

Las Virgenes Municipal Water District - Triunfo JPA
Pure Water Project Demonstration

PURIFICATION SYSTEM PERFORMANCE REPORT

FINAL | August 2022

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PURE WATER PROJECT
LAS VIRGENES-TRIUNFO

Bringing Our Water Full Circle

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Abbreviations

σ	standard deviation
µ	mean
µg/L	micrograms per liter
µm	micrometer
µS/cm	microsiemens per centimeter
A. brasiliensis	*Aspergillus brasiliensis*
Ad2	Adenovirus type 2
ADONA	4,8-dioxa-3H-perfluorononanoic acid
AI	artificial intelligence
Al	aluminum
AOP	advanced oxidation process
AWPF	Advanced Water Purification Facility
BDCM	bromodichloromethane
BPA	Bisphenol A.
CA	calcium
CCR	California Code of Regulations
CECs	constituents of emerging concern
CIP	clean-in-place
Cl_2	chlorine
CLR	calcium, lime, rust
CO_2	carbon dioxide
CO_3	carbonate ion
CT	contact time
CTR	California Toxics Rule
DBCM	dibromochloromethane
DBP	disinfection byproduct
DCBM	dichlorobromomethane
DDW	Division of Drinking Water
Demo	Pure Water Demonstration Project
DL	dose per LRV
dP	differential pressure
EC	electrical conductivity
FB	Flow Balanced
FD	Foulant Density
FD	Foulant Density
FOSA	Perfluorooctanesulfonamide
ft^2	square feet

g/cm^2	grams per square centimeter
GAP	GAP Environmental Laboratories, Canada
gfd	gallons per square foot of membrane area per day
gph	gallons per hour
gpm	gallons per minute
HAA5	total haloacetic acids
HCO_3^-	bicarbonate ion
HMI	human machine interface
HOCl	hypochlorous acid
IC	inorganic carbon
IEP	isoelectric point
IPR	indirect potable reuse
IWC	in-stream waste concentration
JPA	Joint Powers Authority
lbs	pounds
LP	low pressure
LRV	log reduction value
mA	milliamperes
MBAS	methylene blue active substances
MCLs	maximum contaminant level
MCs	maintenance cleans
METI	Japanese Ministry of Economy, Trade and Industry
MF	microfiltration
MFGM	membrane filtration guidance manual
MFL	million fibers per liter
Mg	magnesium
mg/L	milligrams per liter
mgd	million gallons per day
mJ/cm^2	millijoules per square centimeter
ML	machine learning
MS2	MS2 Bacteriophage
MTL	monitoring trigger level
mV	millivolt
mW/cm^2	milliwatts per square centimeter
NaOCl	sodium hypochlorite
NDEA	N-nitrosodiethylamine
NDMA	N-Nitrosodimethylamine
NDMA	N-Nitrosodimethylamine
NDP	normalized differential pressure

NDPA	N-Nitrosodiphenylamine
NEtFOSAA	N-ethyl Perfluorooctane Sulfonamidoacetic acid
ng/L	nanograms per liter
NH_2Cl	monochloramine
NH_3	ammonia
NLs	notification levels
NMeFOSAA	N-methyl Perfluorooctanesulfonamidoacetic acid
NMOR	N-nitrosomorpholine
NPF	normalized permeate flow
NSP	normalized salt passage
NTU	nephelometric turbidity unit
O&M	operations and maintenance
OCl^-	hypochlorite
ORP	oxidation reduction potential
P	phosphorus
PCBs	Polychlorinated biphenyls
pCi/L	picocuries per liter
PDTs	pressure decay tests
PFAS	per-and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutanesulfonic acid
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFDS	perfluorodecanesulfonic acid
PFHpA	perfluoroheptanoic acid
PFHpS	perfluoroheptanesulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexanesulfonic acid
PFNA	perfluorononanoic acid
PFNS	perfluorononanesulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentanesulfonic acid
PFTeA	perfluorotetradecanoic acid
PFTriA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
pg/L	picogram per liter
PM	project memorandum

PMMoV	pepper mild mottle virus
PO_4	phosphate ion
PPCPs	pharmaceuticals and personal care products
psi	pounds per square inch
psig	pounds per square inch gauge
PSS	point source summation
RCs	recovery cleans
RED	reduction equivalent dose
Report	Purification System Performance Report
RO	reverse osmosis
RSD	relative standard deviation
RWQCB	Regional Water Quality Control Board
SDI	silt density index
Si	silicon
SiO2	silicon dioxide
sMCLs	secondary maximum contaminant level
SOPs	standard operator procedures
SVOCs	semivolatile organic compounds
TC	total carbon
TCPP	tris(1-chloro-2-propyl)phosphate
TDS	total dissolved solids
THMs	trihalomethanes
TMP	transmembrane pressure
TMP	trans-membrane pressure
TOC	total organic carbon
TON	threshold odor number
TOP	total oxidizable precursor
TTHM	total trihalomethane
UF	ultrafiltration
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
UV	ultraviolet
UVI	ultraviolet intensity
UVT	ultraviolet transmittance
VFD	variable frequency drive
VOCs	volatile organic compounds
WRF	water reclamation facility
wt	weight

EXECUTIVE SUMMARY

The Las Virgenes - Triunfo Joint Powers Authority (JPA) Pure Water Demonstration Project (Demo) is a potable water reuse demonstration project. This Demo, which utilizes full-scale components and a fully engineered and automated monitoring and control system is used to develop the necessary information to successfully implement a future full-scale potable reuse Advanced Water Purification Facility (AWPF) for surface water augmentation to the Las Virgenes Reservoir.

The feed water to the Demo is effluent from the Tapia Water Reclamation Facility (WRF) which recycles wastewater through primary sedimentation, conventional activated sludge, media filtration, and chloramine disinfection.

The Demo goes far beyond conventional purification, incorporating an outside drought tolerant garden, stormwater capture facilities, and educational facilities about water. The treatment systems themselves are designed around the concept of "Think Big, Build Small", in which full-scale components are used throughout the system to best understand water quality and engineering issues, while reducing construction cost by right-sizing each component. Put together, the project is a museum quality facility utilizing the latest treatment and monitoring systems for the purification of water and the engagement of the public.

The JPA has identified the following as goals of the Demo:

- Provide opportunities for public education, acceptance, and public outreach to the JPA's customers.
- Develop design criteria and operational procedures to inform and improve the full-scale design and provide experience to operators.
- Provide technical documentation and support for permitting the project by the State of California's Division of Drinking Water (DDW) and the Regional Water Quality Control Board (RWQCB) as a surface water augmentation project (DDW, 2018).

The purpose of this Purification System Performance Report (Report) is to summarize the treatment and monitoring system performance, the treatment system operational efficiency, and ability of the treatment and monitoring system to meet State of California regulations for potable water reuse (DDW, 2018).

This report builds upon three completed efforts under different covers:

- **Pure Water Results from Startup Testing –** A project memorandum (PM) dated August 21, 2020, which was an initial analysis of treatment performance and water quality ahead of a ribbon cutting and a purified water tasting event.

- **United States Bureau of Reclamation (USBR) Report –** A detailed report on the Demo was completed in December 2020 and submitted to the USBR, in accordance with grant requirements.
- **Standard Operator Procedures (SOPs)** – SOPs were developed to aid staff in the startup, shutdown, operation, and calibration of the Demo.

The technical analysis in this report ends with testing in the summer of 2021. Several ongoing efforts at the Demo will continue into 2022, including artificial intelligence (AI) and machine learning (ML) studies covered by federal and international grant funding as well as further disinfection byproduct (DBP) minimization efforts and general operations support. Example results of the work completed to date are highlighted below, understanding that this report is extensive and detailed, and thus the full value of the data collected on the Demo can only be obtained by a thorough read of the report.

ES.1 Treatment and Monitoring System Performance

The Demo is essentially made up of three key process units, low pressure membrane filtration (e.g., ultrafiltration (UF)), reverse osmosis (RO), and an ultraviolet (UV) light advanced oxidation process (AOP). Each key process unit has one or more online monitoring systems which is coupled with periodic sampling or measurements of performance. All three treatment and monitoring system couplings demonstrated a high level of performance, with an example presented here for UF and detailed information for all processes presented in Chapter 2. Figures ES.1 and ES.2 show the daily pressure decay test (PDT) results for each of the UF systems. A PDT above 4 indicates that the membrane barrier is intact and is achieving greater than 99.99% removal of *Cryptosporidium* and *Giardia*.

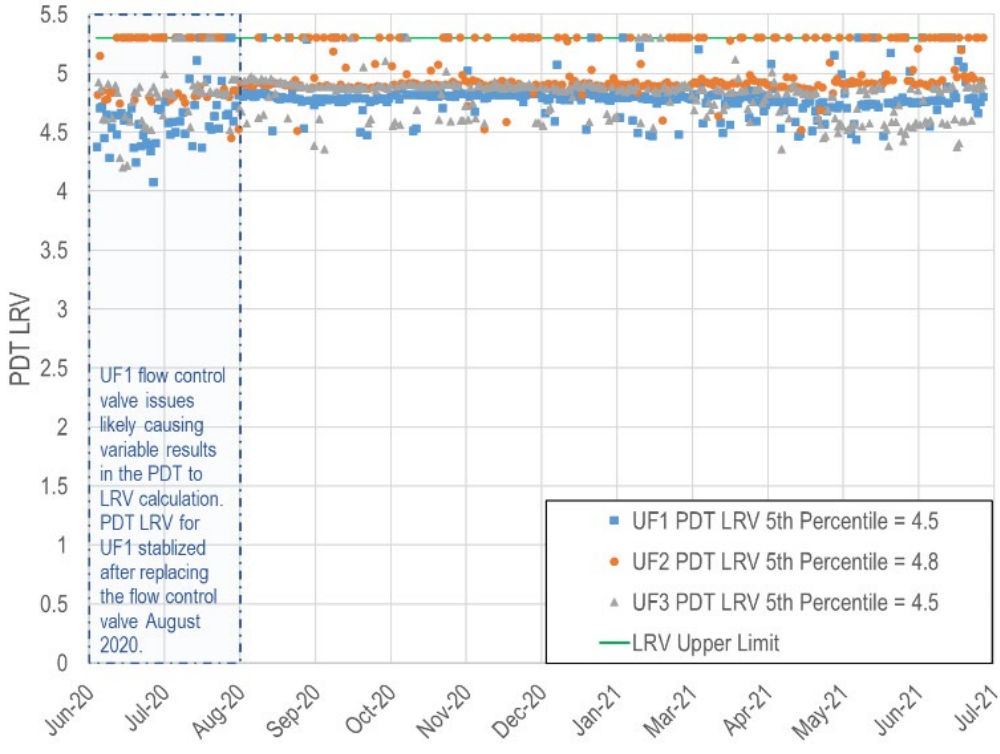


Figure ES.1 Giardia and Cryptosporidium Equivalent Log Reduction Value Calculated From Daily Pressure Decay Tests on Each UF Product Exceeded 4.5 Log Units at the 5th Percentile

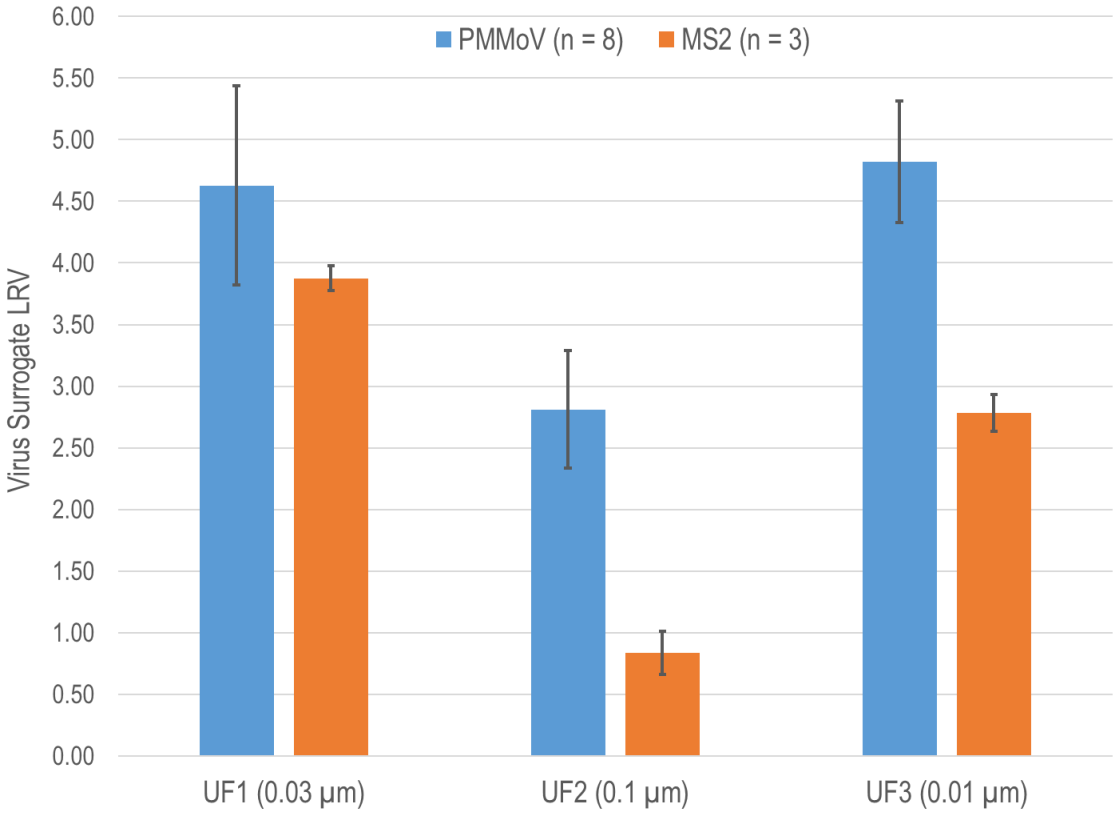


Figure ES.2 Virus Removal Monitoring of Indigenous Pepper Mild Mottle Virus (PMMoV) and Challenge Testing With MS2 Bacteriophage (MS2) Demonstrated a High Level of Virus Removal by the Ultrafiltration Products (UF1 and UF3)

ES.2 Treatment System Operational Efficiency

The treatment processes were designed for the Demo based upon standard engineering principles for this type of project, including conservative flux values for the low pressure membranes, use of 2 and 3-stage RO at 80 percent and 85 percent recoveries, as two examples. The Demo was also built with flexibility, allowing some of the initial design values to be stretched to find greater efficiency for the future full-scale system. One example of this is the low pressure membrane flux, in which the conventional flux values of 25-30 gallons per square foot of membrane area per day (gfd) were pushed up to 40-50 gfd at the Demo, which could result significant savings on the future full-scale system, both for construction and operation. Figure ES.3 shows the impact of UF design flux on cost estimates for the full scale facility.

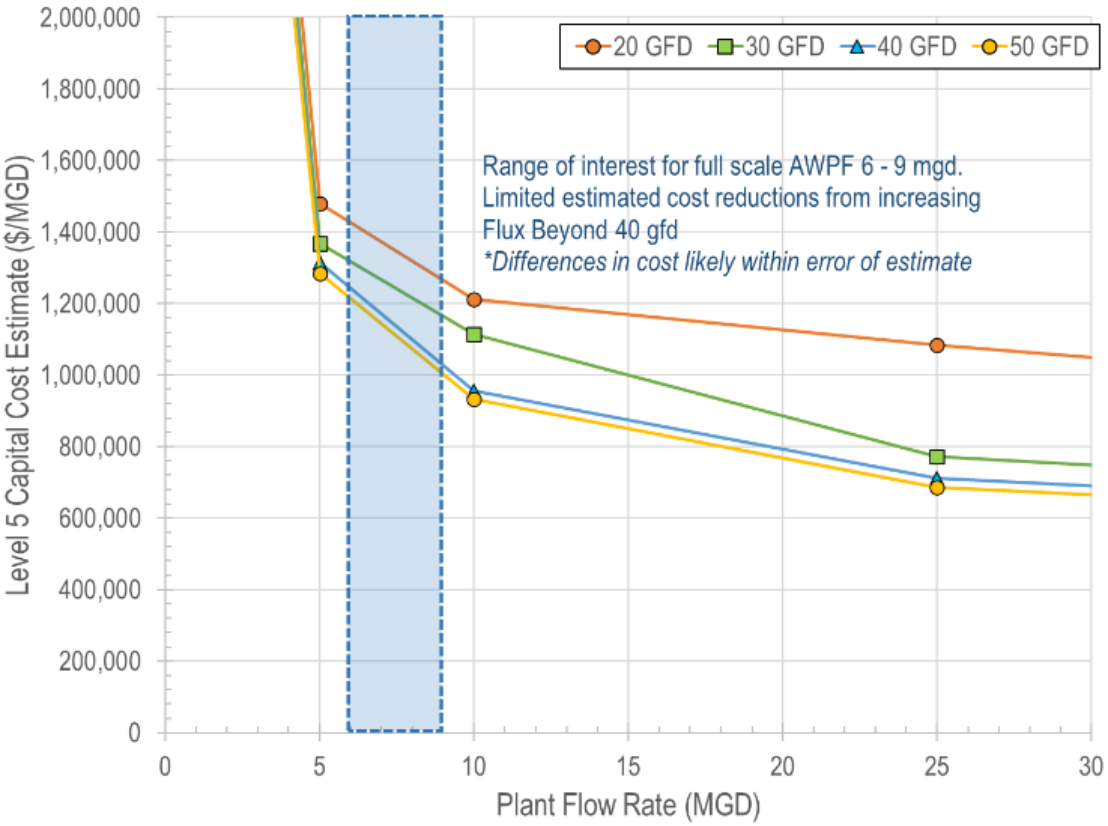


Figure ES.3 Level 5 Cost Estimates Indicate Potential Capital Savings of Over $500,000 From Sustainable Fluxes of 40+ gfd Observed at the Demo

ES.3 Meeting State of California Regulations

The Demo was rigorously examined for chemical pollutants and pathogen reduction and demonstrated full compliance with drinking water requirements for potable water reuse based on 3 significant finished sampling events that measured over 300 regulated and unregulated chemicals. Assessment of compliance included conventional parameters (maximum contaminant level (MCLs), secondary maximum contaminant level (sMCLs), notification levels (NLs)) and new regulated concerns such as per-and polyfluoroalkyl substances (PFAS). Unregulated chemicals were also evaluated, often called constituents of emerging concern (CECs). In addition, the UV system was validated for destruction of N-Nitrosodimethylamine (NDMA) to levels exceeding 99.6 percent. The Demo proved robust in the removal of CECs, as shown on Figure ES.4.

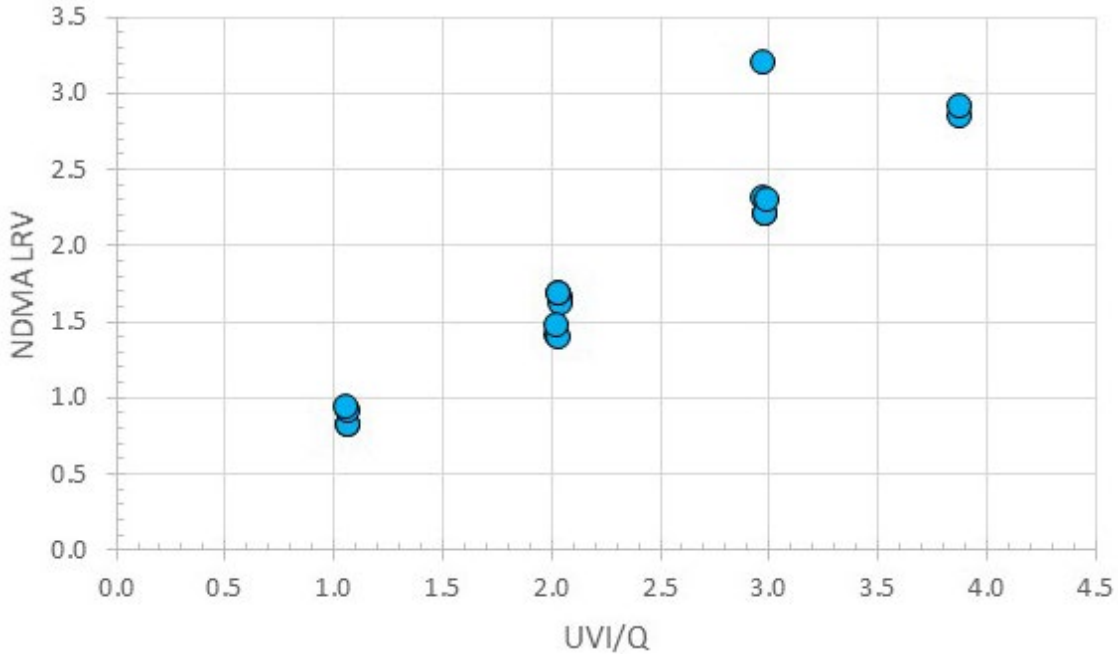


Figure ES.4 The Operating Curve Developed to Calibrate NDMA Destruction Through the UVAOP With Online Monitored and Controlled Parameters UV Intensity (UVI) and Flow (Q)

Chapter 1
INTRODUCTION

1.1 Pure Water Demonstration

The Las Virgenes - Triunfo JPA Demo is a potable water reuse demonstration project. This Demo, which utilizes full-scale components and a fully engineered and automated monitoring and control system is used to develop the necessary information to successfully implement a future full-scale potable reuse AWPF for surface water augmentation to the Las Virgenes Reservoir.

The feed water to the Demo is effluent from the Tapia WRF which recycles wastewater through primary sedimentation, conventional activated sludge, media filtration, and chloramine disinfection.

The Demo goes far beyond conventional purification, incorporating an outside drought tolerant garden, stormwater capture facilities, and educational facilities about water. The treatment systems themselves are designed around the concept of "Think Big, Build Small," in which full-scale components are used throughout the system to best understand water quality and engineering issues, while reducing construction cost by right-sizing each component. Put together, the project is a museum quality facility utilizing the latest treatment and monitoring systems for the purification of water and the engagement of the public.

The Demo was co-funded by the USBR under Title XVI, Agreement No. R17AP00067.

Photos of the Demo are shown on Figure 1.1.

1.2 Potable Water Reuse Background

The Demo is a cornerstone project for the JPA's future potable water reuse program, turning tertiary recycled water into a new potable water supply. The JPA's tagline is "Bringing Our Water Full Circle" (https://www.ourpureh2o.com/home). The origins of the project go back several decades, starting when the Los Angeles RWQCB increased restrictions and requirements related to discharge of highly treated tertiary effluent from the Tapia WRF to local rivers and streams. While the JPA maximizes the use of the tertiary effluent during dry weather for non-potable reuse, there is excess flow in the Fall, Winter, and Spring that is not reused. The JPA evaluated a broad range of options with what to do with the excess water from the WRF, and through a stakeholder-driven process landed upon the development of an indirect potable reuse (IPR) project, now known as the Pure Water Project Las Virgenes – Triunfo JPA. This option will take surplus recycled water from the WRF and process it through an advanced treatment facility; then store it at Las Virgenes Reservoir for later use as drinking water.



Figure 1.1 Photos of the Interior and Exterior of Las Virgenes - Triunfo JPA Potable Water Reuse Demonstration Project

1.3 Regulations

The future potable reuse project will be regulated as a "Reservoir Water Augmentation" project, in which Tapia WRF effluent is purified at a future AWPF, sent to Las Virgenes Reservoir, then extracted and treated at the Westlake Filter Plant to then be distributed to potable water customers. The combined advanced treatment train will be required to meet the treatment requirements defined by the State of California (DDW, 2018), summarized in Table 1.1.

1.4 Treatment Train

The Demo includes the following three critical purification processes:

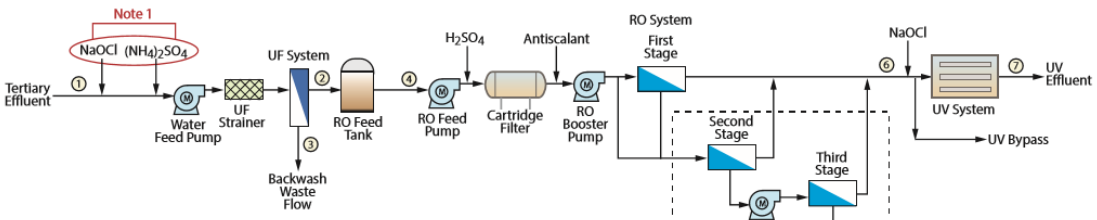
- **Microfiltration (MF) and UF**: One open platform train produces approximately 100 gallons per minute (gpm) of filtered effluent using three different suppliers' membranes (and thus three modules) to undergo simultaneous testing. System documentation (e.g., human machine interface [HMI] labelling) has been set up to refer to any MF/UF as a UF and the term UF is used interchangeably throughout the document.
  - UF1: Dow/DuPont SFD-2880XP:
    - Reported Nominal Pore Size 0.03 micrometer (µm).
    - Classification: Ultrafilter.
  - UF2: Pall UNA-620A:
    - Reported Nominal Pore Size 0.1 µm.
    - Classification: Microfilter.
  - UF3: Toray HFUG Type 2020AN:
    - Reported Nominal Pore Size 0.01 µm.
    - Classification: Ultrafilter.
- **RO**: One train, utilizing Toray TMG10D 4X40 membranes, operates at either 80 percent or 85 percent recovery in the following two modes of operation:
  - **Two-Stage**: 2:1 array with seven 4-inch elements per vessel and an interstage booster pump between stages to produce 10 - 15 gpm.
  - **Three-Stage**: 4:2:1 array with six 4-inch elements per vessel and an interstage booster pumps between stages 2 and 3 to produce 20 - 35 gpm.
- **UV AOP**: One reactor from Xylem, the Spektron 30E, which is capable of treating up to 20 gpm with a dose of 600 millijoules per square centimeter (mJ/cm^2) for NDMA destruction coupled with an upstream dose of sodium hypochlorite for a minimum removal of 0.5-log of 1,4-dioxane. Lower flows are currently being run (approximately 6 gpm) through the system to generate higher dose values sufficient for NDMA destruction and to best understand future AWPF design criteria. At the current flow of 6 gpm, the UV supplier (Xylem/WEDECO) estimates a point source summation (PSS)-based UV dose of ~1500 mJ/cm^2, which is verified as part of testing detailed herein.

Figure 1.2 provides an overview of the process train and corresponding chemicals and maximum design flow rates.

Table 1.1 Title 22 Reservoir Water Augmentation Requirements for Potable Reuse (DDW, 2018)

Parameter	Criteria
Enteric Virus	8-log Reduction(1)
Giardia Cyst	7-log Reduction(1)
Cryptosporidium oocysts	8-log Reduction(1)
Full Advanced Treatment	RO and an AOP that achieves 0.5-log reduction of 1,4-dioxane
Inorganic Chemicals in Table 64431-A(1)	≤ MCLs
Radionuclide Chemicals in Tables 64442 and 64443	≤ MCLs
Organic Chemicals in 64444-A	≤ MCLs
Disinfection Byproducts in Table 64533-A	≤ MCLs
Lead and Copper	≤ Action Levels
Priority Toxic Pollutants in 40 CFR Section 131.38 and DDW-Specified Chemicals	≤ NLs(2)
Minimum Dilution of any 24-hour input of Recycled Water	100:1 with no additional pathogen log reduction 10:1 with 1-log additional pathogen reduction
Minimum Theoretical Reservoir Retention Time	Greater than 120 days with no additional pathogen log reduction Greater than 60 but less than 120 days with 1-log additional pathogen reduction

Notes:
Abbreviations: CFR - Code of Federal Regulations.
(1) Log reductions are from the point of raw wastewater to the point of raw water to downstream surface water treatment plant. If dilution is less than 100:1, one additional log removal is required for all pathogens. If reservoir retention time is less than 4 months, one additional log removal is required for all pathogens. Reservoir retention time must >2 months for all cases.
(2) Notable among which is the NDMA goal of 10 nanograms per liter (ng/L) or less. For discharge to the Las Virgenes Reservoir, due to California Toxics Rule enforcement, the NDMA requirement is 0.69 ng/L, which is below the current laboratory method reporting level of 2 ng/L.



Stream	Description	3rd Stage Operation Max Flow (gpm)	2nd Stage Operation Max Flow (gpm)
1	UF Feedwater	100	100
2	UF Filtrate	96	96
3	UF Backwash Waste	4	4
4	RO Feedwater	44	19
5	RO Concentrate	9	7
6	RO Permeate	35	15
7	UV Effluent	5-10	5-10

Note - The table contains maximum flows.
Maximum concentrate and feed calculated at 80% recovery for maximum permeate.
Maximum permeate from H_20 process narrative.

Note 1 - Dosing point order can be changed to investigate NDMA formation potential. Preformed chloramine could be dosed at either location but would require additional dosing pumps, storage and blending tanks.

Figure 1.2 Process Train Overview

1.5 Ancillary Systems and Components

In addition to three treatment systems (UF, RO, UV AOP), this Demo includes:

- **Online Monitoring Systems**: Each of the three processes is being monitored online (both in real time and periodically) over the demonstration period by the instrumentation summarized in Table 1.2. In addition:
  - The UF system continuously monitors normalized flux, turbidity removal, and transmembrane pressure (TMP). It also conducts daily pressure decay tests (PDTs), and monitors oxidation reduction potential (ORP), pH, free ammonia and total chlorine on the filtrate.
  - The RO system continuously collects detailed online data which is coupled with daily logged data to monitor normalized flux, normalized salt passage/rejection, reduction of total organic carbon (TOC) across the membranes and normalized differential pressure. The RO performance is currently being tracked used calculations spreadsheets provided by Toray (the RO membrane supplier). Daily average flows and pressures are determined from logged data while the RO is operating and used to populate one point per day.
  - The UV system continuously monitors UV dose, based upon an ultraviolet transmittance (UVT) input value (currently set to 98 percent), the online UVI sensor, and flowrate using a PSS calculation. The system also monitors for free and combined chlorine and UVT ahead of and after the UV system, as well as pH in the feed to the UV reactor. The accuracy of that UV dose is documented within this report and compared with the WEDECO online dose calculation.
  - The intent is for all online meters to be calibrated weekly or monthly using either bench-scale calibrated devices or through laboratory analysis.
- **Equipment for Supporting Studies:** In adjacent rooms to the UF, RO, and UV AOP, the project team, depending upon need and budget, can study RO concentrate and finished water qualities through bench-scale or pipe loop studies.
  - No such studies have been completed to date.

Table 1.2 Online Water Quality Monitoring[1]

Parameter	UF Feed	UF Filtrate[2]	RO Feed[2]	RO Permeate[3]	UV AOP Feed[3]	UV AOP Effluent
pH		●	●		●	
Turbidity	●	●(4)				
Temperature	●		●			
Conductivity			●	●(5)		
TOC			●	●		
ORP		●	●			
UVT					●	●
Free Chlorine			●		●	●
Total Chlorine		●			●	●
Free Ammonia		●				

Notes:
Abbreviation: ORP - oxidation reduction potential.
(1) There are no online water quality sensors on the RO concentrate.
(2) UF filtrate refers to monitoring locations prior to chemical additions of the RO feed (I.e. antiscalant and acid). RO feed monitoring locations refer to after chemical additions to the combined UF filtrate stream.
(3) RO permeate refers to monitoring locations prior to additional sodium hypochlorite addition to the UV AOP feed. UV AOP feed refers to monitoring after addition of sodium hypochlorite to the RO permeate.
(4) On filtrate from each UF module.
(5) On permeate from each RO stage (1, 2 and 3) as well as combined RO permeate.

1.6 Test Plan Goals

The JPA has identified the following as goals of the Demo:

- Provide opportunities for public education, acceptance, and public outreach to the JPA's customers.
- Develop design criteria and operational procedures to inform and improve the full-scale design and provide experience to operators.
- Provide technical documentation and support for permitting the project by the State of California's DDW and the RWQCB as a surface water augmentation project (DDW, 2018).

The detailed testing approach for the Demo was provided in the November 2020 report titled "Pure Water Demonstration Test Plan". Within that Test Plan, are detailed approaches to evaluate treatment system performance, divided into Phase 1 and Phase 2. Only Phase 1 work is undertaken at this time, with progress through the effort defined in Table 1.3.

Table 1.3 Core Components of Test Plan

Test Component	Project Phase	Details	Schedule
Pure Water Quality Assessment	Phase 1	Evaluation of water quality in accordance with regulations as part of Grand Opening and Tasting Event.	Work Complete

Test Component	Project Phase	Details	Schedule
Membrane Operational Efficiency Analysis	Phase 1	Evaluation of MF, UF, and RO performance over a range of flux and clean-in-place (CIP) intervals.	Work Complete
Extended Water Quality Testing	Phase 1	Extensive evaluation of water quality across the AWPF.	Work Complete
Process Challenge Testing	Phase 1	Challenge testing of MF, UF, RO, and UV AOP systems.	Work Complete
DBP Analysis	Phase 1 and Phase 2	Evaluation of conventional and emerging DBPs will be included within Phase 1 UV AOP testing. Pipe loop studies with stabilized water should include DBP reformation during Phase 2 of testing.	Phase 1 - Complete Phase 2 - TBD
Production Reliability	Phase 1	Evaluation of production reliability based upon down-time resulting from process and monitoring system challenges.	Work Complete
Artificial Intelligence Investigations	Phase 1 and Phase 2	Evaluation of water quality and membrane process performance as part of grants from Metropolitan Water District of Southern California and Japanese Ministry of Economy, Trade and Industry (METI).	Phase 1 - Complete Phase 2 - TBD
RO Concentrate Analysis	Phase 1 and Phase 2	Evaluation of RO concentrate quality as it may impact NPDES discharge and RO brine line scaling.	Phase 1 - Complete Phase 2 - TBD
Product Water Stabilization	Phase 2	Evaluation of purified water quality and determination (and testing) of stabilization methods	TBD
Pathogen Monitoring	Phase 2	Evaluation of pathogen removal across the Tapia WRF.	TBD
Seasonal Operations Simulation	Phase 2	There is a potential that future AWPF operations are seasonal. The system is designed to allow for some components of the RO to be "mothballed" for periods of time, as is currently being done for some of the membranes.	TBD
Supplemental Flow Simulation	Phase 2	Testing of different water sources by the AWPF, such as brackish groundwater.	TBD

1.7 Report Purpose

The purpose of this Purification System Performance Report (Report) is to summarize the treatment and monitoring system performance, the treatment system operational efficiency, and ability of the treatment and monitoring system to meet State of California regulations for potable water reuse (DDW, 2018).

1.8 Prior Completed Work

This report builds upon three completed efforts, which are briefly summarized below. In general and with a few notable exceptions, the results presented in the three prior documents are not repeated within this report unless significant updates to performance data have been included.

- **Pure Water Results from Startup Testing –** A PM dated August 21, 2020, which was an initial analysis of treatment performance and water quality ahead of a ribbon cutting and a purified water tasting event. Results summarized in this PM include:
  - UF and RO performance with regard to turbidity, electrical conductivity (EC), and TOC were consistently meeting expected performance with no major challenges reported.
  - Pathogen removal, based upon evaluation of surrogates, was robust for the UV, RO, and UV AOP, meeting and in some cases exceeding expected performance.
  - Finished water after the UV AOP was tested for a broad range of regulated and unregulated chemicals. With the initial exception of chlorate and threshold odor number (TON), all tests showed compliance with regulations and robust reduction of unregulated chemicals. Replacement of hypochlorite with fresh hypochlorite resulted in compliance with chlorate and TON requirements.
  - The water meets or exceeds all water quality targets and thus the Demo is operating as intended and the water is safe for consumption during public or private events.
- **USBR Report –** A detailed report on the Demo was completed in December 2020 and submitted to the USBR, in accordance with grant requirements. The report detailed the following:
  - A summary of the Demo treatment facilities, including:
    - Feed water and pretreatment.
    - Local and SCADA controls.
    - UF, RO, and UV AOP HMIs.
    - UF components:
      - UF membrane systems: UF1 (Dow SFD-2880XP), UF2 (Pall [Asahi] una-620-A), and UF3 (Toray HFUG 2020AN).
      - Online monitoring:
        - Water quality – turbidity, total chlorine, free ammonia, pH, and ORP.
        - System integrity and performance - PDT, and system pressures and flow.
      - Chemical feed systems – sodium hypochlorite and ammonium sulfate for chloramination of the UF to control biofouling, sodium hypochlorite, sodium hydroxide, sulfuric acid and citric acid for maintenance cleans (MCs) and recovery cleans (RCs).
    - RO components:
      - RO membranes: Toray TMG10D 4X40.
      - Flexible operation in either 3 stage (4:2:1) or 2 stage (2:1) mode.
      - Online monitoring:
        - Water quality – TOC, EC, and use of previously mentioned total chlorine, free ammonia, and ORP.
        - System integrity and performance – TOC, EC, system pressures and flow.

        - Chemical feed systems – sodium hypochlorite and ammonium sulfate for chloramination of the RO to control biofouling (dosed upstream of UF), sulfuric acid and antiscalant to minimize mineral scaling, and specialty formulated chemicals (Avista L403 and L212 for RO clean in place (CIP).
      - UV components:
        - UV reactor: Xylem Spektron 30E.
        - UV AOP accomplished with UV and sodium hypochlorite.
        - Online monitoring:
          - Water quality – UVT, free chlorine, combined chlorine, pH, UVI.
        - Chemical feed systems – sodium hypochlorite for UV AOP and Lime-A-Way for cleaning the online UVT probes.
    - Regulatory criteria for Reservoir Water Augmentation in California (DDW, 2018), including pathogen log reduction requirements and criteria for chemical compliance.
    - Demonstration of MF, UF, and RO performance in terms of permeability, flux, fouling, chemical cleaning, and water quality through December 2020. All of this information is updated within this Report with more recent data and detail.
    - Demonstration of UV performance in terms of maintenance of UV dose, chemical feed systems, and UVI. All of this information is updated within this Report with more recent data and detail.
    - Preliminary conclusions regarding potential design criteria for UF, RO, and UV AOP systems, which are updated with more information and detail within this Report.
- **SOPs** – SOPs were developed to aid staff in the startup, shutdown, operation, and calibration of the Demo, as follows:
    - Operation Checklists:
      - Described daily and weekly inspection and monitoring tasks.
      - Checklists were subsequently digitized onto a web-based platform to eliminate data entry and permit instantaneous access to plant and consultant staff.
    - Offsite Lab Sampling Checklists:
      - Outlined the sample points and schedule per the test plan.
    - Membrane Cleaning:
      - Described cleaning procedures for the UF and RO membranes.
    - Instrument Maintenance:
      - Outlined maintenance guidelines and provides a quick reference to original equipment manufacturer manuals for the advanced water quality monitoring equipment at the Demo.
    - Advanced Operation:
      - Detailed manual control and set point adjustment for all treatment barriers.

Chapter 2

TREATMENT PROCESSES AND OPERATIONAL PERFORMANCE

This section provides a general overview of each technology and reviews and summarizes the operational performance of the systems (e.g., flux, permeability). Water quality is addressed in subsequent sections.

2.1 General Demonstration Plant Operation and Production Capacity

2.1.1 Commissioning

The Demo was installed and commissioned between the end of May to June 2020. Major operational events are listed in the timeline below.

- June 8, 2020:
  - UF system was online and running in automatic at a low flux of 15 gfd with three modules installed. The initial UF recovery was 15 gfd:
    - After observing minimal fouling for the first overnight run, and to allow sufficient flow for the RO flux was increased targeting 25 gfd and the cycle set to target 95 percent recovery on the UF.
    - Events and operating rationale for the UF are summarized further in Section 2.3.2, Table 2.1.
  - RO system commissioning in manual as a three-stage system, 4:2:1 array with 6 elements per vessel:
    - Low recovery (75 percent) and low flux (10 gfd) to confirm system operability and permit continued operation of the UF system without exceeding feed flow requirements.
    - The RO system was run only under supervision during the day and was switched off at night during initial troubleshooting.
- June 16, 2020:
  - RO system running in automatic at 75 percent recovery, 2 stage 2:1 array, 6 elements per vessel, 10 gfd. The RO system was periodically realigned and operated as a 3 stage system to ensure the stage 1 membranes remained clean.
  - UV system commissioning started.
- June 18, 2020:
  - UV system operating in auto at 6 gpm feed flow with a point source summation dose target of 1200 mJ/cm^2.
  - Data logging was established to the remote historian Intelogx but communication required troubleshooting to improve reliability for all Demo tags.

- June 24, 2020:
  - Stage 1 RO membranes were preserved in a commercial membrane preservative - Preservol (PWT Chemicals, Vista, CA proprietary powdered formulation).
  - RO was reconfigured as a 2 stage, 7 element array with a target average flux of 10.1 gfd and recovery of 80 percent per the test plan. RO automatic operation continued.
- July 1, 2020:
  - All demo unit operations running in automatic per test plan goals.
  - Data collection to the Intelogx historian established for all tags.

  Following commissioning, the Demo was set to run in automatic and setpoints were systematically changed according to the test plan goals. The data presented in this report covers the period from the end of commissioning (July 1, 2020) until June 30, 2021 unless otherwise specified.

2.1.2 Operational Reliability

To provide an overview the operational reliability of the Demo, time online and offline as well as total production capacity was quantified for the first year of Demo data commencing on July 1, 2020 through to June 20, 2021. The information below can provide insight into overall production reliability of a future full-scale system.

During the first year of operation the following quantities of water were produced by each individual treatment process:

- Ultrafiltration - Total Yearly Production - 28.5 million gallons:
  - UF1 - Dow SFD-2880XP - 9.8 million gallons:
    - Installed membrane area - 829 square feet (ft^2).
  - UF2 - Pall UNA 620A- 7.1 million gallons:
    - Installed membrane area - 538 ft^2.
  - UF2 – Toray HFUG 2020AN - 11.6 million gallons:
    - Installed membrane area - 969 ft^2.
- Reverse Osmosis - Total Yearly Production - 8.8 million gallons.
- UV AOP - Total Yearly Production 2.4 million gallons.

2.1.2.1 UF Reliability

The general operational mode percentages including time offline (i.e., not producing or performing planned maintenance) for each UF unit are shown on Figure 2.1

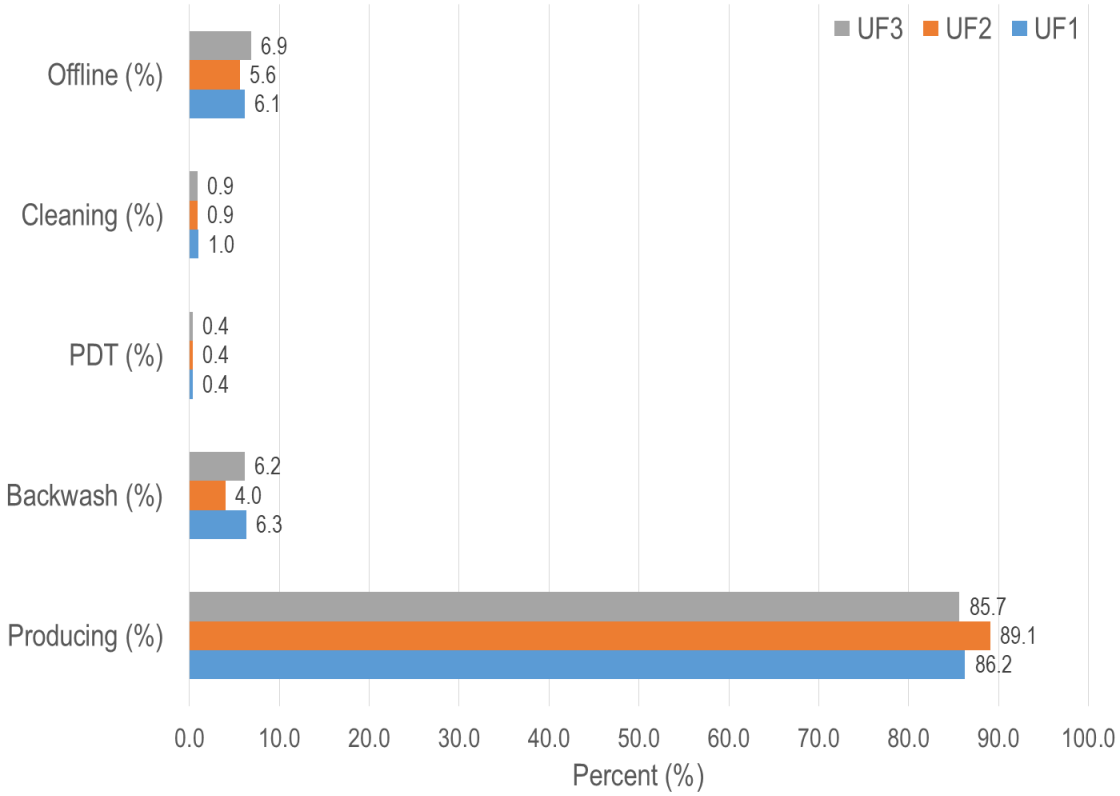


Figure 2.1 UF Production Reliability Shown as Percentage of Time in Operational Modes and Also Time Offline (UF1 = Dow SFD-2880XP, UF2 = Pall UNA-620A, UF3 = Toray HFUG 2020AN)

In general, the UF system operated in a very reliable fashion, with a total operational proportion of between 93.1 to 94.4 percent. During this period, the UF systems were in production between 86.2 - 89.1 percent of the total time, with non-production activities including backwash, cleaning (either MC or RC) or PDT included in time online.

Contributors to the time offline in the UF system included:

- Shutdown for monthly maintenance to clean chemical injection quills - estimated at 1.5-2 percent.
- Unplanned shutdowns due to:
  - Production hold ups due to the shared utility of a CIP system and backwash tank during recovery cleans.
    - Typically, production will halt for all systems during a recovery clean due to reservation of the backwash pump which will place UF systems in standby once the production target of a cycle is exceeded. This will result in the cleaning time offline for each system being cumulative. The total additional impact of this per module is estimated at 2 percent time offline.
  - Programming sequence faults which required programmer intervention:
    - These were rare and largely occurred within the first 2 months of operation and were subsequently resolved.

  - PDT errors due to low air pressure forcing UF shutdown until alarm acknowledgement which occurred less than 3 times during the year and were caused due to a faulty manual air regulator.
  - 2 UF feed pump variable frequency drive (VFD) failures occurred after local power outage events and required replacement of fuses prior to system restart.
- Recovery and Maintenance Cleaning:
  - Each UF takes approximately 3 hours of contact per recovery clean with a high pH oxidant clean conducted first and then a low pH citric acid clean conducted second). Recovery cleans are scheduled 4-6 hours apart to allow for time for the system to heat filtrate as the cleaning solution, dose chemicals and then neutralize post clean. Therefore, conducting recovery cleans is conducted over approximately 36 hours moving sequentially through all modules.
  - At scale, there will be multiple UF trains including an appropriate level of redundancy which will allow individual trains to be isolated from the RO and cleaned independently. The online trains will produce sufficient water to keep the RO operational and not impact overall plant UF production setpoints. Hence, RO shutdown periods due to UF RCs are not expected to influence RO production capacity at scale. There will also be sufficient flushing and diversion to prevent carryover of cleaning residuals to protect the RO.

A majority of the causes for time offline are not anticipated to impact full scale reliability as they can be solved via the presence of multiple membrane trains scheduled to clean and produce in a manner to optimize equipment utility. Power outage events are anticipated to be better managed at full scale through installation of backup sources and more robust electrical equipment. Finally, programming faults are anticipated to be resolved during full scale commissioning.

2.1.2.2 RO and UV AOP Reliability

The general operational mode percentages including time offline (i.e., not producing or performing planned maintenance) for the RO and UV AOP processes are shown on Figure 2.2.

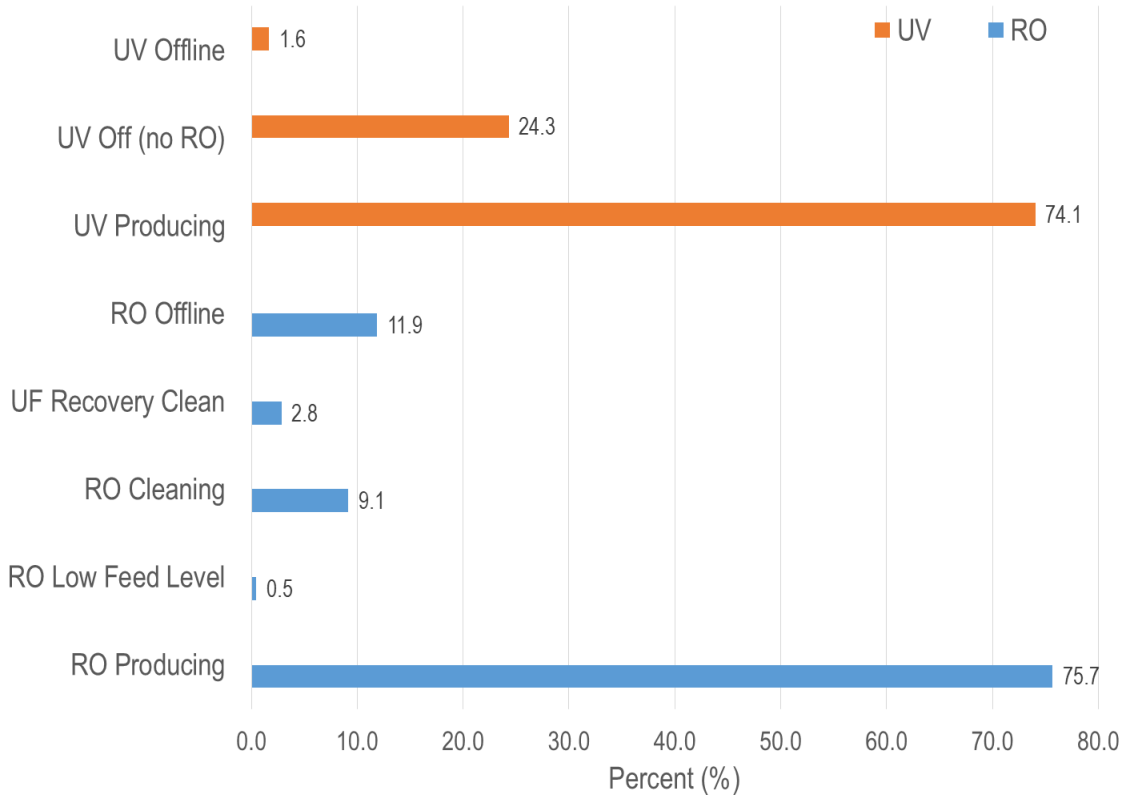


Figure 2.2 RO and UV AOP Production Reliability Shown as Percentage of Time in Operational Modes and Time Offline

The RO system is programed to shut off if the UF filtrate tank reduces below 60 percent. Similarly, the UV AOP system when in auto will not operate if the RO is not in production. The UV system has shown a very high level of utility, and operational data suggests that the UV system could have operated for 98.4 percent of the year if the RO had operated continuously.

The UV system unplanned offline periods have included shutdown for injection quill cleaning and also two unplanned shutdowns due to network communication issues. The UV system is connected and controlled via the UF HMI through the network. Adjustments are made on a dedicated page on the RO HMI. During network upgrades and an initial interruption, there was difficulty troubleshooting UV Alarm clearance which resulted in prolonged days offline. This would not be anticipated to occur with full scale systems.

The RO system was in production for 76 percent of the year. The following factors contributed to the lower production ratio of the RO system:

- RO CIP:
  - Typical RO CIPs have required shutdown for 3-4 days due to the fact that two cleans, each requiring a manual overnight soak are conducted back to back.
  - In a full scale system, automated CIP systems as well as design of parallel trains or stages that can produce and be cleaned independently would mitigate impacts to production.

- RO Offline as a Result of UF Cleaning:
  - The RO is purposefully turned off during UF recovery cleans to prevent the transfer of UF RC residuals downstream which may damage the RO membranes. Note that a description of the length of downtime has been included in the prior UF section.
- RO Feed Level/UF Filtrate Tank Level:
  - During maintenance cleans there may be situations where the UF filtrate tank levels reduces below 60 percent and shuts off the RO, this accounted for 0.5 percent of non-production time.
  - RO Feed level would not be anticipated to impact operability at scale due to the use of multiple parallel production UF trains and increased footprint available for more appropriately sized RO feed tanks.
- RO Offline:
  - The remaining period of time when the RO has been offline (11.9 percent) included:
    - Shutdowns of the UF system where the RO is consequently turned off - approximately 5-6 percent.
    - A single integrity failure event during a CIP and subsequent troubleshooting that occurred between approximately 3-4 percent.
      - Subsequent conductivity probing identified damage to the tail element of stage 3.
      - Autopsy of the damage module identified delamination.
      - The cause of the integrity failure was suspected to be unintentional operation causing higher permeate backpressure than concentrate pressure during a clean.
    - Intentional shutdown of the RO due to loss of normalized permeate flow and periodic flushing prior to CIP due to CIP chemical delivery delays.
  - UF shutdowns are not expected to impact full scale operation to the degree noted at the demonstration plant due to the available production from parallel trains.
  - Integrity failure may result in downtime, however, the particular cause of integrity failure at the Demo was accidental high permeate pressure due to the manual nature of the cleaning process. An automated RO CIP system would be designed such that this event should not occur.
  - Delays due to the delivery of CIP chemicals are anticipated to be mitigated by managed and automated CIP systems, as opposed to the deliveries of small quantities currently in use at the Demo.

In general, the Demo has performed with very high utility and the cause of offline periods are not anticipated to result similar down-time compared to a well-designed full-scale system with appropriate redundancy. Specific maintenance and troubleshooting issues encountered are discussed in further detail for each treatment process in the following sections.

2.2 Pretreatment

2.2.1 System Description

Prior to the UF feed tank, sodium hypochlorite and ammonium sulfate are injected inline to make chloramines. Downstream of sodium hypochlorite, but upstream of ammonia injection an automated screen is installed to remove course particulates and to protect the UF membranes.

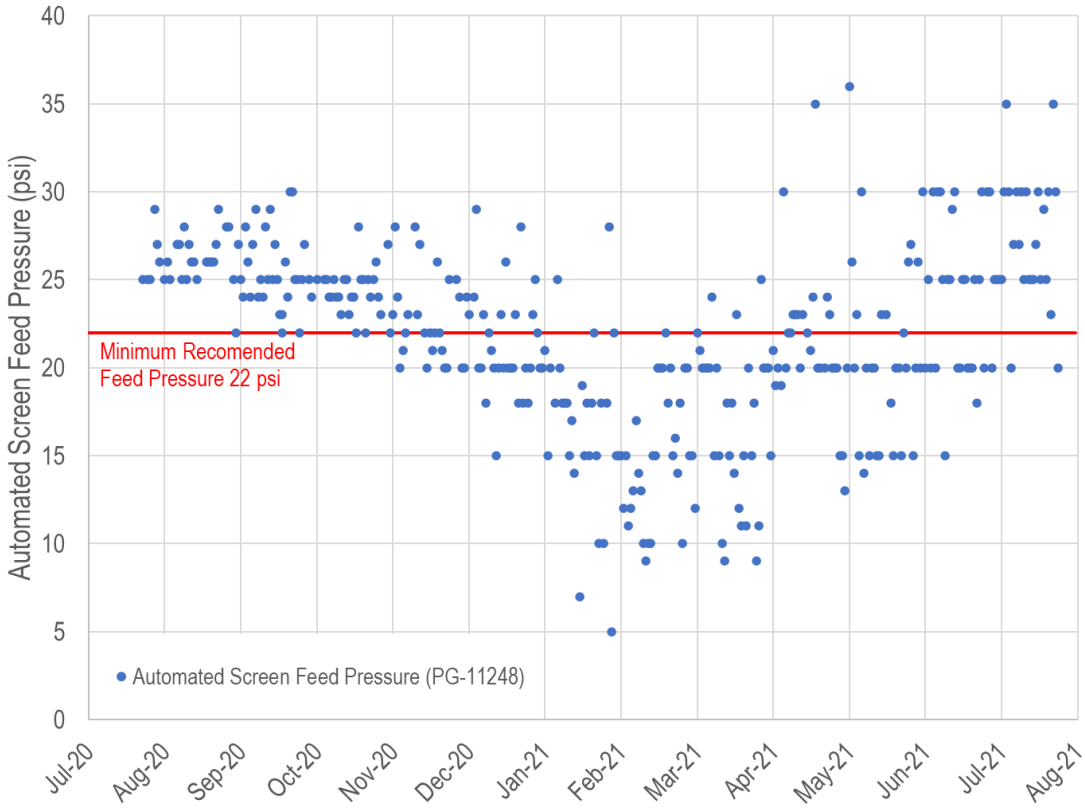
2.2.2 Automated Feed Screen

The Demo is equipped with an Amiad 3-inch TAF 750 automated screen (F-11200) prior to the UF feed tank and ammonia dosing but downstream of sodium hypochlorite addition. The installed screen is a 200-µm stainless steel woven mesh. The screen has been operated with default parameters of one backflush every 8 hours for 16 seconds or if a differential pressure of more than 7 pounds per square inch (psi) occurs.

From June to September 2020, the 200 µm strainer was not installed. The missing strainer was identified in a 3-month follow-up inspection carried out at the end of August 2020. Given the low feedwater (Typically 0.5 nephelometric turbidity unit (NTU)) and UF filtrate turbidity (Typically < 0.05 NTU) and continual demonstration of acceptable PDTs by the UF systems, operation without the strainer in the initial 3 months did not appear to result in UF damage.

The strainer is monitored via an inline pressure gauge (PG-11248) before the strainer. The target inlet pressure for the strainer is greater than 22 psi and less than 120 psi. The minimum inlet pressure is required to ensure adequate flushing performance.

The inlet pressure gauge is monitored on daily Logsheets and data from the end of July 2020 to the end of June 2021, the first year of operation, is shown on Figure 2.3.



Note: Data from daily Logsheets. The approximate screen cleaning frequency was every three months, but limited impact of cleaning on screen feed pressure was observed. Feed pressure was presumed to be related to upstream transfer pump setpoints which are not monitored or controlled by the demonstration plant.

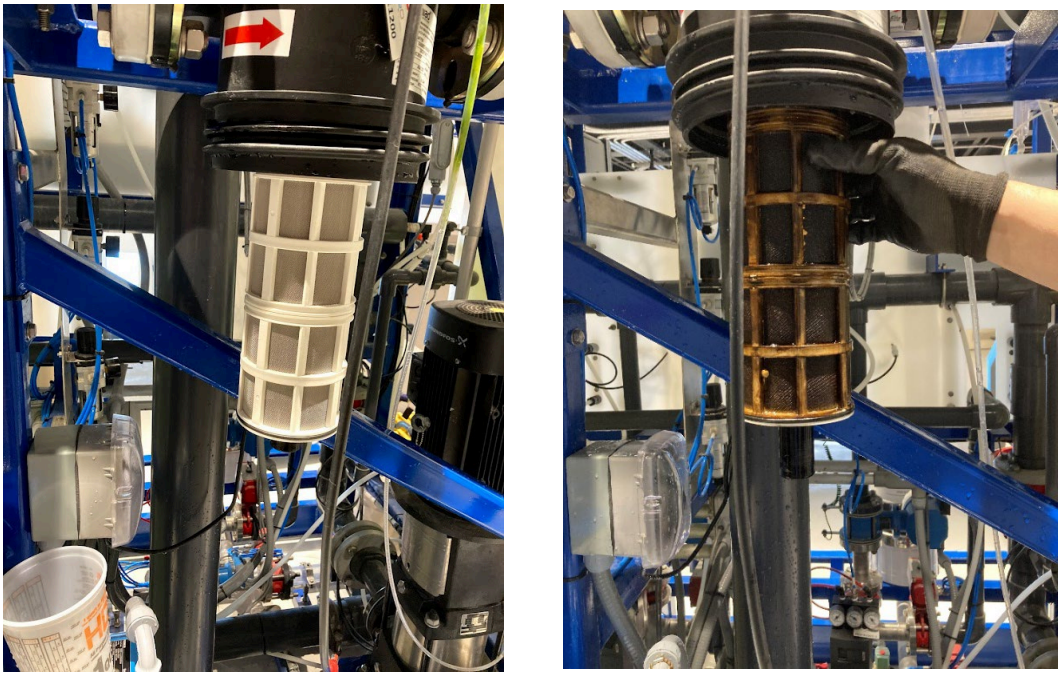
Figure 2.3 Automated Screen Feed Pressure From July 2020 to August 2021

The cause of feed pressure loss was suggested to be related to settings on the upstream valve that directs flow to the Demo from Reservoir 2. There did not appear to be a trend in cleaning and resulting feed screen pressure.

Although the feed pressure did decrease below the minimum recommended, the automated screen appears to have functioned well and has not been observed to hold up production with excessive backwashing or any notable impact on differential pressure.

It has been recommended to manually clean an inspect the screen at an interval of 3 months. The planned maintenance interval is arbitrary as there has been no issue with the unit at this time. Screen cleaning is recommended to include soaking in calcium, lime, rust (CLR) commercial cleaner to remove mineral and organic deposits followed by rinsing with high pressure water.

The automated screen has been observed to capture a dark brown bio-slime type foulant. The foulant was presumed to be biological due to its slimy nature and the fact that it originated from wastewater. No detailed inspection of foulant composition was performed as there did not appear to be significant impact to filter pressures from its occurrence. The occurrence of the foulants suggests that some cleaning strategy should be considered for the full scale filters. However, the foulant did not appear to increase filter differential pressure to a degree that impacted demonstration plant operation. Upon initial inspection, the screen did not appear to have accumulated a significant amount of coarse debris. The foulant appears to be relatively well removed by the cleaning regime noted above. Images of the screen when new, as well as post cleaning are included on Figure 2.4.

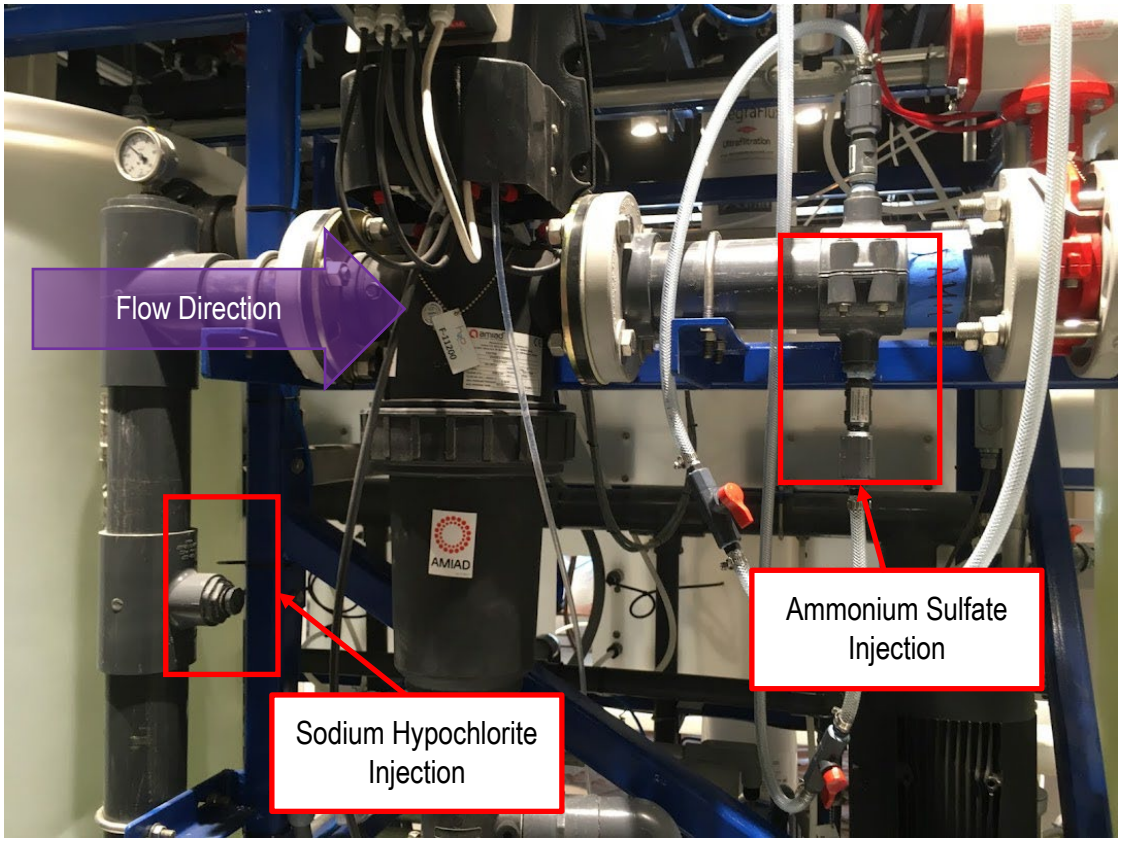


A B

Figure 2.4 Automated Screen (A - Installed Prior to Use; B - After 3 Months of Service and Cleaning)

2.2.3 Chloramination

Chloramination is achieved via dosing of sodium hypochlorite and ammonium sulfate inline at a ratio of approximately 3:1 through the injection ports shown on Figure 2.5. The dosing is flow paced to the UF feedwater flow rate to meet a target concentration which is set on the HMI.



Note: Image shows initial dosing set up with concurrent ammonia and chlorine injection downstream of the strainer which was changed prior to July 2020 as marked.

Figure 2.5 Sodium Hypochlorite and Ammonium Sulfate Dosing Prior to the UF Feed Tank

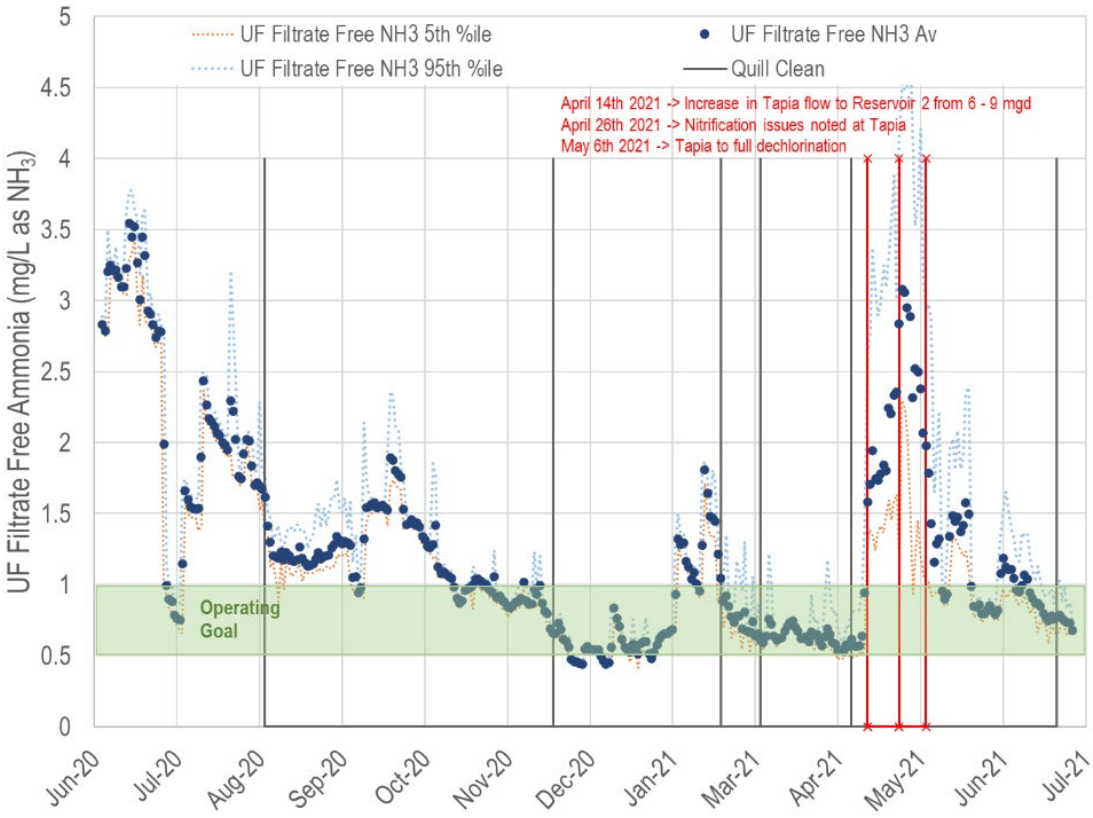
The positioning of sodium hypochlorite injection upstream of ammonium sulfate was performed in an effort to allow the sodium hypochlorite to mix to a low target concentration prior to injection of ammonia in the hope that this would result in an ammonia excess and increase formation of monochloramine, as opposed to di- and tri-chloramines. Subsequent trials are intended to investigate the effectiveness of this strategy.

2.2.3.1 Chemical Dosing Performance

Dosage targets have been adjusted throughout the demonstration period to target a minimum free ammonia residual of 0.5 milligrams per liter (mg/L) (monitored in the UF filtrate – AI-36210) and a total chlorine residual of 2.0 – 2.5 mg/L (monitored in the UF filtrate). The chlorine to ammonia dosage ratio was at maximum 3:1. The target setpoint dosage of sodium hypochlorite [12.5 weight (wt) percent] has remained between 2.5 – 3.5 mg/L with an assumed strength of 11.9 wt percent as chlorine (Cl_2). The target setpoint of ammonium sulfate [40 wt percent] has been set between 0.75 – 1.25 mg/L, with an assumed strength of 10.9 wt percent as ammonia.

Ammonium Sulfate Dosing

The free ammonia concentration expressed as a daily average, with dotted lines indicating the daily 5th and 95th percentile as measured in the UF filtrate is shown on Figure 2.6.



Note: Dots are the daily average and doted lines are the daily 5th and 95th percentile.

Figure 2.6 Free Ammonia (AI-36210) in the UF Filtrate

During initial demonstration plant operation, the corrective action for high ORP or free chlorine at the RO was a system shutdown. This action was perceived to create more of a potential hazard to RO membrane integrity than simply letting a free chlorine spike flush through. A later programming change was made such that high-high alarms on the free chlorine or ORP in the RO feed would instead deactivate chlorine dosing and allow ammonia to flow through the system and neutralize residual. A plot of the ORP is shown on Figure 2.7 for reference.



Note: Dots are the daily average and doted lines are the daily 5th and 95th percentile.

Figure 2.7 ORP (AI-31093) in the UF Filtrate

Until the RO programming changes could be made, what was a high ammonia setpoint to protect the RO (via chloramines) was stepped down conservatively according to the schedule below:

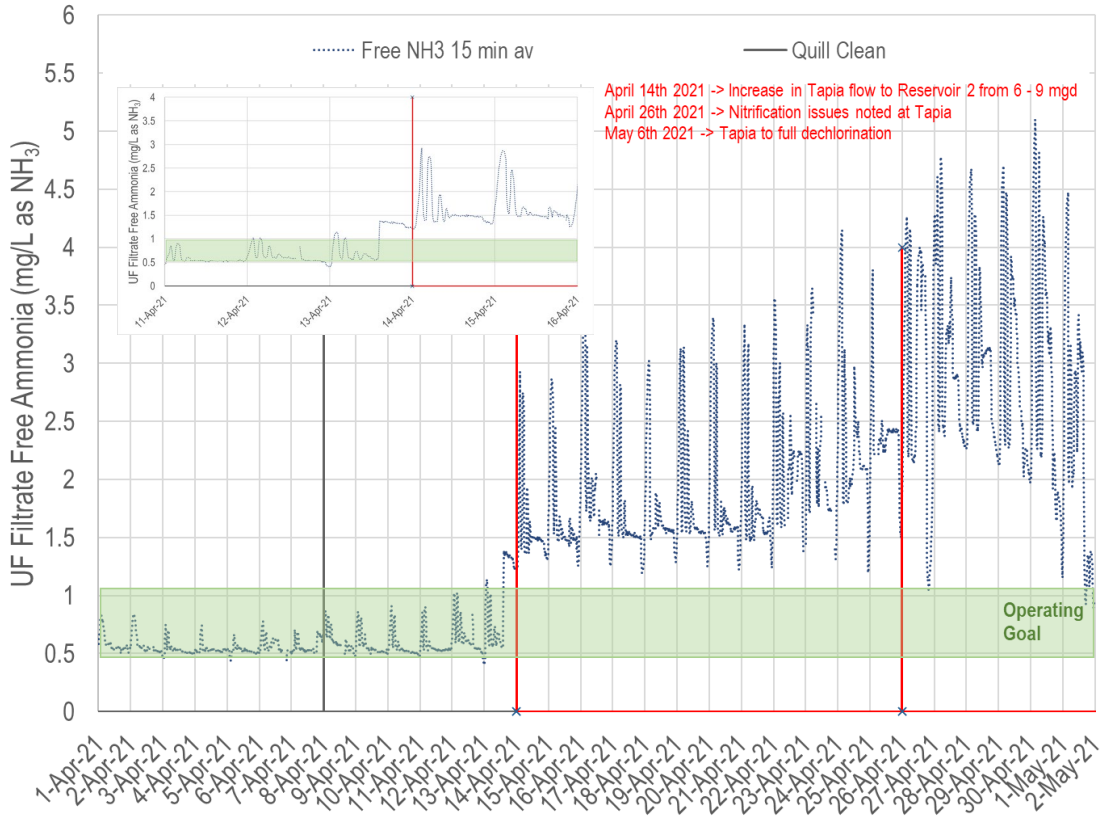
- July 17, 2020 – Dosing target reduced from 2.5 mg/L to 2.0 mg/L.
- July 14, 2020 – Dosing target reduced from 2.0 mg/L to 1.5 mg/L.
- December 11, 2020 – Dosing target reduced to close to 0.5 – 1.0 mg/L with subtle adjustments depending on weekly verifications.

By December 2020, ammonia concentration was typically within the target range of 0.5 - 1.0 mg/L, thus protecting the RO membranes without excessive chemical use. However, spikes did occur between January to March 2021 and from April to June 2021 without corresponding dosing rate changes. There is no explanation for the increase in ammonia observed during January to March 2021. However, changes upstream at the Tapia WRF were made in May to June 2021 that would have impacted observed ammonia concentrations at the Demo including:

- An increase in the Tapia effluent flowrate to Reservoir 2 from 6 to 9 million gallons per day (mgd) in mid-April 2021.
- Nitrification issues at Tapia resulting in generally high ammonia concentrations which were noted as significant in late April 2021.

With the exception of the nitrification upset, ammonia concentrations were typically stable within 0.5 mg/L of the target range.

The period around April 14, 2021, when flow from Tapia was increased to Reservoir 2, is shown with higher frequency data on Figure 2.8. Some diurnal variation in ammonia to the feed to the demo is typical, with between 2-3 spikes observed between 1 a.m. and 7 a.m. each morning. It is unclear if the diurnal spikes are related to pump cycles from Tapia to reservoir 2 or related to additional ammonia loading into Tapia. Nevertheless, the ammonia spikes do transfer through Reservoir 2 into the demo and are likely as a result of Tapia effluent, given that the baseline ammonia level increased when Tapia contributions to Reservoir 2 increased from 6-9 mgd around April 14.



Note: 15-minute average data shown measured in the UF filtrate.

Figure 2.8 Diurnal Behavior of Ammonia at the Demo

As part of ongoing artificial intelligence (AI) work at Tapia (as of October 2021), online ammonia and nitrate sensors were installed on the secondary effluent at Tapia. It is recommended that nitrogen data from Tapia, as well as pumping cycle data to Reservoir 2 is compared with Demo monitoring data to better understand the potential impact of WRF operations on a future full-scale facility. Excessive free ammonia (c. 5 mg/L or higher) could breakthrough RO at levels of approximately 0.5 mg/L. Upon addition of chlorine for the AOP, chloramine would be formed reducing oxidant effectiveness. Monitoring and control of ammonia to an optimum level for chloramination would help to optimize UV AOP performance (Discussed further in Section 4.2.4). Formation of chloramine at the AOP will mean that further chlorine addition to

increase residual or a larger contact basin will be required if virus inactivation by the full scale project via free chlorine is sought.

The demonstration plant operates at flow paced dosing of sodium hypochlorite and ammonium sulfate. This flow paced dosing does not reduce when incoming water quality changes. It is anticipated that full scale designs would make use of ammonia and chlorine monitoring systems linked to control dosing rates, which would significantly stabilize variability of chloramine and ammonia levels at the advanced water treatment facility and provide chemical savings.

Sodium Hypochlorite Dosing

The sodium hypochlorite dosing is monitored via a total chlorine sensor in the UF filtrate (AI-31094). Total chlorine concentration expressed as a daily average, with dotted lines indicating the daily 5th and 95th percentile as measured in the UF filtrate is shown on Figure 2.9.

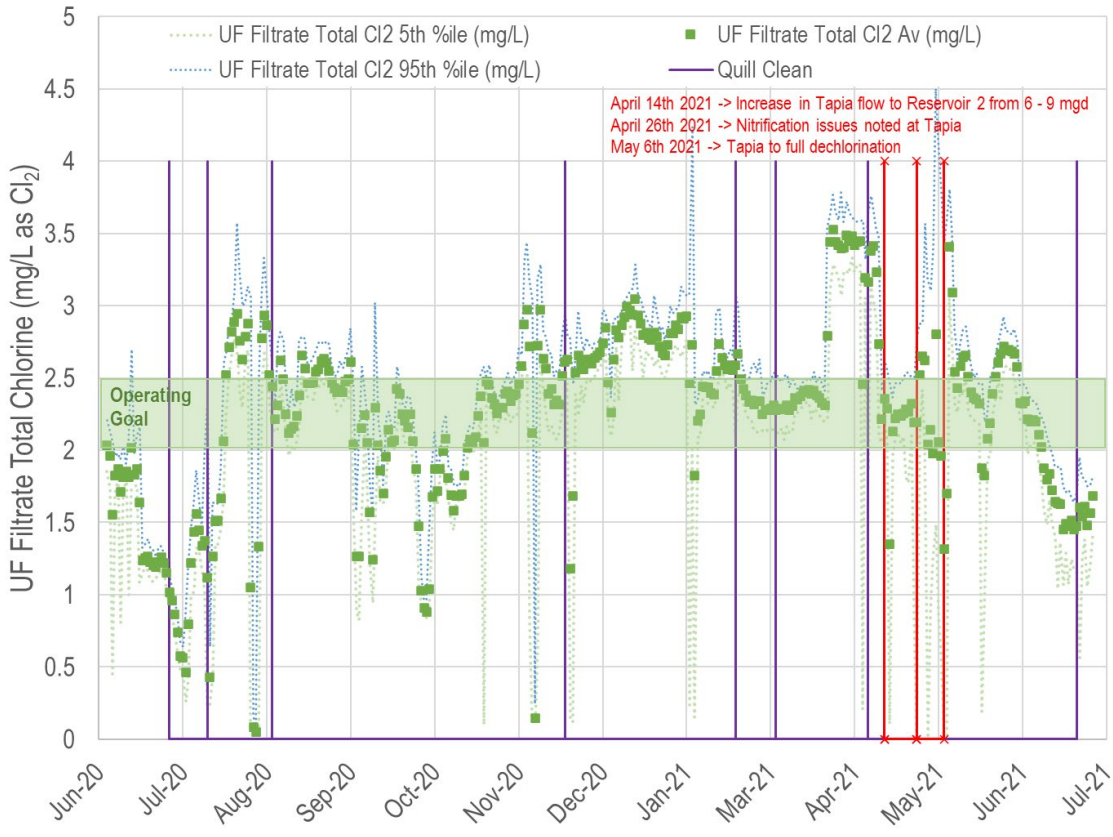


Figure 2.9 Total Chlorine Concentrations Measured in the UF Filtrate

The dosing goal for sodium hypochlorite was to achieve a total chlorine residual (chloramines) between 2-2.5 mg/L as Cl_2. The goal has been challenging to achieve consistently due to the following factors:

- There has been variable quality in the deliveries of sodium hypochlorite, in particular during the first 3 months of operation where significantly degraded product (< 6 percent as sodium hypochlorite (NaOCl)) was received.

- There is natural degradation within the storage area, even when delivery frequency has been optimized and dosing tanks are rotated. The current delivery goal is two weeks and has been maintained for most of the pilot operation.
- There have been multiple instances where injection quills and chemical transfer lines have become plugged and have required flushing and cleaning to restore chemical flow.
- Other sources of variability in total chlorine residual that could benefit from further investigation include: chemical dosing order and variable ammonia (impact to chlorine to Cl_2:Ammonia (NH_3) ratio and chlorine demand associated with it), the chlorine residual remaining from Tapia and any dichlorination (sodium bisulfite) residual remaining from Tapia.

In a full-scale installation, it is likely that the chlorine concentration and dose rate would be controlled via monitoring. However, to achieve better control at the demonstration plant, more frequent verifications and adjustments to the flow paced dosing rate would need to be enacted. In addition, the monthly target of quill and chemical line flushing would need to be met or exceeded. Use of preformed chloramine for addition would also likely minimize quill fouling and have the added benefit of lowering trihalomethane formation, as well as other DBPs.

Changes in September 2021 have been made to help operators better track and manage sodium hypochlorite dosing. These changes include, logsheet spaces to note where dosing changes have been made and also note chemical strength measurements of sodium hypochlorite in the tanks. The collection and use of this data should result in more stable control of monochloramine dosing as well as provide useful information to track the chlorine demand of the source water over time.

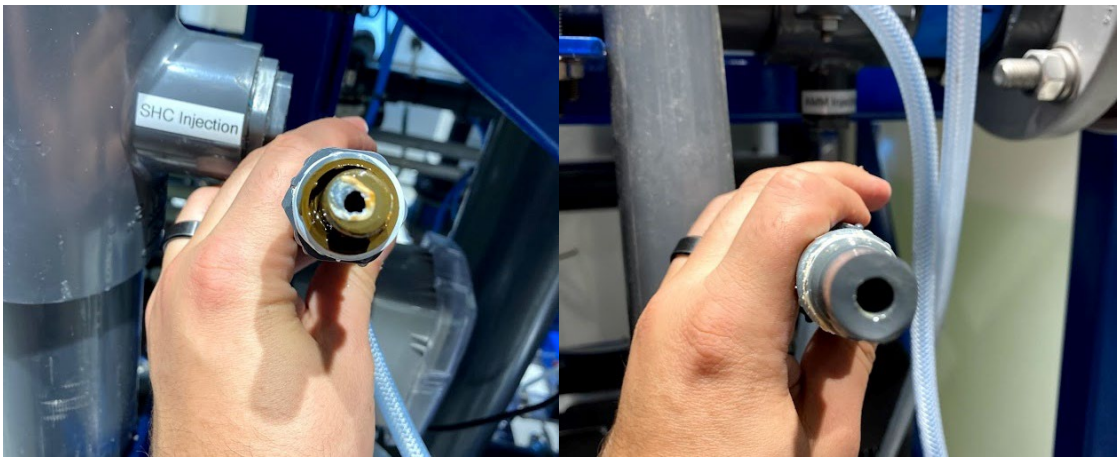
2.2.3.2 Reliability and Maintenance Recommendations

The demonstration plant operates at flow paced dosing of sodium hypochlorite and ammonium sulfate. This flow paced dosing does not reduce when incoming water quality changes, which leads to variability in plant influent concentrations. It is anticipated that full scale designs would make use of ammonia and chlorine monitoring systems linked to control dosing rates, which could help to stabilize control of chloramination. There may also be advantages to equalization of flows and pumping rates from Tapia and linking of upstream disinfection practices to advanced water treatment operation.

Variation in sodium hypochlorite strength could be more frequently measured, on each delivery batch and used to adjust the working concentration on the flow paced dosing set up. If this number were conservatively adjusted, then it is likely that the system would respond better to changes when different drums are delivered. With the new IO sight platform integrated as a remote historian at the Demo, it will likely be possible to program operational recommendations based on monitored ammonia and chlorine in an effort to provide automated advice on when chemical dosage rate changes should be investigated and adjusted.

As noted previously, the sodium hypochlorite chemical transfer line to the UF and the injection quill have been prone to plugging. A photo of the plugging material, which appears to be some sort of hard inorganic deposit, before and after cleaning is shown on Figure 2.10. The cleaning regime typically involves flushing the transfer line with RO permeate and then re-priming with sodium hypochlorite. In addition, the injection quill is rinsed in RO permeate, soaked in CLR and then flushed with RO permeate. This procedure requires a plant shut down and typically takes 2 hours. The quill cleaning is currently recommended to occur monthly. Given the challenges

with maintaining sodium hypochlorite flow, it is recommended that the minimum monthly cleaning frequency is continued.



A B

Note: The white inorganic deposit constricting the inner diameter as well as the brown bioslime.

Figure 2.10 Sodium Hypochlorite Injection Quill (A - Before Cleaning; B - After Cleaning)

The chemical dosing pumps have generally been reliable and depending on flow require diaphragm replacement every 9-12 months. The pumps are inbuilt with operational timers that inform plant staff when maintenance is required. To date, only the UF feed sodium hypochlorite pump, which has the highest flow requirement, has prompted maintenance.

2.3 Microfiltration and Ultrafiltration

This section describes the operation and performance results specific to the MF/UF systems from the start of July 2020 to the end of June 2021.

2.3.1 System Description

The MF/UF skid is an open platform system which is capable of parallel operation and independent monitoring and cleaning of three membrane modules which can be from different vendors. As such, the open platform system allows systematic comparison of different membrane products all fed with the same feedwater. Alternatively, the system could be equipped with 3 identical membrane modules and used to rapidly optimize product specific operational protocols without differences in feedwater composition.

The membrane and turbidity monitoring systems are shown on Figure 2.11.

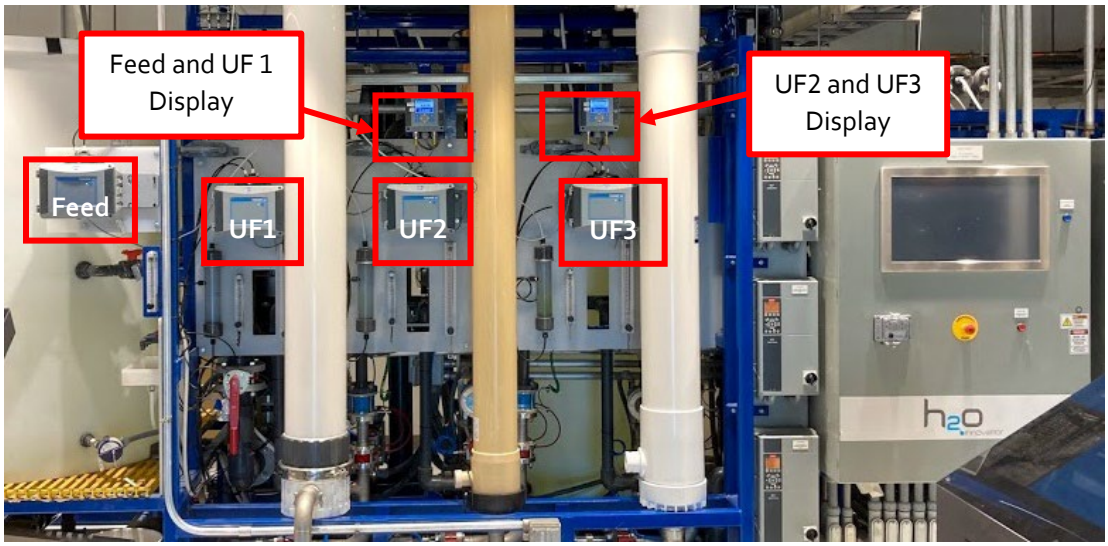


Figure 2.11 MF/UF Modules and Turbidity Monitoring of the Feedwater and Each Independent UF Filtrate to Confirm Membrane Integrity Online

2.3.1.1 Membrane Systems

Currently the Demo is equipped and operating membranes from different vendors including

- UF1 – Dow, which is a true ultrafilter with a nominal pore size of approximately 0.03 μm. The Dow membrane model is the SFD-2880XP.
- UF2 – Pall (Asahi), which is a microfilter with a nominal pore size of approximately 0.1 μm. The Pall membrane model is the UNA-620A.
- UF3 – Toray, which is a true ultrafilter with a nominal pore size of approximately 0.01 μm. The Toray membrane model is the Toray HFUG Type 2020AN.

2.3.1.2 Monitoring Systems

To confirm membrane integrity, the filtrate from each separate UF unit is monitored with a HACH TU5400 high sensitivity laser turbidity meter. The feedwater turbidity is monitored prior to entry into the feed tank with a HACH TU5300 turbidity meter. Filtrate turbidity is monitored continuously per the requirements for indirect integrity monitoring outlined in the United States Environmental Protection Agency (USEPA) membrane filtration guidance manual (MFGM) (USEPA, 2005).

In addition, PDTs are conducted automatically each day to confirm the membrane integrity. The pressure decay rate from the PDT is then used to calculate an effective protozoa log reduction value (LRV) in line with requirements outlined in the USEPA MFGM (USEPA, 2005).

The UF skid also monitors pH, total chlorine, free ammonia and ORP. Total chlorine and free ammonia sensors were discussed in the previous section. pH and ORP are discussed in a later section on sensor reliability. Turbidity meter performance is discussed in this section.

2.3.2 Operational Periods

The MF/UF membranes were operated under constant flux mode. The flux is the flow per unit of active membrane filtration surface area.

MF/UF membranes are subjected to regular low strength MCs and monthly higher strength RCs. The purpose of the cleans is to remove foulant material before it irreversibly reduces the performance of the membrane systems. Fouling rate will increase as flux increases, which will necessitate more frequent cleaning. Therefore, there is a tradeoff between flux selection and cleaning frequency. A higher design flux will mean that water production targets can be met with the purchase of fewer membrane modules. In general, operation at a higher flux with fewer membrane modules will result in a reduction of capital expenditure and a reduction operational expenditure as a result of membrane replacement occurring for less membranes. However, operational expenditure may increase (and so may membrane replacement frequency) if frequent cleans are required to maintain the higher design flux.

During the demonstration period, the membrane flux as well as the cleaning intensity has been systematically varied to identify optimum setpoints for each membrane product.

During commissioning, the membrane vendors each advised starting fluxes of approximately 30 gfd. The maintenance clean recommendation varied between vendors from once per day to once per week. The RC frequency recommended by each vendor was once per month. To adequately compare each module, testing was started at approximately 30 gfd with twice per week MCs and once per month RCs. The test plan intention was to step up the flux each month after seeing at least 30 days at a single setpoint. Later in the trial during higher flux operation, not all modules were increased as there were signs of fouling that required troubleshooting. Membrane vendors were contacted prior to setting original flux and cleaning protocols. Product specific limitations were adopted and applied, for example, a constant backwash rate of 8 gpm for the Pall membrane irrespective of operating flux. The advice from membrane vendors was adopted where possible, but, cleaning concentrations and contact times as well as flux increases were then performed independent of initial vendor recommendations. Upon fouling of UF3, Toray was contacted for comment on safe maximum cleaning recommendations.

The flux and cleaning frequency as well as cleaning chemicals over the trial operational periods are summarized in Table 2.1.

Table 2.1 Operational Setpoint Timeline for the MF/UF System

Dates	Flux Setpoint (gfd)			Cleaning Frequency[5]
	UF1	UF2	UF3	
July 1 - August 28, 2020	25[1]	30	30	2 x 500 mg/L NaOCl MC/week
August 28 - September 28, 2020	35	35	35	2 x 500 mg/L NaOCl MC/week 1 x 2,000 mg/L NaOCl RC/Month 1 x 2,000 mg/L Citric RC/Month
September 28 - November 2, 2020	35	35	35	1 x 500 mg/L NaOCl MC/week 1 x 2,000 mg/L NaOCl RC/Month 1 x 2,000 mg/L Citric RC/Month
November 2, 2020 – January 11, 2021[2]	40	40	40	
January 11 - March 2, 2021	45	45	45	
March 2 - April 1, 2021	50	50	50	
April 1 - May 3, 2021[3]	40	40	40	
May 3 - June 4,2021	40[4]	55	40[4]	
June 4, 2021 – June 30, 2021	40	50	40	2 x 500 mg/L NaOCl MC/week 1 x RC/Month (NaOCl then Citric each 2,000 mg/L)

Notes:
(1) UF1 valve positioner resulting in poor flow control. Left UF1 at a lower flux until the control valve could be rectified. Resolved mid-August 2020.
(2) Attempted to increase flux to 45 gfd on December 2, VFD on the UF feed pump faulted and fuses blew after power outage.
(3) Unsustainable fouling on UF3 and UF1 identified, reduced flux to investigate.
(4) Backwash flow limitation identified and resolved. Backwash ratio targets 1.5.
(5) Cleaning solution concentrations and contact times were adopted to be 1) within acceptable vendor ranges and 2) typical of municipal ultrafiltration frequency and strength.

2.3.3 MF/UF Production Efficiency

Flux, trans-membrane pressure (TMP) and permeability (Flux divided by TMP) are key parameters that quantify how efficiently a MF/UF membrane is performing. These parameters are also corrected for temperature induced viscosity effects using standard equations. As noted previously, the MF/UF systems were controlled on a flux setpoint (not temperature corrected). To that end, the flux (not temperature corrected), as well as the temperature corrected permeability and TMP for each membrane module is shown on Figures 2.12 through 2.14. To remove noise, daily average data is shown. The data has been filtered to only account for periods when each module was in operation.

Conventional targets for maintaining MF/UF production efficiency are 10 percent permeability decline (measured after a RC) over the first year of operation and then a maximum of 30 percent permeability decline across the membrane life. The minimum target permeability was set at 90 percent of the value after equilibration. This appeared to occur at the end of the first week in July 2020, where with MCs only the permeability appeared to plateau. The highest permeability for each module occurred after the first RC in late August.

The TMP is directly proportional to the MF/UF pumping energy. To improve energy efficiency, the TMP should be regulated within acceptable limits by balancing flux with MC and RC frequency.

2.3.3.1 MF/UF Flux, Permeability, and TMP

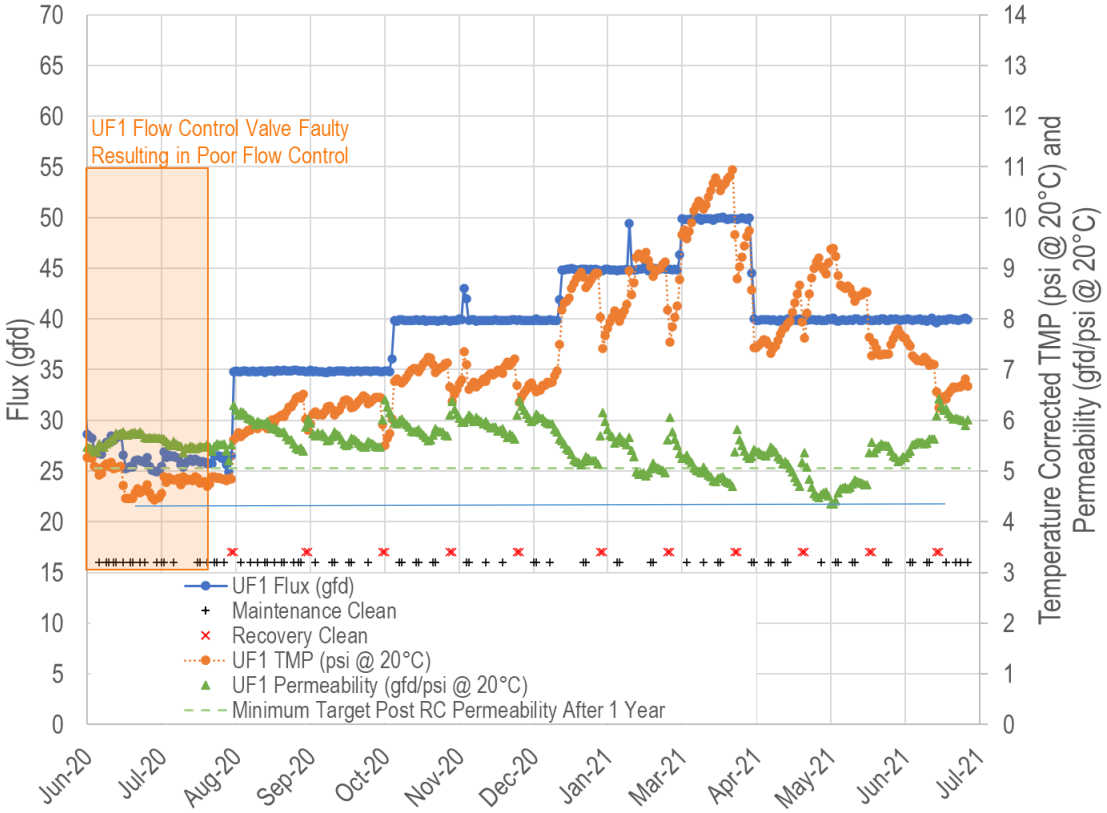


Figure 2.12 UF1 Daily Average Flux, TMP, Permeability and Cleaning Schedule

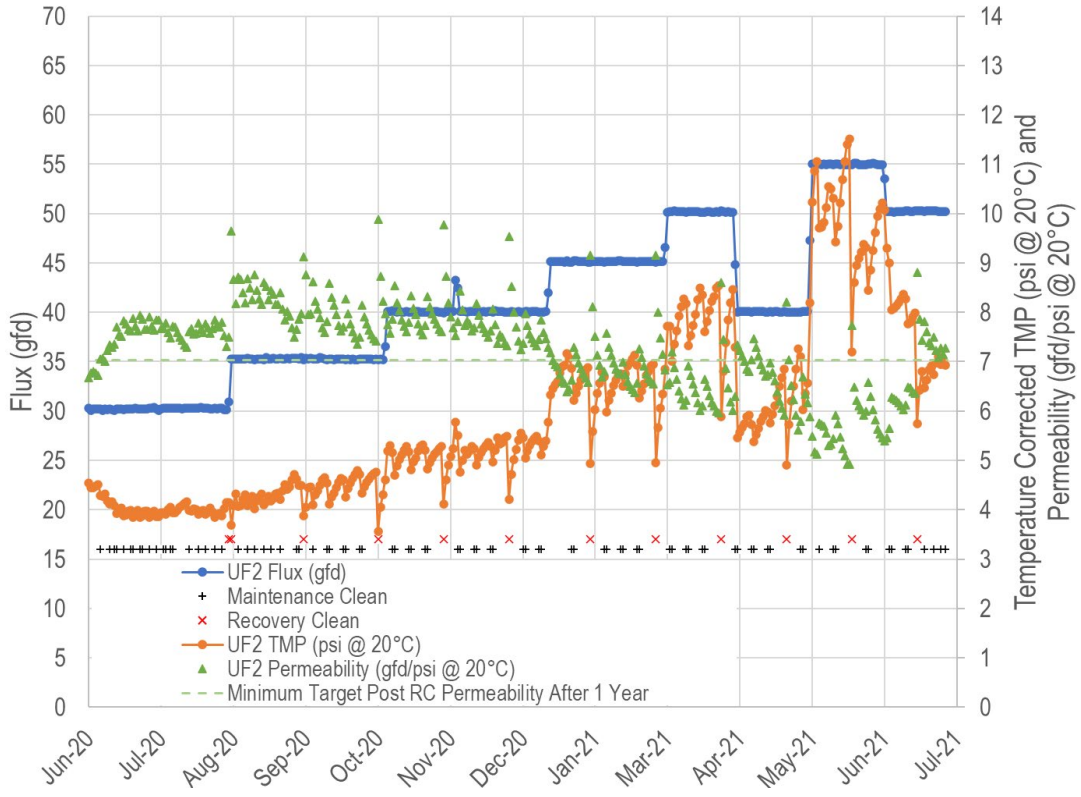


Figure 2.13 UF2 Daily Average Flux, TMP, Permeability and Cleaning Schedule

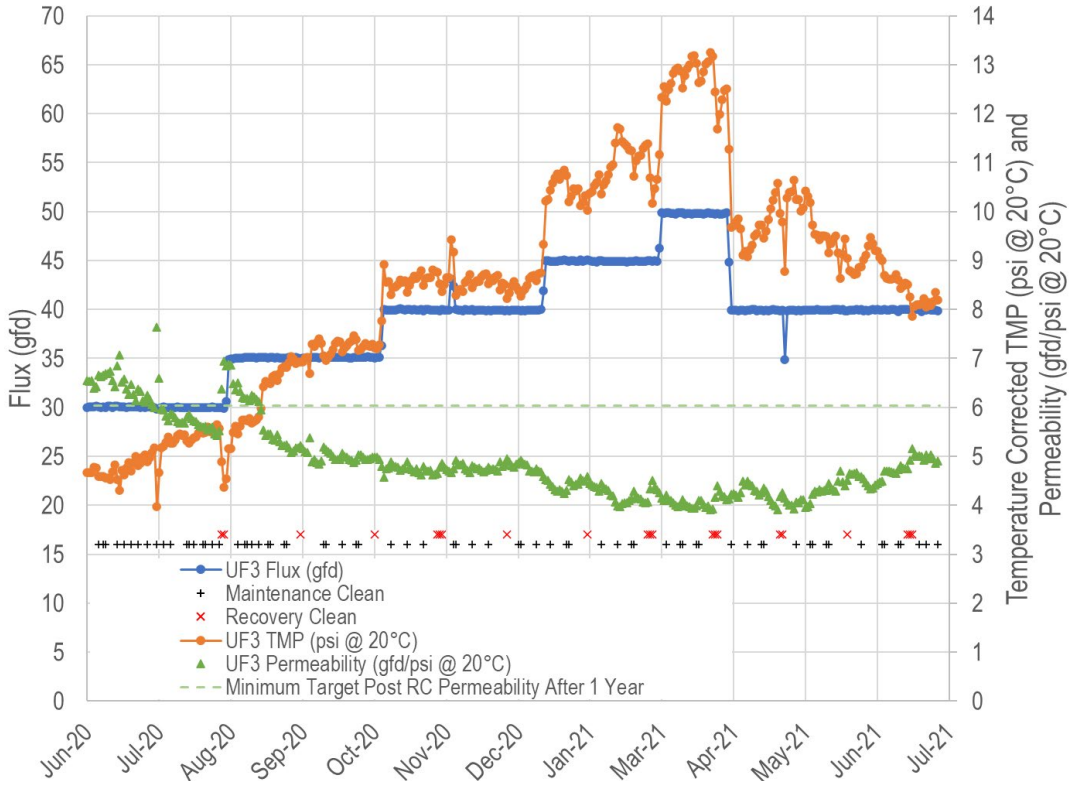


Figure 2.14 UF3 Daily Average Flux, TMP, Permeability and Cleaning Schedule

Based on the results on Figures 2.12 through 2.14, the following observations about the performance of each membrane can be made:

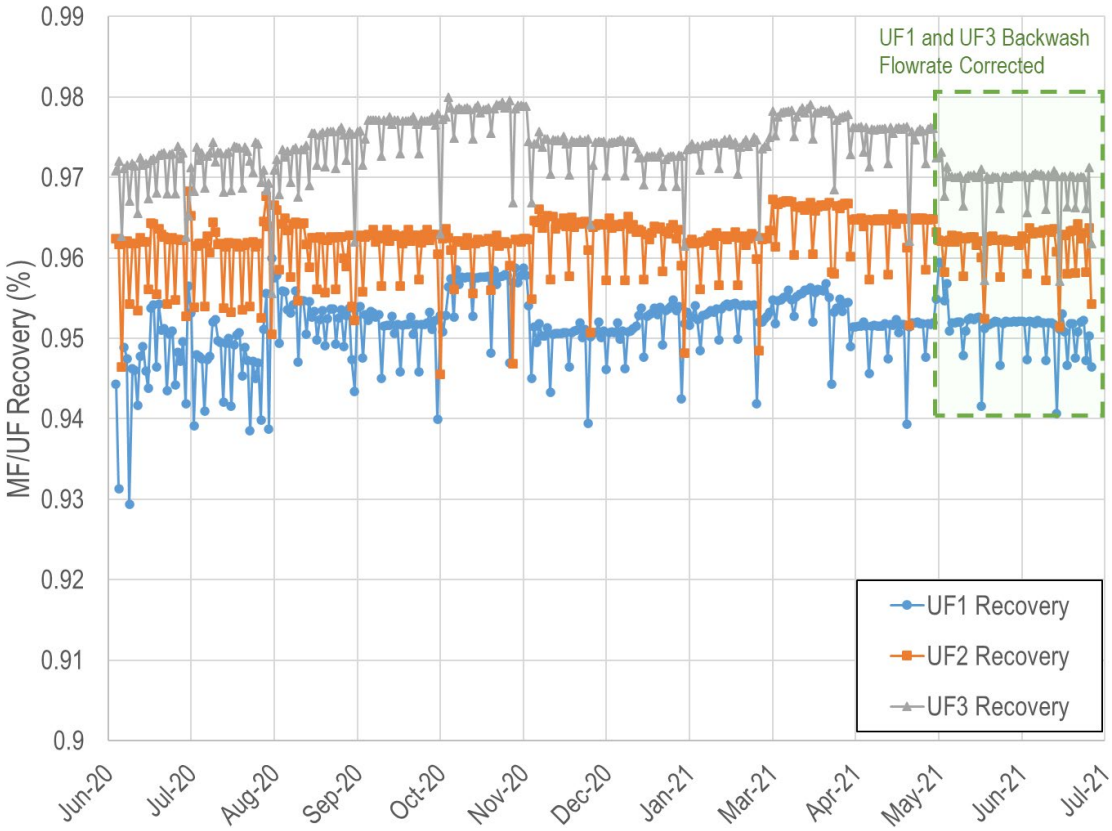
- UF1 – Dow SFD-2880XP:
  - UF1 performed well and showed good permeability restoration as a result of monthly RCs.
  - UF1 permeability began to reduce below target minimum levels when operational flux was pushed beyond 45 gfd.
  - After operation at 50 gfd, UF1 flux was reduced to 40 gfd and permeability decline was further investigated and found to be partially due to poor backwashing performance due to a control valve limitation (See Section 2.3.3.2).
  - The initial stable permeability of UF1 was 5.6 gfd/psi at 20 degrees Celsius (June 2020). The maximum permeability following the first RC was 6.3 gfd/psi.
  - The highest UF1 test flux was 50 gfd and resulted in a maximum TMP of 11 psi, the minimum permeability of 4.5 gfd/psi was observed during 50 gfd operation.
  - In May 2021, a minimum permeability of 4.3 gfd/psi was noted, but this was prior to addressing the backwash flow limitation and just after operation at higher flux.
  - After 1 year, permeability as 5.1 gfd/psi.
  - The backwash limitation for UF1 was resolved in May 2021.
- UF2 – Pall UNA-620A:
  - UF2 demonstrated the highest permeability and was very responsive to both MCs and RCs, which significantly improved permeability.
  - UF2 permeability was significantly improved by chemical cleaning but then declined quickly in a short period following a chemical clean.
  - Rate of permeability decline was the highest for UF2, but, the rate of decline did not exceed the recovery possible by cleaning.
  - UF2 began to decline below the target permeability during the 45 gfd operational period. However, RCs were able to recovery UF2 permeability until a flux setpoint of 55 gfd, with one maintenance clean per week. At this time, UF2 operation was reset to 50 gfd with two maintenance cleans per week.
  - The initial stable permeability of UF2 was 7.8 gfd/psi at 20 degrees Celsius. The maximum permeability occurred following the third RC and was 9.9 gfd/psi.
  - The highest UF2 test flux was 55 gfd and resulted in a maximum TMP of 11.5 psi, the minimum permeability of 4.9 gfd/psi was observed during 55 gfd operation.
- UF3 - Toray HFUG Type 2020AN:
  - With the exception of the first RC, UF3 did not appear to respond to membrane cleaning. Gradually, permeability began to decline to unacceptable levels.
  - UF3 featured the highest packing density and also membrane surface area at 969 ft^2. High packing density modules typically result in lower capital expenditure as less expense is required for membrane racks. It is possible that cleaning regimes need to be further optimized to remove foulants that may be held up due to the tight module internals.
  - UF3 permeability began to reduce below target minimum levels when operational flux was pushed beyond 40 gfd.
  - After operation at 50 gfd, UF3 flux was reduced to 40 gfd and permeability decline was further investigated and found to be partially due to poor backwashing performance due to a control valve limitation (See Section 2.3.3.2). The impact of

the backwash limitation on UF3 was most significant as the large module area was not receiving satisfactory backwash flow to clean it appropriately. After changes were made to the backwash cycle in late April 2021, UF3 permeability did start to gradually increase but has not recovered to the target level after 1 year (> 6 gfd/psi).

- The initial stable permeability of UF3 was 6.9 gfd/psi at 20 degrees Celsius. The maximum permeability following the first RC was 7.6 gfd/psi.
- The highest UF3 test flux was 50 gfd and resulted in a maximum TMP of 13 psi, the minimum permeability of 3.9 gfd/psi was observed during 50 gfd operation.
- The backwash limitation for UF3 was resolved in May 2021.

2.3.3.2 MF/UF Recovery

The recovery of a MF/UF system is the net volume of filtrate produced divided by the total filtrate production. Net volume of filtrate is reduced due to losses as a result of automated backwashes, MCs and RCs. The demo target recovery for each UF module was 95 percent. This recovery is achieved by programming in a batch cycle which accounts for typical hold up volumes, backwash and cleaning frequency and losses. Although the target recovery was 95 percent there were discrepancies between each of the modules with ultimate recovery for UF1 close to 95 percent, UF2 close to 96 percent and UF3 exceeding 97 percent for a majority of the first year (See Figure 2.15).



Note: Recovery is calculated based on daily total permeate relative to feedwater. Dips in recovery occur as a result of MCs and RCs. Target average recovery was 95 percent for all modules. Deviations from the target were due to actual losses not matching predicted losses.

Figure 2.15 MF/UF Recovery for the First Year of Operation

The higher recovery of UF3 was isolated to be due to a control valve which was limiting the programmed backwash flux. As a result, UF3 was not backwashing to the target of 1.5 times the forward flow until the problem was rectified in April 2021. The control valve limitation impacted UF3 to the greatest extent as UF3 is the largest module and requires the highest flow. UF1 was impacted but to a lesser extent. UF2 was not impacted as it was operated per manufacturer advice at a constant backwash flow of 8 gpm, not on a ratio like UF1 and UF3. The impacts of backwash ratio were only noticed when under operation at higher fluxes and can be seen for UF1 and UF3 after November 2020, when target fluxes increased beyond 40 gfd. The effective backwash ratio is shown on Figure 2.16.

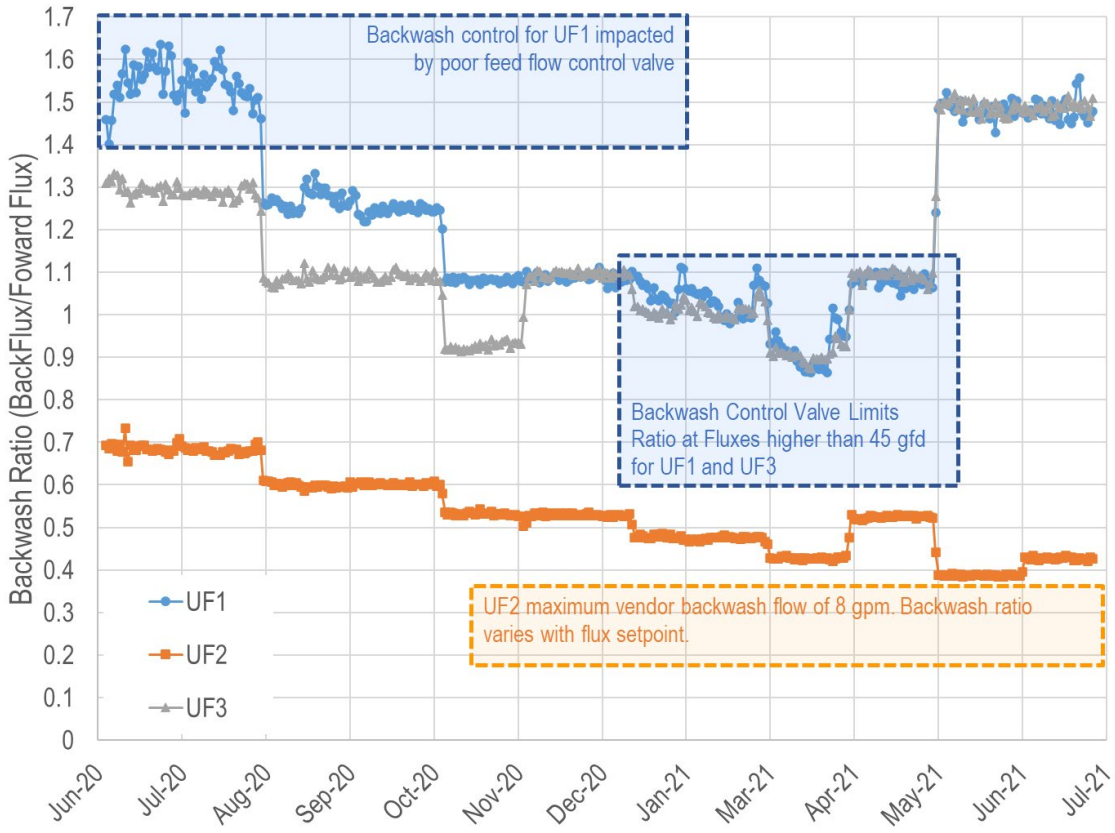


Figure 2.16 Backwash Ratio of the MF/UF Systems During the First Year of Operation

The fact that UF3 was operating at a higher recovery and was backwash limited relative to the target modules may have explained its lower permeability. When the backwash rate was corrected in late April 2021, the permeability of UF3 began to increase (See Figure 2.14)

2.3.4 Maintenance and Recovery Clean Performance

MCs were performed automatically via a scheduling system on the MF/UF HMI. Lower strength cleans (150 mg/L of sodium hypochlorite) were initially used during commissioning. From July 2020, a stronger concentration targeting 500 mg/L of sodium hypochlorite was used. Throughout the first year of operation, the frequency of MCs was varied between once or twice a week, with a majority of the trial utilizing only one MC per week given the generally low fouling rate of the membranes. The total contact time of a MC is approximately 30 minutes and 3 cycles of feed and filtrate flushes of chemicals as well as soaks are performed.

RCs commenced during late August. RCs were also scheduled on the MF/UF HMI and commenced late August. RCs consisted of two sequential cleans. The first clean was 2,000 mg/L of sodium hypochlorite at pH of 11. Although the demo has the ability to also add sodium hydroxide to adjust cleaning solution pH, initial trials indicated that the 2,000 mg/L solution was able to reach the target pH without additional sodium hydroxide. During the first recovery clean, the pH was observed to be 2.8 after dosing of 2,000 mg/L of citric acid equivalent. Based on this result, further acid addition to depress pH was considered not to be necessary. Similar with the sodium hypochlorite cleans, no additional acid addition was necessary to adjust the final cleaning solution pH. The second RC used 2,000 mg/L citric acid at a target pH of 2-3. The RC cycle (for each chemical) involves heating a CIP tank full of UF filtrate up to 95F, dosing chemicals and then 3 cycles of a 15-minute filtrate side flush, a 15-minute feed side flush and a 30-minute soak. This results in a total chemical contact time of 3 hours. After the RC, the modules are backflushed twice with filtrate and returned automatically to service.

2.3.4.1 Quantification of MF/UF Cleaning Performance

MF/UF systems are cleaned to recovery permeability. The relative cleaning performance, based on permeability recovery, can be quantified by comparing permeability before and after cleans. For the first year of operation, the permeability recovery was determined for each MF/UF module and is reported in Table 2.2. UF2 exhibited the best response to cleaning, with an average permeability recovery of 2.53 and 0.56 gfd/psi at 20 degrees Celsius for RCs and MCs, respectively. UF3 exhibited the lowest permeability recovery from cleans. However, for a majority of operation UF3 backwash performance was sub optimal, hence, the results for UF3 below should be considered an underestimate of true performance.

Table 2.2 Permeability Recovery of MCs and RCs for Each Module

UF	Permeability After – Permeability Before Clean (gfd/psi at 20 degrees Celsius)			
	MC Mean (n = 56)	MC St. Dev	RC Mean (n = 12)	RC St. Dev
UF1	0.09	0.05	1.01	0.19
UF2	0.56	0.32	2.53	0.48
UF3	0.18	0.29	0.48	0.46

No optimization of MC or RC recipes has been completed to date; however, these typical dosage rates appear to have exhibited good performance at recovering permeability on UF1 and UF2. Significant optimization of chemical cleaning strength for UF1 and UF2 is not a high priority as there is limited return on investment on such an activity given the low cost and low usage of the UF CIP chemicals. UF3 has not responded to cleaning, with the exception of the first RC, and may benefit from adjustment to the cleaning approach. Given the tighter packing density of UF3, relative to other modules, manual aeration to loosen foulants during the clean has been proposed as an option to improve cleaning performance.

2.3.4.2 Sustainable Flux Assessment

As noted previously, cleaning performance was kept relatively constant (1 MC/week, 1 RC/month) for a majority of the trial. During this time, target flux was systematically increased. To better assess a sustainable flux, the fouling rate (the slope of permeability decline between two subsequent RCs) was assessed for each test period. A relationship between flux and fouling rate was then developed and is shown on Figure 2.17.

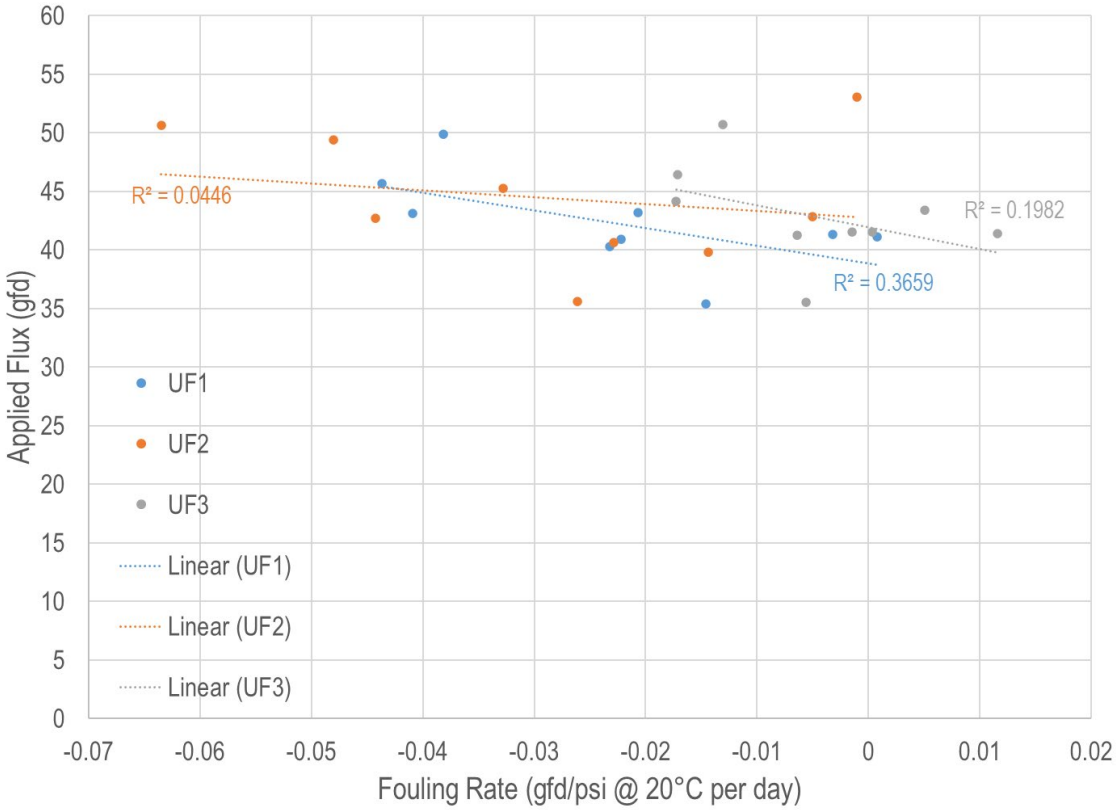
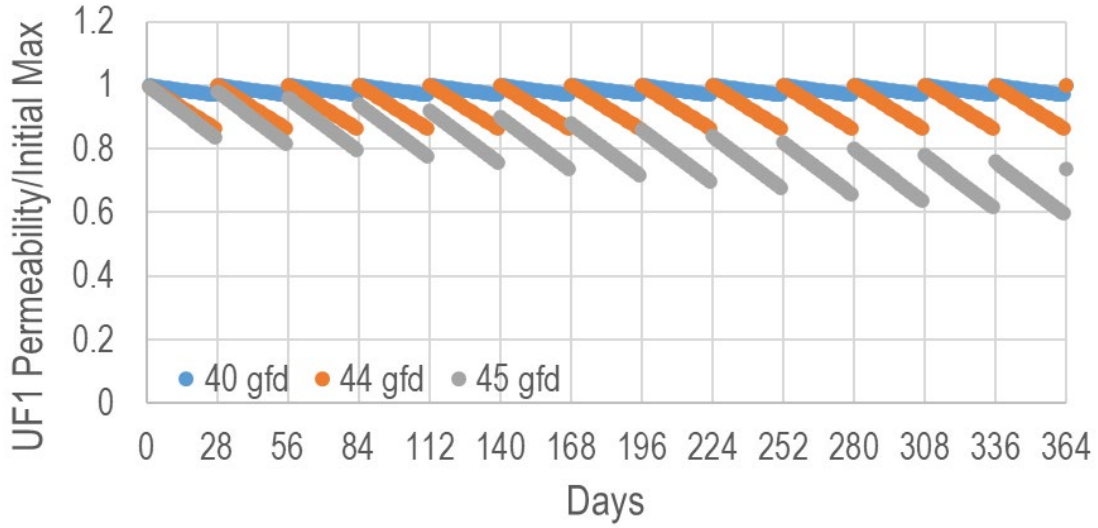


Figure 2.17 Fouling Rate Accounting for 1 MC/Week at Different Fluxes for UF1, UF2 and UF3

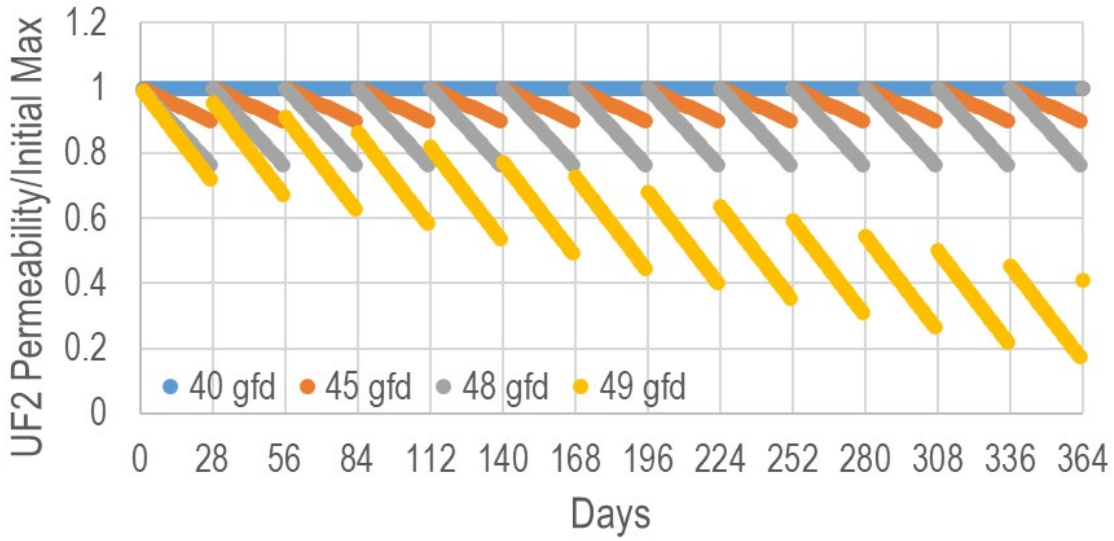
The correlations between fouling rate and flux were very week. Also, for polymeric membranes there are limitations that mean extrapolation of fouling rate using year 1 data may not be appropriate for subsequent years due to chemical alterations of the membrane material. However, the extrapolations using the proposed modelling results below to correspond to fluxes that visually appear to result in stable permeability. To that end, the models below should not be considered accurate predictive tools, but rather a means to semi-quantitatively provide information on a sustainable flux.

Using the regression relationship between fouling rate and flux, as well as permeability recovery due to RCs, it was possible to estimate the permeability decline for each MF/UF unit based on different flux setpoints. Using the acceptable permeability loss criteria of 10 percent per year, a sustainable flux, which would result in less than 10 percent loss could be estimated. The modelled permeability loss at each flux setpoint is shown on Figures 2.18 through 2.20.



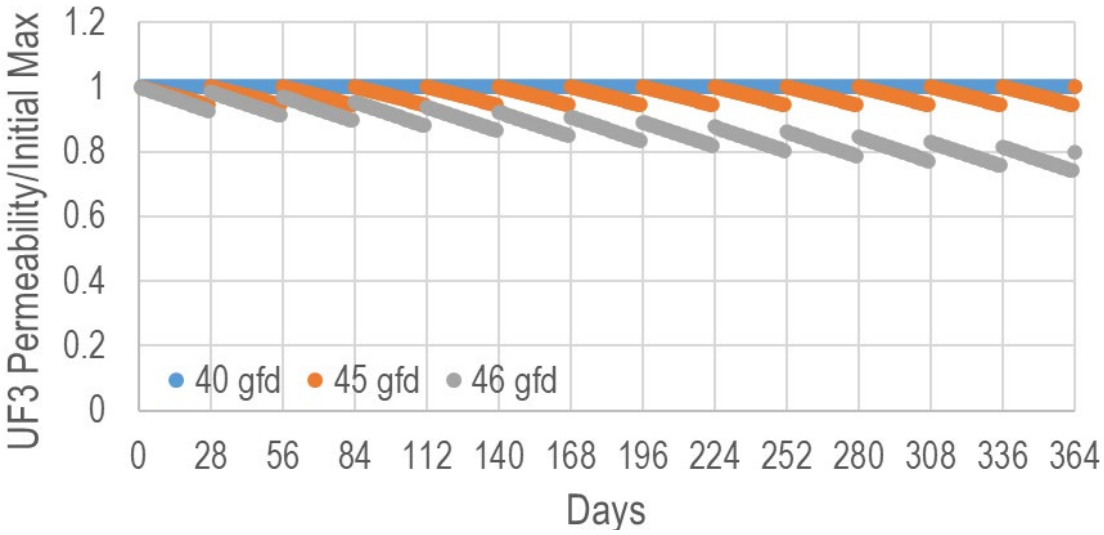
Note: Above 44 gfd, more than 10 percent permeability loss occurs within 1 year.

Figure 2.18 Estimated Permeability Decline of UF1 With Applied Flux, Normalized Based on Maximum Observed Permeability



Note: Above 48 gfd, more than 10 percent permeability loss occurs within 1 year.

Figure 2.19 Estimated Permeability Decline of UF2 With Applied Flux, Normalized Based On Maximum Observed Permeability



Note: Above 45 gfd, more than 10 percent permeability loss occurs within 1 year. However, the results higher than 45 gfd were subject to the backwash limitations noted previously.

Figure 2.20 Estimated Permeability Decline of UF3 With Applied Flux, Normalized Based on Maximum Observed Permeability

The relationship between flux and fouling rate was weak as it does not account for the potential impacts of feedwater variation during the different periods. The fit for UF2 was poor as this unit appeared to foul very rapidly after cleaning, but would then recovery significantly following a clean. This suggested that UF2 may be somewhat flux independent within the range observed, provided chemical cleaning frequency is adequate. Notwithstanding the limitation that this assessment does not account for source water quality variability, the results correspond to long term observations of trends, that is, 40 gfd, appeared to be a sustainable flux for all modules and the strong permeability recovery of UF2 with chemical cleans permitted operation at higher fluxes. Based on this analysis, assuming one maintenance clean per week and one recovery clean per month, sustainable fluxes of 44, 48 and 45 gfd, should be possible for UF1, UF2 and UF3 respectively. When initially specifying modules for the demonstration plant, each vendor recommended a starting flux of 30 gfd. All membrane products were shown to exceed the recommended flux by at least 50 percent.

Evidence suggests that more frequent recovery cleans will likely increase the sustainable flux possible with UF1 and UF2. The recovery clean program for UF3 still requires optimization. Since late June 2021, all UF modules have been operating with twice weekly maintenance cleans which is anticipated to yield information on fouling rate of the membrane products that might decrease fouling rates and result in higher sustainable fluxes.

2.3.5 MF/UF Membrane Integrity Measurement

Turbidity and PDT are used regularly to confirm that the UF system is intact. In addition, virus challenge testing has been conducted with measurements of indigenous PMMoV and spiked MS2 (Presented in Section 2.3.5.4). Online turbidity monitoring of feed and filtrate from each UF module is logged every 30 seconds. PDTs are conducted once per day on each UF module via an automated scheduler. If a PDT fails, the UF unit is taken out of service until an operator resets an alarm and restarts the system.

2.3.5.1 Turbidity Measurement

The daily average and 95th percentile feedwater turbidity for the UF feedwater is shown on Figure 2.21.

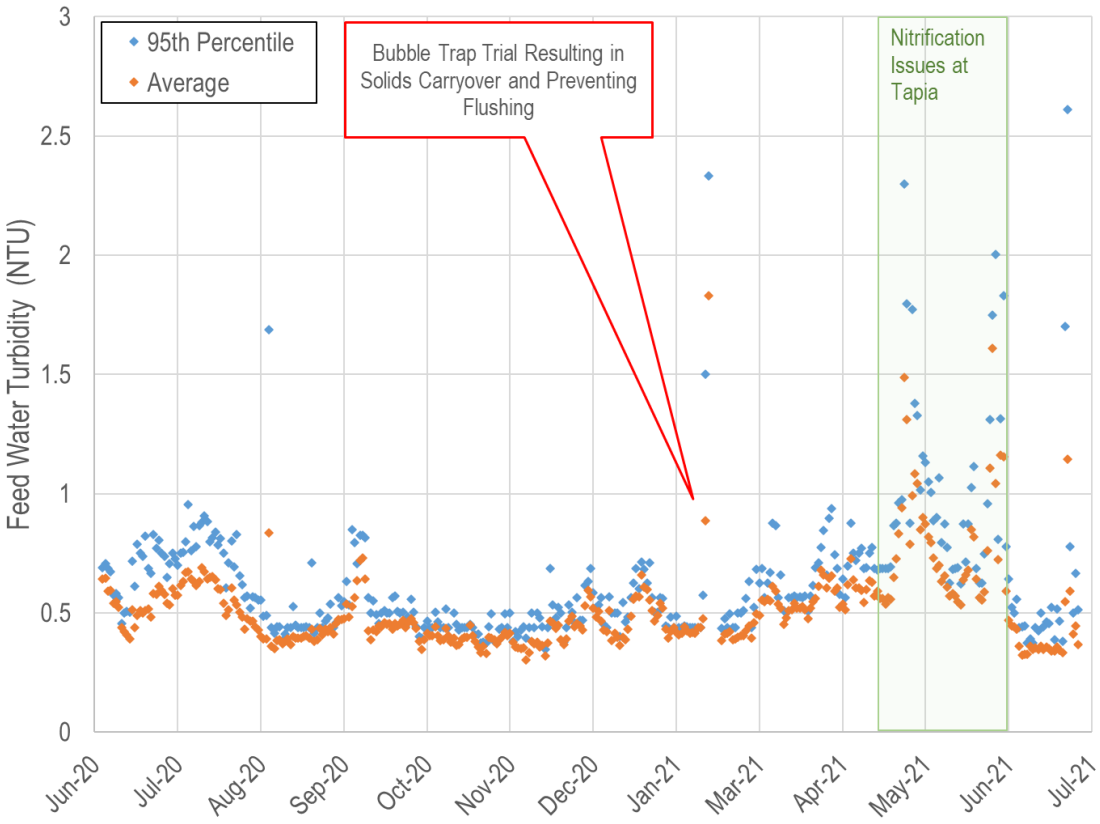


Figure 2.21 Daily Average and 95th Percentile Feedwater Turbidity at the Demo

In general, the feedwater turbidity originating from Tapia WRF, via Reservoir 2 was typically 0.5 NTU, indicating a very clean feed water. The generally close occurrence of the average and 95th percentile indicated that turbidity was typically stable across the day. The exceptions were:

- Periodic spikes when operators would flush the feedwater turbidity lines. Flushing of feedwater turbidity lines would purge brown-red accumulated material through the turbidity meter.
- A trial conducted between February 11, 2021 and February 18, 2021 where a bubble trap was installed prior to the UF feed turbidity meter. This bubble trap resulted in accumulation of the solid material and subsequent flooding of the meter with the solid material. Although the bubble trap stabilized turbidity meter flow and prevented bubbles, it also meant that flushing to remove solid material could not adequately be performed. The bubble trap was removed, and the turbidity meter reconnected as installed.
- There was an event at Tapia WRF in late April to May 2021. This event resulted in higher ammonia concentrations at the Demo as well as increased frequency of turbidity spikes and generally higher turbidity. When the treatment issue at Tapia was resolved and when the feedwater turbidity meter was cleaned, turbidity returned to typical values.

The MF/UF filtrate turbidity is shown as daily average and 95th percentiles on Figure 2.22.

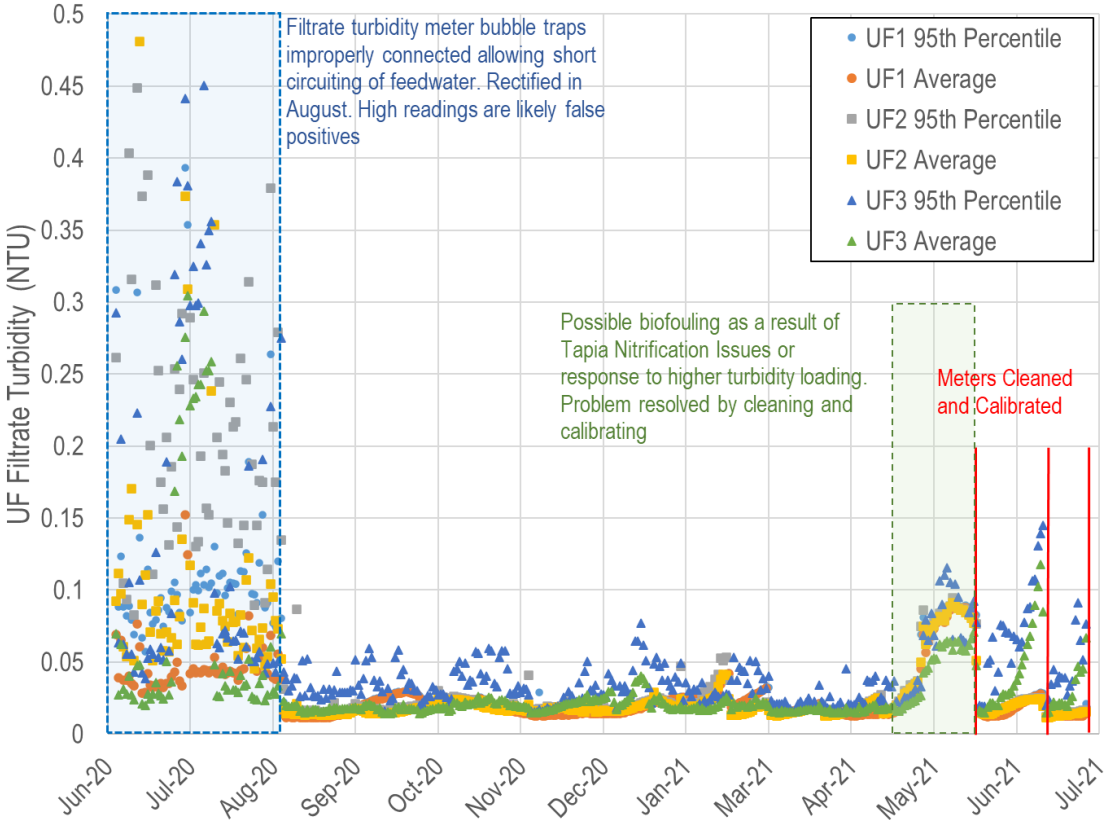


Figure 2.22 Daily Average and 95th Percentile Filtrate Turbidity for UF1, UF2 and UF3

The MF/UF filtrate turbidity was typically very low with 95th percentiles below 0.05 NTU. The exceptions were:

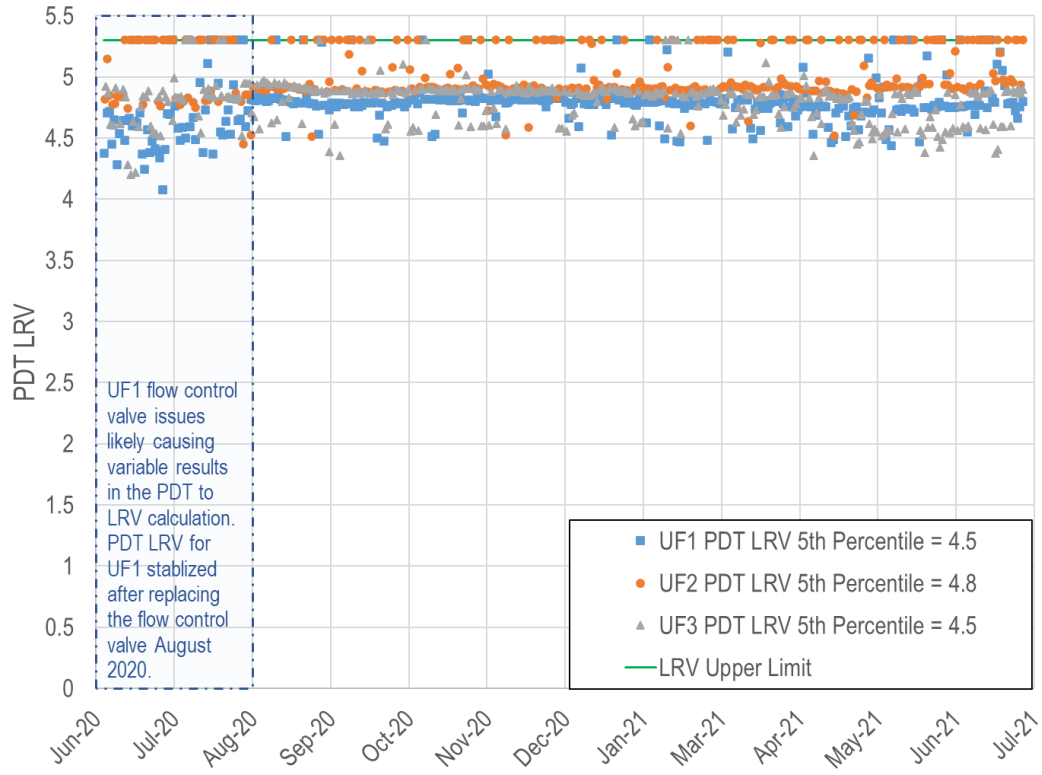
- After initial commissioning, spikes in turbidity would frequently occur soon after backwash. Upon a service visit in August, it was recognized that the bubble traps as installed could allow feedwater to short circuit the UF system and into the filtrate turbidity meter. Once the short circuiting was prevented, and the meters cleaned and calibrated, turbidity meter performance improved significantly. It is suspected that high readings prior to August 2020 are false positives.
- In late April to Early May 2021, the nitrification issues at Tapia appeared to correspond with a rise in both the average and 95th percentile filtrate turbidities. This increase may have been as a result of the significantly higher feedwater turbidities noted at the time. Alternatively, the available nutrients may have facilitated biofouling. Whatever the cause, the filtrate turbidity reduced significantly when the meters were cleaned and calibrated.
- Two subsequent rises in UF3 were also noted in June and July 2021. These rises were halted by cleaning and calibration and are suspected of being false positives due to biofilm growth.
  - Turbidity meter cleaning now occurs as part of monthly maintenance or if there is a variation during weekly meter verifications.

Once the feedwater short circuiting issue was resolved, filtrate turbidity did not exceed 0.2 NTU, the typical compliance level, on any of the UF modules. In general, the turbidity monitoring has indicated that the UF systems are providing a very high-quality filtrate and also that the Tapia WRF effluent that is blended into Reservoir 2 is very low in solids. The low level of solids experienced in the Demo feedwater may be a contributing factor to the higher than originally specified sustainable UF fluxes.

2.3.5.2 Pressure Decay Testing

The MF/UF system automatically pressure decay tests each module every day. During the PDT, the system closes and opens a sequence of valves to first drain the UF and then pressurize the feed side of the module to a minimum test pressure of 20 pounds per square inch gauge (psig). The test pressure of 20 psig is more than sufficient to detect a 3-µm breach in the membrane. *Cryptosporidium*, a protozoan pathogen of concern is larger than 3 µm. By confirming the absence of 3-µm breaches, *Cryptosporidium* removal can be verified. The air compressor is then isolated and the feed side pressure monitored. Any loss of pressure through the membrane indicates a potential integrity breach. The HMI analyzes the pressure loss that occurs over a 2-minute test period. From the resulting pressure decay rate, a calculation defined in the USEPA Membrane Filtration Guidance Manual (USEPA, 2005) is then used to express the PDT as an equivalent LRV for 3 µm or larger particles, such as *Cryptosporidium* and *Giardia*. The alarm limits for PDT are set such that equivalent LRV calculated from PDT always exceeds 4 log units. In doing so, 99.99 percent removal of *Cryptosporidium* and *Giardia* is verified daily across each UF module.

During the first year of operation, there has not been a PDT failure (LRV < 4) due to a membrane integrity issue. There have been at 3 pressurization issues that were the result of a faulty pressure release valve in between the compressor and UF. The PDT results for the first year of operation are shown on Figure 2.23.



Note: The upper limit corresponding to no observable pressure loss is equivalent to an LRV of 5.3.

Figure 2.23 LRV Calculated Based on Daily PDTs for UF1, UF2 and UF3

The following observations apply to PDT results:

- 5th Percentile LRVs based on PDT were 4.5, 4.8 and 4.5 for UF1, UF2 and UF3, respectively. The lower 5th percentile value is typically a value allowed by the California DDW for permitting log removal value (LRV) credits.
- There is no observable decrease in PDT LRV indicating that the pretreatment has adequately protected the membranes and that they all remain intact.
- In the period from June 2020 – August 2020, UF1 was suffering from a faulty flow control valve. Filtrate flow is a parameter in the conversion of PDT results to LRV and the impact of variable flow control can be observed in the UF1 PDT LRV.
- The PDT results suggest a very consistent and high level of protozoa removal by each of the MF/UF products tested.

2.3.5.3 Silt Density Index

Silt Density Index (SDI)-15 is a standard test for studying the filterability of water. RO manufactures typically have acceptable SDI-15 specifications, beyond which water is not sufficient quality to be a feedwater for RO.

The SDI-15 test uses a standard 0.45 µm membrane filter disk. During the test, a sample of water, c. 5 gal, is pumped at a constant pressure of 30 psi through the filter apparatus. The time to filter 500 mL of water is measured at the start of filtration and then after 15 minutes. The ratio of filtration times at the start and after 15 minutes are used to calculate an SDI. If the filtration time at 15 minutes is significantly longer than at time zero, then the test membrane has been fouled by colloidal organics or particulates and the SDI will be high number. Particulate matter

larger than the SDI test filter membrane (0.45 µm) is not anticipated to occur in the UF filtrate to a high degree as the nominal reported pore size of all membranes is less than 0.1 µm. However, pore size is a distribution with polymeric products and the presence of macropores or defects could allow the passage of particulates larger than the nominal pore size. In addition, there may be growth and sloughing of biofilms within permeate pipework. The maximum SDI-15 specified on the Toray TMG10D (the RO membranes used at the demo) data sheet is 5.0 for wastewater treatment. SDI has been conducted on each UF module 1 to 2 times per week for the first year of operation. The SDI results are shown on Figure 2.24.

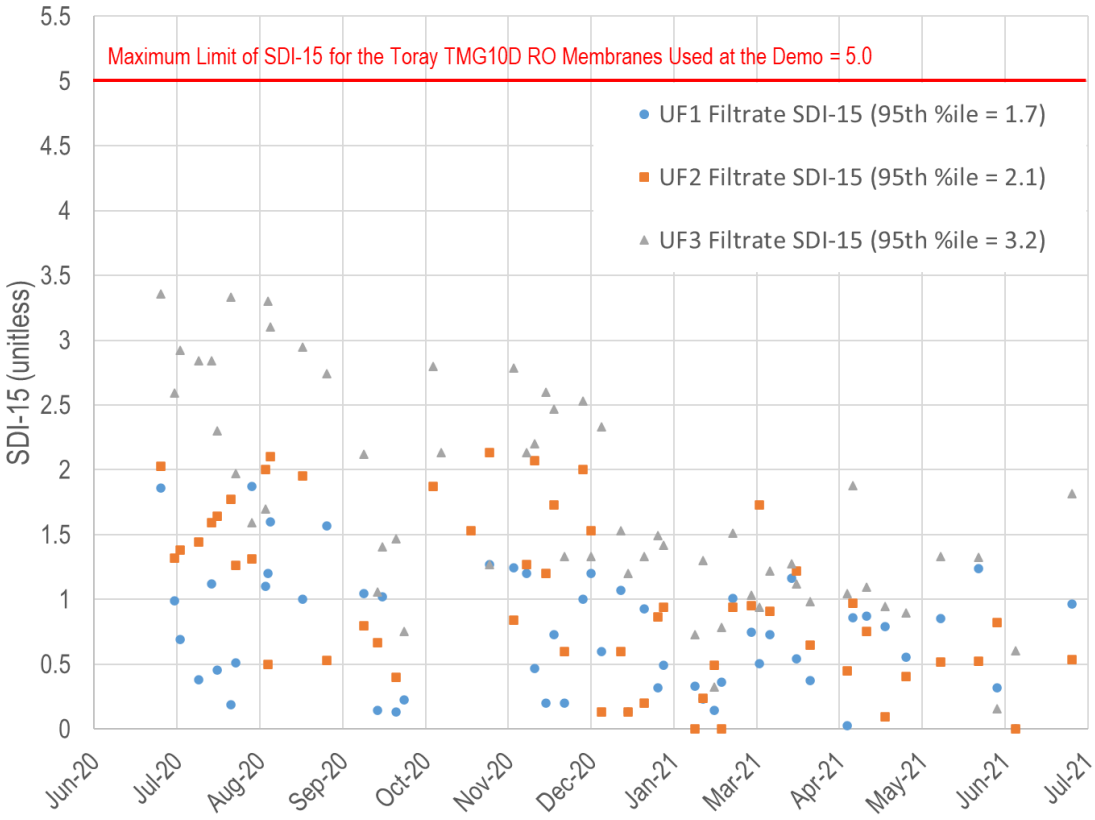


Figure 2.24 SDI-15 Results for the UF1, UF2 and UF3 Filtrate During the First Year of Operation

From the SDI-15 results collected over the first year of operation it can be observed that:

- All three membrane products produce acceptable water for the RO membranes with UF1, UF2 and UF3 95th percentile SDI-15 of 1.7, 2.1 and 3.2 respectively, well below the limit of 5.0.
- As flux was increased beyond 40 gfd in late November 2020, SDI appeared to decrease. In particular this was observed for UF3 and may have been due to additional colloid removal as the membrane fouling layer tightened and permeability reduced.

2.3.5.4 MF/UF Virus Challenge Testing

Two model viruses, PMMoV and MS2, were evaluated across the MF/UF system at the Demo. The characteristics of the two model viruses are summarized below:

- MS2:
  - Is an industry standard for membrane challenge testing membrane systems.

  - Has a low iso-electric point (IEP) of less to 4, which means that at pH > 4 (i.e., most wastewater treatment matrices), MS2 will carry a negative charge and as a result should be dispersed and harder for the membrane to reject (Herath et al., 1999).
  - Is favored as it is small, 20 – 30 nm, which is similar to other pathogenic viruses such as Enterovirus (22 – 30 nm, IEP 4 – 6 (Xagoraraki et al., 2014)).
  - MS2 is not typically at sufficient concentration in wastewater, and it cannot be selectively measured in typical wastewater as the analysis method will co detect other indigenous male-specific coliphages. As a consequence, it is laboratory grown and spiked into membrane feedwater at high concentrations during challenge testing. Spiked challenge testing can be expensive and impractical for large systems.
- PMMoV (Papp et al., 2020):
  - Is a plant virus and is not toxic to humans.
  - Is rod-shaped (18 × 312 nm) RNA virus with a low isoelectric point (IEP) (3.2–4.9).
  - Is abundant in wastewater, which means it does not need to be spiked.
  - Is under investigation to allow automated monitoring and as such is considered a promising surrogate.

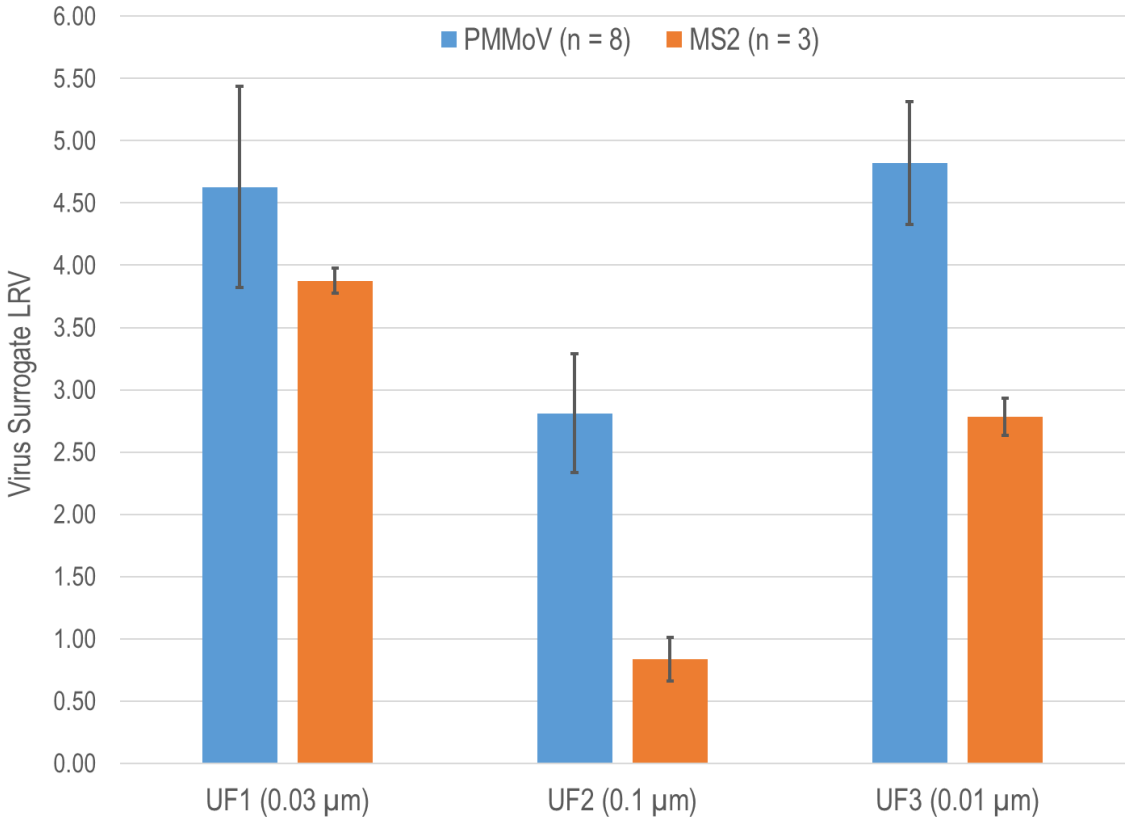
MS2 stock was obtained from GAP Environmental Laboratories, Canada (GAP) for spiking into the feed to the UF systems. MS2 samples were analyzed by GAP. PMMoV was not spiked into the system, as there are high concentrations of PMMoV in secondary or tertiary effluent. PMMoV samples were analyzed by Carollo's Water ARC® laboratories.

MS2 challenge testing was conducted in a single event in early April 2021. During the challenge testing, UF flux for all modules was set at 40 gfd. A pump was used to spike the MS2 stock upstream of the MF/UF feedtank. The spiking was commenced 30 minutes before sampling to allow at least 3 retention times worth of mixing in the feed tank. Spiking concentration was set in line with USEPA recommendations at less than 6.5 log units above the detection limit to avoid potential for agglomeration of virus challenge particles. The spiking concentration was sufficient to allow MS2 detections in all filtrate samples.

3 sets of triplicate samples were taken within the first 15 minutes of a filtration cycle, spaced approximately 5 minutes apart. A feed sample was taken with each set of filtrate samples. The feedwater MS2 concentration was averaged across the 3 sample sets. A virus LRV (log10[concentration in/concentration out]) was then calculated for MS2 using the average MS2 feedwater concentration and each triplicate MS2 concentration. The results were then expressed as a mean and standard deviation for each individual UF module.

PMMoV was semi regularly monitored across the year and on the day of MS2 challenge testing. In total, 8 sets of paired feed and filtrate samples were taken for each UF module. The resulting LRVs were then averaged and reported as a mean and standard deviation.

The comparative LRVs determined for MS2 and PMMoV across each UF unit are shown as average and error bars representing standard deviations on Figure 2.25



Note: Nominal pore size of each UF is shown in brackets.

Figure 2.25 LRV of Virus Surrogates PMMoV and MS2 Across Each MF/UF Module

The following observations can be made based on the virus challenge test results:

- Average MS2 LRV was 3.9, 0.8 and 2.8 for UF1, UF2 and UF3, respectively.
- Average PMMoV LRV was 4.6, 2.8 and 4.8 for UF1, UF2 and UF3, respectively.
- The ultrafilters, UF1 and UF3 achieve higher LRVs of MS2 and PMMoV when compared to UF2, which is expected as UF2 has a larger nominal pore size.
- Typically MF/UF units are not credited with virus LRV, but all of the membrane products above are providing a significant safety margin of virus removal.
- The higher removal of PMMoV relative to MS2 may be due to its longer tail restricting passage if it is not oriented narrow end towards the membrane.
- The virus results suggest that there is an advantage with a smaller nominal pore size membrane for direct filtration of viruses. Should coagulants be used, there may be less influence of pore size.

2.3.5.5 Membrane Integrity Summary

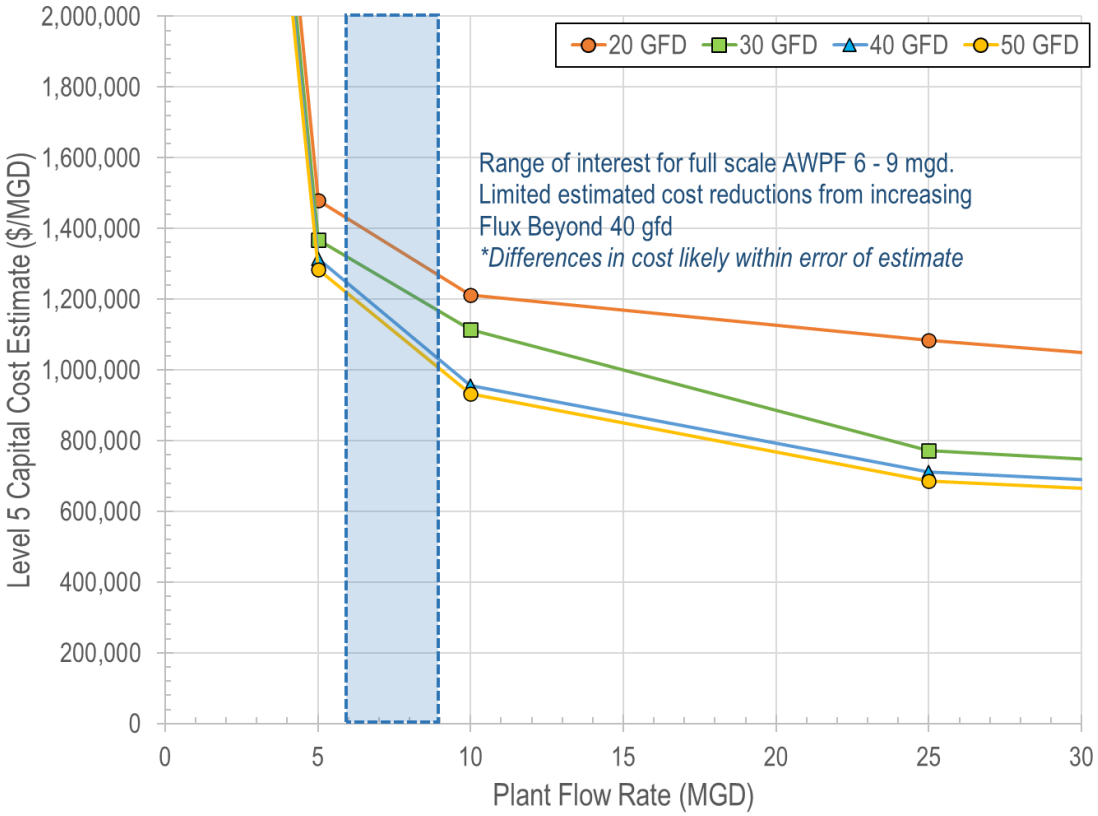
The consistency of PDT LRV, SDI-15 and filtrate turbidity combined with the significant removal of virus challenge organisms by the MF/UF units indicate that all three modules are intact and are capable of providing a significant barrier to protozoan pathogens.

The typical levels of SDI-15 suggest that all three membrane products are providing water of satisfactory quality to feed reverse osmosis.

Virus removal may be enhanced by choosing UF, over MF membranes or by using coagulation. However, until a reliable virus monitoring surrogate is demonstrated, MF/UF will not be credited with virus removal. Thus, the demonstrated virus removal would serve as an uncredited safety buffer.

2.3.6 MF/UF Engineering Economics

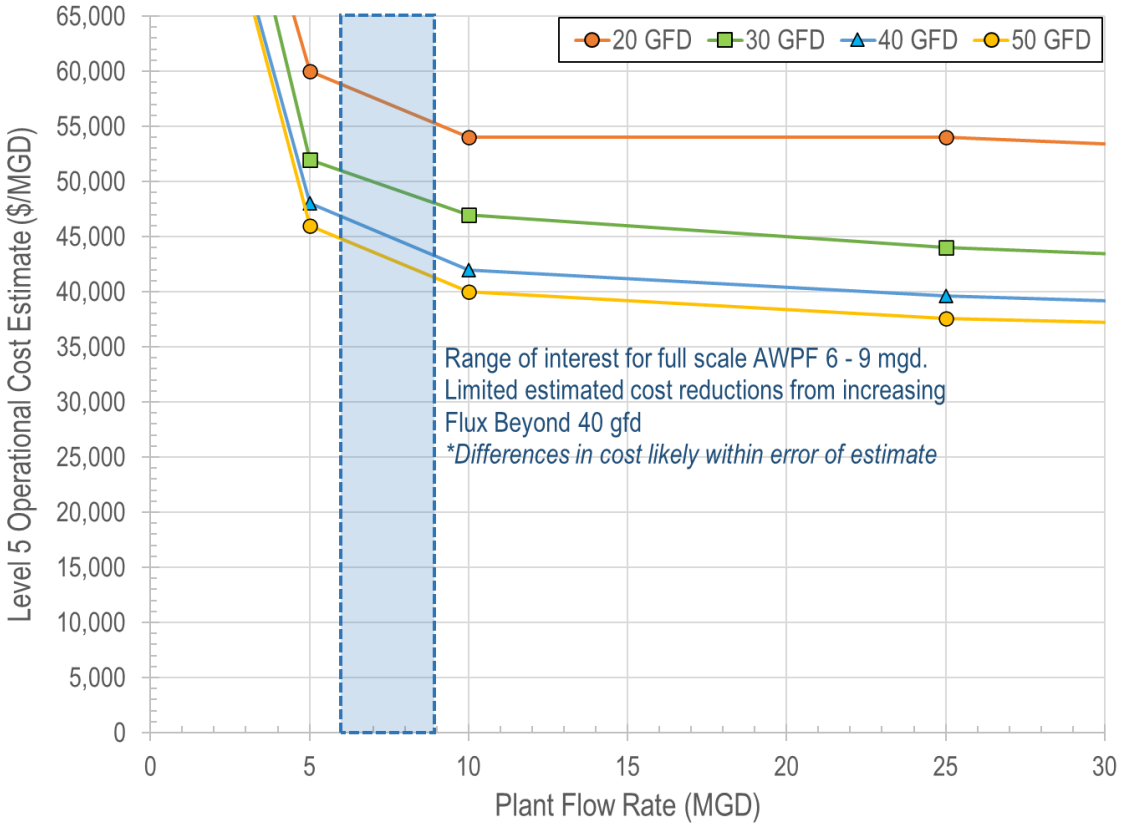
Carollo developed a "Level 5" analysis of MF/UF construction costs and operations costs for a range of production rates (flows) and flux, as shown on Figure 2.26. Typical MF/UF systems for filtration of tertiary effluent have flux values in the range of 25 to 35 gfd. The data presented above for the Demo indicates that a design flux of 40 gfd may provide savings for the future full-scale MF/UF system. However, there is limited cost reduction estimated from increasing flux from 40 to 50 gfd. The curves below, which should be viewed as accurate within a range of +50 percent to -30 percent, and are shown here to demonstrate the potential cost savings of a higher design flux.



Note: Limited benefit from increasing design flux beyond 40 gfd suggested by cost models.

Figure 2.26 Approximate Construction Costs for MF/UF Systems (Level 5 Estimate)

Operational cost (including annualized membrane replacement, electricity use, chemical use and other equipment maintenance) was also estimated and shows a similar trend to capital costs with increases in flux beyond 40 gfd providing less benefit. Operational costs do not include staffing. The operational cost estimates were included on Figure 2.27 to highlight the potential impact of design flux increases.



Note: Limited benefit from increasing design flux beyond 40 gfd suggested by cost models.

Figure 2.27 Approximate Operational Costs for MF/UF Systems (Level 5 Estimate)

2.3.7 MF/UF Performance Summary

All three membrane products produced fit for purpose water at the Demo. In an effort to compare the products a summary table of key performance indicators was included in Table 2.3. The following criteria were selected for comparison:

- Area per module – a higher module area will lead to a reduced footprint, and depending on the module price, may lead to capital savings as less membrane racks will be needed at scale for the same production flow.
- Pore size – nominal membrane pore size provides an indication of the rejection of small colloidal material or viruses– with a higher rejection anticipated for a smaller pore size.
- PDT LRV – a high and consistent PDT provides an indication of the level of *Giardia* and *Cryptosporidium* removal that the module is capable of.
- Average Virus LRV (MS2) – MS2 LRV provides a conservative estimate of the removal of viruses by the membrane product.
- Average PMMoV LRV – PMMoV LRV provides an estimate of the removal of larger indigenous viruses and a conservative estimate for other pathogens larger than 0.3 µm (i.e., bacteria and protozoa).
- Max Daily 95th Percentile Turbidity – a low 95th percentile turbidity is desirable as it indicates that the UF membrane is consistently removing particulate matter. Typical trigger levels are 0.2 NTU and all modules were below this number.

- SDI-15 95th percentile – a SDI-15 indicates a low level of colloidal organic and particular matter and may correlate to improved RO operation of the RO downstream.
- Maximum Modelled Sustainable Flux – A high sustainable flux is desirable as less membrane modules will be required to meet design flow, resulting in lower capital expenditure and plant foot print. It should be noted that Level 5 cost estimates indicate limited impact capex and opex savings from increasing flux beyond 40 gfd for a 5-10 mgd facility. There are apparent cost savings from increasing flux from 30–40 gfd.
- Maximum Permeability – A high maximum permeability is desirable as it will mean less pumping energy is required to produce the design flow.

Table 2.3 Comparative Performance Summary of the MF/UF Products Tested at the Demo in the First Year of Operation

Parameter	UF1	UF2	UF3
Supplier	Dow	Pall	Toray
Area per module (ft^2)	825	538	**969**
Pore size (µm)	0.03	0.1	**0.01**
Protozoa - PDT LRV (5th Percentile)	4.5	**4.8**	4.5
Average Virus LRV (MS2)	**3.9**	0.8	2.8
Average PMMoV LRV	4.6	2.8	**4.8**
Max Daily 95th Percentile Turbidity (NTU)(1)	**0.09**	0.10	0.15
SDI-15 95th Percentile	**1.7**	2.1	3.2
Max Modeled Sustainable Flux (2)	44	**48**	45
95th Percentile Permeability (gfd/psi at 20 degrees Celsius)(3)	6.1	**8.6**	6.7

Notes:
(1) September 2020 – June 2021 – excluded period of cross connection prior to September 2020.
(2) UF1 and UF3 maximum flux likely higher with optimized backwash. Modelled flux only considered 1 MC/week.
(3) Calculated based on daily average data only when the UF is in operation.

Based on comparison of the criteria in Table 2.3, all modules have a generally equal number of advantages and disadvantages. UF1 demonstrated the most stable turbidity, SDI and highest virus removal, UF2 demonstrated the highest production efficiency (flux and TMP) as well as a marginally higher protozoa removal based on PDT and UF3 has the smallest reported nominal pore size, largest surface area per module and also a significant, although not the highest, virus removal based on MS2 and PMMoV.

2.3.8 Approaches for Further MF/UF Evaluation and Optimization

The Demo provides an invaluable facility for community outreach as well as an opportunity to fine tune design information for full scale systems. Over the first year of operation, the following items have been identified for potential future investigation:

- UF3/High Packing Density Module Cleaning Strategies:
  - UF3 permeability has degraded in the first year of operation and it has been speculated that this is due to the high packing density. Also, the backwash performance of UF3 was suboptimal for 10 months of the first year of operation and is likely a contributing factor. UF1 backwash performance was suboptimal for 8 months of the first year.

  - High packing density modules may be cheaper as they will result in a full-scale facility with less membrane racks.
  - It is therefore considered important to experiment with cleaning strategies and adjustments that may improve the permeability of UF3. Over the next year of operation, the following investigations are proposed:
    - Assess the impact of air scour during recovery and maintenance cleans:
      - Additional shear from air scour may help cleaning chemicals to provide more effective cleaning within the tight confines of UF3.
    - Assess and optimize the chemical cleaning recipes and frequency to achieve higher permeability recovery per clean for UF3.
    - Investigate the impact of recovery adjustment of UF3 fouling performance.
    - Given the remote operation and automation capabilities at the Demo, the proposed investigations into UF3 permeability do not require engineering changes or significant impact to site operation.
- Testing of alternative membrane products:
  - The first year of operation has indicated that a successful membrane product should be able to run long term on Demo feedwater at fluxes above 40 gfd.
  - The open platform nature of the Demo provides opportunity to evaluate multiple MF/UF vendors with an aim to supporting final product selection.
  - Fitting alternate membrane products to the Demo may require small engineering changes such as development of module-to-skid adapter fittings.
- General optimization of cleaning frequency and flux:
  - The MF/UF system data will be continually reviewed over the coming year and systematic adjustments will be made to the following parameters with an aim to providing improved understanding of how the operating flux and cleaning frequency can be adjusted for all modules.
  - This investigation requires minimal system changes, outside of typical operation, and does not require engineering changes.
- Machine Learning (ML) for MF/UF performance optimization:
  - Through current and ongoing research grants, ML will be applied to the MF/UF operational data with an aim to providing improved decision support for operators and facilitate process optimization.
  - Process optimization for MF/UF proposed for investigation by ML include fault diagnosis of instruments (e.g., recognition of a turbidity false positive due to biofouling),improved balancing of flux with cleaning frequency and strength by incorporating continual analysis of new data and investigation of whether currently installed online monitoring can aide in the prediction of fouling rates providing an early warning to adjust cleaning frequency.
- Investigation of blended water quality on operation:
  - The full-scale project looks to blending of multiple sources with Tapia WRF effluent for use as a feedwater source.
  - It may be of interest to characterize how the introduction of different source waters may impact MF/UF production efficiency as well as general water quality.
  - The MF/UF system runs typically at 80 – 100 gpm. As such, large quantities of blended test water would be needed to run this trial for a representative period.

- Individual modules can be run in isolation and, modules with lower active surface area and some engineering could be adapted to the system to reduce the flow requirement. However, the UF needs to be operated to maintain sufficient net flux equivalent to more than 35 gpm to support continuous operation of the downstream RO operating as a 3-stage (or 17 gpm as 2 stage).
- While valuable information could be obtained, by looking at blending water supplies this investigation could require significant expense and is not presently planned.

2.4 Reverse Osmosis

This section describes the operation and performance results specific to the RO system from the start of July 2020 to the end of June 2021.

2.4.1 System Description

The RO system was designed to operate in either a 2- or 3-Stage configuration with changes between each stage made with manual valves to alter the flow path. The flow path during each type of operation is illustrated on Figure 2.28.

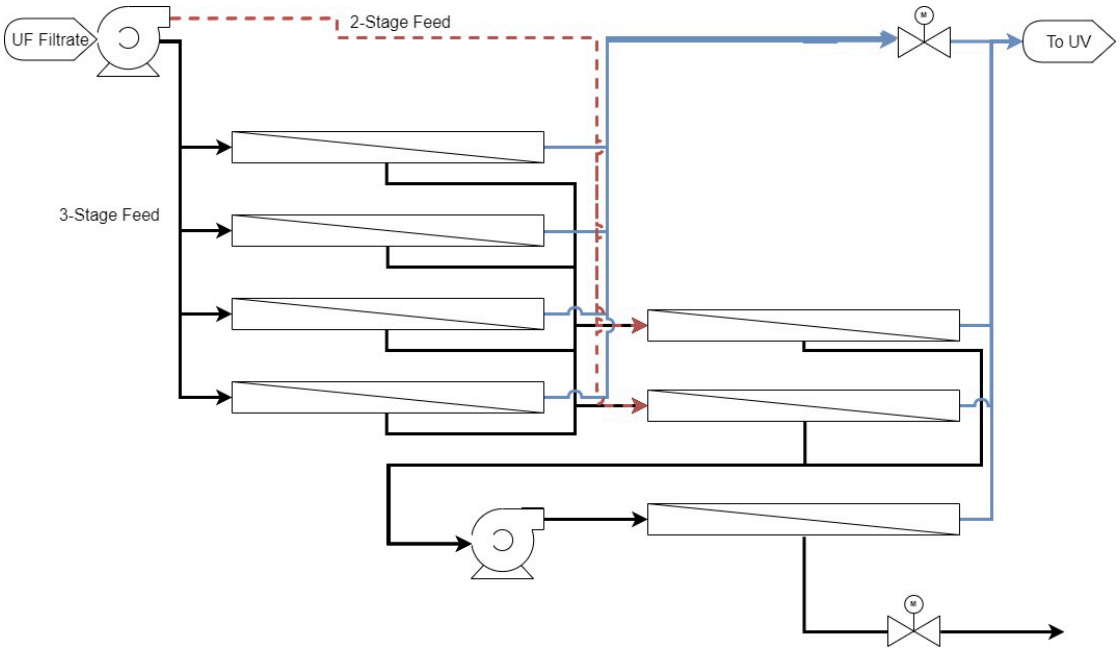


Figure 2.28 The RO Configuration Options for 2 or 3-Stage Operation at the Demo

Since commissioning, the RO system has operated with 4-inch Toray TMG10D membrane modules, which are a typical brackish water RO element applied for water reuse. The membrane specifics for the 2 and 3 stage configuration are summarized in Table 2.4.

Table 2.4 RO Membrane and System Properties

Configuration	2-Stage	3-Stage
Target Average Flux (gfd)	11	11
Vessel Arrays	2:1	4:2:1
Membranes per vessel	7:7	6:6:6
Installed Membrane Area (ft^2)	1827	3654

Configuration	2-Stage	3-Stage
TMG10D Membrane Properties From Vendor Product Data[1]		
Average Sodium Chloride Rejection (%)[1]		99.7
Minimum Sodium Chloride Rejection (%)[1]		99.5
Active Area Per Module (ft^2)		87
Length Per Module (in)		40
Module Diameter (in)		4
Maximum Feed Water SDI-15		5
Production Flow Per Element (gallons per day)[1]		2850

Note:
(1) Standard test conditions for performance data: 15 percent recovery, 25 degrees Celsius, pH 7, 2000 mg/L NaCl, 150 psi Feed Pressure.

The RO system includes the following features:

- Dual stream (RO Feed and combined RO permeate) monitoring of TOC using a Suez Sievers M5310C unit.
- Online electrical conductivity (EC) monitoring on RO feed, Stage 1, Stage 2 and Stage 3 permeate as well as the combined RO permeate.
- Online free chlorine, ORP and pH monitoring on the RO feed.
- Online monitoring of feed pressure to each stage, as well as final concentrate pressure.
- Pressure gauges to monitor RO permeate pressure.
- An interstage booster pump between Stage 2 and Stage 3.

The RO is operated to meet permeate flow and recovery setpoints. On commissioning, and for the first months of operation, the RO was only capable of operating based on a total permeate flow setpoint. This meant that flow was not controlled on each stage. Without flow control for each stage, the permeate flow varied depending on how fouled each stage was.

In Early October 2020, the RO programing was updated and allowed control of permeate flow from each stage based upon the following actions:

- Total Feed Flow Rate (and total permeate production) was controlled by the high-pressure pump.
- Recovery was controlled by adjusting the concentrate valve.
- Stage 2 and Stage 3 flows were balanced by adjusting the interstage booster pump flowrate.
- If operating in 3-stage configuration, Stage 1 permeate flow was regulated by an automated control loop that actuated a control loop on the S1 permeate to meet a flow target.

Permeate flow targets were set based on RO projections run in Toray RO design software to meet 11 gfd average flux and recovery targets for each system configuration.

2.4.2 RO Operational Periods

The intent of the RO test plan was to identify any critical differences of system configuration (i.e., 2- or 3- stage) and recovery, 80 or 85 percent, on RO performance. At each setpoint, it was desired to run for at least 1,000 hours (approximately 45 days) followed by a CIP to return the system to baseline and then move to the next setpoint. As noted in the prior section, the original

installed flow control of the RO unit was not satisfactory to provide an accurate evaluation of operational setpoints. Although the RO was operated from June 2020, effective control was not implemented until programming changes were implemented October 2020. However, preliminary periods are still discussed as they provide information about the long-term reliability of the RO system. The main operational periods are summarized in Table 2.5.

Table 2.5 Operational Setpoint Timeline for the RO System

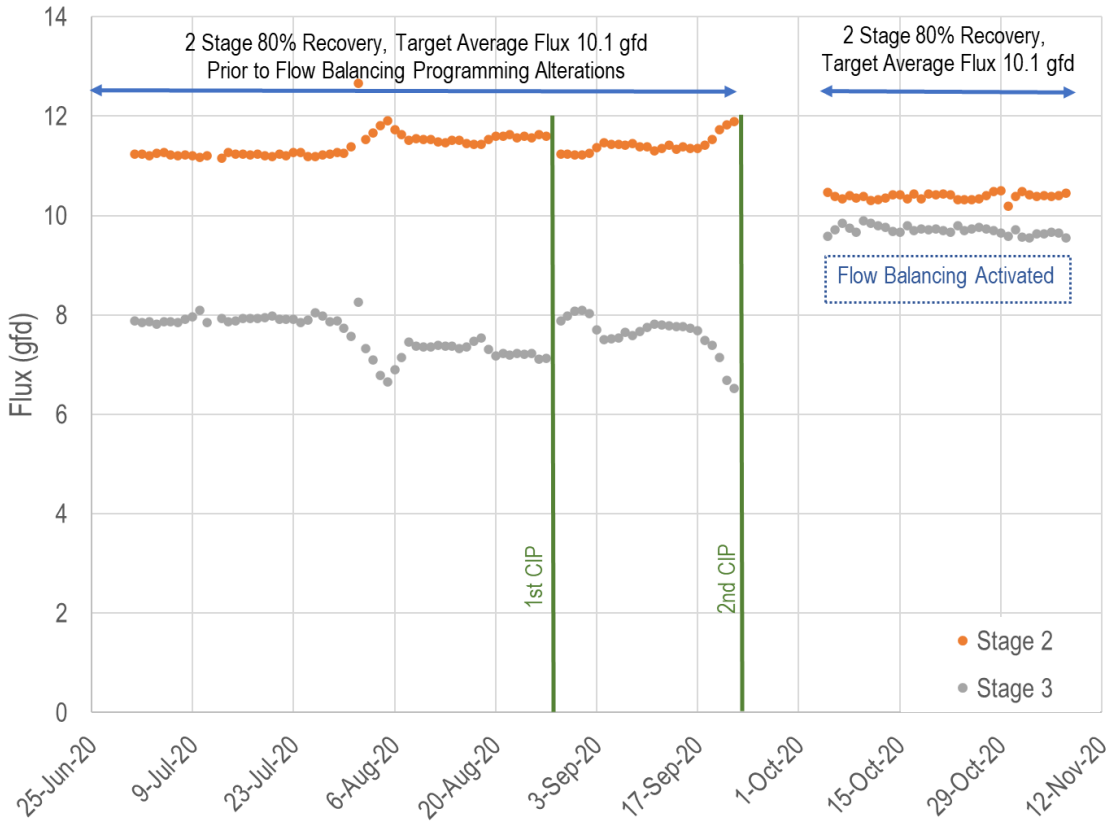
Dates[1,4]	Target Flux (gfd)				Target pH[3]	Target Recovery (%)	Comments
	Av Flux	S1 Flux	S2 Flux	S3 Flux			
June 25 - August 27, 2020[2]	10.1	-	10.3	9.7	6.4	80	2 Stage prior to flow balance
August 29 - September 22, 2020[2]	10.1	-	10.3	9.7	6.4	80	
October 5 - November 7, 2020[2]	10.1	-	10.3	9.7	6.4	80	2 Stage - flow balanced
November 15, 2020 - January 4, 2021	11.0	11.4	10.7	10.0	6.8	80	3 Stage
January 21 - March 11, 2021	11.0	11.5	10.7	10.0	6.8	85	3 Stage
March 14 - May 1, 2021	11.0	-	11.8	9.6	6.8	85	2 Stage
May 2 - June 22, 2021	11.0	-	11.8	9.6	6.8	80	2 Stage
June 22, 2021 - Present	11.0	11.5	10.7	10.0	6.8	80	3 Stage

Notes:
(1) Aim was to operate for 1000 h (c. 45 days) at each setpoint, clean and then move to the next.
(2) Initial fluxes targeted average of 11 gfd, but did not account for increased area of TMG10D compared to the Hydranautics ESPA2-LD4040 which is what initial design was based on. Hence effective target was 8 percent lower.
(3) Target pH was increased following the first autopsy that suggested that increasing pH might reduce aluminum fouling which was implicated in fouling. pH 6.4 was specified in original design projections using Advisor CI software (Avista, CA) but was revised to 6.8 based on autopsy report recommendations, also conducted by Avista.
(4) Target antiscalant dose was 2.0 – 2.5 mg/L based on AdvisorCI (Avista, CA) projections. Antiscalant (Vitec 4000, Avista) was dosed at a constant 3.0 mg/L to allow a safety factor for the trial duration.

2.4.3 Specific Flux, Normalized Permeate Flow, Differential Pressure and Salt Passage

2.4.3.1 Initial Operation - Prior to Flow Control

The RO commenced automatic operation at 2-stage 80 percent recovery in late June 2020. The actual operating flux of each stage is shown on Figure 2.29.



Note the improvement in Flux control when flow programing adjustments were made early October 2020.

Figure 2.29 RO Flux During Preliminary Trial Efforts

During the initial phases of operation, the flux on Stage 2 was higher while the flux on Stage 3 was lower than desired targets. Also, it can be observed that as Stage 3 fouled, its flux decreased and Stage 2's flux increased in order to meet the total permeate flow control setpoint.

Normalized permeate flow (NPF) is a permeate flow metric that adjusts for the temperature and osmotic pressure (as a result of total dissolved solids (TDS)) encountered by each stage. A decrease in NPF indicates fouling on the membrane surface. Generally, a sudden and exponential decrease in NPF is associated with biological fouling or scaling – if accompanied by increased salt passage, while a gradual reduction in NPF is associated with colloidal organic fouling.

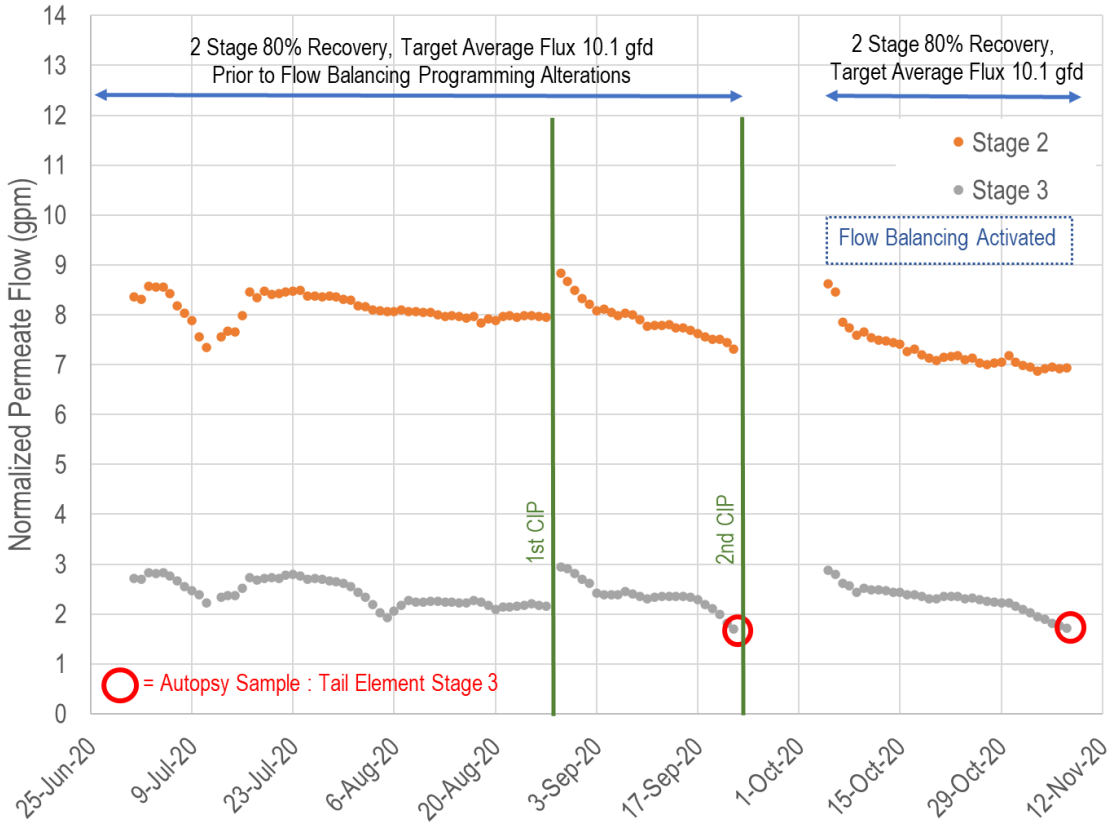
Specific flux is analogous to NPF in that it is a flow metric that is normalized for the effects of temperature and osmotic pressure. In contrast to NPF, specific flux is also normalized by the installed membrane area. Specific flux for RO parallels can be used in the same way that temperature corrected permeability is used for MF/UF systems. Specific flux is advantageous for presentation of later trial results as the membrane area changes between 2- and 3-stage configurations. The change in membrane area leads to difficulties comparing NPF between each configuration, but specific flux allows for appropriate comparisons.

Normalized salt passage (NSP) is an inverse of salt rejection by each stage that is normalized for temperature and osmotic pressure. Sudden increases in NSP can indicate integrity failure. Gradual increases in NSP may indicate inorganic scale formation on the membrane surface or cumulative subtle integrity failure. Reductions in NSP, combined with reductions in NPF,

typically indicate buildup of an organic fouling layer that is acting to further reduce salt passage. It is common to observe slight increases in NSP following CIPs as 1) the CIPs remove the fouling layer and 2) CIPs if not carefully controlled can reduce the salt reduction of the membrane.

Normalized differential pressure (NDP) is the differential pressure from the feed to the concentrate normalized for temperature. Increases in NDP are characteristic of particulate fouling, which will reduce the available feed side channel cross sectional area. Also, increases of NDP can be associated with biological fouling or scaling which may also plug feed side channels if they occur to a significant extent.

The NPF, specific flux, NSP and NDP are shown for the initial trial period, prior to flux increase on Figures 2.30 through 2.33.



Note: 10 - 15 percent reductions in NPF from post clean stabilized values were used to guide schedule CIPs.

Figure 2.30 NPF During Initial RO Operation

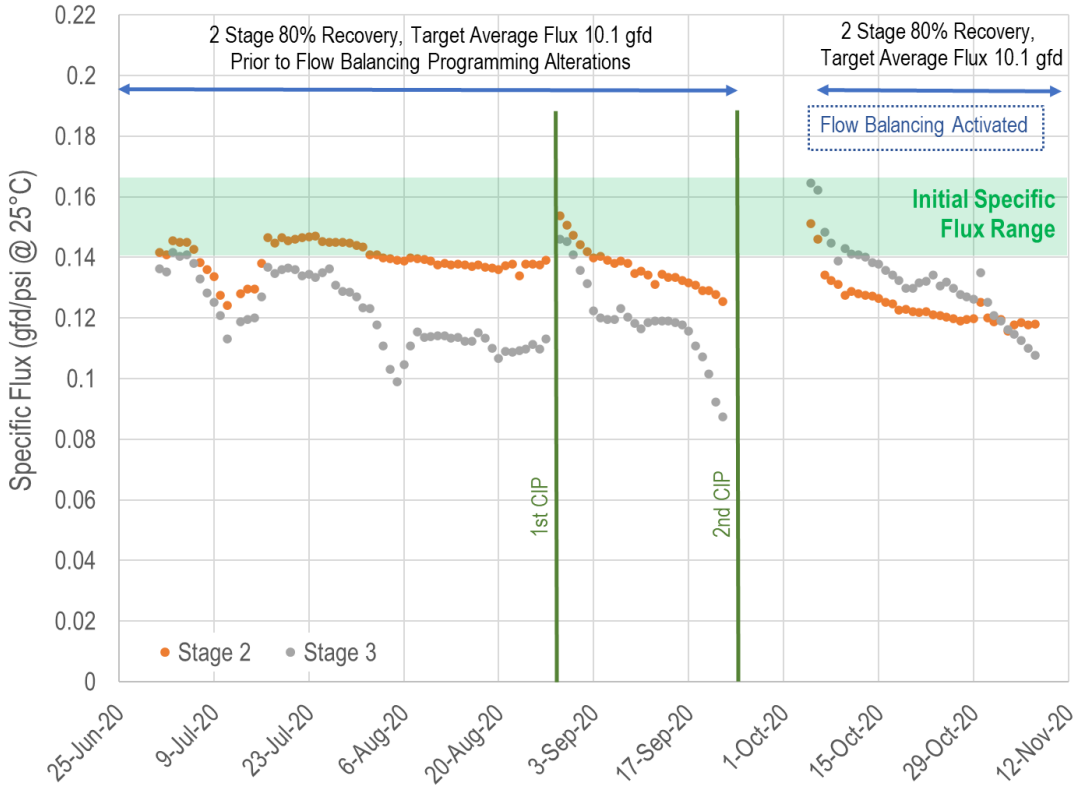


Figure 2.31 Specific Flux During Initial RO Operation

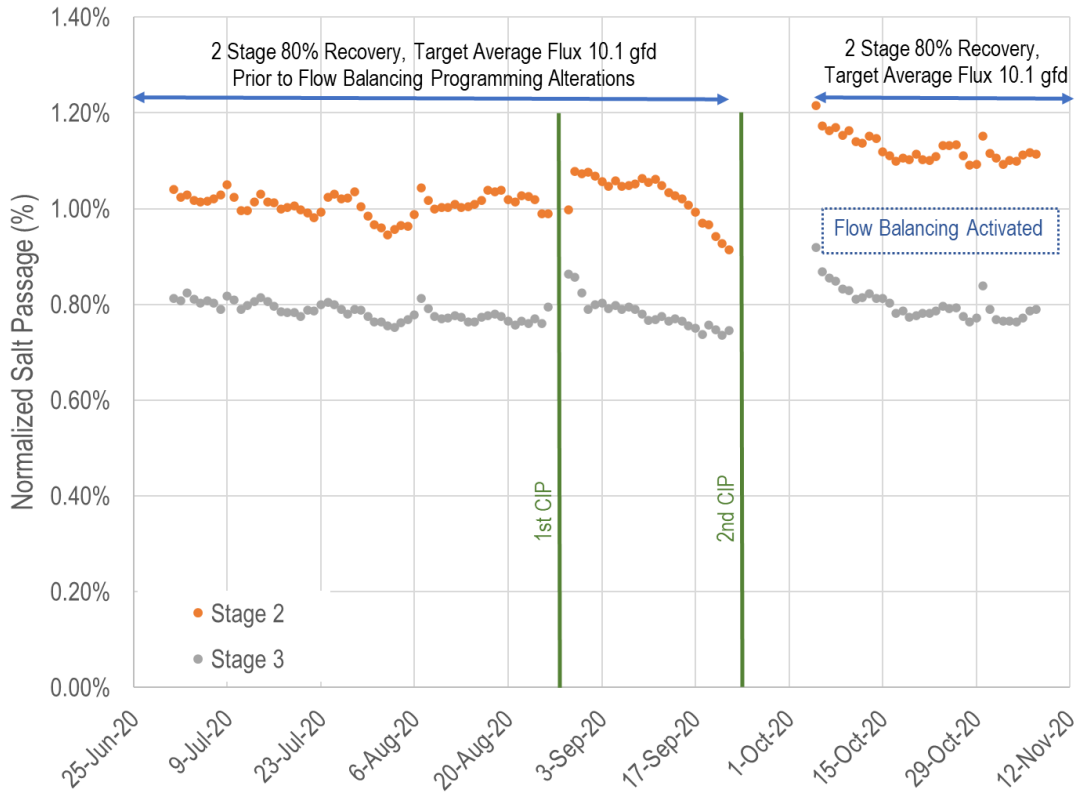


Figure 2.32 Normalized Salt Passage Flux During Initial RO Operation

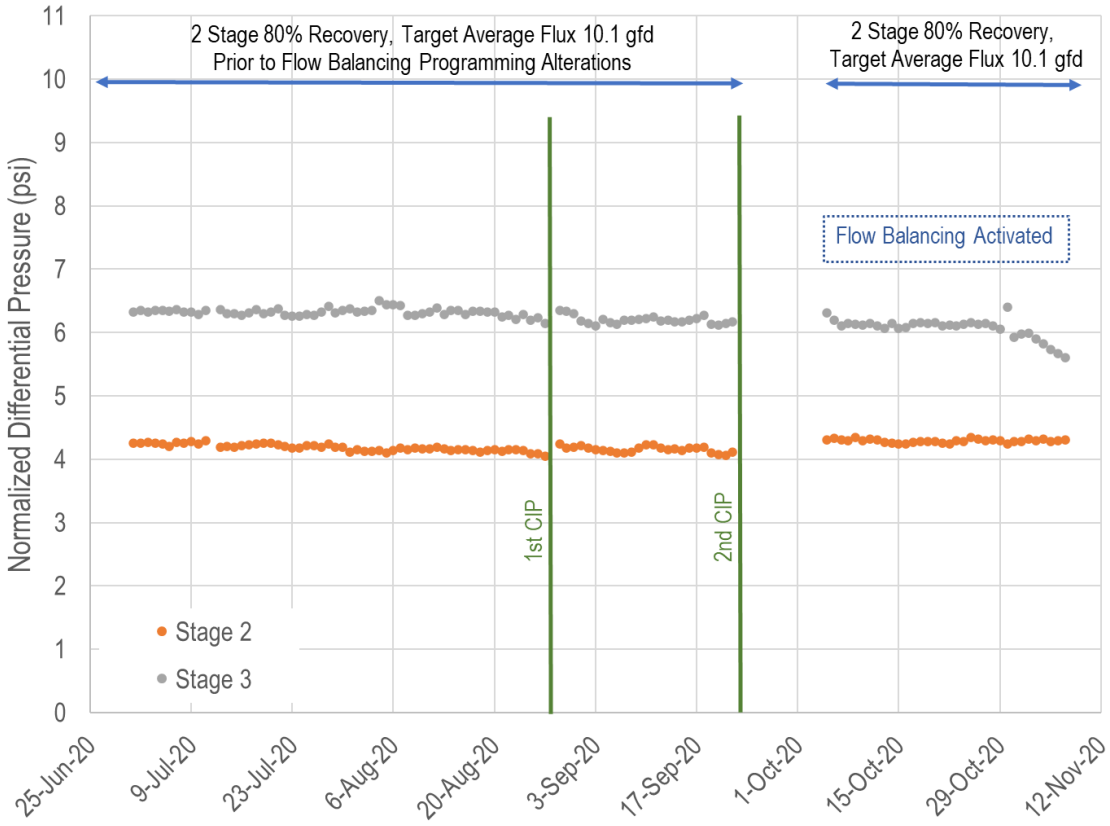


Figure 2.33 Normalized Differential Pressure During Initial RO Operation

Based on the normalized results during the initial period of 2-Stage RO operation, the following observations can be made:

- Initial Run – No Flow Balancing – 2-stage, 80 percent Recovery, 10.1 gfd average flux:
  - During the initial run, minimal fouling was observed on Stage 2, but a general downward trend in both specific flux and NPF was observed for Stage 3.
  - NSP and NDP remained stable.
- 2nd Run Post 1st CIP – 2 stage, 80 percent recovery, 10.1 gfd average flux:
  - During the second run, the rate of decline of specific flux and NPF was more significant than for the first run. The second run was terminated after 26 days and a second CIP was conducted.
  - NSP of Stage 3 gradually declined and NSP of Stage 2 followed an initial gradual and then more rapid decline. The initial then rapid decline of stage 2 may have indicated increased organic fouling. The reduction of NSP may also have been due to the increase in flux of stage 2, relative to stage 3, as the flows were not balanced. At higher flux, RO salt passage will generally be lower.
  - NDP was stable during the second run, indicating that there was no particulate fouling.
  - The rapid decline in NPF and specific flux observed during the second run prompted further investigation. Due to the steep late decline of NPF in Stage 3, it was speculated that scaling had occurred. To that end, the tail element of Stage 3 was

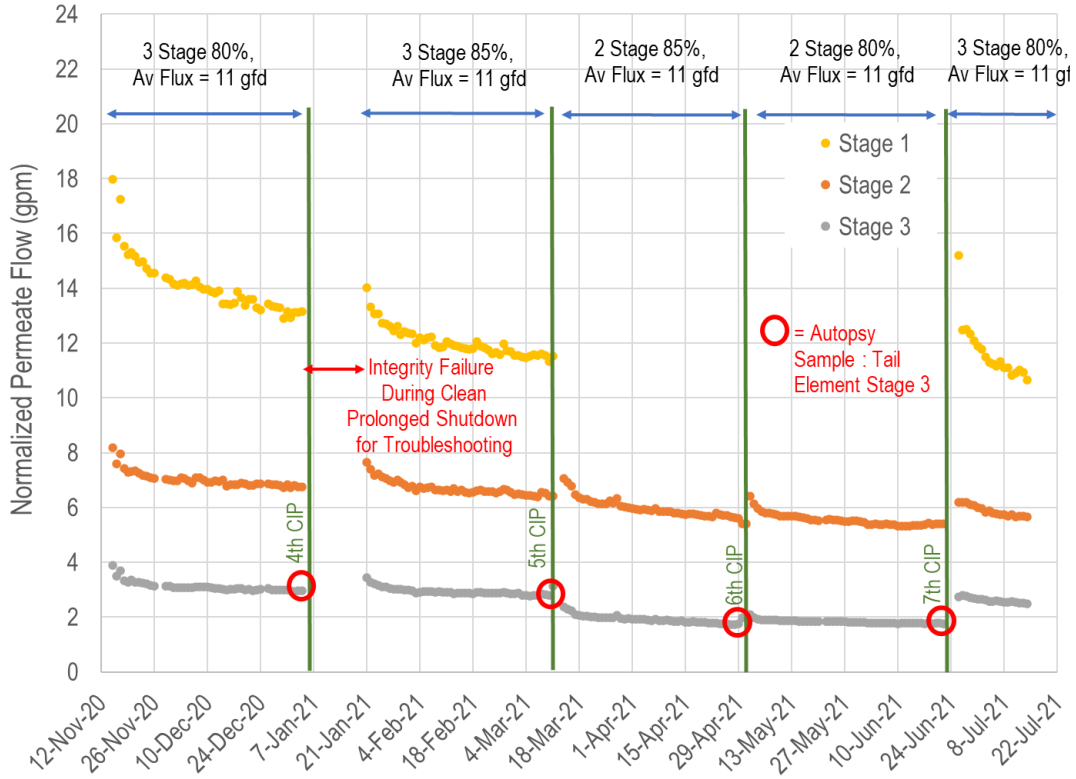
sampled for autopsy. The practice of sending the tail element of Stage 3 for autopsy prior to cleaning was continued for the subsequent trial periods.
  - The rapid decline in NPF and specific flux during the second run occurred unexpectedly and as a result, there was a time delay on availability of cleaning chemicals. During this period, the RO was not operated but was periodically flushed until the CIP chemicals were able to be delivered to site. This, and the desire to update flow control, contributed to the downtime of the RO system between September and October 2020.
- 3rd Run Post 2nd CIP – 2 stage, 80 percent recovery, 10.1 gfd average flux, with flow balanced:
  - With the implementation of flow balancing, the trends in RO performance indicators became more typical.
  - During the third run, specific flux and NPF declined for both Stage 2 and Stage 3 at a similar rate. Towards the end of the third run, the rate of decline for Stage 3 accelerated and this prompted a clean.
  - Salt passage increased following the CIP and then reduced, corresponding to the reduction of NPF and specific flux, suggesting that buildup of an organic fouling layer was enhancing rejection.
  - NDP was very stable, with a slight decrease for Stage 3 towards the end of the run.

2.4.3.2 RO Trial Results

Nearing the completion of the third run, the results of the first autopsy report became available. The report, which is discussed more comprehensively in later sections, suggested that an increase in RO Feed pH may help to reduce organic fouling. Consequently, the target pH was increased from 6.4 to 6.8 by reducing the sulfuric acid dosing setpoint from 40 mg/L to 20 mg/L. In addition, it was recognized that the RO had been operating at a flux of 10.1 gfd due to the larger than normal area of the Toray RO membranes (87 versus 80 ft^2). As a result, new RO projections were run targeting an actual flux of 11 gfd which was then average target for subsequent trials.

Once these system optimizations were made, the test plan was restarted and each planned operational mode (2-stage 80 percent, 2-stage 85 percent, 3-stage 80 percent and 3-stage 85 percent) was then run for at least 45 days followed by a CIP and then moved to the next configuration.

This section contains the NPF, specific flux, NSP and NDP are shown for the test plan trial on Figures 3.34 through 3.37.



Note: Each evaluation period was run for at least 45 days (1000h).

Figure 2.34 NPF During RO Test Plan Operation

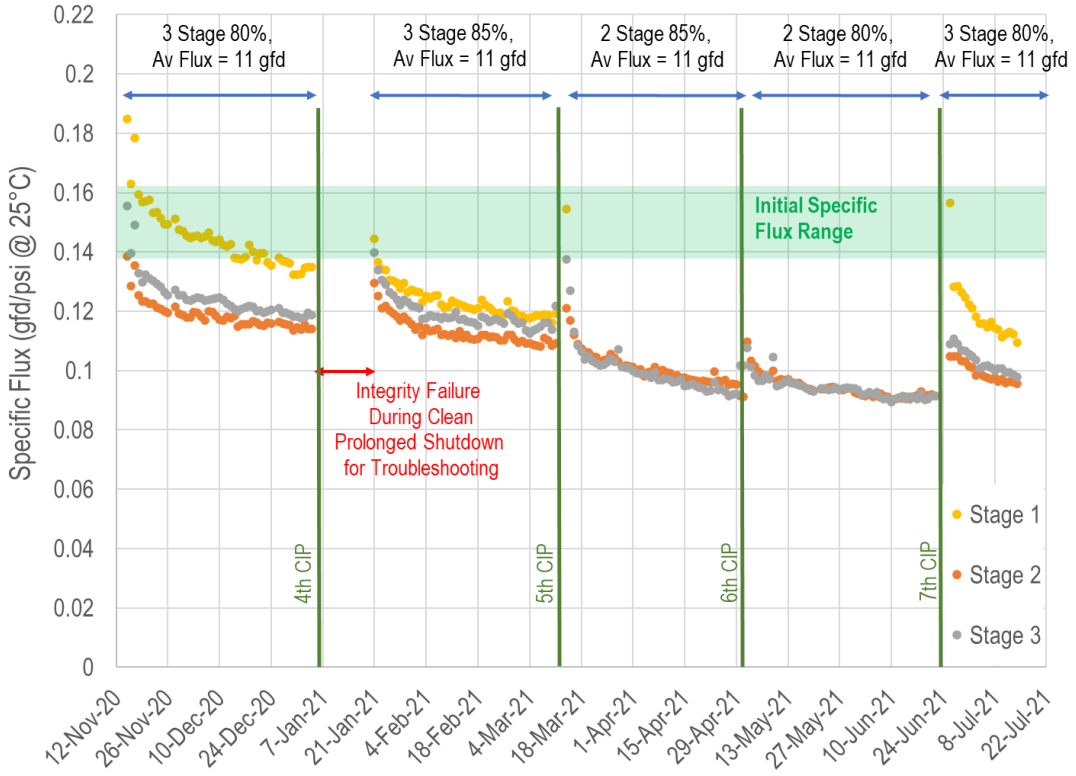


Figure 2.35 Specific Flux During RO Test Plan Operation

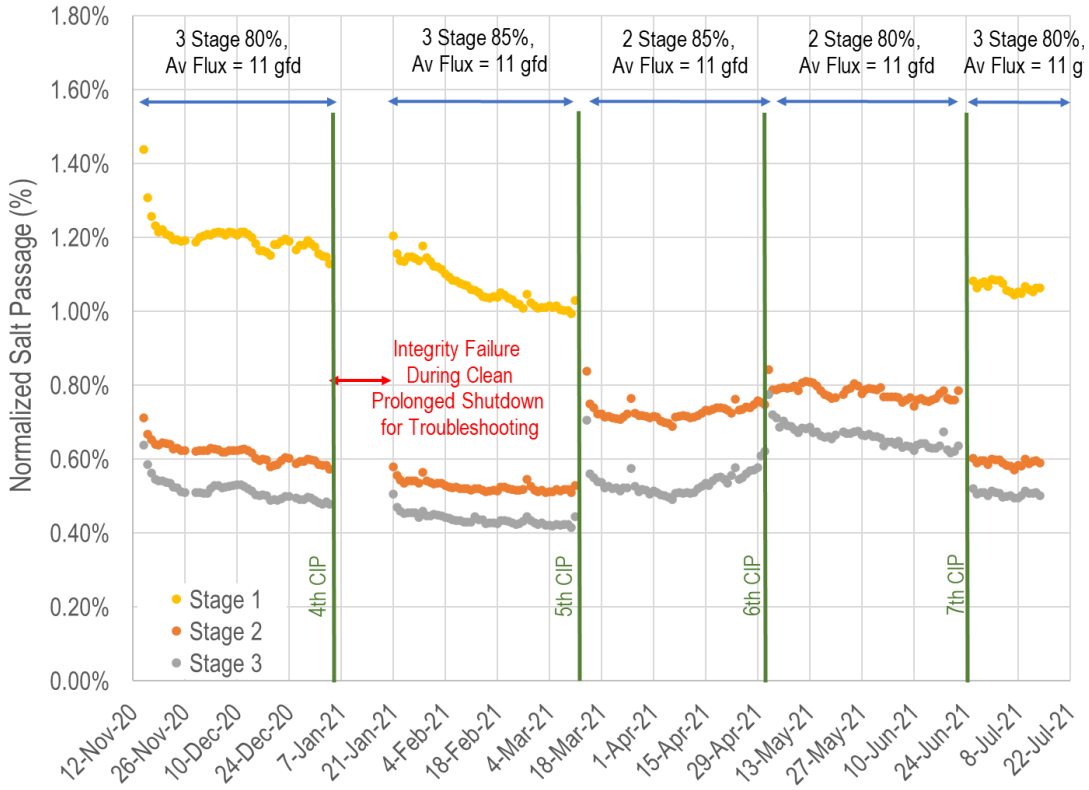


Figure 2.36 NSP During RO Test Plan Operation

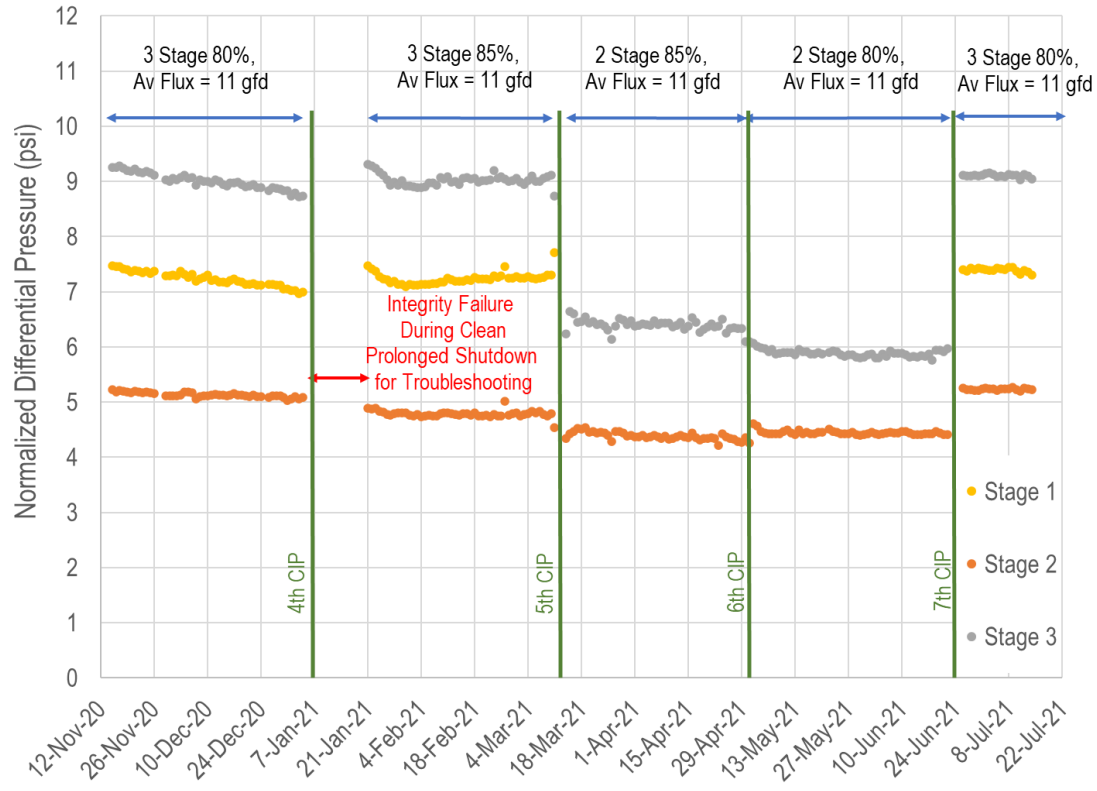


Figure 2.37 NDP During RO Test Plan Operation

During the RO test plan trial, the following observations can be made based on normalized RO performance parameters.

- NDP:
  - NDP was very stable during each trial period which indicates that no observable particulate fouling was occurring and that biofouling, which is expected to result in an increase in first stage NDP was minimal.
  - When converting from 3 stage to 2 stage operation, NDP reduced due to the reduction in effective cross flowrate through each vessel.
    - Cross flow at the end of the vessel (i.e., concentrate flow) during 2-stage 80 percent was 3.5 gpm and was 7 gpm for 3-stage 80 percent operation.
  - Subtle reductions in NDP were observed when changing from 80 to 85 percent recovery as a result of slight reductions in feed flow and recovery per vessel at higher overall system recovery.
- NSP:
  - NSP was typically stable, with slow reductions observed during each trial period. The reductions in NSP were likely due to buildup of an organic fouling layer.
  - During 3 stage 85 percent operation, NSP declined for Stage 1 possibly indicating more significant organic fouling layer buildup.
  - During 2 stage 85 percent operation, NSP for both stages began to trend upward from about the midpoint of the trial. The increase in NSP may have been indicative of scale formation which would increase localized salt concentration at the membrane surface and result in higher diffusion and conductivity in the RO permeate (See Section 2.4.5).
  - After CIPs, NSP typically increased. However, the overall increase in NSP was likely due to removal of the fouling layer and did not appear significant enough to suggest membrane damage. The exception was a single event following the 4th CIP where NSP did significantly increase on Stage 3. This event was traced to delamination of a single element and is discussed further in Section 2.4.6.
- NPF:
  - NPF was generally stable throughout the trial with a slow decline.
  - After each CIP, NPF declined rapidly for the first 5 days of operation and then leveled off for the remaining 40 – 45 days.
  - The rapid initial decline of NPF may have indicated establishment of a colloidal organic fouling layer.
  - NPF for Stage 1 reduced with subsequent trials.
- Specific Flux:
  - Specific flux of all stages showed a steady declining trend and the same initial rapid decline for approximately 5 days following a CIP as was seen with NPF.
  - Also, after the fifth CIP (the second CIP for Stage 1), the specific flux recovery due to CIPs was not sufficient to return the membranes to starting specific fluxes in the range of 0.14 – 0.16. From the seventh CIP and going forward, a number of adjustments are being made to the RO CIP procedure in an effort to improve the specific flux recovery.
  - The fouling rates, and characterization of foulants between different operational periods points are discussed in the next section.

2.4.4 RO Clean in Place Performance (Specific Flux Recovery)

For the first year of operation, the CIP procedure for the RO involved the following steps:

- Hot permeate feedwater side flush (100 gals).
- Low pH Clean (4 wt percent Avista RO clean L403, 95 degrees Fahrenheit).
  - At least 3 hours of contact with at least 2 x 60 minute recirculation of CIP chemicals at 10 gpm per vessel.
  - Each individual stage was recirculated separately.
  - An overnight soak was typically applied in between the 60 minute recirculation's.
- RO Feedwater Flush.
- Operation of the RO to refill the CIP tank with permeate.
- Hot permeate feedwater side flush (100 gals).
- High pH Clean (4 wt percent Avista RO clean L212, 95 degrees Fahrenheit).
  - At least 3 hours of contact with at least 2 x 60 minute recirculation of CIP chemicals at 10 gpm per vessel.
  - Each individual stage was recirculated separately.
  - An overnight soak was typically applied in between the 60 minute recirculation's.
- RO Feedwater Flush.
- Return to Service.

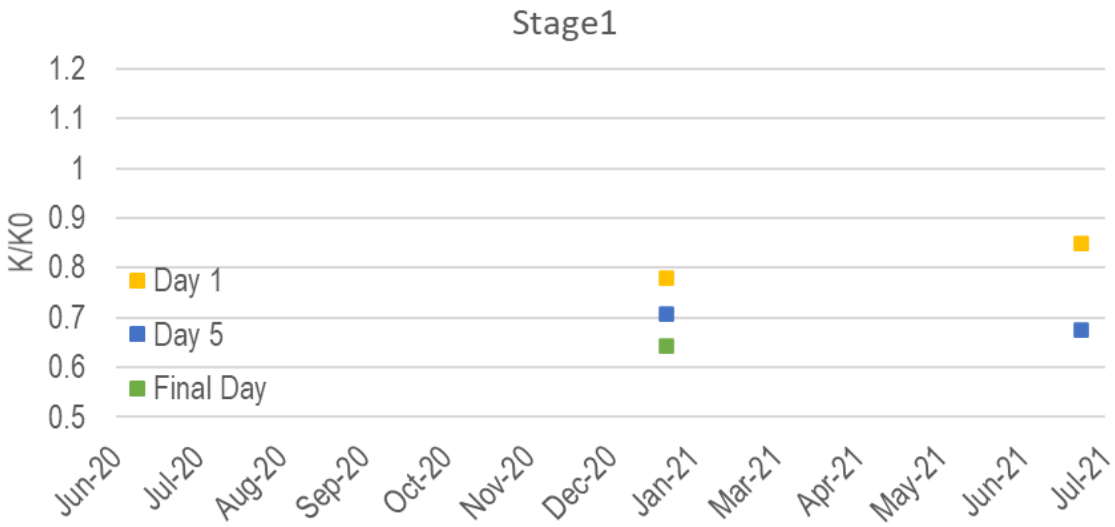
In order to quantify the performance of CIP, the specific flux of each stage was divided by the maximum observed initial specific flux which were:

- Stage 1 – 0.185 gfd/psi at 25 degrees Celsius.
- Stage 2 – 0.151 gfd/psi at 25 degrees Celsius.
- Stage 3 – 0.164 gfd/psi at 25 degrees Celsius.

Due to the way the RO was operated i.e., use of Stage 2 and Stage 3 for both the 2-Stage and 3-Stage configurations, Stage 2 and Stage 3 elements had approximately 3000 hours operation compared to only 48 hours of operation of Stage 1 at the start of November 2020. The prolonged operation and cleaning cycles of Stage 2 and Stage 3 may have contributed to a generally lower specific flux recovery when compared to Stage 1 elements, due to the accumulation of persistent foulants.

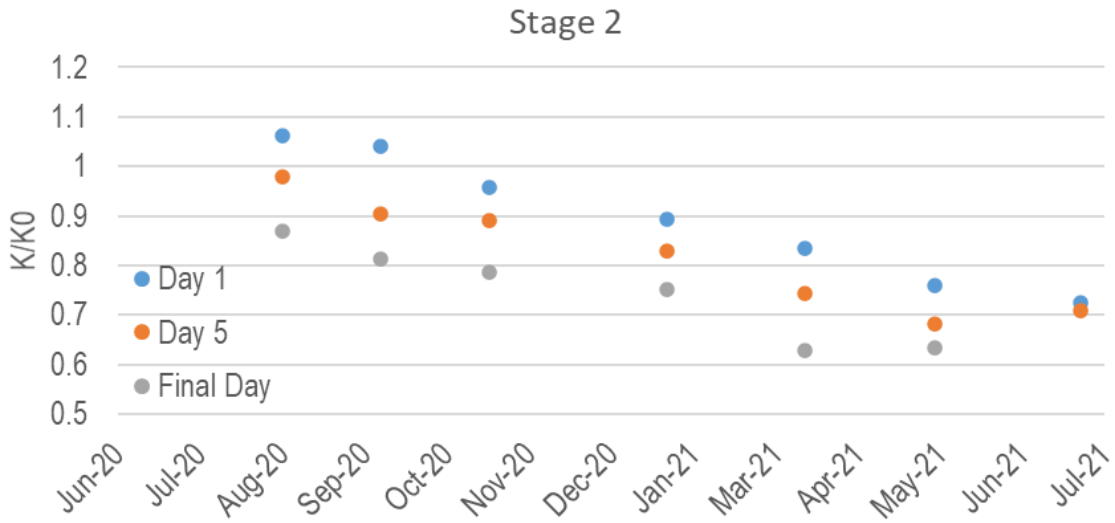
Based on the observed specific fluxes a goal of maintaining post CIP permeability of 0.14-0.16 gfd/psi at 25 degrees Celsius was set as this represents a 10–15 percent decline from the observed maximums. The specific flux relative to the maximum was determined for the first day, the fifth day after initial run in after a CIP and on the final day of each trial set. Differences

between the final and first day of a subsequent trial indicate the specific flux recovery of a CIP. The specific flux data is shown on Figures 2.38 through 2.40.



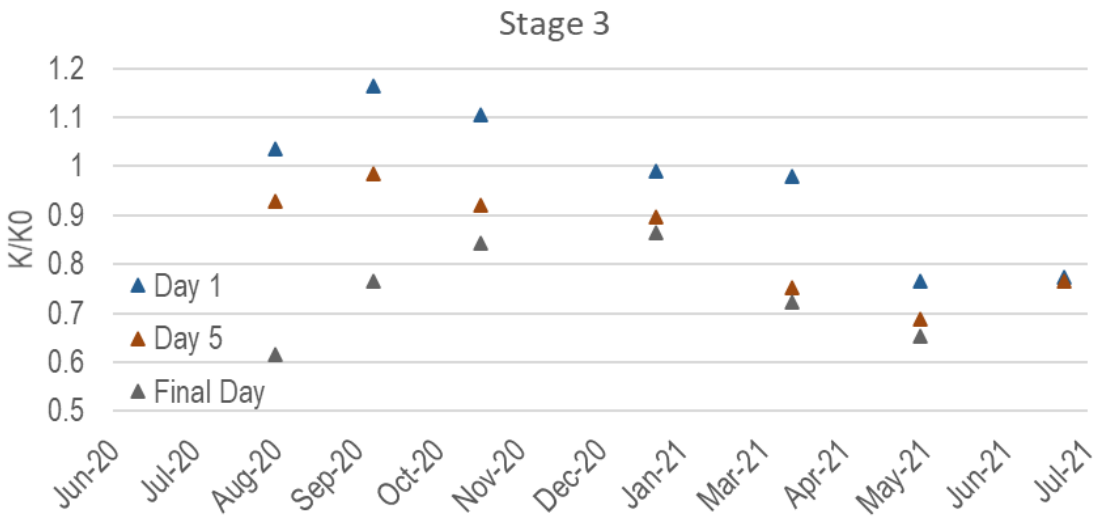
Note: Limited data available due to only 2 full 3-stage operational Trials to date.

Figure 2.38 Specific Flux Divided by Initial Maximum for Stage 1 Membranes



Note: Most specific flux decline occurs in the first 5 days of operation. A general decline in Day 1 specific flux indicates that the CIPs have become less effective with prolonged operation.

Figure 2.39 Specific Flux Divided by Initial Maximum for Stage 2 Membranes



Note: Most specific flux decline occurs in the first 5 days of operation. Similar with Stage 2 the general decline in Day 1 specific flux indicates that the CIPs have become less effective with prolonged operation.

Figure 2.40 Specific Flux Divided by Initial Maximum for Stage 3 Membranes

The data available for Stage 2 and Stage 3 suggests that the current RO CIP protocol is reducing in its effectiveness. The following items have been identified for further investigation:

- CIP chemical exposure:
  - The concentration and time of CIP chemical exposure may need to be increased.
- CIP chemical contact order:
  - There may be synergies to including an additional high pH clean before the low pH clean. Prior work has suggested that CIP cleaning order may impact specific flux recovery.
- CIP Chemical Formulation:
  - The current proprietary formulations may not be effectively targeting primary foulants.
  - Different proprietary formulations will be trialed.
  - Non-proprietary formulations may be trialed as these could help reduce the cost of RO cleaning at scale.
- CIP inter-clean flushing:
  - There is no RO permeate storage tank. As a result, the RO system must be run to produce more permeate in between each clean.
  - Also, before and in-between cleans it is necessary to use RO feed water to flush the vessels.
  - Flushing with higher TDS feedwater may leave residues that reduce the effectiveness of the cleaning chemicals.

- It is suggested that either or both of the following options are trialed to investigate if optimizing inter-clean flushing to avoid contact with high TDS feed could improve CIP performance:
  - Option 1 – Install a temporary tank onsite to provide enough RO permeate storage to complete the CIP without needing to run the RO or flush with RO feed.
  - Option 2 – Install water softening or demineralization equipment and use treated potable water for the RO cleans.

The low rate of specific flux recovery after a CIP may be intrinsic to the particular membrane used during the study (TMG10D). Data will be sought to compare the performance of Toray TMG10D like membranes used for tertiary wastewater desalination with other brackish water RO products. If promising alternative products are identified then it may be of interest to replace the currently installed membranes and assess long term performance of alternate vendors.

2.4.5 Autopsy Results

Autopsies are destructive tests that are conducted on membrane elements with the goal of quantifying the type of fouling as well as the general condition and integrity of the membrane. The initial rapid loss of NPF and specific flux early in the trial prompted a first Autopsy to try and identify if particular operating conditions could be adjusted to better optimize RO operation. Autopsies were then systematically conducted as a means to quantify the major foulants associated with each trial period.

Throughout the first year of operation, 6 elements were extracted from the Tail position on Stage 3 of the RO and sent to Avista for membrane autopsy. The results from each Autopsy are summarized in this section and the full autopsy reports are available in Appendix C.

General autopsy findings are summarized in Table 2.6 and fouling rates vs RO feedwater data for compounds noted in autopsies during each operational period are also summarized in Table 2.7.

Table 2.6 Summary of External Autopsy Findings[1]

Parameter	2 Stage 80% pH 6.3 (25 days)	2 Stage 80% pH 6.4 (34 days)	3 Stage 80% pH 6.7 (48 days)	3 Stage 85% pH 6.5 (50 days)	2 Stage 85% pH 6.7 (49 days)	2 Stage 80% pH 6.8 (51 days)
RO Flux (gfd)	S2: 11.4, S3: 7.6	S2: 10.4, S3: 9.7	S1: 11.5, S2: 10.8, S3: 10.0	S1: 11.4, S2: 10.7, S3: 10.0	S2: 11.7, S3: 9.6	S2: 11.6, S3: 9.8
RO NPF Loss (%/day)	S2: 0.7, S3:1.7	S2: 0.6, S3: 1.2	S1: 0.6, S2: 0.4, S3: 0.5	S1: 0.4, S2: 0.3, S3: 0.2	S2: 0.5, S3: 0.3	S2: 0.3, S3: 0.3
RO Fouling Rate (gfd/psi/day)*1,000[2]	S2: -0.7, S3: -1.4	S2: -0.4, S3: -1.0	S1: -0.5, S2: -0.2, S3: -0.3	S1: -0.3, S2: -0.2, S3: -0.2	S2: -0.3, S3: -0.3	S2: -0.2, S3: -0.2
Bulk FD and Characteristics	Insufficient Material	Insufficient Material	FD: 0.05 mg/cm^2 Moisture: 94% Organic :74%	FD: 0.28 mg/cm^2 Moisture: 96% Organic :55%	FD: 0.05 g/cm^2 Moisture: 69% Organic: 59%	FD: 0.15 g/cm^2 Moisture: 91% Organic: 65%
Foulant Conclusions[3]	Organic and Ca (0.5), P (0.3), Al (0.3)	Organic and Ca (0.8), Al (0.7).	Biological Organic and Ca (0.2), Al (0.1), Si (0.1)	Biological Organic and Ca (0.4)	Organic and Inorganic Ca (15.8), P(8.6), Mg (1.1), Al (0.7), Si (0.6)	Biological Organic and Al (0.2), Si (0.5)
Element Wt (lbs)	8	8	8	8	7	8
Element Wet Test	Q: 0.73 gpm at dP: 3 psi 44% of nominal	Q: 0.42 gpm at dP: 3 psi, 25% of nominal	Q: 0.96 gpm at dP: 3 psi, 57% of nominal	Q: 1.24 gpm at dP: 3.5 psi, 74% of nominal	Q: 0.64 gpm at dP: 3 psi, 44% of nominal	Q: 0.87 gpm at dP: 3 psi, 59% of nominal
Oxidative Damage	Fujiwara: +ive SP: 0.5%	Fujiwara: +ive SP: 0.4%	Fujiwara: +ive SP: 0.4%	Fujiwara: +ive SP: 0.3%[4]	Fujiwara: -ive SP: 0.5%	Fujiwara: -ive SP: 0.6%
Membrane Integrity	Vacuum integrity tests indicated that all modules were intact.					
Biological Activity	All modules were positive for aerobic bacteria growth					
Primary Foulant	Organic/Biological	Organic/Biological	Organic/Biological	Organic/Biological	Inorganic Scale	Organic/Biological

Notes:
Abbreviations: Al - aluminum; CA - calcium; dP -differential pressure; FD - foulant density; g/cm^2 - grams per square centimeter; lbs - pounds; Mg - magnesium; P - phosphorus; Si - silicon.
(1) With the exception of 2-Stage 85 percent operation where inorganic scale was evident, organic and biological fouling was the primary foulant identified in autopsies.
(2) Fouling rate was the specific flux slope of best fit ignoring first 4 days rapid decline (starting on 5th day) after a CIP. Percent NPF loss refers from start to finish. Fouling rates are lower with later runs, but initial permeability after cleaning was also not as high.
(3) Numbers adjacent elements are relative wt percent from SEM EDS not a specific concentration.
(4) Dye testing was conducted only once (i.e., not on other autopsies) and suggested physical damage of coupons that were extracted. The extracted coupons had a much higher salt passage of 0.9 percent. The salt passage is reported for the full module test.

Table 2.7 Water Quality Parameters in RO Feedwater Associated With Fouling Compared to Average Fouling Rate During Each Trial Period

Parameter	2 Stage 80%, not FB, 6.4		2 Stage 80%, not FB, 6.4		2 Stage 80%, FB, 6.4		3 Stage 80%, FB, 6.8		3 Stage 85%, FB, 6.8		2 Stage 85%, FB, 6.8		2 Stage 80%, FB, 6.8	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Stage Average Specific Flux Decline (gfd/psi at 25°C/d) x 1,000	-0.27		-1.03		-0.71		-0.31		-0.21		-0.27		-0.16	
Feed Temperature Fahrenheit	78	1	79	1	77	1	72	2	69	1	72	2	75	1
Feed pH	6.44	0.08	6.31	0.10	6.45	0.06	6.71	0.05	6.54	0.17	6.68	0.04	6.84	0.06
Feed Conductivity (µS/cm)	1216	54	1237	47	1195	36	1209	15	1267	14	1279	13	1263	43
Feed TOC (mg/L)	6.2	0.3	6.6	0.4	6.6	0.3	6.6	0.4	6.8	0.5	7.6	0.5	7.1	0.8
Feed Ca (mg/L)	n.s.		n.s.		68.0	-	60.8	0.4	68.2	1.3	64.8	-	67.3	-
Feed Al (µg/L)	14.0	2.4	13.0	1.4	< 20	-	< 20	-	< 20	-	< 4.4	-	14.0	2.5
Feed PO4 (mg/L)	n.s.		n.s.		2.1	-	2.7	0.3	2.6	0.3	n.s.		n.s.	
Feed SiO2 (mg/L)	21.2	0.4	20.0	0.0	18.0	1.7	17.0	0.0	18.2	0.4	19.0		21.0	1.2

Notes:
Abbreviations: σ - standard deviation; μ - mean; µg/L - micrograms per liter; µS/cm - microsiemens per centimeter; gfd/psi at 25°C/d - Fouling rate in gallons per square foot of membrane area per psi per day adjusted to a reference temperature of 25 Celsius; FB - flow balanced; PO4 - phosphate ion; SiO2 - silicon dioxide.
(1) FB = Flow Balanced at Design Flux for each stage.

Based on the Autopsy results and comparison with feedwater data:

- It was difficult to correlate fouling rate with a single parameter. There did appear to generally be marginally higher fouling rates with higher feedwater temperature.
- The fouling rates at lower run-times appeared to be higher than after the modules had accumulated run time (i.e., modules fouled faster at the beginning). Given the poor CIP recovery, specific flux has generally declined throughout the test period.
- The increase in pH from 6.4 to 6.8 may have decreased organic fouling noting that the fouling rate for pH 6.8 for 2 stage 80 percent was lower than at a pH of 6.4. However, the actual specific flux was lower in general for the second trial.
- Testing of 2-stage 85 percent operation contrasted with other configurations as the module had fouled with a significantly higher level of inorganic scale. The inorganic scaling may have formed due to a combination of:
  - The pH of 6.7 during this test phase was not sufficiently low to inhibit scaling or,
  - The very low cross flow velocities during inherent to 2-Stage 85 percent may have increased the likelihood of scale formation. It is suspected that low cross flow velocities contributed more to scaling given that pH was similar for 85 percent 2 and 3 stage runs.
- When considering the specific flux loss, all configurations performed in an equivalent fashion.

With the exception of 2-stage 85 percent recovery (at pH and crossflow velocities tested), the RO performance results suggest that all tested configurations are viable. However, further work should be performed to extend the interval required for CIP. 2-Stage 85 percent recovery contrasted to other configurations as it experienced significantly more inorganic scaling. Further testing of 2-Stage 85 percent with a reduced pH may provide valuable information on if chemical addition can be optimized to reduce the scaling potential inherent to this configuration. However, a reduction of pH may increase organic fouling of the 2-Stage 85 percent configuration.

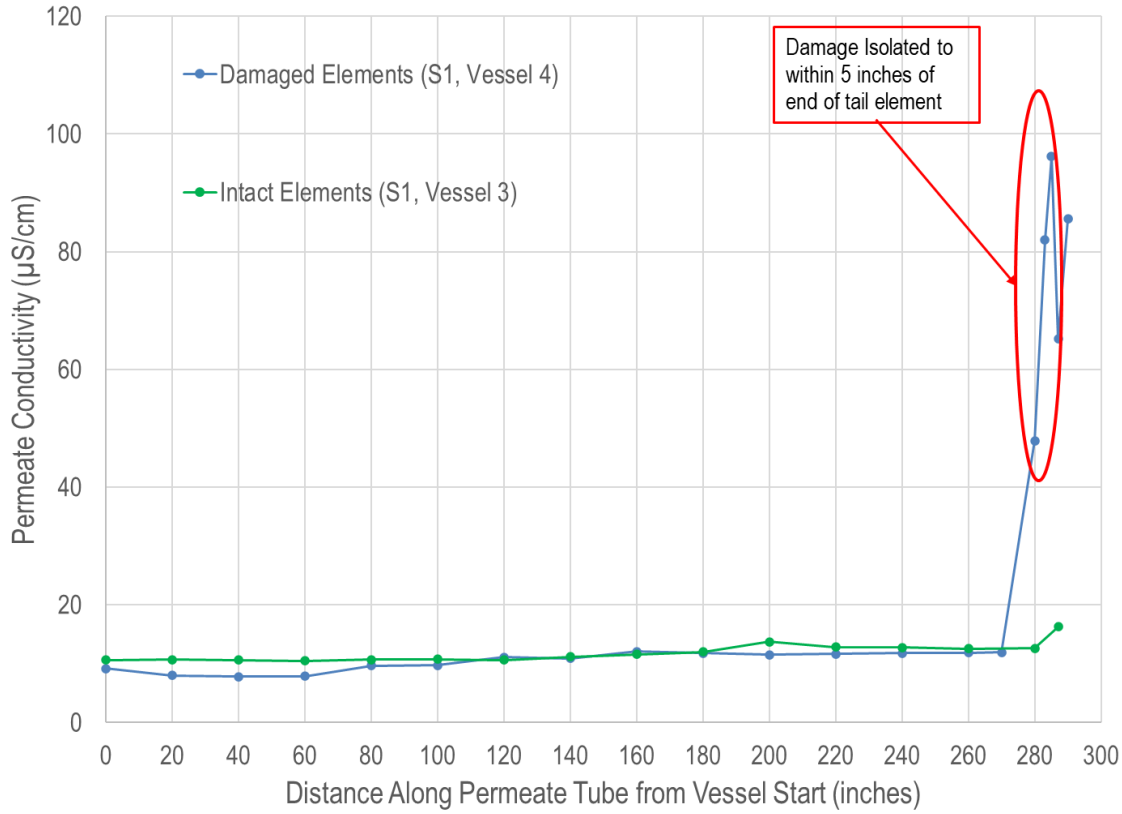
2.4.6 RO Integrity Troubleshooting

When restarting the RO system after completing the low pH clean on January 6, 2021, the third stage permeate conductivity was confirmed via grab sampling to be too high (300-400 µS/cm) compared to typical values (< 30 µS/cm). As a result, the RO unit shut down on high combined permeate conductivity.

In order to continue the clean, the Stage 3 membranes were rotated into Stage 1. Given that Stage 1 had a lower effective feed conductivity than Stage 3, the lower rejection of the membranes would have less impact on the final conductivity. With this change, combined RO permeate conductivity reduced to less than 50 µS/cm and the CIP was continued.

It was speculated that there may have been a problem during initial CIP flushing where permeate pressure exceeded the feed pressure. As a result of this, it is possible that delamination had occurred on the Stage 3 membranes.

To evaluate the damage localization, conductivity was probed along the length of the Stage 1 vessel with the damaged Stage 3 membranes and compared to an adjacent Stage 1 vessel with nominal membranes. The conductivity profile is included on Figure 2.41.



Note: Damage was isolated to the single tail element. Replacement of this element returned the system to normal values.

Figure 2.41 Conductivity Probing Results Following the High Permeate Conductivity Event

The conductivity profile clearly indicated that the damage was within the last 5 inches of the tail element. A later visual inspection by Avista confirmed that the damaged membrane was delaminated towards the concentrate end of the module (See Figure 2.42).

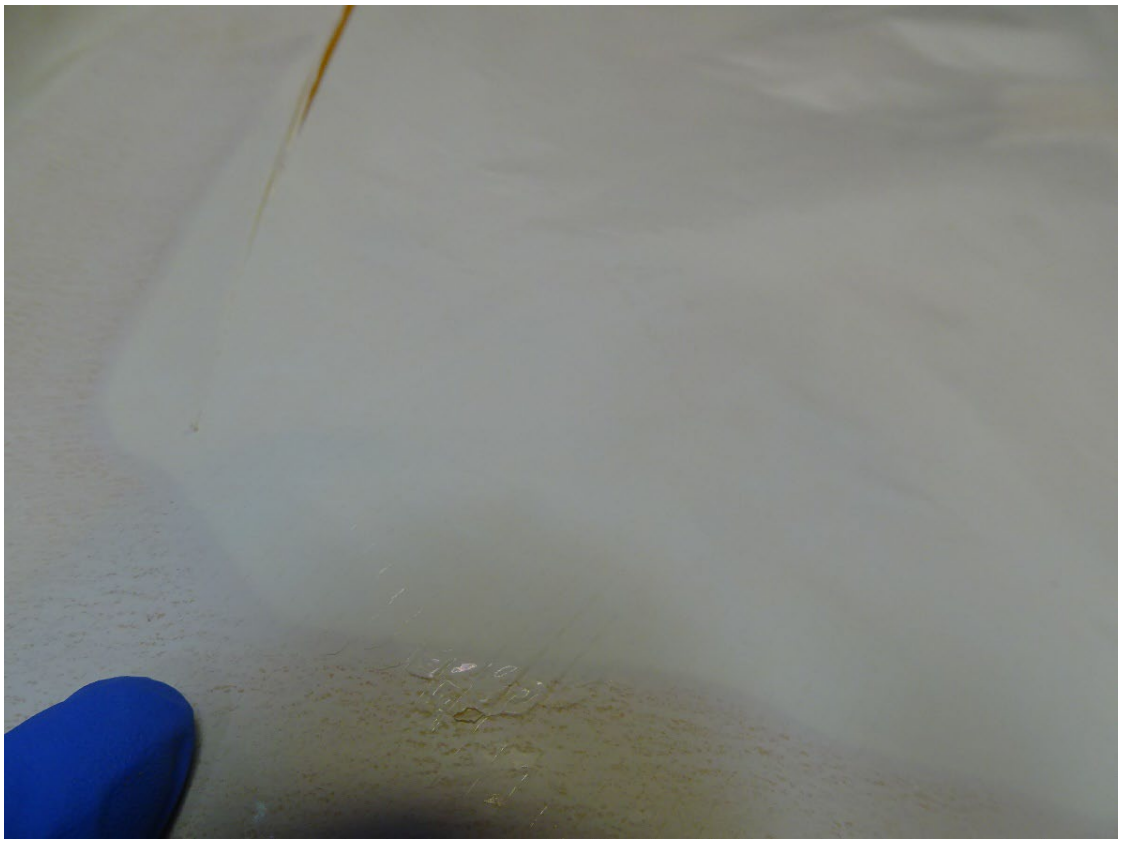


Figure 2.42 Delamination Towards the Concentrate End of the RO Membrane Extracted as a Result of the Conductivity Probing

The damaged tail module was replaced, and the intact modules repositioned into Stage 3. After replacement of the single module, Stage 3 and combined permeate conductivity returned to typical values. Corrections were made to the RO CIP and flushing SOPs to include checks designed to prevent a similar occurrence.

The combined and Stage 3 permeate conductivity increase was rapidly identified and the system was shut off. The further troubleshooting demonstrated how sensitive the conductivity meters were to RO membrane integrity failure. Although resulting in membrane damage, this event tested the response of the RO unit to a real potential failure and demonstrated that the monitoring and control strategies in place were robust and would not allow delivery of off specification water.

2.4.7 RO Membrane Integrity Monitoring

The membrane integrity of the RO system has been verified by calculation of an effective LRV from RO feed to combined permeate for a range of surrogates. These surrogates can be proposed, and when approved by regulators, used for LRV credits for the RO system.

- Online Surrogates:
  - Conductivity.
  - TOC.

- Offline Surrogates:
  - Twice monthly grab samples of non-microbial surrogates including:
    - Sulfate.
    - Strontium.
    - Sucralose.
  - A single MS2 challenge test event in April 2021.

This section reports on the RO integrity monitoring practices to verify pathogen LRV by RO as well as the comparative reliability of each surrogate.

2.4.7.1 Online RO Membrane Integrity Surrogates

Prior to analysis, conductivity and TOC were filtered to ensure that only readings when the system was in operation were counted.

The TOC meter is a Sievers M5310C which is generally considered the gold standard for measurement of TOC removal across RO membranes. The unit is dual-channel and the TOC readings are alternated by means of internal automated valves to measure the RO feed and then the RO permeate. The alternation of sampling typically allows for a reading of feed and then permeate every 20 minutes. This cycle should result in approximately 36 TOC measurements of feed and permeate each per day. To calculate LRV, the closest RO feed and permeate within 20 minutes were paired to calculate an LRV. Even after filtering to when the system was in operation, TOC data still carried a large amount of noise and was further filtered to reject the following data:

- TOC <= 0:
  - The TOC meter measures total carbon (TC) and inorganic carbon (IC). IC is then subtracted from TC to provide TOC. If measurement interferences occur with TC it was observed that negative TOC values could result.
  - TOC values less than or equal to 0 were symptomatic of a measurement error and were excluded.
- RO permeate absolute standard deviation > 0.2 mg/L:
  - The TOC meter performs triplicate measurements of TC-IC and then reports an average. If the absolute standard deviation was > 0.2 mg/L, the data was excluded as it was suspected that contamination from the prior feed sample or sample flow interruptions may have influenced readings.
  - An absolute, rather than relative standard deviation (RSD), was used as small differenced in the typically low TOC of the RO permeate would generally lead to large RSDs.
- RO Feed RSD > 30 percent:
  - Similar to the RO permeate, RO feed readings with an RSD> 30 percent were excluded due to the suspicion that either flow interruptions or sample contamination had influenced the result.

The LRV calculated from conductivity and TOC across the RO system is shown on Figure 2.43 for the first year of operation. Results are expressed as the 5th percentile, average and 95th percentile calculated on a daily basis during operation and subject to the data filtering described above. The daily 5th percentile, average and 95th percentile of the filtered RO permeate TOC and conductivity are also summarized in Table 2.8.

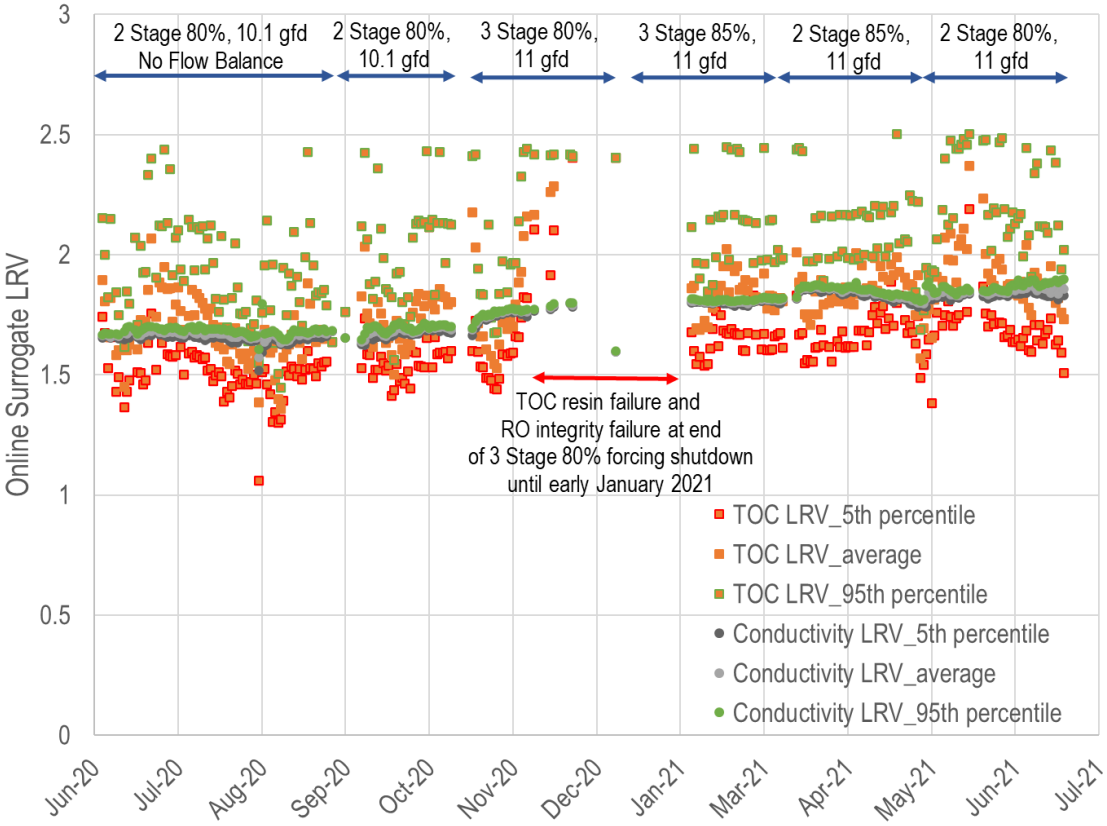


Figure 2.43 LRV of TOC and Conductivity Across the RO for the First Year of Operation

Table 2.8 Daily Summary Statistics for RO Feed and Permeate Conductivity and TOC(1)

Parameter (units)	Daily 5th Percentile	Daily Average	Daily 95th Percentile
RO Feed TOC (mg/L)	5.0 – 8.3	5.8 – 8.8	5.9 – 10.1
RO Permeate TOC (mg/L)	0.03 – 0.25	0.03 – 0.32	0.03 – 0.60
RO Feed Conductivity (µS/cm)	1003 - 1319	1120 - 1338	1189 - 1400
RO Permeate Conductivity (µS/cm)	13 - 32	15 - 34	17 - 37

Note:
(1) Values are reported as the minimum to maximum of each statistic observed for the first year of operation.

From the data in Table 2.8 and Figure 2.43 the following observations can be made:

- The TOC meter was varying by a factor of 10 in the RO permeate. It was suspected that this was not due to poor RO performance as the same variation was not observed for conductivity which varied by less than a factor of 3 throughout the year.
- The variation in RO permeate TOC, led to a large observed variation in the RO TOC LRV which can be observed as the typically large gap between the 5th percentile, average and 95th percentile observed during a single day.
- The stability of conductivity measurements resulted in a typically higher LRV being observed for conductivity than for TOC, the inverse of what is typically seen for RO monitoring in which TOC LRV is greater than EC LRV. The conductivity meters also

measure almost instantaneously, providing greater coverage of LRV throughout the day.

- Based on the observed performance during the first year, the following LRVs could potentially be claimed based on monitoring conductivity and TOC:
  - Daily 5th Percentile LRV:
    - Conductivity = 1.5.
    - TOC = 1.1.
  - The 5th percentile LRV of 1.5 for RO based on conductivity is typical and indicates good removal performance.
  - The 5th percentile LRV for TOC of 1.1 was lower than anticipated and prompted additional investigation into the calibration and accuracy of the TOC meter, as reviewed below.

As a result of the variable TOC meter performance observed for the first year, several requests were made during the annual meter service including:

- Calibration with low range standards.
- Adjustment of the measurement cycle to include a sacrificial flush with RO permeate when switching from a RO feed to an RO permeate measurement.
- Adjustment of 4 – 20 milliamperes (mA) scaling to ensure that the typical meter output for each stream could be accurately differentiated.
- The TOC service technician also recommended a monthly manual flush of the TOC unit using a 1:1 solution of hydrogen peroxide and acetic acid (white vinegar) to remove internal fouling that can lead to sub optimal performance.

Following the maintenance and recalibration activities listed above, the TOC meter functionality improved significantly, and results are shown for the 15-minute average conductivity and instantaneous TOC meter output on Figure 2.44. The comparative data for TOC measurements before after maintenance are included in Table 2.9.

Table 2.9 Daily Summary Statistics for RO Feed and Permeate TOC Before and After Maintenance and Recalibration Activities in June 2021(1)

Parameter	Daily 5th Percentile	Daily Average	Daily 95th Percentile
RO Feed TOC (pre June 2021) (mg/L)	5.0 – 8.3	5.8 – 8.8	5.9 – 10.1
RO Permeate TOC (pre June 2021) (mg/L)	0.03 – 0.25	0.03 – 0.32	0.03 – 0.60
RO Feed TOC (post June 2021) (mg/L)	4.5 – 7.1	5.8 -7.1	6.7 – 8.0
RO Permeate TOC (post June 2021) (mg/L)	0.05 – 0.08	0.06 – 0.08	0.07 – 0.08

Note:
(1) Values are reported as the minimum to maximum of each statistic observed.

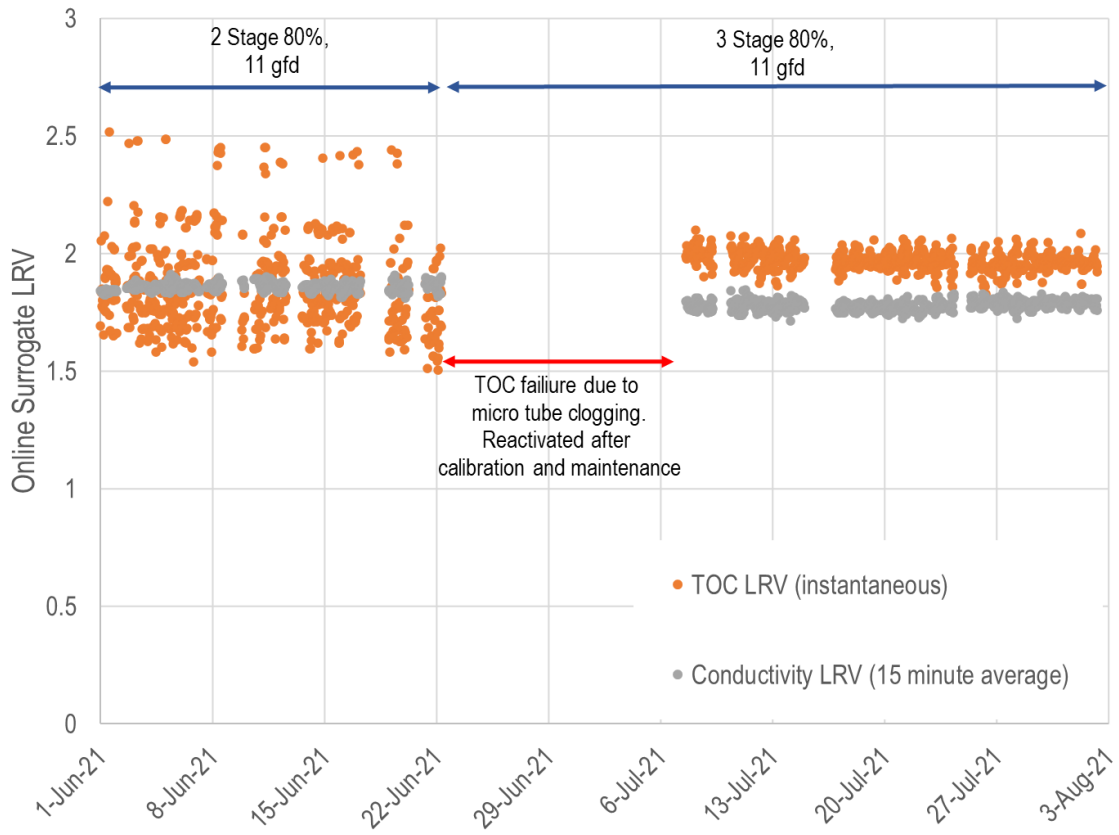


Figure 2.44 Performance of the TOC Meter Before and After Recalibration and Maintenance Activities

The maintenance activities significantly reduced the variability of RO permeate TOC measurements from almost a factor of 10 to less than a factor of 2. The improved permeate monitoring precision resulted in a much higher LRV based on TOC and the minimum observed TOC LRV following maintenance was 1.75.

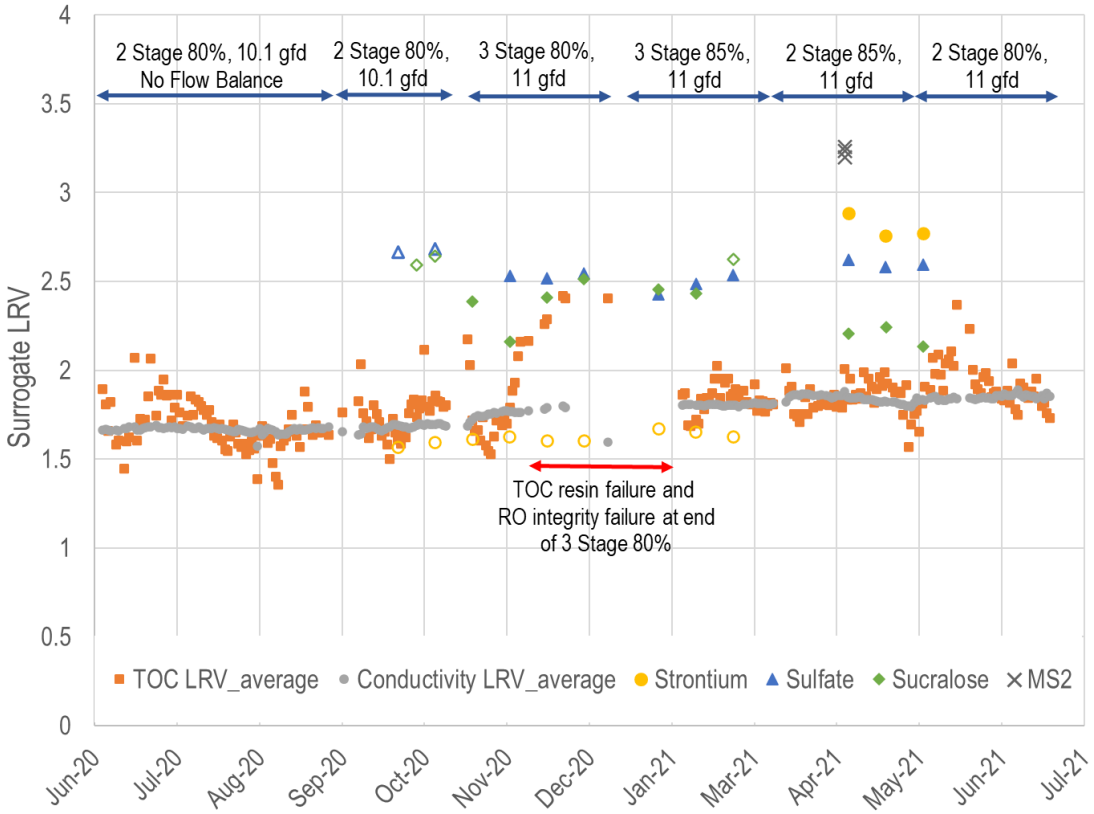
Should TOC LRV reduce or become more variable without corresponding variation in conductivity LRV it is recommended that the unit is serviced and recalibrated.

Following maintenance, both TOC and conductivity confirmed that the RO was performing very well and removing both of these surrogates to typical levels.

2.4.7.2 Offline RO Membrane Integrity Surrogates

Sulfate, strontium and sucralose have been used in other RO studies as single surrogate compounds to indicate LRV of pathogens across RO. MS2 bacteriophage is a standard model virus that has also been used to indicate LRV of virus sized particles by membrane products.

The LRVs determined via grab sampling of sulfate, strontium and sucralose, as well as the one time MS2 virus challenge test are shown relative to the daily average online surrogate LRV on Figure 2.45.



Note: For offline surrogates, open symbols indicate that the LRV has been calculated with the limit of detection and that the true LRV value is higher than shown. Average values of TOC and conductivity refer to daily average data, filtered for when the RO is in production.

Figure 2.45 Comparison of Online and Offline RO Surrogates

The range of LRV demonstrated by each surrogate were:

- Strontium - >1.6 to 2.9.
- Sulfate – 2.4 to >2.7.
- Sucralose – 2.1 - >2.6.
- MS2 – 3.2 – 3.3.

Strontium was not detected in 9 of 12 sampling occasions in the RO permeate, as a result, most of the strontium LRVs are underestimates of the true value. When laboratories were changed in April 2021, the new laboratory reported strontium to a lower limit of detection. As a result, the observed LRV for strontium increased to between 2.7 – 2.9.

Sucralose was not detected in 3 RO permeate samples and demonstrated a LRV of between 2.1 to greater than 2.6.

Sulfate was not detected in 2 of 11 RO permeate samples. Sulfate was able to demonstrate LRVs of between 2.4 to greater than 2.7. The detection limit for sulfate depended on the contract laboratory performing the analysis, the first contract lab was able to report sulfate to 0.5 mg/L, while the alternate was able to report sulfate to 0.24 mg/L. Full water quality sampling results including RO surrogates are included in Appendix B.

The MS2 challenge test results were conducted as triplicate sets, with triplicate analyses of RO feed and RO permeate on a single day in April 2021. The MS2 was spiked at a sufficient concentration that all RO permeate readings were detected. The MS2 challenge testing demonstrated that the RO system was achieving virus LRVs of between 3.2 and 3.3 log units, demonstrating that all tested surrogates are conservative indicators of LRV.

In total, the offline surrogate results demonstrate that there is a potential margin of safety between 1.0 to 1.7 log units when using conductivity to indicate LRV and that true pathogen removal of the RO system is likely above 3.0 log units. Depending upon the pathogen LRV credits needed for RO for the full-scale system, any of the tested surrogates, other than MS2, could be used for regulatory approval, understanding that larger data sets may be necessary for some surrogates. In addition, it is likely that if surrogates were pursued to demonstrate RO LRV, instrumentation would need to be installed onsite so that daily quantification of the LRV were possible. In addition, there may be requirements to test the permeate from individual RO arrays/skids.

2.4.8 RO Engineering Economics

The use of a two-stage and three-stage RO system, at recoveries of 80 percent and 85 percent, result in different economic value per gallon of purified water. Cost estimates for the RO system were determined by scaling ancillary processes relative to equipment costs. RO concentrate disposal costs are not included within the estimates. These estimates typically are accurate to within +- 50 percent and are provided here as a means to identify if cost should guide optimization or design efforts. The cost estimate for a RO facility that produces 6 mgd of RO permeate at 2-Stage 80 percent, 2-Stage 85 percent and 3-Stage 85 percent are included in Table 2.10. 3-Stage 80 percent was not included as it will be marginally more expensive than 2-Stage 80 percent, and performance results from this project indicate that 80 percent recovery can be efficiently performed with a 2-Stage configuration.

Table 2.10 Capital and Operational Cost Estimates for Different RO Configurations Producing 6 mgd of Permeate (Not Including Concentrate Disposal)

	Cost Estimate[1,2]	2 Stage 80%	2 Stage 85%	3 Stage 85%
Totals	Capital Estimate[3]	$6,321,000	$6,321,000	$6,400,000
	Total Annual O&M	$609,000	$578,000	$637,000
O&M Components	*Pump Energy*	*$228,000*	*$216,000*	*$272,000*
	Antiscalant	*$206,000*	*$194,000*	*$194,000*
	Sulfuric Acid	*$82,000*	*$82,000*	*$82,000*
	Membrane Replacement	*$69,000*	*$69,000*	*$72,000*
	Cartridge Filter Replacement	*$20,000*	*$18,000*	*$18,000*
	CIP Chemicals	*$4,000*	*$4,000*	*$4,000*

Notes:
Abbreviation: O&M - operations and maintenance.
(1) Permeate flow target of 6 mgd.
(2) Feed flow target: 80 percent recovery = 7.5 mgd, 85 percent recovery = 7.1 mgd.
(3) Capital Cost Estimate refers to RO equipment only and does not include ancillary structures or delivery and installation.

The following factors contribute to the cost in Table 2.10:

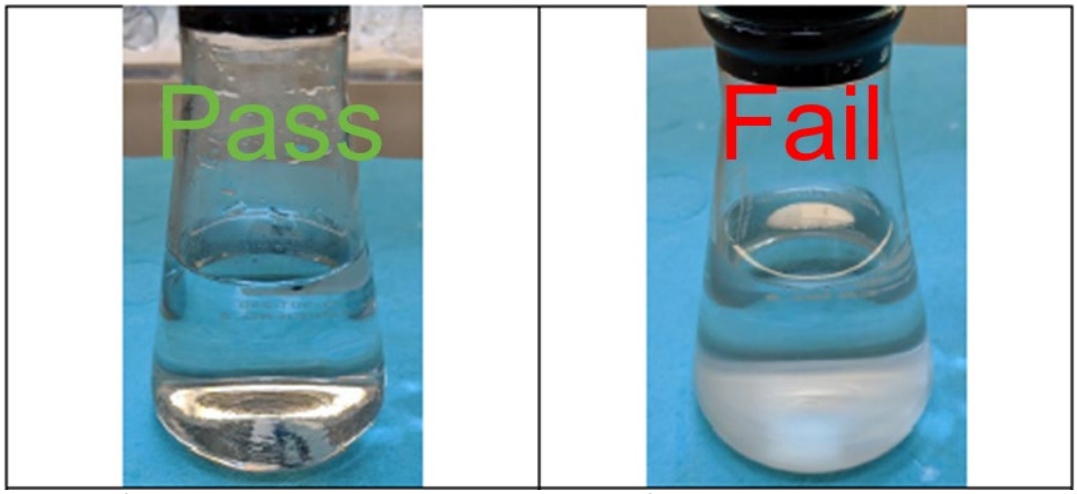
- Capital estimates are largely the same between 2 and 3 stage
- Total annual O&M estimates are similar between each conventional RO configuration.
- Total annual O&M for 2 Stage 85 percent requires less pumping energy and also less total antiscalant use due to the reduced feed flow.
- Membrane replacement for a 2 Stage system is anticipated to be slightly less than for a 3 stage. However, the scaling observed for a 2- Stage 85 percent recovery system may suggest that this configuration needs more frequent cleaning and downtime than the estimates above account for.
- Antiscalants and cartridge filter requirements are lower for 85 percent recovery systems as less feed flow will be treated to produce the same volume of permeate.
- In general, the estimates suggest that cost differences between 2 and 3 stage systems will be small.

2.4.9 Brine Scaling Potential Evaluation

A study was conducted to investigate the impact of antiscalant dosage at mitigating potential scaling within a future RO concentrate (e.g., brine) line. The full study is included in Appendix D and briefly summarized here.

For the scaling potential evaluation, the following activities occurred:

- A large sample of UF filtrate was collected from the Demo. The UF filtrate was collected prior to antiscalant addition and pH reduction.
- The UF filtrate sample was divided and each set was concentrated to different recoveries using Toray TMG10D RO modules (the same as used at the Demo) in a pilot reactor. The variables tested included:
  - Antiscalant doses (Vitec 4000) – 0 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L and 2.5 mg/L.
  - Recoveries – 75 percent, 80 percent, 85 percent, 90 percent.
- For each combination of variables, a sample was retained and visually inspected at 8, 24, 48, and 72 hours after concentration. A pass and fail criteria are shown on Figure 2.46.

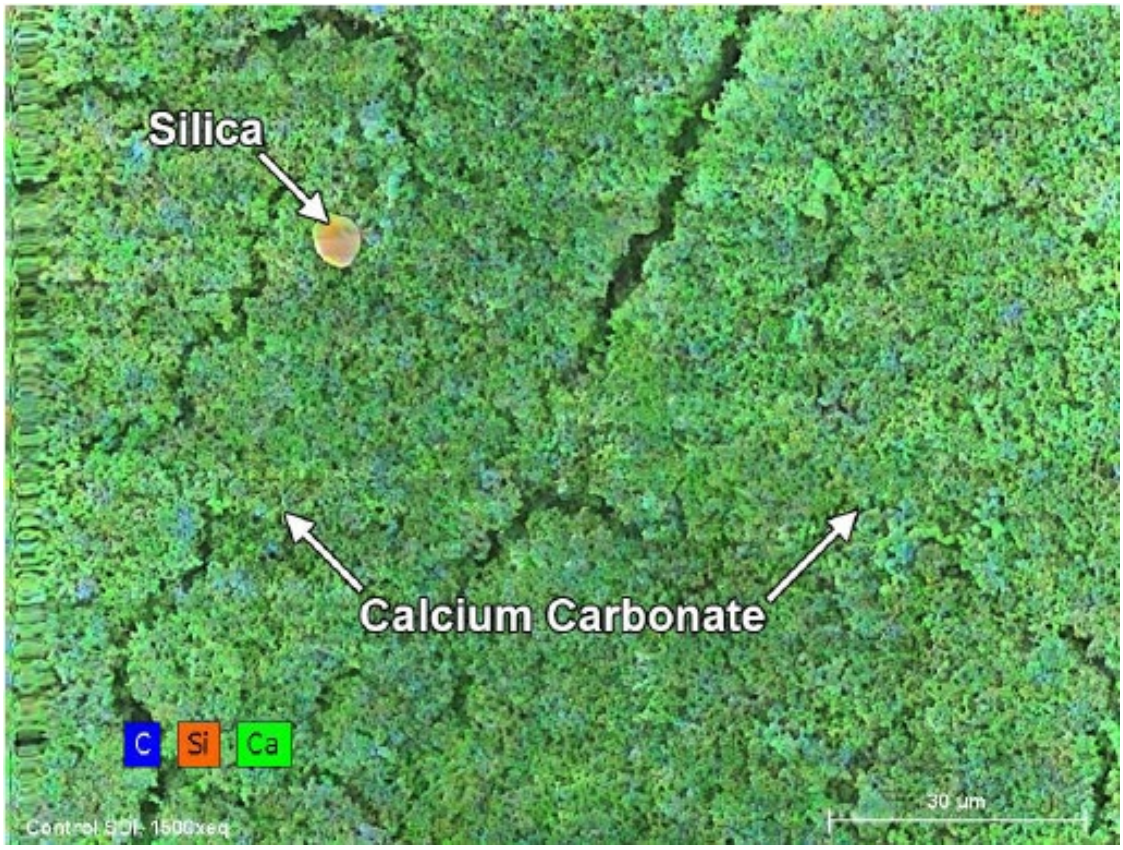


Note: This flask contains no visible precipitation on the surface, side or bottom of the flask.

Note: This flask contains visible precipitation and is considered a failed dose

Figure 2.46 The Pass and Fail Criteria for Visual Inspection and Identification of Scale Formation

- The potential scale forming compounds were estimated using the AdvisorCI software package for each of the recoveries and dosages. Water quality data from operation of the demonstration facility was used to specify the RO feed quality for the advisor CI projections.
- The presence of potential scale formers was then confirmed by running a control. The control was to concentrate the UF filtrate sample to 90 percent recovery with no addition of antiscalant and then to autopsy the membrane. Under these conditions, scale formers could be confirmed via scanning electron microscopy on the membrane surface.



Note: Calcium carbonate and silica identified on the membrane surface, confirming the high likelihood that these compounds would precipitate without mitigation by operation at low recovery or addition of antiscalant.

Figure 2.47 Scanning Electron Micrograph of the RO Membrane Control After 90 Percent Recovery Operation With No Antiscalant

For each dose and recovery pair, the time until scale formation was summarized below:

- 75 Percent Recovery – 0.5 mg/L of antiscalant could inhibit scale formation for 48 hours.
- 80 Percent Recovery – 1.5 mg/L of antiscalant could inhibit scale formation for 24 hours.
- 85 Percent Recovery – 2 mg/L of antiscalant could inhibit scale formation for 8 hours.
- 90 Percent Recovery – 2 mg/L of antiscalant could inhibit scale formation for 8 hours.

The advisor CI software suggested that the following compounds would likely form scale on the future brine line:

- Calcium Carbonate (confirmed with control experiment).

- Calcium Phosphate (significant at recovery > 85 percent).
- Calcium Sulfate.
- Barium Sulfate.
- Silica (Confirmed with control experiment).
- Aluminum.
- Iron.

The general recommendation from the brine scaling study was that recoveries of 80 percent or lower would be required to inhibit scaling in long brine lines.

There were limitations of the scaling study which included:

- The solutions were not pH corrected to lower values which may have reduced scale formation, in particular for calcium carbonate and calcium phosphate.
- The solutions were not created in such a way that could simulate turbulence due to an airgap. An airgap within the brine line might be anticipated to induce scale formation (through off-gassing of carbon dioxide (CO_2) and a subsequent pH increase) which could result in earlier onset of scaling than predicted by the experiment.
- The UF filtrate used for the study was the result of treating the blend of tapia effluent and potable makeup water in reservoir 2 and may be different from the final water quality of the full-scale facility. The potential for blending of alternate water sources seasonally at the full-scale facility may result in different scaling potentials of the brine throughout the year.

If higher recovery RO systems are pursued, this preliminary work suggests that additional treatment of the brine may be required to avoid scale formation of the brine line, such as softening, or acidification of the RO concentrate or operation at a lower RO feed pH setpoint. Further experiments could be performed to address the limitations above.

2.4.10 Approaches for Further RO Optimization

Over the first year of operation, the following items have been identified for potential future investigation:

- CIP specific flux recovery and cleaning interval:
  - The current CIP regime uses proprietary chemicals that would likely contribute significantly to cost of a full-scale installation.
  - In addition, the current CIP regime does not appear to be effective at returning the membranes to near starting conditions.
  - Three approaches should be considered to address the limitations of the current CIP regime (specific flux recovery and frequency):
    - Priority 1 should be to identify if changes can be made to the current CIP chemicals that can improve specific flux recovery. If specific flux could be recovered to close to starting values, then more appropriate comparisons about the impact of different operational configurations could be made.
      - Initial efforts have sourced alternate proprietary blends based on advice from Avista as well as adjusting the contact order as previously noted.

        - Priority 2 should be to identify if, once recovered to nominal specific flux the CIP interval can be increased. A 90 day CIP interval is proposed as a measure of success.
        - Priority 3 should be to identify if a successful cleaning formulation can be created from non-proprietary conventional cleaning chemicals. Success with priority 3 would help reduce the cost per clean of the full-scale installation.
- Alternative membranes:
    - The current challenges with specific flux recovery may be specific to the current vendor. It is recommended to identify if data is available with a side-by-side comparison of the currently installed RO membrane type with alternate suppliers from other sites applying RO to MF/UF treated wastewater. If a promising alternative RO product is identified then it may be of use to replace the membranes at the demonstration facility to perform an onsite evaluation.
- Alternative antiscalants and dosage optimization:
    - Scaling was noted as a fouling mode only for 2-Stage 85 percent recovery.
    - Based on cost estimates, ongoing purchase of antiscalant chemicals will likely be a significant contribution to RO operational expenditure.
    - It may be useful to use the demonstration facility to compare optimized/reduced antiscalant dosages or alternative products that can now be better specified after collection of over one year's operational and water quality data.
- Supplementary brine line scaling potential:
    - The preliminary analysis of brine line scaling potential did not systematically evaluate the potential for accelerated scale formation due to air-gap turbulence.
    - Also, the scaling potential tests were performed with the current antiscalant.
    - Should alternative antiscalants be pursued, it may be of interest to repeat scaling potential testing to investigate the potential impacts to the brine line. At such a time, it may also be of interest to investigate if physical mechanisms, such as an induced air gap could accelerate scaling.
    - In addition, the brine scaling study was conducted without pH adjustment. pH adjustment to lower values may reduce scale formation observed by a subsequent study.

2.5 UV Advanced Oxidation Process

2.5.1 System Description

For UV systems, the performance is impacted by influent UVT, which indicates the ability of UV light to penetrate the water, by the UVI, which quantifies the amount of UV light reaching a sensor in the reactor, by the flow through the reactor (Q) and the reactor ballast power.

The Xylem Spektron 30E UV reactor, as proven below, provides 6 log inactivation of pathogens, photolysis of NDMA, and 0.5 log reduction of 1,4-dioxane through advanced oxidation. UV dose for pathogen inactivation is based on adenovirus, which is the most UV resistant waterborne pathogen identified to date. Adenoviruses comprise a large group of serologically different viruses that can cause a broad spectrum of diseases with varying severity (WRF, 2010). The validated UV dose for 6 log inactivation of adenovirus is 276 mJ/cm^2 (USEPA, 2020).

The UV dose for NDMA reduction varies with water quality and ranges from 600 to 1,100 mJ/cm^2 per log reduction. The required NDMA log reduction depends on the NDMA concentrations in

the RO permeate which to date have been at levels below 20 ng/L (n = 8, see Section 4.2.3). For a reservoir augmentation project which is regulated by the California Toxics Rule (CTR), the allowable NDMA concentration is 0.69 ng/L. With an RO permeate value of 20 ng/L, the minimum NDMA LRV is thus 1.5. The UV dose required for NDMA reduction is determined on-site by measuring NDMA UV dose-response, as is documented further on in this report.

The UV advanced oxidation process for this demonstration system uses sodium hypochlorite and not hydrogen peroxide as an oxidant. The oxidant absorbs UV light forming hydroxyl radicals which in turn react with and reduce 1,4-dioxoane and other chemical pollutants. The combination of UV and oxidant dose required to achieve 0.5 log reduction of 1,4-dioxane depends on the pH of the water and the presence of hydroxyl radical scavengers. Hydroxyl radical scavengers reactor with the hydroxyl radicals reducing the concentration available to react with target pollutants.

The efficiency of UV is impacted by:

- UVT – chemicals in the water absorb UV light. Lower UVT requires more UV energy to deliver same UV dose to water, which means more UV lamps. For RO permeate, UVT will be in the range of 95 percent or higher. As shown in the next section, the primary UV absorbers are chloramines and free chlorine.
- Scaling of Minerals – Minerals in the water, most importantly polyvalent cations, can deposit on the outside of the protective quartz sleeves of UV systems, reducing the amount of UV light penetrating into the water. More scaling results in less UV dose delivery. For RO permeate, the low pH and the lack of minerals in the RO permeate result in little to no scaling.
- Lamp Aging – When UV lamps age, their UV light output diminishes. Old lamps may deliver 80 percent to 90 percent of the intensity of new lamps. Real time monitoring of UVI is needed to properly monitor for and adjust power setpoints to maintain UV dose as the lamps age.
- pH – UV AOP with NaOCl is impacted by pH. When added to RO permeate, NAOCl forms two species, namely hypochlorous acid (HOCl) and hypochlorite (OCl-). Lower pH expected with RO permeate favors the formation of HOCl over OCl-, which leads to much more efficient UV AOP because the hydroxyl radical scavenging demand of HOCl is orders of magnitude lower than the demand of OCl-. Figure 2.48 shows the impact of pH of 1,4-dioxane log reduction with a typical RO permeate water quality.
- Hydroxyl Radical Scavengers – Hydroxyl radical scavengers in RO permeate include chloramines, nitrite, bromide, alkalinity, and TOC as well as the oxidant itself. The total scavenging demand is defined as:

$$Demand = \sum k_{OH,Ci} \times [C_i]$$

Where $[C_i]$ is the molar concentration of the i^{th} scavenger and $k_{OH,Ci}$ is the rate constant for the reaction of the scavenger with the hydroxyl radicals. For RO permeate with Ph 5.5, 96 percent UVT and a 2 mg/L chlorine dose, Table 2.11 lists the scavenger species, potential concentrations in RO permeate, hydroxyl radical rate constants, the

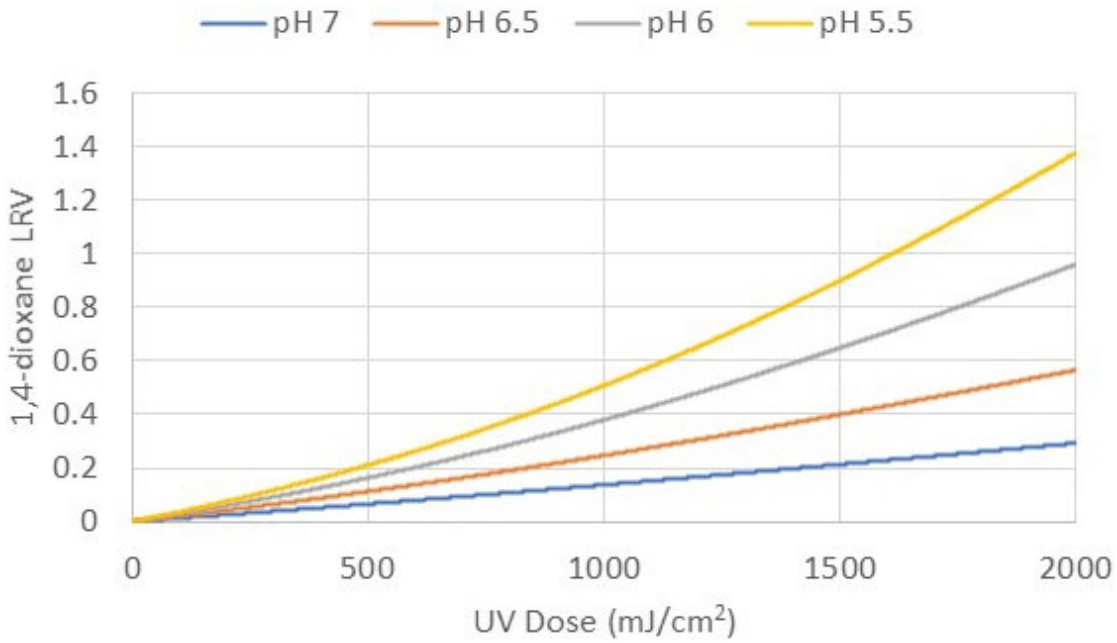
contribution of each scavenger to the demand, and the total demand. Several observations can be drawn from this table:

1. The most significant scavengers are chloramines followed by TOC.
2. Other significant scavengers are OCl^- and bicarbonate ion (HCO_3^-).
3. While nitrite and bromide concentrations with this example are low, these species have a significant scavenging demand because they have very high rate constants.

Table 2.11 Hydroxyl Radical Scavenger Comparison

Scavenger	Concentration (mg/L)	Rate Constant ($M^{-1}s^{-1}$)	Scavenging Demand (s^{-1})
Monochloramine(2)	1.93	5.2×108	14,176
Dichloramine(2)	1.17	2.6×108	4,304
HOCl(2)	1.996	8.46×104	2
OCl^-(2)	0.014	8.8×109	1,744
HCO_3^-(1)	9.9997	8.50×106	1,727
CO_3 (1)	0.0003	3.90×108	2
TOC	0.05	3.0×108	12,500
Nitrite	0.005	1.30×1010	4,643
Bromide	0.005	1.88×1010	1,178
Total			40,276

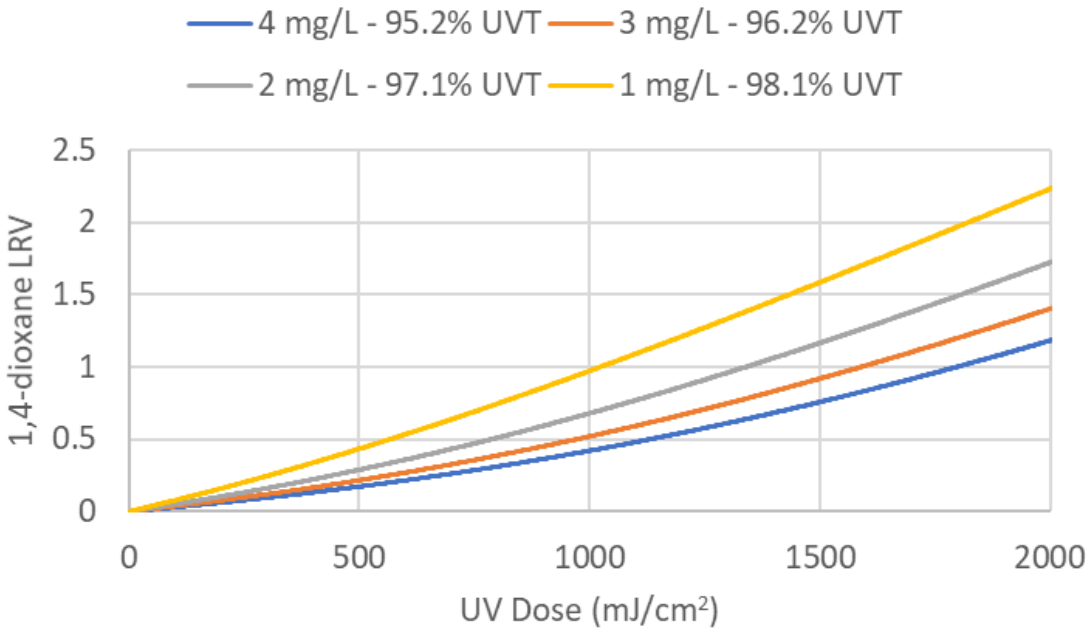
Note:
Abbreviation: CO_3 - carbonate ion.
(1) Concentration as $CaCO_3$.
(2) Concentration as Cl_2.



Note: Free chlorine dose is 2 mg/L. Water quality based on a Hypothetical RO permeate at 96 percent UVT.

Figure 2.48 Modeled Impact of pH on 1,4-Dioxane Reduction by UV/Chlorine AOP

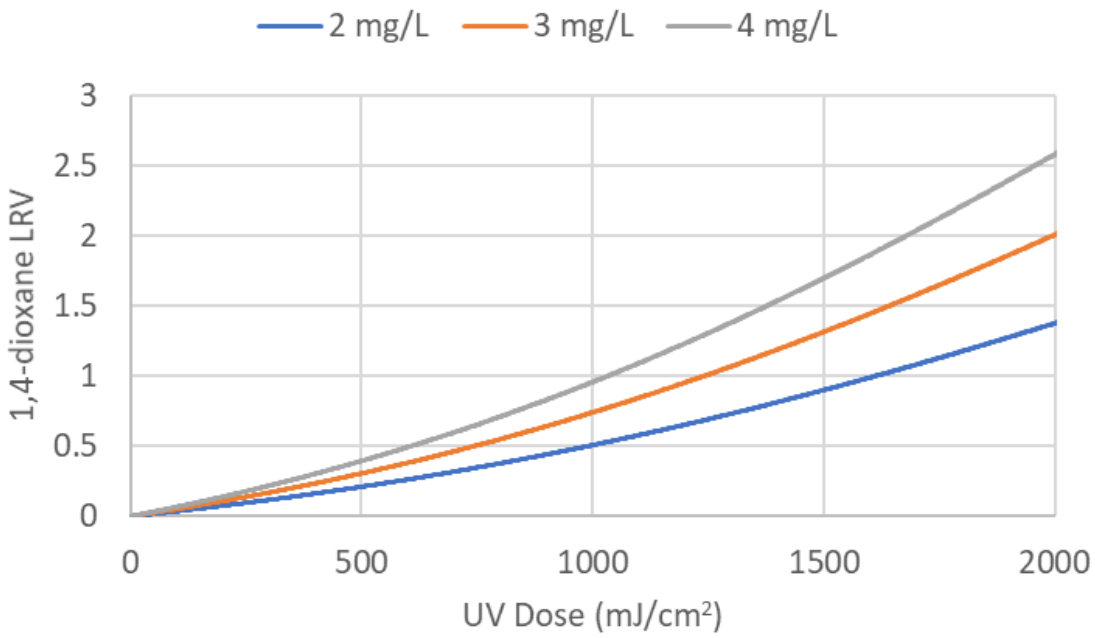
The chloramine levels in the RO permeate occur because chloramines are used to prevent upstream membrane fouling and chloramines pass through the RO membranes. Figure 2.49 shows the impact of chloramine levels on predicted 1,4-dioxane reduction. With Figure 2.49, nitrite and bromide are set to zero. The impact of radical scavengers in RO permeate is evaluated qualitatively as part of the UV AOP challenge testing, detailed further on in this Report.



Note: Free chlorine dose is 2 mg/L. Water quality based on a Hypothetical RO permeate.

Figure 2.49 Modeled Impact of Chloramine Concentration (See Legend) on 1,4-Dioxane Reduction by UV/Chlorine AOP

For a given UV dose and scavenging demand, the log reduction of 1,4-dioxane increases with increasing free chlorine dose, as shown on Figure 2.50. The maximum chlorine dose is set at approximately 4 mg/L to prevent corrosion within the UV reactor.



Note: Water quality based on a Hypothetical RO permeate at 96 percent UVT.

Figure 2.50 Impact of Free Chlorine Dose on 1,4-Dioxane Reduction by UV/Chlorine AOP

2.5.2 Chemical Dosing Performance

For UV AOP, the oxidant injected into the system is sodium hypochlorite. There is also measurable and consistent concentration of chloramines in the RO permeate (chloramines are used to minimize biofouling on the RO membranes).

Both free chlorine and chloramines are reduced by direct photolysis as well as reaction with hydroxyl radicals. Higher concentrations of chloramines and free chlorine do impact UV transmittance (UVT), and thus have a direct negative impact on UV reactor efficiency. The molar extinction coefficients for chlorine species are:

- Monochloramine (NH_2Cl) – 388.4 $M^{-1}cm^{-1}$.
- $NHCl_2$ – 140.14 $M^{-1}cm^{-1}$.
- ClO^- - 58.06 $M^{-1}cm^{-1}$.
- HOCl – 60.83 $M^{-1}cm^{-1}$.

The UV absorbance of the water can be calculated as:

$$UVA = \sum \frac{[C_i] \times \varepsilon_i}{M_i}$$

Where C_i is the concentration of the i^{th} chlorine compound, Mi is the molar mass of the i^{th} chlorine compound, and ε_i is the molar extinction coefficient of the i^{th} compound. The UVT is calculated using:

$$UVT = 100 \times 10^{-UVA}$$

For the majority of time spanning months of operation, the system ran at a constant chloramine dose through the membrane systems and a constant sodium hypochlorite dose across the UV reactor. To best understand the impact of dosing of these chemicals on UVT, we evaluated a

12-hour data set from February 5, 2021 where the UV dose was varied by adjusting the flow with the UV reactor running at a power setting of 50 percent and the free chlorine dose was adjusted by varying the injection rates. Figure 2.51 shows the UV dose reported by the UV reactor. Figures 2.52, 2.53 and 2.54, respectively, show the measured free chlorine, total chlorine, and UVT at the UV reactor influent and effluent. Several conclusions can be drawn from this data:

- At UV dose (as reported by the UV reactor) values of 1,500 mJ/cm^2 and 2,000 mJ/cm^2 free chlorine was reduced by approximately 2 mg/L and approximately 2.8 mg/L, respectively.
- At UV dose (as reported by the UV reactor) values of 1,500 mJ/cm^2 and 2,000 mJ/cm^2 total chlorine was reduced by approximately 3.4 mg/L and approximately 4.4 mg/L, respectively.
- The destruction of both free and total chlorine across UV results in substantially increased UVT, raising the important point on UV dose for this type of UV AOP reactor; the increase in UVT across the reactor also coincides with an increase in UV dose as water moves across the reactor.
- More detailed evaluation of chemical removal performance by the UV AOP is presented in Chapter 4.

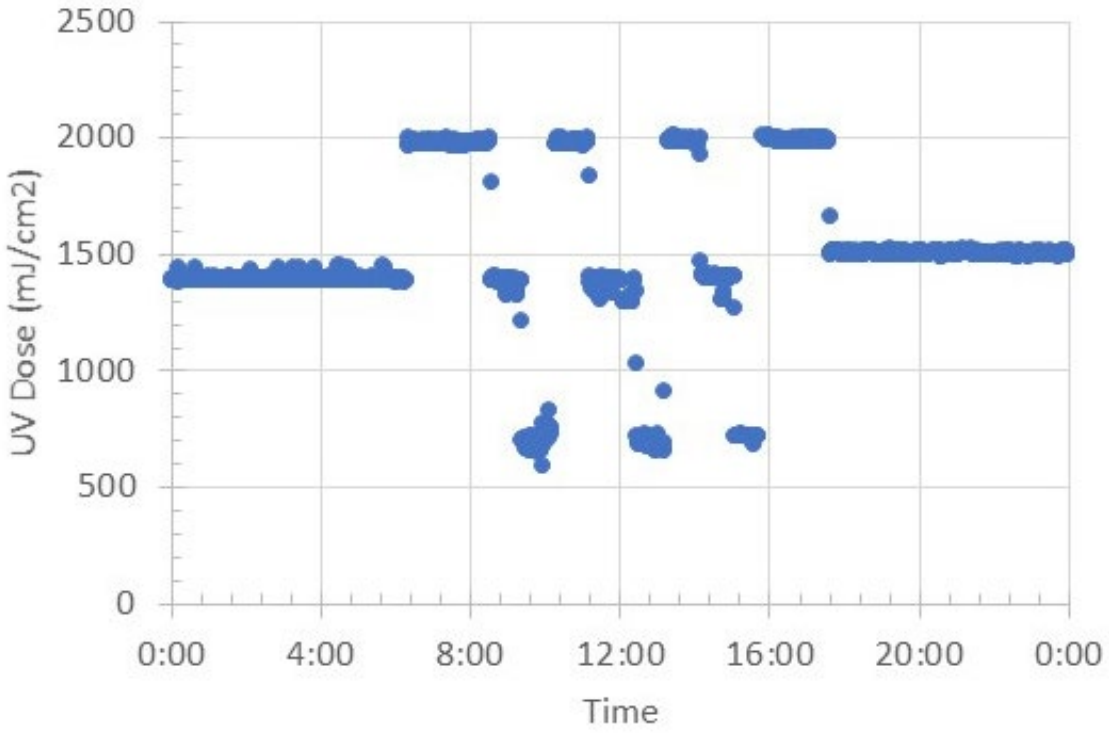


Figure 2.51 UV Dose Variation in 12-Hour Span on February 5, 2021

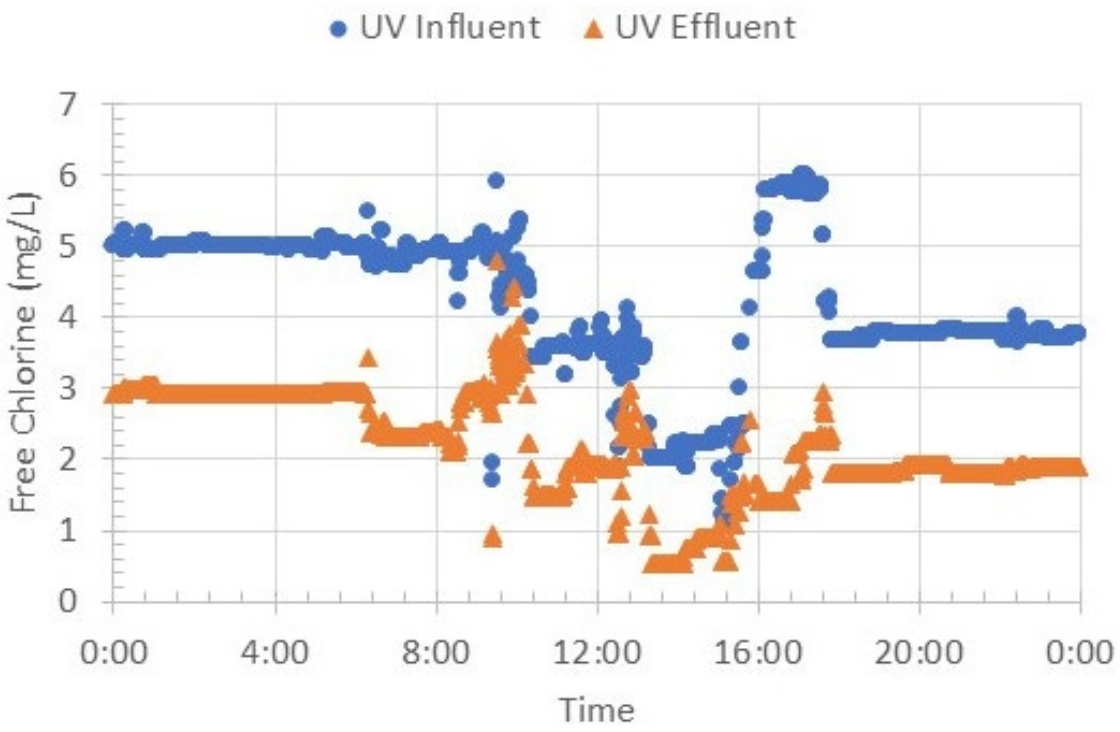


Figure 2.52 Reduction of Free Chlorine Across UV

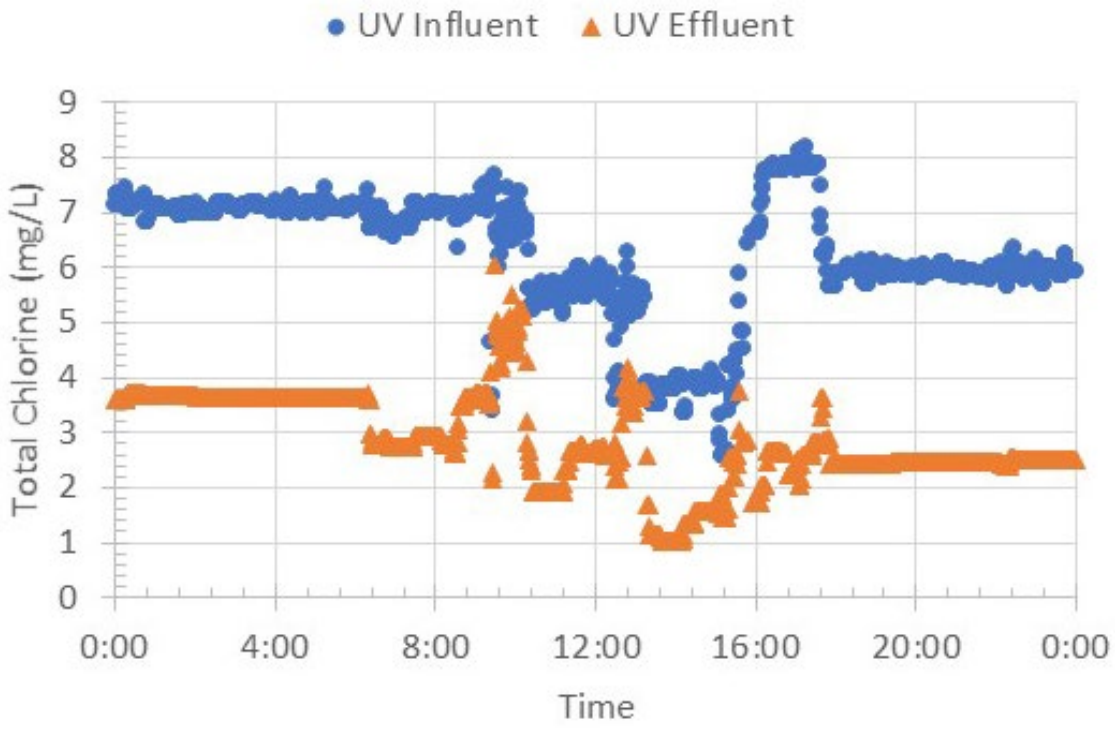


Figure 2.53 Reduction of Total Chlorine Across UV

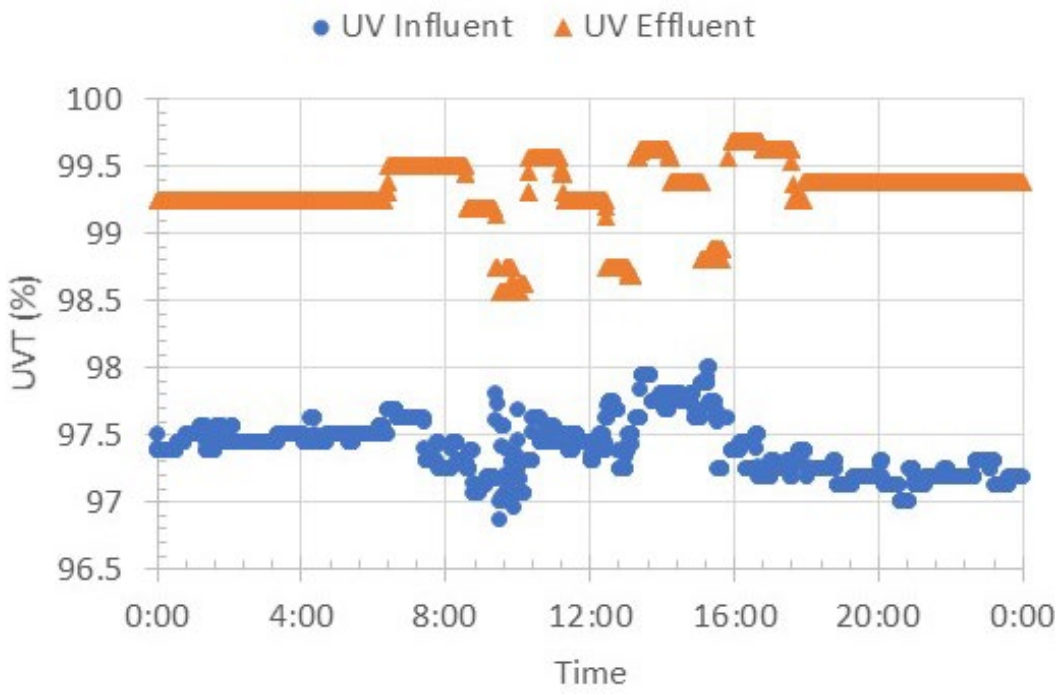


Figure 2.54 Increase in UVT Across UV

The relevant next question is "how to define the impact on UVT of different concentrations of chloramines and free chlorine at the influent to the UV reactor?" A simplistic data evaluation does show a loose correlation, but is unable to distinguish between the impacts of chlorine species (e.g., monochloramine versus free chlorine) as both species existed in the water simultaneously, as shown on Figure 2.55.

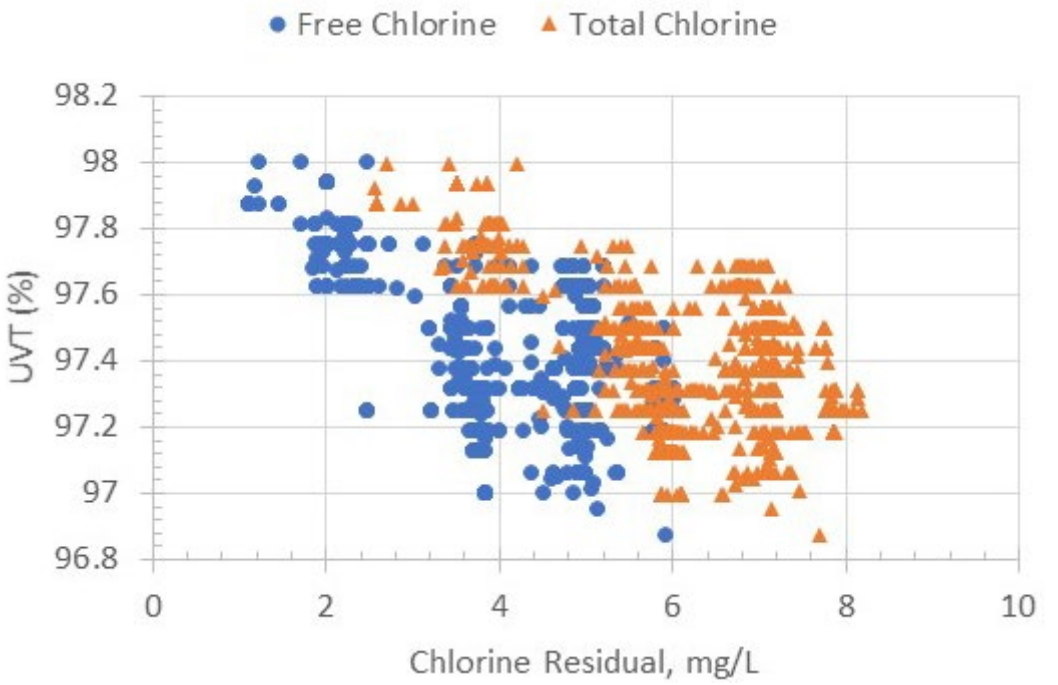


Figure 2.55 Impact of Chlorine Residual on UV Influent UVT

Looking back at the extinction coefficients, and keeping the analysis fairly simple, we can consider:

1. Because the pH is approximately 5.5, the predominant form of free chlorine is HOCl, with an extinction coefficient of 60.83 $M^{-1}cm^{-1}$.
2. Because the reaction time from the hypochlorite injection location to the UV reactor is seconds, and because breakpoint chlorination takes minutes (approximately 20 minutes), the assumption is that combined chlorine is NH_2Cl (monochloramine) with an extinction coefficient of 388.4 $M^{-1}cm^{-1}$.
3. Monochloramine exerts 6.4X more absorbance of UV than hypochlorous acid.

Noting that there are uncertainties in the accuracy of the online probes (UVT, free chlorine, total chlorine), we can estimate the relative impacts of free chlorine and chloramines on UVT using a combined chlorine residual weighted based upon the extinction coefficients as shown in the equation and Figure 2.56:

$$Extinction\ Weighted\ Chlorine\ Residual = HOCl\ X\ [60.83/(60.83 + 388.4)]\ +\ NH2Cl\ X\ [388.4/(60.83 + 388.4)]$$

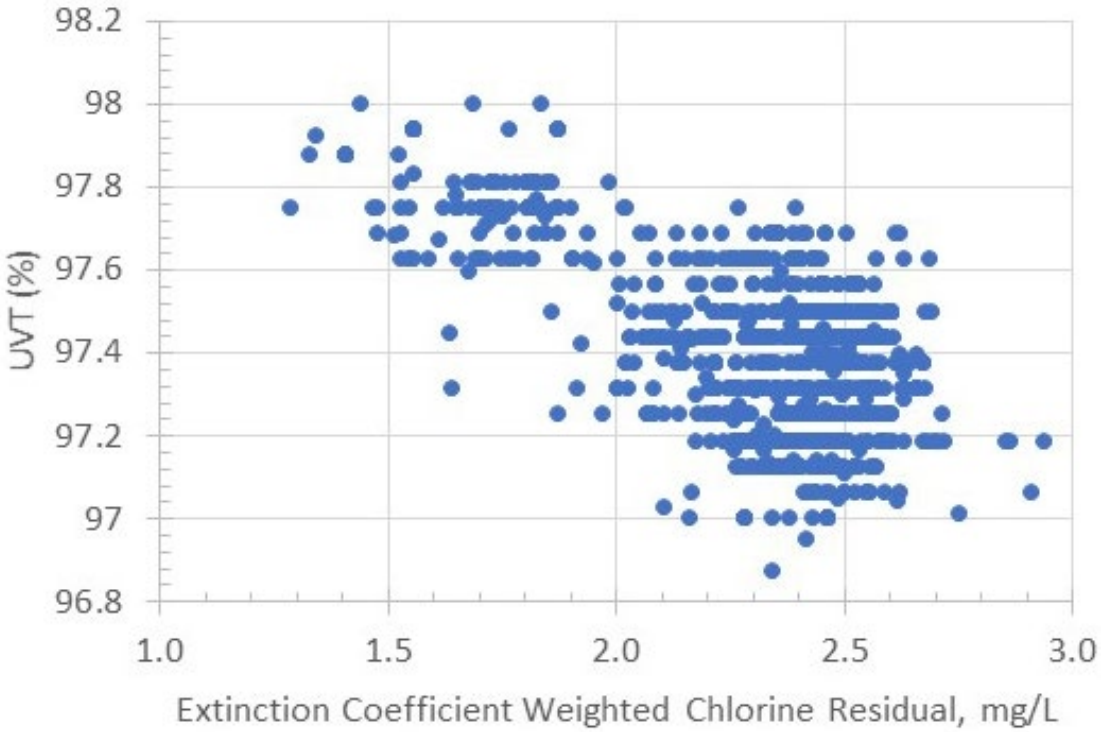


Figure 2.56 Extinction Weighted Chlorine Residual in UV Influent Impact on Influent UVT

Understanding this weighted impact allows for the project team to consider how to minimize over-chlorination's impact on UVT, either via chloramines ahead of the membranes or free chlorine ahead of the UV. Impact of chloramine optimization on power consumption is anticipated to be low (less than $50,000 for the full-scale facility – See Table 2.12). Figure 2.57 illustrates that the biggest impact could be had by minimizing chloramines in the RO permeate.

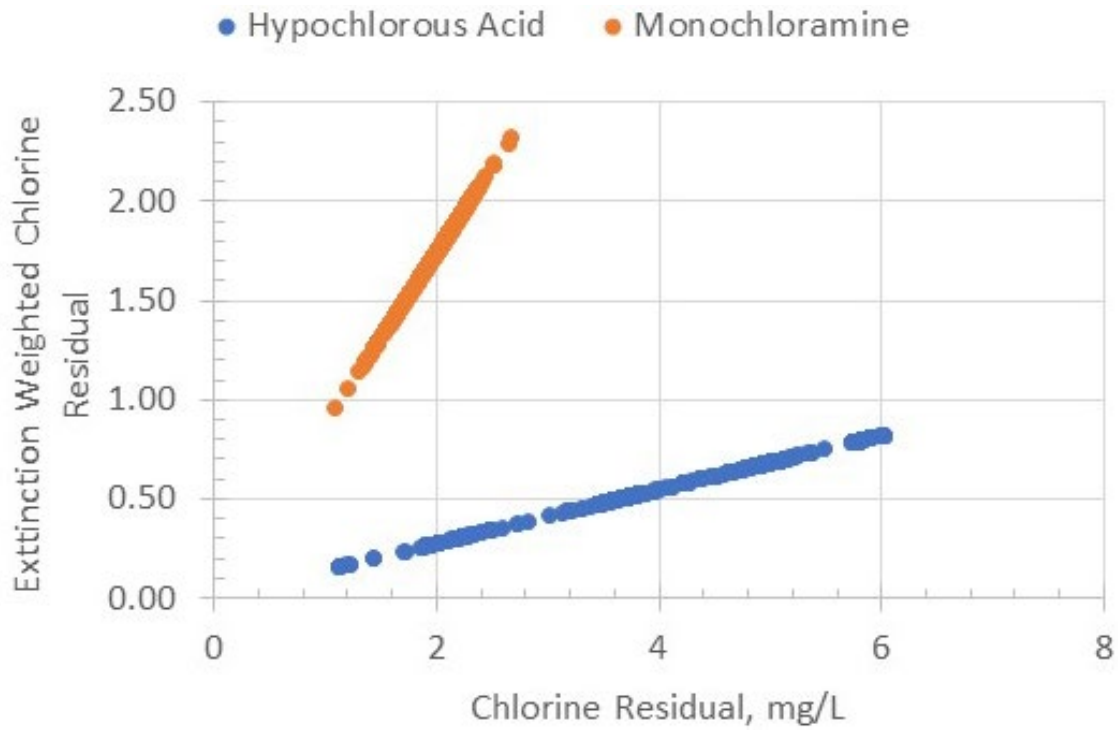


Figure 2.57 Extinction Weighted Chlorine Residual Comparison of Hypochlorous Acid and Monochloramine

2.5.3 Cleaning and Maintenance

No cleaning of the UV reactor has been needed to date.

Flushing of NaOCl dosing line was needed due to scaling. The scaling impact first manifested in broad swings in NaOCl concentrations at the UV system. Initial thoughts focused upon chlorine residual meter errors, but parallel variations in UVT suggested that indeed chlorine levels were varying substantially, indicative of a partially plugged chemical feed line. Purging of the feed line with RO permeate was able to return operation back to normal.

The similar plugging of the NaOCl line was frequently observed on the UF feed injection. Although the UV feed has only plugged once in the year, it is recommended that quarterly flushing of the UV feed NaOCl line be conducted to ensure stable operation.

2.5.4 Reliability

The UV system saw no shutdowns and maintenance over the test period based upon any UV equipment failure, including no lamp or ballast failures. The only issue with the UV system was the UVI sensor falling out of calibration, which happened only one time and was replaced with a new calibrated UVI sensor. Sensors are expected to remain accurate, +/- 10 percent, over a period of 1 to 2 years, which is the case for this data set with the one exception. For the failed sensor, no. 19-19-08, it failed prematurely after several months of operation (failure detected in August of 2020). The original reference sensor, no. 19-19-06, became the duty sensor in August of 2020. A new sensor, no. 19-39-14 became the reference sensor. Figure 2.58 illustrates the ratio of the duty sensor to the reference sensor, including the time in August where the duty sensor was replaced.

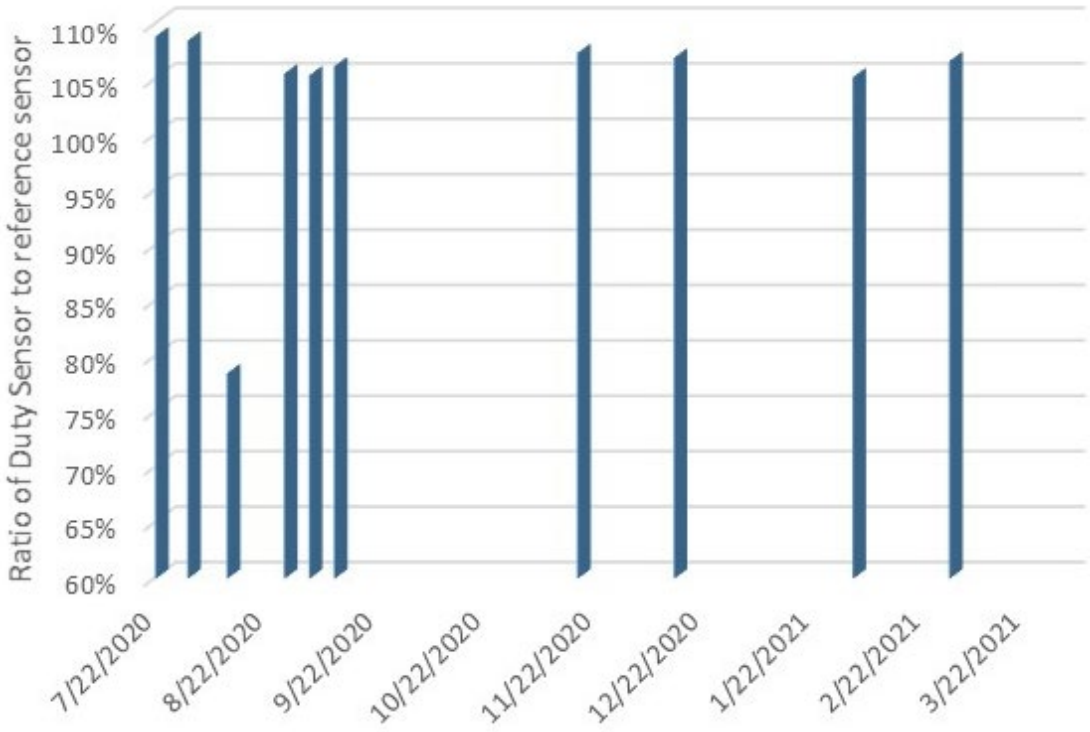


Figure 2.58 Ratio of Duty Sensor to Reference Sensor

For the singular case, the low of UVI was 22 percent below the reference sensor. The result of this reduction would have been, at the full scale, the system turning up the power to account for the lower sensor reading. Such an action would not lead to a shutdown or loss of production.

2.5.5 UV AOP Engineering Economics

The cost of infrastructure and energy use for a UV AOP system is based upon:

- Flow.
- Feed UVT:
  - Feed UVT, in an RO permeate, is impacted by chlorine and chloramine concentrations.
  - UVT is increased across the UV reactor due to destruction of UV absorbers.
- Feed NDMA concentration and regulated finished water NDMA concentration:
  - The feed concentration of NDMA can be impacted by NDMA in the feed water to the Demo or even increased due to chloramination at the Demo. Based upon data presented further in this report, NDMA levels in RO permeate are anticipated to be in the 10 to 20 ng/L range.
  - The effluent NDMA concentration is set to 0.69 ng/L by the California Toxics Rule and related future discharge to Las Virgenes Reservoir.

While the destruction of 1,4-dioxane, at 0.5 log, is a requirement, it does not set the minimum operating UV dose. Similarly, while 6 LRV of virus is also an important goal, it also does not set the minimum UV dose. The minimum UV dose for this project is set by the feed NDMA concentration and the regulated effluent NDMA concentration, requiring between 1 and 1.5 LRV of NDMA to meet the 0.69 ng/L CTR requirement (noting that the DDW requirement is 10 ng/L).

There is room for optimization of the UV AOP process, which is a balance of oxidant and UV dose (more of one allows for less of another). However, because the NDMA destruction is set by feed concentrations and the very low effluent requirement, the oxidant dose for UV AOP is simply minimized and paired with the minimum UV dose for NDMA destruction.

The cost of the UV system is presented in Table 2.12, shown below in terms of UV equipment cost and UV energy use for different UVT values. For this example, the assumed NDMA feed concentration is 20 ng/L and a UV effluent target of 0.69 ng/L (1.5-log LRV) and the dose per log reduction (D_L) for NDMA is 1,000 mJ/cm^2/LRV.

Table 2.12 UVT Impact on UV Costs

Design UVT	No. Reactors (Duty/Redundant)(1,2)	Equipment Costs(3)	Power(4)
95%	1/1	$1.44M	87 kW
97%	1/1	$1.14M	67 kW
99%	1/1	$0.84M	48 kW

Notes:
(1) UV reactor used for this example is the WEDECO K143 Reactor.
(2) UV dose for this example is 1,500 mJ/cm^2.
(3) Based upon 6 mgd of production capacity. Includes one duty and one standby reactor. Does not include construction costs, piping, valving, etc.
(4) Based upon 6 mgd of average flow, duty reactor only.

Chapter 3

ONLINE MONITORING SENSOR PERFORMANCE

In this section, the key water quality monitoring instruments are described, and their reliability is evaluated. This section compares the available verification and calibration sampling for each instrument and also notes any potential monitoring improvements that could benefit a similarly operated full scale facility.

3.1 Monitoring Locations and Instruments

The demonstration facility includes a range of advanced water quality monitoring equipment including:

- pH and ORP.
- EC.
- Turbidity.
- Free and Total Chlorine.
- Ammonia.
- TOC.
- UVT.
- UVI.

The general monitoring locations are for each instrument are shown on Figure 3.1

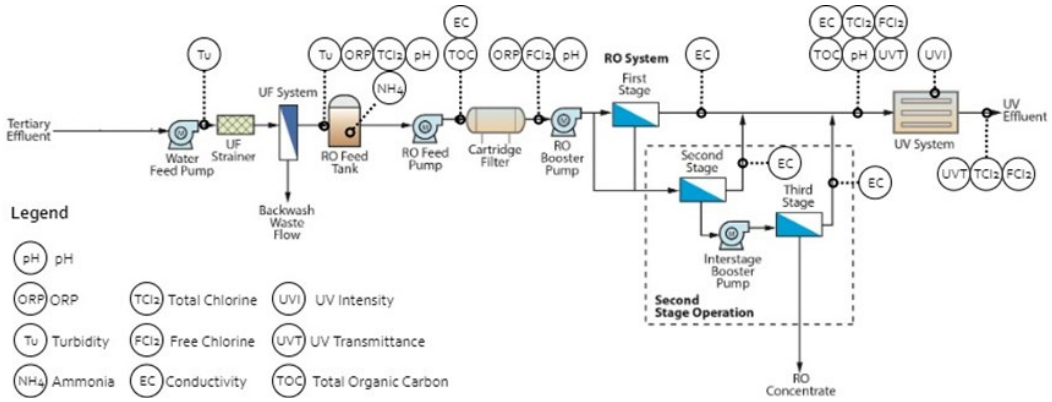


Figure 3.1 Monitoring Instruments and Locations Across the Demo

The following activities have been conducted as part of instrument maintenance:

- **Verification** - Compare the instrument readout with a grab sample measured on a bench top unit or standard solution to check accuracy. Typically, this is performed weekly by plant operations staff.
- **Cleaning** - Clean instrument elements to improve functionality.
- **Calibration** - Calibrate the online instrument to improve accuracy.
- **Instrument Specific Maintenance** - Replace or regenerate instrument components to improve function.

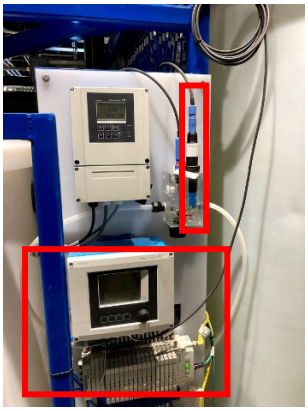
For each instrument, the verification, calibration, cleaning and maintenance activities and frequency are suggested based on original equipment manufacturer data and evaluated with respect to the observed differences between weekly verification and online results.

3.2 pH and ORP Probes

The pilot skid is equipped with three pH meters located on:

- The UF filtrate (AI-31090/AE-31093) pH and ORP.
- The RO feed (AI-40008/AE-40005) pH and ORP.
- The UV inlet (PH-001) pH only.

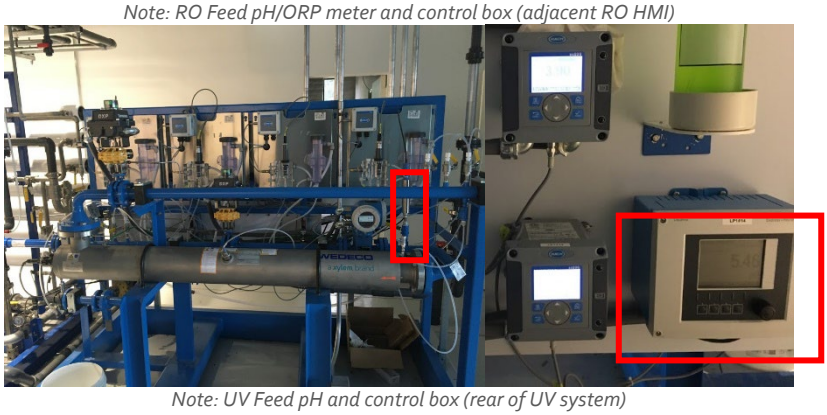
The pH/ORP meters and control boxes are shown as installed on Figure 3.2.



Note: UF Filtrate pH/ORP meter and control box (rear of UF system)



Note: RO Feed pH/ORP meter and control box (adjacent RO HMI)



Note: UV Feed pH and control box (rear of UV system)

Figure 3.2 Locations of pH and ORP Meters at the Demo

The pH meter models on the UF and RO skids are combined pH, ORP and temperature sensors. The pH meter on the UV AOP inlet is pH and temperature only. The model numbers for the pH meters and transmitters are shown in Table 3.1, as well as the OEM recommended cleaning, calibration, and maintenance frequency.

Table 3.1 pH and ORP Meter Locations, Model Numbers and Calibration and Cleaning Frequency

Plant Location	UF Filtrate	RO Feed	UV Inlet
Meter Model	Endress and Hauser CPS76D Series Digital pH and ORP Sensor (#CPS76D-7BB2G)		Endress and Hauser pH Sensor CPS11D
Indicator Tag (pH)	AI-31090	AI-40008	PH-001
Indicator Tag (ORP)	AI-31093	AI-40005	-
Verification	Compare readouts with a calibrated bench top pH probe. pH verification is included in the weekly checklist.		
Cleaning Frequency	Quarterly or required: before calibration, if sensor is visibly fouled, if sensor drifts from grab samples or if response is slow.		
Calibration Frequency	Calibration is required if strict accuracy is required, the grab verification results drift from the online results or the sensor has been in storage for longer than 3 months.		
Maintenance Frequency	No additional maintenance possible with installed sensors. If sensors are faulty or will not hold calibration, they need to be replaced.		

3.2.1 pH and ORP Calibration and Verification

The verification charts are shown for the pH and ORP probes on Figures 3.3 through 3.8. Results are shown as a combination of the relative time series grab samples as well as a relative standard deviation with the grab sample subtracted from the online reading. Calibration events are marked.

With each of the pH meters (UF filtrate, RO Feed and UV Inlet) the following trends were noted on Figures 3.3 through 3.8:

- pH readings were generally very good, with relative standard deviation less than 10 percent.
- Overtime, there was a tendency for pH readings to drift in the upward direction and for the relative standard deviation to increase. Calibration appeared to reset the drift. This was particularly noticeable for the UV inlet pH (see Figure 3.6).
  - The UV inlet pH meter is an important instrument. For efficient UV chlorine radical generation and subsequent advanced oxidation pH should be below 6.5 and ideally below 6.0. Without calibration, this sensor may trigger false positives that AOP effectiveness is not optimal.
  - Calibration of the RO feed pH meter may need to be more frequent at scale as it is likely this meter would be used to control acid dosage.
- The pH meters were calibrated 3 – 4 times over the year. Based on the results collected, maintaining the recommended frequency of 3 months for a calibration (or based on verification discrepancies) should ensure good accuracy (< 10 percent RSD) of the pH meters.
- For the UV inlet pH meter, it is recommended to calibrate the meter based on verifications or if observed pH rises above 5.8.

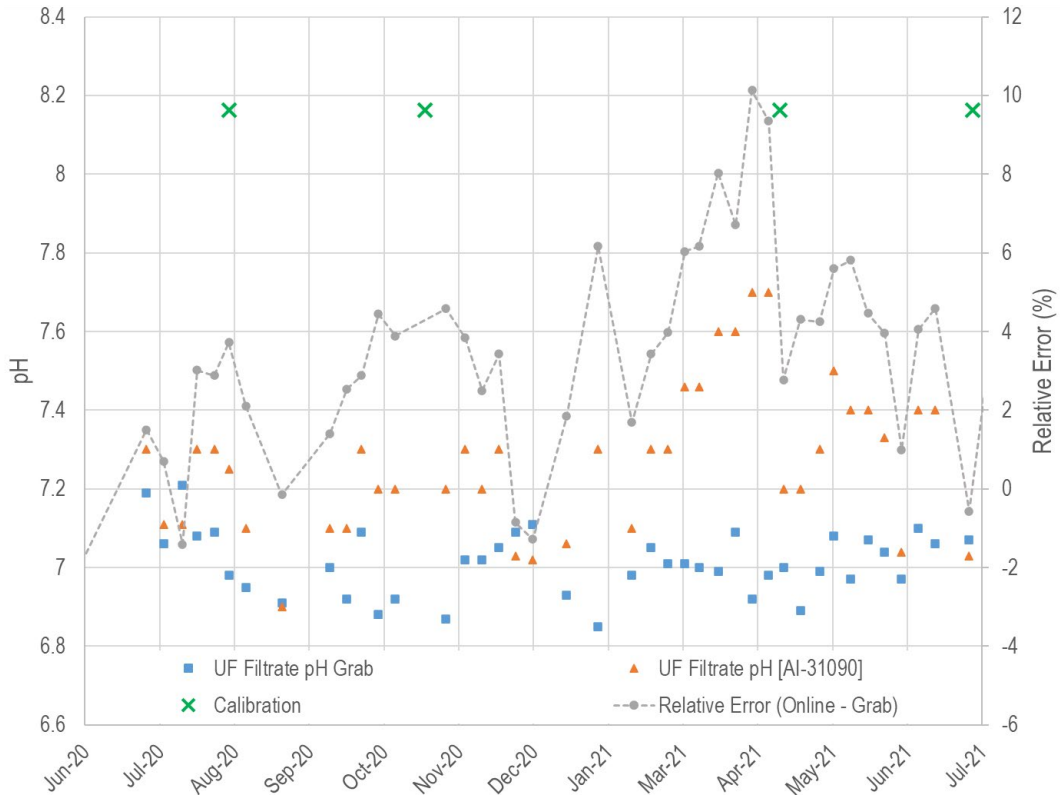


Figure 3.3 UF Filtrate pH Verification Results

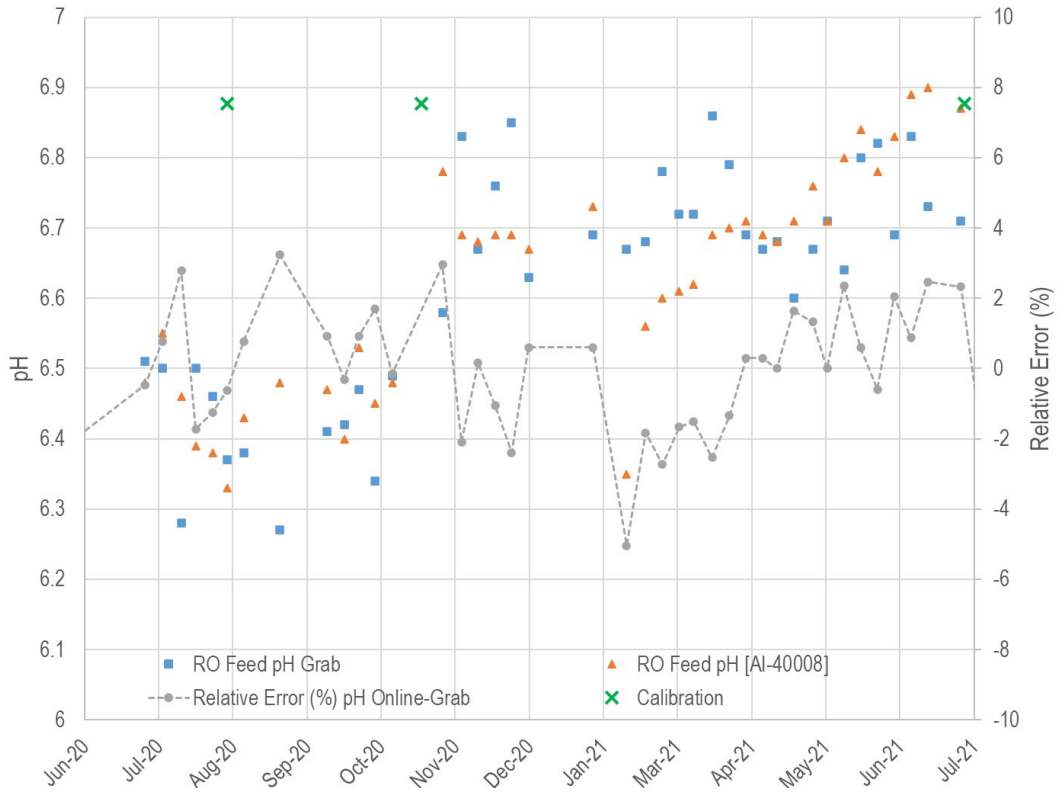


Figure 3.4 RO Feed pH Verification Results

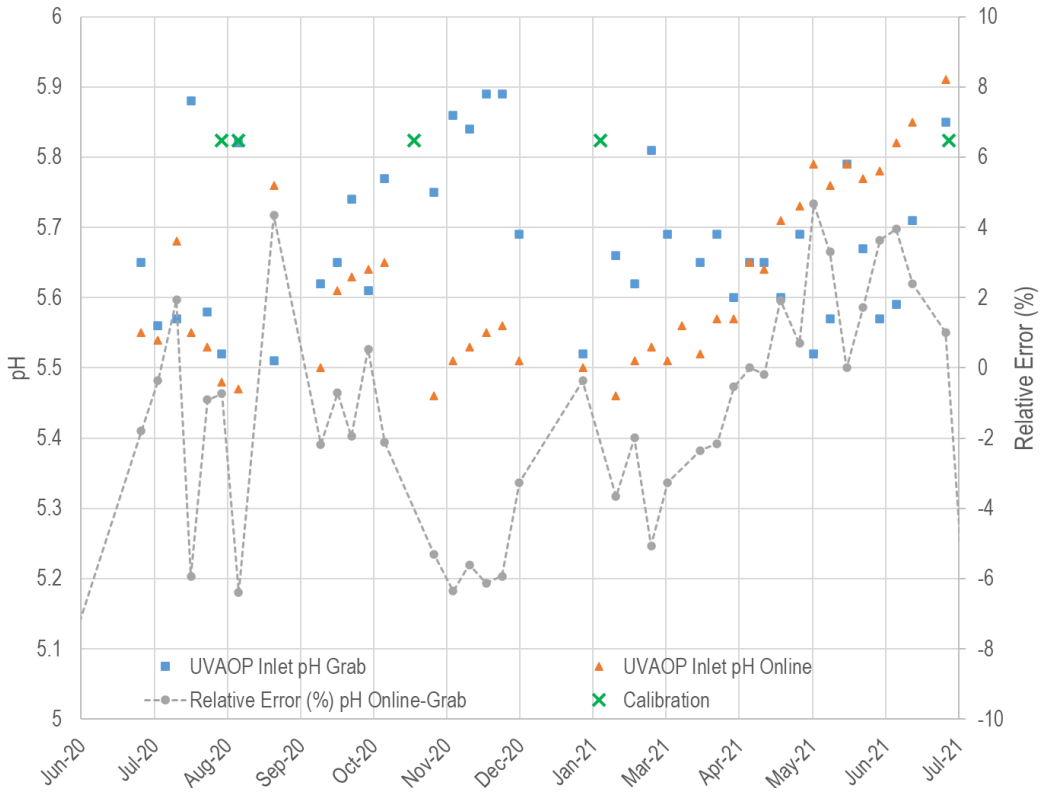
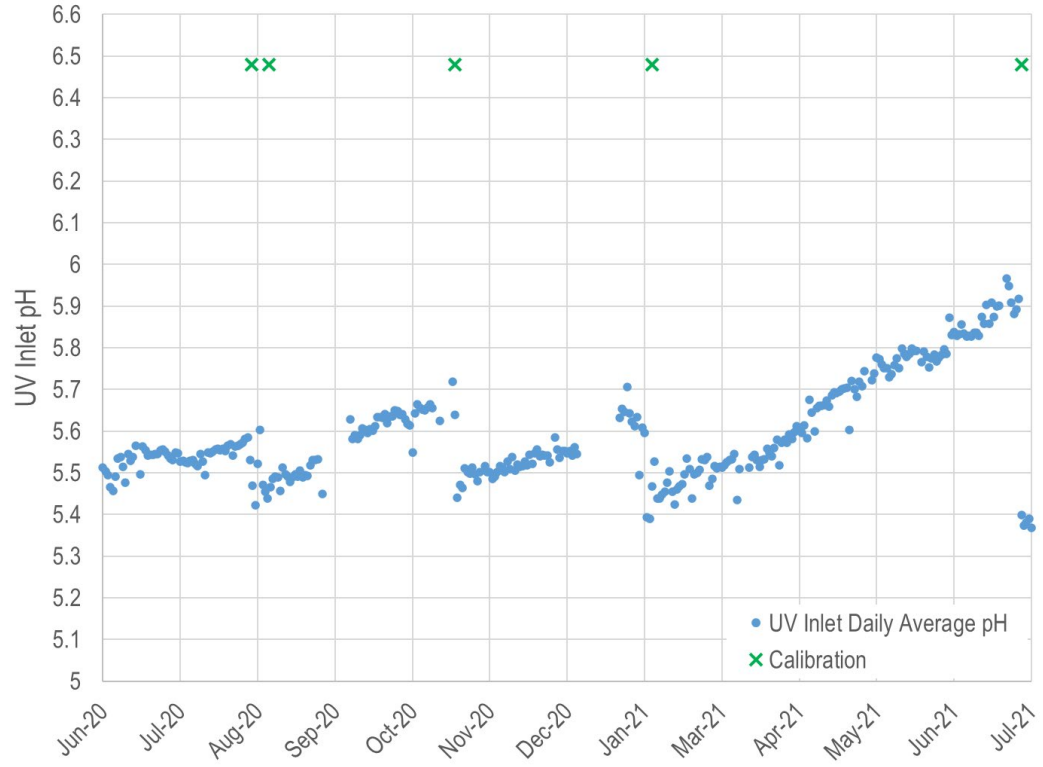


Figure 3.5 UV Inlet pH Verification Results



Note: For efficient UV chlorine radical oxidation pH should remain below 6.5.

Figure 3.6 UV Inlet pH Drift and Reset as a Result of Calibrations

The verification results for the UF filtrate and RO feed ORP meters are shown below.

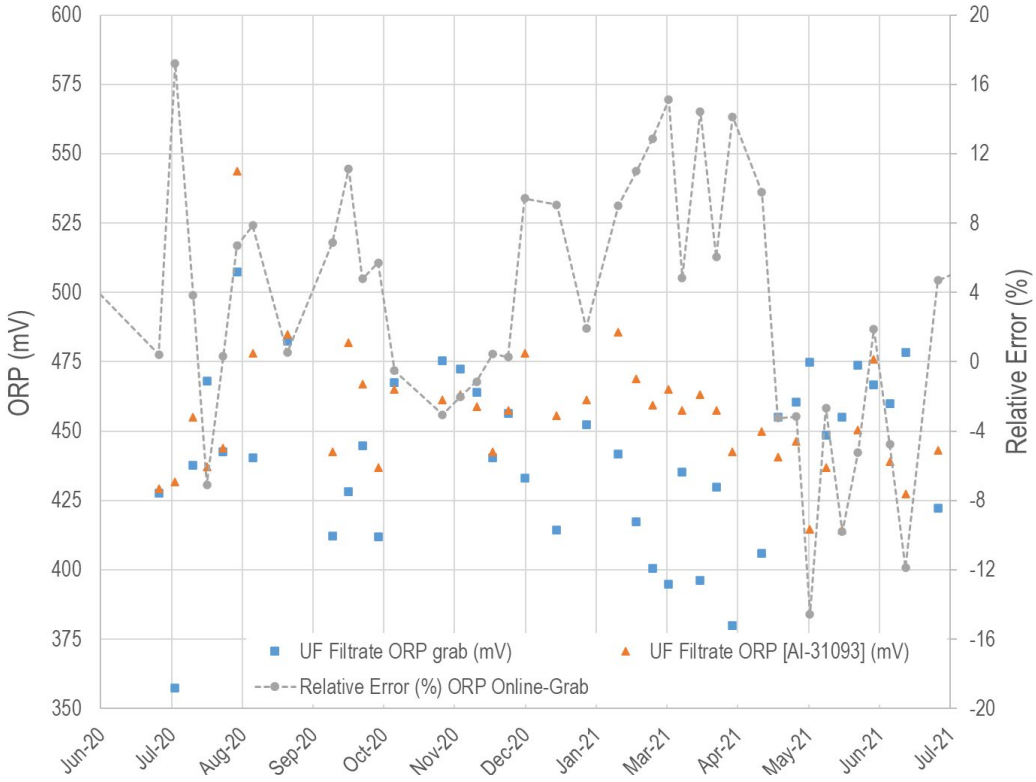


Figure 3.7 UF Filtrate ORP Verification Results

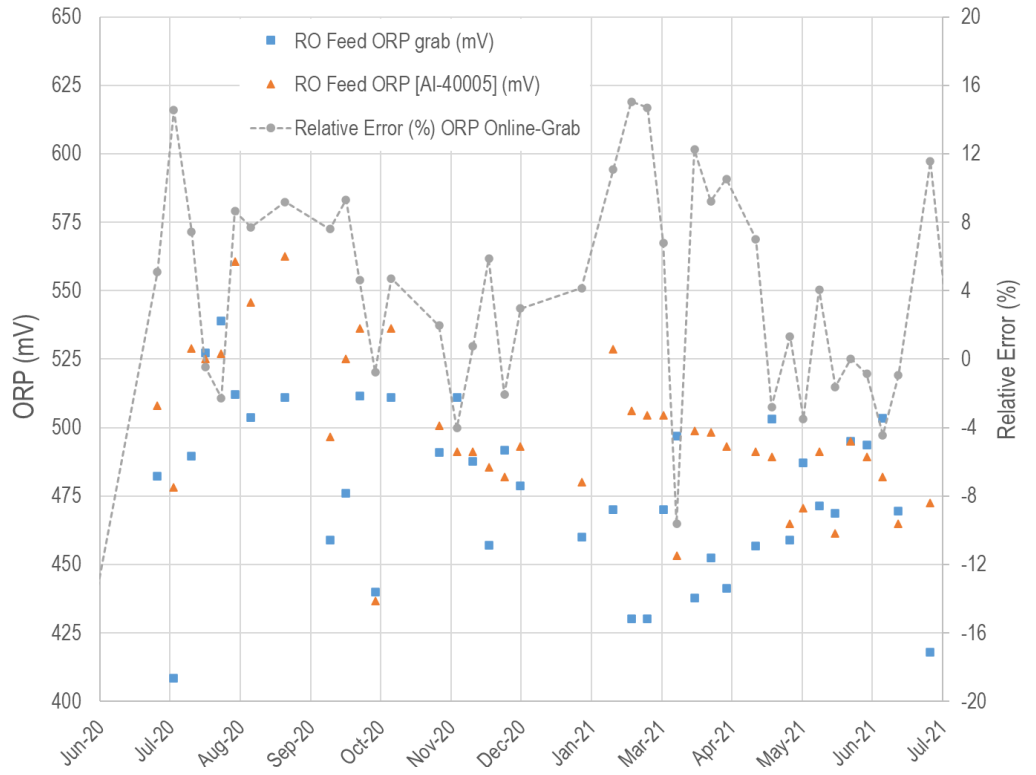


Figure 3.8 RO Feed ORP Verification Results

The ORP meters were not able to be calibrated as the human machine interface for the probe would not allow access to calibrate the ORP function, only the pH function. On two occasions (September 2, 2020 and November 18, 2020), the response of the probe was checked with the zobell's standard solution used to calibrate the grab sample meter and each probe showed satisfactory ORP response. However, the exposure to zobell's standard solution appeared to interfere with the pH readings and the pH required recalibration and time to stabilize.

In general, the ORP meters showed good accuracy, with all grab and verification samples within 50 millivolt (mV), the typical precision of ORP instruments. Relative error was typically less than 10 percent, but there were some occasions where relative error was between 12–16 percent.

The ORP meters are useful for verifying the absence of free chlorine ahead of the RO and appear to be more responsive than the RO free chlorine meter.

If the ORP meter verifications consistently indicate greater than 100 mV between grab and online readings, then the meters should be replaced. Over the first year of operation, the ORP meters have functioned well.

3.3 Turbidity Meters

The Demo is equipped with four turbidity meters located on:

- The combined UF feed, prior to raw water tank (AE-40006).
- The UF filtrate from each module: Module 1 (AE-41092), Module 2 (AE-41292) and Module 3 (AE-41392).

The turbidity meters and control boxes are shown as installed on Figure 3.9.

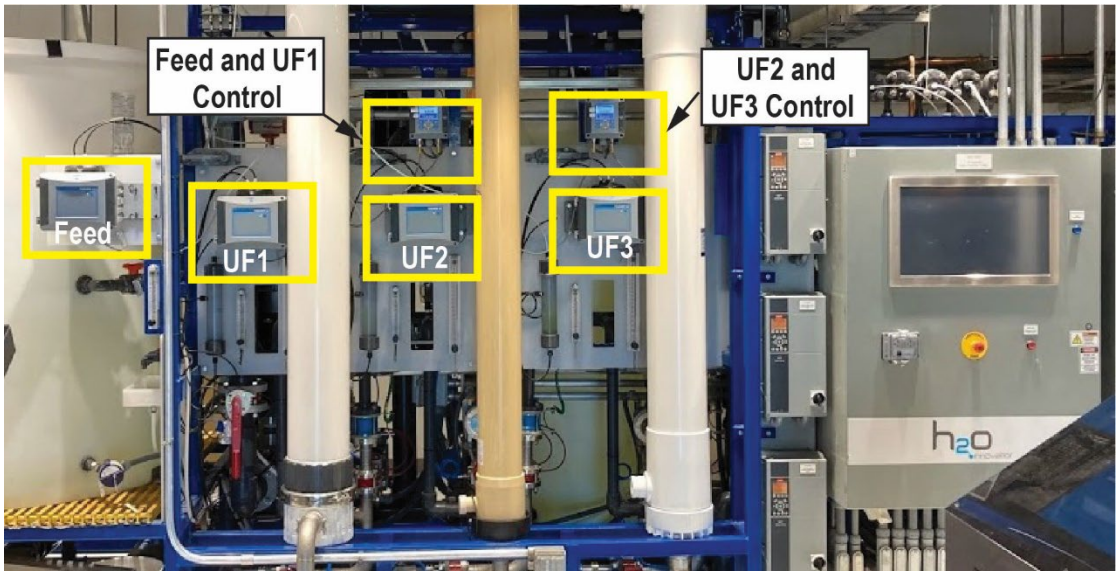


Figure 3.9 Online Turbidity Monitoring on the UF Skid

The turbidity meter model numbers are shown in Table 3.2, as well as the recommended cleaning, calibration and maintenance frequency.

Table 3.2 Turbidity Meter Locations, Model Numbers and Calibration and Cleaning Frequency

Plant Location	UF Feed	Module 1 Filtrate	Module 2 Filtrate	Module 3 Filtrate
Meter Tag	AE-10209	AE-31009-1	AE-31009-2	AE-31009-3
Meter Model	HACH TU5300SC	HACH TU5400SC		
Range	0.01 - 40 NTU	0.0006 - 5 NTU		
Flow rate	Target flow rate 200 - 500 mL/min (3 - 8 gph) - Adjust with flow regulator to unit. Operation at low flow will reduce sensor responsiveness. Operation at high flow may introduce bubble interferences.			
Verification Frequency	Comparison of a grab sample with an online reading is included in the weekly activity checklist. Verification of laser functionality can also be performed with specialized glass rods			
Cleaning Frequency	As needed based on sensor warnings. 1 - 3 months for vial cleaning with acid (CLR).			
Calibration Frequency	Calibration is required after repairs or comprehensive maintenance. The instrument has an inbuilt recommended calibration frequency.			
Maintenance Frequency	Replacement of the measurement vial and desiccant cartridge - 1-2 years or as required.			

Note:
(1) Abbreviation: gph - gallons per hour.

There have been no failures of the turbidity monitoring instruments, with the exception of the first 3 months of operation, when they were incorrectly connected. There have been issues where low flow, particularly in the UF feed turbidity meter can cause accumulation of material. This has been resolved by fast flushing of the units.

Grab sample turbidities of the UF feed were shown to read typically 22 percent higher than the online meter (See Figure 3.11), this led to generally a wide relative deviation between the online and grab sample meters (Figure 3.10). It is suspected that the difference is largely due to:

- The grab and online meter using a slightly different measurement principle. The grab sample uses a conventional light source, whereas the feedwater turbidity meter uses a laser.
- The feedwater turbidity was generally low, which made small absolute deviations i.e., +/- 0.1-0.2 NTU, result in large apparent relative standard deviations of up to 60 percent.

The UF filtrate turbidity meters had a similar issue with the online meters having sufficient resolution to measure down to millionths of an NTU, but the grab meter only able to measure down to 0.06 NTU. As a result, all online UF filtrate turbidity results were lower than the grab verification.

The grab sample meter was of sufficient resolution to identify instances where the online filtrate turbidity meter measurement cells had likely fouled. When cell fouling occurred, the field meter reading exceeded the grab verification. This occurred in May 2021, around the time of the performance issues at Tapia WRF.

The performance of the turbidity meters appears to be adequate. However, the following approaches to assuring reliable operation could be considered:

- To achieve improved verifications with the turbidity meters, it may be necessary to purchase a more sensitive, laser-based unit to perform grab sample analysis:
  - Given the generally good performance of the UF at producing very low turbidity filtrate, this should be a low priority.
- The turbidity meters have been cleaned frequently in 2021. This is good practice and helps reduce false positive increases in turbidity due to biofilm establishment. In lieu of purchasing a higher sensitive grab sample meter, it is recommended that:
  - A calibration frequency of 3 months or according to sensor warnings is followed and
  - The current monthly or as required cleaning frequency is conducted.
- If the current filtrate turbidity or feedwater turbidity readings exceed the grab sample meter, this may be indicative of measurement cell fouling and should trigger a clean of the online unit.

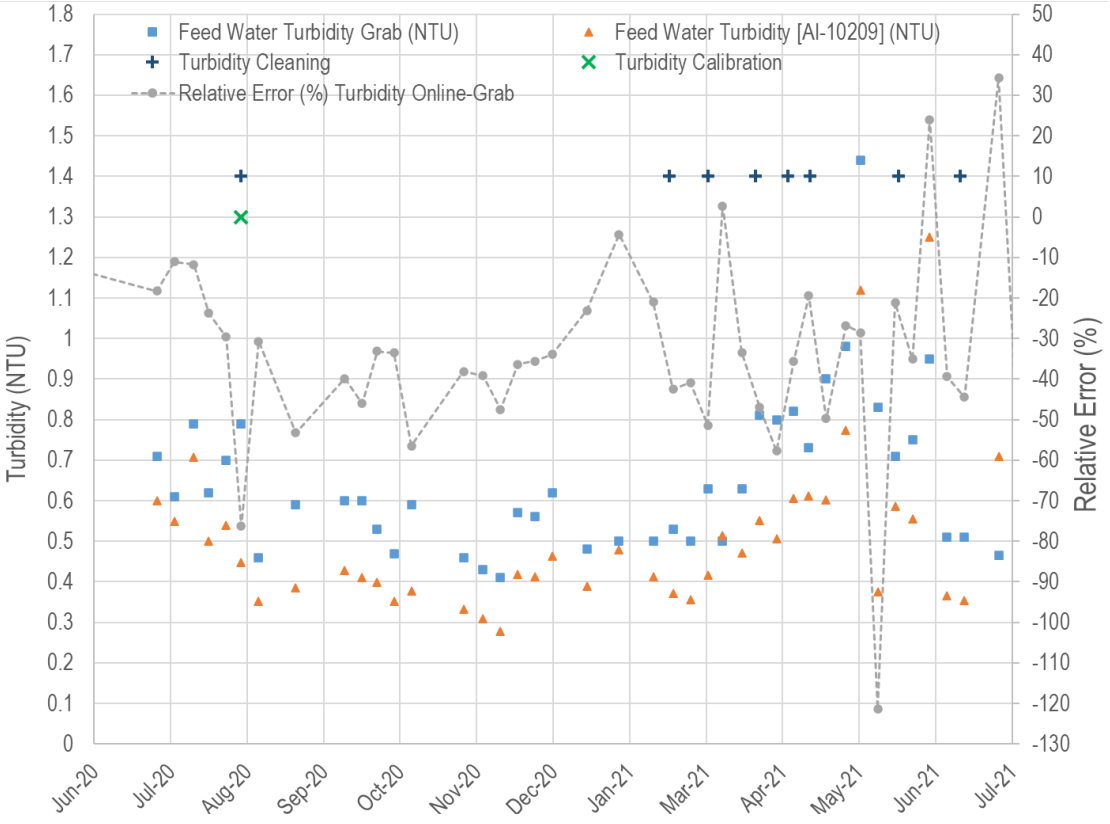
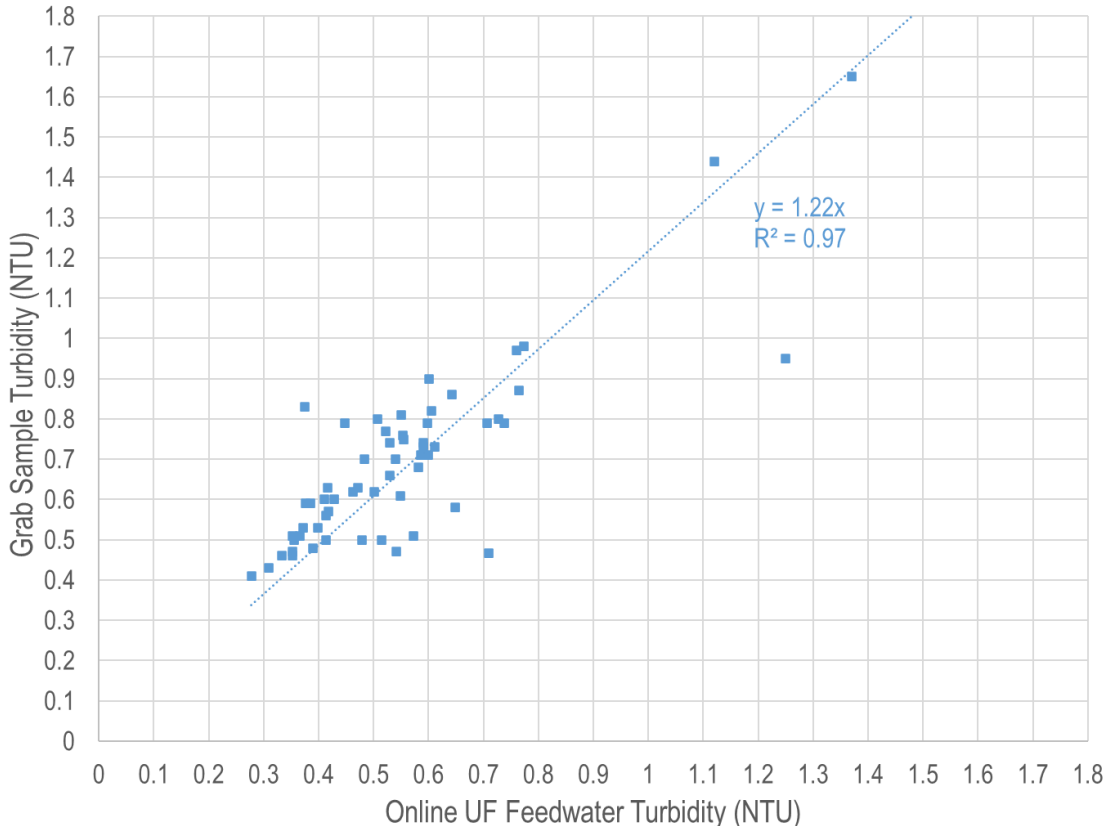
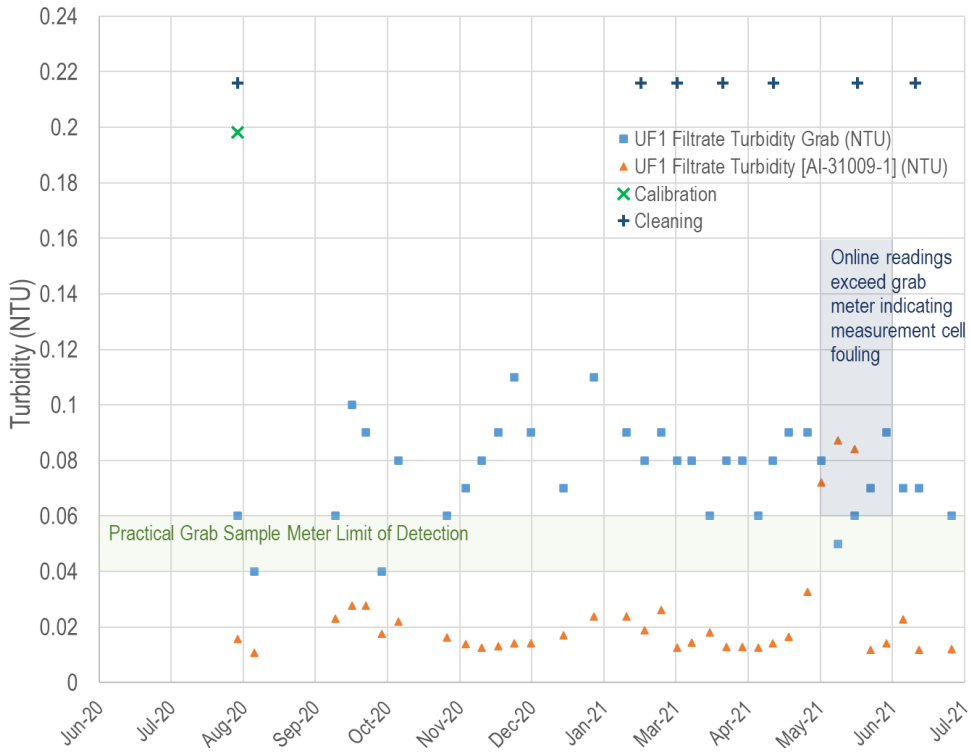


Figure 3.10 UF Feed Turbidity Verification Results



Note: The correlation indicates that the grab sample typically reads 22 percent higher than the online.

Figure 3.11 Correlation Between UF Feed Water Grab Sample Verifications and Online Readings



Note: It was not possible to successfully verify the online meter as the practical limit of detection of the grab sample unit was higher than the online unit. If the online meter exceeded the grab unit, this was indicative of online measurement cell fouling.

Figure 3.12 UF1 Filtrate Turbidity Verifications

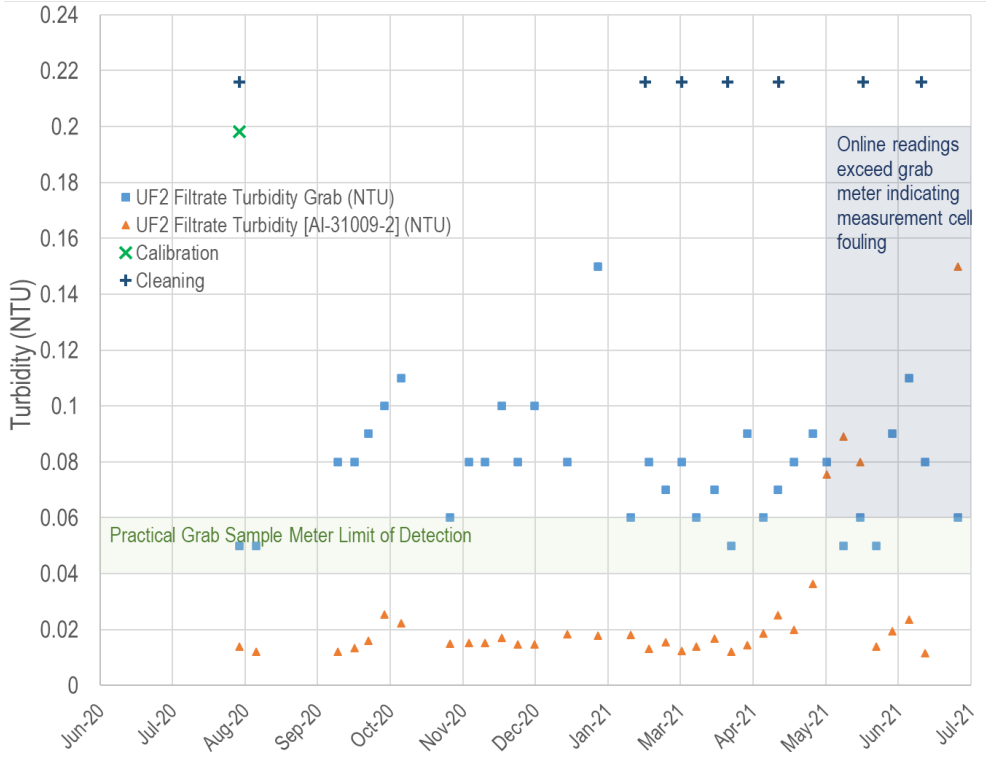


Figure 3.13 UF2 Filtrate Turbidity Verifications

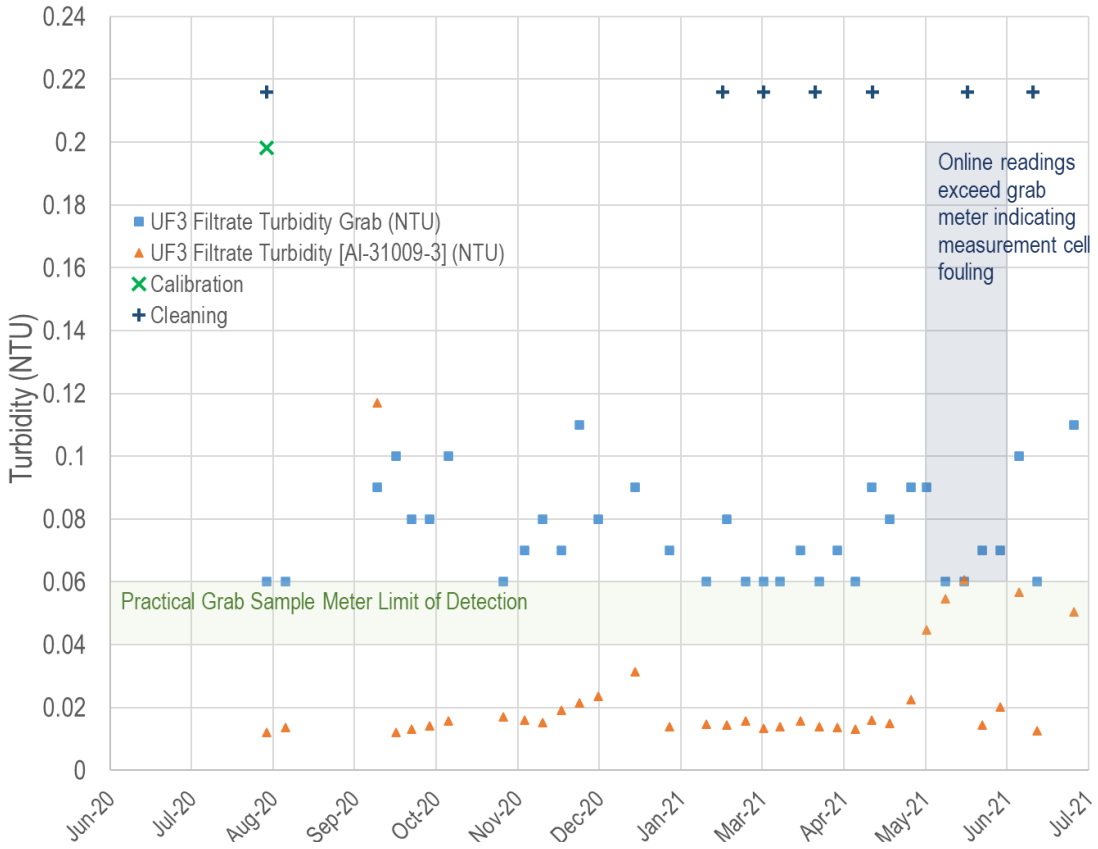


Figure 3.14 UF3 Filtrate Turbidity Verifications

3.4 Chlorine Probes

The calibration and maintenance requirements for free and total chlorine meters are identical in most cases and they are described together in this section along with available verification data from the first year of operation.

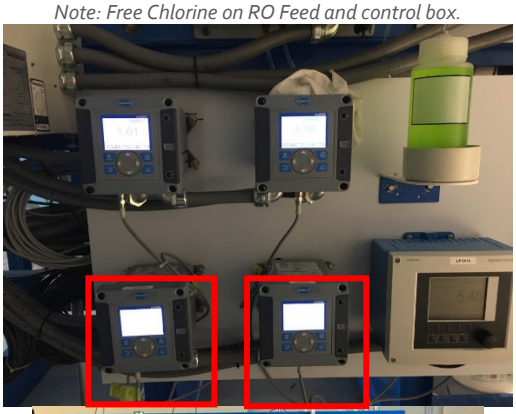
The pilot skid is equipped with three free chlorine amperometric probes located on:

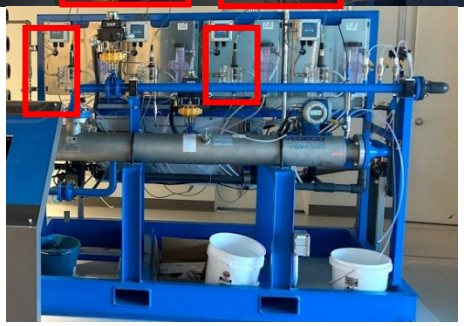
- The combined RO feed, after the cartridge filter (AE-40004).
- The UV AOP inlet (FCl-001) and outlet (FCl-002).

The free chlorine meters and control boxes are shown as installed on Figure 3.15.



Note: Free Chlorine on RO Feed and control box.





Note: Free Chlorine on UV AOP inlet and outlet and control boxes (on rear of skid).

Figure 3.15 Free Chlorine Meter Locations at the Demo

The free chlorine meter model numbers are shown in Table 3.3, as well as the recommended cleaning, calibration and maintenance frequency.

Table 3.3 Free Chlorine Meter Locations, Model Numbers and Calibration and Cleaning Frequency

Plant Location	RO Feed	UV AOP Inlet	UV AOP Outlet
Meter Tag	AE-40004	FCl-001	FCl-002
Meter Model	E&H Chloromax CCS142S (#CCS142D-GDS80)	HACH CLF10 sc	

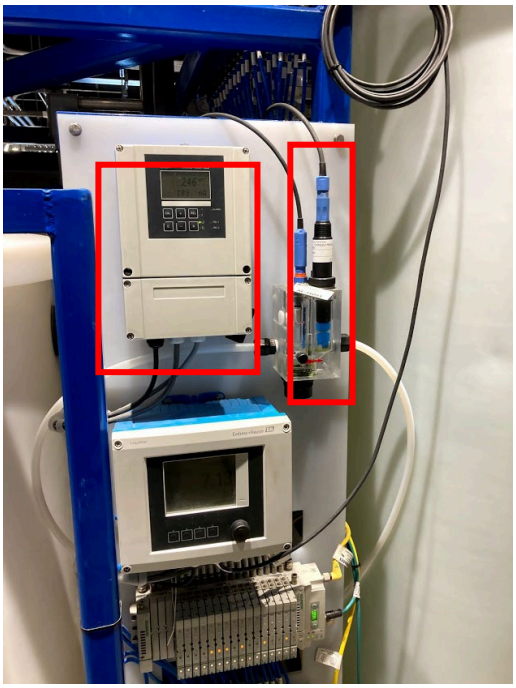
Plant Location	RO Feed	UV AOP Inlet	UV AOP Outlet
Range	0.01 - 5 mg/L	0.1 - 20 mg/L	
Flow(1)	>8 gph	8 - 13 gph, optimal = 10.5 gph	
Verification Frequency	Included on weekly operations verification checklist.		
Cleaning Frequency	Quarterly, or, if verification is poor, if the sensor is visibly soiled or response time is low.	If the flow cell becomes discolored or deposits are observed.	
Calibration Frequency	Slope calibration required every time electrolyte (12 months) or sensor membrane is changed.	Based on automated sensor warnings. The sensor needs to be recalibrated if removed from the water or disconnected from power for more than 15 minutes.	
Maintenance Frequency	Recondition sensor (3 months or if response low) Replace the membrane (if damaged) Replace the electrolyte (12 months)	Replace tubing (12 months) Replace the electrolyte (3 - 6 months) Replace the membrane cap (1 year) Replace the sensor (3 years) Polish the electrode (when sensor readings are unstable or slope is low)	

Notes:
(1) Refers to flow past the sensor in the flow through unit.
(2) Amperometric probes are used for chlorine measurement.

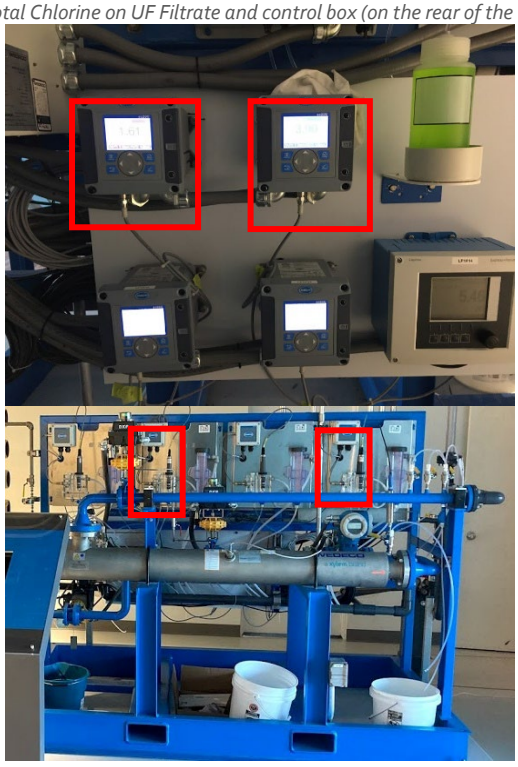
The pilot skid is equipped with three total chlorine amperometric probes located on:

- The combined UF Filtrate, after the filtrate tank (AE-31094).
- The UV AOP inlet (TCl-001) and outlet (TCl-002).

The total chlorine meters and control boxes are shown as installed on Figure 3.16.



Note: Total Chlorine on UF Filtrate and control box (on the rear of the UF skid).



Note: Total Chlorine on UV AOP inlet and outlet and control boxes (on rear of skid).

Figure 3.16 Total Chlorine Meter Locations at the Demo

The total chlorine meter model numbers are shown in Table 3.4, as well as the recommended cleaning, calibration and maintenance frequency.

Table 3.4 Total Chlorine Meter Locations, Model Numbers and Calibration and Cleaning Frequency

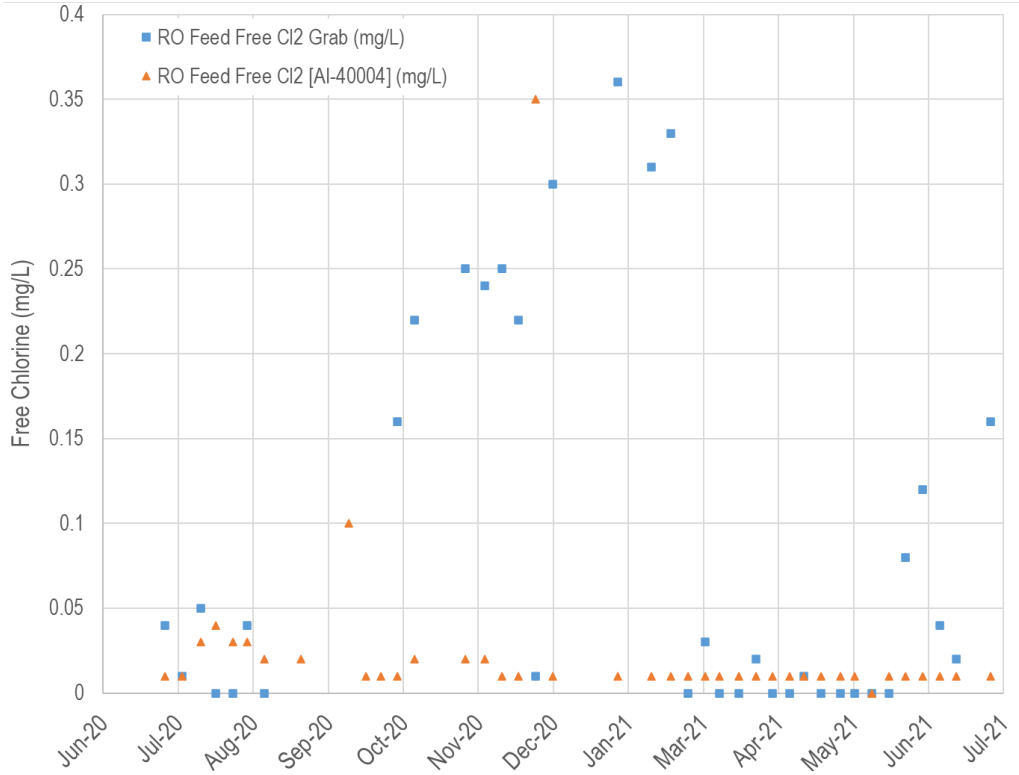
Plant Location	UF Filtrate	UV AOP Inlet	UV AOP Outlet
Meter Tag	AE-31094	TCl-001	TCl-002
Meter Model	E&H Total Chlorine Sensor (#CCS120-AS0)	HACH CLT10 sc	
Range	0.1 - 10 mg/L	0.1 - 20 mg/L	
Flow(1)	>8 gph	8 - 13 gph, optimal = 10.5 gph	
Verification Frequency	Included on weekly operations verification checklist.		
Cleaning Frequency	**Quarterly**, if verification is poor, if the sensor is visibly soiled, or response time is low.	If the flow cell becomes discolored or deposits are observed.	
Calibration Frequency	**Quarterly**, or if verification is poor. Slope calibration required every time electrolyte (12 months) or sensor membrane is changed.	Based on automated sensor warnings. The sensor needs to be recalibrated if removed from the water or disconnected from power for more than 15 minutes.	
Maintenance Frequency	**12 months** or if calibration is not possible. Refill the electrolyte Replace the membrane cap if calibration cannot be carried out.	Replace tubing (12 months) Replace the electrolyte (3 - 6 months) Replace the membrane cap (1 year) Replace the sensor (3 years) Polish the electrode (when sensor readings are unstable or slope is low)	

Notes:
(1) Refers to flow past the sensor in the flow through unit.
(2) Amperometric probes are used for chlorine measurement.

The purpose of each sensor is as follows:

- UF Filtrate Total Chlorine:
  - Monitor chloramine dose.
- RO Feed Free Chlorine:
  - Ensure that the RO membranes are not exposed to free chlorine > 0.1 mg/L which will result in membrane damage.
- UV inlet and outlet free chlorine:
  - Monitor oxidant dose and relative destruction, which is related to advanced oxidation process performance.
- UV inlet and outlet total chlorine:
  - Infer chloramine concentration, which impacts UVT and photolysis.

The verification results for the chlorine sensors are shown on Figures 3.17 through 3.22.



Note: Typically, free chlorine is not detected and is consequently difficult to verify. High free chlorine verification results are typically associated with chloramine interferences to the DPD method used to verify the meter.

Figure 3.17 RO Feed Free Chlorine Verification Results

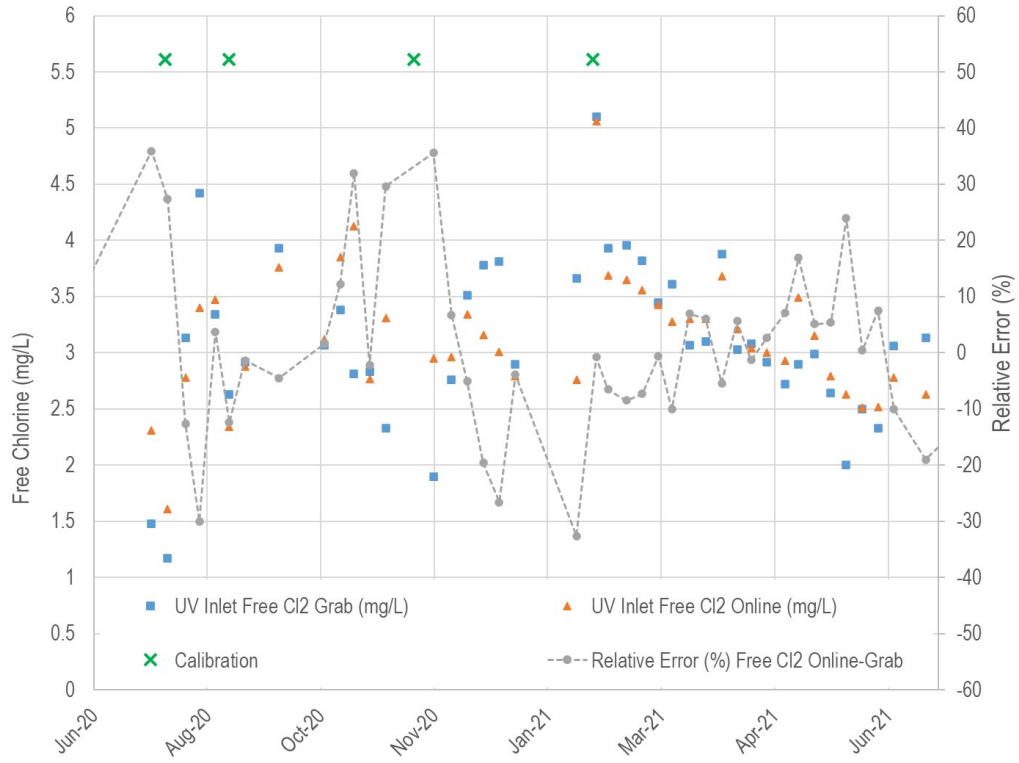


Figure 3.18 UV Inlet Free Chlorine Verification Results

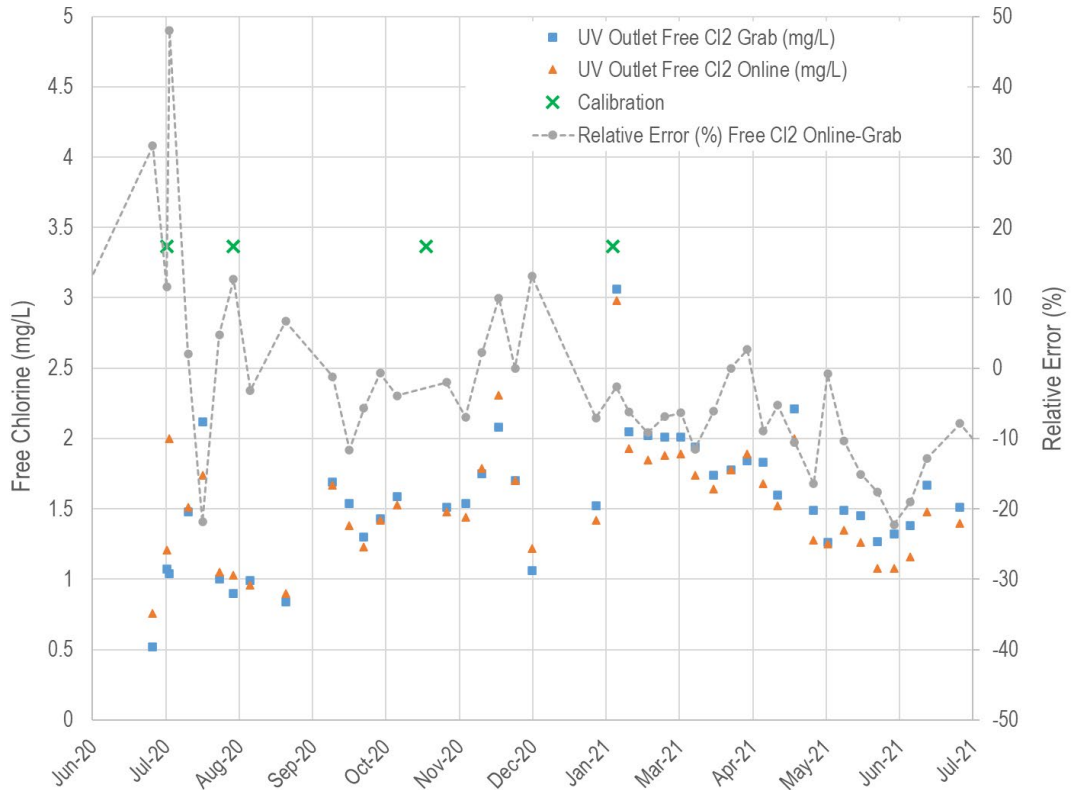


Figure 3.19 UV Outlet Free Chlorine Verification Results

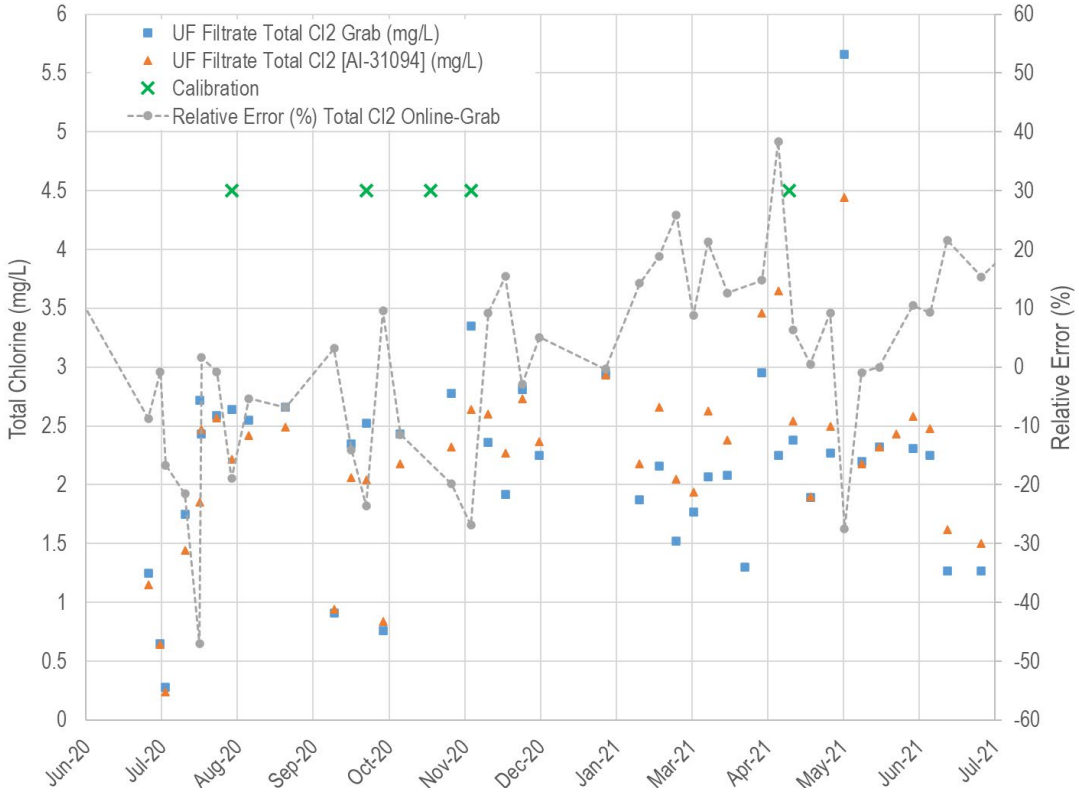


Figure 3.20 UF Filtrate Total Chlorine Verification Results

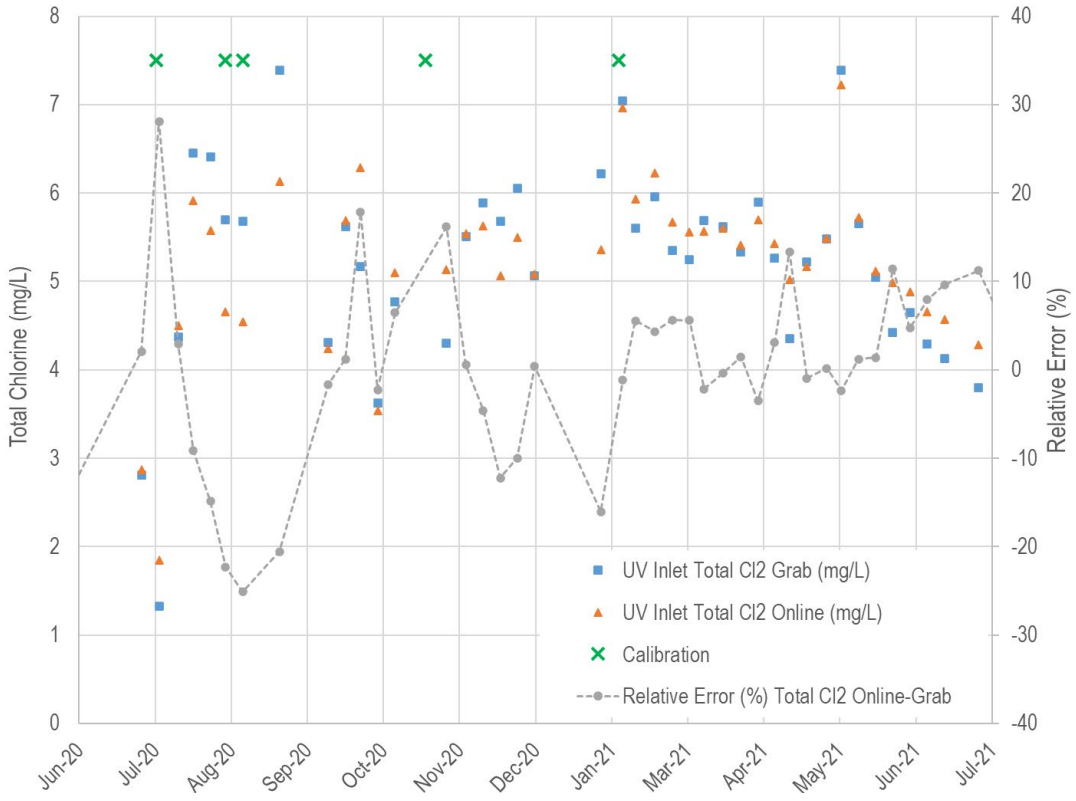


Figure 3.21 UV Inlet Total Chlorine Verification Results

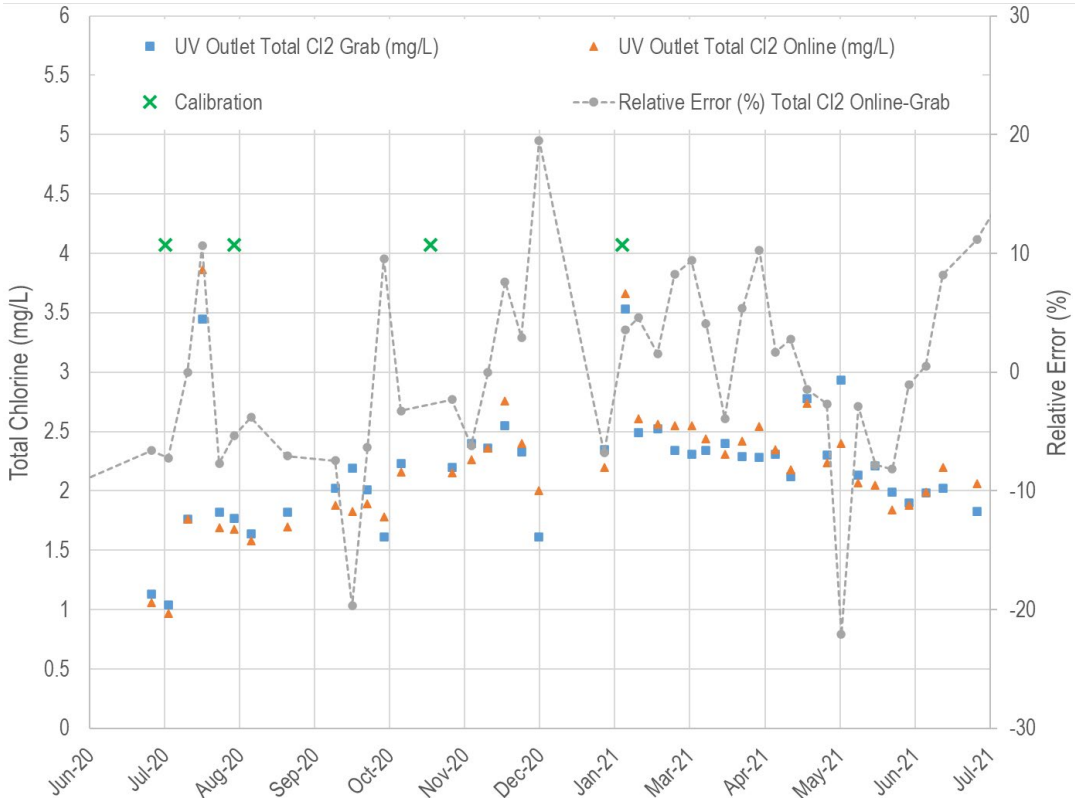


Figure 3.22 UV Outlet Total Chlorine Verification Results

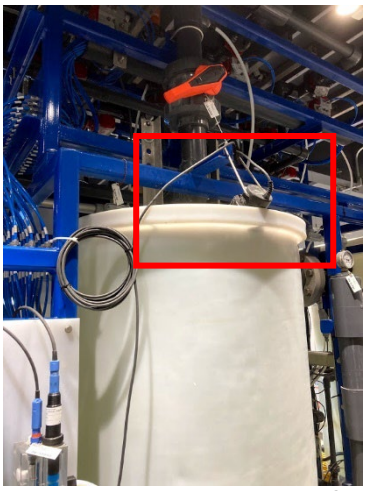
With respect to the chlorine probes, the following observations can be made:

- Free chlorine monitoring on RO feed is challenging to monitor, calibrate and maintain. There are a number of limitations including:
  - The probes are sensitive to pressure and must therefore be calibrated in-situ. As the goal of RO operation is to have no free chlorine, there has been no opportunity to calibrate the RO feed free chlorine without risking damage to the RO.
  - At low free-chlorine levels, chloramine can interfere with the grab verification results, artificially inflating the observed free chlorine. This analytical interference has made verification of the RO feed free chlorine near impossible within its target measuring range.
  - The approach adopted to ensure no-contact of free chlorine with the RO was to conservatively set a free ammonia residual of 0.5 mg/L and also to monitor for ORP spikes which were considered to be more reliable. With an excess free ammonia of 0.5 mg/L, a free chlorine spike exceeding 2.0 mg/L could be absorbed before exceeding breakpoint. Consequently, free chlorine observations of up to 0.5 mg/L are highly likely to be false positives due to the interferences noted above.
  - To improve monitoring to protect the RO, it may be more appropriate to move to reagent based analysis of chloramine and free ammonia, coupled with an ORP probe. Commercial units are available that can accurately measure to the desired range of ammonia and chloramine residual.
- Amperometric chlorine probes function well in RO permeate:
  - The performance of the UV inlet and outlet chlorine probes has been very good. The typical grab verification has been within 20 percent for most of the probes.
  - The UV probes have needed minimal maintenance to remain calibrated and to date have not needed electrolyte or membrane replacement.
  - The improved performance of amperometric probes in this location has been attributed to the stable flow (reducing pressure change interferences) and also the low and stable pH, which improves accuracy. In addition, the target range of chlorine dosage, close to 3 mg/L of free chlorine and up to 5 mg/L of total chlorine is well within the operable range of the probes.
- Compared to the UV inlet and outlet chlorine monitoring, the UF filtrate total chlorine probe suffers from variable pressures, due to UF backwash and cyclical operation and also a higher and more variable pH. Both of these factors contribute to more difficulty gaining a stable reading from the UF filtrate:
  - As noted above, movement to a reagent-based probe would alleviate the pH and pressure sensitivity for this monitoring location, with direct chloramine reagent based meters available.

3.5 Free Ammonia Probe

The pilot skid is equipped with one ammonia sensor (AE-36210) located in the UF filtrate tank.

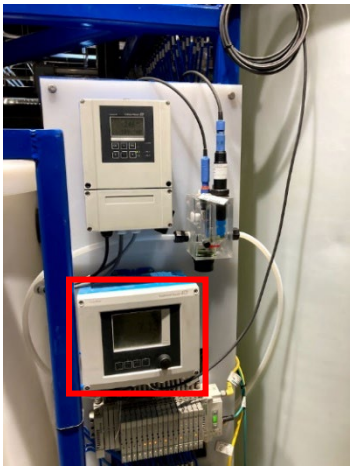
The ammonia sensor and control box are shown as installed on Figure 3.23.



Note: Ammonia sensor mounted on inlet to UF filtrate tank.



Note: Ammonia sensor removed.



Note: Ammonia sensor control box.

Figure 3.23 Free Ammonia Probe Location at the Demo

The ammonia sensor model number is shown in Table 3.5, as well as the recommended cleaning, calibration and maintenance frequency. The ammonia sensor also includes a pH meter which should also be calibrated when verification indicates that the ammonia sensor is not functioning correctly.

Table 3.5 Ammonia Sensor Location, Model Number, Calibration, and Cleaning Frequency

Plant Location	UF Filtrate Tank
Meter Tag	AE-36210
Meter Model	E&H Ammonia Sensor (#CAS40D-AA1A1A2)
Range	0.1 - 1,000 mg/L
Verification Frequency	Included in weekly checks
Cleaning Frequency	Clean the membrane (every 2 weeks)
Calibration Frequency	Quarterly or if verification indicates a problem Slope calibration required every time electrolyte (12 months) or sensor membrane is changed.
Maintenance Frequency	Replace the membrane cap and electrolyte (6months) Replace the pH sensor and o-rings (12 months)

The verification data for the ammonia probe is shown on Figure 3.24.

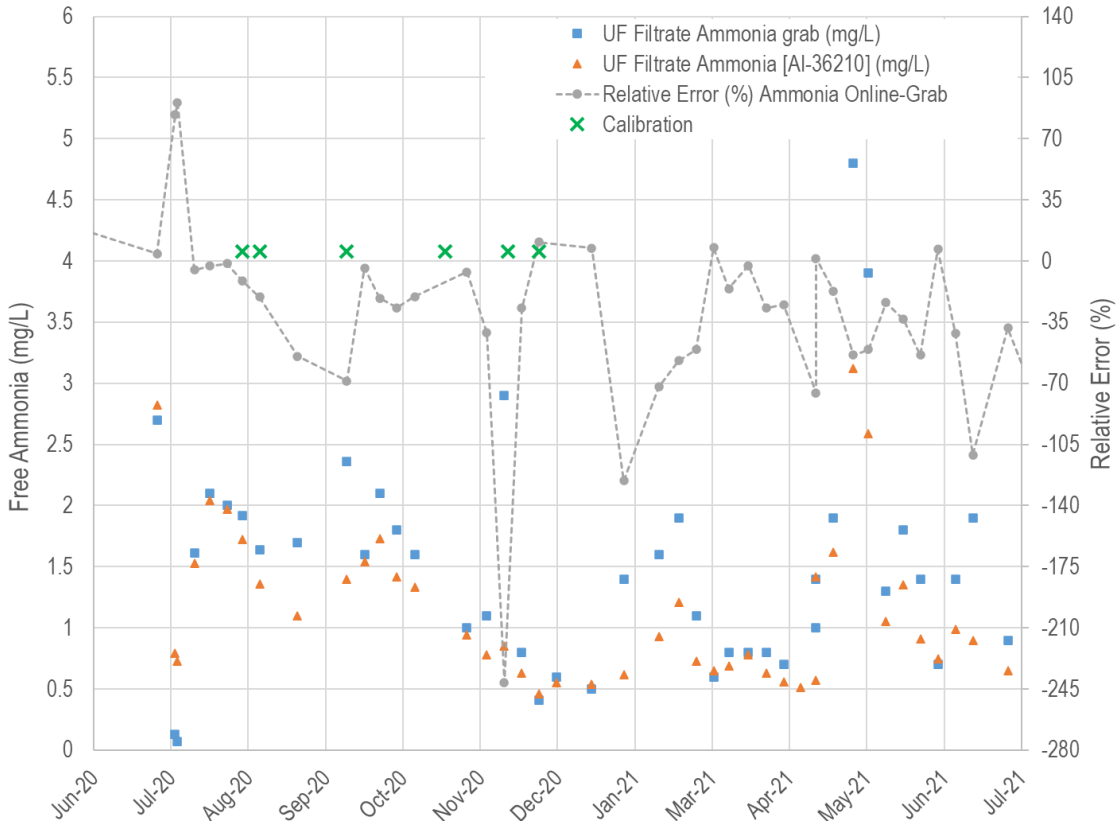


Figure 3.24 UF Filtrate Ammonia Probe Verifications

Based on the first year of ammonia probe verification data, the following observations can be made:

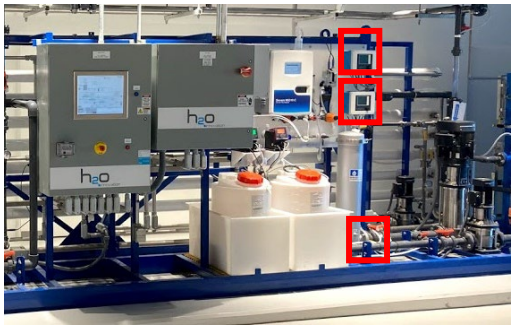
- The ammonia probe had a tendency to under report the true ammonia value as indicated by a negative relative error. While this has not impacted the success of the ammonia probe in protecting the RO, it has meant that on occasion, ammonia dosing was likely set higher than needed to meet the target of 0.5 mg/L as free ammonia – based on the probe.
- Absolute error of the ammonia probe was often high and discrepancies of up to 1 mg/L were noted.
- The poor accuracy of the ammonia probe is likely due to the fact that its target operation range at the Demo was less than 1 mg/L, whereas the unit reports sensitivity from 0.1-1,000 mg/L implying typical applications would have larger ammonia concentrations.
- To measure ammonia in the desired range at the Demo, it will likely be necessary to use a reagent-based meter.

3.6 Conductivity Probes

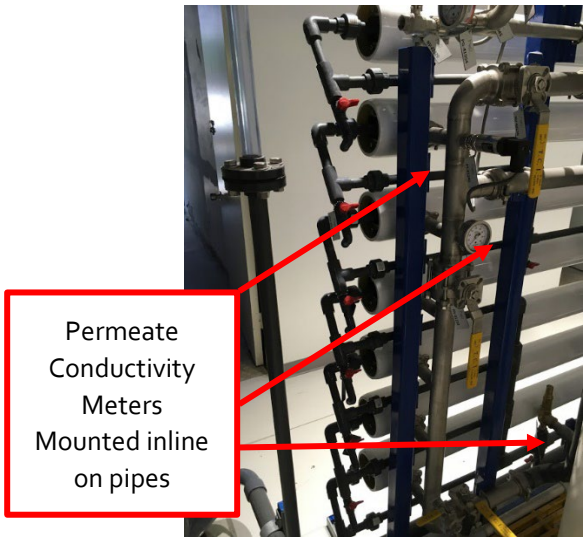
The pilot skid is equipped with five conductivity meters located on:

- The combined RO feed, prior to the cartridge filter (AE-40006).
- The RO permeate from Stage 1 (AE-41092), Stage 2 (AE-41292) and Stage 3 (AE-41392).
- The combined RO permeate (AE-41892).

The location of the conductivity meters and control boxes are shown as installed on Figure 3.25.



Note: Feed Conductivity Meter and control boxes (permeate upper, feed lower control box).



Note: Permeate conductivity meters located on pipework between CIP tank and pressure vessels.

Figure 3.25 Conductivity Meter Locations at the Demo

The conductivity meter model numbers are shown in Table 3.6, as well as the recommended cleaning, calibration and maintenance frequency.

Table 3.6 Conductivity Meter Locations, Model Numbers, Calibration, and Cleaning Frequency

Plant Location	RO Feed	Stage 1 Permeate	Stage 2 Permeate	Stage 3 Permeate	Combined Permeate
Meter Tag	AE-40006	AE-41092	AE-41292	AE-41392	AE-41892
Meter Model	E&H Condumax 2 Electrode (#CLS21D-C1N0)	E&H Condumax CLS15D Series Digital Conductivity Sensor (#CLS15D-B1AO)			
Range	10 - 20,000 µS/cm	0.1 - 200 µS/cm			
Verification	Compare readouts with a calibrated bench top conductivity probe. Conductivity verification is included in the weekly checklist.				
Cleaning Frequency	**Quarterly** - or – as required, if sensor is visibly fouled, if sensor drifts from grab samples or if response is slow.				

Plant Location	RO Feed	Stage 1 Permeate	Stage 2 Permeate	Stage 3 Permeate	Combined Permeate
Calibration Frequency	Factory calibration or sensor replacement required. Replace sensor if verification readings drift from online readings.				
Maintenance Frequency	No additional maintenance possible with installed sensors				

The conductivity meters cannot be calibrated and if calibration drifts, they need to be replaced. Conductivity monitoring is essential for the RO process as the conductivity is used to assure removal performance in real time and to normalize process performance data for TDS.

Verification results for the conductivity meters for the first year of operation are reported on Figures 3.26 through 3.30.

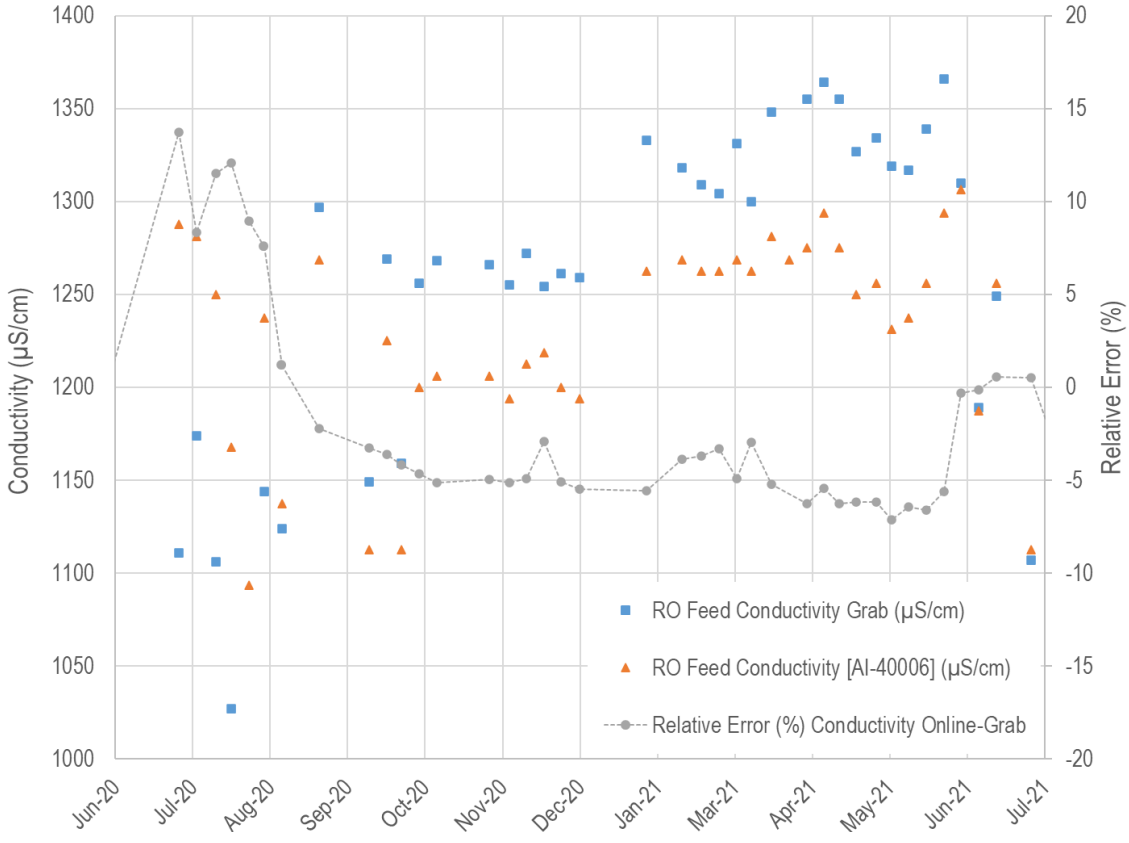


Figure 3.26 RO Feed Conductivity Verifications

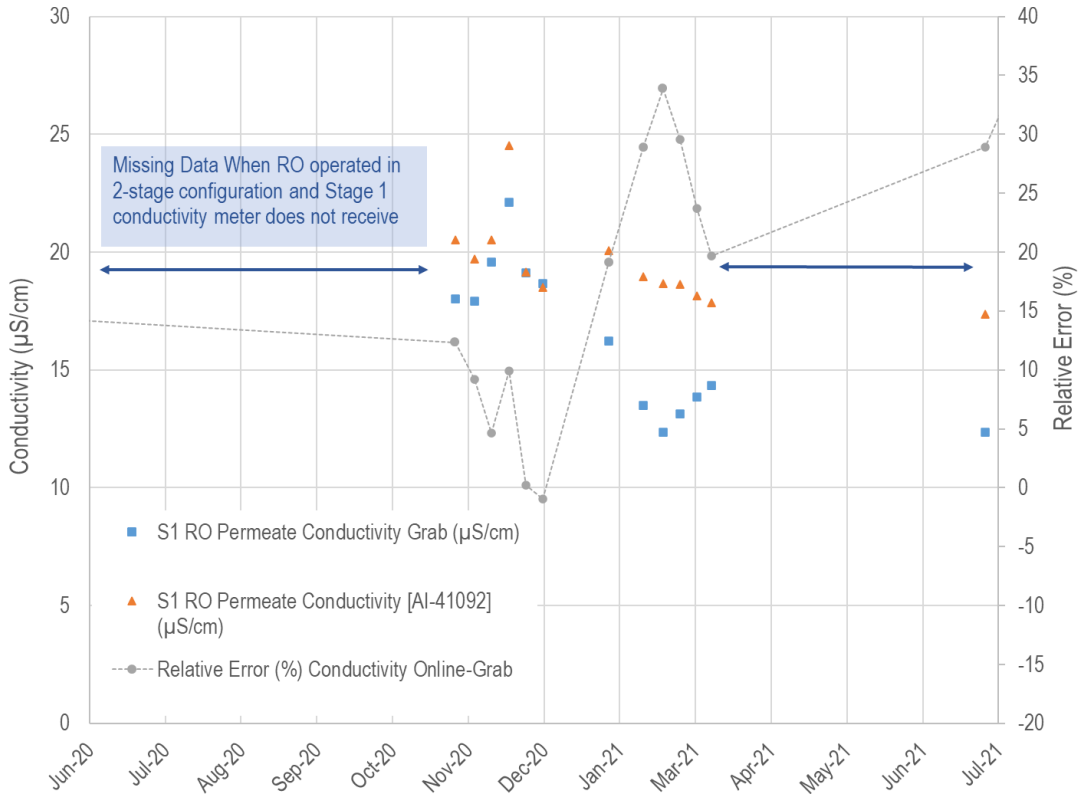


Figure 3.27 RO Permeate Stage 1 Conductivity Verifications

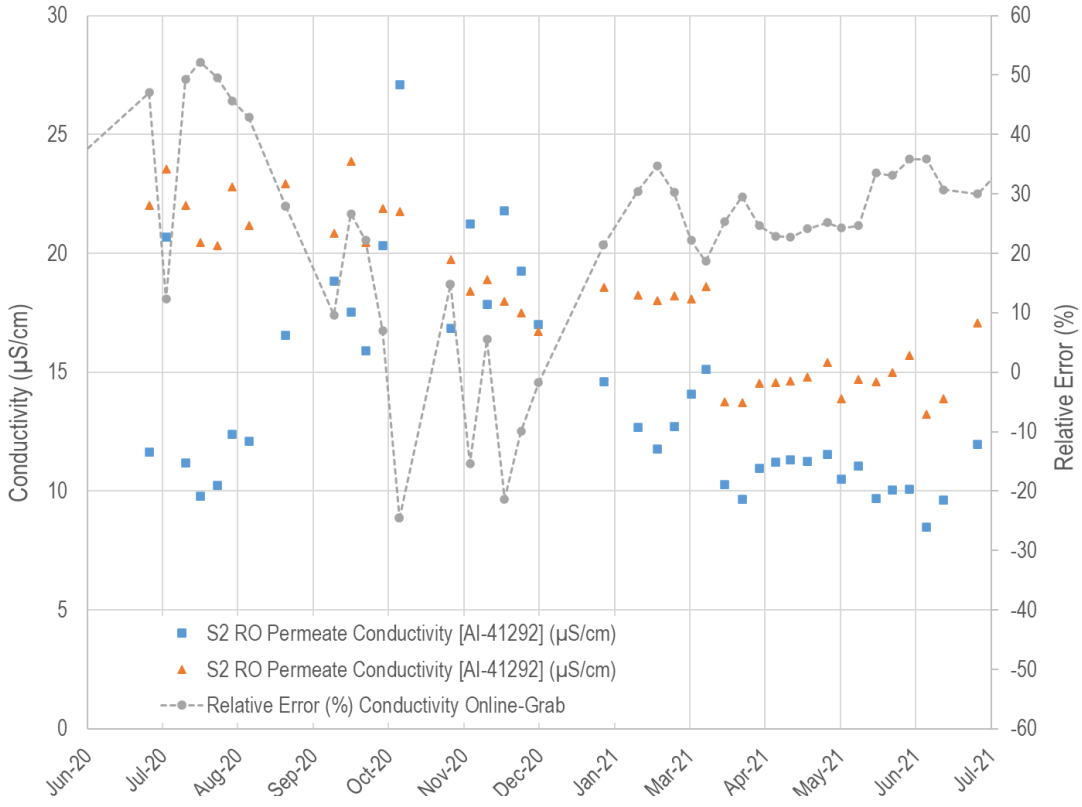


Figure 3.28 RO Permeate Stage 2 Conductivity Verifications

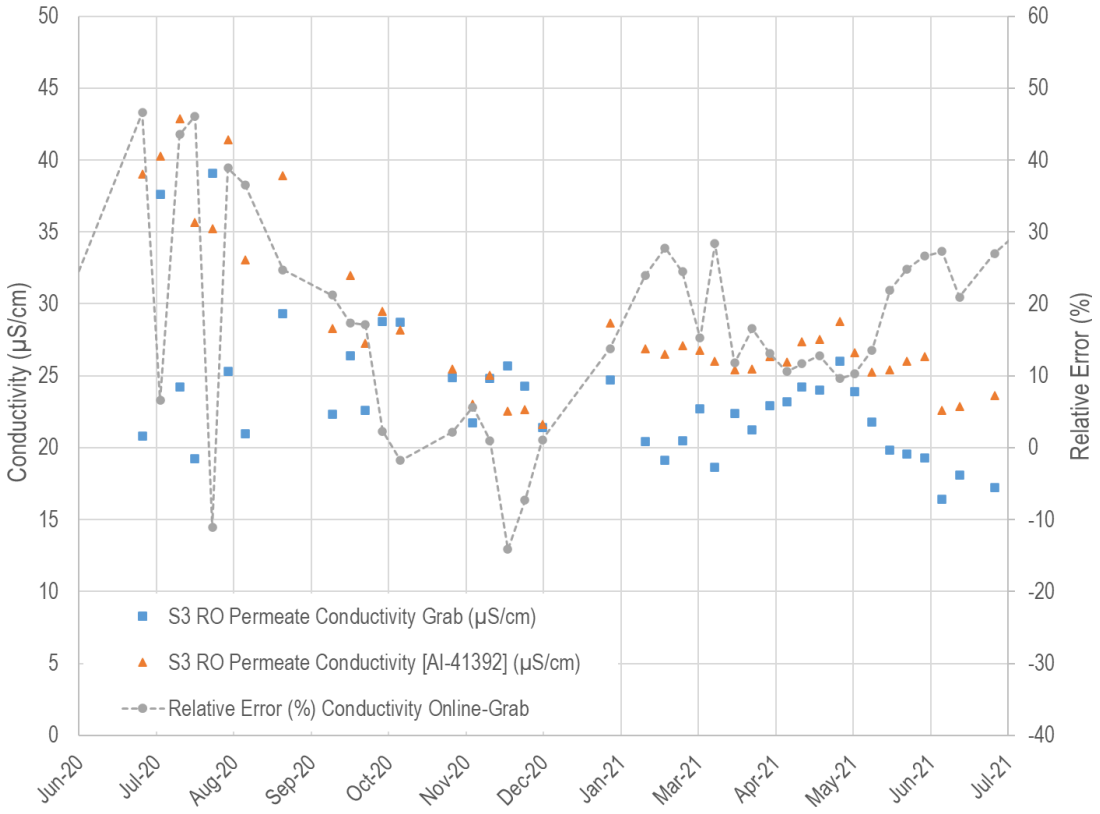


Figure 3.29 RO Permeate Stage 3 Conductivity Verifications

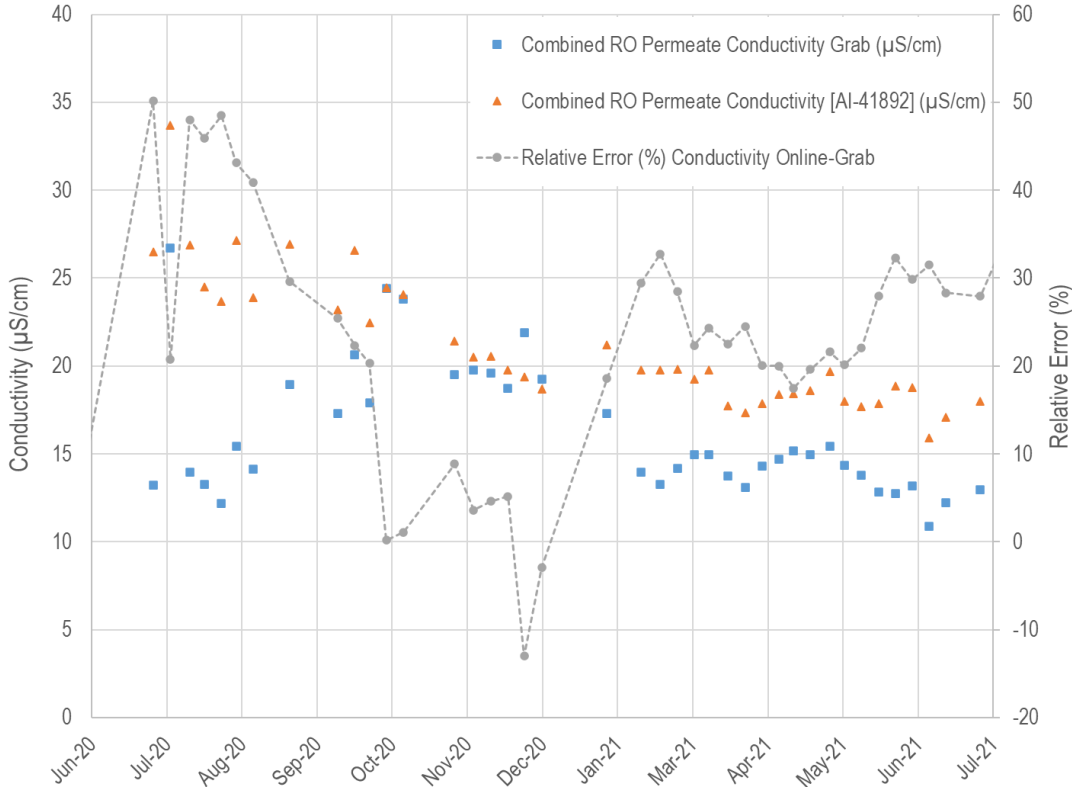


Figure 3.30 Combined RO Permeate Conductivity Verifications

- At higher conductivities, measured in the RO feed, relative error was less than 10 percent, with most readings within 5 percent.
- With the lower conductivity permeate samples, the grab meter had a tendency to read lower than the online probes. This means that the conductivity LRVs, calculated with the online probes are likely conservative, relative to the grab sample unit.
- The generally larger relative deviation noted for the permeate conductivity meters (30 percent) is likely due to the low conductivities in the RO permeate creating challenges for accurate measurements. Noting that a relative devotion in the permeate equates to a maximum absolute variation of 10 µS/cm.
- In general, the conductivity meters displayed very good precision throughout the year and have been very low maintenance.

3.7 Total Organic Carbon Analyzer

The pilot skid is equipped with two total organic carbon sample points located on the RO feed prior to the cartridge filter (AI-40010) and on the combined RO permeate (AI-41810) which are feed to a two-stream analyzer (AE-40010).

The total organic carbon sample points are located near the RO feed and combined permeate conductivity sensors and the control box is shown as installed on Figure 3.31.

The total organic carbon model number is shown in Table 3.7, as well as the recommended cleaning, calibration and maintenance frequency.



Figure 3.31 TOC Online Analyzer Located at the Demo

Table 3.7 Total Organic Carbon Sample Locations, Analyzer Model Number And Calibration, Cleaning And Maintenance Frequency

Plant Location	RO Feed	RO Permeate
Sensor Tag	AI-40010	AI-41810
Meter Tag	AE-40010	
Meter Model	Suez Sievers MS310C TOC Analyzer (#77420-01)	
Range	0.04 - 50 mg/L	
Verification Frequency	Verification samples are sent weekly for analysis at external laboratories.	
Cleaning Frequency	Flush the reagent syringes daily or if the analyzer has not been used for more than 8 hours or when reagents are replaced. Check and fill the deionized water reservoir.	
Calibration Frequency	Calibration is required every **12 months.**	
Maintenance Frequency	**The TOC analyzer monitors consumable levels and will provide a warning approximately 15 days prior to when replacement is anticipated.** As indicated by machine warnings - Check the deionized water reservoir - refill as needed. Replace the oxidant every 3 months or refill as needed. Replace the acid every 12 months or refill as needed. Replace the UV lamp every 6 months. Replace the inline filter as needed. Replace the sample pump heads and resin cartridge every 12 months.	

Verification results for the TOC analyzer are shown on Figures 3.32 and 3.33 for the RO feed and RO permeate analysis.

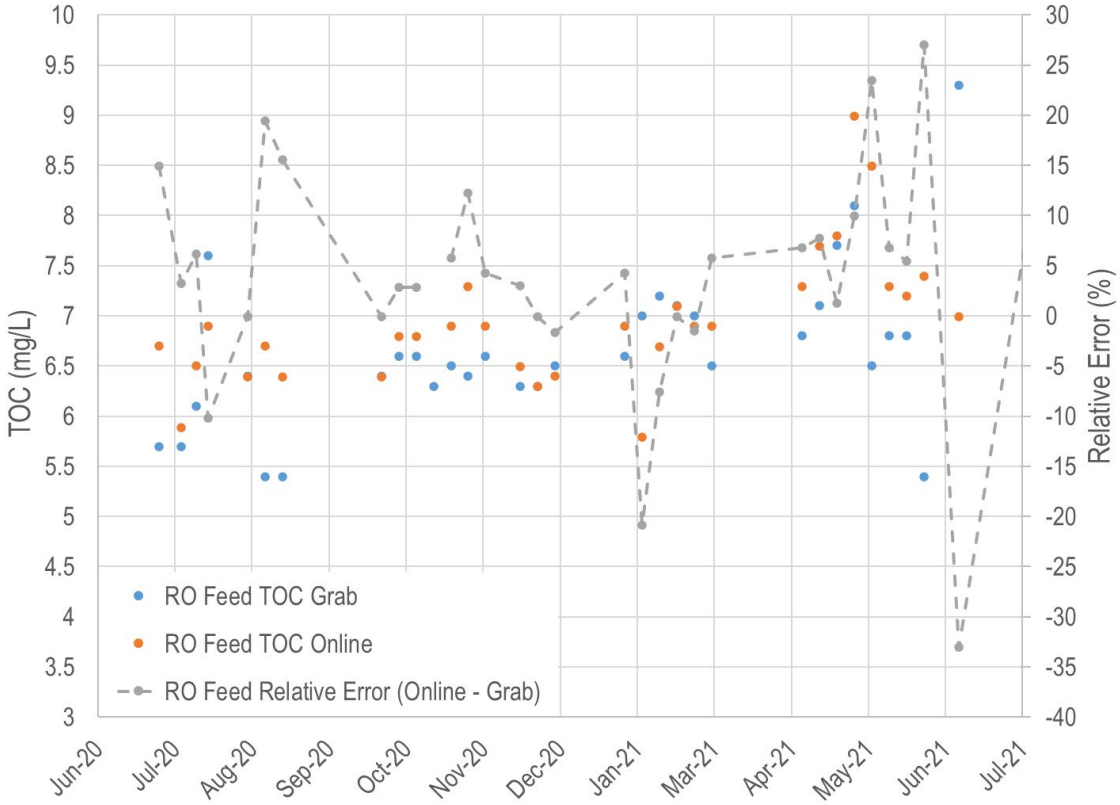


Figure 3.32 RO Feed TOC Verifications

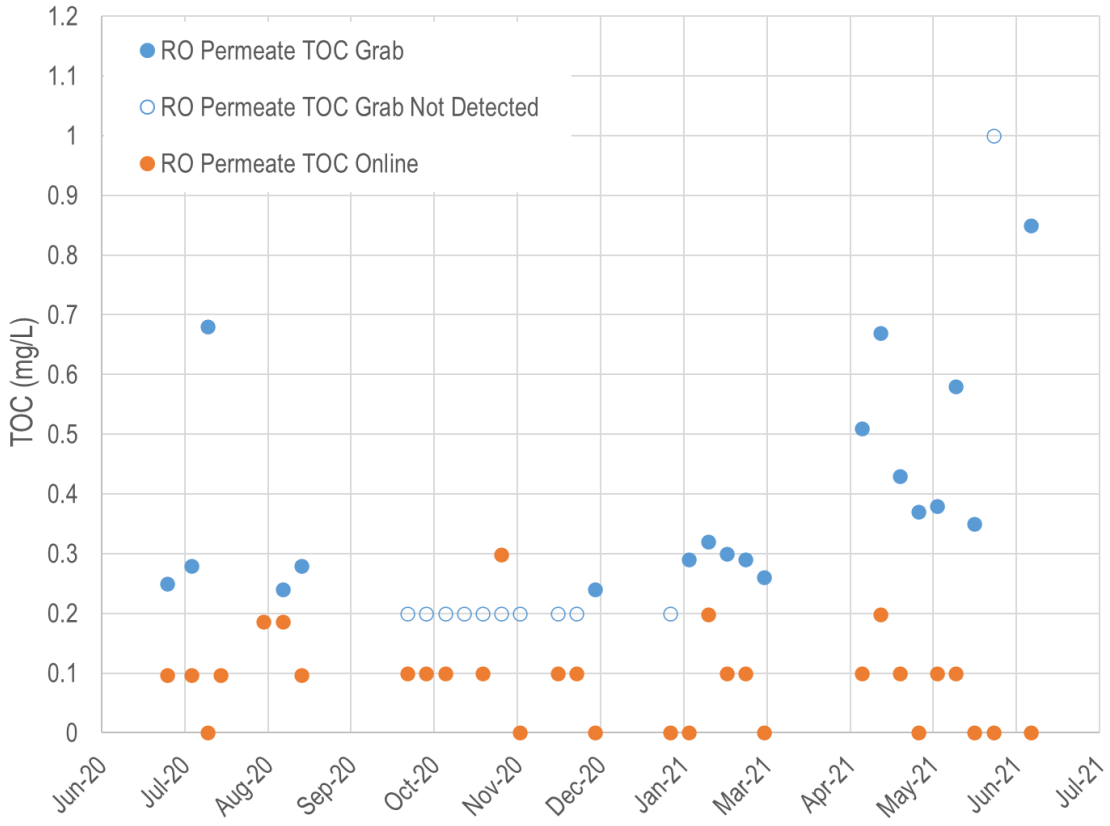


Figure 3.33 RO Permeate TOC Verifications

The TOC meter has been challenging to maintain and verify. Based on the first year of operational data and experience:

- The RO feed has been relatively reproducible with respect to grab sample measurements and the relative deviation is typically within 20 percent with some outliers.
- The RO permeate has been very challenging to verify for the following reasons:
  - Most commercial laboratories do not offer TOC detection limits low enough to verify the typically low inline TOC readings of the RO unit (<<0.2 mg/L).
  - The risk of contamination when measuring TOC < 0.5 mg/L is high and based on the RO permeate results, contamination of grab samples is suspected in a number of samples.
  - It is recommended that the contract laboratories responsible for analysis of the RO permeate TOC are contacted and asked to ensure that blanks are run before each RO permeate sample to ensure that sample carryover from previous analysis is minimized.
- The precision of the RO permeate online TOC meter readings has improved after inclusion of a flush cycle.
- The TOC analyzer requires very frequent maintenance:
  - Daily flushing is required to minimize air bubble interferences and has been consistently conducted by the operators.

- The TOC analyzer uses significant consumables and consumable replacements are required quarterly at the current rate of measurement.
- Resin cartridges in the TOC unit also failed prematurely (at 6 months, relative to 12 months) which impacted accuracy. It is suspected that the chloramine level in the RO feed was responsible for early cartridge exhaustion.
- Calibration must be performed by a highly qualified instrument technician, and the conventional solution for this is a service callout.

When considering the maintenance burden of performing accurate TOC measurements, TOC provides little benefit when compared to the convenience, precision and high frequency coverage provided by conductivity meters.

Unfortunately, TOC is considered an important parameter to verify chemical removal across the RO and is listed as a surrogate in the 2018 California Recycled Water Policy[1]. To that end, continued upkeep and maintenance of the TOC meter is recommended.

3.8 UV Transmittance Meters

The pilot skid is equipped with two UV transmittance sensors located on the UV AOP inlet (UVT-001) and UV AOP outlet (UVT-002).

The UVT meters are shown as installed on Figure 3.34.



Figure 3.34 UVT Meters and Automated Cleaning Systems on the Demo UV AOP

[1] https://www.waterboards.ca.gov/water_issues/programs/recycled_water/

The UVT model number is shown in Table 3.8, as well as the recommended cleaning, calibration and maintenance frequency.

Table 3.8 UVT Meter Locations, Analyzer Model Number and Calibration, Cleaning and Maintenance Frequency

Plant Location	UV AOP Inlet	UV AOP Outlet
Sensor Tag	UVT-001	UVT-002
Meter Model	Real Tech M4150	
Range	74- 100 percent UVT - 150 millimeter (mm) path length	
Verification Frequency	Included in weekly checks	
Cleaning Frequency	Investigate cleaning if verification indicates a discrepancy. An automated cleaning unit is installed and was programmed to clean the units every 3 days.	
Calibration Frequency	Recalibrate if verification indicates a discrepancy.	
Maintenance Frequency	12-18 Months - Replace Lamp and Ribbon Cable	

The verification data for the inlet and outlet UVT meters is shown on Figures 3.35 and 3.36.

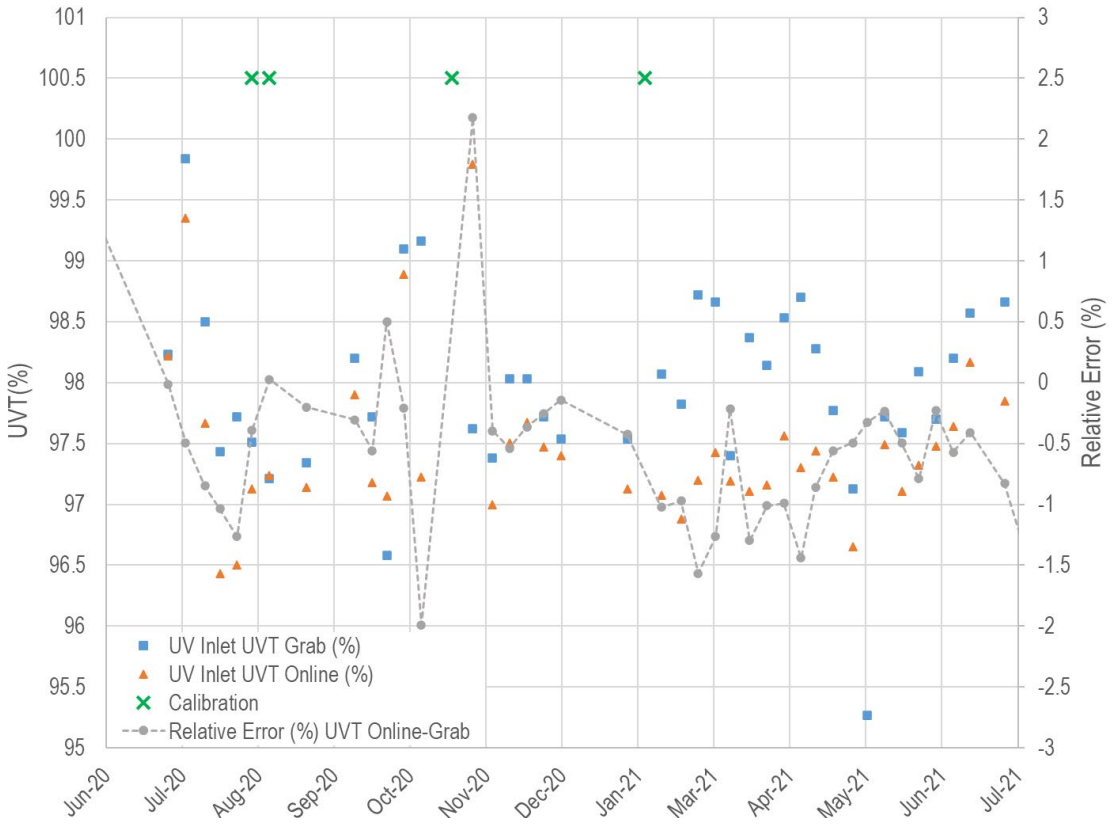
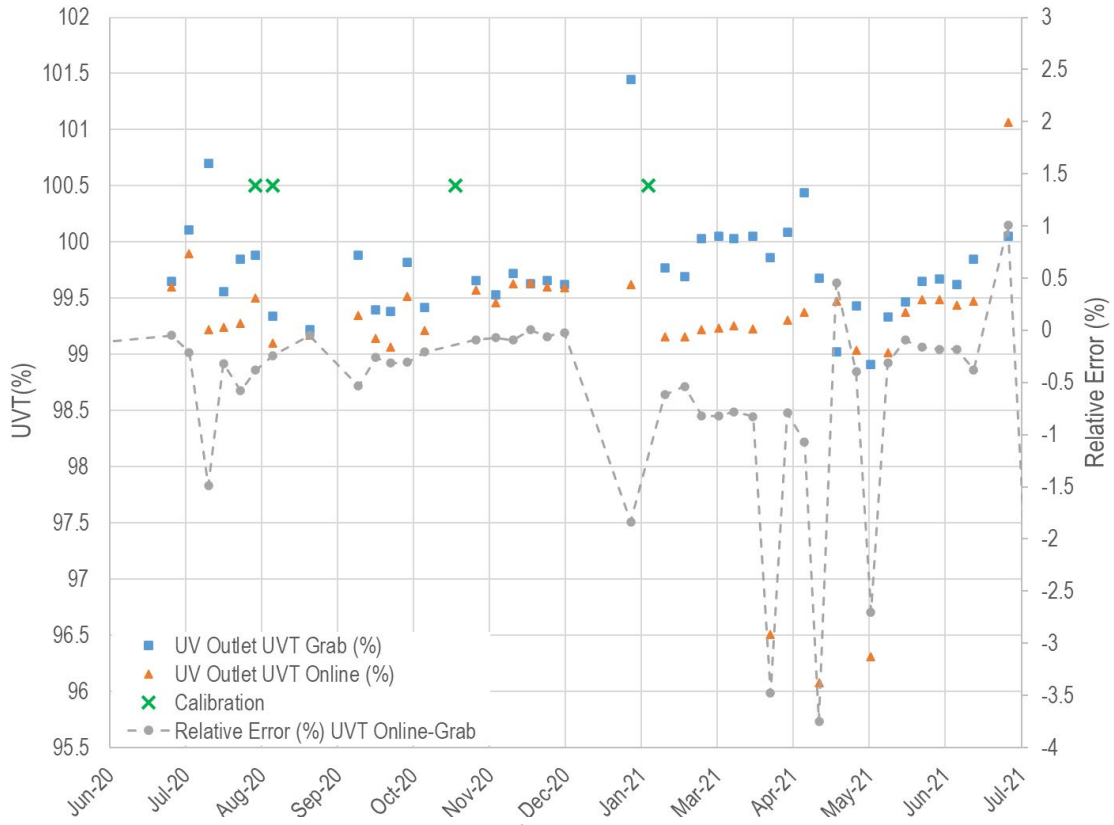


Figure 3.35 UV Inlet UVT Verifications



Note: Drops in relative error are related to online instrument faults.

Figure 3.36 UV Outlet UVT Verifications

The UVT meters have operated very well, with relative errors always below 2 percent for the inlet meter and also for the outlet meter, with the exception of the faults described below. The addition of the automated cleaning system has significantly minimized maintenance requirements. There have been two faults:

- The UV outlet meter automated cleaning system required replacement of the cleaning solution pump tubing.
- The UV outlet meter has a faulty positioner collar which has led to false readings from the instrument approximately 10 percent of the time. The faulty positioner collar is being pursued under warranty.

The UV Inlet UVT meter is important for monitoring UV AOP performance as the inlet water quality will impact the dose delivered. The faults of the outlet meter are not detrimental to performance as they are easily recognized, and the purpose of this meter is to assess relative change through the reactor. It is anticipated that when the positioning collar fault is fixed, the outlet UVT meter should perform as well as the inlet.

3.9 UV Intensity Sensor

The UV intensity sensor has demonstrated very high reliability, with only one quickly recognized and rectified fault during the first year of operation (see Figure 2.57).

It is recommended that operations staff continue to perform UV intensity sensor reference checks on a monthly basis or if the UV intensity readings from the reactor vary by more than

10 percent. A template to capture UV intensity readings has been established on the CarolloAM logsheet interface to capture UV intensity verification data.

3.10 Monitoring Instrument Conclusions

Conductivity, turbidity, UVT (with the exception of the manufacturing fault on the meter on the UV outlet), pH and ORP meters demonstrated good performance and reliability. Of these instruments, the turbidity required frequent cleaning to perform optimally, and the pH meters required frequent calibration. In particular, the UV inlet pH meter benefits from frequent calibration to operate in the very low TDS environment.

The total and free chlorine probes performed well on the UV system when operating in low pH RO permeate with a stable flow. Total and free chlorine probes used upstream of the RO did not perform optimally, likely due to the higher pH, generally low free chlorine level and more variable pressure which impacted stability.

Performance of the ammonia probe has been relatively poor as it is required to measure at the very low end of its operating range.

When set up correctly, the TOC meter performed adequately and is a regulatory requirement for potable reuse. Unfortunately, the maintenance and consumable requirements to achieve reliable operation of the TOC meter are significant and will need to be maintained.

It is recommended to consider reagent-based chlorine/chloramine and free ammonia monitoring ahead of the RO system.

Chapter 4

UV AOP PROCESS VALIDATION

The UV AOP is a critical pathogen and chemical barrier. In this section, the activities to validate the UV AOP to relate its online monitored parameters to pathogen and chemical control are described. The two major UV AOP process validation activities were:

- Quantification of the UV dose delivery via *Aspergillus brasiliensis* (*A. brasiliensis)* challenge testing.
- Quantification of the NDMA and 1,4 Dioxane destruction at a range of anticipated operational set points.

4.1 Disinfection

Research on the dose-response relationship of Adenoviruses, using Low Pressure (LP) UV radiation on a bench-scale collimated beam setup, is mainly limited to Adenovirus types 2, 40, and 41. The dose response relationship at high UV doses (>200 mJ/cm^2) is more widely published for Adenovirus type 2 (Ad2), and shows that 6 LRV of Ad2 may be obtained at a dose of 235 mJ/cm^2 (Gerba et al., 2002). The dose response relationship of Ad2 as well as other viruses is shown on Figure 4.1, demonstrating that Ad2 is a conservative surrogate for a wider range of viruses.

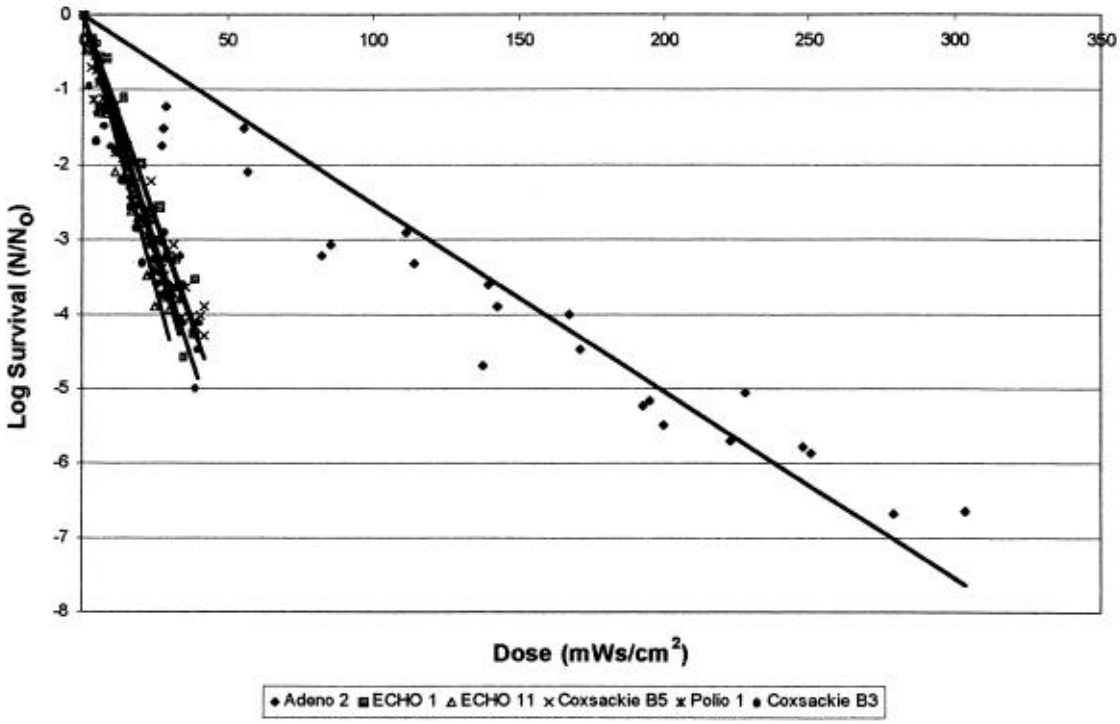


Figure 4.1 LP UV Dose Response Relationship of Ad2 (Gerba et al., 2002)

USEPA (2010) published a dose-response equation for Ad2 of:

$$\text{Log Reduction (Ad2)} = 0.0262 * \text{UV Dose} + 0.2774$$

This dose response relationship is based on a dose range between 20 and 160 mJ/cm^2 (USEPA, 2010). Other studies have shown similar dose responses, consistently indicating that a LP UV dose of up to 235 mJ/cm^2 results in 6 LRV of Ad2.

The USEPA document entitled "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems," (Innovative Approaches for Validation) (USEPA 2018) provides UV dose requirements for 6 log inactivation of Cryptosporidium, Giardia, and adenovirus of 85, 84 and 276 mJ/cm^2, respectively.

For potable reuse systems, in which UV with an advanced oxidation process (UV AOP) is used after RO, UV dose values are commonly in excess of 1,000 mJ/cm^2, which far exceeds the minimum UV dose of 276 mJ/cm^2 for 6 LRV of adenovirus (and thus all pathogens).

4.1.1 Test Goals

A. brasiliensis, a fungal spore, was the challenge organism for UV analysis, as it has a very high UV dose per LRV (DL) of approximately 100 - 120 mJ/cm^2/LRV (Malayeri et al., 2006). The high DL of *A. brasiliensis* was required in order to demonstrate quantifiable LRVs close to the high UV dosages applied in normal operation.

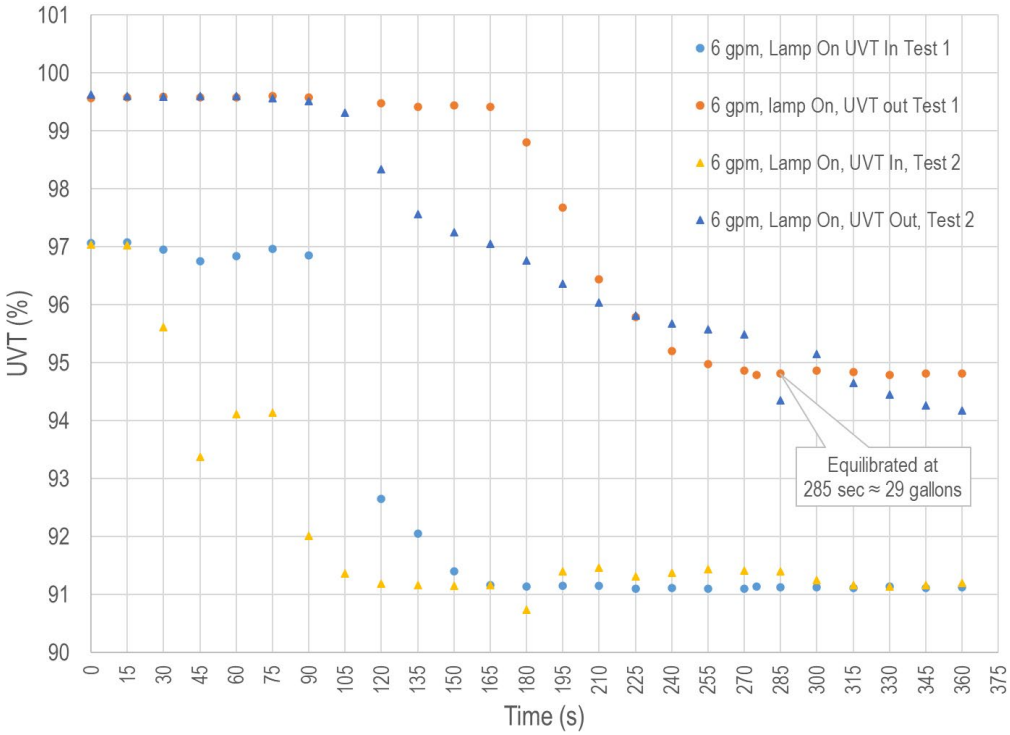
4.1.2 Test Description

A. brasiliensis was spiked directly into the RO permeate at concentrations sufficient to demonstrate an LRV of 4.5. The free chlorine dosing to the UV system was deactivated, as was the chloramine dosing, to avoid any cross disinfection interferences. The UV reactor flow was adjusted so that target dosages, which are calculated in the UV HMI using PSS, could be stabilized at 350, 400, 500, 600 and 800 mJ/cm^2. A sample of the feedwater spiked with *A. brasiliensis* was sent, along with the challenge test samples, to a commercial laboratory for collimated beam analysis in-order to allow determination of a reduction equivalent dose (RED). Samples of UV inlet and outlet were taken and analyzed in triplicate for determination of LRV onsite.

4.1.3 Test Results

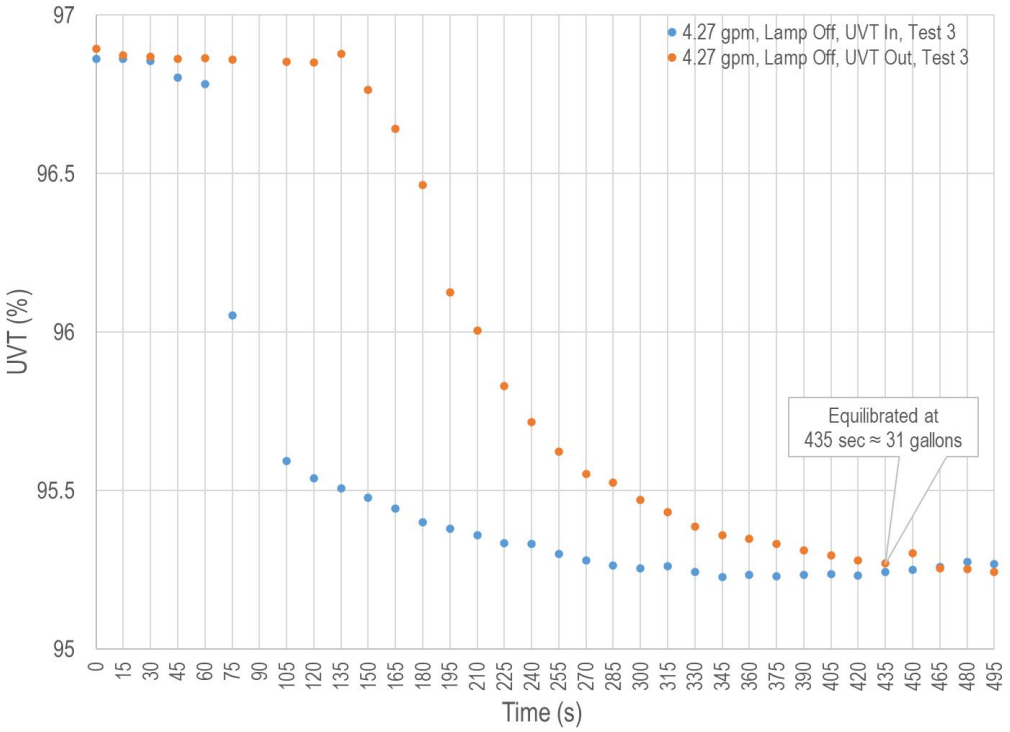
4.1.3.1 Reactor Tracer Test

Prior to both the *A. brasiliensis* and later NDMA/1,4 Dioxane Testing reactor tracing was conducted at flow rates on the lower end of the test range. To perform the tracer tests, humic acid was spiked using the same spiking system as used for the challenge contaminants. The passage of superhume was then monitored through the system with time via the UVT meters. Figures 4.2 and 4.3 show the results of the tracer tests conducted 1) at 6 gpm with the lamps on – which resulted in some humic acid degradation and 2) with the lamps off at 4.27 gpm without the lamps. From the tracer tests, it was established that between 29-31 gallons needed to pass through the reactor before equilibrium was reached between inlet and outlet sample points. Consequently, for each subsequent test at least 8 minutes (which at typical flows is > 40 gallons) was allowed before sampling was conducted.



Note: Time is expressed from when humic acid dosing pumps were activated. With the lamp on, some degradation of humic acid occurred through the reactor.

Figure 4.2 UV Reactor Tracer Test With Lamps on at 6 gpm With Humic Acid



Note: Time is expressed from when humic acid dosing pumps were activated. With the lamp off, the UVT of inlet and outlet approached the same value at equilibrium.

Figure 4.3 UV Reactor Tracer Test With Lamps Off at 4 gpm With Humic Acid

4.1.3.2 *A. brasiliensis* UV Dose per Log and Reduction Equivalent Dose

The collimated beam testing on *A. brasiliensis* was conducted by GAP Analytical out of London, Ontario, Canada. The results in shown on Figure 4.4. These results allow for a calculation of RED for the various pilot test results. The calculation simply measures the log reduction of seeded *A. brasiliensis* across the UV reactor, then converts that LRV to an RED using the collimated beam results.

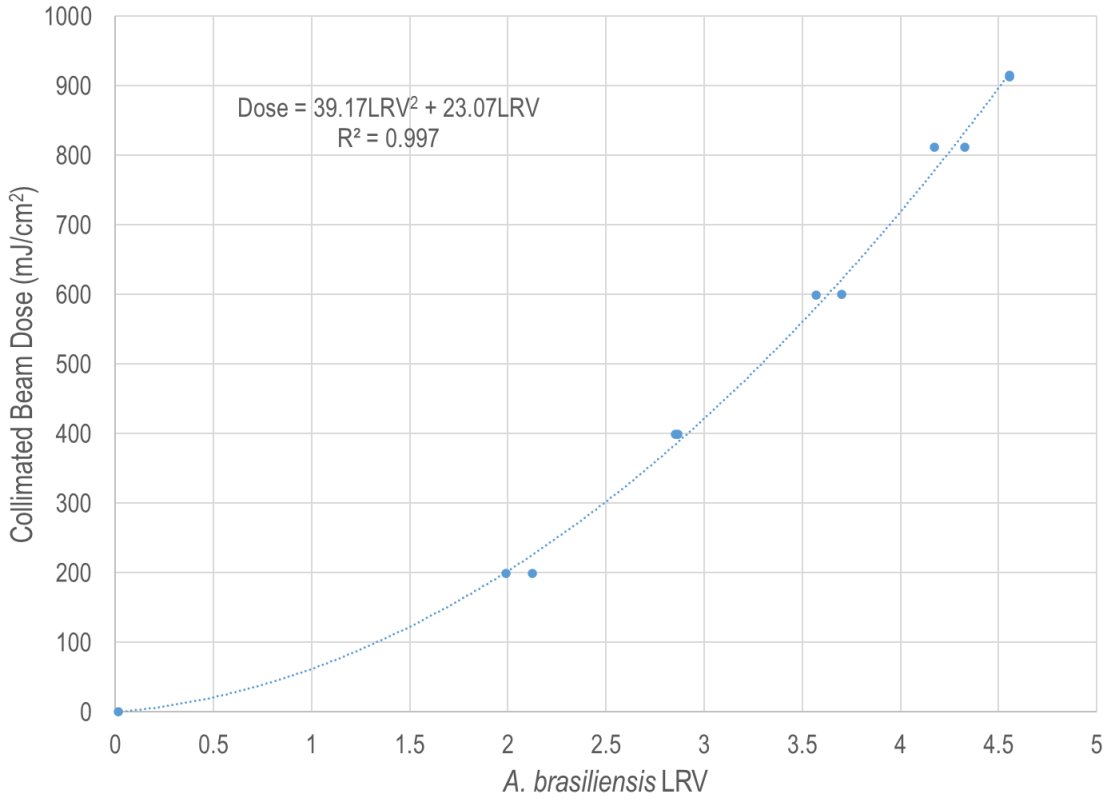


Figure 4.4 *A. brasiliensis* Collimated Beam Results

4.1.3.3 Dose Prediction by UV Intensity and Flow

Eight tests were conducted with seeded *A. brasiliensis*. For these tests, the ballast power was kept to 50 percent and the UVT was approximately 100 percent, as there was no chlorine or chloramines in the RO permeate. At these settings, flow was varied from approximately 11 to 24 gpm to result in WEDECO PSS dose values ranging from 350 to 800 mJ/cm^2 (noting here that this dose value is a PSS dose estimated by the WEDECO HMI). For this analysis, the project team focused upon a simplistic dose "calculation" for the reactor, relying upon the use of the calibrated UVI readings (in milliwatts per square centimeter (mW/cm^2)) and the flow readings (in gpm) to generate a UVI/Q dose value. This UVI/Q approach has proven to accurately predict UV disinfection and NDMA destruction in RO permeate at both full-scale (Oxnard (2018)) and pilot scale (Kothari et al. (2020)). More complex models of reactor performance can be utilized, but was not done so for this effort. The RED for *A. brasiliensis* is shown compared to the UVI/Q approach on Figure 4.5 and demonstrates a significant correlation.

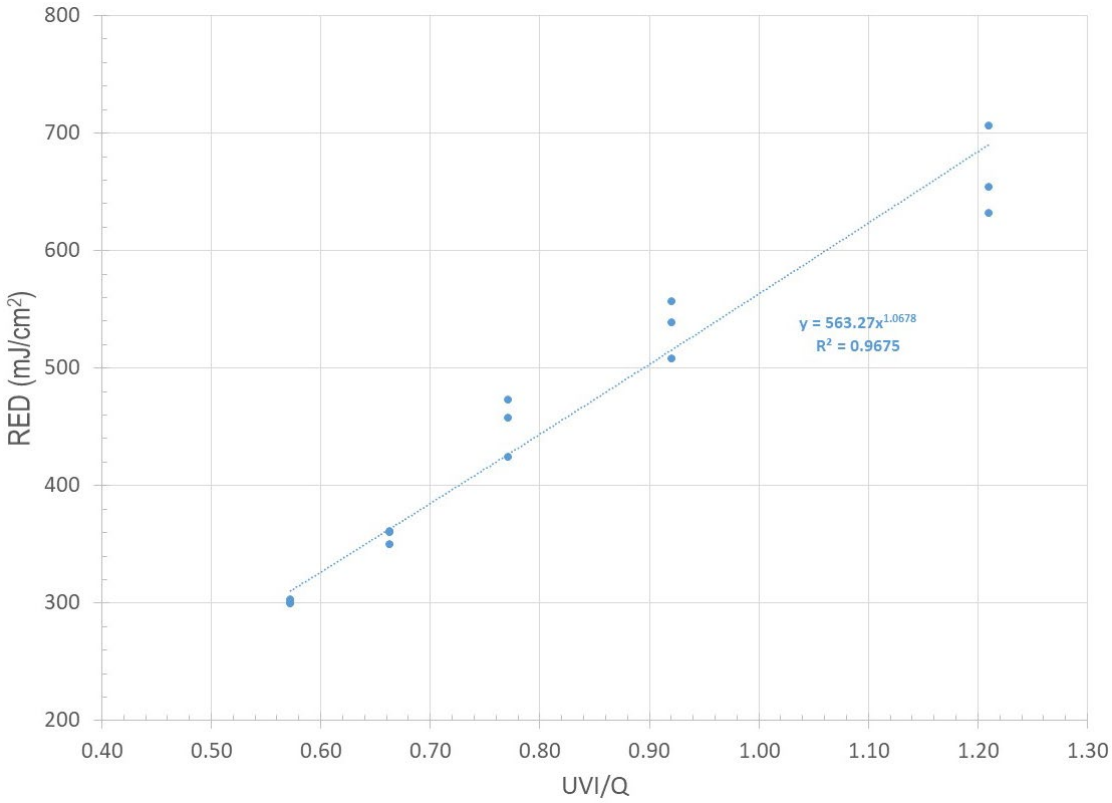


Figure 4.5 RED for the Pilot UV System Correlated to the Ratio of Online Monitored Parameters UVI/Q

4.1.3.4 Comparisons of UVI/Q with the WEDECO PSS Dose Prediction

Figure 4.6 is a plot of the PSS dose vs the RED from the challenge and shows that the PSS dose was reasonably accurate in the range of UVI/Q tested. The Results imply that the ratio of PSS/RED is expected to be within the range of 1.05 to 1.30 during normal operation.

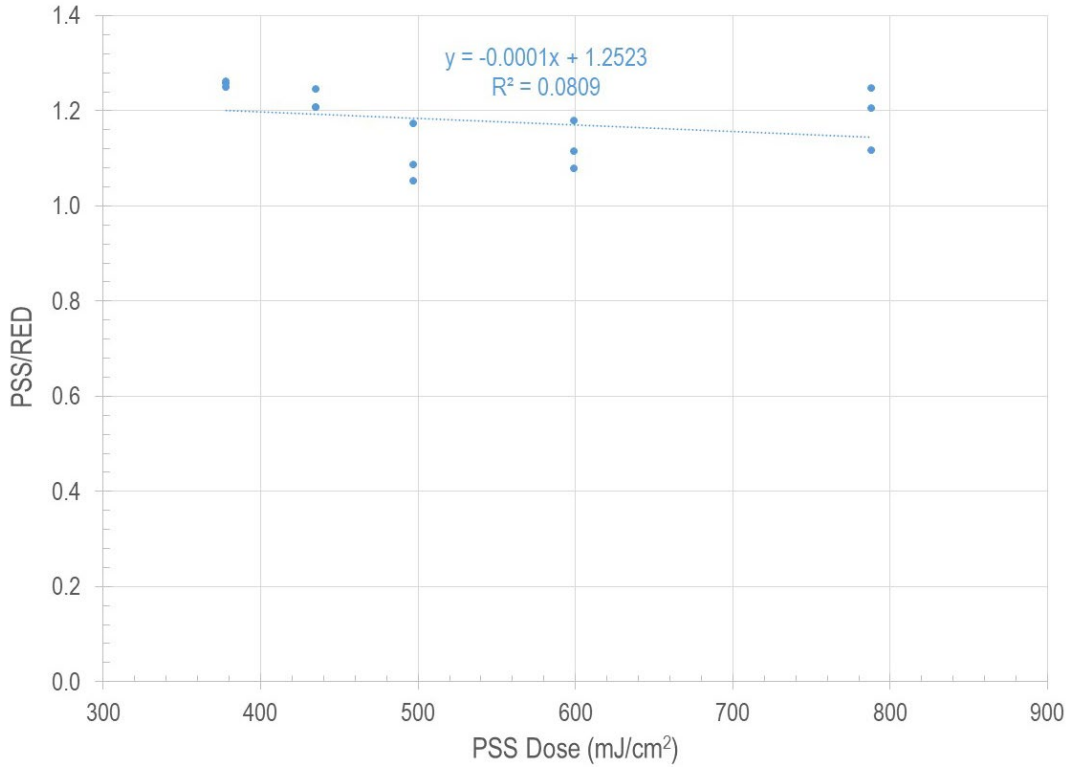


Figure 4.6 Ratio of PSS/RED Over the Range of PSS Doses Evaluated During Challenge Testing

4.1.4 Implications for System Virus LRV

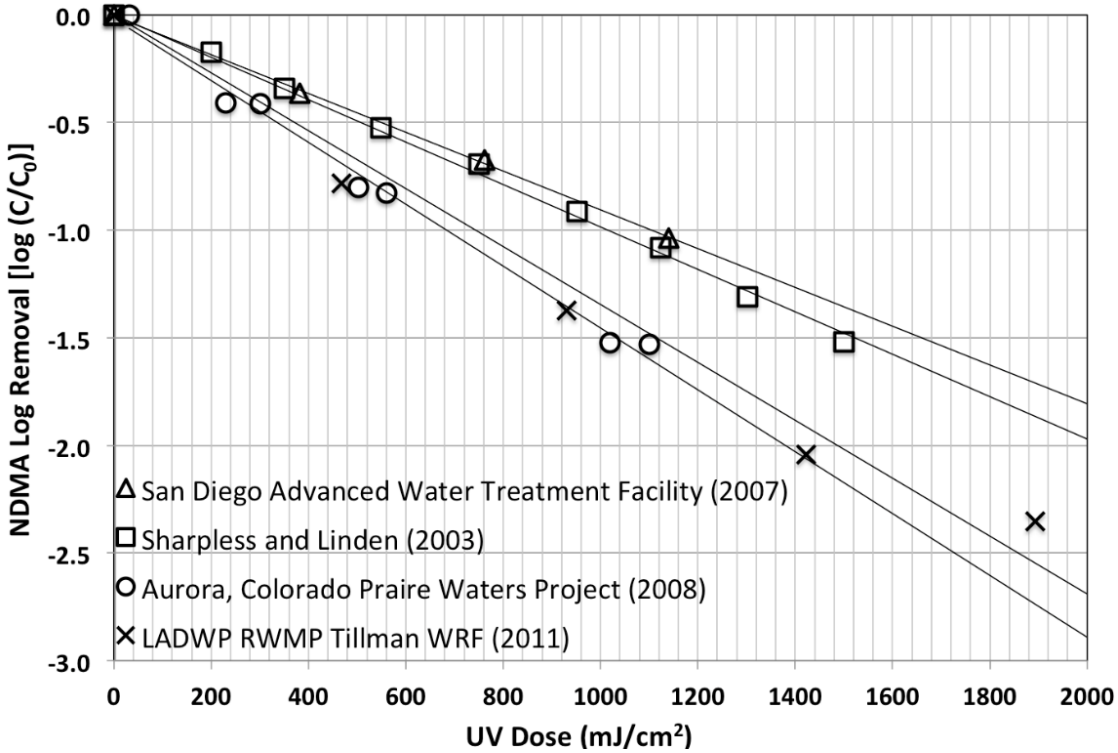
The RED based upon UVI/Q estimation allows for a simple assessment on site of UV reactor disinfection ability (and dose delivery). For reference, the current setpoint for UV operation is at a flow of approximately 6 gpm. UVI values, with chloramine (to limit membrane biofouling) and free chlorine addition (for UV AOP), typically are in the range of 12 to 13 mW/cm^2, resulting in a UVI/Q of >2; a value well above the UVI/Q value of 1.2 that is shown to have an RED of approximately 700 mJ/cm^2. At UVI/Q values of >2, UV dose can be anticipated to be approximately 1,200 mJ/cm^2.

As noted earlier, a dose of 235 mJ/cm^2 is suitable for 6 LRV of adenovirus, one of the most resistant pathogenic viruses to UV treatment and 85 for *Cryptosporidium* and *Giardia*. Based on the RED during normal operation, the LRV of viruses is significantly higher than 6 LRV. As a result, an LRV of 6 is conservatively assumed for all pathogens through the UV AOP.

4.2 NDMA and NMOR

NDMA destruction via photolysis is regulated by DDW (DDW, 2018), with a NL of 10 ng/L. However, the RWQCB is expected to regulate the discharge to the Las Virgenes Reservoir under the CTR. The CTR would require NDMA levels to be 0.69 ng/L, which is below the detection limit (typically 2 ng/L). As such, robust NDMA destruction will be required from the Demo's UV reactor and for the full-scale facility.

The literature indicates that 1 LRV of NDMA occurs within the UV dose range of 700 mJ/cm^2 to 1,100 mJ/cm^2, as shown and referenced on Figure 4.7.



Note: (San Diego, 2007; Sharpless and Linden, 2003; Swaim et al., 2008; Hokanson et al., 2011). Graphic credit: Trussell Technologies.

Figure 4.7 Collimated Beam Bench Testing Results for NDMA Collected in Different Studies

N-nitrosomorpholine (NMOR) is another nitrosamine (like NDMA) which has a monitoring trigger level (MTL) set by the SWRCB at 12 ng/L. Photolysis of NMOR is anticipated at a level similar to NDMA. Due to the low NDMA target (0.69 ng/L), the expectation is that NDMA will be the controlling parameter for UV sizing compared to NMOR.

4.2.1 Test Goals

For this project, pertaining to NDMA, we want to understand the following:

1. Indigenous RO permeate NDMA and NMOR concentrations, which then allow for calculation of the minimum LRV needed through UV photolysis.
2. UV dose needed per log reduction of NDMA, based upon seeded NDMA.
3. NDMA reformation after UV AOP, noting that this phase of work is fairly limited at this time.

4.2.2 Test Description

To meet the above goals, three different tests have been completed.

- First, ongoing sampling for indigenous NDMA and NMOR in RO permeate is part of a broader sampling program. Initial data is presented further on, acknowledging that there remains more sampling to be completed.

- Second, regarding NDMA photolysis by UV, Table 4.1 lists the UV AOP operational conditions for the NDMA challenge study.
- Third, regarding NDMA reformation, limited testing was conducted on the effluent of the UV AOP system during the NDMA challenge studies.
  - Two spiked effluent samples were taken and stored in rinsed cubitainers. The storage times were 1 hour and 24 hours. This provided an estimate of potential near and long term reformation. A blank sample, DI water in a similarly stored cubitainer was also analyzed.

Table 4.1 Planned Seeded NDMA UV Photolysis Test Conditions(1)

Test Condition	RO Feed Total Chlorine, mg/L	UV Feed Free Chlorine, mg/L	PSS UV Dose, mJ/cm^2	Flow, gpm
1a	2	2	600	12
1b	2	3.5	600	12
1c	2	5	600	12
2a	2	2	1,200	6
2b	2	3.5	1,200	6
2c	2	5	1,200	6
3a	2	2	1,800	4
3b	2	3.5	1,800	4
3c	2	5	1,800	4
3d	2	6	2,400	3
4a	2	0	1,200	6
4b	3	0	1,200	6
4c	4	0	1,200	6
5a	0	0	600	13
5b	0	0	1,200	7
5c	0	0	1,800	4
3c-2	2	5	1,800	4
3d-2	2	6	2,400	3

Note:
(1) Reactor power was kept constant at 50 percent during testing. Applied dose was controlled by systematic variation of the flowrate to the reactor.

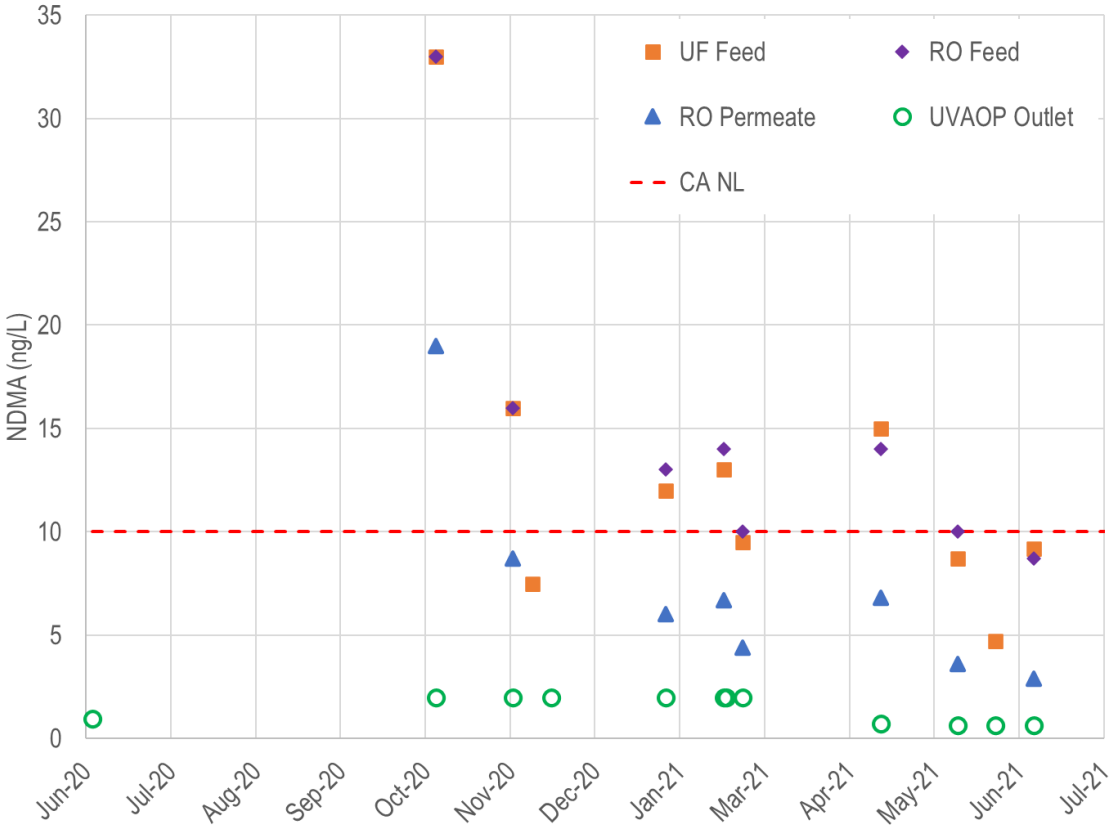
4.2.3 NDMA Results

4.2.3.1 Indigenous NDMA and NMOR Results

Figures 4.8 and 4.9 contained the indigenous NDMA and NMOR concentrations observed during available monthly sampling for the Demo under normal operation. Based on the indigenous NDMA and NMOR data obtained, the following observations were made:

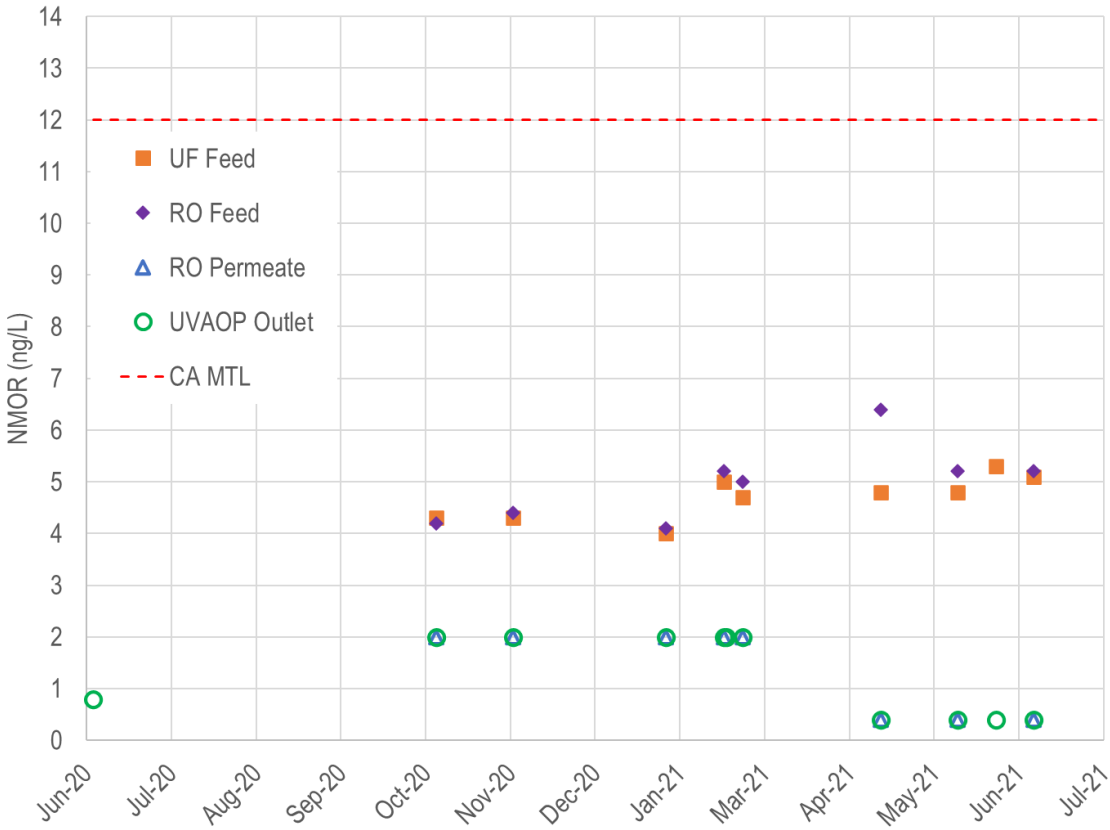
- NMOR was detected in UF and RO feed below the CA MTL and has been consistently removed to below the detection limit in RO permeate. The maximum observed NMOR concentration of 8.2 ng/L was seen in the RO feed and the median was 5.2 ng/L.

- NDMA has exceeded the CA NL of 10 ng/L in UF feed, RO feed and RO permeate (on one occasion).
- NDMA has typically not been detected in the UV AOP outlet. However, there was one reported detection at 2.9 ng/L on June 9, 2021. On this date, the RO permeate was reported as a non-detect. The contract laboratory has been queried about this point as it is suspected that the RO permeate and UV AOP data have been accidentally switched upon report generation. The reasoning behind this is that for an entire year, the RO permeate has been between 3-7 ng/L, while the UV AOP has been non detect.
- The maximum observed NDMA concentration in RO permeate has been 19 ng/L while the median has been 6.7 ng/L.



Note: Empty bars are below the detection limit (<2 ng/L). Detection limits were different depending on the contract laboratory, with the highest detection limit of 2 ng/L.

Figure 4.8 Indigenous NDMA Concentration in UF Feed, RO Feed, RO Permeate and Finished Effluent (UV AOP)



Note: All samples were below the CA MTL and all RO permeate and UV AOP outlet were below the detection limit. Detection limits were different depending on the contract laboratory, with the highest detection limit of 2 ng/L.

Figure 4.9 Indigenous NMOR Concentration in the UF Feed, RO Feed, RO Permeate and Finished Effluent (UV AOP)

4.2.3.2 Seeded NDMA Destruction Results

The NDMA destruction testing occurred over three days, February 2, 3, and 5. The same NDMA feed stock was dosed into the RO permeate for those three days, all at the same RO permeate flow rate and the same NDMA feed pumping rate. Influent samples were not taken for every test condition due to assumed stability of the dosed concentrations. For the analysis, the average UV influent NDMA concentration was used for each day of testing. The NDMA concentrations and LRVs are presented in Table 4.2 alongside the UVI/Q "dose" calculations. The UVI/Q values for the tests are plotted versus NDMA LRV are shown on Figure 4.10.

Table 4.2 Planned Seeded NDMA UV Photolysis Test Conditions

Test Condition	Test Date	UVI, mW/cm^2	Flow, gpm	UVI/Q	UV Influent NDMA, ng/L	UV Outlet NDMA, ng/L	NDMA LRV
1a	2/5/2021	13.0	12.1	1.1	3,100	460	0.8
1b	2/5/2021	13.2	12.3	1.1		470	0.8
1c	2/5/2021	13.1	12.3	1.1		380	0.9
2a	2/5/2021	13.3	6.5	2.0	3,200	68	1.7

Test Condition	Test Date	UVI, mW/cm^2	Flow, gpm	UVI/Q	UV Influent NDMA, ng/L	UV Outlet NDMA, ng/L	NDMA LRV
2b	2/5/2021	13.4	6.6	2.0	3,000	74	1.6
2c	2/5/2021	13.1	6.5	2.0	3,000	64	1.7
3a	2/5/2021	13.3	4.5	3.0	2,900	19	2.2
3b	2/5/2021	13.4	4.5	3.0		15	2.3
3c(1)	2/2/2021	13.3	4.5	3.0		15	2.2
3d(1)	2/2/2021	13.2	3.4	3.9	2,400	3.4	2.8
4a	2/2/2021	13.1	6.5	2.0	2,400	93	1.4
4b	2/2/2021	12.9	6.3	2.0	2,500	97	1.4
4c	2/2/2021	12.3	6.1	2.0	2,200	81	1.5
5a	2/3/2021	13.9	13.1	1.1	3,100	360	0.9
5b	2/3/2021	13.9	6.9	2.0		65	1.7
5c	2/3/2021	13.9	4.7	3.0	3,100	16	2.3
3c-2	2/5/2021	13.0	4.4	3.0		< 2	>3.2
3d-2	2/5/2021	13.2	3.4	3.9		3.8	2.9

Notes:
(1) During the initial run tests 3c and 3d were impacted by poor free chlorine dosing. Although this should not impact NDMA removal, the tests were terminated, the chlorine dosing lines flushed and tests 3c and 3d repeated as 3c-2 and 3d-2. Initial runs 3c and 3d may not be representative of correct operation.

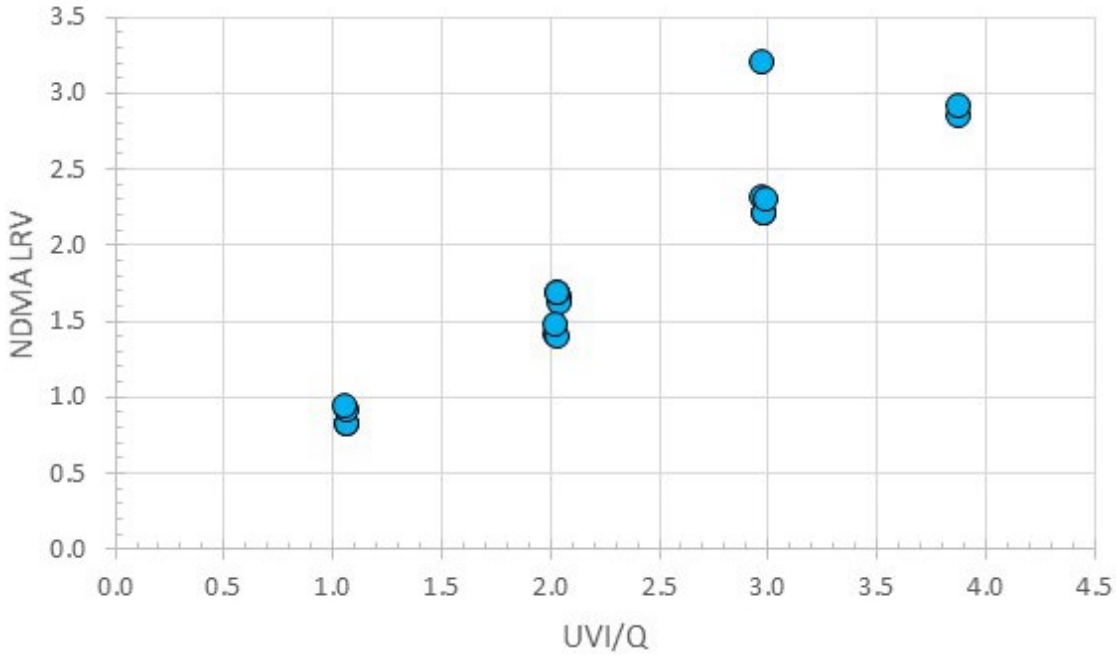


Figure 4.10 NDMA Log Reduction as a Function of UVI/Q

The data above, with the exception of the one apparent data outlier, shows good and predictable performance. A few summary points are presented below.

- A log-linear NDMA reduction as a function of UV dose (UVI/Q) is seen.
- The test conditions included different levels of free and total chlorine, necessary to test different UV AOP dose values (as detailed in a subsequent section on 1,4 dioxane destruction). Those different chlorine dose values do not appear to impact NDMA destruction performance or predictability.
- Assuming an NDMA feed concentration of 20 ng/L, higher than the highest observed RO permeate value of 19 ng/L, and targeting a CTR NDMA value of 0.69 ng/L, approximately 1.5 LRV of NDMA is needed, which correlates to a UVI/Q of approximately 2, which is coincidentally the current UVI/Q operational setpoint for the UV system.
- As a rough estimate of UV dose, the bioassay-based RED for a UVI/Q of 2 is extrapolated to be approximately 1,200 mJ/cm^2, which is a reasonable UV dose for 1.5 LRV of NDMA based upon the literature cited previously.
- This data shows that much higher LRV of NDMA can be obtained and the performance is log-linear and predictable.

4.2.3.3 NDMA Reformation Results

Limited NDMA reformation tests were conducted, with results shown in Table 4.3. The following methods were employed for these tests:

1. Testing was done during NDMA spiking, so the UV effluent concentrations were much higher than would be during normal operation.
2. Time zero samples were collected and placed immediately into sample containers with quenching agents (sodium metabisulfite), similar to all NDMA dose/response challenge testing.
3. Held samples were stored at ambient temperature in cubitainers with no quenching agent. Prior to taking the samples, each cubitainer was filled rinsed several times with UV AOP effluent then finally rinsed with steam distilled DI water, including a field blank. Cubitainers were left to dry overnight prior to receiving samples the following day.
4. At the allocated time value (1 hour and 24 hours), water was poured from the cubitainer to a sample bottle which has the quenching agent.

These results indicate some potential reformation, in the range of 25 to 30 percent within one to 24 hours. Further testing is warranted to understand the reformation under ambient conditions. Toward that goal, sampling of UV influent, UV effluent (time zero), UV effluent (time 1 hour), and UV effluent (time 24 hours) is recommended with sufficient repetition to gain confidence in the data set. Consideration should be given toward stabilization of effluent in a method consistent with future full-scale stabilization methods.

Table 4.3 NDMA Reformation Results

Test Condition	Test Date	Total Chlorine Concentration (grab sample) at UV Effluent, mg/L	Free Chlorine Concentration (grab sample) at UV Effluent, mg/L	UV Effluent NDMA, time zero, ng/L	UV Effluent NDMA, time 1 hour, ng/L	UV Effluent NDMA, 24 hours, ng/L
2b	2/5/21	2.66	2.07	74	73	94
3c	2/2/21	2.08	1.90	15	19	18
Blank	2/3/21	ND	ND	NA	NA	<2

4.2.4 Advanced Oxidation

The UV AOP at the Demo combines high intensity UV light with sodium hypochlorite to generate the necessary radicals for destruction a broad range of other chemical pollutants. DDW (2018) requires all IPR groundwater recharge and reservoir augmentation projects to provide, at a minimum, 0.5-log removal of 1,4-dioxane after the RO process. Destruction of 1,4-dioxane is a surrogate for broader removal of trace pollutants, as demonstrated by Hokanson et al. (2011) (Figure 4.11).

The destruction of 1,4-dioxane has been shown to directly correlate with the combined dose of UV and the oxidant (e.g., hypochlorite) (Oxnard (2018), City of Los Angeles (2018)), noting that performance appears to be site specific, and the dose must be determined on site.

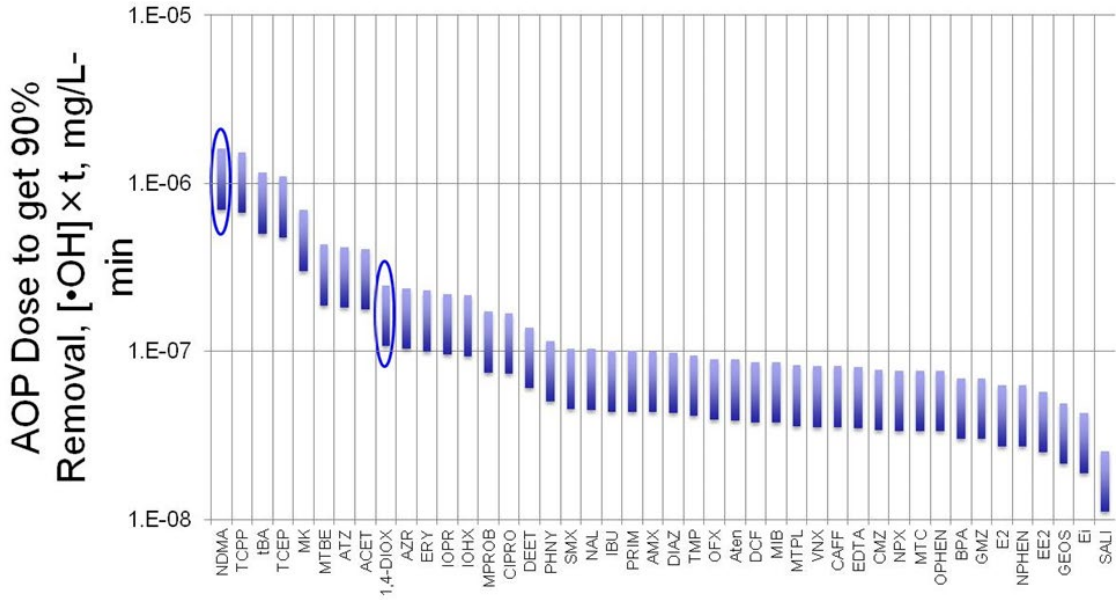


Figure 4.11 Destruction of Trace Pollutants by UV AOP (Hokanson et al., 2011)

4.2.5 Test Goals

For this project, pertaining to 1,4 dioxane, we want to understand:

1. Destruction as a function of UV dose and free chlorine dose.
2. Understanding of water chemistry impacts (e.g., pH, upstream chloramines, UVT).

4.2.6 Test Description

The test conditions for the 1,4 dioxane destruction were the same as for NDMA, but were also sampled to account for variation in applied UV dose and to cover a range of operating chlorine concentrations. The operating conditions are repeated in Table 4.4 with some additional notes as to the intent of each experimental run.

Table 4.4 Planned Seeded 1,4 Dioxane Advanced Oxidation Test Conditions

Test Condition	RO Feed Total Chlorine, mg/L	UV Feed Free Chlorine, mg/L	UV Dose, mJ/cm^2	Flow, gpm
Test 1	**Evaluation of Low UV Dose AOP With Both Chloramines and Free Chlorine**			
1a	2	2	600	12
1b	2	3.5	600	12
1c	2	5	600	12
Test 2	**Evaluation of Medium UV Dose AOP With Both Chloramines and Free Chlorine**			
2a	2	2	1,200	6
2b	2	3.5	1,200	6
2c	2	5	1,200	6
Test 3	**Evaluation of High UV Dose AOP With Both Chloramines and Free Chlorine**			
3a	2	2	1,800	4
3b	2	3.5	1,800	4
3c	2	5	1,800	4
3c-2(1)	2	5	1,800	4
3d	2	6	2,400	3
3d-2(1)	2	6	2,400	4
Test 4	**Evaluation of Destruction by Chloramines Only**			
4a	2	0	1,200	6
4b	3	0	1,200	6
4c	4	0	1,200	6
Test 5	**Evaluation of Destruction With No Chlorine**			
5a	0	0	600	13
5b	0	0	1,200	7
5c	0	0	1,800	4

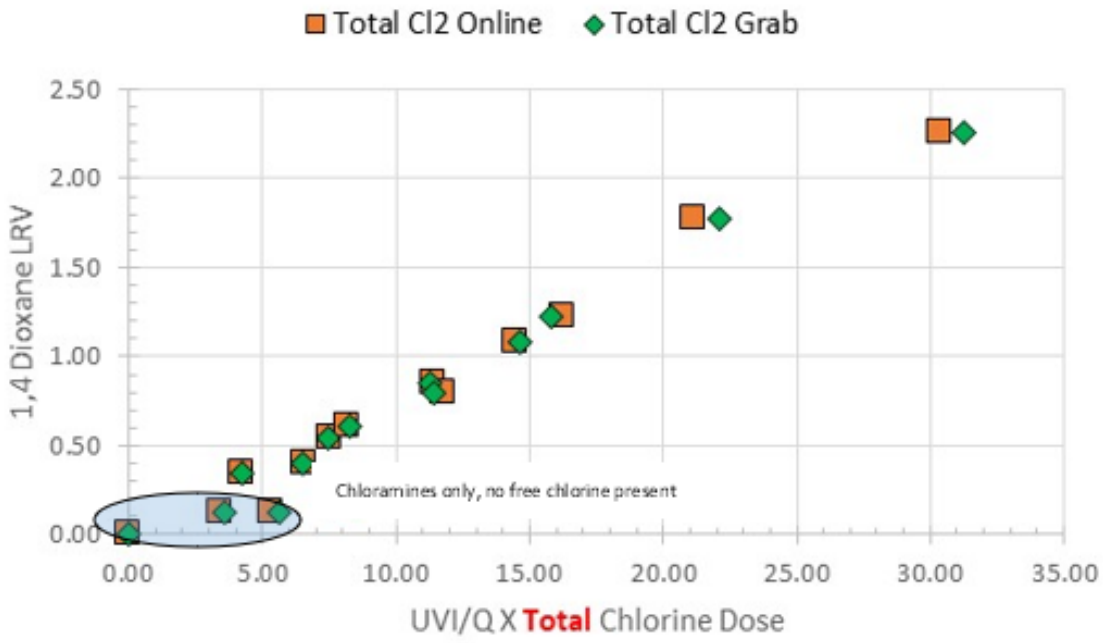
Note:
(1) During the initial run tests 3c and 3d were impacted by poor free chlorine dosing. The tests were terminated, the chlorine dosing lines flushed and tests 3c and 3d repeated as 3c-2 and 3d-2. Initial runs 3c and 3d may not be representative of correct operation.

4.2.7 1,4-Dioxane Removal Results

Figures 4.12 through 4.17 illustrate the robust and predictable 1,4 dioxane destruction as a function of UV dose and oxidant dose. The results allow for conclusions on operational setpoints

for the UV AOP on the demo as well as estimate operational setpoints for future full-scale UV AOP. Conclusions for the data are:

- All tests have chloramines present in the RO permeate, due to the need to minimize membrane biofouling. As such, all free chlorine tests had chloramines in the water.
- UVI/Q*Chlorine dose predicts 1,4 LRV well.
- Data indicates that use of either grab sample data or online data for free and combined chlorine accurately predicts UV AOP dose/response.
- The UV dose (High, Medium, Low) does not result in better or worse performance for the same UVI/Q X Chlorine value.
- Free chlorine UVI/Q substantially outperforms chloramines (only) UVI/Q in limited testing over the same UVI/Q*dose range. Monitoring based upon free chlorine dose appears to be most appropriate.
- Based upon a linear interpretation of the free chlorine UV AOP data set, and understanding that a UVI/Q of 2 provides 1.5 LRV of NDMA (sufficient to take ambient levels below 0.69 ng/L), a free chlorine residual ahead of UV of 2.5 mg/L is needed to maintain 0.5 LRV of 1,4 dioxane. As such, an operational setpoint for free chlorine residual ahead of UV AOP of 3 mg/L coupled with a UVI/Q setpoint of 2 is recommended until further data is collected (e.g., related to disinfection byproducts and reformation).



Note: The oval highlights the lower three results where chloramine and no free chlorine were present.

Figure 4.12 1,4 Dioxane Destruction as a Function of UV Dose Multiplied by Total Chlorine Concentration in UV Influent (Using Both Grab and Continuous Chlorine Data)

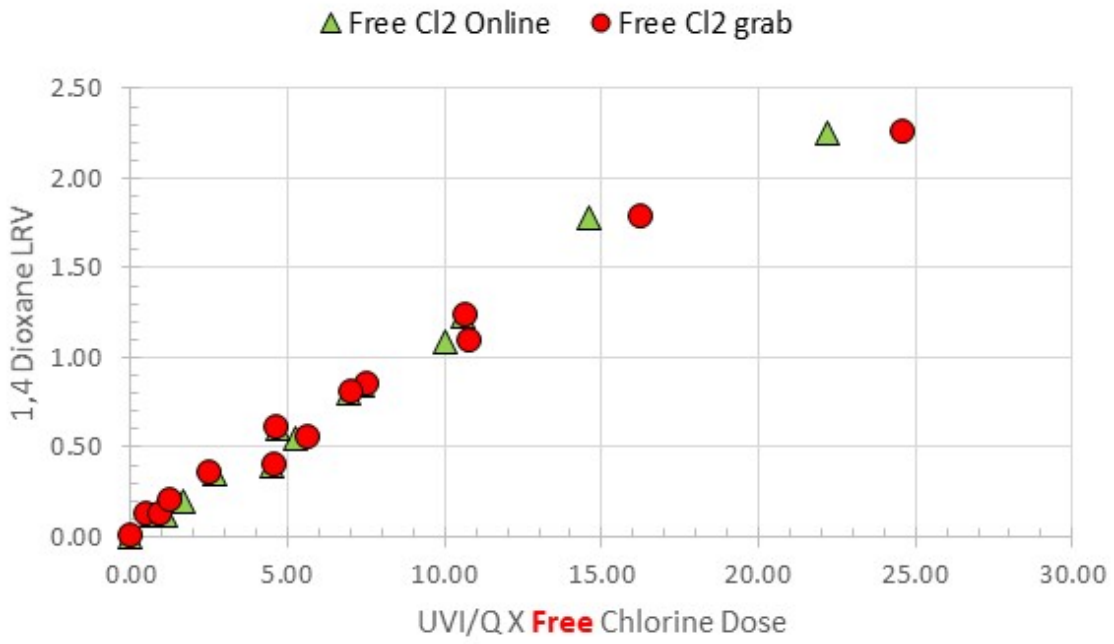
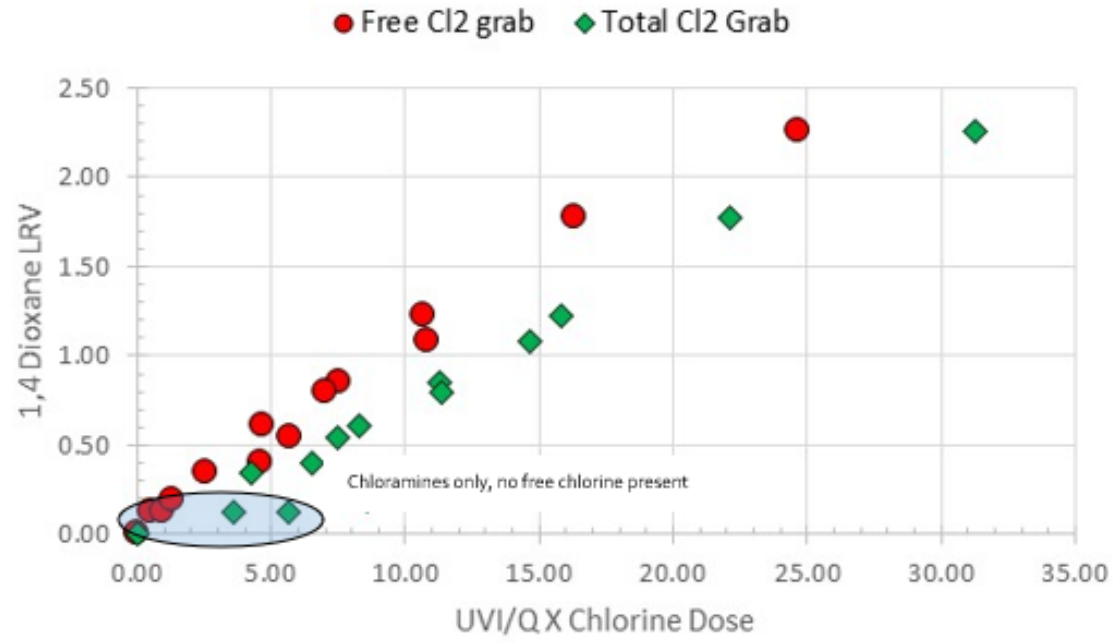


Figure 4.13 1,4 Dioxane Destruction as a Function of UV Dose Multiplied by Free Chlorine Concentration in UV Influent (Using Both Grab and Continuous Chlorine Data)



Note: The oval highlights the lower three results where chloramine and no free chlorine were present.

Figure 4.14 Comparison of Total Chlorine and Free Chlorine UV AOP Destruction of 1,4 Dioxane (Using Grab Sample Chlorine Data Only)

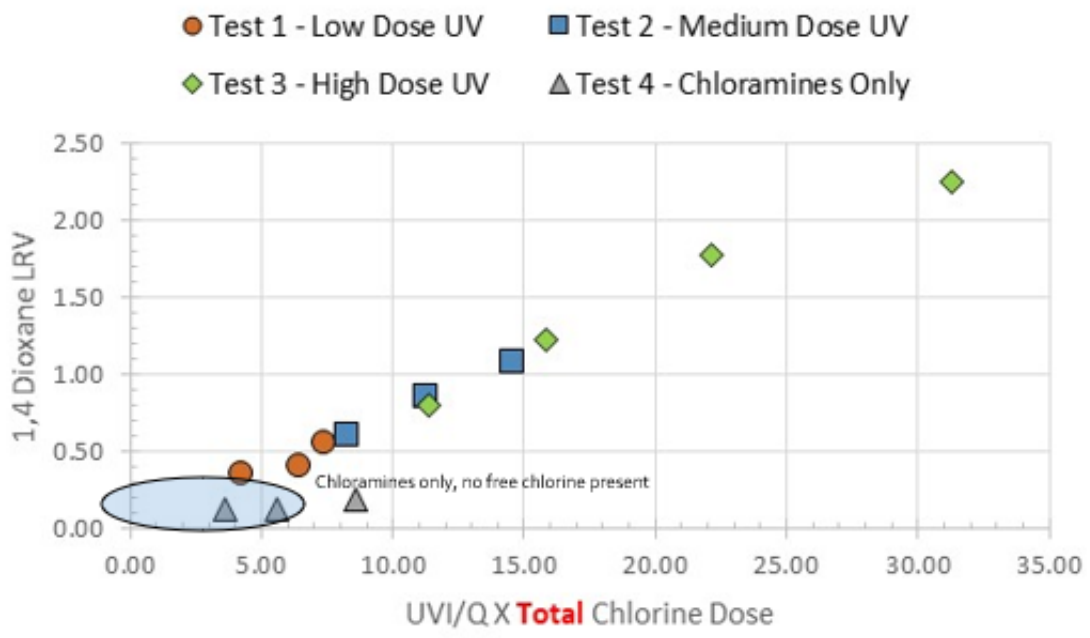


Figure 4.15 Comparison of Total Chlorine UV AOP Destruction of 1,4 Dioxane Differentiated by UV Dose (Using Grab Sample Chlorine Data Only)

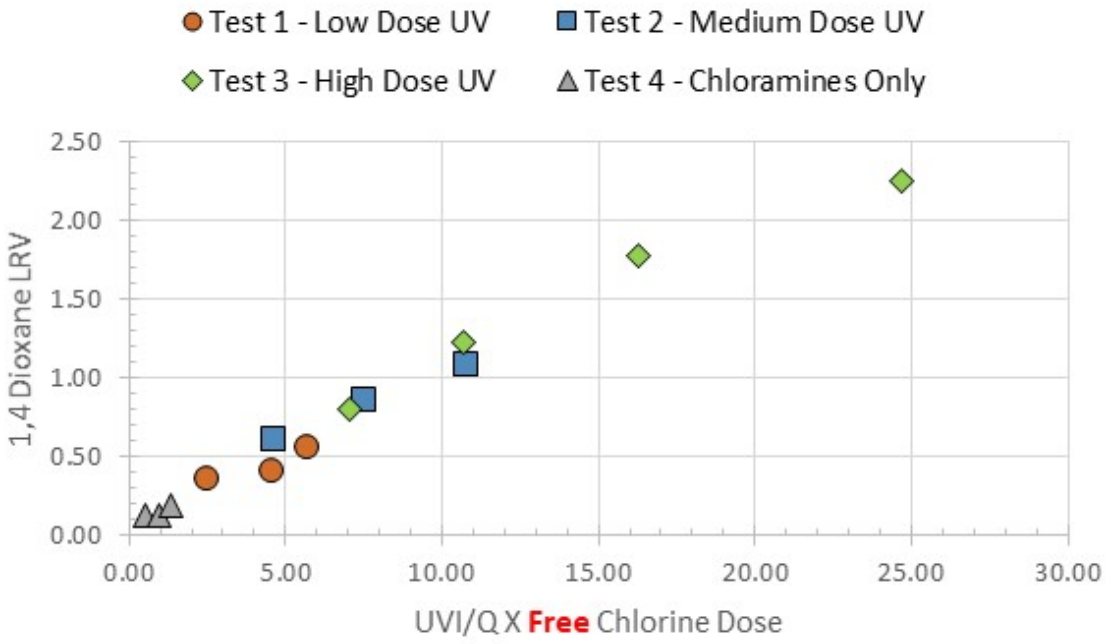


Figure 4.16 Comparison of Free Chlorine UV AOP Destruction of 1,4 Dioxane Differentiated by UV Dose (Using Grab Sample Chlorine Data Only)

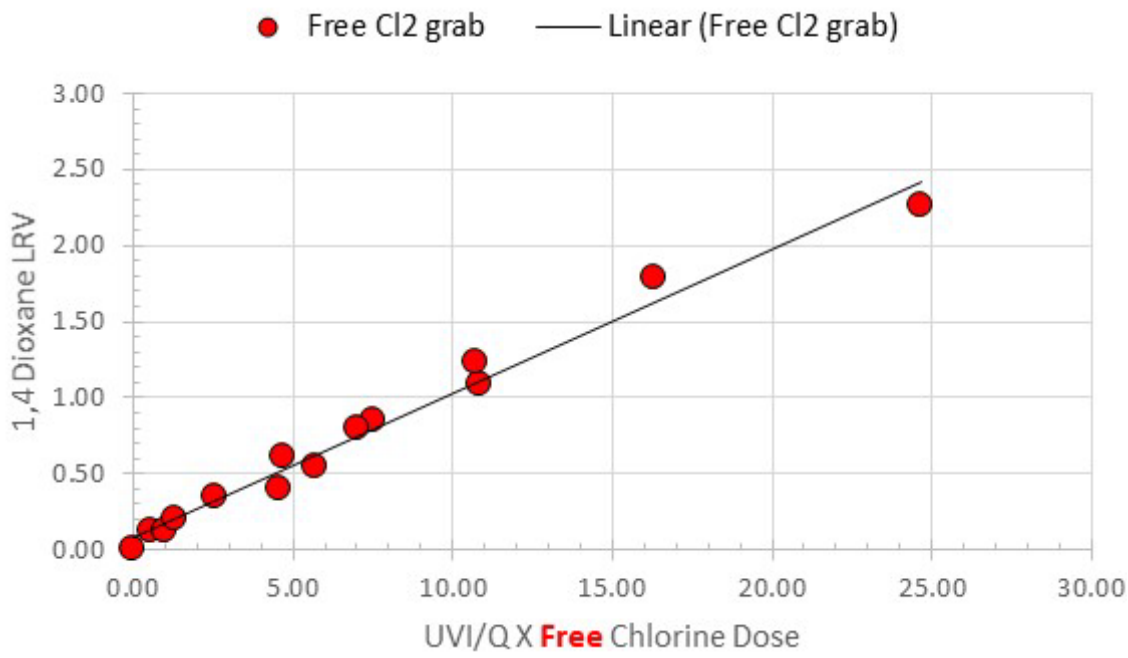


Figure 4.17 Free Chlorine UV AOP Destruction of 1,4 Dioxane (Using Grab Sample Chlorine Data Only)

4.2.8 DBP Monitoring During Challenge Testing

Bromate, bromide, dichlorobromomethane (DCBM) and dibromochloromethane (DBCM) were studied across a subset of test parameters to represent conditions of low UV and chlorine dose, mid-level UV and chlorine dose and high UV and chlorine dose. The results are summarized in Table 4.5.

Table 4.5 Bromate Formation Potential Subsampling During UV AOP Testing

Test	Target Test Parameters			Bromide (µg/L)		Bromate (µg/L) (1)	
	Target RO Feed Total Chlorine (mg/L)	Target UV Feed Free Chlorine (mg/L)	Dose (mJ/cm^2)	UV In	UV Out	UV In	UV Out
1A	2	2	600	6.5	8.8	<1	<1
2B	2	3.5	1200	6.1	7.7	<1	<1
3C	2	5	1800	5.8	<5	<1	<1
3D	2	6	2400	5.2	<5	<1	2.5
4A	2	0	1200	5.7	7.2	<1	<1
5B	0	0	1200	<5	<5	<1	<1

Note:
(1) The CA MCL for bromate is 10 µg/L.

The following observations can be made from the bromate formation analysis:

- Bromide was not detected in UV influent when chloramine dosing was switched off (Test 5B) suggesting its presence was related to upstream chloramination – likely originating from the hypochlorite stock.
- Bromate was only detected in the UV AOP effluent at 2.5 µg/L at the highest applied UV dose of 2,400 mJ/cm^2 and highest applied oxidant dose of 6 mg/L as free chlorine.
- Bromate was not detected above the CA MCL of 10 µg/L under any test condition.

These results suggest that operation at the moderate dose of 3.5 mg/L free chlorine with 1,200 mJ/cm^2 UV dose currently practiced at the Demo would be unlikely to result in bromate formation.

Formation of DBCM and DCBM were anticipated to be related to the applied free chlorine dose. As such, subsampling for each was conducted at constant mid-level dose of 1,200 mJ/cm^2 and varied upstream chloramine and free chlorine concentrations. The occurrence of DBCM during the challenge test event at different applied free chlorine and chloramine doses is shown in Table 4.6.

Table 4.6 Chlorodibromomethane (DBCM) Monitoring During UV AOP Challenge

Test	Target and Predicted Test Parameters			chlorodibromomethane (DBCM) (µg/L)	
	Target RO Feed Total Chlorine (mg/L)	Target UV Feed Free Chlorine (mg/L)	Dose (mJ/cm^2)	UV In	UV Out
2A	2	2	1,207	0.72	<0.5
2B	2	3.5	1,207	<0.5	<0.5
2C	2	5	1,207	0.71	<0.5
4A	2	0	1,207	0.67	<0.5
5B	0	0	1,207	0.56	<0.5

Notes:
(1) Chlorodibromomethane MCL is expressed as total niecetrihalomethanes which must be less than 80 µg/L.
(2) Chlorodibromomethane has a California toxics rule requirement to be less than 0.41 µg/L.

- DBCM was detected in 4 of 5 UV influent samples during the challenge testing, with all detections within 0.3 µg/L of the detection limit of 0.5 µg/L.
- DBCM detections and results did not appear to correlate with applied chlorine or chloramine dosage.
- DBCM was not detected in any of the 5 UV outlet samples suggesting that there may have been some removal through the UV reactor.
- DBCM levels were well below the MCLs – expressed as total trihalomethanes and therefore do not constitute a risk to public health.
- The method reporting limit for DBCM is not sufficient to confirm compliance with the California toxics rule.
- DBCM fate across the plant is discussed further in the water quality section.

The occurrence of BDCM during the challenge test event at different applied free chlorine and chloramine doses is shown in Table 4.7.

Table 4.7 Dichlorobromomethane (BDCM) Monitoring During UV AOP Challenge

Test	Target and Predicted Test Parameters			dichlorobromomethane (BDCM) (µg/L)	
	Target RO Feed Total Chlorine (mg/L)	Target UV Feed Free Chlorine (mg/L)	Dose (mJ/cm^2)	UV In	UV Out
2A	2	2	1207	2.4	2.1
2B	2	3.5	1207	2.5	2
2C	2	5	1207	2.2	2
4A	2	0	1207	2.2	2
5B	0	0	1207	1.9	1.7

Notes:
(1) The Dichlorobromomethane MCL is expressed as total trihalomethanes which must be less than 80 µg/L.
(2) Dichlorobromomethane has a California toxics rule requirement to be less than 0.56 µg/L.

- BDCM was detected in all UV inlet and UV outlet samples at concentrations close to 2 µg/L.
- BDCM levels were well below the MCLs - expressed as total trihalomethanes and therefore do not constitute a risk to public health.
- BDCM levels observed during challenge testing were approximately 4 times higher than the California toxics rule requirement of 0.56 µg/L.
- UV outlet concentrations appeared to be 10-20 percent lower than influent concentrations suggesting some removal.

Both BDCM and DBCM may be removed by the UV AOP. To that end it is recommended to perform some sampling for DCBM and DBCM at higher UV doses of 1,800 and 2,400 mJ/cm^2 to assess if enhanced removal of these compounds can be achieved.

DBCM and BDCM concentrations did not appear to correlate with applied chloramine or free chlorine at the Demo suggesting that their formation may occur upstream. Limited DBP sampling is discussed in Section 5.1.2.2 and DBCM and BDCM were detected at higher concentrations prior to RO - in the UF feed. The fate of DBCM and BDCM are discussed further in the water quality section.

Bromate formation may have occurred at a UV and free chlorine dose 2 x higher than currently applied at the demonstration plant. It is recommended to keep UV dose below 2,400 mJ/cm^2 and free chlorine dose below 6 mg/L to minimize potential for bromate formation.

4.2.9 Recommendations for UV AOP Operation

Based on the UV AOP challenge testing operational recommendations are to operate at a UVI/Q > 2.2 and a free chlorine dose >2.5 mg/L. The current monochloramine dose target of 2-2.5 mg/L appears to result in an inlet UVT transmittance close to 97 percent, where a majority of challenge testing was conducted and should also be maintained. The impact of operation on removal of pathogenic microorganisms, NDMA and 1,4-Dioxane are summarized in Table 4.8.

Table 4.8 Recommended Operational Setpoints on the Demo UV AOP to Achieve Pathogen, NDMA and 1,4-Dioxane Removal

Performance Metric	Free chlorine Dose, mg/L	Demo UV Reactor Dose, UVI/Q ($mW/cm^2/gpm$)	Future Full-Scale UV Reactor, mJ/cm^2
6-log adenovirus	N/A	≥0.6	≥276
1.5 LRV NDMA	N/A	≥2.0	1,050 to 1,650
0.5 LRV 1,4 Dioxane	Flexible, example here is ≥2.5	≥2.0	Flexible, example range for 2.5 mg/L of hypochlorite - 1,050 to 1,650
Current Setpoints	3.2	2.2	

Note:
(1) The current monochloramine dose of 2 – 2.5 mg/L results in a UV inlet UVT close to 97 percent, where challenge testing was conducted.

Further sampling of DBCM and BDCM is recommended at higher doses and also in the UF Feed, RO Feed, and UV AOP influent and outlet to assess the fate and removal across the plant in order to make recommendations on how to meet the California toxics rule with these challenging compounds.

Chapter 5

WATER QUALITY ANALYSIS

5.1 Chemical Water Quality Parameters

5.1.1 Water Quality Sampling

The sampling program was defined in the November 2020 report titled "Pure Water Demonstration Test Plan". Since commencing operations, there have been changes in contract laboratories that have resulted in some challenges collecting the full range of intended data, though what has been collected demonstrates comprehensive system performance to regulatory targets. The sampling program is summarized in Tables 5.1 and 5.2.

Table 5.1 Description of Sample Suites Included in the Demo Water Quality Monitoring Plan

Sample Group	Analyte Description
Weekly	General Water Quality – Nitrogen, TSS, Alkalinity, Iron, Aluminum, TOC, Silica, Manganese, Bromide, Bromate
Two Weeks (Bi-monthly)	RO Surrogates (Sulfate, Strontium, Sucralose,), BOD, COD, TOC
Monthly	RO Feed and Permeate Inorganics (Iron, Aluminum, Manganese, Calcium, Magnesium, Sodium, Potassium, Barium, Chloride, Fluoride, Boron). NDMA and NMOR (UF Feed, RO Feed, RO Permeate, UV AOP Effluent), RO Concentrate (Gross Beta, Tributyltin, Aldrin, Benzidine, Beryllium, Chlordane, Dichlorodiphenyltrichloroethane, 3,3-Dichlorobenzidine, Dieldrin, Heptachlor epoxide, Polychlorinated biphenyls (PCBs), 2,3,7,8-Tetrachlorodibenzodioxin equivalents, Toxaphene). UV AOP outlet total coliforms.
Quarterly	Primary and Secondary MCLs, NLs (UF feed and UV AOP outlet), CECs, pharmaceuticals and personal care products (PPCPs), and DBPs (UF Feed, RO Permeate, UV AOP Outlet)
First Quarter	One off sampling – PFAS EPA 5371.1, TOPA [UF Feed and UV AOP outlet], RO Concentrate Toxicity, Bioassays [RO Feed, RO Permeate UV AOP outlet]
Prior to Tasting	One Off Sampling UV AOP Outlet - Most MCLs, sMCLs, NL.

Table 5.2 Number of Available Sampling Events per Suite for the First Year of Operation

	Weekly	Twice Monthly	Monthly	Quarterly
Number of Events	35	15	10	2(1)

Note:
(1) The prior to tasting sampling event collected a number of analytes that were included in the quarterly suite providing n=3 for a shortlist of the quarterly target analytes.

5.1.2 Finished Water Quality

This section reports on finished water quality at the demonstration plant.

5.1.2.1 Regulated Compounds in Finished Water (MCLs, SMCLs and NLs)

Constituents with MCLs, SMCLs and NLs were targeted to be sample quarterly.

Due to laboratory supply chain and scheduling challenges, it was not possible to gain a complete set of 4 quarterly samples for this report. However, the results from quarterly sampling and also an initial and extensive tasting sampling effort are summarized in Tables 5.3 through 5.8 for the first year of operation.

For regulated compounds with MCLs, SMCLs and NLs, the following observations can be made based on the sampling efforts to date:

- No compounds exceeded regulatory limits, indicating that the Demo is providing water of appropriate quality for potable water reuse.
  - The exception was initial chlorate and threshold odor number (TON) values. During initial sampling, prior to tasting, chlorate was detected at 1100 µg/L, above the NL of 800 µg/L and TON was detected at 12, above the SMCL of 3.
    - The presence of chlorate and the TON exceedance were traced to poor quality sodium hypochlorite which was replaced.
    - Specific follow up sampling was conducted and verified that chlorate and TON had returned to below regulatory limits after rectifying the poor-quality sodium hypochlorite.
    - Following identification of the impact of aged and poor-quality sodium hypochlorite, operations staff have taken the following proactive steps:
      - Adjusting ordering schedules such that sodium hypochlorite is consumed within a target of 2 weeks and does not exceed 1 month storage onsite.
      - Rotating sodium hypochlorite stock such that UV feed and UF feed hypochlorite is always fresh and aged stock is limited for non-consumptive use in UF membrane cleaning.
      - Spot checks of strength and review of production batch dates on receipt of orders.
- A majority of compounds were below laboratory detection limits.
    - If compounds were detected, it was typically close to a detection limit and much lower than the corresponding MCL, SMCL and NL.

Results for regulated chemicals are summarized in Tables 5.3 through 5.8, with the full set of chemical analysis to date attached as a sortable excel spreadsheet in the Appendix B.

Table 5.3 UV AOP Finished Water Quality for MCLs-Inorganic Chemicals per 22 California Code of Regulations (CCR) Tables 64431-A and Table 64432-A (2015)[1]

Constituent	Unit	6/30/20	12/8/20	5/26/21	MCL
Aluminum	µg/L	11	<20	<4.4	200
Antimony	µg/L	<0.045	<1	<0.089	6
Arsenic	µg/L	<0.074	<1	<0.074	10
Asbestos	MFL	<0.2	<0.2		7
Barium	µg/L	0.15	<2	<0.14	1000

Constituent	Unit	6/30/20	12/8/20	5/26/21	MCL
Beryllium	µg/L	<0.033	<1	<0.062	4
Cadmium	µg/L	<0.041	<0.5	<0.042	5
Chromium	µg/L	0.069	<1	<0.089	50
Copper	µg/L	0.25	<2	<0.23	1300 (Action level)
Cyanide	µg/L	<3.8	<25	<3.8	150
Fluoride	mg/L	0.064	<0.05	-	2
Lead	µg/L	<0.031	<0.5	<0.083	15 (Action level)
Mercury	µg/L	<0.017	<0.2	<0.017	2
Nickel	µg/L	0.05	<5	<0.16	100
Nitrate (as NO_3)(2)	mg/L		1.1 ± 0.19 [1.6]		45
Nitrite (as N)(2)	mg/L		[<0.05]		1
Nitrate + Nitrite (as N)(2)	mg/L		0.30 ± 0.04 [<0.4]		10
Perchlorate	µg/L	0.86	<0.5	-	6
Selenium	µg/L	<0.14	<5	<0.067	50
Thallium	µg/L	<0.014	<1	<0.021	2

Notes:
Abbreviation: MFL - million fibers per liter.
(1) Samples below the limit of detection are reported as "<" the detection limit.
(2) Nitrogen species (Nitrate, Nitrite and Nitrate+Nitrite) sampled weekly and n=18, were reported as average ± standard deviation and [maximum observed].

Table 5.4 UV AOP Finished Water Quality for MCLs-Radionuclides per 22 CCR Tables 64442 and 64443 (2015)(1)

Constituent	Units	6/30/20	12/8/20	MCL
Gross Alpha	pCi/L	0.48	<3	15
Gross Beta	4 mrem/year	0.88	<3	4
Radium-226	pCi/L	0.508	<1	-
Radium-228	pCi/L	0.519	<1	-
Combined Radium (226+ 228)	pCi/L	1.03	<2	5
Strontium-90	pCi/L	<0.769	<0.516	8
Uranium Rad	pCi/L	<0.019	<0.7	20
Tritium	pCi/L	<232	<281	20,000

Note:
Abbreviation: pCi/L - picocuries per liter.
(1) Samples below the limits of detection are indicated by "<".

Table 5.5 UV AOP Finished Water Quality for MCLs-Synthetic Organic Chemicals (SVOCs) per 22 CCR Tables 64444-A (2015)(1)

Constituent	Units	6/30/20	12/8/20	5/26/21	MCL/Action Level
Alachlor	µg/L	<0.03	<0.05	<0.03	2
Atrazine	µg/L	<0.03	<0.05	<0.03	1

Constituent	Units	6/30/20	12/8/20	5/26/21	MCL/Action Level
Benzo(a)pyrene	µg/L	<0.02	<0.02	<0.02	0.2
Carbofuran	µg/L	<5	<0.5	<1[2]	40
Chlordane	µg/L	<0.017	<0.1	-[4]	2
Dalapon	µg/L	<0.11	<1	<1.1	200
DBCP	µg/L	<0.0039	<0.01	<0.0039	0.2
Dinoseb	µg/L	<0.055	<0.2	<0.055	7
2,3,7,8-Tetrachlorodibenzodioxin	pg/L	<2.48	<5	<2.48	30
Diquat	µg/L	<0.86	<0.4	<0.86	20
Di-(2-Ethylhexyl)adipate	µg/L	<0.12	<0.6	0.6	400
Di(2-Ethylhexyl)phthalate	µg/L	<0.41	<0.6	0.49	6
Endothall	µg/L	<11	<5	<11	100
Endrin	µg/L	<0.0023	<0.01	-[4]	2
Ethylene dibromide	µg/L	<0.0011	<0.01	<0.0011	0.05
Glyphosate	µg/L	<1.8	<6	<1.8	700
Heptachlor	µg/L	<0.0029	<0.01	-[4]	0.4
Heptachlor Epoxide	µg/L	<0.0017	<0.01	-[4]	0.2
Hexachlorobenzene	µg/L	<0.0009	<0.05	<0.49[3]	1
Hexachlorocyclopentadiene	µg/L	<0.0061	<0.05	<0.98[3]	50
Gamma-BHC (Lindane)	µg/L	<0.0016	<0.01	-[4]	0.2
Methoxychlor	µg/L	<0.0018	<0.05	-[4]	40
Oxamyl	µg/L	<5.3	<0.5	<1.1[2]	200
Picloram	µg/L	<0.038	<0.1	<0.038	500
PCBs, Total	µg/L	<0.049	<0.1	-[4]	0.5
Pentachlorophenol	µg/L	<0.046	<0.04	<0.046	1
Simazine	µg/L	<0.02	<0.005	<0.02	4
Toxaphene	µg/L	<0.066	<0.5	-[4]	3
2,4-D (2,4-Dichlorophenoxyacetic acid)	µg/L	<0.14	<0.05	<0.14	70
2,4,5-TP (Silvex) (2-(2,4,5-trichlorophenoxy) propionic acid)	µg/L	<0.046	<0.2	<0.046	50
Bentazon	µg/L	<0.23	<0.5	<0.23	18
Molinate	µg/L	<0.03	<0.1	<0.03	20
Thiobencarb	µg/L	<0.03	<0.2	<0.03	1

Notes:
Abbreviation: pg/L - picogram per liter; SVOCs - semivolatile organic compounds.
(1) Constituents below the limit of detection are reported as "<" the detection limit.
(2) Sampled 6/9/2021.
(3) Sampled 7/14/2021.
(4) Result not reported.

Table 5.6 UV AOP Finished Water Quality for MCLs-Volatile Organic Chemicals (VOCs) per 22 CCR Tables 64444-A (2015)[1]

Constituent	6/30/20 (µg/L)	7/15/20 (µg/L)	12/8/20 (µg/L)	5/26/2021 (µg/L)	MCL/Action Level (µg/L)
Benzene	<0.15	<0.15	<0.5	<0.15	1
Carbon tetrachloride	<0.12	<0.12	<0.5	<0.12	0.5
cis-1,2-Dichloroethene	<0.11	<0.11	<0.5	<0.11	6
Dichloromethane	0.14	<0.14	-	0.17	5
Ethylbenzene	<0.21	<0.21	<0.5	<0.21	300
Chlorobenzene	<0.15	<0.15	<0.5	<0.15	70
o-Dichlorobenzene (1,2-DCB)	<0.19	<0.19	<0.5	<0.19	600
p-Dichlorobenzene (1,4-DCB)	<0.18	<0.18	<0.5	<0.18	5
Styrene	<0.19	<0.19	<0.5	<0.19	100
Tetrachloroethylene	<0.18	<0.18	<0.5	<0.18	5
Toluene	<0.14	<0.14	<0.5	<0.14	150
trans-1,2-Dichloroethene	<0.11	<0.11	<0.5	<0.11	10
Trichloroethene	<0.18	<0.18	<0.5	<0.18	5
Vinyl chloride	<0.18	<0.18	<0.3	<0.18	0.5
Xylenes, Total	<0.53	<0.53	<0.5	<0.53	1750
1,1-Dichloroethene	<0.16	<0.16	<0.5	<0.16	6
1,1,1-Trichloroethane	<0.11	<0.11	<0.5	<0.11	200
1,1,2-Trichloroethane	<0.19	<0.19	<0.5	<0.19	5
Ethylene dichloride	<0.12	<0.12	<0.5	<0.12	0.5
1,2-Dichloropropane	<0.13	<0.13	<0.5	<0.13	5
1,2,4-Trichlorobenzene	<0.17	<0.17	<0.5	<0.17	5
1,1-Dichloroethane	<0.12	<0.12	<0.5	<0.12	5
1,3-Dichloropropene, Total	<0.26	<0.26	<0.5	<0.26	0.5
Methyl Tert-butyl ether	<0.19	<0.19	<0.5	<0.19	13
1,1,2,2-Tetrachloroethane	<0.2	<0.2	<0.5	<0.2	1200
Trichlorofluoromethane	<0.18	<0.18	<0.5	<0.18	150
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	<1.5	<1.5	<0.5	<1.5	1200

Note:
Abbreviation: VOCs - volatile organic compounds.
(1) Dichloromethane has been detected 30 times lower than the MCL. Constituents below the limit of detection are reported as "<" the detection limit.

Table 5.7 UV AOP Finished Water Quality for Secondary MCLs per 22 CCR Tables 64449-A and 64449-B (2015)[1]

Secondary Constituent	Units	6/30/2020	12/8/20	5/26/2021	MCL/Action Level
Color	ACU	<3	<3	-	15
Bicarbonate Alkalinity (as HCO_3)	mg/L	11	-	-[3]	Non-corrosive
MBAS (Surfactant)	mg/L	<0.017	<0.1	<0.017	0.5
pH	s.u.	6.09	-	-	6.5-8.5
Hardness (as $CaCO_3$)	mg/L	1.02	-	-	250
Odor	TON	12[2]	<1	-	3
TDS	mg/L	19	26	23	500
Aluminum	µg/L	11	<20	<4.4	50-200
Chloride	mg/L	7.8	3.9	4.7	250
Copper	µg/L	0.25	<2	<0.23	1000
Fluoride	mg/L	0.064	<0.05	-	2
Iron	µg/L	<1.1	<20	<3.9	300
Manganese	µg/L	0.081	<2	<0.11	50
Silver	µg/L	<0.062	<0.5	<0.03	100
Sulfate	mg/l	1.5	0.67	0.54	250
Turbidity	NTU	<0.017	<0.1	-	5
Specific Conductance (EC)	µS/cm	49	38	-	900
Zinc	µg/L	<0.94	<20	<0.8	500

Notes:
Abbreviation: MBAS - methylene blue active substances.
(1) Samples below the limit of detection are represented as "<" the detection limit.
(2) High odor detection on June 30, 2020 due to degraded sodium hypochlorite, which was subsequently identified and replaced.
(3) Finished water is not stabilized and has a total alkalinity typically of 4.2 – 11 mg/L as $CaCO_3$.

Table 5.8 UV AOP Finished Water Quality for 2015 Notification Levels[1]

Constituent	Unit	6/30/20	7/15/20	12/8/20	5/26/21	MCL/Action Level
Boron	µg/L	210	-	170	160	1000
n-Butylbenzene	µg/L	<0.29	<0.29	<0.5	<0.29	260
sec-Butylbenzene	µg/L	<0.24	<0.24	<0.5	<0.24	260
tert-Butylbenzene	µg/L	<0.18	<0.18	<0.5	<0.18	260
Carbon disulfide	µg/L	-	-	<0.5	-	160
Chlorate	µg/L	1,100[5]	-	240	-	800
2-Chlorotoluene	µg/L	<0.15	<0.15	<0.5	<0.15	140
4-Chlorotoluene	µg/L	<0.15	<0.15	<0.5	<0.15	140
Diazinon	µg/L	<0.05	-	<0.1	<0.05	1.2

Constituent	Unit	6/30/20	7/15/20	12/8/20	5/26/21	MCL/Action Level
Dichlorodifluoromethane (Freon 12)	µg/L	<0.45	<0.45	<0.5	<0.45	1,000
1,4-Dioxane	µg/L	0.017(2)	-	<1	<0.028	1
Ethylene Glycol	mg/l	<4.7(3)	-	<10	-	14
Formaldehyde	µg/L	6.8	-	<5	1.8	100
HMX	µg/L	<0.19	-	<0.1	-	350
Isopropylbenzene	µg/L	<0.18	<0.18	<0.5	<0.18	770
Manganese	µg/L	0.081	-	<2	<0.11	500
4-Methyl-2-Pentanone	µg/L	<1.8	<1.8	<5	<1.8	120
Naphthalene	µg/L	<0.35	<0.35	<0.5	<0.35	17
NDEA	ng/L	<0.7	-	<2	<0.66	10
NDMA(4)	ng/L	<0.96	<2	<2	<0.63	10
NDPA	ng/L	<0.75	-	<2	<0.8	10
Propachlor	µg/L	<0.004	-	<0.05	-	90
n-Propylbenzene	µg/L	<0.18	<0.18	<0.5	<0.18	260
RDX	µg/L	<0.14	-	<0.1	-	0.3
Tert-butyl alcohol	µg/L	<0.45	-	<2	-	12
1,2,3-Trichloropropane	µg/L	<0.0012	-	<0.005	<0.0012	0.005
1,2,4-Trimethylbenzene	µg/L	<0.2	<0.2	<0.5	<0.2	330
1,3,5-Trimethylbenzene	µg/L	<0.17	<0.17	<0.5	<0.17	330
2,4,6-Trinitrotoluene	µg/L	<0.15	-	<0.1	-	1
Vanadium	µg/L	<0.14	-	<3	-	50

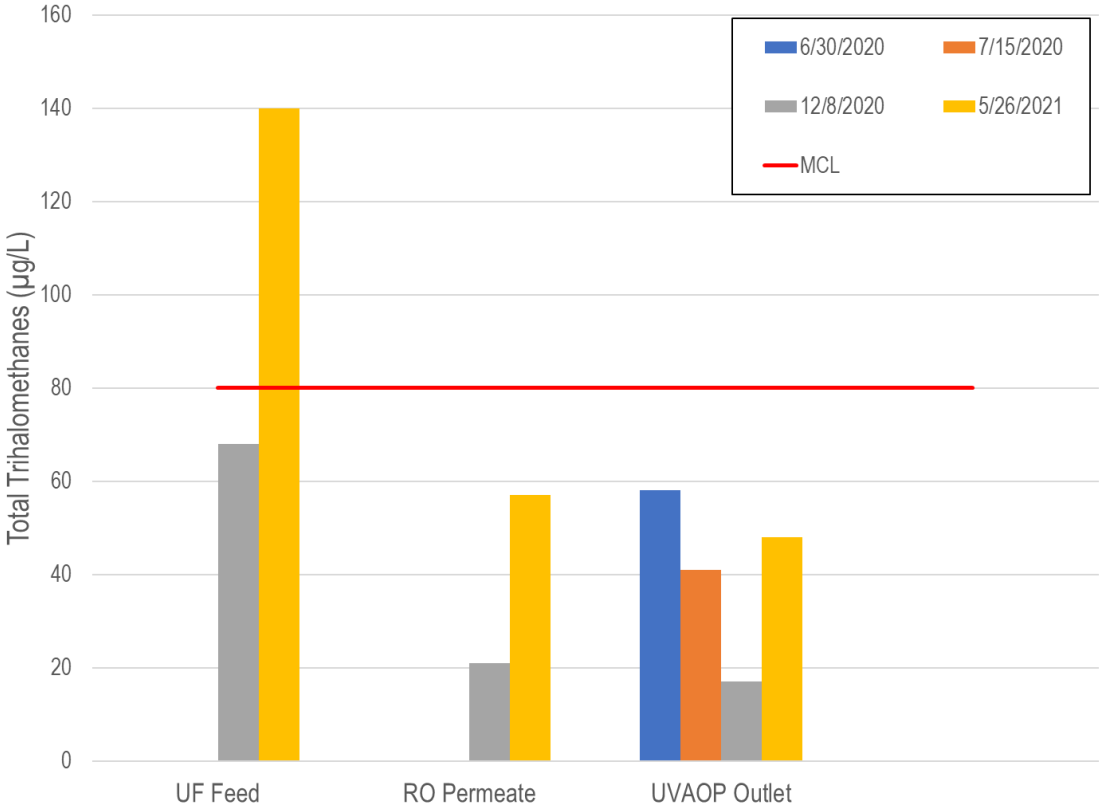
Notes:
Abbreviation: NDEA - N-nitrosodiethylamine; NDMA - N-Nitrosodimethylamine; NDPA - n-Nitrosodiphenylamine.
(1) Samples below the limit of detection are represented as "<" the detection limit.
(2) Sampled June 13, 2020.
(3) Sampled June 14, 2020.
(4) Sampled monthly and always less than 10ng/L, typically non detect at <2ng/L or lower with the exception of one analytical result under investigation that reported 2.9 ng/L.
(5) Degraded sodium hypochlorite was detected on 6/30 (1,100 µg/L). The batch was replaced, and chlorate testing followed in July 2020 to ensure it was corrected.

5.1.2.2 Disinfection Byproducts

Figures 5.1 through 5.5 show the fate of total trihalomethane (TTHM), total haloacetic acids (HAA5), chlorite and chlorate for available samples across the first year of operation.

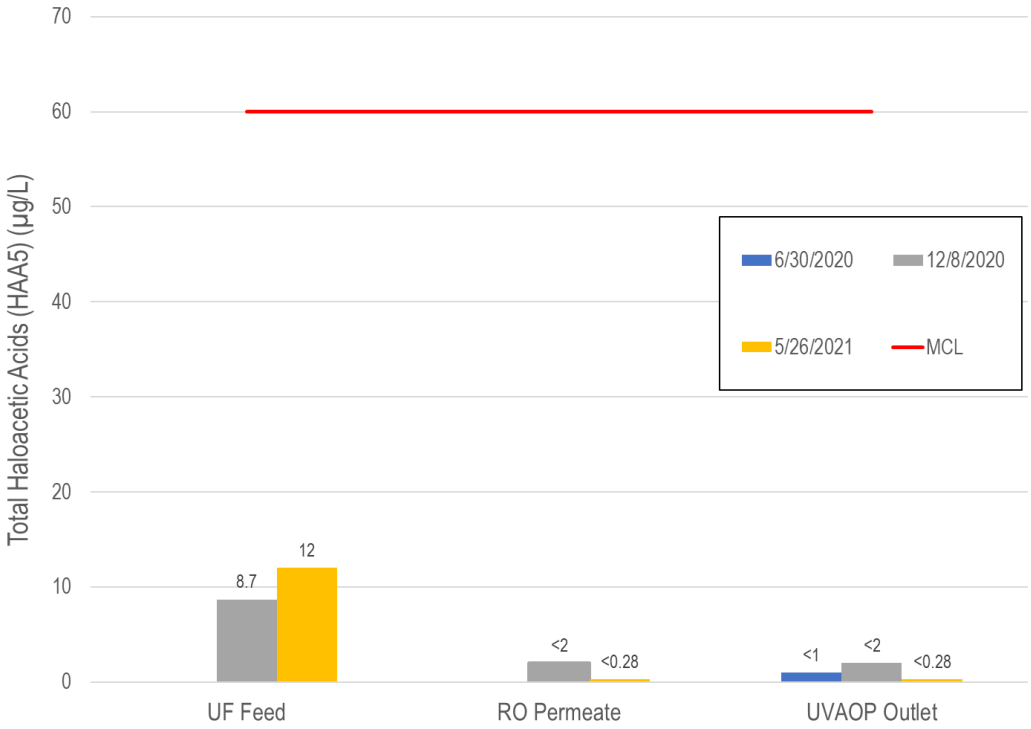
- TTHMs, HAA5 and chlorite were below the MCL in all finished water samples.
- TTHMs, have exceeded the MCL in the untreated raw water in the May 2021 UF feed sample but appear to be reduced by the RO by 60-70 percent and then by the UV AOP by a further 15-20 percent.
- HAA5 and chlorite were significantly below the MCL in all samples (UF Feed, RO permeate and UV AOP Outlet).

- Chlorate had an initial NL exceedance, but this was conclusively shown to be due to poor quality sodium hypochlorite.
  - Chlorate was measured on 7 dates between July and September 2020 in the RO permeate. The range of values in RO permeate was < 1.7 µg/L to 43 µg/L, significantly below the NL.
  - Samples of UV influent and outlet were taken at different applied free chlorine doses in July 2020 with poor quality sodium hypochlorite and in August 2020 with nominal quality sodium hypochlorite (See Figure 5.5).
    - For both data sets, there was a significant linear relationship of chlorate with free chlorine dose.
    - With poor quality hypochlorite, that contained significant chlorate, a free chlorine dose of more than 3 mg/L resulted in exceedances of the NL in the UV AOP outlet.
    - With good quality hypochlorite, there was no observed MCL exceedance, but a regression relationship suggested that a free chlorine dose over 6.7 mg/L of free chlorine might cause an exceedance.
    - The recommended dose of free chlorine for the UV AOP is 2.5-3.0 mg/L, which should be sufficient to stay below half of the chlorate MCL, provided good quality sodium hypochlorite continues to be received.



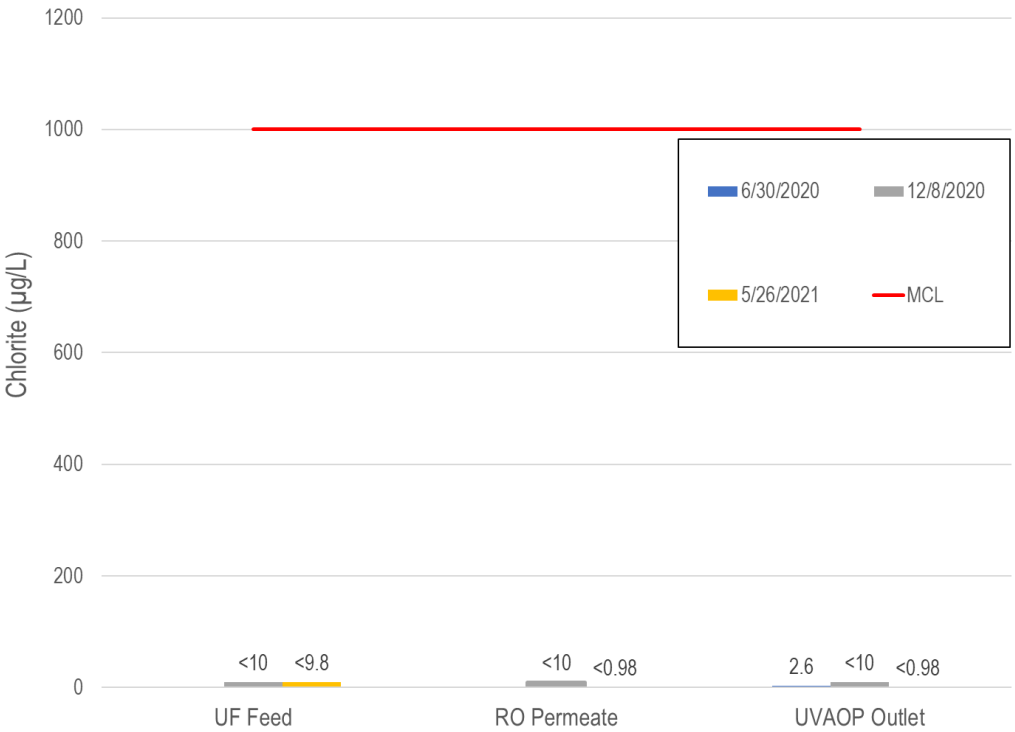
Note: RO permeate and UV AOP outlet samples are always below the MCL. UF feed samples are close to, or higher than the MCL of 80 µg/L. Specific TTHM results are shown in Table 5.9.

Figure 5.1 TTHM Fate Across the Demo



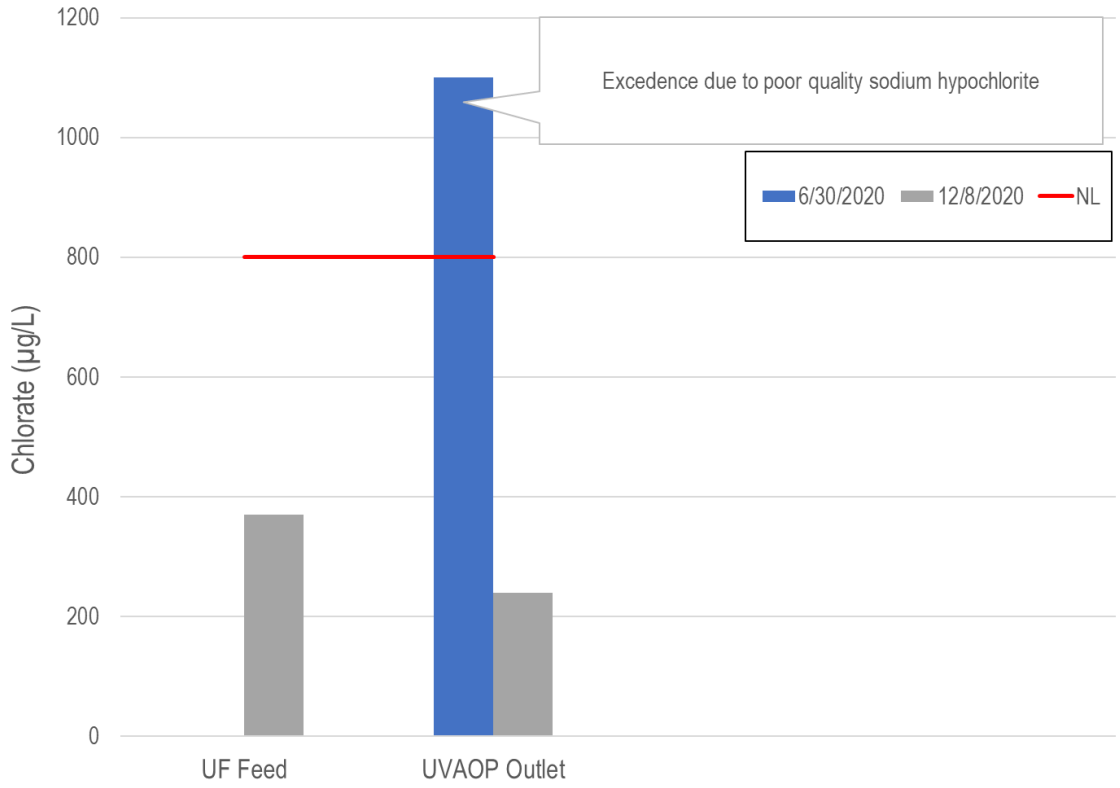
Note: RO permeate and UV AOP outlet samples were always below the MCL and detection limits. UF feed samples were detected but lower than the MCL of 60 µg/L.

Figure 5.2 HAA5 Fate Across the Demo



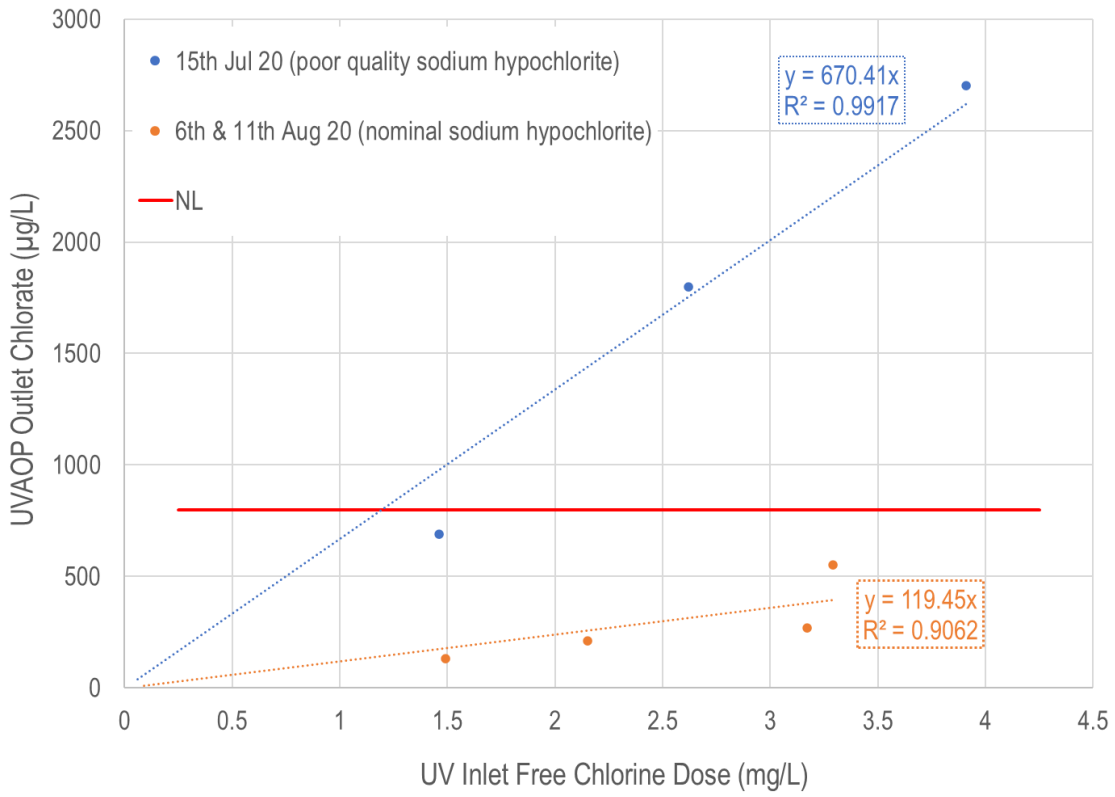
Note: RO permeate and UF feed samples were always below detection limits. There was one detection at 2.6 µg/L in the UV AOP outlet, significantly lower than the MCL of 1000 µg/L.

Figure 5.3 Chlorite Fate Across the Demo



Note: One UV AOP outlet reading exceeded the NL of 800 µg/L and was shown to be due to poor quality sodium hypochlorite.

Figure 5.4 Chlorate in UF Feed and UV AOP Outlet



Note: The significant relationship between free chlorine dose and chlorate level indicates the source of chlorate was degraded sodium hypochlorite.

Figure 5.5 UV AOP Outlet Chlorate Concentrations Taken at Different Applied Free Chlorine Dose and With Nominal and Poor-Quality Sodium Hypochlorite

THMs and CTR Requirements

TTHMs is the addition of the Trihalomethanes (THMs) bromodichloromethane (BDCM), bromoform, DBCM, and chloroform. As contributors to TTHMs, DBCM and BDCM effectively have a high upper concentration limit per the TTHM MCL of 80 µg/L. However, the California Toxic Rule, which must be met as part of Surface Water Augmentation for the JPA's future project, requires that BDCM and DBCM concentrations in the finished water remain below 0.56 and 0.41 µg/L, respectively.

The fate of TTHM components, relative to CTR limits, is summarized in Table 5.9 (excluding data from the UV AOP NDMA challenge test data already discussed).

Table 5.9 Trihalomethane Samples Across the Demo Relative to CTR Limits[1]

Chemical	Sample Date	Concentrations (µg/L)			
		UF Feed	RO Permeate	UV AOP Outlet	CTR Limit
BDCM	6/30/2020[2]	-	-	17	0.56
	7/15/2020[2]	-	-	16	
	12/8/2020	25	8.2	6.2	
	5/26/2021	47	18	15	
	7/14/2021[3]	-	-	4.3	
DBCM	6/30/2020[2]	-	-	2.7	0.41
	7/15/2020[2]	-	-	3.3	
	12/8/2020	11	3.3	1.3	
	5/26/2021	21	6.9	3.0	
	7/14/2021[3]	-	-	0.92	
Chloroform	6/30/2020[2]	-	-	38	No limit specified MCL as TTHM < 80 µg/L
	7/15/2020[2]	-	-	22	
	12/8/2020	30	9.7	9.7	
	5/26/2021	73	32	30	
	7/14/2021[3]	-	-	8.3	
Bromoform	6/30/2020[2]	-	-	<0.19	4.3
	7/15/2020[2]	-	-	0.19	
	12/8/2020	1.5	<0.5	<0.5	
	5/26/2021	1.5	0.45	<0.19	
	7/14/2021[3]	-	-	<0.27	

Notes:
(1) BDCM and DBCM are frequently detected above the CTR limit.
(2) Poor quality sodium hypochlorite in use at site.
(3) EPA 624.1 with a higher detection limit used instead of regular EPA 524.2 method.

THM sampling has only contributed a small number of samples that provide an idea of the potential origin of finished water results. Based on the single complete sampling event conducted as part of quarterly sampling on December 8, 2020:

- THMs appears to originate in the UF feed and are suspected to originate from the upstream WRF:
  - BDCM appears to be removed 62-67 percent by the RO and 17-24 percent by the UV AOP (consistent with challenge test observations (See Table 4.7).
    - Assuming these removal proportions are consistent and using available UV AOP outlet data it would suggest that UF feed BDCM concentrations could vary between 17 – 69 µg/L (based upon back calculation to influent).

- DBCM appears to be removed 67-70 percent by the RO and 57-60 percent by the UV AOP. During UV AOP challenge testing, UV AOP removal was closer to 10-20 percent (See Table 4.6).
  - Assuming 20 percent removal across UV AOP and 70 percent by the RO, UF feed BDCM concentrations could vary between 3-14 µg/L (based upon back calculation to influent).
- Chloroform sampling suggested 68 percent removal by RO and no removal across UV AOP.
  - Assuming 68 percent removal by RO, chloroform concentrations in the UF feed may vary between 26-118 µg/L (based upon back calculation to influent).
- Bromoform has not be detected consistently across the treatment train. However, the one feed sample taken at 1.5 µg/L was below the CTR requirement of 4.3 µg/L and removal across RO is anticipated.

Given the potential for BDCM and DBCM to exceed CTR requirements it is recommended that more sampling is performed on the UF feed, RO permeate and UV AOP outlet to better quantify the removal across the process. Further sampling at Tapia WRF before and after chlorination may help to understand if the origin of these compounds is due to wastewater chlorination or Demo influent chlorination. *This further testing is being planned and will be implemented in late 2021 or early 2022.*

Bromate and Bromide

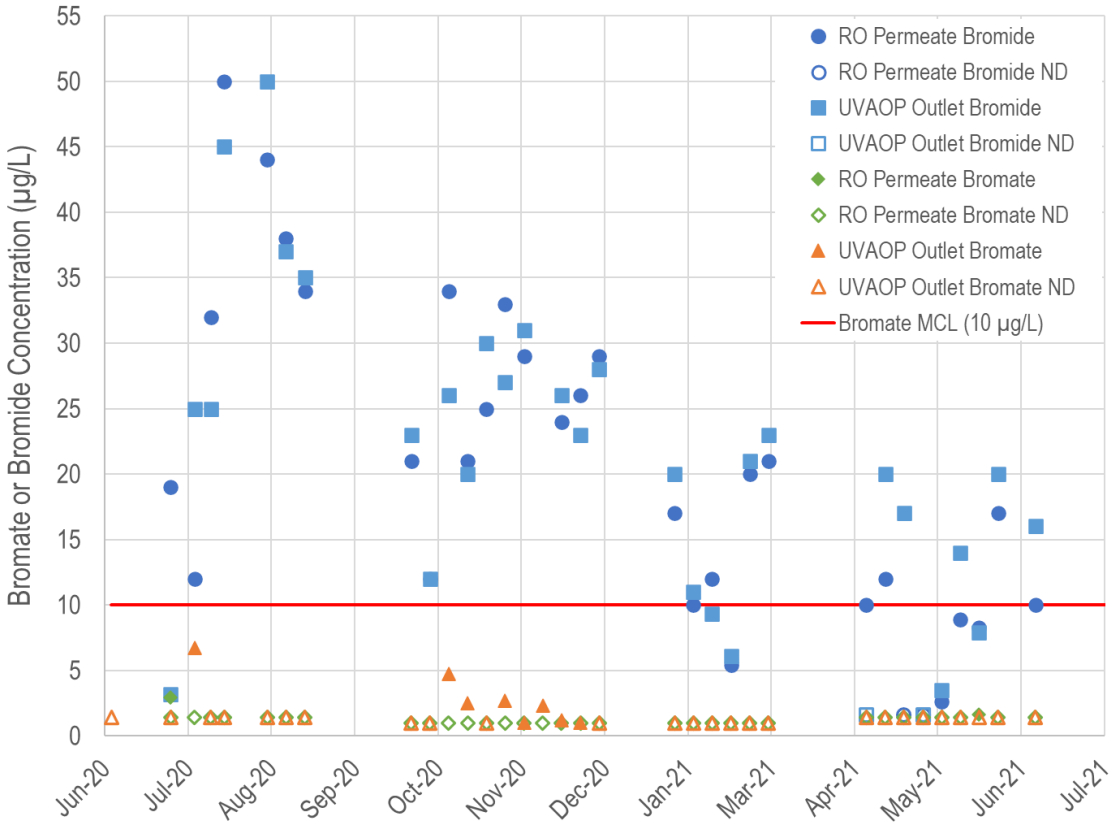
Bromide and Bromate have been sampled weekly in the RO permeate and UV AOP outlet. In addition, Bromate has been characterized twice in the UF feed as part of quarterly sampling.

The bromate results across the treatment train are shown in Table 5.10. Bromide and Bromate from weekly sampling are shown on Figure 5.6.

Table 5.10 Bromate and Bromide Sampling Across the Demo(1)

Date	Chemical	Concentrations (µg/L)			
		UF Feed	RO Permeate	UV AOP Outlet	MCL
12/8/2020	Bromate	1.3	<1	2.3	10
	Bromide	-(2)	-(2)	-(2)	-
5/26/2021	Bromate	<14	<1.4	<1.4	10
	Bromide	-(2)	17	20	-

Notes:
(1) Samples below the detection limit are reported as "<" the detection limit.
(2) Bromide not sampled on UF feed or December 8, 2020.



Note: Bromate has not been observed above the MCL of 10 µg/L.

Figure 5.6 Bromate and Bromide Concentrations in the RO Permeate and UV AOP Effluent

From the weekly bromide and bromate monitoring data for the first year of Demo operation, the following observations can be made:

- Bromide is detected in most RO permeate and UV AOP outlet samples. The concentrations closely follow each other and detections have been observed in 86 percent of samples. The 50 µg/L was the maximum observed bromide concentration in both RO permeate and UV AOP outlet.
- Bromate was detected in 2 (5 percent) RO permeate samples with a maximum concentration of 2.9 µg/L and was detected in 8 (21 percent) UV AOP outlet samples with a maximum concentration of 6.7 µg/L.
- All Bromate concentrations have been below the MCL of 10 µg/L.
- There is some evidence of bromate formation through the UV AOP, but not the extent that MCLs are exceeded.

Nitrosamines

NDMA and NMOR control are discussed in Section 4.2 and indigenous results are presented on Figures 4.8 and 4.9, respectively.

NDMA is typically not observed above the detection limit of 2 ng/L in the UV AOP outlet and has never been observed over the NL of 10 ng/L.

NMOR has never been observed, in any sample of UF Feed, RO permeate or UV AOP effluent above the California MTL of 12 ng/L.

5.1.2.3 Constituents of Emerging Concern

Generally speaking, CECs are unregulated chemicals, typically made up of hormones, pharmaceuticals, and personal care products. For this analysis, we also include PFAS, which is a broad group of chemical pollutants and does include two regulated and closely scrutinized chemicals, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS).

PFAS

A large suite of PFAS, including PFOA and PFOS, was assayed during a one-time tasting event as well as during the first quarterly sample. PFOA and PFOS and the tasting event were analyzed using method 537.1, while the other PFAS species during the first quarterly sample were measured as part of the total oxidizable precursor (TOP) assay, using a modified method 537. The PFAS results are summarized relative to available guideline values in Tables 5.11 through 5.13.

Table 5.11 PFAS Concentration in Source and Finished Water[(1)]

PFAS	Concentration (ng/L)			CA NL (ng/L)
	UF Feed	UV AOP Outlet		
	12/8/20[(2)]	6/30/20[(3)]	12/8/20[(2)]	
PFOS	6.1[(3)]	<0.49	<2[(3)]	6.5
PFOA	15[(3)]	<0.35	<2[(3)]	5.1
Perfluorooctanesulfonamide (FOSA)	<5.0	-	6.2	-
Perfluorohexanoic acid (PFHxA)	28	1.2[(3)]	<5.0	-
Perfluoroheptanoic acid (PFHpA)	5.5	9.9[(3)]	<5.0	-
Perfluorobutanesulfonic acid (PFBS)	5.3	<0.6	<5.0	500
Perfluorobutanoic acid (PFBA)	14	-	<5.0	-
Perfluoropentanoic acid (PFPeA)	29	-	<5.0	-
4,8-dioxa-3H-perfluorononanoic acid (ADONA)	-	<0.41	-	-
4:2 FTS	<50	-	<50	-
6:2 FTS	<50	-	<50	-
8:2 FTS	<50	-	<50	-
11Cl-PF3OUdS (F53B major)	-	<0.56	-	-
9Cl-PF3ONS (F53B minor)	-	<0.73	-	-
HFPO-DA (GenX)	-	<0.73	-	-
N-ethyl Perfluorooctane Sulfonamidoacetic acid (NEtFOSAA)	<50	<0.82	<50	-
N-methyl Perfluorooctanesulfonamidoacetic acid (NMeFOSAA)	<50	<0.73	<50	-
Perfluorodecanoic acid (PFDA)	<5.0	<0.61	<5.0	-

PFAS	Concentration (ng/L)			CA NL (ng/L)
	UF Feed	Finished Effluent		
	12/8/20[2]	6/30/20[3]	12/8/20[4]	
Perfluorododecanoic acid (PFDoA)	<5.0	<0.4	<5.0	-
Perfluoropentanesulfonic acid (PFPeS)	<5.0	-	<5.0	-
Perfluorohexanesulfonic acid (PFHxS)	<5.0	<0.71	<5.0	-
Perfluoroheptanesulfonic acid (PFHpS)	<5.0	-	<5.0	-
Perfluorodecanesulfonic acid (PFDS)	<5.0	-	<5.0	-
Perfluorononanesulfonic acid (PFNS)	<5.0	-	<5.0	-
Perfluorononanoic acid (PFNA)	<5.0	<0.56	<5.0	-
Perfluorotetradecanoic acid (PFTeA)	<5.0	<0.56	<5.0	-
Perfluorotridecanoic acid (PFTriA)	<5.0	<0.37	<5.0	-
Perfluoroundecanoic acid (PFUnA)	<5.0	<0.5	<5.0	-

Notes:
(1) Values that were not detected are reported as "<" the detection limit.
(2) Sample results measured pre-treatment as part of TOP assay using method 537 Modified. Higher detection limit for these samples.
(3) Samples measured using method 537.1, detection limit of 2 ng/L or less.
(4) Blank contamination detected at 10 ng/L for PFHpA and 0.77 ng/L for PFHxA, near the measured sample concentration. Suspect readings are false positives.

- Regulated PFOS and PFOA were not detected in the two UV AOP outlet samples and were below 2 ng/L, lower than the respective notification levels of 6.5 and 5.1 ng/L respectively.
- FOSA was the only PFAS to be detected in the finished water, but was at low level of 6.2 ng/L, very close the reporting limit of 5 ng/L. There is no present guideline value for FOSA.
- PFHxA and PFHpA were detected in the UV AOP outlet. However, the field blank sample also measured similar concentrations. It is suspected that the UV AOP outlet detection of these compounds was a false positive due to contamination.
- In the UF feed, PFOS was close to the notification level and PFOA exceeded the notification level. The RO removed both of these compounds to below the detection limit.
- PFOS, PFOA, PFBS, PFBA and PFPeA were detected in the UF feed, but not the UV AOP outlet, indicating that the RO was removing these compounds successfully to below the detection limit.

The full results of the TOP assay sampling that was conducted on the first quarterly sample are included below. The TOP asset procedure uses an oxidative process and compares the level of PFAS before and after oxidation. An increase in Perfluoroalkyl carboxylic acids (PFCAs) post oxidation indicates the presence of other non-target or precursor polyfluorinated substances in the original sample that could transform into PFAS upon strong oxidation.

Table 5.12 TOP Assay Results for UF Feed and UV AOP Outlet for 12/8/2020 Sampling[1]

PFAS	UF Feed		UV AOP Outlet	
	Pre Oxidation	Post Oxidation	Pre Oxidation	Post Oxidation
PFBA	14	34[2]	<5.0	9.2[3]
PFPeA	29	31	<5.0	<5.0
PFHxA	28	28	<5.0	<5.0
PFHpA	5.5	5.2	<5.0	<5.0
PFOA	15	14	<5.0	<5.0
PFNA	<5.0	<5.0	<5.0	<5.0
PFDA	<5.0	<5.0	<5.0	<5.0
PFUnA	<5.0	<5.0	<5.0	<5.0
PFDoA	<5.0	<5.0	<5.0	<5.0
PFTriA	<5.0	<5.0	<5.0	<5.0
PFTeA	<5.0	<5.0	<5.0	<5.0
PFBS	5.3	5.3	<5.0	<5.0
PFHxS	<5.0	<5.0	<5.0	<5.0
PFHpS	<5.0	<5.0	<5.0	<5.0
PFOS	5.8[4]	<5.0	<5.0	<5.0
PFDS	<5.0	<5.0	<5.0	<5.0
FOSA	<5.0	<5.0	6.2	<5.0
NMeFOSAA	<50	<50	<50	<50
NEtFOSAA	<50	<50	<50	<50
6:2 FTS	<50	<50	<50	<50
8:2 FTS	<50	<50	<50	<50
PFPeS	<5.0	<5.0	<5.0	<5.0
PFNS	<5.0	<5.0	<5.0	<5.0
4:2 FTS	<50	<50	<50	<50

Notes:
(1) Values that were not detected are reported as "<" the detection limit.
(2) Sample quality control results indicated blank contamination to a level of 10.8 ng/L and suggests likely sample contamination to the same level. Subtracting blank contamination, result would be 23.2 ng/L.
(3) Sample quality control results indicated blank contamination to a level of 10.8 ng/L and suggests likely sample contamination to the same level. Subtracting blank contamination, result would be <5.0 ng/L.
(4) A separate sample was taken for the TOP assay as the analysis was subcontracted. Hence, the 12/8/2020 results for not match the prior reported results.

The summary of results for increases in total oxidizable PFCAs from the TOP assay sampling are summarized in Table 5.13.

Table 5.13 UF Feed and UV AOP Total Oxidizable PFCAs from the TOPA Sampling on the 12/8/2020[1]

PFAS	UF Feed (ng/L)	UV AOP Outlet (ng/L)
PFBA	20[2]	9.2[2]
PFPA	2.3	0.0
PFHxA	0.92	0.0
PFHpA	0.0	0.0
PFOA	0.0	0.0
PFNA	0.0	0.0
Total PFCA	21	9.2
Total PFCA – blank contamination[2]	10.2	<0.0

Note:
(1) Results show the difference (post oxidation – preoxidation).
(2) Sample quality control results indicated post treatment blank contamination to a level of 10.8 ng/L and suggests likely sample contamination to the same level. Total PFCA – potential contamination is reported by subtracting from the total.

TOPA results indicate that there are potential non-target or precursor PFAS in the UF Feed sample at concentrations between 10.2-21 ng/L and between 0.0-9.2 ng/L in the UV AOP effluent.

The uncertainty and range of results is due to the subtraction of contamination which occurred for PFBA.

If contamination is taken into account, then the TOPA results suggest that a large proportion of PFAS were detected as part of sampling and that there are negligible PFAS and PFAS precursors in the finished UV AOP effluent.

Pharmaceuticals and Personal Care Products (PPCPs)

PPCPs and their metabolites originate in wastewater due to anthropogenic use. A suite pf PPCPs were targeted for sampling during quarterly sampling events. Because PPCPs are consumer products, there typically are not regulated drinking water levels. As a means to compare the relative risk of these compounds, other health-based screening values from literature were also summarized. In addition, indicative concentrations for Raw Water from State Project Water Sources is included for comparison. The State Project Water values corresponding to analyzed species were taken from literature where available (NWRI 2010). The PPCP results are included in Table 5.14.

Table 5.14 Concentrations of CECs in the UF feed, RO Permeate and UV AOP Outlet From Sampling Events at the Demo[1]

CEC	Concentration (ng/L)							Health Screening Level (ng/L)	Health Screening Reference	State Project Water min – max [median] (ng/L)[2]
	UF Feed		RO Permeate		UV AOP Effluent					
	12/8/2020	5/26/2021	12/8/2020	5/26/2021	6/30/2020	12/8/2020	5/26/2021			
Acetaminophen	<10	<5	<10	<5	<1.4	<10	8.4	175,000	Trussell 2013	<1 – 28 [<1]
Amoxicillin	<20	<20	<20	<20	<400	<20	<20	1,500	Trussell 2015	Max: <10[5]
Atenolol	140	110	<5	<4	<0.2	<5	<4	70,000	Trussell 2013	Max: 18[3]
Atorvastatin	-	<4	-	<4	4.7	-	<4	1,000	Drewes 2018	Max: 1.4[3]
Azithromycin	-	27	-	<20	43	-	<20	120	Drewes 2018	<5 - <5 [<5]
Bisphenol A (BPA)	<10	40	<10	38	13	<10	39	35,000	Trussell 2013	<30 – 140 [<30]
Caffeine	<10	8.5	<10	<4	0.37	<10	<4	35,000	Trussell 2013	<5 – 67 [8]
Carbamazepine	140	73	<5	<4	<0.08	<5	<4	100,000	Trussell 2013	<1 – 26 [4]
Ciprofloxacin	-	<20	-	<20	100	-	<20	23,000	Drewes 2018	<50 - <50 [<50]
Cotinine	32	14	<10	<8	<0.59	<10	<8	1,000	Trussell 2013	Max: 77[3]
DEET	18	160	<10	5.6	3	<10	<4	200,000	Trussell 2013	<20 – 35 [<20]
Diazepam	<5	<4	<5	<4	<0.14	<5	<4	2,500	Drewes 2018	Max: 0.33[3]
Diclofenac	<5	<4	<5	<4	<0.26	<5	<4	2,300,000	Trussell 2015	<5 - <5 [<5]
Fluoxetine	120	36	<10	<4	8.3	<10	<4	2,000	Drewes 2018	Max: 0.82[3]
Gemfibrozil	8.6	<4	<5	<4	<0.08	<5	<4	600,000	Trussell 2013	<5 – 162 [8]
Ibuprofen	<25	25	<25	<20	<0.39	<25	<20	400,000	Trussell 2013	<10 – 47 [<10]
Iohexol	720	-	<20	-	<5	<20	-	720,000	Drewes 2018	Max: < 5[4]
Iopromide	<10	<4	<10	<4	<1.8	<10	<4	750,000	WSAA 2008	Max: 11[3]
Meprobamate	200	160	<5	<4	<0.36	<5	<4	200,000	Trussell 2013	Max: 42[3]
Methadone	13	<4	<5	<4	0.15	<5	<4	700	WRF 2015	Max: 16[3]

CEC	Concentration (ng/L)							Health Screening Level (ng/L)	Health Screening Reference	State Project Water min – max [median] (ng/L)[2]
	UF Feed		RO Permeate		UV AOP Effluent					
	12/8/2020	5/26/2021	5/26/2021	12/8/2020	5/26/2021					
Naproxen	<20	<4	<20	<4	0.4	<20	<4	200,000	Drewes 2018	Max: 3[3]
Phenytoin (Dilantin)	32	53	<20	<4	<65	<20	<4	2,000	Drewes 2018	<5 – 33
Primidone	210	140	<5	<4	<0.6	<5	<4	10,000	Trussell 2013	<2 – 21 [5]
Salicylic Acid	<200	<100	<200	<100	56	<200	<100	110,000	Drewes 2018	Max: 4.7[3]
Sucralose[6]	46,000	16,000	160	110	270	<100	28	150,000,000	Trussell 2013	Max: 140[4]
Sulfamethoxazole	37	6.5	<5	<4	<0.19	<5	<4	35,000	Trussell 2013	5 – 71 [17]
Tris(2-chloroethyl)phosphate	110	77	<10	<10	<5	<10	<10	5,000	Trussell 2013	<5 – 34 [7]
Tris(1-chloro-2-propyl)phosphate (TCPP)	720	2,800	<200	<50	140	<200	<50	10,000	WHO 1998	Max: 510[3]
Tris(1,3-dichloro-2-propyl)phosphate	150	280	<100	<50	<42	<100	<50	800	MDH 2013	Max: 5,500[3]
Triclosan	<25	<8	<25	<8	4.5	<25	<8	2,100,000	Trussell 2013	<5 - <5 [<5]
Trimethoprim	<5	<4	<5	<4	0.24	<5	<4	40,000	Drewes 2018	Max: 11[3]

Notes:
(1) Health screening values and indicative surface water concentrations were included from available literature. There were no CEC concentrations above health screening levels. Values that were not detected are reported as "<" the detection limit.
(2) State Project Water Concentrations where available taken from NRWI 2010 unless otherwise specified. Reported as min to max [median]. Where multiple detection limits were reported and all samples were below detection, the maximum detection limit has been used to express the range of values.
(3) Maximum observed drinking water concentration taken from WRF 2015. Minimum and median concentrations not reported.
(4) Maximum observed concentrations from a surface water site not impacted by reuse or wastewater discharge taken from WRF 2020. Minimum and median concentrations not reported.
(5) Used detection limit from Finnegan et al. 2010 where an antibiotic survey of surface waters was conducted. Amoxicillin was not detected in Finnegan et al. 2010 where the limit of detection as 10 ng/L. Amoxicillin was also not detected in WRF 2015, but no detection limit was reported.
(6) Sucralose has been sampled in the RO feed and RO permeate for use as a removal surrogate. Results reported here are for quarterly sampling only. RO feed data is anticipated to reflect UF feed concentrations and have varied between 13,000 – 46,000 ng/L with an average of 30,667 ng/L [n = 15]. RO permeate data has varied between <100 to 220 ng/L, has been detected in 14 of 17 RO permeate samples and has an average concentration of 122 ng/L. Using average data, sucralose removal across RO is very high, 99.6 percent [equivalent to an average LRV of 2.4].

- 31 CECs were sampled at least twice in the finished water as part of quarterly sampling events.
- Due to the use of different laboratories, detection limits for CECs varied.
- 20 of 31 CECs analyzed were detected in the UF feed and even though this was the source water prior to advanced treatment, no concentrations exceeded available health screening levels.
- 14 of 31 CECs analyzed were detected in the UV AOP outlet but all concentrations were lower than health screening levels. In addition, the UV AOP outlet concentrations were close to, or better than, available surface water data.
- The CEC sampling to date indicates that the Demo provides water of de minimis chemical risk.
- A significant variation in the UF feed concentration of the flame retardant TCPP was noted, between 720 – 2,800. TCPP was also detected in one of three finished water samples. Although the concentrations are below health screening levels, the variability of this compound in the feed water was high and it is recommended that TCPP is continued to be monitored at least quarterly.

Recycled Water Policy

The 2018 update to the California State Water Board's Water Quality Control Policy for Recycled Water[1] includes CEC monitoring requirements for the production and use of recycled water for groundwater recharge and reservoir water augmentation. Project sponsors must develop a quality assurance project plan to ensure CEC monitoring data quality are of known, consistent, and documented quality and to verify that the laboratory can meet the required reporting limits for the targeted CECs and bioanalytical results.

For surface water augmentation, the CECs, performance surrogates and bioassays that are required to be monitored as well as their performance criteria are summarized in Table 5.15. Results are also included based on the performance of the Demo over the first year of operation.

The results from the first year of operation indicate that the current process used at the Demo will meet the requirements set out in the Recycled Water Policy. It is recommended that the surrogates in Table 5.15 are continually monitored at a minimum quarterly to provide data on the Demo's ability to continually meet the Recycled Water Policy requirements.

Table 5.15 CEC, Surrogate and Bioanalytical Screening Tool Monitoring Requirements as Part of the 2018 CA Recycled Water Policy (SWB, 2018) Relative to Demo Performance

Constituent	Relevance	MTL (µg/L)	Maximum Observed Concentration in UV AOP outlet (µg/L)	Example Removal (%)	Demo Removal (%)
1,4-dioxane	Health	1	<1 (n=4)	-	-
NDMA(1)	Health and Performance	0.010	<2 (n = 14)	80	>96.8(6)
NMOR(2)	Health	0.012	<2 (n = 12)	-	-
PFOS	Health	0.013	<0.002 (n = 2)	-	-

[1] Recycled Water Policy

Constituent	Relevance	MTL (µg/L)	Maximum Observed Concentration in UV AOP outlet (µg/L)	Example Removal (%)	Demo Removal (%)
PFOA	Health	0.014	< 0.002 (n = 2)	-	-
Sulfamethoxazole[2]	Performance	-	-	>90	>39 - >86 (n=2)[4]
Sucralose[2]	Performance	-	-	>90	99.6 ± 0.1 (n=15)
Dissolved Organic Carbon[2,5]	Surrogate[3]	-	-	>90	>92[5]
UV Absorbance[2]	Surrogate[3]	-	-	>50	--
Conductivity[2,5]	Surrogate[3]	-	-	>90	>96.8[5]
Estrogen receptor-alpha bioassay[2]	Bioanalytical Screening	3.5 ng/L	< 0.09 ng/L	-	-
Aryl hydrocarbon bioassay[2]	Bioanalytical Screening	0.5 ng/L	< 0.18 ng/L	-	-

Notes:
(1) Health-based CECs and Bioanalytical Screening to be monitored following treatment (i.e., in UV AOP outlet for the Demo).
(2) Performance indicator CECs to be monitored before RO and after treatment (i.e., in UV AOP outlet for the Demo).
(3) Surrogates are provided as examples. Surrogates should be used to demonstrate effectiveness of individual processes for removing CECs.
(4) Calculated with UF feed and ROP sample. Both sulfamethoxazole results were removed below the detection limit in RO permeate, hence, results are a conservative underestimate of removal performance.
(5) 5th percentile RO rejection from online monitoring converted to percent rejection.
(6) Removal percentage based on recommended UV AOP operational conditions to achieve 1.5 LRV of NDMA.

Bioanalytical Screening Tools

The bioanalytical screening tools, Estrogen receptor alpha and Aryl hydrocarbon receptor are highly sensitive assays that are required on finished water as part of the Recycled Water Policy 2018.

Estrogen receptor alpha provides an indication of the potential for feminization, impaired reproduction and cancer that can result from exposure to chemicals such as Estradiol, bisphenol A and nonylphenol. Aryl hydrocarbon receptor provides an indication on the potential for cancer and impaired reproduction from dioxin-like chemicals, polycyclic aromatic hydrocarbons and pesticides.

The two selected bioanalytical screening tools were analyzed on the RO feed, RO permeate and UV AOP outlet as a means to indicate the potential water quality across the Demo treatment train. Estrogen receptor alpha was below detection in all sample points. Aryl hydrocarbon receptor was detected in RO feed, but was then removed to below the detection limit in both RO permeate and UV AOP outlet. Bioanalytical screening tool results are summarized in Table 5.16.

The bioanalytical screening tools, coupled with the broad chemical data set, indicate the success of the Demo treatment train in controlling chemical pollutants and creating a high quality new water.

Table 5.16 Bioanalytical Screening Tool Results Across the Demo Treatment Train

Sample Location	Estrogen receptor alpha (ng/L as 17-B estradiol)	Aryl hydrocarbon receptor (ng/L as 2,3,7,8-Tetrachlorodibenzodioxin)
RO Feed	< 0.35	2.02
RO Permeate	< 0.05	< 0.09
UV AOP Effluent	< 0.09	< 0.18
Monitoring Trigger Level	3.5	0.5

Priority Toxic Pollutants

For Surface Water Augmentation, the finished water quality at the Demo will need to comply with the CTR, as mentioned previously in this report. The CTR includes a list of 121 constituents and includes freshwater limits. Based on available sample data, the CTR chemicals were sorted into the following categories:

- Category 1 – Chemicals that do not appear to pose a risk (Table 5.19).
  - Chemicals that were either detected at concentrations lower than the CTR limit or
  - Chemicals that were not detected and have detection limits lower than the CTR limit.
- Category 2 – Chemicals that are unlikely to pose a risk depending on future CTR limits (Table 5.18).
  - Chemicals that were not detected and do not presently have CTR limits.
- Category 3 – Chemicals that may pose a risk depending on future CTR limits (1 compound):
  - Chemicals that were detected, but do not presently have CTR limits.
  - Chloroform was the only category 3 chemical and was detected at 38 µg/L in the UV AOP outlet in one sample. Chloroform will be included in a future effort to investigate DBP formation at the demo.
- Category 4 – Chemicals with an uncertain risk (Table 5.17):
  - These chemicals were not detected, but the detection limits were higher than CTR limits. Reduction of detection limits, which is expected to happen at some point, will require closer examination.
- Category 5 – Chemicals that exceed CTR requirements (2 compounds):
  - These chemicals were detected at concentrations that exceed CTR requirements.
  - DBCM and BDCM were the only Category 5 chemicals. Efforts are underway to investigate the formation of these compounds.

The chemicals from Categories 1, 2 and 4 are summarized in Tables 5.17 through 5.19 by category. It is recommended that Category 4 and Category 5 chemicals are sampled quarterly in UF feed and UV AOP outlet. This will provide information as to the origin and fate of these chemicals that may help to understand control strategies. When sampling for Category 4 and 5 chemicals, communication with analytical laboratories must stipulate analysis by methods with the lowest possible detection limits.

Table 5.17 Category 4 Priority Toxic Pollutants(1)

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
Benzidine	0.00012	<1.4
N-Nitrosodimethylamine	0.00069	<2
Toxaphene	0.0002	<0.5
PCBs	0.00017	<0.1
N-Nitrosodi-n-Propylamine	0.005	<2
2,3,7,8-Tetrachlorodibenzodioxin	1.3×10^{-8}	$<5.0 \times 10^{-6}$
Indeno(1,2,3-cd) Pyrene	0.0044	<0.55
Benzo(b)Fluoranthene	0.0044	<0.46
Heptachlor Epoxide	0.0001	<0.01
Hexachlorobenzene	0.00075	<0.05
Benzo(k)Fluoranthene	0.0044	<0.22
Heptachlor	0.00021	<0.01
Benzo(a)Anthracene	0.0044	<0.19
Chrysene	0.0044	<0.19
Chlordane	0.00057	<0.017
Aldrin	0.00013	<0.0033
3,3′-Dichlorobenzidine	0.04	<0.99
Acrylonitrile	0.059	<0.63
Dieldrin	0.00014	<0.0014
1,1-Dichloroethylene	0.057	<0.5
Bis(2-Chloroethyl)Ether	0.031	<0.27
1,2-Diphenylhydrazine	0.04	<0.3
Benzo(a)Pyrene	0.0044	<0.02
4,4′-DDE	0.00059	<0.0024
4,4′-DDD	0.00083	<0.0025
1,1,2,2-Tetrachloroethane	0.17	<0.5
4,4′- Dichlorodiphenyltrichloroethane	0.00059	<0.0017
1,2-Dichloroethane	0.38	<0.5

Note:
(1) These compounds were not detected, but detection limits are higher than CTR limits and may warrant further monitoring.

Table 5.18 Category 2 Priority Toxic Pollutants(1)

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
2,4-Dinitrophenol	-	<1.9
Dibenzo(a,h)Anthracene	-	<0.53
Cyanide	-	<3.8

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
3-Methyl-4-Chlorophenol	-	<0.23
1,1,1-Trichloroethane	-	<0.5
Methyl Chloride	-	<0.23
Chloroethane	-	<0.17
1,1-Dichloroethane	-	<0.5
Phenanthrene	-	<0.32
N-Nitrosodiphenylamine	-	<0.19
2-Nitrophenol	-	<0.26
Naphthalene	-	<0.5
4-Nitrophenol	-	<1.2
4-Bromophenyl Phenyl Ether	-	<0.36
2-Chloroethylvinyl Ether	-	<0.19
Bis(2-Chloroethoxy)Methane	-	<0.25
Di-n-Octyl Phthalate	-	<0.46
1,2,4-Trichlorobenzene	-	<0.5
2,4-Dinitrotoluene	-	<0.15
Benzo(g,h,i)Perylene	-	<0.42
Acenaphthylene	-	<0.17
delta-BHC	-	<0.0028
2,6-Dinitrotoluene	-	<0.2
4-Chlorophenyl Phenyl Ether	-	<0.41
Nickel	-	<5
Beryllium	-	<1

Note:
(1) These compounds were not detected and do not presently have CTR limits.

Table 5.19 Category 1 Priority Toxic Pollutants[1]

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
Selenium	5	<5
1,2-Dichloropropane	0.52	<0.5
Hexachlorobutadiene	0.44	<0.4
1,1,2-Trichloroethane	0.6	<0.5
Tetrachloroethylene	0.8	<0.5
Thallium	1.7	<1
alpha-BHC	0.0039	<0.002
Carbon Tetrachloride	0.25	<0.12
Benzene	1.2	<0.5
Mercury	0.05	<0.017

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
Bis(2-Ethylhexyl)Phthalate	1.8	<0.6
Endrin	0.036	<0.01
beta-BHC	0.014	<0.0038
Hexachloroethane	1.9	<0.5
Cadmium	2.2	<0.5
Lead	2.5	<0.5
Trichloroethylene	2.7	<0.5
Zinc	120	<20
Pentachlorophenol	0.28	<0.046
Vinyl Chloride	2	<0.3
Silver	3.4	<0.5
Bromoform	4.3	<0.5
2,4,6-Trichlorophenol	2.1	0.23
2-Methyl-4,6-Dinitrophenol	13.4	<1.4
Chromium (VI)	11	<1[(2)]
gamma-BHC	0.019	<0.0016
Antimony	14	<1
1,3-Dichloropropylene	10	<0.5
beta-Endosulfan	0.056	<0.0019
Methylene Chloride	4.7	0.14
Asbestos fibers/l	7000000	<200000
alpha-Endosulfan	0.056	<0.0015
Isophorone	8.4	<0.21
Nitrobenzene	17	<0.2
Endrin Aldehyde	0.76	<0.0056
Arsenic	150	<1
Methyl Bromide	48	<0.27
Chromium (III)	180	<1[(2)]
Acrolein	320	<1.2
2,4-Dichlorophenol	93	<0.26
2-Chlorophenol	120	<0.28
Copper b	1309	<2
1,4 Dichlorobenzene	400	<0.5
Chlorobenzene	680	<0.5
1,2-Trans-Dichloroethylene	700	<0.5
2,4-Dimethylphenol	540	<0.3
1,3 Dichlorobenzene	400	<0.14

Chemical	CTR Limit (µg/L)	Highest Observed UV AOP Outlet Concentration (µg/L)
Acenaphthene	1200	<0.38
Bis(2-Chloroisopropyl)Ether	1400	<0.38
Fluorene	1300	<0.35
Fluoranthene	300	<0.08
2-Chloronaphthalene	1700	<0.45
Pyrene	960	<0.25
Hexachlorocyclopentadiene	240	<0.05
1,2 Dichlorobenzene	2700	<0.5
Ethylbenzene	3100	<0.5
Toluene	6800	<0.5
Butylbenzyl Phthalate	3000	<0.18
Di-n-Butyl Phthalate	2700	<0.1
Endosulfan Sulfate	110	<0.0016
Anthracene	9600	<0.12
Phenol	21000	<0.16
Diethyl Phthalate	23000	<0.15
Dimethyl Phthalate	313000	<0.18

Notes:
(1) These compounds were either detected at safe levels or were not detected and had detection limits lower than CTR limits. Category 1 chemicals do not present an apparent health risk.
(2) Used result for total chromium as speciation was not analyzed. Finding is therefore conservative.

5.1.3 RO Concentrate

During test plan development, water quality data for Tapia Effluent was extrapolated into an equivalent RO concentrate value assuming 97 percent contaminant rejection and 85 percent recovery. Based on this assessment, 14 of 90 potential constituents were considered potential risks to compliance with the Calleguas NPDES permit and Ocean Plan Effluent limits (Limit/Limits). These 14 contaminants were then included in monthly RO concentrate sampling at the Demo to gain improved understanding of their actual concentration.

The 14 contaminants and their RO concentrate monitoring results from the Demo are included in Table 5.20. RO concentrate estimates for other constituents can be found in Appendix A.

For the Monthly RO sampling results, significant limitations were noted due to the high detection limit of the analytical methods available:

- Gross Beta exceeded the drinking water Limit of 50 pCi/L in 7 of 9 RO concentrate samples consistent with initial projections. A more appropriate limit may need to be established based on brine discharge permit. Gross Beta in the ocean is typically 300 pCi/L and is predominantly due to naturally occurring potassium-40. Maximum RO concentrate gross beta was 160 pCi/L, and even without a dilution credit is almost half the naturally occurring value in sea water. Consequently, screening against the drinking water limit of 50 pCi/L is very conservative.

- Aldrin, benzidine, chlordane, 3,3-dichlorobenzidine, heptachlor epoxide, hexachlorobenzene, all analyzed PCBs (Aroclor 1262, 1260, 1254, 1221, 1232, 1248, 1016 and 1242), total 2,3,7,8-Tetrachlorodibenzodioxin equivalents and toxaphene were not detected in 9 of 9 RO concentrate samples. However, the limits of detection varied and were not low enough to document compliance with the Limits.
- Dichlorodiphenyltrichloroethane was non-detect in 9 of 9 RO concentrate samples. However, the detection limit of 2 of 9 samples was higher than the Limit of 0.012 µg/L. Similarly, the dieldrin detection limit was higher than the Limit in 8 of 9 samples.
- Beryllium was not detected in 9 of 9 RO concentrate samples. Although the limits of detection varied, they were low enough in all cases to demonstrate compliance with the Limit.

In total, only the Gross Beta exceeded the Limit, whereas the detection limits for several other chemicals was not sufficiently low to demonstrate full compliance with Limits. Gross Beta can be examined across the collection system to understand the potential source and methods for reduction. Other chemicals should be monitored once detection limits are reduced, with the timing of such detection limit changes currently uncertain.

Table 5.20 Average, Minimum and Maximum Concentrations of Monthly RO Concentrate Samples Relative to Calleguas NPDES and Ocean Plan Limits

Pollutant	Units	Average RO Concentrate (n = 9)	Min - Max	NPDES and/or Ocean Plan Effluent Limit	Rational for Additional Testing
Gross Beta	pCi/L	74.6	10 - 160	50	Projected RO concentrate too high
Tributyltin	µg/L	<0.0027(1)	<0.0026 – <0.0030	0.1	No tertiary effluent data available
Aldrin	µg/L	<0.01(1,2)	<0.002 - < 0.078	0.0016	Available tertiary effluent data was non-detect but the detection limit was too high to confirm RO concentrate was lower than the regulatory limit
Benzidine	µg/L	<29.2(1,2)	< 1.5 - < 51	0.0050	
Beryllium	µg/L	<0.58(1)	<0.062 - <1.0	1.4	
Chlordane	µg/L	<0.91(1,2)	<0.026 – <2.5	0.0017	
Dichlorodiphenyltrichloroethane	µg/L	<0.012(1,3)	<0.0052 - < 0.028	0.012	
3,3-dichlorobenzidine	µg/L	<15(1,2)	< 0.99 - <25	0.59	
Dieldrin	µg/L	<0.007(1,4)	<0.0021 – <0.02	0.0029	

Pollutant	Units	Average RO Concentrate (n = 9)	Min - Max	NPDES and/or Ocean Plan Effluent Limit	Rational for Additional Testing
Heptachlor epoxide	µg/L	<0.0046(1,2)	<0.002 – <0.01	0.0015	
Hexachlorobenzene	µg/L	<6.0(1,2)	<0.49 - < 10	0.015	
PCBs(5)	µg/L	<4.2(1,2)	<0.15 - <12	0.0014	
2,3,7,8-Tetrachlorodibenzodioxin Equivalents	pg/L	<8.3(1,2) (n = 6)	<1.07 - <10	0.28	
Toxaphene	µg/L	<5.5(1,2)	<0.15 - <20	0.015	

Notes:
(1) Average of detection limits reported.
(2) All samples were below detection limits, but detection limits were not sufficiently low to quantify compliance with limits.
(3) All samples were below detection limits, but 2 of 9 detection limits were not sufficiently low to quantify compliance with limits.
(4) All samples were below detection limits, but 8 of 9 detection limits were not sufficiently low to quantify compliance with limits.
(5) PCBs included Aroclor 1262, 1260, 1254, 1221, 1232, 1248, 1016, 1242 The detection limits for individual species ranged between 0.15 to 12 µg/L and each species was below the detection limit in every sample. Detection limits reported above refer to individual species i.e., not the sum of each detection limit for each species in every sample.

5.1.3.1 RO Concentrate Toxicity

The Calleguas NPDES Permit Conditions regarding toxicity are:

- Comply with Discharge Point 001.
- Initial Dilution Ratio of 72:1.
- Chronic toxicity in-stream waste concentration (IWC) is at 1.37 percent effluent (which is 72:1 dilution).
- "Pass" or Effect <50 percent.

A single sample of RO concentrate was taken and sent for analysis on December 8, 2020 as part of the first quarterly sampling. To assess chronic toxicity, the following experimental conditions were used:

- Diluent:
  - Reconstituted water (DI + minerals): abalone.
  - Lab seawater (natural seawater): topsmelt, sea urchin, sand dollar, kelp.
- IWC = 100 percent and 0 percent (0 percent = diluent):
  - Salinity = 34 ppt (34,000 mg/L).

The results of the chronic toxicity assay are shown in Table 5.21.

Table 5.21 Chronic Toxicity Tests With RO Concentrate Sampled on 12/8/20[(1)]

Species	Test	% Effect	Pass/Fail
Topsmelt (*Atherinops affinis*)	Survival	4.00	Pass
	Growth	-3.21	Pass
Purple sea urchin *(Strongylocentrotus purpuratus)*	Development	-2.53	Pass
	Fertilization	-1.63	Pass
Sand dollar *(Dendraster excentricus)*	Development	-3.66	Pass
	Fertilization	-1.76	Pass
Giant Kelp (*Macrocystis pyrifera)*	Germination	-2.96	Pass
	Growth	0.08	Pass
Red Abalone *(Haliotis rufescens)*	Larval Development	100	Fail

Note:
(1) All RO concentrate samples were tested without dilution at 100 percent IWC. Samples "pass" with effect <50 percent.

Even though the preliminary RO concentrate sample was tested at 100 percent IWC, there was no evidence of significant toxicity for any of the species tested except Red Abalone, where 100 percent effect is noted.

The permit test conditions specify a IWC of 1.37 percent. Therefore, it is recommended to repeat the RO concentrate toxicity testing at conditions that better represent the permit conditions. It is suggested that retesting is only required for Red Abalone as all other test organisms passed at 100 percent IWC.

For a future test, the following conditions are recommended for use with Red Abalone toxicity analysis:

- Diluent: Reconstituted water.
- In-stream waste concentration (IWC) = 0 percent, 0.5 percent, 1.37 percent, 10 percent, 50 percent, 100 percent.
- Salinity = 34 ppt (34,000 mg/L).
- **Abalone only – other species passed at 100 percent concentration.**

Chapter 6
PATHOGEN REMOVAL PERFORMANCE

This section summarizes the pathogen control of each treatment barrier in the Demo.

6.1 Microfiltration and Ultrafiltration

MF/UF performance for pathogen removal has been quantified with the following metrics:

- Protozoa Removal via daily monitoring of PDT.
  - Section 2.3.5.2 of this Report.
- Turbidity filtrate limits.
  - Section 2.3.5.1 of this Report.
- Virus Removal Performance via challenge tests.
  - Section 2.3.5.4 of this report.

Based on the data collected during the first year of operation:

- LRV calculated based on PDT has remained above a 5th percentile of 4.5 for all membrane products indicating effective control of protozoa.
  - UF1 5th Percentile PDT LRV = 4.5.
  - UF2 5th Percentile PDT LRV = 4.8.
  - UF3 5th Percentile PDT LRV = 4.5.
- Filtrate turbidity has remained at very low levels, well below the maximum of 0.15 NTU as an indirect integrity monitoring limit suggested in the USEPA MFGM (USEPA, 2005), indicating consistent removal of particulate matter. After troubleshooting false turbidity positives due to poor meter connection:
  - UF1 Max Daily 95th Percentile Turbidity was 0.09 NTU.
  - UF2 Max Daily 95th Percentile Turbidity was 0.10 NTU.
  - UF3 Max Daily 95th Percentile Turbidity was 0.15 NTU.
- Challenge tests of the UF indicate that a virus LRV of between 0.8 to 3.9, depending on membrane product.
  - UF1 Average MS2 LRV = 3.9.
  - UF2 Average MS2 LRV = 0.8.
    - Note UF2 is a microfilter with a pore size approximately 4 times larger than MS2 and appreciable removal was not expected.
  - UV3 Average MS2 LRV = 2.8.
- Larger indigenous viruses may be moved to a significant (LRV between 2.8 to 4.8 depending on the membrane product) extent based on periodic PMMoV challenge testing.
  - UF1 Average PMMoV LRV = 4.6.
  - UF2 Average PMMoV LRV = 2.8.
  - UV3 Average PMMoV LRV = 4.8.

MF/UF performance results have demonstrated robust pathogen removal across the entire first year of operation.

6.2 Reverse Osmosis

Reverse osmosis pathogen removal performance has been monitored by a range of online and offline surrogates. Surrogate monitoring for RO conventionally assumes a 1:1 relationship between the LRV of all pathogens and the surrogate. This assumption is conservative as most surrogates (except for MS2 bacteriophage) are much smaller than pathogenic microorganisms. Detailed analysis is reported in Section 2.4.7 and key outcomes are summarized here:

- Online Surrogates:
  - Conductivity:
    - The 5th percentile LRV for conductivity monitoring was 1.5.
    - Conductivity is a conservative surrogate for pathogen removal as salts are much smaller than pathogenic microorganisms.
  - TOC:
    - 5th Percentile LRV for TOC removal was 1.1. However, this LRV was influenced by poor meter calibration and operational parameters.
    - After addressing calibration and configuration issues with the TOC meter, the minimum observed LRV based on TOC was 1.7 and the average was 2.0.
    - TOC is similarly conservative to conductivity as a pathogen removal monitoring technique.
- Offline Surrogates:
  - Twice monthly grab samples of non-microbial surrogates including:
    - Sulfate:
      - Sulfate LRV was consistently higher than 2.4 and reached a maximum of > 2.7.
      - LRVs > 2.7 were not able to be demonstrated as there was not sufficient concentration of sulfate in the RO feed to enable detection in the RO permeate.
    - Strontium:
      - Strontium LRV was impacted by RO permeate detection limits.
      - A majority of strontium LRVs were >1.6 and were not able to be detected in the RO permeate.
      - Upon changing analysis laboratories and lowering the RO permeate detection limit, LRVs of up to 2.9 were observed with strontium.
      - The performance of strontium as an LRV surrogate was good, provided a very high resolution method was used to assay RO permeate.
    - Sucralose:
      - Sucralose LRVs were consistently higher than 2.1 and reached a maximum of > 2.6 due to reaching the RO permeate detection limit.
      - Sucralose did not demonstrate LRVs as high as sulfate and was less often detected in RO permeate.
  - MS2 bacteriophage challenge test event in April 2021:
    - MS2 challenge testing indicated the RO was achieving a virus LRV of between 3.2 to 3.3.

Based on conductivity monitoring, the RO system has reliably removed pathogens to an LRV greater than 1.5. Challenge testing indicates that virus removal is greater than 3. It is anticipated that protozoa may be removed to a higher LRV, however, for the purposes of this report it is conservatively assumed that virus and protozoa removal are equivalent.

6.3 UV AOP

Systematic validation testing was performed on the UV AOP to correlate pathogen removal, as well as the removal of chemicals NDMA and 1,4, Dioxane to operational parameters. The testing is described in Chapter 4.

Based on the Testing:

- UVI/Q was shown to hold a strong linear relationship with photolysis of pathogens and NDMA.
- For the current Demo operation:
  - A UVI/Q of > 0.6 mW/cm^2/gpm will result in > 6 LRV of adenovirus removal.
  - A UVI/Q of > 1.9 mW/cm^2/gpm will result in > 1.5 LRV of NDMA, which should result in NDMA consistently below the CTR requirement of 0.69 ng/L based on the maximum observed NDMA RO permeate concentration to date (n = 8, see Section 5.1.2.2.3).
- UVI/Q x Free chlorine dose was shown to hold a strong linear relationship with LRV of 1,4 – Dioxane.
  - A UVI/Q x Free chlorine of > 4.6 mW/cm^2/gpm.mg/L will result in a 1,4-Dioxane LRV of > 0.5.
  - Radical generation should remain effective at pH less than 6.0.
- Challenge testing for the UV AOP was conducted at close to the operating target of 97 percent UVT. Significant reductions in UVT, below 95 percent, may result in a shift in the correlations noted above.
- To account for this, conservatism has been built into the recommended operating limits of UVI/Q and UVI/Q x Free chlorine at the demo which are typically:
  - UVI/Q > 2.2.
  - UVI/Q x Free chlorine > 5.

The UV inlet UVT and pH, as well as the UVI/Q and UVI/Q x Free Chlorine are shown as 15-minute average data in Figures 6.1 and 6.2 covering the first year of operation. Statistical parameters for each are included in Table 6.1.

Table 6.1 Statistics of Key Operational Parameters for UV AOP Performance for the First Year of 15-Minute Average Operational Data

Parameter	UV Inlet pH	UV Inlet UVT (%)	UVI/Q (mW/cm2/gpm)	UVI/Q x Free Chlorine (mg/L.mW/cm^2/gpm)
5th Percentile	5.41	96.63	2.1	4.8
Median	5.55	97.47	2.2	6.8
95th Percentile	5.84	99.06	2.3	7.8

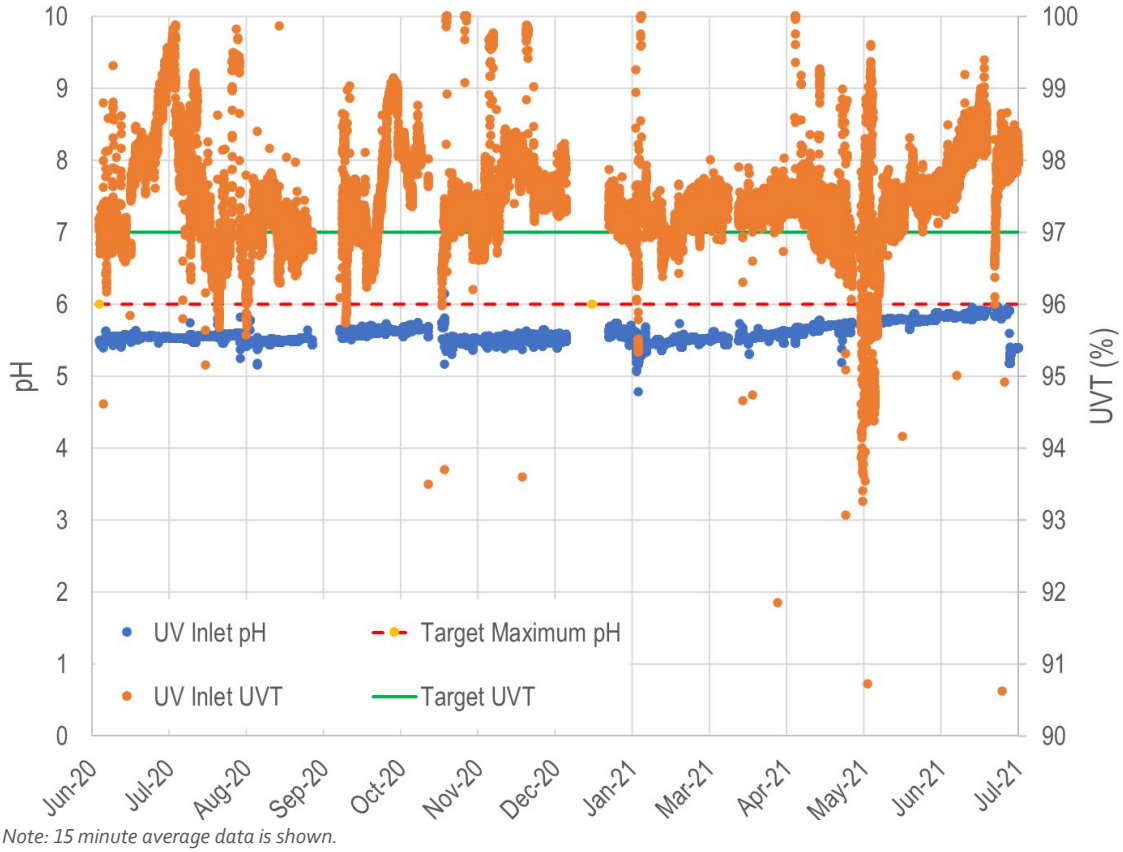
The UV system at the Demo has exceeded 6 LRV of adenovirus, and other pathogens, with a large safety margin.

The 5th percentile UVI/Q was 2.1 mW/cm^2/gpm, indicating that the UV AOP reactor has exceeded 1.5 LRV of NDMA for the entire first year of operation.

The 5th percentile UVI/Q x Free Chlorine was 4.8 mW/cm^2/gpm.mg/L, higher than 4.6 mW/cm^2/gpm.mg/L indicating that the UV AOP reactor has exceeded 0.5 LRV of 1,4-Dioxane for the entire first year of operation.

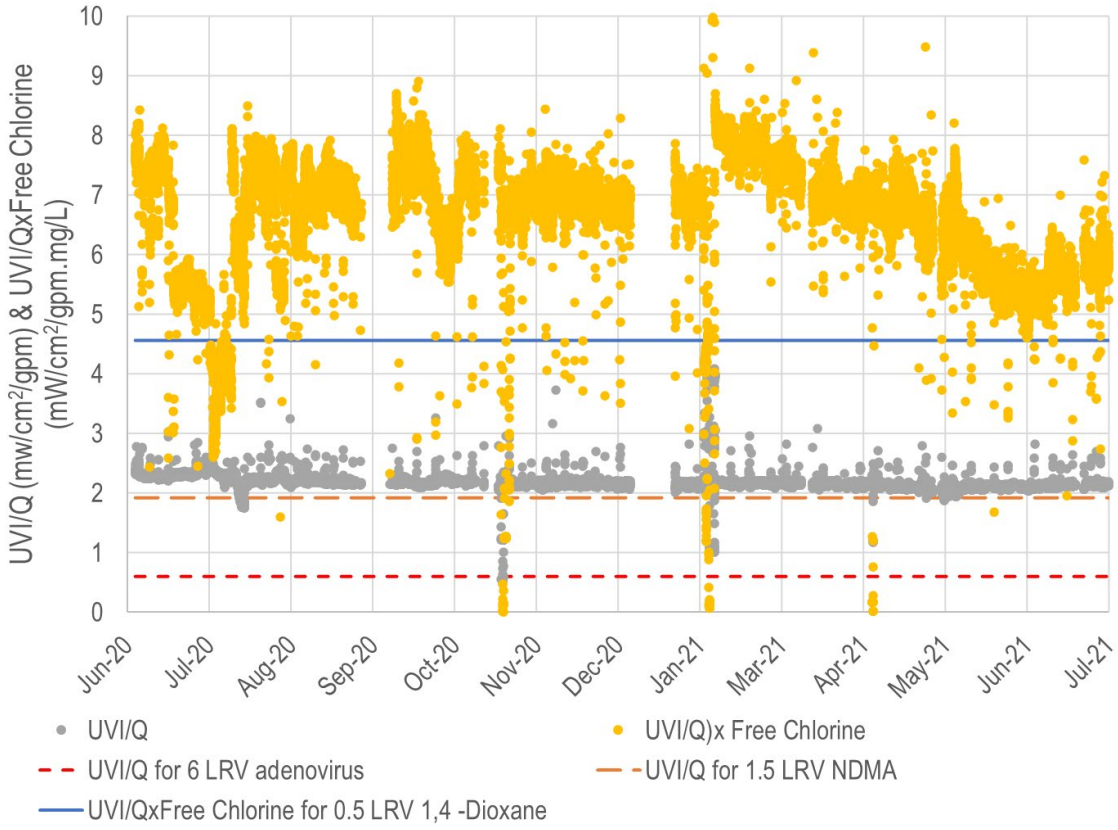
There is some variability in the combined parameters on startup and shut down of the UV system as observed by sporadic low points. Therefore, it is recommended that the UV AOP system is activated and allowed to stabilize for at least 1 hour before sampling or tasting is conducted.

UVT targets (97 percent typical and >95 percent) have generally been met, with the exception of the ammonia breakthrough event in May 2021 where there were high levels of monochloramine. pH has always remained below 6.0 which is favorable for radical production and advanced oxidation performance.



Note: 15 minute average data is shown.

Figure 6.1 UV Inlet pH and UVT Relative to Operational Targets for the First Year of Operation



Note: 15 minute average data is shown.

Figure 6.2 UVI/Q and UVI/QxFree Chlorine Relative to Contaminant Removal Setpoints for the First Year of Operation

6.4 Free Chlorine

In this section, the operation of the tasting tank is described in order to quantify the total LRV of the treatment train. Given the batch nature of the tasting tank, the results within this section are unlikely to correspond to full scale design but can still be evaluated. *Cryptosporidium* and *Giardia* are poorly inactivated by chlorination and are conservatively assumed to result in an LRV of 0.

Prior to tasting, a 30-gallon tank is batch filled and chlorinated. The applied dosage is 5 mg/L of chlorine. Experiments have been conducted to monitor chlorine decay and have noted negligible reduction in free chlorine. The tasting tank is circulated and chilled by means of a continuous recirculation pump to a target temperature of 16 degrees Celsius. The tasting tank is prepared at least 30 minutes before tasting events.

Based on the general procedure above, the contact time (CT) is approximately 150 mg/L.min. At this very high level, it is likely that there will be *Giardia* inactivation, but this is not claimed in this section.

Turbidity of the UV AOP outlet is always less than 0.2 NTU. pH of the UV AOP outlet is always less than 6.

The WaterVal chlorine disinfection document provides CT tables that have been determined in turbidity, pH and temperature ranges (WaterSecure 2017). The CT results for a turbidity of < 0.2 NTU, a pH of < 7 and a max temperature of 15 degrees Celsius are shown below. The

WaterVal tables only contain values to 4 LRV. However, the relationship has been extrapolated to a maximum of 6 LRV in Figure 6.2, with extrapolation approved by the California DDW as part of a water reuse project for the San Francisco Airport (SFO). Inland Empire Utilities Agency have also extrapolated the WaterVal chlorine CT tables for the Chino Basin groundwater recharge program.

Based on the CT LRV relationship within the operational envelope expected for the UV AOP outlet, a virus LRV of 6 should be achieved with a CT of 7.5 mg/L.min. The Demo operates with a much higher CT estimated at 150 mg/L.min, therefore, chlorination practices at the Demo should always exceed an LRV of 6 for virus.

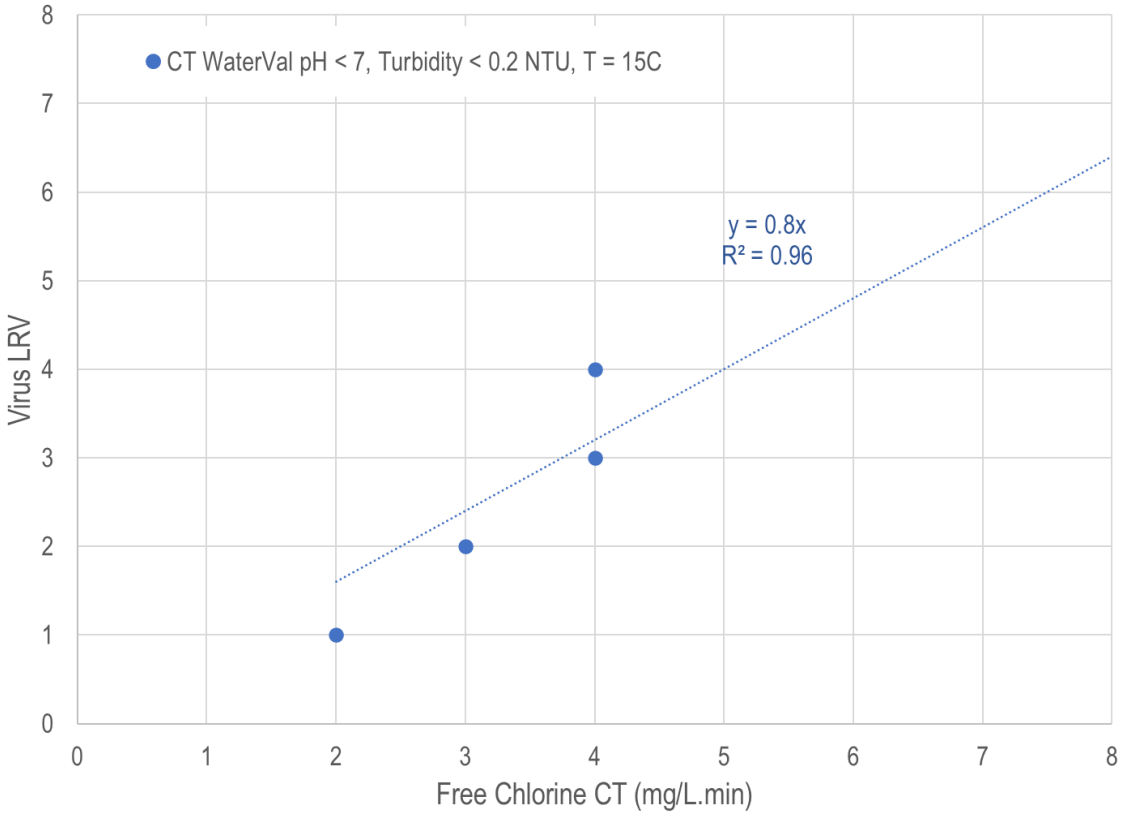


Figure 6.3 CT and Virus LRV Relationship From WaterSecure 2017 for the Demo Tasting Tank Chlorination Operating Envelope

6.5 Cumulative Pathogen Control

Assuming worst case requirements for surface water augmentation, that is, 10:1 dilution and between 2 to 4 months storage, the LRV requirement from raw wastewater would be:

- 14 for viruses.
- 12 for *Cryptosporidium* and *Giardia.*

Based on the analysis above, the demonstration plant achieves:

- 14.3 – 18 LRV of viruses.
- 12 – 13.7 LRV of *Cryptosporidium* and *Giardia.*

The analysis above does not consider the potential contributions to pathogen control of the Tapia WRF or from the Westlake Filtration Plant, both key parts of the future full-scale program. Based on the analysis above, the Demo has shown that robust pathogen control can be achieved and exceeded with the currently applied technologies. However, several items pertaining to full-scale implementation must be considered. First, DDW currently does not credit MF or UF membranes for virus removal, though there are technologies on the horizon that could allow for credit. Second, the stringent CTR must be closely adhered to, which may impact how much free chlorination can be done on the finished water.

Based on the validation results above, the total LRV anticipated across the Demo for each treatment barrier is summarized in Table 6.2.

Table 6.2 Pathogen Removal Summary for Each Barrier at the Demo

Barrier	MF/UF	RO	UV AOP(6)	Chlorination	Total
Probable Virus LRV	2.8(1)	3.2(3)	6	6(7)	18
Probable Protozoa LRV	4.5(2)	3.2+(3,4)	6	0+(8)	13.7
Conservative Virus LRV	0.8(3)	1.5(5)	6	6(7)	14.3
Conservative Protozoa LRV	4.5(2)	1.5	6	0+(8)	12

Notes:
(1) Based on MS2 challenge testing of UF membranes, assumes shut off of MF. Does not consider improved removal demonstrated by PMMoV.
(2) 5th percentile PDT LRV, applies to all MF systems.
(3) Based on worst case MS2 challenge testing from the microfilter UF2 which is not designed to remove viruses.
(4) Protozoa removal anticipated to be higher than virus removal.
(5) Based on 5th percentile conductivity LRV.
(6) UVI/Q always greater than 0.6 mW/cm^2/gpm required for 6 LRV adenovirus. Other pathogens are more susceptible to UV and will be removed to a higher extent. Maximum LRV capped at 6.
(7) Demo CT exceeds projected requirement for a virus LRV of 6 by 20 times. Maximum LRV capped at 6.
(8) At the very high CT some removal of *Giardia* and *Cryptosporidium* will occur but is conservatively assumed not to.

Chapter 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Treatment and Monitoring System Performance

The three key processes of UF (or MF), RO, and UV AOP, coupled with their respective monitoring systems, demonstrated high level reliable performance, with select challenges illustrated within this report. The table below summarizes this performance.

Table 7.1 Qualitative Performance of Key Processes

Process	Monitoring Approach No. 1	Monitoring Approach No. 2	Monitoring Approach No. 3	Pathogen and Chemical Removal
MF/UF	Turbidity	PDT	Pathogen challenge testing	Pathogen removal robust and reliable
RO	EC	TOC	Various grab sample chemical surrogates and pathogen challenge testing	Pathogen and Chemical removal robust and reliable
UV AOP	UVI	UVT change	Total and free chlorine residual change	Pathogen and Chemical removal robust and reliable

7.1.1 Treatment System Operational Efficiency

The treatment processes were designed for the Demo based upon standard engineering principles for this type of project, including conservative flux values for the low pressure membranes, use of 2 and 3-stage RO at 80 percent and 85 percent recoveries, as two examples. The Demo was also built with flexibility, allowing some of the initial design values to be stretched to find greater efficiency for the future full-scale system. The testing documented within this report results in several recommended operational approaches/efficiencies, as shown in Table 7.2.

Table 7.2 Key Process Operational Efficiencies

Process	Process Operational Setpoint No. 1	Process Operational Setpoint No. 2	Process Operational Setpoint No. 3
MF/UF	Membrane Flux – 40 gfd	Weekly MC and Monthly RC with scope for further optimization	
RO	Membrane Flux – 11 gfd	3 Stage 85 percent if high recovery is sought. Further testing is underway	Presently, up to 50 days has been demonstrated. It is anticipated that with further refinements greater than 80 days is possible.
UV AOP	UVI/Q > 2.0	UV Inlet Free Chlorine Dose of >2.5 mg/L	RO Permeate pH < 6.0

7.1.2 Meeting State of California Regulations

The Demo was rigorously examined for chemical pollutants and pathogen reduction and demonstrated full compliance with drinking water requirements for potable water reuse based on 3 significant finished sampling events that measured over 300 regulated and unregulated chemicals. Assessment of compliance included conventional parameters (MCLs, sMCLs, NLs) and new regulated concerns such as PFAS. Unregulated chemicals were also evaluated, often called "Constituents of Emerging Concern" or CECs. In addition, the UV system was validated for destruction of NDMA to levels exceeding 99.6 percent.

7.2 Ongoing Work Recommendations

While the work performed was extensive, implementation of a potable water reuse program does not have a completion date. Said another way, these projects require continued vigilance and re-evaluation. The work within this report documents several near-term areas for further research, as follows:

- Successful/optimum operating conditions:
  - MF/UF:
    - Systematic changes to MC/RC frequency and strength as well as operating flux will be evaluated to enhance predictive AI algorithms and also optimize membrane flux and cleaning frequency balance.
  - RO:
    - RO CIP efficiency is currently under investigation. Different chemicals are being trialed in an effort to better restore and maintain specific flux and increase CIP intervals to reduce maintenance.
    - Alternate CIP products may be trialed if sufficient comparative evidence suggests that alternate products may be able to maintain a more stable specific flux and longer CIP interval.

- Ongoing Work Recommendations:
  - Reformation of NDMA:
    - Further testing will be conducted at ambient NDMA levels to investigate the potential for NDMA reformation and assess operational changes to limit reformation.
  - CTR DBP minimization studies:
    - Systematic sampling will be conducted at the Demo and further upstream to identify options to reduce DBP formation within the plan.
  - RO concentrate gross beta analysis:
    - Gross beta results will be investigated in the source water and the catchment to identify options for utilizing source control to improve RO concentrate compliance.
  - RO concentrate toxicity:
    - Initial RO concentrate toxicity evaluation did not measure realistic dilutions. It is recommended that the RO concentrate is diluted to levels that better represent the toxicity compliance point and testing is repeated.
  - RO concentrate scaling potential:
    - Initial results presented in this report suggest that brine line scaling will be a risk at recoveries higher than 80 percent. This recommendation did not include the impact of potential pH increase due to air gaps and mixing.
    - Further analysis of scaling potential and consideration of alternate acidification, antiscalant dosages and dynamic formation of scale is recommended.

Chapter 8

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Appendix A

INITIAL TEST PLAN PROJECTS OF RO CONCENTRATE

Table A.1 Comparison of Projected RO Concentrate Pollutant Concentrations With NPDES Permit With Ocean Plan WQO Limits – Technology-Based and Bacteriological

Parameter	Units	MDL	Method	Average Monthly Concentration in Tapia Effluent	Projected Average Concentration in AWPF RO Concentrate	Average Monthly NPDES Permit Effluent Limit (mg/L)	30-Day Average Ocean Plan WQO Based Effluent Limit (mg/L)
Biochemical Oxygen Demand (BOD)	mg/L	2.0	SM 5210 B	3.30	21	30	Note(1)
Total Suspended Solids (TSS)	mg/L	1.0	SM 2540 D	2.0	13	60	Note(2)
Grease and Oil	mg/L	1.3	EPA 1664B	Not measured	Note(3)	25	25
Settleable Solids	mL/L	0.2	EPA 160.5	Not measured	Note(3)	1.0	1.0
Turbidity	NTU	0.024	SM 2130 B	Not measured	Note(3)	75	75
pH	s.u.	0	EPA 150.2	7.2	Note(4)	6.0 to 9.0	6.0 to 9.0
Total coliform	MPN/100 mL	0	EPA 1604	Not measured	Note(5)	1,100(6)	1,100(6)
Fecal coliform	MPN/100 mL	0	EPA 1604	Not measured	Note(5)	200(6)	200(6)
Enterococcus	MPN/100 mL	0	EPA 1600	Not measured	Note(5)	100(6)	100(6)

Notes:
Abbreviations: BOD - biochemical oxygen demand; TSS - total suspended solids; mg/L - milligrams per liter; mL/L - milliliters per liter; NTU - nephelometric turbidity unit; s.u. - standard unit; MPN - most probable number; mL - milliliter; MDL - method detection limit; EPA - Environmental Protection Agency; AWPF - Advanced Water Purification Facility; RO - reverse osmosis; NPDES - National Pollutant Discharge Elimination System; WQO - water quality order.
(1) Instead of a numerical WQO for BOD, the Ocean Plan's Chemical Characteristics standards include a provision that dissolved oxygen in the receiving water shall not be depressed more than 10 percent from that which occurs naturally as a result of discharge.
(2) For suspended solids, the Ocean Plan includes a removal target rather than a TSS effluent limit: dischargers shall, as a 30-day average, remove 75 percent of suspended solids from the influent stream before discharging wastewaters to the ocean.
(3) Upstream pretreatment processes at Tapia WRF and at the future AWPF will maintain RO concentrate levels below these regulated thresholds.
(4) pH in RO concentrate will be controlled as necessary at the future AWPF to remain within the acceptable range.
(5) The future AWPF will disinfect RO concentrate as necessary in order to minimize bacteria levels below regulatory threshold.
(6) Calculated as a 30-day geometric mean using the result of the five most recent samples.

Table A.2 Comparison of Projected RO Concentrate Pollutant Concentrations With NPDES Permit With Ocean Plan WQO Limits – Protection of Marine Aquatic Life

Parameter	Units	MDL	Method	Average Monthly Concentration in Tapia Effluent	Projected Average Concentration in AWPF RO Concentrate	6-Month Median NPDES Permit Effluent Limit	6-Month Median Ocean Plan WQO (CO)	Background Seawater Concentration (CS)	6-Month Median Ocean Plan Effluent Limit (Ce) Dm = 72
Arsenic	µg/L	0.074	EPA 200.8	1.8	12.0	370	8	3	368
Cadmium	µg/L	0.041	EPA 200.8	0.2	1.2	73	1		73
Chromium VI	µg/L	0.0048	EPA 218.6	0.2	1.4	150	2		146
Copper	µg/L	0.13	EPA 200.8	3.5	23	75	3	2	75
Lead	µg/L	0.031	EPA 218.6	0.3	2	150	2		146
Mercury	µg/L	0.017	EPA 245.1	0.3	2	2.9	0.04	0.0005	2.9
Nickel	µg/L	0.045	EPA 200.8	3.4	22.2	370	5		365
Selenium	µg/L	0.14	EPA 7741A	0.9	5.6	1,100	15		1,095
Silver	µg/L	0.062	EPA 200.8	0.8	5.1	40	0.7	0.16	40
Zinc	µg/L	0.94	EPA 200.8	37	241	880	20	8	884
Cyanide	µg/L	2.7	EPA 335.4	6.4	42	73	1		73
Total Chlorine Residual	µg/L	2	SM 4500CI-G	1,943	ND(1)	150	2		146
Ammonia as N	µg/L	0.048	EPA 350.1	0.8	5.2	44,000	600		43,800
Phenolic Compounds (non-chlorinated)(2)	µg/L	4.47	EPA 625	2.24	14	2,200	30		2,190
Chlorinated Phenolics(3)	µg/L	1.18	EPA 625	0.59	3.8	73	1		73
Endosulfan	µg/L	0.017	EPA 608	0.0085	0.06	0.66	0.009		0.66
Endrin	µg/L	0.028	EPA 608	0.01	0.09	0.15	0.002		0.15
Hexachlorocyclohexane(4)	µg/L	0.0095	EPA 608	0.0048	0.03	0.29	0.004		0.29
Radioactivity(5)	pCi/L	Varies	EPA 900	15	100	Not to exceed limits specified in Title 22 CCR § 64443			

Notes:
Abbreviations: µg/L - micrograms per liter; CCR - California Code of Regulations; ND - non-detect: pCi/L - picocuries per liter.
(1) Chlorine residual in RO concentrate will be quenched with sodium bisulfite prior to discharge.
(2) Non-chlorinated phenolic compounds represent the sum of 2-nitrophenol; phenol; 2,4-dimethylphenol; 2,4-dinitrophenol; 2-methyl-4,6-dinitrophenol; and 4-nitrophenol.
(3) Chlorinated phenolic compounds represent the sum of 2-chlorophenol; 2,4-dichlorophenol; 2,4,6-trichlorophenol; 4-chloro-3-methylphenol; and pentachlorophenol.
(4) Hexachlorocyclohexane is the sum of alpha, beta, gamma (lindane), and delta isomers of hexachlorocyclohexane.
(5) Title 22 CCR § 64443 specifies Maximum Contaminant Limits (MCLs) for beta/photon emitters, Strontium-90, and Tritium. The 4 millirems/year MCL for beta/photon emitters has an equivalent gross beta particle activity concentration of 4 picocurie/liter (pCi/L). Similarly, Strontium-90 is 8 pCi/L, and Tritium is 20,000 pCi/L. A screening-level of 50 pCi/L gross beta particle activity is used in this characterization to indicate whether further testing for specific radionuclides is deemed necessary.

Table A.3 Comparison of Projected RO Concentrate Pollutant Concentrations with NPDES Permit with Ocean Plan WQO Limits – Protection of Human Health (Non-Carcinogens)

Parameter	MDL	Method	Average Monthly Concentration in Tapia Effluent	Projected Average Concentration in AWPF RO Concentrate	30-Day Average NPDES Permit Effluent Limit (µg/L)	30-Day Average Ocean Plan WQO-Based Effluent Limit (µg/L)	30-Day Average Ocean Plan Effluent Limit (Ce) Dm = 72
Acrolein	2.2	EPA 624	1.1	7.1	16,000	220	16,060
Antimony	0.045	EPA 200.8	0.0225	0.1	88,000	1,200	87,600
Bis(2-Chloroethoxy)Methane	0.25	EPA 625	0.125	0.8	N/A	4.4	321
Bis(2-Chloroisopropyl)Ether	0.27	EPA 625	0.14	0.9	N/A	1,200	87,600
Chlorobenzene	0.21	EPA 624	0.11	0.7	42,000	570	41,610
Chromium (III)	0.035	EPA 218.6, EPA 200.8	0.08	0.54	14,000,000	190,000	13,870,000
Di-n-Butyl Phthalate	0.24	EPA 625	0.12	0.8	N/A	3,500	255,500
Dichlorobenzenes(1)	1.08	EPA 625	1	3.5	N/A	5,100	372,300
Diethyl Phthalate	0.15	EPA 625	0.075	0.5	N/A	33,000	2,409,000
Dimethyl Phthalate	0.18	EPA 625	0.09	0.6	N/A	820,000	59,860,000
4,6-Dinitro-2-Methylphenol	1.7	EPA 625	0.85	5.52	N/A	220	16,060
2,4-Dinitrophenol	1.6	EPA 625	0.80	5.20	N/A	4.0	292
Ethylbenzene	0.17	EPA 624	0.09	0.55	300,000	4,100	299,300
Fluoranthene	0.22	EPA 625	0.11	0.715	N/A	15	1,095
Hexachlorocyclopentadiene	1.5	EPA 625	0.75	4.87	4,200	58	4,234
Nitrobenzene	0.36	EPA 625	0.18	1.17	360	4.9	358
Thallium	0.014	EPA 200.8	0.007	0.0	150	2	146
Toluene	0.22	EPA 624	0.11	0.71	6,200,000	85,000	6,205,000
Tributyltin	0.0012	Krone, et al, 1989	NM	N/A	0.10	0.0014	0.10
1,1,1-Trichloroethane	0.38	EPA 624	0.19	1.23	39,000,000	540,000	39,420,000

Note:
Abbreviation: N/A - not applicable.
(1) Dichlorobenzenes is the sum of 1,2- and 1,3-dichlorobenzene.

Table A.4 Comparison of Projected RO Concentrate Pollutant Concentrations with NPDES Permit with Ocean Plan WQO Limits – Protection of Human Health (Carcinogens)

Parameter	MDL	Method	Average Monthly Concentration in Tapia Effluent	Projected Average Concentration in AWPF RO Concentrate	30-Day Average NPDES Permit Effluent Limit (µg/L)	30-Day Average Ocean Plan WQO-Based Effluent Limit (µg/L)	30-Day Average Ocean Plan Effluent Limit (Ce) Dm = 72
Acrylonitrile	1.8	EPA 624	0.9	5.8	7	0.10	7.3
Aldrin	0.0015	EPA 608	0.00075	0.0049	0.0016	0.000022	0.0016
Benzene	0.23	EPA 624	0.115	0.7	430	5.9	431
Benzidine	3.7	EPA 625	1.9	12	N/A	0.000069	0.0050
Beryllium	0.033	EPA 200.8	0.017	0.1	1.4	0.033	2.41
Bis(2-chloroethyl) ether	0.27	EPA 625	0.14	0.9	N/A	0.045	3.29
Bis(2-ethylhexyl) phthalate	2.3	EPA 625	15	99	N/A	3.5	256
Carbon Tetrachloride	0.33	EPA 624	0.17	1.1	66	0.90	66
Chlordane	0.05	EPA 608	0.025	0.2	0.0017	0.000023	0.0017
Chlorodibromomethane	0.38	EPA 624	13	84	630	8.6	628
Chloroform	0.25	EPA 624	35	225	9,500	130	9,490
Dichloro-diphenyl-trichloroethane	0.005	EPA 608	0.0025	0.016	0.012	0.00017	0.012
1,4-Dichlorobenzene	0.55	EPA 625	0.28	1.8	N/A	18	1,314
3,3-Dichlorobenzidine	1.2	EPA 625	0.6	3.9	N/A	0.0081	0.59
1,2-Dichloroethane	0.24	EPA 624	0.12	0.8	2,000	28	2,044
1,1-Dichloroethylene	0.12	EPA 624	0.06	0.4	66	0.9	65.7
Dichlorobromomethane	0.28	EPA 624	27	176	1,400	6.2	452.6
Dichloromethane (Methylene Chloride)	0.25	EPA 624	0.13	0.8	33,000	450	32,850
1,3-Dichloropropene	0.32	EPA 624	0.16	1.0	650	8.9	650
Dieldrin	0.0021	EPA 608	0.00105	0.0068	0.0029	0.00004	0.0029
2,4-Dinitrotoluene	0.18	EPA 625	0.09	0.6	N/A	2.6	190
1,2-Diphenylhydrazine	0.25	EPA 625	0.125	0.8	N/A	0.16	12
Halomethanes[1]	Note[1]	EPA 624	2.2	14.2	9,600	130	9,490
Heptachlor	0.0017	EPA 608	0.00085	0.0055	0.0037	0.00005	0.0037
Heptachlor Epoxide	0.0019	EPA 608	0.00095	0.0062	0.0015	0.00002	0.0015
Hexachlorobenzene	0.49	EPA 625	0.25	1.6	0.015	0.00021	0.015
Hexachlorobutadiene	0.47	EPA 625	0.24	1.5	1,000	14	1,022
Hexachloroethane	0.52	EPA 625	0.26	1.7	180	2.5	183
Isophorone	0.21	EPA 625	0.11	0.7	53,000	730	53,290
N-nitrosodimethylamine	0.14	EPA 625	0.07	0.5	530	7.3	533
N-nitrosdi-N-propylamine	0.26	EPA 625	0.13	0.8	28	0.38	28
N-nitrosodiphenylamine	0.19	EPA 625	0.095	0.6	180	2.5	183
Polynuclear Aromatic Hydrocarbons[2]	Note[2]	EPA 625	0.005	0.04	N/A	0.0088	0.64

Parameter	MDL	Method	Average Monthly Concentration in Tapia Effluent	Projected Average Concentration in AWPF RO Concentrate	30-Day Average NPDES Permit Effluent Limit (µg/L)	30-Day Average Ocean Plan WQO-Based Effluent Limit (µg/L)	30-Day Average Ocean Plan Effluent Limit (Ce) Dm = 72
Polychlorinated Biphenyls[3]	Note[3]	EPA 625	0.19	1.2	0.0014	0.000019	0.0014
2,3,7,8- Tetrachlorodibenzo-p-Dioxin Equivalents[4]	Note[4]	EPA 1613B	0.00000087	0.0000057	0.00000028	0.0000000039	0.00000028
1,1,2,2-Tetrachloroethane	0.18	EPA 624	0.09	0.6	170	2.3	168
Tetrachloroethylene	0.11	EPA 624	0.06	0.4	150	2.0	146
Toxaphene	0.035	EPA 608	0.018	0.11	0.015	0.00021	0.015
Trichloroethylene	0.27	EPA 624	0.14	0.9	2,000	27	1,971
1,1,2-Trichloroethane	0.25	EPA 624	0.125	0.8	690	9.4	686
2,4,6-Trichlorophenol	0.22	EPA 625	0.11	0.7	N/A	0.29	21
Vinyl Chloride	0.33	EPA 624	0.17	1.1	N/A	36	2,628

Notes:

(1) Halomethanes shall mean the sum of bromoform (MDL = 0.32 µg/L), bromomethane (methyl bromide, MDL = 0.47 µg/L), and chloromethane (methyl chloride, MDL = 0.26 µg/L).

(2) Polynuclear Aromatic Hydrocarbons shall mean the sum of acenaphthylene (MDL = 0.52 nanograms per liter [ng/L]); anthracene (MDL = 0.91 ng/L); 1,2-benzanthracene (MDL = 0.79 ng/L); 3,4-benzofluoranthene (MDL = 1.6 ng/L); benzo(k)fluoranthene (MDL = 0.52 ng/L); 1,12-benzoperylene (MDL = 0.9 ng/L); benzo(a)pyrene (MDL = 0.58 ng/L); chrysene (MDL = 0.52 ng/L); dibenzo(a,h)anthracene (MDL = 1.2 ng/L); fluorene (MDL = 0.75 ng/L); indeno(1,2,3-cd)pyrene (MDL = 0.99 ng/L); phenanthrene (MDL = 0.96 ng/L); and pyrene (MDL = 0.68 ng/L).

(3) Polychlorinated Biphenyls shall mean the sum of chlorinated biphenyls whose analytical characteristics resemble those of Aroclor-1016 (MDL = 0.022 µg/L), Aroclor-1221 (MDL = 0.084 µg/L), Arolclor-1232 (MDL = 0.064 µg/L), Aroclor-1242 (MDL = 0.07 µg/L), Aroclor-1248 (MDL = 0.049 µg/L), Aroclor-1254 (MDL = 0.068 µg/L), and Aroclor 1260 (MDL = 0.02 µg/L).

(4) Polynuclear Aromatic Hydrocarbons Equivalents shall mean the sum of the concentrations of chlorinated dibenzodioxins (2,3,7,8-CDDs) and chlorinated dibenzofurans (2,3,7,8-CDFs) multiplied by their respective toxicity factors. USEPA method 1613 may be used to analyze dioxin and furan congeners. MDLs are assumed to be as follows: 0.543 picogram per liter [pg/L] for 2,3,7,8-tetra CDD, 0.771 pg/L for 2,3,7,8-penta CDD, 1.05 pg/L for 2,3,7,8-hexa CDDs, 1.18 pg/L for 2,3,7,8-hepta CDD, 2.26 pg/L for octa CDD, 0.449 pg/L for 2,3,7,8-tetra CDF, 1.05 pg/L for 1,2,3,7,8 penta CDF, 1.08 pg/L for 2,3,4,7,8-penta CDF, 0.545 pg/L for 2,3,7,8-hexa CDFs, 0.654 pg/L for 2,3,7,8-hepta CDFs, and 1.22 pg/L for octa CDF.

Appendix B

WATER QUALITY DATABASE

All external laboratory testing has been compiled into a database in the excel sheet appended to this report.

Specific parameters can be sorted by date and sample location.

See separately attached excel file.

Appendix C

RO AUTOPSY REPORTS

1ST 2 STAGE 80% WO#092520-1 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Carollo Engineers, Inc.
Attn. Amos Branch, Ph.D.
2795 Mitchell Drive
Walnut Creek, CA 94598

Avista Technologies, Inc.
140 Bosstick Blvd.
San Marcos, CA 92069
United States

Sender: Raul Gonzalez
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Corp Ofc: +1 760 744 – 0536
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November 2, 2020

RE: WO#092520-1 Carollo Engineers – Las Virgenes MWD Autopsy Report

Hello Amos,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220455. The membrane was sent in for autopsy to determine the cause of a flow loss experienced on-site. The element was taken from the tail position of the second stage.

The element produced 44% of normal flow, normal rejection (99.5%) and normal differential pressure (3 psi). The membrane surface had miniscule amounts of visible foulant deposits. The foulant on the membrane surface was determined as organic material. Trace amounts of calcium, phosphorous and aluminum were also present.

The cleaning study showed a single high pH cleaner (RoClean L212) restored membrane performance. This is the same cleaner that has already been used at the Demonstration facility with positive results. I recommend the continued use of RoClean L212 for future cleanings.

Overall, the loss in performance is attributed to organic fouling. It is likely that the higher Vitec 4000 dose added a higher degree of dispersion. I recommend doing a dispersion study to determine the optimal dispersion dose.

Please let me know if you have any questions or would like to discuss this report in more detail.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista TECHNOLOGIES
a Kurita company

Membrane Autopsy Report

Completed for:

Carollo Engineers

Las Virgenes Municipal Water District

Serial Number 2191220455

2nd Stage – Tail Position

10/26/2020 WO#092520-1





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Executive Summary

Background

Carollo Engineers provided 1 Toray TMG10D reverse osmosis (RO) element to Avista Technologies from Las Virgenes Municipal Water District for dissection and analysis. Element Serial Number (SN) 2191220455 was removed from the 2nd Stage, Tail position. The following is a summary of the results.

Initial Element Testing

The element produced lower than normal flow (44% of normal), normal rejection (99.5%) and a differential pressure of 3 psi during initial wet testing. The element passed integrity testing, suggesting the absence of damage to the internal components of the spiral wound element.

External Inspection

The external components (fiberglass casing, brine seal, permeate tube, anti-telescoping devices (ATDs)) were in good mechanical condition. However, a green-colored streak of material was observed on the casing.

Internal Inspection

Miniscule amounts of tan-colored foulant material were observed on the scroll ends and membrane surfaces. The remaining components (feed spacers, glue lines, membrane backing, permeate carriers) were in good mechanical condition.

Foulant Analysis

Aerobic bacteria testing displayed high growth while yeast and mold testing displayed no growth after incubation. No reaction was observed during acid testing, indicating the absence of metals and carbonates. Due to the lack of scrapable foulant material on the membrane surface, foulant density and compositions could not be measured. Microbiological analysis identified amorphous organic material, Gram-negative bacteria, fungi and particles. Fourier Transform Infrared (FT-IR) performed on the membrane surface displayed peaks associated with amino acids and carbohydrates. Energy Dispersive Spectroscopy (EDS) analysis only detected trace amounts (<0.50 wt%) of calcium, phosphorus and aluminum. Chromatic Elemental Imaging℠ (CEI℠) primarily displayed the membrane surface with thin patches of organics (carbon) across the membrane surface.

Based on the analysis, the miniscule amounts of foulant material were identified as organics (e.g. bacteria, bio-slime).

Flat Sheet Performance and Cleaning Study

Flat sheet samples produced 50% of normal permeability and normal salt passage during baseline cell testing. Flat sheet samples were cleaned with RoClean L212 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours. This cleaning regimen restored permeability to the flat sheet samples.

Flat Sheet Damage

Fujiwara testing for the presence of halogen (e.g. chlorine) oxidation was positive. Although the salt passage was within the normal range before and after cleaning, halogen oxidation is progressively damaging and will cause losses in rejection over time. It is recommended they be removed prior to the RO system.

Initial Element Test

Element Weight

All elements are weighed prior to autopsy as weight is often indicative of the degree of fouling. New four-inch elements typically weight between 7 and 10 pounds.

SN 2191220455 weighed 8 pounds.

Full Element Wet Test

Wet test results were normalized to the manufacturer's published test conditions.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220455	0.73	99.5	3
Manufacturer's Specifications	1.67 to 1.98	99.5 to 99.7	≤15

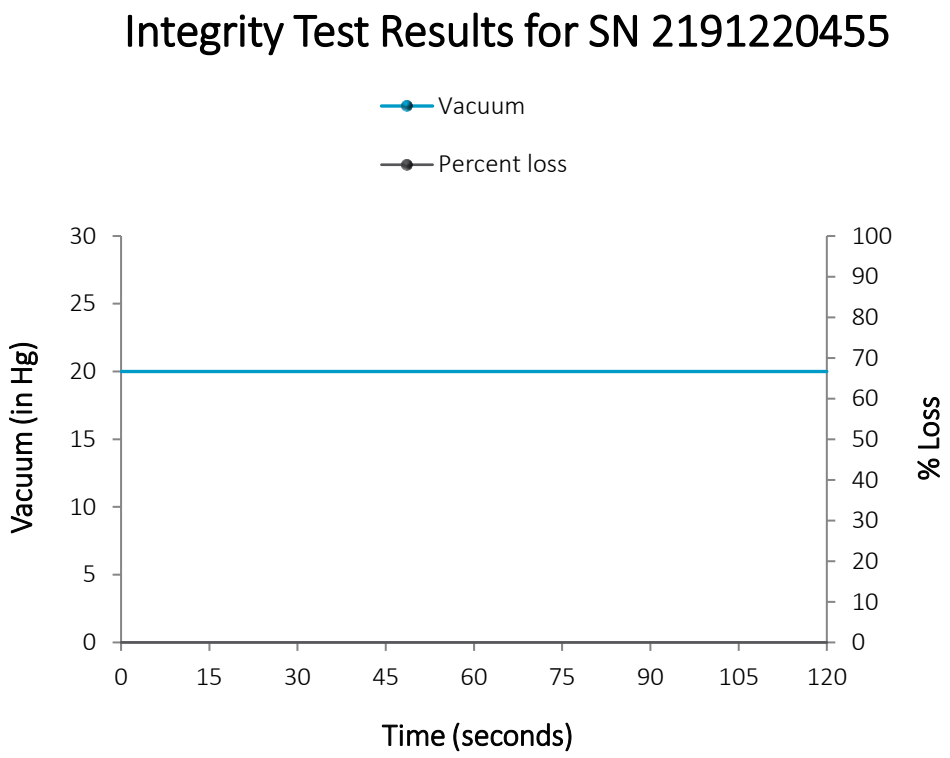


Element wet testing

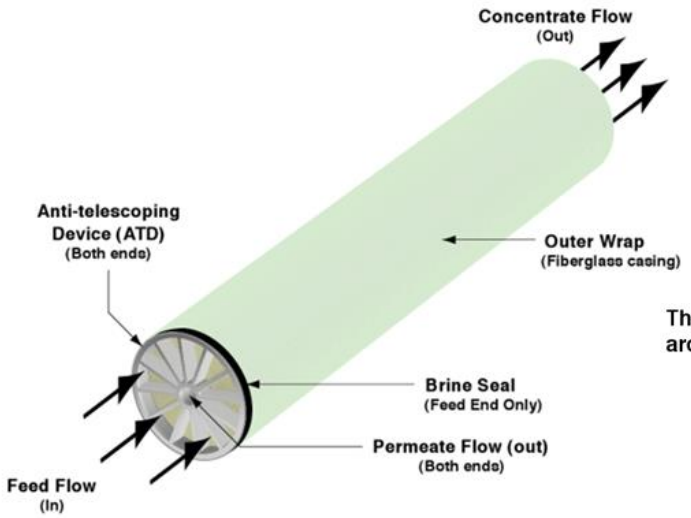
Integrity Test

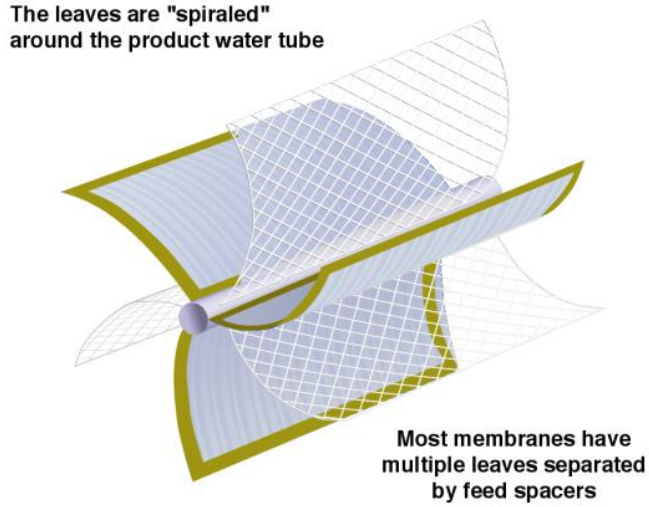
Integrity testing is performed to identify mechanical damage to the internal components of the spiral wound element. In this test, a vacuum of approximately 20 inches Mercury (in. Hg) is applied to the permeate side of the membrane and the membrane is then sealed. The vacuum is monitored for a duration of 120 seconds. Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum within the 120 second period suggests severe physical damage.

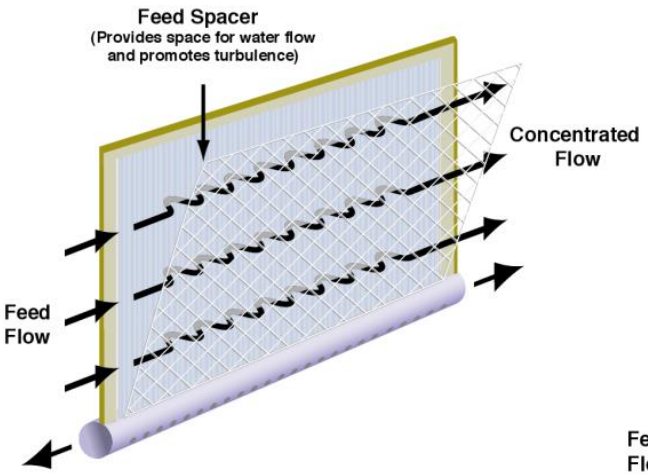
The element passed integrity testing.

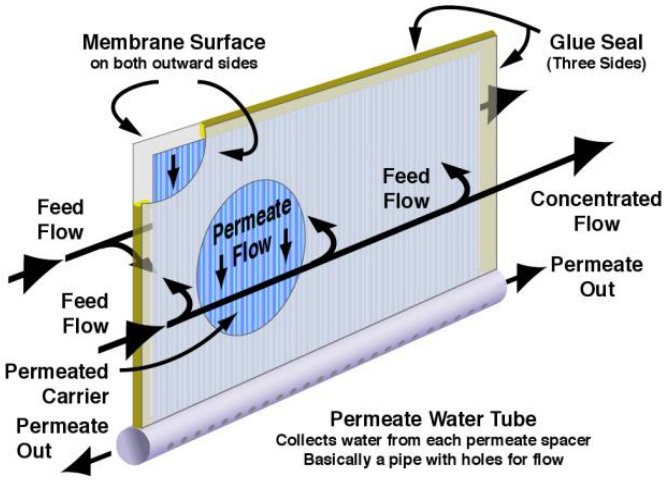


Membrane Construction Diagrams







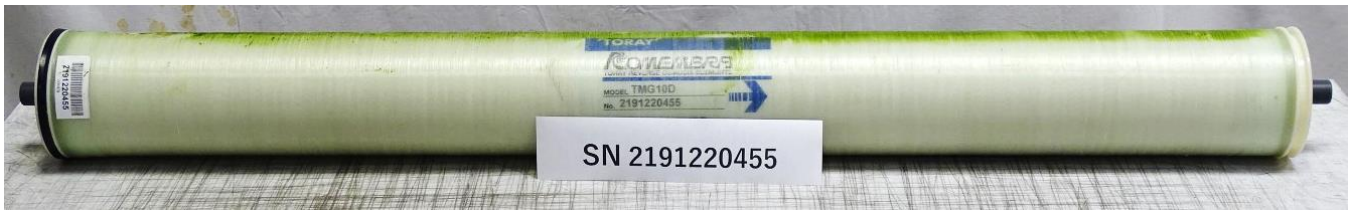


External Inspection

Fiberglass Casing

The purpose of the fiberglass casing is to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the casing can be an indication of rough handling or damage from excessive differential pressure across the element from heavy fouling.

A stripe of green-colored material was observed stretching across the fiberglass casing running parallel to the permeate tube.



Fiberglass casing of SN 2191220455

Brine Seal

The brine seal is used to seal against the inside diameter of the pressure vessels and the outside diameter of the membrane to ensure that all the feed water passes through the element. Feed water passing on the exterior of the element can result in higher pressures, which can cause cracking of the fiberglass casing.

The brine seal was free of damages and in good condition.

Permeate Tube

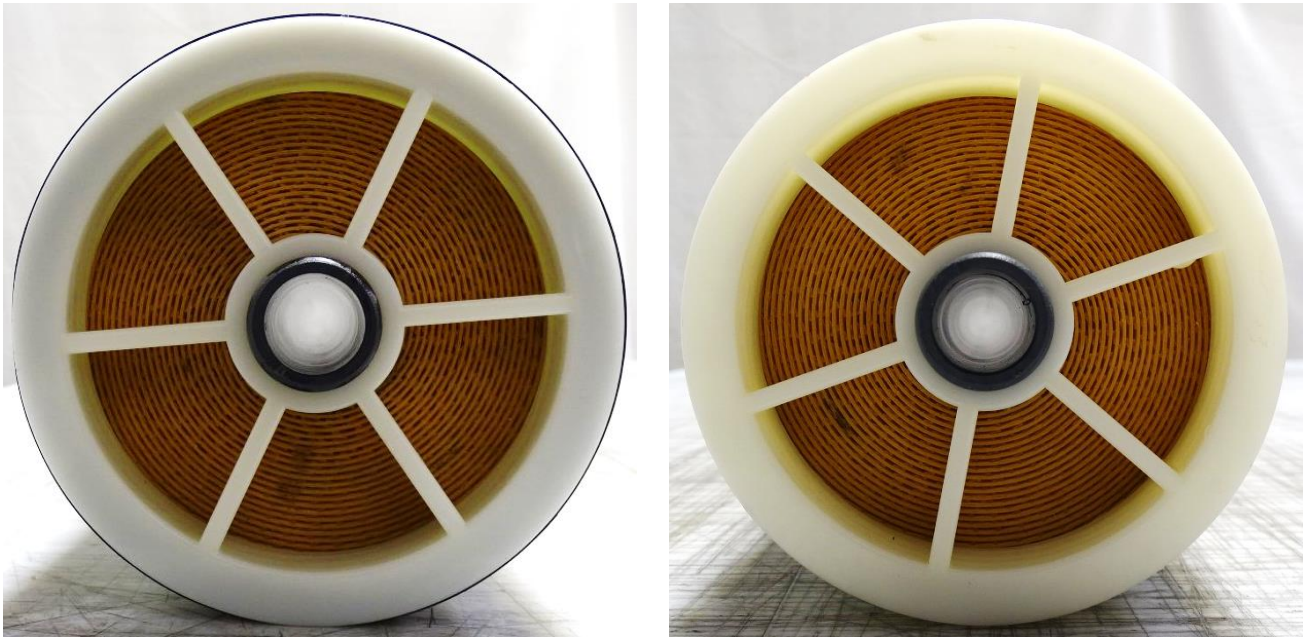
The permeate tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the permeate tube to be collected. Damage to the ends of the permeate tube can lead to o-ring failures, causing bypass of feed or concentrate water into the permeate stream. Cracking of the permeate tube can also result in permeate contamination.

The permeate tube was in good mechanical condition.

Anti-Telescoping Devices (ATDs)

The function of the ATDs is to stabilize the components of the element. This helps to prevent shifting of the internal mechanical components under pressure, also known as telescoping. Telescoping may still occur if pressures exceed the manufacturer's specifications.

No damage or foulant material were observed on the ATDs.



Feed (left) and concentrate (right) ATDs of SN 2191220455

Internal Inspection

Scroll Ends

The ends of the element are called scroll ends. They are examined for the presence of foulant debris and mechanical damage (e.g. gapping, feed spacer extrusion). The presence of foulant on the scroll ends can cause elevated delta pressures while gapping and feed spacer extrusion indicate uneven hydraulics (high flow/low flow regions). In addition, each scroll end is examined for telescoping, the gradual axial shift of the membrane leaves from the outer diameter of the element towards the permeate tube. Telescoping is often caused by the development of high differential pressure (greater than the manufacturer's specification) across the element or when pressure is applied too quickly, causing a water hammer effect.

Small spots of tan discoloration were observed on the scroll ends.



Feed (left) and concentrate (right) scroll ends of SN 2191220455

Membrane Surface

New membrane surfaces are uniform and shiny. Foulant can often be detected through visual examination; however, membrane appearance can be misleading as some foulants are not visible. The presence of foulant on the membrane surface can cause elevated delta pressure, loss in flow and damage if the foulant is abrasive. Additionally, the membrane surface is inspected for damage such as delamination. Delamination is the lifting of the thin-film membrane from the support layer and often occurs due to a positive pressure on the permeate side of the element.

Miniscule amounts of tan-colored foulant material was observed evenly across the membrane surface. The foulant material was scrapable.



Exposed membrane surface of SN 2191220455



Exposed membrane surface from feed end of SN 2191220455

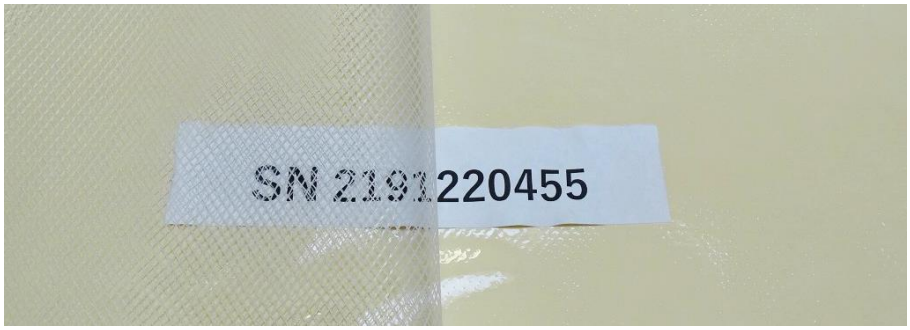


Image of scraped foulant observed on one membrane leaf of SN 2191220455

Feed Spacers

The feed spacer is a plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. Foulant blocking the feed channels causes more resistance for the feed water flowing through the element and results in higher than normal delta pressures.

The feed spacers were free of visible foulant material.



Feed spacer of SN 2191220455

Glue Lines

Membrane leaves are glued on three sides to separate the feed and permeate streams. The glue lines are inspected for specific damage, including glue flaps and pouching. Glue flaps refer to excess inactive membrane material located closest to the ends of the element. Flaps found on the feed end of the element can flare during operation, blocking the feed channels on the scroll end, potentially causing increased differential pressure. Pouching of the glue line, which is often a result of delamination, allows feed water to pass through the inactive membrane at the glue line, contaminating the permeate stream.

The glue lines were in good mechanical condition.

Permeate Carriers and Membrane Backing

The permeate carriers provide a path for permeate water to flow towards the permeate tube, which minimizes permeate-side pressure losses. New permeate carriers and membrane backing are uniform in color. Foulant found on the permeate side of the membrane leaves indicates contamination of the permeate stream.

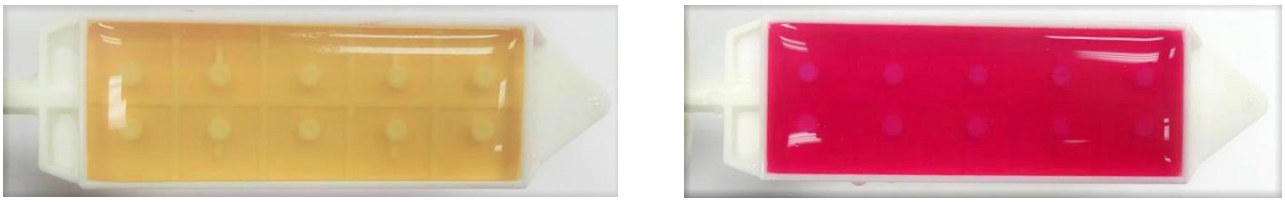
The permeate carriers and membrane backing were in good mechanical condition.

Foulant Analysis

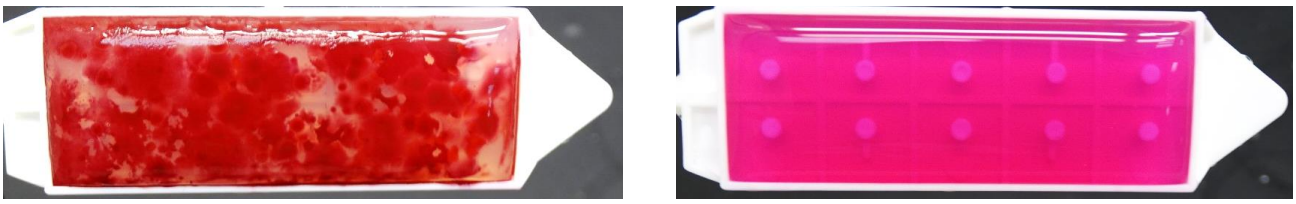
Biological Activity Testing

Dip slides for aerobic bacteria and yeast/mold are exposed to the foulant material on the membrane surface. The slides are incubated for 72 hours and inspected for biological growth. Greater colony density, measured in colony-forming units (CFU)/mL, indicates a more biologically active sample.

The aerobic slide showed high growth with approximately 10^6 CFU/mL while the yeast and mold slide displayed no growth after incubation.



Aerobic bacteria slide (left) and yeast/mold (right) before incubation

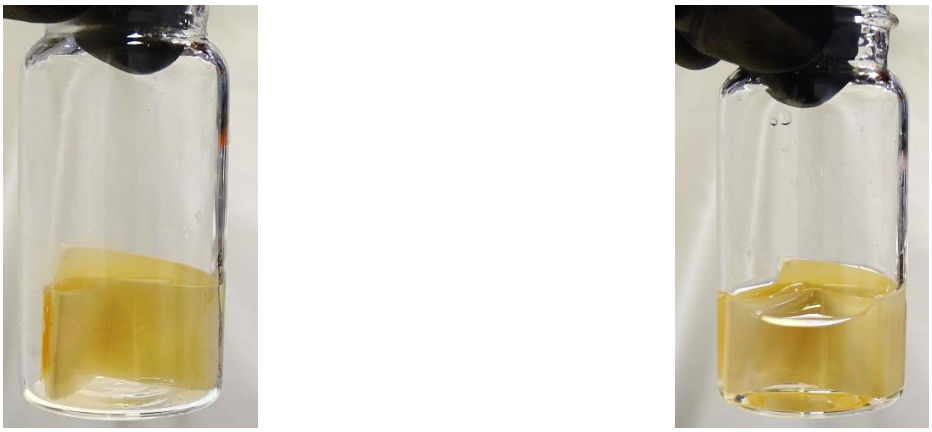


Aerobic bacteria slide (left) and yeast/mold (right) after incubation

Acid Testing

Acid testing is used to determine the presence of carbonates and metals on the membrane surface. In this test, several drops of dilute hydrochloric acid (HCl) were placed on the foulant surfaces. Effervescing indicates the presence of carbonates while a color change is associated with the presence of metals.

Acid testing was negative for the presence of carbonates and metals.



Acid testing before (left) and after (right) the addition of dilute HCl

Foulant Density Measurement and Composition Testing

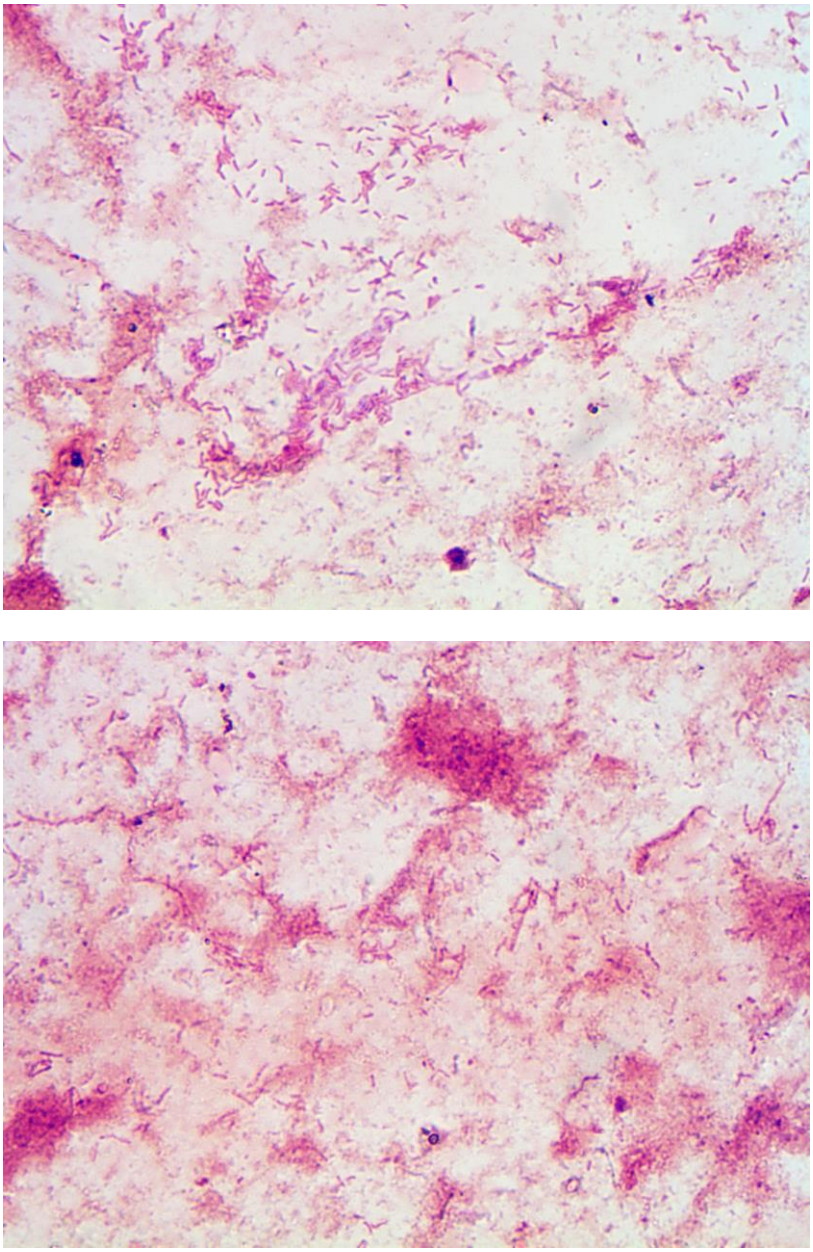
A sample collected from a known area of the membrane surface is weighed before and after drying to determine the foulant density (reported as dry foulant density – mg/cm^2) and moisture content of the sample. Different types of foulant materials exhibit higher moisture contents. Relative water concentrations greater than 95% indicate an extremely hydrated, biological material. Alternatively, scales (crystalline material) typically contain very little moisture. The organic content of the dehydrated material is then measured through loss on ignition (LOI) testing. If the organic content of the total solids is greater than 65%, it is considered primarily organic.

Due to the lack of foulant material on the membrane surfaces, the foulant density and compositions could not be measured.

Microbiological Analysis

This analysis is performed to identify microbiological components of the foulant removed from the membrane surface. Foulant samples are stained and examined with a light microscope at 1000x using an oil immersion lens. Gram-positive bacteria are stained purple while Gram-negative bacteria are stained pink.

Microbiological analysis performed on foulant scraped from the membrane surface identified amorphous organic material, Gram negative bacteria, fungi and particles.

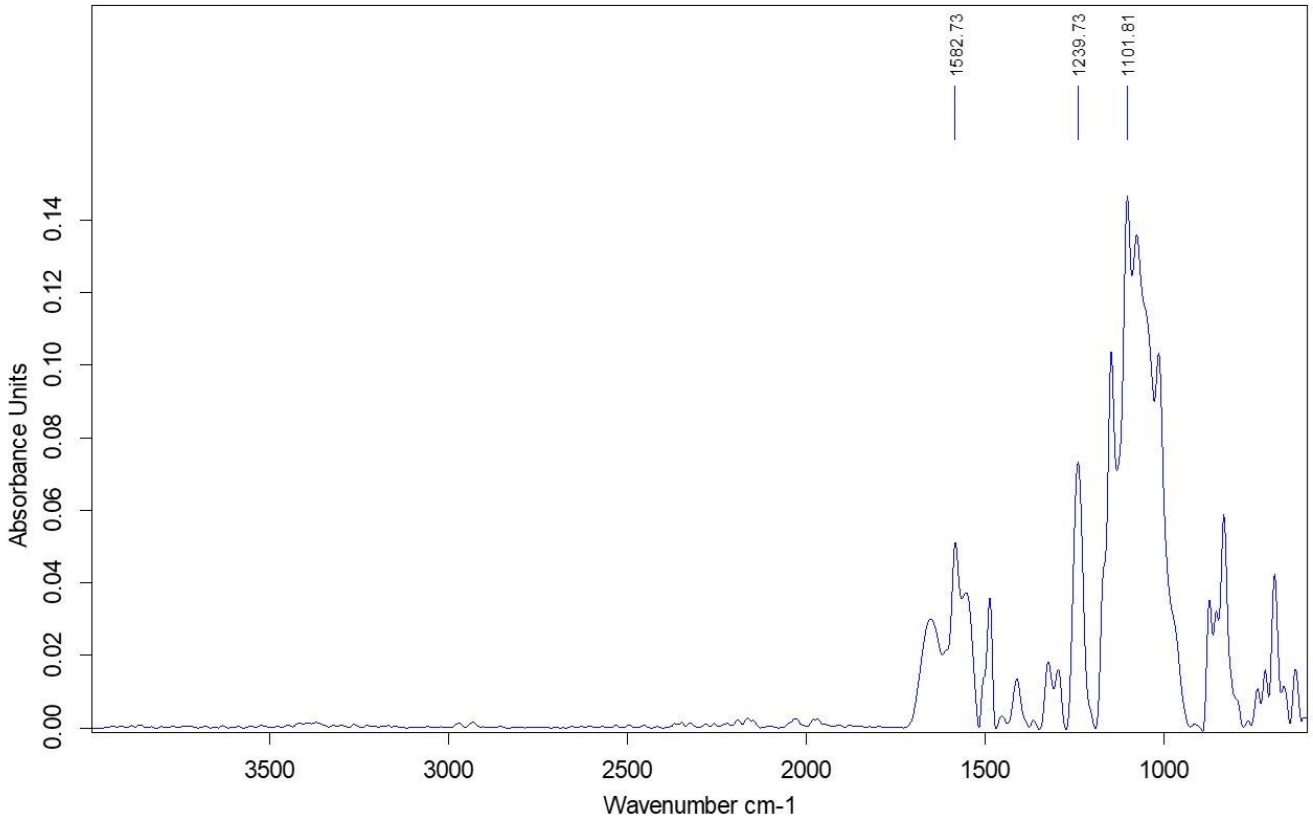


Light microscope images (1000x) of foulant scraped from SN 2191220455

Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) is an analytical technique used to identify functional groups (specific groups of atoms or bonds within molecules). Infrared radiation passes through a sample, with some of the radiation absorbed and some transmitted. A measurement and interpretation of this data produces a spectrum which can then be compared and matched to the known spectra for functional groups based on the wavenumber at which bands appear and their respective shapes (e.g. sharp, broad, strong, weak).

FT-IR spectrum performed on the membrane surface displayed peaks primarily associated with the membrane materials. However, elevated peaks were observed between 1650 and 1500 cm^{-1} which is associated with amino acids (i.e. proteins) and at approximately 1000 cm^{-1} which is due to carbohydrates.



FT-IR spectral image of foulant removed from the membrane surface of SN 2191220455

Energy Dispersive Spectroscopy (EDS) Analysis

Energy Dispersive Spectroscopy analysis is used to determine the relative concentration of elements present in a sample. EDS analysis is performed on a dry membrane sample. The element sulfur is at least in part associated with the membrane support material (polysulfone) rather than a foulant layer. Avista's analysis of new membranes typically detects between 5.00 and 7.00 weight percentage. Relative concentrations below 5.00 percent indicate the presence of a foulant layer masking the membrane surface.

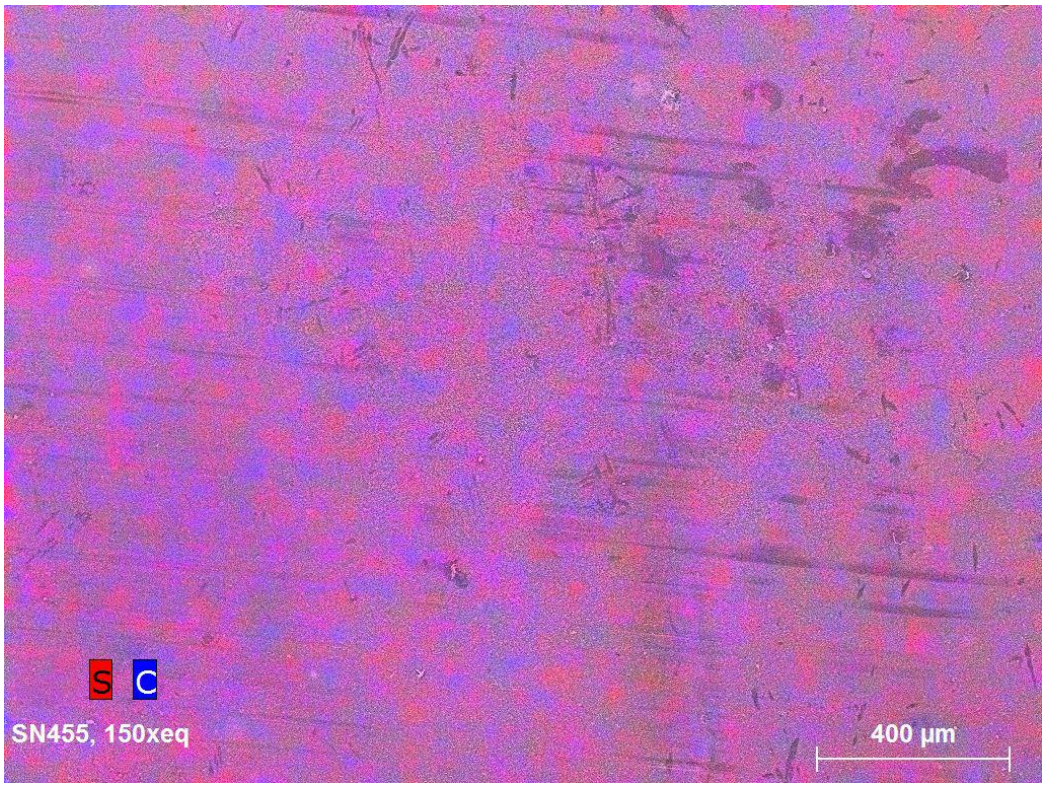
EDS analysis detected trace amounts (<0.50 wt%) of calcium, phosphorus and aluminum as the inorganic elements present in the foulant layer. The carbon weight percent is contributed by the membrane materials but may also be contributed by foreign organic material.

Elements	SN 2191220455 Weight Percent (wt%)
Carbon	72.94
Oxygen	19.10
Sulfur	6.88
Calcium	0.48
Phosphorus	0.32
Aluminum	0.28

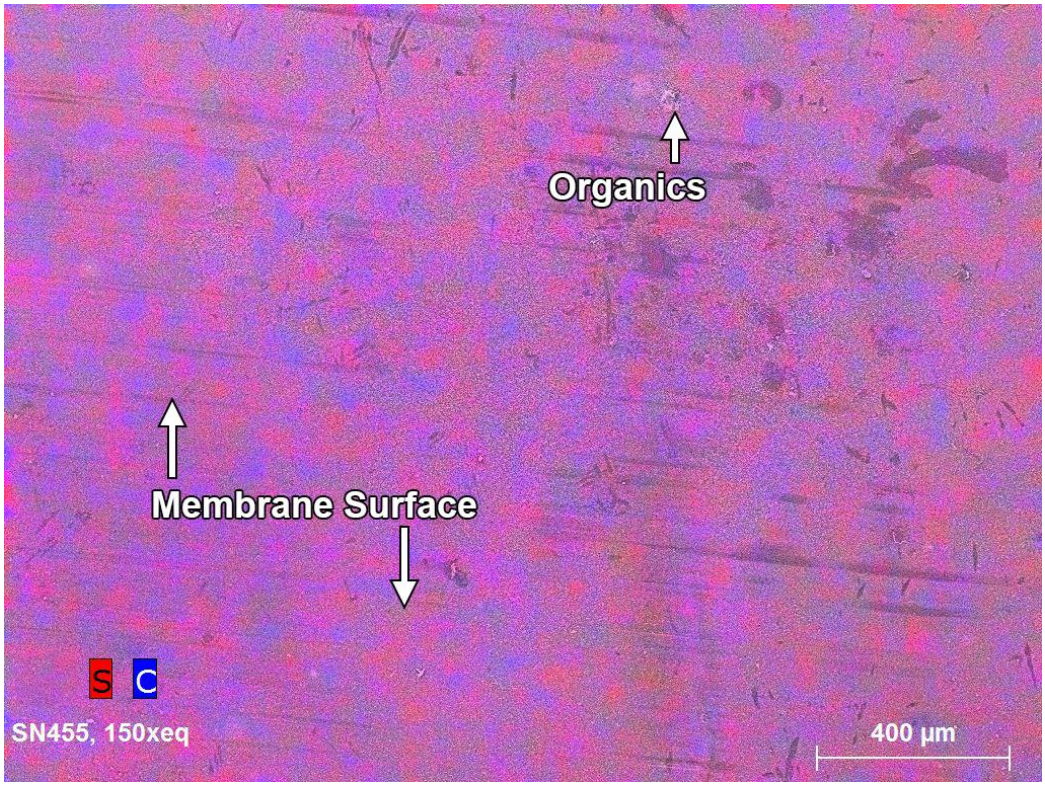
Chromatic Elemental Imaging℠ (CEI℠)

CEI is a high-resolution imaging technique used to determine the spatial distribution of elements in a foulant sample. Each element is assigned a color (shown in a legend on the bottom left corner of the CEI image) and the colors correspond to the location of the elements in the sample. An element's color intensity is associated with its concentration in the sample (i.e. elements present with higher relative concentrations are displayed with greater color intensity in the image). Additionally, a blending of colors signifies a compound (material composed of more than one element such as calcium carbonate).

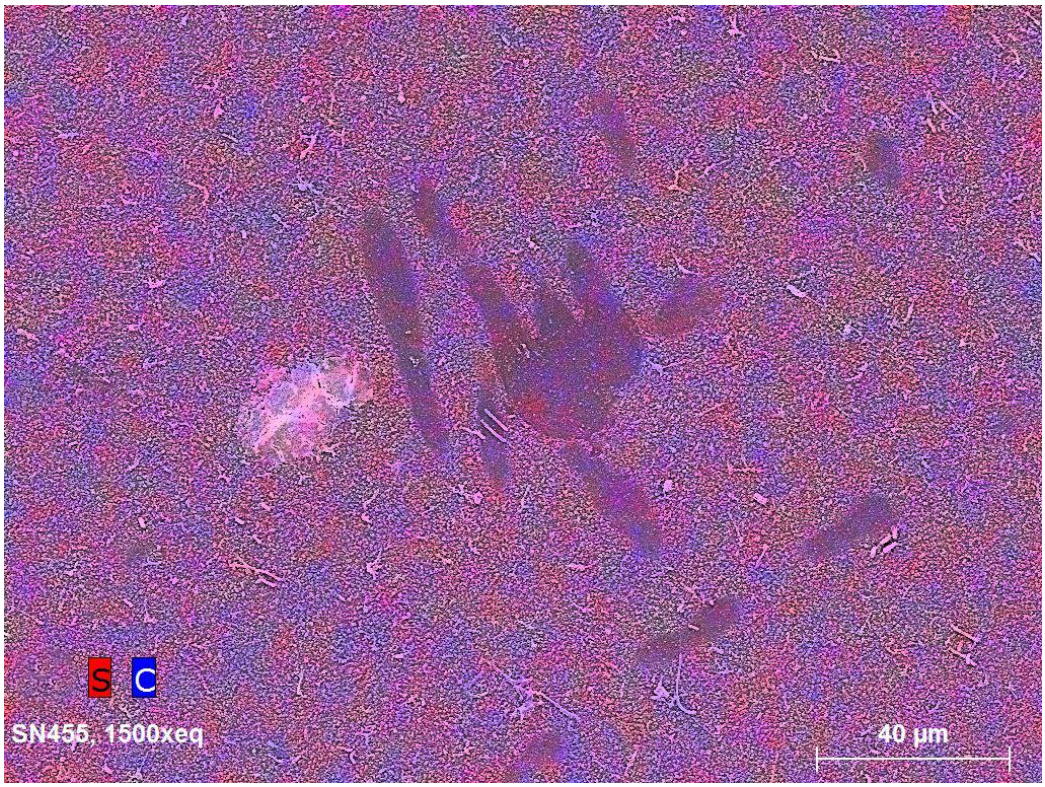
CEI℠ displayed primarily the membrane surface which is denoted by sulfur (red). Small patches of organics – represented by carbon (blue) – were observed across the membrane surfaces.



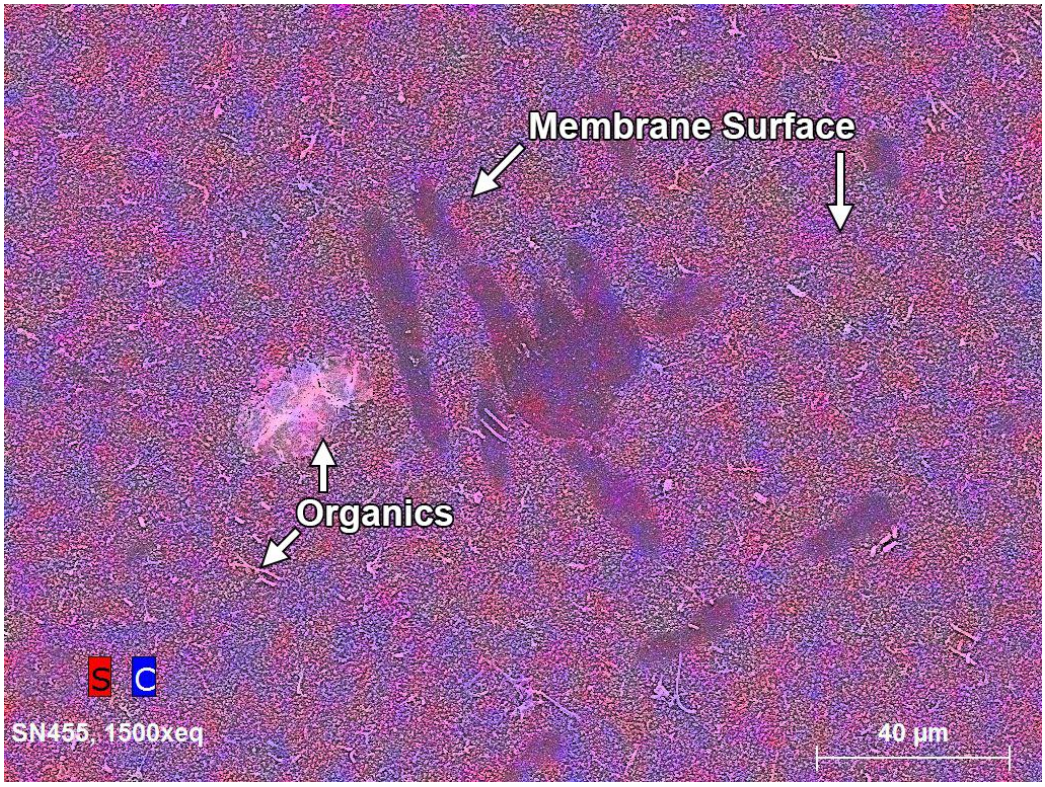
CEI image (150x) of the membrane surface



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface



CEI image (1500x) of the membrane surface with labels

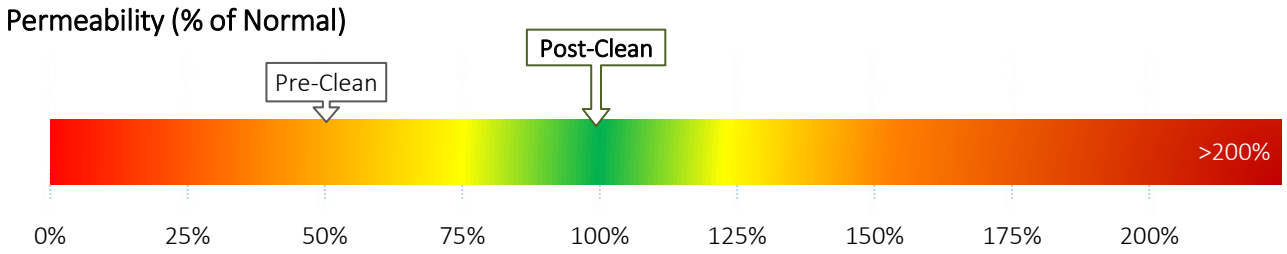
Flat Sheet Performance and Cleaning Study

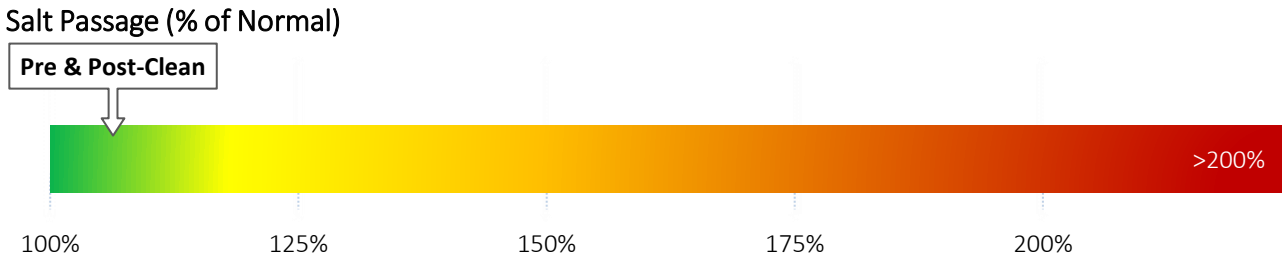
To evaluate flat sheet performance, membrane samples harvested from the full element are tested for permeability and salt passage. The raw flow and conductivity measurements from the test are used to calculate the permeability and salt passage constants, which are independent of pressure, temperature and salt content of the feed stream. The permeability constant is measured in cm/s/atm and the salt passage constant in cm/s. Discrepancies between the flat sheet and full element performance can indicate the presence of mechanical damage.

The flat sheet samples are then cleaned with various Avista chemicals to determine the most effective cleaner combinations and contact times. Cleaner efficacy is based on overall improvement in permeability and salt passage constant as well as visual foulant removal.

The table below shows performance data for the optimum clean. Flat sheet samples were cleaned with RoClean L212 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours. This cleaning regimen restored permeability to the flat sheet samples.

SN 2191220455	Permeability Constant	Salt Passage Constant
Baseline	0.78E-04 50% of Normal	4.70E-06 Normal
Post-Clean	**1.56E-04** **Normal**	**4.78E-06** **Normal**
Manufacturer's Specifications	1.56 to 1.85E-04 Normal Range	4.69 to 7.84E-06 Normal Range





Testing for Flat Sheet Damage

Fujiwara Testing

Fujiwara testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. A color change does not occur if the membranes has not been exposed to halogens. Common symptoms of halogen oxidation include increased flow and loss in permeate quality.

Fujiwara testing was positive for the presence of halogens (e.g. chlorine) in the membrane structure.



Example of a positive Fujiwara color change

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#092520-1	Standard Spiral Autopsy	2191220455	October 26th, 2020

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

Date: 10/26/2020

Signed:

Megan Lee
Laboratory Services Manager

Jaime La Cuesta
Laboratory Services Chemist

2ND 2 STAGE 80% FLOW BALANCED WO#111620-7 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Las Virgenes Municipal Water District
Attn. Steve Jackson
4232 Las Virgenes Road #1994
Calabasas, CA 91302

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January 21, 2021

RE: WO#-111620-7 Las Virgenes Municipal Water District Autopsy Report

Hello Steve,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220194. The membrane was sent in for autopsy to confirm system performance. The element was taken from the tail position of the last stage.

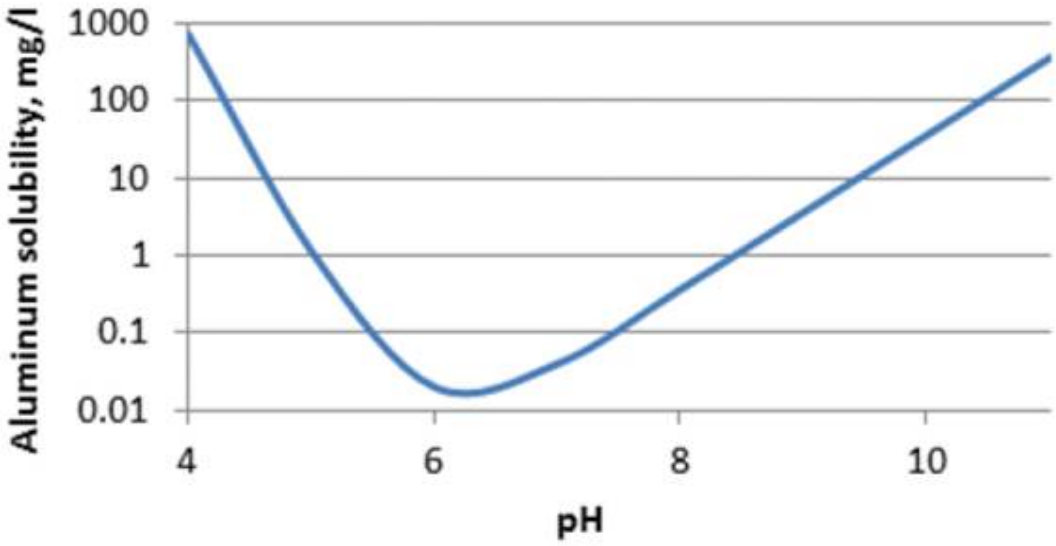
The element produced 25% of normal flow, normal rejection (99.5%) and normal differential pressure (3 psi). The membrane surface revealed small amounts of visible foulant deposits. The foulant on the membrane surface was composed of light organic material, calcium and aluminum.

The cleaning study showed that a light cleaning (1% by weight) of RoClean L403 followed by RoClean L212 restored performance. These are the same cleaners that have been used at the Demonstration facility with positive results. I recommend the continued use of RoClean L212 and RoClean L403 for future cleanings.

The autopsy results are similar to the previous autopsy completed in the Fall. From the water quality provided, the average aluminum concentration in the feed to the MF/UF system is 95 ppb. Due to the location of the acid injection and pH target, it is likely the cause of the aluminum found on the membrane surface. The figure below shows the aluminum solubility versus pH with the lowest solubility between 5.8 to 6.5 pH.

I recommend moving the acid injection point upstream of the MF/UF system to precipitate and filter out the aluminum prior to the RO. Additionally, the water quality shows a non-detected aluminum concentration prior to the RO between October and December of last year. I recommend running an SDI test and analyzing the filter pad to confirm the presence of the aluminum in the RO feed.

Figure 1: Aluminum Solubility



Please let me know when we can setup a time to discuss this report in more detail.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista TECHNOLOGIES
a Kurita company

Membrane Autopsy Report

Completed for:

Las Virgenes Municipal Water District

Serial Number 2191220194

01/08/2021 WO#111620-7





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Creative Chemistry. Smart Solutions.

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Executive Summary

Background

Las Virgenes Municipal Water District provided (1) Toray TMG10D reverse osmosis (RO) element to Avista Technologies for wet testing, dissection and analysis. The element was identified as Serial Number (SN) 2191220194. Below is a summary of the results.

Initial Element Testing

The full element produced 25% of normal flow, normal rejection (99.6%) and a differential pressure of 3 psi. The element passed integrity testing, indicating the absence of damage to the internal components of the spiral wound element.

External Inspection

The external components (fiberglass casing, brine seal, permeate tube, anti-telescope devices (ATDs)) were all in good condition.

Internal Inspection

The scroll ends displayed black discoloration. The exposed membrane surfaces were predominantly clear of visible foulant and contained only a trace amount of fine-granular material. The feed spacers, glue lines, membrane backings and permeate carriers were in good condition.

Foulant Analysis

Foulant density measurement and composition testing could not be performed due to the lack of harvestable foulant material. Biological activity testing displayed moderate-high aerobic bacteria activity and no yeast/mold activity. Acid testing was positive for the presence of metals. Microscope analysis identified primarily amorphous inorganic material. Fourier Transform Infrared (FT-IR) spectroscopy identified only peaks associated with the membrane materials (i.e. polysulfone). Energy Dispersive Spectroscopy (EDS) identified only small amounts of calcium and aluminum. Chromatic Elemental Imaging (CEI) confirmed that the membrane surface contained a light deposition of calcium, aluminum and organics.

Based on the analysis, the small amount of foulant present was comprised of calcium, aluminum and organics.

Flat Sheet Performance and Cleaning Study

Flat sheet samples harvested from the full element displayed 29% of normal permeability and normal salt passage during baseline cell testing. The flat sheet samples were cleaned using RoClean L403 (1% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours followed by RoClean L212 (1% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours. Permeability was completely restored to the manufacturer's specification.

Flat Sheet Damage

Although the flat sheet samples displayed normal salt passage before and after cleaning, Fujiwara testing was positive for the presence of halogens in the membrane structure. The presence of halogens progressively damages polyamide membranes which can lead to increases in flow accompanied by decreases in permeate quality over time.

Initial Element Test

Element Weight

All elements are weighed prior to autopsy as weight is often indicative of the degree of fouling. New elements of this type weigh approximately 30 to 35 pounds.

SN 2191220194 weighed 8 pounds.

Full Element Wet Test

Testing was normalized to the manufacturer's published test conditions.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220194	0.42	99.6	3
Manufacturer's Specifications	1.67 to 1.98	99.5 to 99.7	≤15



Element wet testing

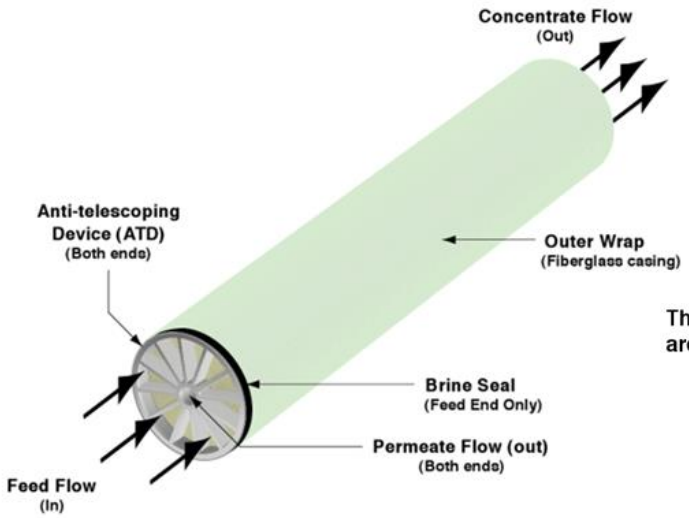
Integrity Test

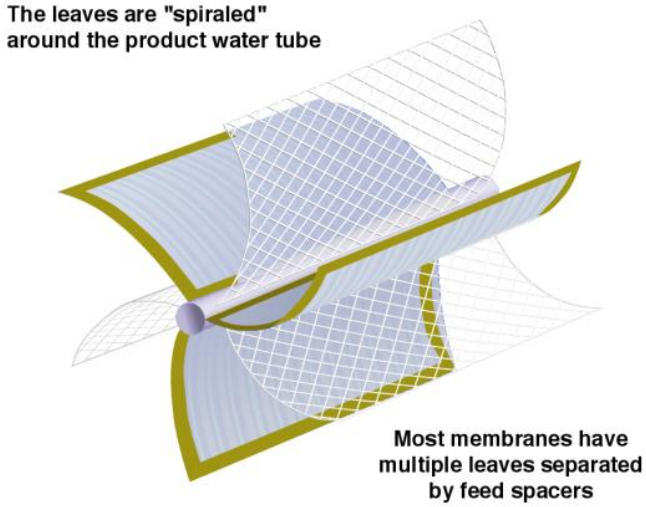
Integrity testing is performed to identify mechanical damage to the internal components of the spiral wound element. In this test, a vacuum of approximately 20 inches Mercury (in. Hg) is applied to the permeate side of the membrane and the membrane is then sealed. The vacuum is monitored for a duration of 120 seconds. Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum within the 120 second period suggests severe physical damage.

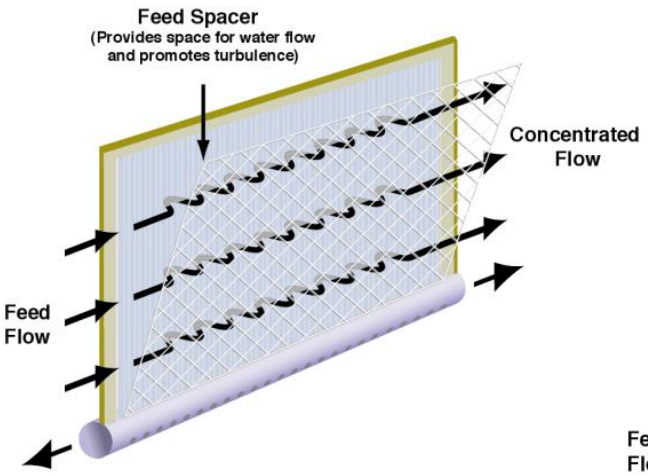
The element passed integrity testing.

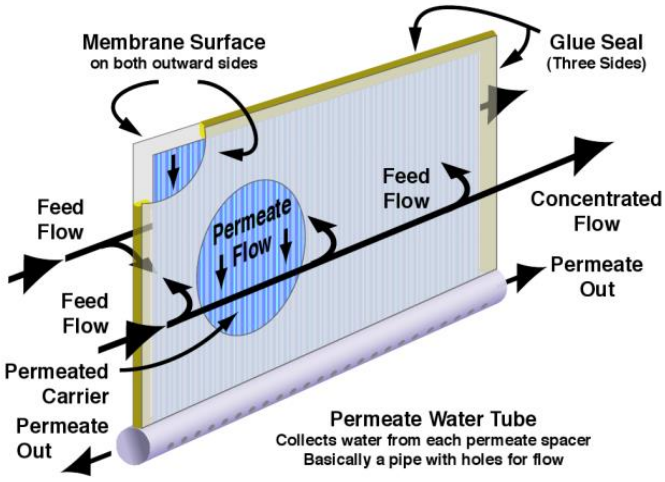


Membrane Construction Diagrams







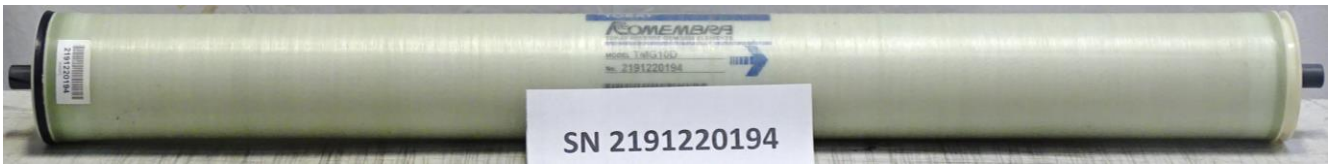


External Inspection

Fiberglass Casing

The purpose of the fiberglass casing is to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the casing can be an indication of rough handling or damage from excessive differential pressure across the element from heavy fouling.

The fiberglass casing was in good mechanical condition.



Fiberglass casing of SN 2191220194

Brine Seal

The brine seal is used to seal against the inside diameter of the pressure vessels and the outside diameter of the membrane to ensure that all the feed water passes through the element. Feed water passing on the exterior of the element can result in higher pressures, which can cause cracking of the fiberglass casing.

The brine seal was in good condition.

Permeate Tube

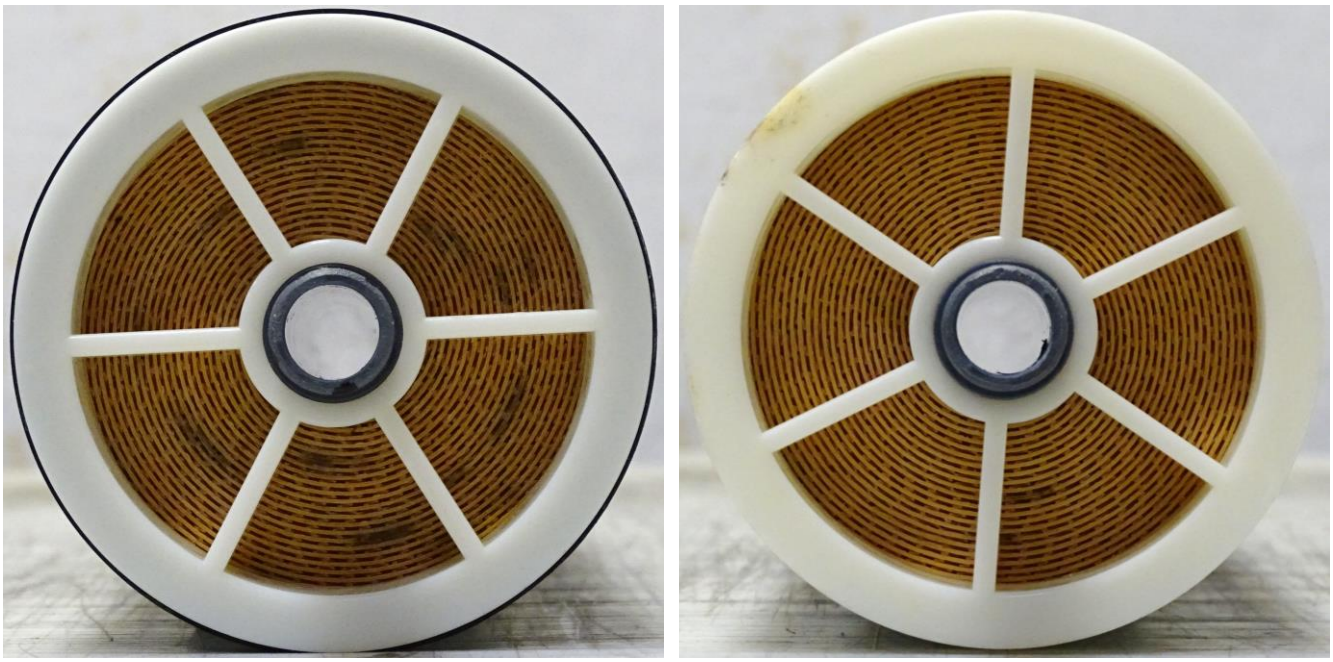
The permeate tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the permeate tube to be collected. Damage to the ends of the permeate tube can lead to o-ring failures, causing bypass of feed or concentrate water into the permeate stream. Cracking of the permeate tube can also result in permeate contamination.

The permeate tube was in good condition.

Anti-Telescoping Devices (ATDs)

The function of the ATDs is to stabilize the components of the element. This helps to prevent shifting of the internal mechanical components under pressure, also known as telescoping. Telescoping may still occur if pressures exceed the manufacturer's specifications.

Both ATDs were in good condition.



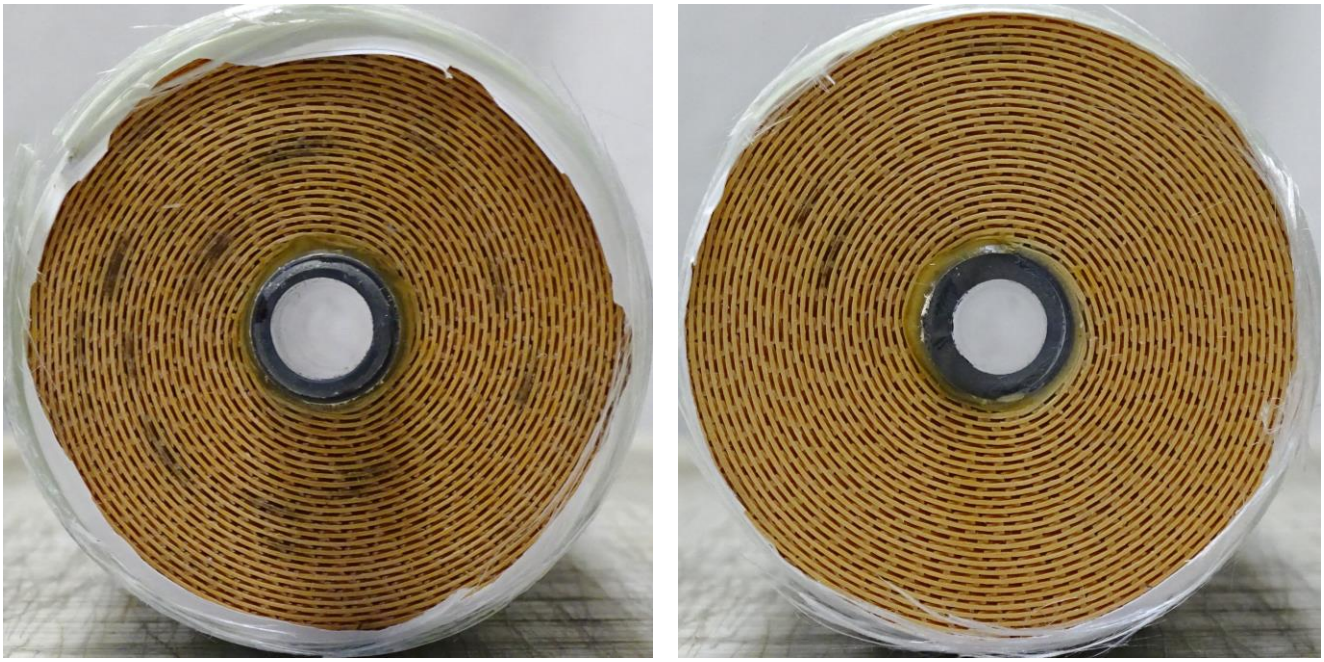
Feed (left) and concentrate (right) ATDs of SN 2191220194

Internal Inspection

Scroll Ends

The ends of the element are called scroll ends. They are examined for the presence of foulant debris and mechanical damage (e.g. gapping, feed spacer extrusion). The presence of foulant on the scroll ends can cause elevated delta pressures while gapping and feed spacer extrusion indicate uneven hydraulics (high flow/low flow regions). In addition, each scroll end is examined for telescoping, the gradual axial shift of the membrane leaves from the outer diameter of the element towards the permeate tube. Telescoping is often caused by the development of high differential pressure (greater than the manufacturer's specification) across the element or when pressure is applied too quickly, causing a water hammer effect.

The scroll ends displayed black discoloration that was more prevalent on the feed end.

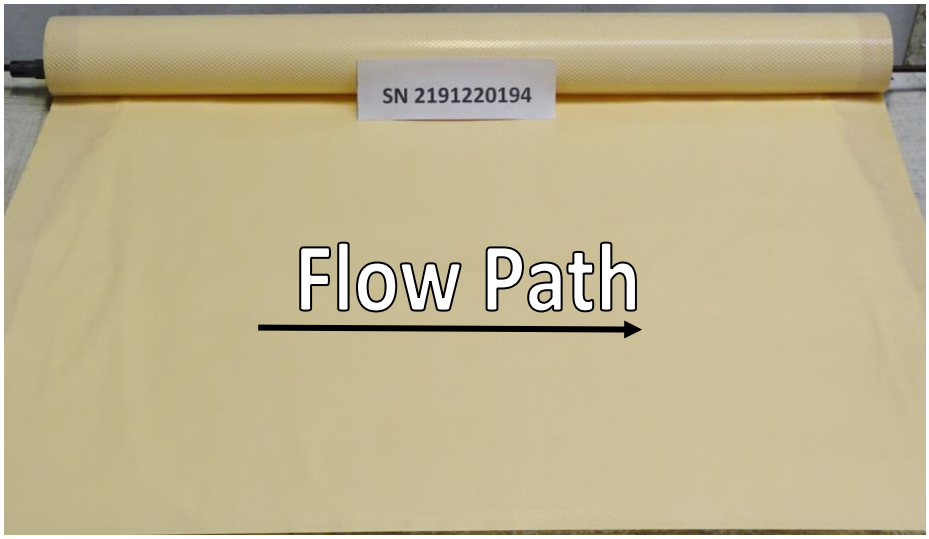


Feed (left) and concentrate (right) scroll ends of SN 2191220194

Membrane Surface

New membrane surfaces are uniform and shiny. Foulant can often be detected through visual examination; however, membrane appearance can be misleading as some foulants are not visible. The presence of foulant on the membrane surface can cause elevated delta pressure, loss in flow and damage if the foulant is abrasive. Additionally, the membrane surface is inspected for damage such as delamination. Delamination is the lifting of the thin-film membrane from the support layer and often occurs due to a positive pressure on the permeate side of the element.

The membrane surfaces were predominantly clear of visible foulant; only a trace amount of fine-granular material was present.



Exposed membrane surface of SN 2191220194



Exposed membrane surface from feed end of SN 2191220194

Feed Spacers

The feed spacer is a plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. Foulant blocking the feed channels causes more resistance for the feed water flowing through the element and results in higher than normal delta pressures.

The feed spacers were in good condition.

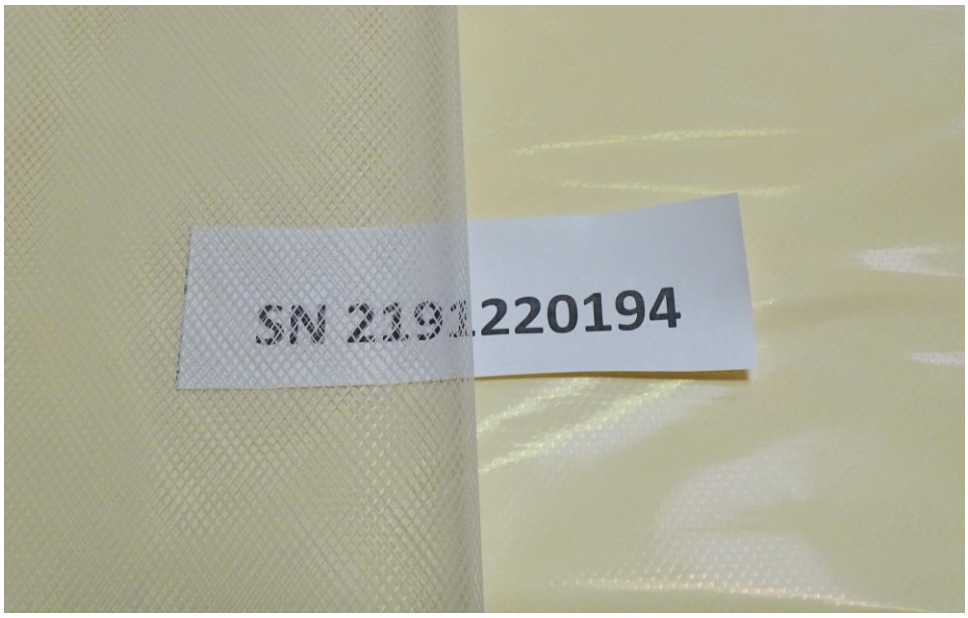


Image of feed spacer of SN 2191220194

Glue Lines

Membrane leaves are glued on three sides to separate the feed and permeate streams. The glue lines are inspected for specific damage, including glue flaps and pouching. Glue flaps refer to excess inactive membrane material located closest to the ends of the element. Flaps found on the feed end of the element can flare during operation, blocking the feed channels on the scroll end, potentially causing increased differential pressure. Pouching of the glue line, which is often a result of delamination, allows feed water to pass through the inactive membrane at the glue line, contaminating the permeate stream.

The glue lines were in good condition.

Permeate Carriers and Membrane Backing

The permeate carriers provide a path for permeate water to flow towards the permeate tube, which minimizes permeate-side pressure losses. New permeate carriers and membrane backing are uniform in color. Foulant found on the permeate side of the membrane leaves indicates contamination of the permeate stream.

The permeate carriers and membrane backings were in good condition.

Foulant Analysis

Foulant Density Measurement and Composition Testing

A sample collected from a known area of the membrane surface is weighed before and after drying to determine the foulant density (reported as wet foulant density – mg/cm^2) and moisture content of the sample. Different types of foulant materials exhibit higher moisture contents. Relative water concentrations greater than 95% indicate an extremely hydrated, biological material. Alternatively, scales (crystalline material) typically contain very little moisture. The organic content of the dehydrated material is then measured through loss on ignition (LOI) testing. If the organic content of the total solids is greater than 65%, it is considered primarily organic.

Foulant density and composition could not be determined due to the lack of harvestable foulant on the membrane surface.

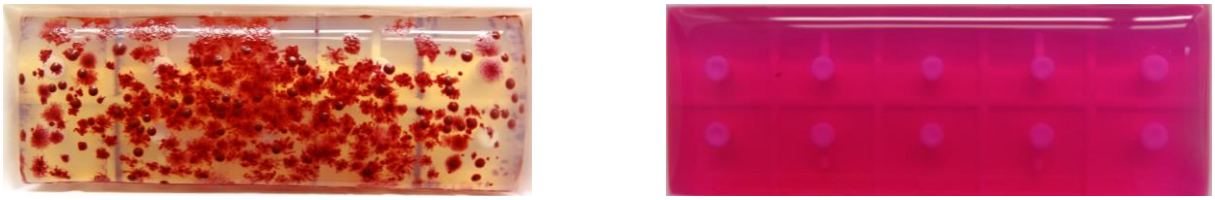
Biological Activity Testing

Dip slides for aerobic bacteria is exposed to the foulant material on the membrane surface. The slide is incubated for 72 hours and inspected for biological growth. Greater colony density, measured in colony-forming units (CFU)/mL, indicates a more biologically active sample.

The aerobic slide showed approximately 10^5 CFU/mL, indicating moderate-high biological activity; the yeast/mold slide showed no growth over the incubation period.



Aerobic bacteria slide (left) and yeast/mold (right) before incubation



Aerobic bacteria slide (left) and yeast/mold (right) after incubation

Acid Testing

Acid testing is used to determine the presence of carbonates and metals on the membrane surface. In this test, several drops of dilute hydrochloric acid (HCl) were placed on the foulant surfaces. Effervescing indicates the presence of carbonates while a color change is associated with the presence of metals.

Acid testing produced a slight yellow color change, indicating the presence of metals.

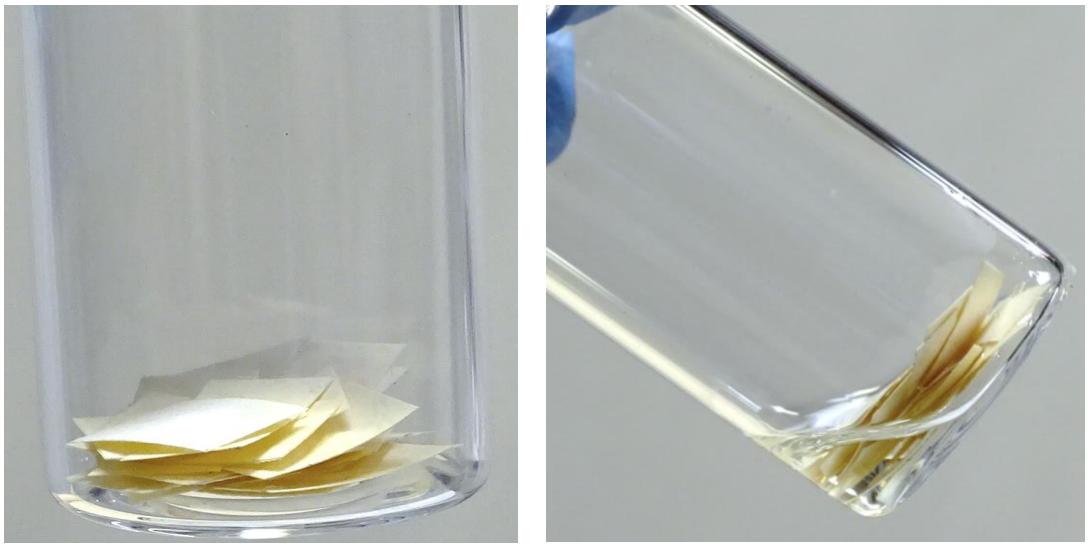
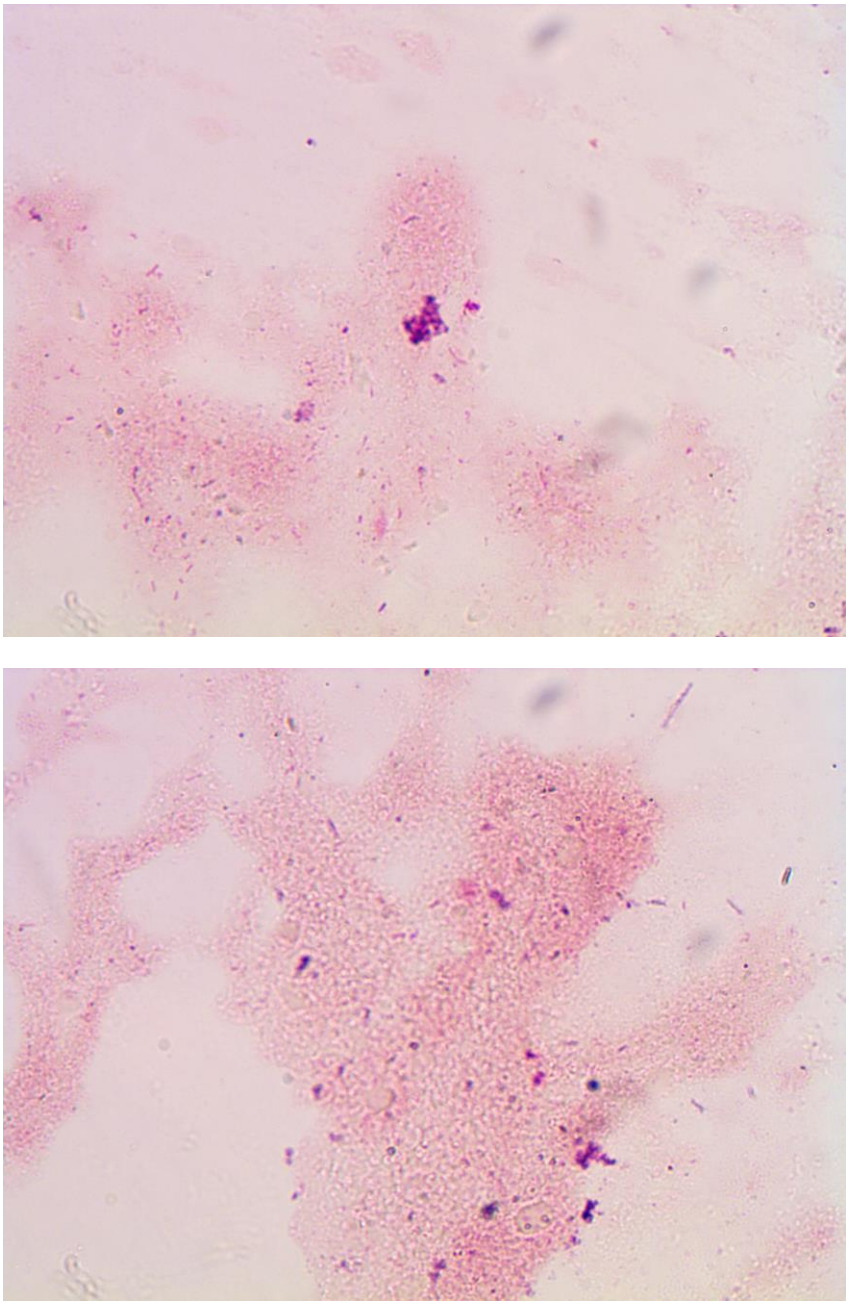


Image of acid testing before (left) and after (right) the addition of dilute HCl

Microbiological Analysis

This analysis is performed to identify microbiological components of the foulant removed from the membrane surface. Foulant samples are stained and examined with a light microscope at 1000x using an oil immersion lens. Gram-positive bacteria are stained purple while Gram-negative bacteria are stained pink.

Microscope imaging of foulant harvested from the membrane surface identified primarily amorphous inorganic material. Lesser amounts of translucent deposits and amorphous organics were also present, as well as miscellaneous particulates and Gram-negative bacteria.

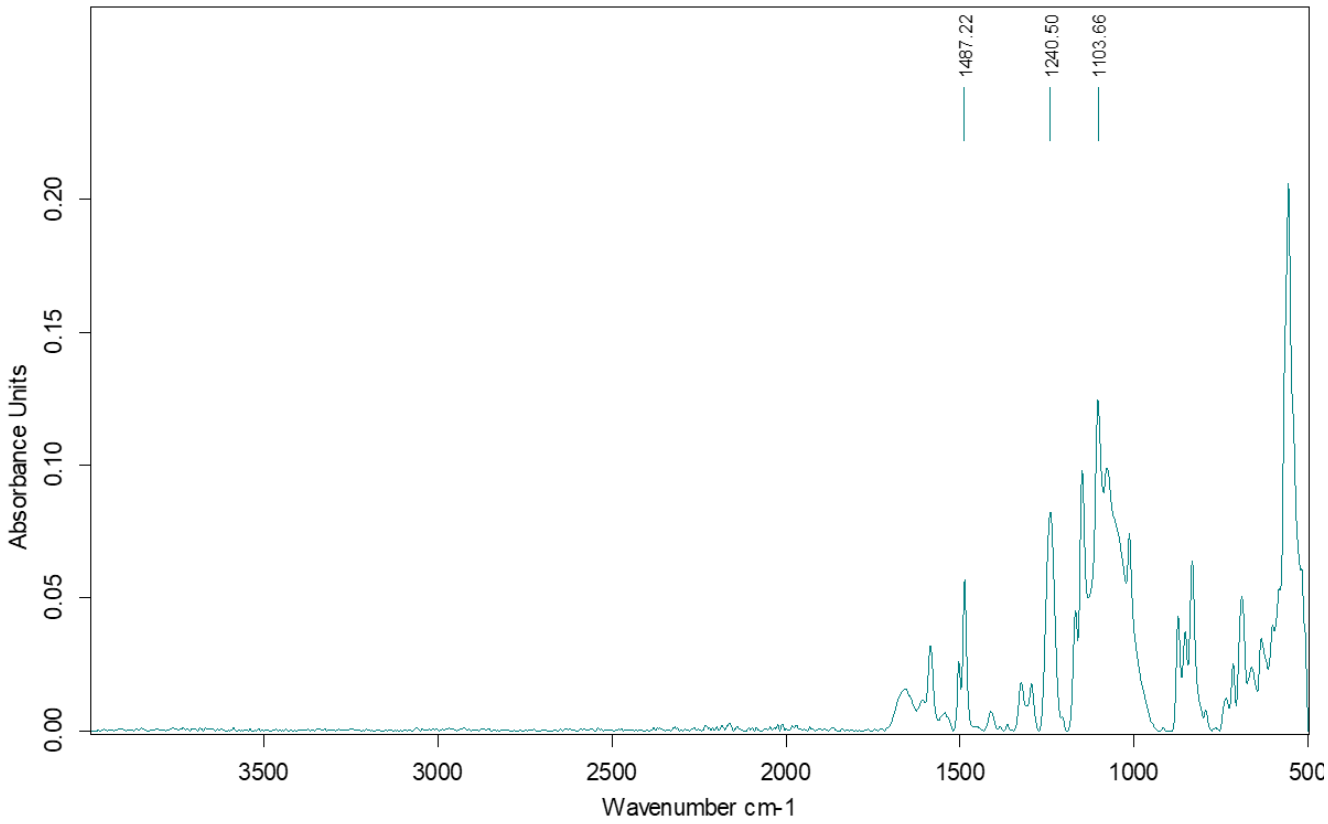


Light microscope image (1000x) of foulant scraped from SN 2191220194

Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) is an analytical technique used to identify functional groups (specific groups of atoms or bonds within molecules). Infrared radiation passes through a sample, with some of the radiation absorbed and some transmitted. A measurement and interpretation of this data produces a spectrum which can then be compared and matched to the known spectra for functional groups based on the wavenumber at which bands appear and their respective shapes (e.g. sharp, broad, strong, weak).

FT-IR spectroscopy performed on the membrane surface identified primarily peaks associated with the membrane materials (i.e. polysulfone).



FT-IR spectral image of foulant removed from the membrane surface of SN 2191220194

Energy Dispersive Spectroscopy (EDS) Analysis

Energy Dispersive Spectroscopy analysis is used to determine the relative concentration of elements present in a sample. EDS analysis is performed on a dry membrane sample. The element sulfur is at least in part associated with the membrane support material (polysulfone) rather than a foulant layer. Avista's analysis of new membranes typically detects between 5.00 and 7.00 weight percentage. Relative concentrations below 5.00 percent indicate the presence of a foulant layer masking the membrane surface.

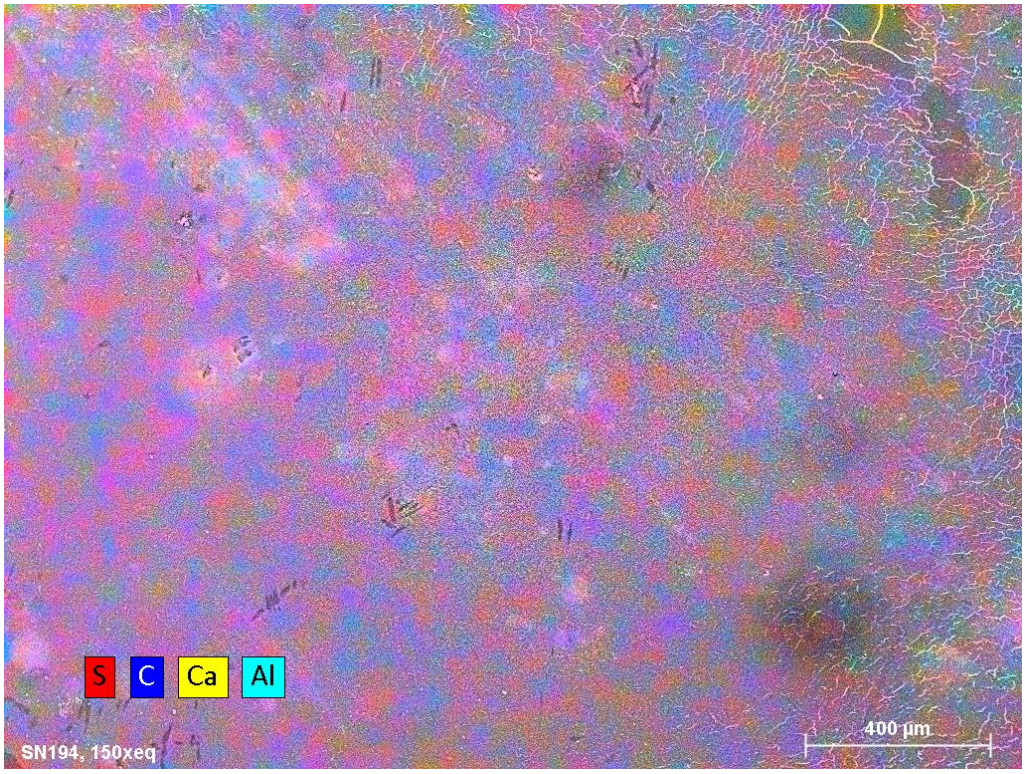
EDS analysis identified small amounts of calcium and aluminum as the only foreign inorganic elements on the membrane surface. The sulfur weight percentage indicates that the membrane surface was not notably masked by a layer of foulant.

Elements	SN 2191220194 Weight Percent (wt%)
Carbon	67.47
Oxygen	24.41
Sulfur	6.65
Calcium	0.79
Aluminum	0.68

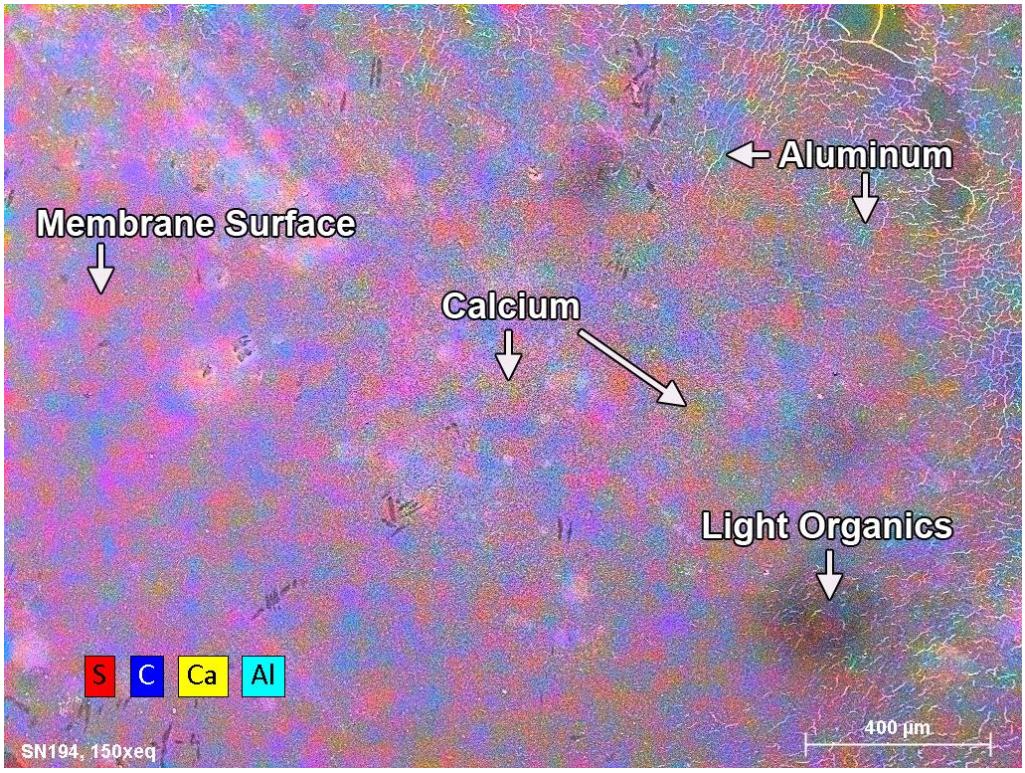
Chromatic Elemental Imaging℠ (CEI℠)

CEI is a high-resolution imaging technique used to determine the spatial distribution of elements in a foulant sample. Each element is assigned a color (shown in a legend on the bottom left corner of the CEI image) and the colors correspond to the location of the elements in the sample. An element's color intensity is associated with its concentration in the sample (i.e. elements present with higher relative concentrations are displayed with greater color intensity in the image). Additionally, a blending of colors signifies a compound (material composed of more than one element such as calcium carbonate).

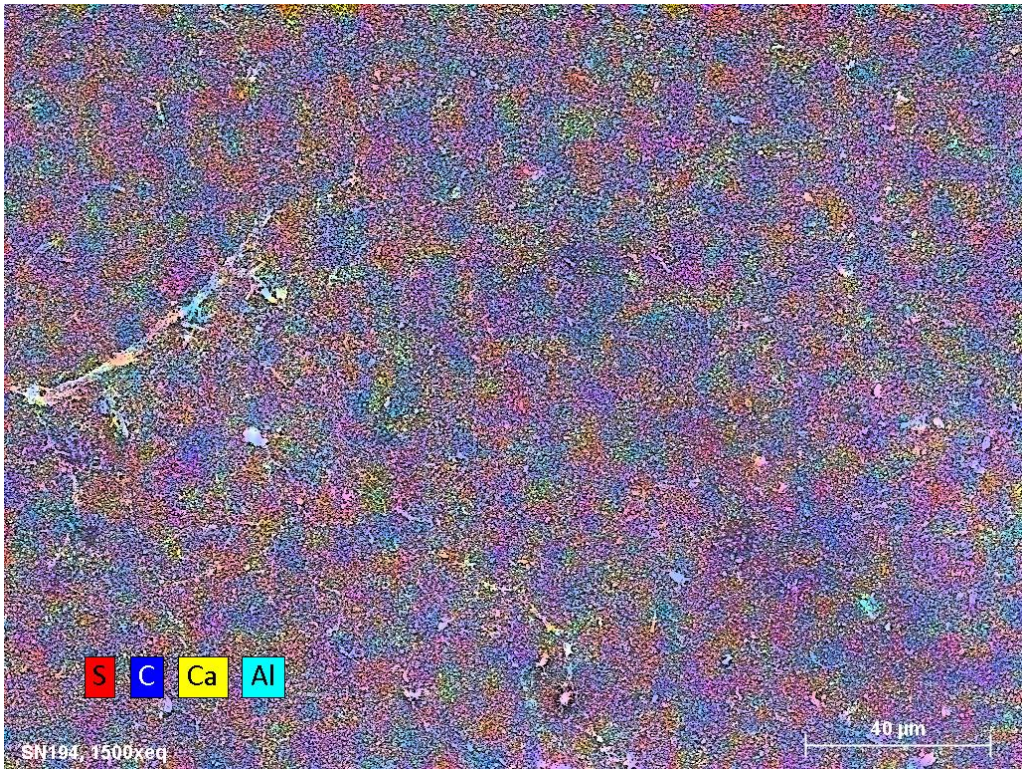
CEI℠ confirmed that the membrane surface was predominantly clear of foulant; however, light deposits of calcium (yellow) and aluminum (light blue) were present across the membrane. Additionally, a small amount of organics (represented by carbon – dark blue) were observed. The membrane surface itself is represented by sulfur (red) and could be clearly seen throughout the imaging area.



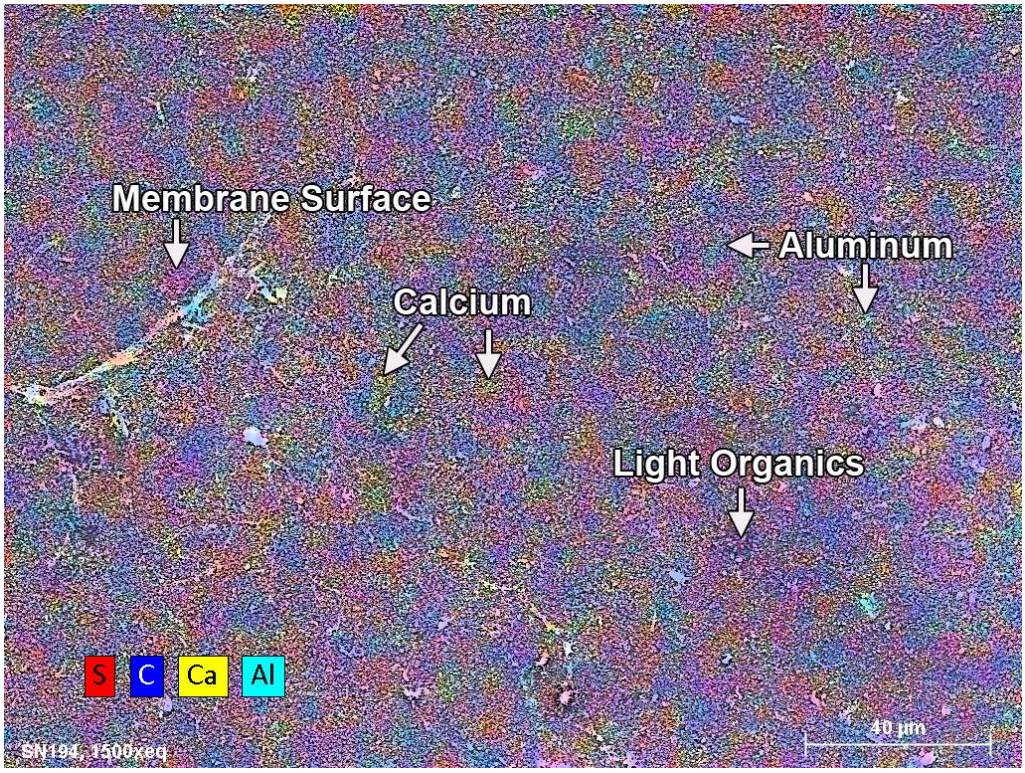
CEI image (150x) of the membrane surface



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface



CEI image (1500x) of the membrane surface with labels

Flat Sheet Performance and Cleaning Study

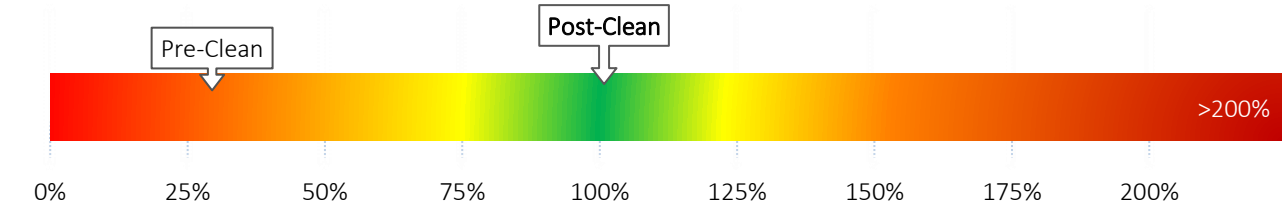
To evaluate flat sheet performance, membrane samples harvested from the full element are tested for permeability and salt passage. The raw flow and conductivity measurements from the test are used to calculate the permeability and salt passage constants, which are independent of pressure, temperature and salt content of the feed stream. The permeability constant is measured in cm/s/atm and the salt passage constant in cm/s. Discrepancies between the flat sheet and full element performance can indicate the presence of mechanical damage.

The flat sheet samples are then cleaned with various Avista chemicals to determine the most effective cleaner combinations and contact times. Cleaner efficacy is based on overall improvement in permeability and salt passage constant as well as visual foulant removal.

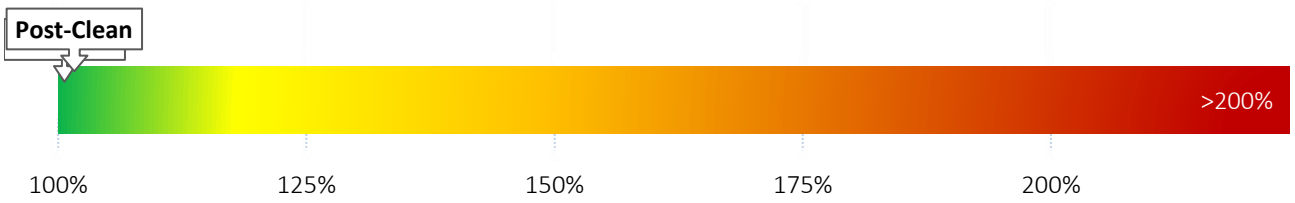
Performance data for the flat sheets is displayed in the table below. Flat sheet samples were cleaned using RoClean L403 (1% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours followed by RoClean L212 (1% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours.

SN 2191220194	Permeability Constant	Salt Passage Constant
Baseline	0.45E-04 29% of Normal	5.55E-06 Normal
Post-Clean	**1.75E-04** **Normal**	**6.19E-06** **Normal**
Manufacturer's Specifications	1.56 to 1.85E-04 Normal Range	4.69 to 7.84E-06 Normal Range

Permeability (% of Normal)



Salt Passage (% of Normal)



Testing for Flat Sheet Damage

Fujiwara Testing

Fujiwara testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. A color change does not occur if the membranes has not been exposed to halogens. Common symptoms of halogen oxidation include increased flow and loss in permeate quality.

Fujiwara testing was positive for the presence of halogens (e.g. chlorine) in the membrane structure.



Example of a positive Fujiwara color change

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#111620-7	Standard Spiral Autopsy	2191220194	January 8th, 2021

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

Date: 01/08/2021

Signed:

Megan Lee
Laboratory Services Manager

Arnell Abad
Laboratory Services Chemist

3RD 3 STAGE 80% WO#011321-3 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Las Virgenes Municipal Water District
Attn. Steve Jackson
4232 Las Virgenes Road #1994
Calabasas, CA 91302

Avista Technologies, Inc.
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United States

Sender: Raul Gonzalez
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Corp Ofc: +1 760 744 – 0536
Mobile: +1 760 566 – 9000

March 29, 2021

RE: WO#-011321-3 Las Virgenes Municipal Water District Autopsy Report

Hello Steve,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220193. The membrane was sent in for autopsy to confirm system performance. The element was taken from the tail position of the last stage.

The element produced 57% of normal flow, normal rejection (99.6%) and normal differential pressure (3 psi). The membrane surface revealed small amounts of visible foulant deposits. The foulant on the membrane surface was determined as primarily organic (74%), with only trace amounts of calcium, aluminum and silicon.

The cleaning study confirmed that a light cleaning (1% by weight) of RoClean L403 followed by RoClean L212 can restored performance. These are the same cleaners that have been used at the Demonstration facility with positive results. I recommend the continued use of RoClean L212 and RoClean L403 for future cleanings.

The autopsy results show a higher organic content when compared to previous autopsies. The pH change appears to have a positive effect in minimizing the amount of aluminum fouling the last stage tail element. I recommend continuing to monitor system performance and aluminum concentration in the feed.

Please let me know when we can setup a time to discuss this report in more detail.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista TECHNOLOGIES
a Kurita company

Membrane Autopsy Report

Completed for:

Las Virgenes Municipal Water District

Serial Number 2191220193

03/19/2021 WO#011321-3





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Executive Summary

Background

Las Virgenes Municipal Water District provided 2 Toray TMG10D reverse osmosis (RO) elements to Avista Technologies. Element Serial Number (SN) 2191220193 was selected for full element autopsy while element SN 2191220196 was selected for element inspection. The positions of the elements were not written on the packaging or element nor was a completed questionnaire provided. The following is a summary of the results pertaining to element SN 2191220193.

Initial Element Testing

The element produced lower than normal flow (57% of normal), normal rejection (99.6%) and a differential pressure of 3 psi during initial wet testing. The element passed integrity testing indicating the absence of damage to the internal components of the spiral wound element.

External Inspection

The external components (fiberglass casing, brine seal, permeate tube, anti-telescoping devices (ATDs)) were in good mechanical condition.

Internal Inspection

Black discoloration was observed on the scroll ends. The membrane surfaces had miniscule amounts of tan-colored foulant material that was smooth-textured and scrapable. The remaining components (feed spacers, glue lines, permeate carriers) were in good mechanical condition.

Foulant Analysis

The wet foulant density was measured at 0.05 mg/cm^2. The moisture and organic contents were 94% and 74%, respectively, indicating the foulant was a hydrated organic material (e.g. bio-slime). Aerobic bacteria testing displayed heavy growth (10^7 CFU/mL) while yeast and mold testing displayed no growth during incubation. Acid testing was negative for the presence of metals and carbonates. Microbiological analysis identified amorphous organic material, fungi and particles. Fourier Transform Infrared (FT-IR) displayed peaks associated with carbohydrates, Silicon-Oxygen bond stretching and amino acids. Energy Dispersive Spectroscopy (EDS) only detected trace amounts (<0.50 wt%) of calcium, aluminum and silicon as the inorganic elements in the foulant layer. Chromatic Elemental Imaging^{SM} (CEI^{SM}) identified the miniscule amounts of foulant as organics with sparse amounts of particles.

Based on the analyses, the miniscule amounts of foulant material were organics.

Flat Sheet Performance and Cleaning Study

Flat sheet samples harvested from the full element produced 60% of normal permeability and normal salt passage during baseline cell testing. Flat sheets were cleaned using RoClean L403 (1% by weight in RO/DI water, heated to approximately 35C and circulated) for 2 hours followed by RoClean L212 (1% by weight in RO/DI water, heated to approximately 35C and circulated) for 2 hours. This cleaning regimen restored permeability to the flat sheet samples.

Flat Sheet Damage

Fujiwara testing for the presence of halogens (e.g. chlorine) in the membrane structure was positive. Although the full element produced normal rejection and the flat sheets samples produced normal salt passage, halogen oxidation is progressively damaging, and can lead to decreases in permeate quality over time.

Initial Element Test

Element Weight

All elements are weighed prior to autopsy as weight is often indicative of the degree of fouling. New four-inch elements weigh approximately 7 to 10 pounds.

SN 2191220193 weighed 8 pounds.

Full Element Wet Test

Test results were normalized to the manufacturer's published test conditions.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220193	0.96	99.6	3
Manufacturer's Specifications	1.67 to 1.98	99.5 to 99.7	≤15

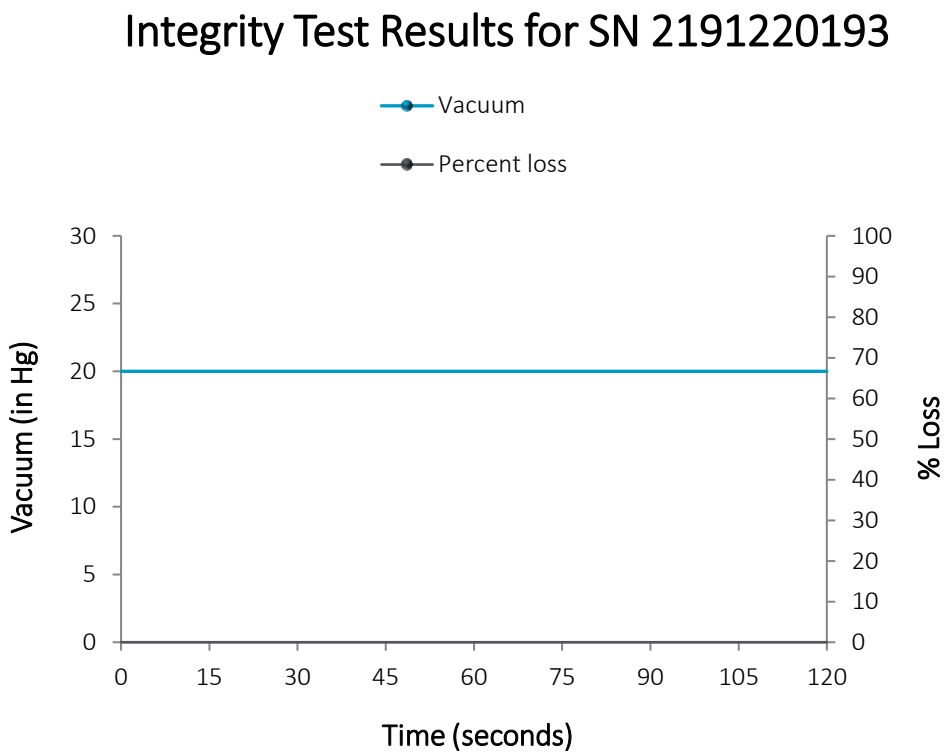


Element wet testing

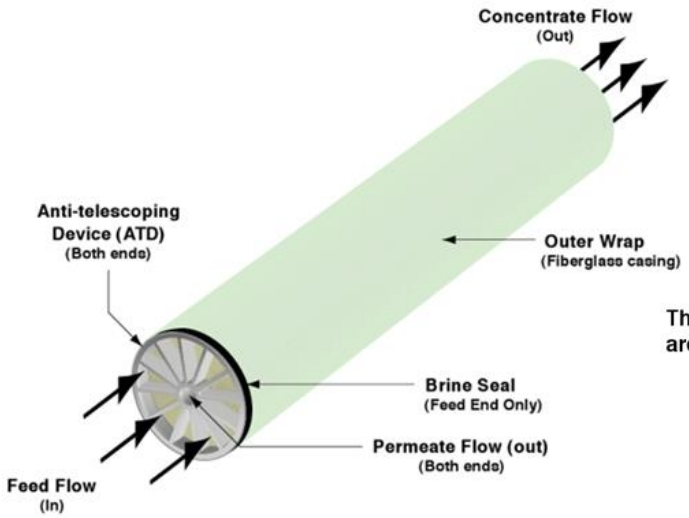
Integrity Test

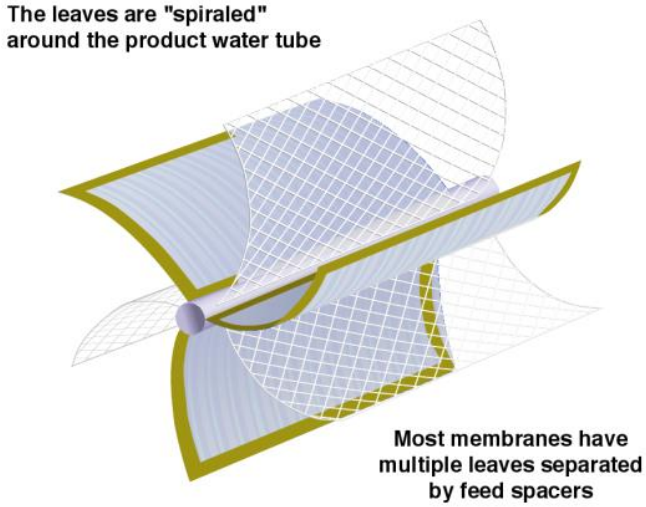
Integrity testing is performed to identify mechanical damage to the internal components of the spiral wound element. In this test, a vacuum of approximately 20 inches Mercury (in. Hg) is applied to the permeate side of the membrane and the membrane is then sealed. The vacuum is monitored for a duration of 120 seconds. Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum within the 120 second period suggests severe physical damage.

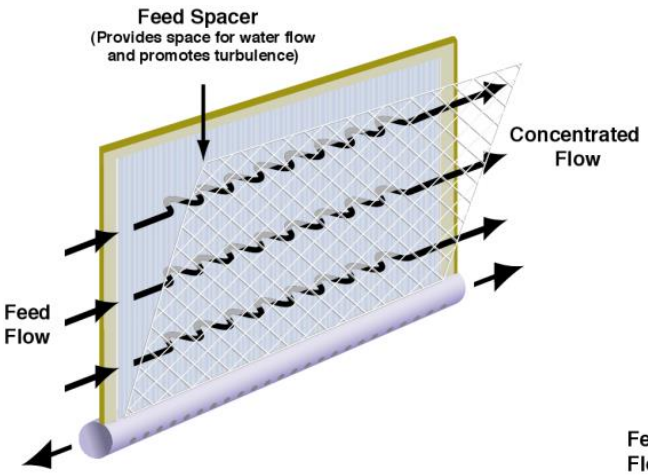
A leak was detected during integrity testing indicating the presence of damage to the internal components of the spiral wound element.

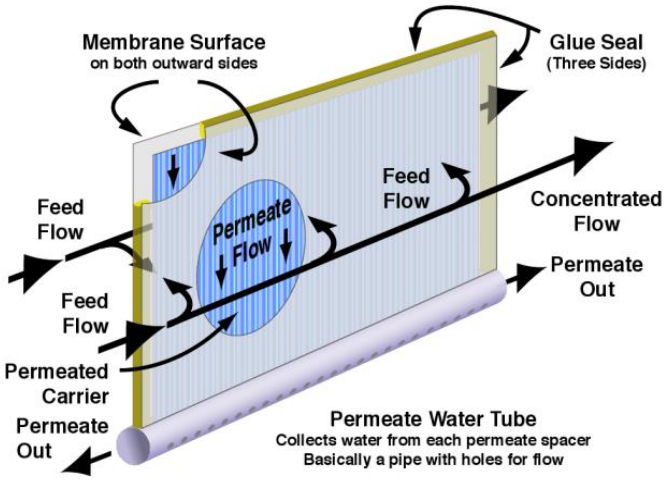


Membrane Construction Diagrams







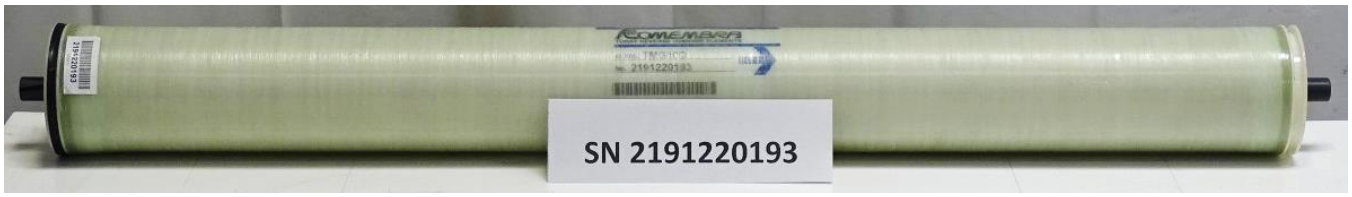


External Inspection

Fiberglass Casing

The purpose of the fiberglass casing is to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the casing can be an indication of rough handling or damage from excessive differential pressure across the element from heavy fouling.

The fiberglass casing was in good mechanical condition.



Fiberglass casing of SN 2191220193

Brine Seal

The brine seal is used to seal against the inside diameter of the pressure vessels and the outside diameter of the membrane to ensure that all the feed water passes through the element. Feed water passing on the exterior of the element can result in higher pressures, which can cause cracking of the fiberglass casing.

The brine seal was in good mechanical condition.

Permeate Tube

The permeate tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the permeate tube to be collected. Damage to the ends of the permeate tube can lead to o-ring failures, causing bypass of feed or concentrate water into the permeate stream. Cracking of the permeate tube can also result in permeate contamination.

The permeate tube was free of damage and foulant.

Anti-Telescoping Devices (ATDs)

The function of the ATDs is to stabilize the components of the element. This helps to prevent shifting of the internal mechanical components under pressure, also known as telescoping. Telescoping may still occur if pressures exceed the manufacturer's specifications.

The ATDs were in good mechanical condition.



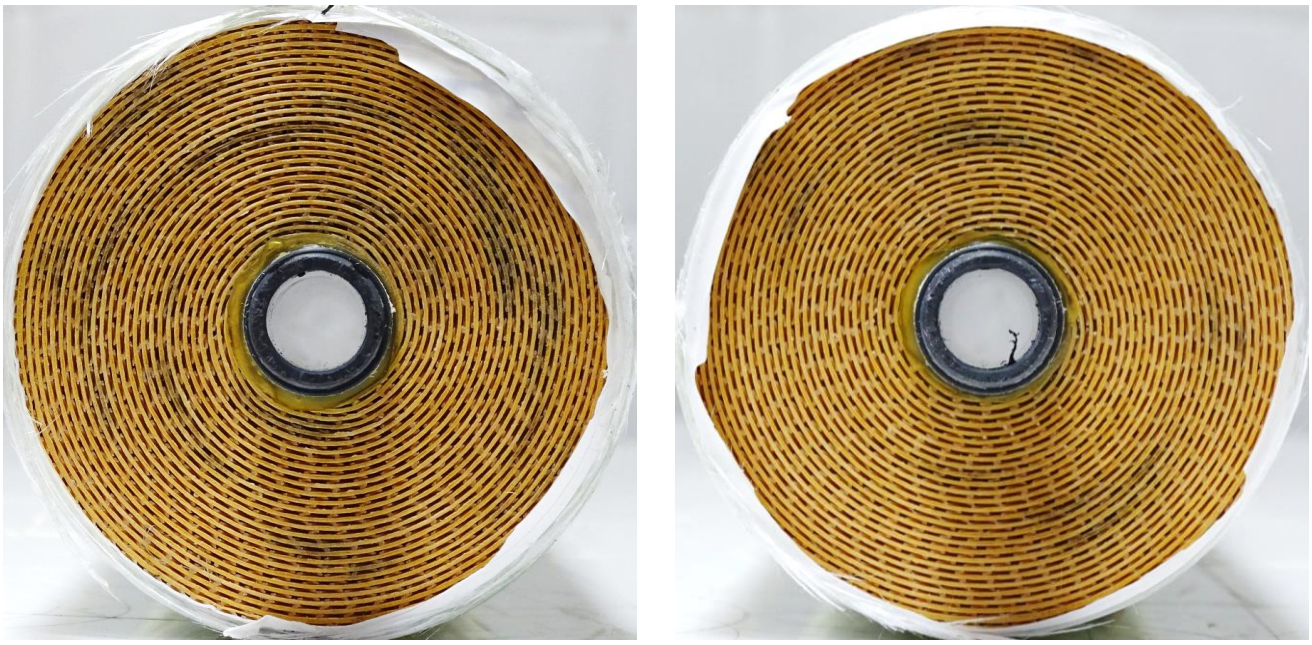
Feed (left) and concentrate (right) ATDs of SN 2191220193

Internal Inspection

Scroll Ends

The ends of the element are called scroll ends. They are examined for the presence of foulant debris and mechanical damage (e.g. gapping, feed spacer extrusion). The presence of foulant on the scroll ends can cause elevated delta pressures while gapping and feed spacer extrusion indicate uneven hydraulics (high flow/low flow regions). In addition, each scroll end is examined for telescoping, the gradual axial shift of the membrane leaves from the outer diameter of the element towards the permeate tube. Telescoping is often caused by the development of high differential pressure (greater than the manufacturer's specification) across the element or when pressure is applied too quickly, causing a water hammer effect.

Small amounts of black discoloration were observed on the scroll ends. No scrapable foulant material was observed on the scroll ends.



Feed (left) and concentrate (right) scroll ends of SN 2191220193

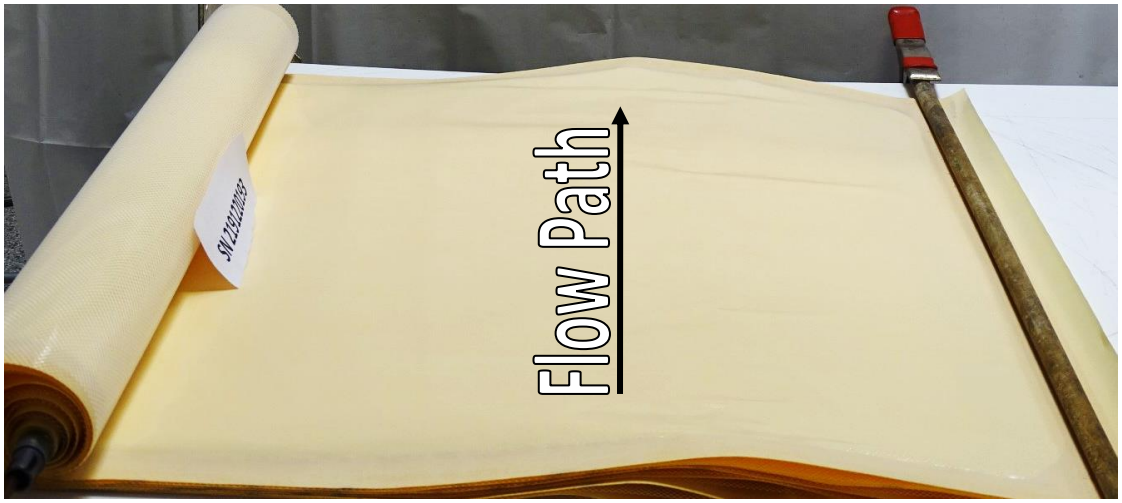
Membrane Surface

New membrane surfaces are uniform and shiny. Foulant can often be detected through visual examination; however, membrane appearance can be misleading as some foulants are not visible. The presence of foulant on the membrane surface can cause elevated delta pressure, loss in flow and damage if the foulant is abrasive. Additionally, the membrane surface is inspected for damage such as delamination. Delamination is the lifting of the thin-film membrane from the support layer and often occurs due to a positive pressure on the permeate side of the element

Miniscule amounts of tan-colored foulant material were observed on the membrane surfaces. The foulant was gelatinous and scrapable.



Exposed membrane surface of SN 2191220193



Exposed membrane surface from feed end of SN 2191220193

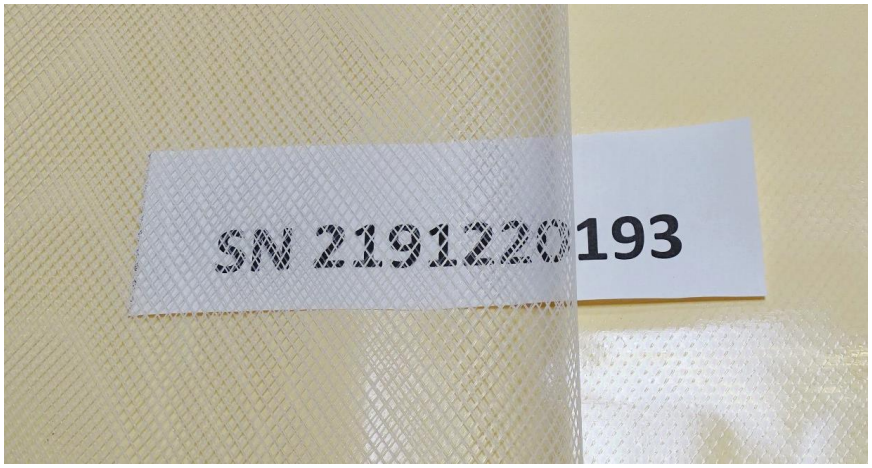


Image of foulant scraped on the membrane surface

Feed Spacers

The feed spacer is a plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. Foulant blocking the feed channels causes more resistance for the feed water flowing through the element and results in higher than normal delta pressures.

The feed spacers were in good condition and virtually free of foulant material.



Feed spacer of SN 2191220193

Glue Lines

Membrane leaves are glued on three sides to separate the feed and permeate streams. The glue lines are inspected for specific damage, including glue flaps and pouching. Glue flaps refer to excess inactive membrane material located closest to the ends of the element. Flaps found on the feed end of the element can flare during operation, blocking the feed channels on the scroll end, potentially causing increased differential pressure. Pouching of the glue line, which is often a result of delamination, allows feed water to pass through the inactive membrane at the glue line, contaminating the permeate stream.

The glue lines were in good condition.

Permeate Carriers and Membrane Backing

The permeate carriers provide a path for permeate water to flow towards the permeate tube, which minimizes permeate-side pressure losses. New permeate carriers and membrane backing are uniform in color. Foulant found on the permeate side of the membrane leaves indicates contamination of the permeate stream.

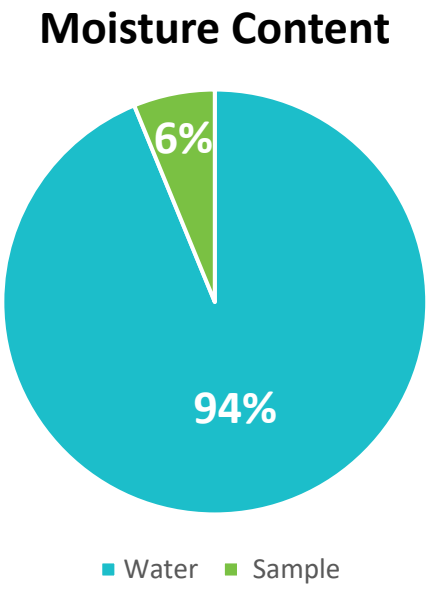
The permeate carriers and membrane backing were in good mechanical condition.

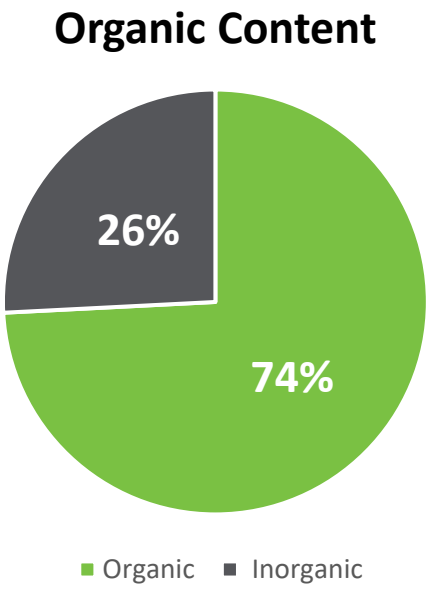
Foulant Analysis

Foulant Density Measurement and Composition Testing

A sample collected from a known area of the membrane surface is weighed before and after drying to determine the foulant density (reported as dry foulant density – mg/cm^2) and moisture content of the sample. Different types of foulant materials exhibit higher moisture contents. Relative water concentrations greater than 95% indicate an extremely hydrated, biological material. Alternatively, scales (crystalline material) typically contain very little moisture. The organic content of the dehydrated material is then measured through loss on ignition (LOI) testing. If the organic content of the total solids is greater than 65%, it is considered primarily organic.

The wet foulant density was measured at 0.05 mg/cm^2. The moisture and organic contents were 94% and 74%, respectively indicating the foulant was primarily a hydrated organic material.





Biological Activity Testing

Dip slides for aerobic bacteria and yeast/mold are exposed to the foulant material on the membrane surface. The slides are incubated for 72 hours and inspected for biological growth. Greater colony density, measured in colony-forming units (CFU)/mL, indicates a more biologically active sample.

The aerobic slide displayed heavy growth with approximately 10^7 CFU/mL after incubation. The yeast and mold slide displayed no growth after incubation.



Aerobic bacteria slide (left) and yeast/mold (right) before incubation

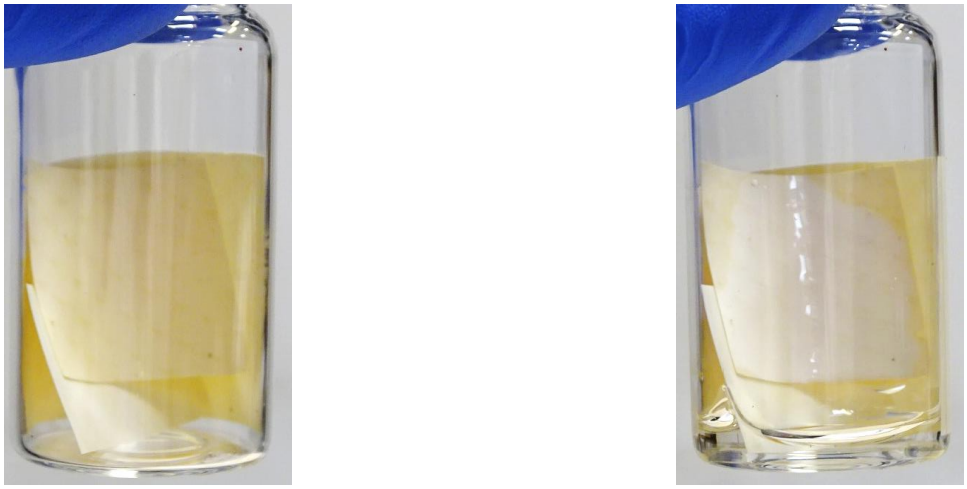


Aerobic bacteria slide (left) and yeast/mold (right) after incubation

Acid Testing

Acid testing is used to determine the presence of carbonates and metals on the membrane surface. In this test, several drops of dilute hydrochloric acid (HCl) were placed on the foulant surfaces. Effervescing indicates the presence of carbonates while a color change is associated with the presence of metals.

Acid testing produced no reaction indicating the absence of metals and carbonates.

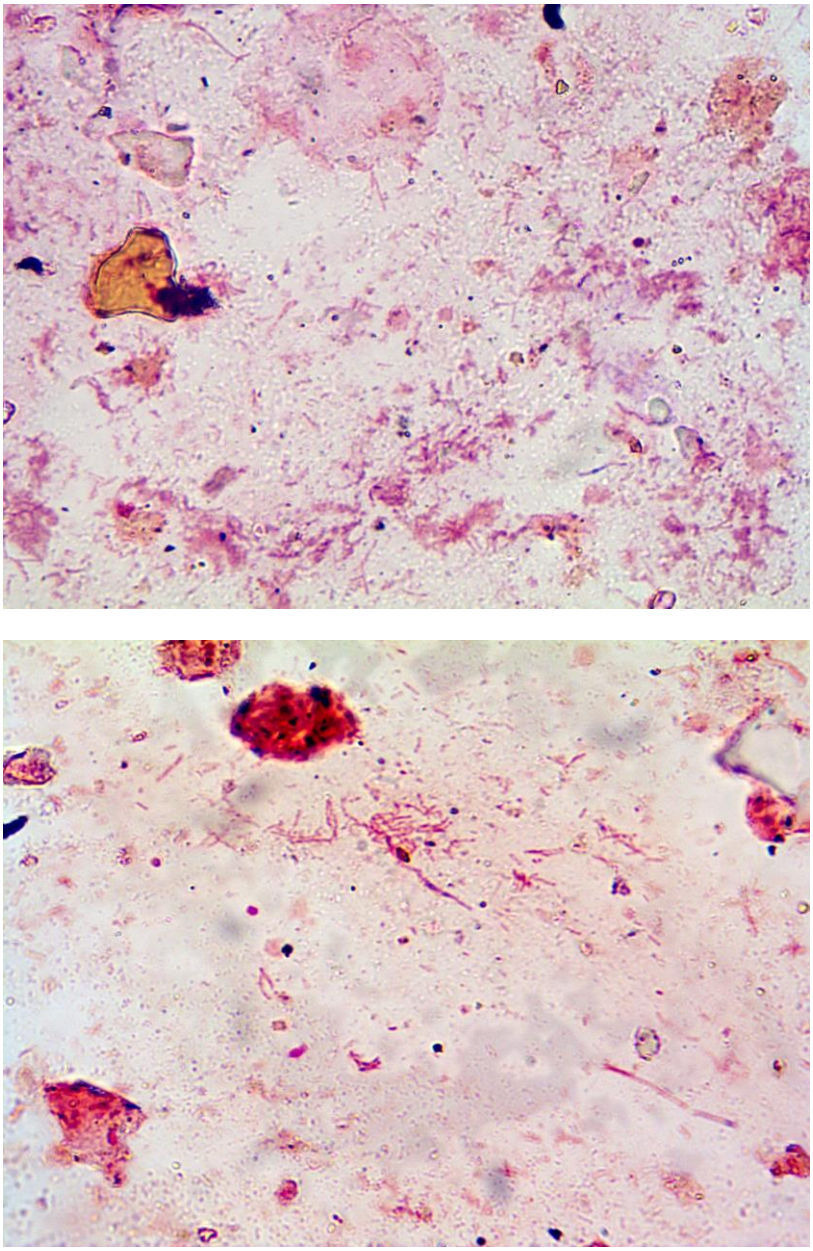


Foulant before (left) and after (right) the addition of dilute HCl

Microbiological Analysis

This analysis is performed to identify microbiological components of the foulant removed from the membrane surface. Foulant samples are stained and examined with a light microscope at 1000x using an oil immersion lens. Gram positive bacteria are stained purple while Gram negative bacteria are stained pink.

Microbiological analysis performed on foulant scraped from the membrane surface identified amorphous organic material (e.g. bio-slime), fungi and particles.

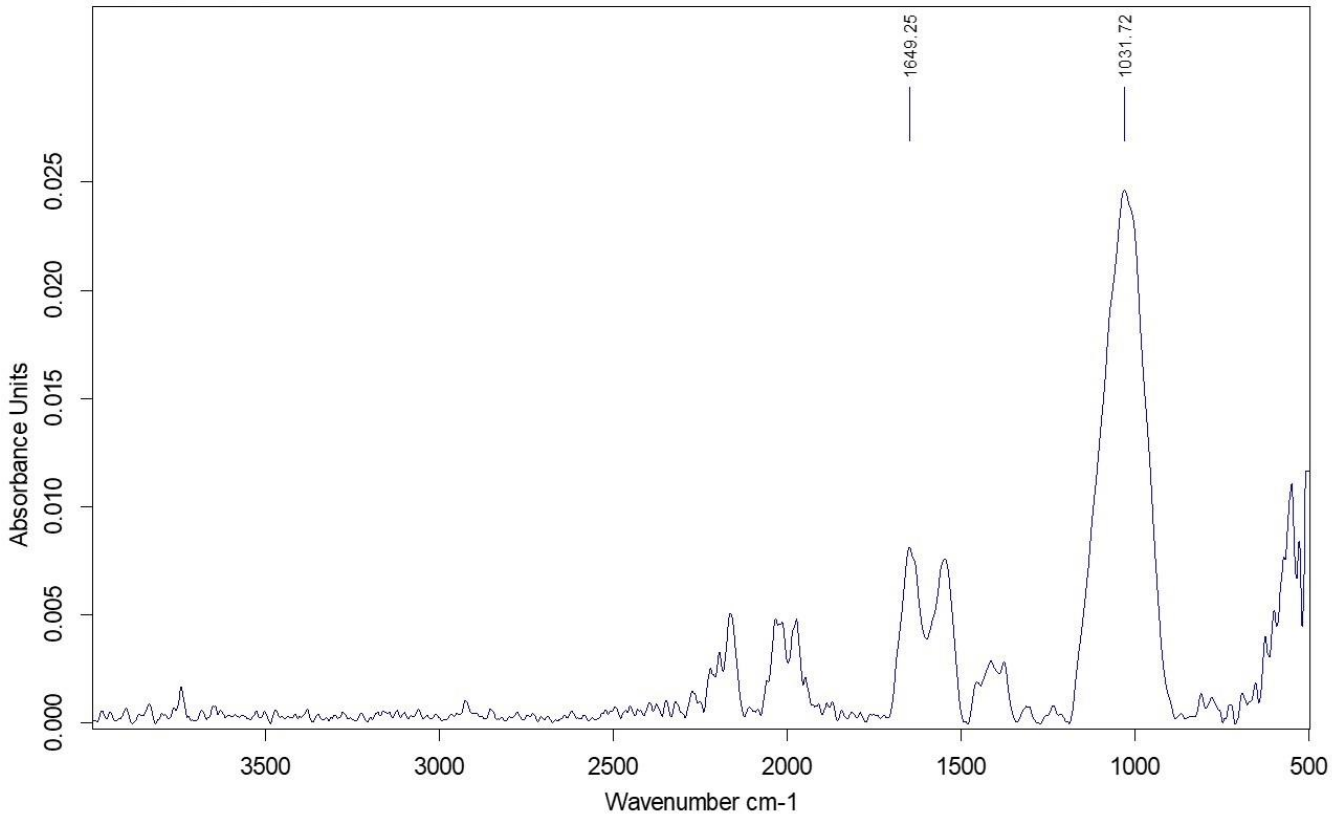


Light microscope images (1000x) of foulant scraped from SN 2191220193

Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) is an analytical technique used to identify functional groups (specific groups of atoms or bonds within molecules). Infrared radiation passes through a sample, with some of the radiation absorbed and some transmitted. A measurement and interpretation of this data produces a spectrum which can then be compared and matched to the known spectra for functional groups based on the wavenumber at which bands appear and their respective shapes (e.g. sharp, broad, strong, weak).

FT-IR spectrum performed on foulant scraped from the membrane surface displayed a peak at approximately 1000 cm^{-1} which is associated with carbohydrates and Silicon-Oxygen bond stretching. The double peak between 1650 and 1500 cm^{-1} is associated with amino acids (i.e. proteins).



FT-IR spectral image of foulant removed from the membrane surface of SN 2191220193

Energy Dispersive Spectroscopy (EDS) Analysis

Energy Dispersive Spectroscopy analysis is used to determine the relative concentration of elements present in a sample. EDS analysis is performed on a dry membrane sample. The element sulfur is at least in part associated with the membrane support material (polysulfone) rather than a foulant layer. Avista's analysis of new membranes typically detects between 5.00 and 7.00 weight percentage. Relative concentrations below 5.00 percent indicate the presence of a foulant layer masking the membrane surface.

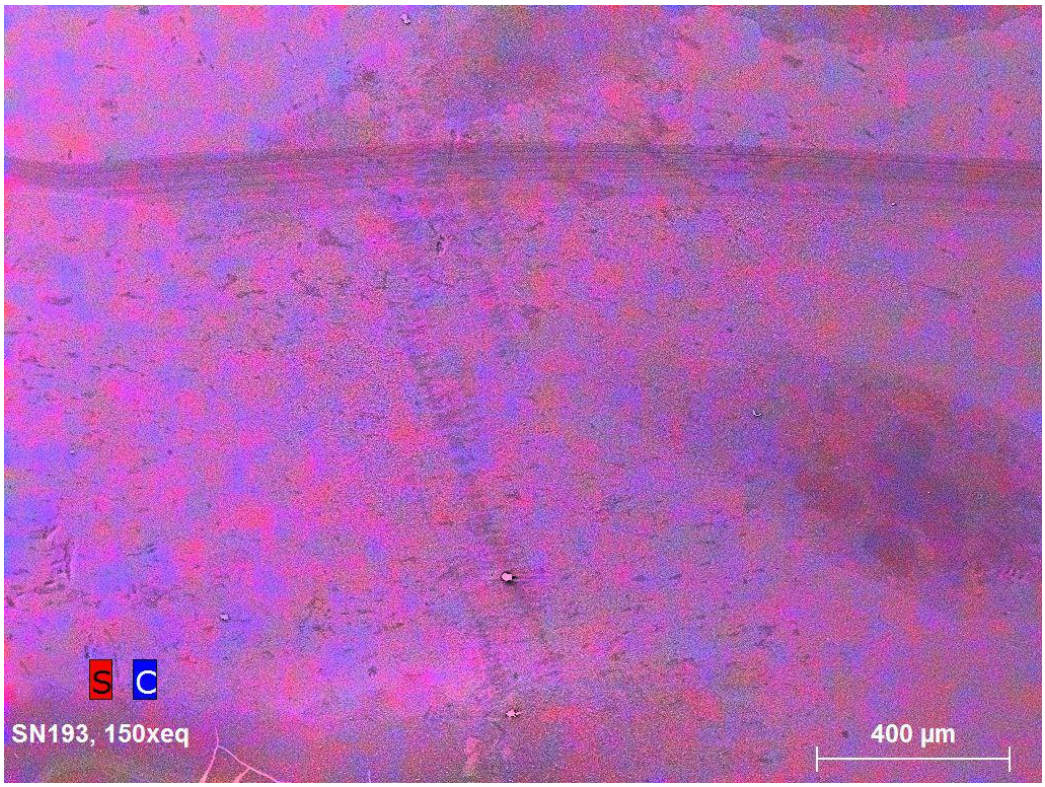
EDS analysis only detected trace amounts (<0.50 wt%) of calcium, aluminum and silicon. The sulfur weight percent (6.91 wt%) was within normal values indicating the foulant layer was thin. Lastly, the carbon weight percent is primarily associated with the membrane materials but may also be contributed by foreign organic material.

Elements	SN 2191220193 Weight Percent
Carbon	76.98
Oxygen	15.71
Sulfur	6.91
Calcium	0.21
Aluminum	0.10
Silicon	0.09

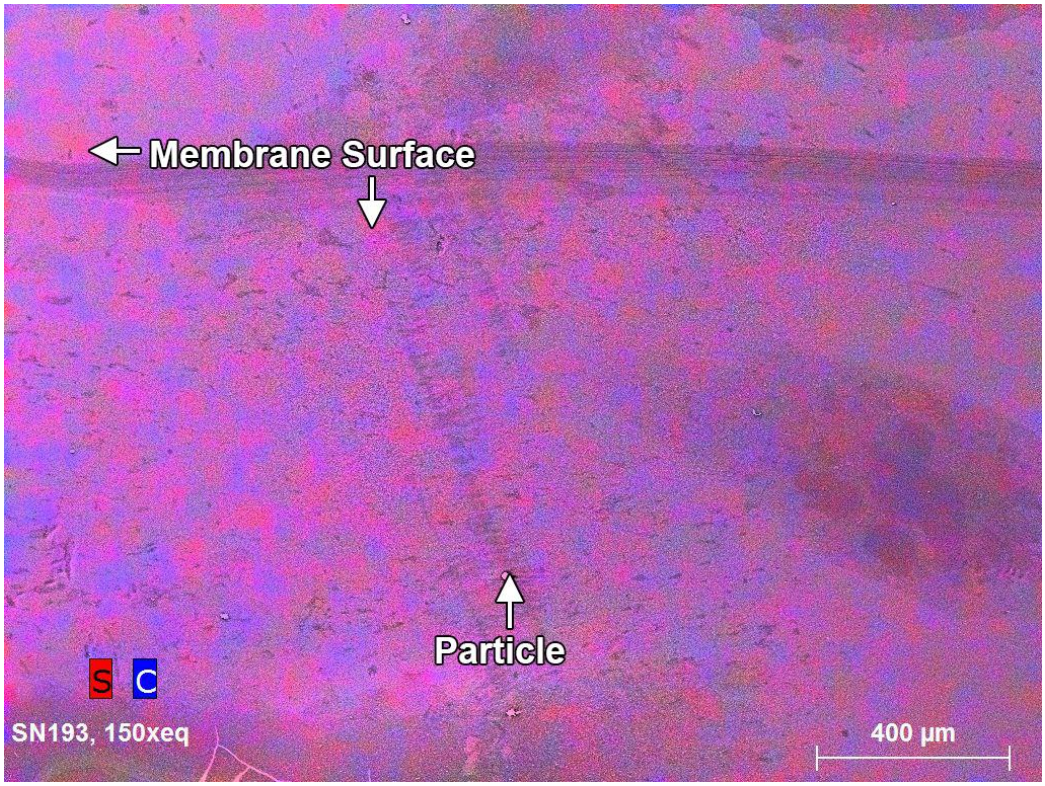
Chromatic Elemental Imaging℠ (CEI℠)

CEI is a high-resolution imaging technique used to determine the spatial distribution of elements in a foulant sample. Each element is assigned a color (shown in a legend on the bottom left corner of the CEI image) and the colors correspond to the location of the elements in the sample. An element's color intensity is associated with its concentration in the sample (i.e. elements present with higher relative concentrations are displayed with greater color intensity in the image). Additionally, a blending of colors signifies a compound (material composed of more than one element such as calcium carbonate).

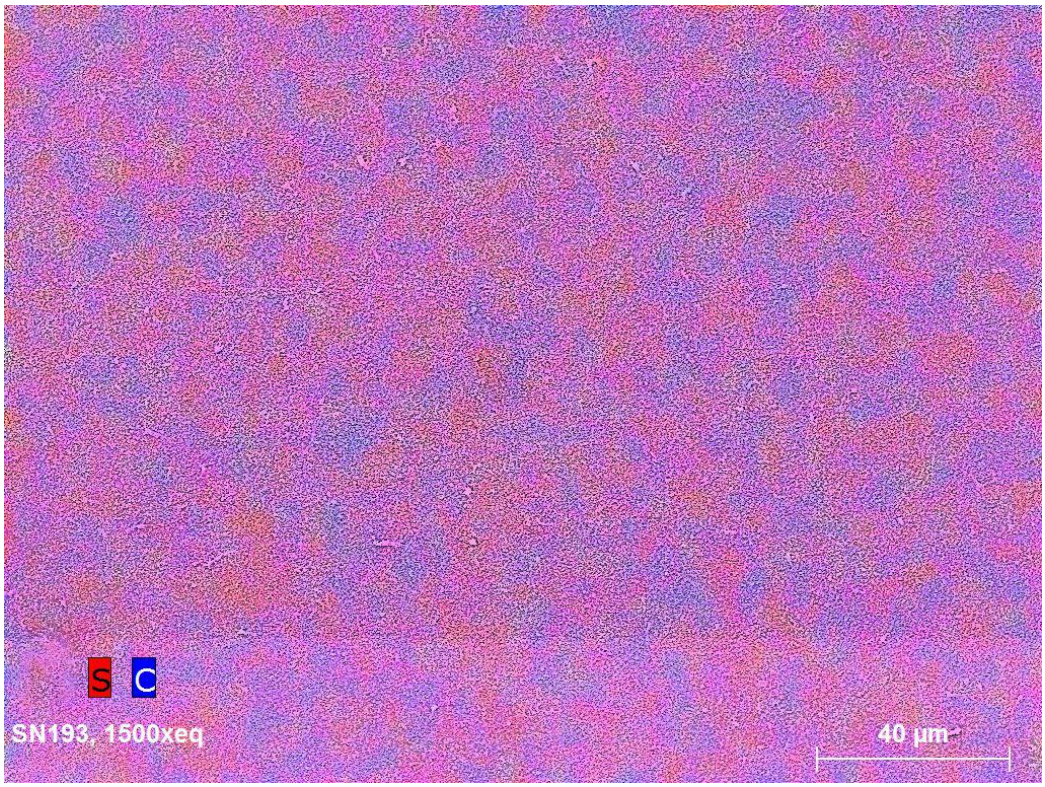
CEI℠ displayed primarily the membrane surface which is denoted by sulfur (red). Miniscule amounts of organics – represented by carbon (blue) – along with sparse particles were distributed across the membrane surface.



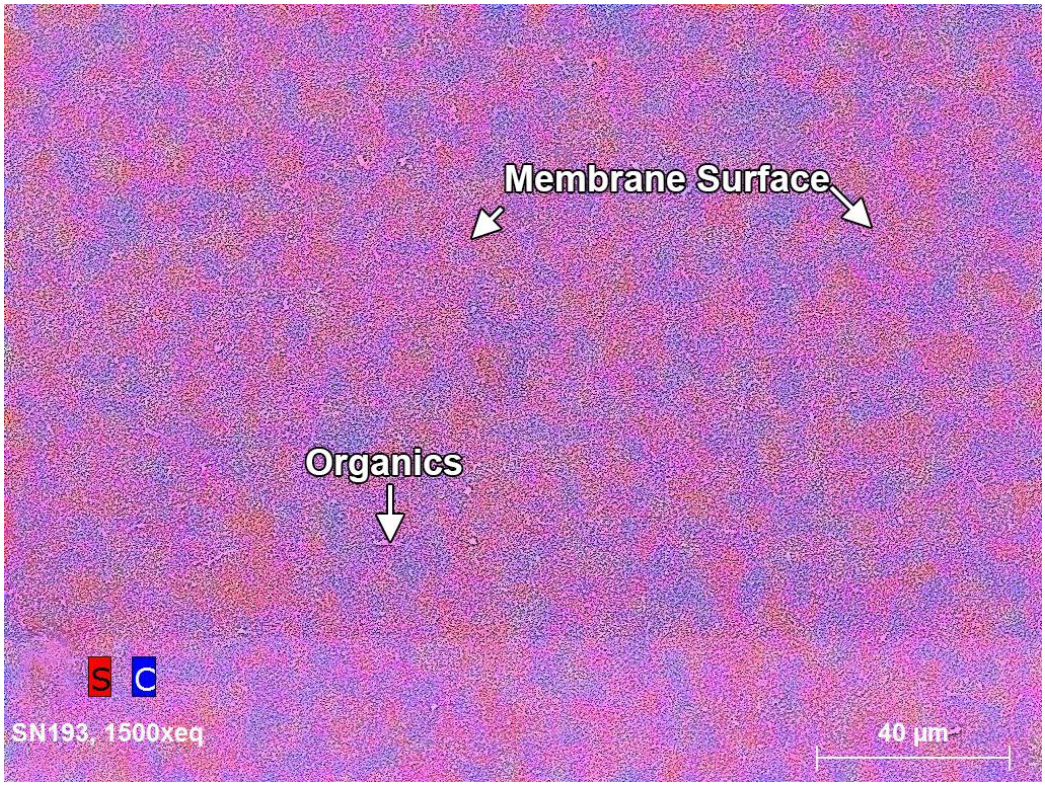
CEI image (150x) of the membrane surface



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface



CEI image (1500x) of the membrane surface with labels

Flat Sheet Performance and Cleaning Study

To evaluate flat sheet performance, membrane samples harvested from the full element are tested for permeability and salt passage. The raw flow and conductivity measurements from the test are used to calculate the permeability and salt passage constants, which are independent of pressure, temperature and salt content of the feed stream. The permeability constant is measured in cm/s/atm and the salt passage constant in cm/s. Discrepancies between the flat sheet and full element performance can indicate the presence of mechanical damage.

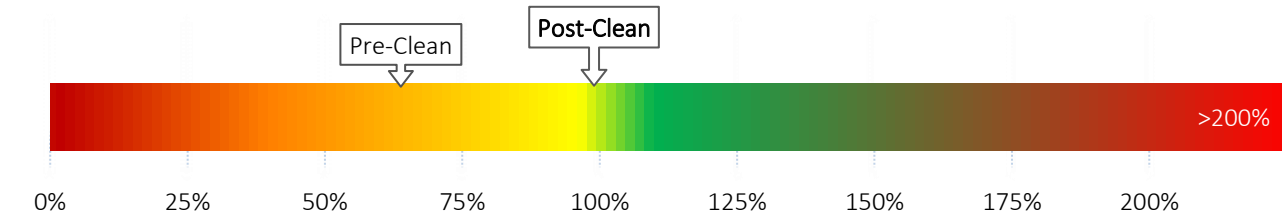
The flat sheet samples are then cleaned with various Avista chemicals to determine the most effective cleaner combinations and contact times. Cleaner efficacy is based on overall improvement in permeability and salt passage constant as well as visual foulant removal.

Flat sheet samples harvested from the full element produced 60% of normal permeability and normal salt passage during baseline cell testing. Flat sheets were cleaned using RoClean L403 (1% by weight in RO/DI water, heated to approximately 35C and circulated) for 2 hours followed by RoClean L212 (1% by weight in RO/DI water, heated to approximately 35C and circulated) for 2 hours. This cleaning regimen restored permeability to the flat sheet samples.

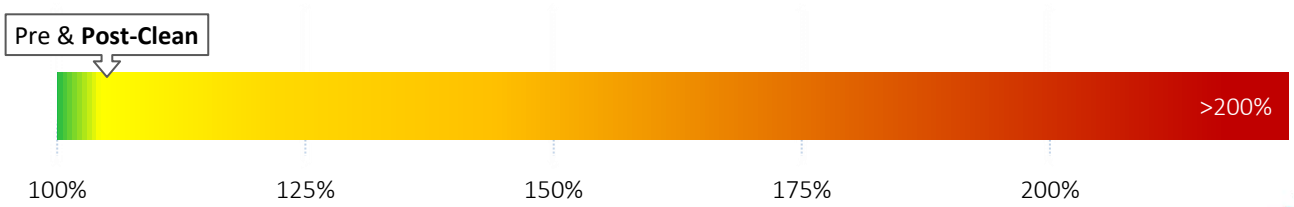
SN 2191220193	Permeability Constant	Salt Passage Constant
Baseline	0.83E-04 60% of Normal	7.01E-06 Normal
Post-Clean	**1.62E-04** **Normal**	**6.74E-06** **Normal**
Manufacturer's Specifications	1.38 to 1.72E-04 Normal Range	4.36 to 7.29E-06 Normal Range

Note: testing conducted with dechlorinated city water from San Marcos, CA

Permeability (% of Normal)



Salt Passage (% of Normal)



Testing for Flat Sheet Damage

Fujiwara Testing

Fujiwara testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. A color change does not occur if the membranes has not been exposed to halogens. Common symptoms of halogen oxidation include increased flow and loss in permeate quality.

Fujiwara testing was positive for the presence of halogens (e.g. chlorine) in the membrane structure.



Example of a positive Fujiwara color change

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#011321-3	Standard Spiral Autopsy	2191220193	March 19th, 2021

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

Date: 03/19/2021

Signed:

Megan Lee
Laboratory Services Manager

Jaime La Cuesta
Laboratory Services Chemist

4TH 3 STAGE 85% WO#032921-4 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Las Virgenes Municipal Water District
Attn. Steve Jackson
4232 Las Virgenes Road #1994
Calabasas, CA 91302

Avista Technologies, Inc.
140 Bosstick Blvd.
San Marcos, CA 92069
United States

Sender: Raul Gonzalez
rgonzalez@avistatech.com
Corp Ofc: +1 760 744 – 0536
Mobile: +1 760 566 – 9000

May 31, 2021

RE: WO#032921-4 Las Virgenes Municipal Water District Autopsy Report

Hello Steve,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220463. The membrane was sent in for autopsy to confirm system performance. The element was taken from the tail position of the last stage.

The element produced 74% of normal flow, normal rejection (99.7%) and normal differential pressure (3.5 psi). The membrane surface revealed a thin layer of visible foulant. The foulant on the membrane surface was determined as primarily organic (55%), with only trace amounts of calcium. This autopsy shows an improvement from the aluminum fouling that was previously seen on membranes from the same position.

The cleaning study showed a higher concentration of RoClean L212 (2% by weight) for 2 hours followed by RoClean L403 (1% by weight) restored permeability. Potentially increasing the concentration and contact time of the high pH cleaner (RoClean L212) will help recover performance loss. I'd be happy to provide field support during the next cleaning cycle.

Please let me know when we can setup a time to discuss this report in more detail.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista | Membrane Autopsy

COMPLETED FOR:

Las Virgenes Municipal Water District

Pure Water Demo

Serial Number 2191220463

Position: Tail – Stage 3

05/24/21 WO#032921-4

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EXECUTIVE SUMMARY

Background Las Virgenes Municipal Water District provided (1) Toray TMG10D reverse osmosis (RO) element to Avista Technologies for a full membrane autopsy. The element, identified as Serial Number (SN) 2191220463, was removed from the Tail position of Stage 3.

Initial Element Testing The element produced 74% of normal flow, a rejection of 99.7% and a differential pressure of 3.5 psi.The element passed integrity testing, indicating the absence of damage to the internal mechanical components.

External Inspection The external components were in good condition, although brown and black-colored foulant material was observed.

Internal Inspection The scroll ends were in good condition. A thin layer of tan-colored foulant material was observed on the exposed membrane surfaces which is likely the cause for the loss in membrane flow. The remaining internal components (feed spacers, glue lines, permeate carriers, membrane backing) were in good condition.

Foulant Analysis The foulant material had a moisture content of 96% and an organic content of 55%, indicating a combination of organics and inorganics. Aerobic bacteria activity was confirmed. Microscope analysis displayed bio-slime containing inorganic deposits and other particulate material; fungi were also present. The bulk of the foulant was identified as organics (bio-slime) and deposits of calcium.

Flat Sheet Performance and Cleaning Study Flat sheet samples harvested from the full element produced 78% of normal permeability and 99.1% rejection. Flat sheet permeability was restored and using RoClean L212 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours followed by RoClean L403 (1% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 1 hour.

Flat Sheet Damage Fujiwara testing was positive for the presence of halogen oxidation. Dye testing displayed severe physical damage (i.e. abrasion).

Autopsy Conclusion The element was fouled with small amounts of organics and calcium. Membrane permeability was restored to normal values. However, membrane rejection remained below normal due to abrasive damage.

TESTS	RESULT	NOTES
Initial Element Testing		
Element Weight		8 lbs
Full Element Flow		74% of normal
Full Element Rejection		99.7%
Full Element Pressure Drop		3.5 psi
Integrity Test		
Inspection		
Fiberglass Casing		
Brine Seal		
Permeate Water Tube		
Anti-Telescoping Devices		
Scroll Ends		
Membrane Surface		Thin layer of tan-colored foulant and black-colored particles
Feed Spacers		
Glue Lines		
Permeate Carriers and Membrane Backing		
Foulant Analysis		
Primary Foulant		Organics and Calcium
Secondary Foulants		Particles
Flat Sheet Performance and Cleaning		
Flat Sheet Permeability		78% of Normal
Flat Sheet Rejection		99.1%
Cleaning Study		
Testing for Damage		
Fujiwara Testing		Positive for halogens
Dye Testing		Shows severe physical damage (abrasion)

The following key will be used throghout the report to demonstrate whether the observation is within or outside normal conditions or if the test was not carried out.

Within normal conditions **Outside normal conditions** **Not tested**

INITIAL ELEMENT TESTING

Element Weight can be indicative of the degree of fouling.

- New elements weigh approximately 7 to 10 pounds

Results**:** 8 lbs.

Full Element Performance Testing results were normalized to the manufacturer's published test conditions.

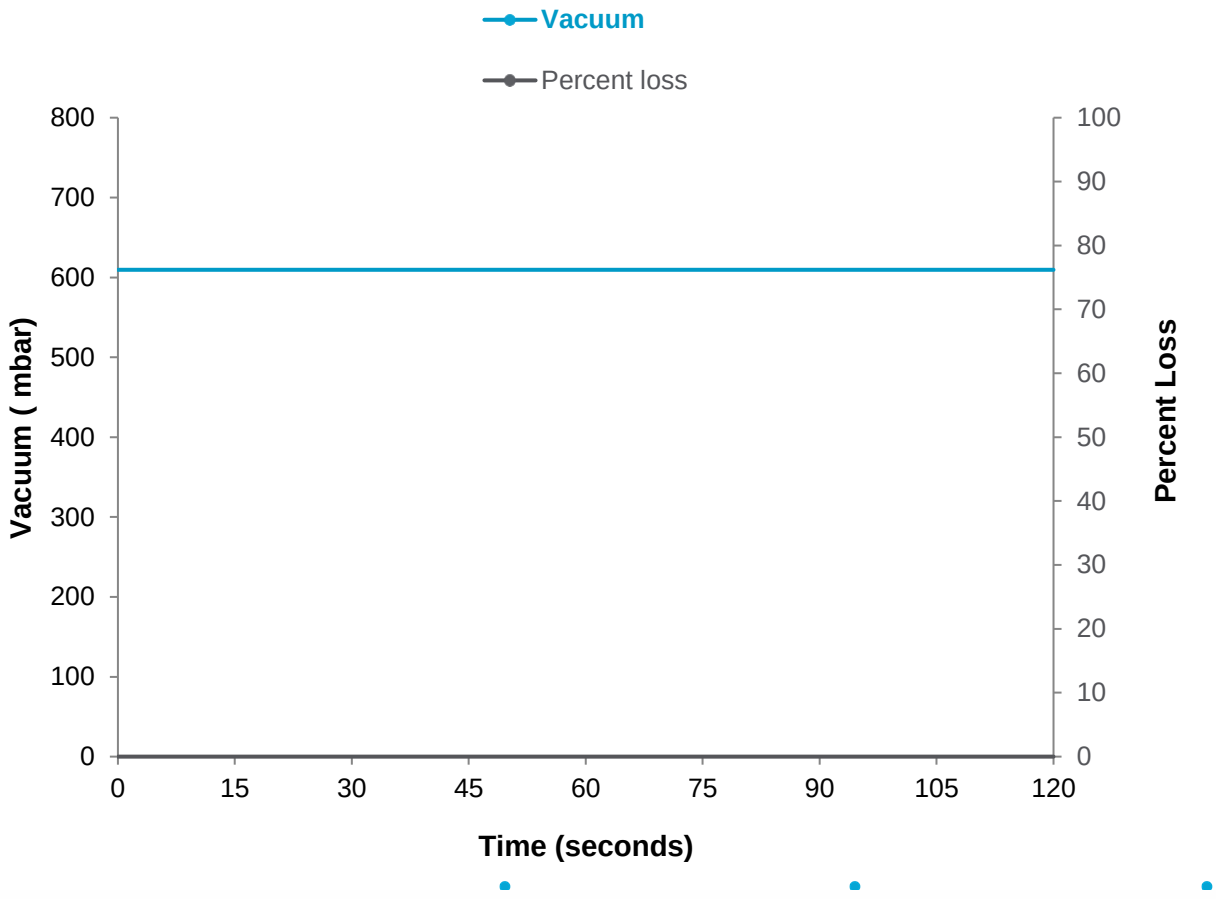
Results: The element produced 74% of normal flow, normal rejection and a differential pressure of 3.5 psi.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220463	1.24	99.7	3.5
Manufacturer's Specifications	1.67 – 1.98	99.5 - 99.7	≤15

Integrity Testing is performed to identify mechanical damage to the internal components of the spiral wound element.

- The permeate tube is sealed and a vacuum of approximately 600 mbar is applied and monitored for 120 seconds
- Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum suggests severe mechanical damage

Results: The element maintained the vacuum, indicating the absence of mechanical damage to the internal components.



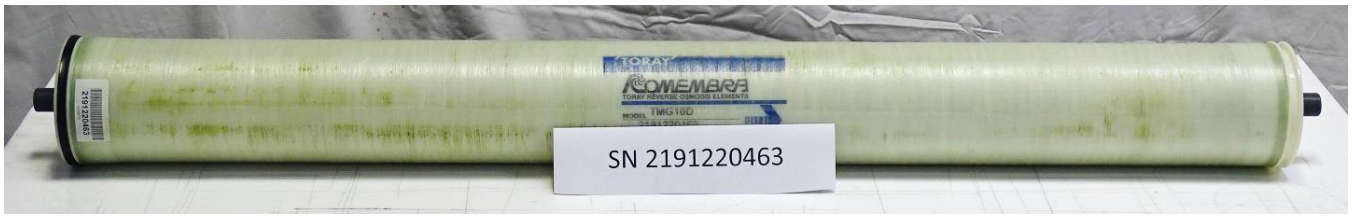
INSPECTION

A thorough inspection of the internal and external components is performed. Membrane construction diagrams are available in Appendix I on page 22 for review.

Fiberglass Casing stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – indicates rough handling or excessive differential pressure from heavy fouling

Results: The fiberglass casing was in good condition.



Fiberglass casing of SN 2191220463

Brine Seal stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – can allow more water to flow across the exterior of the casing

Results: The brine seal was in good condition.

Permeate Water Tube (PWT) is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the PWT to be collected. It is inspected for:

- Foulant – suggests feedwater bypass
- Damage – can lead to o-ring failure or feedwater bypass

Results: The PWT was free of damage.

Anti-Telescope Devices (ATDs) stabilize the components of the element and help to prevent shifting of the internal mechanical components under pressure, also known as telescoping. They are inspected for:

- Foulant – severe fouling can block feed flow and contribute to elevated differential pressure
- Damage – indicates rough handling

Results: The ATDs were in good condition and free of foulant material.

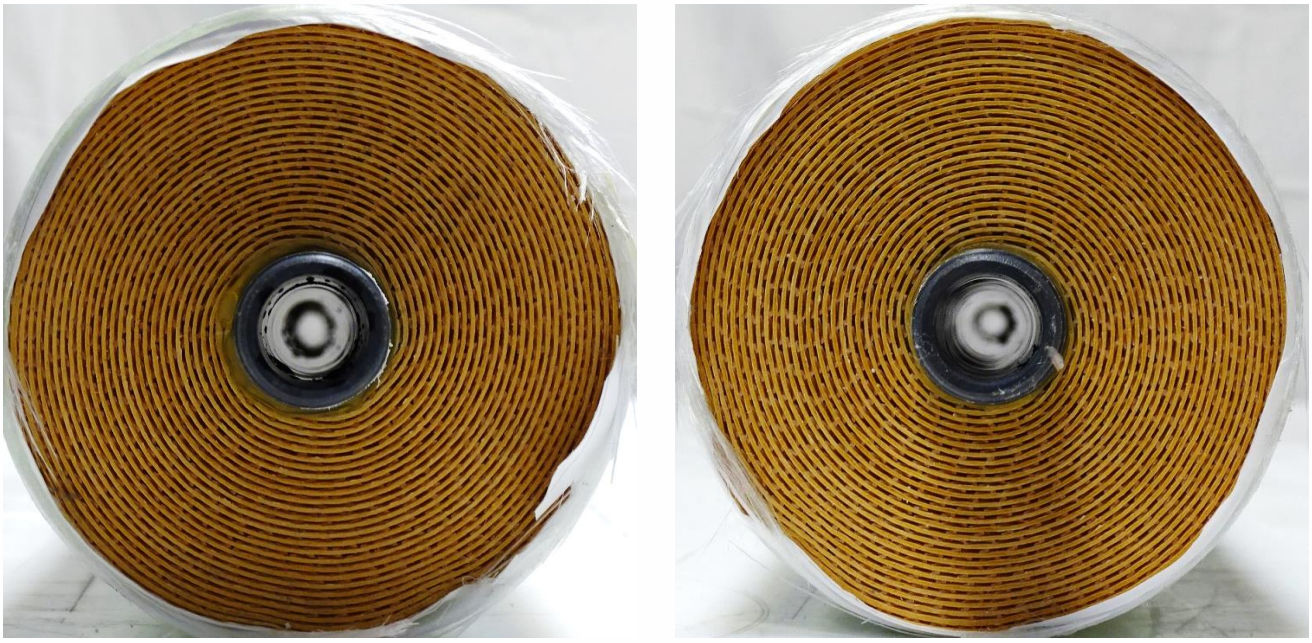


Feed (left) and concentrate (right) ATDs of SN 2191220463

Scroll Ends should be flush with evenly spaced membrane leaves free of debris. The scroll ends are inspected for:

- Foulant – can cause elevated differential pressures
- Scroll gapping and feed spacer extrusion – can lead to uneven hydraulics (high flow/low flow regions), increases cleaning difficulty
- Telescoping – axial shift of the membrane leaves from the outer diameter of the element towards the PWT, commonly caused by excessive fouling and can increase cleaning difficulty

Results: The scroll ends were in good mechanical condition.



Feed (left) and concentrate (right) scroll ends of SN 2191220463

Membrane Surfaces should be uniform and shiny. They are inspected for:

- Foulant – can cause elevated differential pressures, loss in permeate flow and loss in rejection
- Creasing of the membrane surface – more common in the presence of gapping, feed spacer extrusion and telescoping, can cause loss in rejection
- Delamination – lifting of the thin-film membrane from the support layer which is often caused by positive pressure on the permeate side of the element, causes loss in rejection

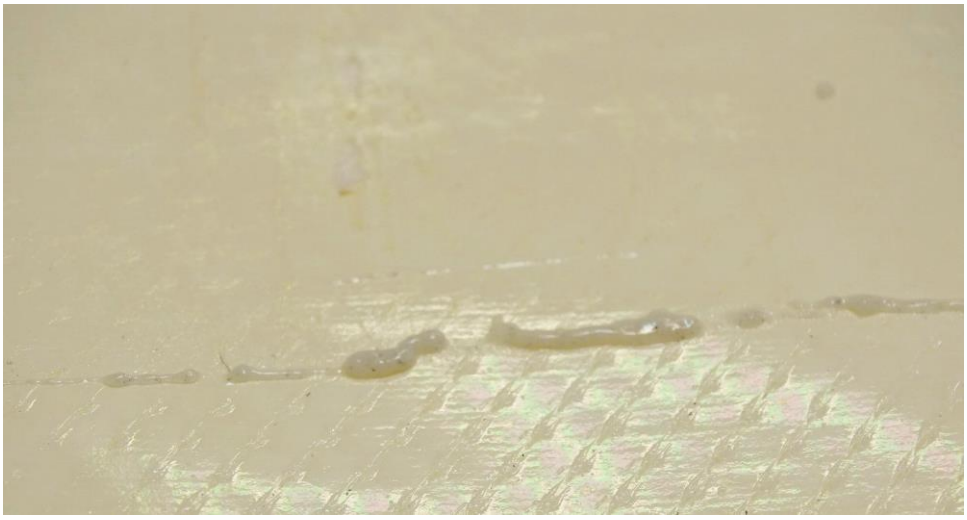
Results: A thin layer of tan-colored foulant was evenly coating the membrane surface along with few black-colored particles. The foulant was gelatinous and easily scrapable.



Exposed membrane surface of SN 2191220463



Exposed membrane surface from feed end of SN 2191220463



Foulant scraped on one membrane leaf of SN 2191220463

Feed Spacers are composed of plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. They are inspected for:

- Foulant – can block the feed channels, causing elevated differential pressure
- Damage – fouling can cause deformation of the material, disrupting the hydraulics of the membrane and increasing cleaning difficulty

Results: The feed spacers of the element were free of visible foulant material.



Feed spacer of SN 2191220463

Glue Lines separate the feed and permeate streams on three sides of membrane leaves. They are inspected for:

- Glue flaps – excess membrane material closest to the end of the element, can block feed channels leading to elevated differential pressure
- Pouching – commonly a result of severe delamination, can lead to feedwater bypass

Results: The glue lines displayed no visible defects or damages.

Permeate Carriers and Membrane Backings are the components of the permeate side of the element. They are inspected for:

- Foulant – indicates a bypass of feedwater

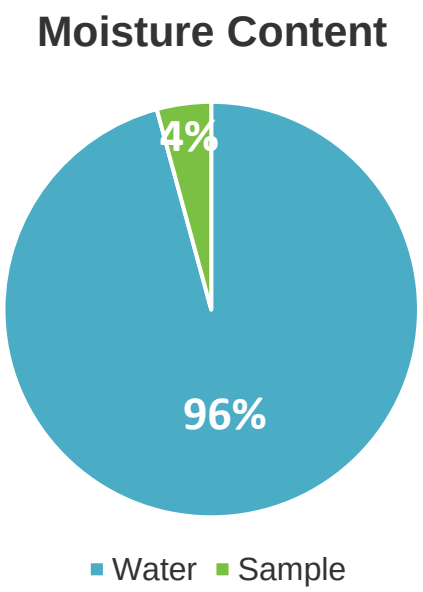
Results: The permeate carriers and membrane backings showed no visible signs of feedwater bypass.

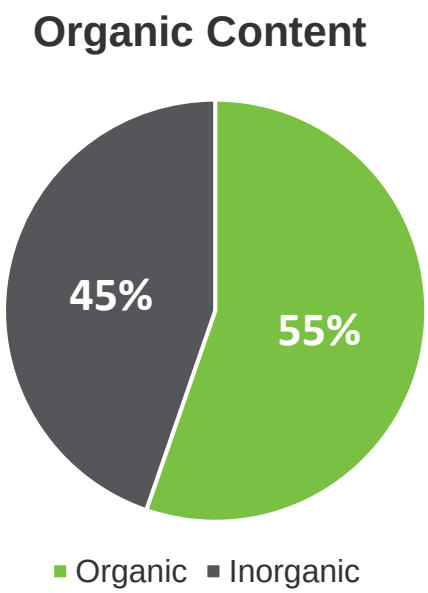
FOULANT ANALYSIS

Foulant Density Measurement and Composition Testing is performed to quantify degree of fouling, which contributes to full element differential pressure, and determine the composition of the foulant:

- Moisture Content – the portion of the foulant that is water. Biological materials tend to have higher moisture contents (>95%)
- Organic Content – the portion of the foulant composed of carbon, which ignites during testing
- Inorganic Content – the portion of the foulant not composed of carbon and does not ignite during testing

Results: The wet foulant density of SN 2191220463 was measured as 0.28 mg/cm^2. The foulant had a high moisture content (96%) and an organic content of 55%, indicating that the foulant was a combination of organic and inorganic material.

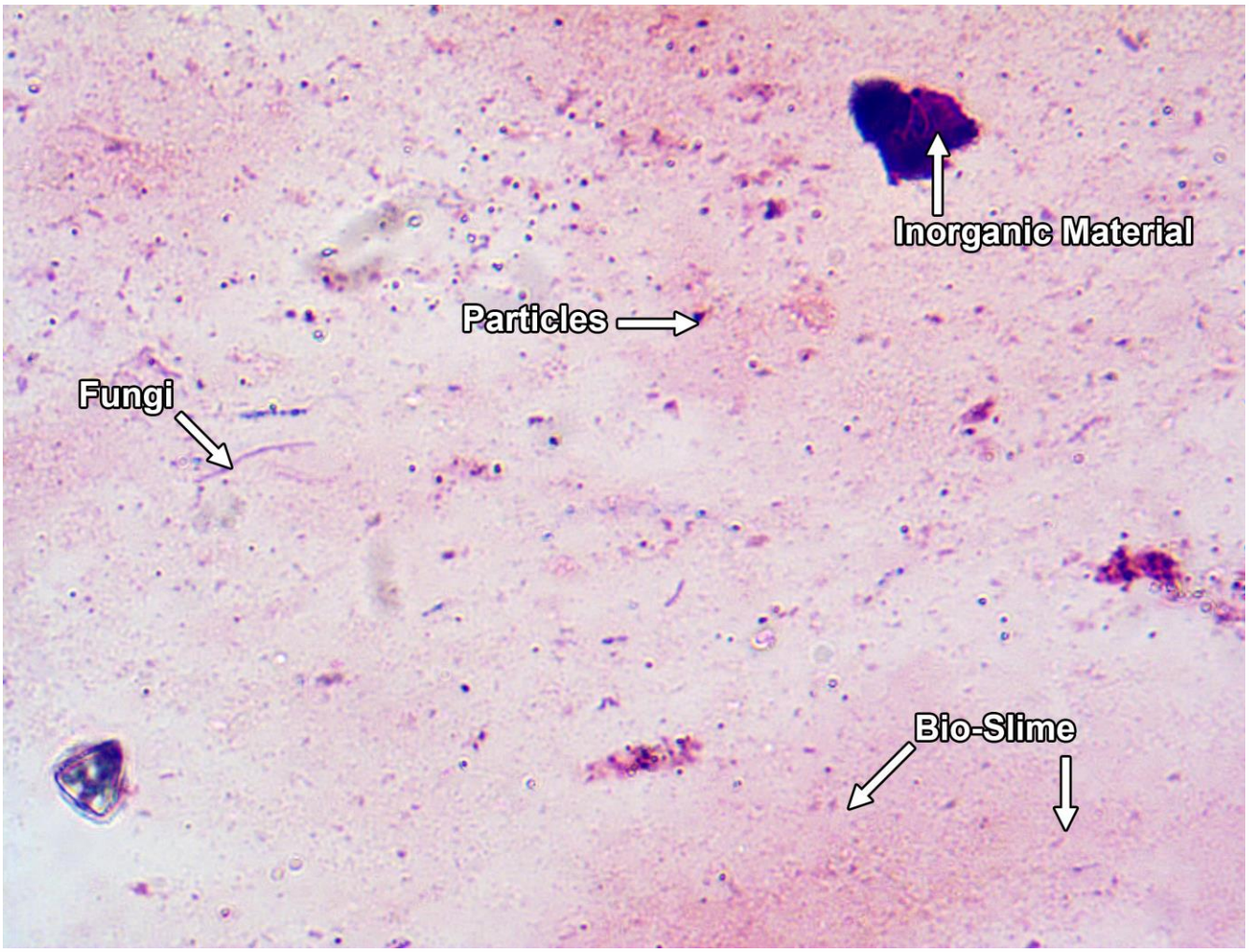




Microscope Analysis is performed on Gram-stained foulant samples using a light microscope at 1000x using an oil immersion lens. Gram-positive bacteria are stained purple while Gram-negative bacteria are stained pink. The following organic and inorganic components can be identified:

- Organics: Bio-slime, humic/fulvic acid, bacteria, yeast, mold, nematodes, microorganism shells
- Inorganics: inorganic material (e.g. metals, clays), translucent crystals, particles

Results: Microscope analysis identified bio-slime containing inorganic deposits and other particulate material. Fungi were also observed.



Light microscope images (1000x) of foulant scraped from SN 2191220463

Biological Activity Testing gives a semi-quantitative result for live aerobic bacteria and yeast/mold content of a sample. Greater colony density, measured in colony-forming units (CFU)/ml, indicates a more biologically active sample.

- Higher biological activity is associated with more biological fouling
- The biological activity rating references are available in Appendix II on page 23.

Results: Highlighted in the table below.

Biological Activity Rating	Aerobic Bacteria	Yeast/Mold
Low	0-100	**0-100**
Moderate	100-10,000	100-10,000
High	**10,000-1,000,000**	10,000-100,000
Very High	1,000,000-TNTC	100,000-TNTC



Aerobic Bacteria



Yeast/Mold

Testing for Carbonates and Metals is performed by applying several drops of dilute hydrochloric acid (HCl) to the foulant surfaces.

- Effervescing (bubbling) – positive for carbonates
- Yellow color change – positive for the presence of metals.

Results: No reaction was observed during acid testing.

Before HCl



After HCl

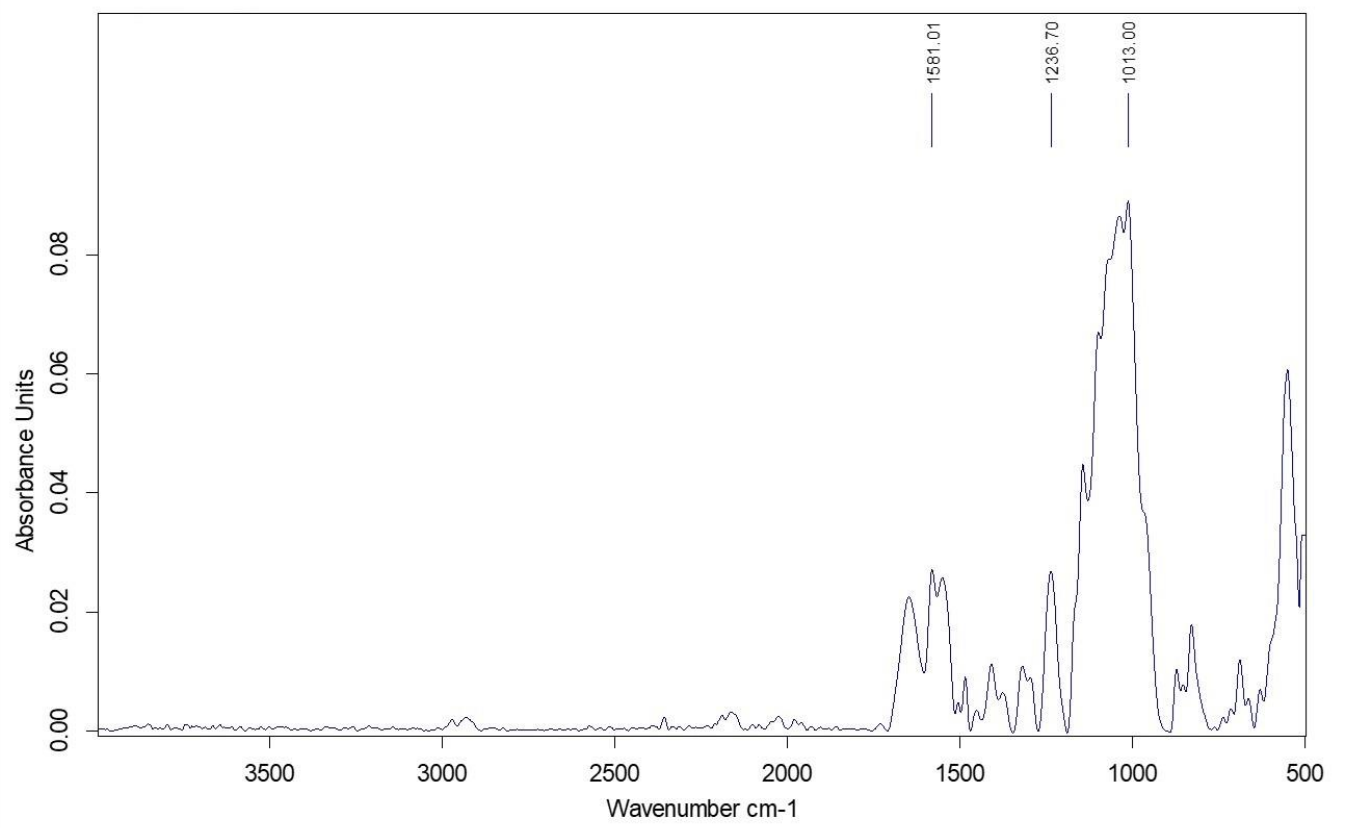


Acid test reaction

Fourier Transform Infrared Spectroscopy (FT-IR) Analysis produces a spectrum of the foulant that is compared to an extensive FT-IR library of known foulants to identify specific compounds (functional groups).

Results: FT-IR identified peaks associated with amino acids and carbohydrates.

Compound	Wavelength (cm^{-1})
Amino Acids	1650-1500
Carbohydrates	1000

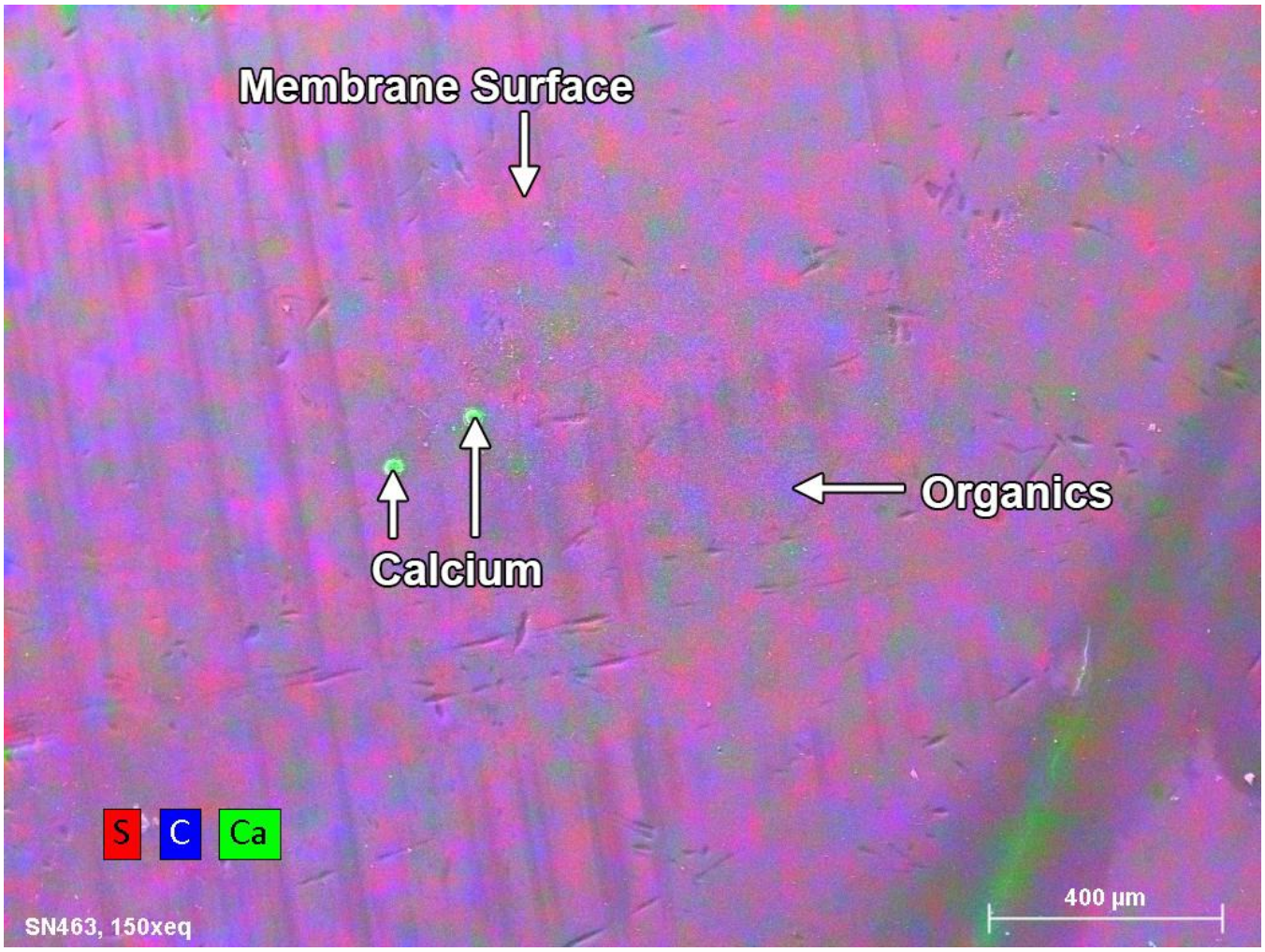


FT-IR spectral image of foulant removed from the membrane surface of SN 2191220463

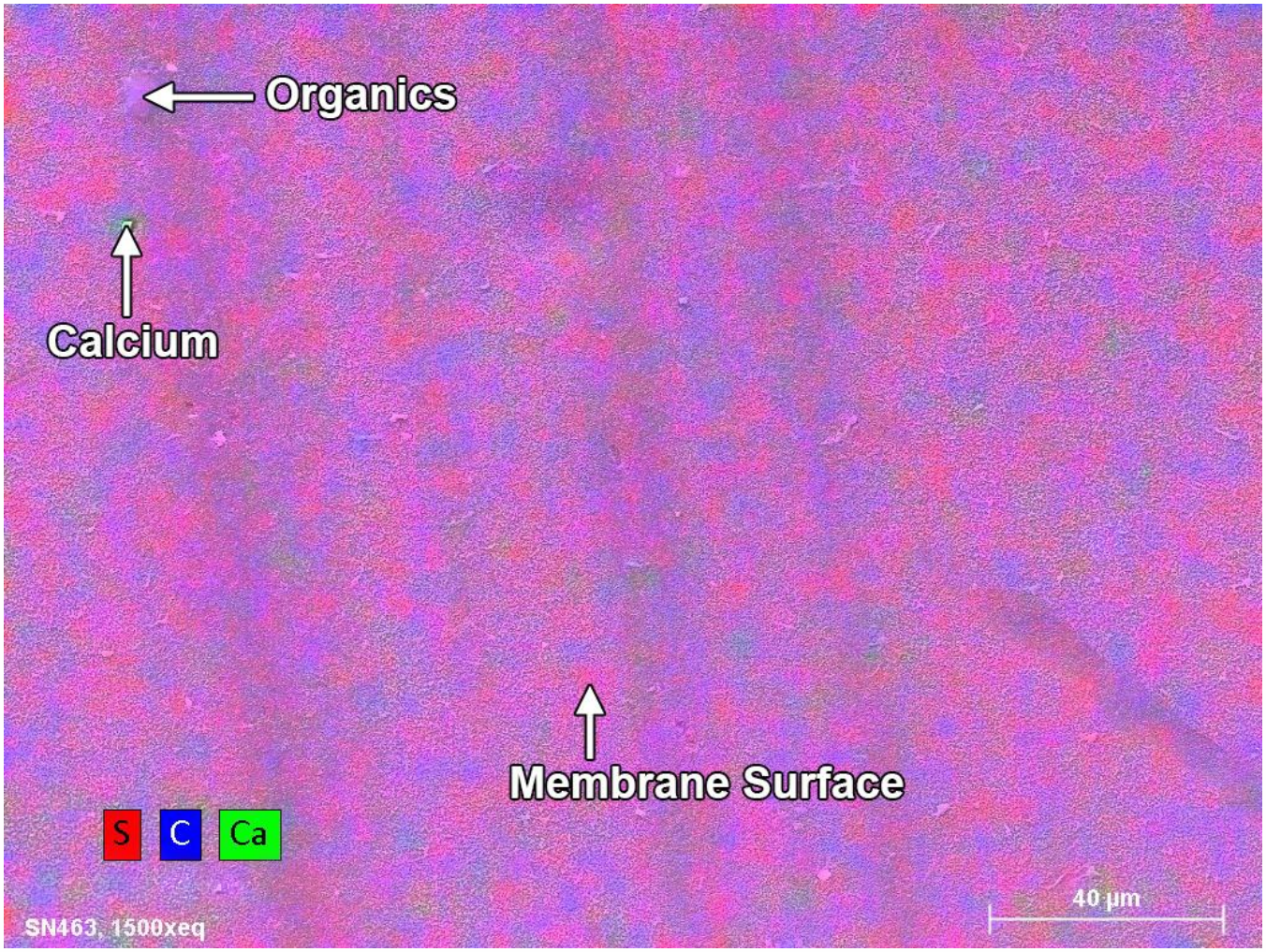
Membrane Surface Imaging and Elemental Composition Testing is used to identify foulants and the degree of fouling. This is accomplished using Chromatic Elemental Imaging[SM] (CEI[SM]) and Energy Dispersive Spectroscopy (EDS) Analysis.

- CEI – high-resolution imaging technique that assigns elements colors to show the spatial distribution, interaction and relative concentration of elements in sample
- EDS – provides the relative concentrations of elements present in a sample

Results: CEI confirmed the presence of a thin layer of organics – represented by carbon (blue) – spread across the membrane surface. Small patches of calcium (green) were also observed. The membrane surface is denoted by sulfur (red) and was visible throughout the image confirming a thin foulant layer.



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface with labels

Results: EDS analysis only detected trace amounts (<0.50 wt%) of calcium on the membrane surface. An excess of carbon was detected indicating the presence of foreign organic material. Additionally, the sulfur weight percent (8.18 wt%) was within normal values indicating the foulant layer was thin.

Elements	SN 2191220463 (Weight Percent, wt%)	New Membrane (Weight Percent, wt%)
Carbon	76.03	40.00-60.00
Oxygen	15.41	30.00-40.00
Sulfur	8.18	5.00-9.00
Calcium	0.38	--

FLAT SHEET PERFORMANCE AND CLEANING STUDY

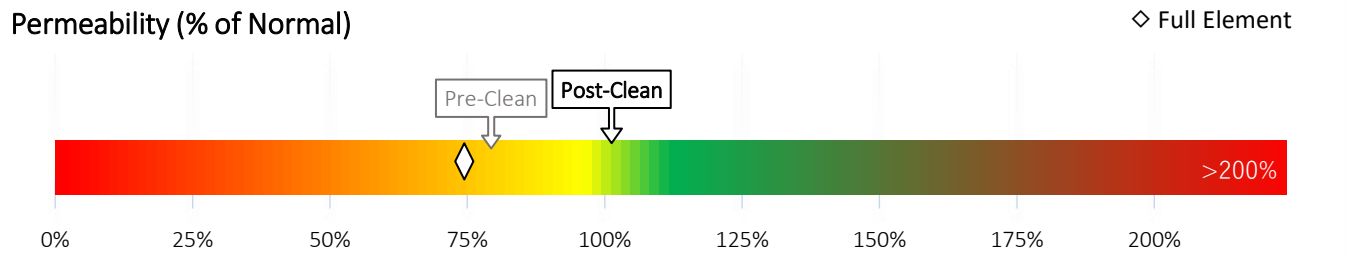
Flat Sheet Cleaning Study is performed in a cell test apparatus to determine the most effective cleaning regimen for overall improvement in permeability, rejection and visual foulant removal.

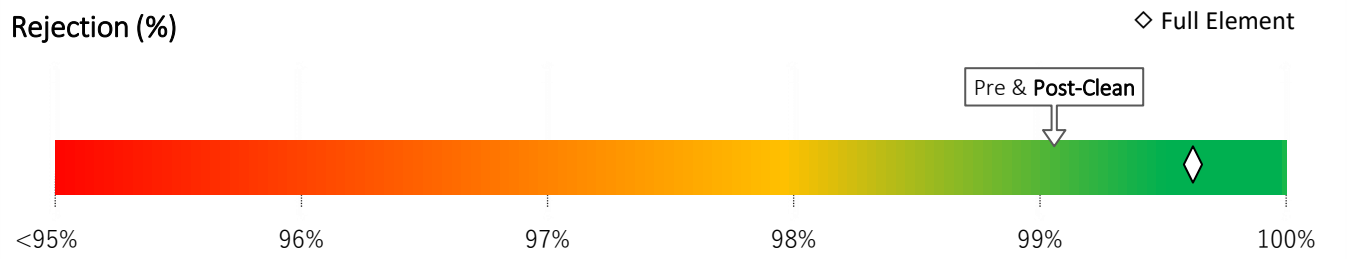
- Flat sheet normalized permeability and rejection before and after cleaning are calculated and compared to the manufacturer's specification for new membranes of the same model
- Calculations are performed using industry standard water passage coefficient (A value) and salt passage coefficient (B value) and converted for ease of understanding. A and B values are available upon request

Results: The following regimen achieved complete visual foulant material, improving permeability and rejection:

1) RoClean L212 (2% by weight in RO/DI water, 35 degrees Celsius and circulated) for 2 hours
2) RoClean L403 (1% by weight in RO/DI water, 35 degrees Celsius and circulated) for 1 hours

Membrane Model	Permeability	Rejection (%)
Full Element	74% of Normal	99.7
Pre-Clean Flat Sheet	78% of Normal	99.1
Post-Clean Flat Sheet	Normal	99.1
Manufacturer's Specification	1.56 to 1.85E-04	99.5 to 99.7





TESTING FOR FLAT SHEET DAMAGE

Fujiwara Testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to halogen (e.g. chlorine, bromine, or iodine) oxidation. Exposure to halogens is progressively damaging to PA membranes, causing increases in flow and losses in permeate quality.

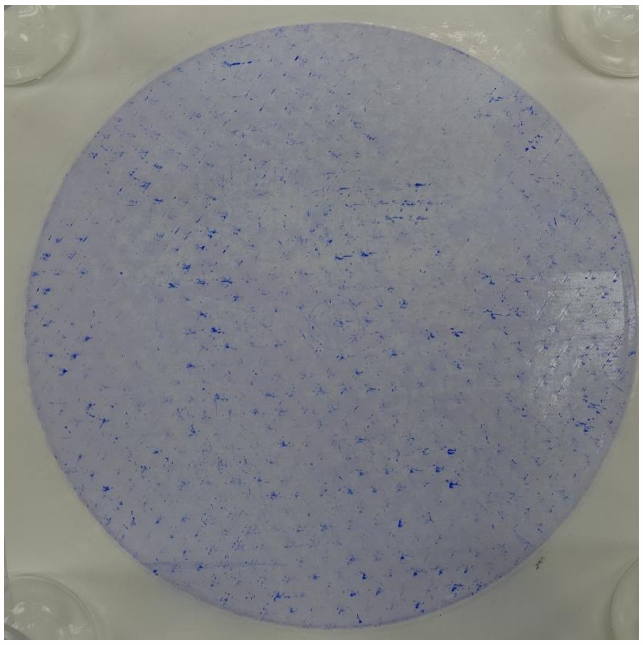
Results: Fujiwara testing was positive for the presence of halogens (e.g. chlorine) in the membrane structure.

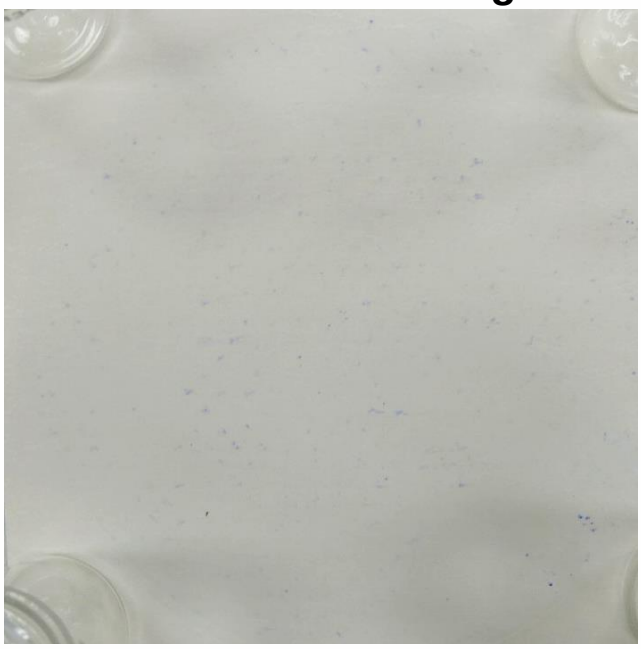
Dye Testing is used to identify the presence and extent of chemical and/or physical damage to membrane flat sheet samples.

- Uneven dye uptake – indicates physical damage
- Even dye uptake – indicates chemical damage
- Dye penetration to the membrane backing – indicates severe damage

Results: Dye testing showed primarily physical damage. The damage was severe, with dye penetration observed on the membrane backing.

Membrane Surface | **Membrane Backing**





Dye test results

CERTIFICATION BY LABORATORY

Report Number	Report Content	Element Serial Number	Report Date
WO#032921-4	Standard Spiral Autopsy	2191220463	05/24/21

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

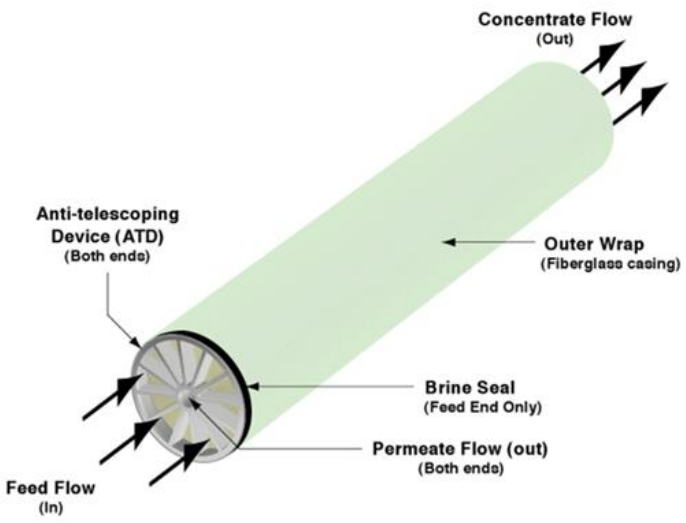
Date: 05/24/21

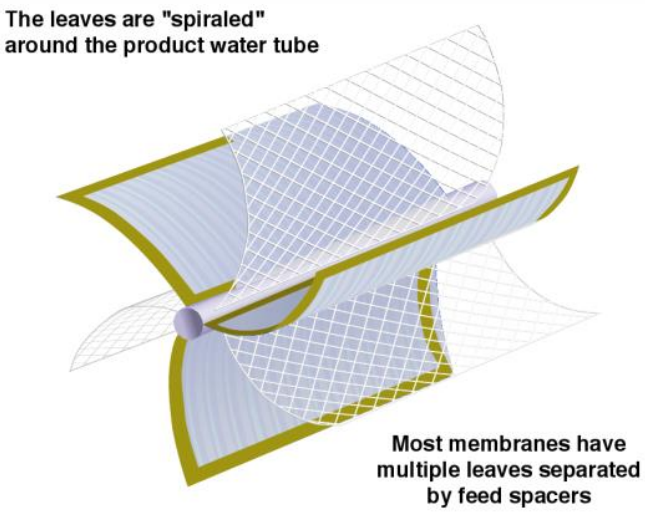
Signed:

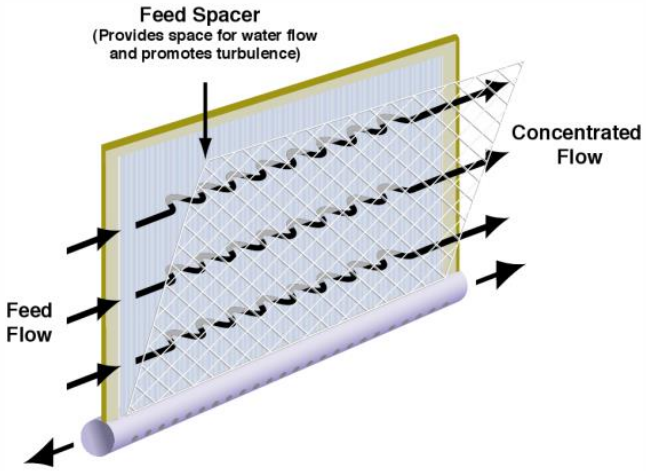
Jessica Foster
Laboratory Services Supervisor

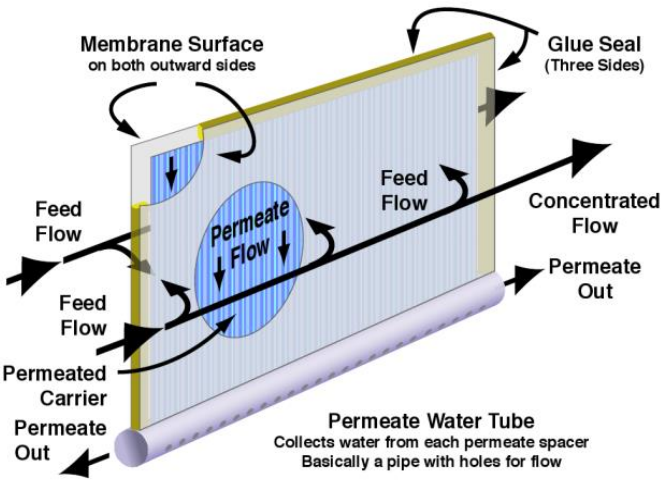
Jaime La Cuesta
Laboratory Services Chemist

APPENDIX I. MEMBRANE CONSTRUCTION DIAGRAMS

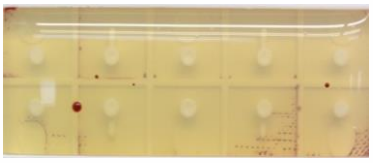
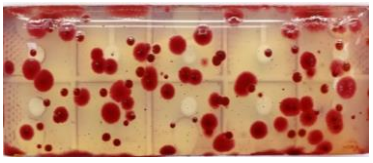
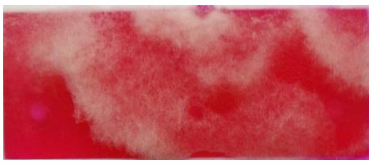








APPENDIX II. BIOLOGICAL ACTIVITY RATINGS

	Aerobic Bacteria	Yeast	Mold
Low			
Moderate			
High			

5TH 2 STAGE 85% WO#051221-3 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Las Virgenes Municipal Water District
Attn. Steve Jackson
4232 Las Virgenes Road #1994
Calabasas, CA 91302

Avista Technologies, Inc.
140 Bosstick Blvd.
San Marcos, CA 92069
United States

Sender: Raul Gonzalez
rgonzalez@avistatech.com
Corp Ofc: +1 760 744 – 0536
Mobile: +1 760 566 – 9000

June 18, 2021

RE: WO#051221-3 Las Virgenes Municipal Water District Autopsy Report

Hello Steve,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220465. The membrane was sent in for autopsy to determine optimal cleaning. The element was taken from the tail position of the last stage during the two-stage operation.

The element produced 44% of normal flow, normal rejection (99.5%) and normal differential pressure (3.0 psi). The membrane surface had a layer of white-colored, granular material. The deposits on the membrane surface were determined as primarily organic (59%). The inorganic portion of the deposits were identified as calcium phosphate.

Calcium phosphate is extremely dependent on ph. I recommend a review of the orthophosphate concentration and pH during the two-stage operation to determine if an excursion took place. I also recommend a review of the hydraulic profile with the two-stage operation, potentially increasing the crossflow velocity may help reduce the level of fouling noted.

For the cleaning, I recommend increasing the concentration and contact time with the low pH cleaner (RoClean L403). The recommended contact time is at least 4 hours for each cleaner. I recommend reviewing the flushing step between cleaners to ensure that there is no cross contamination between each step and the feed water.

Please let me know if you have any questions.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista | Membrane Autopsy

COMPLETED FOR:

Las Virgenes Municipal Water District

Serial Number 2191220465

Stage 2 - Tail

06/11/20 WO#051221-3

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EXECUTIVE SUMMARY

Background Las Virgenes Municipal Water District provided 1 Toray TMG10D reverse osmosis (RO) element to Avista Technologies for a full membrane autopsy. Element Serial Number (SN) 2191220465 was removed from the tail position of Stage 2 in the RO system.

Initial Element Testing Element SN 2191220465 produced 44% of normal flow, a rejection of 99.5% and a differential pressure of 3 psi. The element passed integrity testing, indicating the absence of damage to the internal mechanical components.

External Inspection The external components were in good condition.

Internal Inspection The scroll ends were in good condition. The membrane surfaces were coated with white-colored foulant material with sparse amounts of black-colored particles. The foulant was granular in texture and scrapable for further analysis. The remaining internal components (feed spacers, glue lines, permeate carriers and membrane backings) were in good condition.

Foulant Analysis The foulant material had a moisture content of 69% and an organic content of 59%, indicating the foulant was a combination of organic and inorganic material. Microscope analysis identified primarily bio-slime and Gram-negative bacteria. Aerobic bacteria activity was high during incubation. The bulk of the foulant was identified as organics and calcium phosphate.

Flat Sheet Performance and Cleaning Study Flat sheet samples harvested from the full element produced 48% of normal permeability and 99.5% rejection. Flat sheet permeability was fully restored using RoClean L403 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours followed by RoClean L212 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours.

Flat Sheet Damage Fujiwara testing was negative for the presence of halogen oxidation. Dye testing was not performed as the full element and flat sheet samples produced normal rejection.

Autopsy Conclusion The element was fouled with a combination of organics and calcium phosphate. Permeability was restored to within normal condition and no damage was observed to the membrane.

The following key will be used throghout the report to demonstrate whether the observation is within or outside normal conditions or if the test was not carried out.

Within normal conditions **Outside normal conditions** **Not tested**

INITIAL ELEMENT TESTING

Element Weight can be indicative of the degree of fouling.

- New elements weigh approximately 7 to 9 pounds

Results**:** 7 lbs.

Full Element Performance Testing results were normalized to the manufacturer's published test conditions.

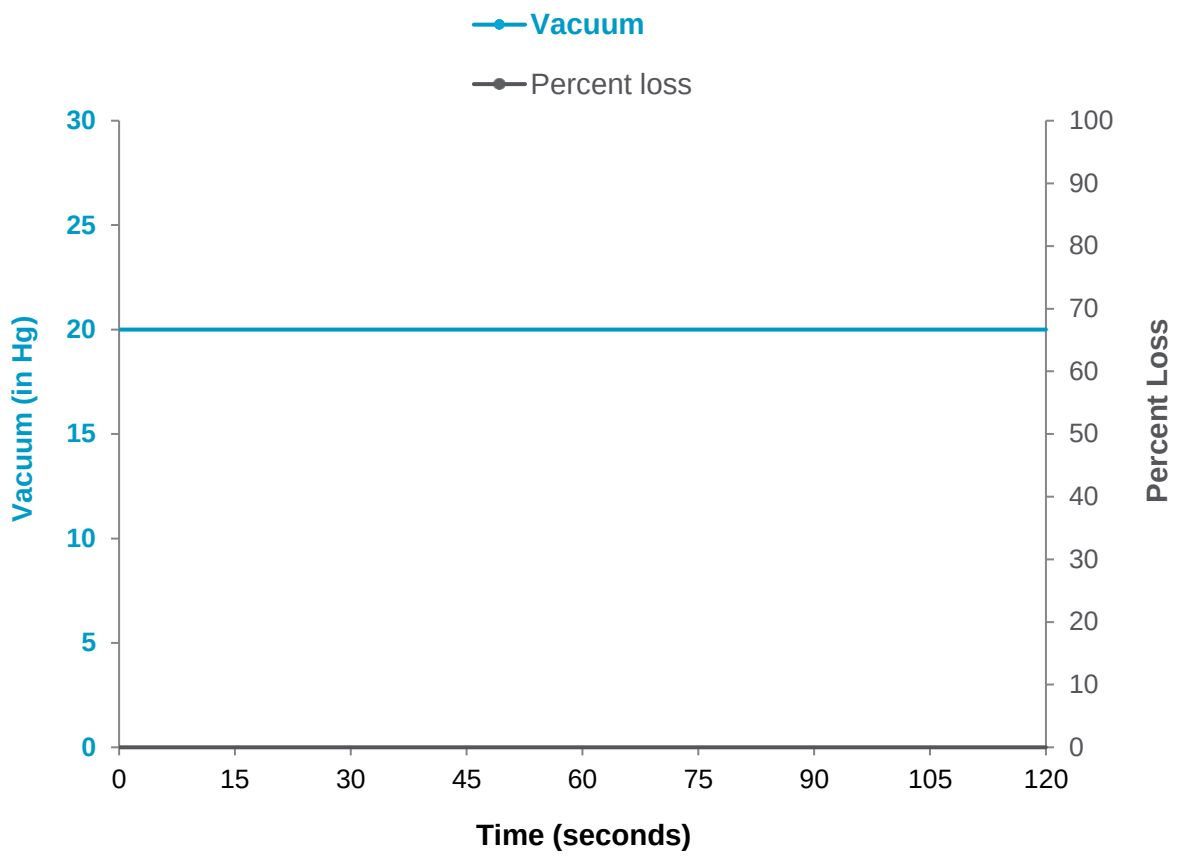
Results: The element produced 44% of normal flow, normal rejection (95.0%) and a differential pressure of 3 psi.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220465	0.64	99.5	3
Manufacturer's Specifications	1.47 – 1.84	99.5 – 99.7	≤15

Integrity Testing is performed to identify mechanical damage to the internal components of the spiral wound element.

- The permeate tube is sealed and a vacuum of approximately 600 mbar is applied and monitored for 120 seconds
- Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum suggests severe mechanical damage

Results: The element maintained the vacuum, indicating the absence of mechanical damage to the internal components.



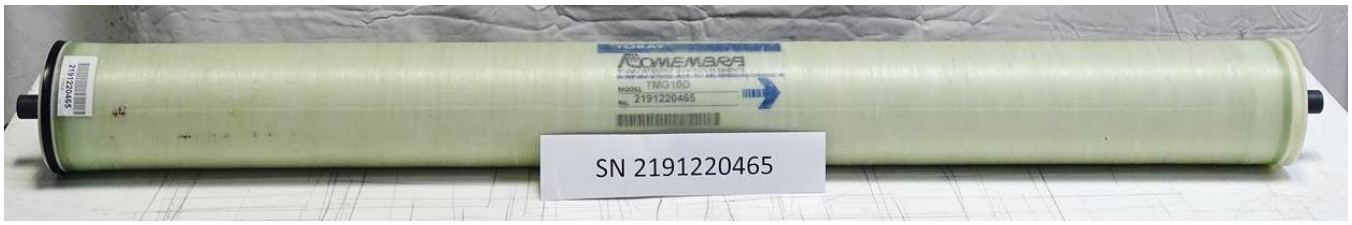
INSPECTION

A thorough inspection of the internal and external components is performed. Membrane construction diagrams are available in Appendix I on page 22 for review.

Fiberglass Casing stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – indicates rough handling or excessive differential pressure from heavy fouling

Results: The fiberglass casing was in good condition.



Fiberglass casing of SN 2191220465

Brine Seal stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – can allow more water to flow across the exterior of the casing

Results: The brine seal was in good condition.

Permeate Water Tube (PWT) is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the PWT to be collected. It is inspected for:

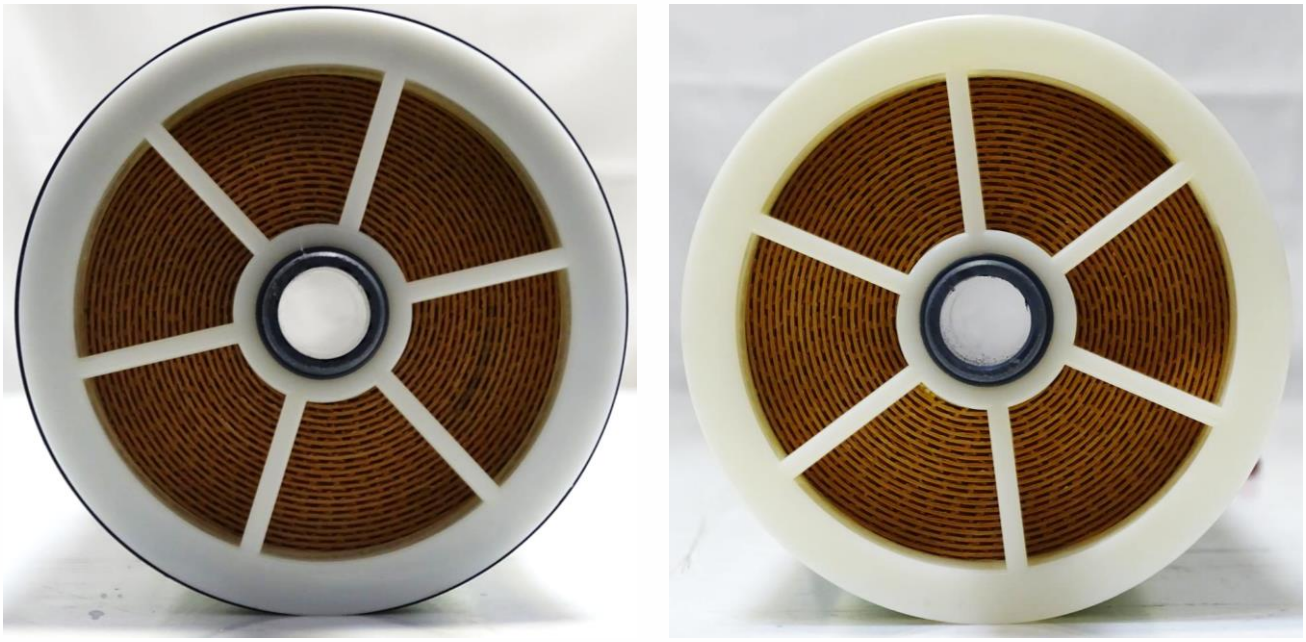
- Foulant – suggests feedwater bypass
- Damage – can lead to o-ring failure or feedwater bypass

Results: The PWT was free of damage.

Anti-Telescope Devices (ATDs) stabilize the components of the element and help to prevent shifting of the internal mechanical components under pressure, also known as telescoping. They are inspected for:

- Foulant – severe fouling can block feed flow and contribute to elevated differential pressure
- Damage – indicates rough handling

Results: The ATDs were in good condition.



Feed (left) and concentrate (right) ATDs of SN 2191220465

Scroll Ends should be flush with evenly spaced membrane leaves free of debris. The scroll ends are inspected for:

- Foulant – can cause elevated differential pressures
- Scroll gapping and feed spacer extrusion – can lead to uneven hydraulics (high flow/low flow regions), increases cleaning difficulty
- Telescoping – axial shift of the membrane leaves from the outer diameter of the element towards the PWT, commonly caused by excessive fouling and can increase cleaning difficulty

Results: The scroll ends were in good condition and free of from foulant material.



Feed (left) and concentrate (right) scroll ends of SN 2191220465

Membrane Surfaces should be uniform and shiny. They are inspected for:

- Foulant – can cause elevated differential pressures, loss in permeate flow and loss in rejection
- Creasing of the membrane surface – more common in the presence of gapping, feed spacer extrusion and telescoping, can cause loss in rejection
- Delamination – lifting of the thin-film membrane from the support layer which is often caused by positive pressure on the permeate side of the element, causes loss in rejection

Results: A thin layer of white-colored foulant material was distributed across the membrane surfaces. The foulant was scrapable and granular in texture.



Exposed membrane surface of SN 2191220465



Exposed membrane surface from feed end of SN 2191220465

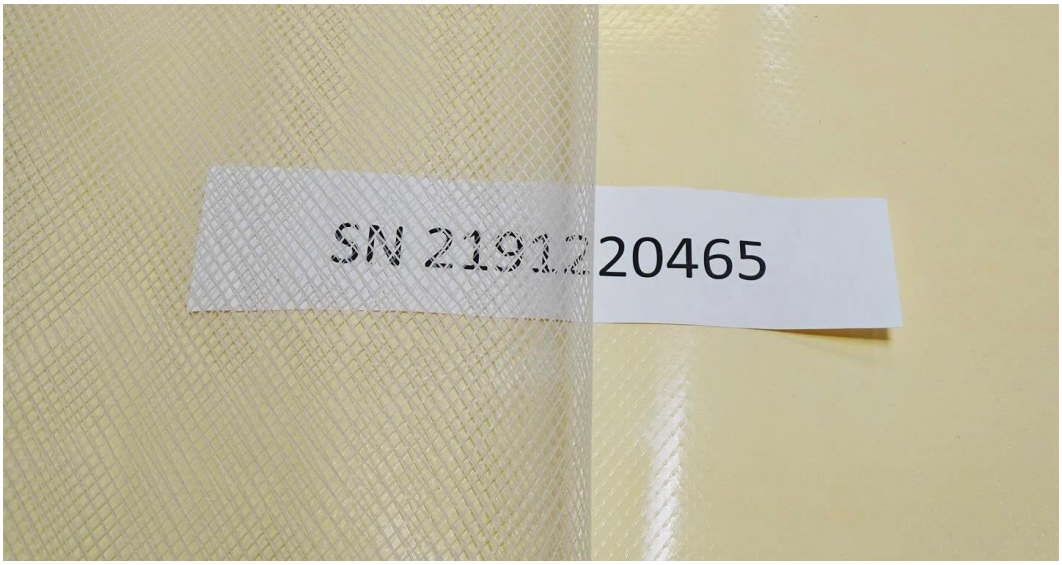


Foulant scraped on one membrane leaf of SN 2191220465

Feed Spacers are composed of plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. They are inspected for:

- Foulant – can block the feed channels, causing elevated differential pressure
- Damage – fouling can cause deformation of the material, disrupting the hydraulics of the membrane and increasing cleaning difficulty

Results: The feed spacers were free of visible foulant material.



Feed spacer of SN 2191220465

Glue Lines separate the feed and permeate streams on three sides of membrane leaves. They are inspected for:

- Glue flaps – excess membrane material closest to the end of the element, can block feed channels leading to elevated differential pressure
- Pouching – commonly a result of severe delamination, can lead to feedwater bypass

Results: The glue lines displayed no visible defects or damages.

Permeate Carriers and Membrane Backings are the components of the permeate side of the element. They are inspected for:

- Foulant – indicates a bypass of feedwater

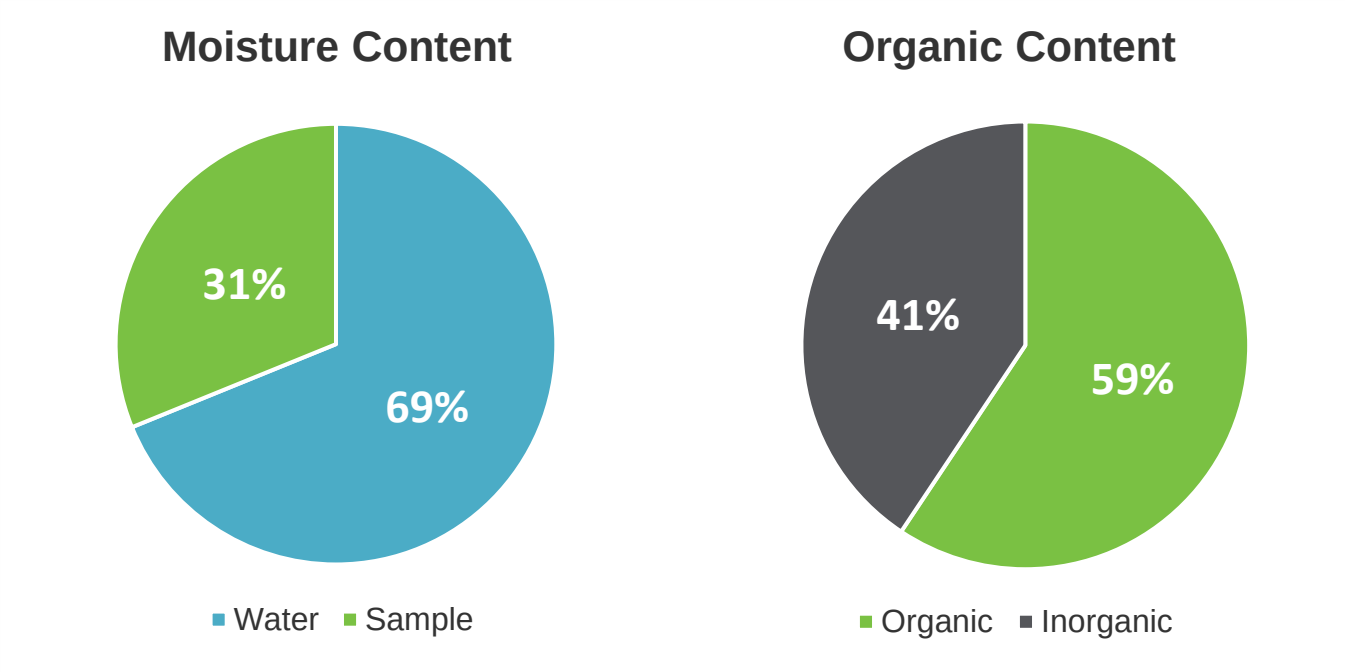
Results: The permeate carriers and membrane backings showed no visible signs of feedwater bypass.

FOULANT ANALYSIS

Foulant Density Measurement and Composition Testing is performed to quantify degree of fouling, which contributes to full element differential pressure, and determine the composition of the foulant:

- Moisture Content – the portion of the foulant that is water. Biological materials tend to have higher moisture contents (>95%)
- Organic Content – the portion of the foulant composed of carbon, which ignites during testing
- Inorganic Content – the portion of the foulant not composed of carbon and does not ignite during testing

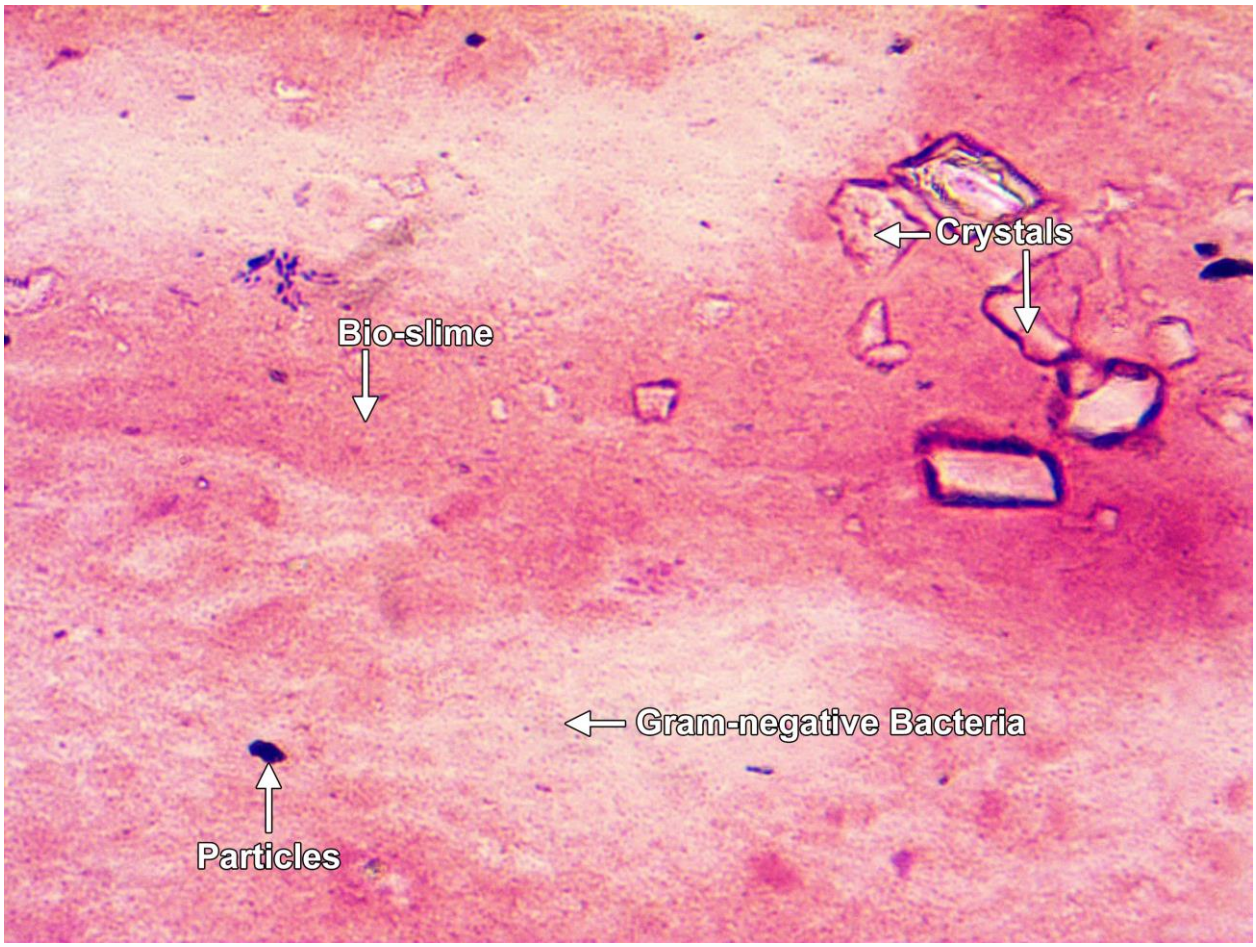
Results: The wet foulant density of SN 2191220465 was measured as 0.05 mg/cm^2. The foulant had a moderate moisture content (69%) and an organic content of 59%, indicating that the foulant was a combination of organic and inorganic material.



Microscope Analysis is performed on Gram-stained foulant samples using a light microscope at 1000x using an oil immersion lens. Gram-positive bacteria are stained purple while Gram-negative bacteria are stained pink. The following organic and inorganic components can be identified:

- Organics: Bio-slime, humic/fulvic acid, bacteria, yeast, mold, nematodes, microorganism shells
- Inorganics: inorganic material (e.g. metals, clays), translucent crystals, particles

Results: Microscope analysis identified the majority of the foulant as bio-slime and Gram-negative bacteria. Lesser amounts of crystals and particles were also observed.



Light microscope images (1000x) of foulant scraped from SN 2191220465

Biological Activity Testing gives a semi-quantitative result for live aerobic bacteria and yeast/mold content of a sample. Greater colony density, measured in colony-forming units (CFU)/ml, indicates a more biologically active sample.

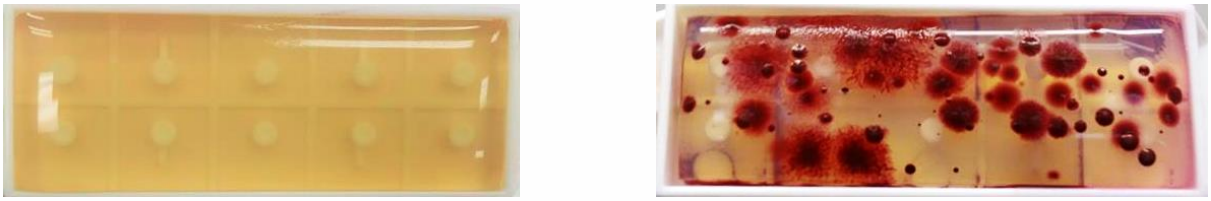
- Higher biological activity is associated with more biological fouling
- The biological activity rating references are available in Appendix II on page 23.

Results: Highlighted in the table below.

Biological Activity Rating	Aerobic Bacteria	Yeast/Mold
Low	0-100	**0-100**
Moderate	100-10,000	100-10,000
High	**10,000-1,000,000**	10,000-100,000
Very High	1,000,000-TNTC	100,000-TNTC

Before Incubation

After Incubation



Aerobic Bacteria



Yeast/Mold

Testing for Carbonates and Metals is performed by applying several drops of dilute hydrochloric acid (HCl) to the foulant surfaces.

- Effervescing (bubbling) – positive for carbonates
- Yellow color change – positive for the presence of metals.

Results: No visible reaction was observed during acid testing indicating the presence of metals and carbonates were below detection limits.

Before HCl



After HCl

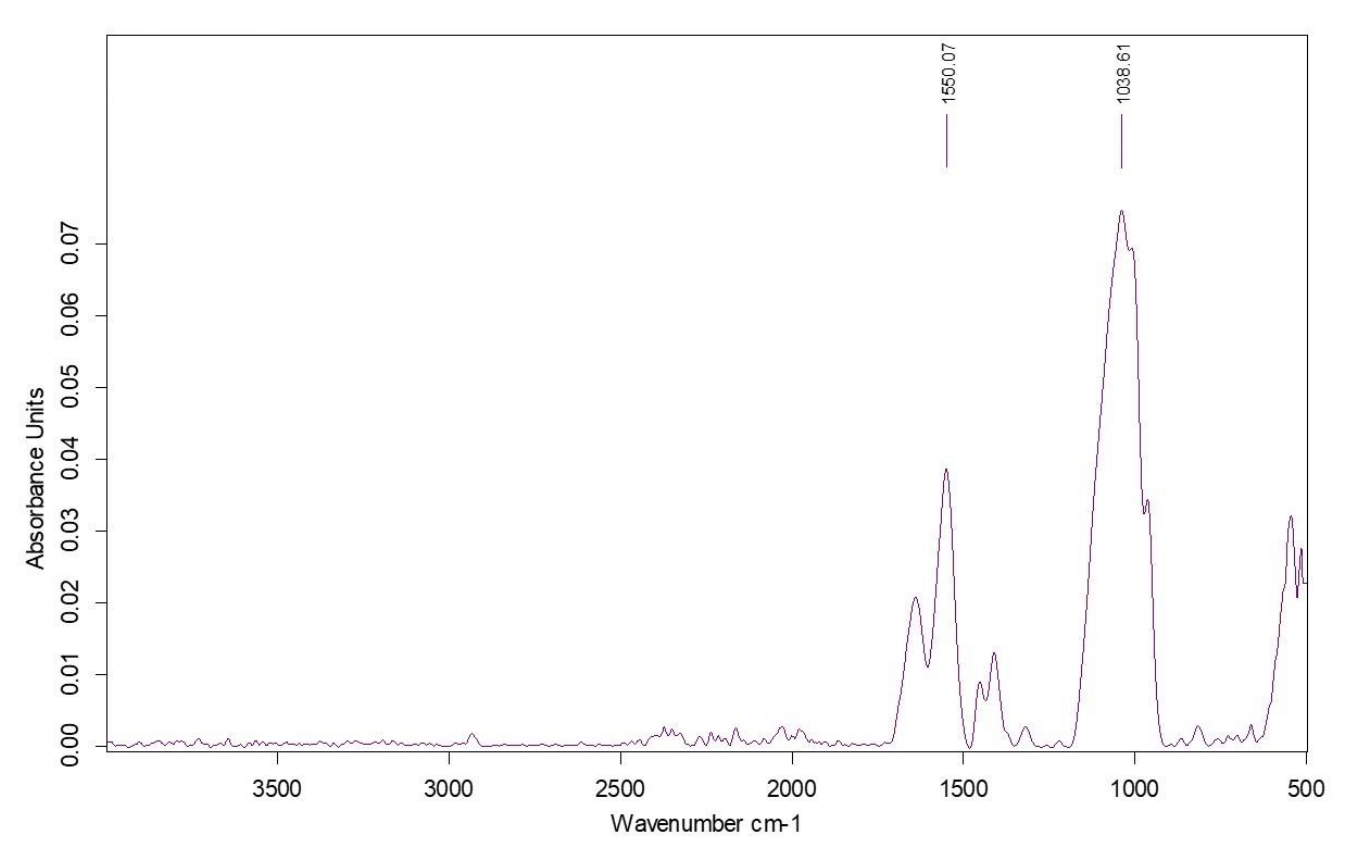


Acid test reaction

Fourier Transform Infrared Spectroscopy (FT-IR) Analysis produces a spectrum of the foulant that is compared to an extensive FT-IR library of known foulants to identify specific compounds (functional groups).

Results: FT-IR identified peaks associated with amino acids, carbohydrates, calcium and phosphorous.

Compound	Wavelength (cm^{-1})
Amino Acids	1600 - 1500
Carbohydrates, Calcium, Phosphorous	1000

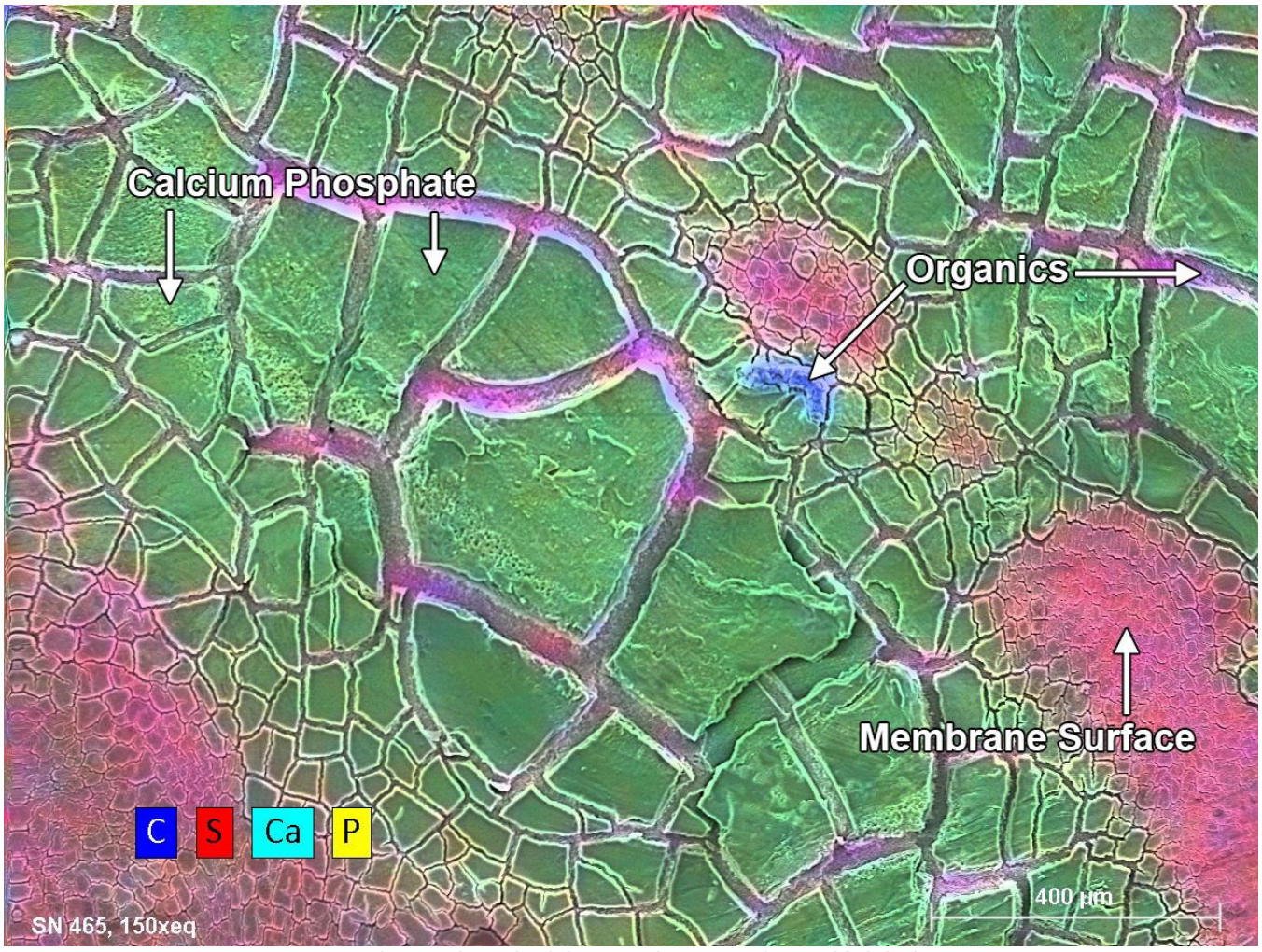


FT-IR spectral image of foulant removed from the membrane surface of SN 2191220465

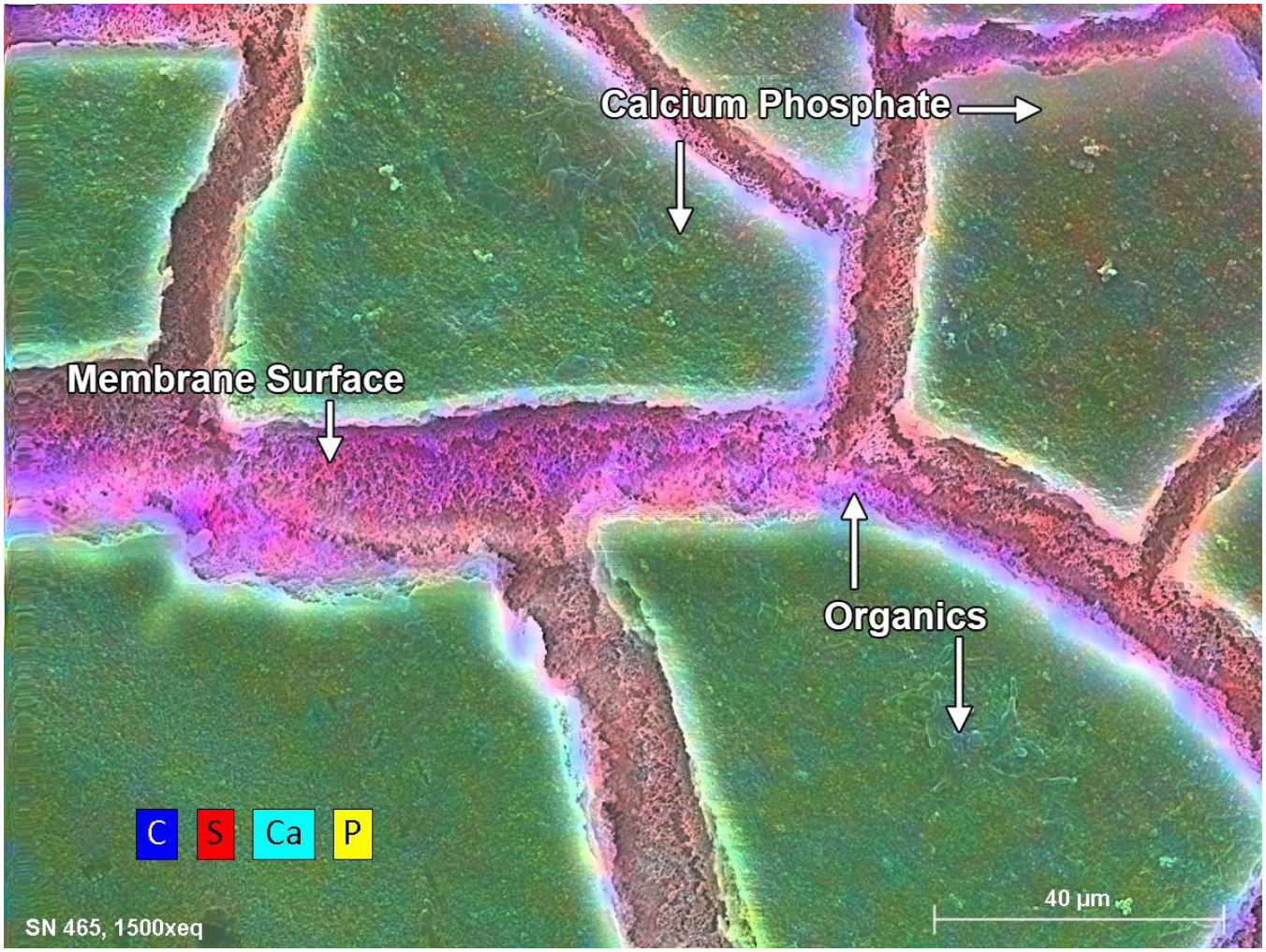
Membrane Surface Imaging and Elemental Composition Testing is used to identify foulants and the degree of fouling. This is accomplished using Chromatic Elemental Imaging[SM] (CEI[SM]) and Energy Dispersive Spectroscopy (EDS) Analysis.

- CEI – high-resolution imaging technique that assigns elements colors to show the spatial distribution, interaction and relative concentration of elements in sample
- EDS – provides the relative concentrations of elements present in a sample

Results: CEI identified the foulant material as a combination of organics – denoted by carbon (dark blue) – and calcium phosphorous complexes (mixture of light blue and yellow). The membrane surface is represented by sulfur (red) and was visible in small patches where the foulant was less prevalent.



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface with labels

Results: EDS analysis confirmed the presence of calcium and phosphorus as the primary inorganic elements present in the foulant layer. Lesser amounts of magnesium, aluminum and silicon were also detected. The sulfur weight percent (4.63 wt%) was below normal values indicating the foulant layer was relatively thick.

Elements	SN 2191220465 (Weight Percent, wt%)	New Membrane (Weight Percent, wt%)
Carbon	35.63	40.00-60.00
Oxygen	32.77	30.00-40.00
Sulfur	4.63	5.00-9.00
Calcium	15.88	--
Phosphorus	8.68	--
Magnesium	1.11	--
Aluminum	0.73	--
Silicon	0.57	--

FLAT SHEET PERFORMANCE AND CLEANING STUDY

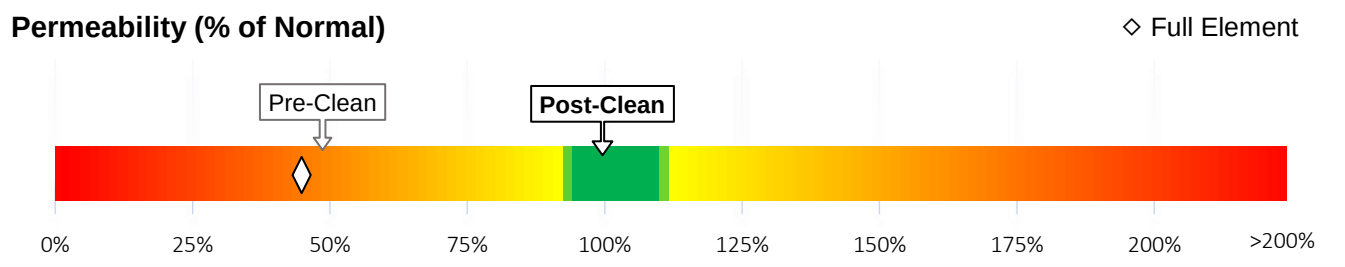
Flat Sheet Cleaning Study is performed in a cell test apparatus to determine the most effective cleaning regimen for overall improvement in permeability, rejection and visual foulant removal.

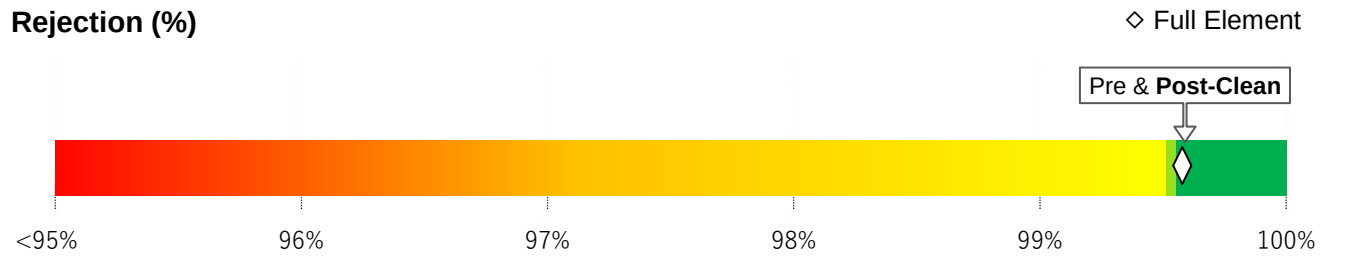
- Flat sheet normalized permeability and rejection before and after cleaning are calculated and compared to the manufacturer's specification for new membranes of the same model
- Calculations are performed using industry standard water passage coefficient (A value) and salt passage coefficient (B value) and converted for ease of understanding. A and B values are available upon request

Results: The following regimen achieved complete visual foulant material, improving permeability and rejection:

1) RoClean L403 (2% by weight in RO/DI water, 35 degrees Celsius and circulated) for 2 hours
2) RoClean L212 (2% by weight in RO/DI water, 35 degrees Celsius and circulated) for 2 hours

Toray TMG10D	Permeability	Rejection (%)
Full Element	44% of Normal	99.5
Pre-Clean Flat Sheet	48% of Normal	99.5
Post-Clean Flat Sheet	100% of Normal	99.5
Manufacturer's Specification	1.38 to 1.72E-04	99.5 to 99.7





TESTING FOR FLAT SHEET DAMAGE

Fujiwara Testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to halogen (e.g. chlorine, bromine, or iodine) oxidation. Exposure to halogens is progressively damaging to PA membranes, causing increases in flow and losses in permeate quality.

Results: Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure.

Dye Testing is used to identify the presence and extent of chemical and/or physical damage to membrane flat sheet samples.

- Uneven dye uptake – indicates physical damage
- Even dye uptake – indicates chemical damage
- Dye penetration to the membrane backing – indicates severe damage

Results: Dye testing was not performed as the full element and flat sheet samples produced normal rejection.

CERTIFICATION BY LABORATORY

Report Number	Report Content	Element Serial Number	Report Date
WO#051221-3	Standard Spiral Autopsy	2191220465	June 11th, 2021

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

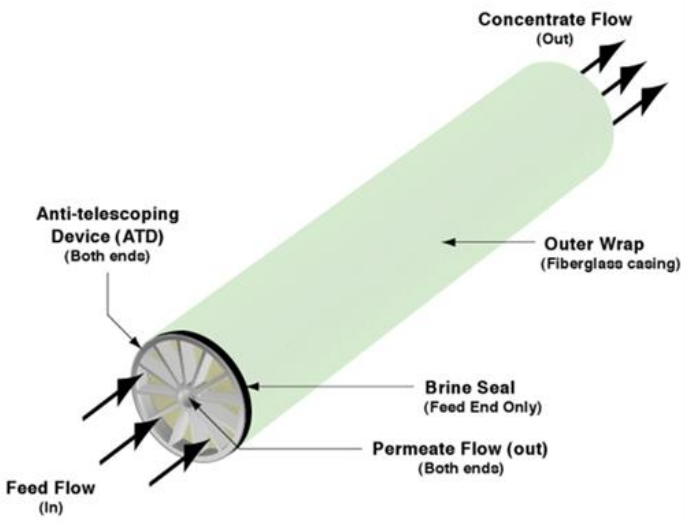
Date: 06/11/21

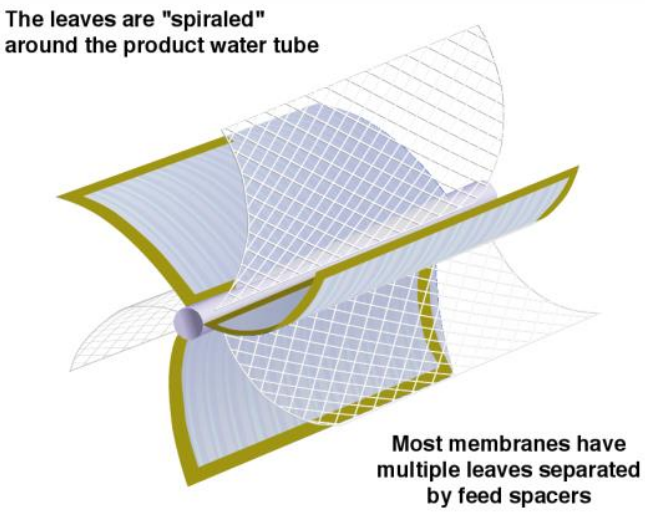
Signed:

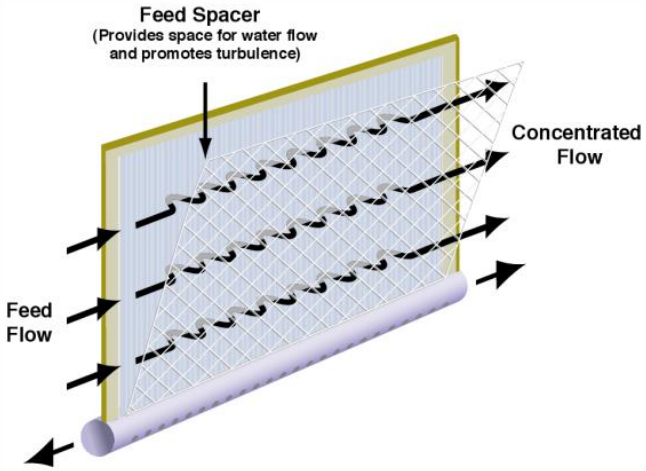
Jessica Foster
Laboratory Services Supervisor

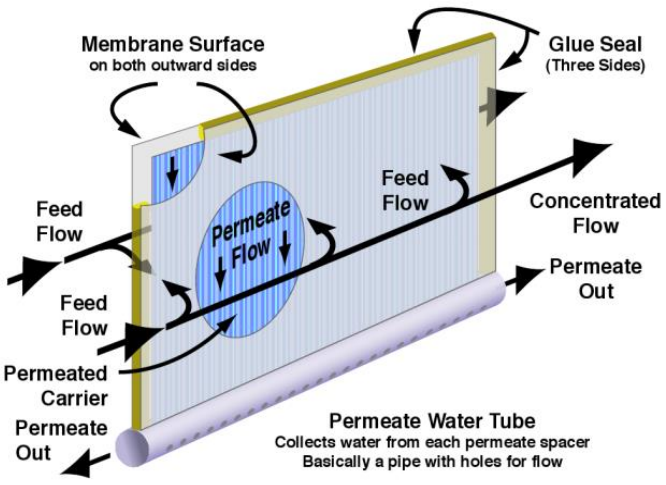
Jaime La Cuesta
Laboratory Services Engineer II

APPENDIX I. MEMBRANE CONSTRUCTION DIAGRAMS

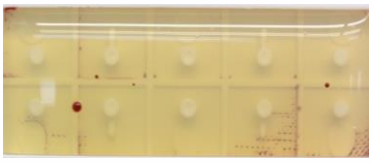
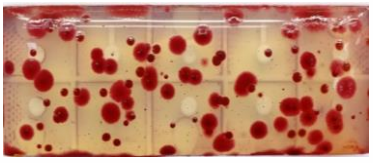
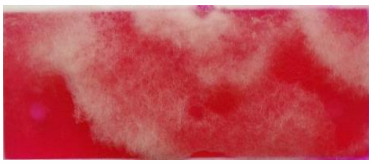








APPENDIX II. BIOLOGICAL ACTIVITY RATINGS

	Aerobic Bacteria	Yeast	Mold
Low			
Moderate			
High			

6TH 2 STAGE 80% WO#070121-8 RO MEMBRANE AUTOPSY REPORT

Avista | Membrane Treatment Solutions

Las Virgenes Municipal Water District
Attn. Steve Jackson
4232 Las Virgenes Road #1994
Calabasas, CA 91302

Avista Technologies, Inc.
140 Bosstick Blvd.
San Marcos, CA 92069
United States

Sender: Raul Gonzalez
rgonzalez@avistatech.com
Corp Ofc: +1 760 744 – 0536
Mobile: +1 760 566 – 9000

August 23, 2021

RE: WO#070121-8 Las Virgenes Municipal Water District Autopsy Report

Hello Steve,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached, please find the autopsy report for the Toray membrane, serial number 2191220269. The membrane was sent in for autopsy to determine foulant composition after on-site cleaning did not restore performance. The element was taken from the tail position of the last stage during the two-stage operation.

The element produced 59% of normal flow, normal rejection (99.4%) and normal differential pressure (3.0 psi). The membrane surface had a layer of white-colored, smooth foulant. The foulant on the membrane was characterized as primarily organic (65%) caused by bio-slime. The inorganic composition of the foulant was identified as silica patches with trace amounts of aluminum.

For the cleaning trials, the membrane was cleaned using RoClean P112. This cleaner has been used for silica and suborn organics. I recommend a cleaning trial with RoClean P112. The recommended contact time is at least 6 hours for the cleaner at a 2% concentration. The elements taken for off-site cleaning showed membrane restoration after being cleaned with the recommended procedure.

Please let me know if you have any questions.

Sincerely,

Raul Gonzalez
Application & Sales, West USA
Avista Technologies

Avista® | OSCAR

Off-site Cleaning and Restoration Results

Customer Information:

Name: Las Virgenes Municipal Water District
End User: Las Virgenes Municipal Water District
Date: 8/20/21
Customer PO: No Charge
Work Order No: 070121-9

Cleaners Used:
RoClean P112

Toray
TMG10D

Normalized Conditions:
Feed Pressure: 150
Recovery: 15%

Manufacturer Specifications:
Flow Rate: 1.47 to 1.84
% Rejection: 99.5% to 99.7%

Serial Number	Test	Delta Pressure psi	Normalized Results		Notes
			Flow, gpm	Rejection, %	
2191220462	Pre Clean	4	0.84	99.5	last membrane
	Post Clean	3	1.50	99.5	
2191220467	Pre Clean	4	0.81	99.5	2nd to last membrane
	Post Clean	3	1.50	99.5	

Thank You For Your Business!

© 2020 Kurita Water Industries.

Avista | Membrane Autopsy

COMPLETED FOR:

Las Virgenes Municipal Water District

Pure Water Demonstration

Stage 2, Tail Element

Serial Number 2191220269

08/09/21 WO#070121-8

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EXECUTIVE SUMMARY

Background Las Virgenes Municipal Water District provided (1) Toray TMG10D reverse osmosis (RO) element from Pure Water Demonstration for wet testing, dissection and analysis. The element was identified as Serial Number (SN) 2191220269 (Stage 2, Tail Element). Below is a summary of the results.

Initial Element Testing The full element produced 59% of normal flow, slightly lower than normal rejection (99.4%) and a differential pressure of 3 psi. The element passed integrity testing, indicating the absence of damage to the internal mechanical components.

External Inspection The external components (fiberglass casing, brine seal, permeate tube, anti-telescope devices (ATDs)) were in good mechanical condition.

Internal Inspection The scroll ends displayed brown-colored deposits, while the exposed membrane surfaces displayed a thin layer of translucent, white-colored foulant material; the foulant had a predominantly smooth texture. The remaining internal components (feed spacers, glue lines, permeate carriers and membrane backings) were in good condition.

Foulant Analysis Wet foulant density on the membrane surface was measured at 0.15 mg/cm^2. Moisture and organic contents of the material were 91% and 65%, respectively, indicating the majority of the foulant was hydrated organics. Moderate aerobic bacteria activity was observed. The foulant layer was confirmed to be a mainly bio-slime with lesser amounts of silica and aluminum.

Flat Sheet Performance and Cleaning Study Flat sheet samples harvested from the full element produced 60% of normal permeability and 99.4% rejection. Complete visual foulant removal was achieved using RoClean P112 (2% by weight in RO/DI water, 35 degrees Celsius and circulated) for 4 hours; permeability and rejection were improved to within the manufacturer's specifications.

Flat Sheet Damage Fujiwara testing was negative for the presence of halogens in the membrane structure.

Autopsy Conclusion The membrane foulant was identified as mainly bio-slime with lesser amounts of silica and aluminum. Complete permeability and rejection recovery was achieved via chemical cleaning.

INITIAL ELEMENT TESTING

Element Weight can be indicative of the degree of fouling.

- New elements weigh approximately 7 to 9 pounds

Results**:** 8 lbs.

Full Element Performance Testing results were normalized to the manufacturer's published test conditions.

Results: The element produced 59% of normal flow, slightly lower than normal rejection and a differential pressure of 3 psi.

Toray TMG10D	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN 2191220269	0.87	99.4	3
Manufacturer's Specifications	1.47 to 1.84	99.5 - 99.7	≤15

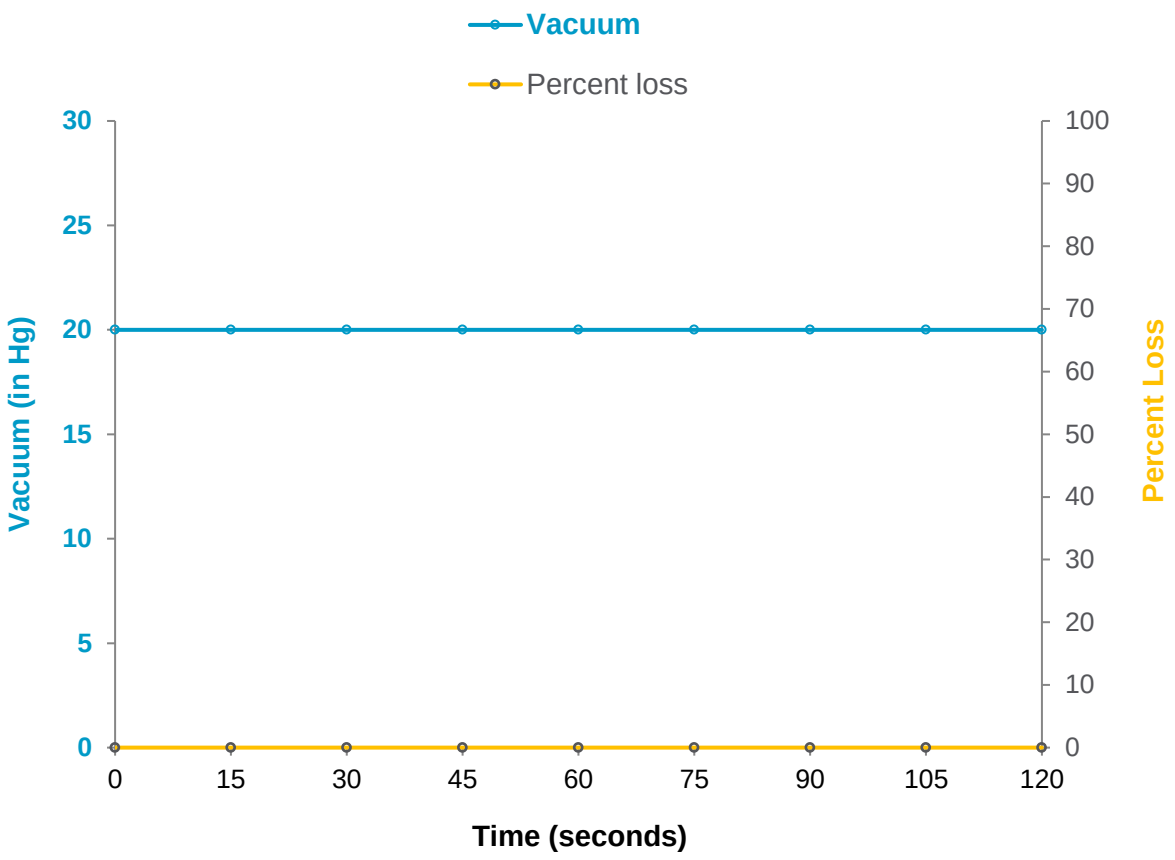
The following key will be used throughout the report to demonstrate whether the observation is within or outside normal conditions or if the test was not carried out.

Within normal conditions **Outside normal conditions** **Not tested**

Integrity Testing is performed to identify mechanical damage to the internal components of the spiral wound element.

- The permeate tube is sealed and a vacuum of approximately 600 mbar is applied and monitored for 120 seconds
- Any loss of vacuum indicates the presence of damage; however, losses of over 35% of the vacuum suggests severe mechanical damage

Results: The element passed integrity testing.



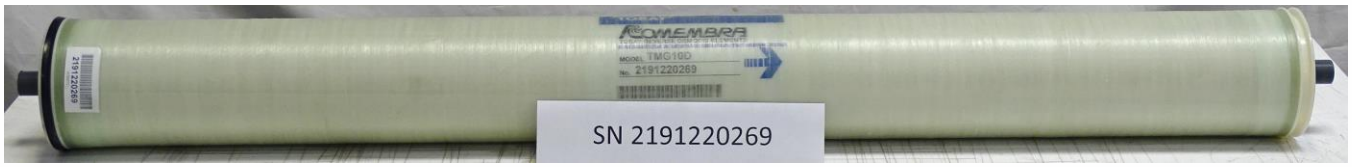
INSPECTION

A thorough inspection of the internal and external components is performed. Membrane construction diagrams are available in Appendix I on page 23 for review.

Fiberglass Casing stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – indicates rough handling or excessive differential pressure from heavy fouling

Results: The fiberglass casing was in good condition.



Fiberglass casing of SN 2191220269

Brine Seal stabilizes the various membrane components in their correct position for optimum performance. It is inspected for:

- Damage – can allow more water to flow across the exterior of the casing

Results: The brine seal was in good condition.

Permeate Water Tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf, allowing permeate water to travel from the leaves into the permeate water tube to be collected. It is inspected for:

- Foulant – suggests feedwater bypass
- Damage – can lead to o-ring failure or feedwater bypass

Results: The permeate water tube was in good condition.

Anti-Telescope Devices (ATDs) stabilize the components of the element and help to prevent shifting of the internal mechanical components under pressure, also known as telescoping. They are inspected for:

- Foulant – severe fouling can block feed flow and contribute to elevated differential pressure
- Damage – indicates rough handling

Results: The ATDs were in good mechanical condition.

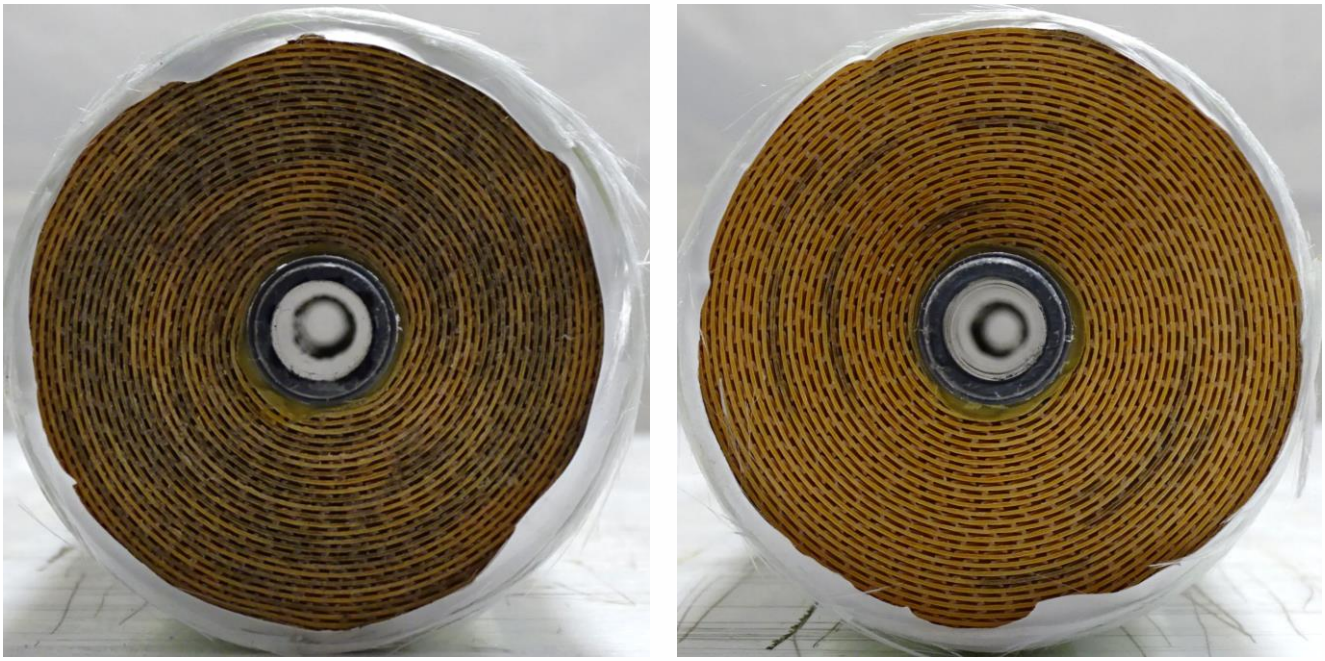


Feed (left) and concentrate (right) ATDs of SN 2191220269

Scroll Ends should be flush with evenly spaced membrane leaves free of debris. The scroll ends are inspected for:

- Foulant – can cause elevated differential pressures
- Scroll gapping and feed spacer extrusion – can lead to uneven hydraulics (high flow/low flow regions), increases cleaning difficulty
- Telescoping – axial shift of the membrane leaves from the outer diameter of the element towards the PWT, commonly caused by excessive fouling and can increase cleaning difficulty

Results: The scroll ends displayed uneven deposition of dark brown-colored material that was heavier toward the feed end.



Feed (left) and concentrate (right) scroll ends of SN 2191220269

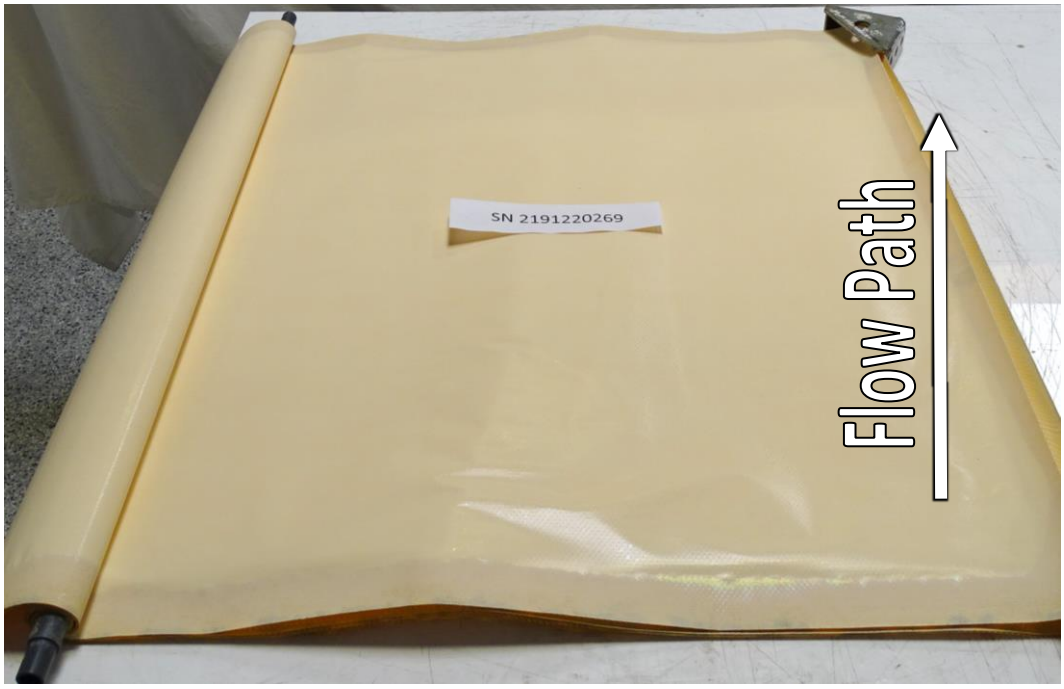
Membrane Surfaces should be uniform and shiny. They are inspected for:

- Foulant – can cause elevated differential pressures, loss in permeate flow and loss in rejection
- Creasing of the membrane surface – more common in the presence of gapping, feed spacer extrusion and telescoping, can cause loss in rejection
- Delamination – lifting of the thin-film membrane from the support layer which is often caused by positive pressure on the permeate side of the element, causes loss in rejection

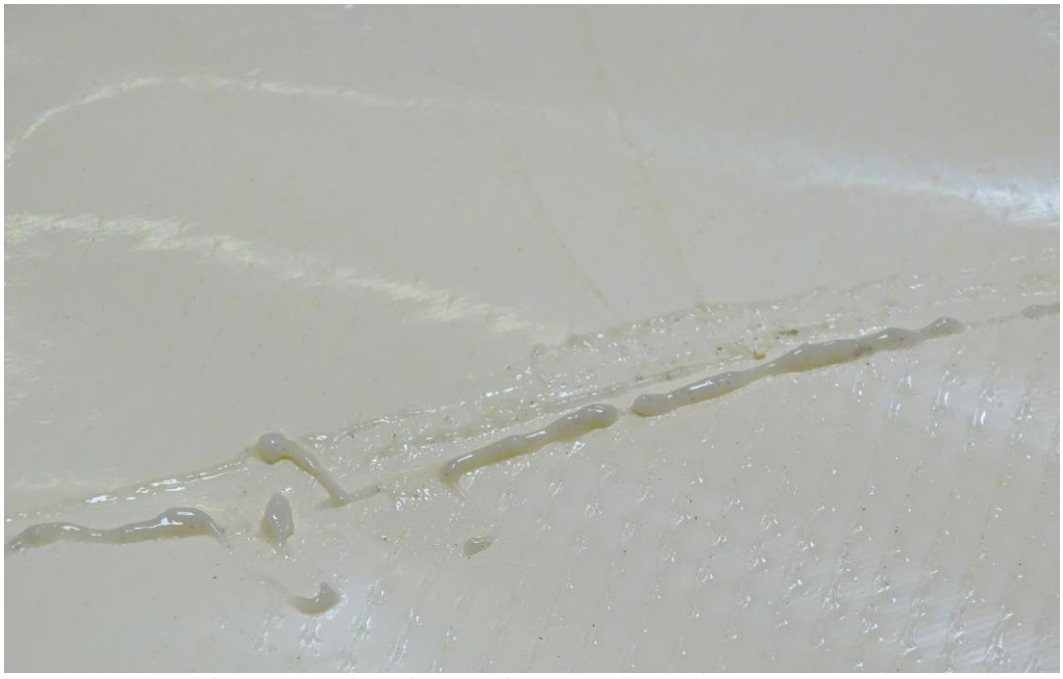
Results: The exposed membrane surfaces displayed a thin layer of translucent, white-colored foulant material with a predominantly smooth texture. The foulant layer was scrapable from the membrane surface.



Exposed membrane surface of SN 2191220269



Exposed membrane surface from feed end of SN 2191220269

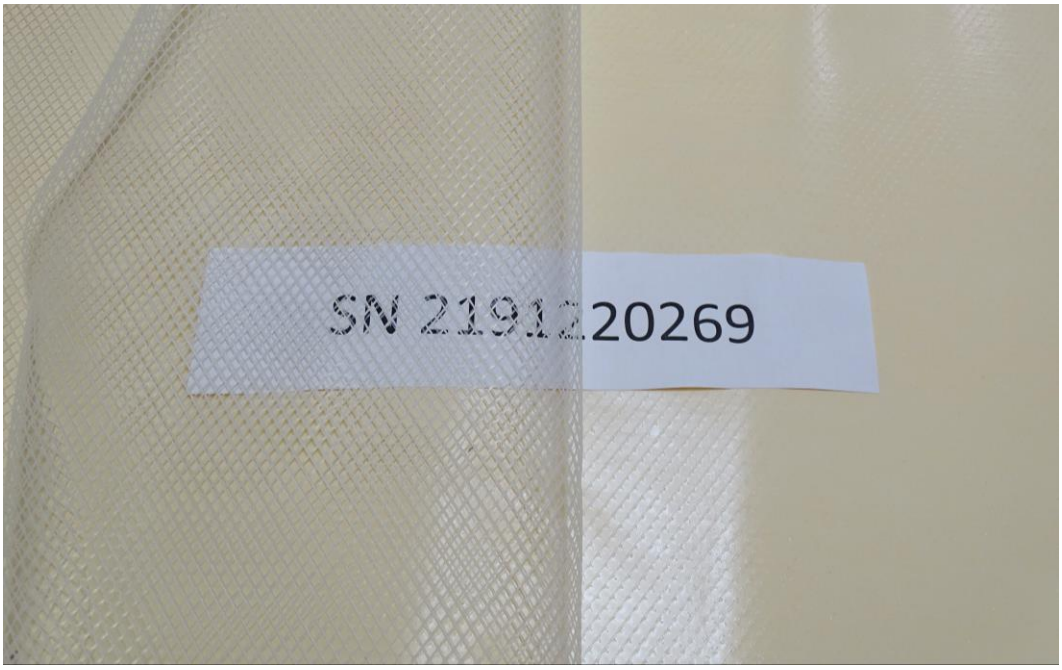


Foulant scraped on the membrane surface of SN 2191220269

Feed Spacers are composed of plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. They are inspected for:

- Foulant – can block the feed channels, causing elevated differential pressure
- Damage – fouling can cause deformation of the material, disrupting the hydraulics of the membrane and increasing cleaning difficulty

Results: The feed spacers were in good condition.



Feed spacer of SN 2191220269

Glue Lines separate the feed and permeate streams on three sides of membrane leaves. They are inspected for:

- Glue flaps – excess membrane material closest to the end of the element, can block feed channels leading to elevated differential pressure
- Pouching – commonly a result of severe delamination, can lead to feedwater bypass

Results: The glue lines were in good physical condition.

Permeate Carriers and Membrane Backings are the components of the permeate side of the element. They are inspected for:

- Foulant – indicates a bypass of feedwater

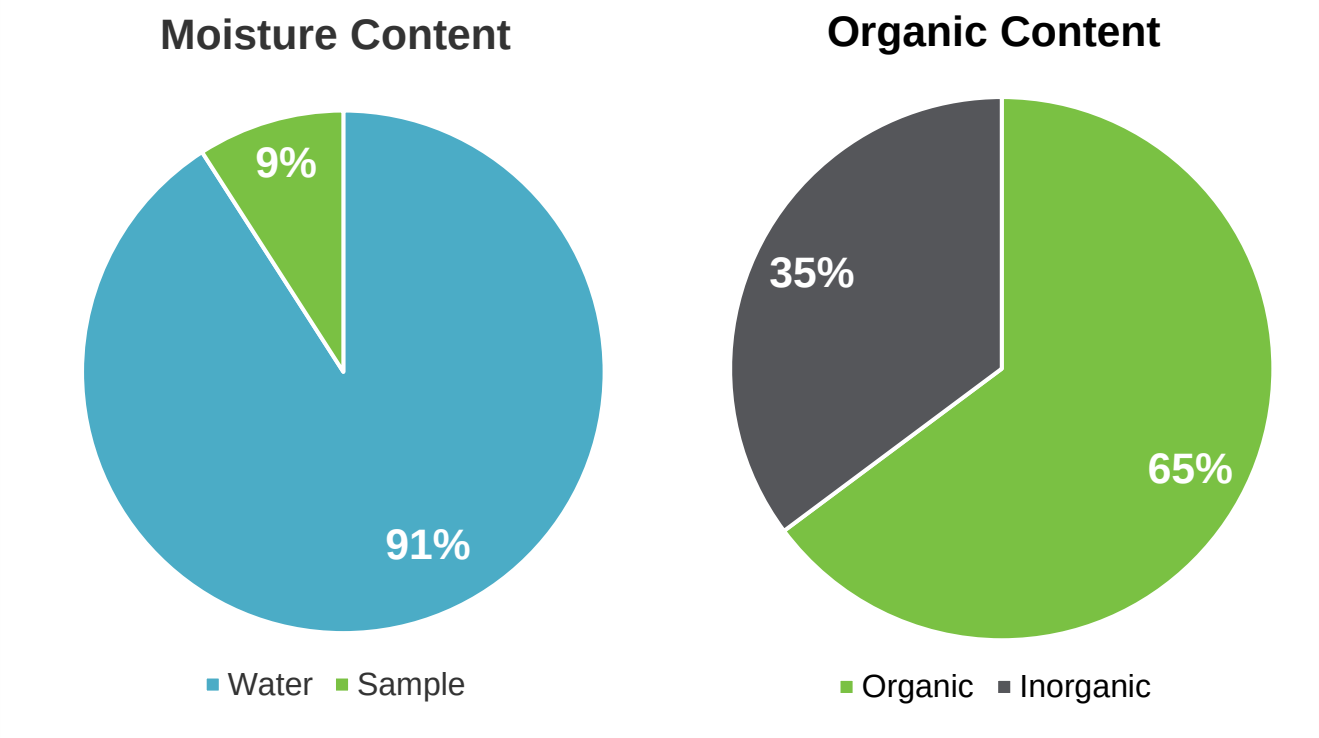
Results: The permeate carriers and membrane backings were absent of visible foulant.

FOULANT ANALYSIS

Foulant Density Measurement and Composition Testing is performed to quantify degree of fouling, which contributes to full element differential pressure, and determine the composition of the foulant:

- Moisture Content – the portion of the foulant that is water. Biological materials tend to have higher moisture contents (>95%)
- Organic Content – the portion of the foulant composed of carbon, which ignites during testing
- Inorganic Content – the portion of the foulant not composed of carbon and does not ignite during testing

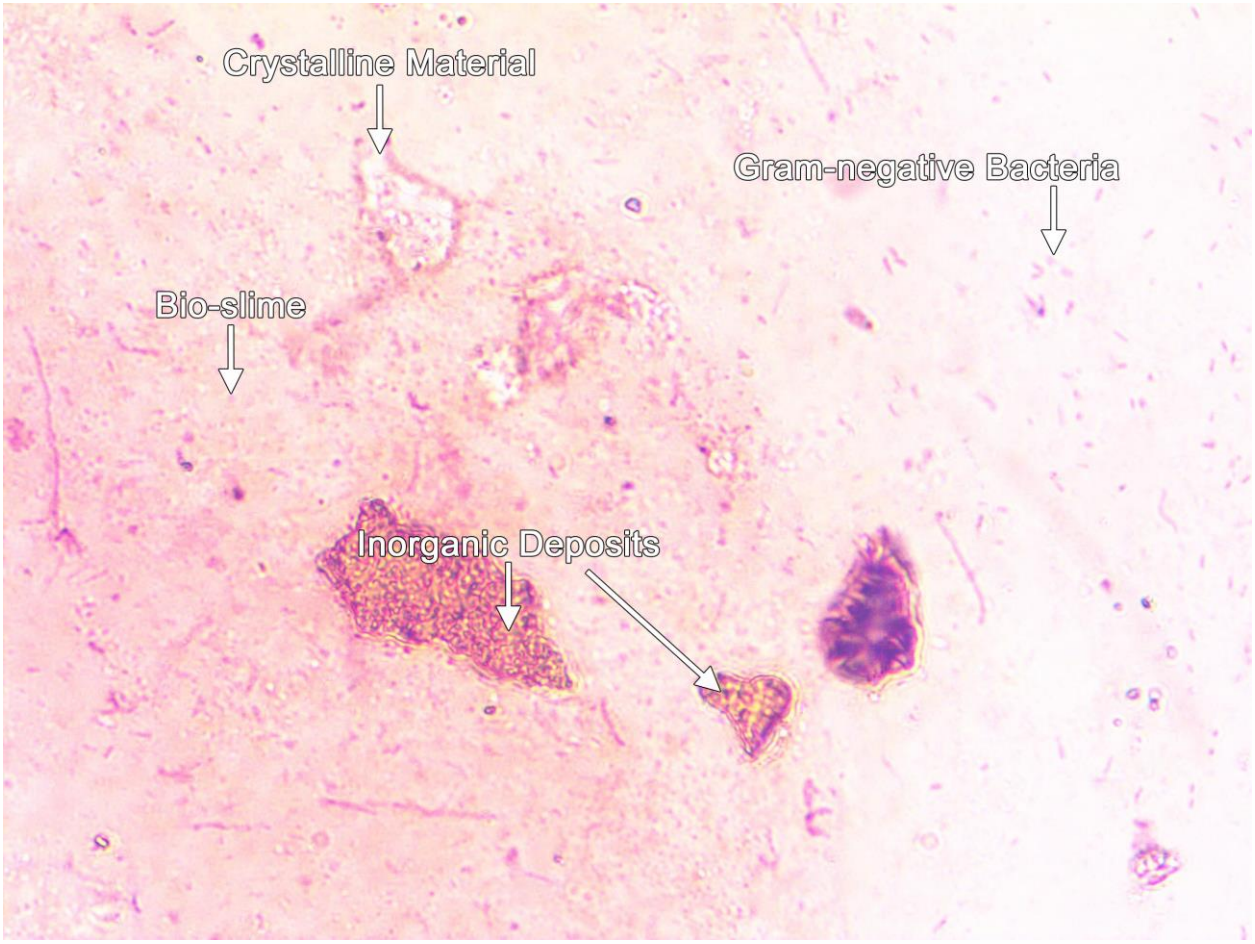
Results: Wet foulant density on the membrane surface was measured at 0.15 mg/cm^2. Composition of the material is displayed in the graphs below.



Microscope Analysis is performed on Gram-stained foulant samples using a light microscope at 1000x using an oil immersion lens. Gram-positive bacteria are stained purple while Gram-negative bacteria are stained pink. The following organic and inorganic components can be identified:

- Organics: Bio-slime, humic/fulvic acid, bacteria, yeast, mold, nematodes, microorganism shells
- Inorganics: inorganic material (e.g. metals, clays), translucent crystals, particles

Results: Microscope analysis of foulant that could be harvested from the membrane identified bio-slime containing translucent crystalline material and other inorganic deposits. Gram-negative bacteria were also observed.



Light microscope images (1000x) of foulant scraped from SN 2191220269

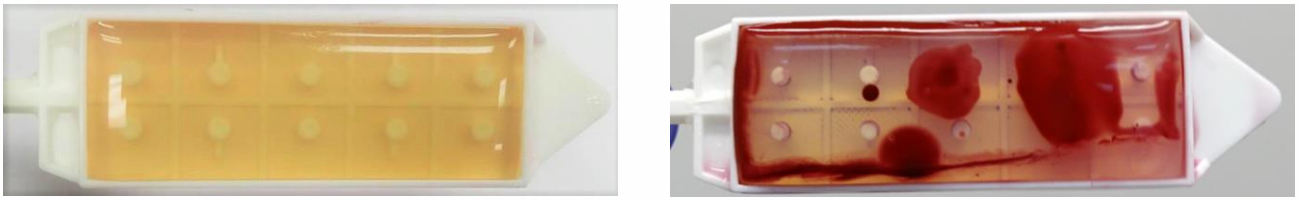
Biological Activity Testing gives a semi-quantitative result for live aerobic bacteria and yeast/mold content of a sample. Greater colony density, measured in colony-forming units (CFU)/ml, indicates a more biologically active sample.

- Higher biological activity is associated with more biological fouling
- The biological activity rating references are available in Appendix II on page 24.

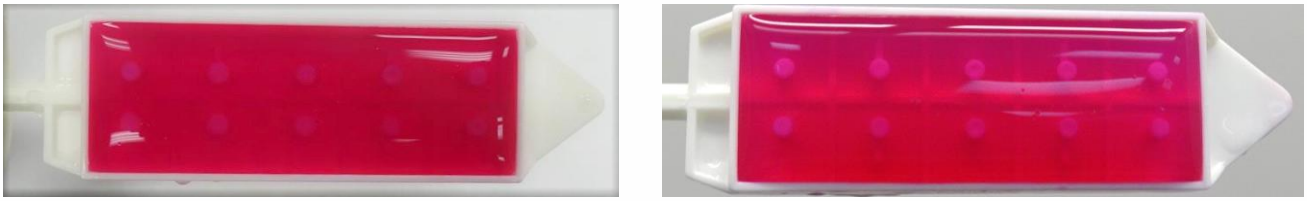
Results: Highlighted in the table below.

Biological Activity Rating	Aerobic Bacteria	Yeast/Mold
Low	0-100	**0-100**
Moderate	**100-10,000**	100-10,000
High	10,000-1,000,000	10,000-100,000
Very High	1,000,000-TNTC	100,000-TNTC

Before Incubation **After Incubation**



Aerobic Bacteria



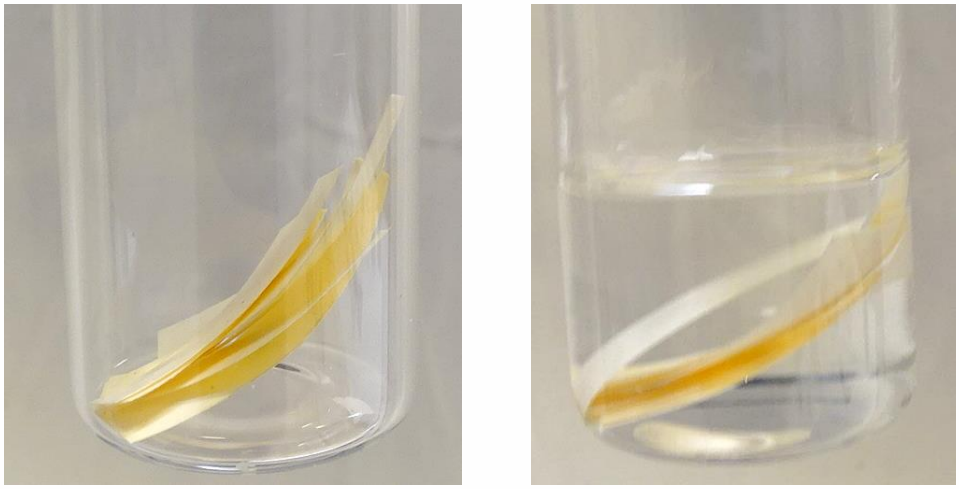
Yeast/Mold

Testing for Carbonates and Metals is performed by applying several drops of dilute hydrochloric acid (HCl) to the foulant surfaces.

- Effervescing (bubbling) – positive for carbonates
- Yellow color change – positive for the presence of metals.

Results: Acid testing produced no visible reaction.

Before HCl **After HCl**

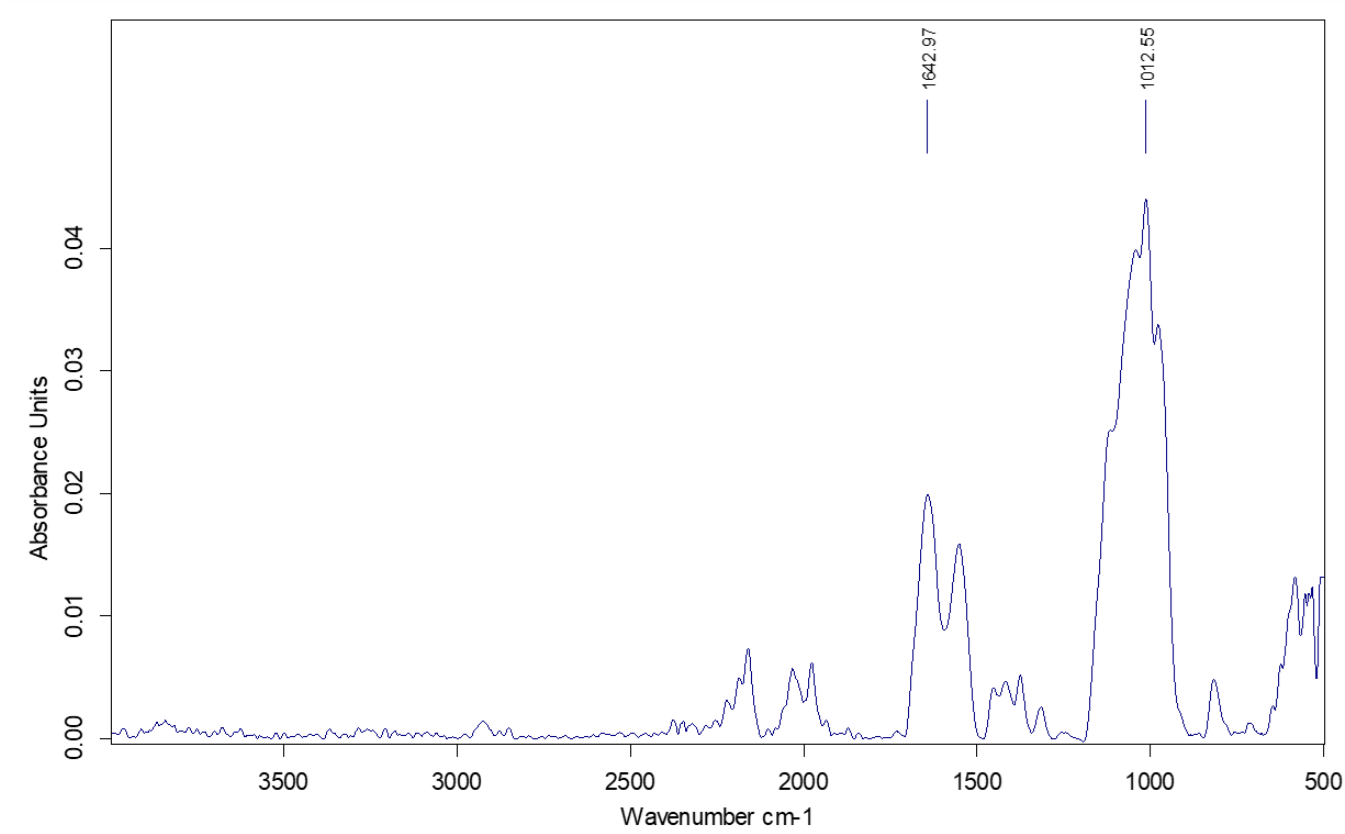


Acid test reaction

Fourier Transform Infrared Spectroscopy (FT-IR) Analysis is performed on either a scraped sample or the membrane surface when foulant cannot be scraped. It produces a spectrum of the foulant or membrane that is compared to an extensive FT-IR library of known compounds to identify specific functional groups.

Results: FT-IR performed on foulant harvested from the membrane surface identified peaks associated with organics (e.g. bio-slime), silicon-oxygen bond stretching (e.g. silica) and proteins (e.g. amino acids from microorganisms).

Compound	Wavelength (cm^{-1})
Silica	1000
Organics	1100-900
Proteins	1650-1500

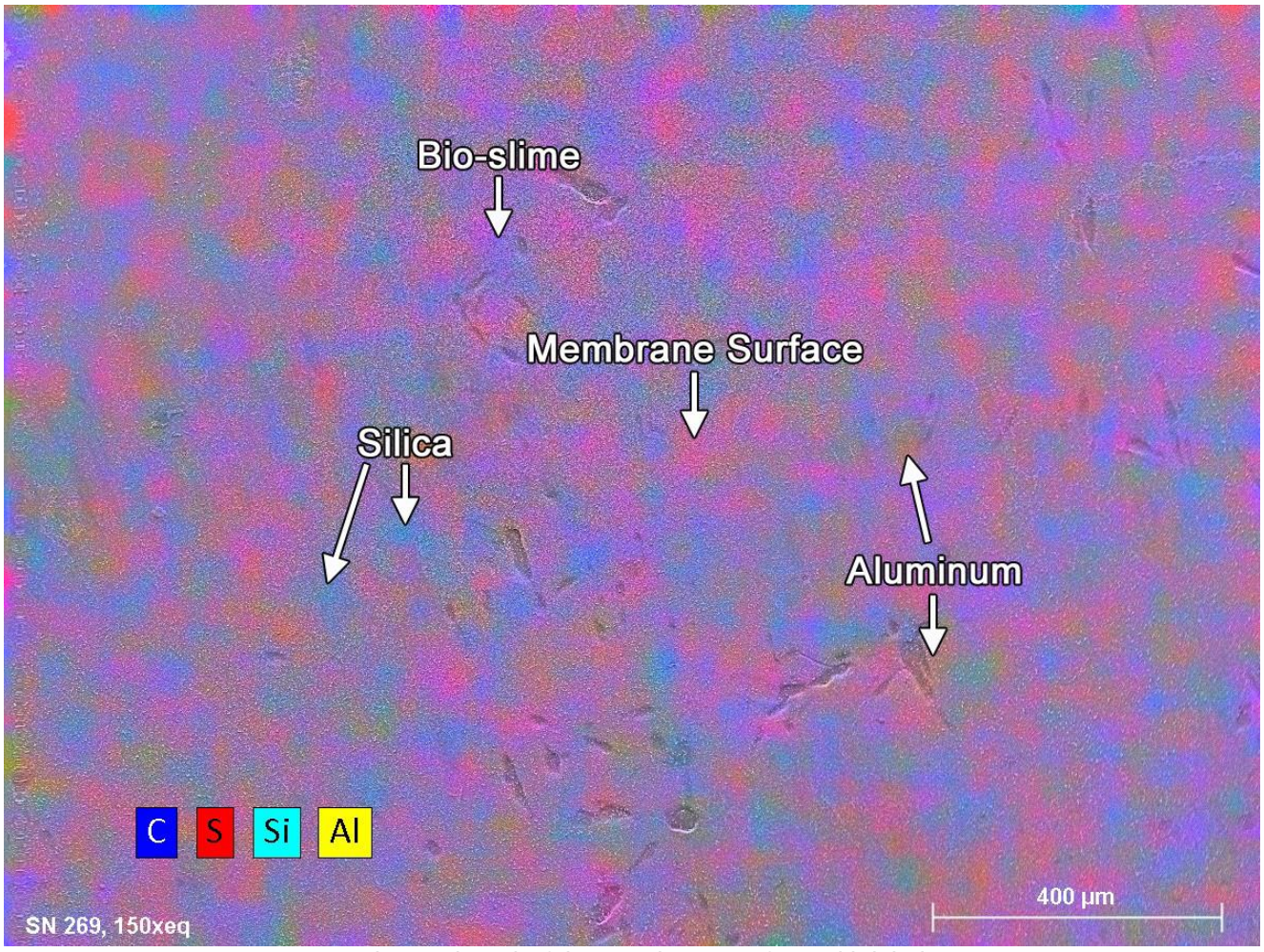


FT-IR spectral image of the membrane surface of SN 2191220269

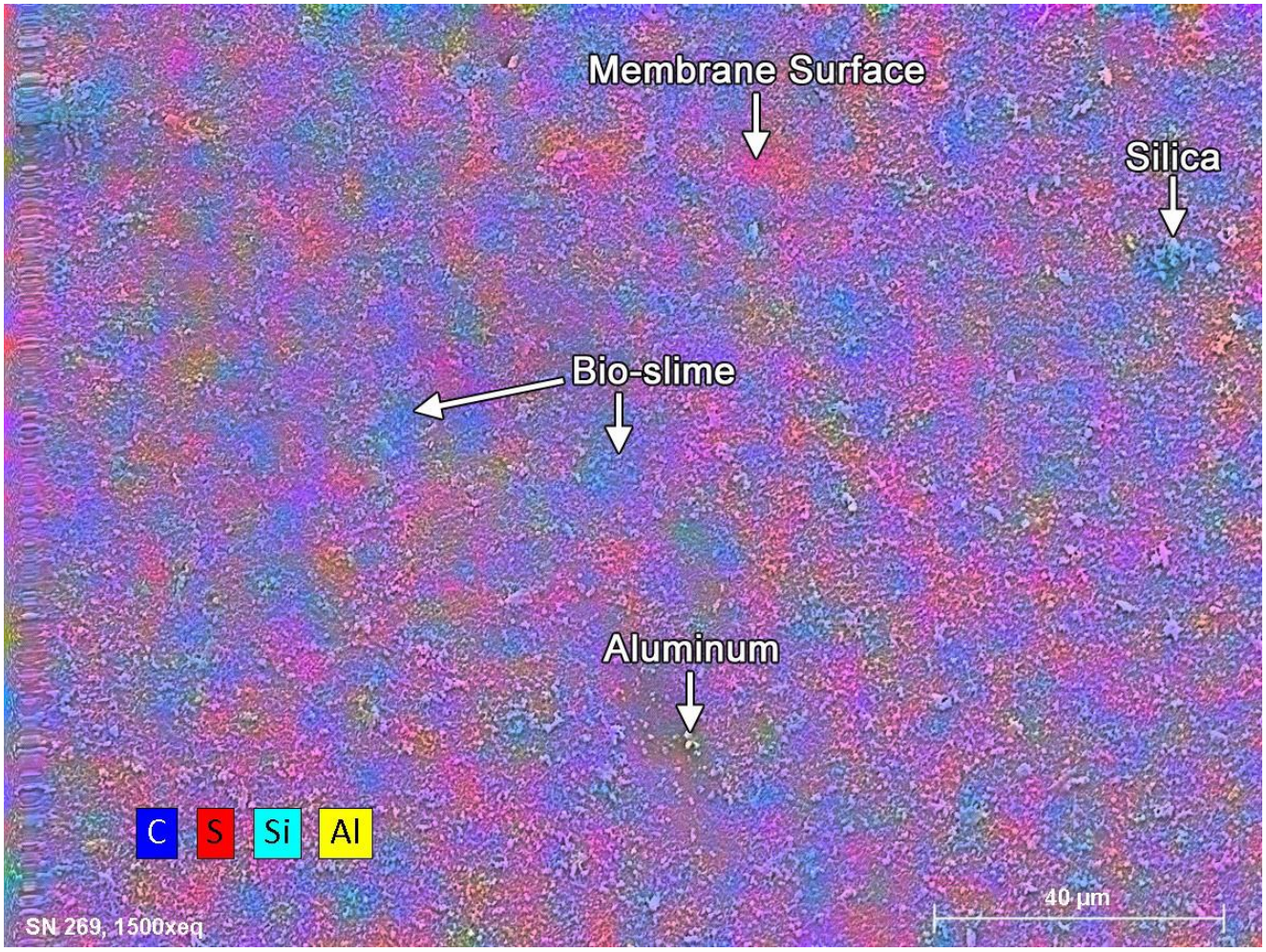
Membrane Surface Imaging and Elemental Composition Testing is used to identify foulants and the degree of fouling. This is accomplished using Chromatic Elemental Imaging[SM] (CEI[SM]) and Energy Dispersive Spectroscopy (EDS) Analysis.

- CEI – high-resolution imaging technique that assigns elements colors to show the spatial distribution, interaction and relative concentration of elements in sample
- EDS – provides the relative concentrations of elements present in a sample

Results: CEI confirmed the membrane surface was coated with a layering of bio-slime (carbon – dark blue). Mixed within the layer of bio-slime were deposits of silica (light blue). Lesser deposits of aluminum (yellow) were also detected.



CEI image (150x) of the membrane surface with labels



CEI image (1500x) of the membrane surface with labels

Results: EDS analysis identified silicon as the most prevalent foreign inorganic element present on the membrane surface. A trace amount (<0.50 wt%) of aluminum was also detected. The excess carbon weight percent can be attributed to the presence of foreign organic material. The sulfur weight percentage was within the normal range, indicating the foulant layer did not notably mask the membrane surface.

Elements	SN 2191220269 (Weight Percent, wt%)	New Membrane (Weight Percent, wt%)
Carbon	70.85	40.00-60.00
Oxygen	20.33	30.00-40.00
Sulfur	8.09	5.00-9.00
Silicon	0.50	--
Aluminum	0.23	--

FLAT SHEET PERFORMANCE AND CLEANING STUDY

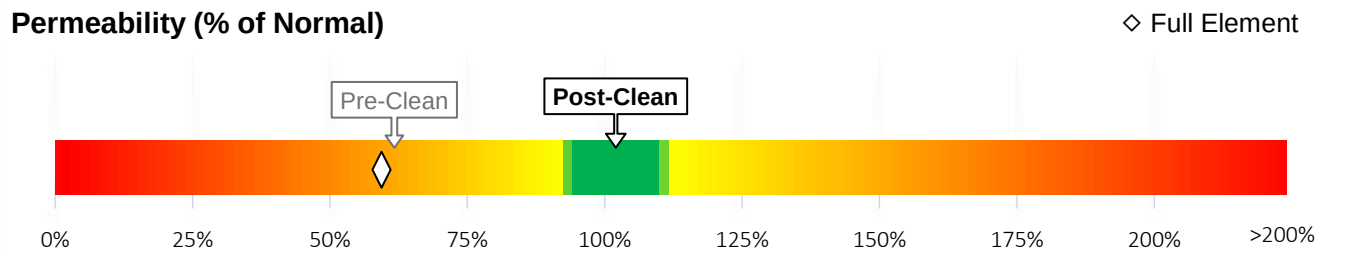
Flat Sheet Cleaning Study is performed in a cell test apparatus to determine the most effective cleaning regimen for overall improvement in permeability, rejection and visual foulant removal.

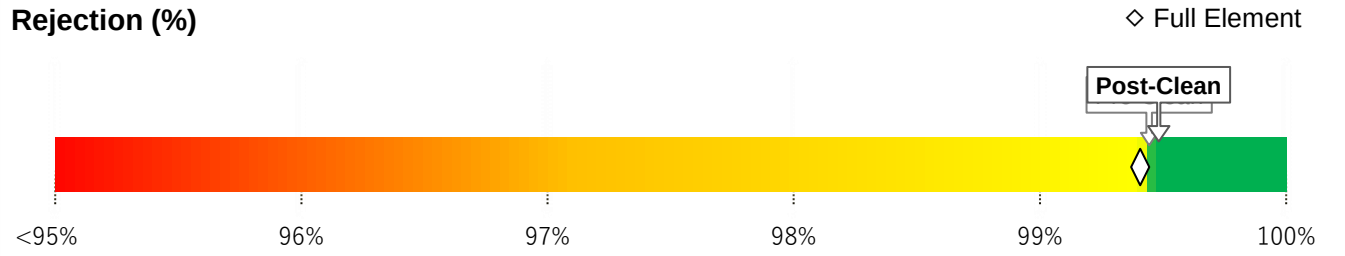
- Flat sheet normalized permeability and rejection before and after cleaning are calculated and compared to the manufacturer's specification for new membranes of the same model
- Calculations are performed using industry standard water passage coefficient (A value) and salt passage coefficient (B value) and converted for ease of understanding. A and B values are available upon request

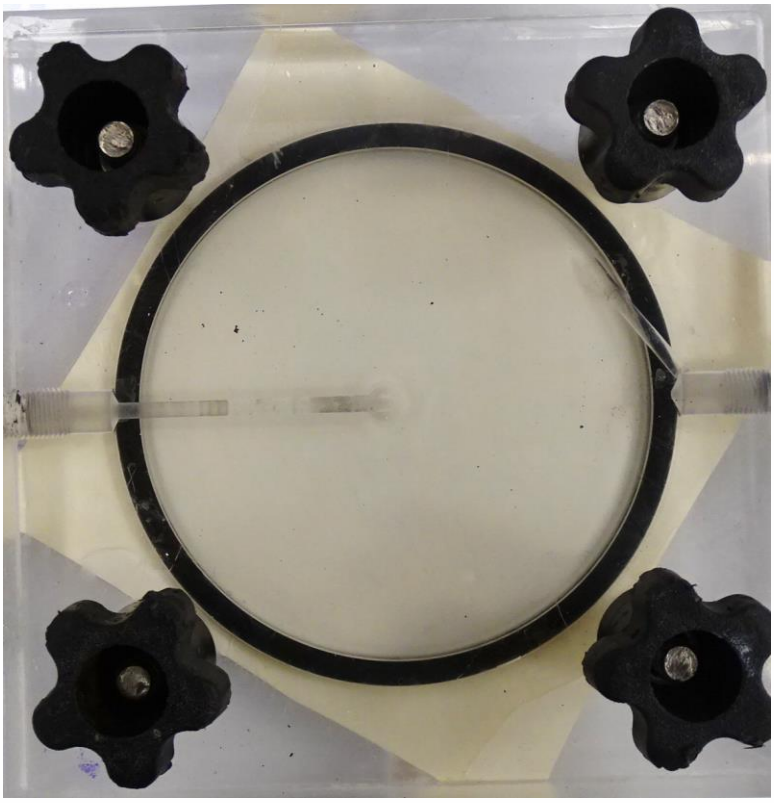
Results: The following regimen achieved complete visual foulant removal, restoring both permeability and rejection:

1) RoClean P112 (2% by weight in RO/DI water, 35 degrees Celsius and circulated) for 4 hours

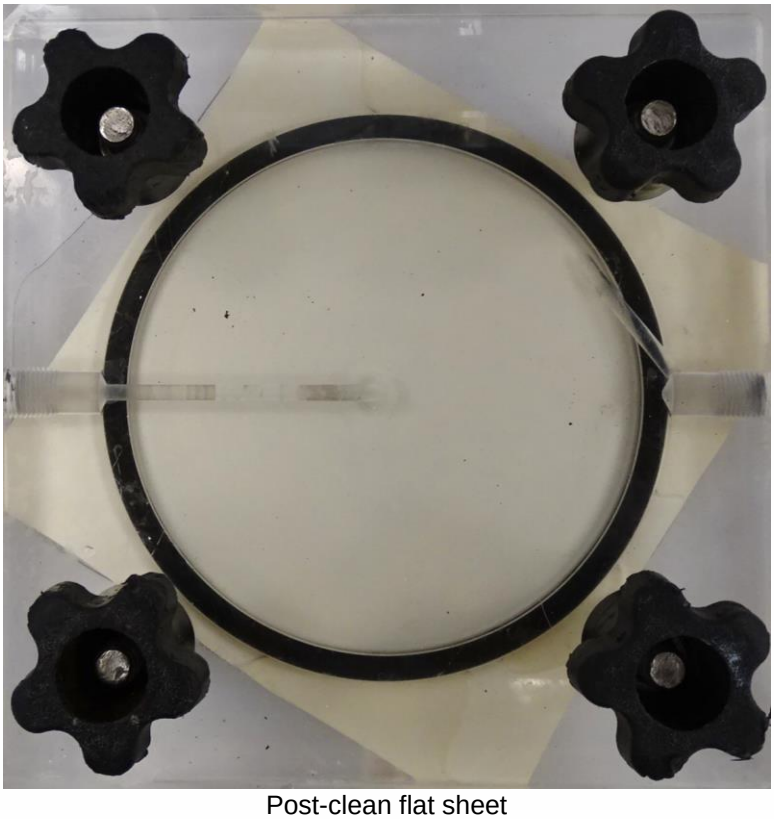
Toray TMG10D	Permeability	Rejection (%)
Full Element	59% of Normal	99.4
Pre-Clean Flat Sheet	60% of Normal	99.4
Post-Clean Flat Sheet	Normal	99.5
Manufacturer's Specification	1.38 to 1.72E-04	99.5 to 99.7







Pre-clean flat sheet



Post-clean flat sheet

TESTING FOR FLAT SHEET DAMAGE

Fujiwara Testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to halogen (e.g. chlorine, bromine, or iodine) oxidation. Exposure to halogens is progressively damaging to PA membranes, causing increases in flow and losses in permeate quality.

Results: Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure.

Dye Testing is used to identify the presence and extent of chemical and/or physical damage to membrane flat sheet samples.

- Uneven dye uptake – indicates physical damage
- Even dye uptake – indicates chemical damage
- Dye penetration to the membrane backing – indicates severe damage

Results: Dye testing was not required at this time as the flat sheets displayed normal rejection after cleaning.

CERTIFICATION BY LABORATORY

Report Number	Report Content	Element Serial Number	Report Date
WO#070121-8	Standard Spiral Autopsy	2191220269	08/09/21

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

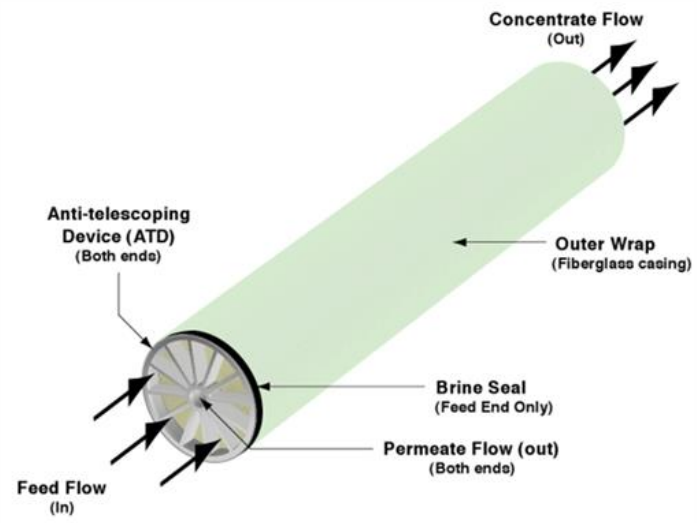
Date: 08/09/21

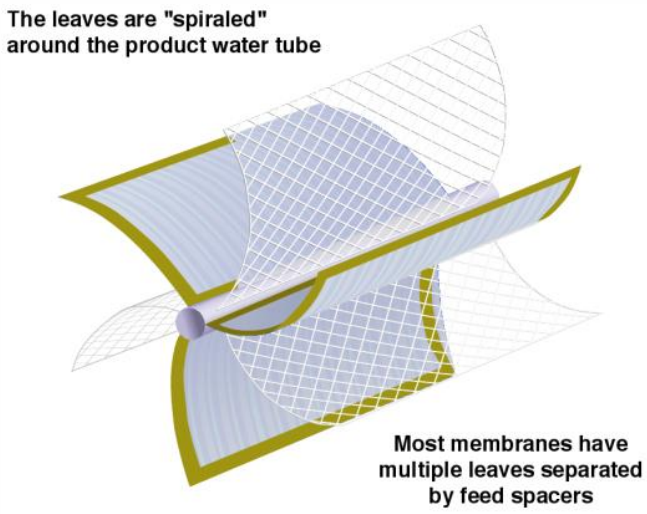
Signed:

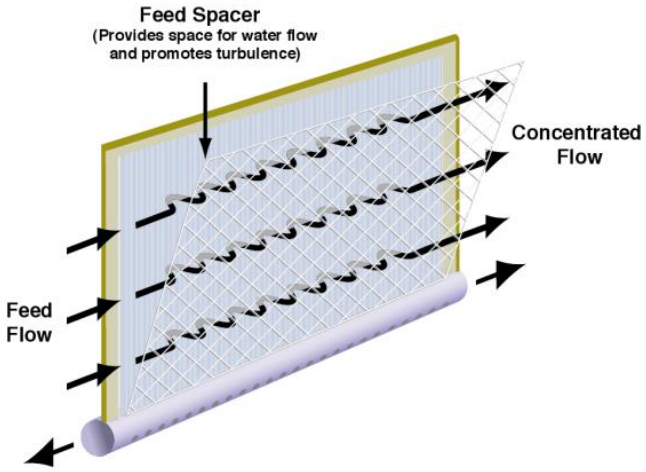
Jessica Foster
Laboratory Services Supervisor

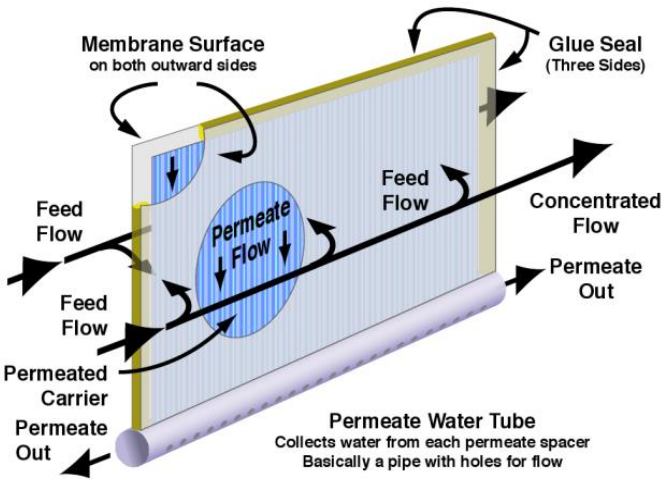
Arnell Abad
Laboratory Services Engineer II

APPENDIX I. MEMBRANE CONSTRUCTION DIAGRAMS

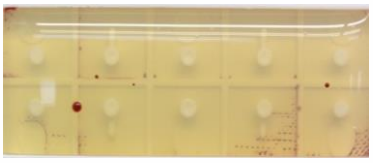
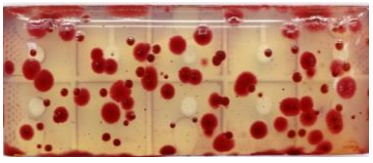
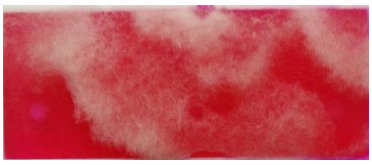








APPENDIX II. BIOLOGICAL ACTIVITY RATINGS

	Aerobic Bacteria	Yeast	Mold
Low			
Moderate			
High			

Appendix D

RO CONCENTRATE SCALING EVALUATION

Avista™ | Membrane Treatment Solutions

COMPLETED FOR:

Las Virgenes Municipal Water District

06/14/2021 WO#011521-6

Dispersion Testing Report

To: Las Virgenes Municipal Water District
From: Avista Technologies Laboratory
Avista WO#: 011521-6

Summary

Avista Technologies received one tote of water from Las Virgenes Municipal Water District. The goal of the study was to determine the optimum dose of antiscalant required to prevent scaling. The AdvisorCi projection using average water analysis data identified silicon and calcium carbonate as the limiting scale. AdvisorCi determined Vitec 4000 was the best Avista product at an optimum dose of 0.50 ppm for a 75% recovery, 1.50 ppm for an 80% recovery, 2.00 ppm dose for an 85% recovery and 2.02 ppm for a 90% recovery. Chromatic Elemental Imaging^{SM} (CEI^{SM}) was performed on a control sample with no antiscalant at a 90% recovery. CEI confirmed that calcium carbonate was the primary precipitate, but some precipitated silica was also present in the filtered sample. The water sample provided was concentrated in a laboratory pilot system to 75%, 80%, 85% and 90% recoveries and samples were dosed with different concentrations of Vitec 4000. The results from the laboratory pilot testing identified an optimum dose range of 2.0 to 2.5 ppm for all recoveries tested; however, for the higher recoveries 85% and 90% the antiscalant could only prevent precipitation for 8 hours. At 80% recovery, precipitation could be delayed for 24 hours and at 75% recovery for 48 hours. For long brine line times, Avista recommends recoveries of 80% or lower.

Water Analysis

Average water analysis data was collected from Las Virgenes Municipal Water District. The table below shows the results for the ions tested. The water analysis results were entered into Avista AdvisorCi at 75%, 80%, 85% and 90% recovery. The projections showed calcium carbonate and silica as the limiting scale. AdvisorCi determined Vitec 4000 was the best Avista product at an optimum dose of 0.50 ppm for a 75% recovery, 1.50 ppm for an 80% recovery, 2.00 ppm dose for an 85% recovery and 2.02 ppm for a 90% recovery.

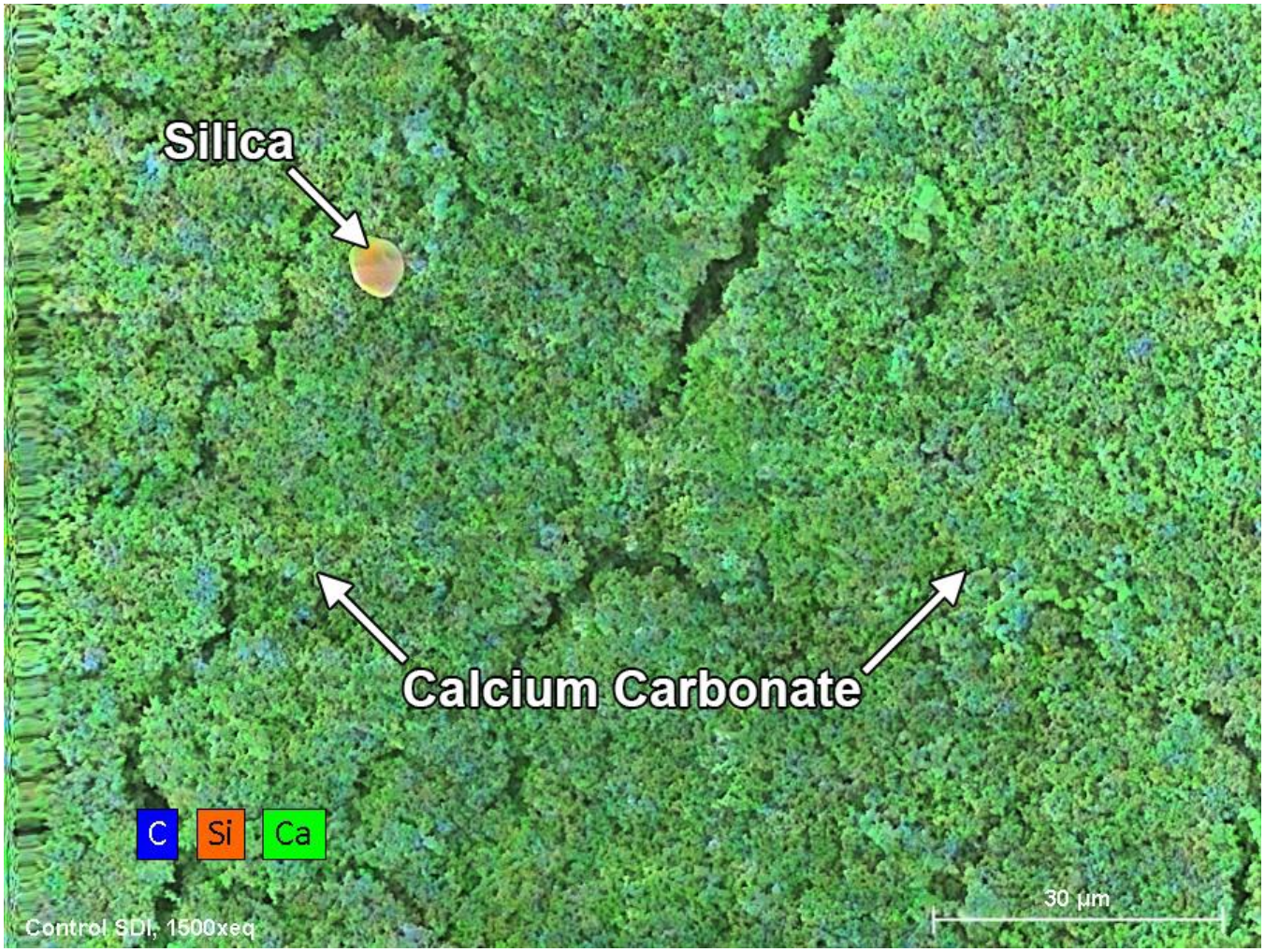
Table 1. Average Water Analysis Results for the Feed water at Las Virgenes Water District

Parameter	As Ion (mg/L)	Detection Limit (mg/L)
Sodium	127.1	0.1
Potassium	17.60	0.1
Calcium	65.00	0.03
Magnesium	30.30	0.03
Iron	0.01	0.02
Manganese	0.01	0.005
Barium	0.03	0.01
Strontium	0.41	0.01
Aluminum	0.01	0.01
Ammonium	0.26	0.10
Chloride	155.70	0.25
Sulfate	218.30	0.1
Bicarbonate	158.60	5
Carbonate	5	5
Nitrate	8.13	0.3
Fluoride	0.66	0.04
Phosphate	2.60	0.06
Silica	18.90	0.1
pH	7.15	0.01

Precipiate Imaging and Elemental Composition Testing is used to identify foulants and the degree of fouling. This is accomplished using Chromatic Elemental Imaging[SM] (CEI[SM]) and Energy Dispersive Spectroscopy (EDS) Analysis.

- CEI – high-resolution imaging technique that assigns elements colors to show the spatial distribution, interaction and relative concentration of elements in sample

Results: CEI identified the precipitate of the control sample with no antiscalant at 90% recovery as primarily calcium carbonate (mixture of green and blue). Few particles composed of silica (orange) were observed as part of the precipitate. This confirms the AdvisorCi projection that the primary precipitate would be calcium carbonate at a 90% recovery.



CEI image (1500x) of the control sample at 90% recovery

AdvisorCi Projection for Las Virgenes Municipal Water District at 75% Recovery

Avista | Advisor Ci

Project: Las Virgenes AWTP

Executive Summary

Recovery: 75%
Customer: Carollo
Engineer: Amos Branch
Note: Average Water Quality

Date: 29-Jun-21
Prepared by: Raul Gonzalez
Water Analysis date: 25-Jun-21

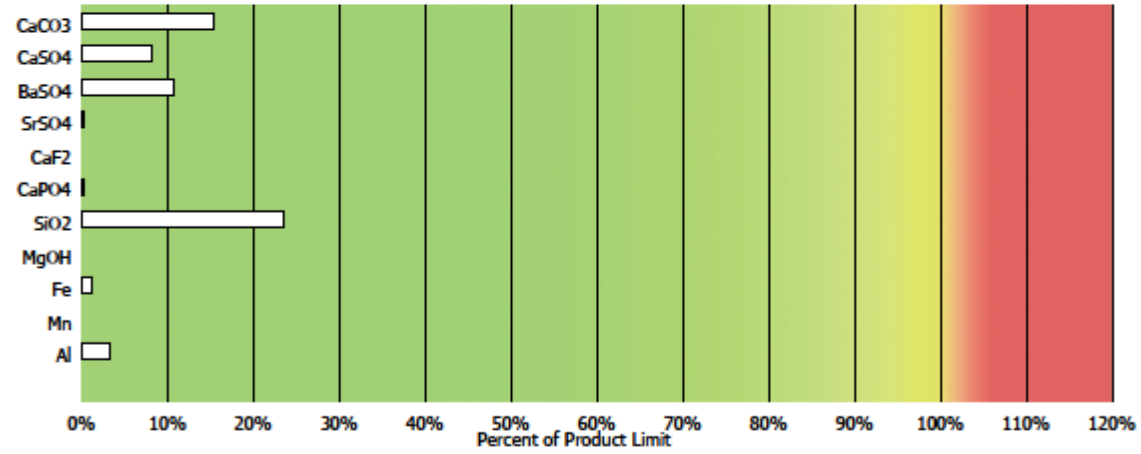
Membrane and Water Type

Feed Source:	**Treated Effluent**
Membrane Manufacturer:	**Default**
Membrane Type:	**High Rej Brackish**

Antiscalant Recommendations

Recommended Product	Recommended Dosage	System Recovery
Vitec 4000	0.50mg/l	75%
Dosed Strength	**Usage Per Day**	**pH Correction**
100%	0.21 lb	-

Saturation Indicies



While every effort has been made to ensure the accuracy of this program, no warranty, expressed or implied, is given as actual application of the products is outside the control of Avista Technologies.

AdvisorCi Version 4.7.0 CI Engine version 190318 Antiscalant data file 2a

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AdvisorCi Projection for Las Virgenes Municipal Water District at 80% Recovery

Avista | Advisor Ci

Project: Las Virgenes AWTP

Executive Summary

Recovery: 80%
Customer: Carollo
Engineer: Amos Branch
Note: Average Water Quality

Date: 29-Jun-21
Prepared by: Raul Gonzalez
Water Analysis date: 25-Jun-21

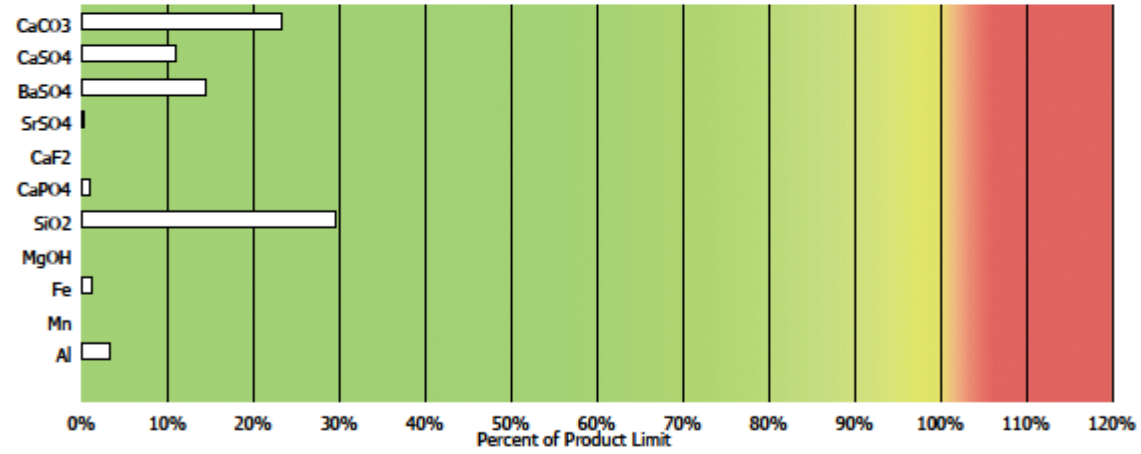
Membrane and Water Type

Feed Source:	**Treated Effluent**
Membrane Manufacturer:	**Default**
Membrane Type:	**High Rej Brackish**

Antiscalant Recommendations

Recommended Product	Recommended Dosage	System Recovery
Vitec 4000	1.50mg/l	80%
Dosed Strength	**Usage Per Day**	**pH Correction**
100%	0.58 lb	-

Saturation Indicies



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AdvisorCi Projection for Las Virgenes Municipal Water District at 85% Recovery

Avista | AdvisorCi

Project: Las Virgenes AWTP

Executive Summary

Recovery: 85%
Customer: Carollo
Engineer: Amos Branch
Note: Average Water Quality

Date: 30-Jun-21
Prepared by: Raul Gonzalez
Water Analysis date: 25-Jun-21

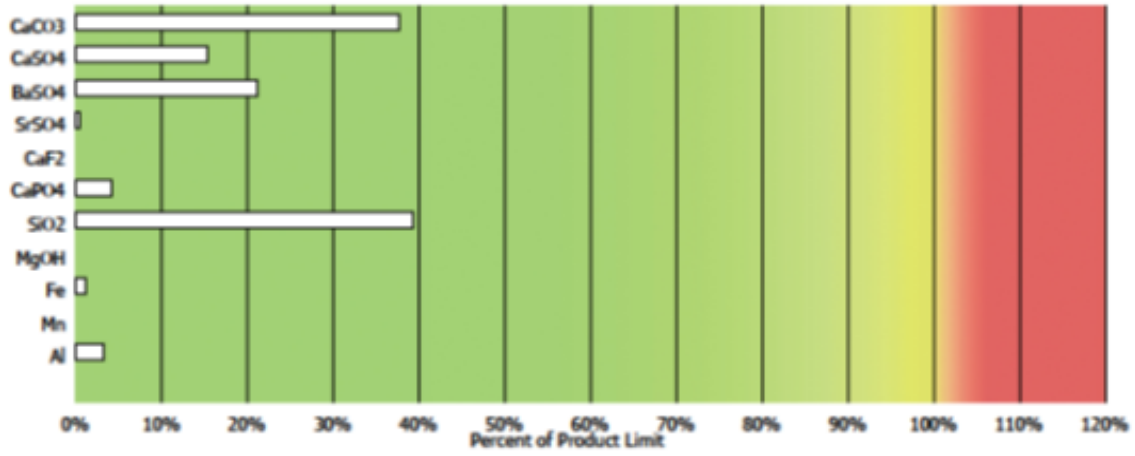
Membrane and Water Type

Feed Source:	**Treated Effluent**
Membrane Manufacturer:	**Default**
Membrane Type:	**High Rej Brackish**

Antiscalant Recommendations

Recommended Product	Recommended Dosage	System Recovery
Vitec 4000	2.00mg/l	85%
Dosed Strength	**Usage Per Day**	**pH Correction**
100%	0.73 lb	-

Saturation Indicies



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AdvisorCi Projection for Las Virgenes Municipal Water District at 90% Recovery

Avista | AdvisorCi

Project: Las Virgenes AWTP

Executive Summary

Recovery: 90%
Customer: Carollo
Engineer: Amos Branch
Note: Average Water Quality

Date: 29-Jun-21
Prepared by: Raul Gonzalez
Water Analysis date: 25-Jun-21

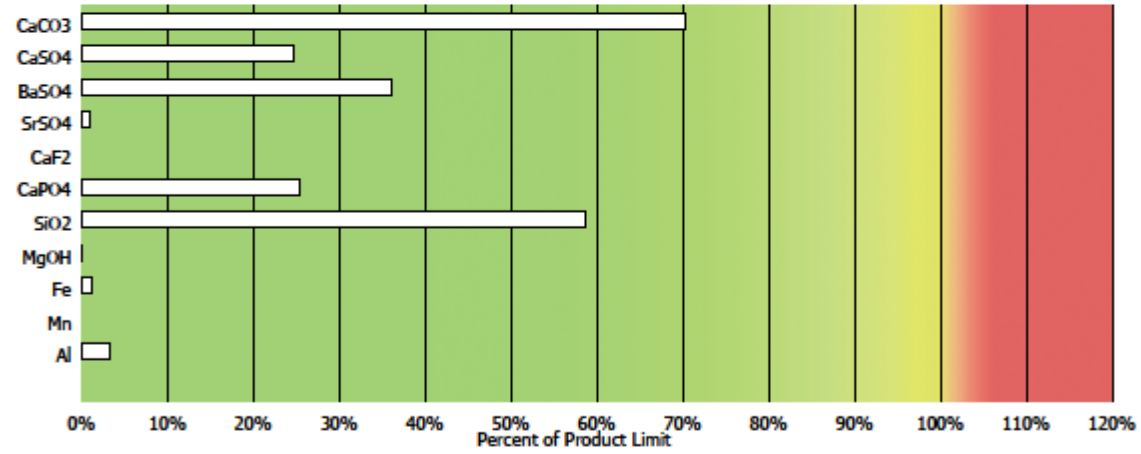
Membrane and Water Type

Feed Source:	**Treated Effluent**
Membrane Manufacturer:	**Default**
Membrane Type:	**High Rej Brackish**

Antiscalant Recommendations

Recommended Product	Recommended Dosage	System Recovery
Vitec 4000	2.02mg/l	90%
Dosed Strength	**Usage Per Day**	**pH Correction**
100%	0.69 lb	-

Saturation Indicies



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AdvisorCi Version 4.7.0 CI Engine version 190318 Antiscalant data file 2

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Testing Procedures

The tote of water sample provided was concentrated in a laboratory pilot system to 75%, 80%, 85% and 90% recoveries. The brine water was collected and dosed with varying concentrations of Vitec 4000. The samples were then visually inspected after 8 hours, 24 hours, 48 hours and 72 hours. The visual inspection consists of examining the sample for visible solids either on the air/water interface, on the sides of the glass equipment or suspended within the solution. The presence of visible solids indicates a "failed" test. The doses of Vitec 4000 tested were 0.5, 1.5, 2.0 and 2.5 ppm at each recovery. Each dosed sample was observed over a 72-hour period.

Results

Samples were collected and observed over a 72-hour period to determine if precipitation would occur and the length of time before precipitation occurred. The 85% and 90% recovery samples were the first to fail visual inspection and displayed precipitation by the 8-hour mark at the 0.5 ppm, 1.0 ppm and 1.5 ppm doses. The 80% recovery samples displayed precipitation by the 24-hour mark at the 0.5 ppm and 1.0 ppm doses. At 75% recovery, samples did not display precipitation until the 72-hour mark for all dosages.

Table 2. Example images of a 'pass' and 'fail' during visual inspection

	
This flask contains no visible precipitation on the surface, side, or bottom of the flask	This flask contains visible precipitation and is considered a failed dose

Table 3. Results of the visual inspection of each sample of 75% Recovery

Vitec 4000 Dosage	Visual Inspection 8 Hours	Visual Inspection 24 Hours	Visual Inspection 48 Hours	Visual Inspection 72 Hours
0.5 ppm	Pass	Pass	Pass	Fail
1.0 ppm	Pass	Pass	Pass	Fail
1.5 ppm	Pass	Pass	Pass	Fail
2.0 ppm	Pass	Pass	Pass	Fail
2.5 ppm	Pass	Pass	Pass	Fail

Table 4. Results of the visual inspection of each sample of 80% Recovery

Vitec 4000 Dosage	Visual Inspection 8 Hours	Visual Inspection 24 Hours	Visual Inspection 48 Hours	Visual Inspection 72 Hours
0.5 ppm	Pass	Fail	Fail	Fail
1.0 ppm	Pass	Fail	Fail	Fail
1.5 ppm	Pass	Pass	Fail	Fail
2.0 ppm	Pass	Pass	Fail	Fail
2.5 ppm	Pass	Pass	Fail	Fail

Table 5. Results of the visual inspection of each sample of 85% Recovery

Vitec 4000 Dosage	Visual Inspection 8 Hours	Visual Inspection 24 Hours	Visual Inspection 48 Hours	Visual Inspection 72 Hours
0.5 ppm	Fail	Fail	Fail	Fail
1.0 ppm	Fail	Fail	Fail	Fail
1.5 ppm	Fail	Fail	Fail	Fail
2.0 ppm	Pass	Fail	Fail	Fail
2.5 ppm	Pass	Fail	Fail	Fail

Table 6. Results of the visual inspection of each sample of 90% Recovery

Vitec 4000 Dosage	Visual Inspection 8 Hours	Visual Inspection 24 Hours	Visual Inspection 48 Hours	Visual Inspection 72 Hours
0.5 ppm	Fail	Fail	Fail	Fail
1.0 ppm	Fail	Fail	Fail	Fail
1.5 ppm	Fail	Fail	Fail	Fail
2.0 ppm	Pass	Fail	Fail	Fail
2.5 ppm	Pass	Fail	Fail	Fail