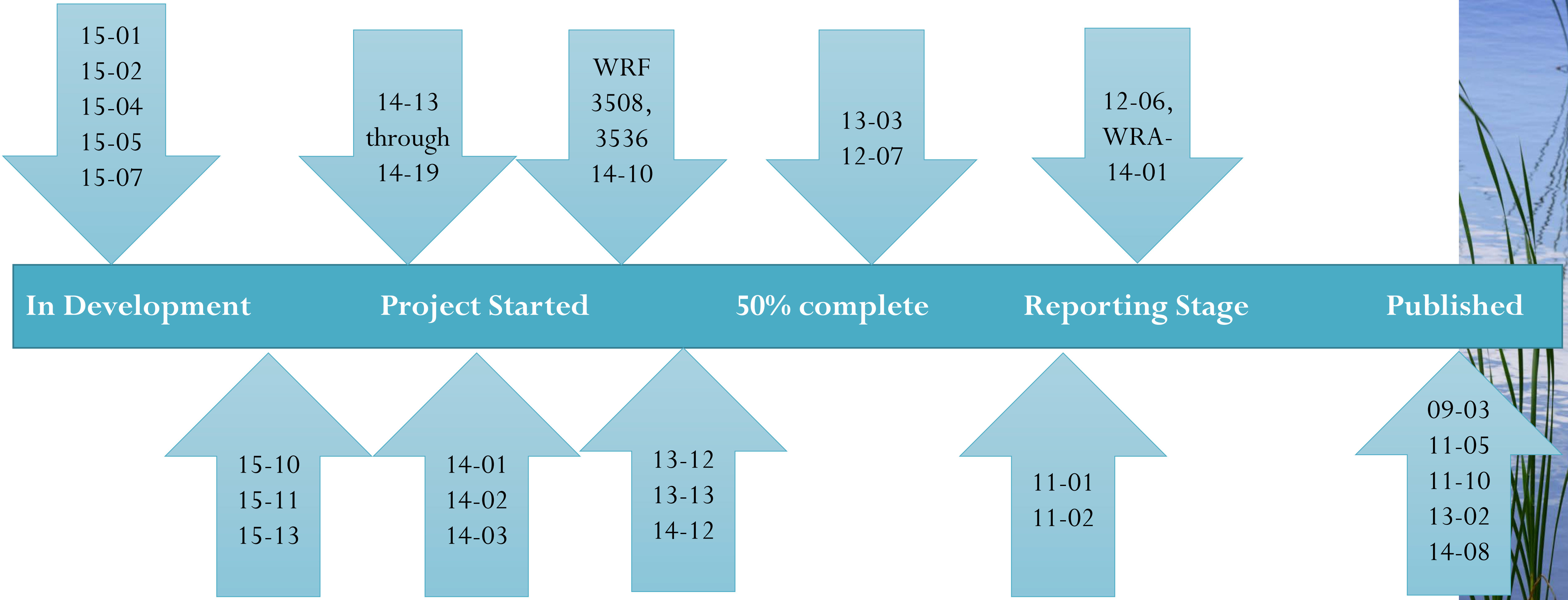


WRRF DPR research program worth over $12M is underway to address these concerns to illustrate the feasibility of DPR

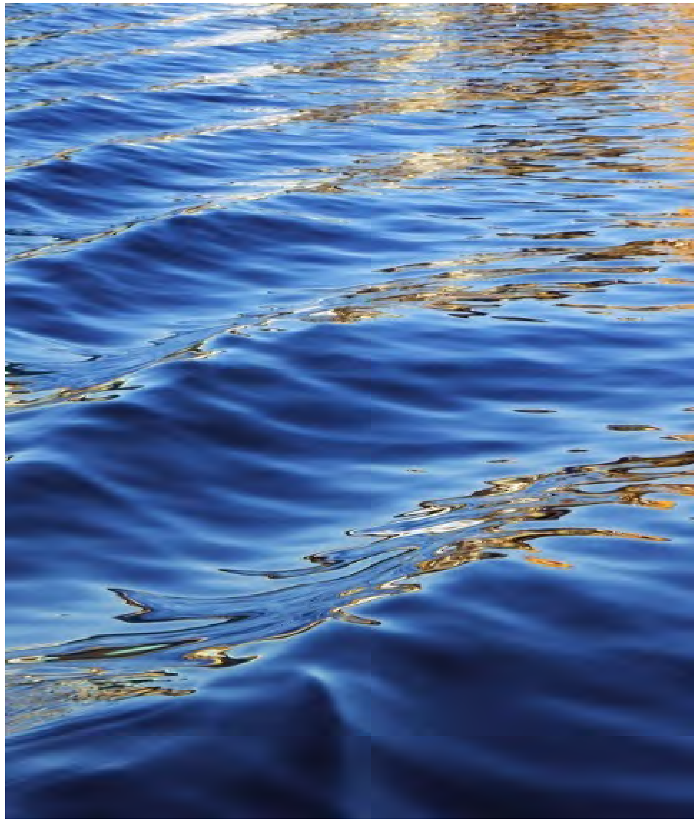
WATEREUSE

Project Status Summary – May 2015



WATEREUSE

2015 Research Program



2015 Solicited Program: DPR Projects

Project Number	Title	Budget
PR-15-01	DPR Research Compilation: Synthesis of Findings from DPR Initiative Projects	$75,000
PR-15-02	Creating a Roadmap for Bioassay Implementation in Reuse Waters: A cross disciplinary workshop	$75,000
PR-15-04	Characterization and Treatability of TOC from DPR Processes Compared to Surface Water Supplies	$350,000
PR-15-05	Developing Curriculum and Content for DPR Operator Training	$100,000
PR-15-07	Molecular Methods for Measuring Pathogen Viability/Infectivity	$350,000

WATEREUSE

2015 Tailored Collaboration Program

Project Number	Title	Principal Investigator	WRRF Budget (total value)
WRRF-15-10	Optimization of ozone-BAC treatment processes for potable reuse applications	Zia Bukhari, American Water	**$120,000** ($512,798)
WRRF-15-11	Demonstration of High Quality Drinking Water Production Using Multi-Stage Ozone-Biological Filtration (BAF): A Comparison of DPR with Existing IPR Practice	Dr. Kati Bell, CDM Smith & Denise Funk, Gwinnett County	**$100,000** ($922,718)
WRRF-15-13	NDMA Precursor Control Strategies for DPR	Roshanak Aflaki, LASAN	**$120,000** ($4,234,260)

FRAMEWORK FOR DIRECT POTABLE WATER REUSE

Colorado Direct Potable Reuse Workshop

May 27, 2015

Jeff Mosher

Executive Director

National Water Research Institute

Fountain Valley, CA

jmosher@nwri-usa.org ♦ +1 714-378-3278

PURPOSE”

PURPOSE

To provide an overview of DPR and to provide a framework for assessing the topics and issues that need to be addressed in the development of future DPR Guidelines.

WATEREUSE
American Water Works Association
Water Environment Federation the water quality people
NWRI National Water Research Institute

NWRI PANEL MEMBERS

George Tchobanoglous, Ph.D., UC Davis (Panel Chair)

Joseph Cotruvo, Ph.D., Consultant (DC)

James Crook, Ph.D., Consultant (MA)

Ellen McDonald, Ph.D., Alan Plummer (TX)

Adam Olivieri, Ph.D., EOA (CA)

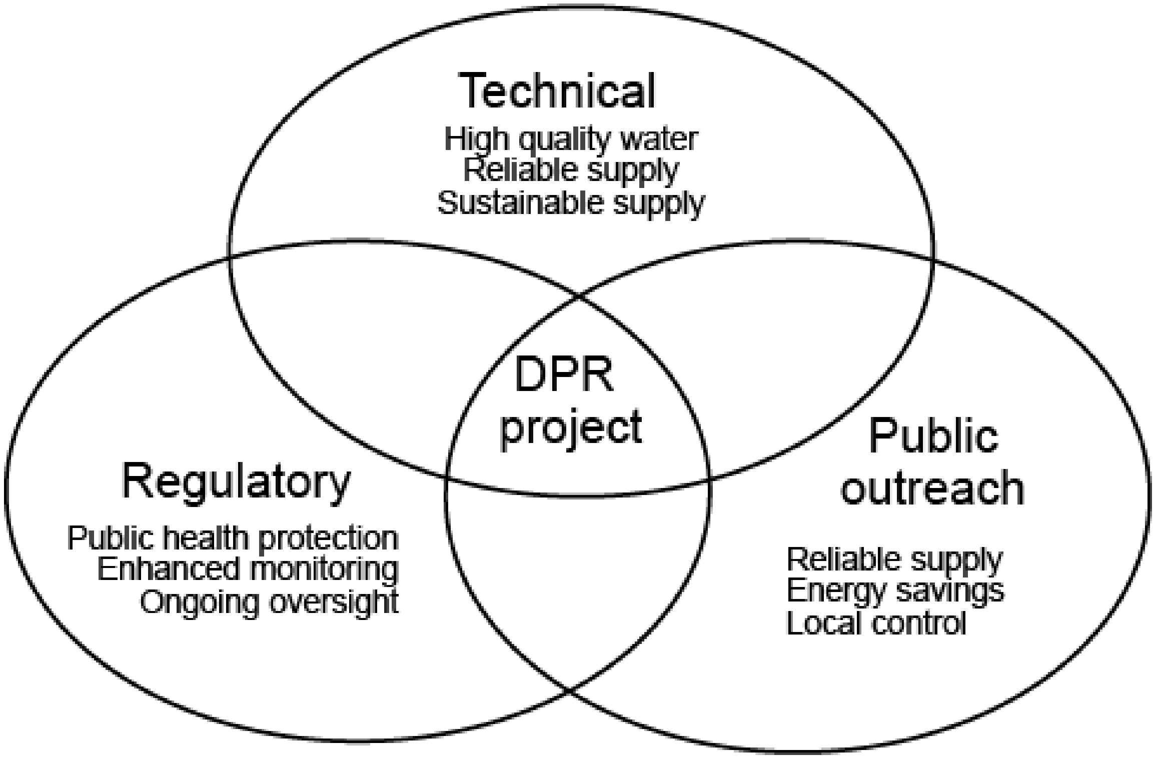
Andrew Salveson, Carollo Engineers (CA)

R. Shane Trussell, Ph.D., Trussell Tech (CA)

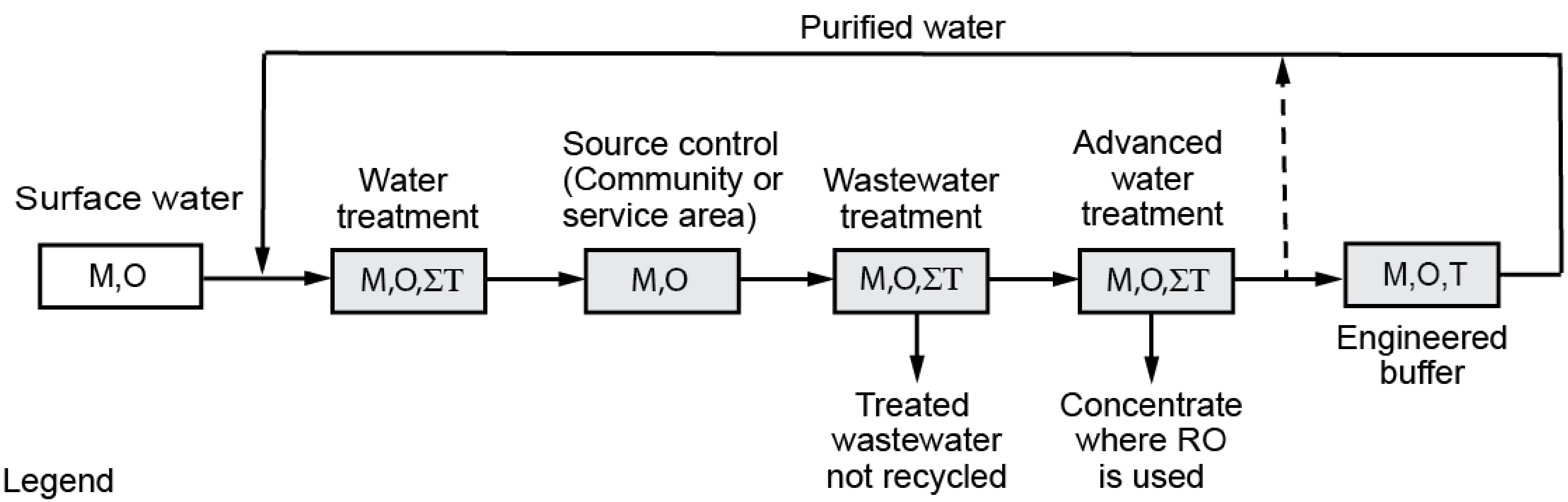
ORGANIZATION OF DPR FRAMEWORK DOCUMENT

1. Introduction
2. What is Direct Potable Reuse?
3. Key Components of a Successful/Sustainable DPR Program
4. Public Health Protection
5. Source Control Programs
6. Wastewater Treatment
7. Advanced Water Treatment
8. Purified and Finished Water Management
9. Monitoring and Instrumentation Requirements
10. Residuals Management
11. Facility Operation
12. Public Outreach
13. Future Developments

KEY COMPONENTS OF A POTABLE REUSE PROGRAM: TECHNICAL, REGULATORY, AND PUBLIC OUTREACH



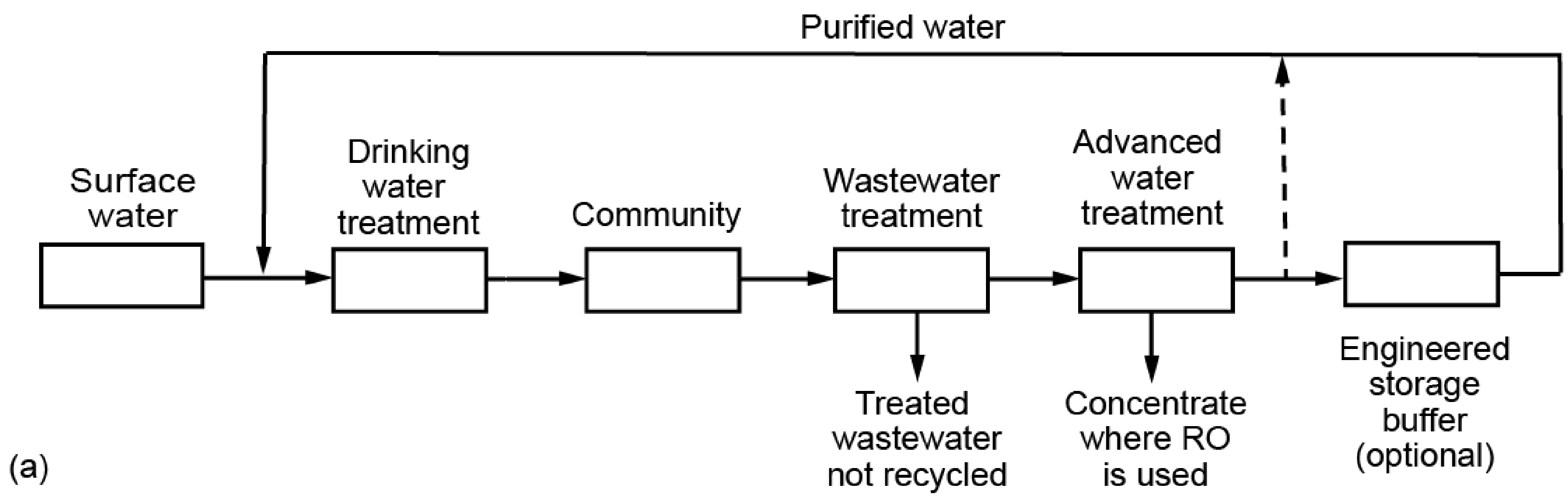
TECHNICAL, OPERATIONAL, AND MANAGEMENT BARRIERS

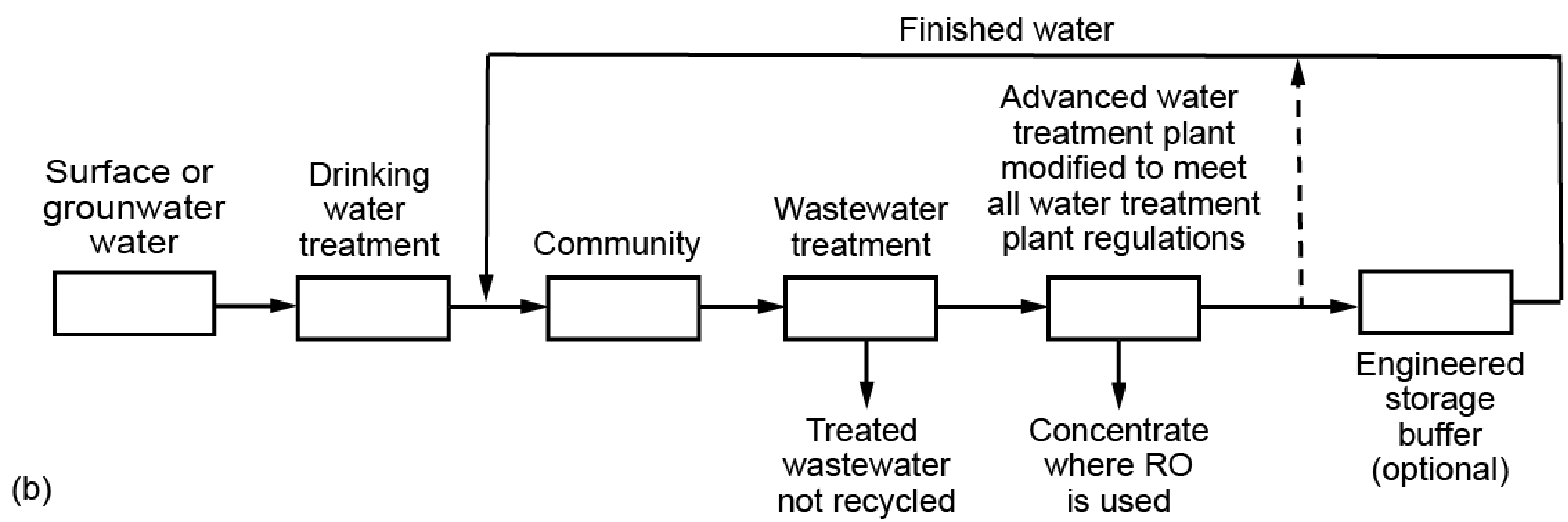


Legend

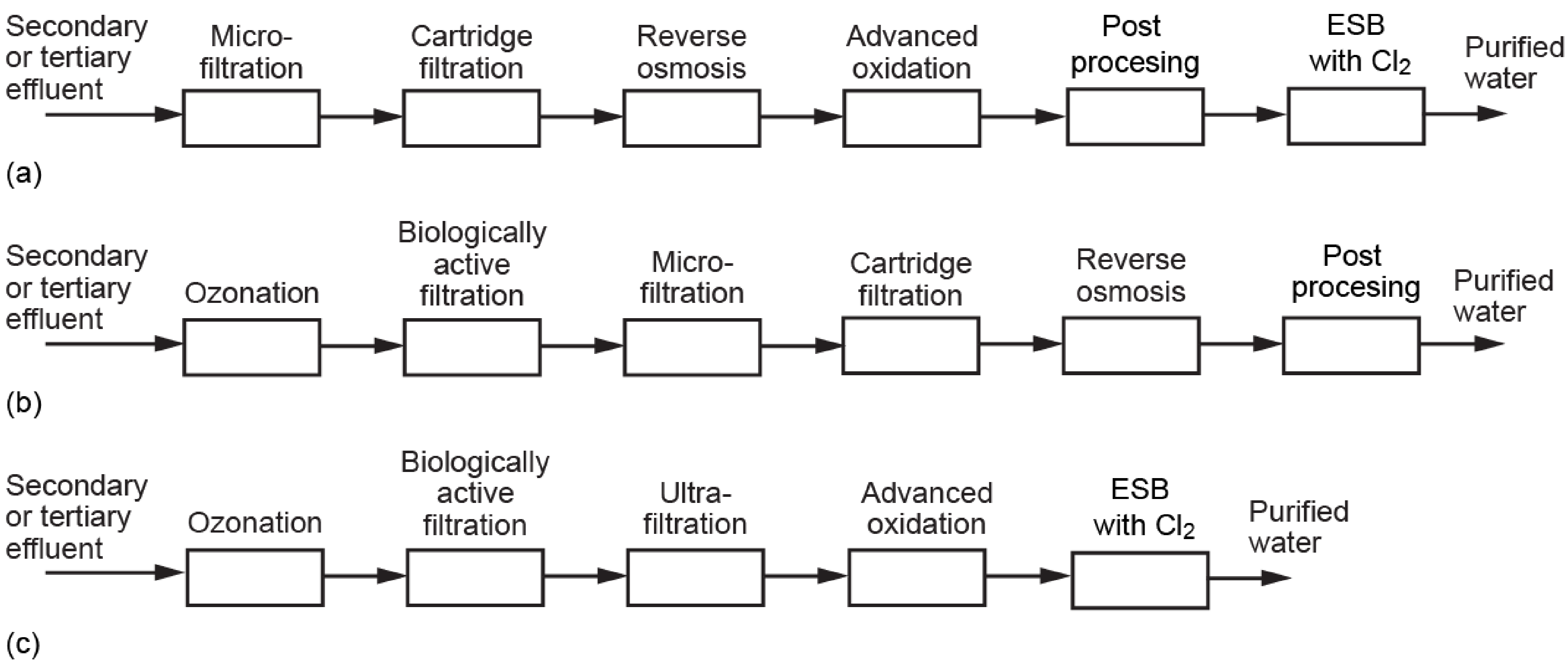
M = Management barrier
O = Operational barrier
T = Technologial barrier
ΣT = Sum of multiple technical barriers

2. OVERVIEW: DIRECT POTABLE REUSE





TREATMENT TRAINS FOR "ADVANCED WATER TREATMENT"



8. FINISHED WATER MANAGEMENT