Potable Reuse Demonstration Test Plan Final Report

Santa Clara Valley Water District

September 2016

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Santa Clara Valley Water District

Potable Reuse

Demonstration Test Plan

Final Report

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Santa Clara Valley Water District

Agreement No. 3769

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carollo

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September 2016

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Acknowledgements

The Potable Reuse Demonstration Test Plan Report is the culmination of two and a half years of collaborative and dedicated efforts to thoroughly investigate the performance of northern California's largest advanced water purification facility for potable reuse at the Silicon Valley Advanced Water Purification Center. The following organizations and individuals provided key contributions to the development of this report.

City of San José and South Bay Water Recycling

We acknowledge their key collaboration and support, including:
Kerrie Romanow, Director, Environmental Services Department, City of San José
Jeff Provenzano, Deputy Director, Environmental Services Department, City of San José
Joanna DeSa, Deputy Director, Wastewater Management, City of San José
Michele Young, Program Manager, South Bay Water Recycling

Santa Clara Valley Water District

We acknowledge contributions by District staff, including:
Norma J. Camacho, Interim Chief Executive Officer
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Katherine Oven, P.E., Deputy Operating Officer, Water Utility Capital Division
Angela Cheung, P.E., T5, Deputy Operating Officer, Water Utility O&M Division

Recycled & Purified Water Program Unit, including:
Hossein Ashktorab, Ph.D., Unit Manager; Luisa Sangines, P.E., Senior Engineer; Luis Jaimes, P.E., Senior Project Manager; Henry Barrientos, Associate Engineer; Jeannine Larabee, Associate Engineer; Ray Wong (retired), Associate Engineer; Miguel Silva, Associate Engineer; Zachary Helsley, Assistant Engineer; Toni Vye, Staff Analyst; and Lucero Villanueva, Graduate Student Intern

Treatment Operations Unit, including:
Pam John, P.E. (retired), Unit Manager; Lei Hong, Ph.D., P.E.: North Water Treatment Operations Unit, Utility Operations & Maintenance Manager; Sam Bogale, T5: South Water Treatment Operations Unit, Water Utility Operations Manager; Kristopher Filice, Senior Water Plant Operator; Michael Crow, Plant Operator; Tim Ayres; Senior Plant Maintenance Mechanic; Jesse Vargas, Assistant Plant Operator; David Wolf, Senior Systems Controls; Dennis Parle, Senior Industrial Electrician; and Albert Howell Jr., Industrial Electrician II

Water Quality Unit, including:
Bruce Cabral, Unit Manager; Johanna Castro, P.E., Senior Engineer; Lale Eristurk, Associate Engineer; Peter Zhou, Associate Engineer; Ryan Klemencic, Assistant Civil Engineer II; and Jinyu Xu, Assistant Civil Engineer I

Groundwater Operations and Analysis Unit, including:
Vanessa De La Piedra, Unit Manager; and Tom Mohr, Senior Water Quality Specialist

Laboratory Services Unit, including**:**
James Scott, Unit Manager; Gregory Gibson, Senior Water Quality Specialist; Rachel Unger, Laboratory Technician; Chung Khong, Laboratory Technician; Matt Bozzo, Laboratory Technician; Triet Trinh, Water Quality Specialist II; Beau Sullivan, Senior Chemist; Milie Sinha, Chemist; Steve Tersigni, Chemist; Andrey Khorst, Chemist; Chris Carbone, Senior Microbiologist; Amy Lazzini, Microbiologist; Katie Vigil, Microbiologist; Tae Pak, Senior Chemist; Maria Hozbor, Chemist; and Mark Ellison, Chemist

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EXECUTIVE SUMMARY

The Santa Clara Valley Water District (District) manages dams, surface water reservoirs, and groundwater, and supplies wholesale water to local municipalities and private water retailers in the Santa Clara County. The District currently manages recycled water for non-potable reuse and is pursuing potable reuse in the near future. Two different applications of potable reuse, both in compliance with California State Water Resources Control Board Division of Drinking Water (DDW) standards (CDPH, 2014), are being considered by the District.

1. Application #1 (Figure ES-1)—The use of advanced treatment of secondary effluent with microfiltration (MF), reverse osmosis (RO), and ultraviolet light with advanced oxidation (UV AOP) to purify the reclaimed water, followed by surface spreading or injection of the purified water into the groundwater basin.
2. Application #2 (Figures ES-2)—The use of advanced treatment of tertiary effluent (already filtered and disinfected) with ozone (O_3) and biologically active filtration (BAF), followed by spreading of the reclaimed water for groundwater augmentation. For this option, a split stream of treatment using MF/RO/UV AOP would be used to reduce TOC and TDS of the combined final purified water.

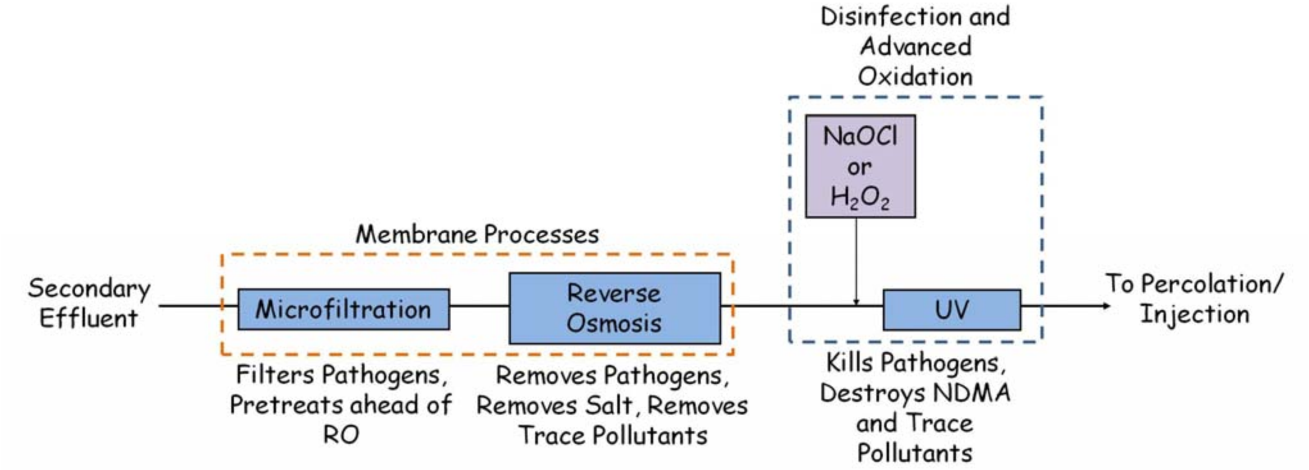

Figure ES-1 Application #1 - Potential Potable Reuse Treatment Train

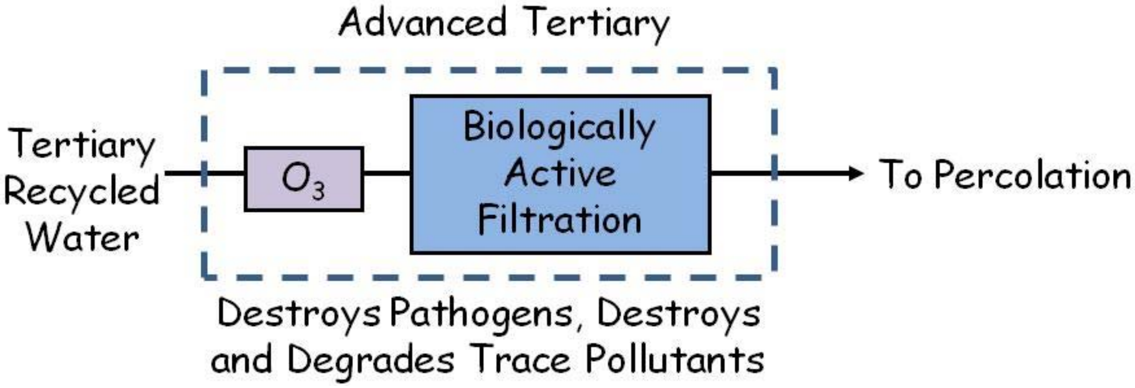

Figure ES-2 Application #2 - Potential Potable Reuse Treatment Train

Indirect potable reuse (IPR) is employed in California, while both IPR and direct potable reuse (DPR) are employed nationally and globally to meet water supply needs. These two types of potable reuse are illustrated by the Orange County Water District (CA) and the Colorado River Municipal Water District (TX), schematically illustrated in Figures ES-3 and ES-4, respectively.

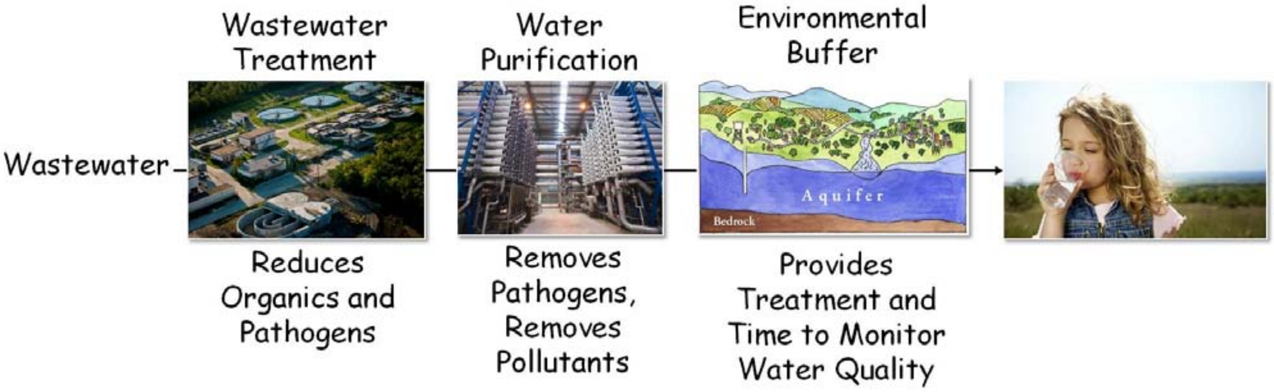

Figure ES-3 Potable Reuse with the Environmental Buffer (IPR)

Figure ES-4 Potable Reuse without the Environmental Buffer (DPR)

The central intent of this performance demonstration project is to demonstrate performance of the District's Silicon Valley Advanced Water Purification Center (SVAWPC) and its ability to meet potable water reuse standards. The conclusions in this demonstration report are based upon the data we have collected during this time period. The SVAWPC is not currently being used to produce potable water. The SVAWPC was constructed with the goal of enhancing the water quality in the existing South Bay Water Recycling (SBWR) non-potable water reuse system. The 8-mgd capacity SVAWPC purifies nitrified (and partially denitrified) secondary effluent from the San Jose-Santa Clara Regional Wastewater Facility (RWF) with MF, RO, and ultraviolet (UV) disinfection (Figure ES-5). The UV system at the SVAWPC UV system is a high dose system, but is not a UV AOP reactor, as no hydrogen peroxide or other oxidant is added upstream of the UV system. The primary objective of the SVAWPC is to produce purified water to reduce TDS, sodium, silica, organics, and other constituents in the blended product water. Additionally, the San Jose-Santa Clara RWF produces tertiary recycled water using sand filtration and chlorination. This filtered and chlorinated effluent is blended with the purified water from SVAWPC to lower the salinity in the recycled water and thus increase its quality and marketability.

Figure ES-5 SVAWPC Full-Scale Advanced Treatment Processes

The overarching goals of this testing are listed below.

- Demonstrate treatment performance in compliance with the IPR standards of the Division of Drinking Water (DDW, CDPH (2014)).
- Examine methods to improve monitoring of potable reuse treatment facilities that may be appropriate for both IPR and DPR applications.
- Examine new methods for UV AOP using different oxidants.
- Examine treatment options to RO, which are capable of providing high quality water for IPR surface spreading operations while using less energy than RO. The most promising option based upon the latest research is O3 with biofiltration.
- Use the performance data to educate District staff, the Public, and regulators regarding the high quality water produced from the SVAWPC.

The research documented within this report focuses on a process by process analysis in parallel with an overall water quality analysis. For each key treatment process, the research evaluated the performance (and conservatism) of monitoring systems using a critical control point (CCP) philosophy. A CCP is where: (1) control can be applied to an individual unit process to reduce, prevent, or eliminate process failure; and (2) monitors are used to confirm the CCP is functioning correctly. For this work, CCPs correspond to individual treatment processes that provide control for pathogens (including the provision of log reduction credits) and chemical constituents. Through a combination of treatment system monitoring, location specific CCP control surrogates, and overall water quality monitoring, the District can have confidence in the quality of the purified water produced from the SVAWPC. A summary of the key research findings as they pertain to a future potable water reuse are shown in Table ES-1. A summary of recommended CCP monitoring for potable reuse is presented in Table ES-2, based on District demonstration in accordance with other projects. The District is conducting, in parallel, groundwater monitoring studies required for permitting, with a separate document focusing on groundwater to come later.

Of important note throughout this document, the SVAWPC was meeting the non-potable water reuse Title 22 permit requirements throughout the demonstration testing period.

Table ES-1 Key Demonstration Testing Findings
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Analysis	Treatment Process	Testing Approach	Findings
Standard Process Monitoring	MF	Normal Operation	• Filtrate turbidity met the permit requirement of 0.2 NTU for all but a few measurements. • High influent turbidities do not impact filtrate turbidities, nor do they correlate with filtrate turbidity. • The filtrate turbidity values are normally distributed, allowing for confidence in future values and alarms when results are outside of normal values. • Pressure Decay Tests (PDTs) are the best CCP currently in use for MF. The PDT results (<0.3 psi/min) demonstrate long-term membrane integrity and 4-log protozoa removal. • With one exception, the PDTs are also normally distributed, allowing for confidence in future values and alarms when results are outside of normal values. • Online mean turbidity values are consistently lower than the mean bench-scale turbidity calibrations (though still within permit requirement). Further refinement of the calibration and monitoring procedures is recommended for a future potable reuse application.
	RO	Normal Operation	• The log reduction of EC across RO is one of several potential CCPs for RO system monitoring. The log reduction of EC across RO is normally distributed, potentially allowing for confidence in future values and alarms when results are outside of normal values. However, there is a recent downward trend in EC log reduction across the RO membranes, which will continue to skew the normal distribution. The decrease in EC log reduction correlated to membrane cleaning schedules and replacement. • The lowest recorded LRV value for EC was 1.47, allowing for 1.47 log credit for both virus and protozoa removal by RO. • The online EC measurements match well with bench-top EC calibration results, providing a high level of confidence in the online monitoring of performance.
	UV	Normal Operation	• For UV systems, the ideal CCP for UV dose delivery is the continuous online monitoring of applied dose, which is a function of online UVT and online sensor intensity. • Bench-top UVT average values match well with online UVT average values, but the online values have higher variability. • Online UVT is trending up, with more variability than should be expected. For potable water reuse applications, the online meter accuracy and calibration procedures should be refined. • Online UV intensity sensors are not sufficiently sensitive to changes in UV power and UVT. For potable water reuse applications, these sensors would need to be replaced with sensors appropriate to monitor the high UVT of RO permeate.
	Quarterly Sampling	Normal Operation	• Hundreds of finished water samples demonstrating high quality water meeting all public health standards, with the exception of three NDMA samples above 10 ng/L. • Of the hundreds of samples collected, 8 chemicals were found in the finished water (Acetaldehyde, Boron, Trichloromethane, Cyanide, Formaldehyde, Nitrate, NDMA, total THMs) and all were below public health standards, except the three NDMA samples mentioned above.
Full-Scale Challenge Testing	MF	Pathogen Removal Challenge	• Complete removal of indigenous bacteria (total and fecal coliform). • Complete removal of protozoa (Giardia and Cryptosporidium). • Substantial removal of particles in the size range of bacteria and protozoa.
	RO	Pathogen and Pollutant Removal Challenges	• 99.9%+ removal of seeded virus. • Demonstrated the conservative nature of several performance surrogate parameters, including TOC, EC, UVA, and color. • Demonstrated ~99% removal of seeded virus under intentionally compromised RO integrity conditions. • Demonstrated >50% removal of NDMA. • TOC reduced to the regulated target of 0.3 mg/L (long-term objective for new membranes).
	UV	Pathogen and Pollutant	• 99.9999% removal of seeded virus over a range of power settings, with all lamps in service and under compromised reactor operation with 1 and 2 lamps out of service. • Removal of lamps from service reduced NDMA destruction, underscoring the importance of UV system maintenance for NDMA destruction.

Table ES-1 Key Demonstration Testing Findings
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Analysis	Treatment Process	Testing Approach	Findings
		Removal Challenges	• Demonstrated a correlation between NDMA destruction and the destruction of surrogate parameters such as total chlorine for CCP monitoring. • >65% removal of NDMA with only one reactor in service, which projects to a finished water with NDMA levels below 10 ng/L with both reactors in service at 100% power (at 1.08 mgd per reactor train).
Pilot-Scale Challenge Testing	UV AOP	Pollutant Removal Challenges	• The pilot-scale UV AOP system better tracked lamp intensity changes due to changes in reactor power, demonstrating the ability to use sensor intensity as a CCP for system monitoring if coupled with an accurate UVT monitor. • The pilot-scale UV AOP system (with H2O2) demonstrated 0.5 log reduction of 1,4-dioxane at UV dose values of >800 mJ/cm2. • The pilot-scale UV AOP system (with NaOCl) was unable to meet the 0.5 log reduction requirement for 1,4-dioxane at the tested dose values. • The pilot-scale UV AOP system was able to consistently reduce NDMA to below 10 ng/L at UV dose values of >700 mJ/cm2 (during NaOCl testing) and >900 mJ/cm2 (during H2O2` testing). • Bench-scale UV AOP testing matched the pilot-scale testing well, including the relative success and lack of success in meeting the 1,4-dioxane target of 0.5 log reduction for UV AOP with H2O2 and with NaOCl. • NDMA destruction correlates with UV dose delivery and with total chlorine destruction, demonstrating the ability to use total chlorine destruction as a CCP for NDMA destruction and UV dose delivery. • Over the testing period for the pilot-scale UV AOP (including both oxidants), and with the exception of NDMA, three trace pollutants were detected in RO permeate and zero trace pollutants were detected after UV AOP.
	O_3/BAF - Treating Tertiary Recycled Water	Pollutant Removal Challenges	• High variability of both total chlorine and free chlorine in the O3/BAF feed resulted in a highly variable O3 demand. • The TOC removal by O3/BAF was anticipated to be in the 30% to 40% range. However, likely due to the variable water quality feeding the pilot, the TOC reduction was ~20%. • BAF successfully reduces TKN by ~80-90%+ and down to near or at the respective detection levels. • Chlorate levels are very high in the O3 Feed, BAF Feed, and BAF effluent, in the 170 to 250+ mg/L range, requiring additional evaluation of subsequent fate as part of potable reuse applications. • Nitrate levels are high in the O3 Feed, BAF Feed, and BAF effluent, in the 40-50+ mg/L range (as nitrate), requiring additional evaluation of subsequent fate as part of surface spreading for potable reuse applications. • NDMA was formed during ozonation and reduced during BAF treatment. However, unlike prior work on the subject, the BAF effluent NDMA concentrations ranged from ~120 to ~170 ng/L. Subsequent treatment through Soil Aquifer Treatment or advanced purification is necessary to meet potable water goals. • 1,4-dioxane was reduced by ozonation, with higher O3/TOC ratios providing greater destruction. • O3 improved the water quality through the reduction of a number of trace pollutants. O3 provided substantial destruction of atenolol, carbamazepine, DEET, dilantin, triclosan, and primidone. Little destruction was seen for meprobamate, PFOS, PFOA, sucralose, and TCEP. Mixed performance was seen for cotinine.(1)
	O_3/BAF - Treating Secondary Effluent Water	Pathogen and Pollutant Removal Challenges	• Testing was conducted on unchlorinated secondary effluent, which resulted in an overall improvement of O3/BAF performance. • The TOC removal by O3/BAF was improved compared to the testing on tertiary recycled water, which contained variable chlorine concentrations. TOC removal was between 20% and 30%, with an average of ~25%. • Similar to the testing of tertiary recycled water, BAF successfully reduces TKN. • Chlorate levels are much reduced compared to the tertiary recycled water, with ~20 mg/L after treatment.

Table ES-1 Key Demonstration Testing Findings
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Analysis	Treatment Process	Testing Approach	Findings
			• Nitrate levels are high in the O3 Feed, BAF Feed, and BAF effluent, in the 80+ mg/L range (as nitrate). Removal of nitrate by RO sufficient to meet regulatory standards can be reasonably assumed. • Bromate levels are low before and after O3/BAF treatment. • NDMA was formed during ozonation and reduced during BAF treatment, with consistently lower levels compared to the tertiary recycled water analysis. Higher O3/TOC ratios resulted in increased NDMA formation, and final treated NDMA values ranged from ~20 to >30 ng/L. BAF performance was improved compared to the tertiary recycled water test results, reducing the treatment demand on subsequent processes. • 1,4-dioxane was reduced by ozonation, with higher O3/TOC ratios providing greater destruction and showing improved performance compared to the tertiary recycled water analysis. • O3 improved the water quality through the reduction of a number of trace pollutants. O3 provided substantial destruction of 4-nonylphenol, atenolol, carbamazepine, cotinine, DEET, triclosan, and primidone. Little destruction was seen for meprobamate, PFOS, PFOA, sucralose, and TCEP. • Virus destruction by O_3 was robust, with O_3/(TOC+nitrite) ratios of ~0.5 and greater resulting in 5+ log reduction of virus (MS-2). Key to this result is that virus kill can be tracked (and credited) for O_3 disinfection without an O_3 residual, assuming no other disinfectant present.

Note:

(1) Cotinine is difficult to measure analytically and is impacted by slight pH changes. It may be possible that the mixed results seen for cotinine are due to an analytical recovery issue more than a true treatment problem.

Table ES-2 Critical Control Point Findings
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Treatment Process	CCP	Pathogens or Trace Pollutants?	Findings
MF	Pressure Decay Test	Pathogens	PDTs are an effective CCP for monitoring the removal of protozoa (*Giardia* and *Cryptosporidium*), allowing for 4+ log reduction of these target pathogens.
RO	Electrical Conductivity and Total Organic Carbon	Both	Log removal of EC and TOC across RO are conservative measurements and effective CCPs for virus and protozoa removal. RO permeate TOC provides for confidence in low organic content of the finished water.
UV	Sensor Intensity and UVT, resulting in Dose Calculation	Pathogens	Online maintenance of UV dose through accurate measurements of sensor intensity and UVT (and flow) allow for an effective CCP for virus and protozoa kill. Current sensors and UVT measurements are insufficiently accurate for CCP for potable reuse applications. Modification of the existing reactors is feasible and recommended
UV	Total Chlorine Destruction	Pathogens and Trace Pollutants	NDMA destruction correlates well with total chlorine destruction across UV, allowing total chlorine destruction to be a CCP for both pathogens and select pollutants (though, only NDMA proven at this time).
UV AOP	Oxidant Weighted UV Dose	Trace Pollutants	Minimum UV dose and oxidant dose combinations can be set to confidently result in the DDW required 0.5-log reduction of 1,4-dioxane, providing for an effective, though not precise, CCP for trace pollutant destruction by UV AOP.
O_3	O_3/ (TOC+nitrite)	Pathogens	O_3/(TOC+nitrite) ratios have proven to provide a reliable CCP for monitoring virus kill by O_3 in the absence of an O_3 residual.
O_3/BAF	Insufficiently documented	Pollutants	O_3 alone and O_3/BAF reduced trace pollutants, but the collected information is not sufficient to document a CCP (such as EBCT, O_3 dose, O_3/TOC, change in UVT) for predictable destruction of TOC, disinfection byproducts, or trace pollutants.

Based upon the data collected in this report, which is supported by parallel efforts in the industry, the following conclusions can be made:

- The District's SVAWPC produces high quality water that meets drinking water regulatory standards, DDW regulations for indirect potable reuse using spreading basins (percolation), and is protective of public health.
- With the proper addition of advanced oxidation, the District's SVAWPC has demonstrated performance in accordance with DDW regulations for indirect potable reuse ***using injection wells*** for groundwater recharge (CDPH, 2014), respectively shown in Tables ES-3 and ES-4. Similarly, new Purification Centers using MF/RO/UV AOP will also meet DDW regulations for indirect potable reuse using either injection wells or spreading basins.
- The use of O_3/BAF on tertiary recycled water, when combined with Soil Aquifer Treatment (SAT), will meet pathogen requirements and many chemical requirements for potable water reuse. As shown in Table ES-5, O_3/BAF may have difficulty meeting DDW regulations for total nitrogen, total organic carbon, and NDMA. Soil column studies and/or blending of O_3/BAF finished water with an advanced treated MF/RO/UV AOP finished water may be necessary to ensure compliance with potable reuse regulations
- The use of O_3/BAF on secondary effluent provided a high level of disinfection and measurable reduction of a range of trace pollutants and TOC. Inclusion of O_3/BAF as part of a direct potable reuse treatment train will thus provide a robust additional treatment barrier for both pathogens and organic contaminants (Table ES-6).

Table ES-3 Demonstration of Compliance with Key Potable Reuse Requirements – Groundwater Injection SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Performance Target	Removal Goal(1)	Primary and Secondary Treatment(2)	MF(3)	RO(4)	UV/H_2O_2(5,6)	Subsurface Travel Time	Total Credits
log viruses	12	1.9	0	1.5	6	3(7)	12.4
log *Giardia* cysts	10	0.8	4	1.5	6	0(7)	12.3
log *Cryptosporidium* oocysts	10	1.2	4	1.5	6	0(7)	12.7
Oxidation of 1,4-Dioxane	0.5 log removal by advanced oxidation				Destruction by UV AOP		
NDMA	<10 ng/L			<20	<10		
Turbidity	<0.2 NTU		<0.2 NTU				
Total Organic Carbon	<0.5 mg/L			<0.3 mg/L			
Drinking Water MCLs	Varies			Meets all standards			

Notes:

(1) CDPH, 2014.

(2) Based upon literature values detailed within this report.

(3) Credit based upon maintenance of <0.3 psi/min pressure decay testing of MF membranes. Protozoa removed to below detection during full-scale testing.

(4) Credit based upon log reduction of both TOC and EC of >1.47 during full-scale testing.

(5) Virus credit based upon log reduction demonstrated by the UV reactors during full-scale testing. No H_2O_2 was added during full scale testing.

(6) 1,4-dioxane destruction based upon small-scale pilot results, projecting a minimum UV dose of 800 mJ/cm^2 and a H_2O_2 dose of 6 mg/L (this was found to be the minimum effective dose). Further oxidant optimization testing will be conducted prior to startup. The UV capacity (per train) to meet this dose target is estimated at 1.08 mgd.

(7) DDW grants 1-log virus credit per month of subsurface travel time, with a minimum of two months required. For this project, unless other virus barriers are in place, 3-log credits are needed in the subsurface, thus requiring a minimum of 3 months of travel time. DDW does not currently grant

protozoa removal credit for potable reuse projects utilizing injection. Ongoing research suggests that protozoa credits should be granted and that work is cited within this text.

Table ES-4 Demonstration of Compliance with Key Potable Reuse Requirements – Surface Spreading using MF/RO/UV AOP
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Performance Target	Removal Goal(1)	Primary and Secondary Treatment(2)	MF(3)	RO(4)	UV/H_2O_2(5,6)	Spreading and Subsurface Travel	Total Credits
log viruses	12	1.9	0	1.5	6	6(7,8)	15.4
log *Giardia* cysts	10	0.8	4	1.5	6	6(7,8)	18.3
log *Cryptosporidium* oocysts	10	1.2	4	1.5	6	6(7,8)	18.7
Oxidation of 1,4-Dioxane	0.5 log removal by advanced oxidation				Destruction by UV AOP		
NDMA	<10 ng/L			<20	<10		
Turbidity	<0.2 NTU		<0.2 NTU				
Total Organic Carbon	<0.5 mg/L			<0.3 mg/L			
Drinking Water MCLs	Varies			Meets all standards			

Notes:
(1) CDPH, 2014.
(2) Based upon literature values detailed within this report.
(3) Credit based upon maintenance of <0.3 psi/min pressure decay testing of MF membranes. Protozoa removed to below detection during full-scale testing.
(4) Credit based upon log reduction of both TOC and EC of >1.5 during full-scale testing.
(5) Virus credit based upon log reduction demonstrated by the UV reactors during full-scale testing. No H2O2 was added during full scale testing.
(6) 1,4-dioxane destruction based upon small-scale pilot results, projecting a minimum UV dose of 800 mJ/cm^2 and a H_2O_2 dose of 6 mg/L. The UV capacity (per train) to meet this dose target is estimated at 1.08 mgd.
(7) For spreading projects, DDW grants 6-log virus and 6-log protozoa credits for spreading projects with at least 6-months of subsurface travel time (CDPH, 2014). If less than 6 months of travel time are applied, then no protozoa removal is credited and virus credit is 1-log per month.
(8) For groundwater recharge projects that utilize surface spreading of tertiary recycled water, DDW grants full 12/10/10 pathogen credit. This proposed treatment train, which utilizes MF/RO/UV AOP, would thus meet DDW requirements with additional redundancy.

Table ES-5 Demonstration of Compliance with Key Potable Reuse Requirements – Surface Spreading Using O_3/BAF
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Performance Target	**Removal Goal(1)**	**Primary and Secondary Treatment(2)**	**Tertiary Filtration and Disinfection(3)**	**O_3(4)**	**BAF**	**Spreading and Subsurface Travel**	**Total Credits**
log viruses	12	1.9	5	5	0	6(6)	17.9
log *Giardia* cysts	10	0.8	0	0	0	6(6)	6.8, 10(7)
log *Cryptosporidium* oocysts	10	1.2	0	0	0	6(6)	7.2, 10(7)
Turbidity	<2 NTU		<2 NTU				
NDMA	<10 ng/L				**>100 ng/L**	**Reduction by SAT or increased blending necessary to meet regulations(8)**	
Total Organic Carbon	<0.5 mg/L after blending with other percolated water supplies				**>2.5 ng/L**	**Reduction by SAT or increased blending necessary to meet regulations(8)**	
Drinking Water MCLs	Varies				**TN>10 ng/L**	**Reduction by SAT or increased blending necessary to meet regulations(8))**	

Notes:

(1) CDPH, 2014.
(2) Based upon literature values detailed within this report.
(3) Virus credit based upon a CT of 450 mg-min/L at the San Jose Santa Clara Water Reclamation Facility, which is the feed water to the O_3/BAF in this example. Some *Giardia* kill can be obtained by free chlorination, but no credit is sought in this example.
(4) Virus credit based upon targeting specific O_3/TOC ratios that correlate directly with virus kill. Operating the O_3 system in a CT mode can provide Giardia kill, but the current approach is not to dose O_3 beyond the O_3 demand of the water (and thus no residual and no CT) to minimize disinfection byproduct

formation. There is some variation in analytical accuracy in monitoring nitrite and TOC removal. The amount of reliability required to prove 5-log reduction has yet to be determined.

(5) Log removal of virus through spreading documented within the literature and is referenced further in this text. Removal of protozoa (Giardia and Cryptosporidium) assumed based upon size exclusion and the virus data set.

(6) For spreading projects, DDW grants 6-log virus and 6-log protozoa credits for spreading projects with at least 6-months of subsurface travel time (CDPH, 2014).

(7) For groundwater recharge projects that utilize surface spreading of tertiary recycled water, DDW grants full 12/10/10 pathogen credit. This proposed treatment train, which utilizes an additional barrier of O_3/BAF, would thus meet DDW requirements with additional redundancy.

(8) TOC, TN, and NDMA values high in O_3/BAF finished water. Reduction by SAT possible, but unclear if SAT treatment will be sufficient to meet regulations. Soil column studies necessary to advance this concept prior to implementation.

Table ES-6 Demonstration of Compliance with Key Potable Reuse Requirements – Direct Potable Reuse
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Performance Target	Removal Goal(1)	Primary and Secondary Treatment(2)	O_3(3)	BAF	MF(4)	RO(5)	UV/ H_2O_2(6,7)	Water Treatment Plant(8)	Total Credits
log viruses	12	1.9	5	0	0	1.5	6	4	18.4
log *Giardia* cysts	10	0.8	0	0	4	1.5	6	3	15.3
log *Cryptosporidium* oocysts	10	1.2	0	0	4	1.5	6	3	14.7
1,4-Dioxane	0.5 log removal by advanced oxidation		Destruction by O_3 based AOP				Destruction by UV AOP		
NDMA	<10 ng/L		Creates NDMA	Reduces NDMA		<20	<10		
Turbidity	<0.2 NTU				<0.2 NTU				
Total Organic Carbon	<0.5 mg/L			Reduces TOC		<0.3 mg/L			
Drinking Water MCLs	Varies					Meets all standards			

Notes:

(1) DPR removal goals are under review in California. However, significant amounts of research support the removal goals shown here (CDPH, 2014).
(2) Based upon literature values detailed within this report.
(3) Virus credit based upon targeting specific O_3/TOC ratios that correlate directly with virus kill. Operating the O_3 system in a CT mode can provide Giardia kill, but the current approach is not to dose O_3 beyond the O_3 demand of the water (and thus no residual and no CT) to minimize disinfection byproduct formation.
(4) Credit based upon maintenance of <0.3 psi/min pressure decay testing of MF membranes. Protozoa removed to below detection during full-scale testing. MF credited with 4-log removal of protozoa, with literature showing the ability of MF to remove 0.5-logs virus, with no virus credit awarded at this time.
(5) Credit based upon log reduction of both TOC and EC of >1.5 during full-scale testing.
(6) Virus credit based upon log reduction demonstrated during full-scale testing. No H2O2 was added during full scale testing. NDMA destruction based upon pilot-scale results and full-scale results assuming both reactors in operation per train.

(7) 1,4-dioxane destruction based upon small-scale pilot results, projecting a minimum UV dose of 800 mJ/cm^2 and a H_2O_2 dose of 6 mg/L.
(8) Assuming standard WTP credits.

1.0 PROJECT GOALS

The purpose of this research effort is to document the treatment performance of the Santa Clara Valley Water District's (District) Silicon Valley Advanced Water Purification Center (SVAWPC) and its ability to meet potable water reuse standards. The SVAWPC is identical to indirect potable reuse (IPR) treatment trains used for groundwater injection in California, with the single exception of UV in place of UV AOP. A secondary purpose of this document is to expand the industry's body of research on advanced treatment and process monitoring for both IPR and direct potable reuse (DPR) through testing of a pilot-scale O_3/BAF system and a pilot scale UV AOP system.

The research documented within this report focuses on a process by process analysis in parallel with an overall water quality analysis. The test plan for this project was developed based on both short term and long term objectives. Short term objectives were intended to compile new information related to the challenge of testing systems that can be used for advancement of IPR. Long term objectives were intended to monitor the system in a way similar to operating IPR systems. For each key treatment process, the research evaluated the performance (and conservatism) of monitoring systems using a critical control point (CCP) philosophy. A CCP is where: (1) control can be applied to an individual unit process to reduce, prevent, or eliminate process failure; and (2) monitors are used to confirm the CCP is functioning correctly. For this work, CCPs correspond to individual treatment processes that provide control for pathogens (including the provision of log reduction credits) and chemical constituents. Through a combination of treatment system monitoring, CCP control, and overall water quality monitoring, the District can have confidence in the quality of the purified water produced from the SVAWPC.

2.0 DISTRICT AND SVAWPC BACKGROUND

The District manages water resources and infrastructure, including groundwater and surface waters in Santa Clara County, as well as dams and surface water reservoirs. The District also supplies wholesale water to local municipalities and private water retailers in the County. The District currently collaborates on recycled water for non-potable reuse development in Santa Clara County and is considering potable reuse in the near future. The majority of recycled water for non-potable use within Santa Clara County comes from the San Jose-Santa Clara Regional Wastewater Facility (RWF), where it undergoes secondary treatment through activated sludge (nitrification with partial denitrification) and subsequent tertiary filtration (deep bed media filtration) and chlorination. The RWF is operated by the City of San Jose (City). The RWF has a treatment capacity of 167 mgd, approximately 10 percent of which is recycled through the South Bay Water Recycling (SBWR) system; the remainder is discharged to the South San Francisco Bay. The SBWR system provides recycled water to over 700 customers in San Jose, Santa Clara, and Milpitas. It is noted that the RWF has additional treatment capacity for recycling in excess of the listed 10 percent. Further, there are other wastewater utilities within Santa Clara County that also produce reclaimed water. The RWF is mentioned here specifically because it is the source of secondary effluent (not tertiary recycled water) for the SVAWPC.

2.1 Silicon Valley Advanced Water Purification Center

The SVAWPC was constructed with the goal of enhancing the water quality in the existing non-potable SBWR system. The 8-mgd capacity SVAWPC treats nitrified secondary effluent from the RWF with MF, RO, and UV disinfection. The primary objective of the SVAWPC is to produce high-purity recycled water to reduce TDS, sodium, silica, organics, and other constituents in the blended product water. The RWF effluent is blended with the advanced-treated effluent from SVAWPC to lower the salinity in the recycled water and thus increases its quality and marketability.

The SVAWPC operates in one of two modes. When demand for recycled water is high (e.g. Summer months), the RO system operates at full capacity to maximize the salinity reduction in the blended water available for delivery to recycled water customers. When recycled water demand is reduced (e.g. winter months), less RO permeate is required to meet TDS goals for the reduced blended water flows, so a portion of the MF filtrate may bypass the RO system and is blended with the RO permeate unless the SBWR has shut down its tertiary filters for repair, in which case the SVAWPC is responsible for producing disinfected tertiary water. Whether operating in 100 percent MF/RO mode or when blending MF/RO water with MF water, UV disinfection is applied to the entire water stream prior to use.

2.1.1 Pall Microfiltration System

The MF system is designed for 11.7 mgd feed flow and 90 percent recovery, resulting in a 10.5 mgd filtrate flow. Flow from the MF membranes is directed to a 250,000 gallon capacity inter-process storage tank designed to equalize the flow between the MF and RO systems. The MF process step is comprised of a Pall® MF system consisting of eight filter racks containing 112 Microzoa® (UNA-620A) modules per rack (896 total with room for 912). Microzoa® MF membranes are rated to 0.3 micron (um) nominal pore size. These are designed to achieve a filtrate turbidity of less than 0.2 NTU.

This pore size is such that viruses will still pass through the MF membranes, but that significant removal of the larger pathogens, including bacteria and protozoa (*Giardia* and *Cryptosporidium*), is expected (Linden *et al.,* 2012).

2.1.2 Reverse Osmosis System

The RO system is from Doosan, using membrane CSM-RE8040-FE. The RO process step consists of three two-stage trains with a total combined capacity of 8 mgd (expandable to 9 mgd). Each train consists of 80 pressure vessels (52 first-stage, 28 second-stage), containing seven RO membrane elements each, resulting in a total of 560 RO membrane elements per train (expandable to 630). The system is designed for a nominal flux of 12 gfd and 85 percent recovery.

The non-porous RO membranes remove salt ions and organic molecules by size exclusion and by electrostatic charge. Although some salts and organic molecules may pass through the membrane by diffusion, their removal rates should generally be greater than 99 percent (nominal salt reduction, per Doosan, is 99.7 percent). Because RO membranes are non-porous, they should form an absolute barrier to pathogens. However, possible defects in the construction of the spiral-wound RO membrane elements and the interconnection of these elements within an operating RO train have the potential to reduce the membranes' capacity to remove constituents, including pathogens, to the degree anticipated based solely on the membrane material.

2.1.3 Xylem/WEDECO UV Disinfection System

The UV Disinfection System has a total capacity of 10 mgd. It consists of six process trains (five duty and one standby) with two closed-vessel Xylem/WEDECO LBX1000 reactors in series for each train. Each LBX 1000 reactor houses forty 330W low pressure high output (LPHO) lamps. LBX1000 reactor has automated physical wipers and online calibrated sensors meeting USEPA standards (USEPA, 2006), though with only one sensor per reactor (1 per 40 lamps). Chemical cleaning with phosphoric acid is part of the system design, using a spray wand that is placed into the center of each reactor. Minimal quartz sleeve fouling is anticipated in RO permeate. MF effluent through the UV reactor may eventually foul the protected quartz sleeves, and thus must be monitored. The baseline sensor values have been recorded as part of startup and will be continually recorded to track lamp aging and sleeve fouling impacts.

For post RO applications for non-potable reuse, the California Division of Drinking Water (DDW, formerly CDPH) typically follows the UV dose requirements found in the 2012 National Water Research Institute (NWRI) UV Guidelines, which stipulate a UV dose of 50 mJ/cm^2. For post MF applications, the DDW has a clear requirement for a UV dose of 80 mJ/cm^2, again following the recommendations of the 2012 NWRI UV Guidelines. Per DDW approval of this specific reactor, each train has a maximum capacity of 3.51 mgd, should the UV transmittance (UVT) be high enough to result in the minimum required UV dose. Each reactor can be operated in one of two modes: “RO flow” and “MF flow.” Trains operating in RO flow mode receive RO permeate as influent whereas trains operating in MF flow receive MF filtrate.

When the SBWR system is experiencing high demand for recycled water and the RO system is operating at full capacity, all UV trains are operated in RO flow mode. During times of lesser water use, certain UV trains may receive water that has bypassed the RO system and are therefore operated in MF flow mode.

2.1.4 Pilot-Scale UV/H_2O_2 Advanced Oxidation System

The advanced oxidation pilot system at the SVAWPC is a smaller-scale version of the LBX1000 UV reactor in use at the full scale. The LBX90 reactor houses four 330W low pressure high output lamps. At low flows, this system provides an extremely high UV dose sufficient for advanced oxidation.

The pilot setup comprises an upstream flash mixer, flow meters, a H_2O_2 storage tank, and a peroxide dosing station. The value of the LBX90 reactor is the ability to run low flows through this system, add in H_2O_2 at various dose values, and generate hydroxyl radicals for advanced oxidation of trace pollutants. As documented in research (e.g., Salveson *et al.*, 2010), RO membranes will periodically pass trace pollutants at the ng/L level and the subsequent advanced oxidation system can be used to destroy many of these pollutants.

2.1.5 Pilot-Scale O_3/Biological Filtration System

The WateReuse Research Foundation (WRRF) is investigating alternative treatment technologies to RO that provide a similar level of pathogen and trace pollutant treatment (Gerringer *et al*., 2014, Steinle-Darling and Salveson, 2013). The most viable combination of technologies to replace RO is O_3 followed by BAF. Further, as many utilities in California consider how to implement DPR, O_3/BAF can provide an additional treatment barrier to pathogens and pollutants, and can be implemented ahead of the conventional IPR treatment train of MF/RO/UV AOP.

Because the District is concerned about the cost of RO treatment and the resulting brine from RO treatment, and because the District is considering how DPR might be implemented, O_3 and biofiltration pilot testing was done on a blended reclaimed water from the South Bay Water Recycling Program (Test 1) and on secondary effluent (Test 2). The pilot equipment from Xylem operated in the range of 15 to 25 gallons per minute (gpm).

2.2 Performance Metrics

Within this report, the project team has detailed the water quality after different levels of treatment and purification. Each treatment process, MF, RO, UV, UV AOP, and O_3/BAF provides either pathogen removal or pollutant removal, or a combination of pathogen and pollutant removal. Within this report, the performance of each treatment process is documented and compared against industry standards and expectations. Table 2.1 presents the log removal credits required for IPR via groundwater replenishment, which is currently the only regulated potable reuse. The final water quality is also compared with DDW regulations for potable water reuse, with the focus on pathogen and chemical concentrations in the final water.

Table 2.1 Treatment Goals for Potable Reuse
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

12-log Removal of Virus	**10-log Removal of *Giardia***	**10-log Removal of *Cryptosporidium***	**Meeting Drinking Water MCLs**	**Reducing/ Removing Trace Pollutants**	**Consistent Process Operation**
✓	✓	✓	✓	✓	✓

2.2.1 Chemical Removal Goals and Requirements

A large number of chemicals known to be detrimental to human health above certain concentrations are regulated through maximum contaminant levels (MCLs). Drinking water must be treated to meet these standards regardless of the source. Therefore, any treated effluent that is proposed for supply augmentation should be tested for the full suite of these compounds.

Besides the chemical (and radiological) constituents explicitly regulated through MCLs, a wealth of research has been conducted on the concentrations of unregulated trace organic constituents (TOrCs) in wastewater, their attenuation through conventional WWTPs, and their further breakdown during advanced treatment (Baronti *et al.*, 2000; Lovins *et al.*, 2002; Schäfer *et al.*, 2005; Sedlak *et al.*, 2006; Steinle-Darling *et al.*, 2010; Linden *et al.*, 2012; Salveson *et al.*, 2010; Snyder *et al.*, 2012, and many others). These constituents include pharmaceuticals, personal care products, consumer chemicals, flame retardants, and others, some of which have endocrine disrupting, carcinogenic, and/or other potentially harmful properties at sufficiently high concentrations. Due to this fact (and some help from media interest), this group of constituents has often been the cause of more public concern than the pathogens discussed below. However, the vast majority of TOrCs are present in treated effluent, if at all, at concentrations that are not of concern for human health (Trussell *et al.*, 2013). Further, various research projects document the ability of advanced treatment to meet stringent water quality standards (Trussell *et al.*, 2013, Salveson *et al.*, 2010, Salveson *et al.*, 2014, Linden *et al.*, 2012).

Disinfection byproducts (DBPs) are another suite of parameters that warrant consideration for potable reuse projects. Conventional DBPs, such as trihalomethanes (THMs), Haloacetic Acids (HAAs), bromate, and chlorate, are regulated by the Stage 1 and Stage 2 Disinfectant and Disinfection Byproduct Rules (USEPA, 1998 and 2006). *N*-Nitrosodimethylamine (NDMA) and other nitrosamines have been considered for regulation by the USEPA for over a decade (they are on the Unregulated Contaminant Monitoring Rule 2 list and the Candidate Contaminant List 3), and NDMA has a California Notification Level of 10 nanograms per liter (ng/L), which is considered the minimum treatment benchmark by the California utilities currently implementing potable reuse.

2.2.2 Pathogen Removal Goals and Requirements

With respect to current drinking water regulations, the pathogens of primary concern for potable reuse include enteric viruses, such as Adenovirus, Norovirus, and Enterovirus, and the protozoa *Giardia* and *Cryptosporidium*. In some cases, enteric bacteria (such as Salmonella) are also considered. Because treated effluent is generally not considered an acceptable “source water” under existing drinking water regulations (it is neither a groundwater, nor a surface water, nor a groundwater under the influence of surface water), the treatment requirements in current drinking water regulations are generally considered inadequate for the protection from the health risk presented by pathogens. Therefore, additional requirements for pathogen control that are specific to indirect potable reuse via groundwater replenishment have been developed by DDW (CDPH, 2014).

Water treatment regulations for pathogens are predicated on reducing the risk of infection to minimal levels. Table 2.2 identifies the concentration end goals for targeted pathogens that correspond to a modeled, annual risk of infection of 1 in 10,000 or less (Trussell *et al.*, 2013). Both DDW (CDPH, 2014) and NWRI (NWRI, 2013) used this risk level to develop their pathogen criteria.

Table 2.2 Pathogen Concentration End Goals for Drinking Water SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Pathogen	*Giardia* (cysts/L)	*Cryptosporidium* (oocysts/L)	Enteric virus (MPN/L)
Potable goal	6.80E-06	3.00E-05	2.22E-07

Notes:

(1) End goals are based on achieving a risk level of 1 in 10,000 annual risk of infection as listed by Trussell *et al.* (2013).

2.2.3 Overall Potable Reuse Water Quality Goals

The National Research Council (NRC, 2012) has determined that the use of advanced purification processes, such as those employed at the SVAWPC, will produce a high quality water that is as safe, or safer, than conventional water supplies in the United States. For advanced treatment trains, most chemicals are not detected; those that are detected are found at levels lower than those found in conventionally treated drinking water supplies (NRC, 2012). Further, NRC (2012) concludes that the risk from pathogens in potable reuse "…does not appear to be any higher, and may be orders of magnitude lower, than currently experienced in at least some current (and approved) drinking water treatment systems (i.e., *de facto* reuse)."

For any future potable reuse system employed by the District, the advanced treatment systems and advanced monitoring systems would be designed meet or exceed the water qualities detailed by the NRC (2012). The research in this report documents the ability to produce such a high quality water at the SVAWPC.

3.0 LONG TERM PERFORMANCE TESTING

The long-term testing at the SVAWPC has demonstrated the following items:

- MF performance is excellent, reducing turbidity consistently below the regulated limit and maintaining membrane integrity within specification. The result is a robust pathogen barrier to bacteria and protozoa. For all but one MF rack, the pressure decay test (PDT) results are normally distributed, allowing for the development of a predictive model of performance for monitoring and control. Online and bench-top turbidity measurements need improved correlation for tighter system monitoring and control.

- RO performance was consistent and normally distributed, with a recent decreasing trend in EC reduction. Online and bench-top measurement of EC correlated well, allowing effective RO monitoring through the use of feed and permeate EC measurements.

- The online UV system performance monitors, primarily UV transmittance (UVT) and UV intensity (UVI), show excessive variability and the lack of ability to track UV dose. Better calibration of UVT meters and installation of improved UV sensors would be necessary for a future potable reuse system.

- Development of a robust statistical data set, such as done here, allows for the development of a rigorous critical control point (CCP) methodology for future potable reuse treatment.

- The quarterly sampling results show high quality water that meets regulatory standards, for potable reuse as well as drinking water, and is protective of public health.

3.1 Critical Control Points for Improved Process Control and System Reliability

For each key treatment process tested here, MF, RO, UV, UV AOP, O_3, and BAF, this project examines the conservative monitoring and control of these systems using a critical control point (CCP) philosophy. The CCP is where: (1) control can be applied to an individual unit process to reduce, prevent, or eliminate process failure; and (2) monitors are used to confirm the CCP is functioning correctly. The CCPs for each of the key processes summarized in Table 3.1 below, and apply to both pathogen removal and removal of chemical pollutants. These CCPs (and others) are reviewed in this chapter and subsequent chapters of this report.

Table 3.1 CCPs for Key Treatment Processes
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Process	CCP	Other Less Accurate or Less Proven Monitoring Techniques
MF	• Pressure Decay Test (PDT) determines membrane integrity and provides confidence in protozoa removal, typically performed daily.	• Filtrate turbidity readings (online) do not provide a direct correlation to membrane integrity, but do provide confidence in high water quality. • Filtrate particle counts (bench top) and reduction of particles across MF provides additional verification of membrane performance, though not sufficiently sensitive to get full pathogen credits for MF. • Online particle counters are not believed to have sufficient sensitivity to achieve the pathogen credits.
RO	• Reduction of electrical conductivity (EC, online) across RO provides confidence in a minimum level of pathogen removal by RO. • Reduction of total organic carbon (TOC, online) across RO provides confidence in a minimum level of pathogen removal by RO. • Maintenance of low RO permeate TOC (online) provides added confidence in organics removal by RO	• Reduction in UV absorbance (UVA, online) across RO is insufficiently sensitive to provide higher pathogen credits than EC and TOC measurements. • Reduction in color (periodic) across RO is insufficiently sensitive to provide higher pathogen credits than EC and TOC measurements. • Online or periodic injection and monitoring of fluorescent dye has been documented (WRRF 14-10 and WaterRF 4536) to have the potential to provide greater sensitivity and accuracy for pathogen removal than all other methods. • A feed and permeate TOC analyzer (online) can provide validation of other monitoring methods as well as potentially increase the log removal credit to 2.0.
UV	• UV dose, which provides pathogen removal and some pollutant destruction (e.g., NDMA) can be continuously monitored online using a	• Destruction of total chlorine (online or periodic) across UV can be correlated with UV dose. • Destruction of NDMA (periodic) across UV can be correlated with UV dose.

Table 3.1 CCPs for Key Treatment Processes
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Process	CCP	Other Less Accurate or Less Proven Monitoring Techniques
	combined input of online UV transmittance (UVT), flow, and UV sensor intensity (UVI).	• Ballast power draw was not considered due to the rare occurrences when a lamp draws power but produces a very low UV output.
UV AOP	• Conventional monitoring uses the Electrical Energy per Order of Magnitude (EEO) method to equate energy use with trace pollutant destruction performance, based upon a known hydrogen peroxide dose. This can be done online.	• The EEO concept has been modified to be a "peroxide weighted dose," in which the UV dose multiplied by the peroxide dose (online). • UV AOP using sodium hypochlorite (free chlorine, measured online) in lieu of hydrogen peroxide will use total chlorine destruction and free chlorine destruction as a surrogate for advanced oxidation performance.
O_3	• O_3 disinfection performance is typically determined based upon the measurement of a known residual (C) and the contact time at the point of sampling for that residual (t), called Ct, and measures as mg-min/L.	• New research documents the accuracy of using O_3/TOC ratios to estimate pathogen disinfection performance and pollutant destruction performance.
BAF	• BAF is for chemical pollutant reduction. No current industry standard for performance monitoring.	• Potential CCPs include the use of TOC reduction across BAF and the reduction of UVA across BAF, both of which can be done periodically or online.

3.2 Data Analysis Approach

The long term testing results presented in this section was performed to provide three main values:

- Set the baseline of system performance, allowing for future data trending and verification.
- Provides immediate value with regard to pollutant and pathogen removal in accordance with industry standards and the design intent.

- Allow a thorough evaluation of how the treatment system is currently operated and how operation may be changed for a potable reuse project.

Regarding treatment process performance, the general assumption on treatment performance data is that it is normally distributed (forming a bell-shaped curve). A normally distributed data set will have a known percentage of data points falling within 1, 2, and 3 standard deviations of the average value. Knowing the “normal” range of performance data allows for a proactive system control, using critical control points (CCPs) or critical operating points (COPs)1 to monitor performance prior to any regulatory violation. With a sufficient body of data, a future potable reuse treatment system can be programmed to look for statistically significant data variation and to create the proper alarms and responses.

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[1] CCPs are specific to a known monitoring technique that confidently predicts treatment performance (e.g., MF PDT results). COPs are defined here as other monitoring techniques that provide a qualitative analysis of performance (e.g., MF filtrate turbidity). COPs can also be used to not only monitor quality, but production capacity (e.g., rise in transmembrane pressure on MF, which will require more time backwashing and cleaning, thus not producing as much water).

3.3 Microfiltration Performance

MF performance analysis is based upon data collected between 3/2014 and 6/2015. Looking to a future potable reuse project, our recommendation is to have District staff update the data set monthly to review performance trends.

MF performance analysis is based upon two parameters: continuous monitoring of turbidity and daily monitoring of pressure decay test (PDT) results. The turbidity monitoring is a gross indication of performance and is called “continuous indirect integrity monitoring” by the U.S. EPA (2005). Effluent turbidity has not been proven to directly correlate with the pathogen removal ability of the MF. PDT is a “direct integrity test” by the U.S. EPA (2005), and results do correlate with protozoa reduction. The PDTs are designed to measure if there is membrane damage sufficient to pass a 3 μm particle, which is the lower bound of the Cryptosporidium size range (U.S. EPA, 2005). When properly maintained, the SVAWPC’s Pall MF system is credited with 4-log removal of protozoa (CDPH, 2011).

3.3.1 Online Turbidity

MF filtrate turbidity is regulated at a value of 0.2 NTU. Low filtrate turbidity is representative of a well-functioning MF system, but does not specifically correlate with a degree of pathogen removal. Daily average influent and effluent turbidity values are shown in Figures 3.1 through 3.7, below and tabulated in Table 3.2. Over the analyzed time span, the following can be stated:

- Filtrate (effluent) turbidity met the permit requirement of 0.2 NTU for all days except two. For those two events, the high turbidity values were due to analyzer cleaning and a rain event. The spikes were verified with grab samples and the readings were below 0.2 NTU.
- Filtrate turbidity is cyclical; corresponding to MF cleaning events.
- Influent turbidity does not correlate with effluent turbidity:
  - The effluent (or filtrate) turbidity is consistently low with a tight distribution of data around the mean. Influent turbidity has more variability but is also tightly distributed. These results suggest good MF performance over an influent range of water quality.
  - As an example, a high influent turbidity value (not shown on the graph) was 20.27 NTU, taken on July 31, 2014. The paired filtrate turbidity for that day was 0.08 NTU. Thus, a high turbidity spike did not impact filtrate water quality. A specific reason for the high influent turbidity is not known, but may be tied to maintenance activities within the treatment plant.
  - As another example, the highest filtrate turbidity was 0.21 NTU on 11/13/14. This high filtrate turbidity value coincided with an influent turbidity of 3.34 NTU, which is not an abnormally high influent turbidity.
- The filtrate turbidity values are tightly distributed through some outlier data; with 85.5 percent of the data is within one standard deviation (Stdev) of the mean (compared to a

68 percent "standard"), 98.7 percent of the data is within two Stdev of the mean (compared to 95 percent "standard"), and 99.1 percent of the data is within three Stdev of the mean (compared to 99.7 percent "standard"). A future control system monitoring scheme could alarm the system based these values, particularly on the high end (as shown in Table 3.3).

- The MF influent turbidity values are also tightly distributed with some outlier data; with 86.9 percent of the data is within one Stdev of the mean (compared to a 68 percent "standard"), 96.8 percent of the data is within two Stdev of the mean (compared to 95 percent "standard"), and 98.9 percent of the data is within three Stdev of the mean (compared to 99.7 percent "standard"). A future control system monitoring scheme could alarm the system based these values, particularly on the high end (as shown in Table 3.4).

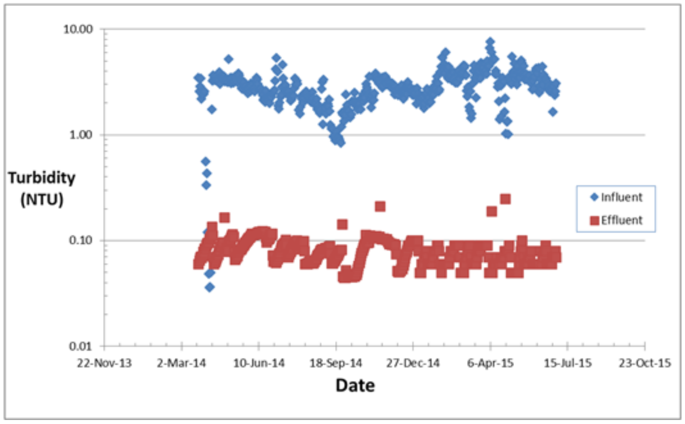

Figure 3.1 Influent and Effluent Turbidity

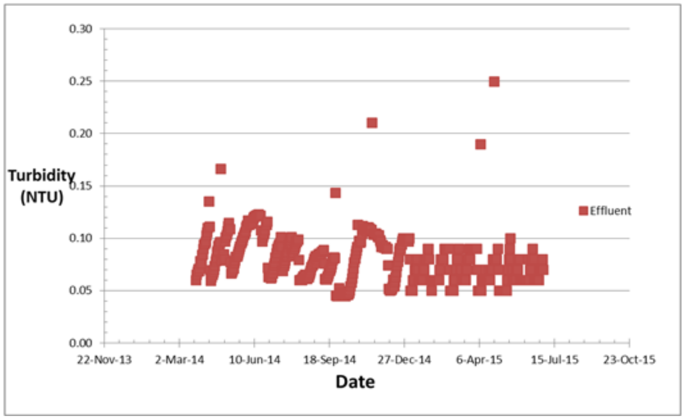

Figure 3.2 Effluent Turbidity

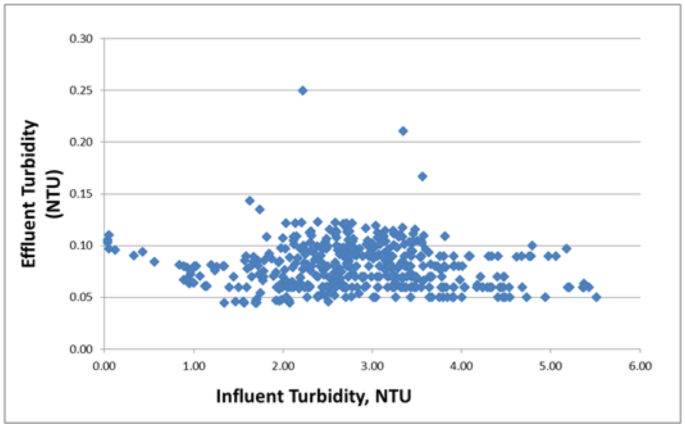

Figure 3.3 Influent and Effluent Correlation

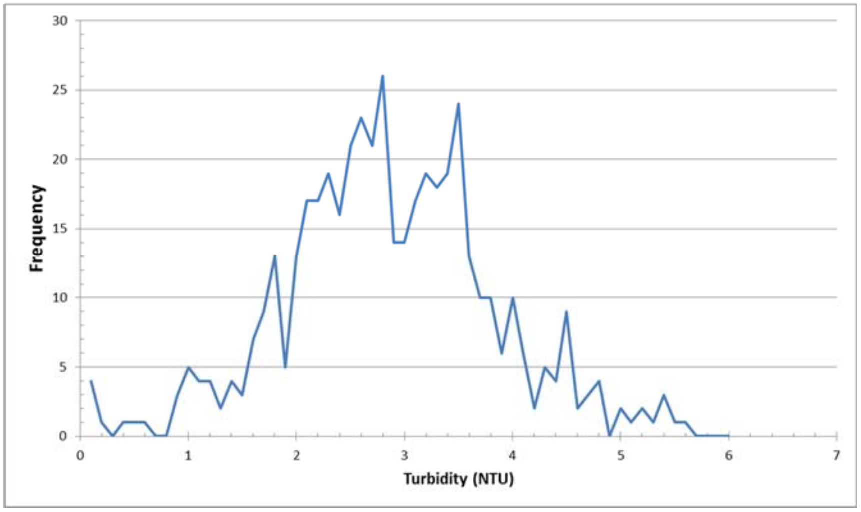

Figure 3.4 Influent Turbidity Data Distribution

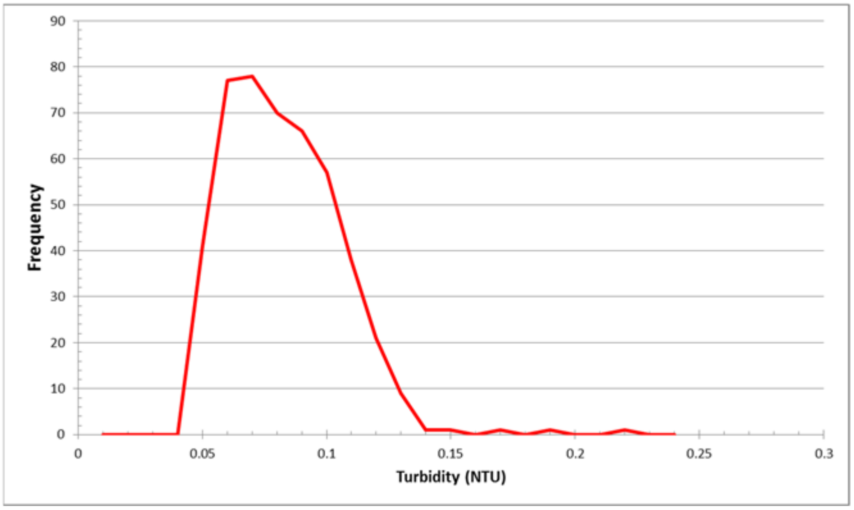

Figure 3.5 Effluent Turbidity Data Distribution

Table 3.2 MF Turbidity Values
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Parameter of Interest	Concern	Mean Value	Mean + 1 Stdev	Mean + 2 Stdev	Mean + 3 Stdev	Action
Influent Turbidity, NTU	High influent turbidity reflects high solids loading on MF.	2.85	3.87 ~86.85% of data below this value.	4.90 ~96.77% of data below this value.	5.92 ~99.14% of data below this value.	Calibrate influent turbidity meter. Contact the RWF to understand potential cause and timing of water quality impacts.
Effluent Turbidity, NTU	High effluent turbidity indicates potential MF breach.	0.08	0.103 *~85.53% of data below this value.*	0.126 *~98.70% of data below this value.*	0.149 *~99.14% of data below this value.*	Calibrate effluent turbidity meter. Take MF train off-line and perform PDT.

Notes:

(1) An influent turbidity of 20.27 NTU on 7/31/2014 was removed from the data set.
(2) An effluent turbidity of 0.62 NTU on 3/11/2015 was removed from the data set.
(3) An effluent turbidity of 0.63 NTU on 3/11/2015 was removed from the data set.

3.3.2 Bench-top Turbidity Calibration/Verification

A comparison of online turbidity and bench top turbidity data for MF feed and MF filtrate is shown in Table 3.3. The bench top data was taken between the 1/1/2015 and 6/30/2015. As is summarized below, the bench top data does not accurately match the online data, suggesting error in one of the two measurement techniques.

Feed Turbidity Comparison:

- The bench top data has a mean value of 5.67 NTU which is considerably higher than the online turbidity data mean of 3.40 NTU. Assuming the bench top data is more accurate (not accounting for human error), these results suggest the online values are not conservative.
- The bench top feed turbidity data also has a higher standard deviation of 5.38 compared the online feed turbidity standard deviation of 1.07. Again assuming the bench top is more accurate, the feed is far more variable in its turbidity than the online data would suggest.
- The considerable difference in means and standard deviations indicated a calibration issue with measurement equipment.
- Analysis using the CORREL function in Excel brings back a value of -0.17 between bench top and online feed turbidity data. This suggests there is little relationship between the two data sets that are measuring the same characteristic. Again this highlights an issue with the accuracy of measuring equipment.

Filtrate Turbidity Comparison:

- The bench top data has a mean value of 0.08 NTU which is similar to the online turbidity data mean of 0.07 NTU. It should be mentioned that although these values are close the bench top data is still greater than the online data. Assuming the bench top data is more accurate indicates the online data is not conservative.
- The bench top data filtrate turbidity standard deviation of 0.019 is greater than the online data filtrate turbidity standard deviation of 0.013. Similarly to the feed turbidity data this indicates the filtrate is more variable in its turbidity than the online data suggests.
- The bench top and online filtrate turbidity means are within one standard deviation of each other.

Table 3.3 MF Bench Top and Online Turbidity Comparison SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

	Mean (NTU)	Standard Deviation (NTU)
Bench Top MF Feed Turbidity	5.67	5.38
Online MF Feed Turbidity	3.40	1.07
Bench Top MF Filtrate Turbidity	0.08	0.019
Online MF Filtrate Turbidity	0.07	0.013

Notes:

(1) A bench top MF feed turbidity value of 182 NTU on 4/14/2015 was removed from the data set.
(1) An online MF filtrate turbidity value of 0.19 NTU on 4/7/2015 was removed from the data set.
(2) An online MF filtrate turbidity value of 0.25 NTU on 4/25/2015 was removed from the data set.

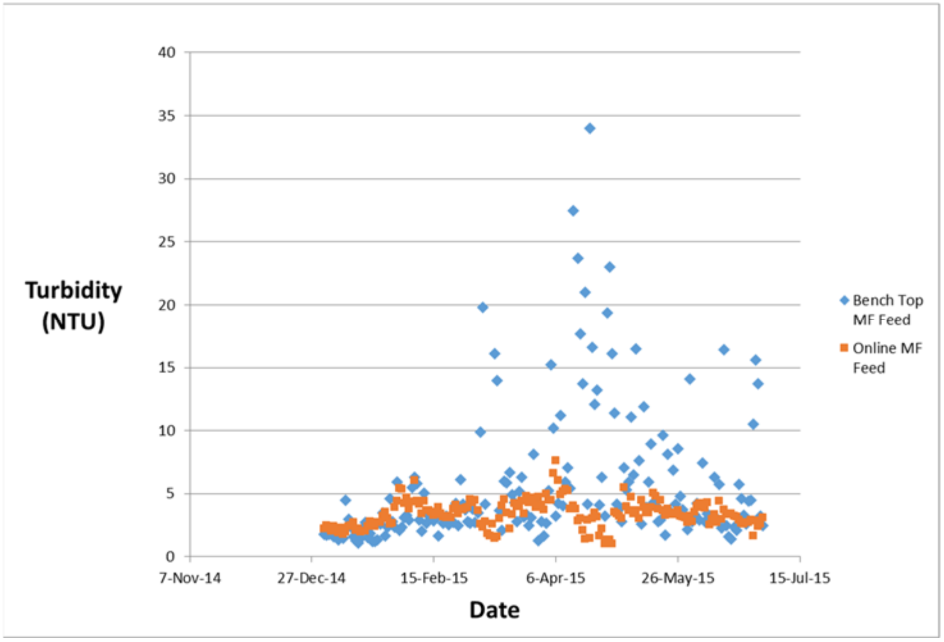

Figure 3.6 Comparison of Bench and Online Turbidity in MF Feed

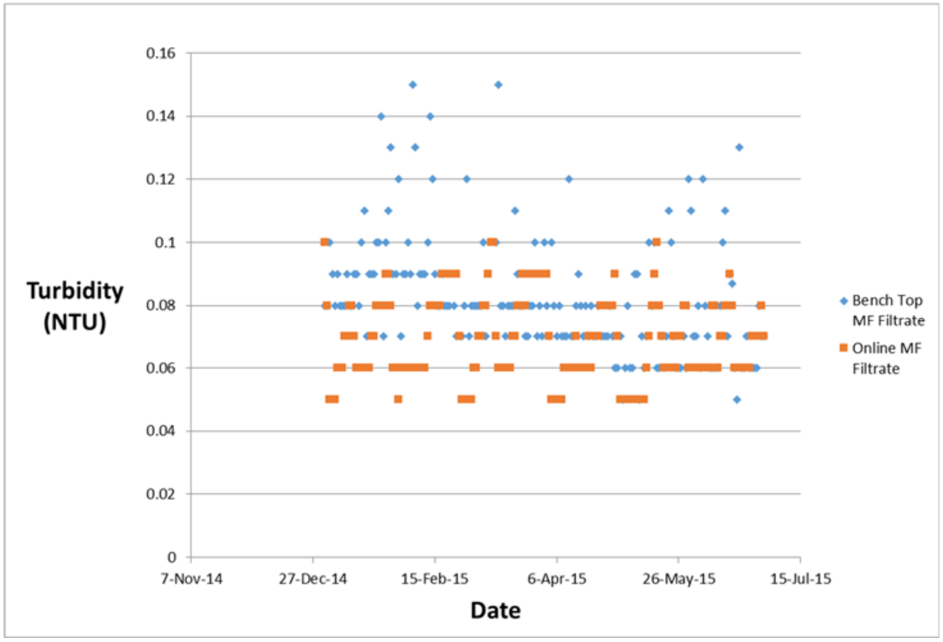

Figure 3.7 Comparison of Bench and Online Turbidity in MF Filtrate

3.3.3 Pressure Decay Testing

PDT results are shown in Figures 3.8 through 3.25, and Table 3.4 below. Over the analyzed time span, the following can be stated:

- PDT results (<0.3 psi/min) demonstrate membrane integrity and at least 4-log protozoa removal.

- The PDTs were trending up in Rack #2, suggesting a gradual impact on MF integrity. Evaluation and repair of Rack #2 resulted in a decrease in PDT. This decrease in PDT was attributed to loose module couplings leading to intermittent integrity test failure. The module couplings (112/rack) were tightened after discovery and the PDT levels stabilized.

- PDT numbers are stable for all other racks. As the values remain below the 0.3 psi/min target, pathogen removal is maintained.

- Because MF effluent turbidity is cyclical, it is difficult to develop a conclusion regarding PDT and effluent turbidity. However, a basic analysis suggests that PDT results and effluent turbidity are not correlated.

- The MF PDT values are also close to normally distributed for Racks 1, 3, 4, 6, 7, and 8, suggesting that these racks are in good condition with no noticeable performance degradation.

- The MF PDT values for Racks 2 and 5 are skewed from a normal distribution. Rack 2's initial data set, from March 2014 to October 2014, is normally distributed. Suspected membrane damage after October 2014 resulted in the rising PDT trend and subsequent repair. Rack 5's data is impacted by several outlier points early in system operation. Removing these outliers makes the Rack 5 data set normally distributed.

- As a quick verification, the normal distribution of the combined data sets from Racks 1, 3, 4, 5 (removing outliers), 6, 7, and 8 can be used as a visual check of future PDT results.
- Table 3.4 details the average and standard deviations of PDTs for each rack. Similar to turbidity, a future control system monitoring scheme could alarm the system based on these values, particularly on the high end or based upon trends.

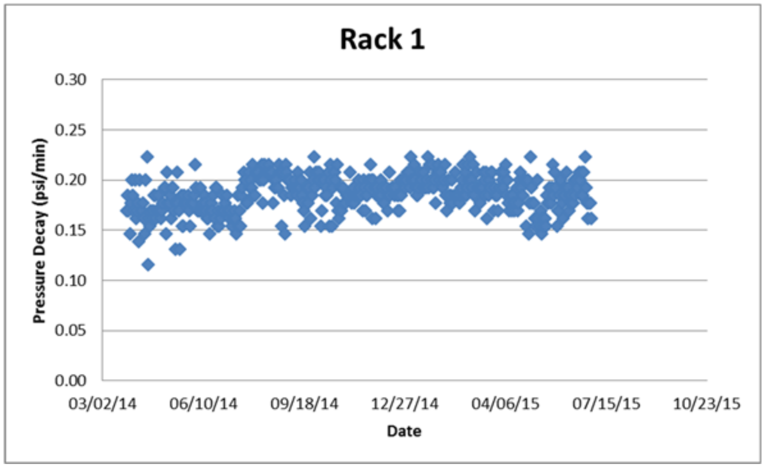

Figure 3.8 MF Rack 1 Raw Data

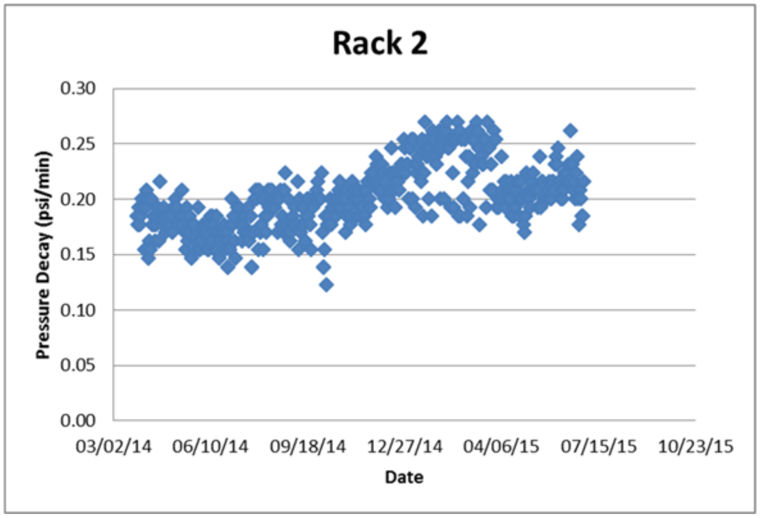

Figure 3.9 MF Rack 2 Raw Data

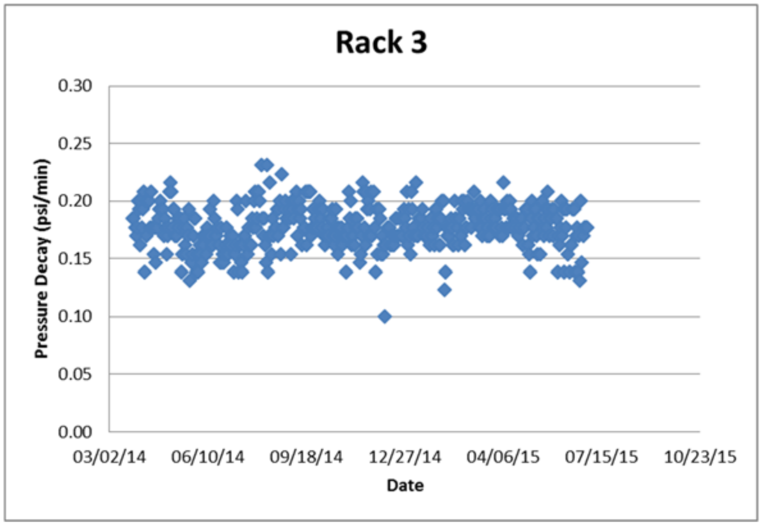

Figure 3.10 MF Rack 3 Raw Data

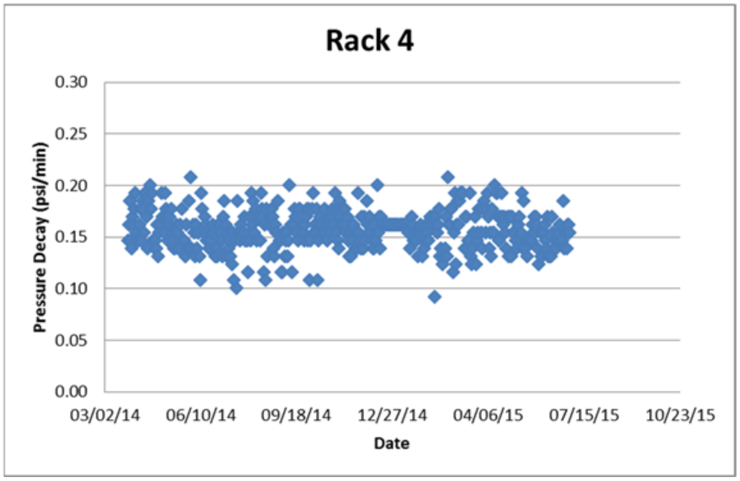

Figure 3.11 MF Rack 4 Raw Data

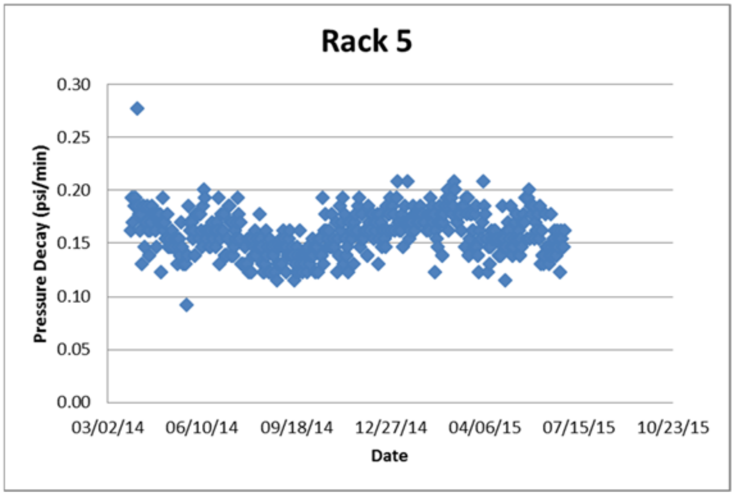

Figure 3.12 MF Rack 5 Raw Data

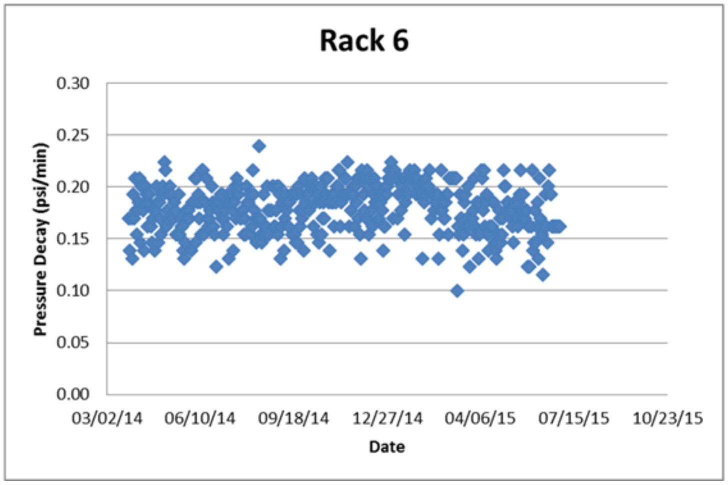

Figure 3.13 MF Rack 6 Raw Data

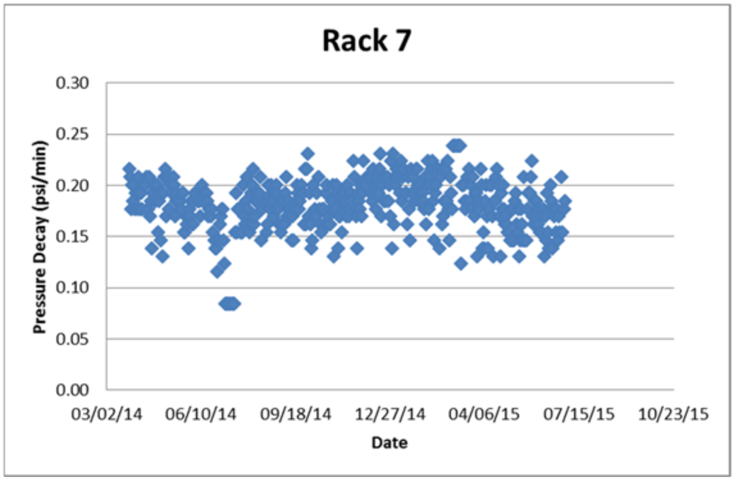

Figure 3.14 MF Rack 7 Raw Data

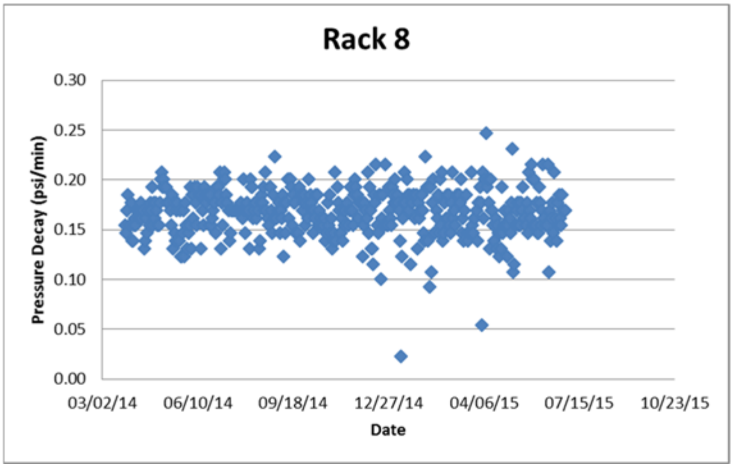

Figure 3.15 MF Rack 8 Raw Data

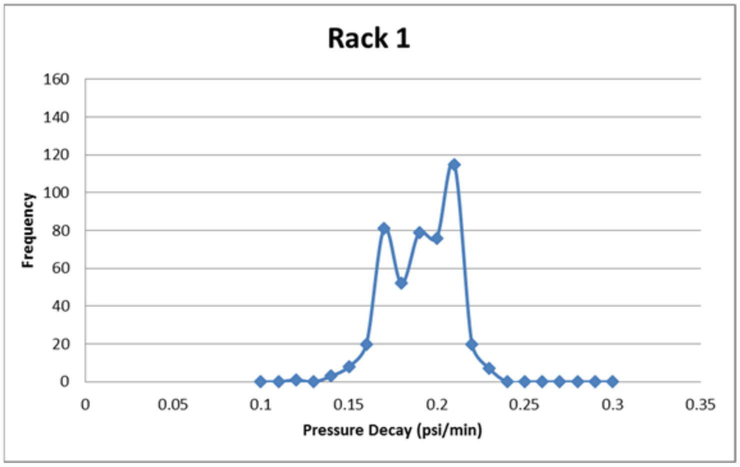

Figure 3.16 MF Rack 1 PDT Results

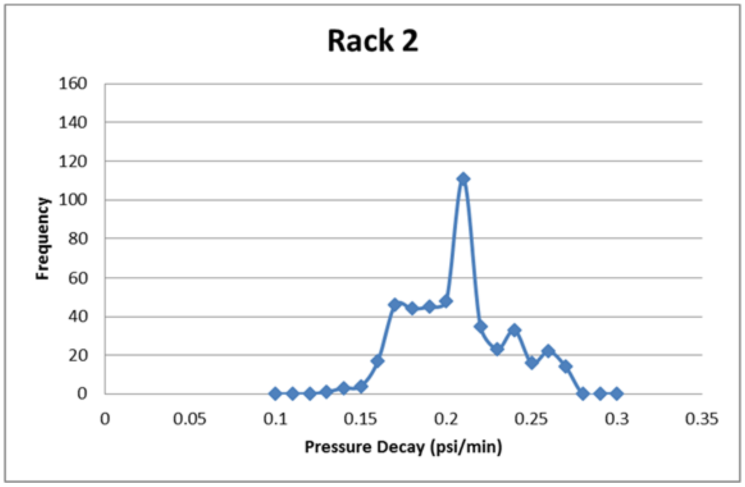

Figure 3.17 MF Rack 2 PDT Results

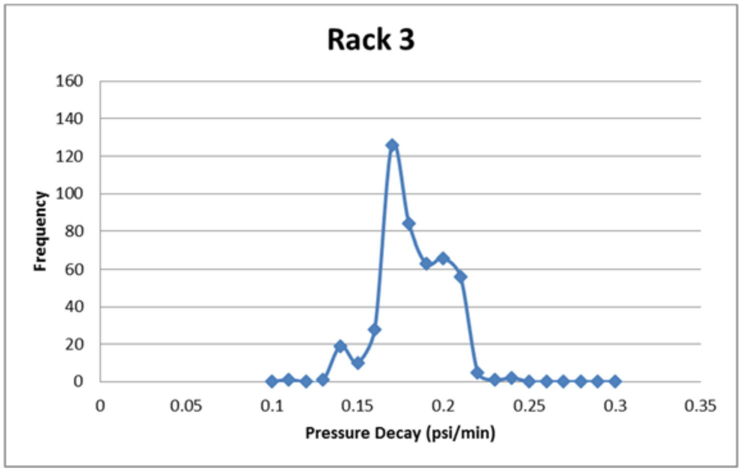

Figure 3.18 MF Rack 3 PDT Results

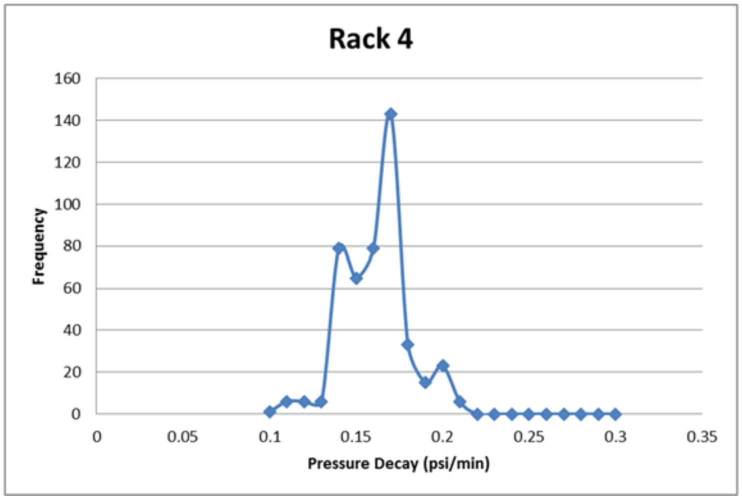

Figure 3.19 MF Rack 4 PDT Results

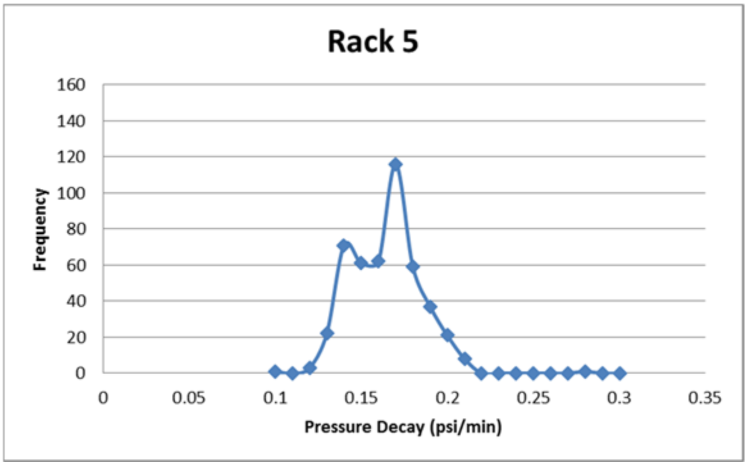

Figure 3.20 MF Rack 5 PDT Results

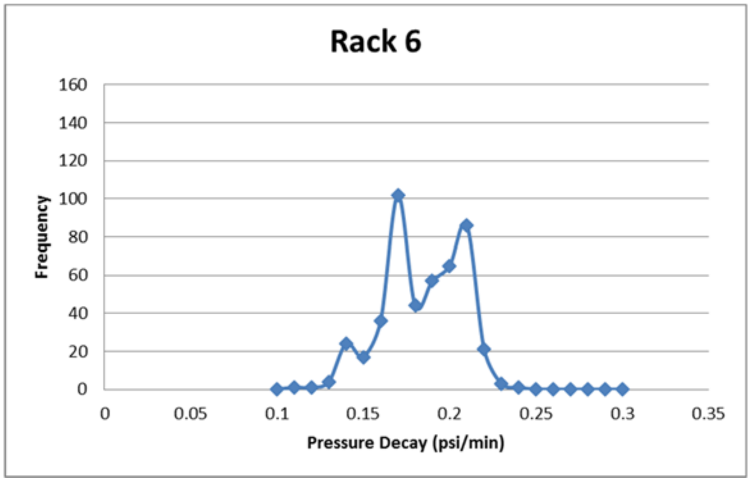

Figure 3.21 MF Rack 6 PDT Results

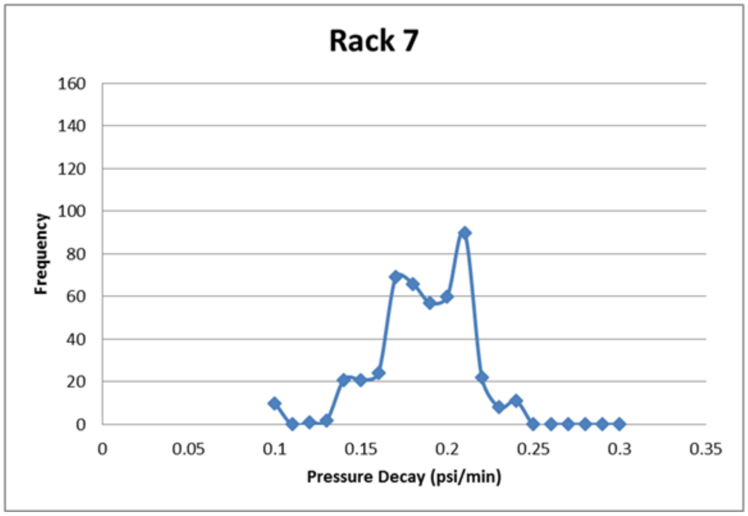

Figure 3.22 MF Rack 7 PDT Results

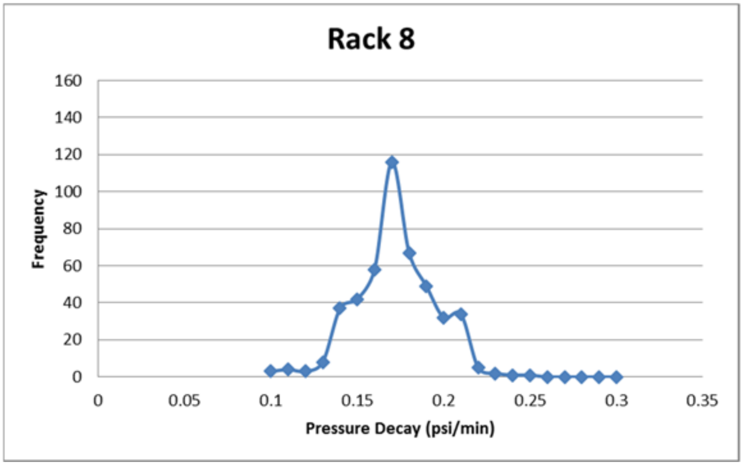

Figure 3.23 Microfiltration Pressure Decay Testing Results (Raw and distributed data across 8 racks)

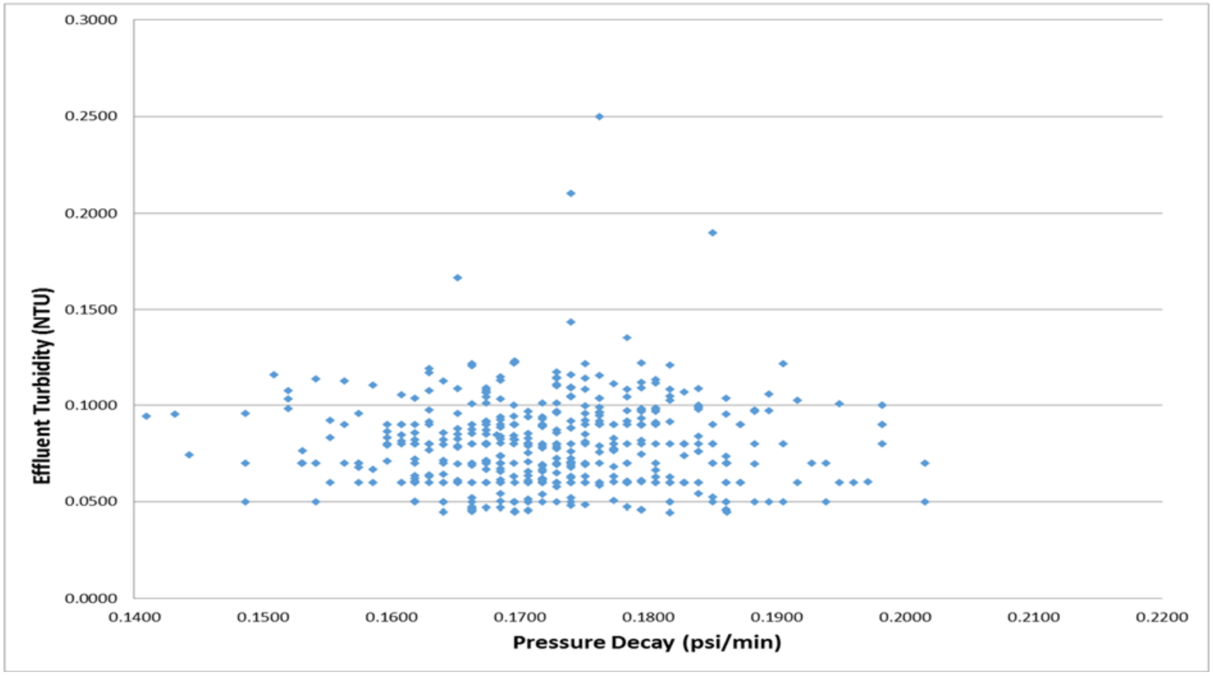

Figure 3.24 MF PDT and Effluent Turbidity Correlation (all Racks except Rack 2 Included)

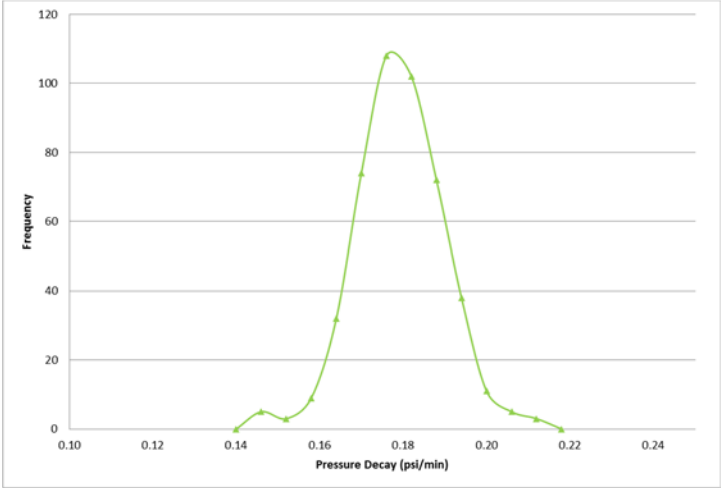

Figure 3.25 Average PDT Distribution

Table 3.4 MF PDT Values
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Rack	Concern	Mean Value	Mean + 1 Stdev	Mean + 2 Stdev	Mean + 3 Stdev	Action
Rack 1	High PDTs reflect membrane damage	0.19	0.20 ~83.33% of data below this value	0.22 ~98.48% of data below this value	0.24 ~100% of data below this value	Pin membranes based upon trending data
Rack 2	High PDTs reflect membrane damage	0.20	0.23 *~81.60% of data below this value*	0.26 *~96.97% of data below this value*	0.29 *~100% of data below this value*	Pin membranes based upon trending data
Rack 3	High PDTs reflect membrane damage	0.18	0.20 ~86.15% of data below this value	0.21 ~98.27% of data below this value	0.23 ~100% of data below this value	Pin membranes based upon trending data
Rack 4	High PDTs reflect membrane damage	0.16	0.18 *~83.33% of data below this value*	0.19 *~98.70% of data below this value*	0.21 *~100% of data below this value*	Pin membranes based upon trending data
Rack 5	High PDTs reflect membrane damage	0.16	0.18 ~85.50% of data below this value	0.20 ~98.92% of data below this value	0.22 ~99.78% of data below this value	Pin membranes based upon trending data
Rack 6	High PDTs reflect membrane damage	0.18	0.20 *~85.28% of data below this value*	0.22 *~99.78% of data below this value*	0.25 *~100% of data below this value*	Pin membranes based upon trending data
Rack 7	High PDTs reflect membrane damage	0.18	0.21 ~82.47% of data below this value	0.24 ~98.27% of data below this value	0.26 ~100% of data below this value	Pin membranes based upon trending data
Rack 8	High PDTs reflect membrane damage	0.17	0.19 *~83.77% of data below this value*	0.22 *~98.05% of data below this value*	0.24 *~99.78% of data below this value*	Pin membranes based upon trending data

3.3.4 Issues to Address for Potable Reuse and MF

The data analysis resulted in several recommendations:

- Filtrate turbidity values were well within regulatory values, with a few exceptions. Consistent calibration/verification of online meters and analysis of data trends is recommended.
- Influent turbidity seems to trend upwards on two separate occasions. Further, there were several occasions with very high influent turbidity values. The District should develop a communication protocol with San Jose RWF staff to discuss influent water quality spikes.
- The higher outlying values of effluent turbidity seem to happen on the end of an upwards trend of effluent turbidity (Figure 3.24). Further monitoring of this possibility is recommended.
- Periodic evaluation of PDT trends (monthly) is recommended. Evaluation should include a visual verification of current values versus historical values and a determination if the current data fits within 1, 2, or 3 standard deviations of the historical data set. Additional verification using a full statistical analysis is also recommended if data is to be used for quantitative problem solving.

3.4 Reverse Osmosis Performance

Low RO permeate TOC is representative of a well-functioning RO system, but does not specifically correlate with a degree of pathogen removal. A second key value of RO is the removal of salts, and hence the reduction and monitoring of EC is also important. From a regulatory perspective for potable reuse, the following applies to RO performance:

- TOC - TOC value of <0.3 at startup and <0.5 mg/L for the duration of operation.
- EC - each membrane element used in the project has achieved a minimum rejection of sodium chloride of no less than 99.0 percent (99.0 %) and an average (nominal) rejection of sodium chloride of no less than 99.2 percent (99.2 %). Importantly, this requirement is a factory specification for new equipment, and is not a performance demonstration in the field.

While RO is technically a “semi-permeable membrane,” constituents smaller than 0.1 to 1 nm can pass through RO (Khulbe *et al.*, 2008, Kosutic and Kunst, 2002). A visual presentation of membrane pore size, and the constituents that can be removed by different membranes is presented below in Figure 3.26. It should be noted that, while Figure 3.26 is correct, there are certain uncharged low-molecular organic compounds which can pass through the membrane, which is why both EC and TOC should be used as testing parameters to evaluate RO performance.

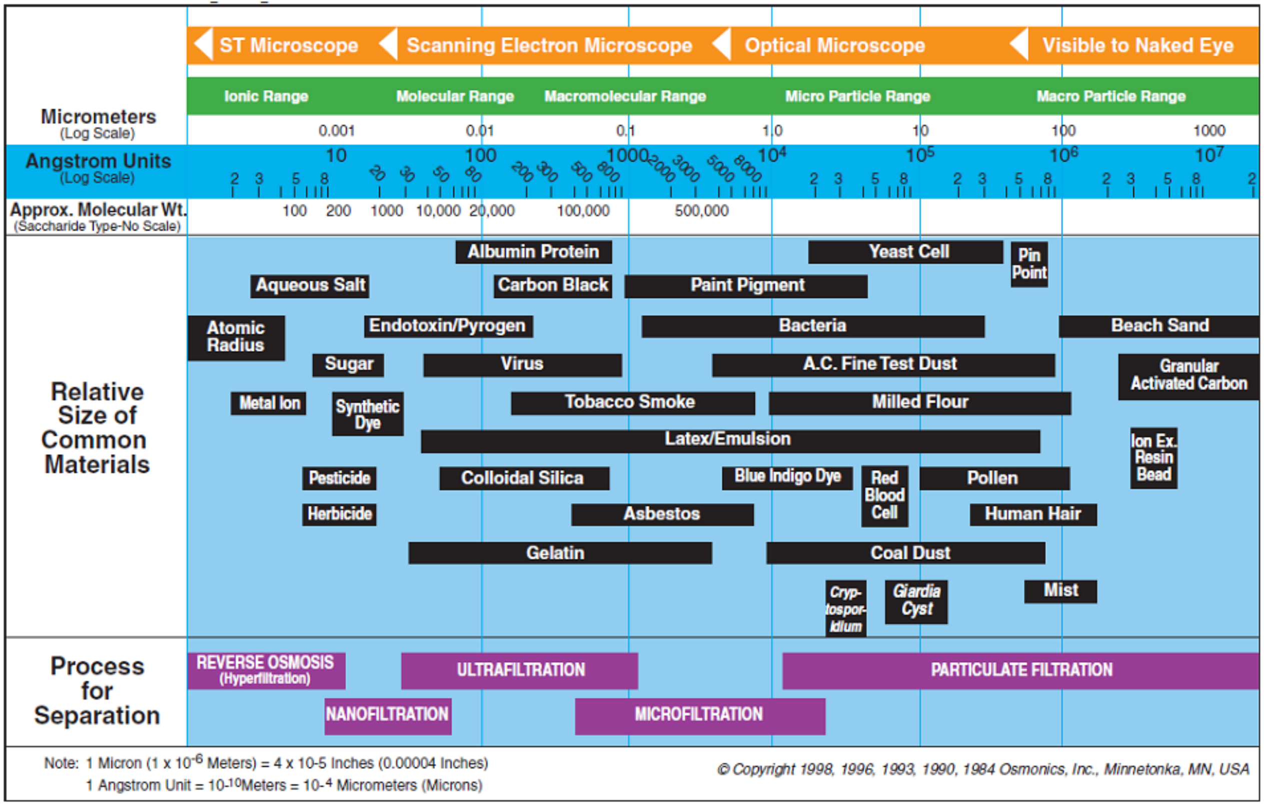

Figure 3.26 Membrane Separation Capabilities

3.4.1 Electrical Conductivity Removal by RO as a Surrogate for Pathogen Removal

The RO system currently does not have online TOC meters installed on the RO influent and effluent. The most accurate TOC meters will be installed for future potable reuse projects. Hence, this section that deals only with existing equipment and long-term operation, focuses entirely upon EC and not TOC. TOC results are presented in the next Chapter as part of RO challenge testing.

The DDW grants RO pathogen credit based upon the use of the log reduction of TOC as conservative surrogate, with the latest approval of 1.5 log reduction credit as part of the Water Replenishment District's potable reuse project (WRD, 2013). However, discussions with DDW indicate that either (or both) the log reduction of TOC and the log reduction of EC can be used.

The RO system is equipped with online EC meters on the influent and the effluent of the RO system. EC has a linear relationship with the total dissolved solids (TDS) in water, but that ratio is site specific. For the District, TDS in mg/L is ~57 percent of the EC value. TDS is commonly referred to as salt, and shown as Aqueous Salt in the above Figure. The EC results are documented in this report as part of the long-term analysis. These results show RO permeate EC in the 20 to 40 *u*S/cm range, correlating to TDS values of 11 to 23 mg/L. The average log reduction of EC is 1.67, with a log reduction of 1.5 99 percent of the time. This EC removal is consistent with other research (Clean Water Services, 2014).

TDS, best characterized and commonly represented as NaCl, is in the size range of 250 pm. This small salt is more than 16 times smaller than any known viral pathogens, more than 800 times smaller than any known bacterial pathogen, and more than 80,000 times smaller than any known protozoan pathogens. Because of this size difference, California regulators (DDW) are confident that the log reduction of EC provides a conservative measure of pathogen reduction performance from RO. For the SVAWPC RO system, ***at least*** 1.5 log reduction of all pathogens can be assumed through RO.

RO performance analysis is based upon data collected between 3/2014 and 7/2015.

3.4.2 Electrical Conductivity Data

Daily average influent and effluent EC values are shown in Figures 3.27 through 3.37, below, and tabulated in Table 3.5, below. Over the analyzed time span, the following can be stated:

- Both RO influent and RO permeate EC values are useful tools to track influent RWF water quality and RO performance for salt rejection. However, salt concentrations (or the resulting EC) in the influent to the RO system or in the RO permeate are not public health concerns (within the possible range of performance). The current data set shows two upward RO permeate EC trends, with a measurable reduction in EC values occurring in December of 2014, followed by the start of a second upward trend. A CIP was performed on 12/17/14 on rack #3 using sodium hydroxide, an additional CIP using sodium hydroxide and citric acid was performed on rack #2 on 12/22/14. On 12/29/14 membranes from RO train #3 vessel 13 (stage 1) and vessel 70 (stage 2) were removed and sent for an autopsy and cleaning. All membranes were then removed to prevent over fluxing per consultant's distribution protocol. Six of the replacement membranes were cleaned by a vendor and restored to the original manufacturer's flow rate and percent rejection specs. The remaining 8 membranes were new.

- Higher influent EC concentrations do result in higher RO permeate EC concentrations, but the statistical correlation is poor.

- From a public health standpoint, the key value is the log removal of EC. As demonstrated in the challenge testing of the SVAWPC RO membranes (presented further on), log removal of EC is a conservative surrogate for virus rejection (and thus also protozoa and bacteria rejection). Accordingly, it is important to understand the statistical significance of variation in EC log removal. The RO EC log reduction values are also close to normally distributed, as shown in Table 3.6, though observation of the data sets and trending show that performance of the RO membranes is changing, which does skew the normal distribution. A future control system monitoring scheme could alarm the system based these values, particularly on the low end. It is recommended to continue this monitoring over the next few years.

- The log reduction in EC is trending down, suggesting a reduction in performance of the RO membranes.

- The lowest recorded LRV value was 1.47.

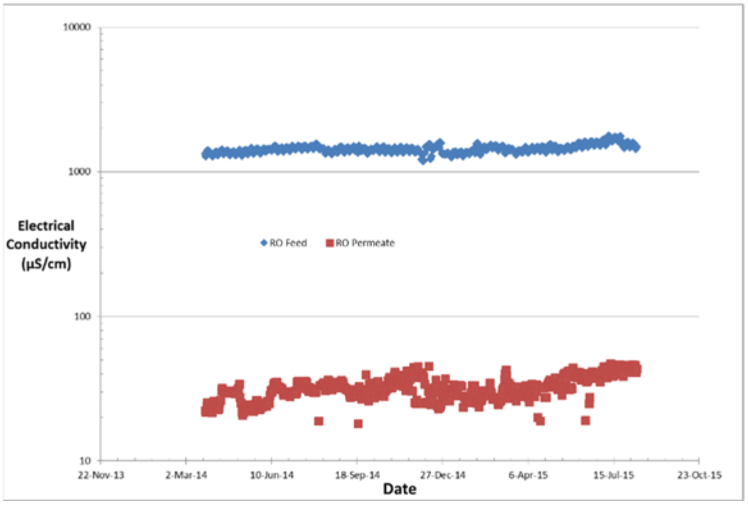

Figure 3.27 RO Influent and RO Effluent (Permeate) EC

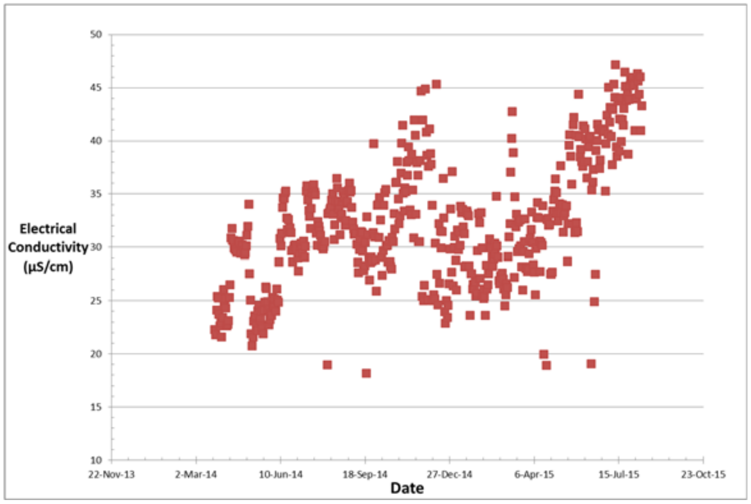

Figure 3.28 RO Effluent (Permeate) EC

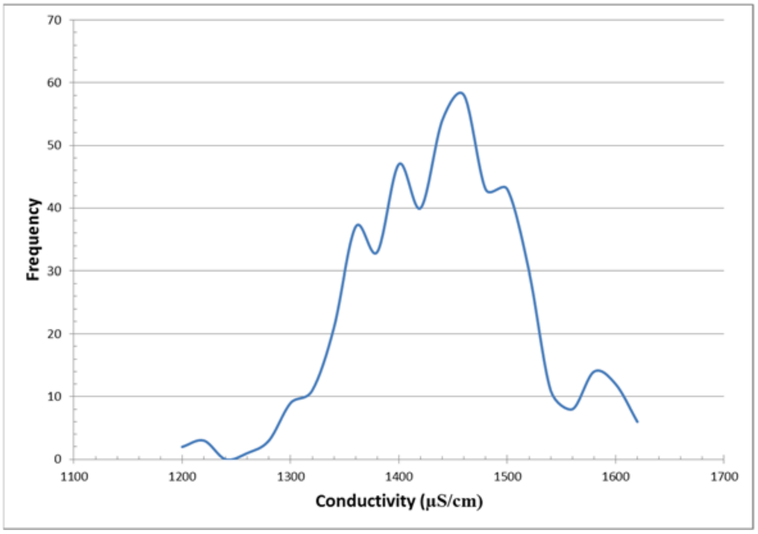

Figure 3.29 RO Influent EC Data Distribution

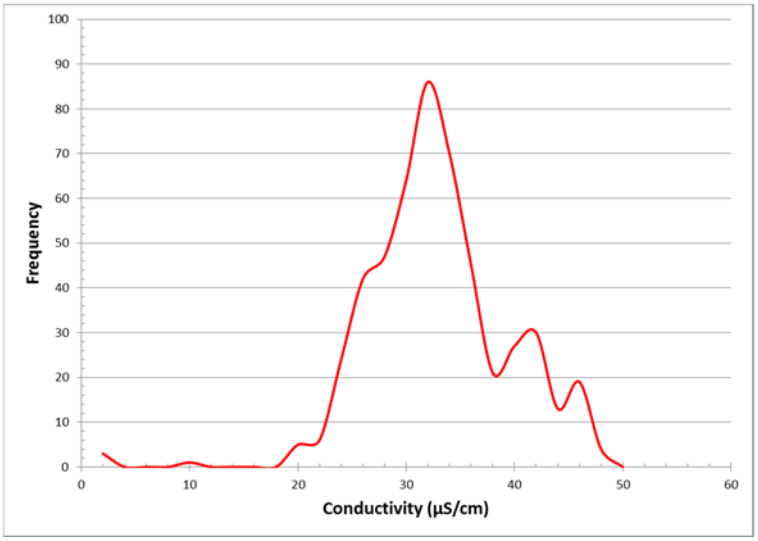

Figure 3.30 RO Permeate EC Data Distribution

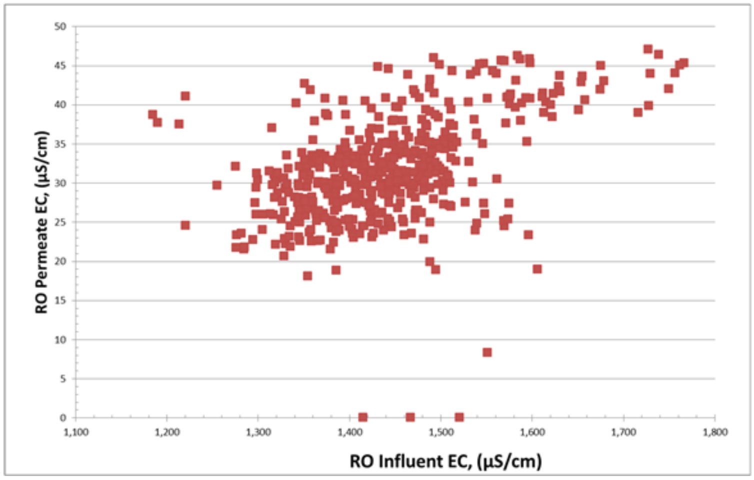

Figure 3.31 RO Influent and RO Permeate EC Correlation

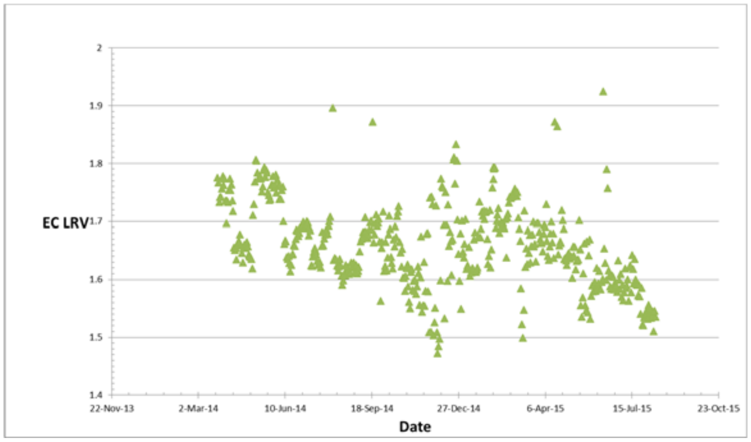

Figure 3.32 EC LRV by RO

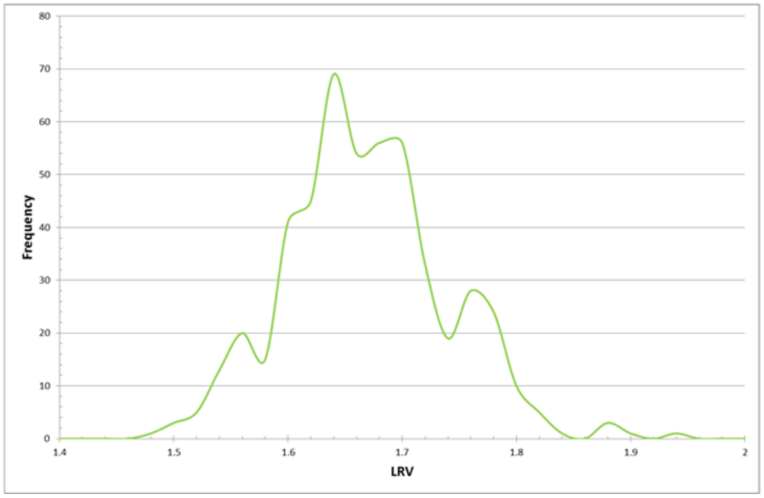

Figure 3.33 EC LRV Data Distribution

Table 3.5 RO EC LRV Statistical Variability
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Parameter of Interest	Concern	Mean Value	Mean - 1 Stdev	Mean - 2 Stdev	Mean - 3 Stdev	Action
RO EC LRV	Low LRVs indicate a compromised RO membrane	1.66	1.58 ~86.31% of data above this value	1.51 ~99.01% of data above this value	1.43 ~100% of data above this value	Calibrate EC meters. Perform TOC monitoring to check performance.

Notes:

(1) An RO EC LRV of 4.05 on 4/19/2015 was removed from the data set.
(2) An RO EC LRV of 4.05 on 4/18/2015 was removed from the data set.
(3) An RO EC LRV of 4.19 on 8/3/2014 was removed from the data set.

3.4.3 Bench-top EC Calibration/Verification

A comparison of online EC and bench top EC data for RO feed and RO filtrate is shown below. The bench top data was taken between the 1/12015 and 7/31/2015. As is summarized below, the bench top data matches the online data, suggesting agreement of the two measurement techniques.

Feed EC Comparison:

- The bench top RO feed EC mean of 1409 µS/cm is similar to the online RO feed EC mean of 1475 µS/cm. Both means are within one standard deviation of another. Visual analysis of the EC feed graph shows the online data consistently greater than the bench top data.
- The bench top RO feed EC standard deviation of 101 µS/cm is very similar to the online RO EC standard deviation of 106 µS/cm.
- Analysis using the CORREL function in excel gives a correlation coefficient of 0.82. This indicated a positive linear relationship between the two data sets that are measuring the same characteristic. Visual analysis of the RO feed EC correlation graph shows the linear relationship described above. When online EC is low, bench top EC is low and when online EC is high, bench top EC is high.
- The data suggests the RO feed online EC meter are well calibrated and provide meaningful results.

Permeate EC Comparison

- The bench top RO permeate EC mean of 34.3 µS/cm is very similar to the online RO permeate EC mean of 33.7 µS/cm. The bench top mean is slightly greater than the online mean; however, the difference is a fraction of a standard deviation.
- The bench top RO permeate EC standard deviation of 7.2 µS/cm is very similar to the online RO permeate EC standard deviation of 6.2 µS/cm.
- Analysis using the CORREL function in excel gives a correlation coefficient of 0.74. This indicated a positive linear relationship between the two data sets that are measuring the same characteristic. Visual analysis of the RO permeate EC correlation graph shows a positive linear relationship; however, it is not as strong as the RO feed EC correlation.
- The results suggest the RO permeate online meter is performing well, coupled with the accurate RO feed EC online meter, the log reduction of EC appears reliable and conservative as a surrogate for pathogen removal credit.

Table 3.6 RO Bench Top and Online EC Comparison SVAWPC Potable Reuse Demonstration Testing Santa Clara Valley Water District		
	Mean (µS/cm)	**Standard Deviation (µS/cm)**
Bench Top RO Feed EC	1409	101
Online RO Feed EC	1475	106
Bench Top RO Permeate EC	34.3	7.2
Online RO Permeate EC	33.7	6.2

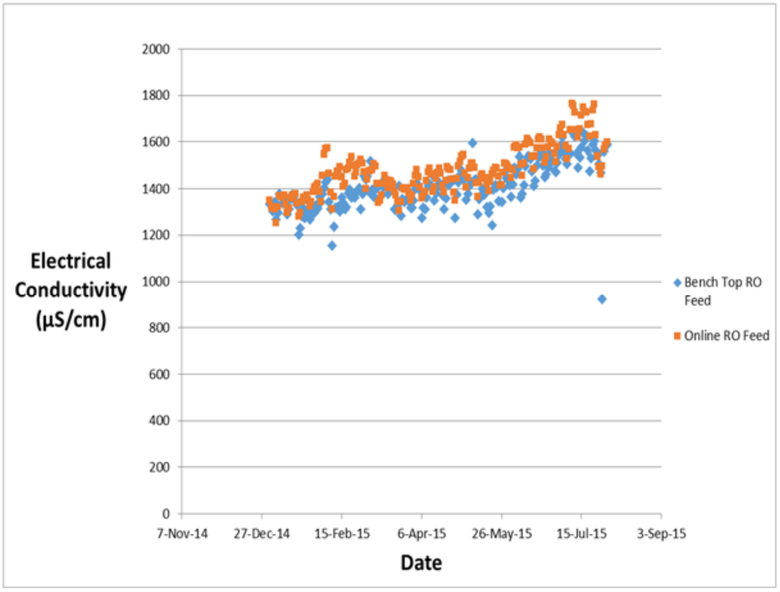

Figure 3.34 Comparison of Bench and Online EC in RO Feed

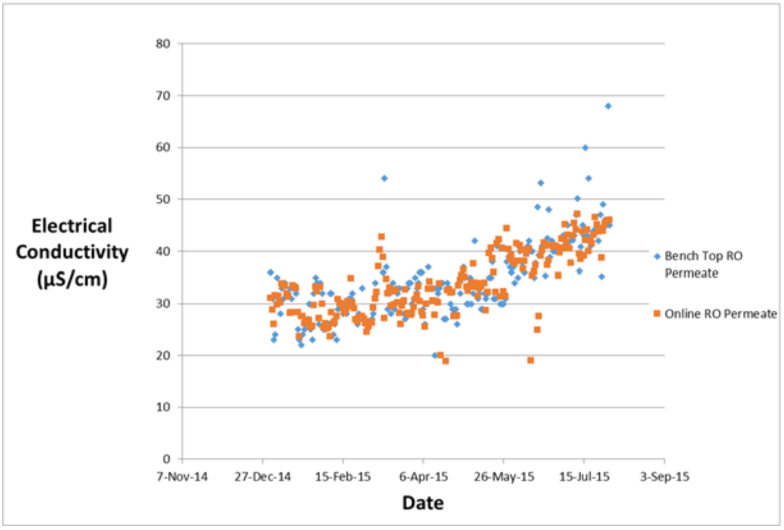

Figure 3.35 Comparison of Bench and Online EC in RO Permeate

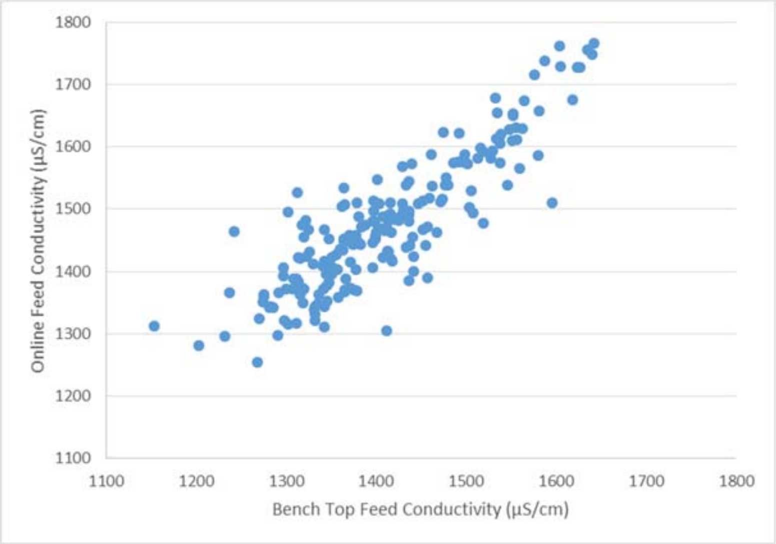

Figure 3.36 Correlation of Online and Benchtop EC Data for RO Feed

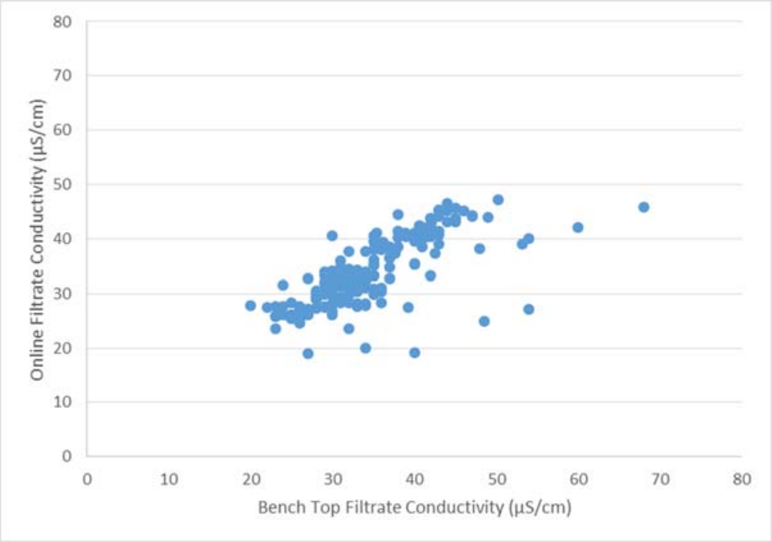

Figure 3.37 Correlation of Online and Benchtop EC Data for RO Permeate

3.4.4 Issues to Address for Potable Reuse for RO

The data analysis resulted in several recommendations are as follows:

- The EC LRV has shown two upward trends in RO permeate EC data. A CIP was performed on 12/17/14 on rack #3 using sodium hydroxide, an additional CIP using sodium hydroxide and citric acid was performed on rack #2 on 12/22/14. On 12/29/14 membranes from RO train #3 vessel 13 (stage 1) and vessel 70 (stage 2) were removed and sent for an autopsy and cleaning. All membranes were then removed to prevent over fluxing per consultant's distribution protocol. Six of the replacement membranes were cleaned by a vendor and restored to the original manufacturer's flow rate and percent rejection specs. The remaining 8 membranes were new.
- The RO permeate EC is trending up, with a corresponding downward trend in the log reduction of EC. For a potable reuse project, the District would want to implement a CCP approach to system monitoring and system maintenance, targeting specific EC log reduction values or trends that result in maintenance activities.
- The LRV falls below a value of 1.5 on three occasions, with a minimum value of 1.47.
- The online EC meters match bench top EC meters, providing confidence in the measured values and the subsequent calculation of pathogen log reduction credit.

3.5 Ultraviolet Disinfection Performance

UV performance analysis is based upon data collected between 3/2014 and 2/2015. This data set can be expanded as more information becomes available. Our recommendation is to update the data set monthly to review performance trends.

UV performance for potable water reuse is typically based upon one primary parameter (dose) that is directly impacted by several parameters (flow, UVT, UV intensity). The dose correlates directly with the disinfection of pathogens and the destruction of trace pollutants (either by photolysis or by advanced oxidation in the case where H2O2 or NaOCl is added ahead of UV). For this analysis, flow measurements are assumed accurate and not detailed here.

3.5.1 Past UV Validation Work

Extensive UV analysis was performed and documented in Carollo (2014). That challenge testing work is detailed in the next Chapter.

3.5.2 Online UVT

UVT is commonly measured as the amount of light that penetrates a 1 cm path-length. Low UVT water will result in a quick absorbance of UV light and reduce the capacity of any UV reactor. RO permeate has exceptionally high UVT, which allows for the delivery of a high UV dose with a reasonable amount of energy. The District measures UVT online using Wedeco TMO-IV UV Transmittance Monitors. The RO permeate UVT values are shown in Figures 3.38 through 3.40, below. Over the analyzed time span, which was through 2/2015[2], the following can be stated:

- The UVT values, as should be expected for RO permeate, are high, with a median value of 98 percent.
- 10 percent of the UVT values are below 96 percent, which is lower than would be expected for RO permeate.
- The UVT values climb with time, and recent values are continually at or around 100 percent.

The variability of the data set and the trending of the data do not allow a normal distribution analysis as conducted for the MF and RO data sets. Further, these data suggest that the online UVT meter and the calibration approach are not accurately tracking the RO permeate UVT. This possible conclusion is supported by the downward trend in EC removal, aligning with other monitoring, which is counter to the rising UVT in the RO permeate.

3.5.3 Bench-top UVT Calibration/Verification

A comparison of online UVT (WEDECO, Model # AF45-WD) and bench top UVT data for RO filtrate is shown below. The data was taken between the dates 5/29/2015 and 2/4/2015.

- The mean online UVT is 97.72 percent which is slightly higher than the mean bench top UVT of 97.49 percent, though the difference is not considered significant from a perspective of impact to UV dose delivery.
- Visual analysis of the online data shows short downward trend which may occur between calibration cycles, suggesting the need for more frequent calibrations.
- The online UVT has a standard deviation of 1.85 percent which is higher than the bench top UVT standard deviation of 1.04 percent (Table 3.7). This is seen visually by the

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[2] The collection and analysis of data through July 2015 could be done and added to this data set, if needed. The variability of data suggests that additional analysis would not alter the listed conclusions.

higher and lower values witnessed with the online meter compared to the steadier bench top UVT data.

- For a future potable reuse project, a review of more accurate online UVT meters designed for RO permeate applications should be considered. This could be coupled with a more accurate bench-top UVT meter, one that utilizes a 4 cm path length instead of the traditional 1 cm path length. Finally, a more aggressive calibration procedure would be recommended.
- Note: for the production of non-potable recycled water, as is currently done, the UVT data and trending do not represent a problem or water quality concern.

Table 3.7 UV Bench-top and Online UVT Measurements
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

	Mean (%)	Standard Deviation (%)
Bench Top UVT	97.49	1.04
Online UVT	97.72	1.85

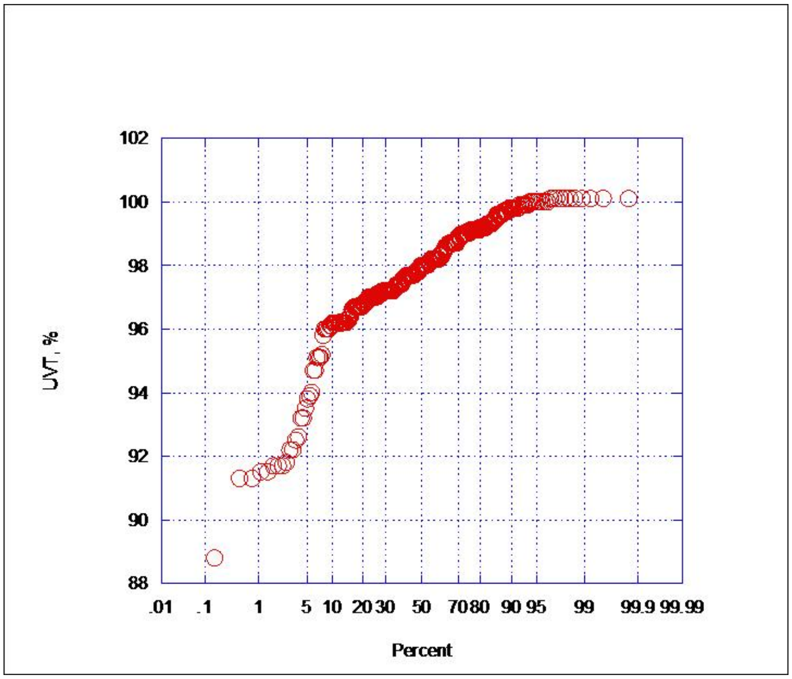

Figure 3.38 Online RO Permeate UVT

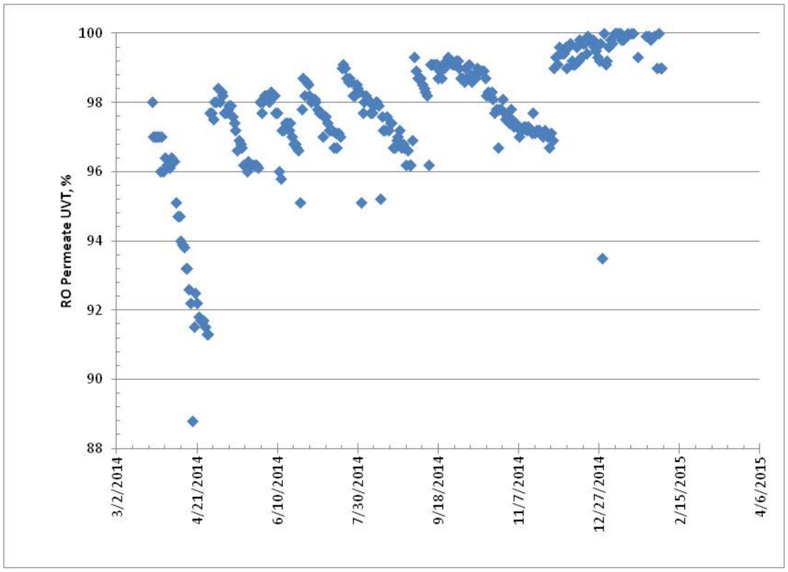

Figure 3.39 RO Permeate UVT with Time

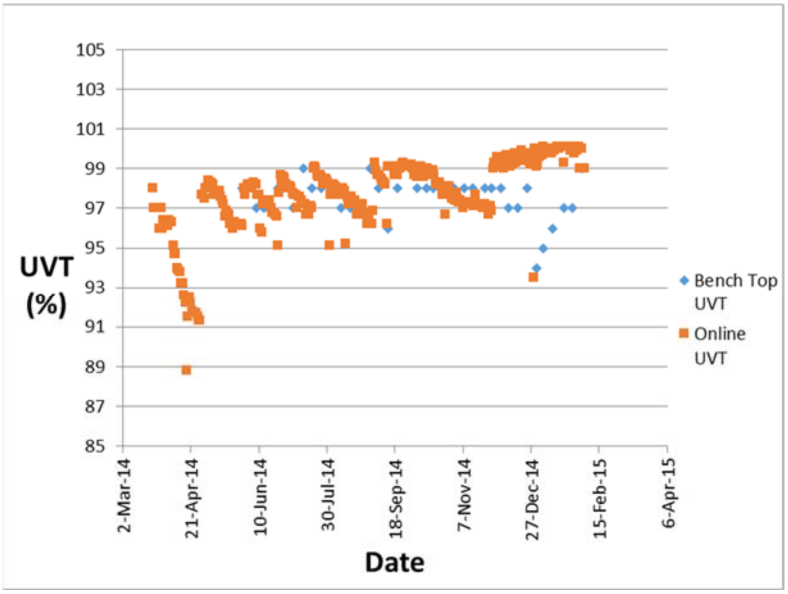

Figure 3.40 Comparison of Bench Top and Online UVT Values in RO Permeate

3.5.4 UVI and UV Dose

The existing UV system was designed to disinfect MF filtrate to Title 22 standards, and is effectively performing this task. When disinfecting RO permeate, the existing monitoring and control system has been demonstrated to conservatively meet non-potable water reuse regulatory standards. With that said, and as documented in Carollo (2014) and as detailed in the next section, the UV system monitoring (sensors measuring UV intensity (UVI)) and controls (dose, which is based upon UVT and UVI and flow) was not designed to accurately measure performance on RO permeate for potable reuse applications. The result is sensors that do not accurately track UVI, which then results in inaccurate UV dose measurement (which is further skewed by the less than ideal measurements of UVT).

For a properly calibrated sensor, it would track changes in power to the reactor and changes to UVT. Figures 3.41 and 3.42 illustrate that the current sensor technologies do not provide accurate monitoring and thus do not allow for confidence in system control. These results are for the entire sensor data set (all 6 trains, 1 sensor per reactor, two reactors per train). Inspection of each UV reactor data set for UVI shows some variability from reactor to reactor (or sensor to sensor), but all data sets show a similar level of inaccuracy tracking changes in UVT and changes in reactor power.

As a final reminder, these sensors (and these reactors) were not designed to provide accuracy for potable reuse applications. Recommendations for a potable reuse project follow below.

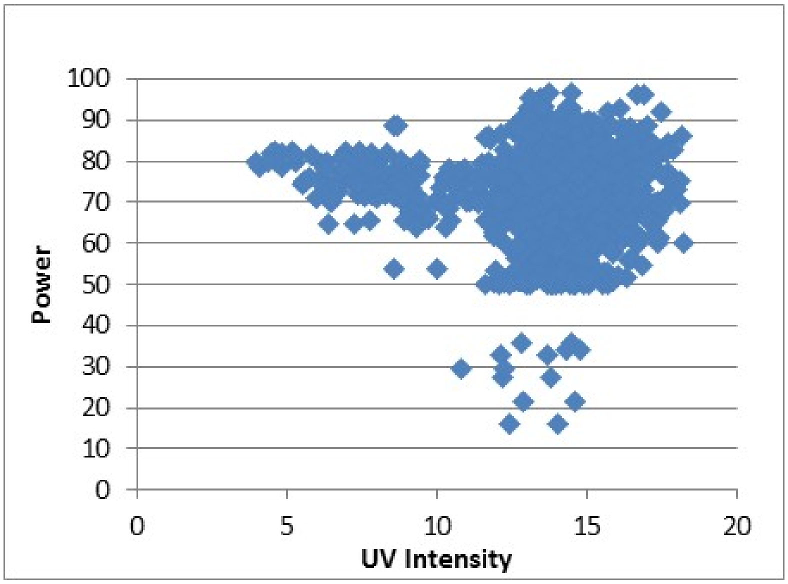

Figure 3.41 UVI and UV System Power

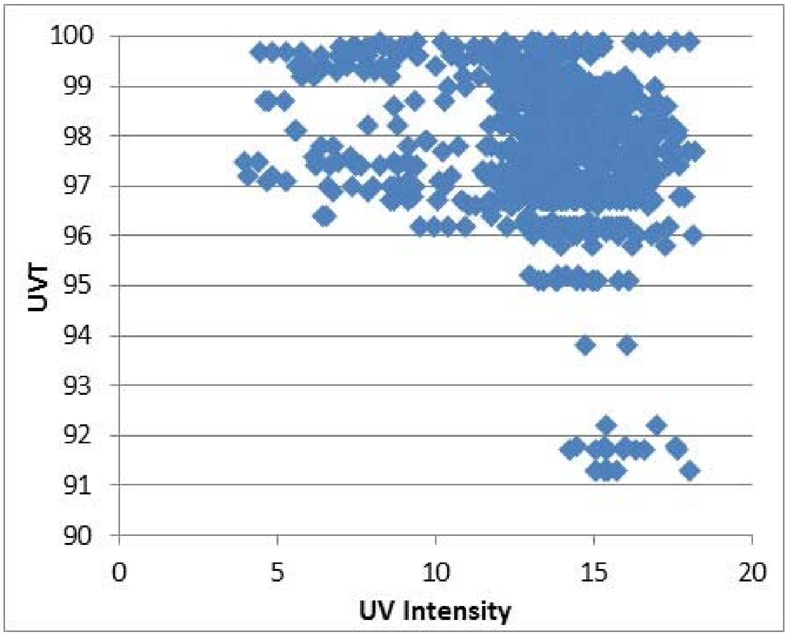

Figure 3.42 UVI and RO Permeate UVT

3.5.5 Issues to Address for Potable Reuse for UV

For a future potable reuse project, the following changes would need to be made to the existing UV system:

- The UVT is not accurately characterized, which is likely a combination of the accuracy of the online meter and the calibration procedures. A 4 cm path length bench-top UVT meter would improve confidence in RO permeate UVT values and allow for a more accurate analysis of the online meter.

- The UVI sensors on the existing UV system do not accurately track changes in light intensity within the reactor. New sensors designed to measure the UVI in an RO permeate application will be implemented for future potable reuse water production. Consultation with Xylem (WEDECO) is recommended to the District when/if potable reuse is implemented.

3.6 System Water Quality Monitoring and Performance

Periodic grab samples after steps in the treatment train, and of the finished water were performed to document the existence and removal of a range of key constituents, including total nitrogen (TN, regulated for potable reuse at <10 mg/L), total organic carbon (TOC, regulated for potable reuse at <0.5 mg/L), NDMA (with a notification level of 10 ng/L for potable reuse), 1,4-dioxane (which is a commonly used surrogate for the measurement of advanced oxidation performance and also has a notification level of 1 *u*g/L), and a range of CECs as well as conventional regulated drinking water pollutants. The monitoring frequency over the performance demonstration test period is shown in Table 3.8.

Table 3.8 Monitoring Frequency and Location
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

	Location			
Frequency	**Influent**	**RO Influent**	**RO Effluent**	**Finished Water**
Bi-weekly				Total Nitrogen
Monthly		NDMA, 1,4-Dioxane	NDMA, 1,4-Dioxane	NDMA, 1,4-Dioxane
Quarterly				Regulated Contaminants, Contaminants with secondary MCL, Chemicals with NLs, lead, copper, NDMA, 1,4-Dioxane, CECs

3.6.1 Bi-monthly TKN and TN Finished Water Monitoring

Total kjeldahl nitrogen, or TKN, and is the total concentration of organic nitrogen and ammonia. TKN values, as shown in Figure 3.43, remained very low over the duration of testing. TN, which is regulated by DDW at 10 mg/L, is TKN plus nitrate and nitrite. Over four quarterly sampling events, nitrate concentrations ranged from 0.94 to 1.5 mg/L while nitrite concentrations were below detection (<0.05 mg/L). The combined result is a TN value of <2 mg/L, well below the regulated value of 10 mg/L.

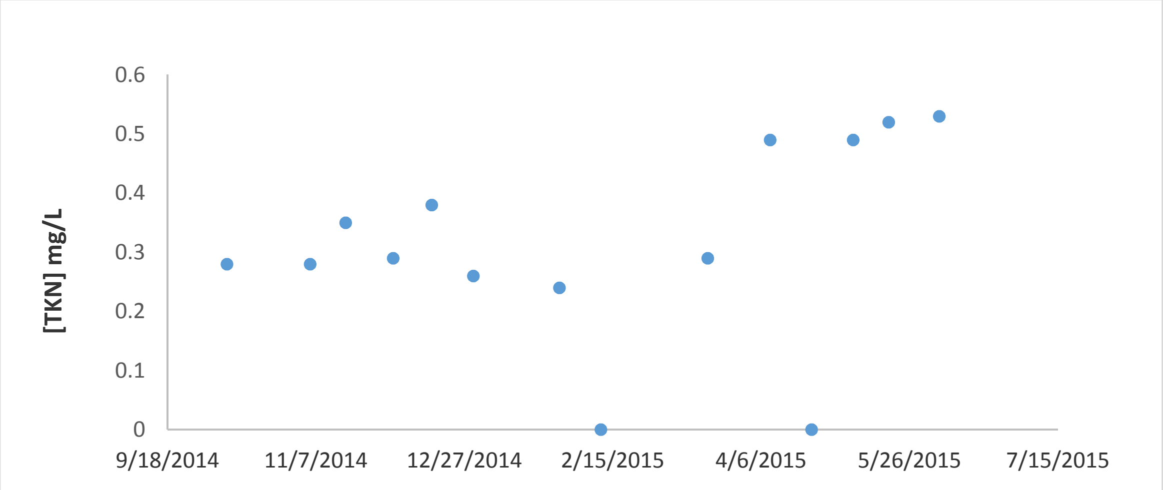

Figure 3.43 Bi-monthly TKN monitoring of finished water

3.6.2 Reverse Osmosis NDMA and 1,4-Dioxane Monitoring

NDMA values in the RO feed had substantial variability, ranging from >45 ng/L to 24 ng/L, which may be the result of variable water quality from the San Jose Santa Clara RWF or may be related to NDMA formation due to chloramination procedures at the SVAWPC. The RO permeate NDMA values were reduced to below the 10 ng/L notification level in one of four instances. This NDMA data is supported by a larger database collected as part of UV specific analysis of NDMA destruction, showing an average NDMA concentration of 30 ng/L in the RO permeate. 1,4-dioxane levels in RO feed are at or above the notification level of 1 ug/L in three of four measurements, and reduced below that notification level by RO.

The log removals for both NDMA and 1,4-dioxane by RO are plotted below. Note that the NDMA log removal by RO exceeds values commonly found in the literature of ~0.5-log (about 70% removal).

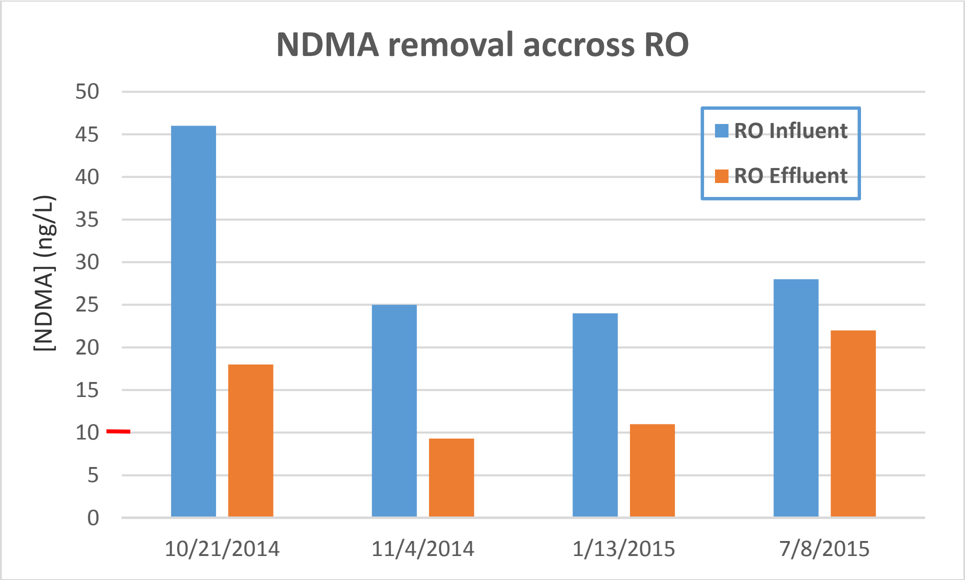

Figure 3.44 RO removal of NDMA under normal operation monitoring, showing a notification level of 10 ng/L for NDMA

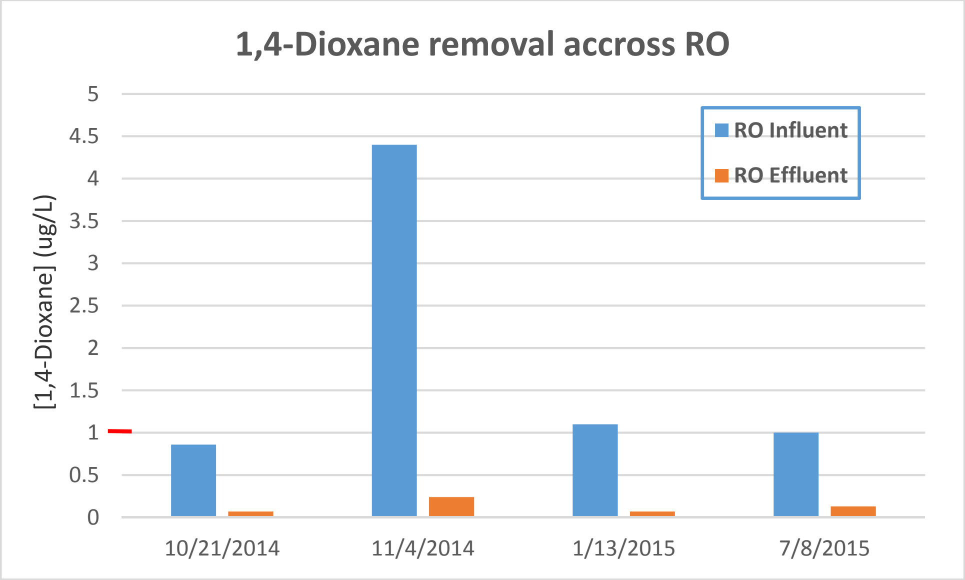

Figure 3.45 RO removal of 1,4-Dioxane under normal operation monitoring, showing a notification level of 1 ug/L for 1,4-Dioxane

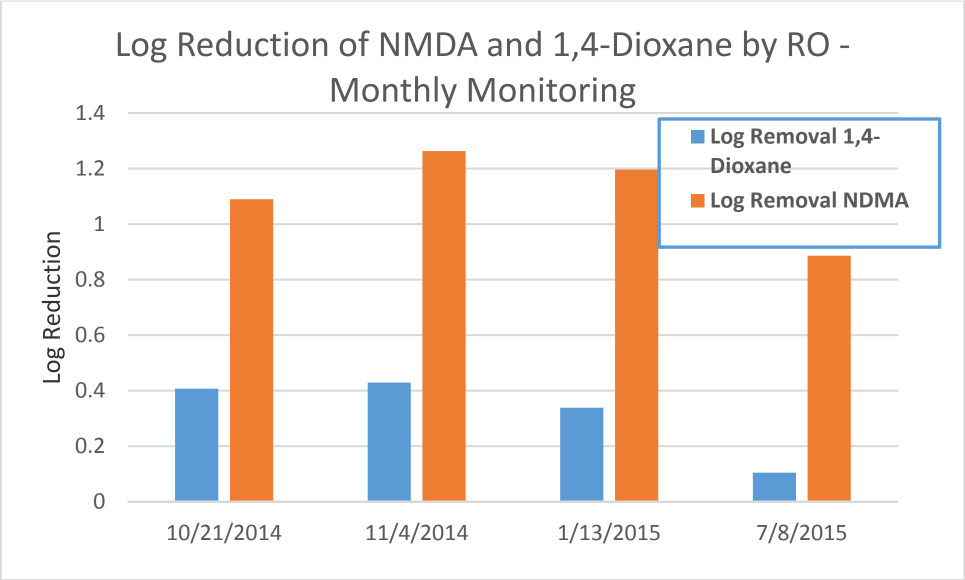

Figure 3.46 Log Removal of NDMA and 1,4-Dioxane under normal operation monitoring

3.6.3 Quarterly Sampling for Regulated and Other Trace Level Pollutants

Quarterly sampling of the finished water from the SVAWPC (and one sample of secondary effluent from the RWF) was collected to document the high quality of the finished water. Extensive laboratory analysis was done on each sample following the drinking water and potable reuse water quality testing requirements (CDPH, 2014), particularly Tables 64431-A, 64442, 64443, 64444-A, 64533-A, Priority Toxic Pollutants, chemicals with California Notification Levels, chemicals with secondary MCLs, and a range of trace level pollutants often referred to as Chemicals of Emerging Concern (CECs). Water quality data was evaluated in accordance with California drinking water regulations (CCR Title 22 Division 1, Chapter 15). If already established, analytical results were reported to the detection limit for purposes of report (DLR). If DLRs were not established, the result was reported to the method reporting limit (MRL). A list of all water quality requirements and their corresponding analytical methods evaluated during the study are presented in Appendix A. All data is presented in Appendix B, and all detected chemicals are shown in Table 3.9, below. ***Of the hundreds of analytical tests for MCLs, NLs, toxic pollutants, and CECs (>1000 analytical tests) spanning a full year of operation***, only 23 chemicals have been found in the SVAWPC effluent (to date), and all have been found well below regulatory standards or health-based levels with the exception of three NDMA samples (29, 28 and 15 ng/L). NDMA is reduced by UV photolysis, and a future potable reuse system would utilize a sufficiently high UV dose to destroy this pollutant.

The analysis also included testing of the feed water to the SVAWPC, which was San Jose Santa Clara RWF secondary effluent, and the corresponding removal of those pollutants by the SVAWPC, as also shown below. These results continue to document the ability of the SVAWPC to reduce pollutants to very low levels, often below detection and always below health levels.

Table 3.9 Detected Trace Chemical Compounds in SVAWPC Finished Water During Quarterly Sampling Events Q1, Q2, Q3 and Q4
SVAWPC Potable Reuse Demonstration Testing
Santa Clara Valley Water District

	Chemical	SVAWPC Finished Water Measurement (Q1, Q2, Q3 and Q4)	Applicable Detection Level	Applicable Regulatory Standard
CECs	1,4-Dioxane	0.11 ug/L	0.07 ug/L	1 ug/L[1]
	4-nonylphenol	130 ng/L	100 ng/L	500,000 ng/L[2]
	DEET	12 ng/L	10 ng/L	2,500 ng/L[2]
	NDMA	29, 3.8, 28, & 15 ng/L	2 ng/L	10 ng/L[1]
Primary MCLs	Ammonia (as N)	0.46, 0.28, 0.26, & 0.75 mg/L	0.05 mg/L	10 mg/L (Total Nitrogen)
	Chloroform (Trichloromethane)	0.62 & 0.78 ug/L	1 ug/L	80 ug/L (Total THMs)
	Cyanide	0.032 mg/L	0.025 mg/L	0.15 mg/L
	Kjeldahl Nitrogen	0.42, 0.3, 0.56, & 0.82 mg/L	0.2 mg/L	10 mg/L (Total Nitrogen)
	Monochloroacetic Acid	3.6 ug/L	2 ug/L	60 ug/L (HAA5)
	Nitrate (as N)	4.2,4.4, 5.1, & 6.9 mg/L	0.4 mg/L	10 mg/L
	Total Haloacetic Acids (HAA5)	4 ug/L	2 ug/L	60 ug/L
	Total Nitrogen	1.4, 1.3, 1.7, and 2.3 mg/L	0.4 mg/L	10 mg/L
	Total THMs	0.62 & 0.78 ug/L	0.5 ug/L	80 ug/L
Secondary MCLs	Chloride	5 & 8 mg/L	5 mg/L	250 mg/L
	Surfactants	0.056 mg/L	0.05 mg/L	0.5 mg/L
	Turbidity	0.17, 0.04, 0.2, & 0.05 NTU	0.1 NTU	5 NTU
Notification Levels	Boron	233, 227, 222, & 306 ug/L	100 ug/ L	1,000 ug/L
	Chlorate	21 & 33 ug/L	20 ug/L	800 ug/L
	Formaldehyde	7.3 & 8.3, 14, & 14 ug/L	5 ug/L	100 ug/L

Table 3.9 Detected Trace Chemical Compounds in SVAWPC Finished Water During Quarterly Sampling Events Q1, Q2, Q3 and Q4

SVAWPC Potable Reuse Demonstration Testing
Santa Clara Valley Water District

Chemical		SVAWPC Finished Water Measurement (Q1, Q2, Q3 and Q4)	Applicable Detection Level	Applicable Regulatory Standard
Unregulated Constituents	Acetaldehyde	1.1, 1.6, 1.6, & 1.1 ug/L	1 ug/L	None
	Phosphate	0.14 & 0.14 mg/L	0.05 mg/L	None
	Potassium	0.6 & 0.6 mg/L	0.5 mg/L	None
	Silica	0.6 mg/L	0.5 mg/L	None

Notes:

1. 1,4-Dioxane and NDMA have CDPH Notification Levels.
2. Health Based Standards for CECs are listed in Appendix A Table A-1.

Table 3.10 Detected Trace Chemical Compounds in SVAWPC Source Water (RWF Secondary Effluent) and Corresponding SVAWPC Finished Water During Quarterly Sampling Events Q3 and Q4

SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Chemical		SVAWPC Source Water Measurement (Q3 and Q4)	SVAWPC Finished Water Measurement (Q3 and Q4)	Applicable Detection Level	Applicable Regulatory Standard
CECs[2]	1,4-Dioxane	1.1 & 1.1 ug/L	ND & 0.11 ug/L	0.07 ug/L	1 ug/L[1]
	4-nonylphenol	680 & 170 ng/L	130 ng/L & ND	100 ng/L	500,000 ng/L
	Atenolol	78 & 51 ng/L	ND & ND	5 ng/L	4,000 ng/L
	Bromide	0.32 & 0.27 mg/L	ND & ND	0.05 mg/L	None
	Carbamazepine	110 & 130 ng/L	ND & ND	5 ng/L	None
	Cotinine	74 & 23 ng/L	ND & ND	10 ng/L	1,000 ng/L
	DEET	56 & 28 ng/L	12 ng/L & ND	10 ng/L	2,500 ng/L
	Meprobamate	19 & 12 ng/L	ND & ND	5 ng/L	200,000 ng/L
	NDMA	100 & 34 ng/L	28 & 15 ng/L	2 ng/L	10 ng/L[1]

Table 3.10 Detected Trace Chemical Compounds in SVAWPC Source Water (RWF Secondary Effluent) and Corresponding SVAWPC Finished Water During Quarterly Sampling Events Q3 and Q4

SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Chemical		SVAWPC Source Water Measurement (Q3 and Q4)	SVAWPC Finished Water Measurement (Q3 and Q4)	Applicable Detection Level	Applicable Regulatory Standard
	PFOS	37 ng/L	ND	5 ng/L	200 ng/L
	PFOA	29 ng/L	ND	5 ng/L	400 ng/L
	Primidone	81 & 75 ng/L	ND & ND	5 ng/L	10,000 ng/L
	Sucralose	14,000 & 7,300 ng/L	ND & ND	100 ng/L	150,000,000 ng/L
	TCEP	190 & 1,000 ng/L	ND & ND	10 ng/L	5,000 ng/L
	Triclosan	39 & 11 ng/L	ND & ND	10 ng/L	2,100,000 ng/L
Primary MCLs	Aluminum	130 ug/L	ND	50 ug/L	1000 ug/L
	Ammonia (as N)	0.26 & 0.2 mg/L	0.86 & 0.75 mg/L	0.05 mg/L	10 mg/L (Total Nitrogen)
	Arsenic	2 ug/L	ND	2 ug/L	10 ug/L
	Cyanide	0.03 mg/L	ND	0.025 mg/L	0.15 mg/L
	Fluoride	0.49 & 1.49 mg/L	ND & ND	0.1 mg/L	2 mg/L
	Gross Beta Particles	21 & 19 pCi/L	ND & ND	4 pCi/L	50 pCi/L
	Kjeldahl Nitrogen	1.9 & 1.9 mg/L	0.56 & 0.82 mg/L	0.2 mg/L	10 mg/L (Total Nitrogen)
	Nitrate (as N)	71.9 & 77.8 mg/L	6 & 7.1 mg/L	1 mg/L	10 mg/L
	Total Haloacetic Acids (HAA5)	1 ug/L	ND	2 ug/L	60 ug/L
	Total Nitrogen	18 & 19 mg/L	1.7 & 2.3 mg/L	0.4 mg/L	10 mg/L
	Trichloroacetic Acid	1.4 ug/L	ND	1 ug/L	60 ug/L (HAA5)
Secondary MCLs	Chloride	210 & 267 mg/L	5 & 8 mg/L	5 mg/L	250 mg/L
	Iron	320 ug/L	ND	100 ug/L	300 ug/L
	Manganese	60.2 & 50.6 ug/L	ND & ND	20 ug/L	50 ug/L
	Sulfate	80.3 & 86.2 mg/L	ND & ND	0.5 mg/L	250 mg/L

Table 3.10 Detected Trace Chemical Compounds in SVAWPC Source Water (RWF Secondary Effluent) and Corresponding SVAWPC Finished Water During Quarterly Sampling Events Q3 and Q4

SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Chemical		SVAWPC Source Water Measurement (Q3 and Q4)	SVAWPC Finished Water Measurement (Q3 and Q4)	Applicable Detection Level	Applicable Regulatory Standard
	Surfactants	0.09 & 0.08 mg/L	0.056 mg/L & ND	0.05 mg/L	0.5 mg/L
	Turbidity	2.9 & 3.7 NTU	0.2 & 0.05 NTU	0.1 NTU	5 NTU
	Zinc	62 ug/L	ND	50 ug/L	5000 ug/L
Notification Levels	Boron	379 & 455 ug/L	222 & 306 ug/L	100 ug/L	1,000 ug/L
	Chlorate	37 ug/L	ND	20 ug/L	800 ug/L
	Formaldehyde	17 & 11 ug/L	14 & 14 ug/L	5 ug/L	100 ug/L
	NDPA	16 ng/L	ND	2 ng/L	10 ng/L
Unregulated Constituents	Acetaldehyde	23 & 3.2 ug/L	1.6 & 1.1 ug/L	1 ug/L	None
	Calcium	42.1 & 44.2 mg/L	ND & ND	0.5 mg/L	None
	Lithium	9.5 & 9.2 ug/L	ND & ND	5 ug/L	None
	Magnesium	23.4 & 26.4 mg/L	ND & ND	0.5 mg/L	None
	Molybdenum	6 & 7.1 ug/L	ND & ND	1 ug/L	None
	Phosphate	3.2 & 6.69 mg/L	0.14 mg/L & ND	0.05 mg/L	None
	Potassium	20.9 & 21 mg/L	ND & 0.6 mg/L	0.5 mg/L	None
	Silica	24 & 18.7 mg/L	ND & 0.6 mg/L	0.5 mg/L	None
	Sodium	133 & 200 mg/L	ND & 14.5 mg/L	0.5 mg/L	None
	Total Organic Carbon	10.3 & 9.6 mg/L	ND & ND	0.3 mg/L	None

Notes:

1. 1,4-Dioxane and NDMA have CDPH Notification Levels.
2. Health Based Standards for CECs are listed in Appendix A Table A-1.

All quarterly monitoring data is included in Appendix B.

Additional analysis of CECs is discussed in Section 5. The UV AOP pilot data demonstrated that CECs are removed to below detectable levels.

3.6.4 Issues to Address for Potable Reuse for Water Quality

The data analysis demonstrated consistent purification of water by the SVAWPC, with the following notes:

- With the exception of three NDMA samples, all measured SVAWPC finished water samples for MCLs, NLs, CECs, and toxic pollutants were almost entirely below detectable limits and always below regulatory standards and health levels.

- For a future potable reuse system, the UV dose would be increased above the values used for disinfection (~80 mJ/cm^2) to ~800 mJ/cm^2, providing NDMA levels in the finished water well below 10 ng/L, as detailed in subsequent sections of this report.

4.0 FULL SCALE SYSTEM PERFORMANCE CHALLENGES

The full-scale challenge testing at the SVAWPC demonstrated the following items:

- MF is meeting performance goals, reducing bacteria and protozoa to below detection. As currently operated, the MF is providing 4-log removal of protozoa and bacteria.
- RO performance is also meeting performance goals, with 3-log removal of virus with the District's RO membranes, equal or greater log removal of protozoa and bacteria.
- Surrogate analysis and RO challenge testing (with removed O-rings) demonstrates the conservative (and thus acceptable) use of online measurements such as TOC, EC, color, and UVA for RO pathogen removal monitoring.
- The currently recommended surrogates for monitoring are TOC and EC, both providing for ~1.5-log reduction credit for pathogens by RO.
- The UV system provides for robust disinfection of seeded virus (6-log+), even with multiple lamps out of service. Such performance allows for flexibility in UV system maintenance.
- NDMA destruction is reduced with lamp outages. If NDMA concentrations are a concern, then rigorous lamp maintenance should be implemented.
- The UV system, with two reactors in series at 100 percent power (at 1.08 mgd per train), produces a high UV dose of ~800 mJ/cm2, sufficient to reduce NDMA well below the regulated target of 10 ng/L and to provide advanced oxidation (if an oxidant such as H2O2 or NaOCl is added).
- Testing at this point suggests a capacity of the UV system of ~5.4 mgd for potable reuse applications (with 5 duty trains and 1 redundant train). Higher capacity may be possible, and verification of this capacity is needed through full-scale challenge testing.
- Overall, the existing SVAWPC provides a high quality water that meets all regulated potable water reuse standards for pathogens and trace pollutants. The addition of an oxidant ahead of the existing UV system (H2O2 or NaOCl) would be required to meet the 1,4-dioxane destruction standard.

4.1 Microfiltration

The Pall MF at the SVAWPC has a nominal membrane pore size of 0.3 µm. The MF serves two purposes. First, it pretreats secondary effluent ahead of RO for turbidity removal. Second, it removes pathogens. The removal of pathogens occurs based upon size exclusion and based upon removal of solids in the secondary effluent that have attached pathogens. Regulatory approval of pathogen removal for this project is based upon size exclusion and the maintenance of properly low PDT results (as demonstrated previously in this report). Table 4.1 is presented here for reference of the size of the different target pathogens.

Table 4.1 Pathogen Size Ranges
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Pathogen	Size (Brock *et al.*, 1997, Strauss and Sinsheimer, 1963, McCuin and Clancy, 2006, Meyer and Jarroll, 1980, Singleton, 1999)
Protozoa	2 to 200 (*Giardia* - 6 to 14 *µm*) (*Cryptosporidium* – 3 to 8 *µm*)
Bacteria	0.1 to 15 (*E. coli* 0.25 *µm* dia X 2 *µm* long) (Salmonella 0.7-1.5 *µm* dia X 2-5 *µm* long)
Enteric Virus	0.01 *µm* to 0.1 *µm*
MS-2	0.027 *µm*

The MF testing occurred in September of 2014. Testing included monitoring the removal of indigenous bacteria (total coliform, fecal coliform, and E. coli), the removal of indigenous protozoa (*Giardia* and *Cryptosporidium*), and the removal of particles across the membrane. The goal of this MF testing was to show for this facility, MF could meet the targeted bacteria and protozoa removal. These limited observations were used to estimate overall removals. These results should be used as a “snap-shot” of performance, as they were conducted over a short period of time. However, the MF membranes were operating in a normal mode, no advanced preparation or adjustment to the membranes was done prior to testing, and thus it is likely that these results are representative of longer-term performance. Repeat testing for the same parameters at a later date is suggested to better confirm this assertion.

4.1.1 Particle Removal

Particle counting, if done on the bench-scale, can be a useful tool to consistently measure MF performance for protozoa and bacteria removal, but not virus. Particle count analysis was done with Carollo’s optical particle sizer/counter (PSS AccuSizer 780/SIS), with a sensitivity down to approximately 1 micron. Protozoa size ranges from 4 to 15 µm and bacteria size is typically <5 µm (Brock *et al.*, 1997, McCuin and Clancy, 2006, Meyer and Jarroll, 1980, Singleton, 1999). Note that online particle counters have not been successful to monitor MF performance due to measurement inaccuracy (Sethi *et al.*, 2004), thus the need for bench-top particle counting as done for this project.

Figures 4.1 through 4.3 and Tables 4.2 and 4.3 present the particle data. The data suggest:

- The MF influent particle counts are fairly consistent, with typically 10 to 40 particle in the size range of 4 µm to 15 µm.
- The MF effluent particle counts have more variability, potentially due to analytical precision with the PSS AccuSizer.
- The results show ~1+ log reduction of particles in the size range of 4 *µm* to 15 *µm*, with the example shown below demonstrating 1.2 log reduction. As shown further on, higher removals of bacteria have been demonstrated by the SVAWPC MF, however these data could be affected by the detection limit.

- Particle counting is insufficiently sensitive to estimate removal of protozoa and bacteria. However, these results can be used for future MF performance comparisons.

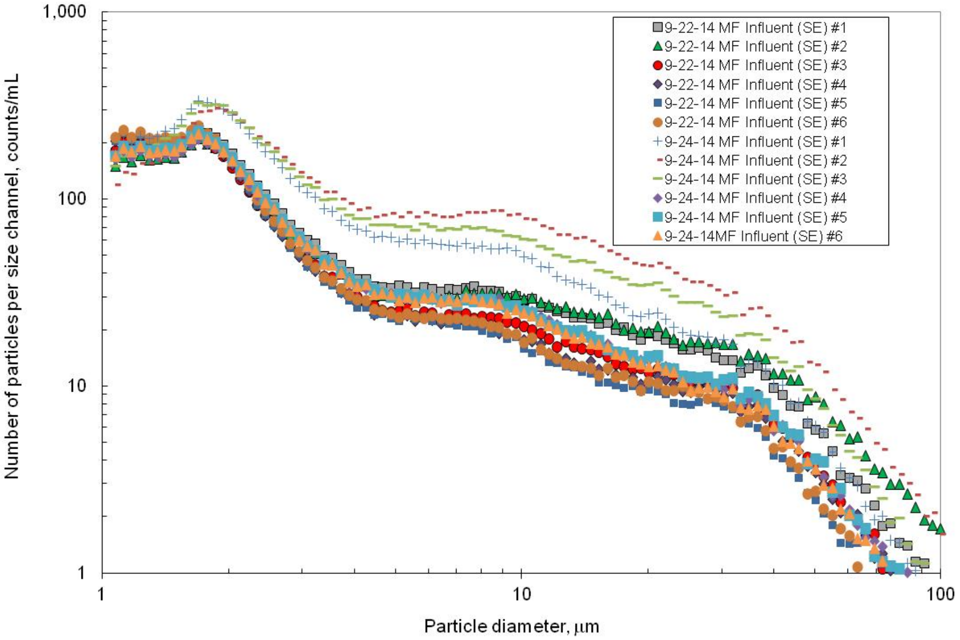

Figure 4.1 Particle Counts in MF Influent

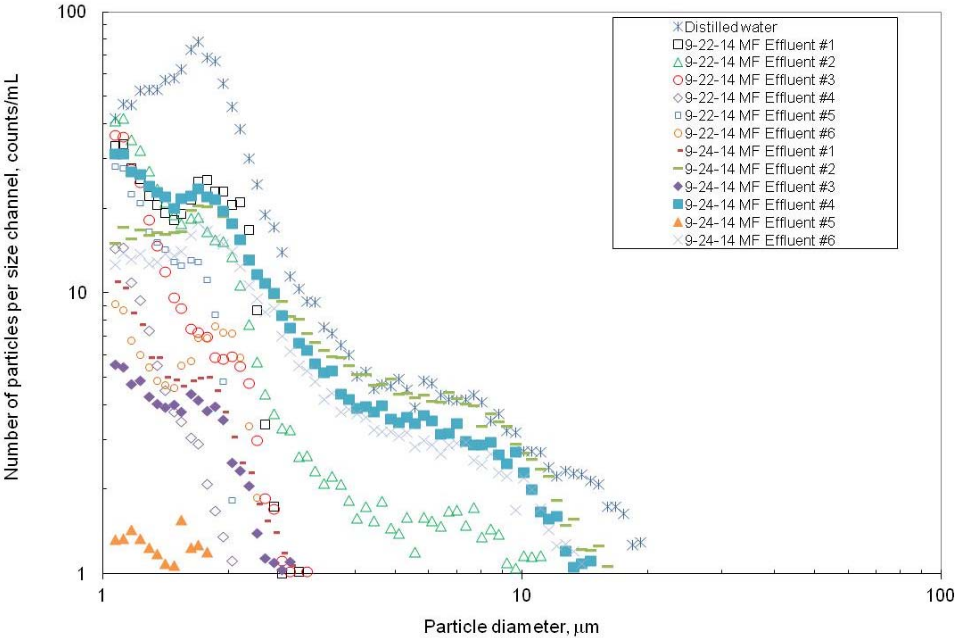

Figure 4.2 Particle Counts in MF Effluent

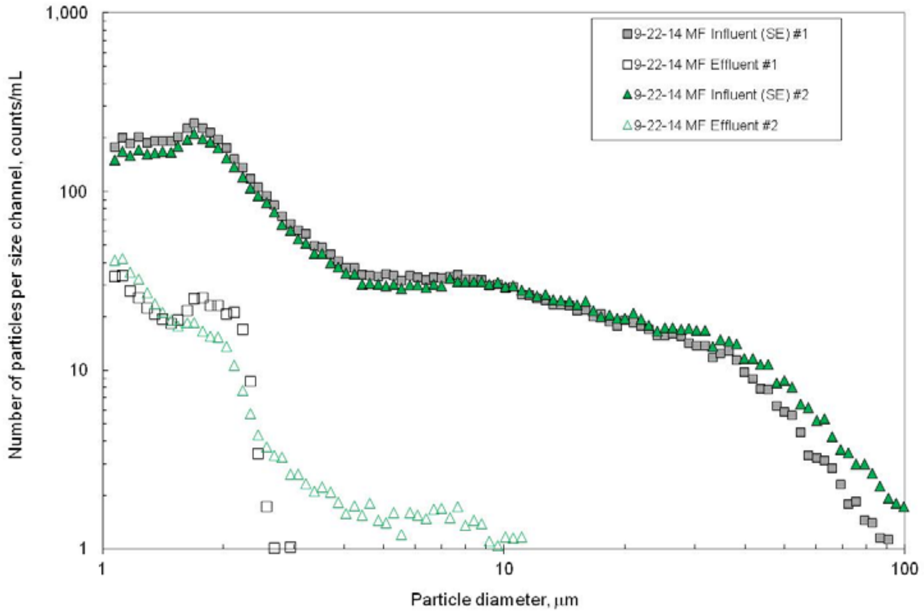

Figure 4.3 Paired MF Influent and Effluent Particle Count Results

4.1.2 Bacteria Removal

As shown in Table 4.2 below, bacteria removal by the MF was robust, with non-detect values for all samples. The log removal of bacteria is >3-log and in some cases almost 4-log.

Table 4.2 Bacteria Removal by MF
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Test ID[1]	Total Coliform	Fecal Coliform	*E. coli*
Influent Concentrations, CFU/100 mL			
1	9000	3000	1200
2	9000	500	579
3	16000	2800	727
4	16000	1100	579
6	9000	300	461
Effluent Concentrations, CFU/100 mL			
1	<2	<2	<1
2	<2	<2	<1
3	<2	<2	<1
4	<2	<2	<1
6	<2	<2	<1

Notes:
(1) Test ID #5 discarded because of abnormally low influent concentrations.

4.1.3 Protozoa Removal

As shown in Table 4.3, below, small counts of *Giardia* were detected in the secondary effluent, while there were no detectable *Cryptosporidium* in the secondary effluent. There were no detectable *Cryptosporidium* or *Giardia* in the MF effluent. The log reduction of protozoa ranged from >1 to >1.9.

Table 4.3 Protozoa Reduction by MF
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Pathogen	Concentration in MF Influent, #/L					
Giardia	2	1	7	3	4	4
Cryptosporidium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pathogen	Concentration in MF Effluent, #/L					
Giardia	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cryptosporidium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pathogen Log Reduction	Log Reduction					
Giardia	>1.3	>1	>1.9	>1.5	>1.6	>1.6
Cryptosporidium	--	--	--	--	--	--

4.2 Reverse Osmosis Challenge Testing

4.2.1 Total Organic Carbon Removal by RO as a Surrogate for Pathogen Removal

The SVAWPC RO system currently does not have online TOC meters installed on the RO influent and effluent. Such meters will be installed for future potable reuse projects. For this analysis, three paired grab samples for TOC removal were done, with RO permeate TOC values below detection (<0.3 mg/L). The log reduction of TOC was >1.4. The TOC reduction from this demonstration is consistent with other research. For example, WateReuse Research Foundation Project 11-02 (Gerringer *et al.*, 2014) showed TOC reduced from 5 mg/L to 0.1 mg/L, a log reduction of 1.7.

As mentioned previously, the DDW grants RO pathogen credit based upon the use of the log reduction of TOC as a conservative surrogate, with the latest approval of 1.5 log reduction credit as part of the Water Replenishment District's potable reuse project (WRD, 2013). As opposed to EC (and TDS), the size of TOC is not well defined and thus some question remains as to the reliability of TOC as a surrogate for pathogen removal. Assuming a properly functioning MF (as is the case for the SVAWPC), the maximum TOC size will be in the range of 0.1 *u*m, as larger TOC will be rejected by the MF. Kim and Dempsey (2008) performed fractionation of effluent organic matter (EfOM, which can be correlated to TOC), and demonstrated that 9 percent of EfOM is >100 kDa (<0.05 *u*m), whereas the remaining 91 percent was under 100 kDa and 62 percent of the EfOM was <1 kDa (<0.0005 *u*m). With the relatively larger size of the smallest pathogens of concern (enteric virus is 0.01 to 0.1 *u*m, MS2 is 0.027 *u*m, as referenced previously), the reduction of TOC is a conservative surrogate for the reduction of virus. However, as the TOC fractionation literature is very limited, EC (and TDS) removal by RO appear to be a more reliable surrogate for RO performance.

Similar to EC removal, the DDW has determined that because of the small size of TOC, the log reduction of TOC is a conservative measure of pathogen reduction performance of RO. For the SVAWPC RO system, the RO process reduced the TOC to <0.3 mg/L, providing confidence in at least 1.4 log reduction of all pathogens through RO, as shown in Figure 4.4 below. This research was conducted as part of a monitoring approach and was not considered a challenge test.

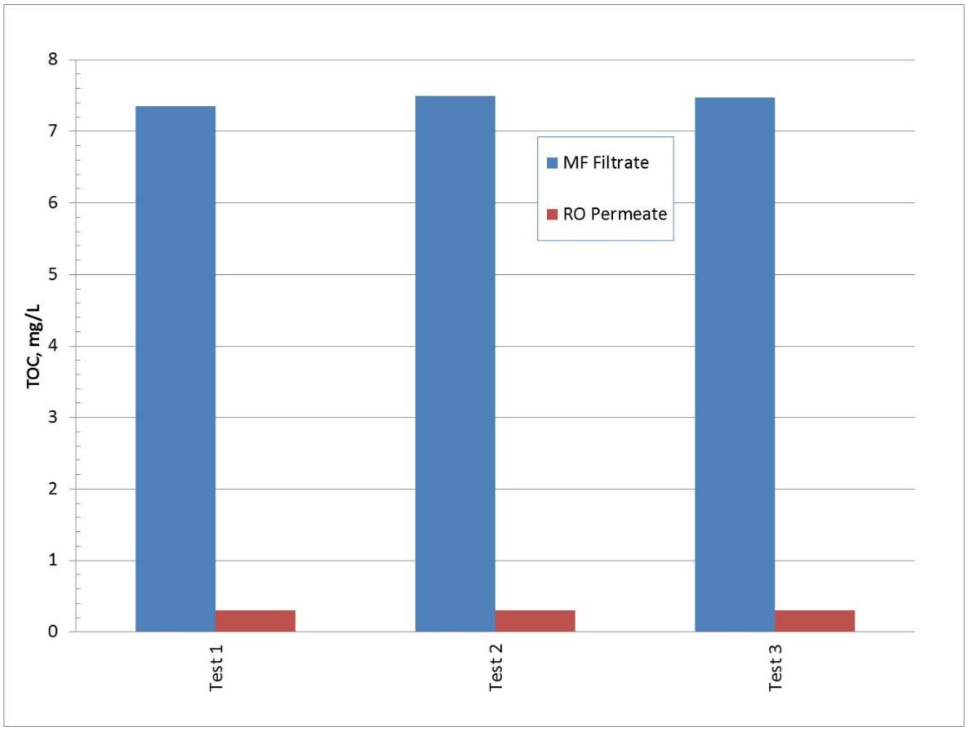

Figure 4.4 TOC Reduction Across RO

Challenge testing was conducted on the full-scale RO system in order to demonstrate removal performance in the presence of a system failure. Two failure scenarios were tested, one with a breach in the O-ring of the system, the other using 6-year old membranes from the Orange County Water District. The 6-year old membranes were removed from service due to reduction in the production capacity of the OCWD membranes.

4.2.2 October 2014 RO Challenges

The SVAWPC's existing RO system (using RO membranes by CSM) was challenged with a seeded MS-2, with concurrent sampling of NDMA, TOC, 1,4-dioxane, and several other parameters. The challenge was not done on the entire RO treatment train. Instead, the challenge was done on one pressure vessel (#5) on one train (#2).

These results are presented in Figures 4.5 through 4.7, below, with the following conclusions:

- Over a series of 9 tests, the MS-2 log reduction ranged from 3.1 to 3.2. Removal of protozoa and bacteria can be assumed to be equal to or greater than these log reduction values based upon the relative difference in size of the organisms.

- Low concentrations of MS2 were consistently found in the RO permeate, which demonstrates good removal of virus, but also demonstrates that RO is not an impermeable barrier and a multi-barrier treatment approach is warranted.

- 1,4-dioxane, color, and TOC were all reduced below detectable levels. Log removal values shown are thus conservative.

- NDMA ranged from 32 to 46 ng/L in the RO influent and ranged from 15 to 18 ng/L in the RO permeate. Additional NDMA data, and the significance of the RO permeate concentrations is detailed in the next section.

- There remains no proven online method to accurately measure pathogen reduction by RO. Other research (WRRF 14-10 in conjunction with WaterRF 4536 is researching the ability of the Trasar compound to properly track RO performance).

As a point of comparison, other RO studies have shown similar results, with 4+ log reduction of seeded MS2, but 1.6 to 1.7 log reduction of TOC (Clean Water Services, 2014).

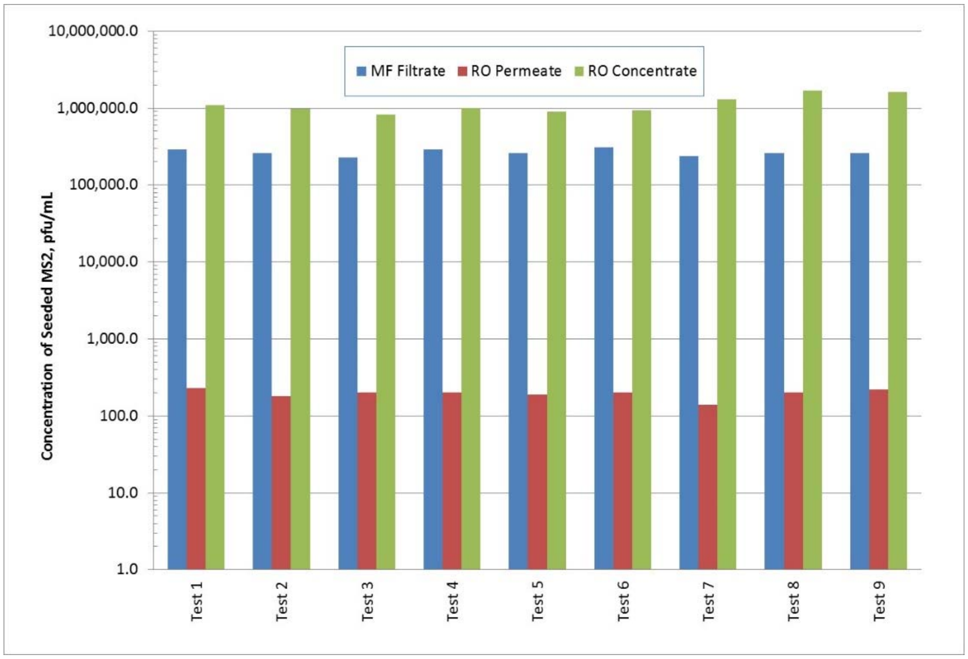

Figure 4.5 Seeded MS2 Concentrations in MF Effluent, RO Permeate, and RO Concentrate (MS2 Detection Limit of 1 pfu/100 mL)

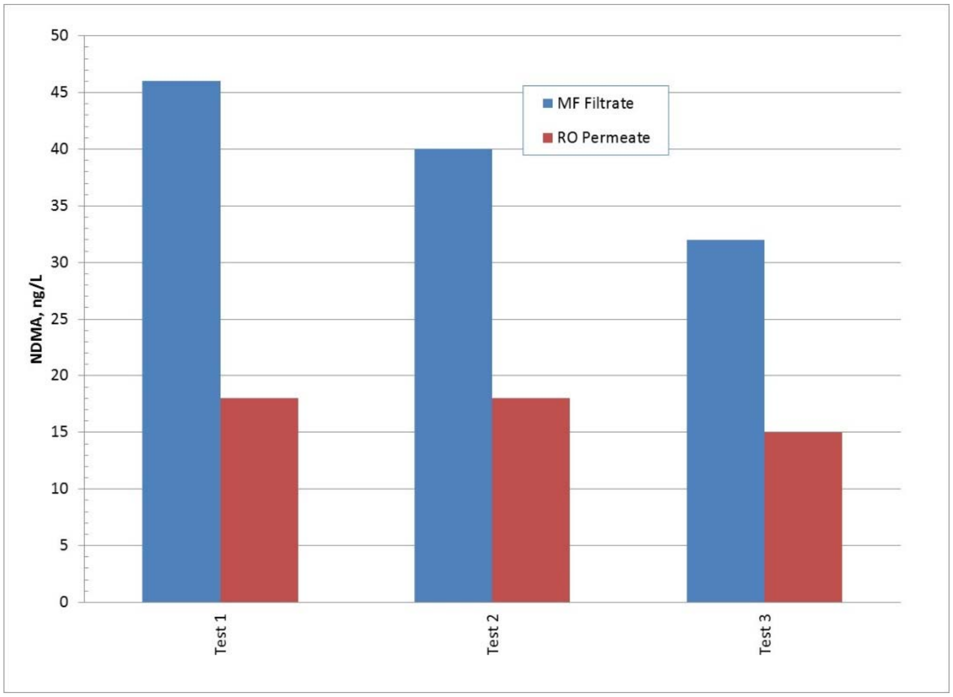

Figure 4.6 Concentration of NDMA in RO Influent and RO Permeate

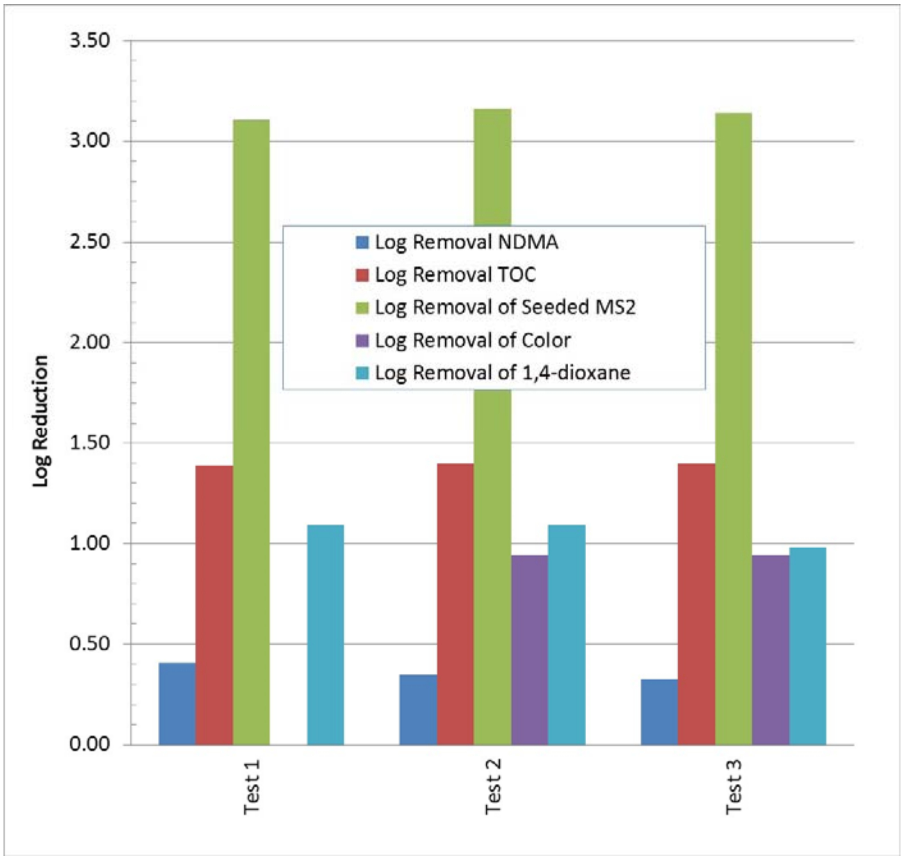

Figure 4.7 Removal of Select Constituents by RO

4.2.3 November 2014 RO Challenge

A second round of RO challenge testing was performed using old, and then old membranes with o-ring damage (removal). The goal of this testing was to evaluate if RO performance degraded with time and to determine if any common water quality measurements can be used to monitor RO membrane failures.

The tested membranes were provided by the Orange County Water District (OCWD[3]) which were installed in place of the CSM membranes in pressure vessel #5 on train #2. The OCWD membranes were Hydranautics ESPA2 membranes and where approximately 6 years old. The elements were taken from OCWD's RO 3rd stage. These elements were the original ones installed in 2008. The elements provided by the OCWD underwent several high pH cleanings and two HF (high flow) cleanings. For this second phase of challenge testing, the membranes were challenged with MS2, and samples were taken for EC, TOC, UVA, and color. The testing was first done with a fully functioning RO membrane, followed by a second comparative set of tests with two o-rings removed from the end of the pressure vessel (Figure 4.8).

These results are presented in Figures 4.9 through 4.10, below, with the following conclusions:

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[3] Special thanks to the OCWD and Tom Knoell for providing the membranes for testing.

- Over a series of 6 tests, the MS2 log reduction with the old RO membranes ranged from 3.9 to 4.2 log, higher than the new(er) CSM membranes installed at the SVAWPC. Further research is necessary to determine the reason why older membranes were more effective.
- The tests done with the missing o-rings results in a substantial reduction in virus removal performance, with log reductions over 6 tests ranging from 2.0 to 2.4, a 99 percent reduction in performance.
- EC, TOC, UVA, and color were all insufficiently sensitive to detect the removal of the o-rings.
- With log reduction values of 1.0 to 1.4, EC, TOC, UVA, and color are all conservative surrogates for pathogen removal (which was still 2.0 to 2.4 log reduction under damaged conditions).

Figure 4.8 O-rings Removed from RO Pressure Vessel

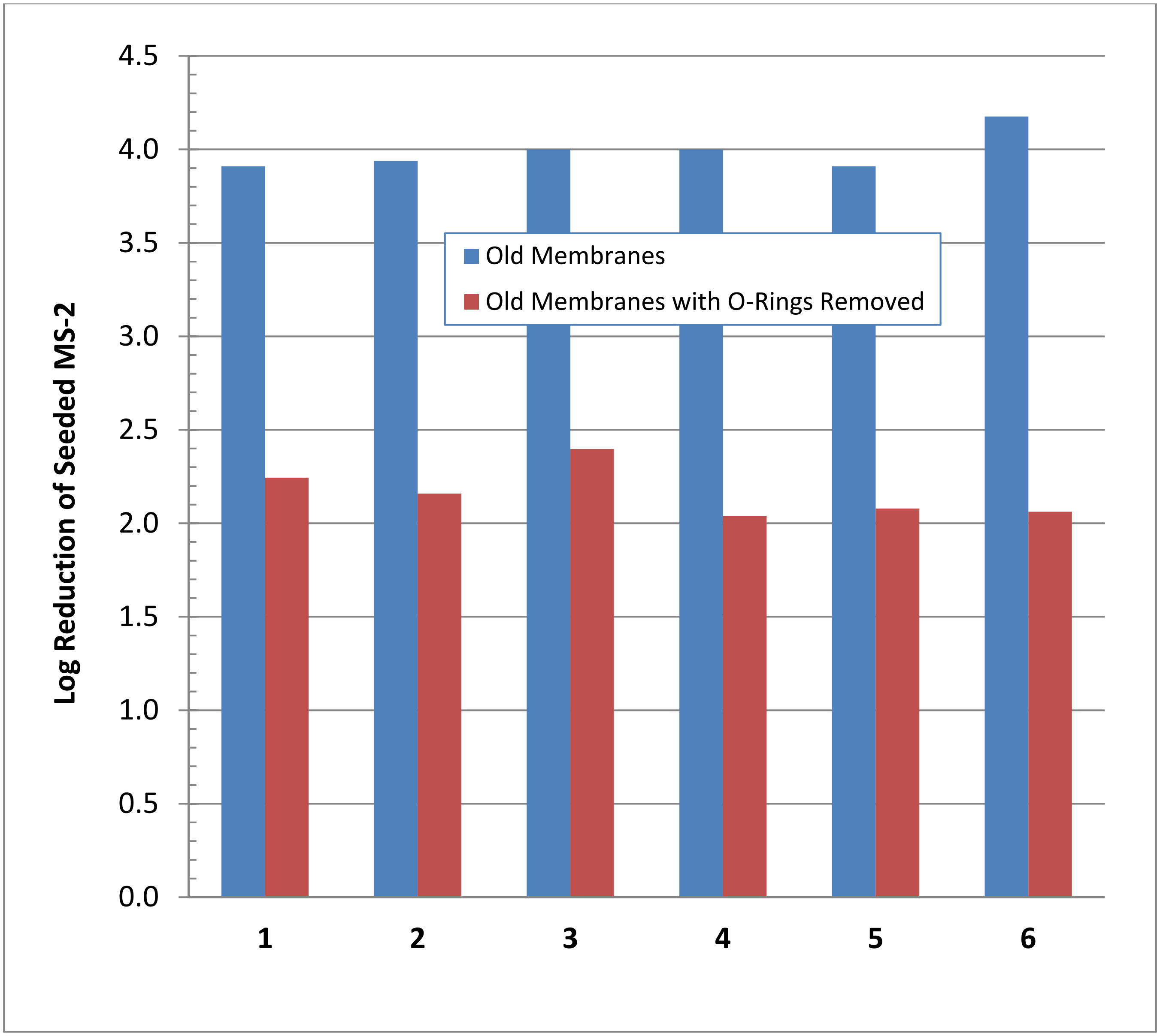

Figure 4.9 Log Removal of Seeded MS2 with Old Membranes, and with and without O-ring failure simulation.

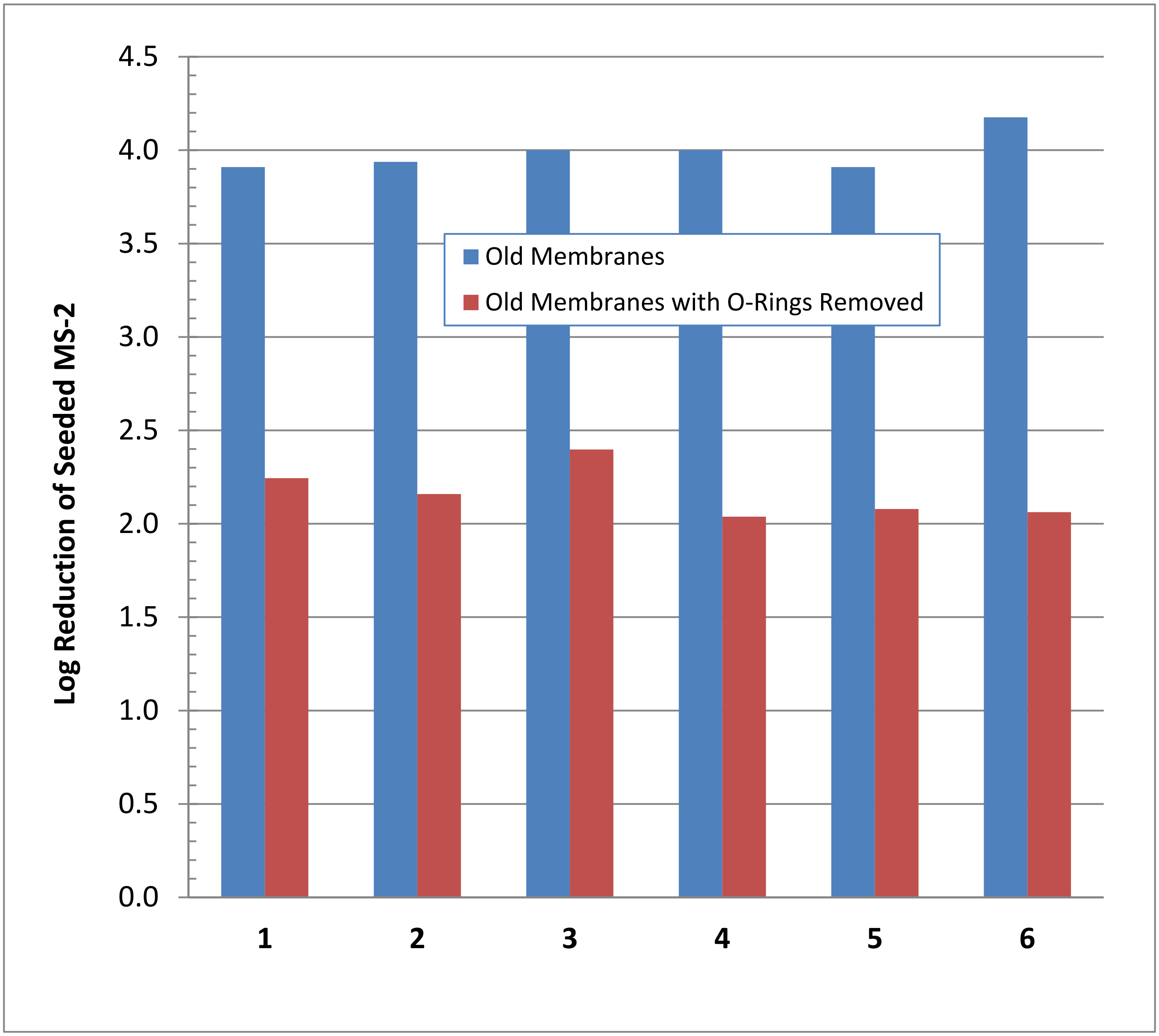

Figure 4.10 Log Removal of Seeded MS2 with Old Membranes and Old and Damaged Membranes

4.3 Ultraviolet Light Disinfection and NDMA Photolysis

The District's UV system was designed for non-potable water reuse applications. Specifically, it was designed to provide a minimum UV dose of 80 mJ/cm^2 to MF effluent (with a UVT of 65 percent). This UV system was tested after startup and received approval from DDW to disinfect the non-potable recycled water.

As previously detailed, the SVAWPC UV system is the WEDECO (Xylem) LBX1000, with six reactor trains, with each train containing two reactors in series, and with 40 lamps in each reactor. The LBX1000 was validated according to National Water Research Institute protocols (Carollo, December 2007) and approved by the DDW. The validation of that reactor was done over a range of flow (0.58 to 3.51 mgd per reactor), over a range of UVT (54 percent to 77 percent), and over a range of sensor intensities (1.9 to 7.5 mW/cm^2). Accordingly, under these ranges of flow, UVT, and sensor intensity, the dose delivery performance of the LBX1000 is predictable and repeatable. The question for the District is: **"How might this LBX1000 perform outside of these validated ranges, such as for high dose potable reuse applications on RO permeate?"**

4.3.1 Prior Reactor Testing

Part of the answer can be found in the test results of the LBX1000 during startup (Carollo, 2014). For that work, an extensive number of tests were done to verify that the installed system can produce the proper disinfection dose. During those tests, the installed system's dose delivery and sensor values were compared with the predicted dose delivery formula and the sensor formulas in Carollo (2007). Regarding the latter sensor values, there was good correlation between measured and calculated sensor values (R^2=0.9756) for tests done on MF filtrate. Regarding dose delivery, the installed system provided more dose than predicted in 9 of 10 tests on MF filtrate, and was on average within 12 percent of predicted values.

Of greater relevance were the tests done on RO permeate. When the SVAWPC utilizes the RO system, the UVT in UV influent (which is RO permeate in this case) exceeds 95 percent and is often 98 to 99 percent. The result is that the UV system can deliver a much higher UV dose. To better understand this higher dose, and as documented in Carollo (2014), 8 disinfection tests were run on RO permeate, with UVT values ranging from 89 percent to 99.7 percent (UVT intentionally suppressed down to 89 percent). For these 8 tests, the extrapolation of predicted dose values from Carollo (2007) was shown to be inaccurate and underestimate the dose delivery in the much higher UVT of RO permeate. Test #18, run at 2.85 mgd, 99.7 percent UVT, and 50 percent power, resulted in a measured dose delivery of 162.3 mJ/cm^2, which was at the higher limit of disinfection based quantification (said another way, running the tests at a higher power value than 50 percent and/or lower flow is not possible due to micro-organism quantification difficulties due to higher dose values). Extrapolation of UV performance outside of validated ranges is inaccurate at best. The high dose of 162.3 mJ/cm^2 (1 reactor at 2.85 mgd set at 50 percent power with 99.7 percent UVT) suggests that two reactors in series at 100 percent power will deliver a very high UV dose that may be acceptable for potable reuse applications. At a flow of 8 mgd, five duty trains will be treating 1.6 mgd. For two reactors in series at 100 percent power treating RO permeate, we are anticipating a UV dose in excess of 500 mJ/cm2. The NDMA destruction testing detailed further on in this document provides a more accurate prediction of performance.

Regarding sensor performance, the LBX1000 sensors were not designed for RO permeate applications. Specifically, any sensor is accurate over a range of intensity, and RO permeate's extremely high UVT, coupled with the UV light emitted by the LBX1000 lamps, results in inaccurate sensor readings. As part of the prior work effort, 8 RO permeate data points where taken, but 7 of the 8 tests had intentionally suppressed UVT of 88 percent to 94 percent. For these 7 data points, the existing LBX1000 sensors appear to accurate measure intensity, following the projected linear extrapolation of the MF filtrate data set (Figure 4.11, below). For the one truly representative RO permeate sensor value, taken at 99.7 percent UVT, the sensor accuracy drops off substantially (as anticipated).

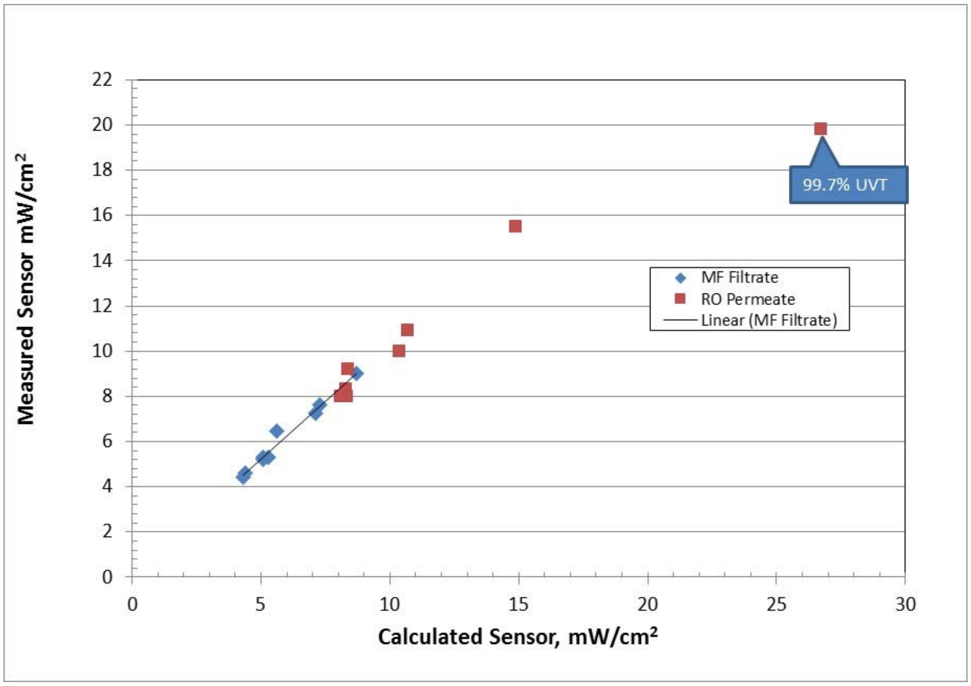

Figure 4.11 Sensor Performance During UV Reactor Testing (Carollo, 2014)

4.3.2 UV for Potable Reuse

For potable water reuse applications, the UV system provides three important benefits. First, it disinfects virus, protozoa, and bacteria. No measurable concentrations of these pathogens are typically found in RO permeate, but the added disinfection is needed to further reduce pathogen concentrations and provide an additional safety barrier. Second, the UV system destroys NDMA, a pollutant that must be reduced to below 10 ng/L (***parts per trillion***). UV is proven to destroy NDMA through photolysis, with 90 percent removal based upon a UV dose of ~900 mJ/cm^2 (Sharpless and Linden, 2003). Third, the UV process, when combined with an oxidant (H_2O_2 or NaOCl) will generate hydroxyl radicals which destroy a wide range of trace level pollutants (Hokanson *et al.,* 2011, Figure 4.12).

4.3.3 Potable Reuse UV Challenge Testing

For this latest work, one UV reactor (Reactor #1 on Train #6) was tested for the removal of seeded virus and the destruction of NDMA. This work was done with a fully functioning reactor and under simulated failure conditions (with one and two lamps removed from service), with testing done at three different UV lamp power settings (50 percent, 75 percent, and 100 percent). The lamp failure simulations were done by disconnecting the electrical power from one and then two of the forty lamps within the reactor. The disconnected lamps were on the perimeter of the reactor, thus representing worst case short-circuiting conditions[4].

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[4] The UV reactor has 40 lamps evenly spaced across the diameter of the reactor. Removing a lamp from service within the middle of the lamp array creates a “hole,” but that hole can be overcome by surrounding lamps. Removing lamps from service from the perimeter of the reactor is more conservative, as the “hole” can only be overcome by radiating lamps on one side.

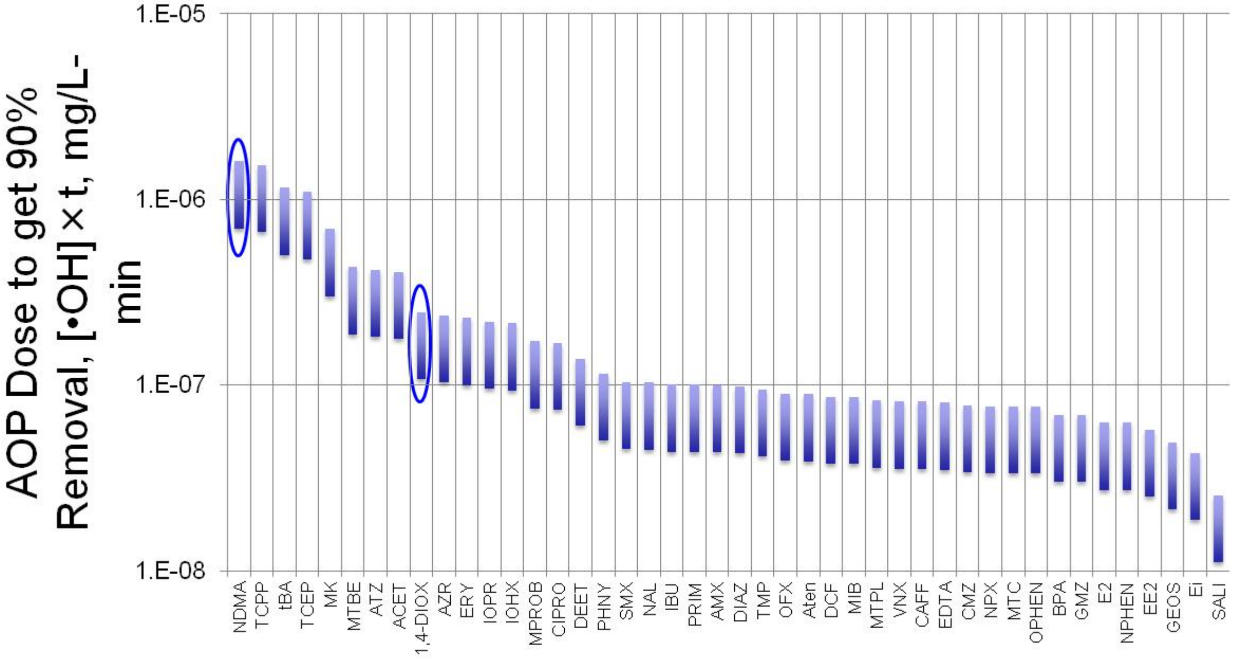

Figure 4.12 Destruction of Trace Pollutants by UV AOP (Hokanson et al., 2011)

The goal of the virus challenge work was to demonstrate robust virus disinfection and understand the impact of lamp outages on disinfection performance. The testing was done at 1.08 mgd (through the test train) at ambient UVT (~98.5 percent). The flow of ~1 mgd was intentionally selected to allow for accurate quantification of NDMA destruction performance at the different power settings (50 percent, 75 percent, and 100 percent); the objective being to run at sufficiently low flows to create high UV dose values and result in substantial NDMA destruction.

The disinfection results (shown in Figure 4.13), done in triplicate, showed complete removal of seeded virus, with >5.9 to >6.4 log reduction. Turning power down (75 percent and 50 percent) and removing 1 and 2 lamps from service did not reduce disinfection performance. This finding is significant, as the system proves 6-log reduction under stressed conditions with only one reactor in service. The high UVT of RO permeate (98.5 percent for all tests) allows for the surrounding UV lamps to compensate for the lamp outages. It should be noted that since all virus challenge testing resulted in nondetect (ND) on the effluent side, one power setting cannot be said to outcompete the other. Detection limits per test are shown in Appendix A.

Knowing the log reduction of MS2 allows estimation of the delivered UV dose based upon known MS2 dose/response relationships (Figure 4.14). For the lowest dose application (with lamp power at 50 percent), the tests showed > 6.35-log reduction of MS2, which correlates to a UV dose of >150 mJ/cm^2. As these tests were done at 50 percent power, the dose will increase at 100 percent power (NDMA data, shown further on, suggest a 60 percent increase in dose at full power compared to 50 percent power). With two reactors in series at 100 percent power, the dose may exceed 460 mJ/cm^2, similar to the projected performance from the 2014 UV testing (Carollo, 2014).

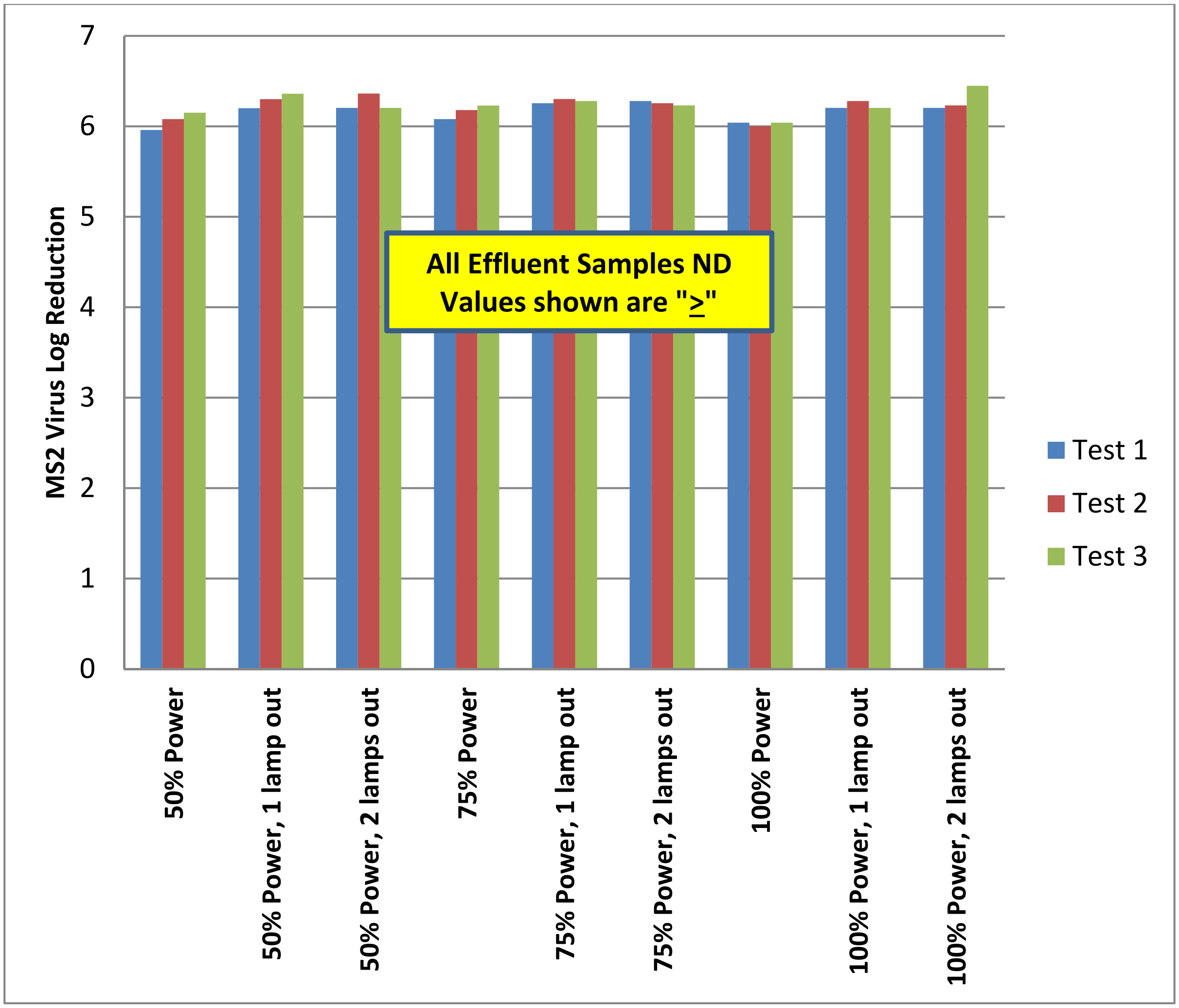

Figure 4.13 MS2 Disinfection For Different Power Settings and Failure Simulations

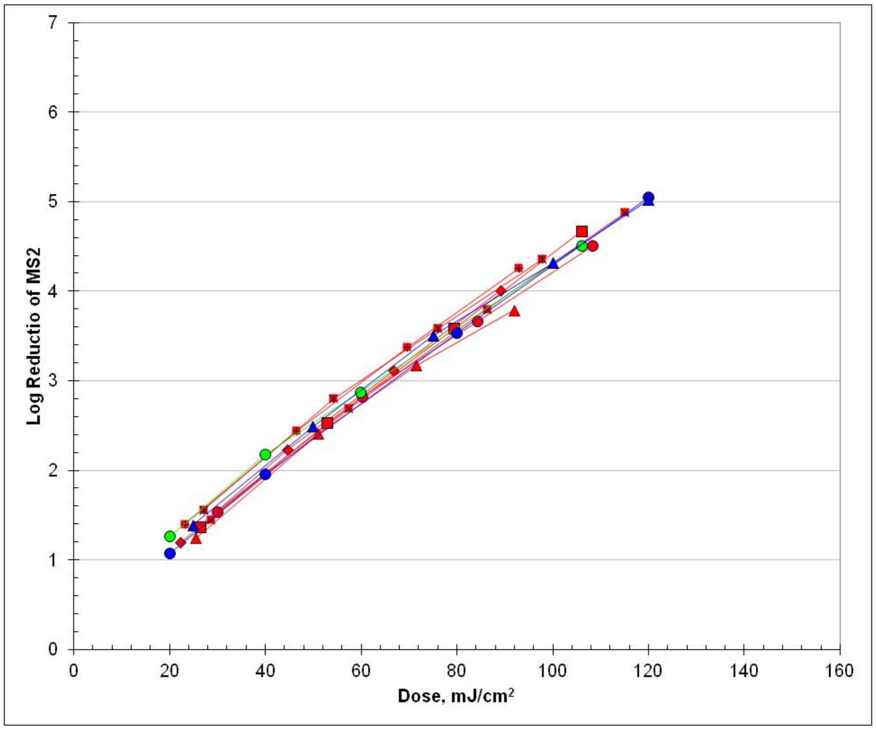

Figure 4.14 UV Collimated Beam MS2 Dose/Response (Carollo, 2014).

4.3.4 NDMA Concentrations and Destruction

For direct injection potable reuse applications, DDW requires the finished water quality to have <10 ng/L of NDMA in the finished water. NDMA is formed through chloramination processes, both in the drinking water process and in the wastewater process. Chloramines are added to the secondary effluent received by the SVAWPC, as well as to the product water prior to distribution. Further, NDMA can be found in some chemicals used in the wastewater treatment process, including chemicals used for filtration enhancement. NDMA removal through RO is moderate (0.3 to 0.4-log shown previously in this report), so the UV system is the primary mechanism for NDMA destruction and thus compliance.

The OCWD designed their post-RO UV reactors to attain 1.2 log removal of NDMA (94 percent reduction), and long-term performance monitoring suggests an energy use of 0.26 to 0.29 kWh/1000 gallons for the 1.2 log removal[5]. This efficiency can be converted into an EEO (Electrical Energy per Order of Magnitude) calculation, resulting in 0.22 to 0.24 kWh/1000 gallons/log removal.

NDMA concentrations in RO influent and in the RO permeate (which is the influent to the UV system) was collected throughout the testing of the SVAWPC. The following conclusions can be made regarding NDMA concentrations and destruction by UV:

- NDMA concentrations vary from 30 to 47 ng/L during one period to 4 to 16 ng/L during other periods (Figure 4.15). This variation suggests impacts stemming from the RWF, or

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[5] Per email conversation with Mehul Patel of OCWD, May 1, 2015.

potentially due to industrial discharge impacts. Understanding these impacts (and controlling them if possible) is recommended for future potable reuse projects.

- Under the full-scale UV challenge test conditions (1.08 mgd, 98.5 percent UVT), UV influent NDMA concentrations ranged from 30 to 47 ng/L and were reduced down to 13 to 27 ng/L by UV photolysis, depending upon UV power setting (50 percent, 75 percent, and 100 percent) and depending upon the number of lamps out of service.

- Using an average of UV influent NDMA concentrations (39 ng/L), one UV reactor at 50 percent, 75 percent, and 100 percent power resulted in 0.28, 0.41, and 0.44 log reduction of NDMA (Figure 4.16). Roughly a doubling of UV reactor power (50 percent to 100 percent) results in a 60 percent increase in dose. Based upon Sharpless and Linden (2003), 0.44 log reduction of NDMA correlates to a UV dose of ~400 mJ/cm^2. For two reactors in series (as is the case for the SVAWPC), the UV dose at 100 percent power can be estimated at 800 mJ/cm^2, which is a potentially sufficient dose to meet both NDMA and advanced oxidation criteria for potable reuse applications.

- For the tested conditions (1.08 mgd, 98.5 percent UVT), the EEO of the LBX1000 was 0.54 (50 percent power), 0.56 (75 percent power), and 0.70 (100 percent power), which is a lower energy efficiency compared to the OCWD values of 0.22 to 0.24. As the LBX1000 reactors were not intended for post RO high dose applications, this energy efficiency difference is not surprising.

- Removing lamps from service (1 lamp, 2 lamps) did reduce NDMA destruction (Figure 4.16), which indicates that NDMA reduction is more sensitive to reactor faults compared to the earlier MS2 data. This conclusion would impact the O&M plans for a future potable reuse system. If high NDMA concentrations are a driving concern, then replacement of faulty lamps becomes a time sensitive replacement, whereas the virus disinfection barrier of the LBX1000 remains intact even with two lamps out of service.

- Total chlorine destruction trends with NDMA destruction and could be used for process control of dose, further data collection in Chapter 5 supports this conclusion (Figure 4.18).

- Both total chlorine destruction and NDMA destruction across UV are sensitive to lamp failures, illustrating the importance of high level system maintenance for future potable reuse applications (Figure 4.19).

- With two reactors in series, at 1.08 mgd per train, projection of data from this work suggests that the existing UV system can consistently reduce NDMA concentrations below the DDW target of 10 ng/L (Figure 4.20).

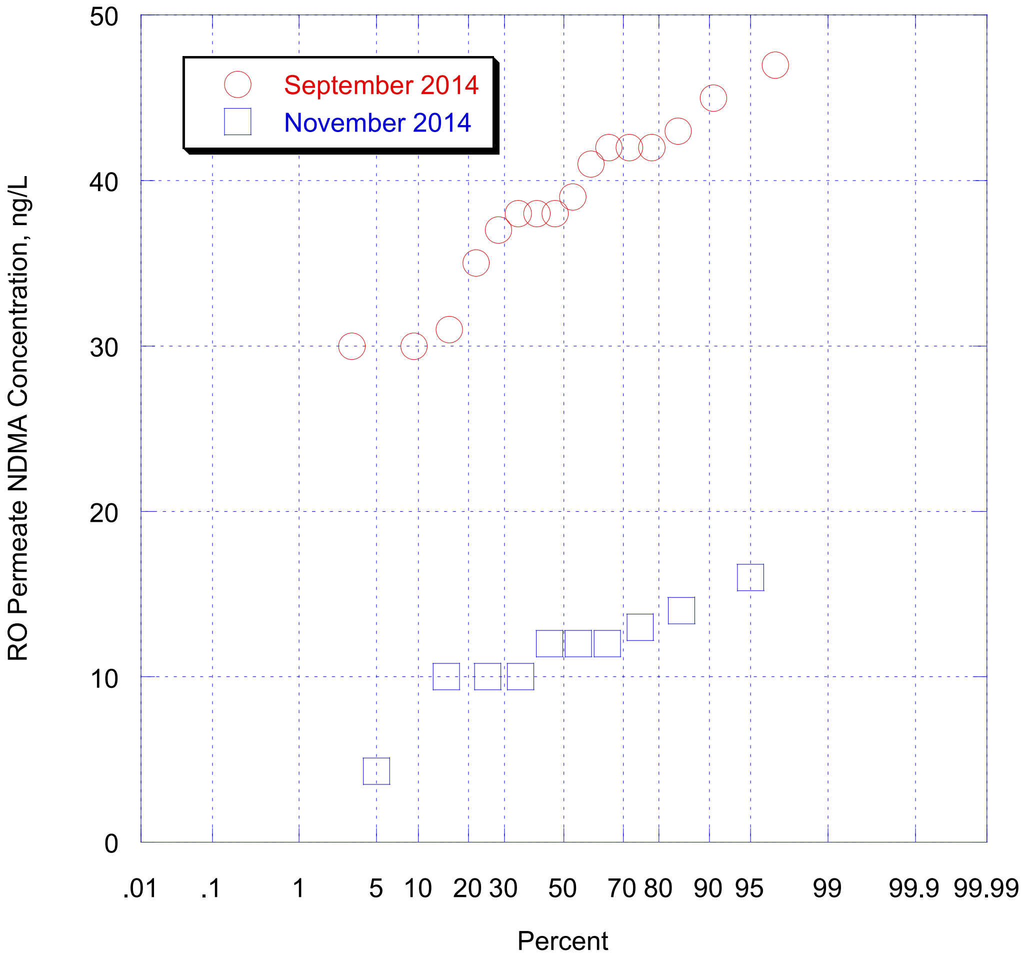

Figure 4.15 Value and Variability of NDMA in RO Permeate

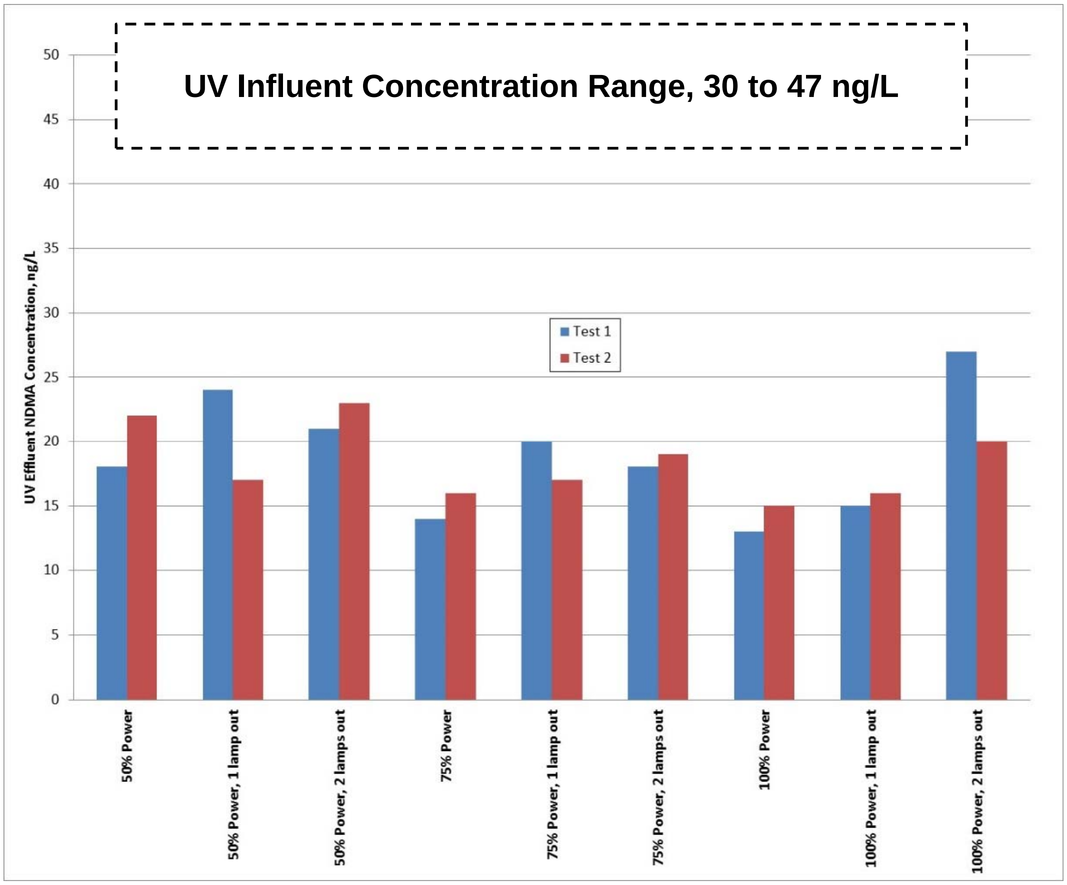

Figure 4.16 UV Effluent NDMA Concentrations For Different Power Settings and Failure Simulations

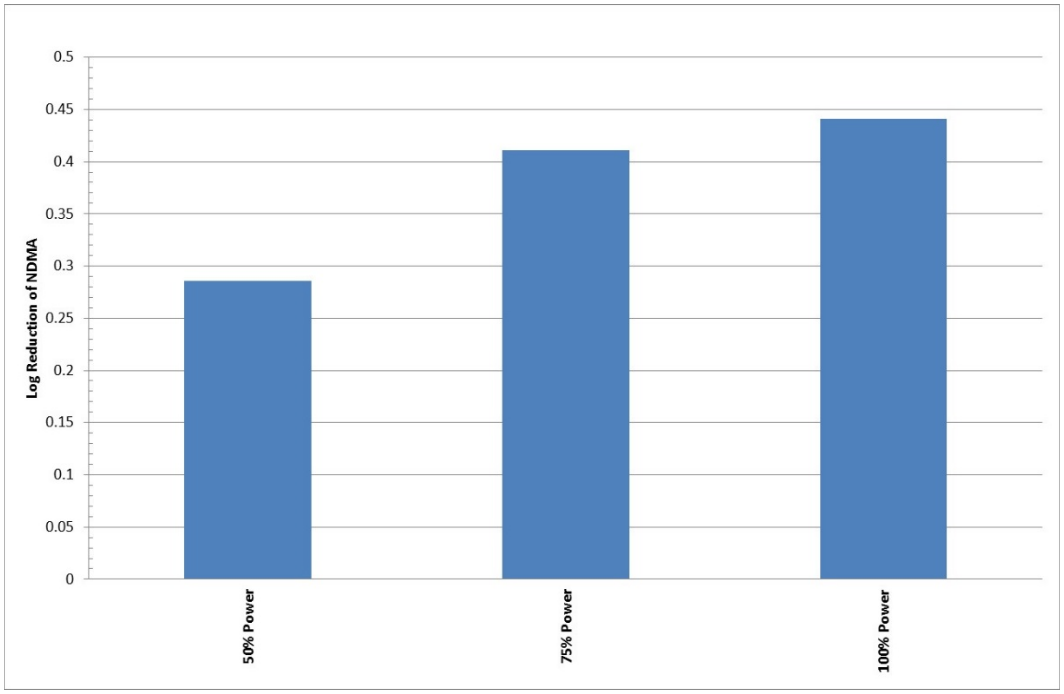

Figure 4.17 NDMA Destruction by UV at Different Power Settings

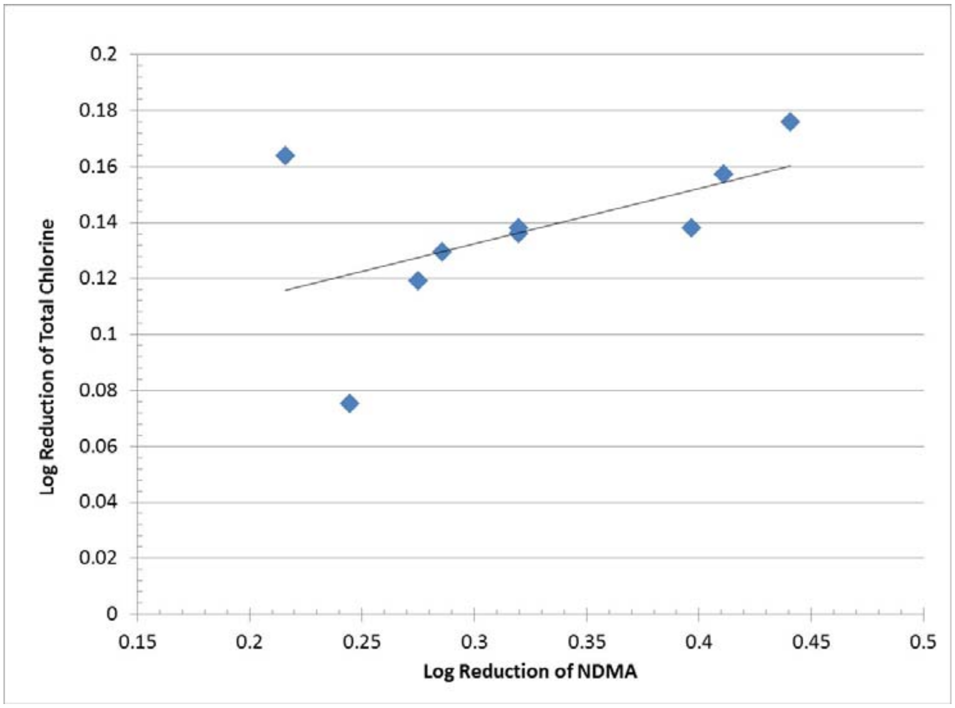

Figure 4.18 Correlation Between NDMA Destruction and Total Chlorine Destruction

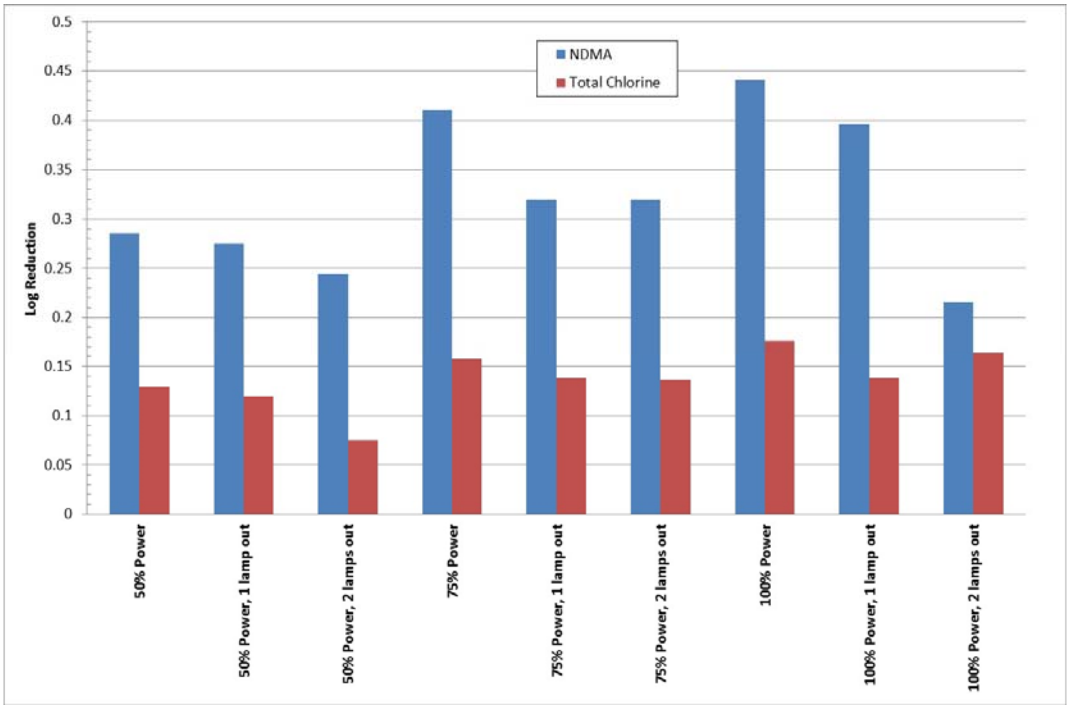

Figure 4.19 Impact of Lamp Power Setting and Lamp Failure on NDMA and Total Chlorine Destruction

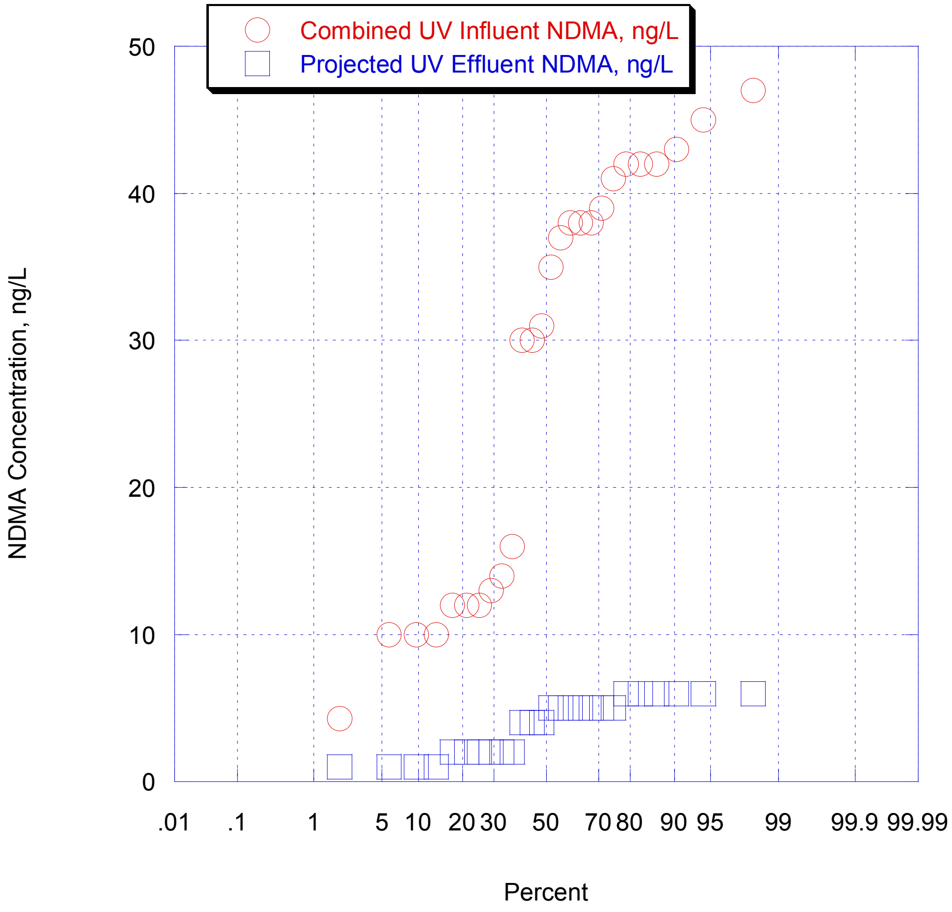

Figure 4.20 Combined UV Influent NDMA Concentrations and Projected UV Effluent Concentrations (1.08 mgd, two reactors in series, 100% power)

4.4 Projected Advanced Oxidation

No advanced oxidation testing was conducted on the full-scale UV system. However, the high potential dose of the system (800 mJ/cm^2 at 1.08 mgd at 98.5 percent UVT) is sufficient to result in advanced oxidation if an oxidant such as H_2O_2 or NaOCl is added ahead of the UV reactors. Research conducted at the City of Los Angeles Terminal Island Advanced Water Purification Facility (Los Angeles Bureau of Sanitation, 2014) demonstrated that 0.5 log reduction of 1,4-Dioxane can be attained at a UV dose of 800 mJ/cm^2 with a 2 mg/L free chlorine residual ahead of the UV reactor. The performance of UV AOP for the SVAWPC, using both H_2O_2 and NaOCl as oxidants, is detailed further on in this report.

4.5 Issues to Address for Potable Reuse Pertaining to the Full-Scale Challenge

The data analysis resulted in several questions that should be answered:

- NDMA variation is substantial. The District should further investigate NDMA concentrations in the RO influent, RO permeate, and UV finished water. For these tests, the UV reactor train to be sampled would be run at 100 percent power with both reactors in operation. Investigation of NDMA concentrations at the RWF is also recommended.

- Concurrent with the NDMA testing above, the District should conduct sampling/recording of the UV reactor train for flow, total chlorine concentrations, and NDMA concentrations.

5.0 PILOT SCALE UV AOP TESTING

The pilot-scale UV AOP testing at the SVAWPC has demonstrated the following items:

- UV AOP with H_2O_2 met and exceeded the 0.5 log reduction requirement for 1,4-dioxane for IPR projects that use groundwater injection. The minimum UV dose of approximately 800 mJ/cm^2 with a 6 mg/L H_2O_2 dose was sufficient to meet the requirements.
- Under the specific testing conditions, UV AOP with NaOCl could not meet the 0.5 log reduction requirement for 1,4-dioxane for IPR projects that use groundwater injection.
- Pilot and bench-top testing results matched well, further substantiating the better performance of UV/H_2O_2 for this particular application (for the tested waters).
- Total chlorine destruction provides a reasonable surrogate, and thus CCP, for NDMA destruction and for pathogen kill by UV.

5.1 Advanced Oxidation Treatment Goals and Test Plan

Per DDW (CDPH, 2014), IPR projects that utilize injection require an advanced oxidation step that provides for a minimum of 0.5-log removal of 1,4-dioxane, which is a conservative surrogate for the destruction of a wider range of trace pollutants. The typical advanced oxidation system for potable reuse utilizes UV light combined with an oxidant. That oxidant is commonly H_2O_2, but can also be NaOCl. A second target for the UV AOP is the destruction of NDMA to below the 10 ng/L Notification Level.

This particular UV AOP study was performed to better understand the optimum UV dose for NDMA destruction and the optimum UV dose, oxidant type, and oxidant dose for 1,4-dioxane destruction, with the tested water being RO permeate in all cases. For this project, the analysis was done using the LBX90 from Xylem (WEDECO, Figure 5.1). The Xylem LBX90 reactor houses four 330W low pressure high output lamps. At low flows, the system provides a sufficiently high UV dose sufficient for advanced oxidation. The advanced oxidation pilot system at the SVAWPC is a smaller-scale version of the LBX1000 UV reactor in use as part of the full-scale UV system.

Figure 5.1 Xylem LBX90 reactor during testing at the SVAWP

The AOP pilot testing included:

- A pilot system validation on 10/20/14 that included varying power levels, flow rates, and testing for NDMA removal in the LBX90 pilot reactor in order to determine the applied UV dose.
- A comparison of an amperometric titration method with the Hach DPD free chlorine measurement method with District lab staff performing titration measurements.
- Two sampling events (11/3/14 and 4/1/15) using H_2O_2 as the oxidant, and seeding 1,4-dioxane into the system to test for removal. Data was collected on NDMA, CEC, TOC, and UV 254 removal.
- Two sampling events (11/4/14 and 5/14/15) using NaOCl as the oxidant, and seeding 1,4-dioxane into the system to test for removal. Data was collected on NDMA, CEC, TOC, and UV 254 removal.

5.2 RO Permeate Water Quality Monitoring

The understanding of RO permeate water quality variability and the relative impact on UV AOP performance is still in the early stages of development. While RO permeate does have very low levels of TOC (<0.5 mg/L) and extremely high UVT (>95 percent), there remains some trace levels of constituents and a low and unbuffered pH. In an effort to better understand the possible impact of influent water quality on UV AOP performance, the project team collected information with each influent sample, as shown in Table 5.1.

Table 5.1 Average AOP Influent Water Quality
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Parameter	Average Concentration	Units
Total Chlorine	2.92	mg/L
Free Chlorine	0.17	mg/L
NDMA	21.9	ng/L
UV 254	0.013	cm-1
TOC	<0.03	mg/L
Nitrite	<0.01	mg/L
UVT	95.3	%
pH	5.5 - 6.0*	--

* The decarbonator units and sodium hydroxide addition were intermittently offline during the AOP challenge testing. The average AOP influent pH reported in the table is not representative of current operating conditions.

The good water quality of the RO permeate can be measured by the UVT and the UVI, both well chronicled in this report and within the industry as critical input to UV dose delivery. The full-scale LBX1000 sensors were ineffective at tracking the impact of variable lamp power on UVI, which was not the case for this LBX90 pilot. The LBX90 pilot was fitted with sensors intended for RO permeate applications, and the result was a repeatable relationship between UVI and power (Figure 5.2).

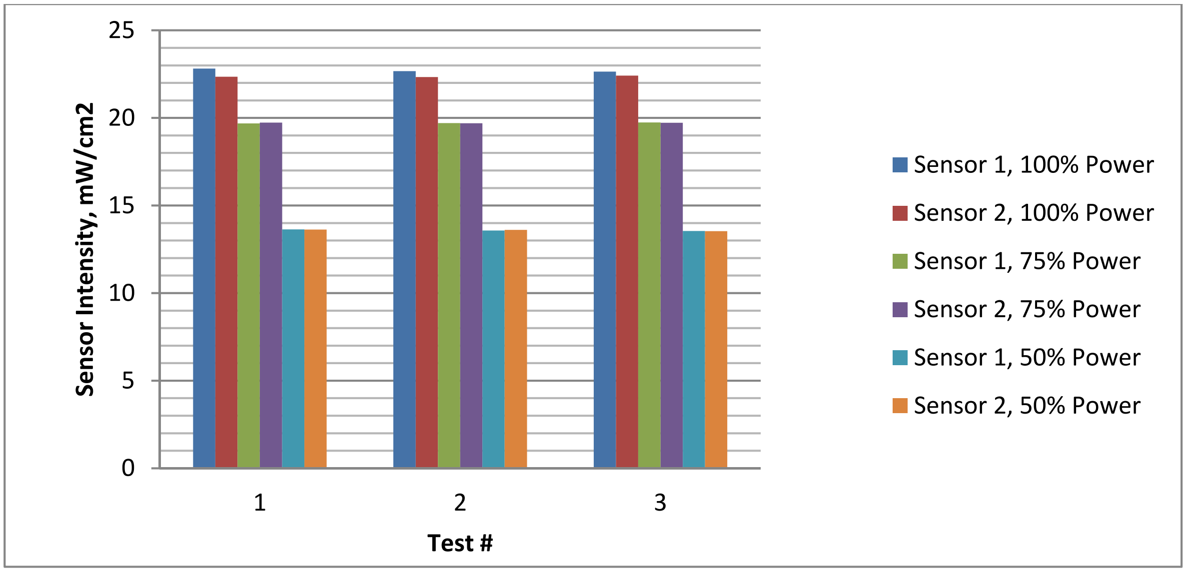

Figure 5.2 Sensor intensity values with varying power levels over 3 repeat measurements

5.3 1,4-Dioxane and NDMA Reduction by UV AOP Pilot

Pilot testing included looking at 1,4-dioxane removal across 4 sampling events, using both H_2O_2 and NaOCl. Prior work demonstrated that only minimal levels of 1,4-dioxane were present in RO permeate. Thus, the testing of 1,4-dioxane was done by seeding in 1,4-dioxane into the feed line to the UV AOP pilot.

H_2O_2 testing was performed on November 3, 2014 and April 1, 2015 with 4 H_2O_2 doses and 4 UV doses. With a dose of >800 mJ/cm^2 and a H_2O_2 dose of 6 mg/L, the 0.5 log removal target for 1,4-dioxane was met (Figure 5.3a). From a CCP standpoint, the concept of a peroxide weighted dose can improve online monitoring confidence (Figure 5.3b).

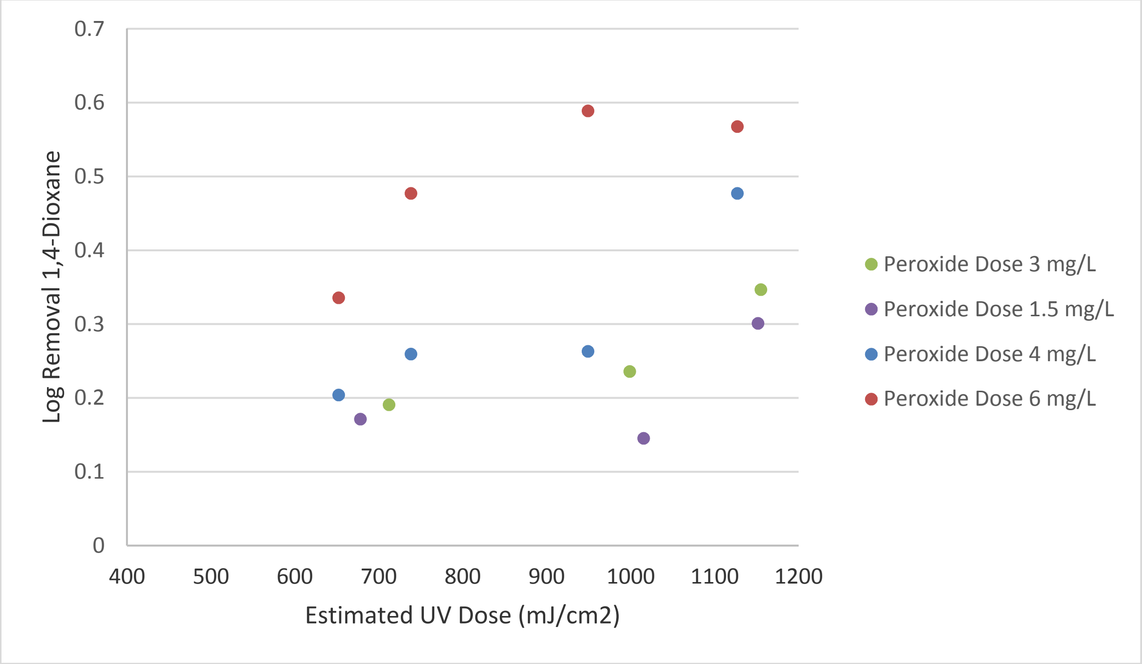

Figure 5.3a   Log-removal of 1,4-Dioxane by UV/H2O2

Unlike prior work with UV/NaOCl (LABOS, 2014), UV AOP with NaOCl as the oxidant was not able to meet 0.5 log removal of 1,4-dioxane at the tested dose values (Figure 5.4). Testing was performed on two dates November 4, 2014 and May 14, 2015. The results of the two tests did not exhibit a conclusive trend with exception of the 2 mg/L of NaOCl tests. Only 0.2 log removal of 1,4-dioxane was achieved with any of the testing conditions.

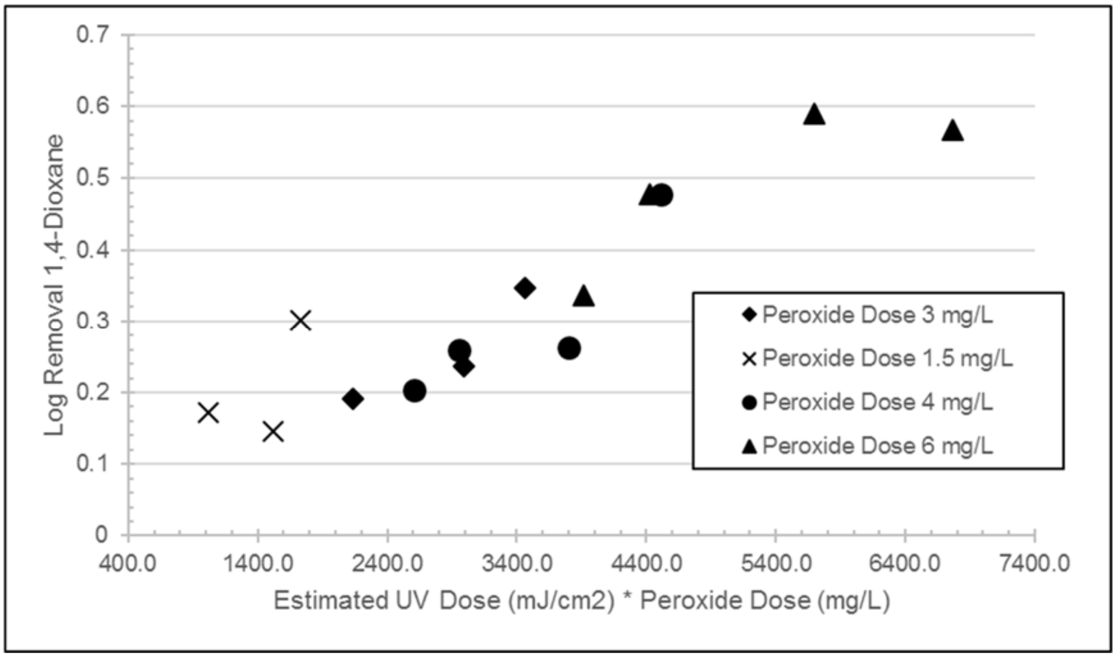

Figure 5.3b   Log-removal of 1,4-Dioxane as a Function of Peroxide Weighted Dose

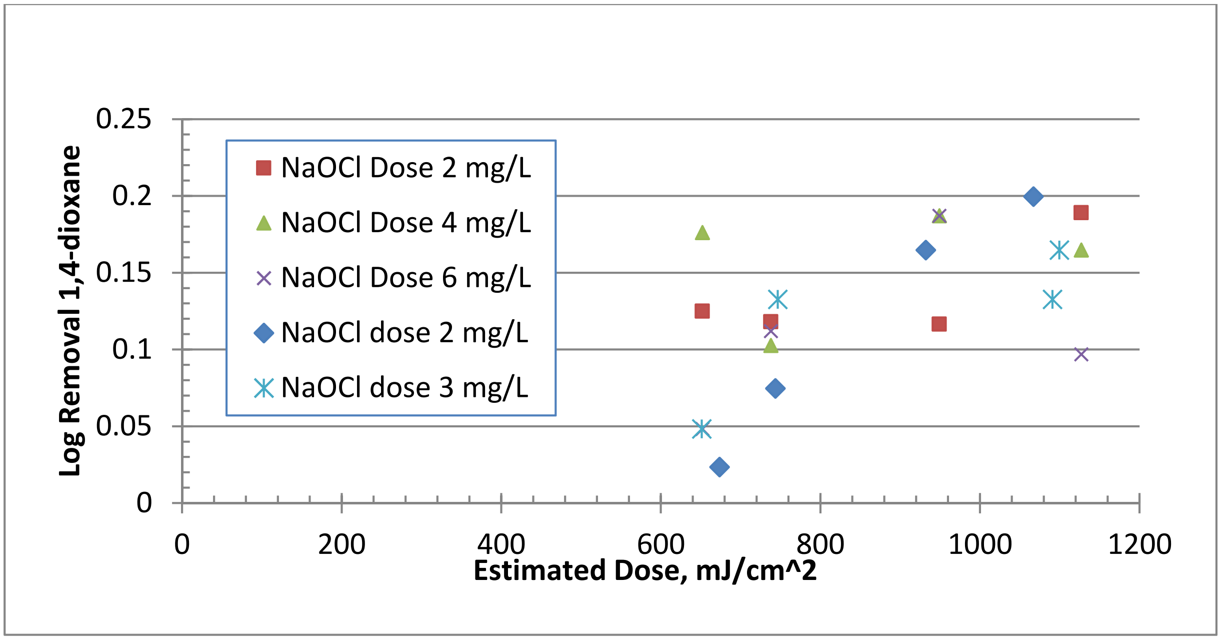

Figure 5.4 Log-removal of 1,4-Dioxane by UV/NaOCl

With 10 ng/L of NDMA in the finished water as the goal in the pilot effluent, NDMA destruction testing was performed with each of the two oxidants and without any oxidant addition. The testing with UV/H_2O_2 suggested the need for a higher UV dose in order to destroy NDMA compared to that of the UV/NaOCl process. Figure 5.5 shows the NDMA finished effluent values after the use of H_2O_2 as an oxidant in the AOP process. For this work, UV dose values of approximately 800 mJ/cm^2 and up were necessary to consistently get below the 10 ng/L target.

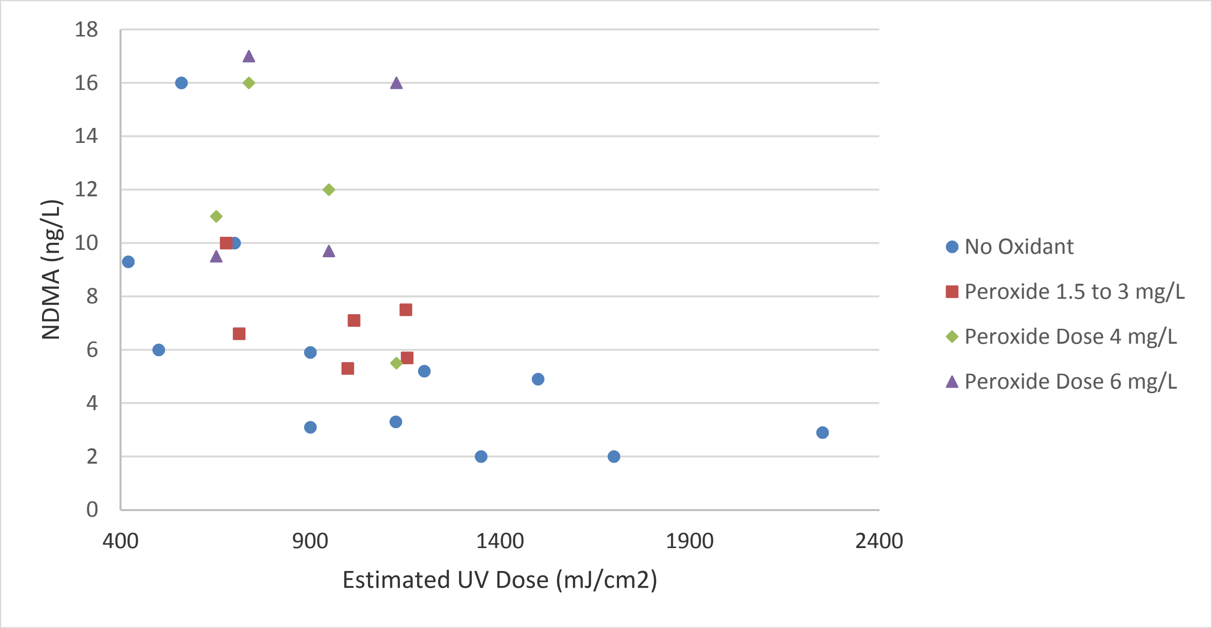

Figure 5.5 Finished water values for NDMA with H_2O_2 at varying UV doses

With chlorine doses of 2 - 6 mg/L, all finished water samples fell below the NDMA goal of 10 ng/L, as shown in Figure 5.6. NDMA photolysis in the reactor without the addition of oxidant is able to consistently achieve NDMA concentrations <10 ng/L within a UV dose range of approximately 900 mJ/cm^2 and up. Within these testing conditions, UV/NaOCl AOP shows consistent removal of NDMA relevant for potable reuse applications.

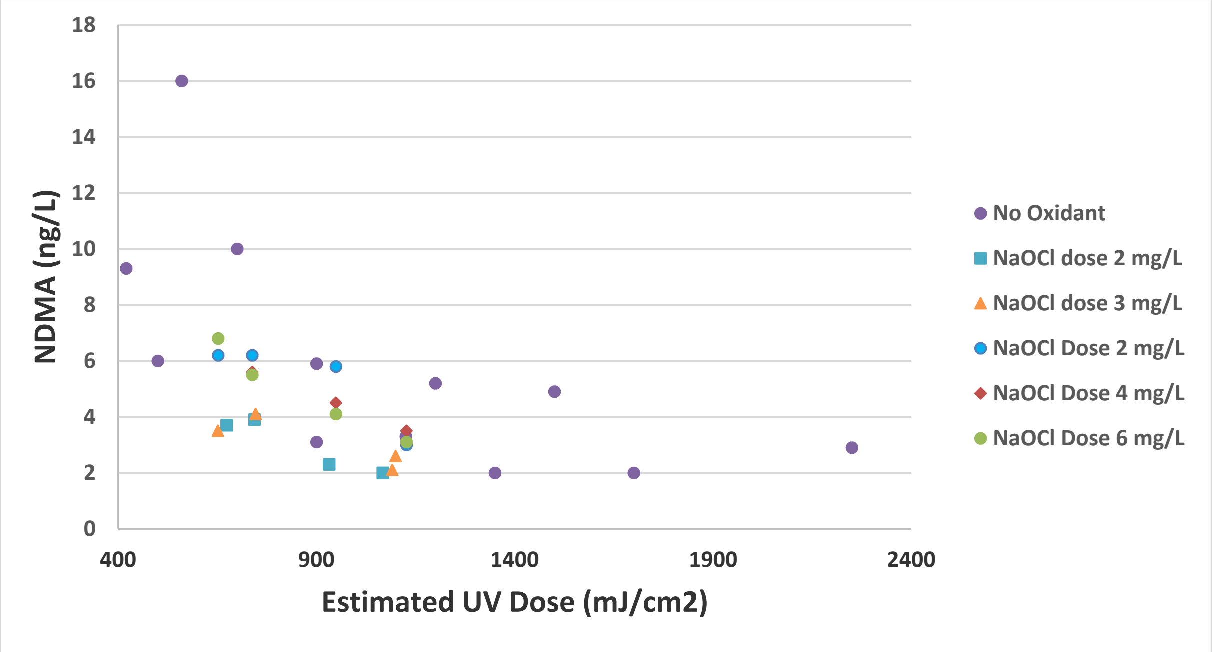

Figure 5.6 Finished water values for NDMA with NaOCl at varying UV dose values

Log removal values of NDMA were varied across oxidant and UV doses with both oxidants for advanced oxidation treatment, with AOP treatment using both NaOCl and H_2O_2 treatment showing similar results. H_2O_2 concentrations of 4 and 6 mg/L do not show enhancement of NDMA removal with higher oxidant concentration. NaOCl concentrations 2-6 mg/L show similar results for NDMA removal with corresponding UV doses. Figure 5.7 and 5.8 show both oxidants and doses versus UV doses and NDMA log removal values for each trial and oxidant. For this work, advanced oxidation looks as if it enhances NDMA removal compared to photolysis alone, adding benefit to the MF-RO train for potable reuse applications.

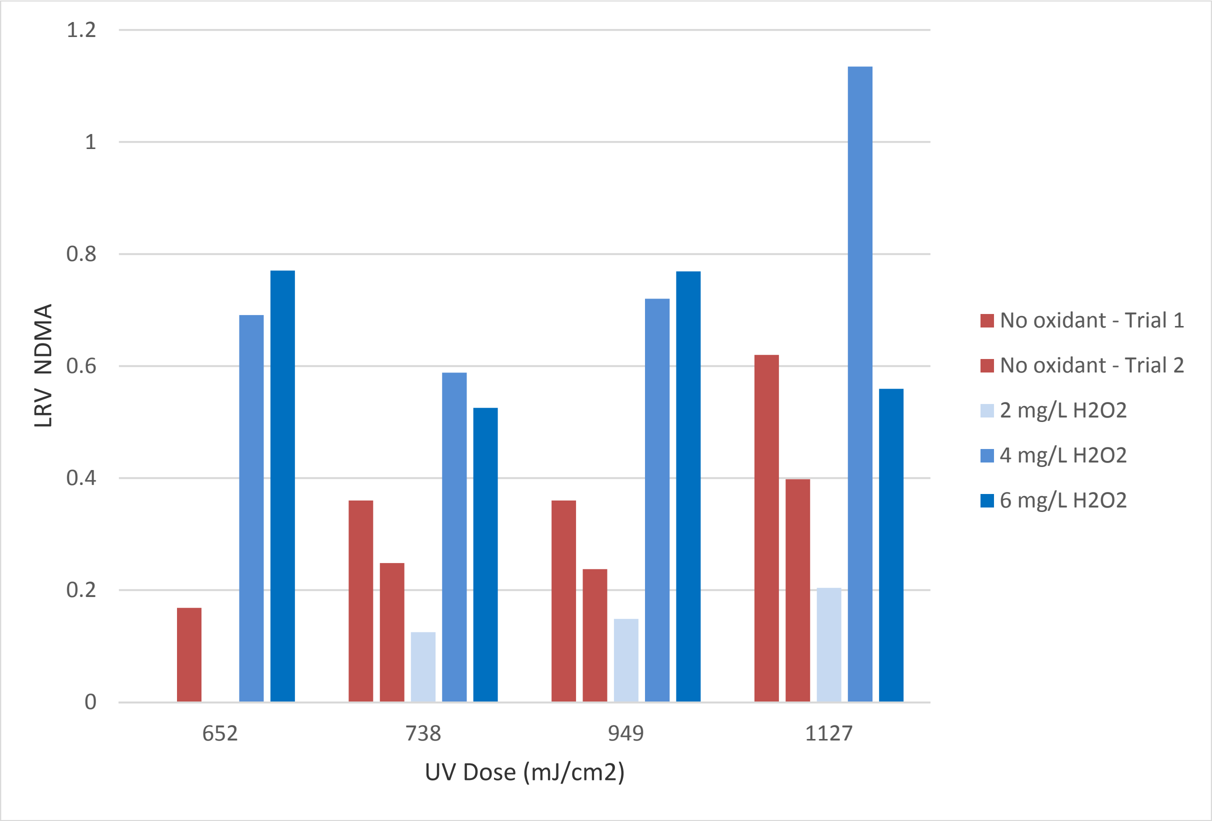

Figure 5.7 **Log-removal of NDMA using hydrogen peroxide with varying estimated UV doses**

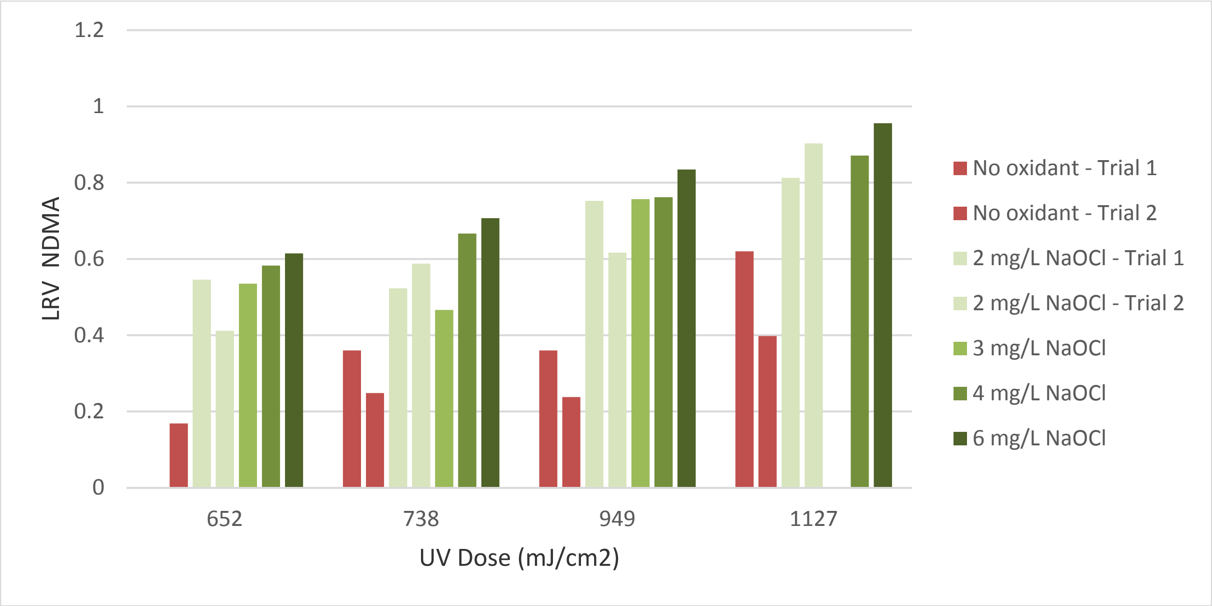

Figure 5.8 **Log-removal of NDMA using hypochlorite with varying estimated UV doses**

5.4 Performance Surrogates and Critical Control Point Monitoring for UV AOP

Based upon the work by LABOS (2014), Total chlorine destruction was tested as a monitoring parameter for correlation with NDMA removal by UV. Two chlorine measurement methods were tested, an amperometric titration method and the Hach DPD colorimeter for both free and total chlorine. The amperometric method requires more expensive materials, time and labor. Both methods were compared to determine if either method could be used to measure total chlorine destruction and predict NDMA destruction (and thus predict UV dose). Figure 5.9. shows a tight correlation between total chlorine destruction using the amperometric titration and the Hach DPD method, suggesting that either method is acceptable as a potential surrogate. Because of the lower cost and ease of testing, the Hach DPD method becomes the best option of the two total chlorine measurement techniques. It is important to note that the addition of H_2O_2 confounded the correlation between the two methods.

Figure 5.10 shows the destruction in NDMA as a function of total chlorine destruction, with different levels of oxidant addition, including zero oxidant.

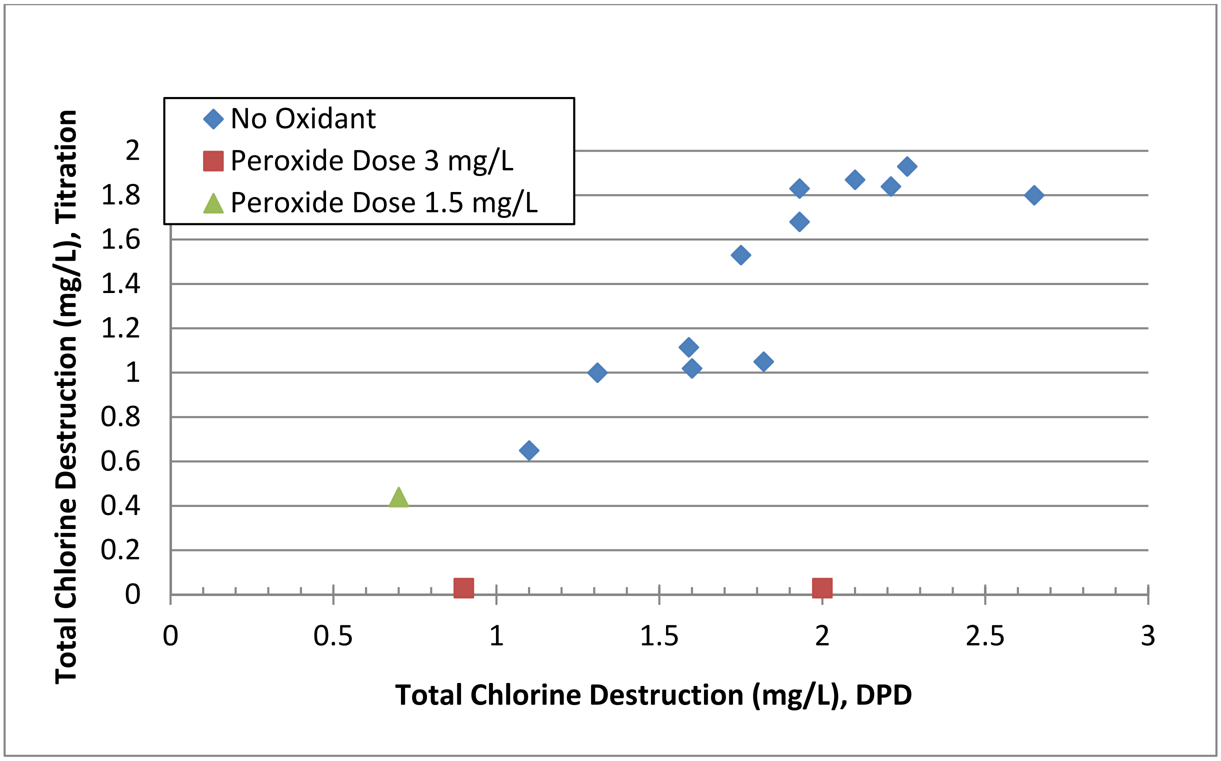

Figure 5.9 Total chlorine destruction by the Hach DPD and amperometric titration methods

Log removal data for NDMA during the UV/NaOCl AOP also correlated with total chlorine destruction, as measured using the Hach DPD method, shown in Figure 5.10. This monitoring tool proves important for the UV/NaOCl AOP, allowing for relatively accurate monitoring of dose delivery, making the measurement of total chlorine destruction a reliable CCP. Additional data collection is encouraged to further increase confidence in this correlation. This data could be used for CCP monitoring of NDMA destruction and pathogen destruction as follows:

- Total chlorine destruction of 2 mg/L resulted in ~0.7 log reduction of NDMA. Thus, if the target NDMA destruction level is known, monitoring of total chlorine destruction can predict performance; and
- 0.7 log reduction of NDMA is equivalent to a UV dose of ~600 mJ/cm2 (using performance ratios based upon Sharpless and Linden, 2003). The 600 mJ/cm2 dose far exceeds the UV dose required to provide 6-log reduction of all pathogens of concern.

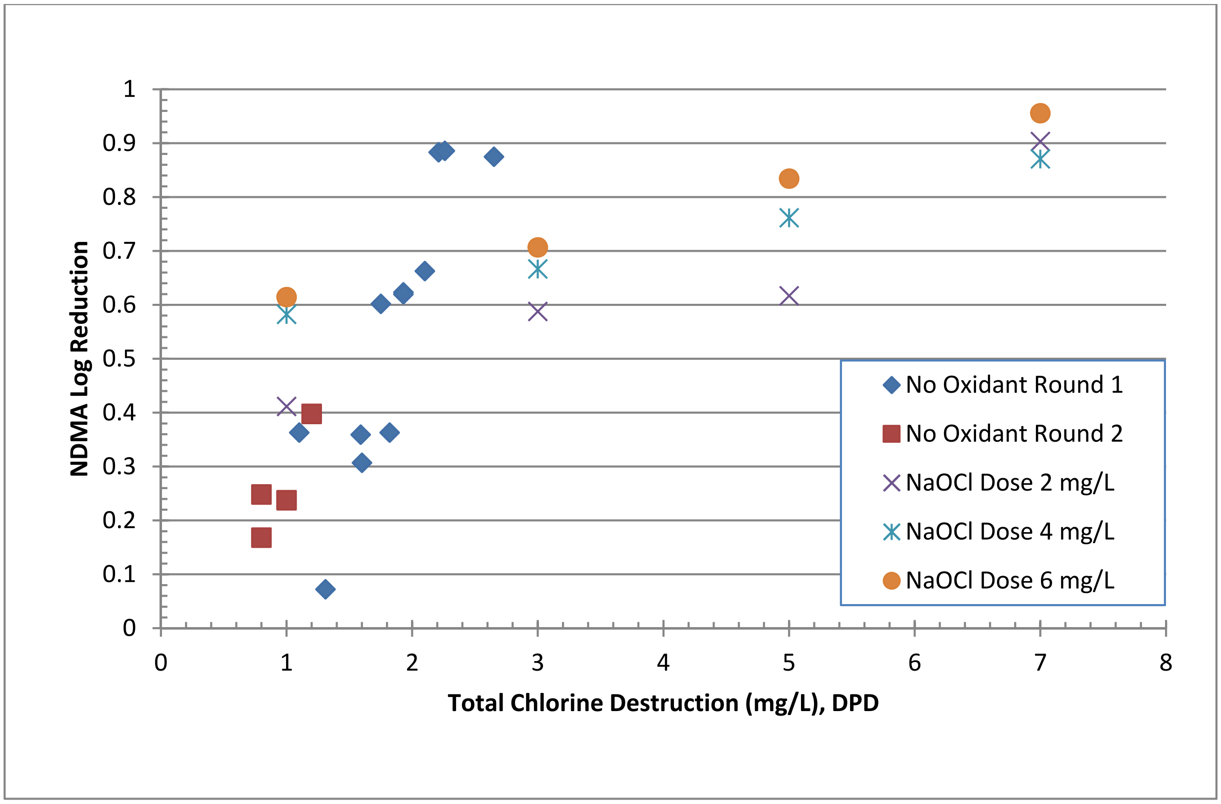

Figure 5.10 *Log-removal of NDMA correlated with total chlorine destruction using the Hach DPD method*

To better support the pilot work, collimated beam testing was performed by Xylem in Charlotte, North Carolina using RO permeate water shipped from SVAWPC the day of testing. The water included the 1,4-dioxane spiked during testing at the SVAWPC, and oxidant was added immediately prior to testing. The purpose of the collimated beam testing was to determine the UV dose required to achieve an effluent water with <10 ng/L NDMA and > 0.5 log 1,4-dioxane removal. This dose can then be correlated to the removal received in the field. If a significant discrepancy is observed between removal in the collimated beam test and field, this is an indication to investigate further potential hydraulic or dosing limitations in the pilot-scale system.

Collimated beam analyses were performed for both UV/NaOCl and UV/H_2O_2 for 1,4-dioxane and NDMA removal. For the collimated beam work, H_2O_2 was a favorable oxidant for NDMA removal with UV AOP, shown in Figure 5.11. This result is in conflict with pilot testing results, which showed a higher log removal of NDMA being achieved with the UV/NaOCl process. The NDMA dose/response was similar to data found in Sharpless and Linden (2003), validating the bench-top testing procedures and results.

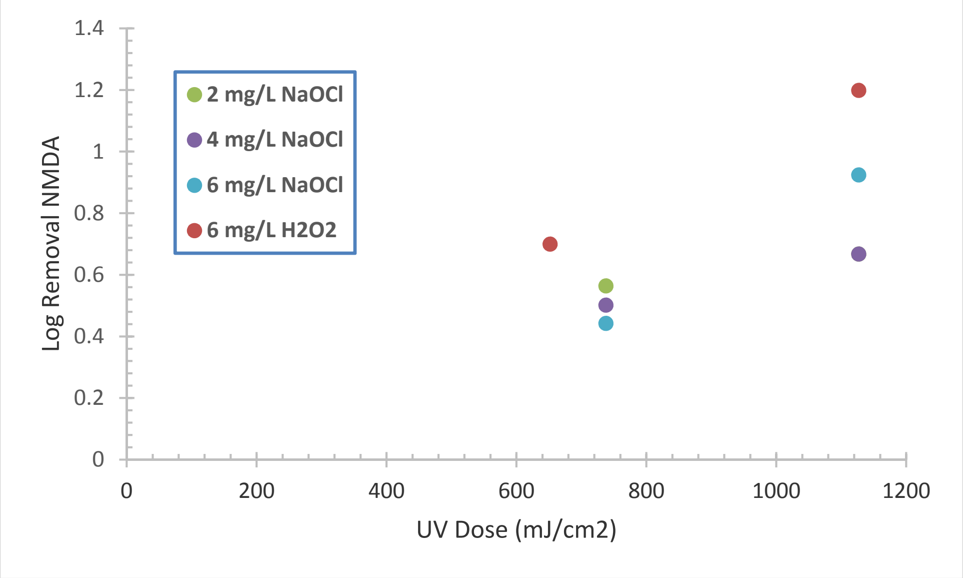

Figure 5.11 Collimated beam UV/H_2O_2 and UV/NaOCl log removal of NDMA

Figure 5.12 shows the removal of 1,4-dioxane by both UV/NaOCl and UV/H_2O_2 in collimated beam testing. With H_2O_2 as an oxidant, the UV/H_2O_2 was able to remove 1,4-dioxane to above the 0.5 log removal goal at UV dose values of ~900 mJ/cm2 with 6 mg/L of H_2O_2, very similar to the pilot-scale results. UV AOP with NaOCl was not able to reach 0.5 log removal of 1,4-dioxane even at high UV doses, again similar to pilot-scale results.

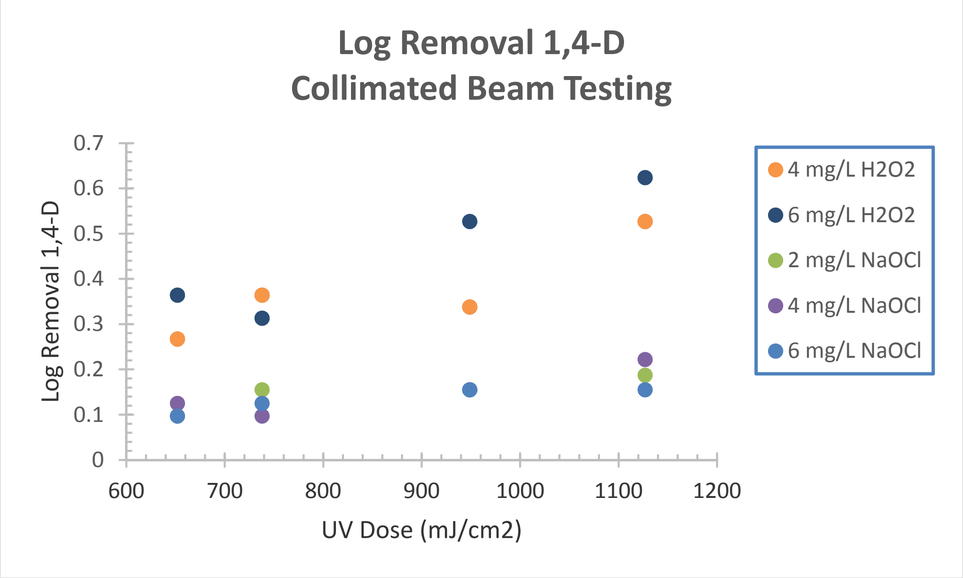

Figure 5.12 Collimated beam UV/H_2O_2 and UV/NaOCl log removal of 1,4-Dioxane

5.5 Destruction of Trace Pollutants by UV AOP

Similar to the testing of the SVAWPC finished water, a wide range of testing for trace constituents was done in the feed to the UV AOP pilot and in the finished water from the UV AOP pilot. Following RO treatment, the only routinely present trace pollutants are NDMA and

1,4-dioxane, and 1,4-dioxane was present at very low levels (except during seeding, of course). During four rounds of UV AOP pilot testing, other than NDMA and 1,4-dioxane, there were three other detected trace pollutants in the RO feed. Table 5.2 shows the pollutants, dates, concentration, and maximum reporting limit for each of the constituents. All three constituents: estradiol, sucralose, and TCEP are close to the detection limit and are likely not significant. Following AOP treatment, all three detectable compounds were below detectable levels.

Table 5.2 Dates and corresponding detectable trace pollutants in the influent to advanced oxidation pilot testing
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Date	Pollutant	Concentration in Influent to UV AOP	Concentration in UV AOP Effluent	MRL	Units
4/1/2015	Estradiol	8	ND	5	ng/L
4/1/2015	Sucralose	110	ND	100	ng/L
5/14/2015	TCEP	15	ND	10	ng/L

5.6 Issues to Address for Potable Reuse UV AOP

- CCP performance is demonstrated for total chlorine destruction as a surrogate for both NDMA destruction and UV dose delivery. The addition of an oxidant may hinder this relationship and further oxidant and UV dose optimization testing is needed.
- UVA destruction did not correlate well with total chlorine destruction, likely due to analytical accuracy at high UVT values. Further testing with a more accurate online UVT meter would be required to develop this concept.
- UV AOP with NaOCl did not perform sufficiently well for 1,4-dioxane destruction and is not recommended without further testing.
- UV AOP with H_2O_2 performed well for 1,4-dioxane destruction and is recommended. Refinement of UV and H_2O_2 dose can be done with further testing as needed.

6.0 O_3/BIOLOGICALLY ACTIVE FILTRATION

Within California, there are two forms of potable water reuse treatment; surface spreading of tertiary recycled water and injection of an advanced treated water using membranes and advanced oxidation (typically MF/RO/UV AOP). Both treatment and recharge methods are approved by DDW (CDPH, 2014) and produce a high quality water for potable use. The District is considering different types of treatment and recharge scenarios, and is looking for lower cost methods to purify water. Linden *et al.* (2012) demonstrated that O_3 was the most cost-efficient method for advanced oxidation in tertiary recycled water compared to UV based processes (UV/H_2O_2, UV/PAA, and UV/TiO_2). Trussell *et al.* (2015) performed the latest extensive evaluation of O_3/BAF for indirect and direct potable reuse projects, including O_3 disinfection studies and biological optimization of Biologically Active Filtration (BAF) based upon different O_3 dose values and BAF empty bed contact times (EBCTs). Based upon these and other O_3 projects, the District conducted O_3/BAF research to better understand two potential applications:

Tapping into tertiary recycled water (filtered and chlorinated, and blended with advanced treated water from the SVAWPC to attain a TDS of 500 mg/L) in the non-potable reclaimed water distribution system, treating it with O_3/BAF, then spreading the treated water for groundwater recharge. The goal of this work is to document a potentially lower cost method to purify water.

Treating secondary effluent with O_3/BAF, then following that treatment with MF, RO, and UV AOP as part of a Direct Potable Reuse treatment process. The goal of this work was to better expand the industry knowledge base for O_3/BAF as part of direct potable reuse treatment trains.

6.1 Relevant Literature

There are three primary benefits of O_3/BAF treatment. One is the reduction of TOC, both from a bulk perspective and from the perspective of trace pollutant removal. The second is for the removal of pathogens. The third is the removal of nitrogen.

The use and performance of O_3/BAF for potable water reuse applications is much less understood compared to the use of membranes and UV AOP. Hence, a literature review of the state of the science is included below to provide a reasonable perspective on performance expectations for the SVAWPC O_3/BAF demonstration.

6.1.1 TOC Reduction

TOC reduction during treatment is a key component for potable reuse projects. DDW (CDPH, 2014) requires <0.5 mg/L of wastewater origin TOC in the groundwater mound. This TOC level can be met above ground (using RO or O_3/BAF, for example) or through the soil aquifer treatment (SAT) process and through blending with groundwater. For surface spreading projects that use only tertiary or advanced tertiary treatment (essentially everything except MF/RO/UV AOP), DDW imposes a maximum recycled water content (RWC) of 20 percent in the groundwater, thus requiring substantial dilution. Based upon that dilution, the 0.5 mg/L target means that the TOC of wastewater origin needs to be reduced to 2.5 mg/L through engineered treatment (such as tertiary or advanced tertiary treatment) and through SAT. The discussion below first highlights the reduction of TOC through O_3/BAF, and then follows with a discussion of TOC reduction through SAT.

A variety of research papers were reviewed to find published data on TOC removal by O_3/BAF. A summary of the TOC removal by O_3/BAF is provided in Table 6.1. Most of the literature reports organic carbon (OC) in terms of dissolved OC (DOC), which is usually the OC measured from a sample filtered through a 0.45 μm filter. Where percent removal has been listed, the actual effluent value of OC is back calculated from the influent OC concentration given. In the research by Kirisits (Kirisits *et al.*, 2001), various electron donors (acetate, lactate, and pyruvate) were added to the reactor influent to drive removal of bromate and perchlorate. These electron donor solutions were added in various quantities and removal of the added carbon was counted as part of the overall system OC removal in addition to the actual removal of the raw influent OC. This is why the percent OC removal for this study varied so widely.

Three major, comparable studies of interest were identified:

- Tampa, FL (CH2M, 1993)
- Reno, NV (Gerrity *et al.*, 2011)
- Hollywood, FL (Hazen and Sawyer, 2015)

The pilot studies for the Tampa Water Resource Recovery Project, while significant at the time (around 1990), are now dated. The pilot plant had multiple trains of which one consisted of a dual media filter, GAC, and O_3. The Reno pilot consisted of two layouts fed by secondary effluent. Both contained O_3/BAF however one was preceded by UF and the other was preceded by sand filtration. Reno removed about 28 percent of its influent TOC which appears to be in the typical range compared to the other O_3/BAF processes reviewed.

The Hollywood pilot by Hazen & Sawyer (H&S) did meet a very low TOC standard, but required the addition of an ion exchange process. Two separate ion exchange (IX) processes (one for ammonia and a second for TOC removal) immediately preceded O_3/BAF. The IX media used was not specified in the report.

As shown in Table 6.1, the OC removal values varied widely, but a number of studies had removals in the 20 to 30 percent range.

Table 6.1 Removal of Organic Carbon (DOC and TOC) Reported by Several Studies SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Reference	Pilot/Plant	TOC/DOC	Influent OC (mg/L)	OC Removal (%)	Effluent OC (mg/L)
Gerrity *et al.* (2011)	Pilot	TOC	6.8		4.9
Hollender *et al.* (2009)	Full-Scale	DOC			5.2 +/-0.6
Kirisits *et al.* (2001)	Pilot	DOC	2.4 to 6	2 to 73	1.2 to 4.4
Macova *et al.* (2010)	Full-Scale	TOC	20		4.0 +/-0.4
Reungoat *et al.* (2012)	3 Full-Scale Plants	DOC	6.5-8.1, 5.8-6.6, 4.2-5.8	17 ± 2, 25 ± 6, 48 ± 10	5.2-6.9, 4.0-5.3, 1.8-3.6
WERF(2014)	Pilot	DOC	6.8	23%	5.24
van der Hoek *et al.* (2000)	Full-Scale and Pilot	DOC		20 to 30	
WQ Res. Australia(2010)	Pilot	DOC		22	
H&S(2014)	Pilot	TOC	7.8		1.1
CH2M (1993)	Pilot	TOC	11.59		1.88

The latest work on TOC removal by O_3/BAF was done as part of WRRF Project 11-02, as documented by Trussell *et al.* (2015), presented in Figures 6.1 and 6.2 below. For this work, the O_3/BAF was performed on a very high quality secondary effluent, with and without microfiltration as pretreatment. Feed TOC values were ~5 mg/L. Removal percentages were higher for MF filtered water (29 percent to 40 percent, average of 34 percent) compared to secondary effluent (26 percent to 33 percent, average of 30 percent). The removal percentage is important, as the end goal is to get the TOC down to 2.5 mg/L through engineered treatment and then through SAT. For the results demonstrated in Trussell *et al.* (2015), the O_3/BAF effluent needs further TOC reduction through SAT to hit the 2.5 mg/L target before dilution.

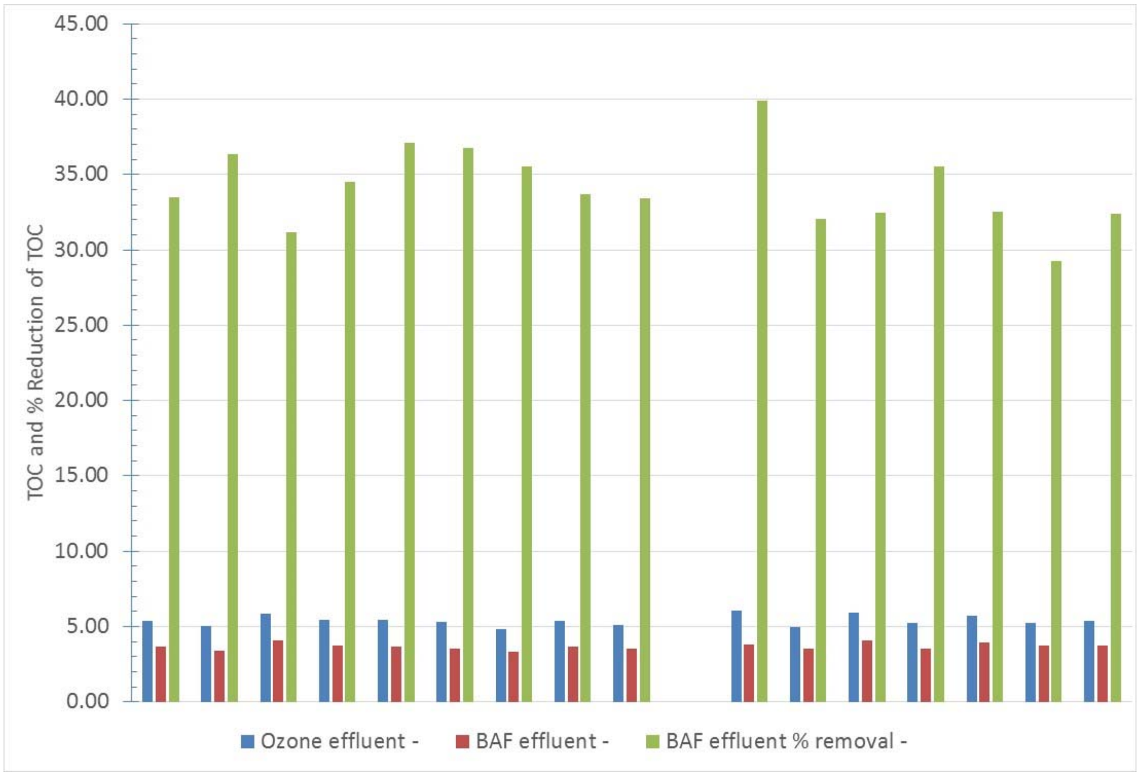

Figure 6.1 ***Reduction of TOC Through BAF, Treating Microfiltered Secondary Effluent at various sampling events (Trussell et al., 2015)***

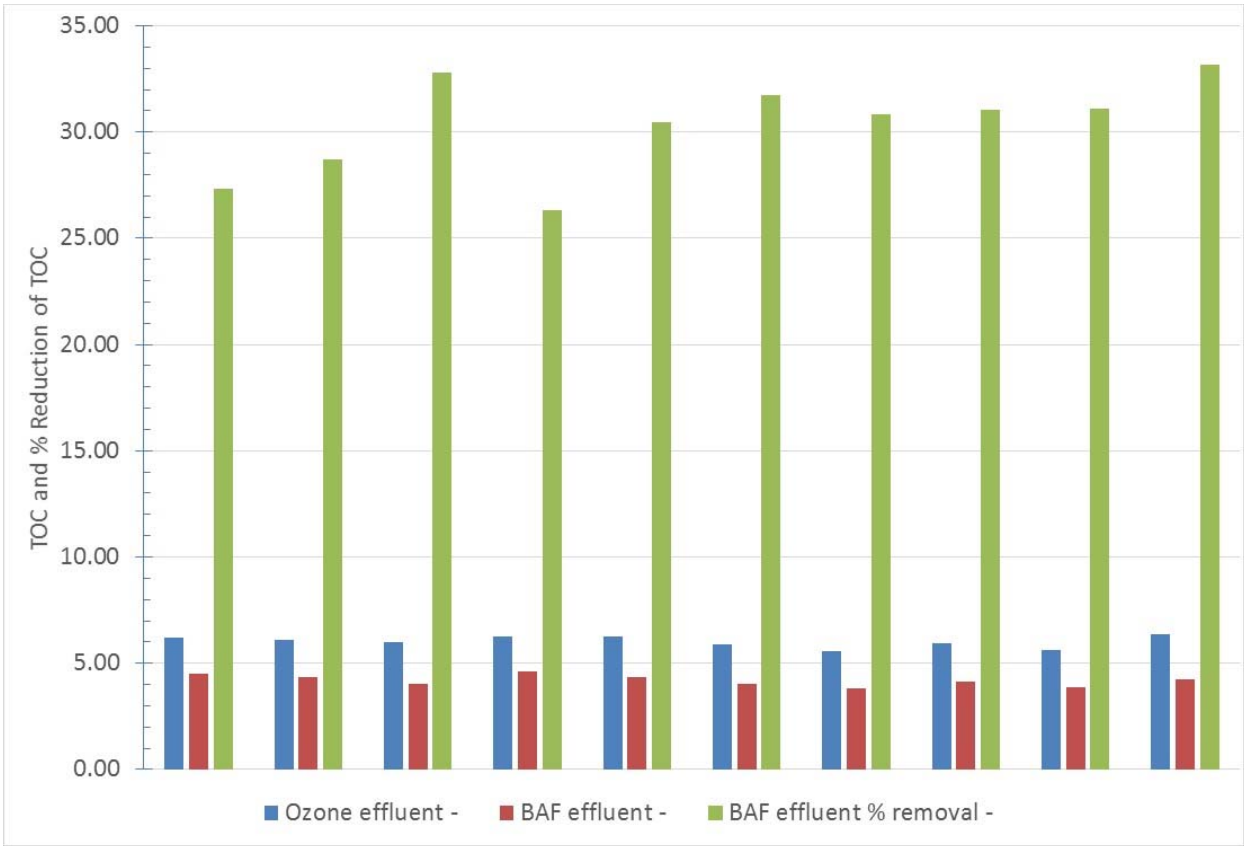

Figure 6.2 **Reduction of TOC Through BAF, Treating Secondary Effluent at various sampling events (Trussell et al., 2015)**

Fox *et al.* (2001b) characterized the factors affecting the removal and transformation of bulk TOC during transport through the SAT infiltration interface, soil percolation zone, and in the underlying groundwater aquifer. Results from the study provide sufficient evidence for the sustainable removal of bulk organics by primarily microbiological removal mechanisms in both laboratory experiments and through monitoring of the water recovered from the full-scale SAT field sites. In the short-term (initial hours to days), TOC attenuation was dependent upon the applied wastewater effluent quality and the portion of biodegradable TOC in the treated wastewater effluent. During long hydraulic retention times in SAT systems (weeks to months), the characteristics of TOC resembled increasingly that of natural organic matter (humic and fulvic acids), whereas TOC concentrations after long-term SAT approached concentrations as a function of the source drinking water TOC and soluble microbial products (SMPs) formed during the wastewater treatment process (resulting from the decomposition of organic compounds during biological wastewater treatment).

In general, the removal of bulk organics during SAT occurred rapidly during time scales of less than 10 days for unsaturated, aerobic conditions, while organic carbon removal was found to be much slower for saturated, anoxic aquifer conditions. However, considering time scales of less than 30 days, both saturated and unsaturated conditions led to similar TOC concentrations. The removal of bulk organics on time scales beyond 30 day retention times continued at very low reaction rates. For reference, a comparison of TOC data collected in 1991-92 and 1997 for a recharge basin located at the Sweetwater Underground Storage and Recovery Facility is presented in Figure 6.3. It is apparent that the TOC attenuation performance of the SAT site during percolation through the vadose zone of 100 ft (30 m) did not decline over an extended period of operation (several years). These findings support the conclusion that SAT can provide sustainable removal of a substantial portion of TOC that is still present in secondary and tertiary municipal effluents during percolation through the vadose and saturated zones. An overview of managed aquifer recharge (MAR) site residence times and TOC removal efficiencies worldwide is also presented in Table 6.2 (Maeng *et al.,* 2011). These results show removal of DOC ranging from 33 percent to >90 percent through SAT, which becomes important and effective method to reduce TOC to DDW regulated levels.

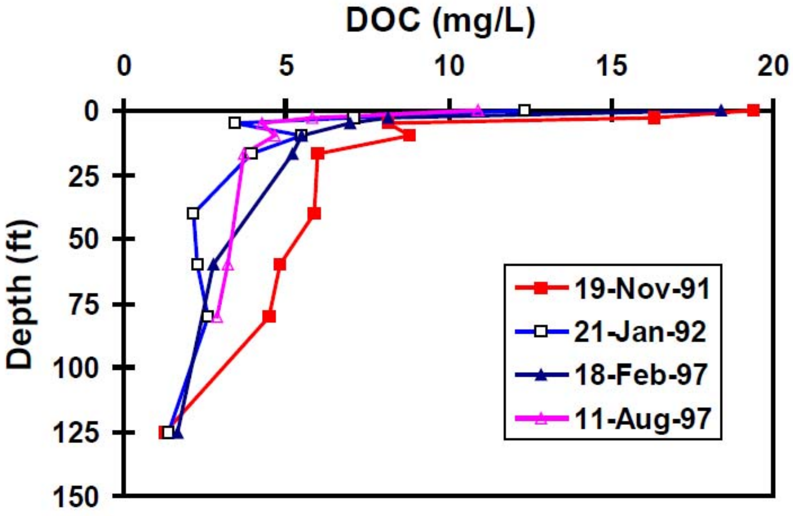

Figure 6.3 Comparison of DOC as a function of soil depth for samples collected in 1991-92 and 1997 from recharge basin RB-001 at the Sweetwater Underground Storage and Recovery Facility. Adopted from (Fox et al., 2001b)

Table 6.2 Overview of MAR Residence Times and TOC/DOC Removal Efficiencies Worldwide. (Adopted from (Maeng *et al.*, 2011))

Site	Distance (meter)	Residence Time (day)	Types	C_o, (TOC/DOC) mg/L	TOC Removal (%)	DOC Removal (%)	Well Type	Capacity (m^3/s)	References
Hämeenlinna, Finland	1000-1300	90	AR[c]	14/	88		V[d]		(Kolehmainen *et al.*, 2007)
Jyväskylä, Finland	200-550	15-30	AR[c]	9/	77		V[d]		(Kolehmainen *et al.*, 2007)
Tuusula, Finland	500-700	30-60	AR[c]	6/	73		V[d]		(Kolehmainen *et al.*, 2007)
Louisville, Kentucky, USA	30.5	120	RBF[a]	2.9/	30	33	H[e]	0.88	(Wang *et al.*, 2002)
Jeffersonville, Indiana, USA	61	3-5	RBF[a]	3.0/2.7	60	58	V[d]	0.23	(Weiss *et al.*, 2004)
Jeffersonville, Indiana, USA	177	13-19	RBF[a]	3.0/2.7	75	74	V[d]	0.23	(Weiss *et al.*, 2004)
Terre Haute, Indiana, USA	27	13-19	RBF[a]	4.7/4.1	67	64	H[e]	0.53	(Weiss *et al.*, 2004)
Terre Haute, Indiana, USA	122	-	RBF[a]	4.7/4.1	88	88	V[d]	0.044	(Weiss *et al.*, 2004)
Parkville, Missouri, USA	37	-	RBF[a]	4.5/3.6	41	35	V[d]	0.075	(Weiss *et al.*, 2004)
Parkville, Missouri, USA	24	-	RBF[a]	4.5/3.6	40	36	V[d]	0.075	(Weiss *et al.*, 2004)
Pembroke, New Hampshire, USA	55	5	RBF[a]	/1.5-7		71	V[d]		(Partinoudi and Collins, 2007)

Table 6.2 Overview of MAR Residence Times and TOC/DOC Removal Efficiencies Worldwide. (Adopted from (Maeng *et al.*, 2011))

Site	Distance (meter)	Residence Time (day)	Types	C_o, (TOC/DOC) mg/L	TOC Removal (%)	DOC Removal (%)	Well Type	Capacity (m^3/s)	References
Berlin (Lake Tegel), Germany	100	135	LBF[b]	/7.5		42	V[d]		(Grunheid *et al.*, 2005)
Berlin (Lake Tegel), Germany	77	117	LBF[b]	/7.2-7.5		34-40	V[d]		(Grunheid *et al.*, 2005)
Berlin (Lake Tegel), Germany	32	50	AR[c]	/7.2-7.5		34-40	V[d]		(Grunheid *et al.*, 2005)
Düsseldorf, Germany	50		RBF[a]	/4.3		40	H[e]		(Schubert, 2002)
Monitoring well-MW5, Tuscon, Arizona, USA	6	11	AR[c]	/14.1		66	V[d]		(Amy and Drewes, 2007)
Monitoring well WR199, Tuscon, Arizona, USA	35	35	AR[c]	/14.1		93	V[d]		(Amy and Drewes, 2007)
Monitoring well-NW4, Mesa, Arizona, USA	388	6-18 (month)	AR[c]	/6.10		76	V[d]		(Amy and Drewes, 2007)
Monitoring well-NW3, Mesa, Arizona, USA	655	6-19 (month)	AR[c]	/6.10		71	V[d]		(Amy and Drewes, 2007)

Table 6.2 Overview of MAR Residence Times and TOC/DOC Removal Efficiencies Worldwide. (Adopted from (Maeng *et al.*, 2011))

Site	Distance (meter)	Residence Time (day)	Types	C_o, (TOC/DOC) mg/L	TOC Removal (%)	DOC Removal (%)	Well Type	Capacity (m^3/s)	References
Monitoring well-NW2, Mesa, Arizona, USA	885	6-20 (month)	AR[c]	/6.10		75	V[d]		(Amy and Drewes, 2007)
Monitoring well-10U, Mesa, Arizona, USA	1950	12-96 (month)	AR[c]	/6.10		81	V[d]		(Amy and Drewes, 2007)
Monitoring well-26U, Mesa, Arizona, USA	1950	12-96 (month)	AR[c]	/6.10		88	V[d]		(Amy and Drewes, 2007)
Monitoring well-44U, Mesa, Arizona, USA	2700	12-96 (month)	AR[c]	/6.10		82	V[d]		(Amy and Drewes, 2007)

Notes:

a RBF: riverbank filtration.
b LBF: lake bank filtration.
c AR: artificial recharge.
d V: vertical well.
e H: horizontal well (radial collector well).

6.1.2 CEC Reduction

O_3 for destruction of trace pollutants is widely documented (Fontaine and Salveson (2014), Linden *et al.* (2012), Trussell *et al.* (2013), Snyder *et al.* (2007)). Results from the pilot testing documented in Fontaine and Salveson (2014) and from Trussell *et al.* (2013) are shown in the figures and table below. The data clearly demonstrates that O_3 alone, and O_3 with BAF, are able to reduce a wide range of trace pollutants, but some pollutants are resistant to oxidation and biodegradation as shown in Figures 6.4 through 6.9.

Table 6.3 Concentrations of Indicator Trace Organic Compounds after Different Levels of Treatment as Reported by Trussell *et al.* (2013)

Compound	Max. Recommended Value, ng/L	Secondary Effluent, ng/L	Tertiary Effluent with UV, ng/L	O_3, BAF, ng/L
Atenolol	70,000	710	120	<25
Atrazine	1,000	28	<10	<10
Bisphenol A	200,000	<50	<50	<50
Carbamazepine	1,000	140	192	<10
DEET	2,500,000	54	232	<25
Diclofenac	1,800	62	57	<25
Gemfibrozil	45,000	31	12	<10
Ibuprofen	400,000	<25	<25	<25
Meprobamate	260,000	41	362	190
Musk Ketone	350,000	<100	<100	<100
Naproxen	220,000	<25	<25	<25
Phenytoin	6,800	110	113	33
Primidone	10,000	67	168	31
Sulfamethoxazole	35,000	570	1,150	<25
Triclosan	350	26	38	<25
Trimethoprim	70,000	280	43	<10
TCEP	1,000	540	349	<200

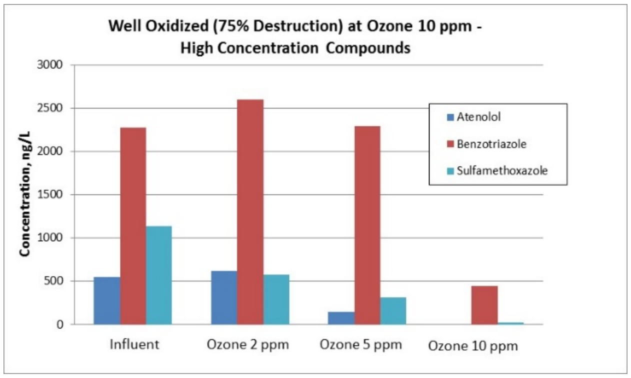

Figure 6.4 O_3 Destruction of High Concentration Oxidizable Compounds

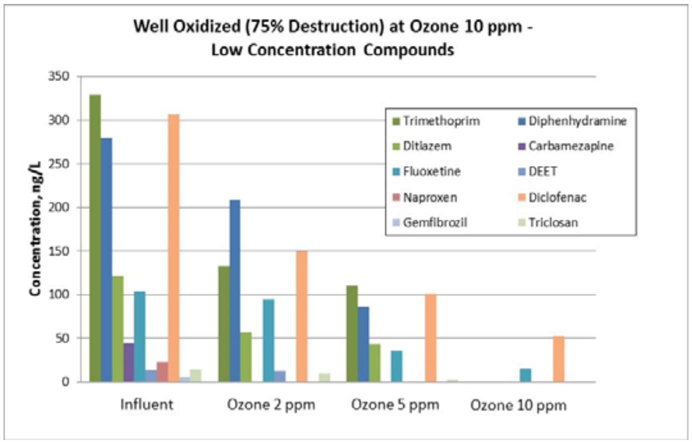

Figure 6.5 O_3 Destruction of Low Concentration Oxidizable Compounds

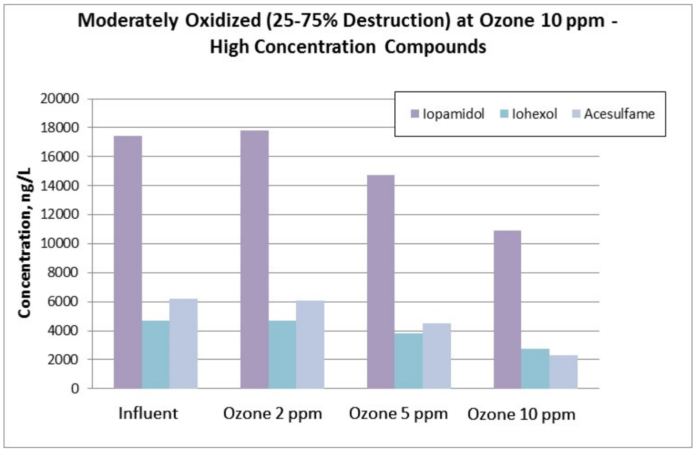

Figure 6.6 O_3 Destruction of High Concentration Moderately Oxidizable Compounds

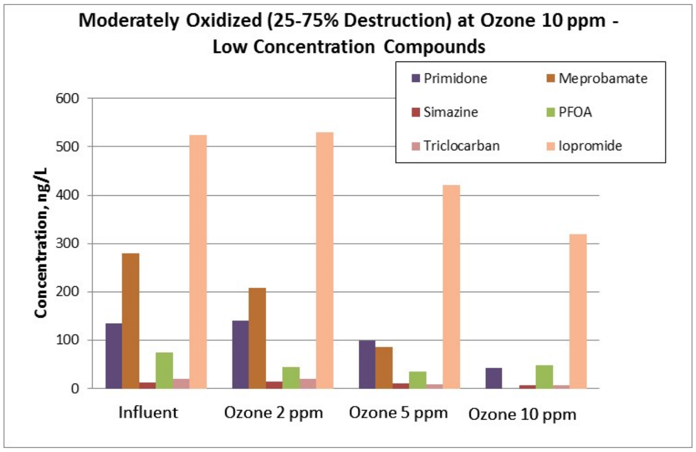

Figure 6.7 O_3 Destruction of Low Concentration Moderately Oxidizable Compounds

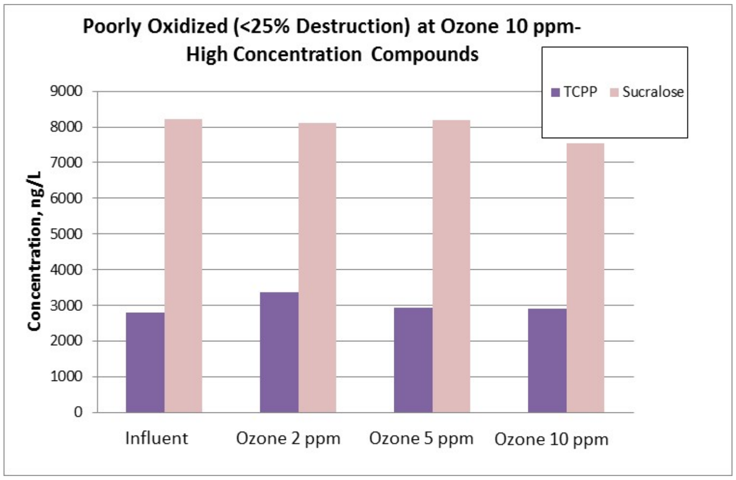

Figure 6.8 O_3 Destruction of High Concentration Poorly Oxidizable Compounds

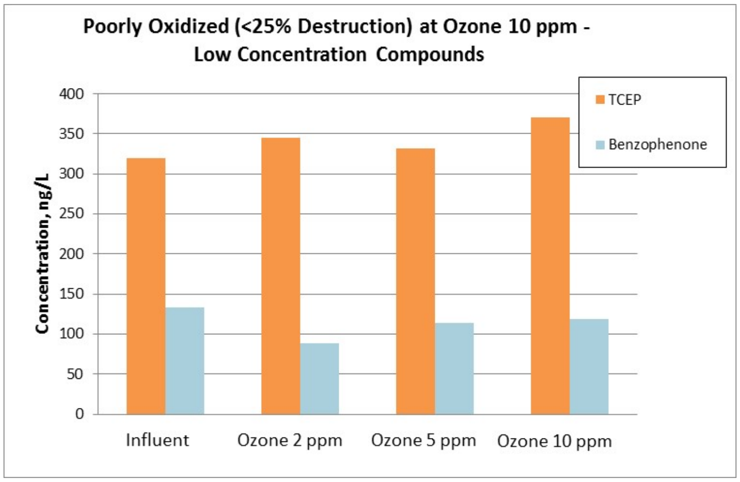

Figure 6.9 O_3 Destruction of Low Concentration Poorly Oxidizable Compounds

CEC attenuation during SAT has been successfully evaluated at several large-scale facilities within the U.S. These facilities include the Sweetwater Underground Storage and Recovery Facility (Tucson, AZ) (Drewes *et al.,* 2001), the Northwest Water Reclamation Plant (Mesa, AZ) (Drewes *et al.,* 2001), the Tres Rios Cobble site (Phoenix, AZ) (Fox 2001) and the Montebello Forebay (Los Angeles County, California) (Laws 2011). In early investigates, the Sweetwater Underground Storage and Recovery Facility and the Northwest Water Reclamation Plant have demonstrated greater than 90 percent biotransformation of complexing agents and surfactants, such as ethylenediaminetetraacetic acid (EDTA), nitrilitriacetic acid (NTA), and alkylphenol polyethoxy carboxylates (APEC), which have served as suitable wastewater indicators for both facilities (Drewes *et al.,* 2001, 2003). Hoppe-Jones *et al.* (2010) later suggested several additional surrogate compounds for use as MAR CEC indicator compounds. Groundwater recharge at these same field sites also offered excellent removal of acidic drugs such as lipid regulators and analgesics. Antiepileptic drugs and X-ray contrast agents did not show significant removal during travel times of more than 6 months, indicating that some CECs are not completely removed during SAT; however, site specific conditions that might enhance CEC attenuation should not be overlooked when investigating new locations for SAT (Maeng *et al.,* 2011a, Nham *et al.,* 2015). More recent research conducted at the Montebello Forebay, which includes the Rio Hondo Spreading Grounds, evaluated the attenuation of a wide range of CECs across a range of travel times (10 hrs to 60 days) (Laws *et al.,* 2011). A total of seventeen CECs were detected in the spreading basin and the concentrations of all were reduced during SAT; eleven of the target compounds were attenuated by greater than 80 percent.

A brief summary of references that describe CEC attenuation in several other large-scale MAR sites, in both the United States (U.S.) and in Europe, is provided in Table 6.4. A recent, and rather thorough, literature review on MAR facilities in the U.S. and in Europe is also available in the literature (Maeng *et al.,* 2011a); both SAT and riverbank filtration are discussed at length.

Table 6.4. MAR Field Sites Investigated for Occurrence and Attenuation of CECs. Adopted from (Maeng *et al.,* 2011)

Location	Aquifer Thickness (m)	Hydraulic Permeability, *k*,(m/s)	Type	Mineralogy	References
Lake Tegel, Germany	<40	$2\text{-}8 \times 10^{-4}$, clogged sand 5×10^{-6}	BF[a]	0.16-1.3% carbonate, 0.02-0.08% organic carbon, 1-2 g/kg iron	Grünheid *et al.* (2005), Pekdeger (2006)
Lake Tegel, Germany	<40	$2\text{-}8 \times 10^{-4}$	AR[b]	0.0-2.3% carbonate, 0.0-2.1% organic carbon, 1.8 g/kg iron, 0.1 g/kg manganese	Grünheid *et al.* (2005), Massmann *et al.* (2006)
Lake Wannsee, Germany	<40	1×10^{-4} to 1×10^{-6}	BF[a]	0-1% carbonate, 0.1-2% organic carbon, 0.2-1 g/kg iron	Pekdeger (2006)
RhineA, Germany	12-15	12×10^{-3}	BF[a]	-	Schmidt *et al.* (2007)
RhineB, Germany	10-12	3×10^{-3} to 6×10^{-3}	BF[a]	-	Schmidt *et al.* (2007)
Elbe, Germany	40-55	0.6×10^{-3}	BF[a]	-	Schmidt *et al.* (2007)
Ruhr, Germany	5	10^{-1} to 10^{-3}	BF[a]	-	Schmidt *et al.* (2007)
Tucson	37-45	9×10^{-4} to 7×10^{-3}	AR[b]	-	Fox *et al.* (2001)
Mesa	30 (UAU[c])	7×10^{-5} to 1×10^{-3}	AR[b]	-	Mansell and Drewes (2004)

[a] BF: bank filtration,

[b] AR: artificial recharge.

[c] UAU: upper alluvial unit.

6.1.3 Disinfection

As part of water reuse research of O_3 on filtered secondary effluent, DDW granted 5-log virus disinfection approval for O_3 disinfection based upon a minimum CT of 1.0 mg-min/L (Ishida *et al.*, 2008). WateReuse Research Foundation Project 11-02, in the yet to be published final report (Trussell *et al.,* 2015), documented similar virus inactivation as that shown by Ishida *et al.* (2008) and defined virus dose/response as a function of transferred O_3 dose to total organic carbon (TOC) ratios (O_3/TOC), also detailed in Fontaine and Salveson (2014). This work consistently demonstrated >7-log reduction of seeded MS2 for O_3/TOC ratios of 1.0 and greater. Such log reduction of MS2 is conservatively equivalent to 5-log reduction of poliovirus (Ishida *et al*., 2008, Fontaine and Salveson (2014)). Note that the O_3 dose in the O_3/TOC ratio is a transferred O_3 dose and the ratio should be adjusted for nitrite concentration in the water (which will exert an O_3 demand). Sigmon *et al.* (2015) demonstrated greater than 4-log reduction of *E. coli*, various bacteriophages (T1, T4, PRD-1, PhiX174, MS2) and human enteric viruses (poliovirus 1, echovirus 11, coxsackievirus B5, and adenovirus 2) at Ct values of less than 1 mg-min/L, and log removal of *E. coli* was documented as a conservative surrogate for disinfection of pathogenic virus.

6.1.4 TN Reduction

Reduction of TN through O_3/BAF is not well studied, with no literature referenced here.

Nitrogen removal has been observed during SAT at many sites that recharge ammonia-nitrogen laden effluents. A common hypothesis for this nitrogen removal is the two-step process of autotrophic nitrification and heterotrophic denitrification. Recharge basins are typically operated based on a wetting cycle, where water is first applied and then followed by a drying cycle. Due to the net positive charge of the ammonium ion, it is sorbed onto the soil in the upper region of the vadose zone during the wetting cycle, at which time oxygen is not available for nitrification. As the soil dries and air/oxygen enters the soil, the oxidation of ammonia to nitrate by autotrophic nitrifiers can occur. This process results in a high nitrate concentration at the beginning of the following wetting cycle. This nitrate, which tends to be more mobile, is transported with the water deeper into the vadose zone of the SAT system. Once the nitrate reaches an anoxic zone, heterotrophic denitrification may convert the nitrate to nitrogen gas in the presence of an organic carbon electron donor. This mechanistic process is consistent with field observations where nitrogen removal efficiencies of 25 to 90 percent have been observed; however, few SAT systems have the biochemical organic carbon (BOD) to Nitrogen ratios in the infiltrated wastewater that can sustain heterotrophic denitrification. Most SAT systems have BOD:N ratios of 1, whereas a BOD:N ratio of greater than 3 is necessary to sustain high nitrogen removal efficiencies. Therefore, researchers have investigated the possibilities of alternative nitrogen removal pathways in the subsurface of SAT systems besides conventional heterotrophic denitrification.

Based on typical BOD/nitrogen ratios, heterotrophic denitrification would only explain nitrogen removal efficiencies of about 30 percent, whereas much higher nitrogen removal efficiencies have been observed in SAT systems. And indeed, other mechanisms, i.e., Anaerobic Ammonium Oxidation (ANAMMOX) have been demonstrated to occur in soil systems contributing to additional nitrogen removal in SAT systems (Hu *et al*., 2013). ANAMMOX bacteria convert ammonia and nitrite to nitrogen gas consuming less oxygen and organic carbon than with the heterotrophic denitrification pathway. ANAMMOX activity has been confirmed in soils obtained from the Sweetwater Underground Storage and Recovery Facility, demonstrating that this nitrogen attenuation process could provide sustainable removal of nitrogen in SAT systems where applied waters contain ammonia or a mixture of ammonia and nitrite.

Spreading of a fully nitrified water with a reduced BOD level, as would be the case for a project with the District, may not result in much reduction of TN during the SAT. Numerous studies have investigated TN reduction through Rapid Infiltration Basins (RIBs), in which the applied water was secondary effluent with low ammonia and with low BOD levels. These studies have shown marginal further reduction of TN through the RIBs (e.g., Leach and Enfield, 1983).

6.2 O_3/BAF Pilot System and Test Overview

The O_3/BAF pilot used for Trussell *et al.* (2015) is the exact pilot unit used for the District testing documented further on, allowing for a reasonable comparison of performance between the two projects. The two components of the system are the O_3 system (Mipro advanced oxidation pilot system from Xylem) and the BAF (Leopold Biofiltration). Figures 6.10 and 6.11 show the O_3 and BAF pilots on-site at the SVAWPC.

Figure 6.10 Interior of the Xylem Mipro advanced oxidation pilot system trailer on-site at the District

Figure 6.11 Leopold Biofiltration skid next to the Xylem advanced oxidation pilot at the District.

Testing of the O_3/BAF was performed with the two different water qualities (tertiary recycled water and secondary effluent) at different O_3 dose values, and with different BAF empty bed contact times (EBCTs), based upon the results from Trussell *et al.* (2015). The goal of the different operational scenarios was to maximize TOC reduction and destroy or reduce trace organic constituents, all the while minimizing the construction cost of a future O_3/BAF (lower EBCTs and lower O_3 dose values translate to lower capital costs).

The EBCT values of 20 to 30 minutes were examined. The initial O_3 dose values (referring here to the transferred O_3 dose, which accounts for O_3 loss due to off-gassing) were intended to be relatively low, resulting in O_3/TOC ratios of <1. However, the high O_3 demand of the tertiary recycled water (due to chlorine) required components of this testing to use much higher O_3/TOC ratios, as detailed below.

6.3 Test Results—O_3/BAF Treating Tertiary Recycled Water

The first series of tests with O_3/BAF was done with the blended tertiary recycled water, simulating a potential future District project that could take blended tertiary recycled water from the existing "purple pipe" distribution system and further treat that water with O_3/BAF prior to spreading that water. The focus of this particular research was on the removal of TOC, CECs, and TN, as detailed below.

6.3.1 Blended tertiary recycled water Quality

Influent water quality plays an important role in O_3 demand and O_3 dosing costs. A stable influent water quality lessens operational effort with a streamlined dosing system for both O_3 and BAF. BAF operates most effectively with consistency in water quality. Figure 6.12 shows nitrogen species concentrations in the blended tertiary recycled water providing influent to the O_3/BAF system for testing. Nitrite, ammonia, and free ammonia concentrations were within an expected range. However, nitrate concentrations were higher than expected, between 34.1 to 77.9 mg/L (nitrate as nitrate, which is 8 to 18 mg/L nitrate as N).

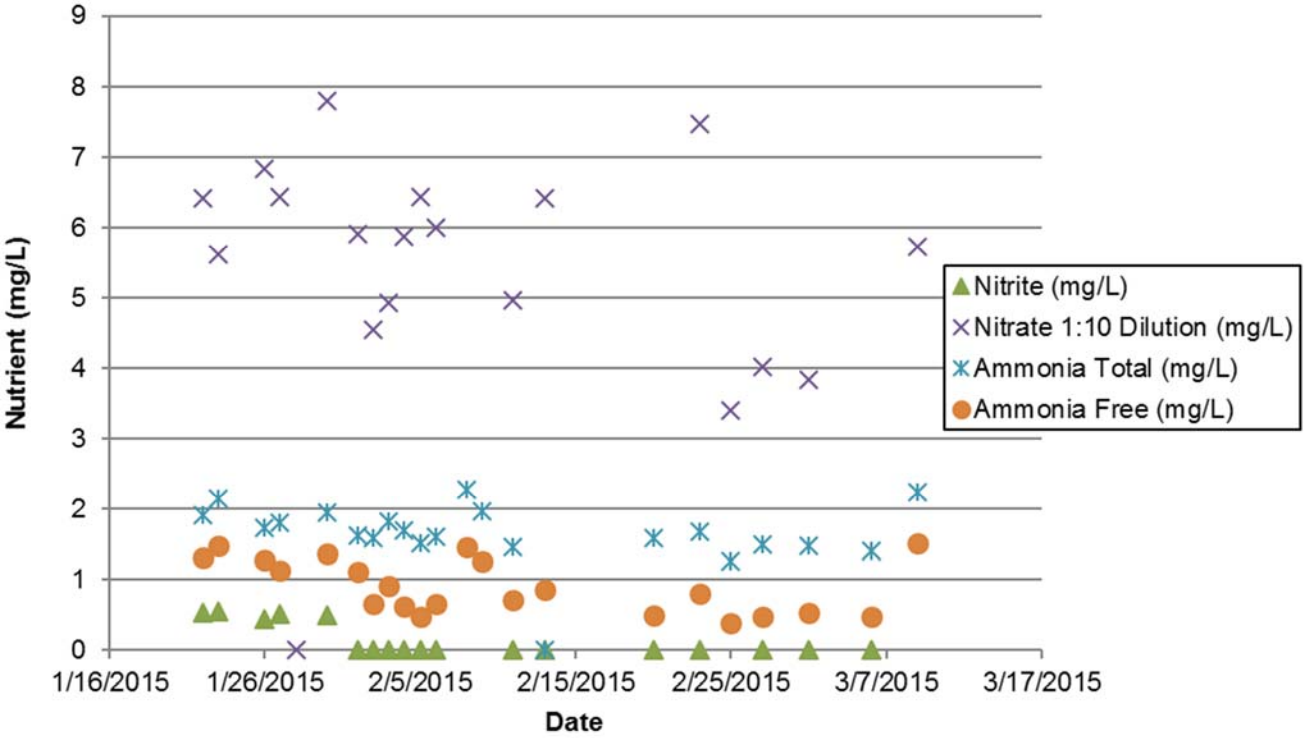

Figure 6.12 Tertiary blended recycled water nitrogen species concentrations providing influent water for O_3/BAF system

Influent chlorine concentrations were not a concern during pilot startup, as water quality monitoring during startup showed consistently low free and total chlorine concentrations. However, due to operational changes in the tertiary recycled operations during testing, the influent chlorine concentration spiked and caused a sharp increase in the O_3 demand. Prior to the spike, total chlorine concentrations were between 1 - 2 mg/L and free chlorine concentrations between 0.2 - 0.5. Figure 6.13 shows total and free chlorine monitoring after operational inefficiencies were found regarding the influent O_3 demand. Total chlorine concentrations in the influent water quality varied daily between 1.6 to >8.8 mg/L, with 8.8 being the maximum detection limit for total chlorine. Free chlorine concentrations varied between 0.12 to 3.5 mg/L. These concentrations are both high and variable. With regard to O_3 dose control, the lack of a consistent O_3 demand in the influent water makes O_3 dosing and performance more challenging for this pilot system because it did not have online monitoring of O_3 demand and system control. Daily grab samples were taken by District staff and the O_3 dose was adjusted accordingly daily, however, the level of chlorine was not consistent throughout the day, and this lead to a domino effect on BAF. Without consistency in O_3 dosing, the BAF system was also not receiving consistent influent water quality, possibly stunting microbial growth and function.

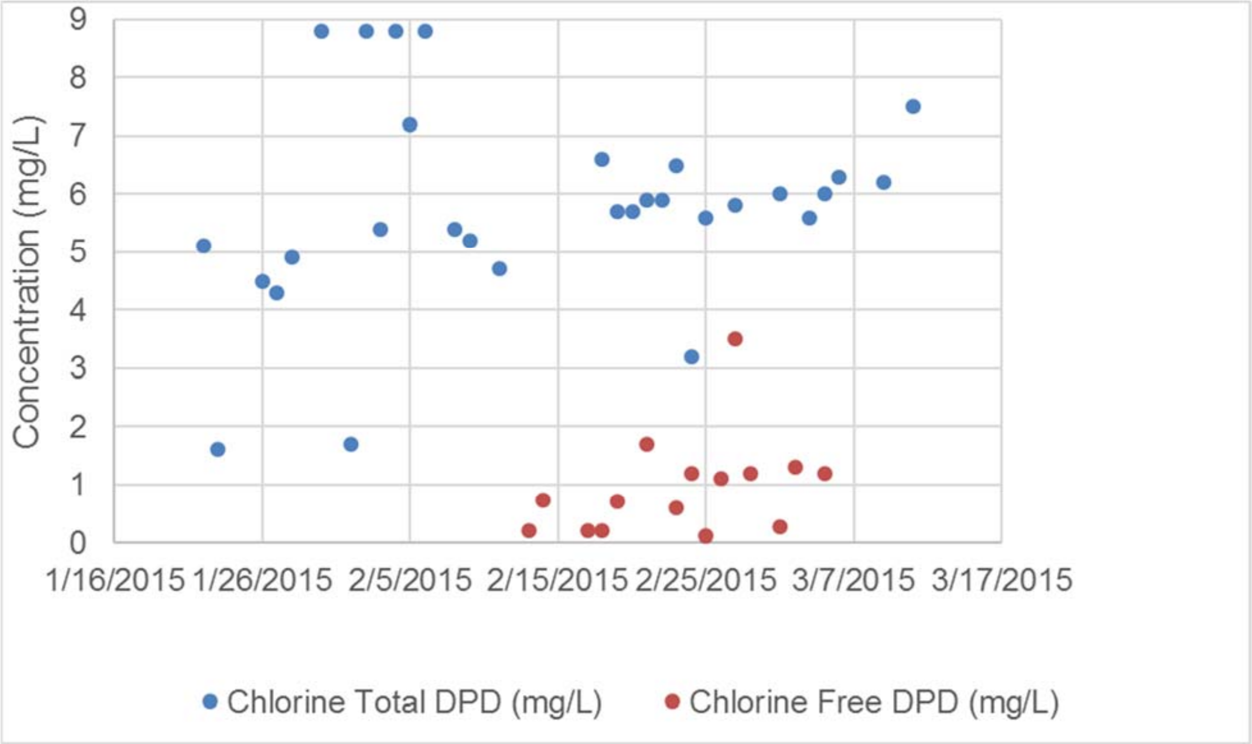

Figure 6.13 Tertiary blended recycled water free and total chlorine concentrations over the duration of the pilot

6.3.2 TOC Removal

The pilot goal was to remove 30 percent - 40 percent of influent TOC, keeping in mind that the latest work by Trussell *et al.* (2015) demonstrated ~34 percent removal on a microfiltered secondary effluent and 30 percent removal on a secondary effluent using the same pilot unit. Overall, the TOC removal from the District O_3/BAF pilot, treating the blended tertiary recycled water, was approximately 20 percent (Figure 6.14). The effluent TOC from the O_3/BAF pilot ranged from 2 to 7 mg/L. Speculation on this reduced level of performance focuses upon the variable water quality of the feed water, particularly due to the large variation in chlorine concentration and type (free or combined). Periodic breakthrough of chlorine to the BAF has the opportunity to continuously hamper the biological function of the BAF.

Pertaining to TOC requirements for recharge, recall that the target TOC level of 2.5 mg/L allows for recharge of 20 percent recycled water and 80 percent dilution water. The O_3/BAF finished water TOC levels of 2 to 7 mg/L are reduced by between 30 percent and 90 percent through SAT, likely sufficient to meet the 2.5 mg/L target. However, SAT performance is site specific and column testing is recommended if a surface spreading project with tertiary or advanced tertiary treatment is to be implemented.

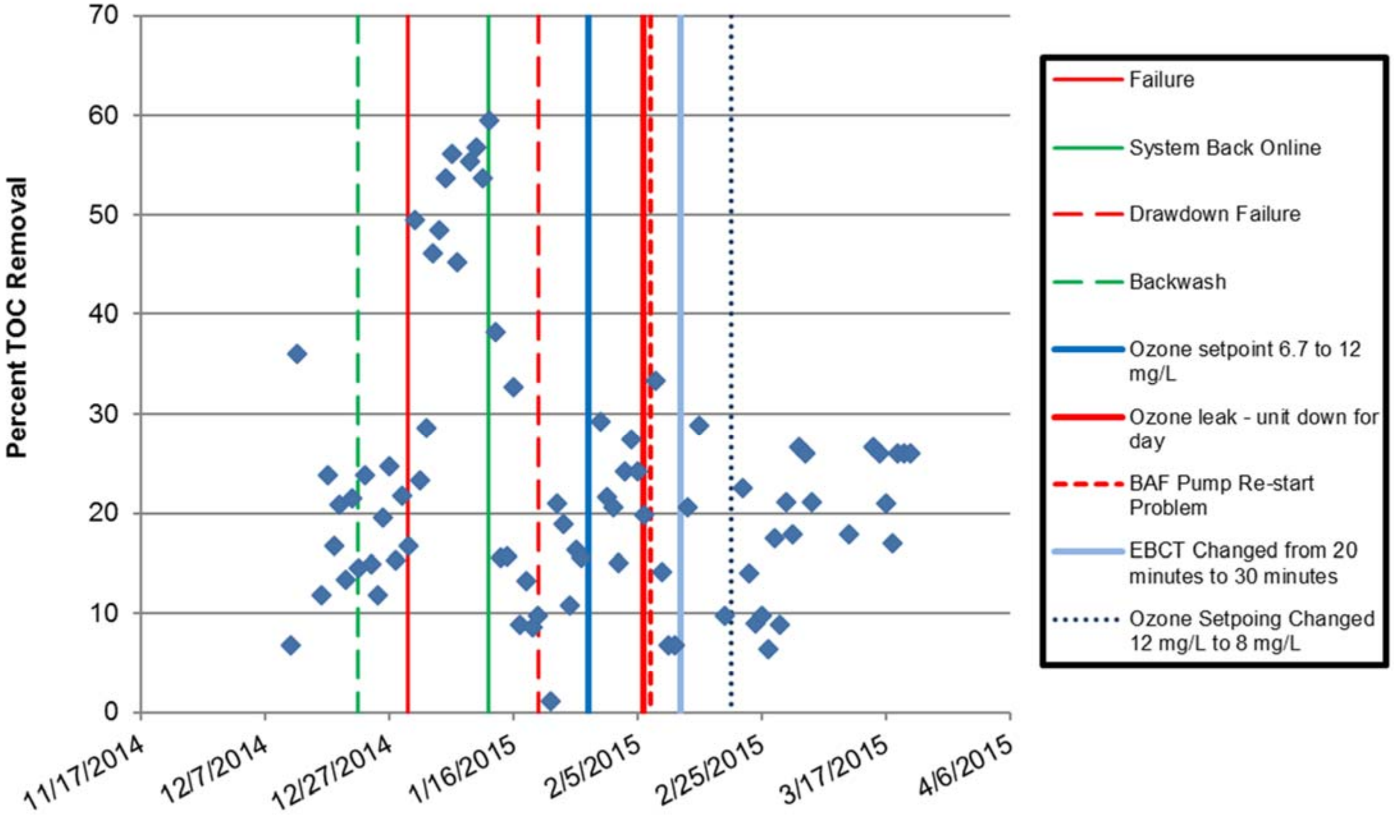

Figure 6.14 **Percent TOC removal from tertiary blended recycled water influent monitored with grab samples including performance and operational changes and upsets**

6.3.3 Nutrient Reduction and DBP Formation and Removal

Results are presented in Figures 6.15, 6.16, 6.17, 6.18, 6.19, and 6.20. As stated previously, DDW requires potable reuse projects to maintain a total nitrogen (TN) level of <10 mg/L. These results show that TKN feed water levels <3 mg/L, and that the BAF further reduces the TKN down to <0.5 mg/L. Ammonia reduction makes up a large percentage of TKN reduction. TN, which is the TKN plus nitrate and nitrite. Nitrite values were <1 mg/L, whereas nitrate values ranged from 48 to 67 mg/L (as nitrate), which equates to 11 to 15 mg/L (as nitrate-N). The result is that the TN value of 10 mg/L is exceeded (with potential TN values of 15+ mg/L of TN). As referenced previously, denitrification (conversion of nitrate to nitrogen gas) may account for another 30 percent removal of TN through the SAT, reducing the TN levels to values close to the MCL of 10 mg/L. Further study of nitrate removal through SAT is recommended prior to implementing a SAT project with the subject water.

Disinfection byproduct formation, particularly bromate, chlorate, and NDMA, was measured through the O_3/BAF process.

Bromate—Bromate has an MCL of 10 ug/L. O_3 is shown to make bromate, and biofiltration provided a measure of reduction. Higher O_3/TOC ratios resulted in higher bromate formation (as expected). In all tested cases, the O_3/BAF finished water bromate concentration was less than the MCL.

Chlorate—Chlorate has a NL of 0.8 mg/L. Chlorate levels were low in the feed to the O_3/BAF, with no measurable increase by ozonation or decrease through BAF. For all tests, the O_3/BAF finished water chlorate concentration was less than the NL.

NDMA—NDMA has a NL of 10 ng/L. Consistent with other work, ozonation increases NDMA formation, and biofiltration reduces NDMA concentrations. With that said, the O_3/BAF feed NDMA concentrations are very high, in the 200+ ng/L level (compared to 40 to 60 ng/L in undisinfected secondary effluent). Ozonation increased the NDMA levels by up to 50 ng/L. Biofiltration reduced NDMA concentrations in the finished water to ~120 ng/L to ~180 ng/L, which is well above the NL. Subsequent reduction of NDMA through SAT is necessary. Drewes *et al.* (2006) documented greater than 90 percent removal of NDMA during SAT. Assuming a similar performance as part of a future District project, SAT may reduce the 120 to 180 ng/L NDMA values to <20 ng/L, but possibly not below the NL of 10 ng/L. Future study of performance is recommended prior to implementing a SAT project with the tested waters.

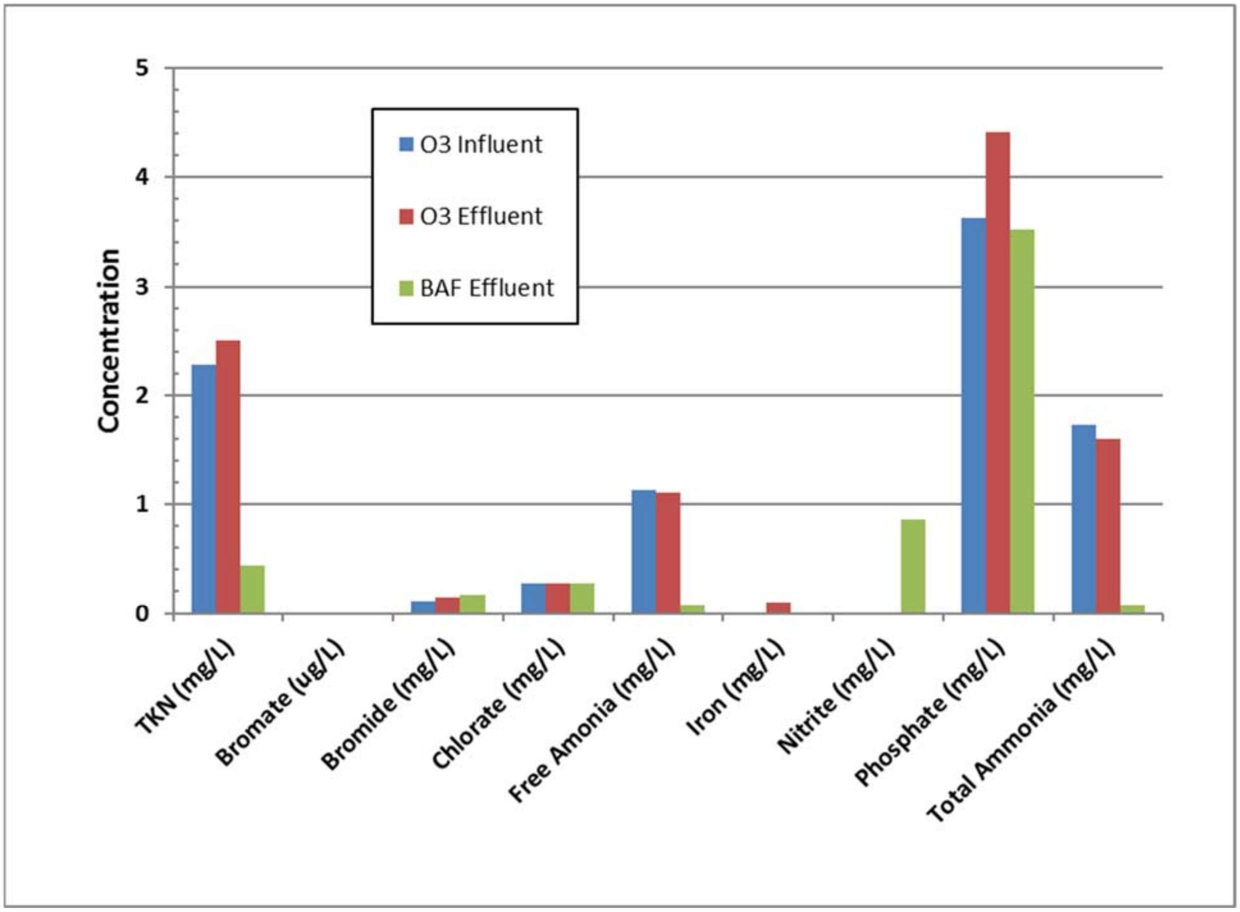

Figure 6.15 Nutrient and DBP formation and removal in tertiary blended water source at an O_3:TOC ratio of 1.01 and an 18.9 min. EBCT

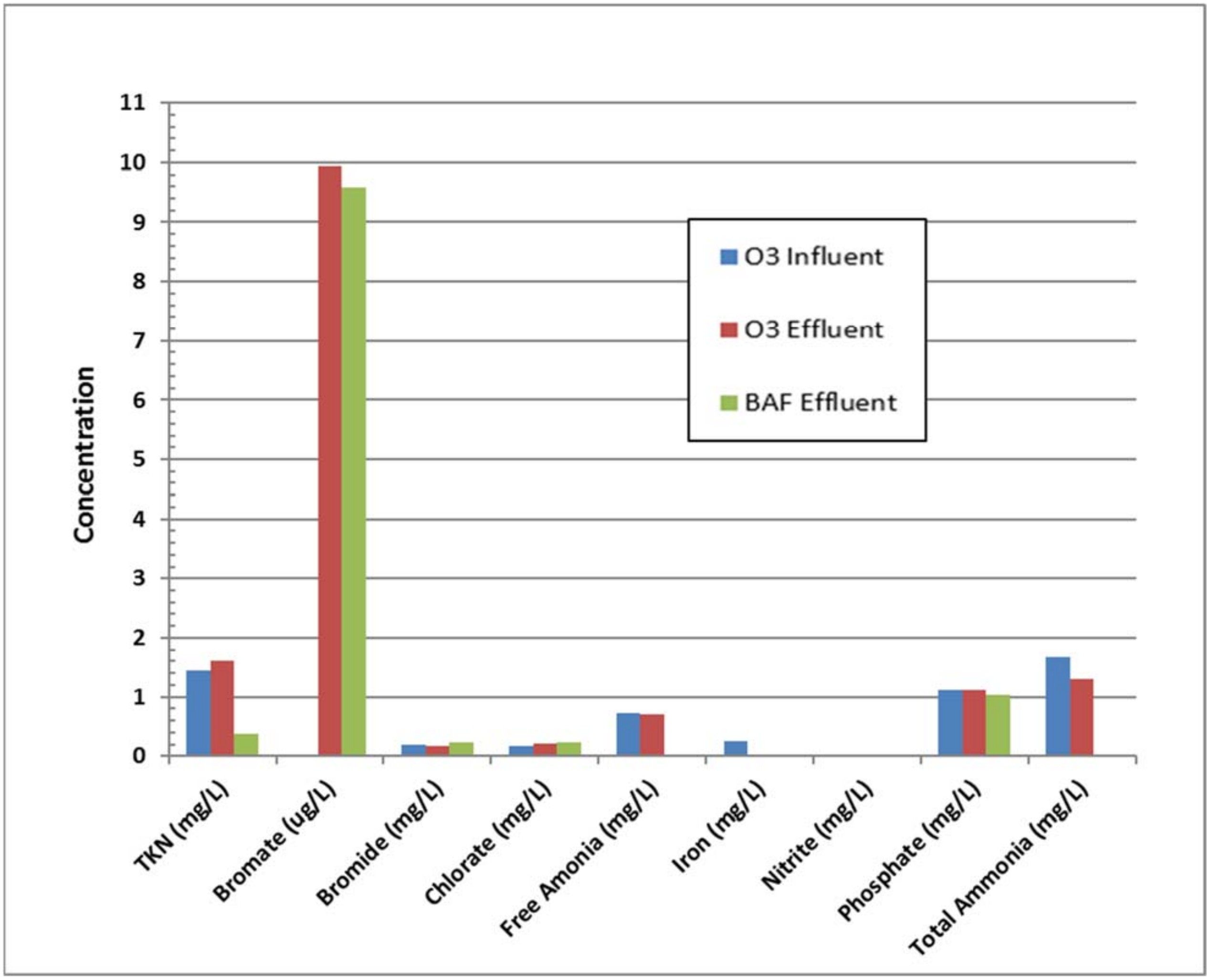

Figure 6.16 Nutrient and DBP formation and removal in tertiary blended water source at an O_3:TOC ratio of 1.95 and a 28.2 min. EBCT

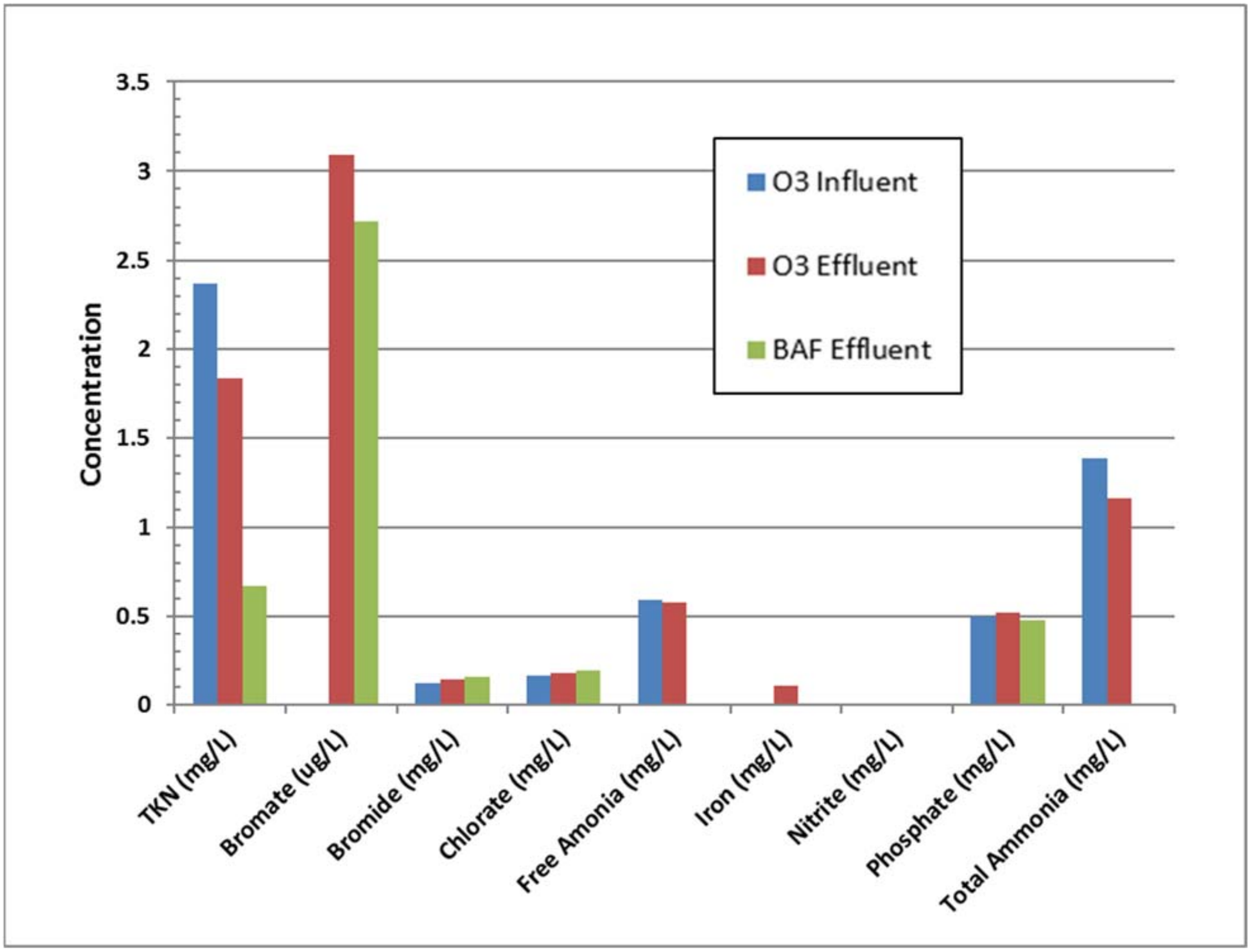

Figure 6.17 Nutrient and DBP formation and removal in tertiary blended water source at an O_3:TOC ratio of 1.48 and a 29.7 min. EBCT

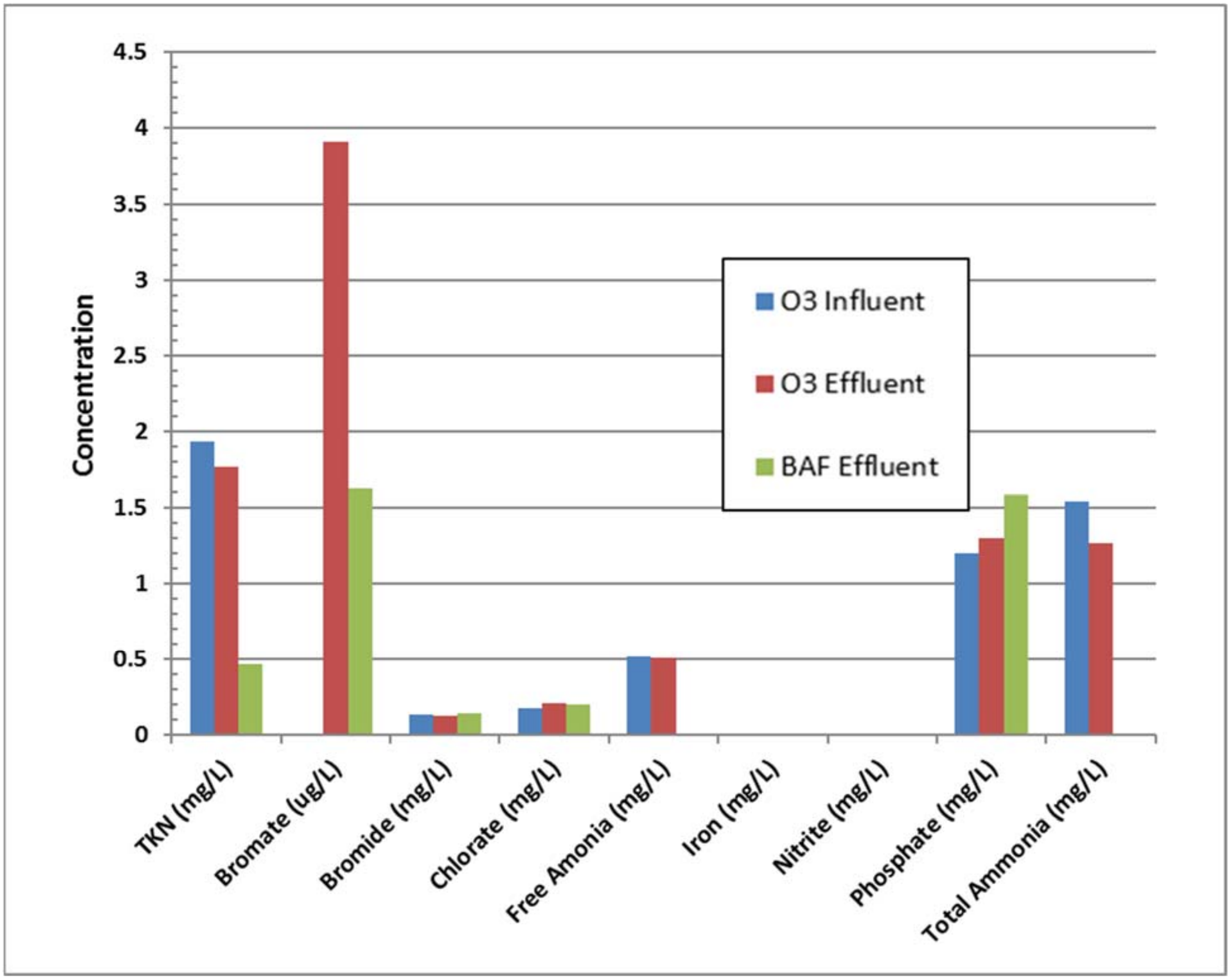

Figure 6.18 Nutrient and DBP formation and removal in tertiary blended water source at an O_3:TOC ratio of 1.56 and a 31.2 min. EBCT

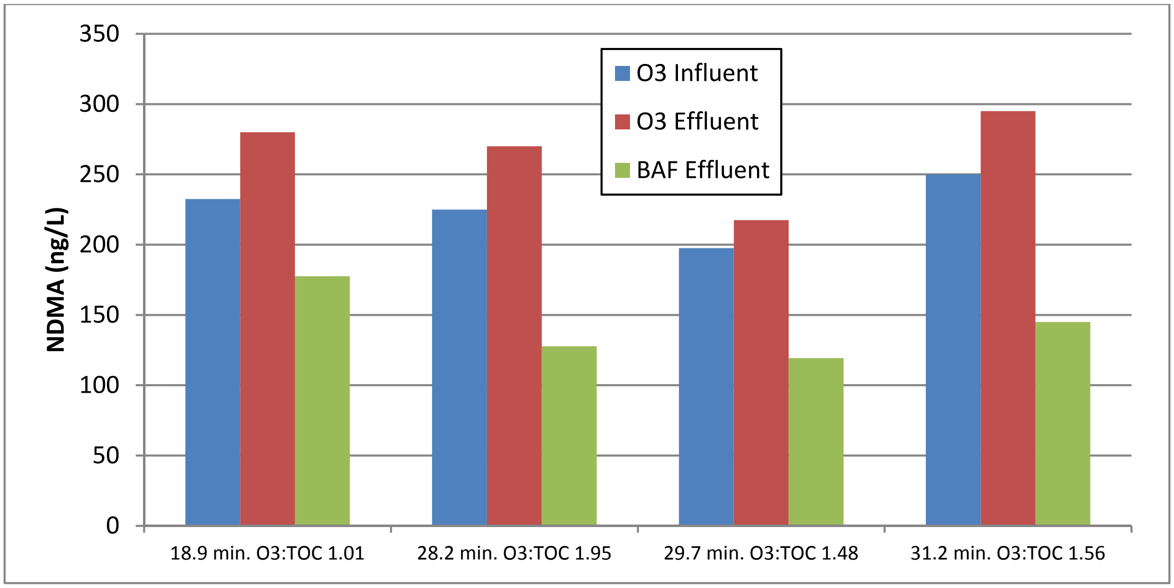

Figure 6.19 NDMA removal through O_3/BAF in tertiary blended water source at varying transferred O_3:TOC ratios

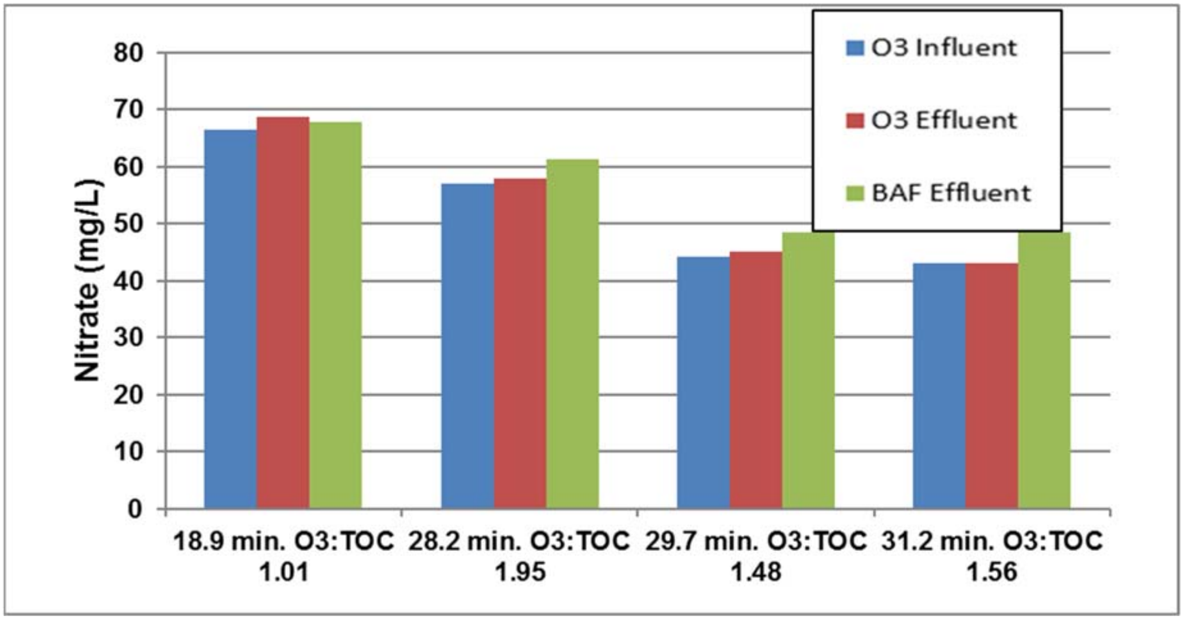

Figure 6.20 Nitrate concentrations (presented as nitrate, not as nitrate-N) following O_3 Biofiltration treatment across all test conditions with blended tertiary recycled water

6.3.4 Trace Pollutant Removal

As documented in other studies, the O_3/BAF process can provide for substantial removal of a range of trace pollutants. Results from this testing program are presented below. Key findings include:

- O_3 consistently reduced a group of pollutants for all tests, though some pollutants were recalcitrant.
- BAF provided minimal improvement to the water quality.

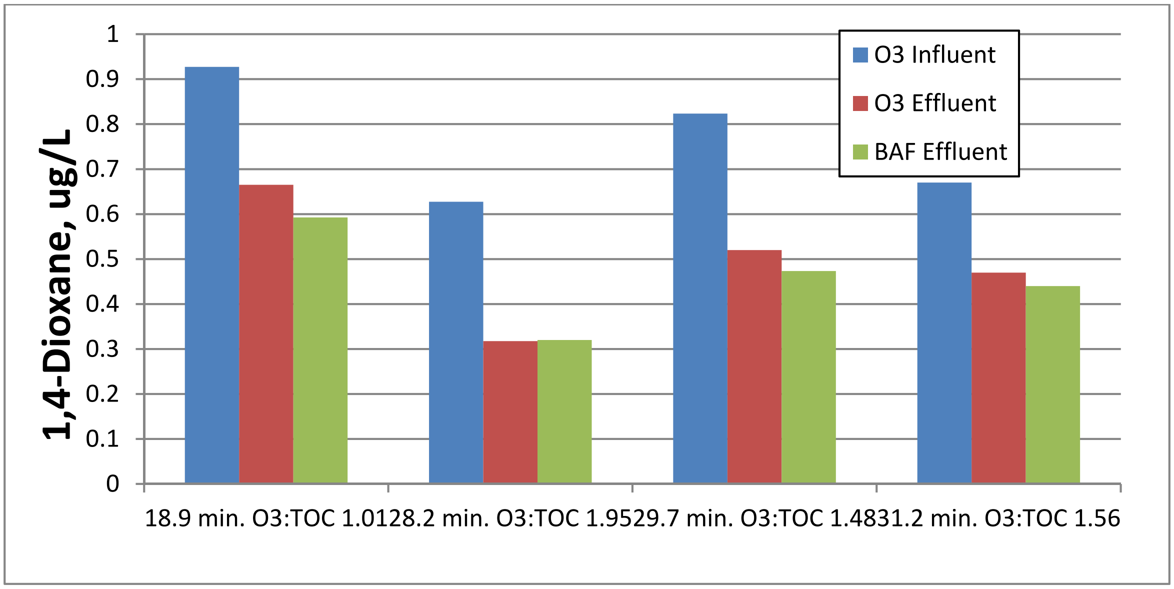

Figure 6.21 1,4-dioxane removal through O_3/BAF in tertiary blended water source at varying transferred O_3:TOC ratios

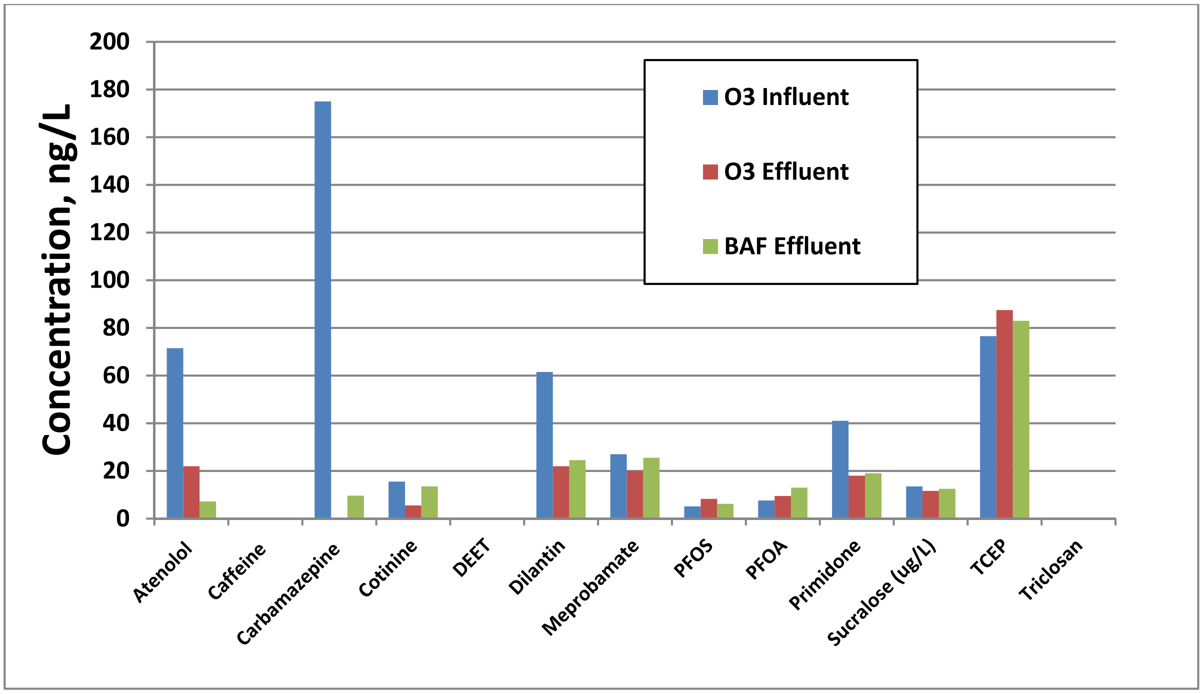

Figure 6.22 ***Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.01 and an 18.9 minute EBCT***

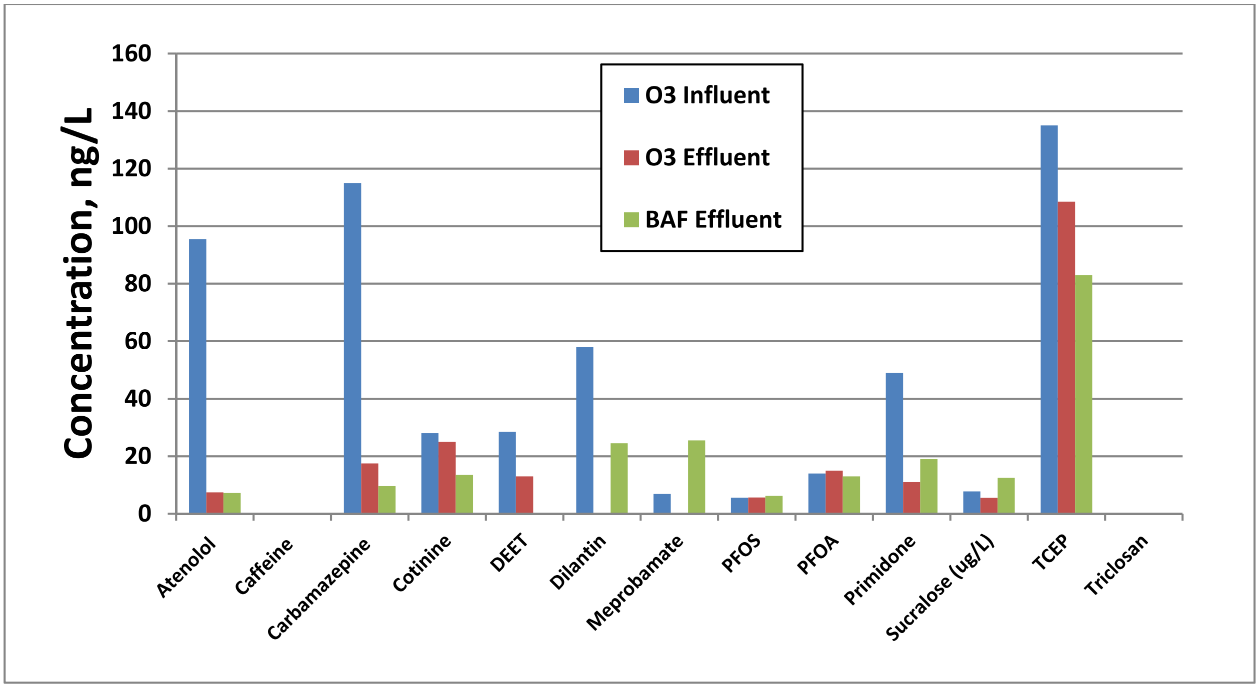

Figure 6.23 ***Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.95 and a 28.2 minute EBCT***

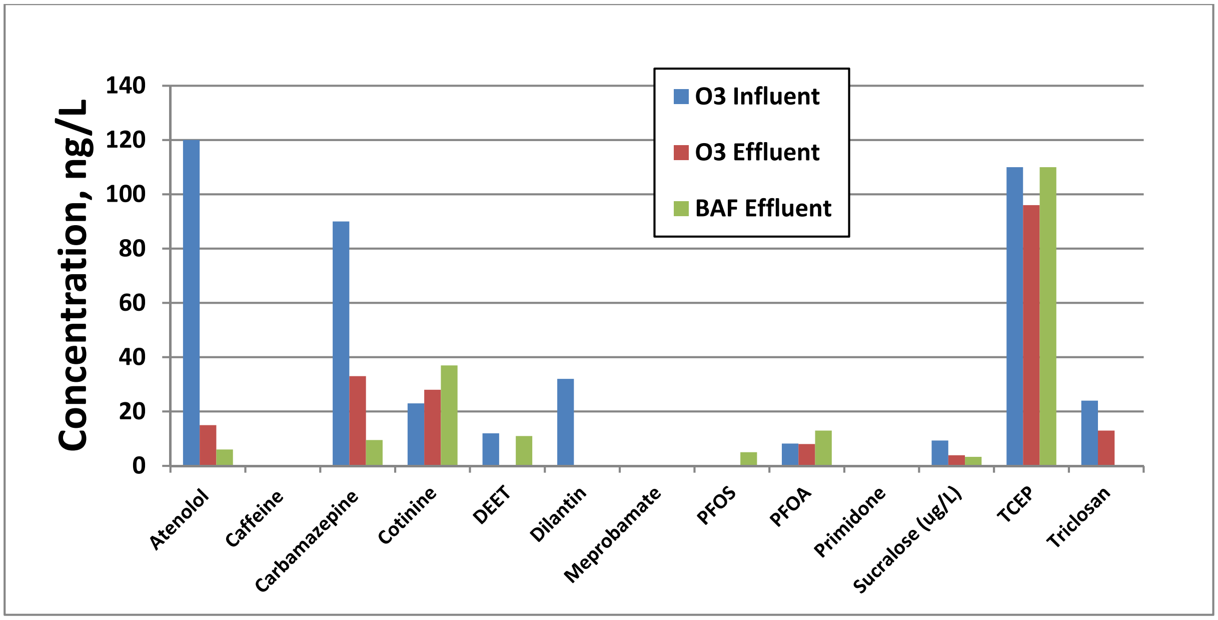

Figure 6.24 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.48 and a 29.7 minute EBCT

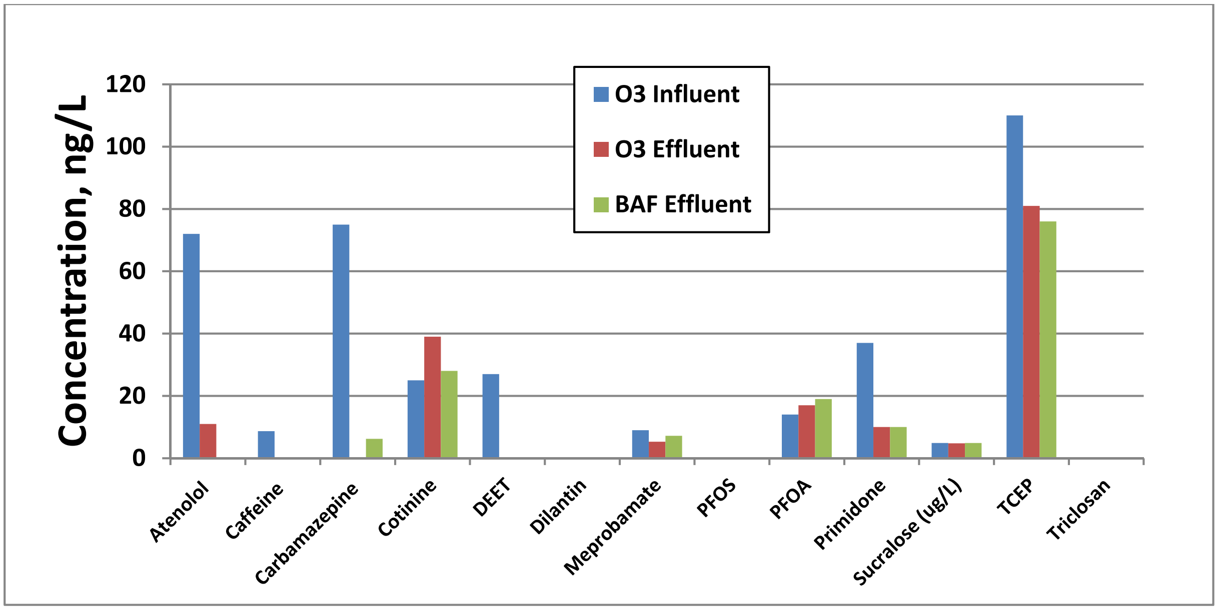

Figure 6.25 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.56 and a 31.2 minute EBCT

6.3.5 Implications for Potable Reuse

The pilot testing results for O_3/BAF on blended tertiary recycled water results in the following implications and recommendations for a future potable water reuse project:

- Varying water quality, specifically variations in total and free chlorine concentrations feeding the pilot, reduced the biological performance of the BAF.

- TOC reduction was ~20 percent, below other recent O_3/BAF projects treating secondary effluent and microfiltered secondary effluent. Further reduction of TOC through SAT may result in meeting the 2.5 mg/L target for a 20/80 blend of recycled water with blending water. Testing with soil columns is recommended before proceeding with a spreading project utilizing O_3/BAF.

- TN reduction through O_3/BAF occurs, but high nitrate levels in the feed water result in a TN value of 15+ mg/L in the finished water. SAT will reduce the TN further, potentially below the 10 mg/L regulated value. Testing with soil columns is recommended before proceeding with a spreading project utilizing O_3/BAF.

- Bromate and Chlorate DBP formation was not significant and finished water from the O_3/BAF meets regulatory criteria.

- NDMA concentrations in the O_3/BAF feed water are very high. Ozonation does increase NDMA while BAF reduces NDMA. SAT will further reduce NDMA, but potentially not enough to meet the 10 ng/L NL. Testing with soil columns is recommended before proceeding with a spreading project utilizing O_3/BAF.

- O_3 alone consistently reduces a number of trace pollutants, in some cases below detectable levels (<1 ng/L). Some trace pollutants are not impacted by ozonation.

- Biofiltration does not further reduce the trace pollutants tested as part of this project.

- ***Overall, due to concerns about TOC, TN, and NDMA, testing with soil columns is recommended before proceeding with a spreading project utilizing O_3/BAF.***

- ***The same limitations with regard to TOC, TN, and NDMA could be improved by blending an advanced treated water with MF/RO/UV AOP purified water, which can act as a portion or all of the blending water for a spreading project.***

6.4 Analytical Results—O_3/BAF Treating Secondary Effluent

The second series of tests with O_3/BAF was done with secondary effluent, simulating a potential future direct potable reuse scenario in which O_3/BAF is followed by MF (or UF), RO, and UV AOP, then the water is blended with other raw water supplies and treated at one of the District's water treatment plants. The focus of this particular research was on the removal of TOC, CECs, TN, and pathogens, as detailed below.

Because the feed water is unfiltered secondary effluent, there was no chlorine (free or combined) in the feed to the O_3/BAF pilot. The anticipated impact of the lack of chlorination is reduced NDMA concentrations and improved biofiltration, resulting in increased reduction (by percentage) of TOC and trace constituents.

6.4.1 TOC Removal

As a direct point of comparison, the same O_3/BAF pilot demonstrated a TOC removal of 30 percent on secondary effluent at the prior pilot site (LACSD San Jose Creek, as documented in Trussell *et al.*, 2015). Overall, the TOC removal from the District O_3/BAF pilot, also treating secondary effluent, was approximately 20 percent to 30 percent, with an average of 25 percent (Figure 6.26). The feed TOC was higher for this series of tests (compared to the blended tertiary recycled water), so even with a higher percent reduction, the finished water TOC from the O_3/BAF pilot ranged from ~6 to ~9 mg/L (online data shown in Figure 6.27). The finished water TOC value for this test series is not critical, as a future direct potable reuse scenario would have MF (or UF), RO, and UV AOP following O_3/BAF. The RO process will reduce the TOC to <0.5 mg/L.

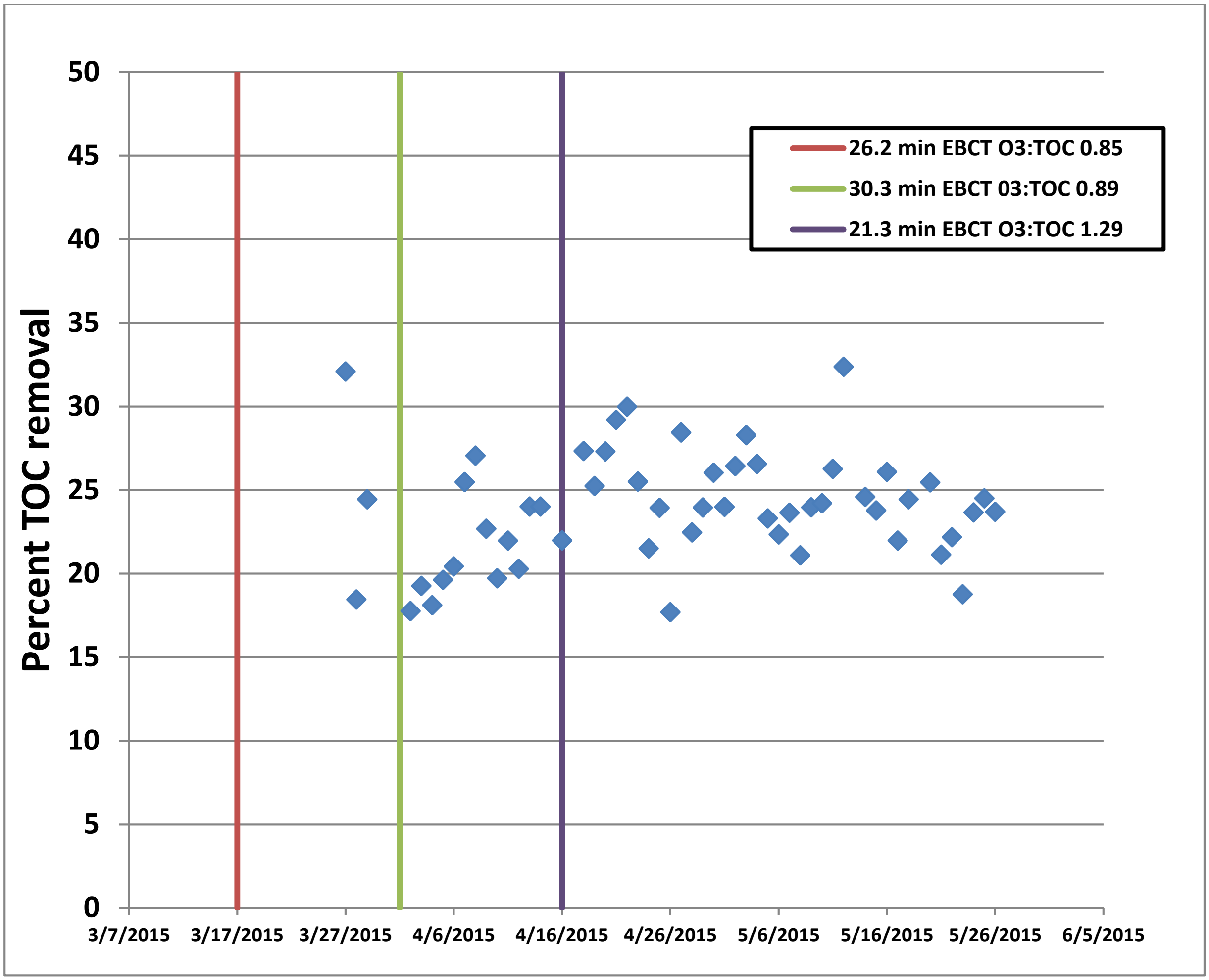

Figure 6.26 Percent TOC removal across the secondary effluent O_3/Biofiltration pilot duration (grab samples were not taken 3/7-3/20)

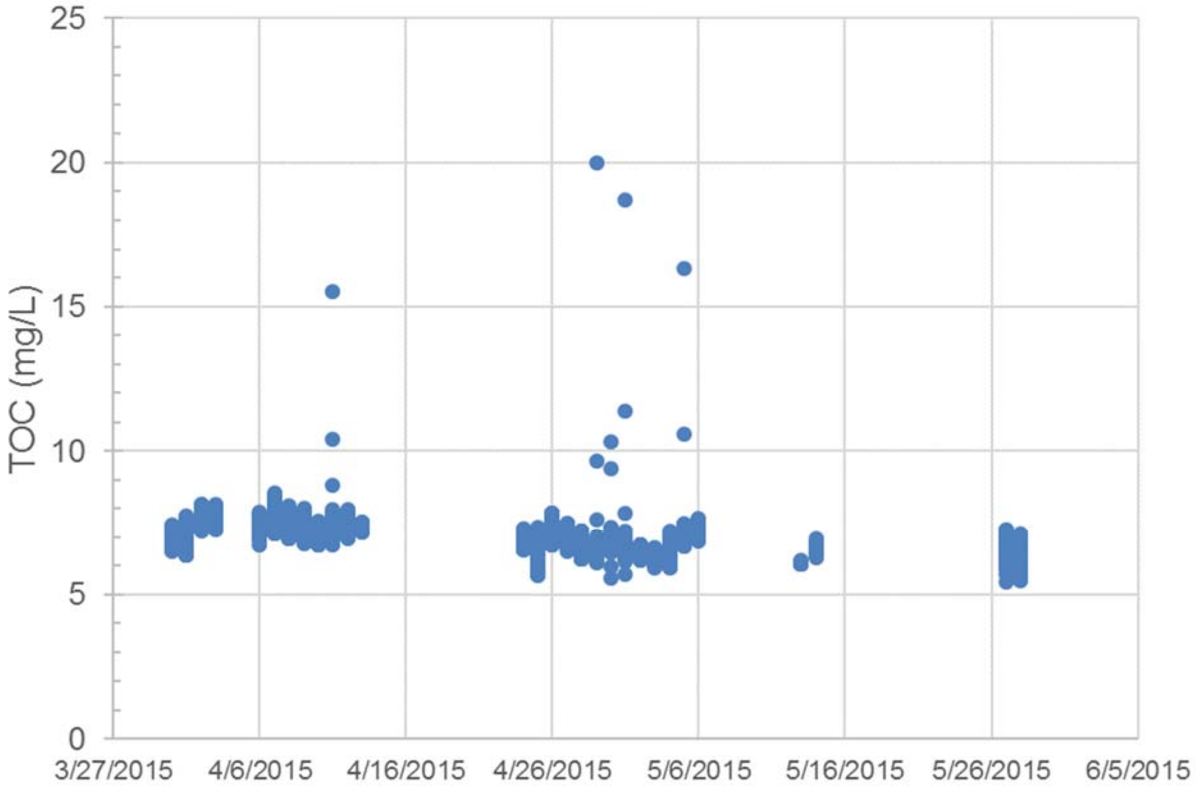

Figure 6.27 Online TOC monitoring of the Biofiltration effluent of the O_3/Biofiltration pilot with secondary effluent feed water

6.4.2 Nutrient Reduction and DBP Formation and Removal

Results are presented in Figures 6.28, 6.29, 6.30, 6.31, 6.32, and 6.33.

As stated previously, DDW requires potable reuse projects to maintain a total nitrogen (TN) level of <10 mg/L. Because the potential direct potable water reuse treatment train would follow O_3/BAF with membranes (MF or UF followed by RO), TN will be reduced below the regulated value regardless of O_3/BAF performance. However, the biological activity and degradation of TOC and reduction in nutrients results in a reduced treatment burden on downstream membrane processes (Trussell *et al.*, 2015).

These results show that TKN feed water levels are <3 mg/L, and that the BAF further reduces the TKN down to <1 mg/L. Unlike the prior testing with blended tertiary recycled water, less ammonia is in the secondary effluent and thus TKN removal is more about the reduction in organic nitrogen than it is about ammonia reduction. Nitrite values were <1 mg/L, whereas nitrate was not reduced measurably through O_3/BAF and finished water values ranged from 81 to 92 mg/L (as nitrate), which equates to 18 to 21 mg/L (as nitrate-N).

Disinfection byproduct formation, particularly bromate, chlorate, and NDMA, was measured through the O_3/BAF process.

Bromate—Bromate has an MCL of 10 ug/L. In this case, bromate formation was either extremely limited or non-existent, resulting in O_3/BAF finished water bromate concentrations less than the MCL.

Chlorate—Chlorate has a NL of 0.8 mg/L. In this case, chlorate formation was either extremely limited or non-existent, resulting in O_3/BAF finished water chlorate concentrations less than the NL.

NDMA—NDMA has a NL of 10 ng/L. Consistent with other work, ozonation increases NDMA formation, and biofiltration reduces NDMA concentrations. For this case, the unchlorinated secondary effluent had less NDMA, with 50 to 60 ng/L in the pilot feed water. After an increase by O_3 and a reduction by BAF, the final effluent feed water NDMA concentrations ranged from 19 to 33 ng/L, resulting in >50 percent removal of NDMA through the coupled O_3/BAF process which showed much better performance when compared to the pilot performance treating blended tertiary recycled water.

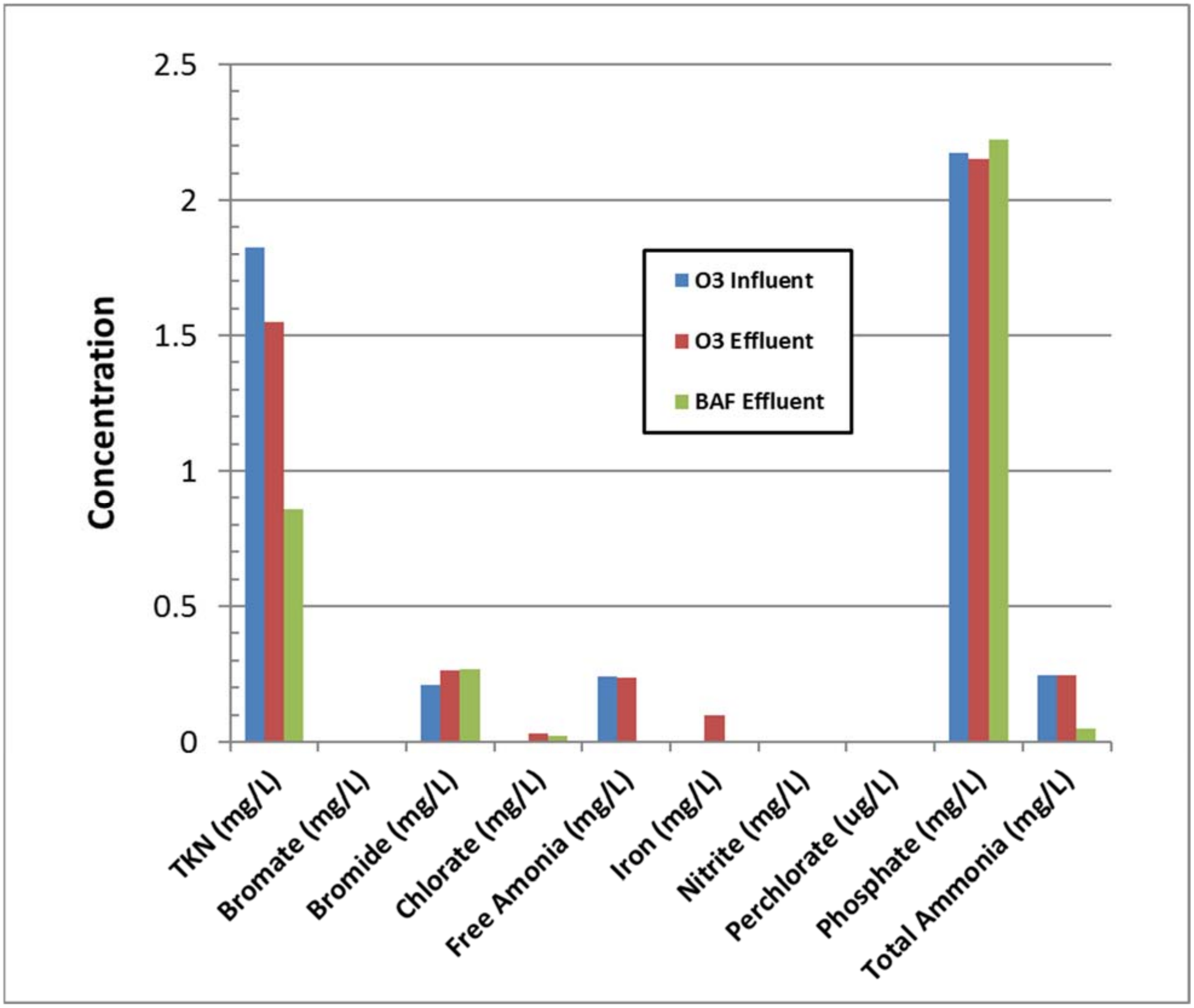

Figure 6.28 Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 0.85 and a 26.2 min. EBCT

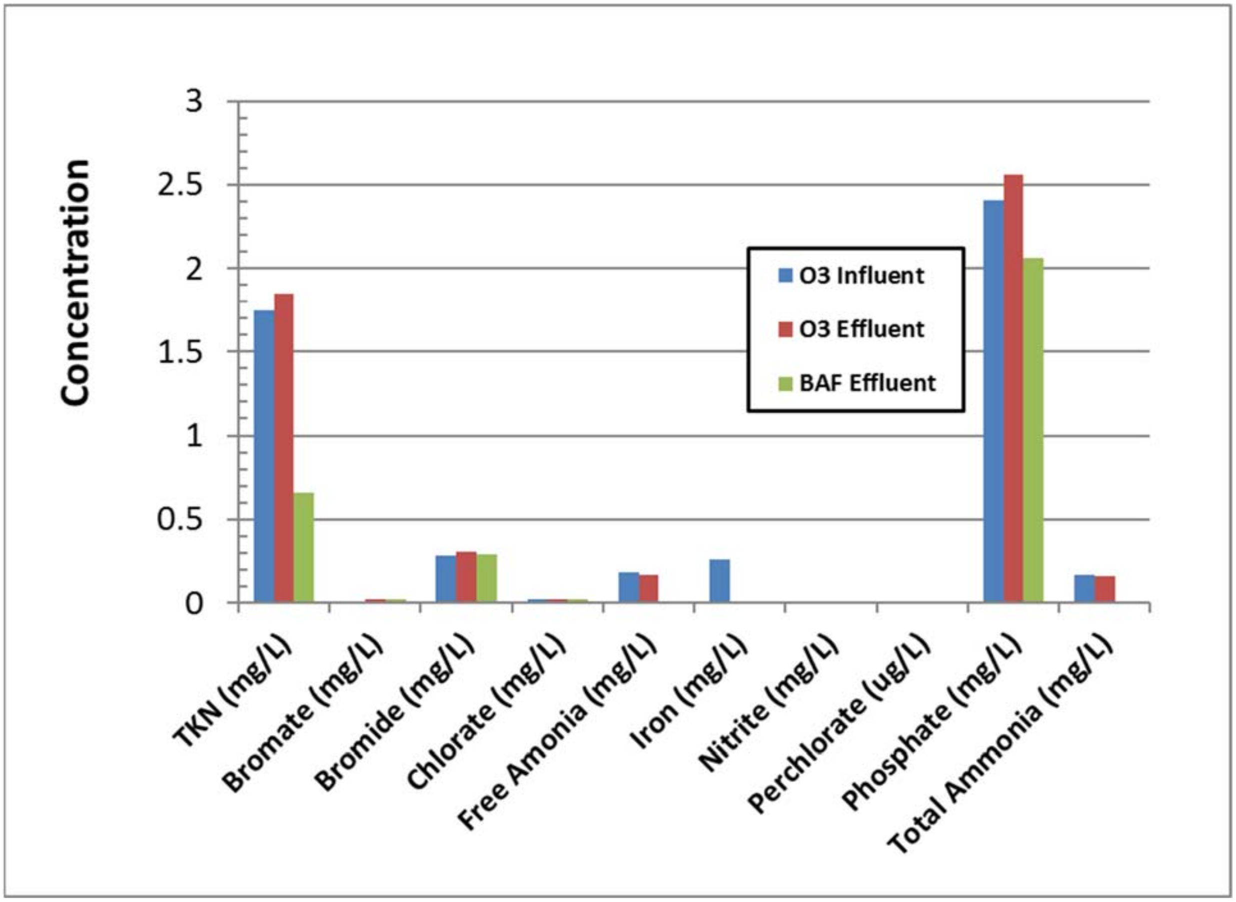

Figure 6.29 Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 0.89 and a 30.3 min. EBCT

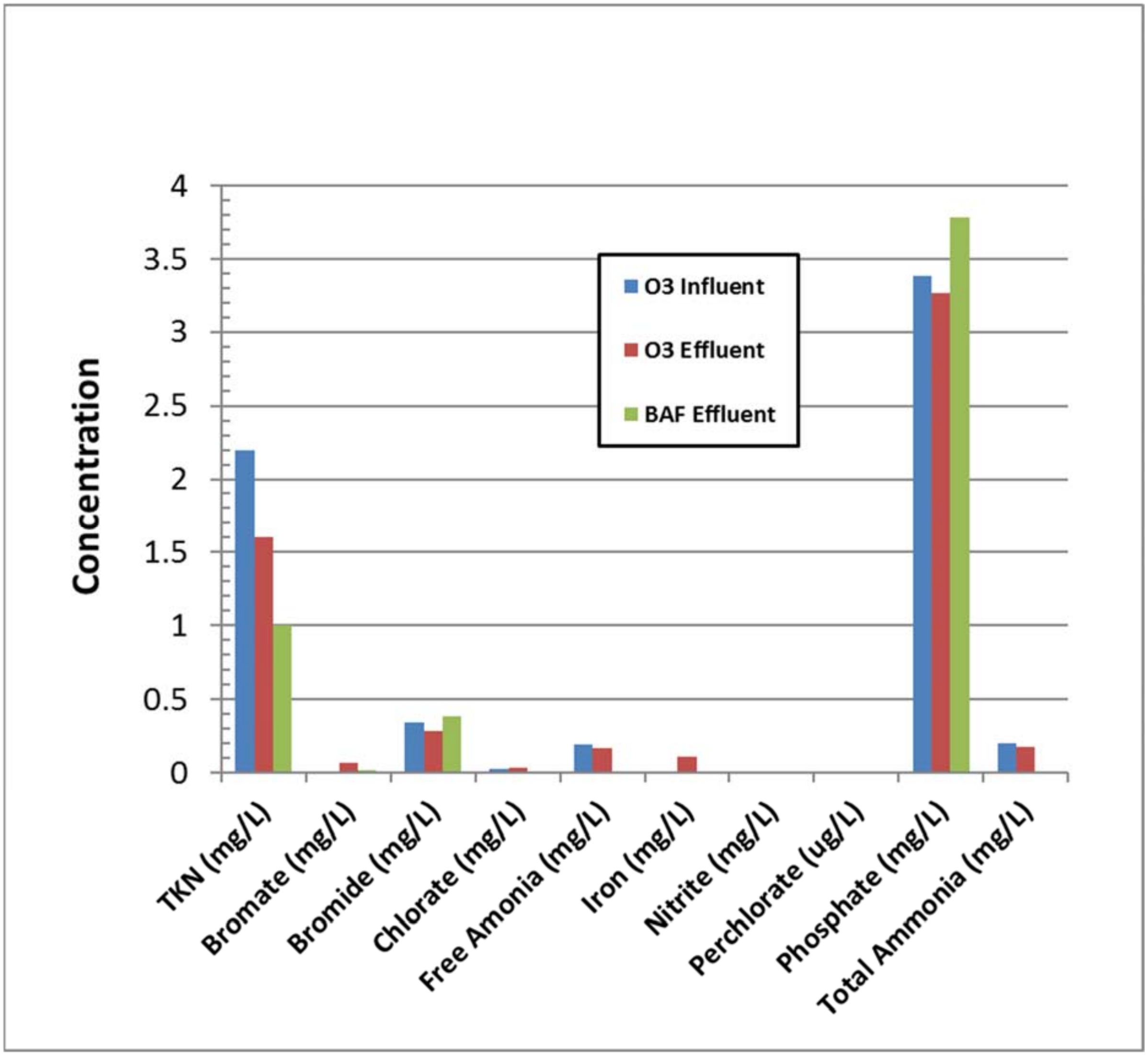

Figure 6.30 Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 1.29 and a 21.3 min. EBCT

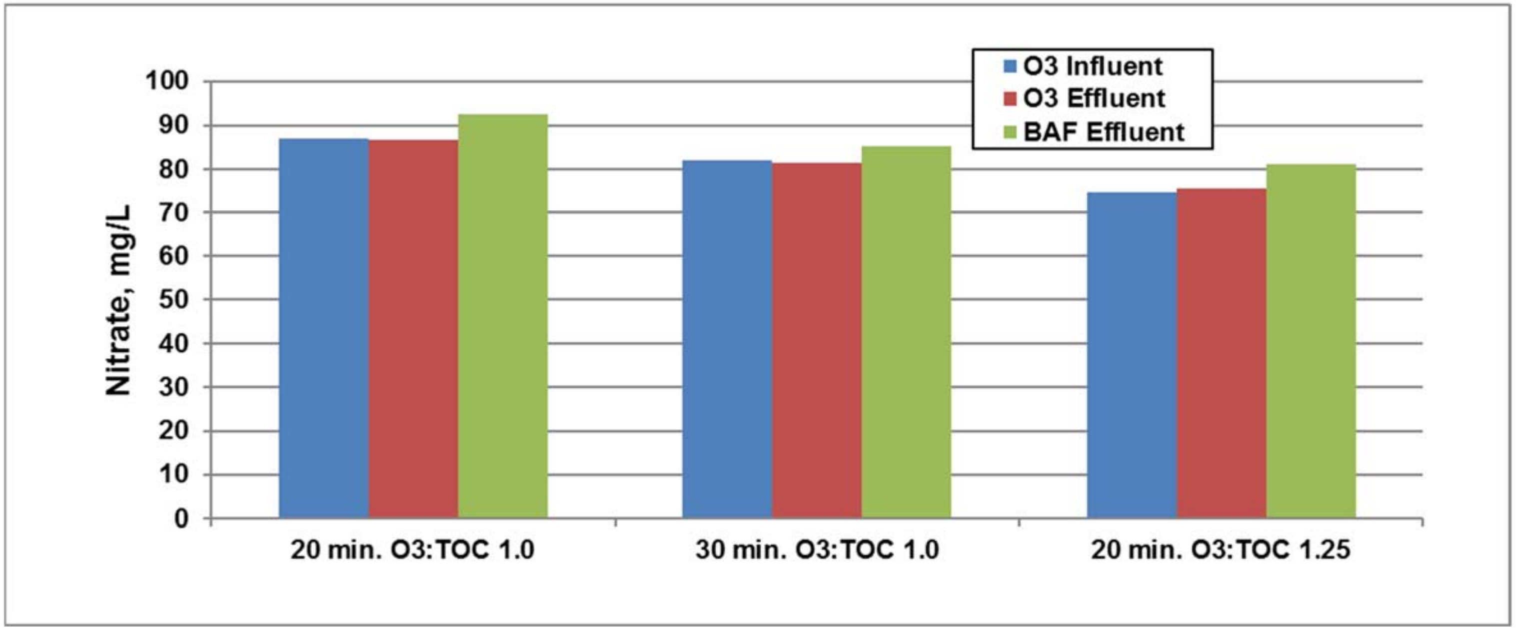

Figure 6.31 ***Nitrate concentrations following O_3 Biofiltration treatment across all test conditions with secondary treated wastewater***

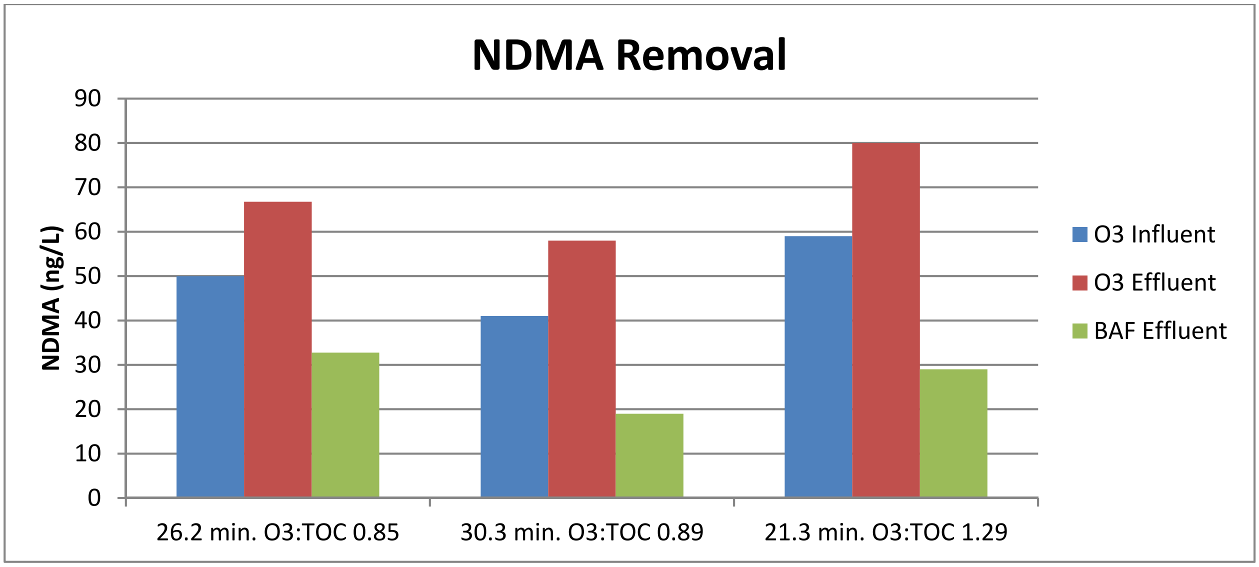

Figure 6.32 NDMA removal through O_3/BAF in secondary treated wastewater influent water source at varying transferred O_3:TOC and EBCT ratios

6.4.3 Trace Pollutant Removal

As documented previously, the O_3/BAF process can provide for substantial removal of a range of trace pollutants. Results from this testing program are presented below. Key findings include:

O_3 performance is increased compared to the performance on blended tertiary recycled water. 1,4-dioxane destruction is >50 percent in all cases, compared to 30 percent to 50 percent removal on blended tertiary recycled water. Note that 1,4-dioxane has been shown to be a conservative surrogate for the advanced oxidation of a wide range of trace pollutants (Hokanson *et al.*, 2011, shown in Figure 4.12). This increased performance is likely due to the O_3 demand impact of chlorination.

1,4-dioxane increased after BAF for all three test runs. Further testing would be needed to verify and/or better understand these limited results.

Similar to prior results, O_3 was able to reduce the concentration of a number of pollutants, often to below detectable levels. Some pollutants are not significantly impacted by ozonation at the tested dose values.

Biofiltration is capable of further reducing some of the trace pollutants, though many appear recalcitrant to further reduction. In general, biofiltration appears to perform better as part of O_3/BAF of secondary effluent compared to O_3/BAF on blended tertiary recycled water.

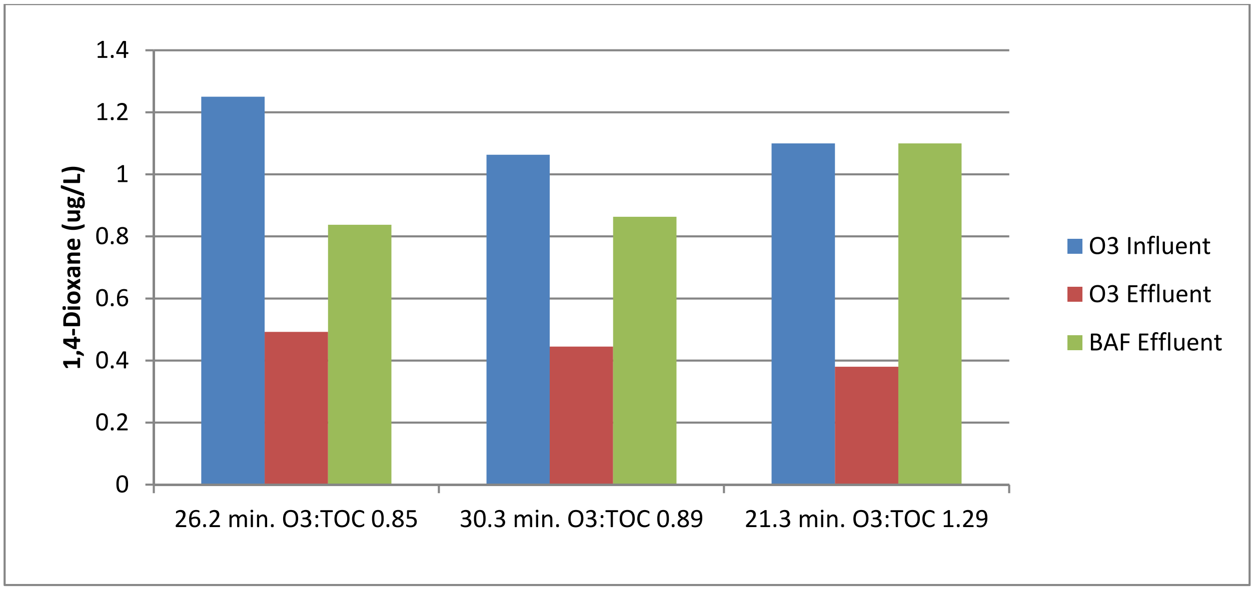

Figure 6.33 **1,4-dioxane removal through O_3/BAF in secondary treated wastewater source at varying transferred O_3:TOC and EBCT ratios**

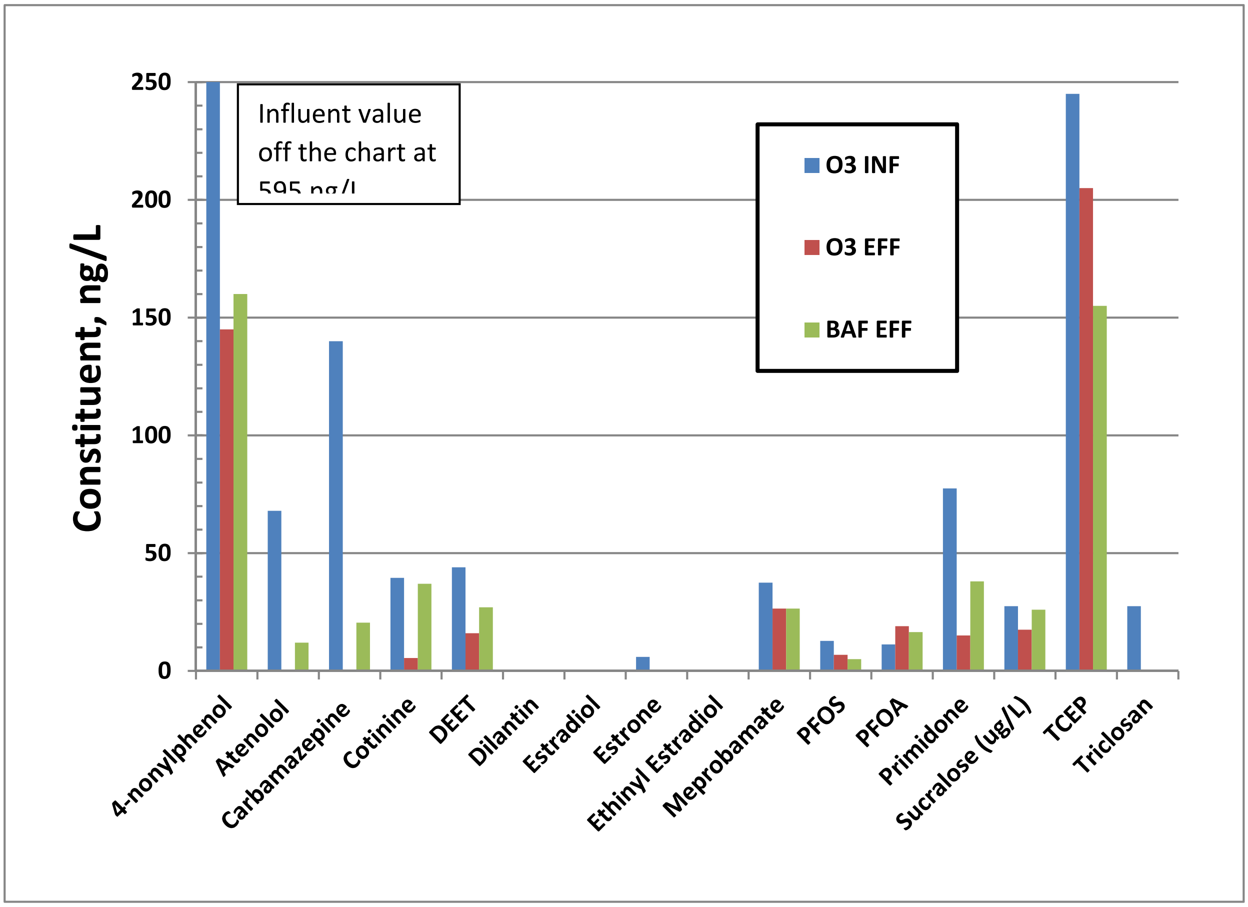

Figure 6.34 Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 0.85 and a 26.2 minute EBCT

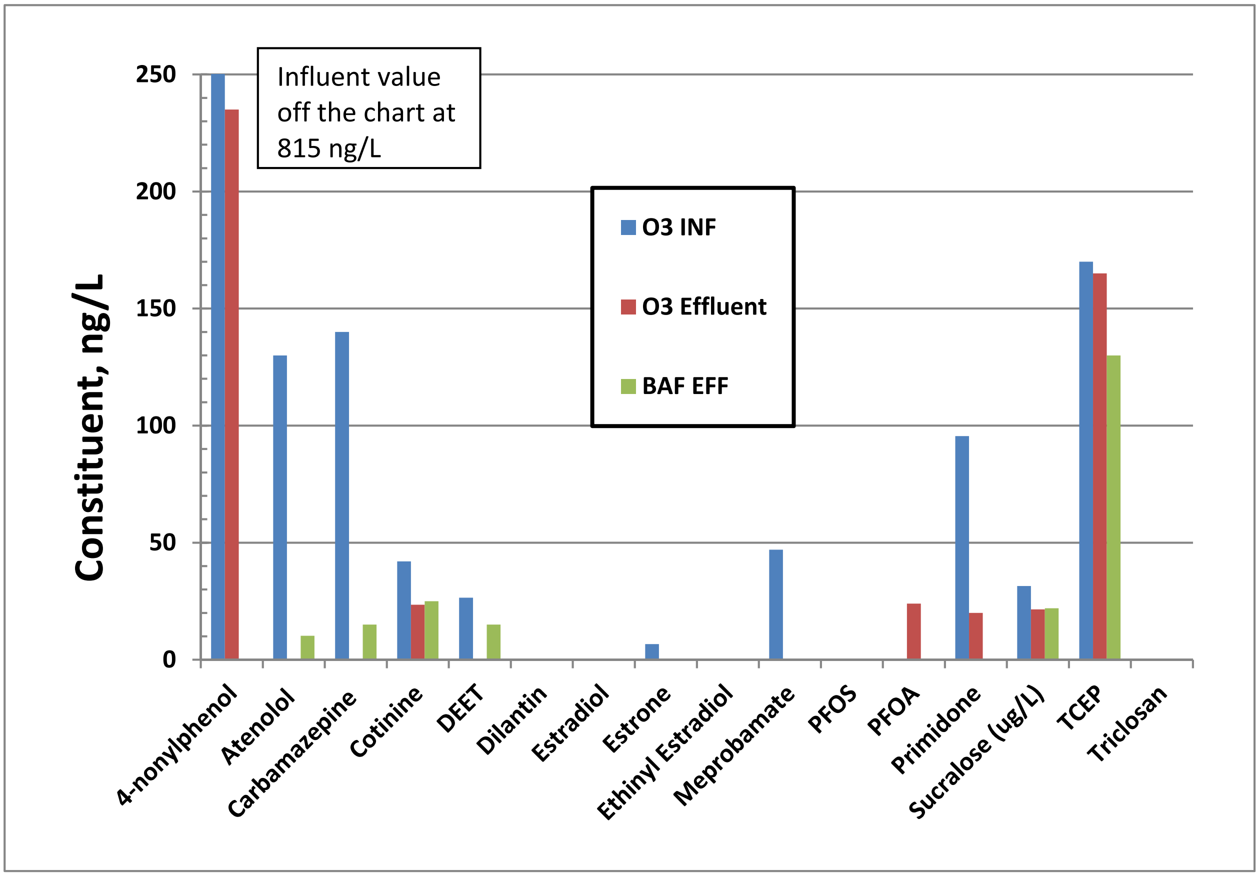

Figure 6.35 **Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 0.89 and a 30.3 minute EBCT**

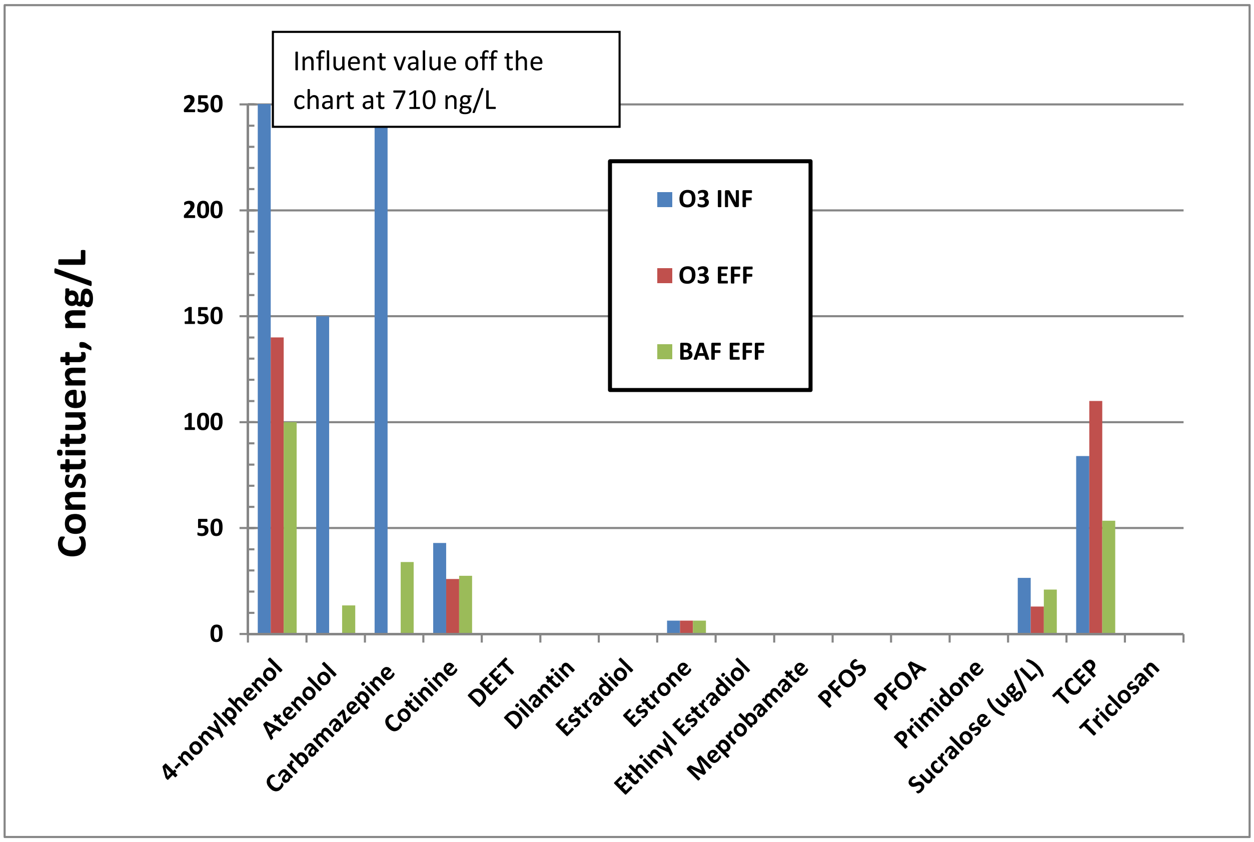

Figure 6.36 **Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.29 and a 21.3 minute EBCT**

6.4.4 Disinfection

O_3 disinfection testing was only performed on the secondary effluent feed water, as the project team expected significant complications to the disinfection results for a feed water with free chlorine, as was the case for the first set of O_3/BAF testing of blended tertiary recycled water.

The most detailed and published evaluation of virus disinfection by O_3 was performed as part of Trussell *et al.* (2015). For six of seven data sets, the O_3/(TOC+Nitrite) ratio clearly defined virus disinfection performance (Figure 6.37). This ratio is intended to provide an accurate CCP based approach to O_3 disinfection control and regulatory credit.

For this project, MS2 coliphage was seeded into the secondary effluent ahead of the O_3/BAF unit. Testing was conducted across the O_3 system only. Results are shown in Figures 6.38 and 6.39, documenting a clear trend of virus disinfection performance as a function of the O_3/(TOC+Nitrite) ratio, noting that nitrite was below detection during this testing. The trend matches well with the data from Trussell *et al.* (2015) shown in Figure 6.37.

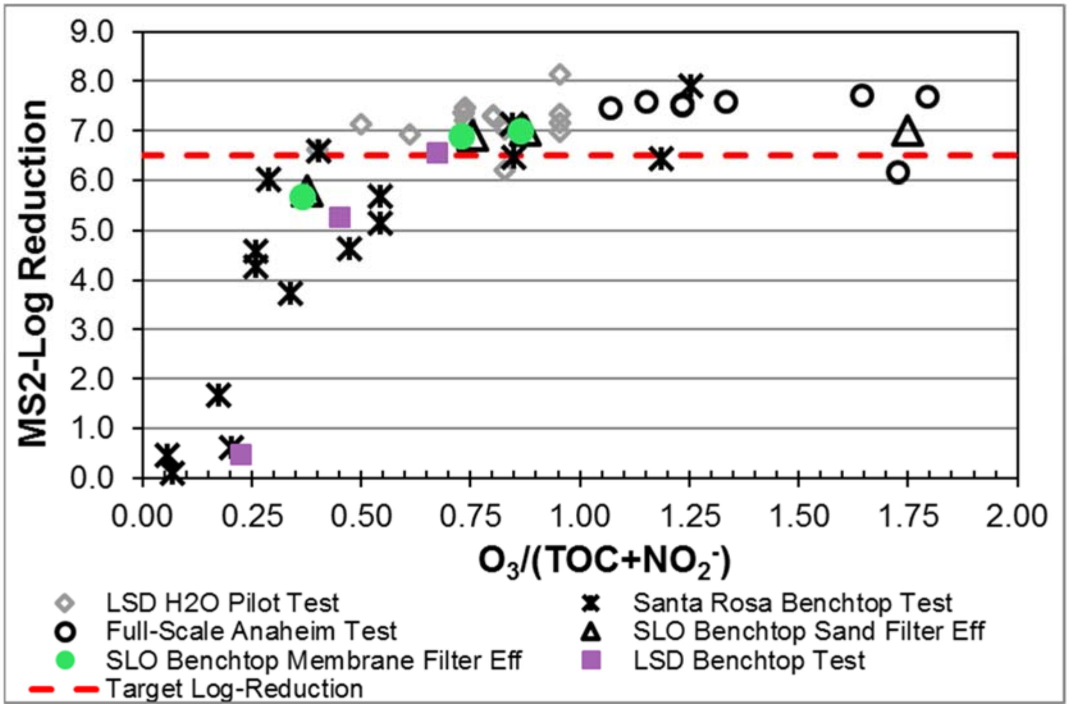

Figure 6.37 O_3 disinfection performance as a function of $O_3/(TOC+No_2^-)$ ratios

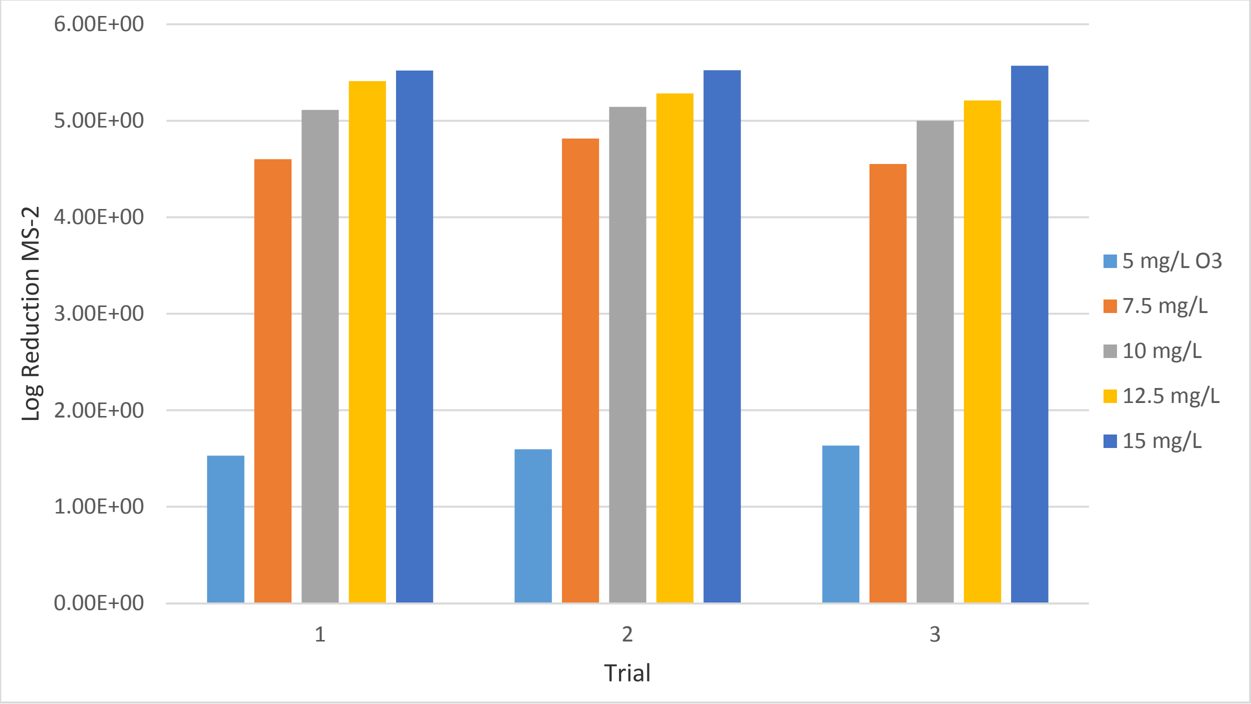

Figure 6.38 *Log reduction of MS-2 by applied O_3 doses ranging from 5 - 15 mg/L, performed in triplicate on secondary treated wastewater effluent*

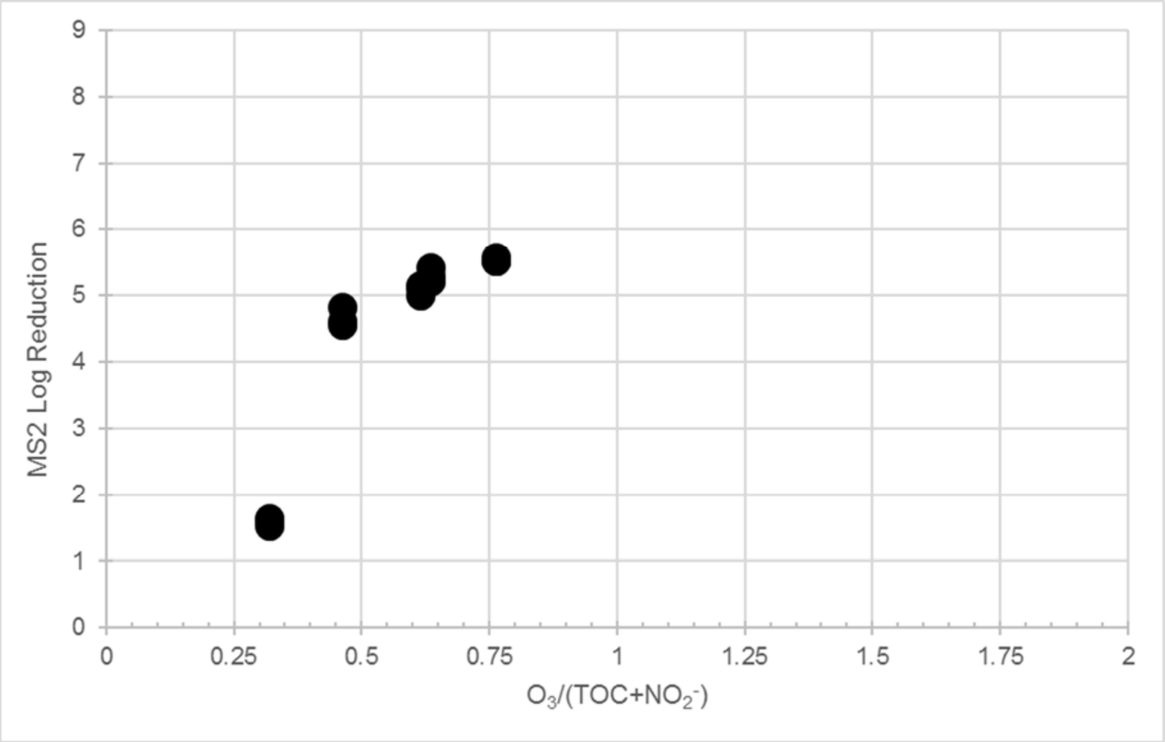

Figure 6.39 Log reduction of MS-2 compared to an $O_3/(TOC+No_2^-)$ ratio in secondary treated wastewater effluent

6.4.5 Implications for Direct Potable Reuse

The pilot testing results for O_3/BAF on secondary effluent results in the following implications and recommendations for a future direct potable water reuse project:

- TOC removal through O_3/BAF averaged 25 percent, just below the 30 percent results from Trussell *et al.* (2015) also performed on a secondary effluent.

- BAF reduced the TKN of the tested water to <1 mg/L. Nitrate was not reduced by the BAF.

- Bromate and chlorate (both DBPs) were not formed at a substantial level through the O_3 process, BAF did appear to reduce bromate in select cases, and finished water from O_3/BAF was well below regulated levels.

- O_3 increases NDMA formation, and biofiltration reduces NDMA concentrations. When compared to O_3/BAF tertiary effluent treatment, the unchlorinated secondary effluent had less NDMA, with 50 to 60 ng/L in the pilot feed water. After an increase by O_3 and a reduction by BAF, the final effluent feed water NDMA concentrations ranged from 19 to 33 ng/L, resulting in >50 percent removal of NDMA through the coupled O_3/BAF process. This lower level of NDMA is advantageous and will reduce the treatment cost for UV photolysis in a future direct potable reuse treatment train.

- The lack of chlorine demand improved the O_3 performance and destruction of trace pollutants, particularly 1,4-dioxane, a chemical that is a conservative surrogate for the advanced oxidation of a wide range of pollutants (Hokanson *et al.*, 2011, shown in Figure 4.12).

- BAF treatment resulted in a repeated increase in 1,4-dioxane. Further testing would be required to better understand these results.

- O_3 was able to reduce the concentration of a number of pollutants, often to below detectable levels. Some pollutants are not significantly impacted by ozonation at the tested dose values. For direct potable reuse, these remaining pollutants would be subjected to treatment through membranes (including RO) before final polishing with a UV AOP system.

- Biofiltration is capable of further reducing some of the trace pollutants, though many appear recalcitrant to further reduction. This increased biodegradation is anticipated to benefit subsequent membrane performance, as documented in Trussell *et al.* (2015).

6.5 Online O_3/BAF Performance Monitoring

Online monitoring tools were included with the Xylem and Leopold pilot systems to provide the research team rapid access to data and performance trends.

- The influent flow for both water sources is shown in Figure 6.40. The performance monitoring of tertiary blended recycled water (until 3/27/15), shows a steady influent flow and pressure. The secondary treated effluent flow into the pilot did not have consistent flow or pressure into the system, making performance monitoring, dosing, and operation less efficient.

- Online UVT monitoring was placed before and after the O_3 system, as testing on prior systems using grab sampling shows a correlation between O_3 dose (transferred) and an increase in UVT (the O_3 MS2 challenge work as part of Trussell *et al.*, 2015). The online UVT meters experienced frequent fouling and calibration issues, leading to widely variable UVT measurements (Figure 6.41). Other than a general conclusion that increased O_3 results in increased UVT, no further conclusions can be made from this data set.

- Online monitoring of O_3 dosing conditions (Figure 6.42) illustrates the impact of variable flow and variable influent water quality on the ability (or lack thereof) to maintain a target O_3 dose.

- With several notable exceptions, flow into and out of the BAF was maintained at the target EBCTs (Figure 6.43).

- The dissolved oxygen (DO) into and out of the BAF varied substantially over the test period. For every 1 mg/L of O_3 dosed into the system, ~9 mg/L of DO is added to the system. Variations in both O_3 dose and water quality will impact the DO levels into the BAF. For the BAF, the intent is to maintain aerobic conditions (and stable conditions), which proved difficult with this pilot system.

- With several exceptions, the BAF was able to produce a filtered effluent turbidity below the CCR Title 22 requirement of 2 NTU. This information, coupled with the virus disinfection results on the secondary effluent by O_3, have two significant implications.
  - O_3 on secondary effluent can be used to meet the 5-log virus disinfection criteria for Title 22.
  - O_3/BAF finished water meets the Title 22 turbidity.

- The result is that O_3/BAF, with a polishing disinfectant to meet total coliform standards, can meet the filtration and disinfection requirements of Title 22 for non-potable water reuse, which then qualifies as an acceptable technology combination for tertiary treatment ahead of surface spreading.

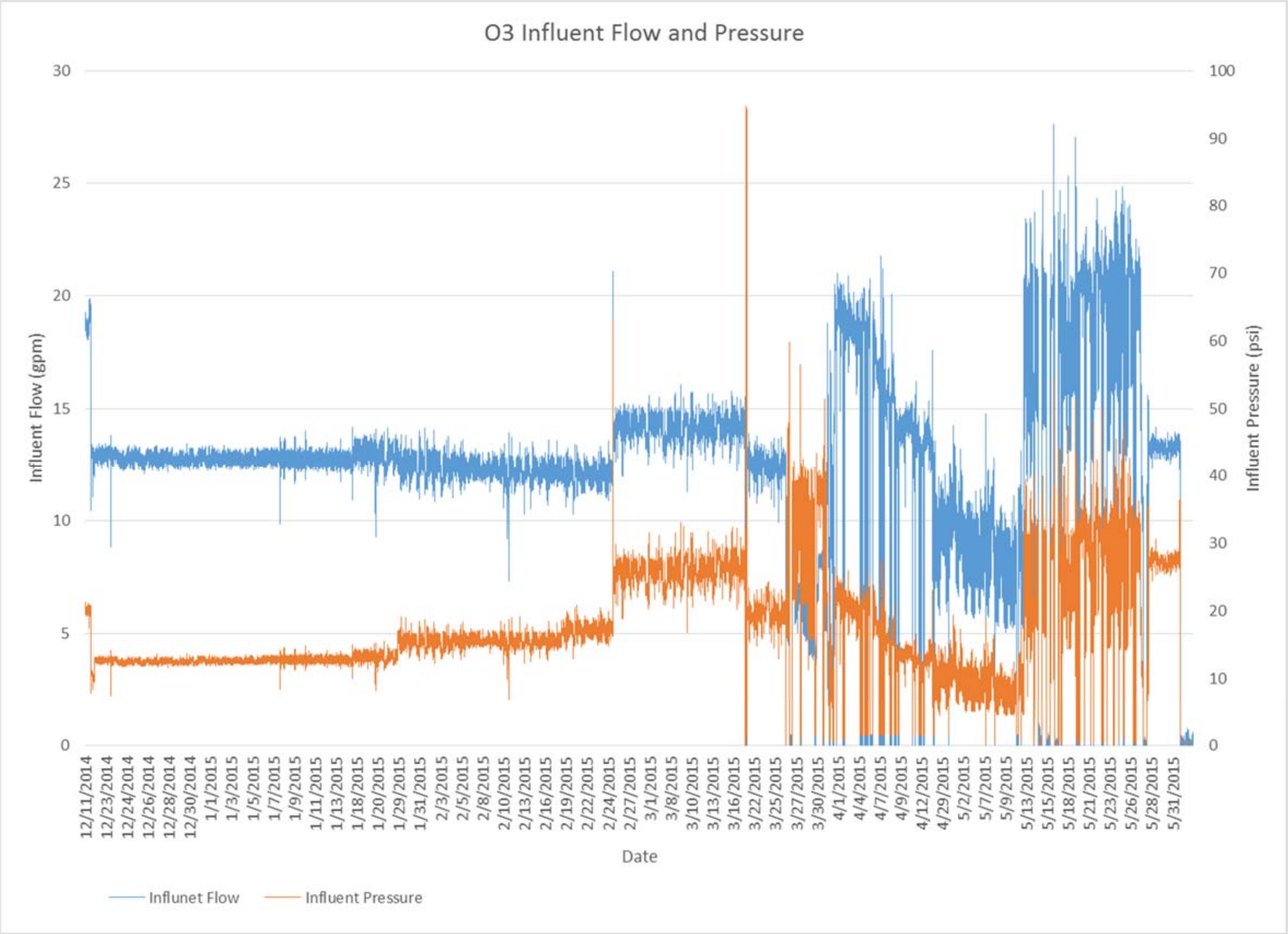

Figure 6.40 Online influent flow and pressure into the O_3/Biofiltration pilot during the full duration of the pilot

Figure 6.41 Online UVT for the influent and effluent of the O_3 pilot skid over the duration of the pilot

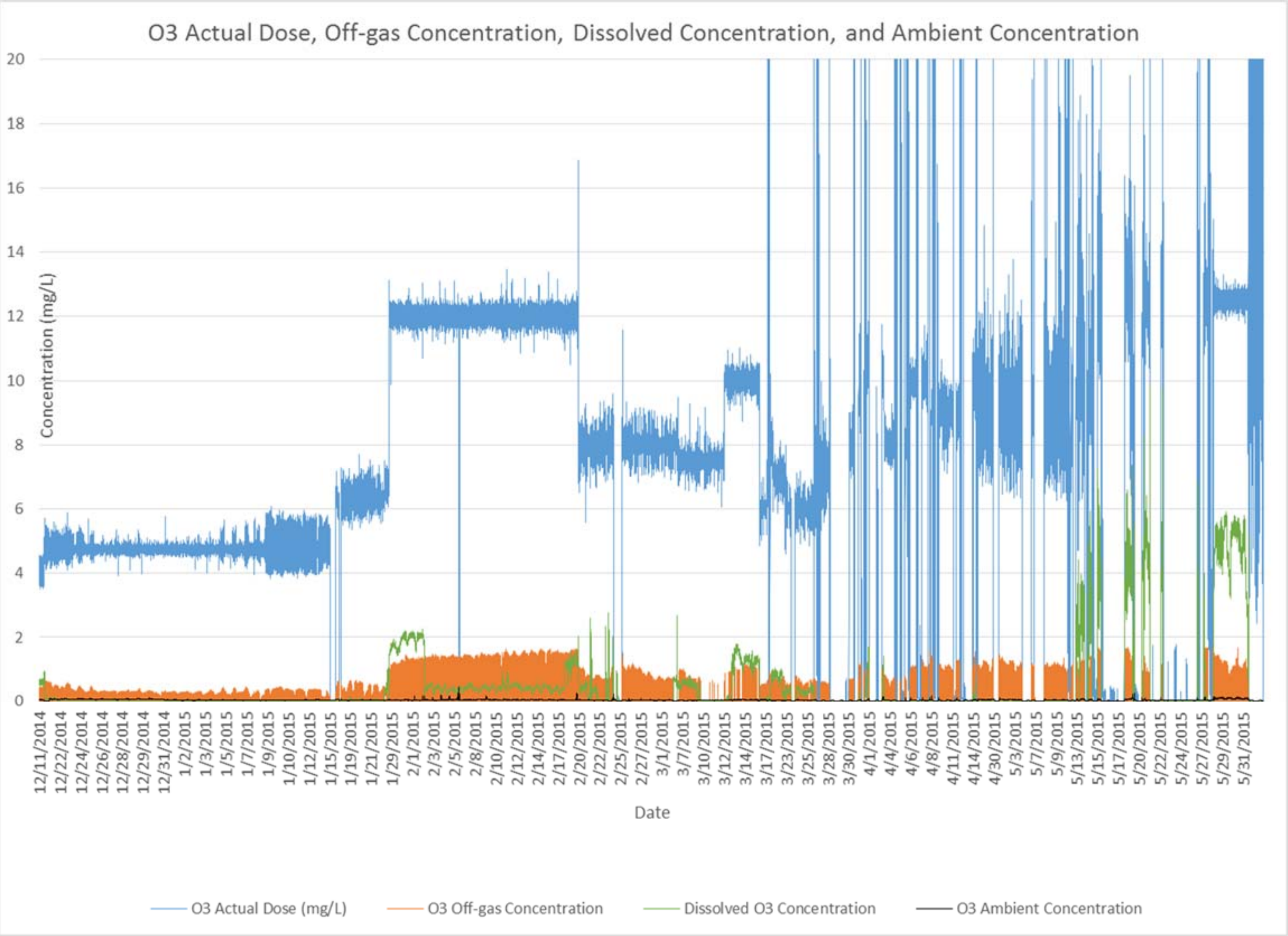

Figure 6.42 *Online monitoring of the O_3 dose, off-gas concentration, dissolved O_3 concentration, and ambient O_3 concentration over the duration of the O_3 pilot system*

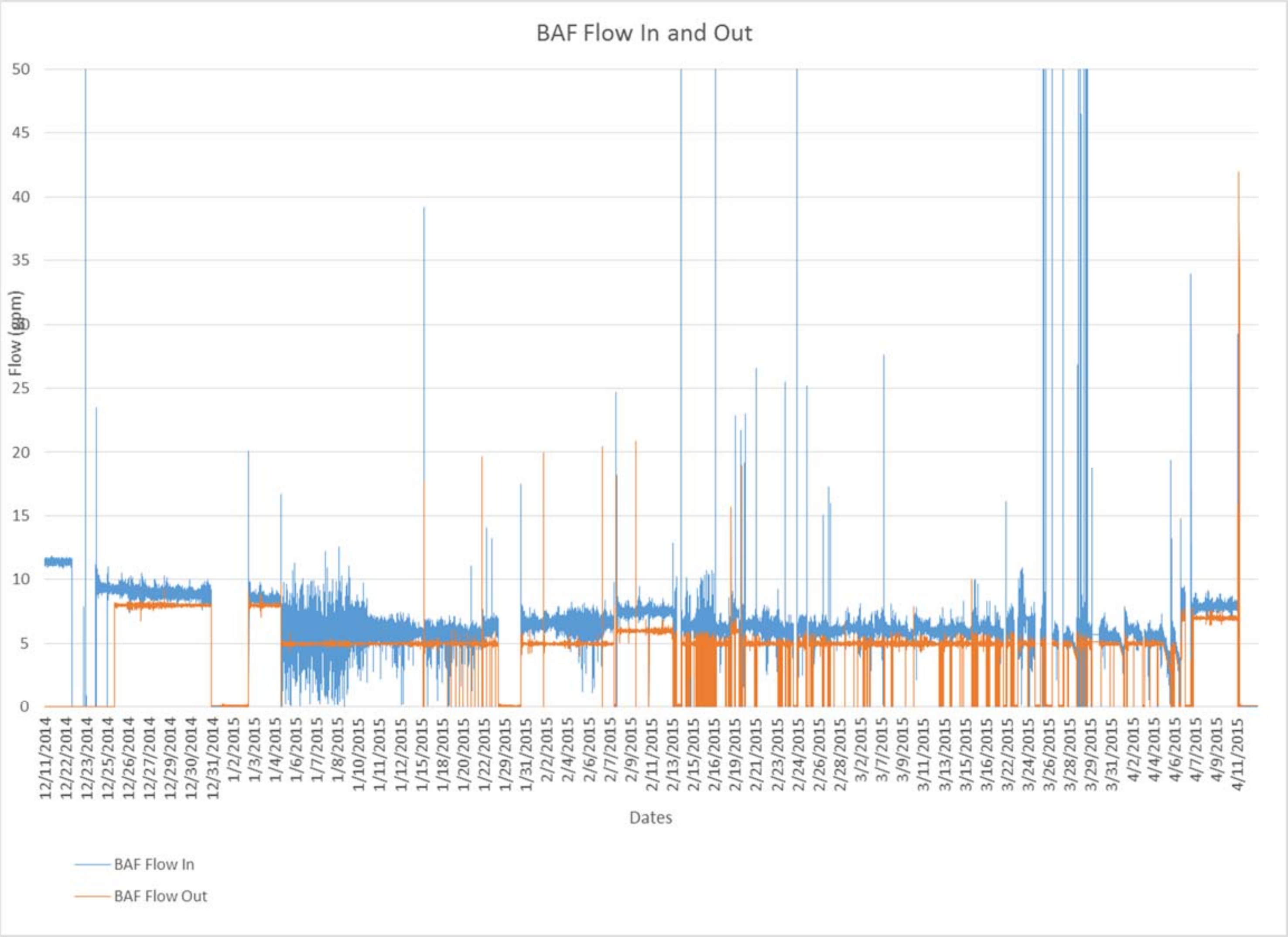

Figure 6.43 **Online monitoring of influent and effluent flow of the Leopold Biofiltration system, following the O_3 pilot over the duration of the pilot**

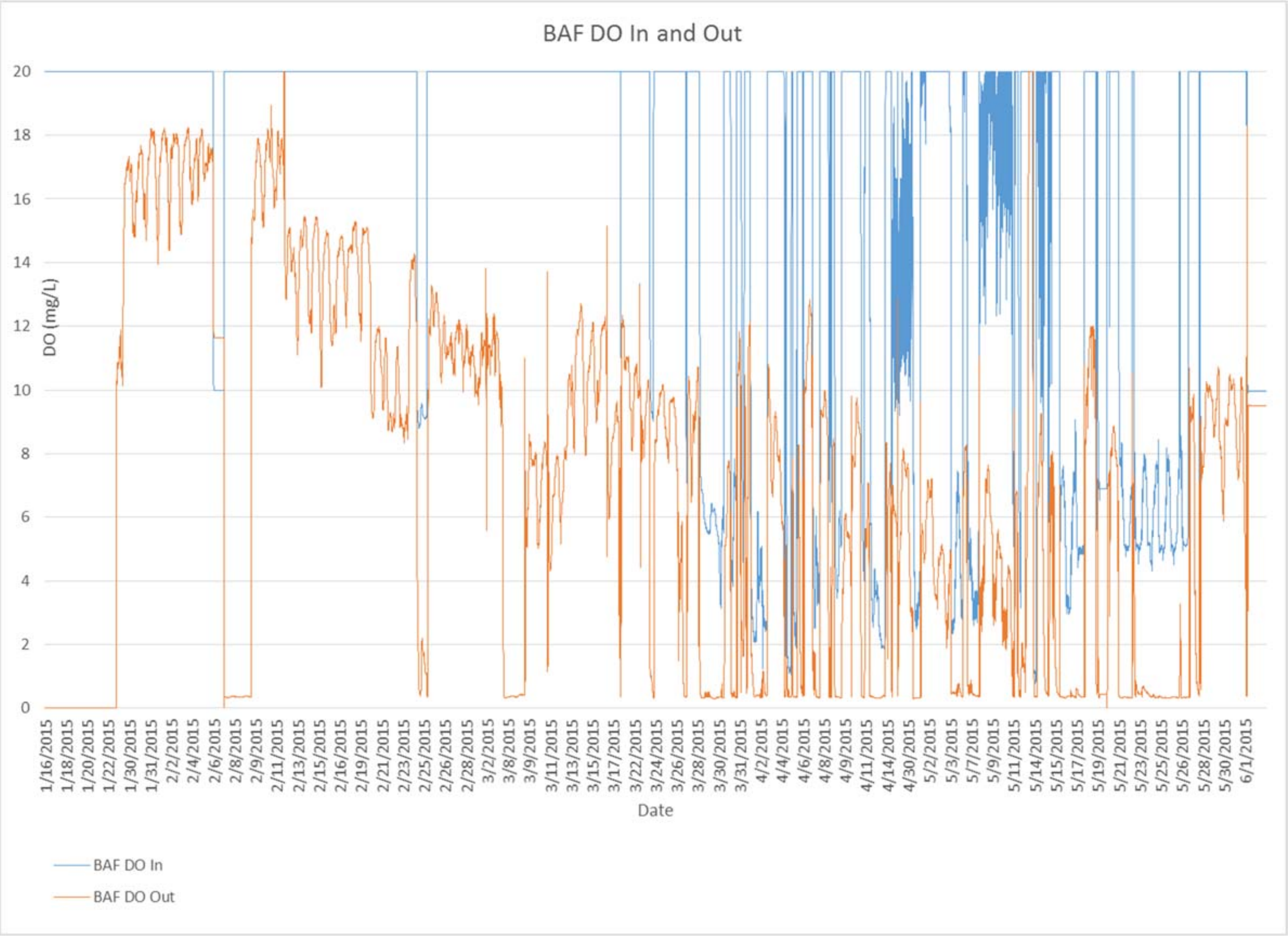

Figure 6.44 **Online monitoring of influent and effluent Biofiltration dissolved oxygen over the duration of the pilot**

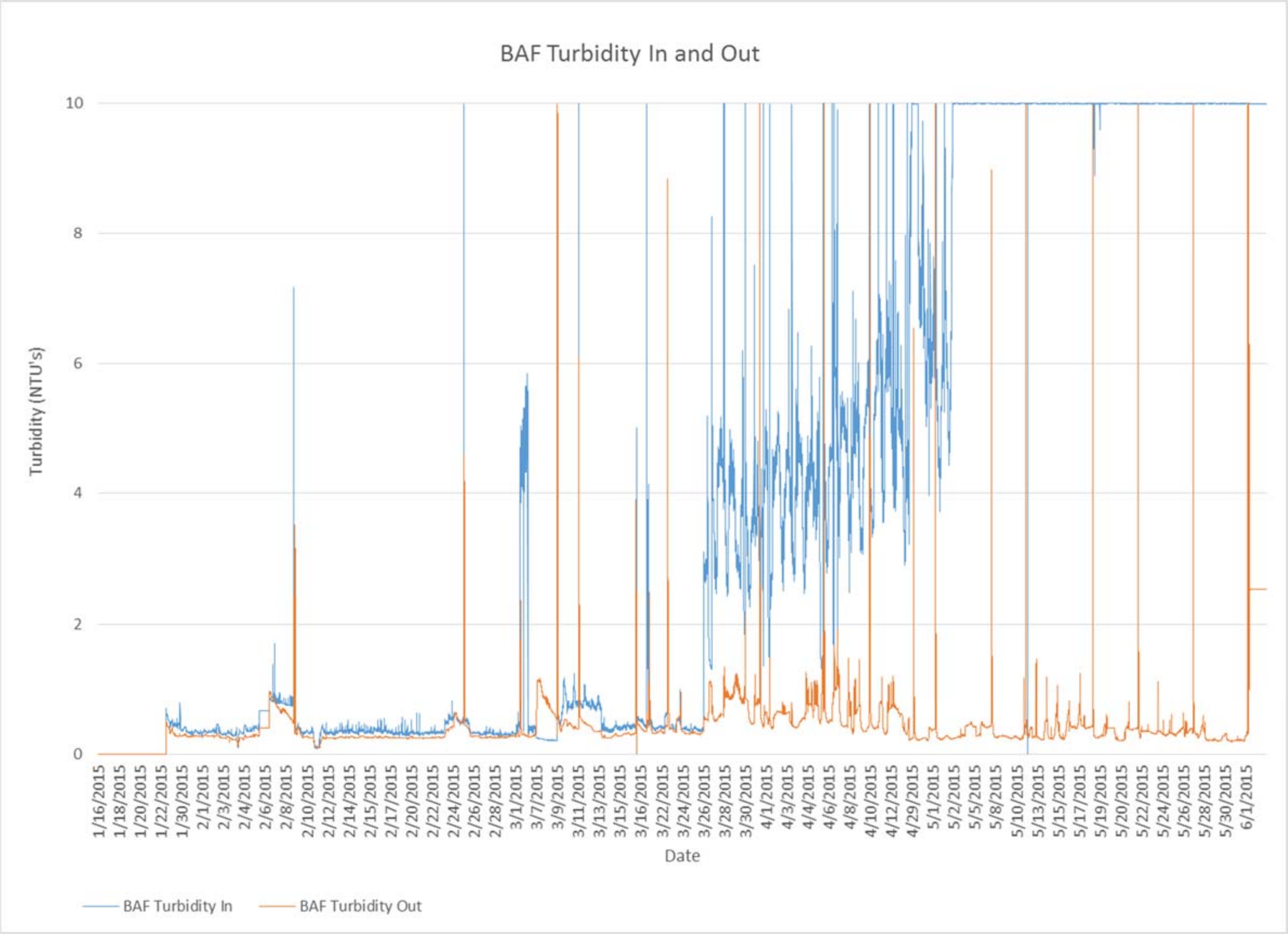

Figure 6.45 Online monitoring of influent and effluent Biofiltration turbidity over the duration of the pilot

7.0 KEY FINDINGS

The detailed conclusions from this research and demonstration effort are detailed in the Executive Summary and within each chapter of this report. Hence, these details are not included here. This final section of the report is intended to address the several different applications of potable reuse that may apply to the District. This final section of the report also includes a concluding section on innovations.

7.1 Potable Reuse Scenarios and Related Findings

7.1.1 Indirect Potable Reuse Using MF/RO/UV AOP for Groundwater Injection or Surface Spreading

- The District's SVAWPC produces high quality water that meets drinking water regulatory standards and is protective of public health.

- With the proper addition of advanced oxidation, the District's SVAWPC has demonstrated performance in accordance with DDW regulations for indirect potable reuse using injection wells or spreading basins (percolation) for groundwater recharge (CDPH, 2014). The estimated capacity of the existing UV system for indirect potable reuse applications is ~1.08 mgd per treatment train (5 duty and one standby).

- System monitoring using CCPs and improved calibration of online meters is recommended for a future potable reuse system.

- UV/H_2O_2 was demonstrated through both pilot and bench-top testing as the preferable UV AOP for the District. Additional testing may allow for future consideration of UV/NaOCl as an alternative UV AOP.

7.1.2 Indirect Potable Reuse Using O_3/BAF for Surface Spreading

- The highly variable water quality in the blended tertiary recycled water impacted the performance of O_3/BAF. The primary problem appears to be the variable nature of both free and combined chlorine within the water matrix.

- The use of O_3/BAF on tertiary recycled water, when combined with Soil Aquifer Treatment (SAT), will meet pathogen requirements and many chemical requirements for potable water reuse. However, O_3/BAF may have difficulty meeting DDW regulations for TN, TOC, and NDMA. Soil column studies and/or blending of O_3/BAF finished water with an advanced treated MF/RO/UV AOP finished water may be necessary to ensure compliance.

7.1.3 Direct Potable Reuse

- A future direct potable reuse treatment system, which utilizes O_3/BAF/MF/RO/UV AOP, followed by blending with other raw water supplies and final treatment at a District WTP will result in treatment that far exceeds regulatory standards for potable water reuse and provides multiple barriers to both trace pollutants and pathogens.

- The use of O_3/BAF on secondary effluent provided a high level of disinfection and measurable reduction of a range of trace pollutants and TOC. Inclusion of O_3/BAF as part of a direct potable reuse treatment train will thus provide a robust additional treatment barrier for both pathogens and organic contaminants.

7.2 Innovative Findings

7.2.1 Critical Control Points

The concept of using online or grab sample results as a surrogate for treatment performance is long standing and accepted within our industry. This research and demonstration testing was intended to further develop the concept of precise and conservative monitoring as it applies to potable water reuse. Critical Control Points, CCPs, were evaluated for each key treatment process, with some processes having multiple CCPs. These CCPs are defined in Table 7.1, below. These CCPs, if properly implemented, allow for a more precise and demonstrated conservative approach to potable reuse process monitoring.

7.2.2 UV AOP

Contrary to LABOS (2014), this testing by the District demonstrated that UV/NaOCl was not sufficiently effective to reduce 1,4-dioxane by the regulated value of 0.5 log (CDPH, 2014). The reasons for this difference are not clear, and further investigation within the industry is warranted. For the District, UV/H_2O_2 was able to meet the 0.5 log standard and is thus the recommended UV AOP for the District until further data suggests otherwise.

7.2.3 O_3/BAF

The O_3/BAF system, treating secondary effluent, met the virus standard for non-potable water reuse (5-log) and met the turbidity requirement for non-potable water reuse (2 NTU). Providing for a final polishing level of disinfection (e.g., low dose chloramination) to reduce total coliform to the regulated value of 2.2 MPN/100mL would create a new treatment train for tertiary recycled water operation. This treatment train, because of the use of O_3/BAF, would have a reduced TOC, and a reduced number and concentration of trace pollutants compared to conventional tertiary treatment trains.

For a future spreading project, the results from this study demonstrate that using O_3/BAF on secondary effluent results in a higher quality water with more effective oxidation and biofiltration compared to using O_3/BAF on tertiary recycled water.

Table 7.1 Critical Control Point Findings
SVAWPC Potable Reuse Demonstration Testing

Santa Clara Valley Water District

Treatment Process	CCP	Pathogens or Trace Pollutants?	Findings
MF	Pressure Decay Test	Pathogens	PDTs are an effective CCP for monitoring the removal of protozoa (*Giardia* and *Cryptosporidium*), allowing for 4+ log reduction of these target pathogens.
RO	Electrical Conductivity and Total Organic Carbon	Both	Log removal of EC and TOC across RO are conservative measurements and effective CCPs for virus and protozoa removal. RO permeate TOC provides for confidence in low organic content finished water.
UV	Sensor Intensity and UVT, resulting in Dose Calculation	Pathogens	Online maintenance of UV dose through accurate measurements of sensor intensity and UVT (and flow) allow for an effective CCP for virus and protozoa kill. Current sensors and UVT measurements are insufficiently accurate for CCP for potable reuse applications. Modification of the existing reactors is feasible.
UV	Total Chlorine Destruction	Pathogens and Trace Pollutants	NDMA destruction correlates well with total chlorine destruction across UV, allowing total chlorine destruction to be a CCP for both pathogens and select pollutants (only NDMA proven at this time).
UV AOP	Oxidant Weighted UV Dose	Trace Pollutants	Minimum UV dose and oxidant dose combinations can be set to confidently result in the DDW required 0-.5-log reduction of 1,4-dioxane, providing for an effective, though not precise, CCP for trace pollutant destruction by UV AOP.
O_3	O_3/ (TOC+nitrite)	Pathogens	O_3/(TOC+nitrite) ratios have proven to provide a reliable CCP for monitoring virus kill by O_3 in the absence of an O_3 residual.
O_3/BAF	Insufficiently documented	Pollutants	O_3 alone and O_3/BAF reduced trace pollutants, but the collected information is not sufficient to document a CCP (such as EBCT, O_3 dose, O_3/TOC, change in UVT) for predictable destruction of TOC, disinfection byproducts, or trace pollutants.

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Appendix A. Constituent List

Constituent Tables for Testing With Corresponding Maximum Reporting Limits (MRLS) and Regulatory Limits (If Applicable).

Table A-1 CEC Analysis Information and Laboratory Responsibilities

Laboratory	Contaminant	Health Based Standard	MDL	MRL	Units	Test Method	Hold Time (days)	Sampling Container
Eurofins and District	17α, Ethinyl estradiol	350[1]	0.0032	0.005	ng/L	LC-MS-MS	28	40 mL amber glass vial
	17B-Estradiol	1[1&2] 93[3] 175[3]	4.41	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Atenolol	[5] 70[1&2]	0.00388	0.005	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Caffeine	350[2]	4.31	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Carbamazepine	--	1.21	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Cotinine	1,000[4]	4.85	10	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Dilantin	--	0.0125	0.02	ug/L	LC-MS-MS	28	40 mL amber glass vial
	DEET	2.5[1] 200[5]	0.00108	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Estrone	0.32[5] 0.35[1]	0.0039	0.005	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Primidone	10,000[4&5]	4.77	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Sucralose	150,000[5]	0.042	0.1	ug/L	LC-MS-MS	28	40 mL amber glass vial
	TCEP	5[4]	0.00318	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Triclosan	2,100[4]	0.00632	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
District WQ Lab	Perchlorate	6[4]		4	ug/L	EPA 314.0	28	250 mL Poly
	Bromate	0.01[4]		5000	mg/L	EPA 300.1	28	250 mL Poly

Table A-1 CEC Analysis Information and Laboratory Responsibilities

Laboratory	Contaminant	Health Based Standard	MDL	MRL	Units	Test Method	Hold Time (days)	Sampling Container
	Bromide	--		0.05	mg/L	EPA 300.0	28	500 mL Poly
Eurofins	Meprobamate	200,000[4&5]	2.03	5	ng/L	LC-MS-MS	28	40 ml amber glass preserved
	NDMA	10[4]	0.962	2	ng/L	EPA 521	7	500 ml amber glass preserved
	Nonylphenol	500,000[1]	50	100	ng/L	LC-MS-MS	28	40 ml amber glass preserved
	PFOA	400[6]	0.55	5	ng/L	LC-MS-MS	28	125 ml poly unpreserved
	PFOS	200[6]	0.239	5	ng/L	LC-MS-MS	28	125 ml poly unpreserved
	1,4-Dioxane	0.1[7]	0.035	0.07	ug/L	EPA 522	14	125 ml amber glass preserved

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Table A-2 Nutrient Analysis all to take place at District WQL

	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Iron[1]	EPA 200.7	ug/L	180	100	20	500 mL Poly
Ammonia	SM 4500-NH3 D	mg/L	1	--	0.05	500 mL Poly
Nitrite[2]	SM 4500-NO2- B	mg/L	2	0.4	0.01	250 mL Poly
Nitrate[2]	EPA 300.0	mg/L	2	2	0.05	500 mL Poly
Total Nitrogen (TN)[2]	SM 4500-N D	mg/L	1	--	0.05	500 mL Poly
Phosphorus	EPA 300.0	mg/L	2	--	0.05	500 mL Poly

Notes:

(1) Included in contaminants with secondary MCL.

(2) Included in regulated contaminants.

Table A-3 Regulated Contaminants and Sampling Collection Information								
Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
Inorganics (Table 64431-A)								
Aluminum[1]	1	District WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly
Antimony	0.006	District WQL	EPA 200.8	ug/L	180	6	1	500 mL Poly
Arsenic	0.01	District WQL	EPA 200.8	ug/L	180	2	1	500 mL Poly
Asbestos	7 MFL[2]	District WQL	EPA 200.8	ug/L	180	2	1	500 mL Poly
Barium	1	District WQL	EPA 200.8	ug/L	180	100	5	500 mL Poly
Beryllium	0.004	District WQL	EPA 200.8	ug/L	180	1	1	500 mL Poly
Cadmium	0.005	District WQL	EPA 200.8	ug/L	180	1	0.2	500 mL Poly
Chromium	0.05	District WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Copper[1]	1[3]	District WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
	1.3[4]	District WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
Cyanide	0.15	Eurofins	SM 4500CN-F	mg/L	14	0.006	0.025	250 mL Poly Preserved
Fluoride	2	District WQL	EPA 300.0	mg/L	28	0.1	0.05	500 mL Poly
Hexavalent Chromium	0.01	District WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly

Table A-3 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Lead	0.015[4]	District WQL	EPA 200.8	ug/L	180	5	0.5	500 mL Poly
Mercury	0.002	District WQL	EPA 245.1	ug/L	28	1	1	500 mL Poly
Nickel	0.1	District WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Nitrate[5]	45 (as NO_3) 10 (as N)	District WQL						
Nitrite (as N)[5]	1	District WQL						
Total Nitrate/Nitrite (as N)[5]	10	District WQL	EPA 300.0	mg/L	2	2	0.05	500 mL Poly
Perchlorate	0.006	District WQL	EPA 314.0	ug/L	28	4	4	250 mL Poly
Selenium	0.05	District WQL	EPA 200.8	ug/L	180	5	5	500 mL Poly
Thallium	0.002	District WQL	EPA 200.8	ug/L	180	1	1	500 mL Poly
Radionuclides (Tables 64442 and 64443)								
Uranium	20 pCi/L[7]	Eurofins	EPA 200.8	pCi/L	180	0.022	0.7	500 ml poly preserved
Combined radium-226 & 228	5 pCi/L	Eurofins	GA Method	pCi/L	180	1	1	3 Liter poly preserved
Gross Alpha particle activity	15 pCi/L	Eurofins	EPA 900.0	pCi/L	180	2.68	3	500 ml poly preserved

Table A-3 Regulated Contaminants and Sampling Collection Information								
Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
Gross Beta particle activity	50 pCi/L	Eurofins	EPA 900.0	pCi/L	180	2.66	3	500 ml poly preserved
Strontium-90	8 pCi/L	Eurofins	EPA 905.0	pCi/L	180	2	2	1 Liter poly preserved
Tritium	20,000 pCi/L	Eurofins	EPA 906.0	pCi/L	180	300	300	500 ml amber glass unpreserved
Organic Chemicals (Table 64444-A)								
VOCs								
Benzene	0.001	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Carbon Tetrachloride	0.0005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichlorobenzene	0.6	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,4-Dichlorobenzene	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1-Dichloroethane	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichloroethane	0.0005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1-Dichloroethylene	0.006	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
cis-1,2-Dichloroethylene	0.006	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA

Table A-3 **Regulated Contaminants and Sampling Collection Information**								
Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
trans-1,2-Dichloroethylene	0.01	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Dichloromethane	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,3-Dichloropropene	0.0005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichloropropane	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Ethylbenzene	0.3	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Methyl-tert-butyl ether (MTBE)	0.005[3]	District WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
	0.013	District WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
Monochlorobenzene	0.07	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Styrene	0.1	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1,2,2-Tetrachloroethane	0.001	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Tetrachloroethylene	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Toluene	0.15	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2,4 Trichlorobenzene	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1,1-Trichloroethane	0.2	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA

Table A-3 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
1,1,2-Trichloroethane	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Trichloroethylene	0.005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Trichlorofluoromethane	0.15	District WQL	EPA 524.2	ug/L	14	5	2.5	40 mL VOA
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.2	District WQL	EPA 524.2	ug/L	14	10	2	40 mL VOA
Vinyl chloride	0.0005	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Xylenes	1.75	District WQL	EPA 524.2	ug/L	14	--	--	40 mL VOA
SVOCs								
Alachlor	0.002	District WQL	EPA 505	ug/L	7	1	1	40 mL VOA
Atrazine	0.001	District WQL	EPA 525.2	ug/L	30	0.5	0.25	1 L Brown Glass
Bentazon	0.018	District WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Benzo(a) Pyrene	0.0002	District WQL	EPA 525.2	ug/L	30	0.1	0.1	1 L Brown Glass
Carbofuran	0.018	District WQL	EPA 531.1	ug/l	14	5	5	40 mL VOA
Chlordane	0.0001	District WQL	EPA 505	ug/L	7	0.1	0.1	40 mL VOA

Table A-3 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Dalapon	0.2	District WQL	EPA 515.3	ug/L	14	10	10	60 mL VOA Amber
Dibromochloropropane	0.0002	District WQL	EPA 504.1	ug/L	14	0.01	0.01	40 mL VOA
Di(2-ethylhexyl)adipate	0.4	District WQL	EPA 525.2	ug/L	30	5	0.5	1 L Brown Glass
Di(2-ethylhexyl)phthalate	0.004	District WQL	EPA 525.2	ug/L	30	5	0.5	1 L Brown Glass
2,4-Dichlorophenoxyacetic acid (2,4-D)	0.07	District WQL	EPA 515.3	ug/L	14	10	10	60 mL VOA Amber
Dinoseb	0.007	District WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Diquat	0.02	District WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Endothall	0.1	District WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Endrin	0.002	District WQL	EPA 505	ug/L	7	0.1	0.1	40 mL VOA
Ethylene Dibromide	0.00005	District WQL	EPA 504.1	ug/L	14	0.02	0.02	40 mL VOA

Table A-3 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Glyphosate	0.7	District WQL	EPA 547	ug/L	14	25	25	250 mL Brown Glass
Heptachlor	0.00001	District WQL	EPA 505	ug/L	7	0.01	0.01	40 mL VOA
Heptachlor Epoxide	0.00001	District WQL	EPA 505	ug/L	7	0.01	0.01	40 mL VOA
Hexachlorobenzene	0.001	District WQL	EPA 505	ug/L	7	0.5	0.5	40 mL VOA
Hexachlorocyclopentadiene	0.05	District WQL	EPA 505	ug/L	7	1	1	40 mL VOA
Lindane	0.0002	District WQL	EPA 505	ug/L	7	0.2	0.2	40 mL VOA
Methoxychlor	0.03	District WQL	EPA 505	ug/L	7	10	10	40 mL VOA
Molinate	0.02	District WQL	EPA 525.2	ug/L	30	2	0.5	1 L Brown Glass
Oxamyl	0.05	District WQL	EPA 531.1	ug/L	14	20	20	40 mL VOA
Pentachlorophenol	0.001	District WQL	EPA 525.2	ug/L	30	--	1	1 L Brown Glass
Picloram	0.5	District WQL	EPA 515.3	ug/L	14	1	1	60 mL VOA Amber
Polychlorinated Biphenyls	0.0005	District WQL	EPA 505	ug/L	7	0.5	0.5	40 mL VOA

Table A-3 Regulated Contaminants and Sampling Collection Information								
Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
Simazine	0.004	District WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Thiobencarb	0.07	District WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
	0.001[3]	District WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Toxaphene	0.003	District WQL	EPA 505	ug/L	7	1	1	40 mL VOA
2,3,7,8-TCDD (Dioxin)	$3x10^{-8}$	District WQL	EPA 505	ug/L	7	1	1	40 mL VOA
2,4,5-TP (Silvex)	0.05	District WQL	EPA 515.3	ug/L	14	1	1	60 mL VOA Amber
Disinfection Byproducts (Table 64533-A)								
Total trihalomethanes	0.08	District WQL	EPA 502.2	ug/L	14	--	1	40 mL VOA
Total haloacetic acids	0.06	District WQL	EPA 557	ug/L	21	--	--	60 mL VOA Amber
Bromate[6]	0.01	District WQL	EPA 317.-	ug/L	28	1	1	250 mL Poly
Chlorite	1.0	District WQL	SM 4500-Cl D	mg/l	28	--	5	1 L Poly

Notes:

(1) Included in Secondary MCL List (sampling for both will be conducted with timing of regulated contaminants)

Table A-3 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container

(2) MFL = million fibers per liter; for fibers > 10 microns long

(3) Secondary MCL

(4) Action Level per California Lead and Copper Rule

(5) Included in nutrient sampling (included in nutrient sampling (at different locations); sampling required for both sets.

(6) Included in CEC recommendation list (sampling for bromate will be conducted in CEC sampling).

(7) pCi/L = pico Curie per liter

Table A-4 Contaminants with Secondary MCLs sampling information

Contaminant	CDPH MCL	Units	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Table 64449-A									
Aluminum[1]	0.2	mg/L	District WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly
Color	15	Units	District WQL	SM 2120 C	Color Units	2	--	--	1 L Poly
Copper[1]	1	mg/L	District WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
Foaming Agents	0.5	mg/L	Eurofins	SM 5540C	mg/L	2	0.014	0.05	500 mL Poly unpreserved
Iron[2]	0.3	mg/L	District WQL	EPA 200.7	ug/L	180	100	20	500 mL Poly
Manganese	0.05	mg/L	District WQL	EPA 200.8	ug/L	180	20	1	500 mL Poly
Methyl-*tert*-butyl ether (MTBE)[1]	0.005	mg/L	District WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
Odor-Threshold	3	Units	District WQL						
Silver	0.1	mg/L	District WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Thiobencarb[1]	0.001	mg/L	District WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Turbidity	5	Units	District WQL	SM 2130 B	NTU	2	--	--	1 L Poly
Zinc	5	mg/L	District WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly

Table A-4 Contaminants with Secondary MCLs sampling information

Contaminant	CDPH MCL	Units	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Total Dissolved Solids	500	mg/L	District WQL	SM 2540 C	mg/L	7	--	--	2 L Poly
Specific Conductance	900	uS/cm	District WQL	SM 2510 B	umhos/cm	28	--	--	1 L Poly
Chloride	250	mg/L	District WQL	SM 4500-Cl D	mg/L	28	--	5	1 L Poly
Sulfate	250	mg/L	District WQL	EPA 300.0	mg/L	28	0.5	0.5	500 mL Poly

Notes:

(1) Included in regulated contaminants (sampling in regulated contaminants will be sufficient for both requirements).

(2) Included in nutrients (sampling at different locations, sampling required for both).

Table A-5 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Boron	1000	District WQL	EPA 200.8	ug/L	180	100	100	500 mL Poly
n-Butylbenzene	260	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
sec-Butylbenzene	260	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
tert-Butylbenzene	260	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Carbon disulfide	160	Eurofins	EPA 524.2	ug/L	14	0.085	0.5	40 mL amber glass preserved
Chlorate	800	District WQL	EPA 300.1	ug/L	28	20	20	250 mL Poly
2-Chlorotoluene	140	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
4-Chlorotoluene	140	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Diazinon	1.2	Eurofins	EPA 525.2	ug/L	14	0.025	0.2	1 L amber glass preserved
Dichlorodifluoromethane (Freon 12)	1000	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,4-Dioxane	1	Eurofins	EPA 522	ug/L	14	0.035	0.07	125 mL amber glass preserved
Ethylene glycol	14000	Eurofins	EPA 8015B	mg/L		4	5	1 Liter amber glass unpreserved
Formaldehyde	100	Eurofins	EPA 556	ug/L		0.81	5	40 ml amber glass preserved

Table A-5 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
HMX[1]	350	Eurofins	LC-MS-MS	ug/L		0.05	0.1	40 ml amber glass preserved
Isopropylbenzene	770	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Manganese	500	District WQL	EPA 200.8	ug/L	180	20	1	500 mL Poly
Methyl isobutyl ketone (MIBK)[2]	120	Eurofins	EPA 524.2	ug/L	14	0.683	5	40 mL amber glass preserved
Naphthalene	17	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
N-Nitrosodiethylamine (NDEA)	0.01	District WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
N-Nitrosodimethylamine (NDMA)	0.01	District WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
N-Nitrosodi-n-propylamine (NDPA)	0.01	District WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
Propachlor	90	District WQL	EPA 525.2	ug/L	30	0.5	0.5	1 L Brown Glass
n-Propylbenzene	260	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
RDX[3]	0.3	Eurofins	LC-MS-MS	ug/L	14	0.05	0.1	40 mL amber glass preserved
Tertiary butyl alcohol (TBA)	12	District WQL	EPA 524.2	ug/L	14	2	2	40 mL VOA

Table A-5 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
1,2,3-Trichloropropane (1,2,3-TCP)	0.005	District WQL	EPA 524.2	ug/L	14	--	0.5	40 mL VOA
1,2,4-Trimethylbenzene	330	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,3,5-Trimethylbenzene	330	District WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
2,4,6-Trinitrotoluene (TNT)	1	Eurofins	LC-MS-MS	ug/L	14	0.05	0.1	40 mL amber glass preserved
Vanadium	50	District WQL	EPA 200.8	ug/L	180	3	3	500 mL Poly

Notes:

(1) HMX is an explosive, and is commonly found with the explosive RDX.
(2) MIBK is a commonly found solvent.
(3) RDX is an explosive, and is listed on the USEPA Candidate Contaminant List 3 (CCL3)

Appendix B. Quarterly Monitoring Data

Quarterly Monitoring Data for All 4 Rounds of Sampling, Notification Levels, Regulatory Limits, Detection Limits and Results

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
1,1,1,2-Tetrachloroethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
1,1,1-Trichloroethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	200	ug/L	0.5	0.5	EPA 524.2
1,1,2,2-Tetrachloroethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1	ug/L	0.5	0.5	EPA 524.2
1,1,2-Trichloroethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
1,1-Dichloroethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
1,1-Dichloroethylene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	6	ug/L	0.5	0.5	EPA 524.2
1,1-Dichloropropene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
1,2,3-Trichlorobenzene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
1,2,3-Trichloropropane	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	0.005	ug/L	0.5	0.005	EPA 524.2
1,2,4-Trichlorobenzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
1,2,4-Trimethylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	330	ug/L	0.5	0.5	EPA 524.2
1,2-Dichlorobenzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	600	ug/L	0.5	0.5	EPA 524.2
1,2-Dichloroethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.5	ug/L	0.5	0.5	EPA 524.2
1,2-Dichloropropane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
1,3,5-Trimethylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	330	ug/L	0.5	0.5	EPA 524.2
1,3-Dichlorobenzene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
1,3-Dichloropropane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
1,3-Dichloropropene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.5	ug/L	0.5	0.5	EPA 524.2
1,4-Dichlorobenzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
1,4-Dioxane	CECs	<MRL	<MRL	<MRL	1.1	0.11	1.1	1	ug/L	0.07	1	EPA 522
2,2-Dichloropropane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
2,3,7,8-TCDD	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	0.03	pg/L	5	5	EPA 1613B
2,4,5-TP	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	50	ug/L	1	1	515.3
2,4,6-Trinitrotoluene (TNT)	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1	ug/L	0.1		LC-MS-MS
2,4-D	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	70	ug/L	10	10	515.3
2,4-Dinitrotoluene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.1	5	EPA 525.2
2-Butanone (MEK)		<MRL	<MRL	NS	NS	NS	NS		ug/L	5		EPA 524.2
2-Chlorotoluene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	140	ug/L	0.5	0.5	524.2
3-Hydroxycarbofuran		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	3	3	531.1
4-Chlorotoluene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	140	ug/L	0.5	0.5	524.2
4-Methyl-2-Pentanone (MIBK)	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	120	ug/L	5	5	EPA 524.2
4-nonylphenol - semi quantitative	CECs	<MRL	<MRL	130	680	<MRL	170	500,000	ng/L	100		LC-MS-MS
Acenaphthylene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.1	5	EPA 525.2
Acetaldehyde		1.1	1.6	1.6	23	1.1	3.2		ug/L	1		EPA 556

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
Acifluorfen		<MRL	<MRL	<0.5	<0.5	<0.5	<0.5		ug/L	0.5		515.3
Alachlor	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	2	ug/L	1	1	EPA 525.2
Aldicarb (Temik)		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	3	3	531.1
Aldicarb Sulfone		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	3	4	531.1
Aldicarb Sulfoxide		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	3	3	531.1
Aldrin		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	0.075	EPA 525.2
Alpha, Gross	Regulated Contaminants	<MRL	<MRL	<MRL	NS	<MRL	NS	15	pCi/L	3	3	EPA 900.0
Alpha, Min Detectable Activity		3	3	2.9	1.4	2.8	1.4		pCi/L	Â		EPA 900.0
Alpha, Two Sigma Error		2.2	2.4	2.9	0.19	2.6	0.23		pCi/L	Â		EPA 900.0
alpha-Chlordane		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Aluminum	Regulated Contaminants	<DLR	<DLR	<DLR	130	<DLR	<DLR	1,000 (primary), 200 (secondary)	ug/L	20	50	200.7
Anthracene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.02	5	EPA 525.2
Antimony	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	6	ug/L	1	6	200.8
Apparent Color	Secondary MCLs	<2.5	<2.5	<2.5	66	<2.5	68	15	Color Units	3		2120 C
Arsenic	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	2	50	ug/L	1	2	200.8
Asbestos by TEM - >10 microns	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	7	MFL	0.2	0.2	EPA 100.2
Atenolol	CECs	<MRL	<MRL	<MRL	78	<MRL	51	4,000	ng/L	5		LC-MS-MS
Atrazine	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1	ug/L	0.05	0.5	EPA 525.2
Barium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1,000	ug/L	5	100	200.8
Baygon (Propoxur)		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	2		531.1
Bentazon	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	18	ug/L	2	2	515.3
Benz(a)Anthracene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	10	EPA 525.2
Benzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1	ug/L	0.5	0.5	EPA 524.2
Benzo(a)pyrene	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	0.2	ug/L	0.1	0.1	EPA 525.2
Benzo(b)Fluoranthene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.02	10	EPA 525.2
Benzo(g,h,i)Perylene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	10	EPA 525.2
Benzo(k)Fluoranthene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.02	10	EPA 525.2
Beryllium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	4	ug/L	1	1	200.8
Beta, Gross	Regulated Contaminants	<MRL	<MRL	<MRL	21	<MRL	19	50	pCi/L	3	4	EPA 900.0
Beta, Min Detectable Activity		3	3	1.7	1.1	2.5	1.2		pCi/L	Â		EPA 900.0
Beta, Two Sigma Error		1.8	2	1.7	2	2.5	1.9		pCi/L	Â		EPA 900.0
Bicarbonate (as HCO3)		29	19	20	185	27	156		mg/L	5		2320 B

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
Bicarbonate Alkalinity (as CaCO3)		24	16	17	152	22	128		mg/L	5		2320 B
Boron	Contaminants with NLs	233	227	222	379	306	455	1,000	ug/L	50	100	200.7
Bromacil		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.2	10	EPA 525.2
Bromate	CECs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	10	ug/L	1	1	317.0
Bromide	CECs	<0.05	<0.05	<0.05	0.32	<0.05	0.27		mg/L	0.05		300.0
Bromobenzene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Bromochloromethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Bromodichloromethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	1	EPA 524.2
Bromoethane		<MRL	<MRL	NS	NS	NS	NS		ug/L	0.5		EPA 524.2
Bromoform		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	1	EPA 524.2
Bromomethane		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		524.2
Butachlor		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	0.38	EPA 525.2
Butylbenzylphthalate		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		EPA 525.2
Cadmium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.2	1	200.8
Caffeine	CECs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ng/L	5		LC-MS-MS
Caffeine by method 525mod		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Calcium		<MRL	<MRL	<MRL	42.1	<MRL	44.2		mg/L	0.5		200.7
Calcium AS CaCO3		<MRL	<MRL	<MRL	105	<MRL	110		mg/L	3		200.7
Carbamazepine	CECs	<MRL	<MRL	<MRL	110	<MRL	130		ng/L	5		LC-MS-MS
Carbaryl		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	5		531.1
Carbofuran (Furadan)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	18	ug/L	5	5	531.1
Carbon disulfide	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	160	ug/L	0.5	0.5	EPA 524.2
Carbon Tetrachloride	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.5	ug/L	0.5	0.5	EPA 524.2
Carbonate (as CO3)		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		mg/L	5		2320 B
Carbonate Alkalinity (as CaCO3)		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		mg/L	5		2320 B
Chlorate	Contaminants with NLs	<DLR	<DLR	21	<DLR	33	37	800	ug/L	20	20	300.1
Chlordane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.1	ug/L	0.1	0.1	505
Chloride	Secondary MCLs	<MRL	<MRL	5	210	8	267	250	mg/L	5		4500-Cl D
Chlorobenzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	70	ug/L	0.5	0.5	EPA 524.2
Chloroethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Chloroform (Trichloromethane)		0.62	0.78	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	1	EPA 524.2
Chloromethane(Methyl Chloride)		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
Chrysene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.02	5	EPA 525.2
cis-1,2-Dichloroethene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		524.2
cis-1,2-Dichloroethylene	Regulated Contaminants	<MRL	<MRL	NS	NS	NS	NS	6	ug/L	0.5	0.5	EPA 524.2
cis-1,3-Dichloropropene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		EPA 524.2
Cobalt		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	1		200.8
Conductivity		61	36	52	1340	74	1550		umhos/cm			2510 B
Copper	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1,300 (primary) 1,000 (secondary)	ug/L	0.5	50	200.8
Cotinine	CECs	<MRL	<MRL	<MRL	74	<MRL	23	1,000	ng/L	10		LC-MS-MS
Cyanide	Regulated Contaminants	<MRL	0.032	<MRL	0.03	<MRL	NS	0.15	mg/L	0.025	0.1	SM4500CN-F
Dalapon	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	200	ug/L	10	10	515.3
DEET	CECs	<MRL	<MRL	12	56	<MRL	28	2,500	ng/L	10		LC-MS-MS
Di(2-Ethylhexyl)adipate	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	400	ug/L	0.5	5	EPA 525.2
Di(2-Ethylhexyl)phthalate	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	4	ug/L	0.5	3	EPA 525.2
Diazinon (Qualitative)	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1.2	ug/L	0.1		EPA 525.2
Dibenz(a,h)Anthracene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	5	EPA 525.2
Dibromoacetic Acid		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	1	1	552.3
Dibromochloromethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	1	524.2
Dibromochloropropane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.2	ug/L	0.01	0.01	504.1
Dibromomethane		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Dicamba		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	1.5	1.5	515.3
Dichloroacetic Acid		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	1	1	552.3
Dichlorodifluoromethane	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1,000	ug/L	0.5	0.5	EPA 524.2
Dichloromethane (methylene chloride)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
Dieldrin		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.2	0.02	EPA 525.2
Dieldrin		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.02	0.02	505
Diethylphthalate		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5	5	EPA 525.2
Di-isopropyl ether		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	2	3	EPA 524.2
Dilantin	CECs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1,000	ng/L	20		LC-MS-MS
Dimethoate		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.1		EPA 525.2
Dimethylphthalate		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5	5	EPA 525.2
Di-n-Butylphthalate		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	1	5	EPA 525.2
Dinoseb	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	7	ug/L	2	2	515.3
Diquat	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	20	ug/L	0.4	4	EPA 549.2
Dissolved Organic Carbon		NS	<0.3	NS	NS	NS	NS		mg/L	0.64		5310 C

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1	Quarter 2	Quarter 3	Quarter 3	Quarter 4	Quarter 4	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
		10/15/2014	1/13/2015	4/1/2015	4/1/2015	7/8/2015	7/8/2015					
Endothall	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	100	ug/L	5	45	EPA 548.1
Endrin	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	2	ug/L	0.1	0.1	EPA 525.2
Estradiol - 17 beta	CECs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ng/L	5		LC-MS-MS
Estrone	CECs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	320	ng/L	5		LC-MS-MS
Ethinyl Estradiol - 17 alpha	CECs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ng/L	5		LC-MS-MS
Ethyl benzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	300	ug/L	0.5	0.5	EPA 524.2
Ethylene Dibromide	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.05	ug/L	0.02	0.02	504.1
Ethylene Glycol	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	14	mg/L	10		8015B
Fluoranthene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.1	5	EPA 525.2
Fluorene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	5	EPA 525.2
Fluoride	Regulated Contaminants	<DLR	<DLR	<DLR	0.49	<DLR	1.49	2	mg/L	0.05	0.1	300.0
Formaldehyde	Contaminants with NLs	7.3	8.3	14	17	14	11	100	ug/L	5		EPA 556
Free Ammonia Nitrogen	Regulated Contaminants	0.19	0.18	0.24	0.24	0.22	0.19	10 (as Total Nitrogen)	mg/L	0.05		4500-NH3 D
gamma-Chlordane		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Glyphosate	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	700	ug/L	25	25	547
Gross Alpha + adjusted error	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	4	15	pCi/L	3		EPA 900.0
Hardness		<MRL	<MRL	<5	244	<10	236		mg/L	10		2340 C
Heptachlor	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.01	ug/L	0.01	0.01	EPA 525.2
Heptachlor Epoxide (isomer B)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.01	ug/L	0.01	0.01	EPA 525.2
Hexachlorobenzene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1	ug/L	0.5	0.5	EPA 525.2
Hexachlorobutadiene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Hexachlorocyclopentadiene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	50	ug/L	1	1	EPA 525.2
Hexavalent Chromium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	10	ug/L	1	1	218.6
HMX	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	350	ug/L	0.1		LC-MS-MS
Hydroxide (as OH)		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		mg/L	5		2320 B
Hydroxide Alkalinity (as CaCO3)		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		mg/L	5		2320 B
Indeno(1,2,3,c,d)Pyrene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05	10	EPA 525.2
Iron	Nutrients	<DLR	<DLR	<DLR	<DLR	<DLR	320	300 (secondary)	ug/L	20	100	200.7
Isophorone		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5	10	EPA 525.2
Isopropylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	770	ug/L	0.5	0.5	EPA 524.2
Kjeldahl Nitrogen	Regulated Contaminants	0.42	0.3	0.56	1.9	0.82	1.9	10 (as Total Nitrogen)	mg/L	0.2		EPA 351.2
Lead	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	15(2)	ug/L	0.5	5	200.8

	Category	Sample Location and Date of Testing						Regulatory Limit (as applicable)	Units	MRL	DLR	Method
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
		Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015					
Lindane	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	0.2	ug/L	0.04	0.2	EPA 525.2
Lithium		<MRL	<MRL	<MRL	9.5	<MRL	9.2		ug/L	5		200.7
m,p-Xylenes		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Magnesium		<MRL	<MRL	<MRL	23.4	<MRL	26.4		mg/L	0.5		200.7
Manganese	Secondary MCLs	<DLR	<DLR	<DLR	60.2	<DLR	50.6	50	ug/L	1	20	200.8
Meprobamate	CECs	<MRL	<MRL	<MRL	19	<MRL	12	200,000	ng/L	5		LC-MS-MS
Mercury	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	2	ug/L	1	1	245.1
Methiocarb		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	2		531.1
Methomyl		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	2	2	531.1
Methoxychlor	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	30	ug/L	10	10	EPA 525.2
Methyl Tert-butyl ether (MTBE)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	13 (primary) 5 (secondary)	ug/L	2	3	EPA 524.2
Metolachlor		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Metribuzin		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Molinate	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	20	ug/L	0.5	2	EPA 525.2
Molybdenum		<MRL	<MRL	<MRL	6	<MRL	7.1		ug/L	1		200.8
Monobromoacetic Acid		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	1	1	552.3
Monochloroacetic Acid		<DLR	<DLR	3.6	<DLR	<DLR	<DLR		ug/L	2	2	552.3
Naphthalene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	17	ug/L	0.5	0.5	EPA 524.2
n-Butylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	260	ug/L	0.5	0.5	EPA 524.2
Nickel	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	100	ug/L	1	10	200.8
Nitrate	Nutrients	4.5	4.4	5.1	71.9	6.9	77.8	10	mg/L	0.05	0.4	300.0
Nitrate as Nitrogen by IC	Regulated Contaminants	0.94	0.99	1.1	16	1.5	17	10	mg/L	0.1	0.4	EPA 300.0
Nitrate as NO3 (calc)	Regulated Contaminants	4.2	4.4	5	72	6.8	77	45	mg/L	0.4	2	EPA 300.0
Nitrite as Nitrogen	Nutrients	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1	mg/L	0.05		4500-NO2 B
Nitrite Nitrogen by IC	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1	mg/L	0.05	0.4	EPA 300.0
N-Nitrosodiethylamine (NDEA)	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	10	ng/L	2		EPA 521
N-Nitroso-dimethylamine (NDMA)	CECs	29	3.8	28	100	15	34	10	ng/L	2		EPA 521
N-Nitrosodi-n-propylamine (NDPA)	Contaminants with NLs	<MRL	<MRL	<MRL	16	<MRL	<MRL	10	ng/L	2		EPA 521
n-Propylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	260	ug/L	0.5	0.5	EPA 524.2
Odor T.O.N.	Secondary MCLs	1.0	NS	NS	NS	NS	NS	3	T.O.N.	1		ODOR
Oxamyl (Vydate)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	50	ug/L	20	20	531.1
o-Xylene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.5	0.5	EPA 524.2
Paraquat		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	2		EPA 549.2

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
Pentachlorophenol	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1	ug/L	0.2	0.2	EPA 525.2
Perchlorate	CECs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	6	ug/L	4	4	314.0
Perfluoro octanesulfonic acid - PFOS	CECs	<MRL	<MRL	<MRL	37	<MRL	<MRL	200	ng/L	5		MWH PFC
Perfluoro octanoic acid - PFOA	CECs	<MRL	<MRL	<MRL	29	<MRL	<MRL	400	ng/L	5		MWH PFC
pH		NS	7.6	7	7.4	8.1	7.3		pH units			PH
Phenanthrene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.04	5	EPA 525.2
Phosphate	Nutrients	<MRL	0.14	0.14	3.2	<0.05	6.69		mg/L	0.05		300.0
Picloram	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	500	ug/L	1	1	515.3
p-Isopropyltoluene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		EPA 524.2
Potassium		0.6	<MRL	<MRL	20.9	0.6	21		mg/L	0.5		200.7
Primidone	CECs	<MRL	<MRL	<MRL	81	<MRL	75	10,000	ng/L	5		LC-MS-MS
Propachlor	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	90	ug/L	0.05	0.5	EPA 525.2
Pyrene		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	0.05	5	EPA 525.2
Radium 226	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	5 (combined 226 and 228)	pCi/L	1	1	Ra-226 GA
Radium 226 Min Detect Activity	Regulated Contaminants	0.43	0.5	0.61	0.46	0.38	0.38		pCi/L	Â		Ra-226 GA
Radium 226 Two Sigma Error	Regulated Contaminants	0.23	<MRL	<MRL	<MRL	<MRL	<MRL		pCi/L	Â		Ra-226 GA
Radium 228	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		pCi/L	1	1	RA-228 GA
Radium 228 Min Detect Activity	Regulated Contaminants	0.7	1.1	1.4	0.83	0.54	0.72		pCi/L	Â		RA-228 GA
Radium 228 Two Sigma Error	Regulated Contaminants	0.62	<MRL	<MRL	<MRL	0.28	<MRL		pCi/L	Â		RA-228 GA
RDX	Contaminants with NLs	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	0.3	ug/L	0.1		LC-MS-MS
sec-Butylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	260	ug/L	0.5	0.5	EPA 524.2
Selenium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	50	ug/L	5	5	200.8
Silica		<MRL	<MRL	<MRL	24	0.6	18.7		mg/L	0.5		200.7
Silver	Secondary MCLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	100	ug/L	1	10	200.8
Simazine	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	4	ug/L	0.25	1	EPA 525.2
Sodium		12.4	9.4	<MRL	133	14.5	200		mg/L	0.5		200.7
Strontium 90 (sub)	Regulated Contaminants	<0.346	<0.400	<0.204	1.61	<.538	<1.64	8	pCi/L	1.6	2	EPA 905.0
Strontium-90, MDA	Regulated Contaminants	0.346	0.4	0.204	0.472	0.538	1.64	8	pCi/L	Â	2	EPA 905.0
Strontium-90, Two Sigma Error	Regulated Contaminants	0.145	0.169	0.116	0.316	0.245	0.633	8	pCi/L	Â	2	EPA 905.0
Styrene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	100	ug/L	0.5	0.5	EPA 524.2
Sucralose	CECs	<MRL	<MRL	<MRL	14000	<MRL	7300	150,000,000	ng/L	100		LC-MS-MS

		Sample Location and Date of Testing										
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
	Category	Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015	Regulatory Limit (as applicable)	Units	MRL	DLR	Method
Sulfate		<DLR	<DLR	<DLR	80.3	<DLR	86.2	250	mg/L	0.5	0.5	300.0
Surfactants	Contaminants with Secondary MCLs	<MRL	<MRL	0.056	0.09	<MRL	0.08	0.5	mg/L	0.05		SM 5540C/EPA 425.1
TCEP	CECs	<MRL	<MRL	<MRL	190	<MRL	190	5000	ng/L	10		LC-MS-MS
Temperature		NS	21	22	22	25	26		Deg. C			TEMP
tert-amyl Methyl Ether		<DLR	<DLR	<DLR	<DLR	<DLR	<DLR		ug/L	3	3	EPA 524.2
tert-Butyl Alcohol	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	12	ug/L	2	2	524.2
tert-Butyl Ethyl Ether		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	3		EPA 524.2
tert-Butylbenzene	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	260	ug/L	0.5	0.5	EPA 524.2
Tetrachloroethylene (PCE)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
Thallium	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	2	ug/L	1	1	200.8
Thiobencarb (ELAP)	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	70 (primary) 1 (secondary)	ug/L	0.2	1	EPA 525.2
Toluene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	150	ug/L	0.5	0.5	EPA 524.2
Total Alkalinity (as CaCO3)		24	16	17	152	22	128		mg/L	5		2320 B
Total Ammonia Nitrogen	Regulated Contaminants	0.46	0.28	0.86	0.26	0.75	0.2	10 (as Total Nitrogen)	mg/L	0.05		4500-NH3 D
Total Filterable Residue at 180C		46	54	34	784	44	910		mg/L			2540 C
Total Haloacetic Acids (5)	Regulated Contaminants	<MRL	<MRL	4	<MRL	<MRL	1	60	ug/L			552.3
Total Nitrate, Nitrite-N, CALC	Regulated Contaminants	0.94	0.99	1.1	16	1.5	17	10	mg/L	0.1	0.4	EPA 300.0
Total Nitrogen-Calc	Regulated Contaminants	1.4	1.3	1.7	18	2.3	19	10	mg/L	0.2	0.4	EPA 353-351
Total Organic Carbon		<DLR	<DLR	<DLR	10.3	<DLR	9.6		mg/L	0.3	0.3	5310 C
Total PCB's (as DCB)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.5	ug/L	0.5	3	505
Total THM	Regulated Contaminants	0.62	0.78	<MRL	<MRL	<MRL	<MRL	80	ug/L	0.5	0.5	EPA 524.2
Total xylenes	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	1750	ug/L			EPA 524.2
Toxaphene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	3	ug/L	1	1	505
trans-1,2-Dichloroethylene	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	10	ug/L	0.5	1	EPA 524.2
trans-1,3-Dichloropropene		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.5		EPA 524.2
trans-Nonachlor		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.05		EPA 525.2
Trichloroacetic Acid		<DLR	<DLR	<DLR	<DLR	<DLR	1.4		ug/L	1	1	552.3
Trichloroethylene (TCE)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	5	ug/L	0.5	0.5	EPA 524.2
Trichlorofluoromethane	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	150	ug/L	2.5	5	EPA 524.2
Trichlorotrifluoroethane (Freon 113)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	1200	ug/L	2	10	EPA 524.2
Triclosan	CECs	<MRL	<MRL	<MRL	39	<MRL	11	2,100,000	ng/L	10		LC-MS-MS
Trifluralin		<MRL	<MRL	<MRL	<MRL	<MRL	<MRL		ug/L	0.1		EPA 525.2

	Category	Sample Location and Date of Testing						Regulatory Limit (as applicable)	Units	MRL	DLR	Method
		SVAWPC Finished Water (UV Effluent)	SVAWPC Finished Water (UV Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)	Finished Water (UV Effluent)	Influent Water (Secondary Effluent)					
		Quarter 1 10/15/2014	Quarter 2 1/13/2015	Quarter 3 4/1/2015	Quarter 3 4/1/2015	Quarter 4 7/8/2015	Quarter 4 7/8/2015					
Tritium	Regulated Contaminants	<174	<183	<181	<188	<190	<184	20,000	pCi/L	300	1000	EPA 906.0
Tritium, Mimimum Dectectable		174	183	181	188	190	184	20,000	pCi/l	0		EPA 906.0
Tritium, Two Sigma Error		171	180	178	182	180	176	20,000	pCi/l	0		EPA 906.0
True Color		<2.5	<2.5	NS	39	<2.5	41		Color Units			2120 C
Turbidity	Secondary MCLs	0.17	0.04	0.2	2.9	0.05	3.7	5	NTU		0.1	2130 B
Uranium by ICPMS as pCi/L	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	20	pCi/L	0.7	1	EPA 200.8
Uranium ICAP/MS	Regulated Contaminants	<MRL	<MRL	<MRL	<MRL	<MRL	<MRL	20	ug/L	1	1	EPA 200.8
Vanadium	Contaminants with NLs	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	50	ug/L	3	3	200.8
Vinyl chloride (VC)	Regulated Contaminants	<DLR	<DLR	<DLR	<DLR	<DLR	<DLR	0.5	ug/L	0.5	0.5	EPA 524.2
Zinc	Secondary MCLs	<DLR	<DLR	<DLR	62	<DLR	<DLR	5,000	ug/L	10	50	200.7

Appendix C. Raw Data for Figures and Tables

Raw data collected as part of this test plan effort for all figures. Corresponding data and figure number are included in the tables below, labeled as figure number and then table.

Figure 4.4 TOC Reduction Across RO

	TOC, mg/L		
	Test 1	**Test 2**	**Test 3**
MF Filtrate	7.35	7.49	7.47
RO Permeate	0.3	0.3	0.3

Figure 4.5 Seeded MS2 Concentrations in MF Effluent, RO Permeate, and RO Concentrate (MS2 Detection Limit of 1 pfu/100 mL)

	Seeded MS2 Concentration								
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
MF Filtrate	2.90E+05	2.60E+05	2.30E+05	2.90E+05	2.60E+05	3.10E+05	2.40E+05	2.60E+05	2.60E+05
RO Permeate	2.30E+02	1.80E+02	2.00E+02	2.00E+02	1.90E+02	2.00E+02	1.40E+02	2.00E+02	2.20E+02
RO Concentrate	1.10E+06	9.80E+05	8.20E+05	1.00E+06	9.00E+05	9.40E+05	1.30E+06	1.70E+06	1.60E+06

Figure 4.6 Concentration of NDMA in RO Influent and RO Permeate

	NDMA, ng/L		
	Test 1	**Test 2**	**Test 3**
MF Filtrate	46	40	32
RO Permeate	18	18	15

Figure 4.7 Removal of Select Constituents by RO

	NDMA, ng/L		
	Test 1	**Test 2**	**Test 3**
Log Removal NDMA	0.41	0.35	0.33
Log Removal TOC	1.39	1.40	1.40
Log Removal of Seeded MS2	3.11	3.16	3.14
Log Removal of Color	NT	0.94	0.94
Log Removal of 1,4-dioxane	1.09	1.09	0.98

Figure 4.9 Log Removal of Seeded MS2 with Old Membranes, and with and without O-ring failure simulation.

	LRV of Seeded MS2					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
Old Membranes	3.9	3.9	4.0	4.0	3.9	4.2
Old Membranes with O-Rings Removed	2.2	2.2	2.4	2.0	2.1	2.1

Figure 4.10 Log Removal of Seeded MS2 with Old Membranes and Old and Damaged Membranes

	Test 1, Old Membranes	**Test 2, Old Membranes**	**Test 3, O-Rings Removed**	**Test 4, O-Rings Removed**
MS2	3.9	4.0	2.3	2.1
TOC	1.4	1.4	1.4	1.4
Conductivity	1.4	1.3	1.3	1.3
UVA	1.1	1.2	1.1	1.1
Color	1.0	1.0	1.0	1.0

Figure 4.13 MS2 Disinfection For Different Power Settings and Failure Simulations

MS2 LRV								
50% Power	**50% Power, 1 lamp out**	**50% Power, 2 lamps out**	**75% Power**	**75% Power, 1 lamp out**	**75% Power, 2 lamps out**	**100% Power**	**100% Power, 1 lamp out**	**100% Power, 2 lamps out**
5.96	6.20	6.20	6.08	6.26	6.28	6.04	6.20	6.20
6.08	6.30	6.36	6.18	6.30	6.26	6.00	6.28	6.23
6.15	6.36	6.20	6.23	6.28	6.23	6.04	6.20	6.45

Figure 4.14 UV Collimated Beam MS2 Dose/Response

Original Validation

4/1/2003		4/1/2003		4/15/2003		4/29/2003		4/30/2003		5/13/2003		5/14/2003	
Delivered UV Dose, mJ/cm2	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose, mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose, mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose, mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**	**Delivered UV Dose mJ/cm2**	**Log Inact of MS-2(1) pfu/mL**
30	1.54	25.56	1.24	22.29	1.19	26.4	1.37	23.2	1.4	28.76	1.45	27.15	1.56
60.17	2.82	51.12	2.41	44.58	2.23	53	2.53	46.5	2.44	57.52	2.69	54.2	2.8
84.24	3.66	71.57	3.17	66.88	3.11	79.5	3.58	69.7	3.37	86.29	3.8	76.03	3.58
108.31	4.51	92.02	3.79	89.17	4.01	106	4.67	93	4.26	115.05	4.88	97.75	4.36

LACSD

5/22/2007	Average UV Dose	Log Reduction
LACSD - 5/22/2007	0	
	20	1.07
	40	1.96
	80	3.53
	120	5.05
LACSD - 7/31/2007	0	
	25	1.39
	50	2.49
	75	3.50
	100	4.32
	120	5.02
LACSD - 4/23/2008	0	
	25	1.50
	50	2.80
	75	3.90
	100	4.70
	120	5.50

DSRSD

DSRSD - 2006	Dose, mJ/cm^2	Log Reduction
	0	0.00
	20	1.27
	39.9	2.18
	59.9	2.88
	106	4.51

Figure 4.16 UV Effluent NDMA Concentrations For Different Power Settings and Failure Simulations

Effluent NDMA

50% Power	50% Power, 1 lamp out	50% Power, 2 lamps out	75% Power	75% Power, 1 lamp out	75% Power, 2 lamps out	100% Power	100% Power, 1 lamp out	100% Power, 2 lamps out
18	24	21	14	20	18	13	15	27
22	17	23	16	17	19	15	16	20

Figure 4.17 ***NDMA Destruction by UV at Different Power Settings***

	50% Power	75% Power	100% Power
log reduction of NDMA	0.2858	0.4108	0.4407

Figure 4.18 ***Correlation Between NDMA Destruction and Total Chlorine Destruction***

	50% Power	50% Power, 1 lamp out	50% Power, 2 lamps out	75% Power	75% Power, 1 lamp out	75% Power, 2 lamps out	100% Power	100% Power, 1 lamp out	100% Power, 2 lamps out
LRV NDMA	0.286	0.275	0.244	0.411	0.320	0.320	0.441	0.397	0.216
LRV Total Chlorine	0.129	0.119	0.075	0.157	0.138	0.136	0.176	0.138	0.164

Figure 4.19 ***Impact of Lamp Power Setting and Lamp Failure on NDMA and Total Chlorine Destruction***

	50% Power	50% Power, 1 lamp out	50% Power, 2 lamps out	75% Power	75% Power, 1 lamp out	75% Power, 2 lamps out	100% Power	100% Power, 1 lamp out	100% Power, 2 lamps out
LRV NDMA	0.286	0.275	0.244	0.411	0.320	0.320	0.441	0.397	0.216
LRV Total Chlorine	0.129	0.119	0.075	0.157	0.138	0.136	0.176	0.138	0.164

Figure 5.2 *Sensor intensity values with varying power levels over 3 repeat measurements*

Test	**Power**	**UVT%**	**Sensor 1 (mW/cm^2)**	**Sensor 2 (mW/cm^2)**
1	100%	96.8	22.82	22.35
	100%	99.2	22.67	22.33
	100%		22.64	22.42
2	50%	94.2	13.64	13.63
	50%	97.8	13.57	13.61
	50%		13.55	13.54
3	75%	96.4	19.69	19.73
	75%	97.5	19.71	19.70
	75%		19.74	19.72

Figure 5.3a *Log-removal of 1,4-Dioxane by UV/H2O2*

Peroxide (mg/L)	**Dose (mJ/cm2)**	**1,4-dioxane**
3	712	0.191
3	999	0.236
3	1155	0.347
1.5	1152	0.301
1.5	1015	0.145
1.5	678	0.171
4	652	0.204
4	738	0.260
4	949	0.263
4	1127	0.477
6	652	0.336
6	738	0.477
6	949	0.589
6	1127	0.568

Figure 5.3b ***Log-removal of 1,4-Dioxane as a Function of Peroxide Weighted Dose***

Peroxide (mg/L)	Peroxide Weighted Dose	1,4-dioxane
3	2136	0.191
3	2996	0.236
3	3465	0.347
1.5	1727	0.301
1.5	1523	0.145
1.5	1017	0.171
4	2608	0.204
4	2952	0.260
4	3796	0.263
4	4508	0.477
6	3912	0.336
6	4428	0.477
6	5694	0.589
6	6762	0.568

Figure 5.4 ***Log-removal of 1,4-Dioxane by UV/NaOCl***

NaOCl (mg/L)	Dose (mJ/cm2)	LRV 1,4 Dioxane
2	674	0.023
2	744	0.075
2	932	0.165
2	1067	0.200
3	651	0.048
3	747	0.133
3	1091	0.133
3	1100	0.165
2	652	0.125
2	738	0.118
2	949	0.117
2	1127	0.189
2	652	0.176
4	738	0.103
4	949	0.187
4	1127	0.165
4	652	0.048
6	738	0.112
6	949	0.187
6	1127	0.097

Figure 5.5 *Finished water values for NDMA with NaOCl at varying UV doses*

Peroxide (mg/L)	Estimated Dose (mJ/cm2)	Effluent NDMA (Finished Water Concentration)
0	420	9.3
0	500	6
0	900	3.1
0	1350	2
0	560	16
0	700	10
0	1200	5.2
0	1700	2
0	900	5.9
0	1125	3.3
0	1500	4.9
0	2250	2.9
1.5	1152	7.5
1.5	1015	7.1
1.5	678	10
3	712	6.6
3	999	5.3
3	1155	5.7
4	652	11
4	738	16
4	949	12
4	1127	5.5
6	652	9.5
6	738	17
6	949	9.7
6	1127	16

Figure 5.6 ***Finished water values for NDMA with NaOCl at varying UV dose values***

NaOCl (mg/L)	Estimated Dose (mJ/cm2)	Effluent NDMA (Finished Water Concentration)
0	420	9.3
0	500	6
0	900	3.1
0	1350	2
0	560	16
0	700	10
0	1200	5.2
0	1700	2
0	900	5.9
0	1125	3.3
0	1500	4.9
0	2250	2.9
2	674	3.7
2	744	3.9
2	932	2.3
2	1067	2
3	651	3.5
3	747	4.1
3	1091	2.1
3	1100	2.6
2	652	6.2
2	738	6.2
2	949	5.8
2	1127	3
2	652	6.8
4	738	5.6
4	949	4.5
4	1127	3.5
4	652	6.8
6	738	5.5
6	949	4.1
6	1127	3.1

Figure 5.7 ***Log-removal of NDMA using hydrogen peroxide with varying estimated UV doses***

Figure 5.8 ***Log-removal of NDMA using hypochlorite with varying estimated UV doses***

		UV Dose (mJ/cm2)			
		652	**738**	**949**	**1127**
		LRV NDMA			
H2O2 (mg/L)	0		0.360	0.360	0.620
	2		0.125	0.149	0.204
	3		0.260	-0.091	0.244
	4	0.691	0.588	0.720	1.135
	6	0.770	0.525	0.769	0.559
NaOCl (mg/L)	0	0.168	0.249	0.238	0.398
	2	0.546	0.523	0.752	0.813
	2	0.412	0.588	0.617	0.903
	3	0.535	0.466	0.757	
	4	0.582	0.667	0.762	0.871
	6	0.615	0.707	0.834	0.956

Figure 5.9 ***Total chlorine destruction by the Hach DPD and amperometric titration methods***

Peroxide (mg/L)	**Total Chlorine Destruction (mg/L)**	
	DPD	**Titration**
0	1.1	0.65
0	1.6	1.02
0	2.1	1.87
0	2.65	1.8
0	1.31	1
0	1.59	1.115
0	1.75	1.53
0	2.21	1.84
0	1.82	1.05
0	1.93	1.83
0	1.93	1.68
0	2.26	1.93
3	2	0.03
3	0.9	0.03
3	-0.5	0.66
1.5	0.7	0.44
1.5	0.5	-0.1

Figure 5.10 Log-removal of NDMA correlated with total chlorine destruction using the Hach DPD method

Total Chlorine Destruction		
Oxidant Dose (mg/L)	**DPD**	**NDMA LRV**
0	1.10	0.3632
0	1.60	0.3073
0	2.10	0.6631
0	2.65	0.8751
0	1.31	0.0726
0	1.59	0.3593
0	1.75	0.6021
0	2.21	0.8835
0	1.82	0.3632
0	1.93	0.6235
0	1.93	0.6198
0	2.26	0.8861
0	0.80	0.1684
0	0.80	0.2485
0	1.00	0.2376
0	1.20	0.3979
2	2.30	0.4117
2	1.80	0.5878
2	4.10	0.6168
2	4.80	0.9031
2	3.90	0.5825
4	4.70	0.6668
4	4.90	0.7618
4	6.00	0.8709
4	1.60	0.6146
6	1.60	0.7068
6	4.80	0.8344
6	5.10	0.9558

Figure 5.11 ***Collimated beam UV/H2O2 and UV/NaOCl log removal of NDMA***

H2O2 (4/1/2015)

UV Dose	Oxidant Dose (mg/L)	log Removal NDMA
652	6	0.6990
1127	6	1.1984

NaOCl (5/14/2015)

UV Dose	Oxidant Dose (mg/L)	log Removal NDMA
0	0	0
738	2	0.5637
1127	2	0.6668
738	4	0.5012
1127	4	0.6668
738	6	0.4418
1127	6	0.9236

Figure 5.12 ***Collimated beam UV/H2O2 and UV/NaOCl log removal of 1,4-Dioxane***

H2O2 (4/1/2015)

UV Dose	Oxidant Dose (mg/L)	Log Removal 1,4-D
0	0	0
0	4	0.0497
652	4	0.2672
738	4	0.3641
949	4	0.3378
1127	4	0.5268
652	6	0.3641
738	6	0.3129
949	6	0.5268
1127	6	0.6237

NaOCl (5/14/2015)

UV Dose	Oxidant Dose (mg/L)	Log Removal 1,4-D
0	0	
652	2	0.0969
738	2	0.1549
949	2	0.1549
1127	2	0.1871
652	4	0.1249
738	4	0.0969
949	4	0.1549

1127	4	0.2218
652	6	0.0969
738	6	0.1249
949	6	0.1549
1127	6	0.1549

Figure 6.12 Tertiary blended recycled water nitrogen species concentrations providing influent water for O_3/BAF system

Figure 6.13 Tertiary blended recycled water free and total chlorine concentrations over the duration of the pilot

	DPD Total Chlorine (mg/L)	**DPD Free Chlorine (mg/L)**	**Nitrite (mg/L)**	**Nitrate (mg/L)**	**Nitrate 1:10 (mg/L)**	**Total Ammonia Nitrogen (mg/L)**	**Free Ammonia Nitrogen(mg/L)**
			DLR (0.4) MRL (0.01)	**DLR (2) MRL (0.05)**		**MRL (0.05)**	**MRL (0.05)**
Date	**Influent (SP 108)**						
1/22/2015	5.1	0.2	0.54	64.1	6.41	1.92	1.32
1/23/2015	1.6	0.74	0.56	56.1	5.61	2.14	1.48
1/26/2015	4.5	0.2	0.45	68.4	6.84	1.73	1.28
1/27/2015	4.3	0.2	0.52	64.4	6.44	1.8	1.14
1/28/2015	4.9	0.7	NT	NT	NT	NT	NT
1/30/2015	8.8	1.7	0.49	77.9	7.79	1.95	1.36
2/1/2015	1.7	0.6	ND	59.1	5.91	1.63	1.12
2/2/2015	8.8	1.2	ND	45.4	4.54	1.58	0.66
2/3/2015	5.4	0.12	ND	49.2	4.92	1.82	0.92
2/4/2015	8.8	1.1	ND	58.7	5.87	1.7	0.62
2/5/2015	7.2	3.5	ND	64.3	6.43	1.52	0.48
2/6/2015	8.8	1.2	ND	59.9	5.99	1.6	0.66
2/8/2015	5.4	0.26	NT	NT	NT	2.28	1.46
2/9/2015	5.2	1.3	NT	NT	NT	1.96	1.26
2/11/2015	4.7	1.2	ND	49.7	4.97	1.46	0.71
2/13/2015	NT	NT	ND	64.2	6.42	NT	0.86
2/18/2015	6.6	1.4	NT	NT	NT	NT	NT
2/19/2015	5.7	0.6	NT	NT	NT	NT	NT
2/20/2015	5.7	1.4	ND	NT	NT	1.58	0.5
2/21/2015	5.9	0.2	NT	NT	NT	NT	NT
2/22/2015	5.9	0.1	NT	NT	NT	NT	NT
2/23/2015	6.5	4.6	ND	74.7	7.47	1.68	0.8
2/24/2015	3.2	0.11	NT	NT	NT	NT	NT
2/25/2015	5.6	1.1	NT	34.1	3.41	1.26	0.38
2/27/2015	5.8	1.4	ND	40.2	4.02	1.5	0.47
3/2/2015	6	1.2	ND	38.4	3.84	1.48	0.53
3/4/2015	5.6	1	NT	NT	NT	NT	NT
3/5/2015	6	1.1	NT	NT	NT	NT	NT
3/6/2015	6.3	1.5	ND	NT	NT	1.4	0.47
3/9/2015	6.2	1.1	NT	57.2	5.72	2.24	1.52
NT = Not-Tested							

ND = Non-Detect

Figure 6.14 ***Percent TOC removal from tertiary blended recycled water influent monitored with grab samples including performance and operational changes and upsets***

	TOC (mg/L)
	DLR (0.3) MRL (0.3)
Date	% TOC Removal
12/11/2014	6.742
12/12/2014	36.06
12/16/2014	11.82
12/17/2014	23.81
12/18/2014	16.67
12/19/2014	20.89
12/20/2014	13.35
12/21/2014	21.47
12/22/2014	14.51
12/23/2014	23.79
12/24/2014	14.96
12/25/2014	11.82
12/26/2014	19.62
12/27/2014	24.75
12/28/2014	15.24
12/29/2014	21.71
12/30/2014	16.67
12/31/2014	49.45
1/1/2015	23.31
1/2/2015	28.54
1/3/2015	46.15
1/4/2015	48.45
1/5/2015	53.68
1/6/2015	56.22
1/7/2015	45.15
1/9/2015	55.44
1/10/2015	56.77
1/11/2015	53.70
1/12/2015	59.51
1/13/2015	38.29
1/14/2015	15.61
1/15/2015	15.73
1/16/2015	32.72
1/17/2015	8.82
1/18/2015	13.24
1/19/2015	8.63
1/20/2015	9.73
1/22/2015	1.18
1/23/2015	21.00

1/24/2015	18.88
1/25/2015	10.84
1/26/2015	16.29
1/27/2015	15.50
1/30/2015	29.23
1/31/2015	21.65
2/1/2015	20.58
2/2/2015	15.00
2/3/2015	24.17
2/4/2015	27.42
2/5/2015	24.15
2/6/2015	19.79
2/8/2015	33.29
2/9/2015	14.13
2/11/2015	20.60
2/13/2015	28.81
2/17/2015	9.71
2/20/2015	22.50
2/21/2015	14.00
2/22/2015	8.94
2/23/2015	9.78
2/24/2015	6.35
2/25/2015	17.44
2/26/2015	8.91
2/27/2015	21.14
3/2/2015	17.89
3/6/2015	26.69
3/9/2015	26.03
3/11/2015	26.18
3/14/2015	20.44
3/19/2015	24.07
3/20/2015	21.70
3/21/2015	20.55
3/22/2015	22.61
3/24/2015	24.03
3/25/2015	25.46
3/26/2015	23.97

Figure 6.15 ***Nutrient and DBP formation and removal in tertiary blended water source at an O$_3$:TOC ratio of 1.01 and an 18.9 min. EBCT***

Figure 6.16 ***Nutrient and DBP formation and removal in tertiary blended water source at an O$_3$:TOC ratio of 1.95 and a 28.2 min. EBCT***

Figure 6.17 ***Nutrient and DBP formation and removal in tertiary blended water source at an O$_3$:TOC ratio of 1.48 and a 29.7 min. EBCT***

Figure 6.18 ***Nutrient and DBP formation and removal in tertiary blended water source at an O$_3$:TOC ratio ratio of 1.56 and a 31.2 min. EBCT***

Figure 6.20 ***Nitrate concentrations (presented as nitrate, not as nitrate-N) following O$_3$ Biofiltration treatment across all test conditions with blended tertiary recycled water***

	Date	**Sample ID**	**EBCT**	**O3:TOC**	**TKN**	**UV 254**	**Bromate**	**Bromide**	**Chlorate**	**Free Amonia**	**Iron**	**Nitrate**	**Nitrite**	**Phosphate**	**Total Ammonia**	**TOC**
Units			**min**	**n/a**	**mg/L**	**cm-1**	**ug/L**	**mg/L**	**ug/L**	**mg/L**	**ug/L**	**mg/L**	**mg/L**	**mg/L**	**mg/l**	**mg/L**

MRL					**0.2**	**0.009**	**1**	**0.05**	**20**	**0.05**	**20**	**0.05**	**0.01**	**0.05**	**0.05**	**0.3**
	1/28/2015	O3 INF AM	18.9	1.01	2.28	0.13	0	0.12	278	1.13	0	66.6	0	3.63	1.73	6.09
	1/28/2015	O3 EFF AM	18.9	1.01	2.50	0.10	0	0.15	280	1.11	100	68.6	0	4.41	1.61	5.76
	1/28/2015	BAF EFF AM	18.9	1.01	0.44	0.08	0	0.17	280	0.08	0	67.8	0.86	3.52	0.08	5.07
	2/18/2015	O3 INF AM	28.2	1.95	1.45	0.13	0	0.19	173	0.72	260	57.0	0	1.11	1.68	5.62
	2/18/2015	O3 EFF AM	28.2	1.95	1.60	0.08	9.94	0.18	218	0.71	0	58.0	0	1.11	1.31	5.64
	2/18/2015	BAF EFF AM	28.2	1.95	0.37	0.06	9.58	0.23	240	0	0	61.3	0	1.04	0	4.25
	3/4/2015	O3 INF AM	29.7	1.48	2.37	0.12	0	0.12	163	0.59	0	44.4	0	0.50	1.39	5.39
	3/4/2015	O3 EFF AM	29.7	1.48	1.83	0.08	3.09	0.15	178	0.58	110	45.2	0	0.52	1.17	5.46
	3/4/2015	BAF EFF AM	29.7	1.48	0.67	0.06	2.72	0.16	190	0	0	48.5	0	0.48	0	4.32
	3/16/2015	O3 INF AM	31.2	1.56	1.93	0.14	0	0.14	178	0.52	0	43.2	0	1.20	1.54	6.49
	3/16/2015	O3 EFF AM	31.2	1.56	1.77	0.10	3.91	0.13	208	0.51	0	43.2	0	1.30	1.27	6.25
	3/16/2015	BAF EFF AM	31.2	1.56	0.47	0.07	1.62	0.14	203	0	0	48.5	0	1.58	0	4.91

Figure 6.19 NDMA removal through O_3/BAF in tertiary blended water source at varying transferred O_3:TOC ratios

Figure 6.21 1,4-dioxane removal through O_3/BAF in tertiary blended water source at varying transferred O_3:TOC ratios

	Date	Sample ID	EBCT	O3:TOC	Average NDMA	Average 1,4-Dioxane
Units			**min**	**n/a**	**ng/L**	**ug/L**
MRL					**2**	**0.07**
	1/28/2015	O3 INF AM	18.9	1.01	233	0.93
	1/28/2015	O3 EFF AM	18.9	1.01	280	0.67
	1/28/2015	BAF EFF AM	18.9	1.01	178	0.59
	2/18/2015	O3 INF AM	28.2	1.95	225	0.63
	2/18/2015	O3 EFF AM	28.2	1.95	270	0.32
	2/18/2015	BAF EFF AM	28.2	1.95	128	0.32
	3/4/2015	O3 INF AM	29.7	1.48	198	0.82
	3/4/2015	O3 EFF AM	29.7	1.48	218	0.52
	3/4/2015	BAF EFF AM	29.7	1.48	119	0.47
	3/16/2015	O3 INF AM	31.2	1.56	250	0.67
	3/16/2015	O3 EFF AM	31.2	1.56	295	0.47
	3/16/2015	BAF EFF AM	31.2	1.56	145	0.44

Figure 6.22 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.01 and an 18.9 minute EBCT

Figure 6.23 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.95 and a 28.2 minute EBCT

Figure 6.24 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.48 and a 29.7 minute EBCT

Figure 6.25 Detected trace pollutant removal from tertiary blended water by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.56 and a 31.2 minute EBCT

	Date	Sample ID	EBCT	O3:TOC	4-nonylphenol	Atenolol	Caffeine	Carbamazepine	Cotinine	DEET	Dilantin	Meprobamate	PFOS	PFOA	Primidone	Sucralose	TCEP	Triclosan
Units			**min**	**n/a**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**µg/L**	**ng/L**	**ng/L**
MRL					**100**	**5**	**5**	**5**	**10**	**10**	**20**	**5**	**5**	**5**	**5**	**100**	**10**	**10**
	1/28/2015	O3 INF AM	18.9	1.01	ND	71.5	ND	175	15.5	ND	61.5	27	5.1	7.6	41	13.5	76.5	ND
	1/28/2015	O3 EFF AM	18.9	1.01	ND	22	ND	ND	5.5	ND	22	20	8.25	9.5	18	11.65	87.5	ND
	1/28/2015	BAF EFF AM	18.9	1.01	ND	7.2	ND	9.6	13.5	ND	24.5	25.5	6.2	13	19	12.5	83	ND
	2/18/2015	O3 INF AM	28.2	1.95	ND	95.5	ND	115	28	28.5	58	6.9	5.6	14	49	7.8	135	ND
	2/18/2015	O3 EFF AM	28.2	1.95	ND	7.45	ND	17.5	25	13	ND	ND	5.65	15	11	5.55	108.5	ND
	2/18/2015	BAF EFF AM	28.2	1.95	ND	ND	ND	17	31.5	25	ND	8.6	ND	14.5	ND	5.75	104	ND
	3/4/2015	O3 INF AM	29.7	1.48	ND	120	ND	90	23	12	32	ND	ND	8.2	ND	9.3	110	24
	3/4/2015	O3 EFF AM	29.7	1.48	ND	15	ND	33	28	ND	ND	ND	ND	8	ND	3.9	96	13
	3/4/2015	BAF EFF AM	29.7	1.48	ND	6	ND	9.5	37	11	ND	ND	5	13	ND	3.3	110	ND
	3/16/2015	O3 INF AM	31.2	1.56	ND	72	8.7	75	25	27	ND	9	ND	14	37	4.9	110	ND
	3/16/2015	O3 EFF AM	31.2	1.56	ND	11	ND	ND	39	ND	ND	5.3	ND	17	10	4.8	81	ND
	3/16/2015	BAF EFF AM	31.2	1.56	ND	ND	ND	6.2	28	ND	ND	7.2	ND	19	10	4.9	76	ND

Figure 6.26 Percent TOC removal across the secondary effluent O_3/Biofiltration pilot duration (grab samples were not taken 3/7-3/20)

Collect_Date	O3 Influent	BAF Eff	% TOC Removal
3/27/2015	10.5	7.13	32.095
3/28/2015	9.97	8.13	18.455
3/29/2015	9.57	7.23	24.451
4/2/2015	10.3	8.47	17.767
4/3/2015	10.9	8.8	19.266
4/4/2015	10.1	8.27	18.119
4/5/2015	10.7	8.6	19.626
4/6/2015	11.4	9.07	20.439
4/7/2015	11.5	8.57	25.478
4/8/2015	10.9	7.95	27.064
4/9/2015	10.8	8.35	22.685
4/10/2015	10.8	8.67	19.722
4/11/2015	10.6	8.27	21.981
4/12/2015	10.2	8.13	20.294
4/13/2015	10.7	8.13	24.019
4/14/2015	10.7	8.13	24.019
4/16/2015	9.87	7.7	21.986
4/18/2015	9.4	6.83	27.340
4/19/2015	10.3	7.7	25.243
4/20/2015	9.63	7	27.310
4/21/2015	9.93	7.03	29.204
4/22/2015	9.57	6.7	29.990
4/23/2015	9.8	7.3	25.510
4/24/2015	9.9	7.77	21.515
4/25/2015	9.9	7.53	23.939
4/26/2015	8.87	7.3	17.700
4/27/2015	10.3	7.37	28.447
4/28/2015	10.1	7.83	22.475
4/29/2015	9.6	7.3	23.958
4/30/2015	10.1	7.47	26.040
5/1/2015	10	7.6	24.000
5/2/2015	10.1	7.43	26.436
5/3/2015	9.9	7.1	28.283
5/4/2015	9.3	6.83	26.559
5/5/2015	9.87	7.57	23.303
5/6/2015	9.53	7.4	22.350
5/7/2015	9.6	7.33	23.646
5/8/2015	9.67	7.63	21.096
5/9/2015	9.47	7.2	23.970
5/10/2015	9.5	7.2	24.211
5/11/2015	9.63	7.1	26.272
5/12/2015	10.5	7.1	32.381
5/14/2015	9.15	6.9	24.590
5/15/2015	9.8	7.47	23.776

5/16/2015	9.43	6.97	26.087
5/17/2015	9.1	7.1	21.978
5/18/2015	9.57	7.23	24.451
5/20/2015	9.7	7.23	25.464
5/21/2015	9.13	7.2	21.139
5/22/2015	9.6	7.47	22.188
5/23/2015	8.9	7.23	18.764
5/24/2015	9.17	7	23.664
5/25/2015	9.63	7.27	24.507
5/26/2015	9.83	7.5	23.703

Figure 6.28 ***Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 0.85 and a 26.2 min. EBCT***

Figure 6.29 ***Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 0.89 and a 30.3 min. EBCT***

Figure 6.30 ***Nutrient removal in secondary treated wastewater at a transferred O_3:TOC ratio of 1.29 and a 21.3 min. EBCT***

Figure 6.31 ***Nitrate concentrations following O_3 Biofiltration treatment across all test conditions with secondary treated wastewater***

	Date	**Sample ID**	**EBCT**	**O3:TOC**	**TKN**	**UV 254**	**Bromide**	**Free Amonia**	**Nitrite**	**Perchlorate**	**Phosphate**	**Total Ammonia**	**Chlorate**	**Nitrate**	**Iron**	**TOC**	**Bromate**
Units			**min**	**n/a**	**mg/L**	**cm-1**	**mg/L**	**mg/L**	**mg/L**	**ug/L**	**mg/L**	**mg/l**	**ug/L**	**mg/L**	**ug/L**	**mg/L**	**ug/L**
MRL					**0.2**	**0.009**	**0.05**	**0.05**	**0.01**	**4**	**0.05**	**0.05**	**20**	**0.05**	**20**	**0.3**	**1**
	4/14/2015	O3 INF AM	26.2	0.85	1.83	0.18	0.21	0.24	0	ND	2.17	0.25	0.0	86.9	0	10.5	0
	4/14/2015	O3 EFF AM	26.2	0.85	1.55	0.09	0.26	0.24	0	ND	2.15	0.25	31.0	86.6	100	11.2	0
	4/14/2015	BAF EFF AM	26.2	0.85	0.858	0.10	0.27	0	0	ND	2.22	0.05	22.5	92.4	0	8.2	0
	5/12/2015	O3 INF AM	30.3	0.89	1.75	0.18	0.29	0.18	0	ND	2.41	0.17	22.0	81.9	260	9.9	0
	5/12/2015	O3 EFF AM	30.3	0.89	1.85	0.10	0.30	0.17	0	ND	2.56	0.16	22.0	81.6	0	10.5	21.6
	5/12/2015	BAF EFF AM	30.3	0.89	0.66	0.09	0.29	0	0	ND	2.06	0	22.0	85.3	0	7.3	18.9
	5/27/2015	O3 INF AM	21.3	1.29	2.2	0.18	0.34	0.19	0	ND	3.38	0.20	21.7	74.6	0	10.2	0
	5/27/2015	O3 EFF AM	21.3	1.29	1.6	0.09	0.28	0.17	0	ND	3.27	0.17	30.0	75.5	110	10.4	66.2
	5/27/2015	BAF EFF AM	21.3	1.29	1	0.11	0.39	0	0	ND	3.79	0	0.0	81.0	0	7.7	18.4

Figure 6.32 **NDMA removal through O$_3$/BAF in secondary treated wastewater influent water source at varying transferred O$_3$:TOC and EBCT ratios**

Figure 6.33 **1,4-dioxane removal through O$_3$/BAF in secondary treated wastewater source at varying transferred O$_3$:TOC and EBCT ratios**

	Date	Sample ID	EBCT	O3:TOC	NDMA	1,4-Dioxane
Units			**min**	**n/a**	**ng/L**	**ug/L**
MRL					**2**	**0.07**
	4/14/2015	O3 INF AM	26.2	0.85	50	1.25
	4/14/2015	O3 EFF AM	26.2	0.85	67	0.49
	4/14/2015	BAF EFF AM	26.2	0.85	33	0.84
	5/12/2015	O3 INF AM	30.3	0.89	41	1.06
	5/12/2015	O3 EFF AM	30.3	0.89	58	0.45
	5/12/2015	BAF EFF AM	30.3	0.89	19	0.86
	5/27/2015	O3 INF AM	21.3	1.29	59	1.10
	5/27/2015	O3 EFF AM	21.3	1.29	80	0.38
	5/27/2015	BAF EFF AM	21.3	1.29	29	1.10

Figure 6.34 **Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 0.85 and a 26.2 minute EBCT**

Figure 6.35 **Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 0.89 and a 30.3 minute EBCT**

Figure 6.36 **Detected trace pollutant removal from secondary effluent by O_3/BAF with a transferred O_3 dose to TOC ratio of 1.29 and a 21.3 minute EBCT**

Date	Sample ID	EBCT	O3:TOC	4-nonylphenol	Atenolol	Carbamazepine	Cotinine	DEET	Dilantin	Estradiol	Estrone	Ethinyl Estradiol	Meprobamate	PFOS	PFOA	Primidone	Sucralose	TCEP	Triclosan
		min	**n/a**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**µg/L**	**ng/L**	**ng/L**
				100	**5**	**5**	**10**	**10**	**20**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**100**	**10**	**10**
4/14/2015	O3 INF AM	26.2	0.85	595	68	140	39.5	44	0	0	6	0	37.5	12.75	11.25	77.5	27.5	245	27.5
4/14/2015	O3 EFF AM	26.2	0.85	145	0	0	5.5	16	0	0	0	0	26.5	6.85	19	15.1	17.5	205	0
4/14/2015	BAF EFF AM	26.2	0.85	160	12	20.5	37	27	0	0	0	0	26.5	5	16.5	38	26	155	0
5/12/2015	O3 INF AM	30.3	0.89	815	130	140	42	26.5	0	0	6.7	0	47	0	0	95.5	31.5	170	0
5/12/2015	O3 EFF AM	30.3	0.89	235	0	0	23.5	0	0	0	0	0	0	0	24	20	21.5	165	0
5/12/2015	BAF EFF AM	30.3	0.89	0	10.2	15	25	15	0	0	0	0	0	0	0	0	22	130	0
5/27/2015	O3 INF AM	21.3	1.29	710	150	240	43	0	0	0	6.35	0	0	0	0	0	26.5	84	0
5/27/2015	O3 EFF AM	21.3	1.29	140	0	0	26	0	0	0	6.35	0	0	0	0	0	13	110	0
5/27/2015	BAF EFF AM	21.3	1.29	100	13.5	34	27.5	0	0	0	6.35	0	0	0	0	0	21	53.5	0

Figure 6.38 Log reduction of MS-2 by applied O_3 doses ranging from 5 - 15 mg/L, performed in triplicate on secondary treated wastewater effluent

Figure 6.39 Log reduction of MS-2 compared to an O_3/(TOC+No_2^-) ratio in secondary treated wastewater effluent

	O3 Dose	MS-2 (PFU/mL)	O3/(TOC+NO2-)	Log Removal MS-2
INF	5.54	4.40E+07	0.32	1.53
EFF	5.54	1.30E+06	0.32	
INF	5.54	3.00E+07	0.32	1.60
EFF	5.54	7.60E+05	0.32	
INF	5.54	3.10E+07	0.32	1.63
EFF	5.54	7.20E+05	0.32	
INF	7.79	2.80E+07	0.46	4.60
EFF	7.79	7.00E+02	0.46	
INF	7.79	5.10E+07	0.46	4.82
EFF	7.79	7.80E+02	0.46	
INF	7.79	3.10E+07	0.46	4.55
EFF	7.79	8.70E+02	0.46	
INF	9.18	4.40E+07	0.62	5.11
EFF	9.18	3.40E+02	0.62	
INF	9.18	4.60E+07	0.62	5.14
EFF	9.18	3.30E+02	0.62	
INF	9.18	4.00E+07	0.62	5.00
EFF	9.18	4.00E+02	0.62	
INF	10.86	4.90E+07	0.64	5.41
EFF	10.86	1.90E+02	0.64	
INF	10.86	4.60E+07	0.64	5.28
EFF	10.86	2.40E+02	0.64	
INF	10.86	6.00E+07	0.64	5.21
EFF	10.86	3.70E+02	0.64	
INF	13.59	4.30E+07	0.76	5.52
EFF	13.59	1.30E+02	0.76	
INF	13.59	5.00E+07	0.76	5.52
EFF	13.59	1.50E+02	0.76	
INF	13.59	5.20E+07	0.76	5.57
EFF	13.59	1.40E+02	0.76	

Appendix D. Quality Assurance Project Plan

The quality assurance project plan (QAPP) was developed before the start of the project in order to provide robust coordination and sample collection throughout the project with all particpiants. The QAPP shows the frequency and rational behind sampling triplicates and additional monitoring. Tables 2.8 through 2.12 have been updated throughout the life of the project and may differ from those currently in Appendix A.

QUALITY ASSURANCE PROJECT PLAN

Silicon Valley Advanced Water Purification Center Potable Reuse Testing Plan.

September 14, 2016

Carollo Engineers
Quality Assurance Project Plan

Santa Clara Valley Water District
Silicon Valley Advanced Water Purification Center Potable Reuse Testing

Title and Approval Sheet

Quality Assurance Project Plan for Silicon Valley Advanced Water Purification Center Potable Reuse Testing

Prepared by:
Carollo Engineers, Inc.
2700 Ygnacio Valley Road, Suite 300
Walnut Creek, CA 94598

Approval by:	Approval Date:
______________________________	______________
Andrew Salveson, P.E. Carollo Engineers, Inc.	Date

Santa Clara Valley Water District

Silicon Valley Advanced Water Purification Center Potable Reuse Testing

QUALITY ASSURANCE PROJECT PLAN

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PROJECT DESCRIPTION

0 GENERAL OVERVIEW

This Quality Assurance Project Plan (QAPP) presents the Quality Assurance & Quality Control (QA/QC) criteria and procedures that will be used over the course of the study entitled “Silicon Valley Advanced Water Purification Center Potable Reuse Testing.” This project is funded by the Santa Clara Valley Water District (District), with intent demonstrate advanced treatment to potable standards. This project has an anticipated duration of one year of monitoring and laboratory analysis, plus additional report and permit writing. This QAPP was prepared by following the “Guidance for Quality Assurance Project Plans (EPA QA/G-5)” published by the USEPA.

Contact List

Table 1.1 Contact List

Responsible Person	**Contact Information**	
Carollo	Primary	Andrew Salveson asalveson@carollo.com Desk: 925-788-9857
	Secondary	Austa Parker aparker@carollo.com Desk: 303-404-6308 Cell: 864-350-3730
District Engineering	Primary	Pam John pjohn@valleywater.org Desk: (408) 630-3003 Cell: (408) 499-4018
	Secondary	Hossein Ashktorab hashktorab@valleywater.org Desk: (408) 630-2291 Cell: (408) 513-4482
District Operations	Primary	Sam Bogale sbogale@valleywater.org Desk: (408) 630-3505 Cell: (408) 930-2640
	Secondary	Crystal Yezman cyezman@valleywater.org Desk: (408) 630-2115 Cell: (408) 784-4031
District Laboratory	Primary	Greg Gibson ggibson@valleywater.org Desk: (408) 630-3219 Cell: (408) 979-5680

Table 1.1 Contact List

Responsible Person	**Contact Information**	
	Secondary	Jim Scott jscott@valleywater.org Desk: (408) 630-3228 Cell:408) 589-7443
District Water Quality	Primary	Lale Guven lguven@valleywater.org Desk: 408) 630-2748 Cell:408) 599-0445
	Secondary	Bruce Cabral bcabral@valleywater.org Desk: (408) 630-2796 Cell: 408) 309-2966

Background Information

Demonstration of treatment performance compliance with IPR standards for the State Water Resources Control Board Division of Drinking Water (DDW) is the main goal for this project. Thinking forward, demonstration of potential future DDW requirements for Direct Potable Reuse (DPR) is also accounted for in the test plan. The current facility is looking to lower energy costs by examining and potentially replacing RO with treatment options that are capable of providing high quality water for IPR surface spreading operations, such as ozone with biofiltration.

Project Definition and Objectives

The objectives of the full-scale and pilot testing detailed in this plan include:

1. Demonstrate SVAWPC Performance According to Design Parameters
2. Demonstrate Pathogen Removal Appropriate for IPR Permit Approval
3. Demonstrate CECs Removal Appropriate for IPR Permit Approval
4. Investigate Innovative Monitoring Techniques and Treatment Modifications
5. Investigate Innovative Treatment Alternatives for Potable Reuse Applications

0 TASK DESCRIPTION

Experimental Design

This project includes challenge testing of the existing full-scale systems as well as pilot testing of new technologies. Challenge testing will involve the MF, RO, and UV systems currently in place, with an anticipated duration of 2 weeks. During this time, performance of existing facilities in removing specific challenge microorganisms and pollutants will be evaluated (Table 1.2). Pilot testing will follow challenge testing and will include both UV AOP

(H_2O_2 or NaOCl addition) and ozone/biofiltration systems. The anticipated outcome of pilot testing is an evaluation of removal rates of specific challenge microorganisms and pollutants through both systems. This information will provide necessary knowledge in order to make an informed decision on appropriate technologies for potable reuse operations.

Table 1.2 Scope of Work

What will be done?	**General Testing Description**
Challenge Testing	
MF Challenge Testing	• Existing full-scale MF will be evaluated for removal of *cryptosporidium*, and fecal coliforms. Particle counting will be performed concurrent with *Cryptosporidium* testing. • Performed in conjunction with influent and effluent turbidity and daily membrane integrity testing.
UV Challenge Testing	• Full-scale UV reactors will be tested for removal of MS-2 Coliphage and NDMA. UVA, Nitrite, and chloramines samples will be taken. • Failure testing will include UV lamp and ballast failure with varying degrees of power input and testing of the effluent. • Perfromed with influent and effluent UVA, UV sensor measurments.
RO Challenge Testing	• Full-scale RO membranes will be evaluated for removal of MS-2 Coliphage, NDMA, and pre-determined CECs. Trasar (TBD), UVA, EC, and TOC will be followed as surrogates for removal of constituents. • Failure testing will include O-ring failure and a membrane breach. These failures will be followed using Trasar (TBD) and MS-2. • Performed with influent and effluent TOC.
UV AOP Pilot Testing	
Pilot Validation	• Pilot will be first validated using 50, 75, and 100% Power with sampling at various UV doses, and measuring for NDMA destruction.
UV/H2O2	• UV doses of 0, 100, 350, 750, and 1000 mJ/cm^2 will be coupled with hydrogen peroxide dosing of 0, 3, and 5 mg/L. • NDMA, seeded 1,4-dioxane, CECs, TOC, nitrite, and chloramines will be tested for removal.
UV/NaOCl	• UV doses of 0, 100, 350, 750, and 1000 mJ/cm^2 will be coupled with sodium hypochlorite dosing of 0, 1, 2, and 4 mg/L. • NDMA, seeded 1,4-dioxane, CECs, TOC, nitrite, chloramines, and free chlorine will be tested for removal.
Ozone/Biofiltration Pilot Testing	
Pilot Mobilization	• Three water sources will be used; with tertiary recycled water from a location nearby trucked in. • Xylem will deliver the pilot trailer which includes fully automated O_3 generation and necessary O_3 off-gas monitoring and destruction.

Table 1.2 Scope of Work

What will be done?	General Testing Description
Biological acclimation	• The ozone and biological filtration step will being with a 4 week acclimation period. • The O_3:TOC ratio will be set at 0.75. • EBCT of biofilter will be 10 minutes. • TOC (online and grab samples), ozone residual concentrations, and UVA (online and grab samples) will be used to monitor the acclimation of the biofilter over this period.
Pilot Testing	• Several testing conditions will be studied during the pilot, including O_3:TOC ratios of 0.75 and 1.0 accompanied by changing EBCTs of the biofilter: 10, 20, and 30 minutes. • After the ozone dose and EBCT are changed, a 2 week acclimation period allows for stabilization before sampling on 2 consecutive days. • Residual ozone monitoring, TOC, UVA, seeded MS-2 Coliphage, NDMA, Nutrients, Bromate, Bromide, CECs, and seeded 1,4-dioxane will be tested for removal. • Testing locations include pilot influent, ozone effluent, and Biofiltration effluent.
Batched Water Testing	• The reclaimed water source must travel several miles, and therefore contains a higher NDMA formation potential due to travel time, and will be batch tested for NDMA formation/destruction. • Batched systems will be tested in 2 full days total with O_3:TOC ratios of 0.75 and 1.0 and EBCT of 10, 20, and 30 minutes. • Monitoring will include online and TOC grab samples, UVA, ozone residual, NDMA, nutrients, bromate and bromide.
Water Quality Monitoring of plant influent, RO influent, RO effluent, and finished water.	
Monthly	• Bi-monthly monitoring of existing plant effluent for total nitrogen (TN).
Quarterly	• Effluent monitoring for NDMA, 1,4-Dioxane, CECs, Regulated Contaminants, regulated contaminants with secondary MCLs, chemicals with NLs and lead and copper will be monitored. • RO influent and effluent will be monitored for 1,4-Dioxane and NDMA quarterly. • Influent water quality will be monitored using online TOC measurements.

Pilot Testing and Evaluation Plan

UV AOP System

The LBX90 advanced oxidation pilot system at the SVAWPC is a smaller-scale version of the Xylem/WEDECO LBX1000 UV reactor in use at the full scale. The LBX90 reactor houses four 330W low pressure high output lamps. The pilot setup includes an upstream flash mixer, flow meters, a chemical storage tank, and a chemical dosing station. The value of the LBX90 reactor is the ability to run low flows through this system, add in H_2O_2 and NaOCl at various dose values, and generate hydroxyl radicals for advanced oxidation of trace pollutants.

Removal will be evaluated using spiked NDMA, seeded 1,4-dioxane, CECs, TOC, nitrite, UVA, chloramines, and free chlorine influent and effluent monitoring over specific UV and oxidant doses and time points. The ability to destroy NDMA and 1,4-dioxane will provide the optimized UV and oxidant (H_2O_2 or NaOCl) dose for the most efficient removal.

Ozone/Biofiltration System

Fully-automated Ozone and Biofiltration pilot systems will be provided by Xylem. Two ozone to total organic carbon (O_3:TOC) ratios (0.75 and 1.0) with three EBCTs (10, 20, and 30 minutes) will be used to optimize pilot performance and evaluate removal. Removal of MS-2 coliphage, NDMA, nutrients, bromated, bromide, CECs, and 1,4-dioxane will be the main points of evaluation.

0 SAMPLING AND EXPERIMENTAL TESTING SCHEDULE

A general project schedule by quarter is found in Table 1.3 with the majority of the sampling and analytical effort to take place in Q1. Specific testing by day is shown in process sampling effort and scheduling (Table 2.1 through Table 2.5). All challenge testing on existing processes (MF, RO, and UV) will be performed in quarter 1 during the first 2 weeks. The UV AOP pilot will be started following challenge testing with validation and testing of hydrogen peroxide versus sodium hypochlorite. The ozone/Biofiltration pilot will be started during week 3 with 4 weeks of acclimation following, and then testing with varying O3:TOC ratios and EBCT; which will continue through Quarter 2 and into Quarter 3. Water quality monitoring will be conducted throughout the study for the full duration (1 year) of this sampling effort.

Table 1.3 Quarterly Sampling Schedule

	Q1	Q2	Q3	Q4
MF Challenge Testing	▨			
UV Challenge Testing	▨			
RO Challenge Testing	▨			
UV AOP Pilot	▨			
O3/Biofiltration Pilot	▨	▨	▨	
WQ Monitoring	▨	▨	▨	▨

0 PROJECT ORGANIZATION

The project will be run by the District Recycled Water Unit, District Operations/water quality unit, District Lab Unit-Water Quality Lab, and Carollo Engineers, as shown in Table 1.4. The

District Recycled Water Unit and Carollo will oversee all testing, analysis, reporting and regulatory efforts. The operations unit will work with the management team and the water quality laboratory for sampling efforts and operational efforts related to challenge and pilot testing as needed. The Water Quality Lab (WQL) for the district will assist with sample collection and a large portion of sampling analysis as outlined in Table 2.7**.**

Table 1.4 Organizational Responsibilities of the Project

Organization	**Role**	**Responsibility**
District Recycled Water Unit/Carollo	Management	• Management of all testing, analysis reporting and regulatory efforts.
District Operations Unit/Water Quality Unit	Operations and pilot installation	• Operation of full-scale treatment system during challenge testing and monitoring. • Installation and operation of all pilot treatment systems. • Daily/routine sampling in the detailed testing in this protocol. • Installation of particle counters ahead and after MF for challenge testing. • Also working with Carollo during RO challenge testing.
District Lab Unit – Water Quality Lab (WQL)	Laboratory analysis and sampling	• Assistance with all sample collection, and sample analysis where possible.

Table 1.4 Organizational Responsibilities of the Project

Organization	**Role**	**Responsibility**
Carollo Engineers	Development of protocols and sample coordination.	• Development of pilot test protocol. • Development of a QAPP (this document) • Provide assistance to WQL with coordination to outside labs regarding analytical methods, frequency of testing, number of samples and necessary detection limits. • Sampling and field assistance during all challenge testing of full-scale and pilot systems. • Development of summary report. • Provide regulatory assistance, when needed.
Outside laboratories (several)	Laboratory Analysis of Samples Collected	• Provide measurements and analytical assistance on necessary samples.
NWRI Independent Advisory Panel (IAP)	Review	• Provide review of test protocol, subsequent data and reports related to work.

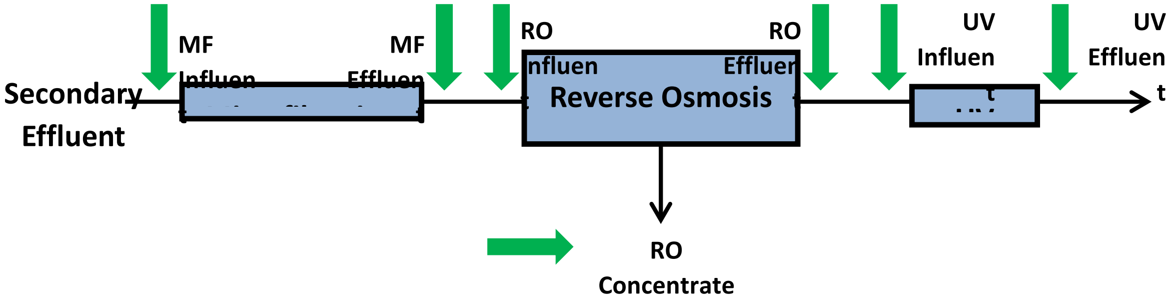
Data Generation and Acquisition

0 SAMPLING PLAN

Challenge Testing

The existing facility will be sampled at the influent to the plant, pre and post-MF for challenge testing, pre, post, and brine from RO for challenge testing, and pre and post- UV for challenge testing (Figure 2.1). Sampling labels correspond to sample location in Tables Table 2.1 through Table 2.5.

Figure 2.1 Existing facility processes and locations to be sampled for challenge testing.



Sampling Frequency and Timing

MF Challenge Testing

Microfiltration challenge testing will include sampling at the influent (MF Influent) and effluent (MF effluent) locations. Testing will include both online and grab turbidity samples, *E. coli*, fecal coliform, *Cryptosporidium*, and particle counting testing. Pressure decay testing will be performed on the membranes in an effort to track membrane performance over time. Sampling efforts will require low effort for plant operations staff, and will be conducted over one day, repeated once for a total of two days of sampling (Table 2.1).

Table 2.5 Microfiltration Challenge Testing Sampling Plan

					MF Influent						MF Effluent				
Week	**Day**	**Test Description**	**Systems to Be Tested**	**Testing Plan**	**Turbidity (online and grab)**	**E. coli**	**Fecal Coliform**	**Pressure Decay Testing**	**Crypto**	**Particle**	**Turbidity (online and grab)**	**E. Coli**	**Fecal Coliform**	**Crypto**	**Particle Counting**
1	Monday AM	MF Challenge Test	MF	Normal Operation	1	3	3	1	3	3	1	3	3	3	3
	Monday PM				1	3	3	1	3	3	1	3	3	3	3
	Wednesday AM	MF Challenge Test	MF	Normal Operation	1	3	3	1	3	3	1	3	3	3	3
	Wednesday PM				1	3	3	1	3	3	1	3	3	3	3

UV Challenge Testing Plan

UV Challenge testing will take place at the influent and effluent of the UV reactor post – reverse osmosis. UV Testing will include several UV fluence levels dictated by flow, reactors in series, and UV power being applied by the lamps. Failure testing includes one ballast out of service in one and two reactors with varying levels of power (50, 75, and 100% UV power). Sampling efforts will include duplicate sampling for NDMA, seeded MS-2 coliphage (triplicate), UVA (online and grab samples), nitrite, total chlorine and free chlorine residual, and TOC grab samples. A high level of effort from plant operations staff will be required for testing, and testing is planned to take place in one day (Table 2.2).

Table 2.6 UV Challenge Test Sampling Plan

						UV Influent							UV Effluent						
Week	Day	Test Description	Systems to Be Tested	Testing Plan	UV Fluence (mJ/cm^2)	NDMA, duplicate sampling	MS-2 Coliphage (seeded, triplicate sampling)	UVA (online and grab)	Nitrite	Total Chlorine Residual	Free Chlorine Residual	TOC (grabs, not online)	NDMA, duplicate sampling	MS-2 Coliphage (seeded, triplicate sampling)	UVA (Online and grab)	Nitrite	Total Chlorine Residual	Free Chlorine Residual	TOC (grabs, not online)
1	Tuesday	UV Challenge Testing	UV	1.6 MGD per train, 2 reactors in series, 50% UV Power	≈ 550	2	3	1	1	1	1	1	2	3	1	1	1	1	1
				1.6 MGD per train, 2 reactors in series, 75% UV Power	≈ 675	2	3	1	1	1	1		2	3	1	1	1	1	
				1.6 MGD per train, 2 reactors in series, 100% UV Power	>800	2	3	1	1	1	1		2	3	1	1	1	1	
				Failure Condition 1 - 1.6 MGD per train, 2 reactors in series, 50% UV Power, one ballast out of service in one reactor	<550	2	3	1	1	1	1	1	2	3	1	1	1	1	1
				Failure Condition 1 - 1.6 MGD per train, 2 reactors in series, 75% UV Power, one ballast out of service in one reactor	<675	2	3	1	1	1	1		2	3	1	1	1	1	
				Failure Condition 2 - 1.6 MGD per train, 2 reactors in series, 100% UV Power, one ballast out of service in one reactor	<800	2	3	1	1	1	1		2	3	1	1	1	1	
				Failure Condition 3 - 1.6 MGD per train, 2 reactors in series, 50% UV Power, one ballast out of service in both (two) reactors	<550	2	3	1	1	1	1	1	2	3	1	1	1	1	1
				Failure Condition 3 - 1.6 MGD per train, 2 reactors in series, 75% UV Power, one ballast out of service in one reactor.	<675	2	3	1	1	1	1		2	3	1	1	1	1	
				Failure Condition 4 - 1.6 MGD per train, 2 reactors in series, 100% UV Power, one ballast out of service in one reactor.	<800	2	3	1	1	1	1		2	3	1	1	1	1	

RO Challenge Testing Plan

Challenge testing for the existing reverse osmosis (RO) system will take place at three locations: RO influent (MF effluent), RO effluent (UV influent), and RO concentrate. RO challenge testing will include duplicate testing of both RO ring failure and membrane failure as well as testing on normal operations. Turbidity, electrical conductivity, CECs, seeded MS-2 and 1,4-Dioxane, NDMA, Trasar (TBD), UVA (online and grab), TOC (online and grab), and color will be tested for in both the influent and effluent samples. RO concentrate will have more limited testing of CECs (under normal operation), seeded MS-2 coliphage, trasar (TBD), and online UVA. A small amount of effort will be required by plant operations staff for the first day of RO challenge testing under normal operations, and a larger amount of effort will be needed for failure testing in week 7 (Table 2.3). This section will be modified and expanded based on results from the RO Challenge Testing in Big Spring, TX.

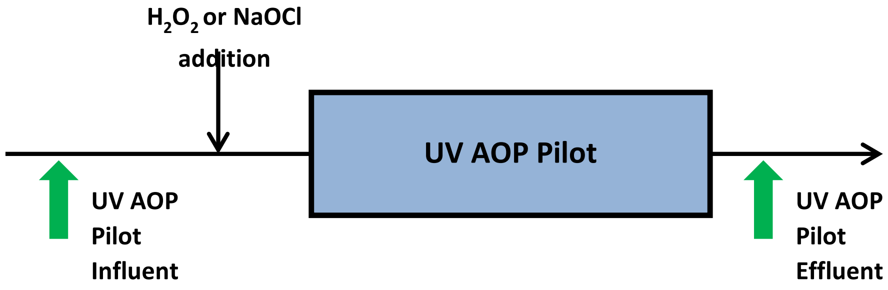
Table 2.7 RO Challenge Testing Sampling Plan

					RO Influent												RO Effluent												RO Concentrate			
Week	Day	Test Description	Systems to Be Tested	Testing Plan	Turbidity	Electrical conductivity (EC, online)	CECs	1,4-Dioxane	NDMA	MS-2 Coliphage (seeded,	Trasar (TBD)	UVA (online)	UVA (grab)	TOC (grab)	TOC (online)	Color	Turbidity	Electrical conductivity (EC), online	CECs	1,4-Dioxane	NDMA	MS-2 Coliphage (seeded,	Trasar (TBD)	UVA (online)	UVA (grab)	TOC (grab)	TOC (online)	Color	CECs	MS-2 Coliphage (seeded)	Trasar (online), use	UVA (online)
3	Tuesday AM	RO Challenge Testing	RO	Normal Operation	1	Online	1	1	2	3	Online	Online	1	1	Online	1	1	Online	1	1	2	3	Online	Online	1	1	Online	1	1	3	Online	Online
	Tuesday Noon				1		1	1	2	3			1	1		1	1		1	1	2	3			1	1		1	1	3		
	Tuesday PM				1		1	1	2	3			1	1		1	1		1	1	2	3			1	1		1	1	3		
7	Wednesday AM	RO Challenge	RO	O-Ring Failure (Test 1)	1					3			1	1		1	1					3			1	1		1		3		
	Wednesday AM		RO	O-Ring Failure (Test 2)	1					3			1	1		1	1					3			1	1		1		3		
	Wednesday PM		RO	Membrane Breach (Test 1)	1					3			1	1		1	1					3			1	1		1		3		
	Wednesday PM		RO	Membrane Breach (Test 2)	1					3			1	1		1	1					3			1	1		1		3		

UV AOP Pilot Testing

The UV AOP pilot will be sampled at the influent and effluent with both UV/H_2O_2 and UV/NaOCl processes (Figure 2.2).

Figure 2.2 UV AOP pilot sampling locations for NaOCl and H_2O_2 pilot testing addition.



UV AOP pilot testing will take place in the first 3 months of the project, beginning on week 3 of testing with validation of the pilot reactor with no oxidant dosing. Oxidant dosing will follow starting in Week 5 of the testing effort. NDMA removal will be determined to properly evaluate the UV dose applied in the reactor. Testing of two oxidations (NaOCl and H2O2) will take place subsequently and compared for removal of NDMA, 1,4-Dioxane, CECs, and residual chloramines and free chlorine will be monitored. Several UV doses and oxidant doses will be tested for removal of target compounds and background constituents, as shown in Table 2.4.

Table 2.8 UV AOP Pilot Testing Sampling Plan

								UV AOP Pilot Influent									UV AOP Pilot Effluent								
Week	Day	Test Description	Systems to Be Tested	Testing Plan	UV Fluence (mJ/cm²)	[H2O2] (mg/L)	NaOCl (mg/L)	NDMA	1,4-Dioxane (seeded)	CECs	pH	TOC (grab, not online)	Nitrite	UVA (grab, not online)	Chloramines	Free Chlorine	NDMA	1,4-Dioxane	CECs	pH	TOC (grab, not online)	Nitrite	UVA	Chloramines	Free Chlorine
3	Monday	UV AOP Pilot (Validation)	UV AOP	50% Power	100			1				1	1	1	1	1	1				1	1	1	1	1
					350			1						1	1	1	1					1	1	1	1
					750			1						1	1	1	1					1	1	1	1
					1000			1						1	1	1	1					1	1	1	1
		UV AOP Pilot (Validation)	UV AOP	75% Power	100			1				1	1	1	1	1	1				1	1	1	1	1
					350			1						1	1	1	1					1	1	1	1
					750			1						1	1	1	1					1	1	1	1
					1000			1						1	1	1	1					1	1	1	1
		UV AOP Pilot (Validation)	UV AOP	100% Power	100			1				1	1	1	1	1	1				1	1	1	1	1
					350			1						1	1	1	1					1	1	1	1
					750			1						1	1	1	1					1	1	1	1
					1000			1						1	1	1	1					1	1	1	1
5	Monday	UV AOP Pilot (UV/H2O2)	UV AOP	UV/H2O2	0	0									1									1	
					100			1	1	1	1	1	1	1	1		1	1		1		1	1	1	
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1		1		1	1	1	
					1000									1	1		1	1	1	1	1	1	1	1	
				UV/H2O2	0	3											1	1	1	1		1	1	1	
					100			1	1		1	1	1	1	1		1	1		1		1	1	1	
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1	1	1		1	1	1	
					1000									1	1		1	1		1	1	1	1	1	
				UV/H2O2	0	5											1	1	1	1		1	1	1	
					100			1	1	1	1	1	1	1	1		1	1		1		1	1	1	
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1	1	1		1	1	1	
					1000									1	1		1	1		1	1	1	1	1	
				UV/H2O2	0	0											1	1		1		1	1	1	
					100			1	1	1	1	1	1	1	1		1	1		1		1	1	1	
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1		1		1	1	1	
					1000									1	1		1	1		1	1	1	1	1	
				UV/H2O2	0	3											1	1		1		1	1	1	
					100			1	1		1	1	1	1	1		1	1		1		1	1	1	

Table 2.8 UV AOP Pilot Testing Sampling Plan

								UV AOP Pilot Influent									UV AOP Pilot Effluent								
Week	Day	Test Description	Systems to Be Tested	Testing Plan	UV Fluence (mJ/cm²)	[H2O2] (mg/L)	NaOCl (mg/L)	NDMA	1,4-Dioxane (seeded)	CECs	pH	TOC (grab, not online)	Nitrite	UVA (grab, not online)	Chloramines	Free Chlorine	NDMA	1,4-Dioxane	CECs	pH	TOC (grab, not online)	Nitrite	UVA	Chloramines	Free Chlorine
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1		1		1	1	1	
					1000									1	1		1	1		1	1	1	1	1	
				UV/H2O2	0	5											1	1		1		1	1	1	
					100			1	1	1	1	1	1	1	1		1	1		1		1	1	1	
					350									1	1		1	1		1		1	1	1	
					750									1	1		1	1		1		1	1	1	
					1000									1	1		1	1		1	1	1	1	1	
	Tuesday	UV AOP Pilot (UV/NaOCl)	UV AOP	UV/NaOCl	0		0									1	1	1	1	1		1	1	1	1
					100			1	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1		1		1	1	1	1
					1000									1	1	1	1	1	1	1	1	1	1	1	1
				UV/NaOCl	0		1										1	1	1	1		1	1	1	1
					100			1	1		1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1	1	1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1
				UV/NaOCl	0		2										1	1	1	1		1	1	1	1
					100			1	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1	1	1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1
				UV/NaOCl	0		4										1	1	1	1		1	1	1	1
					100			1	1		1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1	1	1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1
				UV/NaOCl	0		0										1	1		1		1	1	1	1
					100			1	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1		1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1

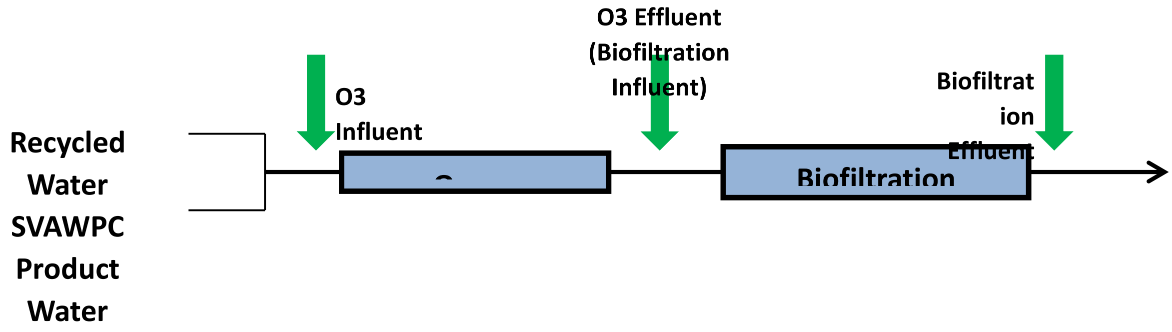
Table 2.8 UV AOP Pilot Testing Sampling Plan

								UV AOP Pilot Influent									**UV AOP Pilot Effluent**								
Week	**Day**	**Test Description**	**Systems to Be Tested**	**Testing Plan**	**UV Fluence (mJ/cm^2)**	**[H2O2] (mg/L)**	**NaOCl (mg/L)**	**NDMA**	**1,4-Dioxane (seeded)**	**CECs**	**pH**	**TOC (grab, not online)**	**Nitrite**	**UVA (grab, not online)**	**Chloramines**	**Free Chlorine**	**NDMA**	**1,4-Dioxane**	**CECs**	**pH**	**TOC (grab, not online)**	**Nitrite**	**UVA**	**Chloramines**	**Free Chlorine**
				UV/NaOCl	0		1										1	1		1		1	1	1	1
					100			1	1		1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1		1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1
				UV/NaOCl	0		2										1	1		1		1	1	1	1
					100			1	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1		1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1
				UV/NaOCl	0		4										1	1		1		1	1	1	1
					100			1	1		1	1	1	1	1	1	1	1		1		1	1	1	1
					350									1	1	1	1	1		1		1	1	1	1
					750									1	1	1	1	1		1		1	1	1	1
					1000									1	1	1	1	1		1	1	1	1	1	1

Ozone/Biofiltration Pilot Testing

O_3/Biofiltration will be sampled at the influent, post-O_3 (also biofiltration influent) and post-biofiltration points (Figure 2.3).

Figure 2.3 Ozone/biofiltration pilot sampling locations corresponding to sampling plan.



Testing of the Ozone/Biofiltration pilot will take place in quarters 1 through 3 of the project (7 months), with startup requiring 4 weeks of acclimation with monitoring during that time. Each EBCT and TOC:O_3 ratio requires 2 weeks of acclimation after changes have been made. After 2 weeks of acclimation, testing will follow, as shown in Table 2.5. After optimization of EBCT and O_3:TOC ratios have been sampled, a sampling effort with water source with potentially higher NDMA formation will be studied (batched water testing). Additional constituents (such as aldehydes) to test for in the O_3/biofiltration process could potentially be added after review.

Table 2.9 Ozone and Biofiltration Pilot Testing Sampling Plan

						O3 Influent												O3 Effluent (Biofiltration Influent)											Biofiltration Effluent										
Week	Day	Test Description	Testing Plan	O3:TOC	Biofilter EBCT (min)	TOC (mg/L) (grab	TOC (mg/L) (online)	[O3] mg/L, Dose	UVA (grab)	MS-2 Coliphage	NDMA	Nutrients	Bromate	Bromide	CECs	1,4-Dioxane (seeded)	UVA (online)	TOC (mg/L) (grab	[O3] mg/L	UVA (grab)	MS-2 Coliphage	NDMA	Nutrients	Bromate	Bromide	CECs	1,4-Dioxane (seeded)	UVA (online)	TOC (mg/L) (grab	TOC (mg/L) (online)	[O3] mg/L	UVA (grab)	NDMA	Nutrients	Bromate	Bromide	CECs	1,4-Dioxane (seeded)	UVA (online)
10	Monday	O3 and Biofiltration Startup	Startup Activities (4-weeks)	0.75	10	1	Continuous	Continuous									Continuous	1										Continuous	1	Continuous									
	Tuesday			0.75	10	1												1											1										
11, 12, & 13	Monitoring O3/BAF (daily monitoring of ozone dose and residual, TOC across system (ozone influent, effluent and BAF effluent)). Monitoring done by District Staff	O3 and Biofiltration Startup	Startup Activities (4-weeks)	0.75	10																																		
14	Monday AM		Normal Operation	0.75	10		continuous																																
	Monday AM	O3/BAF Pilot Testing	0.75 O3:TOC @ 10 min EBCT	0.75	10	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Monday PM			0.75	10	1		1	1	3	1	1	1	1		1		1	1	1	3	1	1	1	1		1		1		1	1	1	1	1	1		1	
	Tuesday AM			0.75	10	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Tuesday PM			0.75	10	1		1	1	3	1	1	1	1		1		1	1	1	3	1	1	1	1		1		1		1	1	1	1	1	1		1	
	Wednesday	O3/BAF Pilot Acclimation	1.0 O3:TOC @ 10 min EBCT	1	10																																		
	Thursday			1	10																																		
	Friday			1	10																																		
15	Monday			1	10																																		
	Tuesday			1	10																																		
	Wednesday			1	10																																		
	Thursday			1	10																																		
	Friday			1	10																																		
16	Monday			1	10																																		
	Tuesday			1	10																																		
	Wednesday AM	O3/BAF Pilot Testing		1	10	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Wednesday PM			1	10	1		1	1	3	1	1	1	1		1		1	1	1	3	1	1	1	1		1		1		1	1	1	1	1	1		1	

Table 2.9 Ozone and Biofiltration Pilot Testing Sampling Plan

						O3 Influent												O3 Effluent (Biofiltration Influent)											Biofiltration Effluent										
	Thursday AM			1	10	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	▨
	Thursday PM			1	10	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	▨
	Friday	O3/BAF Pilot Acclimation	0.75 O3:TOC @ 20 min EBCT	0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
17	Monday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Tuesday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Wednesday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Thursday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Friday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
18	Monday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Monday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Tuesday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Wednesday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Thursday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
	Friday			0.75	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	▨
19	Monday AM	O3/BAF	0.75 O3:TOC @ 20 min EBCT	0.75	20	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	continuous
	Monday PM			0.75	20	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Tuesday AM			0.75	20	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Tuesday PM			0.75	20	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Wednesday	O3/BAF Pilot Acclimation	1.0 O3:TOC @ 20 min EBCT	1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Friday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
20	Monday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Tuesday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Wednesday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Friday			1	20	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
21	Monday	O3/BAF		1	20	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
	Tuesday			1	20	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
	Wednesday AM			1	20	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Wednesday PM			1	20	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Thursday AM			1	20	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	

Table 2.9 Ozone and Biofiltration Pilot Testing Sampling Plan

						O3 Influent												**O3 Effluent (Biofiltration Influent)**											**Biofiltration Effluent**										
	Thursday PM			1	20	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Friday	O3/BAF Pilot Acclimation	0.75 O3:TOC @ 30 min EBCT	0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
22	Monday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Monday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Tuesday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Wednesday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Friday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
23	Monday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Tuesday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Wednesday			0.75	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday	O3/BAF		0.75	30	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
	Friday			0.75	30	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
24	Monday AM			0.75	30	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Monday PM			0.75	30	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Tuesday AM			0.75	30	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Tuesday PM			0.75	30	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Wednesday	O3/BAF Pilot Acclimation	1.0 O3:TOC @ 30 min EBCT	1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Friday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
25	Monday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Tuesday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Wednesday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Thursday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Friday			1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
26	Monday	O3/BAF		1	30	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨		▨	▨	▨	▨	▨	▨	▨	▨	
	Monday			1	30	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
	Tuesday			1	30	▨		1	1	▨	▨	▨	▨	▨	▨	▨		▨	1	1	▨	▨	▨	▨	▨	▨	▨		▨		1	1	▨	▨	▨	▨	▨	▨	
	Wednesday AM			1	30	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	
	Wednesday PM			1	30	1		1	1	3	1	1	1	1	▨	1		1	1	1	3	1	1	1	1	▨	1		1		1	1	1	1	1	1	▨	1	
	Thursday AM			1	30	1		1	1	3	1	1	1	1	1	1		1	1	1	3	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	

Table 2.9 Ozone and Biofiltration Pilot Testing Sampling Plan

						O3 Influent												**O3 Effluent (Biofiltration Influent)**											**Biofiltration Effluent**										
	Thursday PM			1	30	1		1	1	3	1	1	1	1		1		1	1	1	3	1	1	1	1		1		1		1	1	1	1	1	1		1	
	Friday	O3/BAF Pilot Acclimation	0.75O3:TOC @ 10 min EBCT	0.75	10																																		
27	Monday AM	Batched Water Pilot Testing (Table 7)	0.75 O3:TOC @ 10 min EBCT	0.75	10	1	Continuous	1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			Continuous
	Monday AM		1.0 O3:TOC @ 10 min EBCT	1	10	1		1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			
	Monday PM		0.75 O3:TOC @ 20 min EBCT	0.75	20	1		1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			
	Monday PM		1.0 O3:TOC @ 20 min EBCT	1	20	1		1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			
28	Monday AM	Batched Water Pilot Testing (Table 7)	0.75 O3:TOC @ 30 min EBCT	0.75	30	1		1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			
	Monday AM		1.0 O3:TOC @ 30 min EBCT	1	30	1		1	2		2	1	1	1				1	1	2		2	1	1	1				1		1	2	2	1	1	1			

Monitoring

Monitoring requirements include monitoring for CECs, 1,4-Dioxane and NDMA at the RO influent and effluent as well as finished water quality monitoring that includes: regulated contaminants, contaminants with secondary MCLs, chemicals with notification levels, lead, copper, NDMA, 1,4-Dioxane and CECs.RO Influent and effluent TOC and EC must be measured and online at all times. Bi-weekly total nitrogen samples are also required for all four quarters in the finished effluent, as listed in Table 2.6.

Table 2.10 Monitoring Frequency and Location

	Location			
Frequency	**Influent**	**RO Influent**	**RO Effluent**	**Finished Water**
Continuous	TOC	TOC, EC	TOC, EC	
Bi-weekly				Total Nitrogen
Monthly		NDMA, 1,4-Dioxane	NDMA, 1,4-Dioxane	NDMA, 1,4-Dioxane
Quarterly				Regulated Contaminants, Contaminants with secondary MCL, Chemicals with NLs, lead, copper, NDMA, 1,4-Dioxane, CECs

0 ANALYTICAL METHODS, SAMPLING CONTAINERS, HOLD TIME, AND REPORTING LIMITS FOR LABORATORIES

Laboratory Responsibility

The SCVWD water quality laboratory, AWPC operations, and Eurofins Laboratories will all be responsible for analytical analysis of samples in this study. A listing of laboratory sampling responsibilities can be found in Table 2.7. Analytical methods, sampling container to be used, and the method detection limit (MDL) can be found in Table 2.8 through Table 2.12.

Table 2.11 Laboratory Responsibility for Analytical Analysis

Laboratory	Samples to Analyze
Water Quality Lab	Turbidity, Total Coliform, Fecal Coliform, Cryptosporidium, Lead, Copper, TOC, Electrical Conductivity, Color, Bromate, Bromide, Nutrients
AWPC Operations	Total Chlorine Residual, Free Chlorine Residual, Trasar, 1,4-Dioxane (seeding)
Outside Lab	MS2 Samples, Particle Counting, NDMA, UVA (grab), 1,4-Dioxane Monitoring, Total Nitrogen
Mix: Water Quality Lab and Outside Lab	CECs, Regulated Contaminants, Contaminants with Secondary MCLs, Chemicals with NLs

Sampling Tables and Responsibilities

Testing for CECs, nutrients, regulated contaminants, contaminants with secondary MCLs and contaminants with NLs requires a mixture of District (WQL) and outside laboratory efforts. These efforts are outlined in Table 2.8 through Table 2.12 along with reporting limits, holding times, and sampling containers needed for each chemical to be analyzed.

Table 2.12 CEC Analysis Information and Laboratory Responsibilities

Laboratory	Contaminant	Criteria	MDL	MRL	Units	Test Method	Hold Time (days)	Sampling Container
Eurofins and District	17α, Ethinyl estradiol	--	0.0032	0.005	ng/L	LC-MS-MS	28	40 mL amber glass vial
	17B-Estradiol	--	4.41	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Atenolol	4	0.00388	0.005	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Caffeine	--	4.31	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Carbamazepine	--	1.21	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Cotinine	1000	4.85	10	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Dilantin	1	0.0125	0.02	ug/L	LC-MS-MS	28	40 mL amber glass vial
	DEET	200	0.00108	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Estrone	0.32	0.0039	0.005	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Primidone	1000	4.77	5	ng/L	LC-MS-MS	28	40 mL amber glass vial
	Sucralose	150,000	0.042	0.1	ug/L	LC-MS-MS	28	40 mL amber glass vial
	TCEP	5	0.00318	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
	Triclosan	21,000	0.00632	0.01	ug/L	LC-MS-MS	28	40 mL amber glass vial
SCVWD WQ Lab	Perchlorate	6		4	ug/L	EPA 314.0	28	250 mL Poly
	Bromate	0.01		5000	mg/L	EPA 300.1	28	250 mL Poly
	Bromide	--		0.05	mg/L	EPA 300.0	28	500 mL Poly
Eurofins	Meprobamate	--	2.03	5	ng/L	LC-MS-MS	28	40 ml amber glass preserved
	NDMA	1	0.962	2	ng/L	EPA 521	7	500 ml amber glass preserved
	Nonylphenol	--	50	100	ng/L	LC-MS-MS	28	40 ml amber glass preserved
	PFOA	0.4	0.55	5	ng/L	LC-MS-MS	28	125 ml poly unpreserved
	PFOS	0.2	0.239	5	ng/L	LC-MS-MS	28	125 ml poly unpreserved
	1,4-Dioxane	0.1	0.035	0.07	ug/L	EPA 522	14	125 ml amber glass preserved

Table 2.13 Nutrient Analysis all to take place at SCVWD WQL

	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Iron [1]	EPA 200.7	ug/L	180	100	20	500 mL Poly
Ammonia	SM 4500-NH3 D	mg/L	1	--	0.05	500 mL Poly
Nitrite [2]	SM 4500-NO2- B	mg/L	2	0.4	0.01	250 mL Poly
Nitrate[2]	EPA 300.0	mg/L	2	2	0.05	500 mL Poly
TN[2]	SM 4500-N D	mg/L	1	--	0.05	500 mL Poly
Phosphorus	EPA 300.0	mg/L	2	--	0.05	500 mL Poly

Notes:
(1) Included in contaminants with secondary MCL.
(2) Included in regulated contaminants.

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Inorganics (Table 64431-A)								
Aluminum[1]	1	SCVWD WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly
	0.2(2)	SCVWD WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly
Antimony	0.006	SCVWD WQL	EPA 200.8	ug/L	180	6	1	500 mL Poly
Arsenic	0.05	SCVWD WQL	EPA 200.8	ug/L	180	2	1	500 mL Poly
Asbestos	7 MFL(3)	SCVWD WQL	EPA 200.8	ug/L	180	2	1	500 mL Poly
Barium	1	SCVWD WQL	EPA 200.8	ug/L	180	100	5	500 mL Poly
		SCVWD WQL	EPA 200.8	ug/L	180	100	5	500 mL Poly
Beryllium	0.004	SCVWD WQL	EPA 200.8	ug/L	180	1	1	500 mL Poly
Cadmium	0.01	SCVWD WQL	EPA 200.8	ug/L	180	1	0.2	500 mL Poly
	0.005	SCVWD WQL	EPA 200.8	ug/L	180	1	0.2	500 mL Poly
Chromium	0.05	SCVWD WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Copper [1]	1(2)	SCVWD WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
	1.3(4)	SCVWD WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
Cyanide	0.2	Eurofins						

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
	0.15	Eurofins	SM 4500CN-F	mg/L	14	0.006	0.025	250 mL Poly Preserved
Fluoride	2	SCVWD WQL	EPA 300.0	mg/L	28	0.1	0.05	500 mL Poly
Lead	0.05(5)	SCVWD WQL	EPA 200.8	ug/L	180	5	0.5	500 mL Poly
	0.015d	SCVWD WQL	EPA 200.8	ug/L	180	5	0.5	500 mL Poly
Mercury	0.002	SCVWD WQL	EPA 245.1	ug/L	28	1	1	500 mL Poly
Nickel	0.1	SCVWD WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Nitrate[2]	(as NO_3) 45	SCVWD WQL						
Nitrite (as N) [2]	1	SCVWD WQL						
Total Nitrate/Nitrite (as N) [2]	10	SCVWD WQL	EPA 300.0	mg/L	2	2	0.05	500 mL Poly
Selenium	0.01	SCVWD WQL	EPA 200.8	ug/L	180	5	5	500 mL Poly
	0.05	SCVWD WQL	EPA 200.8	ug/L	180	5	5	500 mL Poly
Thallium	0.002	SCVWD WQL	EPA 200.8	ug/L	180	1	1	500 mL Poly
Radionuclides (Tables 64442 and 64443)								
Uranium	20 pCi/L	Eurofins	EPA 200.8	pCi/L	180	0.022	0.7	500 ml poly preserved

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Combined radium-226 & 228	5 pCi/L	Eurofins	GA Method	pCi/L	180	1	1	3 Liter poly preserved
Gross Alpha particle activity	15 pCi/L	Eurofins	EPA 900.0	pCi/L	180	2.68	3	500 ml poly preserved
Gross Beta particle activity	50 pCi/L(6)	Eurofins	EPA 900.0	pCi/L	180	2.66	3	500 ml poly preserved
Strontium-90	8 pCi/L(6)	Eurofins	EPA 905.0	pCi/L	180	2	2	1 Liter poly preserved
Tritium	20,000 pCi/L(6)	Eurofins	EPA 906.0	pCi/L	180	300	300	500 ml amber glass unpreserved
Organic Chemicals (Table 64444-A)								
VOCs								
Benzene	0.001	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Carbon Tetrachloride	0.0005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichlorobenzene	0.6	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,4-Dichlorobenzene	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1-Dichloroethane	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichloroethane	0.0005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1-Dichloroethylene	0.006	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	**CDPH MCL (mg/L)**	**Laboratory**	**Test Method**	**Units**	**Hold Time (days)**	**DLR**	**MRL**	**Sampling Container**
cis-1,2-Dichloroethylene	0.006	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
trans-1,2-Dichloroethylene	0.01	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Dichloromethane	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,3-Dichloropropene	0.0005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2-Dichloropropane	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Ethylbenzene	0.68	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
	0.7	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
	0.3	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Methyl-tert-butyl ether (MTBE) [1]	0.005(2)	SCVWD WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
	0.013	SCVWD WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
Monochlorobenzene	0.03	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
	0.07	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Styrene	0.1	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
1,1,2,2-Tetrachloroethane	0.001	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Tetrachloroethylene	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Toluene	0.15	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,2,4 Trichlorobenzene	0.07	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
	0.07	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1,1-Trichloroethane	0.2	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,1,2-Trichloroethane	0.032	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
	0.032	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Trichloroethylene	0.005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Trichlorofluoromethane	0.15	SCVWD WQL	EPA 524.2	ug/L	14	5	2.5	40 mL VOA
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.2	SCVWD WQL	EPA 524.2	ug/L	14	10	2	40 mL VOA
Vinyl chloride	0.0005	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Xylenes	1.75	SCVWD WQL	EPA 524.2	ug/L	14	--	--	40 mL VOA
SVOCs								

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Alachlor	0.002	SCVWD WQL	EPA 505	ug/L	7	1	1	40 mL VOA
Atrazine	0.003	SCVWD WQL	EPA 525.2	ug/L	30	0.5	0.25	1 L Brown Glass
	0.001	SCVWD WQL	EPA 525.2	ug/L	30	0.5	0.25	1 L Brown Glass
Bentazon	0.018	SCVWD WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Benzo(a) Pyrene	0.0002	SCVWD WQL	EPA 525.2	ug/L	30	0.1	0.1	1 L Brown Glass
Carbofuran	0.018	SCVWD WQL	EPA 531.1	ug/l	14	5	5	40 mL VOA
Chlordane	0.0001	SCVWD WQL	EPA 505	ug/L	7	0.1	0.1	40 mL VOA
Dalapon	0.2	SCVWD WQL	EPA 515.3	ug/L	14	10	10	60 mL VOA Amber
Dibromochloropropane	0.0001	SCVWD WQL	EPA 504.1	ug/L	14	0.01	0.01	40 mL VOA
	0.0002	SCVWD WQL	EPA 504.1	ug/L	14	0.01	0.01	40 mL VOA
Di(2-ethylhexyl)adipate	0.4	SCVWD WQL	EPA 525.2	ug/L	30	5	0.5	1 L Brown Glass
Di(2-ethylhexyl)phthalate	0.004	SCVWD WQL	EPA 525.2	ug/L	30	5	0.5	1 L Brown Glass

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
2,4-D	0.1	SCVWD WQL	EPA 515.3	ug/L	14	10	10	60 mL VOA Amber
	0.07	SCVWD WQL	EPA 515.3	ug/L	14	10	10	60 mL VOA Amber
Dinoseb	0.007	SCVWD WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Diquat	0.02	SCVWD WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Endothall	0.1	SCVWD WQL	EPA 515.3	ug/L	14	2	2	60 mL VOA Amber
Endrin	0.0002	SCVWD WQL	EPA 505	ug/L	7	0.1	0.1	40 mL VOA
	0.002	SCVWD WQL	EPA 505	ug/L	7	0.1	0.1	40 mL VOA
Ethylene Dibromide	0.00002	SCVWD WQL	EPA 504.1	ug/L	14	0.02	0.02	40 mL VOA
	0.00005	SCVWD WQL	EPA 504.1	ug/L	14	0.02	0.02	40 mL VOA
Glyphosate	0.7	SCVWD WQL	EPA 547	ug/L	14	25	25	250 mL BrnGlass
Heptachlor	0.00001	SCVWD WQL	EPA 505	ug/L	7	0.01	0.01	40 mL VOA

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Heptachlor Epoxide	0.00001	SCVWD WQL	EPA 505	ug/L	7	0.01	0.01	40 mL VOA
Hexachlorobenzene	0.001	SCVWD WQL	EPA 505	ug/L	7	0.5	0.5	40 mL VOA
Hexachlorocyclopentadiene	0.05	SCVWD WQL	EPA 505	ug/L	7	1	1	40 mL VOA
Lindane	0.004	SCVWD WQL	EPA 505	ug/L	7	0.2	0.2	40 mL VOA
	0.0002	SCVWD WQL	EPA 505	ug/L	7	0.2	0.2	40 mL VOA
Methoxychlor	0.1	SCVWD WQL	EPA 505	ug/L	7	10	10	40 mL VOA
	0.04	SCVWD WQL	EPA 505	ug/L	7	10	10	40 mL VOA
	0.03	SCVWD WQL	EPA 505	ug/L	7	10	10	40 mL VOA
Molinate	0.02	SCVWD WQL	EPA 525.2	ug/L	30	2	0.5	1 L Brown Glass
Oxamyl	0.2	SCVWD WQL	EPA 531.1	ug/L	14	20	20	40 mL VOA
	0.05	SCVWD WQL	EPA 531.1	ug/L	14	20	20	40 mL VOA
Pentachlorophenol	0.001	SCVWD WQL	EPA 525.2	ug/L	30	--	1	1 L Brown Glass
Picloram	0.5	SCVWD WQL	EPA 515.3	ug/L	14	1	1	60 mL VOA Amber
Polychlorinated Biphenyls	0.0005	SCVWD WQL	EPA 505	ug/L	7	0.5	0.5	40 mL VOA

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Simazine	0.01	SCVWD WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
	0.004	SCVWD WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Thiobencarb[1]	0.07	SCVWD WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
	0.001(2)	SCVWD WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Toxaphene	0.005	SCVWD WQL	EPA 505	ug/L	7	1	1	40 mL VOA
	0.003	SCVWD WQL	EPA 505	ug/L	7	1	1	40 mL VOA
2,3,7,8-TCDD (Dioxin)	$3x10^{-8}$	SCVWD WQL	EPA 505	ug/L	7	1	1	40 mL VOA
2,4,5-TP (Silvex)	0.01	SCVWD WQL	EPA 515.3	ug/L	14	1	1	60 mL VOA Amber
	0.05	SCVWD WQL	EPA 515.3	ug/L	14	1	1	60 mL VOA Amber
Disinfection Byproducts (Table 64533-A)								
Total trihalomethanes	0.1	SCVWD WQL	EPA 502.2	ug/L	14	--	1	40 mL VOA
Total haloacetic acids		SCVWD WQL	EPA 557	ug/L	21	--	--	60 mL VOA Amber

Table 2.14 Regulated Contaminants and Sampling Collection Information

Contaminant	CDPH MCL (mg/L)	Laboratory	Test Method	Units	Hold Time (days)	DLR	MRL	Sampling Container
Bromate[3]		SCVWD WQL	EPA 317.-	ug/L	28	1	1	250 mL Poly
Chlorite		SCVWD WQL	SM 4500-Cl D	mg/l	28	--	5	1 L Poly

Notes:

(1) Included in Secondary MCL List (sampling for both will be conducted with timing of regulated contaminants)

(2) Included in nutrient sampling (included in nutrient sampling (at different locations); sampling required for both sets.

(3) Included in CEC recommendation list (sampling for bromated will be conducted in CEC sampling).

Table 2.15 Contaminants with Secondary MCLs sampling information

Contaminant	**CDPH MCL**	**Units**	**Laboratory**	**Test Method**	**Units**	**Hold Time**	**DLR**	**MRL**	**Sampling Container**
Table 64449-A									
Aluminum[1]	0.2	mg/L	SCVWD WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly
Color	15	Units	SCVWD WQL	SM 2120 C	Color Units	2	--	--	1 L Poly
Copper [1]	1	mg/L	SCVWD WQL	EPA 200.8	ug/L	180	50	0.5	500 mL Poly
Foaming Agents	0.5	mg/L	Eurofins	SM 5540C	mg/L	2	0.014	0.05	500 mL Poly unpreserved
Iron[3]	0.3	mg/L	SCVWD WQL	EPA 200.7	ug/L	180	100	20	500 mL Poly
Manganese	0.05	mg/L	SCVWD WQL	EPA 200.8	ug/L	180	20	1	500 mL Poly
Methyl-*tert*-butyl ether (MTBE)[1]	0.005	mg/L	SCVWD WQL	EPA 524.2	ug/L	14	3	2	40 mL VOA
Odor-Threshold	3	Units	SCVWD WQL						
Silver	0.1	mg/L	SCVWD WQL	EPA 200.8	ug/L	180	10	1	500 mL Poly
Thiobencarb[1]	0.001	mg/L	SCVWD WQL	EPA 525.2	ug/L	30	1	0.25	1 L Brown Glass
Turbidity	5	Units	SCVWD WQL	SM 2130 B	NTU	2	--	--	1 L Poly
Zinc	5	mg/L	SCVWD WQL	EPA 200.8	ug/L	180	50	10	500 mL Poly

Table 2.15 Contaminants with Secondary MCLs sampling information

Contaminant	CDPH MCL	Units	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Total Dissolved Solids	500	mg/L	SCVWD WQL	SM 2540 C	mg/L	7	--	--	2 L Poly
Specific Conductance	900	uS/cm	SCVWD WQL	SM 2510 B	umhos/cm	28	--	--	1 L Poly
Chloride	250	mg/L	SCVWD WQL	SM 4500-Cl D	mg/L	28	--	5	1 L Poly
Sulfate	250	mg/L	SCVWD WQL	EPA 300.0	mg/L	28	0.5	0.5	500 mL Poly

Notes:
(1) Included in regulated contaminants (sampling in regulated contaminants will be sufficient for both requirements).
(2) Included in nutrients (sampling at different locations, sampling required for both).

Table 2.16 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Boron	1000	SCVWD WQL	EPA 200.8	ug/L	180	100	100	500 mL Poly
n-Butylbenzene	260	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
sec-Butylbenzene	260	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
tert-Butylbenzene	260	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Carbon disulfide	160	Eurofins	EPA 524.2	ug/L	14	0.085	0.5	40 mL amber glass preserved
Chlorate	800	SCVWD WQL	EPA 300.1	ug/L	28	20	20	250 mL Poly
2-Chlorotoluene	140	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
4-Chlorotoluene	140	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Diazinon	1.2	Eurofins	EPA 525.2	ug/L	14	0.025	0.2	1 L amber glass preserved
Dichlorodifluoromethane (Freon 12)	1000	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
1,4-Dioxane	1	Eurofins	EPA 522	ug/L	14	0.035	0.07	125 mL amber glass preserved
Ethylene glycol	14000	Eurofins	EPA 8015B	mg/L		4	5	1 Liter amber glass unpreserved
Formaldehyde	100	Eurofins	EPA 556	ug/L		0.81	5	40 ml amber glass preserved
HMX[1]	350	Eurofins	LC-MS-MS	ug/L		0.05	0.1	40 ml amber glass preserved

Table 2.16 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
Isopropylbenzene	770	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
Manganese	500	SCVWD WQL	EPA 200.8	ug/L	180	20	1	500 mL Poly
Methyl isobutyl ketone (MIBK) [2]	120	Eurofins	EPA 524.2	ug/L	14	0.683	5	40 mL amber glass preserved
Naphthalene	17	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
N-Nitrosodiethylamine (NDEA)	0.01	SCVWD WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
N-Nitrosodimethylamine (NDMA)	0.01	SCVWD WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
N-Nitrosodi-n-propylamine (NDPA)	0.01	SCVWD WQL	EPA 521	ng/L	28	--	2	1 L Brown Glass
Propachlor**	90	SCVWD WQL	EPA 525.2	ug/L	30	0.5	0.5	1 L Brown Glass
n-Propylbenzene	260	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
RDX[3]	3	Eurofins	LC-MS-MS	ug/L	14	0.05	0.1	40 mL amber glass preserved
Tertiary butyl alcohol (TBA)	12	SCVWD WQL	EPA 524.2	ug/L	14	2	2	40 mL VOA
1,2,3-Trichloropropane (1,2,3-TCP)	0.005	SCVWD WQL	EPA 524.2	ug/L	14	--	0.5	40 mL VOA
1,2,4-Trimethylbenzene	330	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA

Table 2.16 Contaminants with Notification Levels (NLs)

Chemical	Chemical Notification Level (ug/L)	Laboratory	Test Method	Units	Hold Time	DLR	MRL	Sampling Container
1,3,5-Trimethylbenzene	330	SCVWD WQL	EPA 524.2	ug/L	14	0.5	0.5	40 mL VOA
2,4,6-Trinitrotoluene (TNT)	1	Eurofins	LC-MS-MS	ug/L	14	0.05	0.1	40 mL amber glass preserved
Vanadium	50	SCVWD WQL	EPA 200.8	ug/L	180	3	3	500 mL Poly

Notes:

(1) HMX is an explosive, and is commonly found with the explosive RDX.

(2) MIBK is a commonly found solvent.

(3) RDX is an explosive, and is listed on the USEPA Candidate Contaminant List 3 (CCL3)

0 QUALITY CONTROL OBJECTIVES

Precision

The precision of duplicate samples is assessed by calculating the relative percent difference (RPD) according to:

$$RPD = \frac{|S - D|}{\frac{(S + D)}{2}} \times 100\%$$

where, S = Sample concentration and D = Duplicate sample concentration.

If calculated from three or more replicates, the precision is determined using the relative standard deviation (RSD):

$$RSD = \frac{SD}{Average} \times 100\%$$

where , SD = Standard deviation for the replicate samples.

Sample Replicates

Sampling will take place in single, duplicate, or triplicate samples as listed in Table 3.1 below. Samples will be taken and repeated at multiple sampling events for each type of testing of constituent listed. Cryptosporidium is suggested to have a minimum number of 12 sample pairs during MF challenge testing, which is achieved with triplicate sampling across 4 sampling events. MS-2 Coliphage sampling is expected to contain some variability, and therefore triplicate sampling across multiple sampling events for RO and UV challenge testing is suggested. NDMA analysis and sampling is expected to contain less variability than that of MS-2, and therefore duplicate sampling is recommended.

Table 3.17 Replicates and Associated Number of Sampling Events

Test Plan Operation	Parameter to Analyze	Replicates for each sampling event	Number of Sampling Events
MF Challenge Testing	Total Coliform, Fecal Coliform, *Cryptosporidium*, particle counting	Triplicate	4
	Turbidity and Pressure Decay Testing	None	4
UV Challenge Testing	MS-2 Coliphage	Triplicate	8
	NDMA	Duplicate	8
	UVA, Nitrite, Total Chlorine Residual, Free Chlorine Residual, TOC	None	8
RO Challenge Testing	MS-2 Coliphage	Triplicate	7
	NDMA	Duplicate	3
	CECs, 1,4-Dioxane	None	3
	UVA, TOC, Color, Turbidity	None	7
UV AOP Pilot	NDMA, 1,4-Dioxane, pH, TOC, Nitrite, UVA, Chloramines, Free Chlorine	Duplicate	20
	CECs	None	8
O_3/Biofiltration Pilot	MS-2 Coliphage	Triplicate	4 for each condition
	O_3 residual, UVA, NDMA, Nutrients, Bromate, Bromide, 1,4-Dioxane	None	4 for each condition
	CECs	None	2 for each condition
Water Quality Monitoring	Total Nitrogen	None	2 per week
	Regulated Contaminants, Contaminants with Secondary MCLs, Chemicals with NLs, Lead and Copper, NDMA, 1,4-Dioxane, CECs	None	1 per quarter

Accuracy

For measurements where matrix spikes (constituent seeding) are used, accuracy is evaluated by calculating the percent recovery (R):

$$R(\%) = \frac{S - U}{C_{SA}} \times 100\%$$

where, S = Measured concentration in spiked sample, U = Measured concentration in unspiked sample, and C_{SA} = Calculated concentration of spike in sample.

When a standard reference material (SRM) is used, the percent recovery is determined by:

$$R(\%) = \frac{C_m}{C_{SRM}} \times 100\%$$

where, C_m = Measured concentration of SRM and C_{SRM}:= Actual concentration of SRM.

Matrix spiking will occur when constituents are seeded to follow process performance. MS-2 Coliphage, 1,4-Dioxane, and potentially Trasar will be seeded in this study, with all other constituents listed being found in the influent water supply. Listed seeded chemicals for each process (used for matrix spikes) can be found in Table 3.2.

Table 3.18 Matrix Spiking Events

Test Plan Operation	Constituent(s) to be Spiked
MF Challenge Testing	• N/A
UV Challenge Testing	• MS-2 Coliphage
RO Challenge Testing	• MS-2 Coliphage • Trasar (TBD)
UV AOP Pilot	• 1,4-Dioxane
O_3/Biofiltration Pilot	• MS-2 Coliphage • 1,4-Dioxane

Method Detection Limit (MDL)

Known MDLs are reported for all concentrations being measured in the included tables.

To determine the MDL, at least seven replicates of a laboratory fortified blank at a concentration of three to five times the estimated instrument detection limit is analyzed through the entire analytical method. The MDL for each constituent tested will be determined by the laboratory in accordance with the standard method listed for each constituent. It is important to show that the detection limit for each chemical parameter is sensitive enough such that it can measure below the regulatory limit, and show appropriate removal of each compound in question. The MDL is calculated using the following equation:

$$MDL = (t) \times (SD)$$

where, t = Student's *t* value for 99 percent (*t* for 7 replicates= 3.14) and SD = Standard deviation for the replicates samples.

Comparability

Much of the critical data will be analyzed on-site, and outside laboratory analysis will take place at Eurofins laboratories, see Table 2.7. It is therefore important to prove consistency between laboratories and have a common practice to ensure quality control across various laboratories. Comparability is the degree of consistency between a data set obtained at one laboratory and data sets from another. It is achieved by use of consistent methods and materials (i.e., standards). Comparability of data will be promoted by adherence to the analytical methods decided by each outside laboratory.