WateReuse Colorado
Advancing Direct Potable Reuse to Optimize Water Supplies and Meet Future Demands

Technical Memorandum 3

POTABLE REUSE PLANNING TOOLS AND CASE STUDIES

FINAL | September 2018

WateReuse Colorado

Advancing Direct Potable Reuse to
Optimize Water Supplies and Meet Future Demands

Technical Memorandum 3
POTABLE REUSE PLANNING TOOL AND CASE STUDIES

COLORADO REGISTERED
JOHN PETER REHRING
31351
Digitally signed by John P. Rehring
Contact Info: Carollo Engineers, Inc.
Date: 2018.09.06 08:54:55-06'00'
PROFESSIONAL ENGINEER

Contents

Tables

Figures

Abbreviations

AWTF	advanced water treatment facility
BAF	biologically active filtration
Binney	Peter D. Binney Water Treatment Facility
CDPHE	Colorado Department of Public Health and Environment
Ct	product between chlorine concentration (C) and contact time (t)
DPR	direct potable reuse
EEQ	estradiol equivalency
GAC	granular activated carbon
GMF	granular media filtration
H_2O_2	hydrogen peroxide
LRV	log removal value
MCL	maximum contaminant level
MF	microfiltration
mg/L	milligrams per liter
mJ/cm^2	millijoule per square centimeter
mgd	million gallons per day
mg/L	milligrams per liter
NDMA	N-nitrosodimethylamine
NF	nanofiltration
ng/L	nanograms per liter
PCWPF	Plum Creek Water Purification Facility
PCWRA	Plum Creek Water Reclamation Authority
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
RO	reverse osmosis
RBF	riverbank filtration
RWHTF	Robert W. Hite Treatment Facility
SCWRF	Sand Creek Water Reuse Facility
TM	technical memorandum
TOC	total organic carbon
TOrC	trace organic chemicals
USEPA	United States Environmental Protection Agency
UV	ultraviolet
UV AOP	ultraviolet light advanced oxidation process
WRCO	WateReuse Colorado

Technical Memorandum 3

POTABLE REUSE PLANNING TOOL AND CASE STUDIES

This technical memorandum (TM) provides a brief summary on water quality and public health pertaining to direct potable reuse (DPR) and a case study evaluation of three utilities in Colorado. Planning tools for DPR already exist. However, based on technology improvements and interest expressed by Colorado utilities for alternatives to reverse osmosis (RO) based treatment trains, updates to these planning tools were considered necessary to evaluate advanced water treatment facility (AWTF) options.

To apply planning tools to DPR systems, it was first important to understand the level of pathogen/target chemical removal provided by various treatment technologies and the associated removal levels. WateReuse Colorado (WRCO) TM 1 (July 2018) summarized other states' approaches to potable reuse regulation. DPR regulations are under development for Colorado. The Colorado Department of Public Health and Environment (CDPHE) is considering a range of approaches implemented by other states, or a combination of other states' approaches that may best serve Colorado utilities' needs while protecting public health.

1.0 Introduction to the Potable Reuse Planning Tool

A potable reuse planning tool (IT3PR, short for "Integrated Treatment Train Tool for Potable Reuse") was originally developed as part of WateReuse Research Foundation Project No. 11-02 to evaluate alternative treatment trains for various potable reuse scenarios (Trussell et al., 2016). This tool was then augmented and refined through funding from the Texas Water Development Board to include additional aspects important to planning and permitting DPR projects in Texas (Steinle-Darling et al., 2016).

A third update to the tool was completed as part of this project in order to accommodate specific unit process needs for potential Colorado-based DPR scenarios. A summary of the tool, and the updates made for this project are provided in this section.

This third updated version of the IT3PR tool completed for WRCO included an extensive back-end reprogramming effort that migrated the existing code base from Microsoft Excel into Python for more streamlined and reliable calculations, which is an important step as the tool grows in complexity. An updated graphical user interface (such as a web portal) was not within the scope of these updates but version 3.0 of the tool allows users familiar with Python to quickly and easily run different scenarios with much more flexibility and accuracy than previous versions.

1.1 Pathogen and Chemicals Tracked within the Planning Tool

Several states' approaches were highlighted in WateReuse Colorado TM 1 on regulating DPR for Colorado. California's standards for pathogen removal in indirect potable reuse applications (surface or groundwater augmentation) are summarized in Table 1 alongside Texas' minimum pathogen removal standards for DPR applications. Importantly, California's potable reuse standards for pathogen removal are based on treating raw wastewater to potable quality, while Texas' standards are for treating secondary- or tertiary-treated wastewater to potable water quality. Both sets of standards are used as benchmarks to compare the removal of these three pathogens calculated by the tool for the Colorado potable reuse case studies discussed below. However, the Texas standards are more applicable to the case studies as secondary (or tertiary) effluent is the starting point for analysis in each case.

Table 1 Pathogens Tracked by the Planning Tool with DPR Log_{10} Removal Goals

Parameter	Default (California)	Data Driven (Texas' Minimum Requirements)
Starting Location for Log_{10} Removal Calculations	Raw Wastewater	Secondary Effluent
Virus	12-log	8-log
Cryptosporidium	10-log	5.5-log
Giardia	10-log	6-log

Table 2 provides a summary of the chemical parameters tracked by the planning tool, which represent key industry reference standards for chemical constituents potable reuse applications.

Table 2 Chemical Parameters Tracked by the Tool with Concentration Goals

Parameter	Goal Concentration in Drinking Water
Total Organic Carbon (TOC)	2-3 mg/L(1)
Nitrate as N	7 mg/L(2)
Trace Organic Chemicals (TOrC)	1 µg/L(3)
Estradiol Equivalency (EEQ)	1 ng/L(3)
N-nitrosodimethylamine (NDMA)	10 ng/L(4)
Perfluorooctanoic Acid (PFOA) + Perfluorooctane Sulfonate (PFOS)	70 ng/L (combined)(5)

Notes:
(1) Realistic TOC goals for non-RO based treatment range between 2 milligrams per liter (mg/L) and 3 mg/L. Similar to conventional surface water treatment, TOC must be limited in order to prevent excessive formation of disinfection byproducts; precise TOC goals should be established based on site-specific evaluations.
(2) The United States Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for nitrate as N = 10 mg/L. A value of 70% of the MCL was chosen to provide a safety margin to the MCL.
(3) Steinle-Darling et al. (2016)
(4) California State Water Resources Control Board Division of Drinking Water Notification Level of 10 ng/L for NDMA.
(5) USEPA Health Advisory level of 70 ng/L for the total concentration of PFOA and PFOS.
µg/L micrograms per liter
mg/L milligrams per liter
ng/L nanograms per liter

1.2 Unit Treatment Processes Modeled Using the Planning Tool

For purposes of the WateReuse Colorado project, RO was considered to be a proven and well-understood treatment technology. In addition, several Colorado utilities expressed an interest in non-RO based processes due to brine disposal challenges. For these reasons, RO was not evaluated in this pathogen removal treatment train analysis, while recognizing that it remains an important option for treatment. The treatment technologies modeled for the case studies include:

- River bank filtration (RBF),
- Aquifer recharge and recovery,
- Conventional flocculation/sedimentation treatment (conventional),
- Softening,
- Ozone,
- Biologically activate filtration (BAF),
- Microfiltration (MF),
- Granular media filtration (GMF),
- Granular activated carbon (GAC),
- UV (UV) Disinfection,
- UV advanced oxidation process (UV AOP),
- Free chlorination, and
- Chloramination.

Additional treatment processes, such as nanofiltration, RO, and others are available within the planning tool. Details regarding the effectiveness of most treatment processes and how they are represented within the planning tool are provided by Steinle-Darling et al (2016). The processes introduced as part of the current set of updates are an exception, and include:

- Riverbank filtration,
- Conventional water treatment (flocculation, sedimentation, and filtration), and
- GAC adsorption.

These are not discussed in the existing tool manual (Steinle-Darling et al., 2016) and thus more detail is provided below.

1.3 Riverbank Filtration

In accordance with the USEPA's Long Term 2 Enhanced Surface Water Treatment Rule Microbial Toolbox, riverbank filtration is awarded *Cryptosporidium* and *Giardia* log removal value (LRV) credit as a function of setback from the river, with no credit for setbacks less than 25 feet, 0.5-log credit for setbacks between 25 feet and 50 feet, and 1-log credit given for setbacks of more than 50 feet. For the City of Aurora/Prairie Waters case study, greater than 50 feet of setback were assumed.

TOC removal is set at a constant rate of 30 percent in accordance with project experience. No other chemical removal is assumed due to a lack of industry-wide data. Site specific chemical monitoring could be utilized if data exists to support an individual constituent.

1.4 Conventional Water Treatment

For conventional treatment, pathogen removal credits were given in accordance with standard surface water treatment guidance: 2-log virus, 2-log *Cryptosporidium*, and 2.5-log *Giardia*. In addition, a blanket 15 percent TOC removal is assumed to capture a relatively conservative value across the possible spectrum of TOCs. This may overestimate TOC removal in low-TOC systems; however, in those systems TOC is unlikely to represent the most important treatment challenge. No other chemical removal is assumed.

1.5 Granular Activated Carbon

GAC is difficult to model as a single unit process as its performance varies dramatically as a function of influent TOC and other background constituents in the water. Also, it does not operate as a steady-state process; filtrate concentrations are low at first, and rise as various chemicals begin to break through. Average treatment effectiveness is wholly a function of when the media is replaced.

For the purposes of this model, GAC was modeled as a polishing process after most if not all TOC has been removed from the water. Effectively, the planning tool recommends that this GAC unit process model only be employed after nanofiltration (NF), RO, or the combination of ozone and biofiltration.

In that context, the GAC process is modeled as providing 30 percent removal TOC, 80 percent removal of TOrCs, 80 percent of EEQ, 50 percent of PFOS+PFOA. No pathogen removal credit is given for GAC, nor is any removal of NDMA assumed.

1.6 Other Process Adaptations

Some processes in each case study were modeled using a similar process. For example, chemical softening was modeled as conventional treatment and aquifer recharge and recovery was modeled as a direct-injection process. These adaptations are discussed on a case-by-case basis below.

2.0 Colorado DPR Case Study Analyses Using the Updated Planning Tool

As a demonstration of the updated planning tool, hypothetical future DPR supply systems were assessed for three Colorado utilities. A treatment gap analysis was performed for each of the three DPR scenarios to model various treatment trains and to compare the resulting water quality relative to the pathogen and trace chemical standards presented earlier in this TM.

The three participating utilities are not currently pursuing implementation of DPR, but volunteered to help provide data and insight into what a DPR scenario might entail should they choose to integrate DPR into their future water supply systems. The participating utilities included the City of Aurora (City), Denver Water, and Plum Creek Water Reclamation Authority (PCWRA) in conjunction with the Town of Castle Rock. Results from each case study provided valuable insight into the use of the updated planning tool, and into the effectiveness of planned treatment technologies relative to finished water quality goals for pathogens and TOrCs.

2.1 City of Aurora

The City provides drinking water to its customers and non-potable reclaimed water from its Sand Creek Water Reuse Facility (SCWRF) to irrigation users through a dedicated distribution network. A constant rate of approximately 5 million gallons per day (mgd) of wastewater from the City is treated year-round at the SCWRF; the remainder is sent to a regional water reclamation facility for treatment. Of the 5 mgd treated at the SCWRF, tertiary treated reclaimed water is either pumped to non-potable reuse customers or discharged to Sand Creek, depending on seasonal reuse demands. Portions of the water discharged to Sand Creek or treated at the regional water reclamation facility are eventually confluent to the lower South Platte River, from which the City withdraws supplies as part of an indirect potable reuse project referred to as its Prairie Waters system.

As one of the three case studies for this project, a DPR scenario was analyzed for the City where tertiary treated denitrified reclaimed water from the SCWRF would be treated to potable standards. For this analysis, it was assumed that SCWRF discharges could be recovered from Sand Creek via alluvial wells, providing RBF treatment, then recharged in intentional aquifer recharge and recovery wells for further treatment benefits before conveying the water to the South Platte treatment train at Aurora's existing Peter D. Binney Water Treatment Facility (Binney). Altogether, the modeled treatment train includes RBF ("Bank Filtration"), aquifer recharge and recovery ("Direct Injection"), softening, UV AOP ("Advanced Oxidation"), media filtration, and GAC (Figure 1). To accommodate the planning tool's limitations, the softening and media filtration steps were modeled as a single "conventional treatment" step.

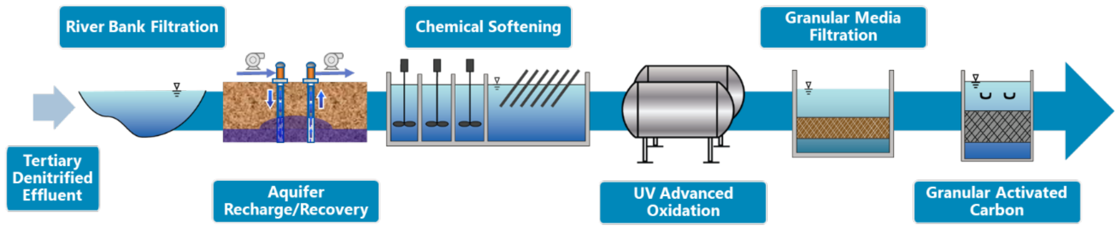

Figure 1 City of Aurora DPR Case Study Treatment Train

Pathogen removal was calculated with several design assumptions, including 1 month of travel time in the aquifer recharge/recovery process and a UV dose of 700 millijoules per square centimeter (mJ/cm^2) at the Binney facility. The contributions of each process to virus (9-log total), *Giardia* (9.5-log total), *Cryptosporidium* (9-log total) inactivation are shown in Figure 2. While the analysis shows adequate pathogen credits to meet the minimum "baseline" treatment requirements for a DPR project using the "data driven" approach applied in Texas, and the treatment provided by SCWRF is excellent (suggesting treatment requirements close to the baseline numbers may be appropriate), case-specific pathogen data for SCWRF effluent would be needed to confirm the adequacy of this treatment process for pathogen inactivation in a DPR scenario.

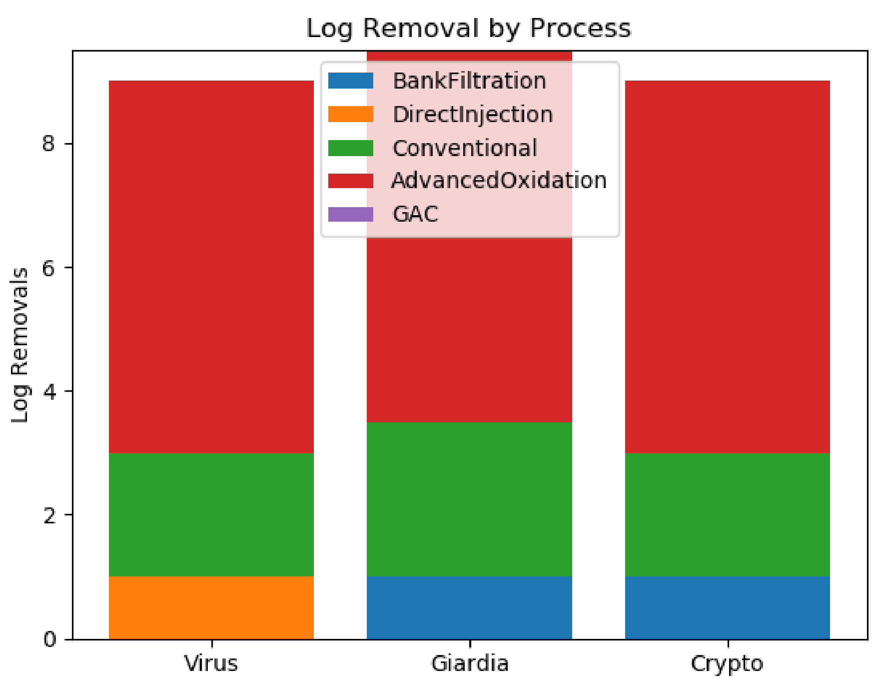

Figure 2 Pathogen Removal Results for the City of Aurora DPR Case Study

Chemical removals are summarized in Figure 3. Starting concentrations for various chemicals were left at the default concentrations for "tertiary denitrified effluent" which constitute TOC = 5 mg/L, Nitrate as N = 5 mg/L, TOrCs = 3 µg/L, EEQ = 2 mg/L, NDMA = 20 ng/L, PFOS+PFOA = 10 ng/L. None of these constituents were modeled to be present above goal values after treatment. It is noted that prior efforts have shown NDMA removal through RBF, but due to the lack of long-term monitoring data for NDMA, the standard modeling assumptions of no NDMA removal through RBF were assumed.

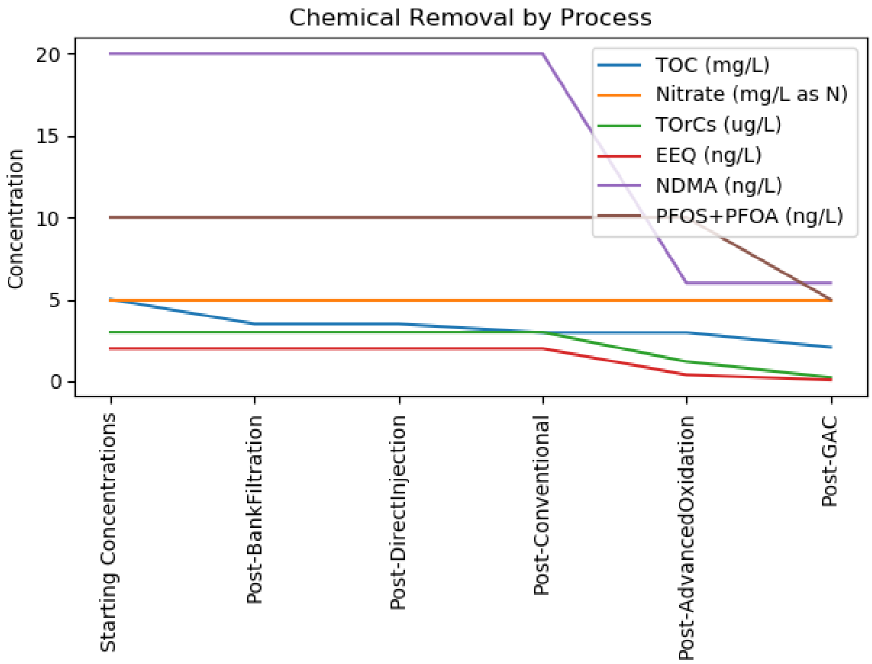

Figure 3 Chemical Removal Results for the City of Aurora DPR Case Study

2.2 Denver Water

Denver Water provides drinking water and also provides non-potable reclaimed water to irrigation and industrial customers from its Recycling Plant. The Recycling Plant is fed from secondary treated wastewater supplied by the Metro Wastewater Reclamation District's Robert W. Hite Treatment Facility (RWHTF).

The Denver Water case study modeled a DPR scenario where the RWHTF secondary treated effluent would be treated using an AWTF onsite at the Recycling Plant, rather than going through the existing Recycling Plant's non-potable treatment train. This same AWTF treatment train was used for the PureWater Colorado DPR Demonstration Project onsite at the Denver Water Recycling Plant from January 2018 through April 2018. The modeled treatment train includes ozonation, BAF, MF, GAC, UV AOP, and chloramination (Figure 4).

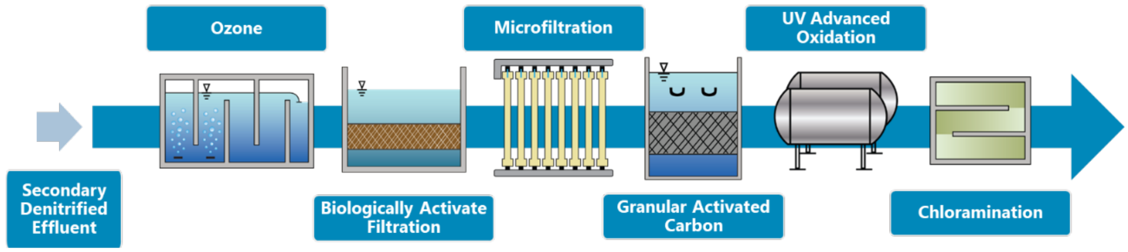

Figure 4 Denver Water DPR Case Study Treatment Train

Pathogen removal was calculated with several design assumptions, including an ozone-to-TOC ratio of 1.0, a UV dose of 800 mJ/cm^2 and a chloramines concentration of the product between chlorine concentration (C) and contact time (t), or Ct of 450 mg/L-min at 15 degrees Celsius. The contributions of each process to virus (12-log total) *Giardia* (10.6-log total), and *Cryptosporidium* (10-log total) inactivation are shown in Figure 5. This analysis indicates that the proposed treatment train would meet pathogen inactivation requirements for DPR under each of the potential regulatory frameworks (without counting treatment provided by the RWHTF).

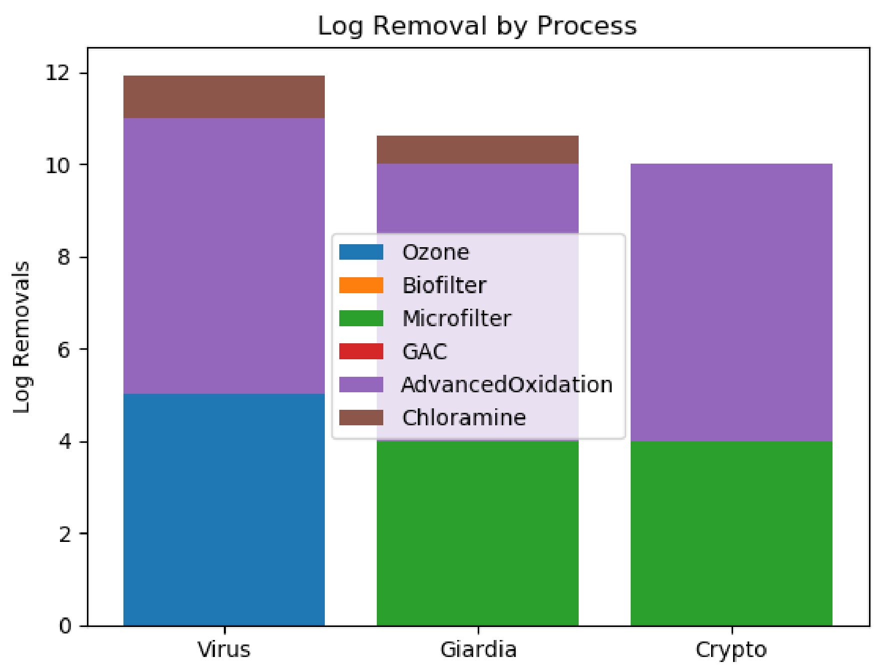

Figure 5 Pathogen Removal Results for Denver Water DPR Case Study

Chemical removals are summarized in Figure 6. Starting concentrations for various chemicals were initially left at the default concentrations for "secondary denitrified effluent" which constitute TOC = 20 mg/L, Nitrate as N = 8 mg/L, TOrCs = 3 µg/L, EEQ = 2 mg/L, NDMA = 20 ng/L, PFOS+PFOA = 10 ng/L. However, TOC data from the DPR pilot facility indicated that a starting value of TOC = 10 mg/L was a more appropriate starting concentration. Thus, the default influent TOC concentration was replaced with a value (10 mg/L) representative of the actual water quality produced by RWHTF.

After the adjustment on influent TOC concentrations, none of the chemical constituents were modeled to be present above goal values after treatment.

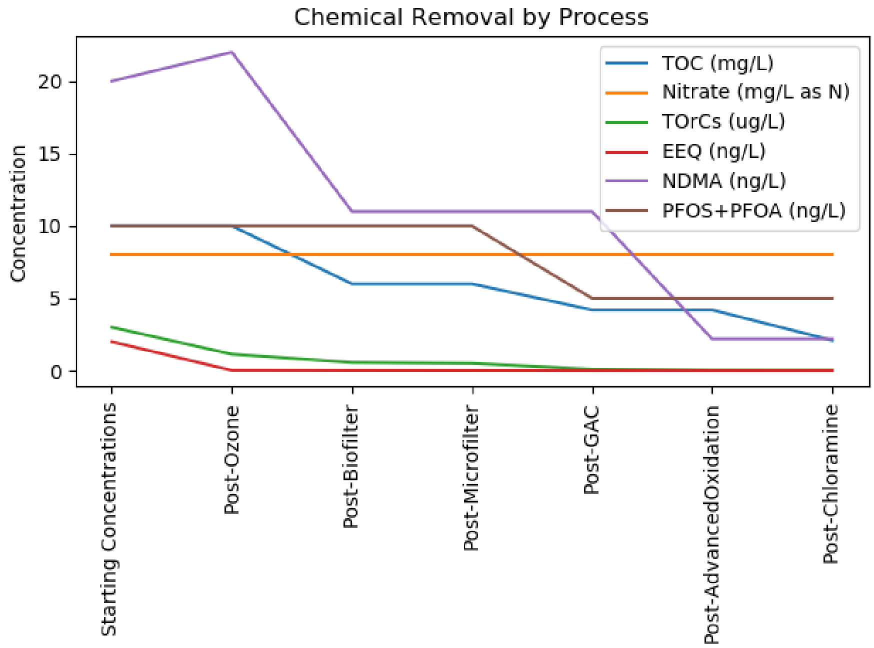

Figure 6 Chemical Removal Results for Denver Water DPR Case Study

2.3 PCWRA/Castle Rock

PCWRA treats wastewater from the Town of Castle Rock, Castle Pines Metro District, and Castle Pines North Metro District. Tertiary treated denitrified effluent is discharged to Plum Creek, and some irrigation demands in the PCWRA service area are met through operation of a non-potable reuse distribution system.

The Town of Castle Rock is upgrading its Plum Creek Water Purification Facility (PCWPF) to allow it to divert water from Plum Creek well downstream of the discharge. This will allow the Town to recover reusable return flows for treatment and distribution for potable use. The upgraded PCWPF is currently in design, and the Town is considering the water treatment scheme to be an indirect potable reuse system. However, the Town is implementing provisions that could allow adaptation of the infrastructure to allow future conversion to a DPR system by piping the effluent directly to the PCWPF.

For the purposes of the PCWRA/Castle Rock case study, this scenario was modeled with 12 hours of travel time in Plum Creek between the tertiary effluent discharge and water treatment to assess the pathogen and chemical removal of the proposed system. The treatment train will include pre-ozonation, conventional treatment, BAF, MF, ozone AOP, GAC, UV disinfection, and chlorination (Figure 7).

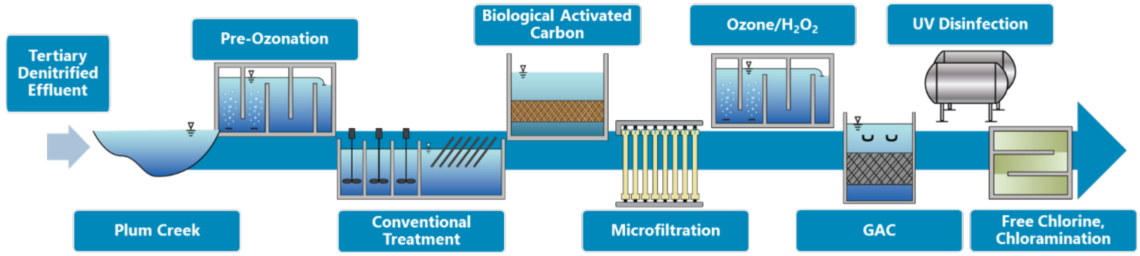

Figure 7 PCWRA/Castle Rock DPR Case Study Treatment Train

Pathogen and chemical removals was calculated using a number of design assumptions, which are listed in Table 3.

Table 3 Design Assumptions for PCWRA/Castle Rock Potable Reuse Case Study

Process	Basis of Analysis
Plum Creek Travel Time	0.5 days(1)
Pre-Ozone	O_3:TOC = 0.5(2)
Ozone/Hydrogen Peroxide (H_2O_2)	O_3:TOC = 1.0(2)
UV Disinfection	UV Dose = 60 mJ/cm^2(2)
Free Chlorine, Chloramination	Ct = 4 mg/L-min free Ct(1)

Notes:
(1) Assumed value for purposes of this case study.
(2) Adapted from Town of Castle Rock Plum Creek Water Purification Facility Bench-Scale Treatability Testing Report (CH2M 2017).

The contributions of each process to virus (12.9-log total) *Giardia* (12.6-log total), *Cryptosporidium* (12.0-log total) inactivation are shown in Figure 8. This analysis indicates that the proposed treatment train would meet pathogen inactivation requirements for DPR under each of the potential regulatory frameworks (without counting treatment provided by the PCWPF).

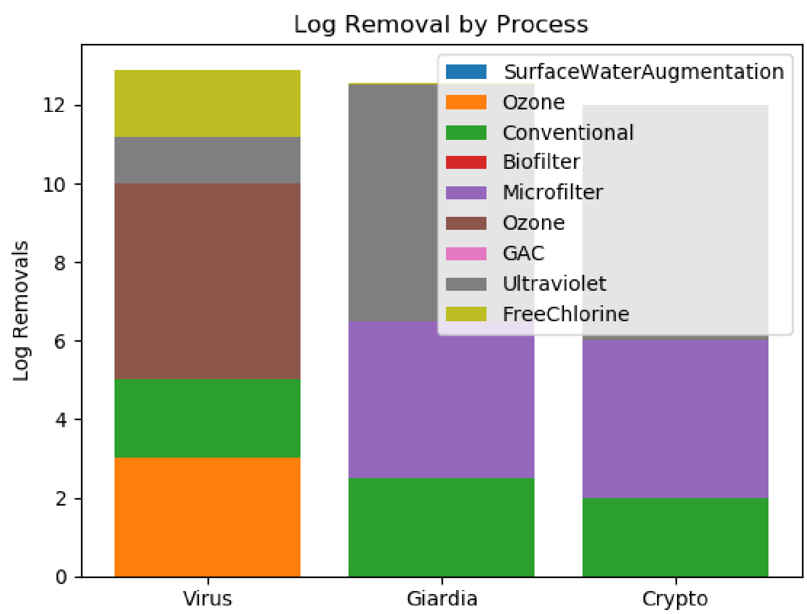

Figure 8 Pathogen Removal Results for PCWRA/Castle Rock DPR Case Study

Chemical removals are summarized in Figure 9. Starting concentrations for various chemicals were initially left at the default concentrations for "tertiary denitrified effluent" which constitute TOC = 5 mg/L, Nitrate as N = 5 mg/L, TOrCs = 3 µg/L, EEQ = 2 mg/L, NDMA = 20 ng/L, PFOS+PFOA = 10 ng/L. However, plant-specific information was available for PCWRA that indicated 3 mg/L Nitrate as N and 10 ng/L NDMA were more appropriate starting concentrations. Thus, these values were used instead of the defaults.

None of the chemical constituents were modeled to be present above goal values after treatment.

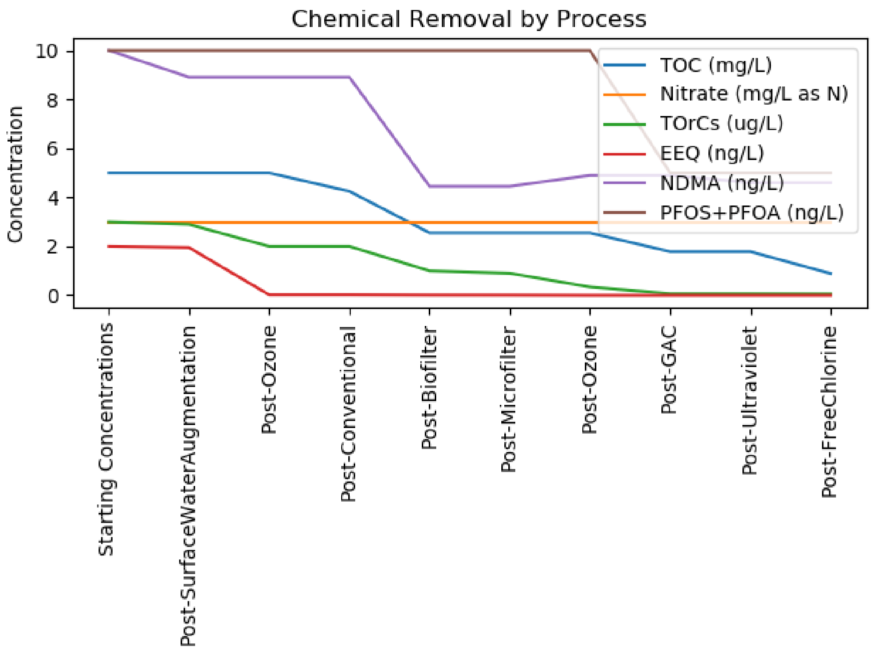

Figure 9 Chemical Removal Results for PCWRA/Castle Rock DPR Case Study

3.0 Conclusions

Version 3.0 of the IT3PR potable reuse planning tool was developed to address Colorado-specific needs for potable reuse planning and is now available for additional planning work.

Three hypothetical Colorado-based potable reuse case studies were evaluated with respect to pathogens and chemical constituents. Each case study met at least the minimum level of pathogen inactivation applied to DPR projects. While the Aurora/Prairie Waters scenario might benefit from some additional pathogen data collected from the SCWRF effluent to confirm that pathogen inactivation is adequate to address final drinking water goals, the case studies evaluated for PCWRA/Castle Rock and the Denver Water DPR scenarios provided sufficient inactivation to meet all pathogen benchmarks. In addition, all three case studies met concentration targets established for all modeled chemical parameters.

In summary, potable reuse, including DPR, appears feasible for several Colorado communities, even without the application of RO. As in any potable reuse application, site-specific analyses of salinity management should be considered when planning a treatment and water management system to determine whether and how RO should play a role in meeting the overall water quality objectives of the utility's water supply system.

4.0 References

CH2M, 2017. Plum Creek Water Purification Facility Bench-Scale Treatability Testing Report. Prepared for the Town of Castle Rock.

Steinle-Darling E, Salveson A, Russell C, He C., Chiu, C-A, Lesan, D, 2016. User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0, submitted to the Texas Water Development Board under Contract # 1348321632 in December 2016. *Download available from the Texas Water Development Board website via the direct link above, or by navigating to: http://www.twdb.texas.gov/innovativewater/reuse/index.asp and following links to deliverables for the project titled, "Testing Water Quality at the Raw Water Production Facility in Big Spring."*

Trussell, R.R., Salveson, A., Snyder, S., Trussell, R.S., Gerrity, D. 2016. Equivalency of Advanced Treatment Trains for Potable Reuse, Water Environment & Research Foundation, Project Reuse-11-02-4 Final Report.