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BARRIERS TO THE IMPLEMENTATION OF DIRECT POTABLE REUSE IN COLORADO
-DRAFT-

by:
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AOP	Advanced Oxidation Process
AWTF	Advanced Water Treatment Facility
BAC	Biologically Activated Carbon
CDPH	California Department of Environmental Health
CDPHE	Colorado Department of Health and Environment
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-nitrodimethylamine
NF	Nanofiltration
NOM	Natural Organic Matter
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
SWTR	Surface Water Treatment Rule
TCEP	Tris (2-Carboxyethyl) phosphine hydrochloride
TDS	Total Dissolved Solids
TTHM	Total Trihalomethane
UV	Ultraviolet
USEPA	United States Environmental Protection Agency
WQCC	Water Quality Control Commission
WRRF	WateReuse Research Foundation
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

Background

Sustained growth for the State of Colorado requires water. Water reuse is identified by Colorado Water Plan as an important tool in closing the future supply-demand gap. Direct potable reuse (DPR), a technique which directly uses a highly treated wastewater as a supply for a drinking water treatment plant, is potential method for supplementing drinking water supplies in the future.

Objective

The objective of this white paper is to identify barriers to the implementation of DPR in Colorado in four critical areas:

- Regulatory development for DPR systems.
- Technical design of DPR systems.
- Operational issues involving DPR systems.
- Public acceptance of DPR.

This white paper does not consider issues related to water allocation. It is assumed that the implementation of DPR in Colorado must respect existing water allocations.

Conclusions

Direct potable reuse is a technically feasible method for supplementing drinking water supplies. The primary barriers to implementation of DPR in Colorado in the four areas listed above are:

- Need for a regulatory framework addressing DPR suited to Colorado's water quality and supply situation.
- Need for more cost effective methods for disposal of RO membrane concentrate from treatment processes.
- Need for evaluation of non-RO treatment technologies suitable for DPR.
- Need to educate public officials and the public in general regarding potable reuse in order to encourage acceptance of DPR.

Recommendations

The State of Colorado should advance the potential of future DPR projects by:

- Bring together a broad range of experts and interested parties to develop a better understanding of the barriers to DPR in Colorado and produce a roadmap for the State of Colorado to follow in developing DPR as an alternative in bridging Colorado's future water supply gap.

- Partner in research projects that advance knowledge related to the key barriers identified by this white paper, including better RO concentrate management techniques and evaluation of non-RO treatment technologies.
- Partner with other semi-arid, inland states like Arizona and New Mexico that are actively considering DPR as a solution to future water supply gaps.

Chapter 1.0
OVERVIEW

1.1 Introduction

Sustained economic growth for the State of Colorado requires water. The Colorado Water Plan provides 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. Direct potable reuse (DPR) is a technologically feasible and potentially cost effective water reuse technique which is gaining wide acceptance in water limited areas of the nation.

1.2 Objective of White Paper

The objective of this paper is to identify potential barrier to the implementation of DPR in Colorado. It is assumed that the implementation of DPR in Colorado must respect existing water allocations. Direct potable reuse touches on a broad range of issues: legal, political, societal, and economic. It is not the intent of this paper to address all these issues. Instead it focuses on four areas critical to the implementation of DPR in Colorado:

- Regulatory development.
- Technical design.
- Operational issues.
- Public acceptance of DPR.

1.3 Classification of Potable Reuse

Potable reuse can be divided into three categories:

Direct potable reuse is the process of providing highly treated recycled (reclaimed) water to drinking water distribution systems for public consumption and use. The DPR process involves a direct connection between the effluent of an advanced wastewater treatment facility (AWTF) and the supply of a drinking water treatment plant (WTP). This connection may be diluted by native water sources. Taken together, the integrated treatment capabilities of the AWTF and WTP are designed to produce water 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. In the IPR process, the WTP treats water that is under the influence of the effluent of the AWTF. The intent is that the 'identity' of the AWTF effluent, either through natural degradation of contaminants or dilution with native water, is lost as it passes through the environmental buffer. Until recently, environmental buffers were considered mandatory for the implementation of potable reuse.

***De facto* potable reuse** is recognition that, in many cases, the existing source water for a WTP does, in fact, contain wastewater treatment plant (WWTP) effluent. *De facto* potable reuse acknowledges that water treated by the WTP is under the influence of effluent from the WWTP. Ideally, by the time the WTP treats the water, the 'identity' of the effluent of the WWTP is lost, through natural degradation of contaminants or dilution by native water. But the assumption that wastewater effluent is significantly diluted by native water can be erroneous in western states like Colorado where the effluent of a WWTP can be a large percentage of the flow of a receiving stream. For example, flow in the South Platte River downstream of Denver is dominated by wastewater effluent for much of the year.

Examples of *de facto* potable reuse, IPR and DPR are illustrated in Figure 1.1.

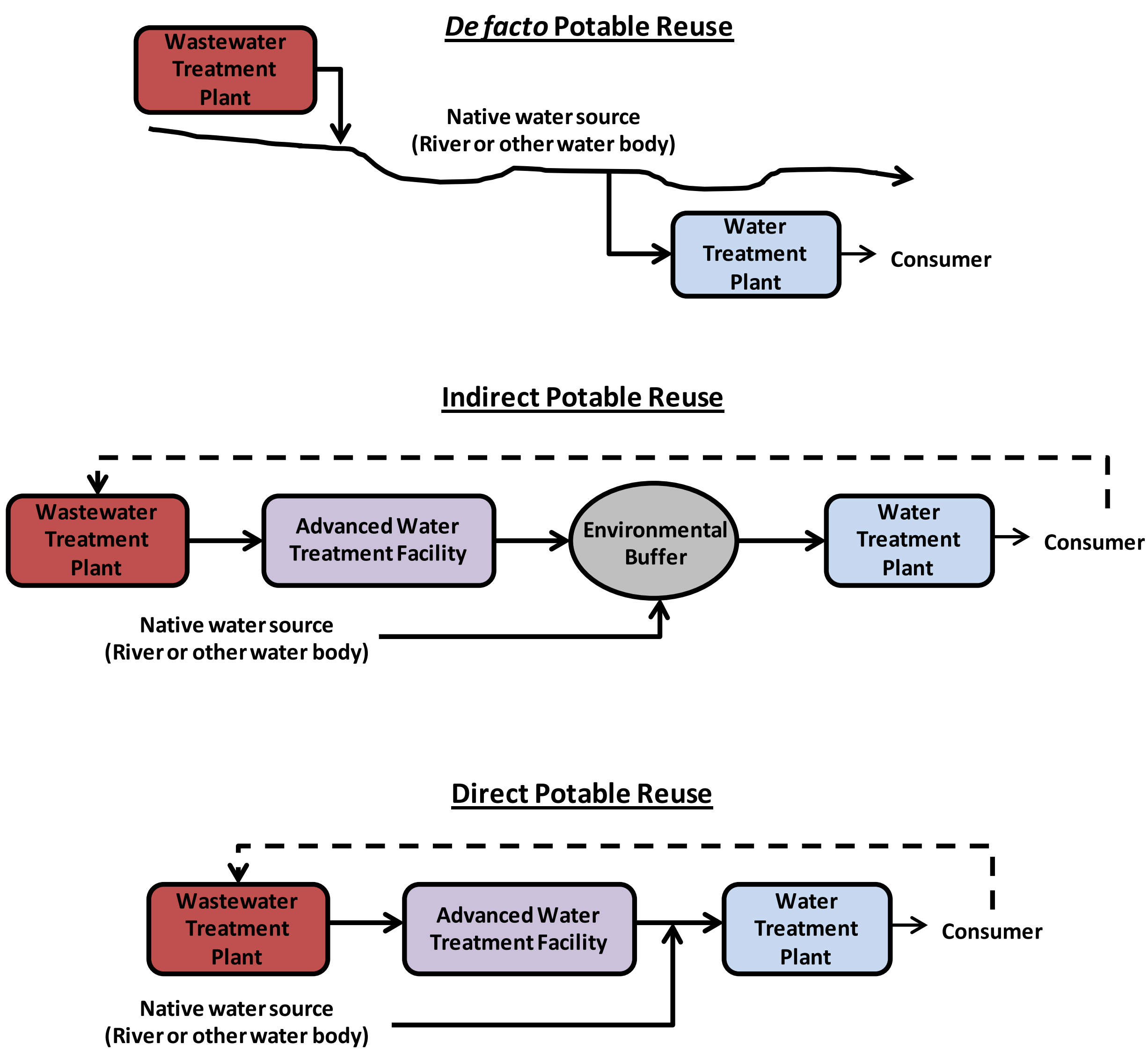

Figure 1.1 Comparison of *De facto*, Indirect and Direct Potable Reuse.

1.4 Potable Reuse in Colorado

De facto potable reuse is a common situation in Colorado. Many of the major rivers in Colorado, such as the Platte, Arkansas, Colorado and their tributaries have drinking water plants located downstream from the outfall of a wastewater plant. The plants on these river systems practice *de facto* reuse. Indirect potable reuse has also been implemented in Colorado, by Aurora's Prairie Water Project. Although DPR was researched extensively by Denver Water during the 1980's and 90's, no DPR projects are currently planned or in operation in Colorado. In the past, DPR has been avoided due to unresolved health concerns, uncertain regulatory environment, possible high cost and potential lack of public acceptance.

1.5 The Changing Environment for DPR

Many technical advancements and additional study of potable reuse have occurred since the conclusion of Denver Water's DPR project. Two reports published in 2012 reflected the advancement of 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. A second report authored by USEPA, *Guidelines for Water Reuse* (USEPA 2012) reflected a dramatic change in the agency's attitude toward DPR. While the prior version of *Guidelines* discouraged DPR, the USEPA now concluded DPR is "…a reasonable option based on (the) significant advances in treatment technology and monitoring methodology of the last decade…"

In anticipation of the changing attitude to DPR 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, in association with a number of interested public and private parties, kicked-off the California Direct Potable Water Reuse Initiative. This initiative is committing over $5.4 million to investigate 22 priority projects related to DPR. Basic and applied research into DPR funded by this initiative is on-going. Findings from this initiative will be applicable to DPR in general and Colorado in particular.

Aurora's Prairie Waters Project has demonstrated successful implementation of IPR in Colorado and many issues regarding IPR in Colorado have been addressed because of this project. Recent research has made a compelling case for DPR as a more efficient approach to potable reuse than IPR (Raucher et al. 2014). 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 project in operation or under construction nationally and internationally.

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 treated wastewater is directly blended in the potable water in the pipeline that feeds the potable water distribution system. The Goreangab project provides 35% of the total water supply for the City of Windhoek.

1.6.2 Village of Cloudcroft, NM

The Village of Cloudcroft, NM is building a DPR system to respond to highly variable potable water demands associated with its popularity as a holiday resort and skiing destination. Highly treated wastewater will be blended with either surface or ground water at a ratio not to exceed 49% recycled water, 51% surface/groundwater in a bending tank with a detention time of approximately 14 days. The blended water then undergoes additional treatment prior to being distributed to consumers. The facility is scheduled to begin operation in 2015.

1.6.3 Big Springs, TX

Since 2013 the Colorado River Municipal Water District has used wastewater from the City of Big Springs, TX as a water source. Highly treated wastewater is blended with surface water and subsequently treated in a water treatment plant and distributed to consumers.

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. Highly treated wastewater is blended with surface water in a lagoon on a 50:50 basis. This water is treated in a conventional water treatment plant and distributed to consumers.

Table 1.1 DPR Projects in Operation or Under Construction.

Country	City, State	Capacity	Facility Began Operation
USA	Cloudcroft, NM	< 0.5 MGD	2015
USA	Wichita Falls, TX	5 MGD	2014
USA	Big Spring, TX	16 MGD	2013
Namibia	Windhoek	15 MGD	1968

Chapter 2.0
Regulatory Barriers

2.1 Challenges in Developing DPR Regulations

The potential implementation of DPR will create unique regulatory challenges for the State of Colorado. Some of these challenges are inherent to DPR while others are unique to Colorado. Current regulation of drinking water, as set by the Safe Drinking Water Act (SDWA) and Colorado regulations assume the treatment of high quality source water, with minimal background anthropogenic (manmade) contamination. These regulations are not adequate to fully protect human health when practicing DPR. Some of the difference when practicing DPR and treating high quality water source, as assumed by the SDWA include:

- DPR regulations must assume the actual presence of pathogenic organisms, not their possible occurrence in source water.
- DPR regulation must consider a broader range of contaminants that may threaten human health, including many that are anthropogenic in nature. These contaminants often occur at trace (nanogram/liter) concentrations.
- DPR regulations must take into consideration the impact wastewater treatment practices have on the character of organic matter in DPR water and the potential implication these difference have on the formation of disinfection byproducts (DBPs).
- DPR regulations must account for the increased potential for the formation of regulated DPBs and the opportunity to form a broader range of unregulated DPBs.

Overlying these challenges is the fact that regulatory development is typically a contentious and difficult process with difference in opinion on how to perform risk assessments and interpret the available science.

Table 2.1 Identifies four major areas of regulatory concern for the implementation of DPR

Table 2.1 Areas of Regulatory Concern for DPR.

Category	Subcategory	Examples	Concern
Microbial pathogens	Virus	Enterovirus, adenovirus, rotavirus, others	Acute infection
	Protozoa	*Cryptosporidium*, *Giardia*	Acute infection
Chemical	Nutrients	Nitrate, phosphorus	Toxicity, aquatic eutrophication
	Metals	Arsenic, chromium, silver, selenium, uranium others	Toxicity Carcinogenicity
	Trace organics	Personal care products, pharmaceuticals, flame retardants, degradation products, others	Endocrine disruption Carcinogenicity
Organic matter	Natural organic matter (NOM)	Humic acids, fluvic acids	Precursor for disinfection byproduct formation
	Wastewater derived (Effluent organic Matter – EfOM)	Soluble microbial products, products from NOM degradation, others	Precursor for disinfection byproduct formation
Disinfection byproducts	Currently regulated	TTHM, HAA, bromate	Carcinogenicity
	Currently unregulated	N-nitrodimethylamine (NDMA) Chlorate	Carcinogenicity Toxicity

In addition to establishing water quality requirements, operational issues, like establishing DPR unique operator certification requirements may be needed as well.

2.2 Colorado Regulatory Environment

Both the SDWA and the Clean Water Act (CWA) include provisions for the states to obtain authority to administer programs under their respective boundaries, so long as the regulations are at least as stringent as set in the federal laws. In obtaining this authority, 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 Colorado Department of Public Health and Environment (CDPHE). CDPHE regulations most pertinent to the drinking water and wastewater industries are summarized in Table 2.2.

Table 2.2 CDPHE Regulations Pertinent to Drinking Water and Wastewater.

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 landscape irrigation, agricultural irrigation, fire protection, industrial, and commercial uses.

Colorado has not established regulations or guidance regarding DPR. As described in the table above, Regulations No. 11 and 41 specify 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. Regulation No. 84 is specifically written for reclaimed water, but it does not address IPR or DPR. 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'[1] reuse. Regulation 86 is currently under development by the WQCC.

2.3 Regulatory Efforts Related to DPR

2.3.1 USEPA

No national regulatory framework for DPR has been promulgated by USEPA. Given the highly site specific nature of DPR, it is unlikely the USEPA 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 framework compatible with existing regulations derived from the SDWA and CWA.

2.3.2 California

California has taken important steps regarding the regulation of potable reuse water. In 2010 the California State Senate directed the California Department of Public Health (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. But 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 proposed for potable reuse via groundwater recharge (item 1 above) and promulgated by California in 2014 provides some insight into the minimum set of requirements that a DPR facility in Colorado may have to meet. 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 potable reuse.

[1] Sources of graywater include discharges from bathroom and laundry room sinks, bathtubs, showers, and laundry machines. Graywater does not include the wastewater from toilets, urinals, kitchen sinks, dishwashers, or non-laundry utility sinks.

Table 2.3 California Water Quality Parameters for Potable Reuse via Groundwater Recharge.

Parameter	Criterion[2]
Virus	$\geq 12 \log_{10}$ reduction
Giardia	$\geq 10 \log_{10}$ reduction
Cryptosporidium	$\geq 10 \log_{10}$ reduction
SDWA contaminants	Meet all Maximum Contaminant Levels (MCLs)
Total nitrogen	$\leq$ 10 mg/L- N
Total organic carbon	$\leq$ 0.5 mg/L - C

In addition to meeting the performance requirements of Table 2.3, California requires 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. It is apparent that any regulatory approach for DPR in Colorado will be predicated on a multi-barrier approach.

When injecting treated wastewater directly into an aquifer, a multi-barrier approach called Full Advanced Treatment (FAT) of the WWTP effluent is mandated by California and has been used in Texas. Full Advanced Treatment consists of microfiltration, reverse osmosis (RO) and advanced oxidation. While FAT is capable of meeting all probable potable reuse treatment requirements, the dependence of the FAT on RO technology limits FAT’s suitability for in-land applications, like Colorado, due to the cost and complexity of concentrate disposal. More information about treatment trains is presented in Section 3.0.

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 and represent a comprehensive approach for specifying what constitutes DPR water that is safe and aesthetically acceptable for human consumption. The WRRF recommendations are a logical point of departure for the

[2] 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.

development of a regulatory framework 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
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
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
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
Pharmaceuticals	• Cotinine • Primidone • Meprobanate • Atenolol • Carbamazepine	1 μg/L 10 μg/L 2 μg/L 200 μg/L 4 μg/L
Steroidal hormones	• Ethinyl Estradiol • 17-β-Estradiol	None detected None detected
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
Aesthetic	• Color • Odor • Total dissolved solids (TDS) • Total Organic Carbon (TOC) • Effluent organic matter (EfOM)	< 5 Apparent color unit ≤ 3 Total odor number (TON) Similar to local supply ≤ 0.5 mg/L-C 90% reduction in fluorescence

[1]Measured from raw wastewater to point of compliance

It should be emphasized that the information in Table 2.4 should be viewed only as a point of departure for Colorado regulatory development. The criteria in Table 2.4 provides a high level of protection from microbial pathogens, which are indeed present in untreated wastewater. Yet some contaminants, like perchlorate or 1-4, Dioxoane, are probably not of great concern for Colorado. The advantage of Table 2.4 is that it takes into account many representative anthropogenic contaminants concentrated in wastewater but not considered for regulation by the SDWA.   Table 2.4 is a logical point of departure for regulatory development in Colorado.

Chapter 3.0
Technical Barriers

3.1 Treatment Required to Implement DPR

In order to implement DPR in Colorado, additional treatment will be required to bridge the gap between the capabilities of existing wastewater treatment plants (WWTP) and drinking water treatment plants (WTP). Conceptually this role would be filled by an advanced water treatment facility (AWTF). The AWTF is designed to supplement the combined treatment capabilities of the WWTP and WTP. Physically the AWTF could be co-located with the WWTP, 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:

- 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 can be thought of as a 'tool box' in which various technologies 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 a higher level of certification to operate that typical treatment plants.

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 (Prairie Water) (Others?)
		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 (Prairie Water)
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

Full advanced treatment (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. Consisting of microfiltration, reverse osmosis and advanced oxidation, FAT is capable of removing natural and effluent organic matter, metals and nutrients as well as removing or destroying trace organic contaminants. In addition, FAT provides an almost absolute barrier to microbial pathogens along with substantial reduction of salinity (Gerrity et al. 2015). The technologies used in the FAT train are mature, and the operational performance of FAT is well documented. While currently only employed for IPR in California, FAT is likely to meet any treatment goal specified for DPR in the future.

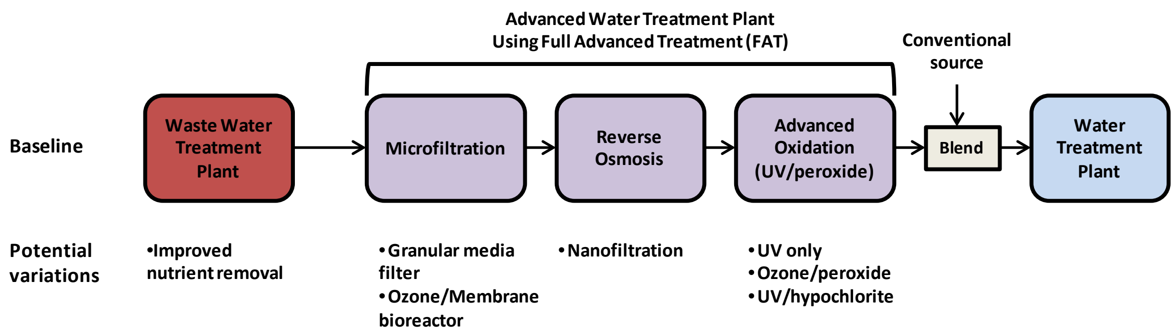

Figure 3.1 DPR Treatment Using FAT

The primary limitation on FAT's suitability for use in Colorado is its dependence on RO technology. While RO is to a large degree responsible for FAT's superior performance, the disposal of concentrate (waste stream) from the RO process is a significant barrier 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. In a pilot project sponsored by the State of Colorado, the volume of concentrate to be disposed from a RO process was reduced from 22% to 2% of the treated flow (Brandhuber et al. 2014). But the technology was judged to be too immature for current use in Colorado.

Alternative treatment trains, built around ozone and biological treatment processes are a possible alternative to FAT. Figure 3.2 present 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 FAT. In addition, these treatment trains do not reduce salinity[3]. Substantial blending with low (and 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 stream to manage the salinity of complete system.

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

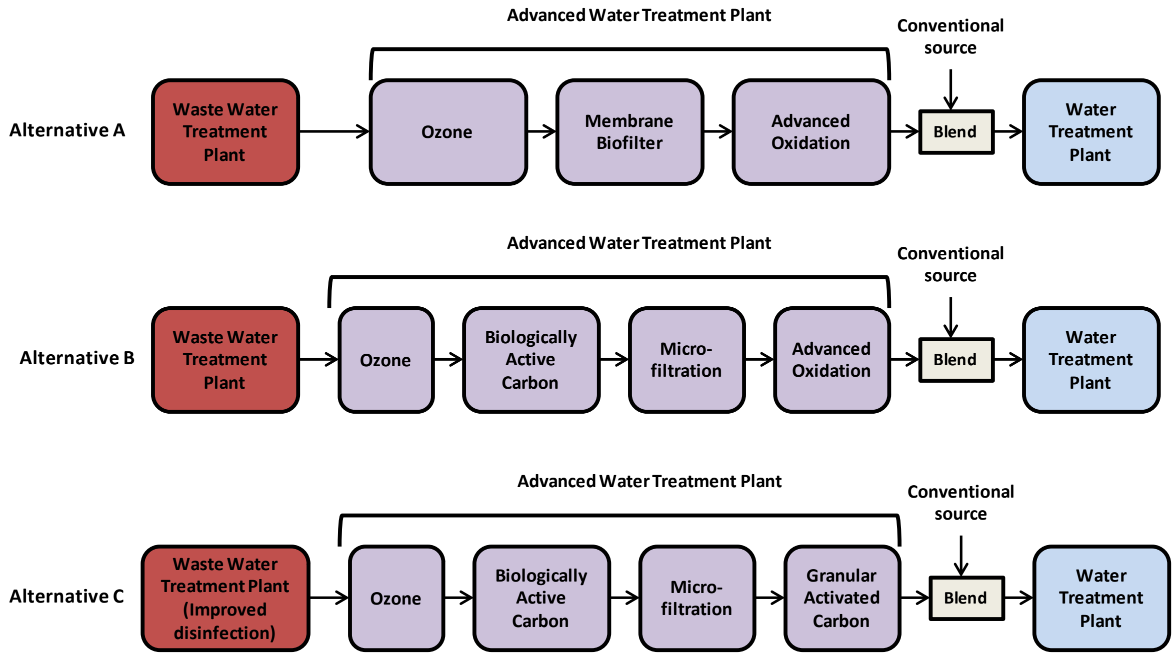

Figure 3.2 Potential DPR Treatment Scenarios Which Avoid RO

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 face severe limitations in Colorado without the development of more cost efficient and practical methods for concentrate treatment and disposal. This is a major barrier to the implementation of DPR in Colorado. Alternative treatment trains, 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
Operation Barriers

4.1 Operability of DPR System

The current state of water treatment engineering is sufficiently advanced that appropriately designed treatment trains, such as FAT, 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. 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 WWTP, 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 speed at which operators of an AWTF can respond to a failure is governed by rapidity at which the failure can be detected. Clearly, the amount of time it takes to detect a failure serious enough to risk public health should not exceed the amount of time it takes for water to complete treatment and be distributed to consumers. An engineered buffer, with residence time greater than the time it takes to verify the safety of the water, will be included in the design of the AWTF. While caution favors a building a large engineered buffer to isolate consumers from off-specification water, improved real-time monitoring capabilities will likely provide better health protection at lesser cost. 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.

Colorado should consider if the use of risk assessment tools, like HACCP, are of benefit in improving the safety and public acceptability of DPR.

4.3 Validation of Pathogen Removal

Exposure to pathogens is a primary concern for potable reuse; yet real-time pathogen detection is not possible at present. 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 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, there is no standard in Colorado nor is there a nationally recognized standard for validating process performance. Multiple criteria exist to define which validation requirements should be met, leading to inconsistency and duplication of efforts. Colorado will probably need to establish validation criteria to take advantage of treatment train validation and rely less on the development of real-time pathogen detection technology.

4.4 Source Control

Source control of inputs to the collection system of the WWTP is more critical for potable reuse than a non-potable reuse scenario. Unauthorized or illegal inputs to the WWTP collection system from industrial, commercial or domestic sources which unintentionally pass through the WWTP could impact the performance of the AWTF. Similarly, infiltration into collection systems during storm events may cause unacceptable variations in the performance of the WWTP. A greater degree of understanding of the impacts of WWTP sources under conditions unique to Colorado should be developed prior to implementation of DPR.

Chapter 5.0
Public Acceptance Barriers

5.1 Acceptance of DPR by the General Public

Probably the largest single barrier to the implementation of DPR is public acceptance. 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.”[4] This cartoon is a humorous illustration of what is called the ‘yuck factor’. The ‘yuck factor’ a deep seated negative response to a practice which is obviously harmful. The ‘yuck factor’ should not be considered silly or irrational; consuming untreated wastewater *is* hazardous to human health. Instead, the ‘yuck factor’ is a natural response by a public who has not been given the 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 which *de facto* reuse occurs in arid states like Colorado.

An Advisory Panel was convened by the WateRuse Arizona in July 2013 to explore 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 that should consider 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.

5.2 Acceptance of DPR by the Public Officials

The support of public officials is also critical to the implementation of potable reuse projects. A WateRuse Research Foundation funded study (Millan et al. 2014) interviewed 34 California State legislators regarding their perceptions and attitudes toward potable reuse. While the political environments in California and Colorado are different, both states face a similar

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[4] Another cartoon, supportive of potable reuse, depicted a dog looking at a toilet thinking, “Ten million dogs can’t be wrong.”

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 segments of the public may find it unfair to drink recycled water 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, gained within Colorado from the Prairie Waters Project and outside Colorado 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 and environmentally responsible manner while respecting existing water allocations. To be protective of public health, water from DPR projects must reduce the presence of:

- Microbial pathogens to levels that poses minimal acute risk to human health.
- Chemical contaminants to levels that poses minimal chronic risk to human health.

At the same time, the water that is produced by DPR must be aesthetically acceptable. The water should 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 human wastes. 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 and academia and researchers. Each group provides unique insights and contributions to the process. State and public officials provide the regulatory framework, 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 to design technologies capable of meeting those standards. All groups must 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.

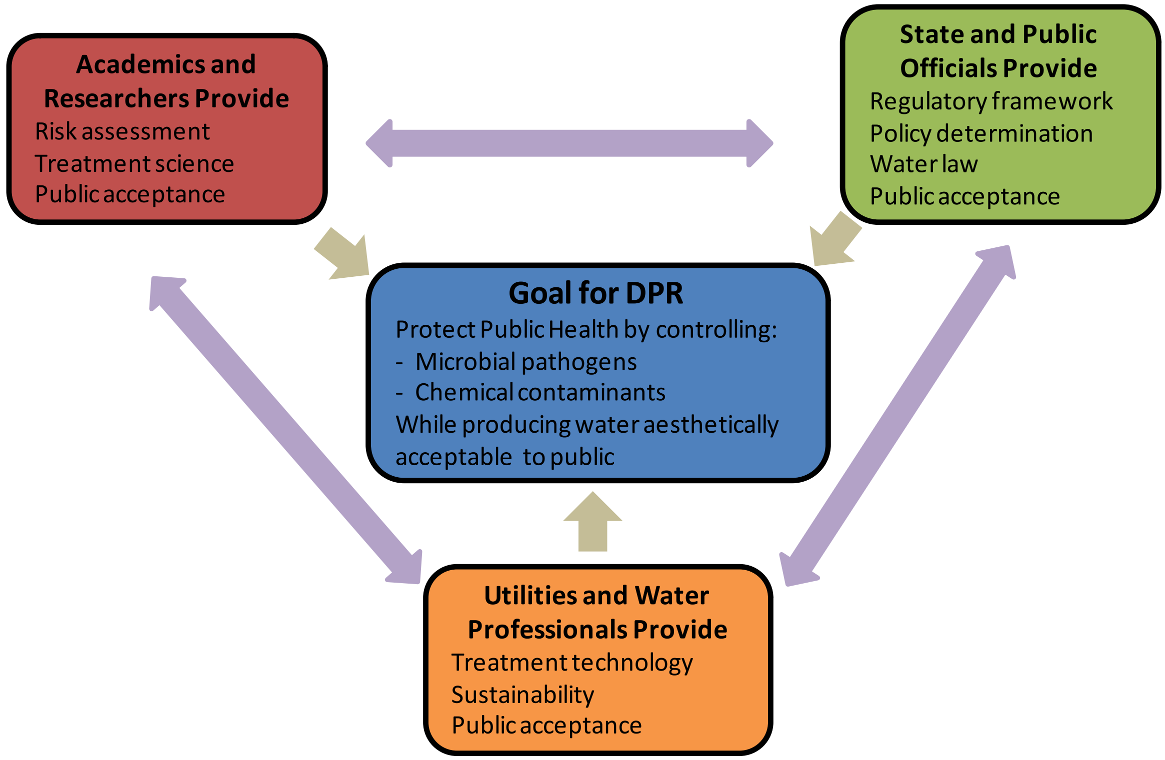

Figure 6.1 Roles in Advancing DPR in Colorado.

Chapter 7.0
Conclusions/Recommendations

7.1 Conclusions

Direct potable reuse is one of a number of tools that the State of Colorado should consider in closing the gap between future water supply and future demand. Existing water treatment science and engineering is technically capable of treating recycled water to potable water standards in a DPR scenario. This white paper reviewed barriers to the implementation of DPR in Colorado related to:

- Regulatory development.
- Technical performance of treatment systems.
- Operational issues related running a DPR system.
- Public acceptance of DPR.

The primary barriers to implementation of DPR in Colorado are the:

- Need for a regulatory framework addressing DPR suited to Colorado's water quality and supply situation.
- Need for more cost effective methods for disposal of RO membrane concentrate.
- Need for evaluation of non-RO treatment technologies suitable for DPR.
- Need to educate public officials and the public in general regarding potable reuse in order to encourage acceptance of DPR.

7.2 Recommendations

The State of Colorado should advance the potential of future DPR projects by:

- Bring together a broad range of experts and interested parties to develop a better understanding of the barriers to DPR in Colorado and produce a roadmap for the State of Colorado to follow in developing DPR as an alternative in bridging Colorado's future water supply gap.
- Partner in research projects that advance knowledge related to the key barriers identified by this white paper, including better RO concentrate management techniques and evaluation of non-RO treatment technologies.
- Partner with other semi-arid, inland states like Arizona and New Mexico that are actively considering DPR as a solution to future water supply gaps.

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Page Number	Section Number	Reviewer	Comment	Response
1	Cover Page	Reviewer 3	Suggest changing this from “Barriers..” to “Defining a Path…” throughout the document.	Name has been revised
1-1	Chapter 1	Reviewer 1	By no means is this the only reason we need water. We want strong economy but we also need water for residential needs, ag, rec, env. I’d reword to be much broader. Grab some language from Water Plan.	Actually the first sentence was taken directly from the water plan.
1-1	Chapter 1	Reviewer 1	May not be “native”, e.g. stream flow could include ag or now diluted further upstream muni return flows from transbasin imports.	Reworded
1-1	Chapter 1	Reviewer 1	For clarity, maybe reword to discuss water quality and constituents of concern rather than “identity and being “under the influence”.	Reworded
1-1	Chapter 1	Reviewer 3	If you decide to keep the “barrier” terminology, change barrier to barriers here	Removing the term barriers from the document
1-1	Chapter 1	Reviewer 3	Suggest saying water rights instead (including all subsequent uses of the term)	OK
1-1	Chapter 1	Reviewer 3	I strongly suggest changing terminology throughout. See WRRF 13-02-1 for some guidance.	Have revised terminology to match Water Reuse glossary on WateRuse web site
1-1	Chapter 1	Reviewer 3	I don’t think we’re simply trying to give it a new name. The environmental buffer can provide natural attenuation, response time (to react to a process upset), and provide some public perception benefits (via “natural” systems). Same comment for next paragraph.	Reworded
1-1	Chapter 1	Reviewer 5	Isn’t the more cost effective water reuse technique to develop irrigation distribution systems (non potable) given the fact that 90% of treated potable water does not go toward human consumption? This should be evaluated also.	Yes, but that evaluation is not the intent of this document. It could be a recommendation of the workshop
1-1	Chapter 1	Reviewer 5	These are considerable barriers that should not be left out.	Absolutely, but beyond the scope of this document
1-1	Chapter 1	Reviewer 5	Again, we do not agree that this is a barrier, at least not worded this way.	Changed
1-1	Chapter 1	Reviewer 5	This is the main barrier.	Maybe, I think we should let the workshop make its own conclusions.
1-1	Chapter 1	Reviewer 5	The highlighted sentence is effectively the crux of the regulatory issue – if there is no interaction with native water, then then Clean Water Act doesn’t apply to the wastewater plant, and the ‘raw’ drinking water is the black water influent to the WWTP. This blurs the line with IPR. We believe that the definition should preclude a discharge to state waters, if possible.	This is a very good point, which I'm not sure how to capture in this section.
1-2	Chapter 1	Reviewer 1	This seems to be obfuscating that we’re talking about WQ. Reword here and throughout to say something more along the lines of “In many cases but the time a downstream WTP diverts water containing WWTP effluent, contaminants have natural degraded and been diluted by other water sources.	Agreed, reworded
1-2	Chapter 1	Reviewer 1	Search and replace or delete the word “native” throughout the doc – and also in pics such at Fig 1.1 below.	Revised
1-2	Chapter 1	Reviewer 1	Hi. I’m not sure how to fix this but aren’t the “Native watersource” and “Environmental Buffer” essentially the same thing? If so, should they be represented the same for de facto and IPR? (maybe for IRP add in parenthesis under River or other water body (intentional environmental buffer). Also, see my comment about not using the work “native”	Revised

1-2	Chapter 1	Reviewer 2	This seems a bit confusing. Are you suggesting blending with native water source prior to entering WTP?	Revised
1-2	Chapter 1	Reviewer 3	This should reference the fact that Colorado's water quality standards and CDPS discharge permit system explicitly recognize (and provide at least some protection for) the fact that this is a common occurrence. Water Supply is a designated use for water bodies that governs the stream standards (e.g., NO3), which in turn drive discharge permit conditions. So de facto reuse is not a new regulatory concept, and it's not "unaddressed" in our current regs, though there could be divergent viewpoints on whether it provides adequate protection.	Agreed, reworded. One observation through… The last several comments are well taken and section has been reworded. But somewhere along the line we need to recognize that the water we are dealing with is fundamentally different in quality (eg municipal wastewater) than a typical water source. This is the crux of the matter.
1-2	Chapter 1	Reviewer 5	Regardless of this concept, since a discharge exists – the clean water act regulates the discharge of the WWTP.	OK
1-3	Chapter 1	Reviewer 1		
1-3	Chapter 1	Reviewer 1	The way this was written read to me like those two reports are all that have been done.	Yes, there are others, but these are the key reports that were game changers
1-3	Chapter 1	Reviewer 1	I get attitudes are changing but a big part of this is we're running out of other options.	Reworded
1-3	Chapter 1	Reviewer 1	I only see one study referenced (Raucher et al. 2014). Much better to reference several studies but if they don't exist (I'm guessing they do), this needs to change to "This study"	True, added other studies
1-3	Chapter 1	Reviewer 1	Add discussion of TX and NM projects and what got them going?	Added
1-3	Chapter 1	Reviewer 2	This sentence seems out of place. Not sure it is relevant to the rest of the section. Might be better to include above as suggested.	Revised
1-3	Chapter 1	Reviewer 3	Aurora historically has not referred to this as an IPR project. Might consider checking with them before referencing it as such throughout this white paper. As written, this implies there is only one IPR project but there are more (e.g., Parker WSD augmentation of Rueter-Hess Reservoir).	Revised
1-3	Chapter 1	Reviewer 5	As shown on the drawing a clean water NPDES permit may not be needed for DPR if the native water is truly drawn in. This is very important for the regulatory structure and should be specifically stated.	Not sure how to handle
1-3	Chapter 1	Reviewer 5	This fact makes it questionable as to the level of effort that should be expended on developing a regulatory structure.	Yes, this is a very valid point.
1-4	Chapter 1	Reviewer 1	Consider starting this list with projects that are closer to home then go outside of the country. I understand that this is a well-established project, but I think more local examples are better. I'd go with projects in place (TX) and then NM, then international	Appreciate the suggestion, but the point of the section is to identify some key project that may be relevant to Colorado, not to provide a comprehensive listing of projects
1-4	Chapter 1	Reviewer 1	A little distracting, sounds like a tourism ad.	Reworded
1-4	Chapter 1	Reviewer 1	Is this level of detail consistent with other examples and does it add to this section? If not, delete this.	Revised to provide similar level of detail for each project
1-4	Chapter 1	Reviewer 1	So this is it in the US for now? What does San Diego have in place? See http://www.sandiego.gov/water/purewater/demo/index.shtml Worth mentioning?	Good point, added reference to San Diego

1-4	Chapter 1	Reviewer 1	There are other DPR projects around the world I believe in Australia, Singapore, and others. Add a few more from more developed countries (discuss above too) and be sure to clearly state that they are illustrative examples only and that others exist – unless you can provide a comprehensive list.	See comment above
1-4	Chapter 1	Reviewer 3	Check numbers vs latest from the DPR initiative progress reports, these are out of date.	Checked against website
1-5	Chapter 1	Reviewer 3	Terminology	OK
1-5	Chapter 1	Reviewer 3	Describe the treatment in more detail (e.g., process overview diagram); this under-represents the incredibly advanced treatment going in at Cloudcroft (and arguably makes it sound "easy"). Similar for Big Spring and Wichita Falls below.	See comment above
1-5	Chapter 1	Reviewer 3	Is it wastewater solely from this city? Or is it just that the CRMWD is located in Big Spring? The "raw water" produced by the plant feeds a source shared by three communities.	Reworded
1-5	Chapter 1	Reviewer 3	Might also mention that DPR is an interim solution for Wichita Falls, the ultimate plan is to transition from DPR to IPR.	Reworded
1-5	Chapter 1	Reviewer 3	Not 16 mgd. Maybe 1.6 mgd?	Revised
2-1	Chapter 2	Reviewer 1	This is definitely not my area of expertise, so defer to comments by others here, but what about communities with existing de facto reuse? Are you saying that the existing SDWA isn't protective of the communities currently using these supplies? Consider framing this in that additional regulations specifically focused on DPR could be more protective given that….	I've reworded. The stock answer is the SDWA is fully protective even in the case of de facto reuse. Yet I think most drinking water treatment folks are uneasy about this.
2-1	Chapter 2	Reviewer 3	This section should be enhanced to reflect: - Regulatory development processes going on in concert with the Big Spring and Cloudcroft projects - Use of expert panels to support those regulatory development processes - Value that we would gain from collaborating with NM, TX, and other states that are developing regs - National guidelines for potable reuse under development - Role of past/ongoing applied research in addressing the regulatory challenges and supporting regulatory development	Section has been revised
2-1	Chapter 2	Reviewer 3	Also should somehow address the fact that regs do not only cover water quality, they also address treatment technologies, monitoring, certifications, and reporting.	Wording added
2-1	Chapter 2	Reviewer 3	Not necessarily. See previous comment on stream standards and discharge permits.	Reworded
2-1	Chapter 2	Reviewer 3	Explain this or soften it – e.g., Other states have concluded that…"	Wording has been softened
2-1	Chapter 2	Reviewer 5	State statute C.R.S. 25-1.5-202 prohibits developing more stringent contaminant standards than the SDWA without extensive effort. A barrier would be a lack of resources to go through such an effort and implement a regulatory structure.	Added
2-1	Chapter 2	Reviewer 5	DPR does not necessarily need to be handled via regulation.	But some pathway needs to be established for utilities to follow

2-1	Chapter 2	Reviewer 5	Actually, the requirement of multiple barriers in the surface water treatment rule to treat for 4 log virus, 3 log giardia, and 2 log crypto assumes a relatively impaired water in terms of quality. Colorado waters are typically higher quality than other waters around the nation, but the SDWA treatment requirement still assumes a basic level of impairment.	Good point - revised wording
2-1	Chapter 2	Reviewer 5	The SWTR assumes that pathogens are actually present.	See comment above
2-1	Chapter 2	Reviewer 5	According to the SDWA, a clear relationship between either acute or chronic threats to human health and the contaminant of concern must be established.	But I don't think the SDWA seriously considers municipal wastewater as the ultimate source that is being treated.
2-1	Chapter 2	Reviewer 5	Short of establishing new regulated DBPs through the SDWA, the regulations cannot take new DBPs into consideration.	But is this approach protective of human health in the case of DPR?
2-1	Chapter 2	Reviewer 5	Implementation and resources to implement regulations are also involved.	Add sentence about sufficient resources need to be available
2-2	Chapter 2	Reviewer 1	Of the items above, which are currently regulated and which are not? Consider adding a column with this heading. Seems a little additional discussion of what's currently regulated and what's not, where this is heading, what research is being done to advance this, etc.. could be helpful.	Added SDWA column
2-2	Chapter 2	Reviewer 2	May want to identify which of these contaminants are currently regulated under the SDWA since trace organics are not currently regulated.	See Table 2-4
2-2	Chapter 2	Reviewer 3	Aquatic toxicity? Why are these items a concern for DPR? Perhaps wrt nitrification in the distribution system?	Revised - see footnote
2-2	Chapter 2	Reviewer 3	Human or aquatic? Aquatic would be N/A.	Revised - see footnote
2-2	Chapter 2	Reviewer 3	Full suite of MCLs should be cited somewhere in this table.	Disagree that this is needed for this level of document
2-2	Chapter 2	Reviewer 3	Should flag these as being not (all) regulated, much like the DBPs are flagged below.	See Table 2-4
2-2	Chapter 2	Reviewer 5	Viruses and Giardia/Crypto are already covered by the SWTR.	True see discussion for Table 2-3.
2-2	Chapter 2	Reviewer 5	Wouldn't matter in 'direct' reuse. More of a concern in 'indirect' reuse	Revised - see footnote
2-2	Chapter 2	Reviewer 5	Covered by existing SDWA	Yes
2-2	Chapter 2	Reviewer 5	These compounds are a concern in non-DPR applications	Revised - see footnote
2-2	Chapter 2	Reviewer 5	Additional regulatory concerns may be the presence of ammonia at levels that will adversely effect the operation of a chlorination system.	Added
2-2	Chapter 2	Reviewer 5	These are not a statute.	Revised
2-3	Chapter 2	Reviewer 1	New uses may be added.	Revised
2-3	Chapter 2	Reviewer 1	See Damian's comments on this. I believe Denver Water is working to add "edible crops" to the list of approved uses.	Revised
2-3	Chapter 2	Reviewer 3	This should be clarified to reflect the statutory prohibition on using Reg 84 to regulate potable reuse. Check the Reg 84 Statements of Basis and Purpose, or the statute.	Revised
2-3	Chapter 2	Reviewer 5	If the DPR project did not include a discharge to waters of the state then Regs. 31, 41 and 84 would not apply.	OK

2-3	Chapter 2	Reviewer 5	Perhaps only if there is a discharge to waters of the state. These may still meet the definition of a wastewater treatment works, and so we will need to investigate applicability to DPR if no discharge to state waters is involved.	OK
2-3	Chapter 2	Reviewer 5	Reg 41 is not governed by the Colorado Primary Drinking Water Regulations	Revised
2-3	Chapter 2	Reviewer 5	The Act doesn't apply at all if the discharge is not to waters of the state.	Revised
2-4	Chapter 2	Reviewer 1	Is this correct? Again, not my area of expertise, but if regs are based on public safety, why couldn't national acceptable constituent levels be developed? Wouldn't/couldn't this just entail adding MCLs/log reductions for new constituents?	Frankly, this is more complex issue than can be address by this paper
2-4	Chapter 2	Reviewer 1	Any rationale for this transfer to would be insightful to include?	Disagree
2-4	Chapter 2	Reviewer 3	Gray water is not going to be used as a source of potable water supply – suggest either explaining the relevance or deleting this paragraph.	Given the current activity in this area, I think it should be mentioned
2-4	Chapter 2	Reviewer 3	Update this to reflect the work that is being done by NWRI, WateReuse, WEF, and AWWA to develop a national guidance manual for potable reuse. Draft due out in April.	Revised
2-4	Chapter 2	Reviewer 3	Regs, probably no – guidance, yes.	Used the word 'guidance'
2-4	Chapter 2	Reviewer 3	Add subsections on what NM and TX are doing to develop DPR regs – they are the only two states that are implementing it at this time, and TX currently has the only two operating DPR systems in the US (or western hemisphere).	We added Texas, but were unable to make a contact in NM.
2-4	Chapter 2	Reviewer 5	This will likely be finished before this paper is published.	Great
2-4	Chapter 2	Reviewer 5	We believe that it would be possible to do this now, and potentially do this with only limited change to regulation and handle primarily via policy and design criteria.	OK
2-4	Chapter 2	Reviewer 5	Suggest deleting.	Disagree, the WRRF recommendations should be considered in determining how Colorado regulates DPR WQ.
2-5	Chapter 2	Reviewer 1	Based on what? Not doubting this statement but what is it based on? Statements by CDPHE?	The multi-barrier approach is fundamental to drinking water treatment
2-5	Chapter 2	Reviewer 3	The State of California / DDW has moved away from using the FAT terminology and no longer uses a name/acronym for this process train. Update throughout this white paper.	Tried to minimize the use of the FAT terminology in paper. But since it is in the literature, it is introduced.
2-5	Chapter 2	Reviewer 5	What is the health basis for the treatment requirements above? Can these even be measured? 10 log is 99.99999999% reduction of giardia. How can that be properly quantified or verified?	You can't. The typical away around this is to assign log-removal credits for particular treatment technologies along with a procedure to validate the integrity of performance. Colorado will need to determine if current assignment of credits is appropriate for DPR
2-6	Chapter 2	Reviewer 1	Does WateReuse have something comparable that could/should also be included? Damian or John might know.	That is what Table 2-4 represents
2-6	Chapter 2	Reviewer 1	Useful to add a column comparing to SDWA regs? Or if the same value could add a footnote and note which constituents are already covered. As someone who is not a water treater, I'm interested in knowing this	Added
2-6	Chapter 2	Reviewer 1	Seems high. Are there health studies for each of these values? I see that PH professionals reviewed them.	This is correct
2-6	Chapter 2	Reviewer 2	This is stated too often in this section.	Deleted
2-6	Chapter 2	Reviewer 5	I am not sure CDPHE agrees with this.	Yes, and this is a point of discussion

2-6	Chapter 2	Reviewer 5	Same comments as above – how can this be verified?	See response above
2-6	Chapter 2	Reviewer 5	Are these levels based on chronic human health data?	They are based on a several criteria - see WRRF 11-02 for details
2-7	Chapter 2	Reviewer 2	I'd be careful with this statement. Are we sure the contaminants haven't been included in either the UCMR or Contaminant Candidate list? Because if they have, then this statement would not be true.	See footnote
2-7	Chapter 2	Reviewer 3	Explain rationale for this statement; wouldn't it be site specific (and of great concern if/where it was prevalent)?	Reworded, also reference to study to justify perchlorate occurrence statement
2-7	Chapter 2	Reviewer 3	Not certain how far we might "depart" from these.	This is a topic of discussion that Colorado needs to address
2-7	Chapter 2	Reviewer 5	Not necessarily – as CDPHE has a burden when creating drinking water regulations to clearly establish the threat to human health. The list of contaminants may have little-to-no effect on human health, therefore setting regulatory limits on these contaminants may be viewed as arbitrary and open to challenges.	Add statement about difficulty CDPHE has in being more restrictive than SDWA regulations
2-7	Chapter 2	Reviewer 5	In developing regulations, implementation must also be considered including: Monitoring location, Monitoring frequency, Reporting, What constitutes a violation? Annual average? Running Annual Average? Any one result over the target? Etc., Database must be developed to handle all the date and run compliance, Public notice language for violations, etc. This is part of why we question whether a regulatory structure is needed when no one is pursuing this kind of project right now. The lack of resources and funding to create such a framework and take on efforts like pathogen inactivation mentioned below is not listed as a barrier in this paper. This should be discussed.	Yes all these things must be done, hence the importance of this discussion
3-1	Chapter 3	Reviewer 3	Cite author for this – to my knowledge these "4 Rs" were first introduced by Pecson et al (most recently published in JAWWA March 2015).	Citation added
3-1	Chapter 3	Reviewer 5	Much of this is driven by need to meet public perception.	Yes
3-1	Chapter 3	Reviewer 5	Great summary!	THANKS
3-2	Chapter 3	Reviewer 5	Is this comment supposed to be in this document?	Deleted
3-2	Chapter 3	Reviewer 5	All granular media plants require an A or B operator anyway.	Made general statement about additional training may be required
3-3	Chapter 3	Reviewer 2	Not sure this is necessary to include.	Deleted
3-3	Chapter 3	Reviewer 2	Not sure this is necessary to include.	Deleted
3-3	Chapter 3	Reviewer 3	There are others. Either delete references to PW, qualify it with an e.g., or list all the installations.	Deleted references
3-3	Chapter 3	Reviewer 3	See previous comment. Terminology no longer in use.	Revised wording
3-4	Chapter 3	Reviewer 1	I'd like to read more hear about this. 22 to 2% is huge so why considered immature and what needs to change? What can we do?	We did extensive pilot testing regarding this topic. Do you want a copy of the report?
3-4	Chapter 3	Reviewer 2	May want to elaborate on this statement. What does immature mean? May also want to explain why RO concentrate is difficult to dispose in an arid state like Colorado.	Reworded
3-4	Chapter 3	Reviewer 3	Modify terminology in the figure to correspond to modifications to terminology in the text (as needed)	Revised

3-4	Chapter 3	Reviewer 3	Suggest adding: Some facilities, including Colorado's East Cherry Creek Valley Water and Sanitation District Northern Water Treatment Facility, have demonstrated the ability to consistently exceed 90 percent recovery using RO technologies.	Reworded
3-4	Chapter 3	Reviewer 3	Reference WRRF research projects that specifically investigated this, e.g., 02- 009, 11-10, 11-02-1, 11-02-2.	So has WERF
3-4	Chapter 3	Reviewer 3	Unclear, is this referring to split stream treatment (X percent through RO, remainder through non-RO)?	Reworded
3-4	Chapter 3	Reviewer 5	This is no different for DPR as opposed to other uses. We do have deep well injection occurring.	Yea, but it isn't a very attractive option
3-5	Chapter 3	Reviewer 5	The City of Sterling is treating with R/O and deep well injecting. Are we sure we can make this conclusion without evaluating the cost more specifically?	And paying a pretty penny too…
3-5	Chapter 3	Reviewer 5	Overall – a lot of great summary info. in this section.	THANKS again
4-1	Chapter 4	Reviewer 1	I get that the risks are (likely) higher for a DPR system but how much of this is relevant regardless of if it's DPR or just a standard WTP? Seems that any drinking water plant is going to have many of these same requirements. Maybe add some clarification language as to where additional attention needs to be paid.	Reworded. But given the source being treated, the consequences of a failure are possibly greater than compared to a traditional source.
4-1	Chapter 4	Reviewer 2	This reads somewhat awkwardly to me. I might suggest something along these lines: Failure of any process within the AWTF should be detected in ample time to prevent unsafe or improperly treated water from reaching the consumer.	Reworded, thanks
4-1	Chapter 4	Reviewer 3	Perhaps. See previous comment suggesting references to WRRF research products. In particular, WRRF 11-10 Risk Reduction Principles for DPR is relevant here. Other ongoing research (e.g., failure response time concepts and strategies per WRRF 12-06) is not published yet but could be referenced from conference proceedings.	Added reference to on-going WRRF project
4-1	Chapter 4	Reviewer 3	Suggest further emphasis on the need for advanced training and operator skills. Just knowing how to run a WRF or a WTP doesn't mean you're ready to run a DPR process, either in terms of the treatment technologies, monitoring requirements, response and reporting requirements, etc. This is one of the NWRI expert panels' and regulators' primary concerns, particularly at Cloudcroft. Also consider referencing WRRF 13-13: Operation and Maintenance Plan and Training and Certification Framework for DPR Systems.	See above
4-2	Chapter 4	Reviewer 1	Maybe this section isn't necessary for this paper? Is it a little in the weeds?	The point I am trying to make is a more formalized risk assessment process will probably need to be implemented by utilities. The idea is to give the reader an idea of what such a program may entail
4-2	Chapter 4	Reviewer 2	This sounds too opinionated rather than sticking to the facts.	Reworded
4-3	Chapter 4	Reviewer 2	Not sure I like the structure of this sentence. In addition, I would suggest recommendations of this nature be captured in the conclusion of the document.	Deleted
4-3	Chapter 4	Reviewer 2	This is a great recommendation and one that should be further evaluated and studied. I think this would be true to any region or state considering DPR and not just Colorado.	Thanks

4-3	Chapter 4	Reviewer 3	Refer back to the 4Rs – the treatment processes have to be able to handle this kind of variability.	True
4-3	Chapter 4	Reviewer 5	This would be an incredible burden for a single state to take on and needs to be managed at the national level. Have CA and TX done this? I doubt it. We do not agree with this.	Yes, Colorado will need to decide which technologies are acceptable for use in Colorado
5-1	Chapter 5	Reviewer 1	I don't know if this is true. People understand – more and more each day – the limitations on our water supply. And who has quantified that public acceptance is a bigger barrier than others raised throughout this paper?	Reworded
5-1	Chapter 5	Reviewer 1	See attached 2015 Poll by Colorado College. A few related excerpts about reuse, not DPR, but is relevant. People want to see more reuse so we can help make the link and stress important of DPR.	Added references
5-1	Chapter 5	Reviewer 1	You might want to rewrite this to just capture the concern rather than having an entire paragraph about the "yuck factor". Could focus on the negative a little less.	Softened, but I believe the point is valid
5-1	Chapter 5	Reviewer 2	I would recommend including the cartoon(s) in the document if you intend to mention them in the document.	That involves securing copyright permission for publication - don't want to go there
5-1	Chapter 5	Reviewer 3	Suggest using alternate terminology in technical papers such as this.	The reuse community doesn't like this term, but it is there, so we should deal with it.
5-1	Chapter 5	Reviewer 3	Suggest replacing or augmenting this discussion with discussion of WRRF 13-02-1 (see also comment below) and Ways of Water video. Is there a product or reference from the SCAPR work that can be cited here? Also consider referencing the outreach work that has been done for years/decades in places such as San Diego, OCWD, El Paso.	Good point, but getting beyond scope of paper.
5-1	Chapter 5	Reviewer 5	We agree this is biggest barrier. It should be highlighted as such much earlier.	Let's see what the workshop says
5-1	Chapter 5	Reviewer 5	We agree with this and would work with an entity to help build public acceptance.	Let's see what the workshop says
5-2	Chapter 5	Reviewer 3	This study was not limited to public officials' views. It provides guidance on potable reuse public outreach at both the state level and the local level.	Added 'as part of'
6-1	Chapter 6	Reviewer 1	Again, I don't think this is the right language	Revised
6-1	Chapter 6	Reviewer 1	Maybe this is how the industry uses this terminology, but you also don't want chemicals at acute levels, right?	Revised
6-1	Chapter 6	Reviewer 1	Not trying to skirt the issue here and get the need to be upfront and honest but this paper is designed to advance DPR so maybe being this descriptive isn't necessary? Also contains dishwasher, sink, washing machine wastewater.	I disagree, the paper is to stimulate a discussion of what would be involved in implementing DPR. We will not know if DPR makes sense for Colorado until we understand what is involved in its implementation.
6-1	Chapter 6	Reviewer 3	Some chemicals pose acute risks too, e.g., NO3.	Good point - reworded
6-1	Chapter 6	Reviewer 3	this amongst a group of Coloradans. An equally (if not more) powerful approach would be to collaborate and exchange information and approaches with regulators and utilities implementing potable reuse in other states. We can learn a lot from their experiences.	Absolutely, the groups mentioned in the figures envision drawing on experts from both in and out of the state
6-1	Chapter 6	Reviewer 5	As indicated above, we question the need to develop a regulatory framework at this time. Who would pay for this when no one is pursuing a DPR project.	Absolutely, If no one is interested, or there are reasons why DPR is not suitable for Colorado, there is no need for this effort. But DPR is a water supply option, and in the context of the water plan it should be investigated.
6-1	Chapter 6	Reviewer 5	We agree with this and doing so without an overly burdensome regulatory framework should be the goal.	Yes

6-2	Chapter 6	Reviewer 1	What about conservation organizations? I'm ok with this figure and am not really advocating for an addition, but FYI in CO conservation/environmental orgs are working to advance reuse by working with state and public officials and water utilities because of the environmental benefits to reusing existing water supplies which decreases the need for new diversions leaving that water in streams. Recent polls show – see attached poll…. We are able to help educate the public and to link their environmental values to reuse and conservation.	Added advocacy groups to text
6-2	Chapter 6	Reviewer 5	Same comment as above regarding regulatory framework.	OK
7-1	Chapter 7	Reviewer 1	See edits made up front in Exec Summary section.	OK
7-1	Chapter 7	Reviewer 3	Explain what we'll partner with them to do. TX and NM are implementing (have implemented in TX) DPR, not just considering. CA is much further down the path and could offer some beneficial lessons learned. Exchanges should be used to advance our approach to technologies, regs, operations, and outreach.	OK
7-1	Chapter 7	Reviewer 5	CDPHE doesn't really view the current regulatory environment as a 'barrier'.	Removed the word barrier
7-1	Chapter 7	Reviewer 5	Same comments as above.	
7-1	Chapter 7	Reviewer 5	Assess the true need and interest in DPR should be recommendation. Based on the need, then a determination about the level of resources and funding to devote to such an effort could be considered.	Absolutely
7-1	Chapter 7	Reviewer 5	What about "encourage the USEPA to develop nationally accepted standards for all states to implement for DPR as part of the existing SDWA". That type of achievement at the national level would ensure that each state would not have to 'reinvent' the wheel.	Maybe that can be a recommendation from the workshop
ES-1	Executive Summary	Reviewer 1	I'm not sure if you need to say this. There isn't a lot of momentum in changing Co water law.	The intent is to point out that water law has a role in the discussion of DPR, even if not covered in white paper
ES-1	Executive Summary	Reviewer 1	I don't think this read quite correct. Does this or something like it work? Could also list what supplies can be used, grab language from the Water Plan maybe.	Actually the words used came from the Water Plan
ES-1	Executive Summary	Reviewer 1	This is going to be the case anywhere so seems obvious so doesn't need to be stated here.	True, but it is an issue for *Colorado*
ES-1	Executive Summary	Reviewer 2	Just a technicality, but I think it would be better to align the paragraphs throughout the document with the edge of the document rather than indent.	The format of the document is specified by WERF

ES-1	Executive Summary	Reviewer 3	Consider changing terminology throughout to purified water, water reclamation facilities, etc. We have limited opportunities to make this a positive discourse in the industry's and public's eyes, and this is one of them. Suggest changing all references to WWTP, wastewater reuse, treated effluent, etc. to more commonly accepted industry terminology.	Have revised terminology to match Water Reuse glossary on WateRuse web site
ES-1	Executive Summary	Reviewer 3	the terminology we use. Applies throughout the document.	Name revised
ES-1	Executive Summary	Reviewer 3	Define RO. Document needs a close read through by an editor for defining acronyms on first use and not again thereafter.	Done
ES-1	Executive Summary	Reviewer 3	The State, as in state agencies? Identify them. Or does this instead intend to refer to water industry stakeholders in Colorado?	Named CWCB
ES-1	Executive Summary	Reviewer 5	It should be clear at some point in the paper that discharge to state waters is or is not involved.	Done later in paper
ES-1	Executive Summary	Reviewer 5	This is the primary barrier in our view and should be listed first and have extensive content of the paper devoted to it.	Chapter 5 discusses this issue
ES-1	Executive Summary	Reviewer 5	CDPHE does not necessarily agree that this is a barrier. We could work through a DPR situation with an entity right now. We believe that many stakeholder would view more regulations as a barrier instead of removing a barrier.	Removed the word barrier, but at present there appears to be no road map for a utility to follow if they decide to pursue DPR
ES-1	Executive Summary	Reviewer 5	Based on the nature of a landlocked state – these seem common issues to all reuse nationwide other than coastal regions. Additionally, disposing of brine is not just a DPR issue, but is a statewide issue. Entities are disposing of brine, it is just costly. We don't see a magic bullet arising here, so perhaps cost should simply be listed as a barrier. DPR is likely inherently costly.	True, hence the recommendation for the State to support development of more cost effective concentrate management
ES-1	Executive Summary	Reviewer 5	Again, we view this as the main true barrier. Should be listed first.	Reworded to avoid the word barrier
ES-2	Executive Summary	Reviewer 1	Above you include a project so NM isn't just considering but is pursuing. Also what exactly does "partner with" mean? Isn't clear to me. Do you mean learn from? Info share with? Other?	Tried to clarify - not sure we want to provide too much detail - The workshop should flesh this out
ES-2	Executive Summary	Reviewer 3	Consider rewording. These have been studied quite a bit already. See references below for specific WRRF projects.	True, but *cost effective* disposal is still elusive
ES-2	Executive Summary	Reviewer 3	To do what? Certainly there are opportunities to collaborate and not start from scratch on things like regulatory development. We should learn from and build on others' experiences and apply that here. We should also make sure we are fully leveraging the vast amount of research work that's already been conducted (and continues) on DPR. Explain what we'll partner with them to do. TX and NM are implementing (have implemented in TX) DPR, not just considering. CA is much further down the path and could offer some beneficial lessons learned. Exchanges should be used to advance our approach to technologies, regs, operations, and outreach.	True, included in recommendations
ES-2	Executive Summary	Reviewer 5	EPA should like be involved in the group.	Yes
ES-2	Executive Summary	Reviewer 5	And Texas, right?	Yes