Eastern Municipal Water District

Final
Pilot Plant Report

Purified Water Replenishment
Brine Concentration Pilot Project

Client:
EMWD
2270 Trumble Road
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Date:

October 7, 2021

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Section 1

Introduction

1.1 Project Background

Eastern Municipal Water District (EMWD), through their integrated resources planning process, has identified potable reuse as a key component in their strategy to increase local water resources and improve overall water supply reliability. Potable reuse also supports EMWD's goal of maximizing water use efficiency by minimizing recycled water discharges.

EMWD's potable reuse project is called the Purified Water Replenishment (PWR) project. The PWR project will replenish groundwater with a blend of tertiary treated and advanced treated recycled water. Due to challenges associated with the disposal of brine, part of the PWR project's objectives is to minimize brine using a high recovery treatment process.

EMWD's PWR Brine Concentration Pilot Project studied a high recovery treatment train involving membrane filtration (MF) pretreatment along with DuPont-Desalitech's proprietary closed-circuit reverse osmosis (CCRO) process to produce advanced treated water at the San Jacinto Valley Regional Water Reclamation Facility (SJVRWRF). The CCRO process has demonstrated an ability to achieve higher system recoveries when compared with conventional RO while at the same time providing the same level of treatment as a conventional RO system. For inland desalination locations, even small increases in water recovery provide meaningful reductions in the amount of brine generated, resulting in a reduced environmental impact and project lifecycle savings.

1.2 Source & Permeate Water Quality

The SJVRWRF receives raw wastewater from the surrounding community and uses this as the source water for its water recycling portfolio. The tertiary effluent from this facility is pre-treated through activated sludge and cloth filters prior to disinfection.

Filtered tertiary effluent, sourced from the end of the facility's Chlorine Contact Basin, was used as the feed water to the pilot unit. This water was chosen as the supply for this evaluation because it is representative of the source water for the full-scale AWPF. Water quality data (feed to the MF pretreatment, feed to the CCRO, and CCRO brine/permeate) are provided in the table below. Average and maximum values are based on 8 samples collected between October 28th, 2020 and March 3rd, 2021.

Table 1-1 Water Quality Summary (Oct-28-2021 through March-3-2021)

Parameter	Units	MF Influent		CCRO Influent		CCRO Permeate		CCRO Brine	
		Avg	Max	Avg	Max	Avg	Max	Avg	Max
pH	-	7.2	7.4	5.8	6.3	5.4	5.7	6.3	7.1
Temperature	°C	19.6	23.6	20.1	23.4	18.7	19.7	19.2	21.4
Conductivity (EC)	us/cm	1,017	1,150	1,036	1,138	87	153	9,713	13,940
Chloride	mg/L			132.5	160.0	7.4	13.0	1,624	2,700
Fluoride	mg/L			0.2	0.3			2.3	3.1
Sulfate as SO4	mg/L			171.3	210.0	0.7	1.0	2,313	3,800
Turbidity	NTU	0.4	0.6	0.1	0.2	0.1	0.1	0.9	3.6
Ammonia as N	mg/L			2.2	8.9			11	18
Nitrate (as N)	mg/L			10.8	15.0	3.2	4.2	102	130
Alkalinity as CaCO3	mg/L			41.5	77.0	7.6	9.4	273	440
Total Dissolved Solids (TDS)	mg/L			611	660	42.6	68.0	7,550	11,000
Total Suspended Solids (TSS)	mg/L							ND	41.0
Chlorine Residual, Free	mg/L	2.6	3.3	0.3	0.7				
Chlorine Residual, Total	mg/L	4.0	4.7	1.4	2.4				
Total Organic Carbon (TOC)	mg/L			5.4	5.8	0.5	0.9	75	120
UV 254	% T	80.4	81.3	80.2	80.9	97.9	98.4		
Barium, Total	mg/L			0.027	0.036			0.35	0.47
Calcium, Total	mg/L			53.5	58.2	0.2	0.2	692.5	974.0
Iron, Total	mg/L			0.0	0.1			0.55	0.94
Magnesium, Total	mg/L			8.22	9.37			106.4	168.0
Manganese, Total	mg/L			0.0071	0.0120			0.10	0.18
Phosphorus as PO4, Total	mg/L			7.5	15.0			96	150
Potassium	mg/L			19	20	1.9	2.7	233	320
Silica as SiO2	mg/L			21	23			249	310
Sodium	mg/L			111	130	10.8	16.0	1,336	2,100
Strontium	mg/L			0.31	0.33			4.1	5.9
Aluminum	mg/L			ND	0.035			0.13	0.26
E. Coli	MPN/100ml	ND	ND	ND	ND	ND	ND	ND	ND
Total Coliforms	MPN/100ml	ND	ND	ND	10	ND	ND	ND	ND

1.3 Pilot Location and Configuration

The pilot facility was located next to the Chlorine Contact Basin and the fenced property boundary, with the MF and CCRO equipment trailers installed end-to-end. For a general layout of the MF equipment trailer, refer to Appendix A. For a general layout of the CCRO equipment trailer, refer to Appendix B.

The MF Filtrate Tank, Waste Tank, and CIP Tank were located adjacent to the MF equipment trailer on a separate pad, while the process tanks for the CCRO pilot (Flushing and CIP Tanks) were located within the equipment trailer. Chemicals for the MF process (described further below) were stored inside the equipment trailer, however, the CCRO chemical storage tanks (antiscalant and sulfuric acid) were stored outside, adjacent to the CCRO equipment trailer.

Feed water for the pilot facility was sourced from two submersible pumps installed within the Chlorine Contact Basin (near its discharge end). MF filtrate was directed to a Filtrate Tank, which served as a source of water for backwashing the MF and to act as a balance tank upstream of the

CCRO process. Filtrate was pumped from the MF Filtrate Tank to the CCRO system by a booster pump located prior to the CCRO high pressure pump. Both CCRO permeate and brine were returned back to the Chlorine Contact Basin.

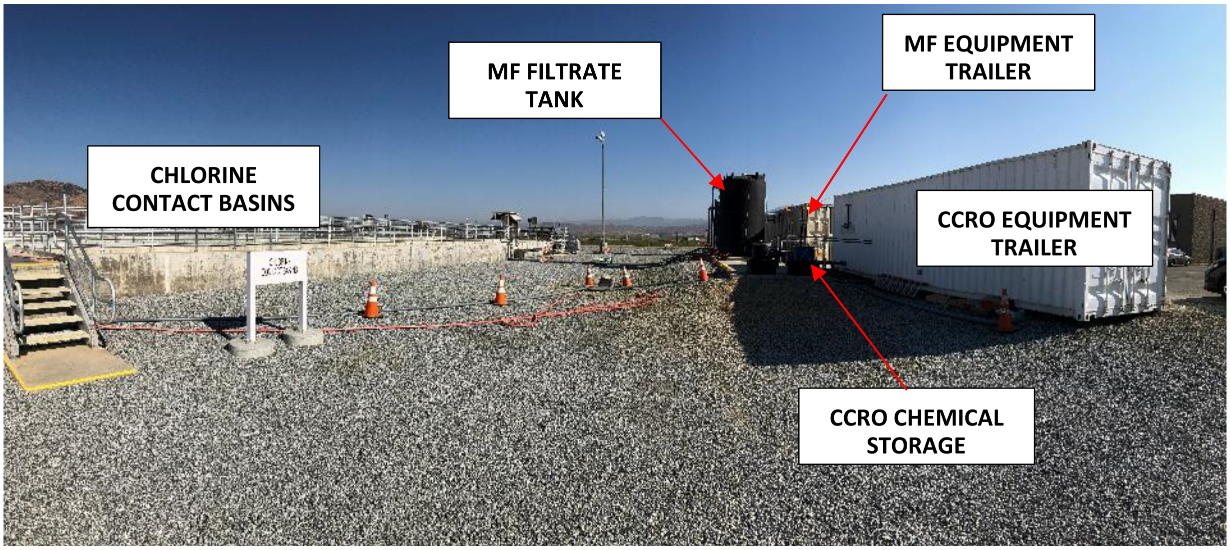

Figure 1-1
Pilot Plant and Adjacent Chlorine Contact Basins at the SJVRWRF

1.4 MF System Overview

The MF system provided suspended solids and turbidity removal ahead of the CCRO system via pressurized polyvinylidene difluoride (PVDF) MF modules, manufactured by Toray, using the thermal induced phase separation (TIPS) manufacturing process. Feed water chemical adjustment included both liquid ammonium sulfate and sodium hypochlorite to achieve a target chloramine concentration of 1.5 to 2.5 mg/L in the MF filtrate feeding the CCRO.

Two MF trains were used to treat the flow under various operating conditions.

Details of the selected membranes are provided in the table below. For P&IDs of the MF system, refer to Appendix C.

Table 1-2 MF Membrane Specification

Parameter	Value
Number of MF Trains Installed	2
Number of MF Membranes per Train	4
Membrane Vendor	Toray
Membrane Model	HFU-2020AN
Membrane Classification	Ultrafiltration (UF)
Nominal Pore Size	0.01 µm
Material	PVDF
Membrane Area per Module	775 ft^2/module (72 m^2/module)
Flow Direction	Outside-In

Parameter	Value
Module Diameter	8.5 inch (216 mm)
Module Length	85.0 inch (2,160 mm)

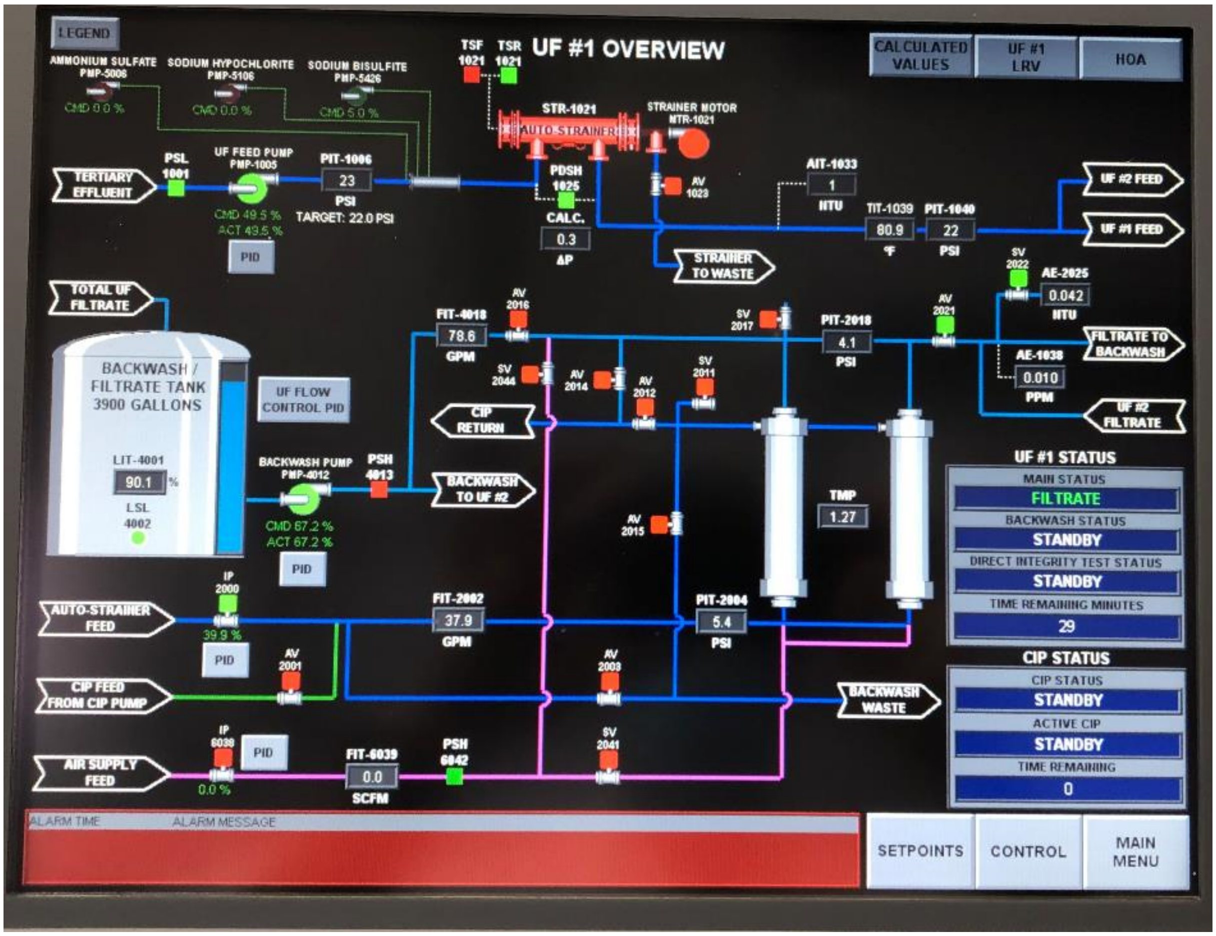

Figure 1-2
HMI Screen for MF Train 1

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Key operating parameters for the MF System are provided in the table below.

Table 1-3 MF Equipment Design and Operational Parameters

Parameter	Value
Maximum Instantaneous Flux	26 gfd
Membrane Train Filtered Water Flow Rate	56 gpm
Total System Filtered Water Flow Rate	112 gpm
Design Water Temperature	~13 to 22 ºC
Backwash Interval	45 min
Backwash Configuration	Air (30 sec) Water (30 sec)
Minimum CIP Membrane Cleaning Interval under Design Conditions	21 days
Minimum CEB Membrane Cleaning Interval under Design Conditions	24 hours
Minimum Design Water Recovery	90%
Maximum Design Transmembrane Pressure during Filtration	22 psi
Chemicals (Feed Water Adjustment)	Liquid Ammonium Sulfate Sodium Hypochlorite Sodium Bisulfite
Chemicals (CEB/ CIP & Neutralization)	Sodium Hydroxide Citric Acid Sodium Hypochlorite Sodium Bisulfite
Autostrainer Filtration Degree	200 micron

1.5 CCRO System Overview

1.5.1 CCRO vs Conventional RO

Unlike conventional RO, which generates a continuous concentrate stream, CCRO is operated in a cyclic batch mode and thus generates a periodic stream of concentrate or brine. During the recirculation cycle, 100 percent of the RO brine is re-circulated from the tail element to the feed of the lead RO membrane element. At the same time that brine is being recycled, the RO high pressure pump continuously provides feed water to the system at a flow rate equal to the target permeate production rate, thereby producing a continuous stream of permeate. During recirculation, salt concentrations in the feed water continuously concentrate up until a specified volumetric recovery value is achieved, at which point a valve on the brine line is opened to allow the brine to be flushed out along with raw feed water. Compared with conventional high recovery RO, the repetitive disruption of scale formation with lower salinity feed water which occurs during the CCRO batch process has been found in some applications to:

- allow for higher system recoveries;
- reduce membrane fouling; and

- inhibit membrane scaling.

1.5.2 CCRO Process Description

The CCRO system is operated in an alternating manner between the following two modes:

- PFD (plug flow desalination)
- CCD (closed circuit desalination)

1.5.2.1 CCD Cycle

During the CCD cycle, MF filtrate (feed water) is mixed with a recirculated stream of concentrate rejected by the membranes. The concentrate flow rate, in conjunction with the permeate flow setpoint, defines the unit's module recovery (MR). A MR of approximately 25 to 30 percent was used during the pilot trials. The role of the circulation pump creates the cross flow required for the CCRO process.

During CCD, ions rejected by the membrane are accumulated inside the closed system volume (circulation loop). As a result, the osmotic pressure of the water increases over the course of the cycle, requiring a simultaneous increase in feed pressure to drive water flow pass the membranes and maintain a constant permeate flow. The feed pump is equipped with a VFD to fulfill this task. Since the feed flow is kept constant during the CCD cycle, the accumulation rate of all ions is constant and the increase in pressure between start/end of the CCD cycle is linear.

The recovery in CCRO cannot be calculated as a simple ratio of permeate to feed flow rates because it is not a steady state process as a traditional RO process. Instead, total Volumetric Recovery (VR) is calculated over a complete CCD+PFD cycle and is equal to the permeate volume produced divided by total feed consumed. The counters used in the PLC for this calculation are set to zero at the start of each PFD cycle.

1.5.2.2 PFD Cycle

The transition from CCD to PFD is performed by opening the brine valve and is triggered by the total volumetric recovery and/or module inlet pressure set points. During this brief cycle, concentrate is purged from the system with new feed water and the membranes are operated in a conventional RO configuration (i.e. plug flow).

1.5.3 Permeate Water Quality

The permeate produced is derived from the feed water that is concentrating inside the circulation loop. Thus, during the CCD cycle, permeate conductivity will increase. Average permeate quality is the average quality of all permeate produced during the entire PFD and CCD cycles. At the beginning of the PFD step, the permeate conductivity is normally highest as a result of the relatively low operating flux and concentrated nature of the water matrix in contact with the membranes at the end of the CCD cycle. In most cases, however, the contribution of the PFD step to overall permeate quality is negligible due to the small volume of permeate produced relative to the permeate volume produced during the entire CCD step.

1.5.4 CCRO System Overview

Major system components for the CCRO unit are listed in the table below along with key design criteria. For a P&ID of the CCRO system, refer to Appendix D.

Table 1-4 CCRO Major Equipment and Design Criteria

Parameter	Value
RO Skid Quantity	One
Overall Recovery	Up to 97%
Design Permeate Flow Rate	70 gpm
Design Flux	10 gfd
No. Stages	1
No. Pressure Vessels (membrane array)	Five – 8M (450 psi)
Total No. Membranes Installed	Twenty-five
Membrane Vendor	DuPont
Membrane Element Model	FilmTec Fortilife CR100, 8” x 40”, 34 mil spacers
Cartridge Filter Rating	1-micron
Chemical Dosing (Feed Water Adjustment)	Sulfuric Acid (CCRO influent) Antiscalant (CCRO influent)

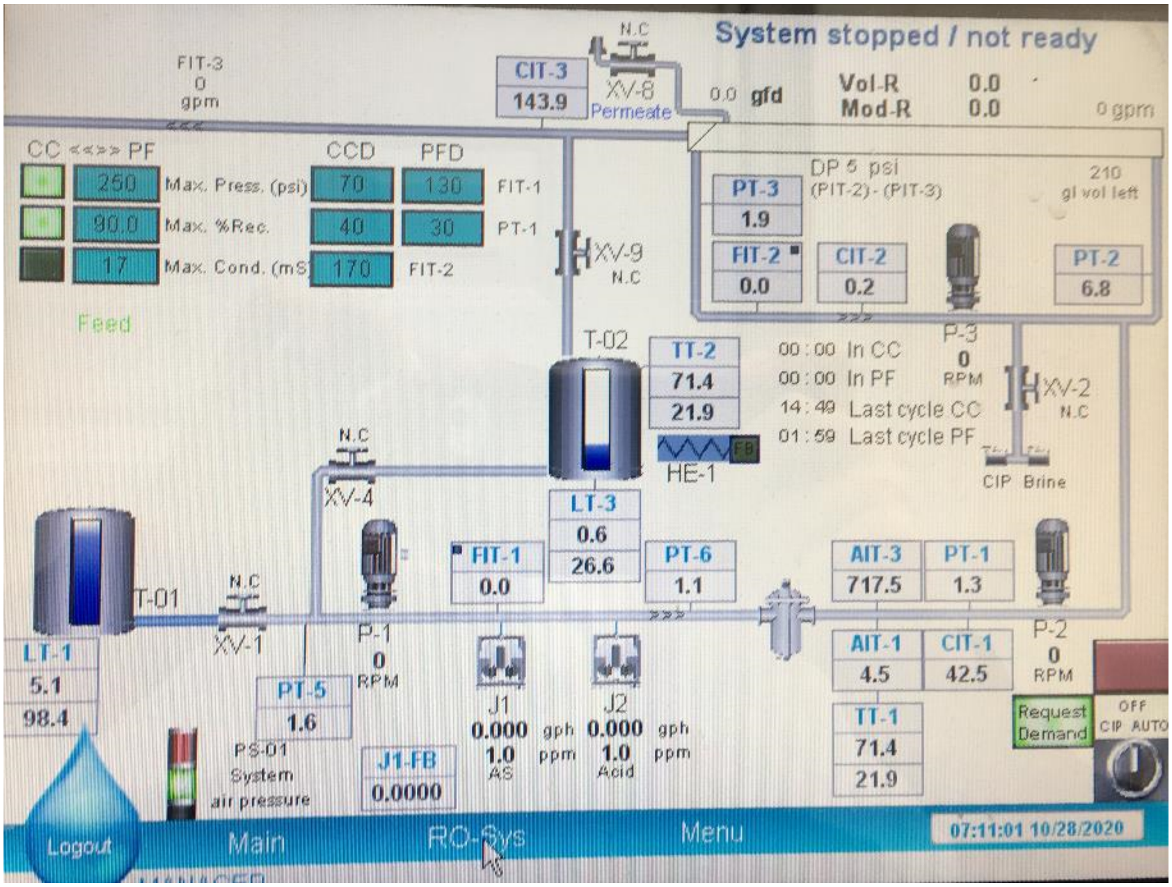

Figure 1-3
HMI Overview Screen for CCRO

Section 2

Pilot Data

2.1 CCRO

2.1.1 Summary of Operations

The official start date for the trending of CCRO data was established on October 23, 2020 (i.e. Day 0). Prior to this date, the pilot was operated intermittently with old membranes, as commissioning and startup efforts for the overall pilot project were being finalized. The CCRO pilot's initial setpoints were established as follows:

- Recovery = 90%
- Target Permeate Flow (during CCD) = 70 gpm (10 gfd)
- Target pH = 6.1 (to prevent calcium phosphate scale formation)
- Antiscalant dose = 3.3 mg/L (using Avista Vitec 4000)

During the first several weeks of the pilot trials, the operating setpoints were left unchanged to confirm the behavior and performance of the system at a conservative recovery rate and the overall reliability of the full treatment train (including MF pretreatment). Refer to Figure 3-1 through 3-6 for normalized data collected over the course of the pilot trial.

At the start of December, the recovery rate was increased from 90 to 92 percent and allowed to stabilize. After approximately two weeks of stable operation, the setpoint was increased to 93 percent on December 16. Overnight, feed pressures climbed on the pilot and it was shut down on the morning of December 17. Subsequently, a series of permeate flushes and soaks were performed to determine how much of the membrane scaling could be removed with permeate alone. Over the course of a few days, the pilot's recovery rate was slowly increased back up to 92 percent and operating data indicated the membranes were performing similar to what had been observed prior to the setpoint change on December 16. The project team, in consultation with Dupont, decided to adjust the CCRO pilot's operating parameters to increase crossflow during the PFD and CCD cycles, and made a slight reduction in the feed pH (from 6.1 to 5.9). The pilot operated stably from December 21 through January 14, 2021 with these setpoints.

Prior to initiating a second attempt to operate the pilot at a recovery setpoint of 93 percent, a CIP was performed on the membranes on January 6 (Day 75) using a proprietary high pH cleaner manufactured by Avista (RoClean P112). Due to an issue with the pilot's cloud-based communication link, operating data was lost between Day 73 and 82, which prevented an analysis of the post-CIP performance and pushed back the start data for increasing the recovery. On January 14 (Day 83), after the communication link had been restored, the recovery was increased from 92 to 93 percent and the pH setpoint was reduced from 5.9 to 5.6. No adjustment was made to the antiscalant dose, which remained 3.3 mg/L.

Between January 14 and February 10 (Day 83 and 110 respectively), the pilot's recovery setpoint was gradually increased from 93 to 95%. During this period, changes to the pH setpoint were made concurrently to account for increased calcium phosphate scale formation at the higher recoveries. After operating for just under 10 days at 95% recovery, reductions in the normalized permeate flow data suggested percentage losses were increasing unsustainably and the decision was made to carry out a CIP on the membranes for a second time.

A high pH CIP was performed on the membranes on February 11 (Day 111). To evaluate the performance of alternative antiscalants, the Avista product that had been used to date was changed out for a product by AWC prior to restarting the pilot. Once the pilot was placed back online, the recovery setpoint was gradually increased on the pilot from 90 to 95 percent over approximately one week, while the pH setpoint was reduced from 5.5 to 5.0. One day after increasing the recovery setpoint to 95 percent on Day 118, reductions in normalized permeate flows indicated that the operating conditions were not sustainable and the pilot was again taken offline to soak in RO permeate.

Following the soak, a 2-step CIP was performed which involved both high and low pH components. The intent of including a low pH CIP after the high pH CIP was to ensure any scale formation which may have been developed on the membranes during the high pH CIP was effectively removed before placing the pilot back into service.

Considering that the previous two consecutive runs at 95% recovery had resulted in significant reductions in the normalized permeate flow over a short operating timeframe, it was decided to trial a recovery setpoint of 94%. Prior to restarting the pilot, and in consultation with AWC, it was decided to increase the antiscalant dose rate from 6 to 12 mg/L to account for worst-case phosphate levels, one of the potential sources for the observed performance loss.

Between February 24 (Day 124) and April 11 (Day 170), the pilot operated at 94% recovery with an antiscalant dose rate of 12 mg/L and a pH setpoint of 5.0. Approximately 10 days into the run at 94% recovery, an antiscalant supply issue resulted in the pilot having to be placed offline while waiting for delivery of additional product. As a result, between the March 6 (Day 135) and the March 15 (Day 143), the pilot was placed offline and regular permeate flushes of the membranes were performed by the operations staff. Accounting for this time offline, the pilot operated at 94% recovery for approximately 38 days between CIPs.

A 2-step CIP was performed on the membranes over April 12 and 13 (Day 172 and 173 respectively) based on a normalized permeate flow decrease of approximately 15% from the baseline. A slight reduction in the normalized salt passage could also be detected, suggesting the foulant was more organic than inorganic. Prior to initiating the CIP, a tail element was pulled for autopsy and a new membrane was installed as a replacement.

The pilot's final run was initiated on April 13, with the same setpoints as those used on the previous run. The intent of operating with identical conditions was to confirm the repeatability of operating at 94 percent recovery. The final run concluded on May 7 (Day 196) prior to a series of programmed power outages planned, which were planned to take place over a 2-week period on the full-scale facility. At this time, the pilot had operated for approximately 24 days and normalized permeate flow losses were approximately 10% off of the estimated baseline. No meaningful reduction in the normalized salt passage or differential pressure were detected over this period.

Table 2-1 Summary of Operating Parameter Changes and CIP Events

Date	Days of Operation	Recovery (%)	pH	Antiscalant (mg/L)	Notes
23-Oct-20	0	90	6.1	3.3	Avista Vitec 4000 antiscalant
2-Dec-20	40	92	6.1	3.3	
16-Dec-20	55	93	6.1	3.3	
17-Dec-20	56	90	6.1	3.3	
21-Dec-20	59	92	5.9	3.3	Concentrate Flow SPs increased during PFD & CCD cycles
6-Jan-21	75	High pH CIP (2% Avista RoClean P-112)			
14-Jan-21	83	93	5.6	3.3	
26-Jan-21	95	94	5.4	3.3	
28-Jan-21	97	94	5.1	3.3	
2-Feb-21	102	95	5.1	3.3	
5-Feb-21	105	95	4.9	3.3	
11-Feb-21	111	High pH CIP (1% Avista RoClean P-112)			
11-Feb-21	111	90	5.5	4.5	Antiscalant changed to AWC A-112
14-Feb-21	114	92	5.5	4.5	
16-Feb-21	116	94	5.0	6.0	
17-Feb-21	117	95	5.0	6.0	
23-Feb-21	123	High pH CIP (1% Avista RoClean P-112) Low pH CIP (2% Avista RoClean L403)			
24-Feb-21	124	94	5.0	12.0	
12-Apr-21	171	High pH CIP (1.8% AWC C-227LF) Low pH CIP (1.7% AWC C-209)			
13-Apr-21	172	94	5.0	12.0	

2.1.2 Performance Data

The performance data were calculated using the following equations:

- Normalized Permeate Flow per ASTM D4516 – 19a ($Norm.Q_p$):

$$Norm.Q_p = Q_{p\,(Act.)} \times \frac{\left(P_{Feed\,(Ref.)} - {}^{\Delta P_{Ref.}}/_{2} - P_{Perm\,(Ref.)} - \pi_{fc\,(Ref.)} + \pi_{Perm\,(Ref.)}\right)}{\left(P_{Feed\,(Act.)} - {}^{\Delta P_{Act.}}/_{2} - P_{Perm\,(Act.)} - \pi_{fc\,(Act.)} + \pi_{Perm\,(Act.)}\right)} \times \frac{TCF_{Ref.}}{TCF_{Act.}}$$

- Temperature Correction Factor (TCF):

$$TCF = EXP\left\{2640 \times \left[\frac{1}{298} - \frac{1}{(273+T)}\right]\right\} \; where\ T \ \geq 25°C$$

$$TCF = EXP\left\{3020 \times \left[\frac{1}{298} - \frac{1}{(273+T)}\right]\right\} \; where\ T \ \leq 25°C$$

- Average Feed Conductivity ($Cond_{Feed\,(Avg)}$):

$$Cond_{Feed\,(Avg)} = \frac{Cond_{Feed} \times \ln\left(\frac{Cond_{Concentrate}}{Cond_{Feed}}\right)}{1 - \frac{Cond_{Feed}}{Cond_{Concentrate}}}$$

- Feed-Concentrate Osmotic Pressure & Permeate Osmotic Pressure (π_{fc} & π_{Perm}):

$$\frac{C_{fc} \times (T + 320)}{49{,}100} \; bar\ (for\ C_{fc} < 20{,}000\ mg/L)$$

$$where: C_{fc} = Concentration\ Feed - Concentrate$$

- Concentration Feed-Concentrate (C_{fc}):

$$C_{fc} = C_f \times \frac{\ln\left(\frac{1}{1-MR}\right)}{MR} \quad (mg/L)$$

- Module Recovery (MR):

$$MR = \frac{Permeate\ Flow}{(Feed\ Flow + Concentrate\ Flow)}$$

- Feed Concentration (C_f):

$$C_f = 0.67 \times \{[Cond_{Feed} \times MR] + [Cond_{Concentrate} \times (1 - MR)]\} \quad (mg/L)$$

- Net Driving Pressure (NDP):

$$NDP = P_{Feed} - \frac{\Delta P}{2} - \pi_{fc} - P_{Perm} + \pi_{Perm} \quad (bar)$$

- Normalized Average Salt Passage:

$$\frac{TCF_{Ref.}}{TCF_{Act.}} \times \left[1 - \left(\frac{Cond_{Feed\ (Avg.)} - Cond_{Perm}}{Cond_{Feed(Avg.)}}\right)\right] \qquad (\%)$$

Key performance data (Normalized Permeate Flow, Differential Pressure (ΔP), Normalized Salt Passage, and Net Driving Pressure (NDP)) for the CCRO are presented in Figure 3-1 through Figure 3-6, which have been summarized in Table 3-2 below. Each set of trends have been presented for two different date ranges:

- The full data set (Day 0 to 196), and
- The final two operating runs at 94% (Day 124 to Day 196).

The intent behind providing the data across a restricted timeframe is to improve the legibility of the data. Given the nature of the CCRO process, operating with a variable recovery rate generates operating data with a greater distribution compared with traditional RO. To reduce the visual "noisiness" of the plotted data, zooming in on a particular time frame, in this case the two final runs at 94%, it is possible to observe trends in the data with more clarity. For all figures, the operating data presented was also limited to operational recoveries between 75% and the maximum value in order to present only the data generated at the highest recovery values.

Table 2-2 Summary of CCRO Figures

Figure No.	Trend Data	Recovery Range
3-1	▪ Normalized Permeate Flow ▪ Differential Pressure (ΔP)	~75 to 94% (since Feb. 23 CIP, Day 123)
3-2	▪ Normalized Permeate Flow ▪ Differential Pressure (ΔP)	~75 to 95%
3-3	▪ Lead Element (Feed) Pressure ▪ Net Driving Pressure (NDP) ▪ Temperature	~75 to 94% (since Feb. 23 CIP, Day 123)
3-4	▪ Lead Element (Feed) Pressure ▪ Net Driving Pressure (NDP) ▪ Temperature	~75 to 95%
3-5	▪ Normalized Salt Passage ▪ Recovery	~75 to 94% (since Feb. 23 CIP, Day 123)
3-6	▪ Normalized Salt Passage ▪ Recovery	~75 to 95%

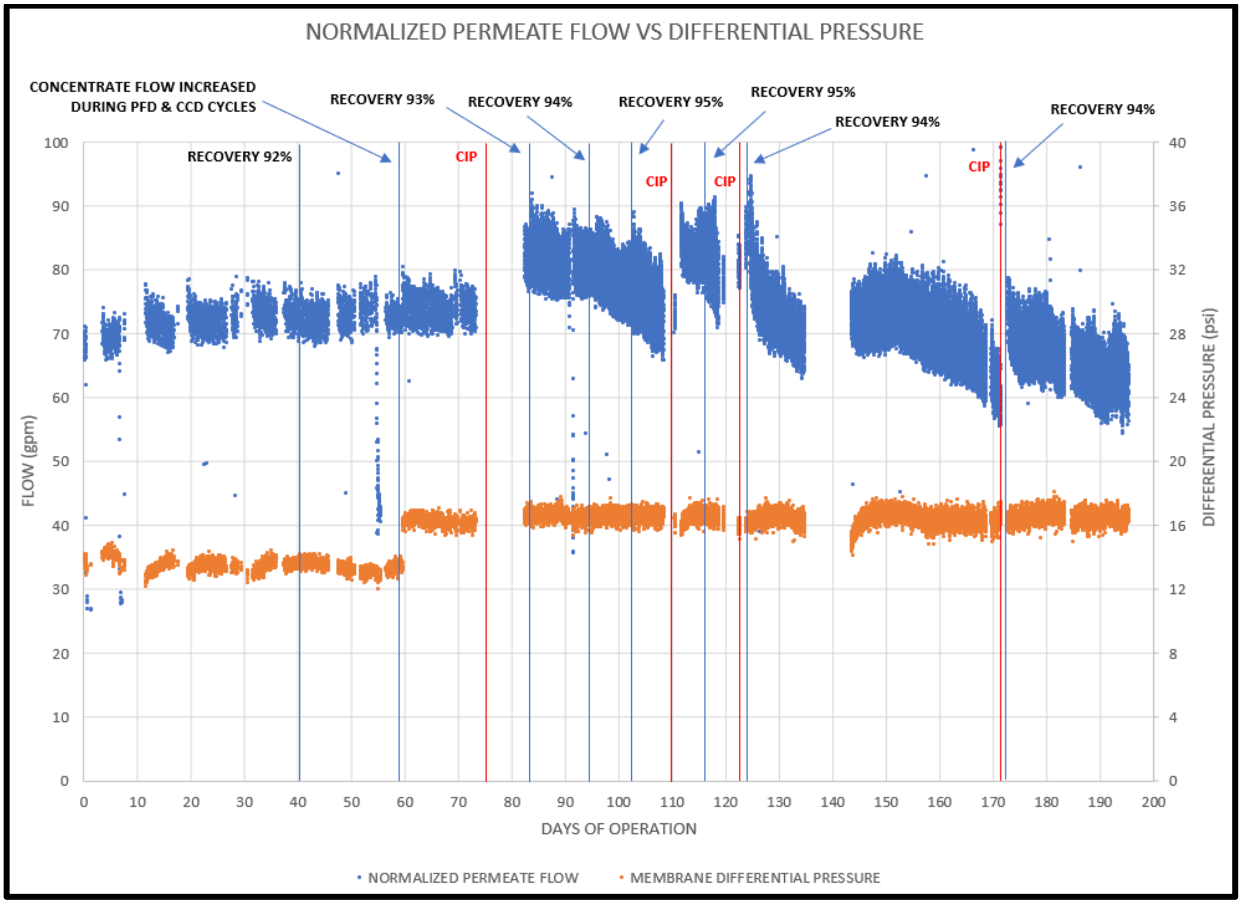

Figure 2-1
Normalized Permeate Flow & ΔP (~75 to 95% Recovery)

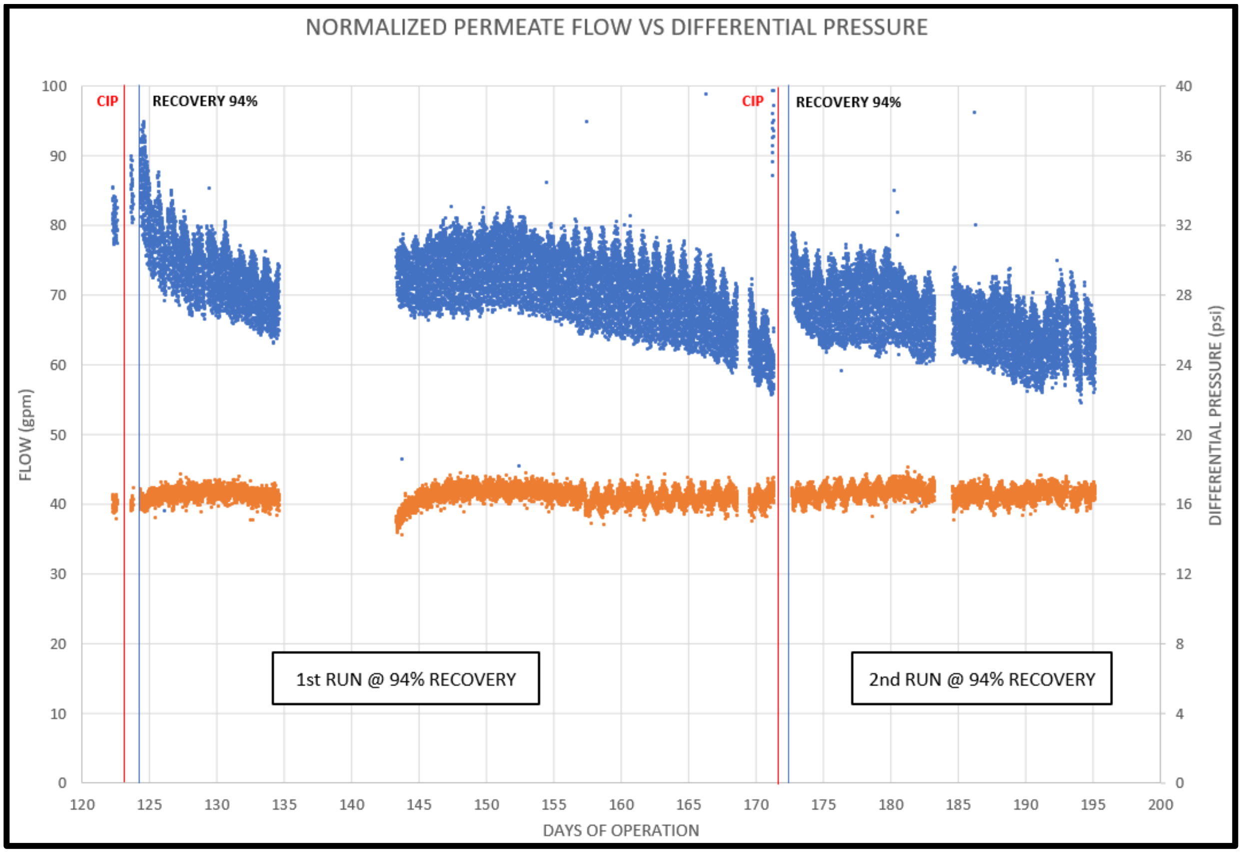

Figure 2-2
Normalized Permeate Flow & ∆P (~75 to 94% Recovery) Feb. 23 to May 7

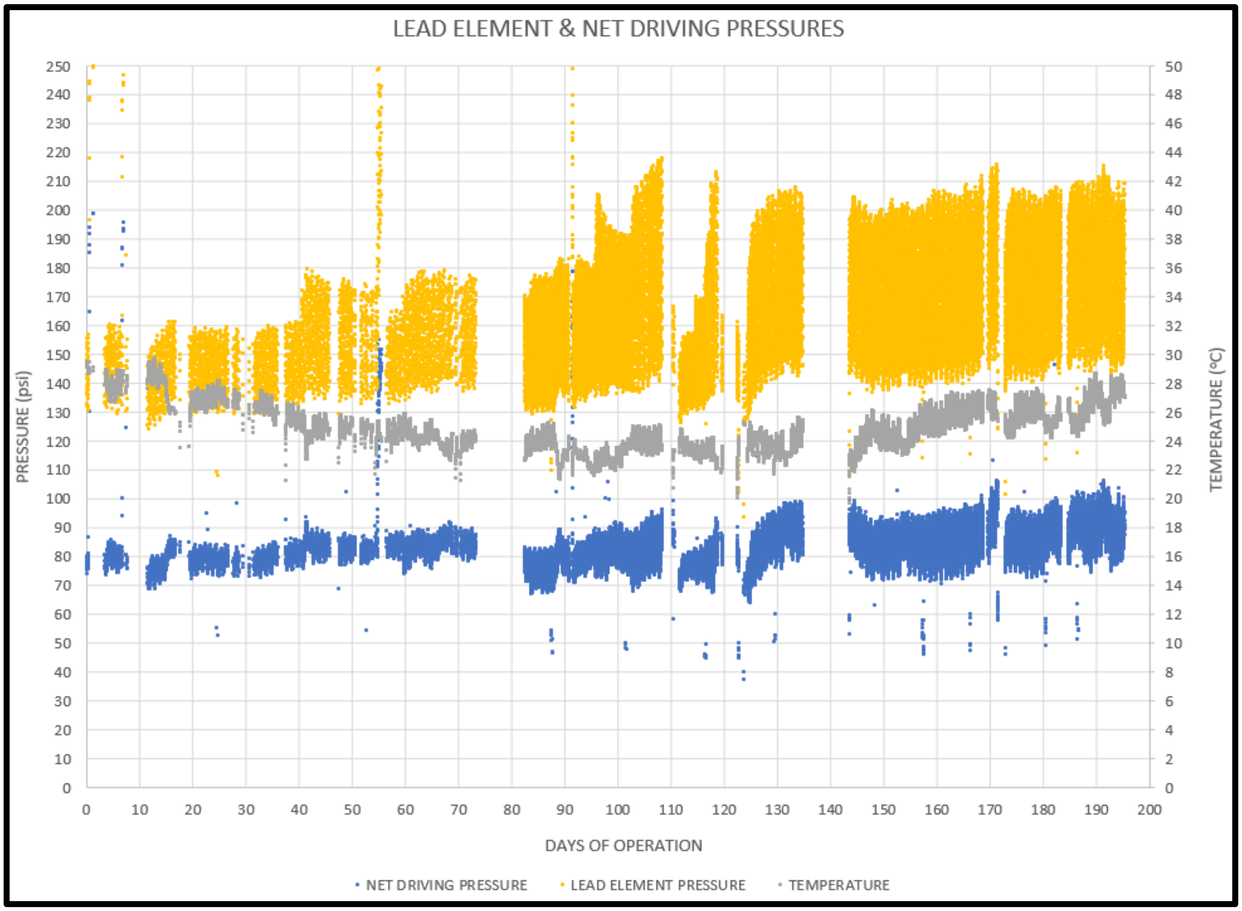

Figure 2-3
Feed Pressure vs NDP vs Temperature (~75 to 95% Recovery)

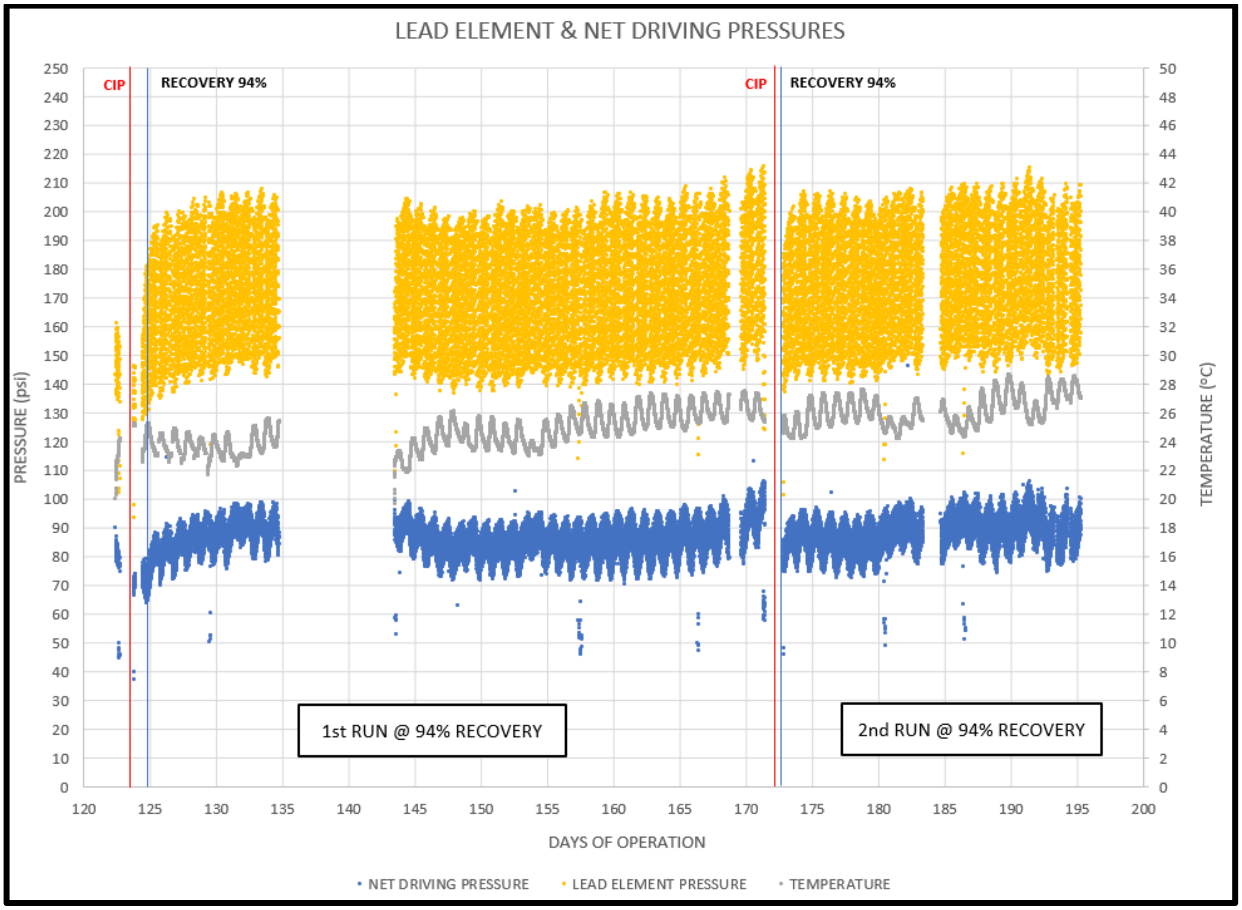

Figure 2-4
Feed Pressure vs NDP vs Temperature (~75 to 95% Recovery) Feb. 23 to May 7

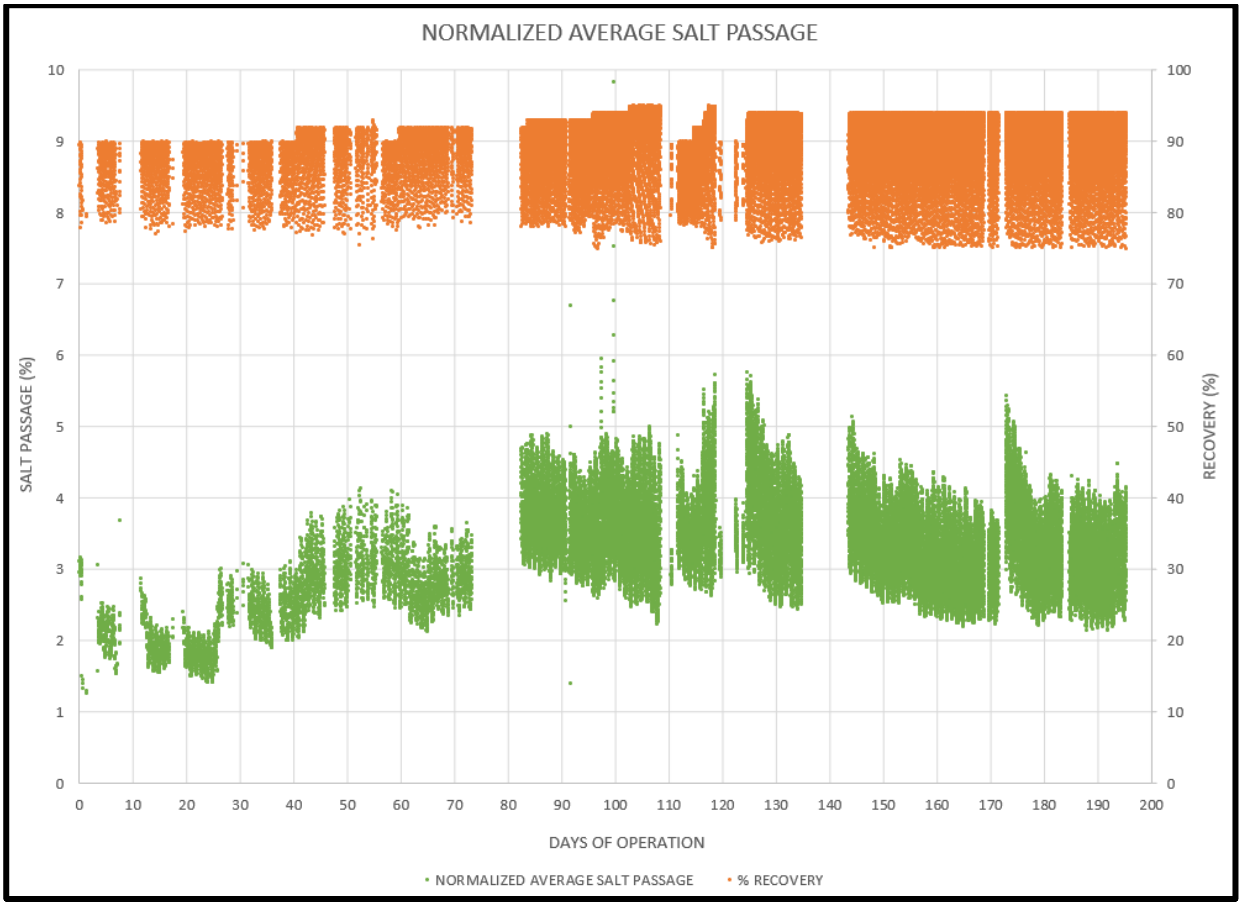

Figure 2-5
Normalized Avg Salt Passage vs Recovery (~75 to 95% Recovery)

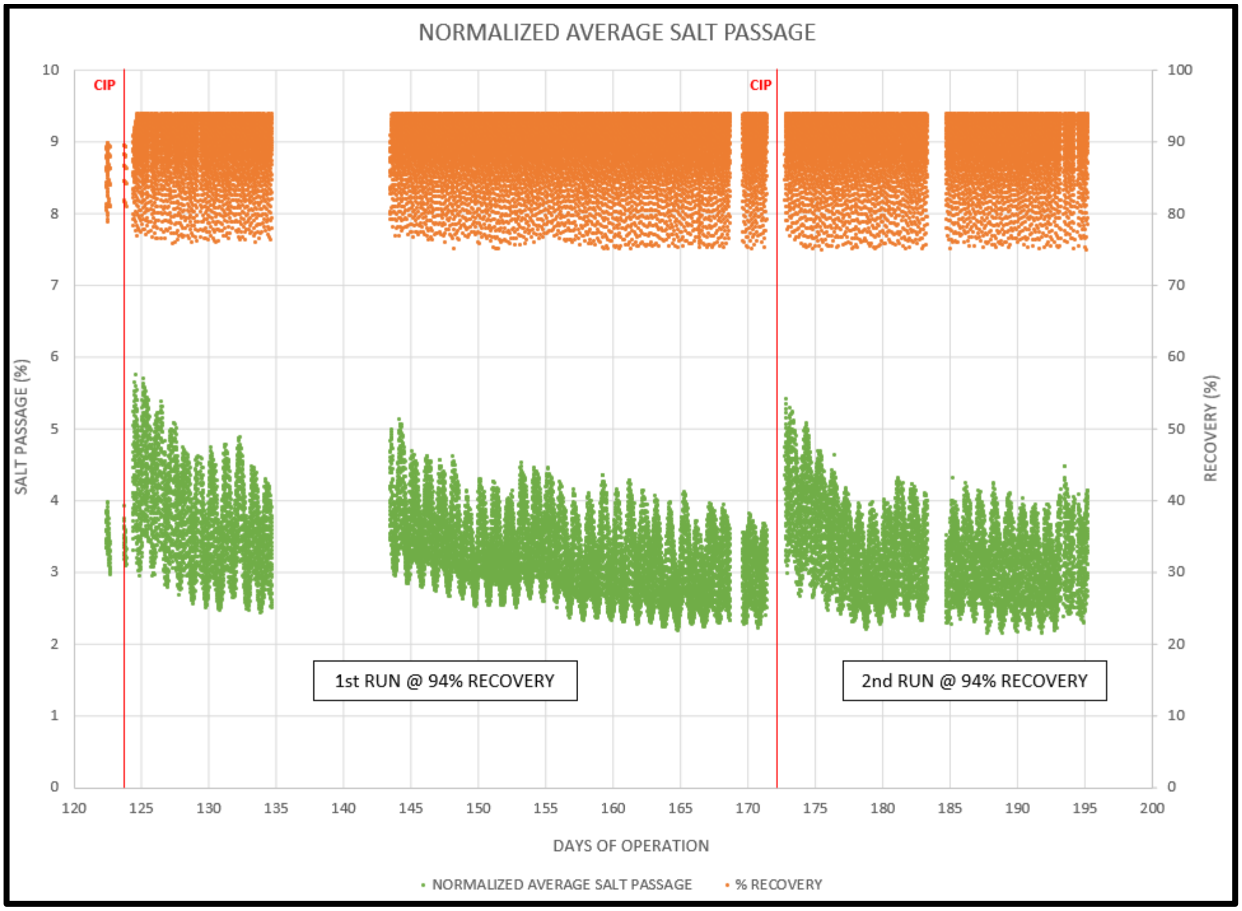

Figure 2-6
Normalized Avg Salt Passage vs Recovery (~75 to 94% Recovery) Feb. 23 to May 7

2.1.3 Membrane Autopsy

A tail element was removed prior to the CIP performed on Day 171 and sent off for a membrane autopsy. AWC carried out the autopsy at their Florida laboratory and were on hand to assist with preparing the membrane for shipment.

A copy of the autopsy report is included in Appendix E. Key findings from the autopsy report were:

- Membrane was in very good visual condition upon arrival. A light foulant deposition was observed on the membrane leaves. However, the foulant density was ~0.19 μg/cm^2 when dehydrated, which was considered extremely low;
- Initial wet testing found that the membrane flux to be ~2.68% below manufacturer's nominal specification; and
- Flat sheet testing with coupons collected along the flow path of the membrane performed:

- Initial cell testing, performed on coupons that had been soaked in deionized water for 24 hours prior to testing, found permeability to be approximately 20% greater than the manufacturer's nominal specification, though salt rejection was within specification.

- The membrane coupons were cleaned first with 2% AWC C-227, a high pH chemical cleaner for organic based matter. The cleaning was performed at pH 11.9 and 35°C for 6 hours. Permeability increased significantly, with a slight decrease in salt rejection.

- A follow up cleaning was performed with 2% AWC C-234, a low pH chemical cleaner. The cleaning was performed at pH ~1.7 and 27°C for 2 hours. A marginal decrease in permeability was observed, with a slight increase in salt rejection.

- Overall, membrane permeability increased by approximately 45% over the nominal specification. The salt rejection, when normalized for flux, was within specification.

AWC concluded that even though the membrane, upon arrival, only exhibited a slight loss of permeability compared with the manufacturer's nominal specification, the results of the cleaning study suggested that an organic foulant had been removed from the membrane surface, given the significant increase in permeability above the nominal specification.

Although such high permeability relative to the nominal specification could have been indicative of underlying membrane deterioration due to minor halogenation (oxidant damage), the Fujiwara test was negative and salt rejection was within specification. The results suggest that the membrane was substantially more permeable than would have been expected based on the manufacturer's data sheet.

2.2 MF Pretreatment

As it was not the primary focus of the pilot investigation, the MF pilot's operating setpoints remained the same throughout the duration of the trials. The setpoints were set up to provide conservative operating conditions in order to guarantee relatively trouble-free performance, and reduced cleaning demand, in order for the pilot study to focus primarily on optimizing the CCRO process. To ensure sufficient filtrate for the CCRO, but avoid overflow of the MF Filtrate Tank, the MF pilot flow rate was automatically ramped up/down to maintain a constant operating level in the tank.

Setpoints included:

- Maximum Filtrate Flow = 57 gpm (~26 gfd)
- Minimum Filtrate Flow = 20 gpm (~9 gfd)
- Time Between Backwashes = 45 min

With the above setpoints, the MF system operated with a recovery around 98% throughout the trial.

Mini-CIPs (i.e. maintenance cleans) were initiated manually and generally occurred bi-weekly. Only caustic/ hypochlorite cleans were necessary. The cleaning events are summarized in the table below:

Table 2-3 Mini-CIP Cleaning Events

Date	Type of Mini-CIP
4-Nov-2020	Caustic/ Sodium Hypochlorite
16-Nov-2020	Caustic/ Sodium Hypochlorite
30-Nov-2020	Caustic/ Sodium Hypochlorite
7-Dec-2020	Caustic/ Sodium Hypochlorite
14-Dec-2020	Caustic/ Sodium Hypochlorite
04-Jan-2021	Caustic/ Sodium Hypochlorite
18-Jan-2021	Caustic/ Sodium Hypochlorite
01-Feb-2021	Caustic/ Sodium Hypochlorite
16-Feb-2021	Caustic/ Sodium Hypochlorite
01-Mar-2021	Caustic/ Sodium Hypochlorite
15-Mar-2021	Caustic/ Sodium Hypochlorite
29-Mar-2021	Caustic/ Sodium Hypochlorite
21-Apr-2021	Caustic/ Sodium Hypochlorite
27-Apr-2021	Caustic/ Sodium Hypochlorite

Based on the transmembrane pressure (TMP) and permeability data, membrane performance was relatively stable and only minor fouling was observed throughout the trial. Although gradual declines in permeability (and concurrent rise in TMP) were observed on occasion, especially when the mini-CIP frequency extended beyond a two-week period, the mini-CIPs were generally effective in restoring the membrane's baseline performance and a full-strength CIP was never performed. In some cases, membrane performance was not fully restored after the mini-CIP event, but was restored after the subsequent cleaning two weeks later. Because of the intermittent use of the MF pilot's sodium hypochlorite dosing system, air locks in the dosing line did occur and were not always fully purged during the cleaning cycle resulting in Train 1 receiving less available chlorine compared with Train 2. This issue could be remedied by priming the line manually before the initiation of the first clean.

Figure 3-7 and Figure 3-8 below present the cumulative trends of performance data for UF Trains 1 and 2 that have been collected off the HMI over the testing cycle. The caustic/hypo mini-CIP events performed on the membranes are noted with red lines overlaid on these figures. As noted earlier, the large variation in flux data (red) is a result of the feed pump control algorithm, which was configured to ensure a constant level in the Filtrate Tank while avoiding overflow conditions.

The performance data were calculated using the following equations:

- Transmembrane Pressure (TMP):

$$TMP = P_{Feed} - P_{Filtrate} + h \quad (psi)$$

$$where: h = Elevation\ Difference\ of\ Pressure\ Transducers$$

- Flux (J):

$$J = \frac{Flow\ (gpm) \times 1440}{Membrane\ Area} \quad (gfd)$$

$$where:\ Membrane\ Area = 4 \times 775\ ft^2$$

- Viscosity (μ):

$$\mu = 1.75 - 0.049T + 0.0006T^2 \quad (cP)$$

- Temperature Corrected Flux at 20°C (J_{20}):

$$J_{20} = \mu \times J \quad (gfd)$$

- Permeability at 20°C:

$$Permeabilty_{20} = \frac{J_{20}}{TMP} \quad (\frac{gfd}{psi}\ @\ 20°C)$$

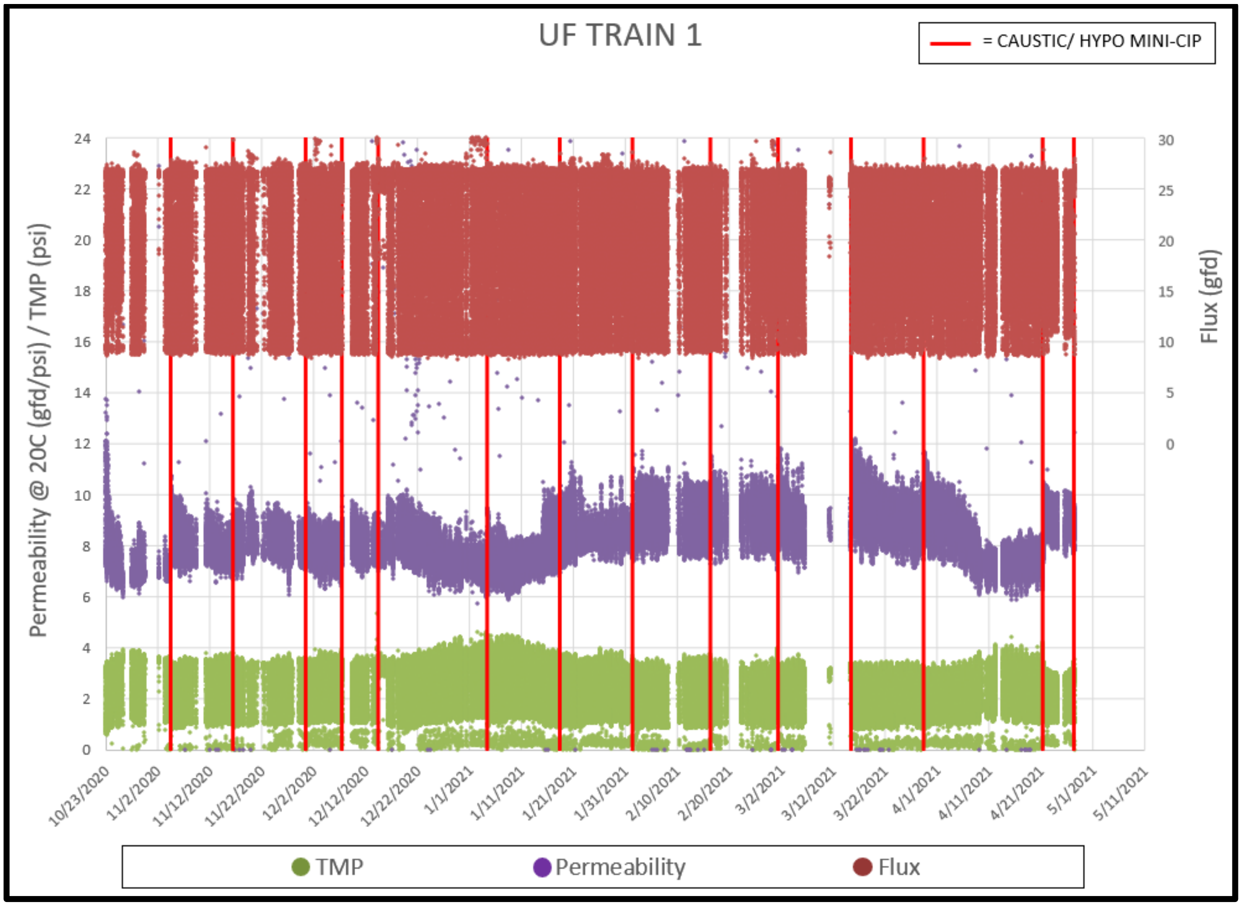

Figure 2-7
UF Train 1 Cumulative Performance (Oct-23-2020 to May-1-2021)

Figure 2-8
UF Train 2 Cumulative Performance (Oct-23-2020 to May-1-2021)

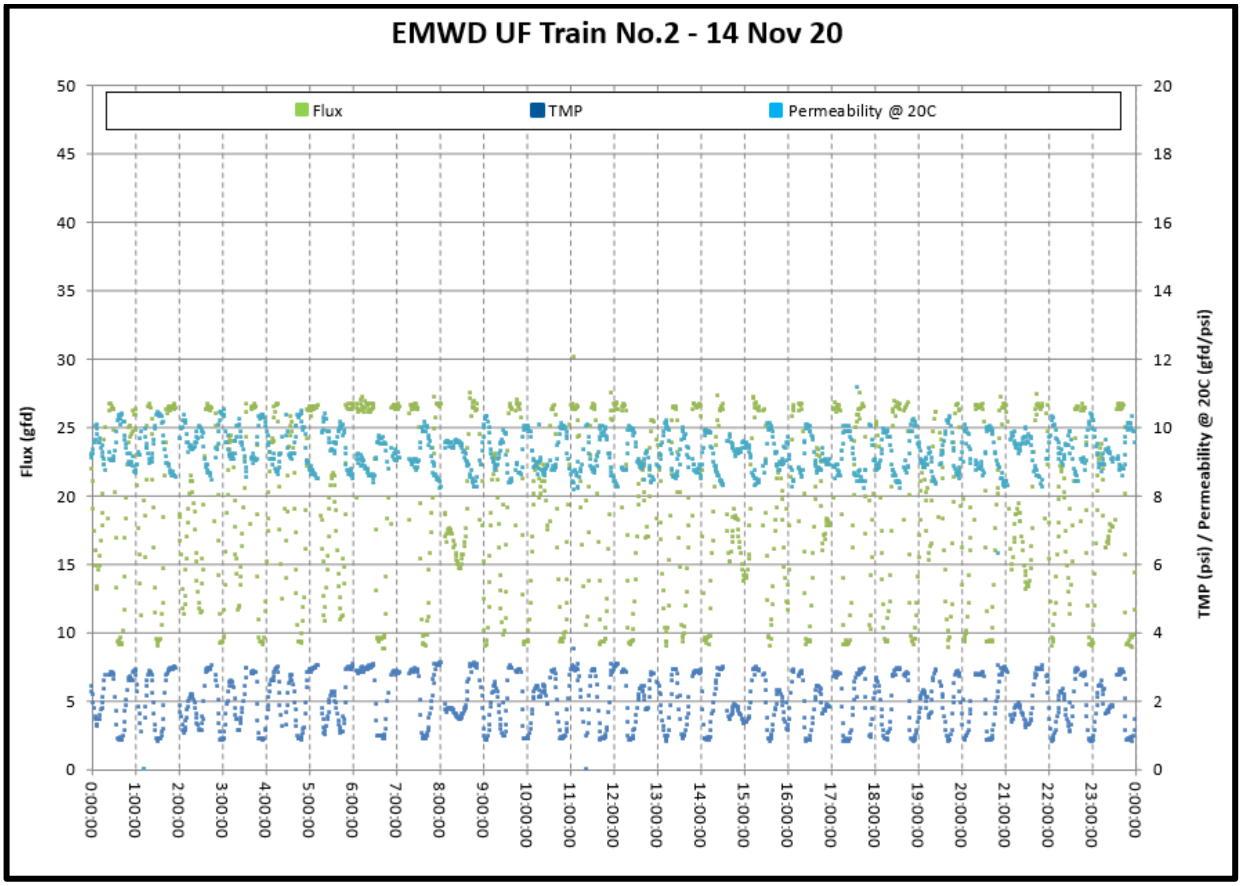

Figure 2-9
Representative 24-hr Run Cycle (Train 2)

Section 3

Cost Comparison

To compare the cost effectiveness of utilizing CCRO in favor of a conventional 3-stage RO design for the full-scale facility, this section compares budgetary level capital construction (equipment costs only) and operations and maintenance (O&M) costs for the two systems, including evaporation ponds. Although the CCRO may provide a slight overall improvement in overall recovery (94% vs approximately 93%), for the purposes of simplification, this report assumes that all other project components (buildings, ancillary systems, pretreatment, etc.) are identical and are not covered in this comparison.

3.1 Assumptions

The assumptions include:

- Process equipment sized to provide 2 mgd of treated water (~1,370 gpm), approximately 2000 acre-ft/year.
- Conventional 3-Stage RO design based on the following:
  - 2 x 2.0 mgd trains (1 Duty/ 1 Standby)
  - Average Flux = 12 gfd
  - Recovery (2-stage) = 85%
  - Recovery (3rd stage) = 52%
  - Overall Recovery = 92.8%
  - Flow Factor = 0.85
- CCRO design based on the following:
  - 3 x 1.0 mgd trains (2 Duty/ 1 Standby)
  - Average Flux = 10 gfd
  - Recovery = 94%
  - Flow Factor = 0.85
- Feed water quality based on average values measured during the pilot study.
- Design present worth period assumed to be 30 years with a discount rate of 3.5 percent.
- An escalation rate of 5% was applied to annual O&M costs.

3.2 Annual Operation and Maintenance (O&M) Costs

Annual O&M costs are divided among the following:

- Power – Power costs associated with RO systems only. Power estimates were generated by vendor software used to model the specific RO design and calculate antiscalant dose rates.
- Chemicals – Includes chemical usage for 93% sulfuric acid and antiscalant, the two chemicals associated with RO treatment. As the CCRO utilizes a higher antiscalant dose rate compared with a conventional 3-stage design, the selected antiscalant product for this system is based on a formulation that is twice as concentrated as the formulation selected for the 3-stage RO design. Acid and antiscalant dosing rates were calculated using AWC's proprietary Proton software. Antiscalant dose rates for the CCRO were adjusted up based on the piloting investigation, which employed AWC's A-112 product at a dose of 12 mg/L.
- Replacement – Includes replacement costs for RO membranes. This estimate assumes a 5-year membrane useful life.
- Maintenance – Includes assumed routine maintenance and materials costs. The assumption is that annual maintenance including ultimate replacement costs are on the order of 2% of the equipment capital costs.
- Labor costs are assumed to be similar between the two systems and are thus not included for comparison.

A 10% contingency is added to the O&M costs.

Table 3-1 O&M Cost Comparison – CCRO vs Conventional 3-Stage RO

Treatment Option	Category	Cost ($)
Conventional 3-Stage RO	Power	$131,000
	Chemical Costs	$123,000
	Replacement Costs	$34,000
	Maintenance Costs	$48,000
	Subtotal Annual O&M Costs	**$336,000**
	Contingency (10%)	$33,600
	Annual O&M Costs	**$369,600**
CCRO	Power	$154,000
	Chemical Costs	$198,000
	Replacement Costs	$60,000
	Maintenance Costs	$54,000
	Subtotal Annual O&M Costs	**$409,000**
	Contingency (10%)	$40,900
	Annual O&M Costs	**$449,900**

3.3 Capital Cost Summary

The table below summarizes the capital costs for the two different RO systems. Because of the customizable nature of conventional RO design, it is assumed that a single duty train capable of producing 2.0 mgd will provide the lowest net present value (NPV). Unlike conventional RO, Desalitech's pre-fabricated CCRO skids are available in discrete sizes. A high level assessment by the vendor suggested that three 1.0 mgd trains would be the most economical for this project.

Table 3-2 Capital Cost Summary – CCRO vs Conventional 3-Stage RO

Treatment Option	Category	No. Units	Cost ($/unit)	Total Cost ($)
Conventional 3-Stage RO	2 x 2.0 mgd RO skids (3-stage)	2	$1,200,000	$2,400,000
CCRO	3 x 1.0 mgd CCRO skids	3	900,000	$2,700,000

3.4 Evaporation Pond Considerations

In the May 2018 Preliminary Design Report for the PWR prepared by CDM Smith, a capital cost for the evaporation ponds associated with the full-scale 2,000 AFY AWPF was estimated at $9,200,000. To bring this value into 2021 dollars, an escalation rate of 5.0 percent was applied to come up with a revised value of $10,580,000.

A 2 mgd CCRO process operating at 94% would produce approximately 89 gpm of brine compared with a conventional 3-stage RO operating at 92.8%, which would produce approximately 108 gpm. This represents a reduction in the flow to the Evaporation Ponds of approximately 18%.

Assuming the pond size between the two treatment options would decrease proportionally with brine flow, the total cost for evaporation ponds with the CCRO option is reduced to approximately $8,718,700.

For this cost exercise, although smaller ponds could impact the number of evaporators required, as the final number has not been optimized, no decrease in O&M costs have been assumed.

3.5 Overall Cost Comparison

A 30-yr NPV is presented below for each system along with cost/acre-foot based on a 30-yr production period.

Table 3-3 Overall Cost Comparison – CCRO vs Conventional 3-Stage RO

Treatment Option	Category	Value
Conventional 3-Stage RO	Annual O&M Costs	$369,600
	Capital Costs – 3-Stage RO	$2,400,000
	Capital Costs – Evaporation Ponds	$10,580,000
	30-yr NPV	$26,508,000
	Total Yield (30 years)	60,000 AF
	NPV/AF	**$442/AF**
CCRO	O&M Costs	$449,900
	Capital Costs – CCRO	$2,700,000
	Capital Costs – Evaporation Ponds	$8,718,700
	30-yr NPV	$28,033,000
	Total Yield (30 years)	60,000 AF
	NPV/AF	**$467/AF**

The results indicate that conventional RO still provides an improvement in 30-year life cycle cost when compared to CCRO ($442/AF vs. $467/AF).

However, one potential option for improving the cost effectiveness of the CCRO process could involve automatic adjustment of the target pH setpoint during the closed circuit cycle, rather than maintaining a constant pH target as was done during the pilot study. Based on initial modeling work using AWC's Proton antiscalant projection software, along with average water quality data gathered during the pilot study, no pH adjustment is required until the recovery exceeds approximately 65% (i.e. after which at least one scale warning is generated by the antiscalant vendor's software without some degree of pH reduction).

When such pH optimization is considered, it may be possible to reduce acid consumption on the order of 30 to 50% (depending on feed water characteristics), representing a chemical cost savings between $30,000 and $60,000 per year. When the cost of smaller ponds is factored in, the 30-year life cycle cost of the CCRO with pH optimization is reduced down to a range of $446 to $424/AF, essentially the same or better than the cost of the conventional three-stage system described in the Preliminary Design Report (PDR) for the full-scale facility. Considering that the CCRO provides operational flexibility not available with conventional RO, such as the ability to adjust recoveries in real-time based on changes in feed water quality, there appears to be sufficient justification in considering CCRO a cost-effective alternative to the conventional 3-stage approach.

Section 4

Conclusions

The following key observations and summaries are made with respect to the overall treatment train at the conclusion of this pilot study which was conducted from October 23, 2020 through May 7, 2021:

- The MF system design parameters, namely the maximum instantaneous flux (approx. 26 gfd) and backwash interval (45 minutes), provided for reliable operation and extended run time, generally two weeks, between mini-CIP events. As a result of the general effectiveness of the mini-CIPs, a full CIP was not performed during the trial. Based on these results, the ability to achieve further optimization of the MF process is expected.
- Stability of the CCRO process was similar to conventional RO when operated up to the recovery values typically utilized for conventional RO in reuse applications treating this quality of feed water (92 to 93%). The pilot operated for approximately 55 days at 92% with little to no change in the normalized data.
- RO performance loss was primarily expressed as a reduction in the normalized permeate flow, though changes in normalized salt passage were observed, particularly during the first extended run at 94% recovery.
- The CCRO process became slightly less robust as the recovery increased beyond 92%, however, it was possible to achieve run times around 30 days between CIP events at 94% recovery, a common benchmark for establishing sustainability relative to the selected design criteria.
- CIP events on the CCRO pilot were initiated when normalized permeate flow losses exceeded 15% relative to the estimated baseline. In some cases, membranes were cleaned simply in response to a large decrease relative to the baseline, in order to ensure the validity of the performance data for the subsequent run. This approach was deliberately conservative and intended to ensure no irreversible fouling of the membranes occurred during the time available to operate the pilot. It is important to note that in many reuse applications, normalized permeate flow losses may be allowed to reach 20 to 25% without impacting the ability to restore clean membrane conditions.
- pH suppression/control is critical for controlling calcium phosphate scaling of the RO membranes.
- The RO membrane autopsy indicated little to no evidence of scale on the surface of the tail element, indicating the effectiveness of the antiscalant and pH setpoints that were used during the run. Given this observation, it is assumed that some degree of optimization for both these chemicals is possible.

- The autopsy performed on a tail RO membrane pulled at the end of the first extended run at 94% recovery indicated that the primary cause of permeability loss was related to an organic foulant. Taken together, both soaking in deionized water, and a generic high pH clean, were able to increase membrane permeability by approximately 45% over the nominal membrane specification.
- Cost modelling indicates that the 30-yr NPV for a conventional 3-stage RO design operating at approximately 92.8% overall recovery and producing 2,000 AFY is approximately $442/AF. This figure includes the cost of the evaporation ponds detailed in the PDR, which was updated to 2021 dollars. The 30-yr NPV for a CCRO system operating at 94% overall recovery and producing 2,000 AFY is approximately $467/AF, which includes the adjusted cost for smaller ponds.
- Initial modelling work performed using AWC's antiscalant projection software indicates significant chemical savings, on the order of $30,000 to 60,000/yr, could be realized if automatic pH adjustment were incorporated into the CCRO operating cycle. When this cost savings is factored into the life cycle cost, the 30-yr NPV is reduced from $467 to between $424 and $446/AF, which is the same value or better than what is calculated for the conventional 3-stage RO design.

Section 5

Next Steps

Based on results of this pilot, we would recommend the following be pursued as part of the upcoming detail design activities:

- Review piloting results and identify most cost-effective approach for incorporating CCRO into the overall treatment process;
- Expand the cost review to include upstream processes in order to improve the accuracy of the life cycle cost estimates and the overall comparison between RO design approaches; and
- Consider restarting the CCRO pilot in order to test pH optimization and confirm estimated savings determined by the desktop study.

Appendix A

MF Pilot Plant Layout

CONNECTION SCHEDULE

#	DESCRIPTION	TYPE	SIZE
1	TERTIARY EFFLUENT FROM TF	150# FLG	4.00
2	UF FILTRATE TO BW TNK	150# FLG	3.00
3	BW WASTE TO DRAIN	150# FLG	2.00
4	WASTE FROM INST. FLOOR DRAIN	FNPT	2.00
5	BW PUMP SUPPLY	150# FLG	3.00
6	UF CIP RETURN	150# FLG	2.00
7	SULFURIC ACID FROM CCRO	FNPT	0.50
8	CIP PUMP SUPPLY	150# FLG	3..00
9	CIP WASTE	150# FLG	2.00
10	AMMONIUM SULFATE FILL PORT	FNPT	1.00
11	NaOCL FILL PORT	FNPT	1.00
12	CITRIC ACID FILL PORT	FNPT	1.00
13	SODIUM HYDROXIDE FILL PORT	FNPT	1.00
14	SODIUM BISULFITE FILL PORT	FNPT	1.00
15	EYE WASH STATION	FNPT	0.50

PLAN
3/4" = 1'-0"

FRAC	DECIMALS	ANGLES
± 3	.X ±	±
	.XX ±	
	.XXX ±	

TOLERANCES UNLESS NOTED

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)
NOTE 1. EST. SHIPPING WEIGHT: 19,570 LB
NOTE 2. EST. OPERATING WEIGHT: 21,500 LB
NOTE 3. CONTAINER EXTERIOR AND INTERIOR TO BE WHITE
NOTE 4.
NOTE 5.
NOTE 6.

DRAWING NOTES

REV	DATE	DWN	APVD	DESCRIPTION
B	1/16/20	TJC	MMS	RELEASED FOR PRODUCTION
D	1/29/30	TJC		UPDATED CHEM FEED
E	4/28/20	NDL		AS-BUILTS
F	10/5/20	ECP	MMS	UPDATED PER FIELD MOD RECOMMENDATIONS

DRAWN BY	DATE
TJC	11/25/19
CHK'D BY	**DATE**
EIP	12/6/19
SIZE	**SCALE**
D	NONE

FILE TYPE ACAD

TITLE GENERAL ARRANGEMENT CONTAINERIZED UF SYSTEM PLAN VIEW

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD) UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-100-1	1 OF 5	F

WIGEN SINCE 1965
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302 LAKE HAZELTINE DRIVE
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952-448-4884
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3E-140-F-D Size Title Block_REV B

CONNECTION SCHEDULE			
#	DESCRIPTION	TYPE	SIZE
1	TERTIARY EFFLUENT FROM TF	150# FLG	4.00
2	UF FILTRATE TO BW TNK	150# FLG	3.00
3	BW WASTE TO DRAIN	150# FLG	2.00
4	WASTE FROM INST. FLOOR DRAIN	FNPT	2.00
5	BW PUMP SUPPLY	150# FLG	3.00
6	UF CIP RETURN	150# FLG	2.00
7	SULFURIC ACID FROM CCRO	FNPT	0.50
8	CIP PUMP SUPPLY	150# FLG	3..00
9	CIP WASTE	150# FLG	2.00
10	AMMONIUM SULFATE FILL PORT	FNPT	1.00
11	NaOCL FILL PORT	FNPT	1.00
12	CITRIC ACID FILL PORT	FNPT	1.00
13	SODIUM HYDROXIDE FILL PORT	FNPT	1.00
14	SODIUM BISULFITE FILL PORT	FNPT	1.00
15	EYE WASH STATION	FNPT	0.50

SECTION A 1/5

3/4" = 1'-0"

TOLERANCES UNLESS NOTED		
FRAC	DECIMALS	ANGLES
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	.XX ±	
	.XXX ±	

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DRAWING NOTES

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NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

REV	DATE	DWN	APVD	DESCRIPTION
B	1/16/20	TJC	MMS	RELEASED FOR PRODUCTION
D	1/29/20	TJC		UPDATED CHEM FEED
E	4/28/20	NDL		AS-BUILTS
F	10/5/20	ECP	MMS	UPDATED PER FIELD MOD RECOMMENDATIONS

DRAWN BY	DATE
TJC	11/25/19
CHK'D BY	DATE
EIP	12/6/19
SIZE	SCALE
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FILE TYPE	
ACAD	

TITLE: GENERAL ARRANGEMENT CONTAINERIZED UF SYSTEM FRONT ELEVATION

CLIENT NAME: EASTERN MUNICIPAL WATER DISTRICT (EMWD) UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-100-1	2 OF 5	F

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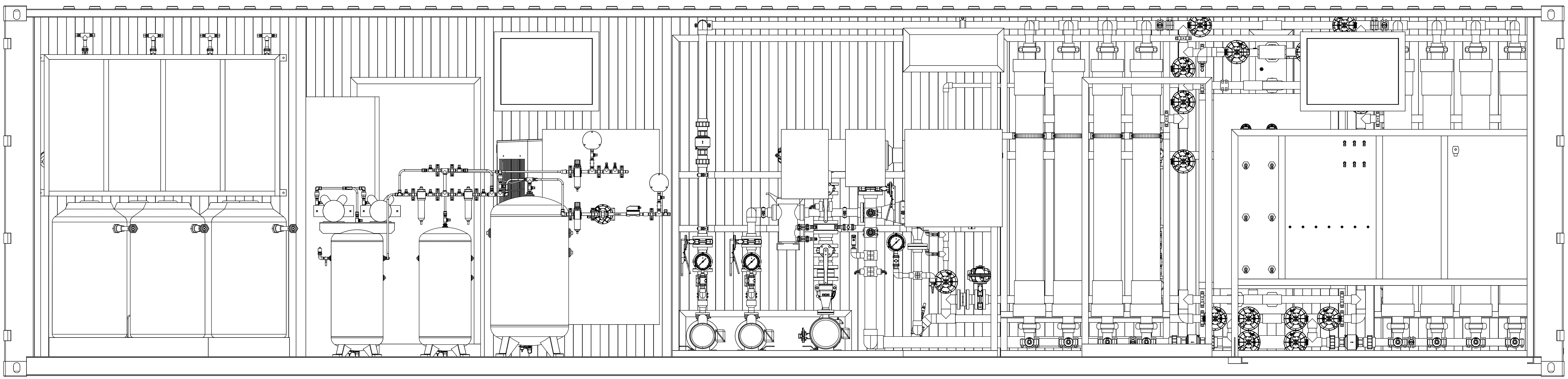

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3/4" = 1'-0"

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DRAWING NOTES
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REV	DATE	DWN	APVD	DESCRIPTION
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D	1/29/20	TJC		UPDATED CHEM FEED
E	4/28/20	NDL		AS-BUILTS
F	10/5/20	ECP	MMS	UPDATED PER FIELD MOD RECOMMENDATIONS

DRAWN BY	DATE
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CHK'D BY	**DATE**
EIP	12/6/19
SIZE	**SCALE**
D	NONE
FILE TYPE	
ACAD	

TITLE GENERAL ARRANGEMENT CONTAINERIZED UF SYSTEM BACK ELEVATION

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD) UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-100-1	3 OF 5	F

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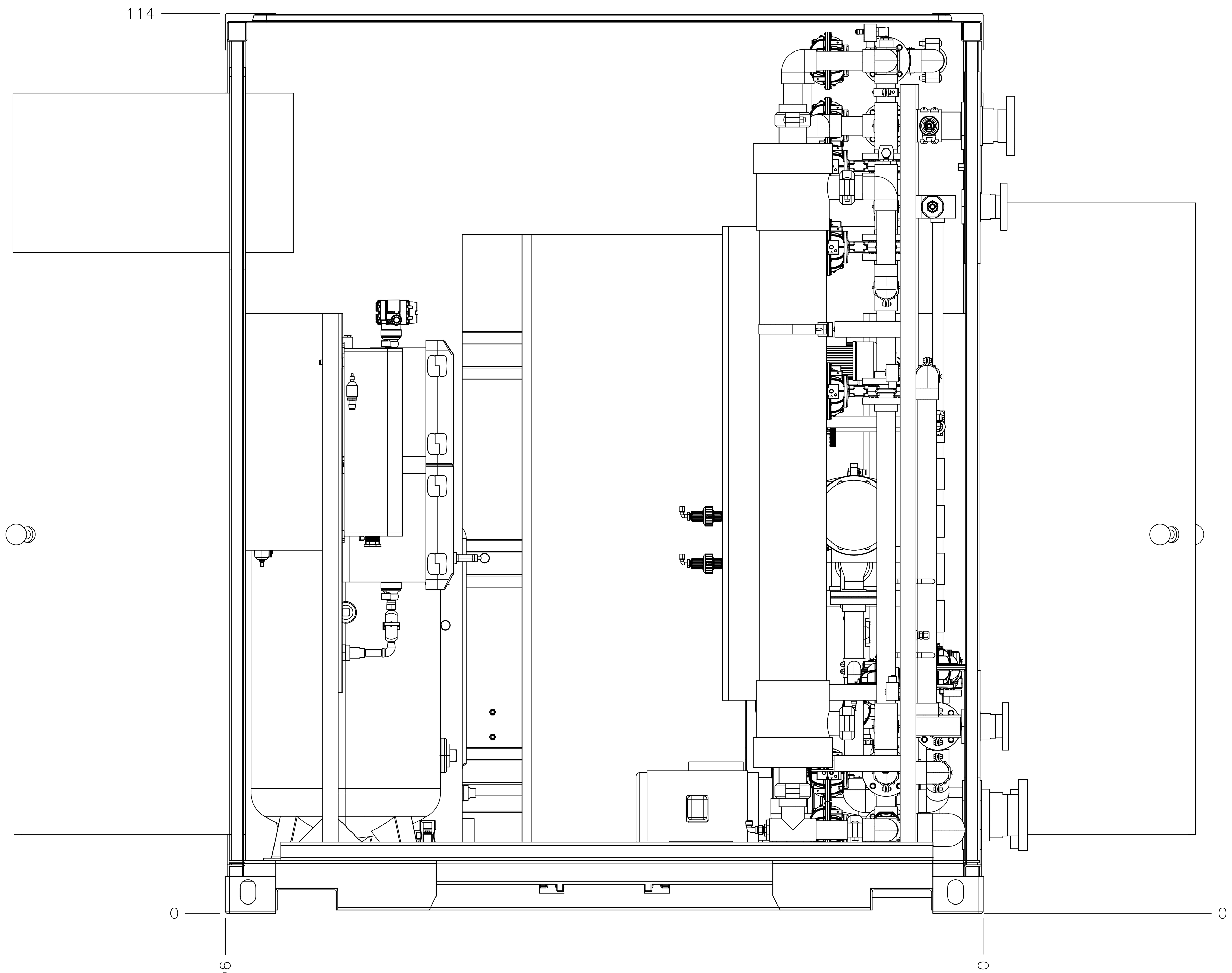

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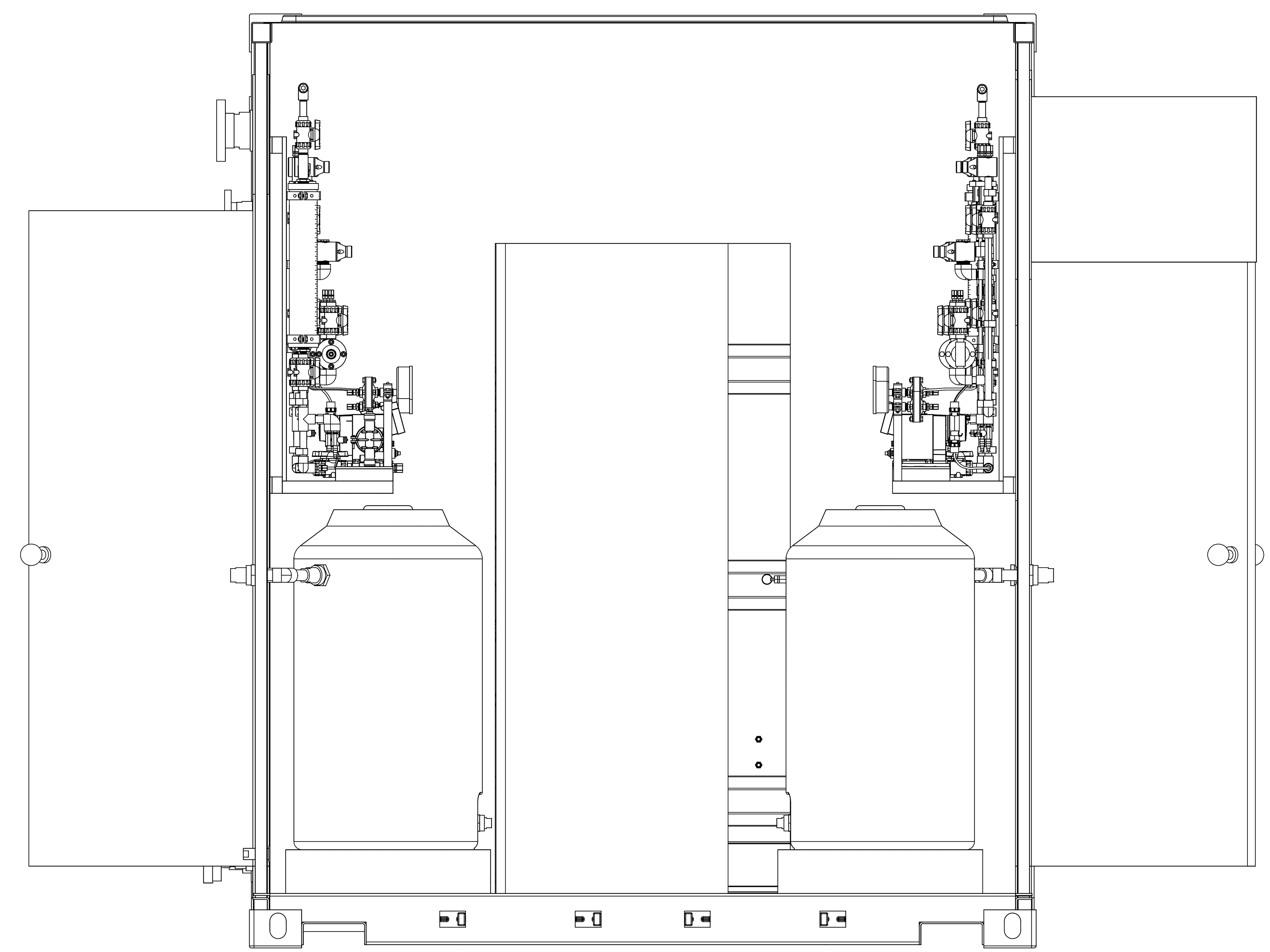
1-1/8" = 1'-0"



SECTION (D 1/5)
1-1/8" = 1'-0"

TOLERANCES UNLESS NOTED		
FRAC	DECIMALS	ANGLES
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	.XX ±	
	.XXX ±	

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

DRAWING NOTES
- NOTE 1.
- NOTE 2.
- NOTE 3.
- NOTE 4.
- NOTE 5.
- NOTE 6.

REV	DATE	DWN	APVD	DESCRIPTION
B	1/16/20	TJC	MMS	RELEASED FOR PRODUCTION
D	1/29/20	TJC		UPDATED CHEM FEED
E	4/28/20	NDL		AS-BUILTS
F	10/5/20	ECP	MMS	UPDATED PER FIELD MOD RECOMMENDATIONS

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TITLE GENERAL ARRANGEMENT
CONTAINERIZED UF SYSTEM
END ELEVATIONS

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-100-1	4 OF 5	F

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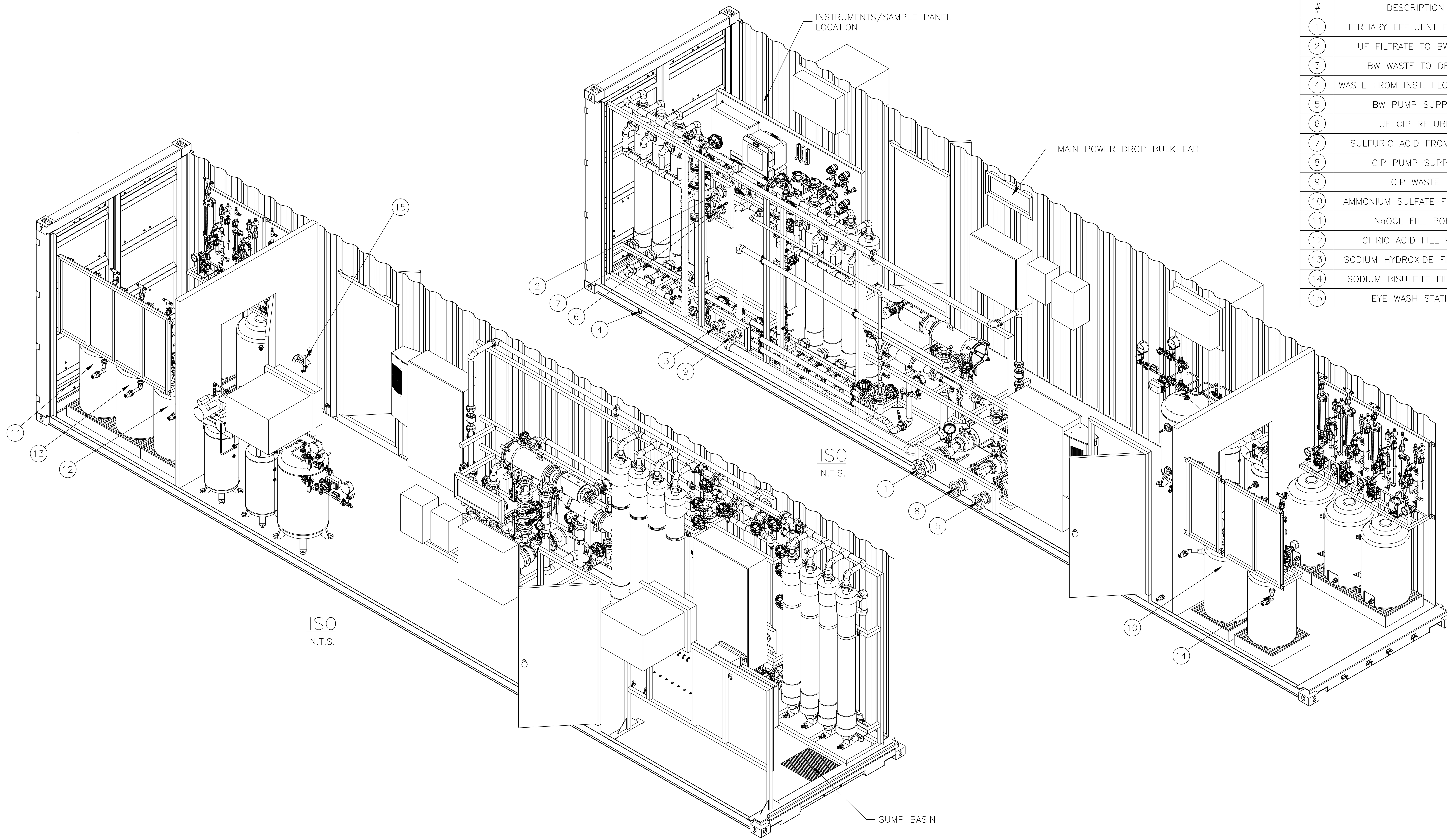

CONNECTION SCHEDULE

#	DESCRIPTION	TYPE	SIZE
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2	UF FILTRATE TO BW TNK	150# FLG	3.00
3	BW WASTE TO DRAIN	150# FLG	2.00
4	WASTE FROM INST. FLOOR DRAIN	FNPT	2.00
5	BW PUMP SUPPLY	150# FLG	3.00
6	UF CIP RETURN	150# FLG	2.00
7	SULFURIC ACID FROM CCRO	FNPT	0.50
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10	AMMONIUM SULFATE FILL PORT	FNPT	1.00
11	NaOCL FILL PORT	FNPT	1.00
12	CITRIC ACID FILL PORT	FNPT	1.00
13	SODIUM HYDROXIDE FILL PORT	FNPT	1.00
14	SODIUM BISULFITE FILL PORT	FNPT	1.00
15	EYE WASH STATION	FNPT	0.50

TOLERANCES UNLESS NOTED

FRAC	DECIMALS	ANGLES
± 3	.X ±	±
	.XX ±	
	.XXX ±	

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

DRAWING NOTES

NOTE 1.
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NOTE 6.

REV	DATE	DWN	APVD	DESCRIPTION
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D	1/29/20	TJC		UPDATED CHEM FEED
E	4/28/20	NDL		AS-BUILTS
F	10/5/20	ECP	MMS	UPDATED PER FIELD MOD RECOMMENDATIONS

NOTICE ON REPRODUCTIONS

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CHK'D BY: EIP	DATE: 12/6/19
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CONTAINERIZED UF SYSTEM
ISO VIEWS

CLIENT NAME: EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-100-1	5 OF 5	F

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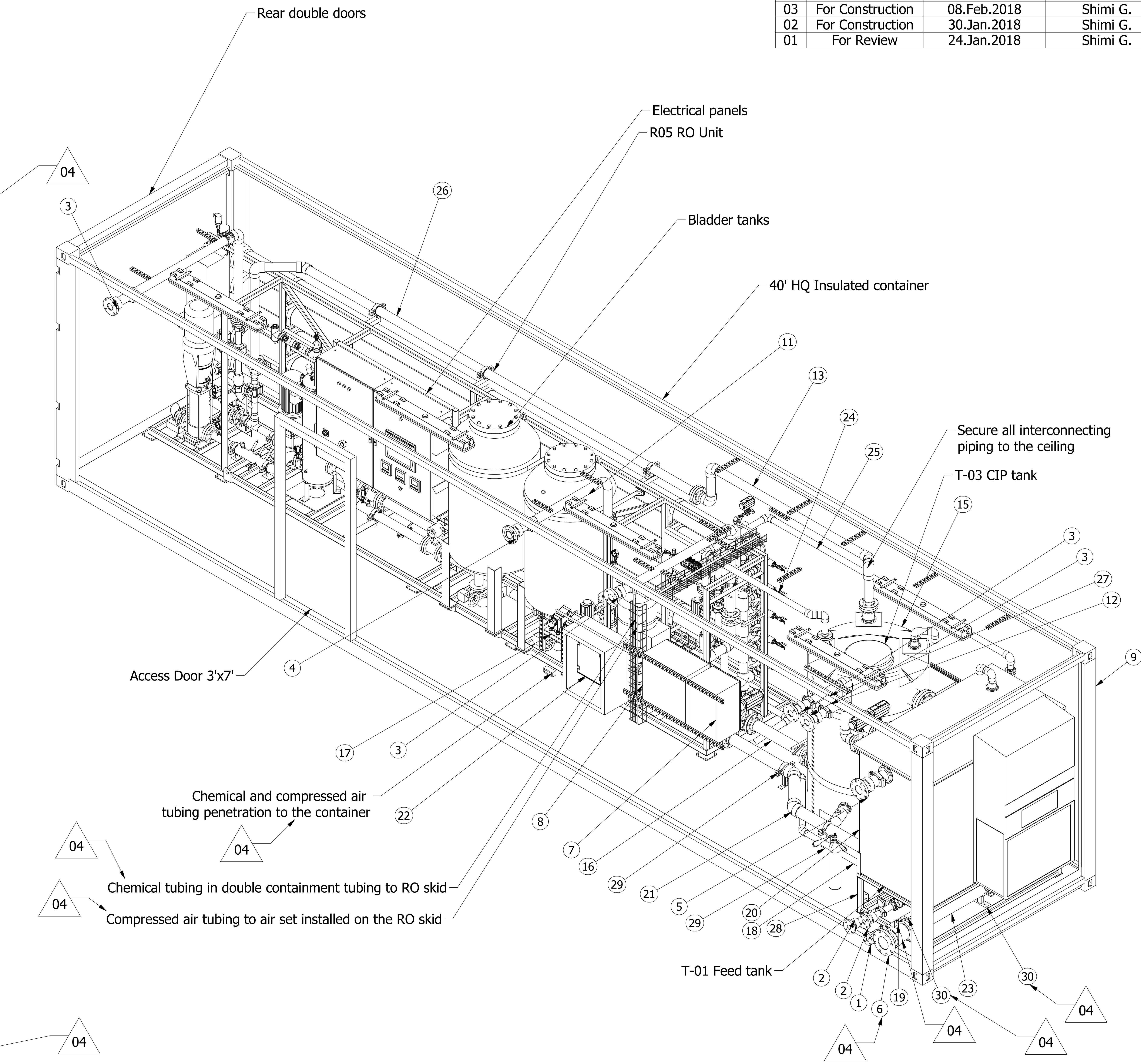
Appendix B

CCRO Pilot Plant Layout

REVISION HISTORY			
REV	Status	Checked Date	Checked By
04	For Construction	13.Feb.2018	Shimi G.
03	For Construction	08.Feb.2018	Shimi G.
02	For Construction	30.Jan.2018	Shimi G.
01	For Review	24.Jan.2018	Shimi G.

PARTS LIST

ITEM	PART NUMBER	DESCRIPTION	QTY/ Length
1	1.5in Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	1
2	2in Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	2
3	3in Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	4
4	3in SS316 Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	1
5	4in Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	1
6	6in Flange Adapter	See drawing "IS-FLA-EMWD-R05-01"	1
7	AE 1338.500 (1)	120V Load panel	1
8	AE 1360.500 (1)	Transformer enclosure	1
9	Assembly - Container	See drawing "SC-EMWD-R05-01"	1
10	Band for CIP tank		2
11	Brine Feed Inlet Int.	See drawing "PI-FD-EMWD-R05-05"	1
12	Brine inlet to Feed tank	See drawing "IS-BR-EMWD-R05-03"	1
13	Brine to CIP Tank Line2	See drawing "IS-BR-EMWD-R05-02"	1
14	Brine to Drain Int.	See drawing "IS-BR-EMWD-R05-04"	1
15	CIP Tank 550 GAL	See drawing "WT-CIP-EMDW-R05-01"	1
16	CIP Tank to Feed Line	See drawing "IS-CIP-EMWD-R05-01"	1
17	Dosing pumps box	See drawing "DP-EMWD-R05-01"	1
18	Drain line Int	See drawing "IS-DR-EMWD-R05-02"	1
19	Drain of CIP tank	See drawing "IS-DR-EMWD-R05-03"	1
20	Feed tank	See drawing "WT-FEED-EMDW-010-01"	1
21	From Feed tank to RO	See drawing "IS-FD-EMWD-R05-02"	1
22	NSYPLM43	Power Supply connection box	1
23	OF of CIP tank	See drawing "IS-OF-EMWD-R05-01"	1
24	Permeate to CIP Tank Line	See drawing "SC-PR-EMWD-R05-02"	1
25	Permeate to Feed tank Line	See drawing "IS-PR-EMWD-R05-03"	1
26	RO R5	See drawing "GA-EMWD-R05-02"	1
27	Raw inlet to Feed tank	See drawing "IS-FD-EMWD-R05-04"	1
28	Skid for Feed tank	See drawing "STR-EMWD-R05-02"	1
29	Pipe Support Parallel Welded Clamp 4"	DWG No. GD-STR-51 "Type 1"	3
30	Pipe Support Parallel Welded Clamp 6"	DWG No. GD-STR-51 "Type 1"	3



For Construction

NOTES:
1) All dimensions in inches.
2) For details and dimenions see sheet 2/3.
3) For external piping connections details see sheet 3/3.
4) Secure all equipment to the container . Add additional supports if require .

Designed by:	Checked by:	Approved by:	Project:
Igor Komkov 30.Jan.2018	Shimi G. 13.Feb.2018		EMWD Reflex R05

DESALITECH
One Gateway Center,
Suite 809Newton,
MA 02458
Phone: (617) 564 1647

Desalitech Advanced Desalination Technologies

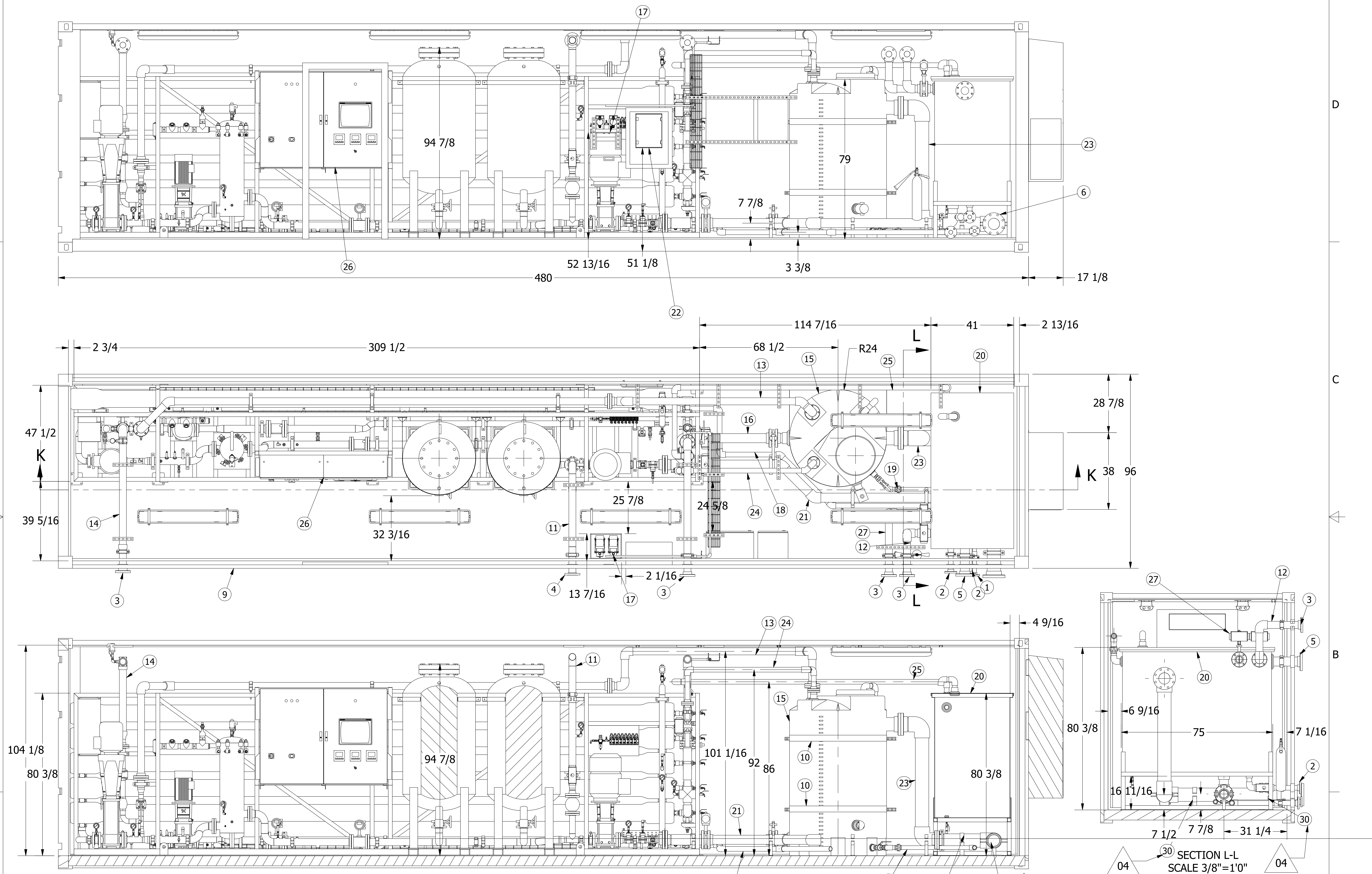
Unless Other Specified:
All Dimentions are in inches.
Tolerances:
Linear ±1/16"; Angular ±0.5'

First Angle Projection

Part Number: EMWD GA R05

Drawing Number: GA-EMWD-R05-01

Size:	Scale:	Revision:	Sheet:
C	3/8"=1'0"	04	1 of 3

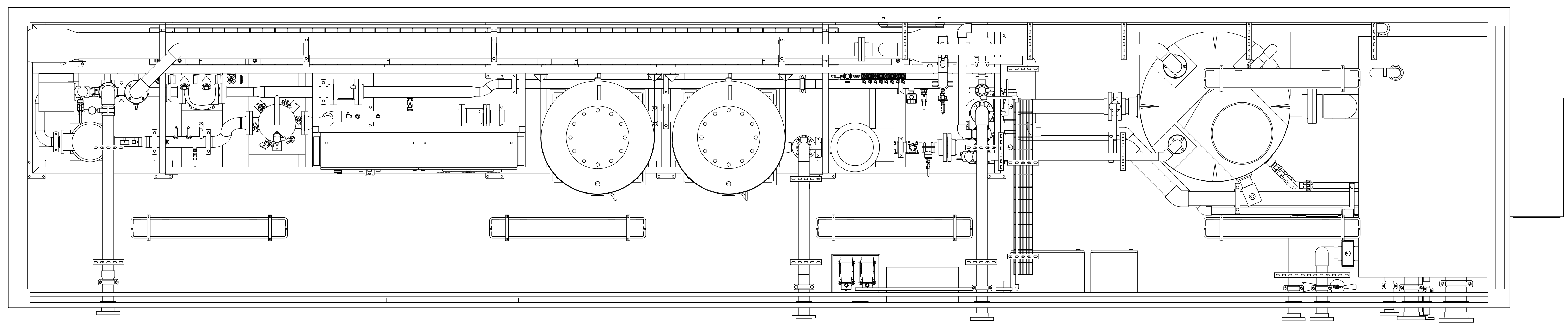


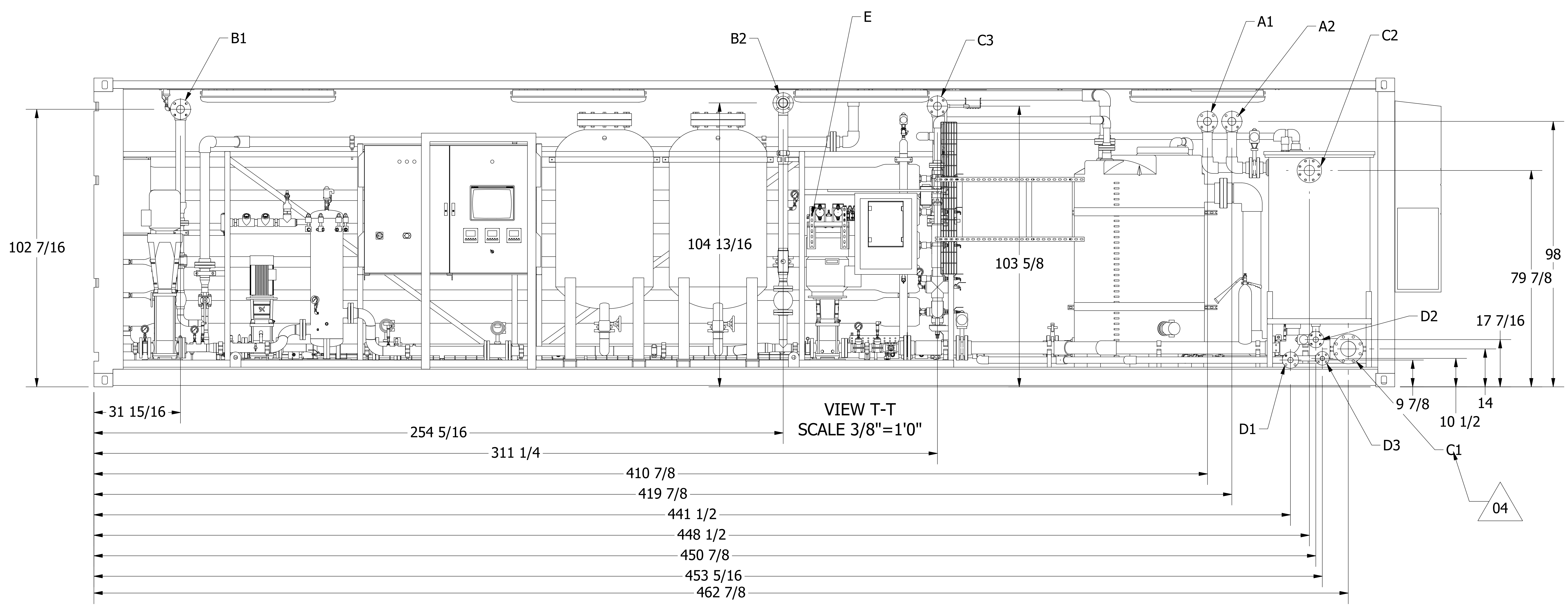
SECTION K-K
SCALE 3/8"=1'0"

For Construction

NOTES:
1) All dimensions in inches.

Designed by:	Checked by:	Approved by:	Project:
Igor Komkov 30.Jan.2018	Shimi G. 13.Feb.2018		EMWD Reflex R05
DESALITECH One Gateway Center, Suite 809Newton, MA 02458 Phone: (617) 564 1647 Desalitech Advanced Desalination Technologies		Unless Other Specified: All Dimentions are in inches. Tolerances: Linear ±1/16"; Angular ±0.5'	Part Number: EMWD GA R05
		First Angle Projection	Drawing Number: GA-EMWD-R05-01
			Size: C / Scale: 1/2"=1'0" / Revision: 04 / Sheet: 2 of 3





EXTERNAL PIPING CONNECTIONS

No.	Name of Connection	SIZE	Type of Connection
A1	Raw Inlet to Feed tank	3"	PVC Flange #150
A2	Brine Inlet to Feed tank	3"	PVC Flange #150
B1	Brine to Drain	3"	PVC Flange #150
B2	RO Feed Brine	3"	PVC Flange #150
C1	Overflow of CIP T-03 tank	4"	PVC Flange #150
C2	Overflow of Feed T-01 tank	4"	PVC Flange #150
C3	RO Permeate outlet	3"	PVC Flange #150
D1	Drain collector to Drain	2"	PVC Flange #150
D2	Drain outlet of Feed tank	2"	PVC Flange #150
D3	Drain of CIP tank	1 1/2"	PVC Flange #150
E	Comp. Air to RO	3/8"	Tube adapter

04

NOTES:
1) All dimensions in inches.

For Construction

Designed by:	Checked by:	Approved by:	Project:
Igor Komkov 30.Jan.2018	Shimi G. 13.Feb.2018		EMWD Reflex R05

DESALITECH
One Gateway Center,
Suite 809Newton,
MA 02458
Phone: (617) 564 1647

Desalitech
Advanced Desalination Technologies

Unless Other Specified:
All Dimentions are in inches.
Tolerances:
Linear ±1/16"; Angular ±0.5'

First Angle Projection

Part Number:
EMWD GA R05

Drawing Number:
GA-EMWD-R05-01

Size:	Scale:	Revision:	Sheet:
C	3/4"=1'0"	04	3 of 3

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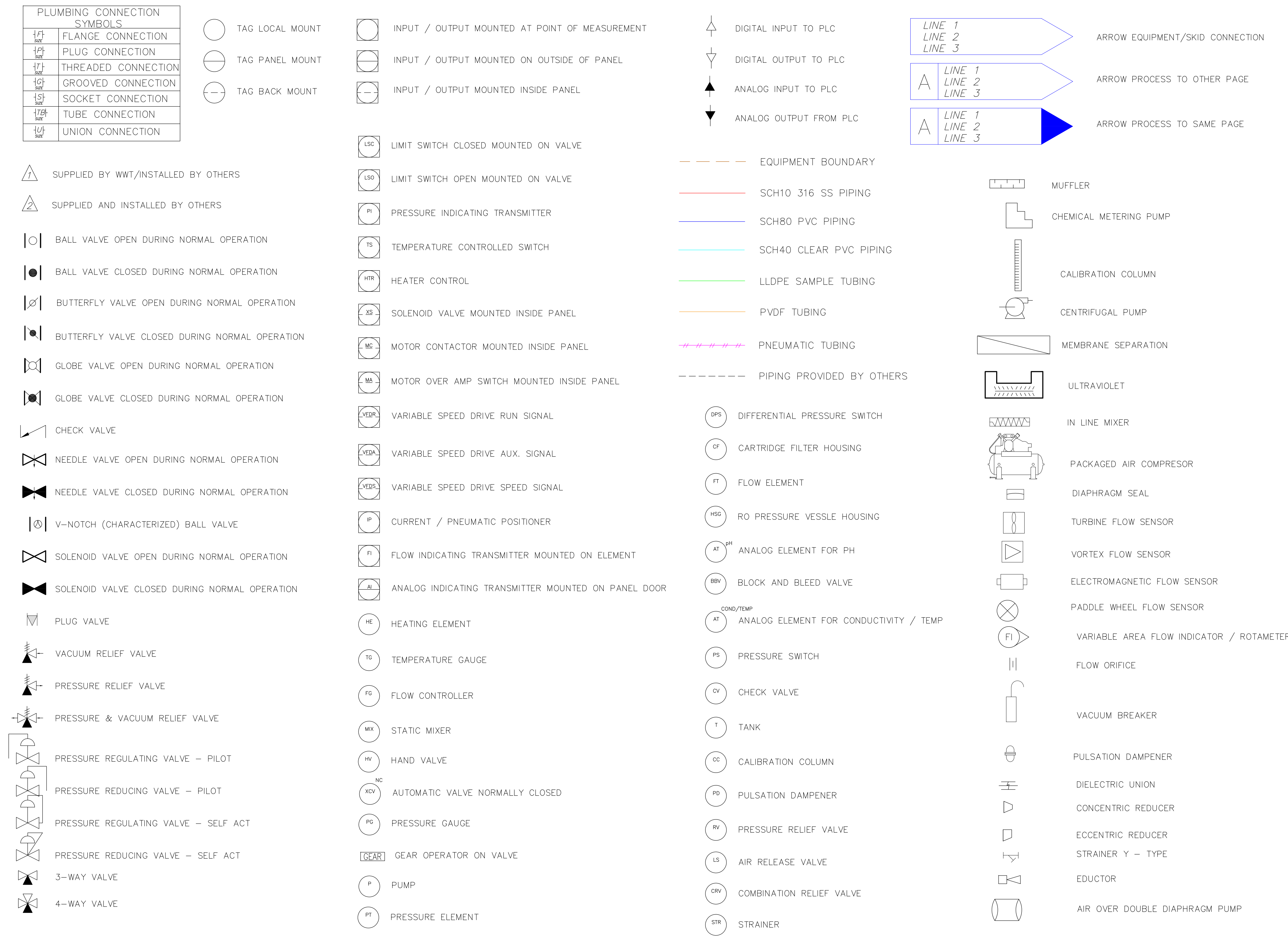
Appendix C

MF P&IDs



UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

DRAWING NOTES	REV	DATE	DWN	APVD	DESCRIPTION
NOTE 1.	B	9/29/20	EIP	SAB	ADDED AODD PUMP SYMBOL AND STR LABEL
NOTE 2.					
NOTE 3.					
NOTE 4.					
NOTE 5.					
NOTE 6.					

DRAWN BY	DATE
EIP	10/29/19
CHK'D BY	**DATE**
SAB	11/15/19
SIZE	**SCALE**
D	NONE
FILE TYPE	
ACAD	

TITLE PROCESS AND INSTRUMENTATION DIAGRAM
P & ID LEGEND

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-200-1	1 OF 1	B

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302 LAKE HAZELTINE DRIVE
CHASKA, MN 55318 USA
952-448-4884
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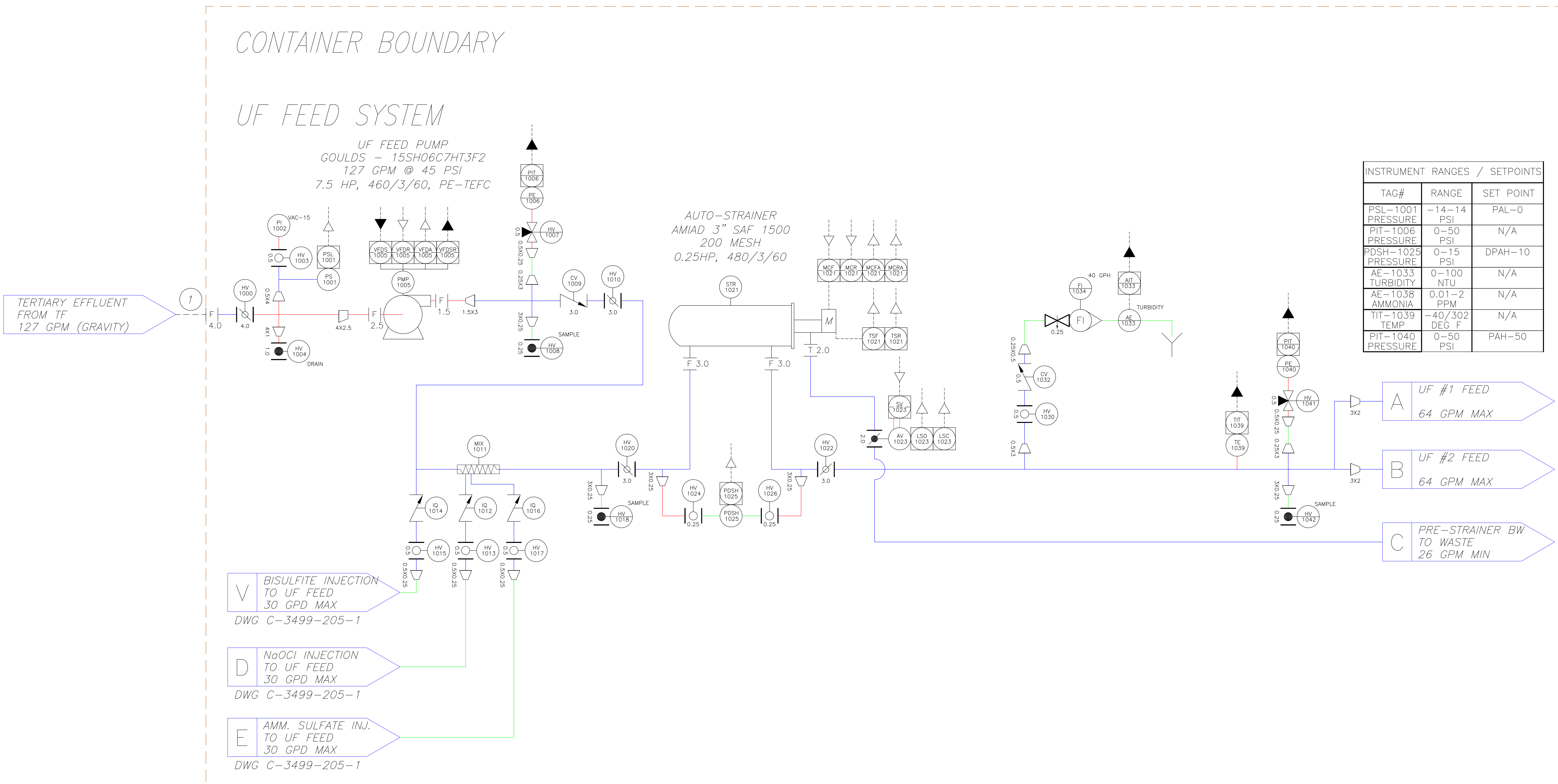

INSTRUMENT RANGES / SETPOINTS		
TAG#	RANGE	SET POINT
PSL-1001 PRESSURE	-14-14 PSI	PAL-0
PIT-1006 PRESSURE	0-50 PSI	N/A
PDSH-1025 PRESSURE	0-15 PSI	DPAH-10
AE-1033 TURBIDITY	0-100 NTU	N/A
AE-1038 AMMONIA	0.01-2 PPM	N/A
TIT-1039 TEMP	-40/302 DEG F	N/A
PIT-1040 PRESSURE	0-50 PSI	PAH-50

CONTAINER CONNECTIONS PER DWG C-3499-100-1

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

DRAWING NOTES

REV	DATE	DWN	APVD	DESCRIPTION
B	1/10/20	EIP	BCC	ADDED BISULFITE INJ, MOVED AMMONIA ANA. TO UF FILTRATE - TO SHOP
C	4/1/20	EIP	SAB	CHANGE TAG # ON SOD. BISULFITE INJECTION QUILL / HV
D	9/29/20	EIP	SAB	CHANGED TURB METER RANGE, AS STARTED UP

DRAWN BY	DATE
EIP	10/29/19
CHK'D BY	DATE
SAB	11/15/19
SIZE	SCALE
D	NONE

FILE TYPE: ACAD

TITLE: PROCESS AND INSTRUMENTATION DIAGRAM
UF FEED EQUIPMENT

CLIENT NAME: EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-201-1	1 OF 1	D

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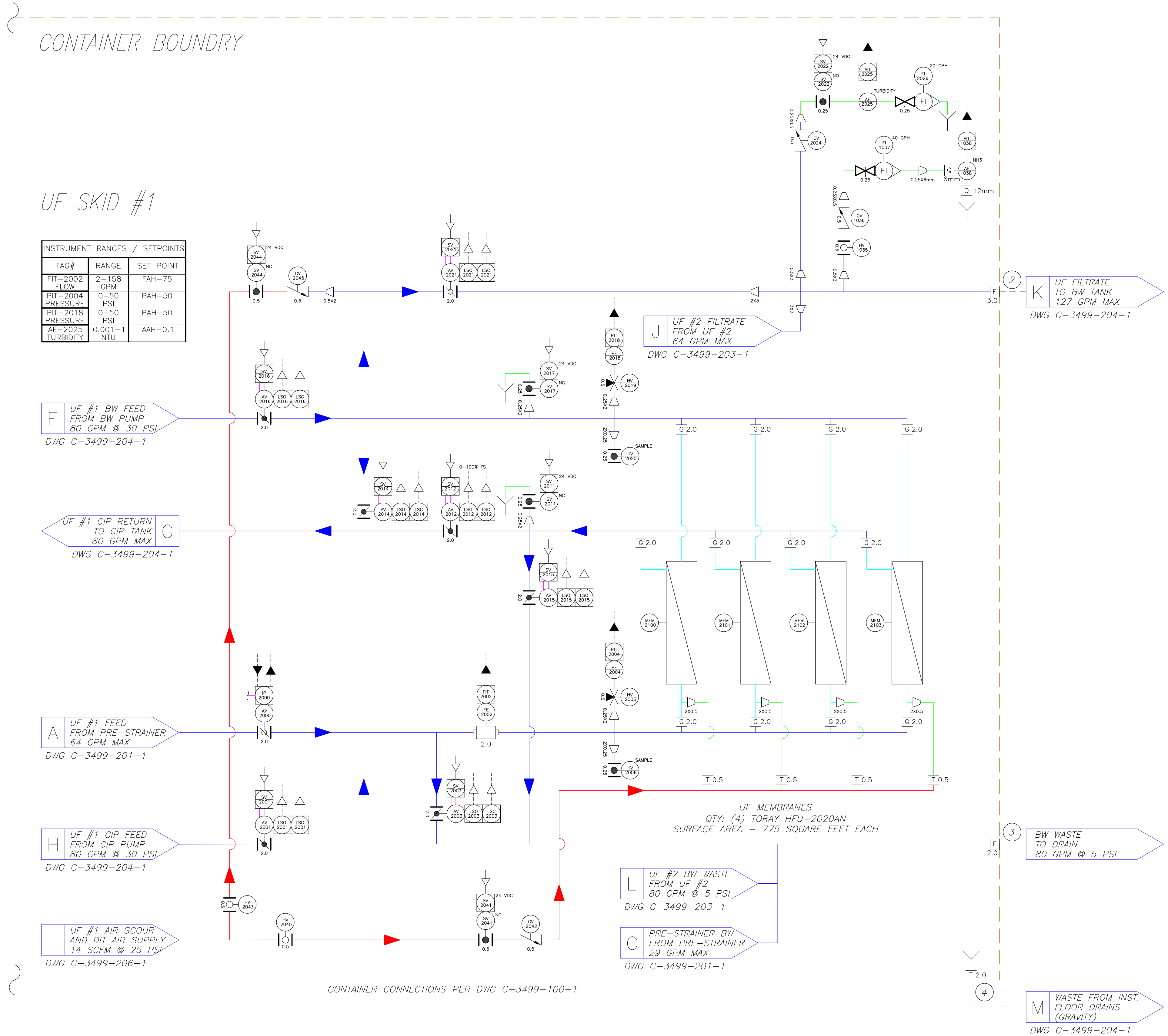

INSTRUMENT RANGES / SETPOINTS

TAG#	RANGE	SET POINT
FIT-2002 FLOW	2-158 GPM	FAH-75
PIT-2004 PRESSURE	0-50 PSI	PAH-50
PIT-2018 PRESSURE	0-50 PSI	PAH-50
AE-2025 TURBIDITY	0.001-1 NTU	AAH-0.1

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DRAWING NOTES

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

REV	DATE	DWN	APVD	DESCRIPTION
B	1/10/20	EIP	SAB	MOVE AMMONIA ANA. TO UF FILTRATE - TO SHOP
C	9/29/20	EIP	SAB	CHANGED RANGE OR FILTRATE TURB. METER, AS STARTED UP

DRAWN BY	DATE
EIP	10/29/19
CHK'D BY	**DATE**
SAB	11/15/19
SIZE	**SCALE**
D	NONE
FILE TYPE	
ACAD	

TITLE PROCESS AND INSTRUMENTATION DIAGRAM
UF MEMBRANE RACK #1

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-202-1	1 OF 1	C

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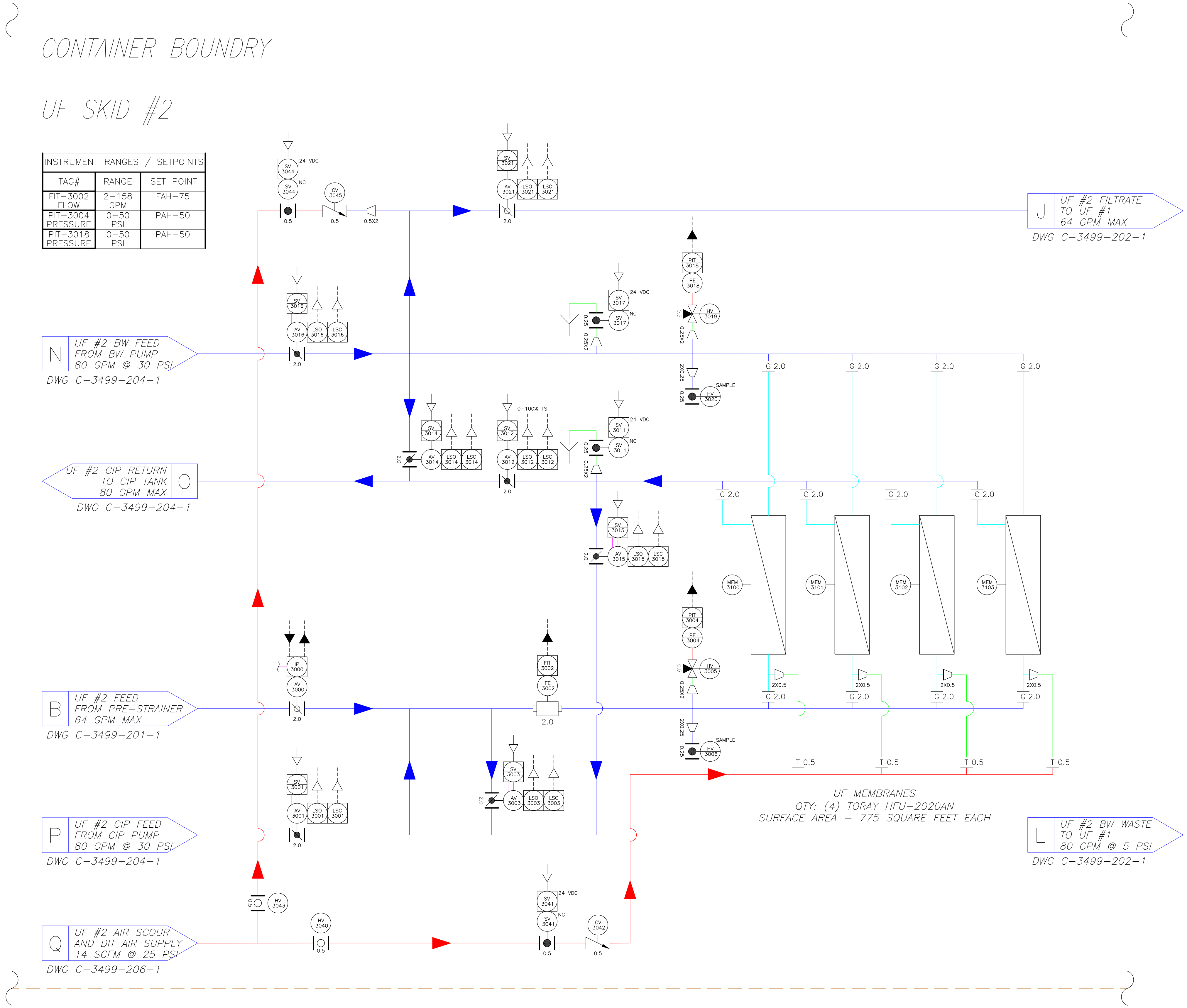
8 7 6 5 4 3 2 1



INSTRUMENT RANGES / SETPOINTS		
TAG#	RANGE	SET POINT
FIT-3002 FLOW	2-158 GPM	FAH-75
PIT-3004 PRESSURE	0-50 PSI	PAH-50
PIT-3018 PRESSURE	0-50 PSI	PAH-50

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

DRAWING NOTES

REV	DATE	DWN	APVD	DESCRIPTION
B	1/15/20	EIP	BCC	FIXED TAG NUMBERS - TO SHOP

DRAWN BY	DATE	CHK'D BY	DATE	SIZE	SCALE	FILE TYPE
EIP	10/29/19	SAB	11/15/19	D	NONE	ACAD

TITLE PROCESS AND INSTRUMENTATION DIAGRAM
UF MEMBRANE RACK #2

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD)
MF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-203-1	1 OF 1	B

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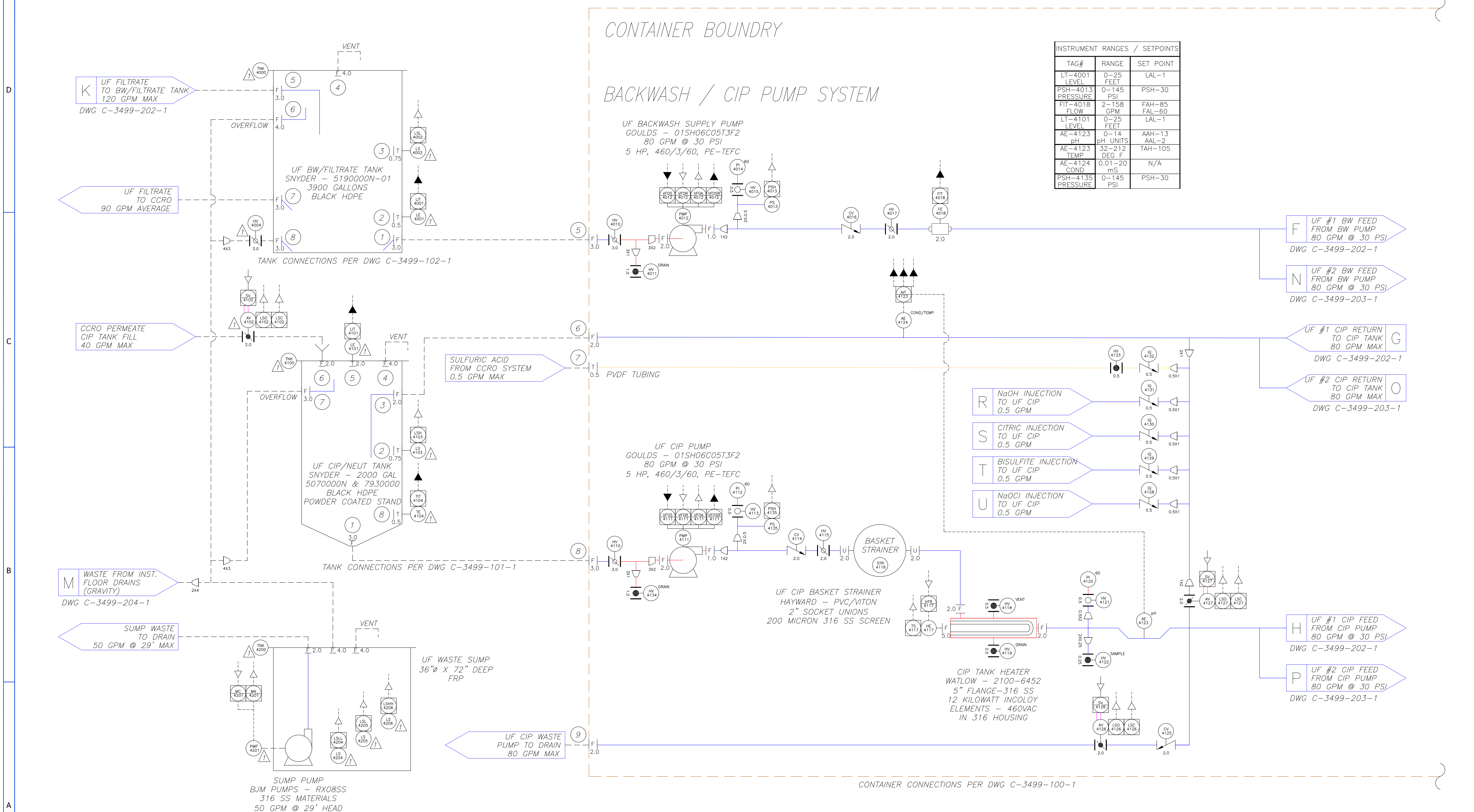
8 7 6 5 4 3 2 1



INSTRUMENT RANGES / SETPOINTS		
TAG#	RANGE	SET POINT
LT-4001 LEVEL	0-25 FEET	LAL-1
PSH-4013 PRESSURE	0-145 PSI	PSH-30
FIT-4018 FLOW	2-158 GPM	FAH-85 FAL-60
LT-4101 LEVEL	0-25 FEET	LAL-1
AE-4123 pH	0-14 pH UNITS	AAH-13 AAL-2
AE-4123 TEMP	32-212 DEG F	TAH-105
AE-4124 COND	0.01-20 mS	N/A
PSH-4135 PRESSURE	0-145 PSI	PSH-30

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

REV	DATE	DWN	APVD	DESCRIPTION
B	12/11/19	EIP	TJC	CHANGED TO 3900 GALLON FILTRATE TANK VOLUME, HEATER MODEL
C	9/29/20	EIP	SAB	REMOVED CIP TANK DRAIN VALVE, CCRO INLET VALVE, SUMP VALVES

DRAWING NOTES

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

DRAWN BY	DATE	CHK'D BY	DATE	SIZE	SCALE	FILE TYPE
EIP	10/29/19	SAB	11/15/19	D	NONE	ACAD

TITLE PROCESS AND INSTRUMENTATION DIAGRAM FILTRATE / BACKWASH / CIP EQUIPMENT

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD) UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-204-1	1 OF 1	C

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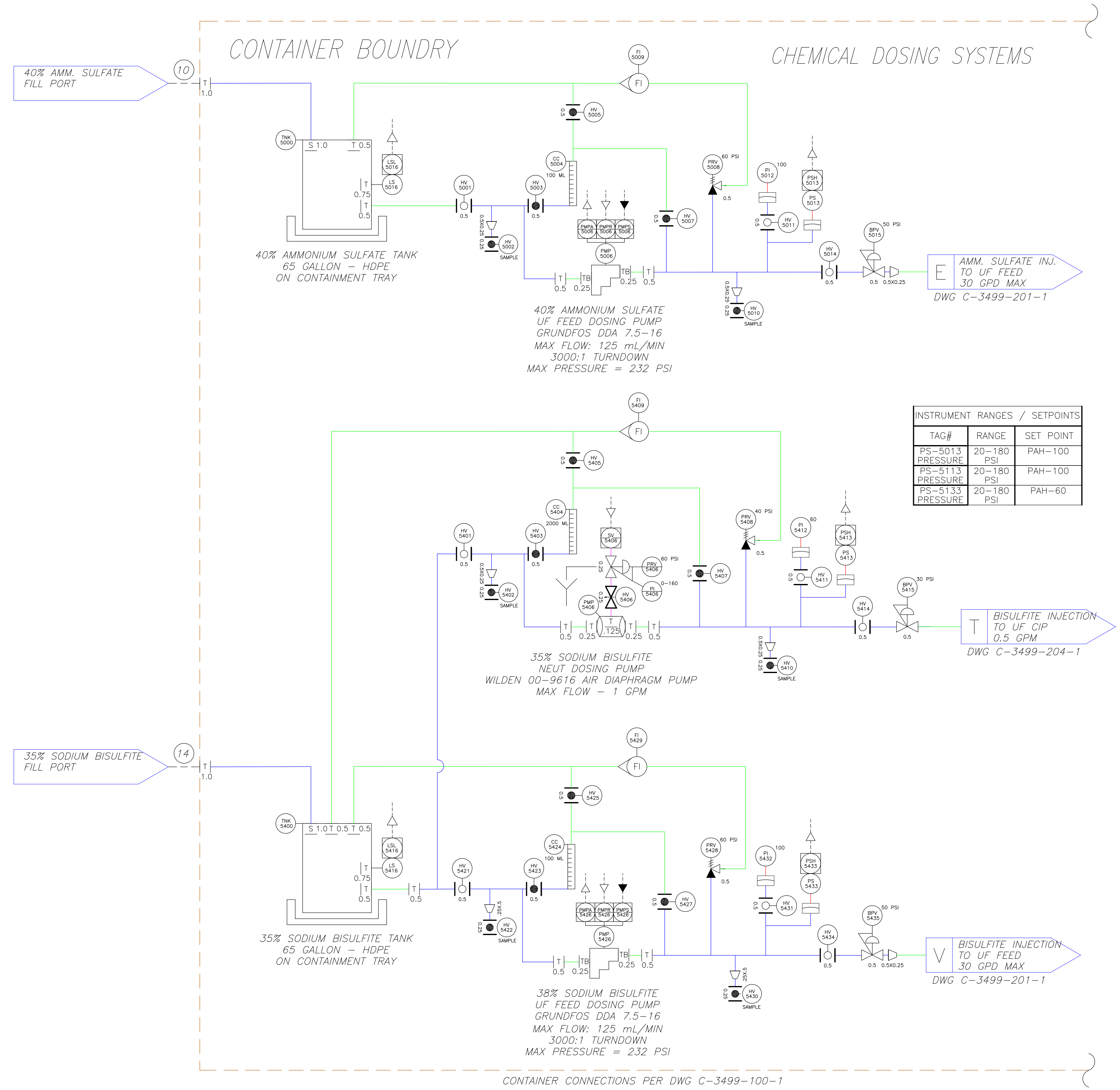
T:3.3F - D Size Title Block_REV A



INSTRUMENT RANGES / SETPOINTS

TAG#	RANGE	SET POINT
PS-5013 PRESSURE	20-180 PSI	PAH-100
PS-5113 PRESSURE	20-180 PSI	PAH-100
PS-5133 PRESSURE	20-180 PSI	PAH-60

DRAWING NOTES	REV	DATE	DWN	APVD	DESCRIPTION
UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)	B	1/15/20	EIP	BCC	FIXED VALVE TYPE, TAG NUMBER - TO SHOP
NOTE 1.	C	1/21/20	EIP	BCC	ADDED FEED BISULFITE INJECITON SYSTEM
NOTE 2.	D	3/27/20	EIP	SAB	ADDED PRV / NEDDLE VALVE TO AIR PUMPS
NOTE 3.	E	9/29/20	EIP	SAB	CHANGE LOCATION OF BISULFITE / CHLORINE PUMPS, AS STARTED UP
NOTE 4.					
NOTE 5.					
NOTE 6.					

DRAWN BY: EIP	DATE: 10/29/19	TITLE	PROCESS AND INSTRUMENTATION DIAGRAM CHEMICAL DOSING SYSTEMS
CHK'D BY: SAB	DATE: 11/15/19	CLIENT NAME	EASTERN MUNICIPAL WATER DISTRICT (EMWD) UF CONTAINERIZED SYSTEM
SIZE: D	SCALE: NONE		
FILE TYPE: ACAD	PROJECT NUMBER: C-3499-1019	DRAWING NUMBER: C-3499-205-1	SHEET: 1 OF 2, REV: E

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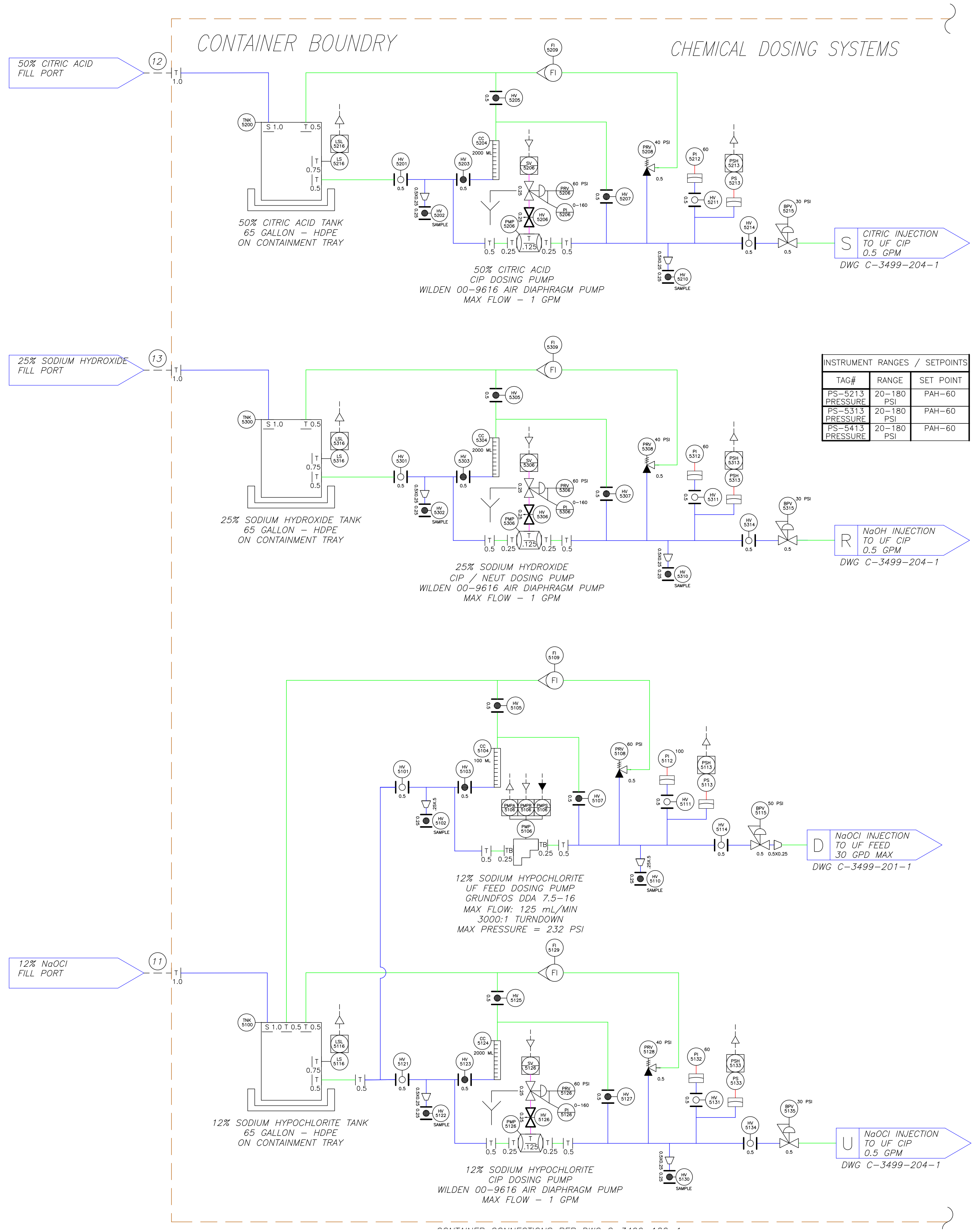

INSTRUMENT RANGES / SETPOINTS		
TAG#	RANGE	SET POINT
PS–5213 PRESSURE	20–180 PSI	PAH–60
PS–5313 PRESSURE	20–180 PSI	PAH–60
PS–5413 PRESSURE	20–180 PSI	PAH–60

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

DRAWING NOTES

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

REV	DATE	DWN	APVD	DESCRIPTION
B	1/15/20	EIP	BCC	FIXED TAG NUMBER. VALVE TYPE - TO SHOP
C	1/21/20	EIP	BCC	ADDED FEED BISUFITE INJECTION SYSTEM
D	3/27/20	EIP	SAB	ADDED PRV / NEDDLE VALVE TO AIR PUMPS
E	9/29/20	EIP	SAB	CHANGED LOCATION OF BISULFITE / CHLORINE PUMPS, AS STARTED UP

DRAWN BY	DATE	CHK'D BY	DATE	SIZE	SCALE	FILE TYPE
EIP	10/29/19	SAB	11/15/19	D	NONE	ACAD

TITLE PROCESS AND INSTRUMENTATION DIAGRAM
CHEMICAL DOSING SYSTEMS

CLIENT NAME EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-205-1	2 OF 2	E

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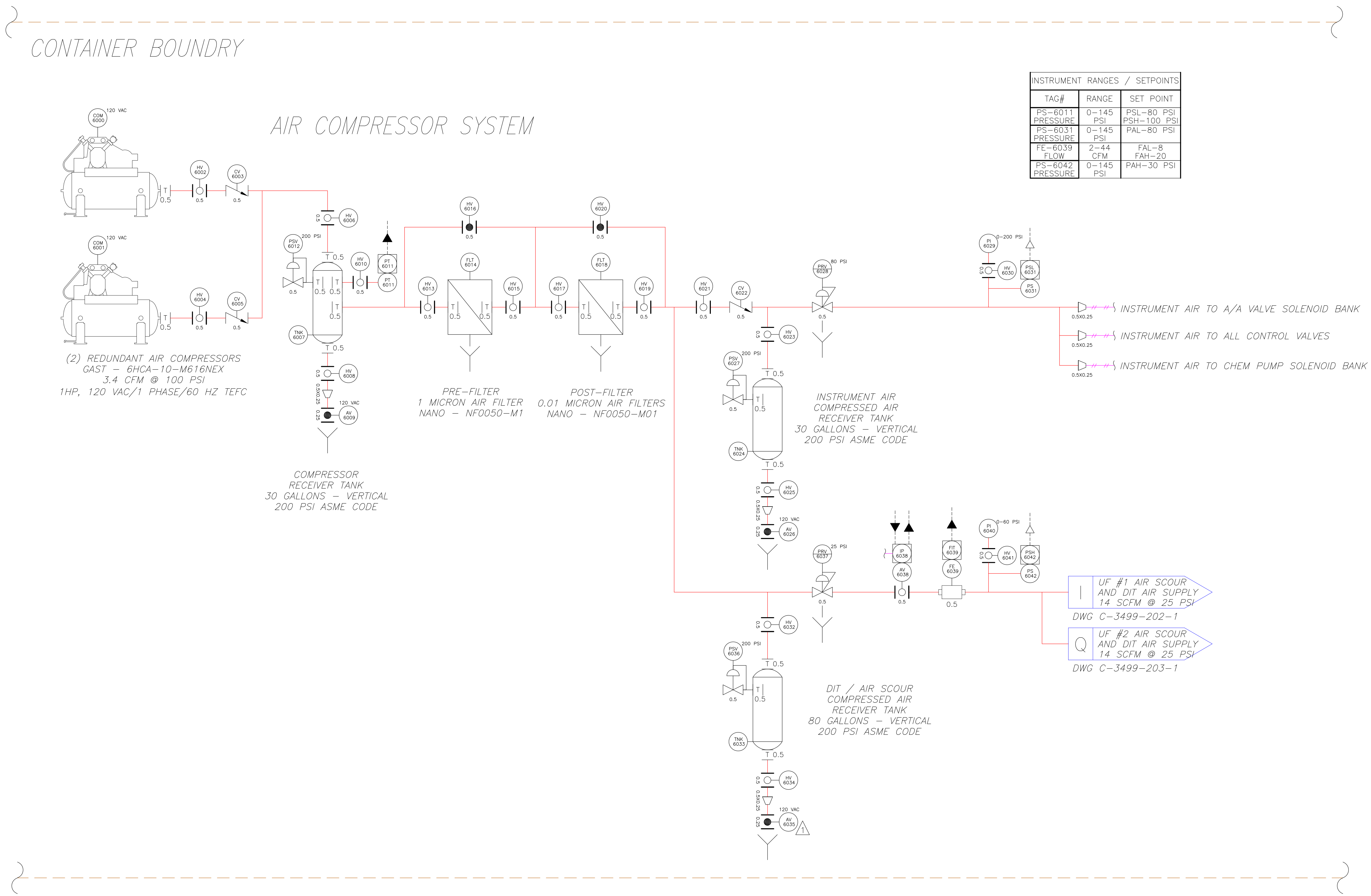

INSTRUMENT RANGES / SETPOINTS		
TAG#	RANGE	SET POINT
PS-6011 PRESSURE	0-145 PSI	PSL-80 PSI PSH-100 PSI
PS-6031 PRESSURE	0-145 PSI	PAL-80 PSI
FE-6039 FLOW	2-44 CFM	FAL-8 FAH-20
PS-6042 PRESSURE	0-145 PSI	PAH-30 PSI

UNCONTROLLED IF PRINTED (UNLESS STAMPED OTHERWISE)

NOTE 1.
NOTE 2.
NOTE 3.
NOTE 4.
NOTE 5.
NOTE 6.

DRAWING NOTES

REV	DATE	DWN	APVD	DESCRIPTION
B	1/15/20	EIP	BCC	REMOVED INSTALLED BY OTHERS TAG - TO SHOP
C	3/27/20	EIP	SAB	MOVED AIR CHEM PUMPS PRV TO EACH PUMP
D	9/29/20	EIP	SAB	CHANGED PS ON REC. TANK TO PT, REMOVED PI ON PRESSURE REG.

NOTICE ON REPRODUCTIONS

DRAWN BY	DATE	CHK'D BY	DATE	SIZE	SCALE	FILE TYPE
EIP	10/29/19	SAB	11/22/19	D	NONE	ACAD

TITLE: PROCESS AND INSTRUMENTATION DIAGRAM
AIR COMPRESSOR EQUIPMENT

CLIENT NAME: EASTERN MUNICIPAL WATER DISTRICT (EMWD)
UF CONTAINERIZED SYSTEM

PROJECT NUMBER	DRAWING NUMBER	SHEET	REV
C-3499-1019	C-3499-206-1	1 OF 1	D

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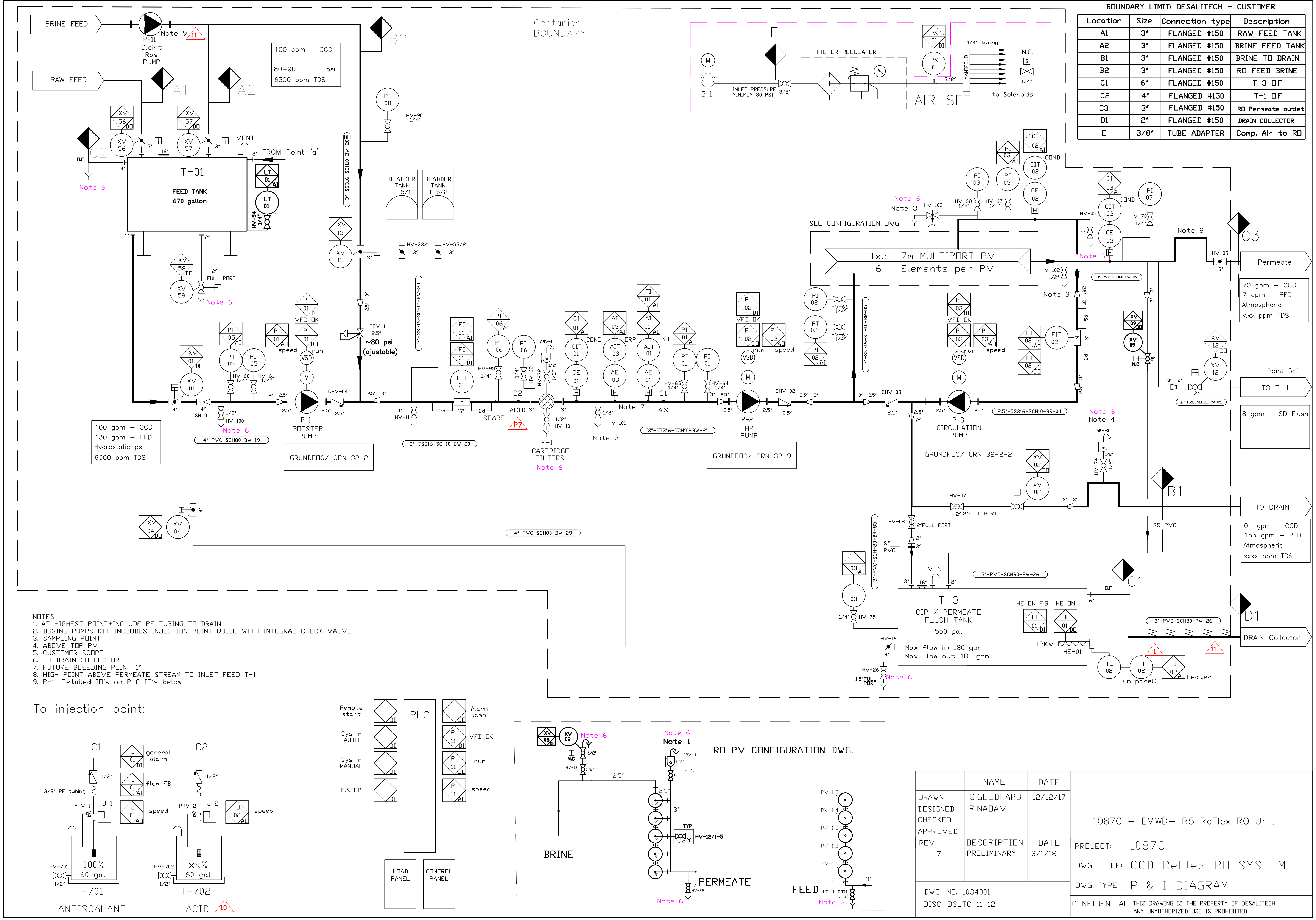
Appendix D

CCRO P&ID



BOUNDARY LIMIT: DESALITECH – CUSTOMER

Location	Size	Connection type	Description
A1	3"	FLANGED #150	RAW FEED TANK
A2	3"	FLANGED #150	BRINE FEED TANK
B1	3"	FLANGED #150	BRINE TO DRAIN
B2	3"	FLANGED #150	RO FEED BRINE
C1	6"	FLANGED #150	T-3 O.F
C2	4"	FLANGED #150	T-1 O.F
C3	3"	FLANGED #150	RO Permeate outlet
D1	2"	FLANGED #150	DRAIN COLLECTOR
E	3/8"	TUBE ADAPTER	Comp. Air to RO

NOTES:
1. AT HIGHEST POINT+INCLUDE PE TUBING TO DRAIN
2. DOSING PUMPS KIT INCLUDES INJECTION POINT QUILL WITH INTEGRAL CHECK VALVE
3. SAMPLING POINT
4. ABOVE TOP PV
5. CUSTOMER SCOPE
6. TO DRAIN COLLECTOR
7. FUTURE BLEEDING POINT 1"
8. HIGH POINT ABOVE PERMEATE STREAM TO INLET FEED T-1
9. P-11 Detailed IO's on PLC IO's below

	NAME	DATE
DRAWN	S.GOLDFARB	12/12/17
DESIGNED	R.NADAV	
CHECKED		
APPROVED		
REV.	DESCRIPTION	DATE
7	PRELIMINARY	3/1/18

DWG. NO. 1034001
DISC: DSLTC 11-12

1087C – EMWD– R5 ReFlex RO Unit

PROJECT: 1087C
DWG TITLE: CCD ReFlex RO SYSTEM
DWG TYPE: P & I DIAGRAM

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Appendix E

Membrane Autopsy Report

Membrane Autopsy Report

Silver Level

Report Issued:

05-31-2021

Tests Performed For:

EMWD CCRO Pilot
SPI Engineering

Manufacturer: Filmtec
Model: Fortilife CR100i
Position: Tail Position
Serial #: T7784622
AWC LSA#: 0221078

Project Reference: EMWD CCRO Pilot

Tests Performed By:

Vana Abbas
Joshua Utter
Juliette Hernandez
Omar Mulla-Saleh
David Brown

Table of Contents

Introduction

On 04/26/2021, a membrane was received for autopsy. This report describes the membrane autopsy procedures performed for SPI Engineering- EMWD CCRO Pilot.
The observed findings are presented herein.

Membrane Information

Element Position	Manufacturer	Model Number	Serial Number	Element Diameter
Tail Position	Filmtec	Fortilife CR100i	T7784622	8”

Table 1: Membrane Information.

Figure 1: Membrane Information.

Figure 2: Serial number.

Shipping and Handling Condition

The element arrived at AWC's facility packaged in a cardboard box and closed with tape. The element was packaged in a cardboard box. The element was placed inside plastic bags and closed with tape.

Figure 3:The element arrived at AWC's facility packaged in a cardboard box and closed with tape.

Figure 4: The element was placed inside membrane bags and closed with tape.

Figure 5: The element was placed inside plastic bags and closed with tape.

Element Weight

The module was weighed as received in wet condition.

Results

Manufacturer	Model	Membrane (as received) wet weight (lbs)	Typical Clean Membrane wet weight (lbs)
Filmtec	Fortilife CR100i	29.8 lbs	32-35 lbs

Table 2: Weight Test Results.

External Inspection

The external condition of the element was inspected and recorded.

Fiberglass Shell and Anti-telescoping Devices (ATDs)

The element appeared to be in good condition.

Figure 6: Fiberglass shell.

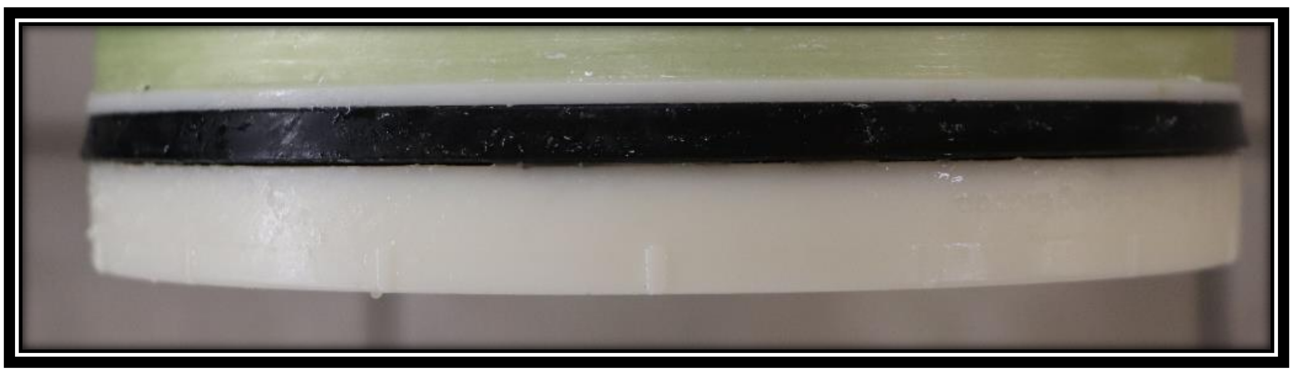


Figure 7: Brine seal.

Figure 8: Outer diameter of the feed ATD, after removing the brine seal.

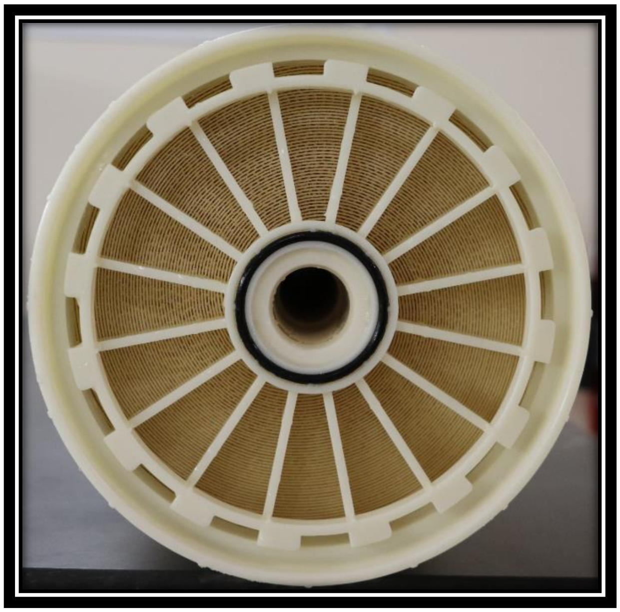


Figure 9: Feed ATD.

Figure 10: Feed ATD.

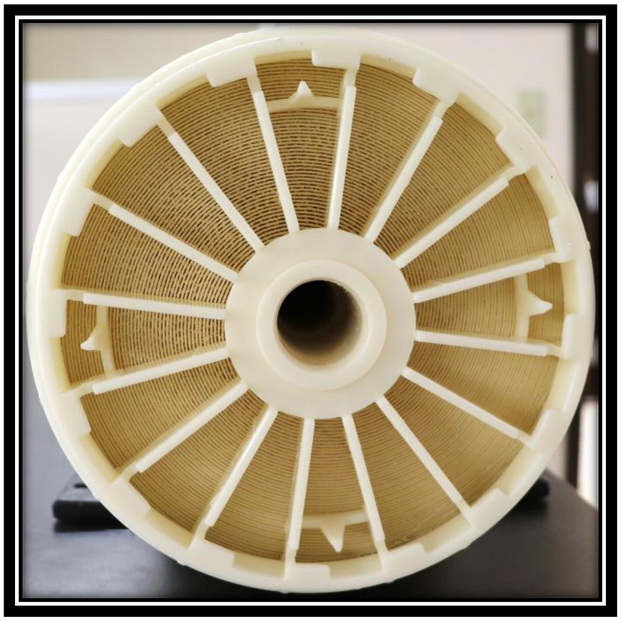


Figure 11: Concentrate ATD.

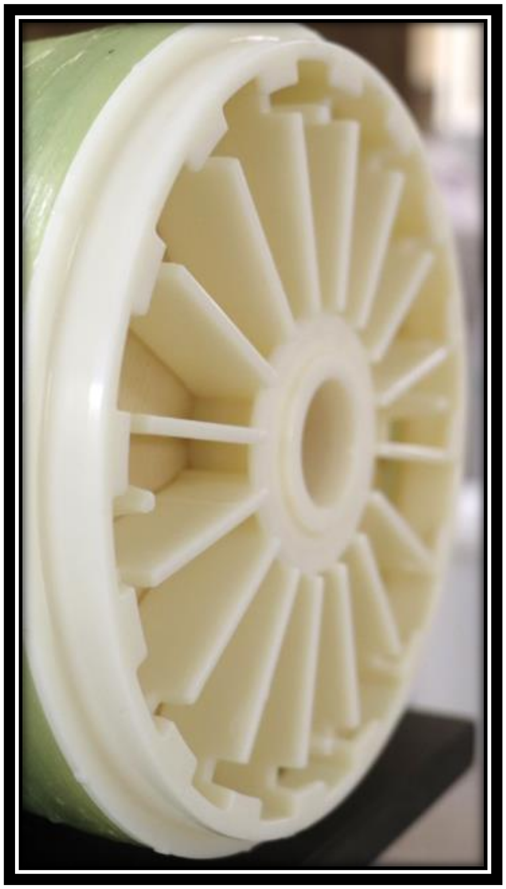


Figure 12: Concentrate ATD.

Full Element Performance Test

A wet test was performed prior to opening the membrane.

Test Conditions:

Test Protocol (Specific to membrane manufacturer's spec sheet)	
Membrane Make and Model:	Filmtec Fortilife CR100i
Membrane Serial Number:	T7784622
Membrane Position:	Tail (CCRO)
Feed Solution and Concentration (ppm):	2000 ppm, NaCl
Feed solution pH:	8
Feed solution Temperature (°C):	25°C
Feed Pressure (PSI):	225 psi
Feed Flow (gpm): (Target)	53.24
Spec QC range (max/min):	+15%
	-15%

Results

Initial performance testing showed membrane flux to be ~2.68% below manufacturer’s nominal specification. Membrane salt rejection (normalized for flux) was ~0.14% above the manufacturer’s nominal specification. The differential pressure across the element was within the expected range.

Full Element Performance Test
S#T7784622

Feed Temperature (°C):	30.0
Feed Solution pH:	7.51
VFD Setting (Hz):	50.0

				GPM	**GPD**
Feed NaCl:	2028	PPM	**Feed Flow**	53.6	77186
Concentrate NaCl:	2433	PPM	**Concentrate Flow**	44.6	64224
Permeate NaCl:	4	PPM	**Permeate Flow**	9.0	12962
Feed Conductivity:	3920	µs/cm	**Differential Pressure (PSI)**	1.9	
Concentrate Conductivity:	4689	µs/cm	**Applied Pressure (PSI)**	225	
Permeate Conductivity:	8.63	µs/cm	**Average Pressure (PSI)**	224	
SDI of Test Solution Before Testing:	1.02		**Membrane Surface Area (ft^2)**	400	
SDI of Test Solution After Testing:	3.95				

Recovery based on Flow Rates (%)	16.79%
Flux (GFD)	32.4
Specific Flux (GFD/PSI)	0.14
Temperature Correction Factor	1.1574
Temperature Corrected Flow (GPM)	7.78
Temperature Corrected Salt Rejection (%)	99.84%

	Manufacturer Specification (nominal)	**Manufacturer Specification (minimum)**	**AWC Wet Test Result (Normalized to 25°C)**	**%Difference from Nominal Specification**	**%Difference from Minimum Specification**
Permeate Flow (GPD)	11500	9775	11199.5	-2.61%	+14.57%
Recovery (%)	15.0%	12.8%	14.6%	-2.61%	+14.57%
Flux (GFD)	28.75	24.44	28.00	-2.61%	+14.57%
Specific Flux	0.146	0.124	0.142	-2.68%	+14.49%
Salt Rejection (%) (NaCl)	99.70%	99.40%	99.84%	+0.14%	+0.44%
Salt rejection normalized for flux	-	-	99.84%	+0.14%	+0.44%
ΔP – Spec Test Condition Avg. Flow	4.3*	4.3*	-	-	-
ΔP – Measured Avg. Flow	4.2*	-	2.0	-52.56%	-

* Estimated based on Reynolds number (function of feed spacer height, temperature, cross-flow velocity) and friction coefficient of $6.23Re^{0.3}$.

Vacuum Test

A vacuum test is performed in order to determine the presence of leaks in the membrane. Leaks may occur through damage of the membrane surface by abrasion, delamination or water hammer. While the membrane is completely drained, the element is evacuated to 1.5 - 4.5 psi absolute pressure. An isolation valve is then closed and the element monitored for pressure decay. A rapid pressure gain greater than 1.5 psi per minute would be indicative of a significant breach in integrity.

Results

The membrane passed the vacuum integrity test.

	Start Pressure (PSI)	Pressure after 1 min (PSI)	Pressure after 2 min (PSI)	Pressure Gain (PSI)	Pass/Fail
Trial #1	-3.21	-2.14	-2.99	+0.22	Pass
Trial #2	-3.27	-3.15	-3.05	+0.22	Pass

Table 3: Vacuum test results.

ATD and Fiberglass Shell Removal

No telescoping was observed at the concentrate end of the element.

Figure 13: The feed end of the element.

Figure 14: The feed end of the element.

Figure 15: The concentrate end of the element.

Figure 16: No telescoping was observed on the concentrate end of the element.

Inspection of Membrane Leaves and Foulant Collection

Light foulant deposition was observed on the membrane leaves.

Figure 17: Membrane unraveled.

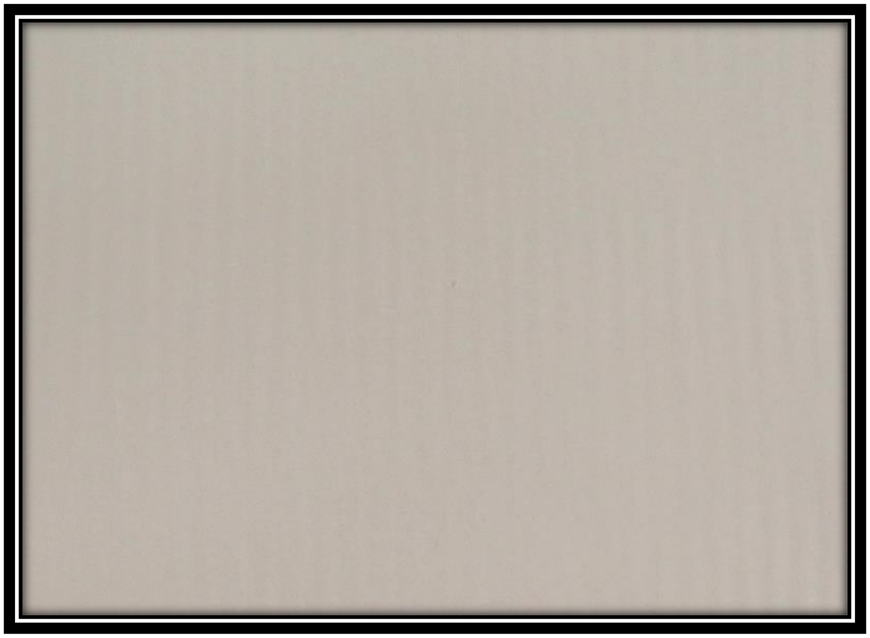


Figure 18: Light foulant deposition was observed on the membrane leaves.

Figure 19: Foulant collected after addition of water.

Figure 20: Collection from one leaf was slightly turbid.

Inspection of Membrane Feed Spacers

The feed spacers appeared clean and intact to the naked eye.

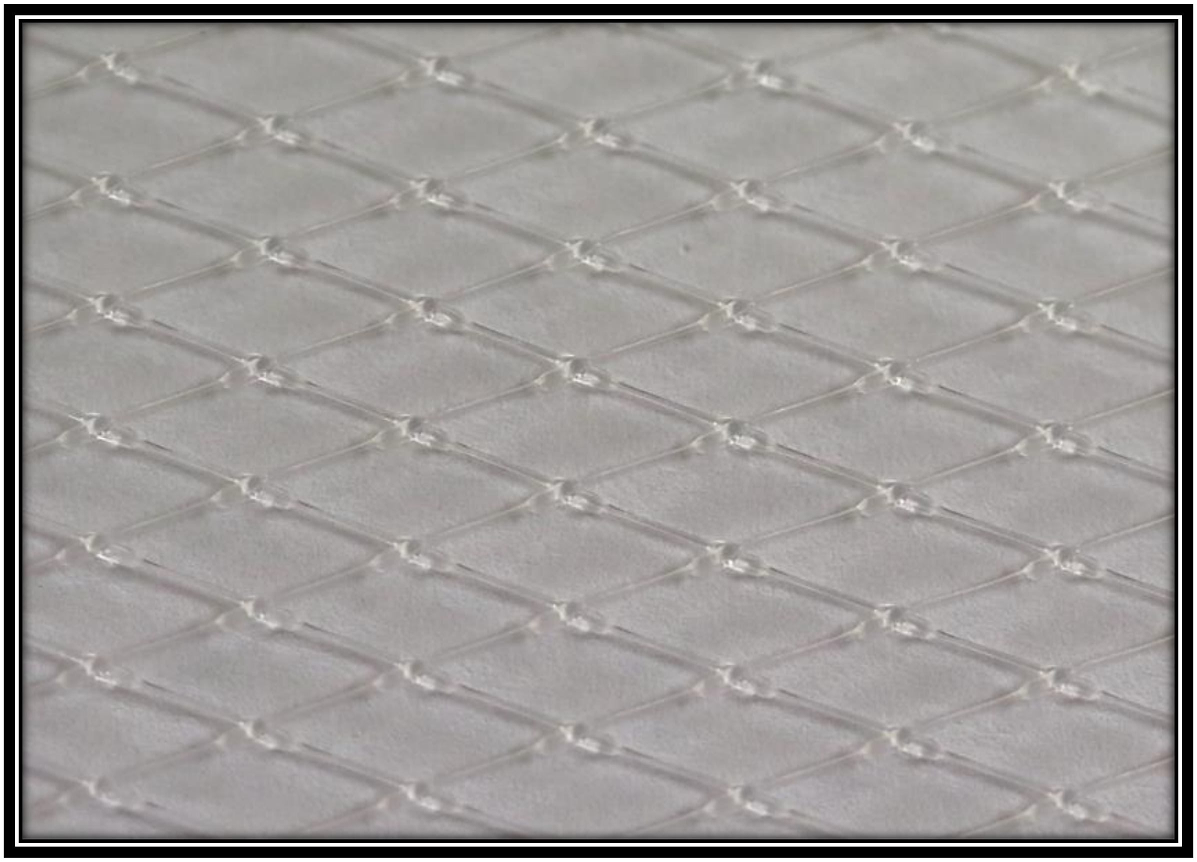


Figure 21: The feed spacers appeared clean and intact to the naked eye.

Inspection of Membrane Glue Lines

No osmotic bubbling was observed along the glue line.

Figure 22: No osmotic bubbling was observed along the glue line.

Inspection of Permeate Side of Membrane leaves

The permeate side of the membrane appeared clean and intact to the naked eye.

Figure 23: The permeate side of the membrane.

Figure 24: The permeate side of the membrane appeared clean and intact to the naked eye.

Inspection of Permeate Spacers

The permeate spacers appeared clean and intact to the naked eye.

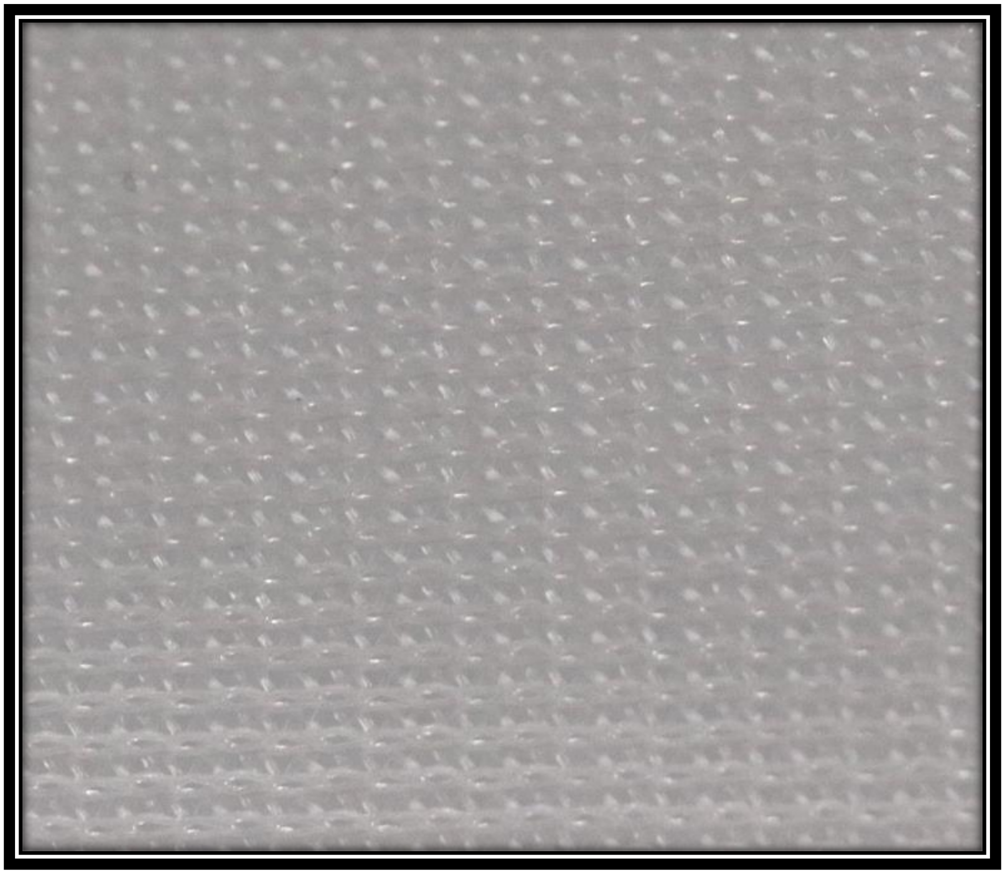


Figure 25: The permeate spacers appeared clean and intact to the naked eye.

Foulant Surface Density

The foulant surface density is used to quantify the extent of fouling and/or scaling on the membrane surface by calculating the ratio of foulant mass to the surface area from which it was collected. The calculation is performed on the foulant upon collection, and again after dehydration at 105°C. Since all elements are performance tested prior to autopsy, water introduced during the testing will interfere with the foulant density values. This test is limited to material that can be scraped from the surface using a spatula; in cases where the foulant is tightly adhered to the membrane surface; deionized water is sprayed on the surface to facilitate collection. For these reasons, only the dehydrated foulant surface density value is consistently reliable.

Results

The foulant density was ~0.19 µg/cm^2 when dehydrated; this was considered extremely low.

	Wet	Dehydrated	DI Water Spray required (Y/N)
Foulant Surface Density	--	0.19 µg/cm^2	Y

Loss on Ignition Test of Foulant

A Loss on Ignition (LOI) test is performed to determine the organic/inorganic content of the foulant. The collected foulant samples are first heated at 105 °C overnight to remove moisture and volatile compounds. The dehydrated samples are then fired at 450 °C for 8 hours to combust any organic materials. The percentages of moisture, organics and inorganics are then calculated based on the loss of mass. This test is limited to material that can be scraped from the surface using a spatula, and the results should be considered within that context.

Results

The foulant that could be collected with a spatula was insufficient to perform this test.

Chemical Solubility Testing of Foulant

Samples collected from the membrane surface are tested for solubility in concentrated acid.

Effervescence in the presence of acid usually indicates the presence of carbonate salts such as calcium carbonate.

Results

The dehydrated foulant was not visibly soluble in the ~37% HCl solution.

No effervescence was observed upon the addition of acid to the dehydrated foulant.

Foulant

Figure 26: The dehydrated foulant was not visibly soluble in the ~37% HCl solution.

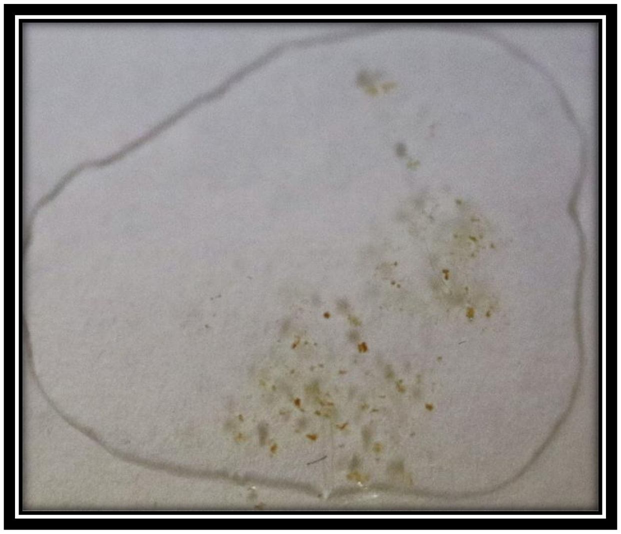


Figure 27: No effervescence was observed upon the addition of acid to the dehydrated foulant.

Cell Test & Cleaning Study

Cell testing is performed in order to determine the performance of the membrane. Samples of the membrane are collected from the element and soaked in deionized water for 24 hours to help remove fouling. They are then tested using the performance test conditions set by the manufacturer. Salt rejection and flux measurements are compared with the manufacturer's specifications and the initial full element performance tests. Cell tests were performed before and after cleaning.

Test Conditions:

Feed Pressure	225 psi
Feed Concentration	2000 ppm
Concentrate Flow	0.8 gpm
Feed Temperature	25°C

Results

Initial cell testing found permeability to be greater than the manufacturer's specification, though salt rejection was within specification.

The membrane coupons were cleaned first with 2% AWC C-227, a high pH chemical cleaner for organic based matter. The cleaning was performed at pH 11.9 and 35°C for 6 hours. Permeability increased significantly, with a slight decrease in salt rejection.

A follow up cleaning was performed with 2% AWC C-234, a low pH chemical cleaner. The cleaning was performed at pH ~1.7 and 27°C for 2 hours. A marginal decrease in permeability was observed, with a slight increase in salt rejection.

Overall, the membrane cleaning procedure caused further increase in membrane permeability above the nominal specification. The salt rejection when normalized for flux was within specification.

Summary

	Manufacturer's Specifications (nominal)	Manufacturer's Specifications (minimum)	AWC full element wet test results
% Salt Rejection	99.70%	99.40%	99.84%
Specific Flux (gfd/psi)	0.146	0.124	0.142

	Initial Flat Sheet Performance	High pH: 2% AWC C-227 at pH 11.9 35ºC For 6 hours	Low pH: 2% AWC C-234 at pH 1.7 27ºC For 2 hours	%Difference Final Vs. Spec (nominal)	%Difference Final Vs. Spec (minimum)	%Change from initial	Final Salt Rejection Normalized for Flux	%Difference Flux Normalized Rejection Vs. Spec
Salt Rejection (%)	99.75%	99.69%	99.70%	+0.00%	+0.31%	-0.05%	99.56%	-0.14%
Membrane Specific Flux (gfd/psi)	0.176	0.221	0.213	+45.81%	-71.54%	+21.52%	N/A	N/A

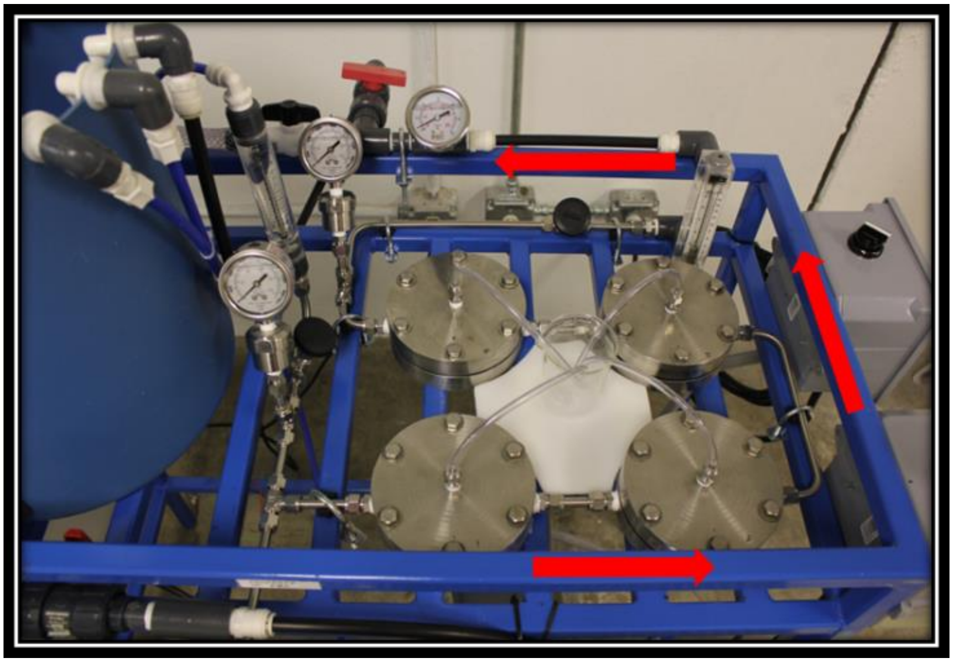


Figure 28: Cell test using 2000 ppm NaCl solution at 225 PSI.

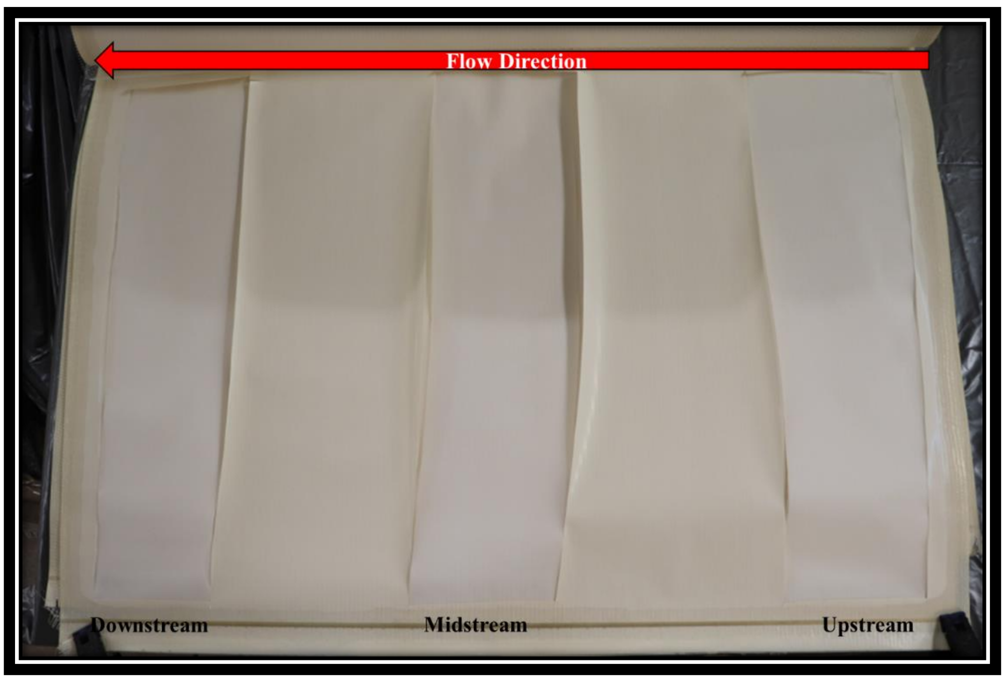


Figure 29: Coupons collected from the membrane.

Dye Test

In this test, a dye solution is applied under pressure to the feed side of the membrane sheet, after cell testing and cleaning of the membrane coupons. This allows for exposure of any damage beneath the foulant, and can be correlated to the cell test salt rejection and flux results. The membrane coupons are tested in the same cells in which cleaning had been performed, eliminating the risk of surface damage due to mishandling. If the membrane is damaged mechanically or chemically, the dye color will penetrate to the permeate side of the membrane.

Results

Minimal dye penetration to the permeate side of the membrane was observed.

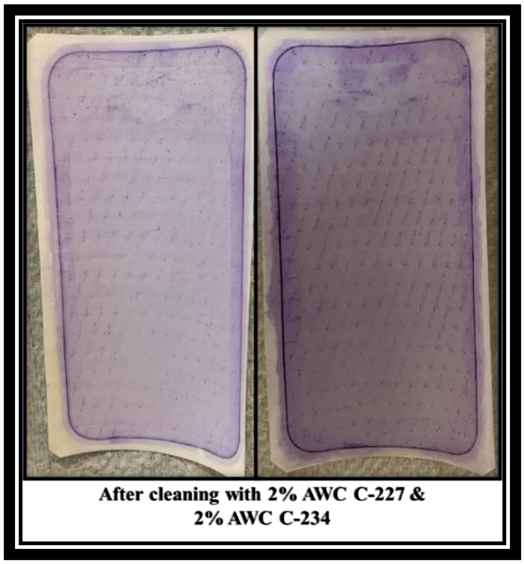


Figure 30:Pressurized dye testing – feed side.

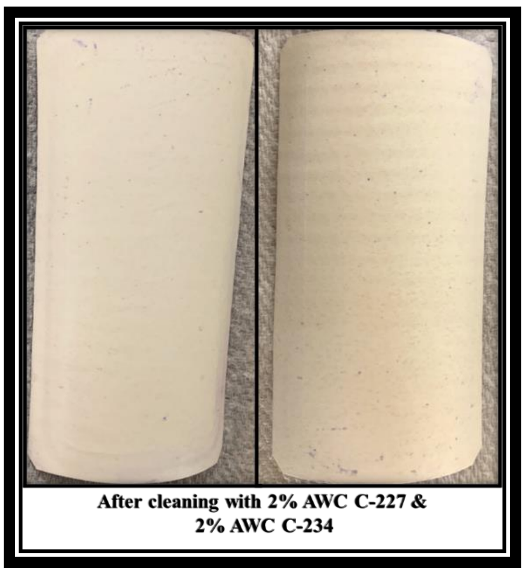


Figure 31: Minimal dye penetration to the permeate side of the membrane was observed.
*Note that permeate side images were flipped horizontally for easier visual comparison.

Fujiwara Test

This test is performed to determine whether the membrane surface or foulants have been exposed to a halogen, such as Chlorine or Bromine. It is standard procedure to perform a Fujiwara test on a membrane that exhibits behavior associated with oxidation damage. However, this test is only qualitative, and has low sensitivity. The results are therefore always reviewed within the context of membrane performance and the results of other tests.

Results

The membrane coupons tested negative for halogen exposure.

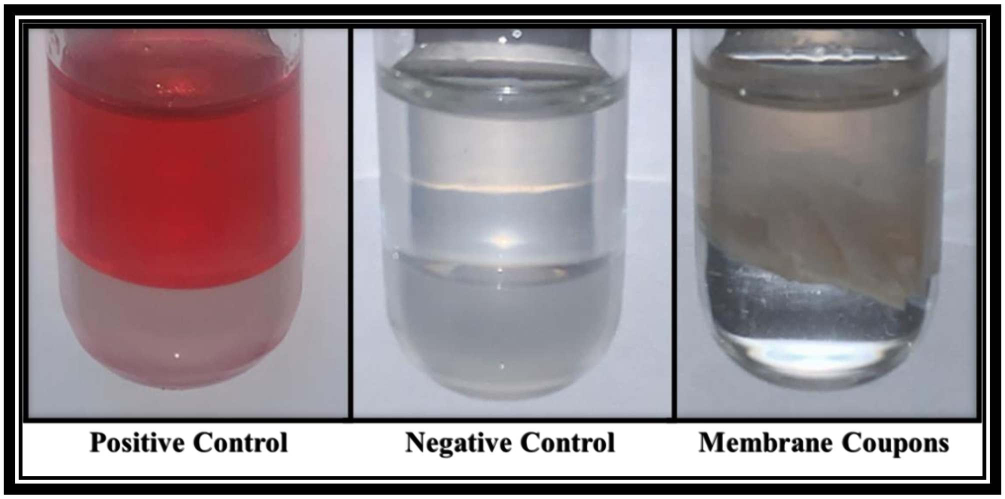


Figure 32: The membrane coupons tested negative for halogen exposure.

Electron Microscopy and X-Ray Spectroscopy Analysis
Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI®)

Scanning Electron Microscopy (SEM) analysis is used to determine the topography and morphology of a sample. The SEM shows very detailed 3-dimensional images at much higher magnification than an optical microscope.

Energy Dispersive X-ray Spectroscopy (EDS) analysis is generally performed together with electron microscopy to identify and quantify the elemental composition of a sample surface. The sample material is bombarded with electrons from an SEM which produce X-rays. The produced X-rays are then measured by an X-ray dispersive spectrometer. Every chemical element has its own characteristic wavelength by which it can be identified. EDS spectra, together with composition (Weight percent and Atomic percent) are attached in the section.

Results

No inorganic deposits were found on the membrane surface.

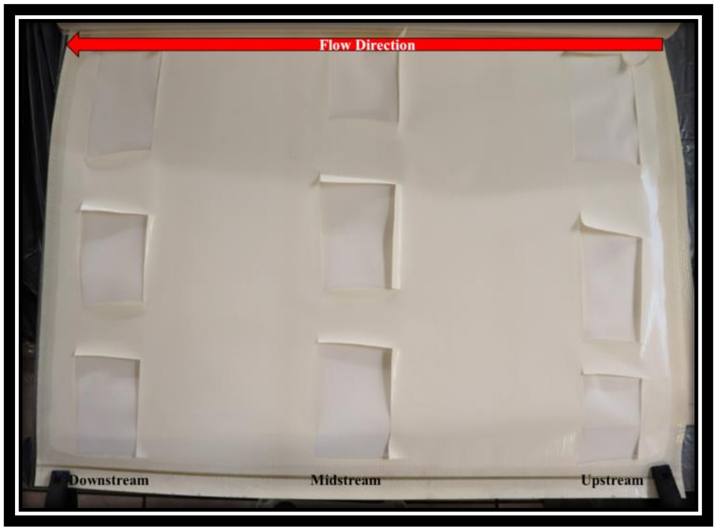


Figure 33: Samples collected from the membrane.

Fouled membrane surface

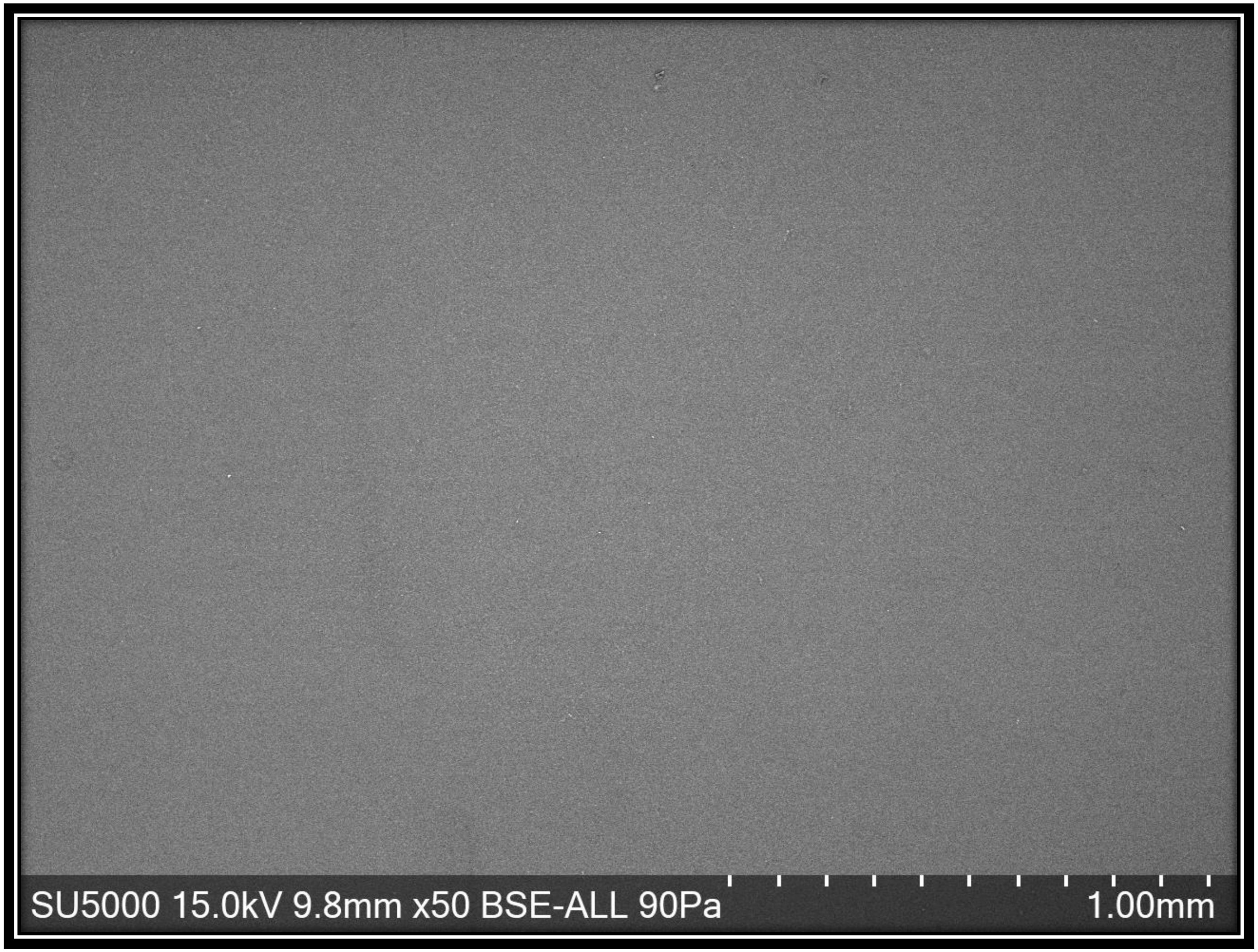


Figure 34: Electron micrograph of the membrane surface at 50X magnification.

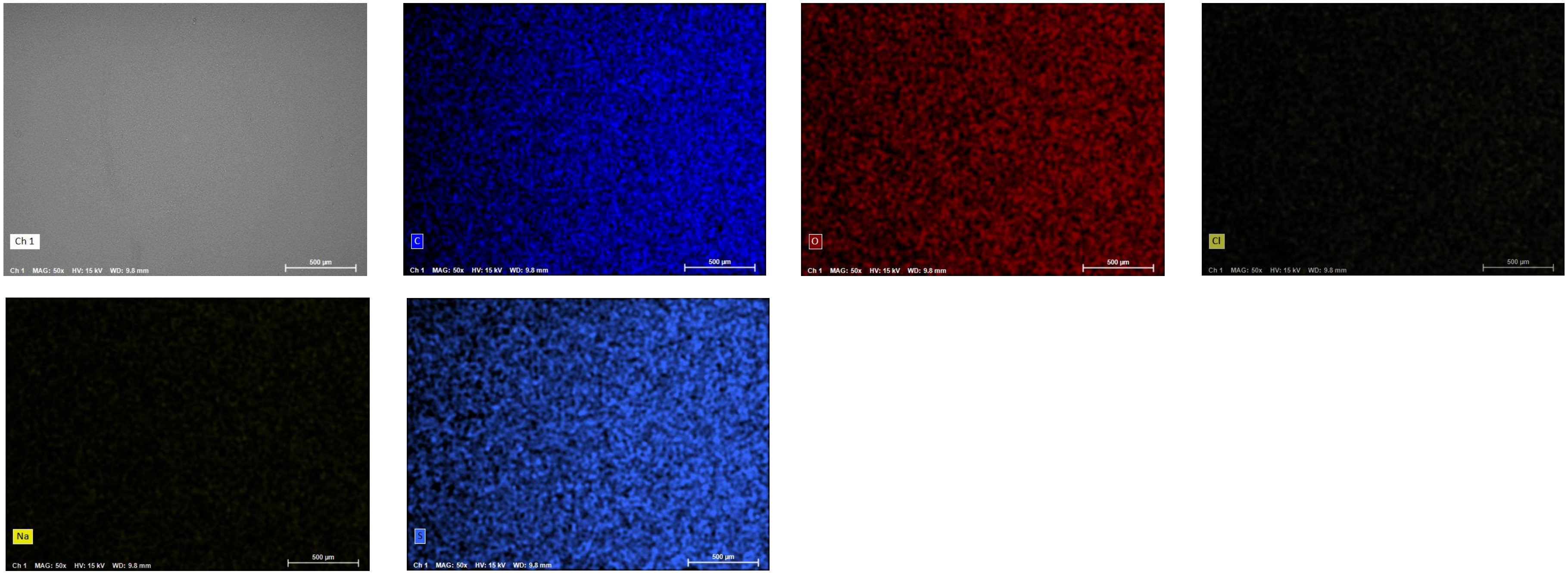


Figure 35: Prismatic Elemental Delineation (PED®) of membrane surface at 50X magnification. Deposits found: No inorganic deposits were found.

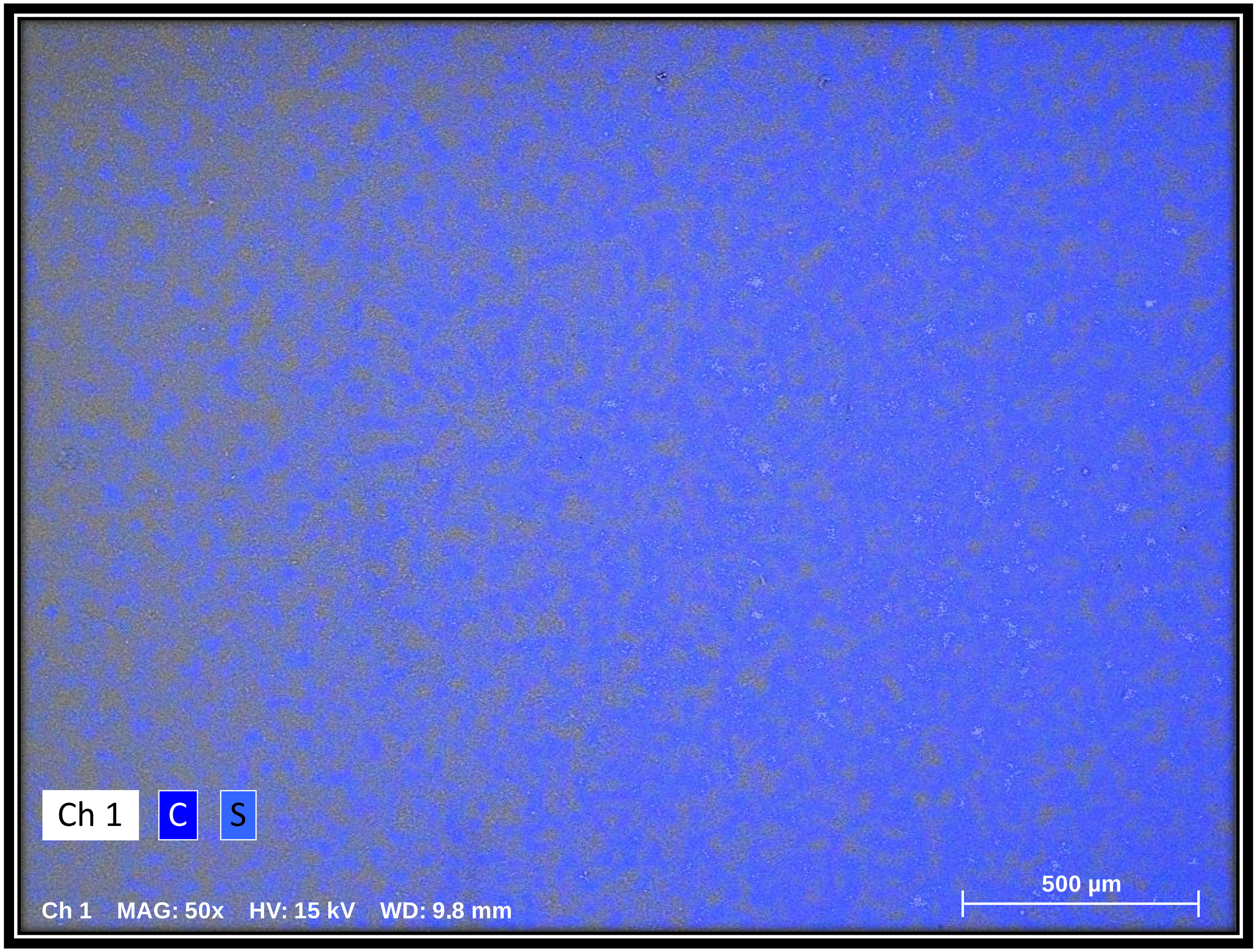
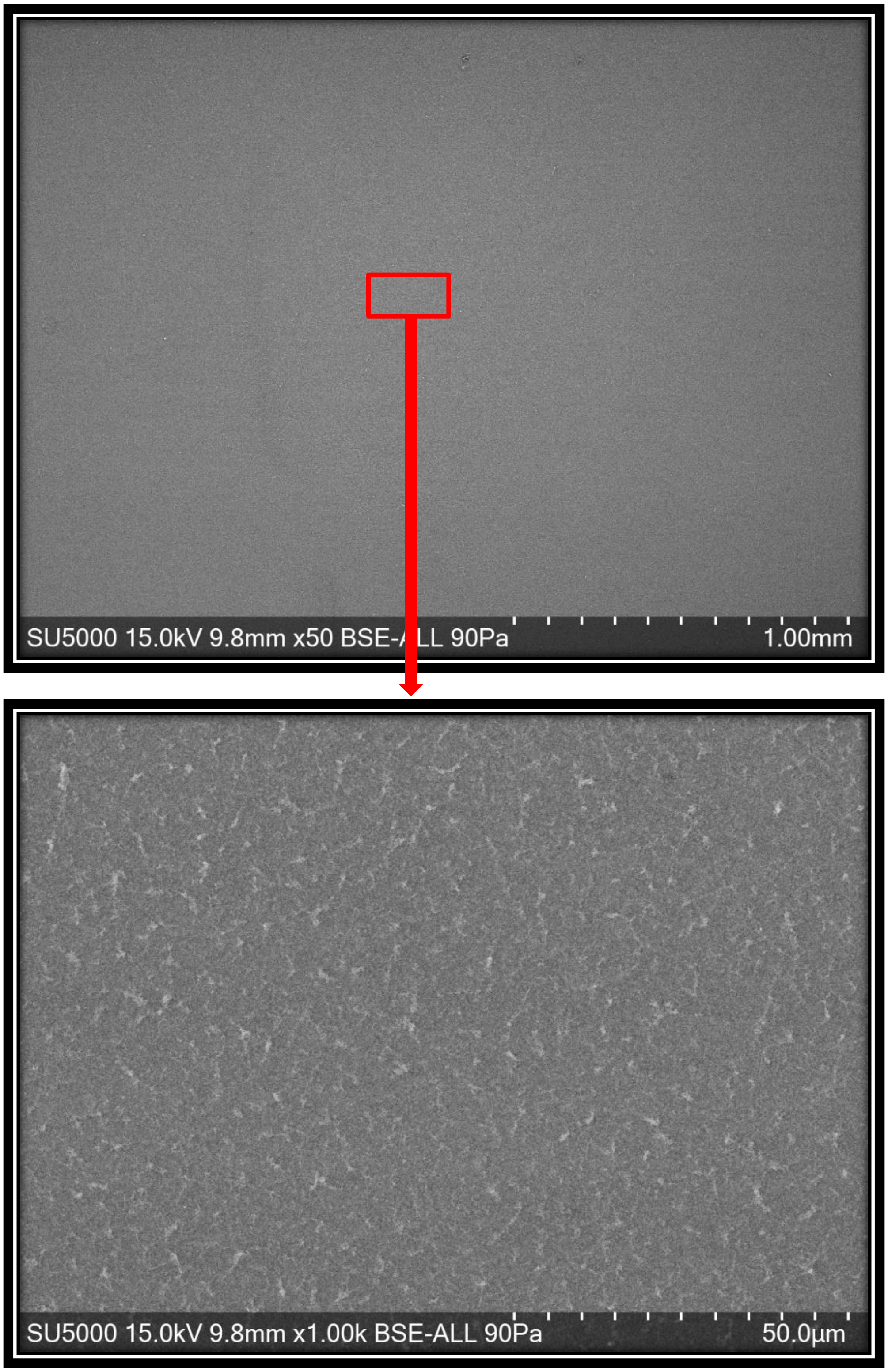


Figure 36: Superimposed Elemental Imaging (SEI®): No inorganic deposits were found.


SU5000 15.0kV 9.8mm x50 BSE-ALL 90Pa
1.00mm
SU5000 15.0kV 9.8mm x1.00k BSE-ALL 90Pa
50.0µm

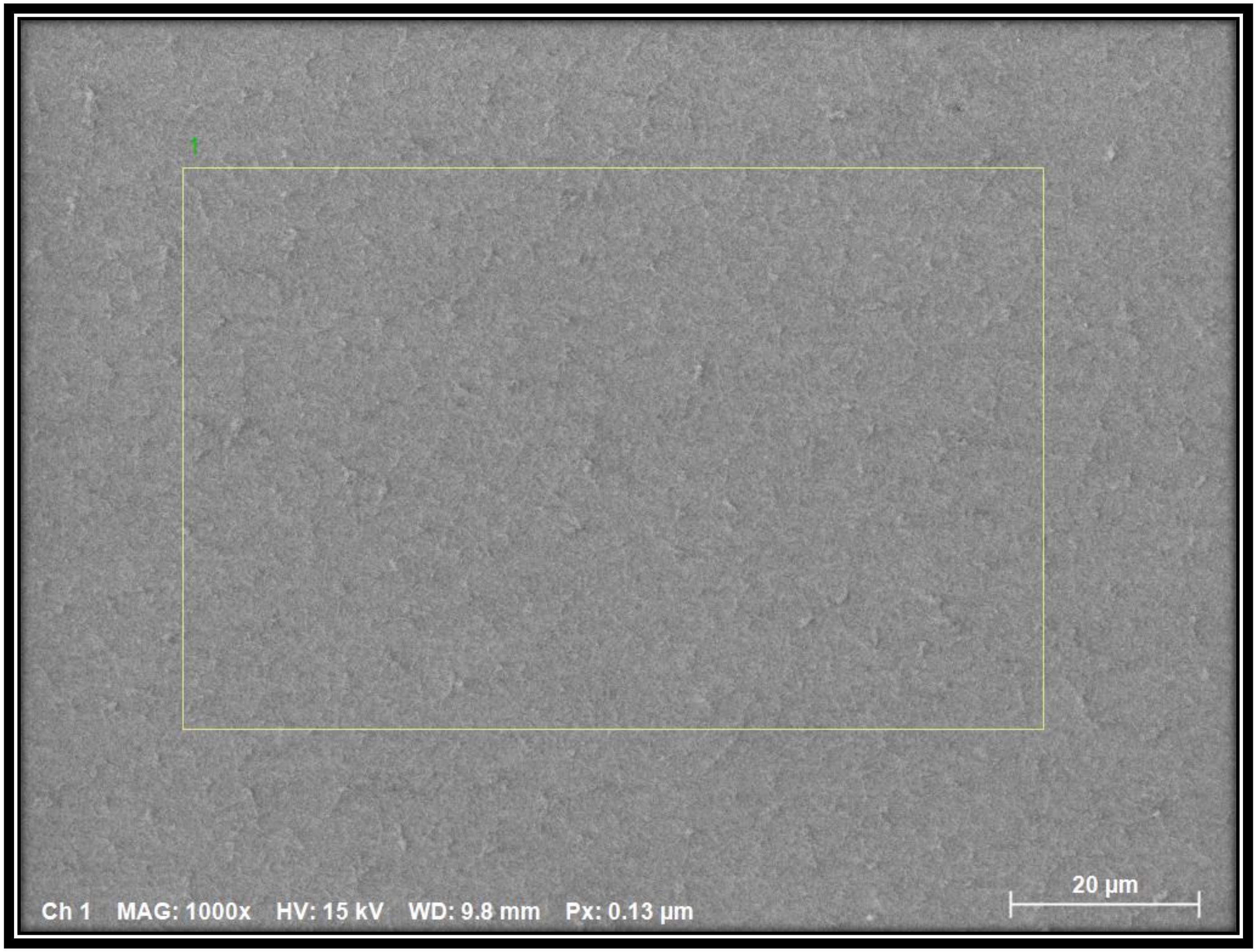


Figure 37: Electron micrograph of the membrane surface at 1000X magnification (Spectrum 1).

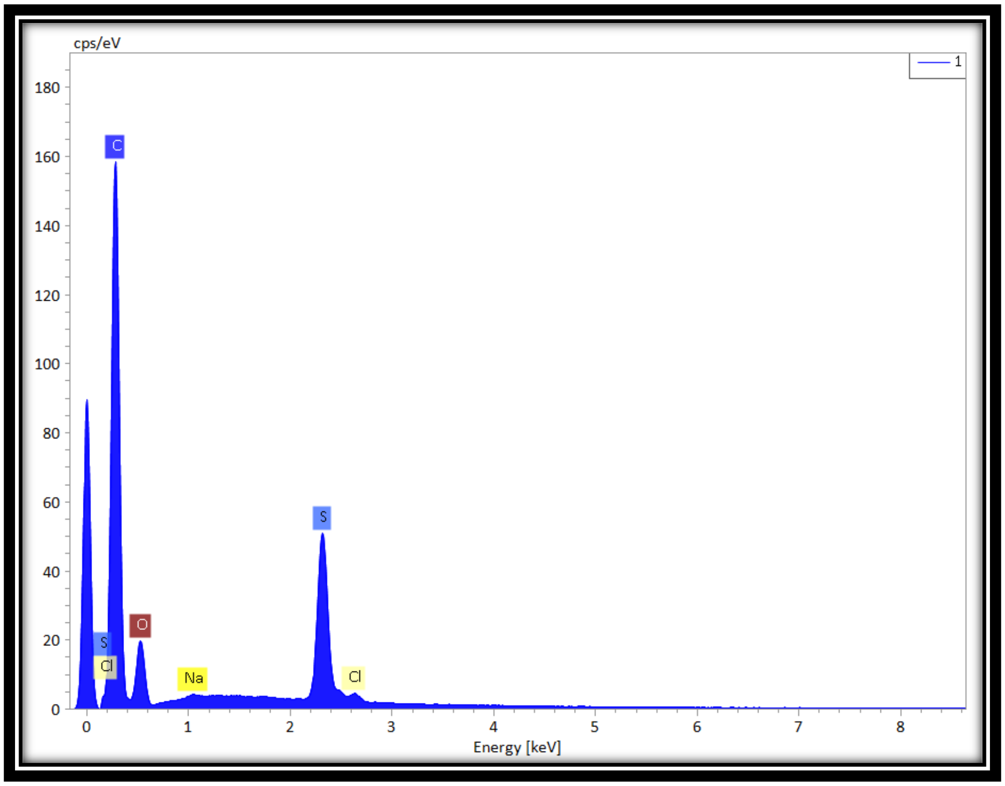


Figure 38: EDS and composition bar graph analysis of the membrane deposit from Spectrum 1.

1

Element	Atom [%]
Carbon	83.93
Oxygen	12.84
Sulfur	2.82
Chlorine	0.13
Sodium	0.29
	100.00

Carbon and Oxygen Ignored 1

Element	Atom [%]
Sulfur	87.21
Chlorine	3.95
Sodium	8.84
	100.00

Table 4: Composition table from the EDS spectrum of localized deposit from Spectrum 1.

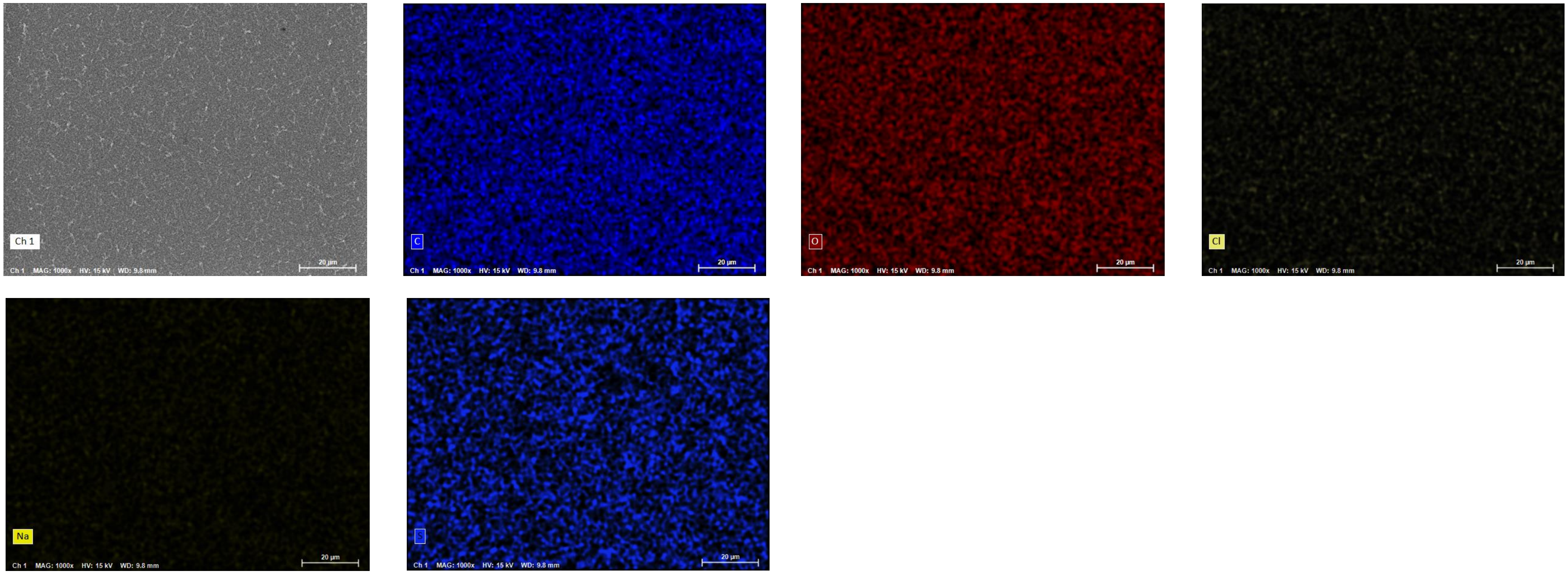


Figure 39: Prismatic Elemental Delineation (PED®) of membrane surface at 1000X magnification. Deposits found: No inorganic deposits were found other than sodium chloride residue from membrane performance testing.

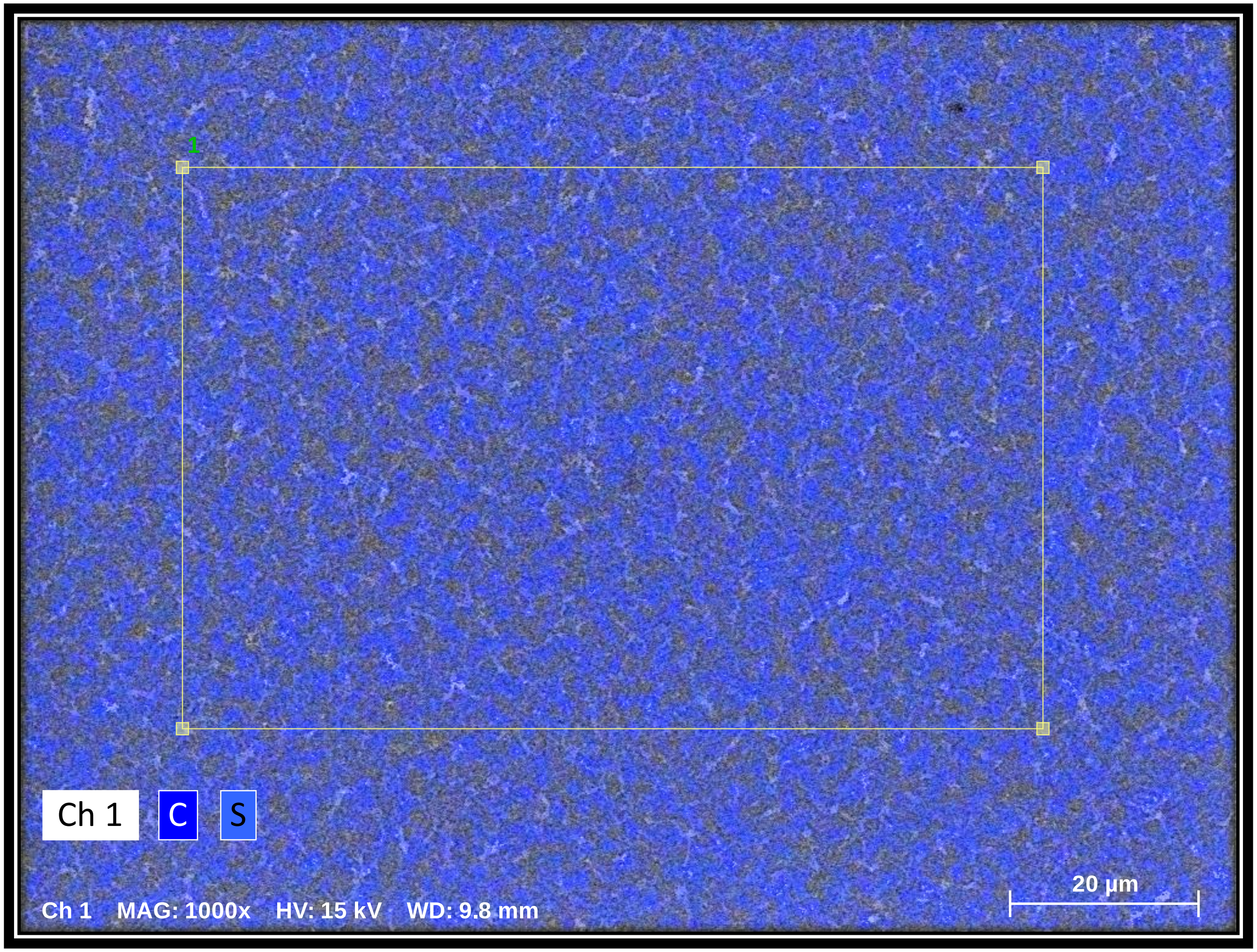


Figure 40: Superimposed Elemental Imaging (SEI®): No inorganic deposits were found.

FTIR analysis

Fourier Transform Infrared spectrometer (FTIR) is a powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic to the chemical bond. The tested material can be identified by comparing its spectrum to the spectra of documented compounds in the database.

The following samples were analyzed with FTIR:

- The fouled membrane surface (see Figure 41).
- The cleaned membrane surface (see Figure 42).

Results: Fouled membrane surface

The spectrum of the fouled membrane surface had a strong correlation to the virgin membrane surface (99% correlation).

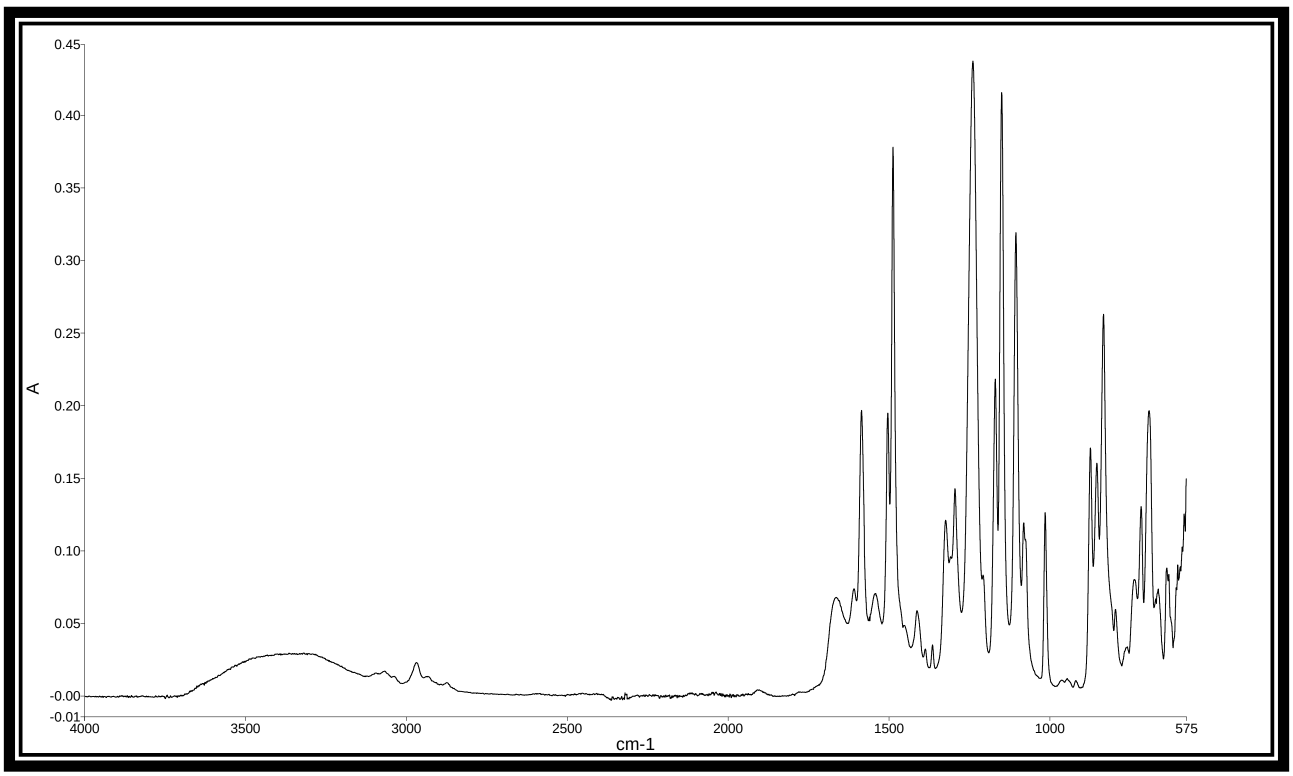


Figure 41: FTIR spectrum of the fouled membrane surface.

Results: Cleaned membrane

The cleaned membrane coupon (from the benchtop cleaning study) was directly scanned by FTIR. The cleaned surface was found to strongly correlate (99% correlation) to the fouled membrane suggesting that any fouling was less than 0.5 µm in thickness and therefore could not be detected by FTIR.

A virgin BW30XFR is comparable to a CR100 according to Dupont. The cleaned surface was found to strongly correlate to a virgin membrane.

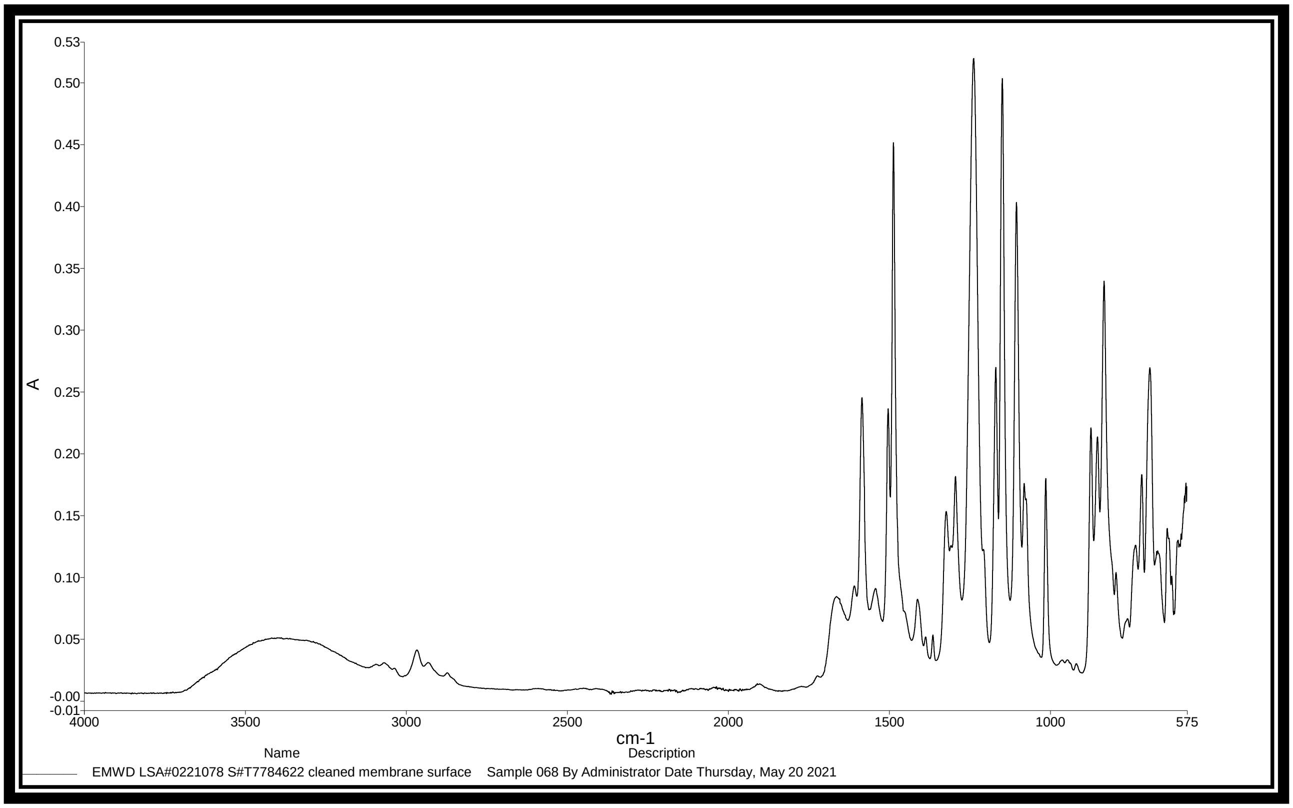


Figure 42: FTIR spectrum of the cleaned membrane surface.

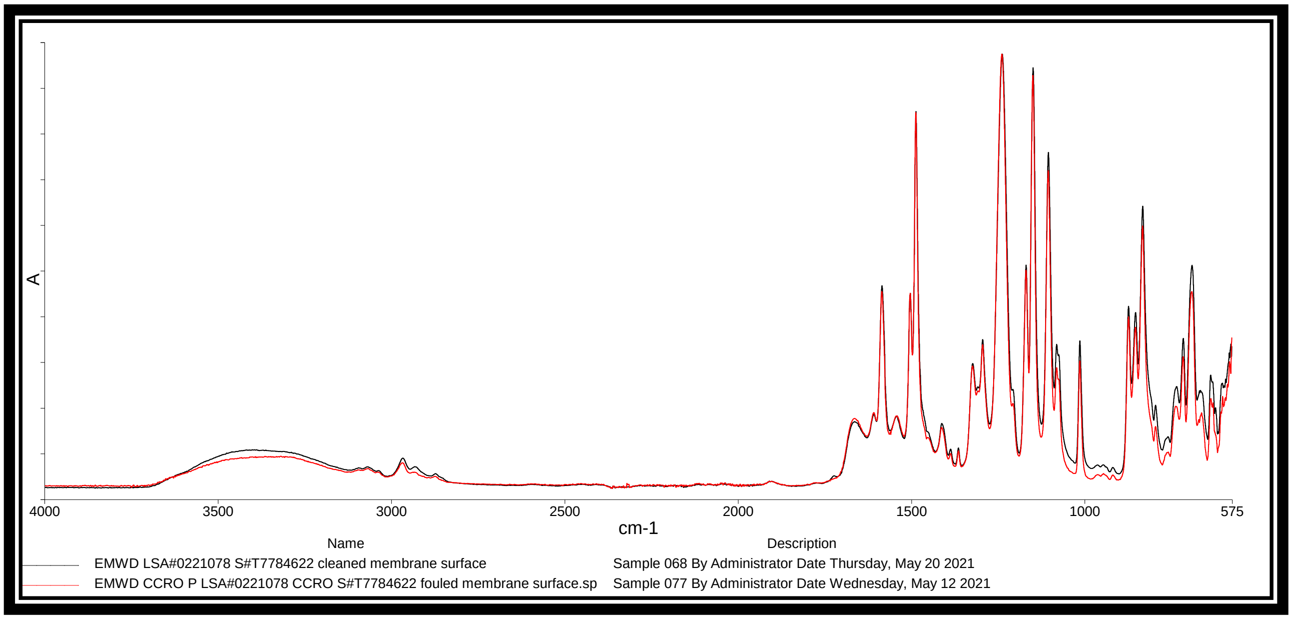


Figure 43: FTIR spectrum of the cleaned membrane surface had a ~99% correlation to the fouled membrane surface.

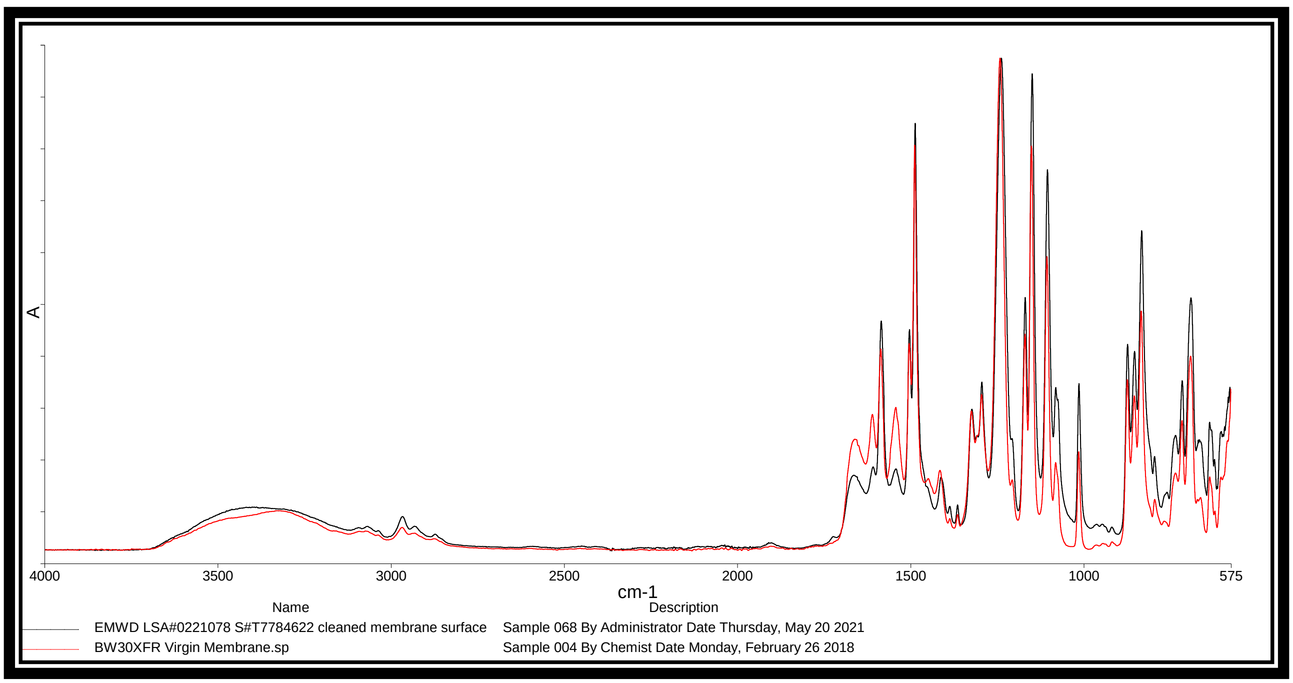


Figure 44: FTIR spectrum of the cleaned membrane surface had a ~94% correlation to a virgin membrane.

Biological Activity Reaction Test (BART)

Slime forming bacteria and heterotrophic aerobic bacteria (HAB) tests were performed. When the BART tests are performed using biofilm rather than water samples, the population counts should only be used comparatively to determine the most dominant types of bacteria.

It is important to note that the membrane is exposed to aerated water during performance testing (typically a standard test in AWC autopsy), and this may have an impact on HAB results.

Results

The dominant types of bacteria detected were heterotrophic aerobic bacteria.

Test	Test duration (days)	Day of failure	Population Cfu/mL
Slime forming bacteria	8	Did not fail	--
Heterotrophic aerobic bacteria	4	4	7,000

Table 5: BARTS test results

Figure 45: SLYM – start (left), negative for slime forming bacteria (right).

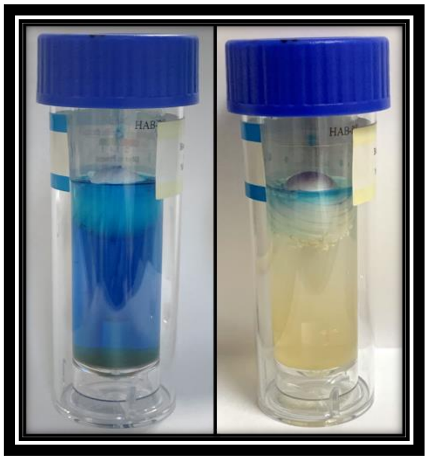


Figure 46: HAB – start (left), positive for heterotrophic aerobic bacteria (right) on day 4.

Results Summary

Initial performance testing showed membrane flux to be ~2.68% below manufacturer's nominal specification. Membrane salt rejection (normalized for flux) was ~0.14% above the manufacturer's nominal specification. The differential pressure across the element was withing the expected range.

Light foulant deposition was observed on the membrane leaves. The foulant density was ~0.19 $\mu g/cm^2$ when dehydrated; this was considered extremely low.

Flat sheet testing was performed using coupons collected along the flow path of the membrane:

> Initial cell testing found permeability to be greater than the manufacturer's specification, though salt rejection was within specification.
>
> The membrane coupons were cleaned first with 2% AWC C-227, a high pH chemical cleaner for organic based matter. The cleaning was performed at pH 11.9 and 35°C for 6 hours. Permeability increased significantly, with a slight decrease in salt rejection.
>
> A follow up cleaning was performed with 2% AWC C-234, a low pH chemical cleaner. The cleaning was performed at pH ~1.7 and 27°C for 2 hours. A marginal decrease in permeability was observed, with a slight increase in salt rejection.
>
> Overall, the membrane cleaning procedure caused further increase in membrane permeability above the nominal specification. The salt rejection when normalized for flux was within specification.

Dye testing found minimal dye penetration to the permeate side of the membrane coupon.

The Fujiwara test was negative for halogen exposure.

SEM/EDS/SEI/PED analysis found no inorganic deposits on the membrane surface.

FTIR analysis of the fouled membrane surface had a 99% correlation to a virgin membrane; suggesting that any fouling was less than 0.5 µm in thickness and therefore could not be detected by FTIR.

BART testing found the dominant types of bacteria detected to be heterotrophic aerobic bacteria.

Discussion and Conclusions

The element upon arrival was in excellent condition.

SEM/EDS/SEI/PED analysis found no inorganic deposits on the membrane surface.

Performance testing of the element found the permeability and salt rejection to both be within the manufacturer's minimal specification. Soaking the coupons in deionized water for 24 hours resulted in a permeability that was ~20% above the nominal specification. Cleaning with AWC C-227 followed by AWC C-234 further increased the permeability to ~45% above the nominal specification. The results of this cleaning study suggest that an organic foulant had been removed from the membrane surface, but they are also indicative of underlying membrane deterioration. The high permeability was suggestive of minor halogenation, however, the Fujiwara test was negative.

A sample provided from the outer shell of the membrane element was analyzed (Appendix C) and determined to consist of a silicate-based material with some calcium sulfate inclusions. No such deposits were identified on the membrane surface. It's not unusual to find scale formations in the stagnant solution around the membrane elements when operating with highly concentrated solutions in systems operating at high recovery.

Appendix A: Fortilife CR100i

Product Data Sheet

FilmTec™ Fortilife™ CR100i Element
Highly Durable, Contaminant Resistant, Biofouling Resistant, Brackish Water RO Element

Description

The FilmTec™ Fortilife™ product family offers industrial users a reliable and highly efficient option to help solve highly difficult water challenges, such as wastewater reuse and minimal liquid discharge.

The FilmTec™ Fortilife™ CR100i Element is one of the industry's most advanced fouling resistant element technology specially designed to provide relief from biological fouling. The element's ultra-low differential pressure (Figure 1) provides improved hydraulic balance (more even distribution of flux across all the elements in the system) in a biological fouling environment such as wastewater treatment. This product also boasts a reliable and durable membrane chemistry, providing organic fouling resistance, cleanability, low energy operation, and excellent solute rejection.

With FilmTec™ Fortilife™ CR100i, an end user that performs frequent cleanings due to biofouling, typically indicated by a rapid increase of the 1st stage differential pressure, can expect[1]:

- Up to 50% reduction in the number of cleanings
- More effective and efficient cleaning of biofilm, organic compounds and scale, achieved through the widest pH range in cleaning (pH 1 – 13), made possible by the most advanced FilmTec™ RO membrane sheet available today
- Up to 10% energy savings at the same water productivity
- Includes iLEC™ interlocking end caps, reducing system operating costs and the risk of o-ring leaks that can cause poor water quality

[1]Relative to leading fouling resistant products currently available in the market

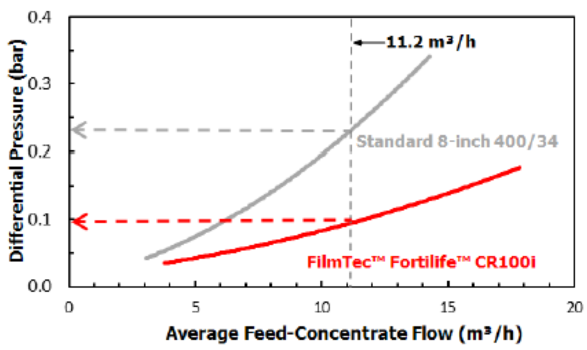


Figure 1: Element differential pressure as a function of flow rate for FilmTec™ Fortilife™ CR100i Elements vs. standard elements

Product Type

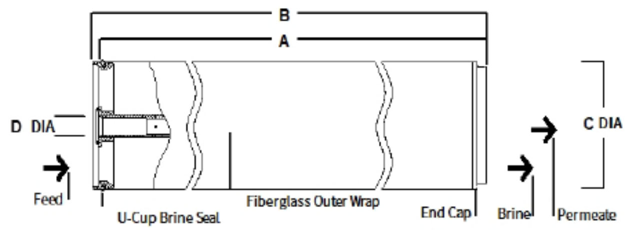
Spiral-wound element with polyamide thin-film composite membrane

Typical Properties

FilmTec™ Element	Active Area ft^2 (m^2)	Permeate Flow Rate gpd (m^3/d)	Minimum Salt Rejection (%)	Stabilized Salt Rejection (%)	Element dP typical (bar)[5]
FilmTec™ Fortilife™ CR100i	400 (37)	11,500 (44)	99.4	99.7	0.1

1. Permeate flow and salt (NaCl) rejection is based on the following standard test conditions: 2,000 ppm NaCl, 225 psi (15.5 bar), 77°F (25°C), pH 8 and 15% recovery.
2. Flow rates for individual elements may vary but will be no more than +/-15%.
3. Sales specifications may vary as design revisions take place.
4. Active area guaranteed +/-3%. Active area as stated by DuPont Water Solutions is not comparable to nominal membrane area often stated by some manufacturers.
5. Element dP (differential pressure) is a typical value for an element operated with a permeate flow of 11,500 gpd and 15% recovery (average feed-concentrate flow: 11.2 m^3/h)

Element Dimensions



	Dimensions – inches (mm)				1 inch = 25.4 mm
FilmTec™ Element	**Feed Spacer (mil)**	**A inch (mm)**	**B inch (mm)**	**C inch (mm)**	**D inch (mm)**
FilmTec™ Fortilife™ CR100i	34	40.0 (1,016)	40.5 (1029)	7.9 (201)	1.125 ID (29)

1. Refer to FilmTec™ Design Guidelines for multiple-element systems of 8-inch elements (Form No. 45-D01695-en).
2. Element to fit nominal 8-inch (203 mm) I.D. pressure vessel
3. Individual elements with iLEC™ endcaps measure 40.5 inches (1,029 mm) in length (B). The net length (A) of the elements when connected is 40.0 inches (1,016 mm).

Operating and Cleaning Limits

Membrane Type	Polyamide Thin-Film Composite
Maximum Operating Temperature[a]	113 °F (45 °C)
Maximum Operating Pressure	600 psig (41 bar)
Maximum Element Pressure Drop	15 psig (1.0 bar)
pH Range	
Continuous Operation[a]	2 - 11
Short-Term Cleaning (30 min.)[b]	1 - 13
Maximum Feed Silt Density Index (SDI)	SDI 5
Free Chlorine Tolerance[c]	< 0.1 ppm

a. Maximum temperature for continuous operation above pH 10 is 95 °F (35 °C)
b. Refer to guidelines in Cleaning Guidelines (Form No. 45-D01696-en) for more information.
c. Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature failure. Since oxidation damage is not covered under warranty, DuPont recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to Dechlorinating Feedwater (Form No. 45-D01569-en) for more information.

Form No. 45-D01760-en, Rev. 2
January 2021

Additional Important Information

Before use or storage, review these additional resources for important information:

- Usage Guidelines for FilmTec™ 8" Elements (Form No. 45-D01706-en)
- Start-Up Sequence (Form No. 45-D01609-en)
- Storage and Shipping of New FilmTec™ Elements (Form No. 45-D01633-en)

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled Start-Up Sequence (Form No. 45-D01609-en) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.

Please refer to FilmTec™ Reverse Osmosis Membranes Technical Manual (Form No. 45-D01504-en).

Product Stewardship

DuPont has a fundamental concern for all who make, distribute, and use its products, and for the environment in which we live. This concern is the basis for our product stewardship philosophy by which we assess the safety, health, and environmental information on our products and then take appropriate steps to protect employee and public health and our environment. The success of our product stewardship program rests with each and every individual involved with DuPont products—from the initial concept and research, to manufacture, use, sale, disposal, and recycle of each product.

Customer Notice

DuPont strongly encourages its customers to review both their manufacturing processes and their applications of DuPont products from the standpoint of human health and environmental quality to ensure that DuPont products are not used in ways for which they are not intended or tested. DuPont personnel are available to answer your questions and to provide reasonable technical support. DuPont product literature, including safety data sheets, should be consulted prior to use of DuPont products. Current safety data sheets are available from DuPont.

Please be aware of the following:

- The use of this product in and of itself does not necessarily guarantee the removal of cysts and pathogens from water. Effective cyst and pathogen reduction is dependent on the complete system design and on the operation and maintenance of the system.
- Permeate obtained from the first hour of operation should be discarded.

Have a question? Contact us at:

www.dupont.com/water/contact-us

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DUPONT™

Appendix B: COC and Questionnaire:

AWC American Water Chemicals

1802 Corporate Center Lane, Plant City, Florida 33563, USA
Tel: 813-246-5448 - Fax: 813-623-6678
Website: www.membranechemicals.com

CHAIN OF CUSTODY RECORD

Laboratory Service Authorization #: 0221078

PROJECT REFERENCE	PROJECT NO. (if applicable)	PROJECT LOCATION (STATE)
EMWD CCRO PILOT		CALIFORNIA

P.O. NUMBER	CLIENT PHONE
	(805) 816-5633

CLIENT NAME	CLIENT EMAIL
MIKE DUMMER	mDUMMER@SPI-Engineering.com

CLIENT ADDRESS: 3152 LIONS HEAD AVE. CARLSBAD CA 92010

COMPANY CONTRACTING THIS WORK (if applicable)	SAMPLER'S NAME (please print)
SPI engineering	MIKE DUMMER

Reason for Analysis Request:

Pilot.

Requested Completion Date: ___/___/___

Total number of samples submitted: 2

SAMPLE DATE	SAMPLE TIME	SAMPLE IDENTIFICATION (If membrane please include model, position and S/N)	Membrane	Water	Filter	Other:	Platinum Autopsy	Silver Autopsy	Cleaning Study	Performance Testing	SEM/EDS	FTIR	Full Water Analysis	Well water analysis	Finished water analysis	Antiscalant Projection	Offsite Cleaning	Other:	REMARKS
4/12/2021	10:55AM	DOW/DUPONT FILMTEC FORTILITE CR100i	X				X	X	X	X	X	X				X			
		TAIL-POSITION T7784622-C/N																	
4/12/2021	10:55AM	SCALE SAMPLE				X					X	X						X	

RELINQUISHED BY: (SIGNATURE)	DATE	TIME	REMARKS:
TIFFANY LE	4/12/2021	11:03AM	

RECEIVED BY: (SIGNATURE)	DATE	TIME	REMARKS:
Juliette Hernandez	4/26/21		

Additional Comments: Lost in mail for ~1 week for Silver

AWC Form 424 - R7 12.2.19

Return to AWC with Sample(s) -
Please Complete This Form to the Best of Your Ability.

Page 1 of 1

Membrane Questionnaire

LSA Number ____________

Site/Project Name: EMWD CCRO Pilot

Please answer all questions to the best of your knowledge. Please provide as much information about the system and process as possible.

Check which service(s) you wish performed. If both an autopsy and cleaning study are desired, two parallel membranes must be provided.

- **Note that an autopsy is a destructive test.**

☑ AUTOPSY ☐ CLEANING STUDY

1. What problems are you currently experiencing? Why do you want to perform an autopsy and/or cleaning study?

   Specific Flux decline

2. Please identify the feed water source (circle all specifics):

   ☐ City/Municipal Drinking Water
   ☐ Groundwater (shallow/deep)
   ☐ Surface Water (Pond/River/Lake/Seawater)
   ☐ Industrial Effluent (Specify upstream process)
   ☑ Municipal Effluent
   ☐ Other (Specify):______________________

3. Please **attach** a feed water analysis.

4. What is the % Recovery at which the system operates?

   94%

5. What is the temperature range of the feed water?

   70-80F

6. List all pretreatment equipment in the same order as the process (example: Raw Water, PACl injection, Cationic Polymer Injection, Clarifier, Multimedia Filter, Sulfuric Acid Injection, Chlorination, Activated Carbon Filter, Microfiltration Unit, Antiscalant Injection, Cartridge Filter, RO Unit).

   Please **attach** a process flow diagram if one is available.

   Chlorine Contact Chamber, NH4 injection, SBS injection, strainers, Toray UF HFU-2020AN, 4000 gal filtrate tank, 93% sulfuric acid injection, 5 um Cartridge Filter, AS injection, CCRO unit.

American Water Chemicals, Inc. • 1802 Corporate Center Lane • Plant City, FL 33563 USA • Tel: 813.246.5448 • Fax: 813.623.6678
www.membranechemicals.com

AWC Form No. 434 R7 03.11.20

7. Is there any chlorination or chloramination in the pretreatment or feed water source?

yes

8. What is the configuration of the system? (number of pressure vessels per stage, and number of membranes per pressure vessel)

Stage 1:		Stage 2:		Stage 3:	
#PV:	5	#PV:		#PV:	
#Elements:	5	#Elements:		#Elements:	

9. What is the membrane make and model that is used in the system? (Example: Hydranautics ESPA2LD) Please specify the information for each stage. If there is a mix of different elements within a stage, please specify (Example: Stage 2: first 5 elements ESPA2 Max, last 2 elements ESPA4Max).

Stage 1:		Stage 2:		Stage 3:	
Manufacturer:	Filmtec	Manufacturer:		Manufacturer:	
Model #:	CR100	Model #:		Model #:	

10. What is the system feed pressure?

~200 psi

11. What is the pressure drop (ΔP) across each stage?

Stage 1: 15 psi Stage 2: Stage 3:

12. What was the position of the element that was sent for testing?
(Example: Skid 3, 2nd Stage, Position)

13. Was this element previously in a different position? (If so, please explain why it was moved.)

No

14. How many hours per day, and days per week does the system operate?

24/7/365

15. What is the maximum downtime for the system?

7 days

16. Prior to shutdown, is the unit flushed? ☑ Yes ☐ No?

Type of flush water used:

☐ Pretreated Feed Water ☑ Permeate/Filtrate ☐ Other (specify):

LSA Number _______________

17. Have the membrane elements/modules ever been subject to dehydration? (System drained and left without water for extended time during shutdown, unloaded membrane left around a few days without bagging airtight, etc…)

    no

18. What is the average lifetime of elements/modules in the system?

    unknown

19. How long have the elements/modules been in service?

    Since October 12, 2020

20. Have there been any recent operational upsets in your system? Please specify:

    No

21. List the cleaning chemicals used for the RO system, and attach the cleaning protocol typically used.

    1-2% Avista P112, pH ~12.5, 25-35C, 2-4 hrs of circulation
    1-2% Avista L403, pH ~3, 25-35C, 2-4 hrs of circulation

22. Are there any design limitations regarding membrane cleaning that we should be aware of?

    ~450 gal CIP tank, CIP chemicals must be pumped in

22. How frequently is membrane cleaning performed? (please specify frequency for high pH and low pH)

    3 times since install (10/2020)

23. What is the antiscalant being used? What is the dosage?

    AWC A-112 - 12ppm

24. Please **include** your normalized permeate flow, normalized salt passage and normalized differential pressure charts with this questionnaire.

25. Do you want the membrane element(s) to be returned after testing is complete? ☐ Yes ☑ No

Additional comments: (please mention any additional information that you think may be helpful in interpreting our findings)

AWC A-112 dosing was started while membranes were still fouled,

Appendix C: White Material from Pressure Vessels

A small bag of white material was received with the membrane element for autopsy. The sample was collected from the pressure vessel when the element was removed from the system.

Figure 47: White material from pressure vessels sample arrived with the membrane.

Electron Microscopy and X-Ray Spectroscopy Analysis

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) with Superimposed Elemental Imaging (SEI®)

Scanning Electron Microscopy (SEM) analysis is used to determine the topography and morphology of a sample. The SEM shows very detailed 3-dimensional images at much higher magnification than an optical microscope.

Energy Dispersive X-ray Spectroscopy (EDS) analysis is generally performed together with electron microscopy to identify and quantify the elemental composition of a sample surface. The sample material is bombarded with electrons from an SEM which produce X-rays. The produced X-rays are then measured by an X-ray dispersive spectrometer. Every chemical element has its own characteristic wavelength by which it can be identified. EDS spectra, together with composition (Weight percent and Atomic percent) are attached in the section.

Results: White Material from Pressure Vessels

The deposit consisted mainly of a silicate-based material with some calcium sulfate inclusions

White Material From Pressure Vessel

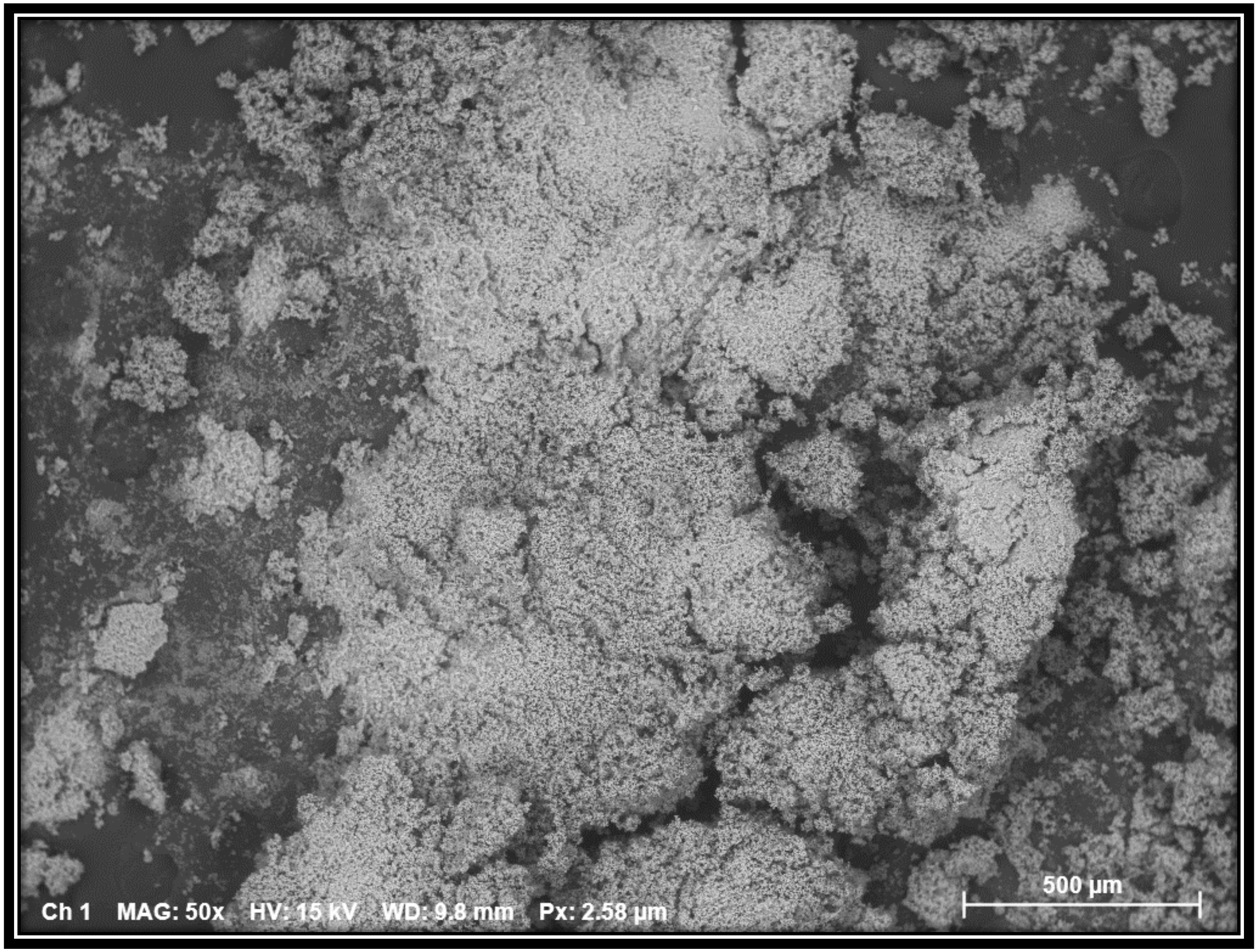


Figure 48: Electron micrograph of the deposit at 50X magnification.

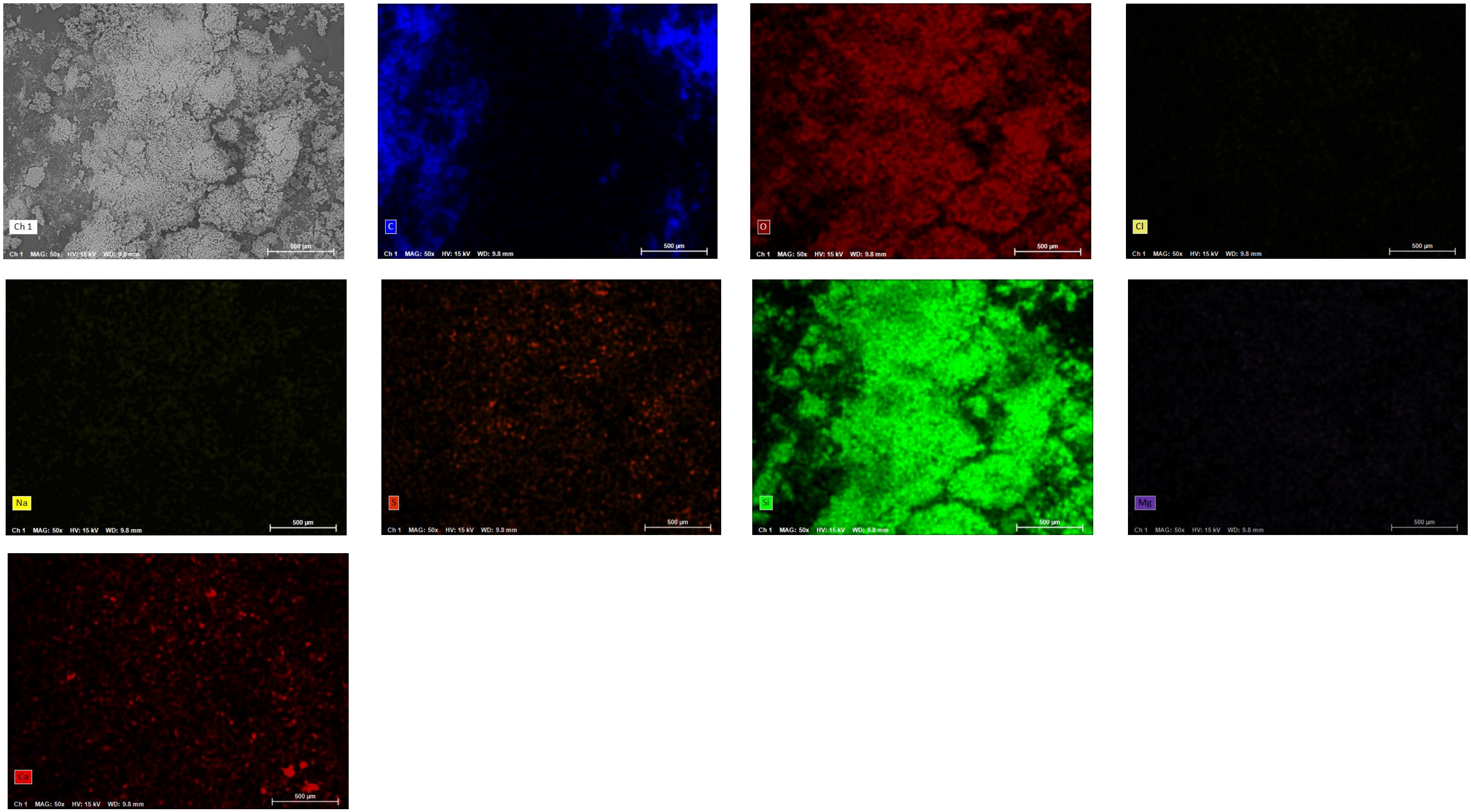


Figure 49: Prismatic Elemental Delineation (PED®) of the deposit at 50X magnification. Deposits found: Silicate-based material with some calcium sulfate inclusions.

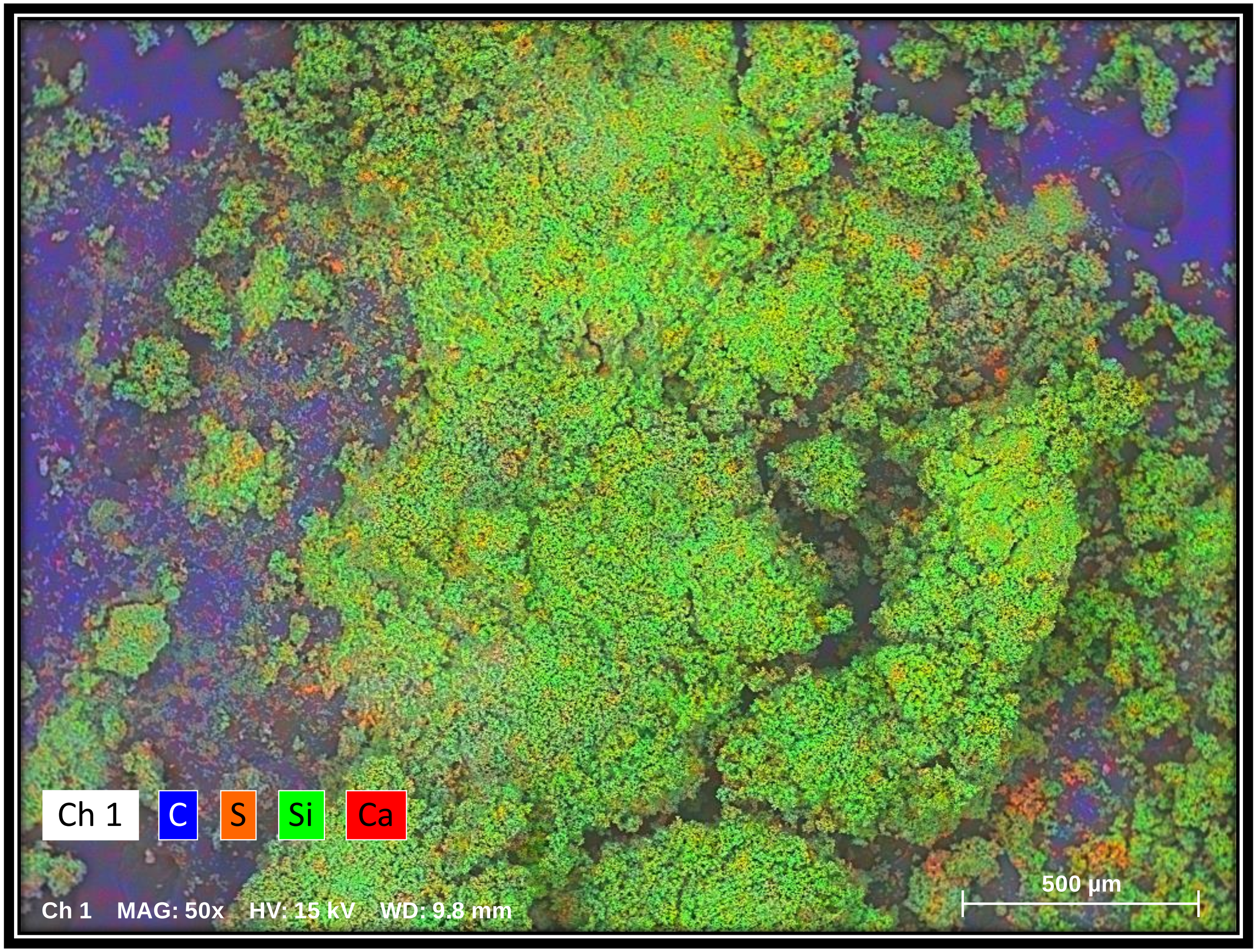
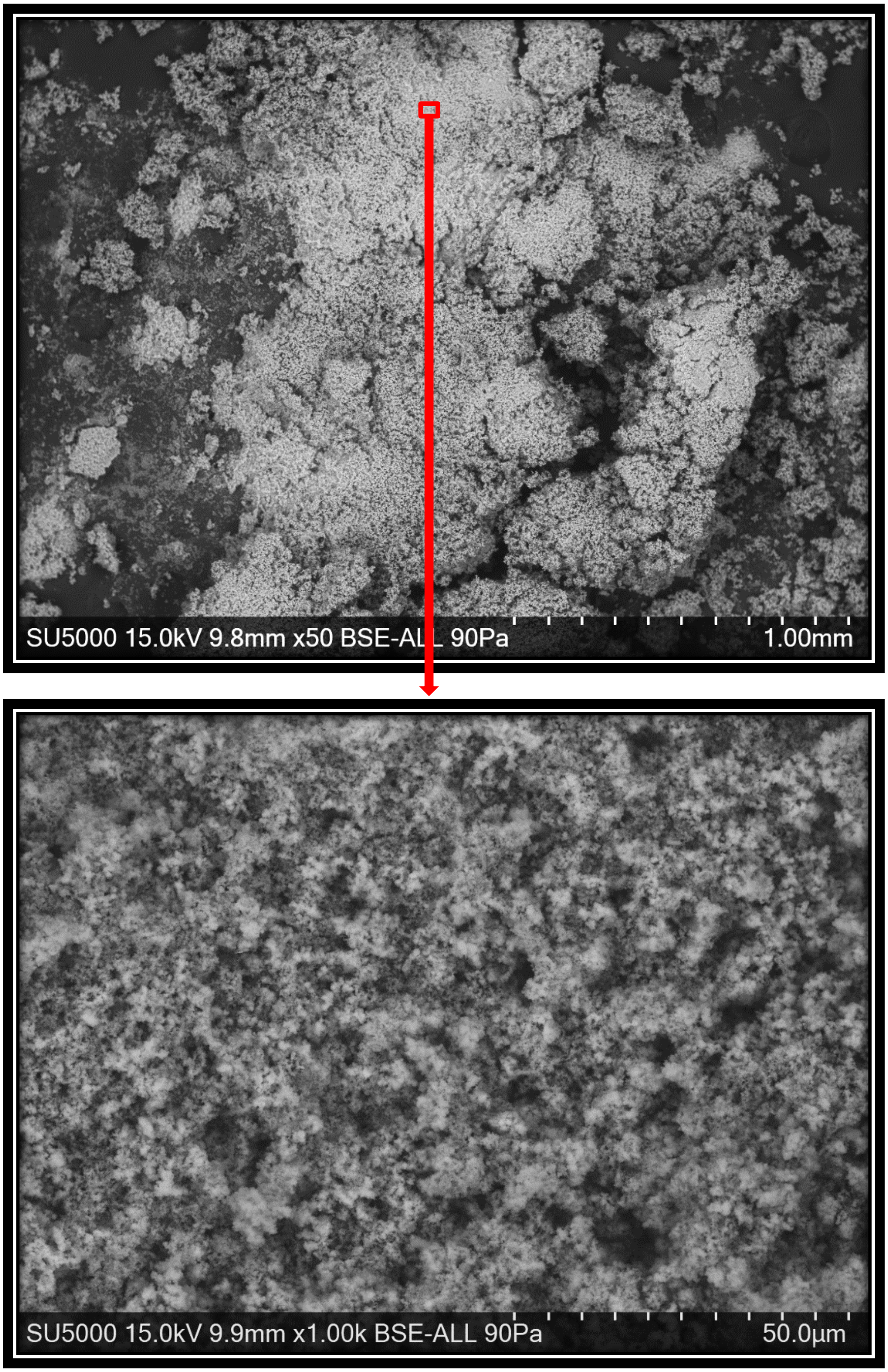
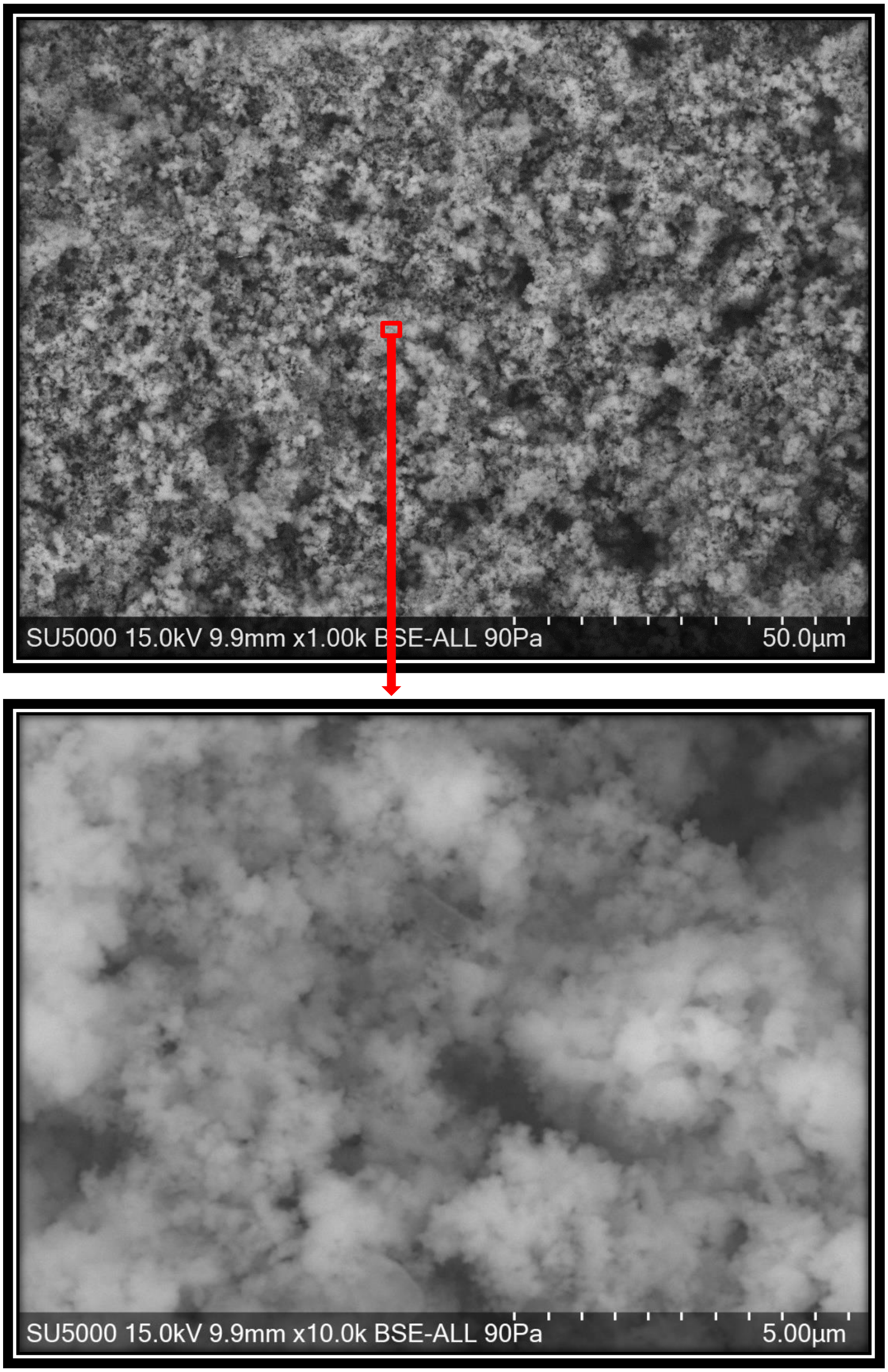


Figure 50: Superimposed Elemental Imaging (SEI®): Silicate-based material with some calcium sulfate inclusions.


SU5000 15.0kV 9.8mm x50 BSE-ALL 90Pa
1.00mm
SU5000 15.0kV 9.9mm x1.00k BSE-ALL 90Pa
50.0µm


SU5000 15.0kV 9.9mm x1.00k BSE-ALL 90Pa
50.0µm
SU5000 15.0kV 9.9mm x10.0k BSE-ALL 90Pa
5.00µm

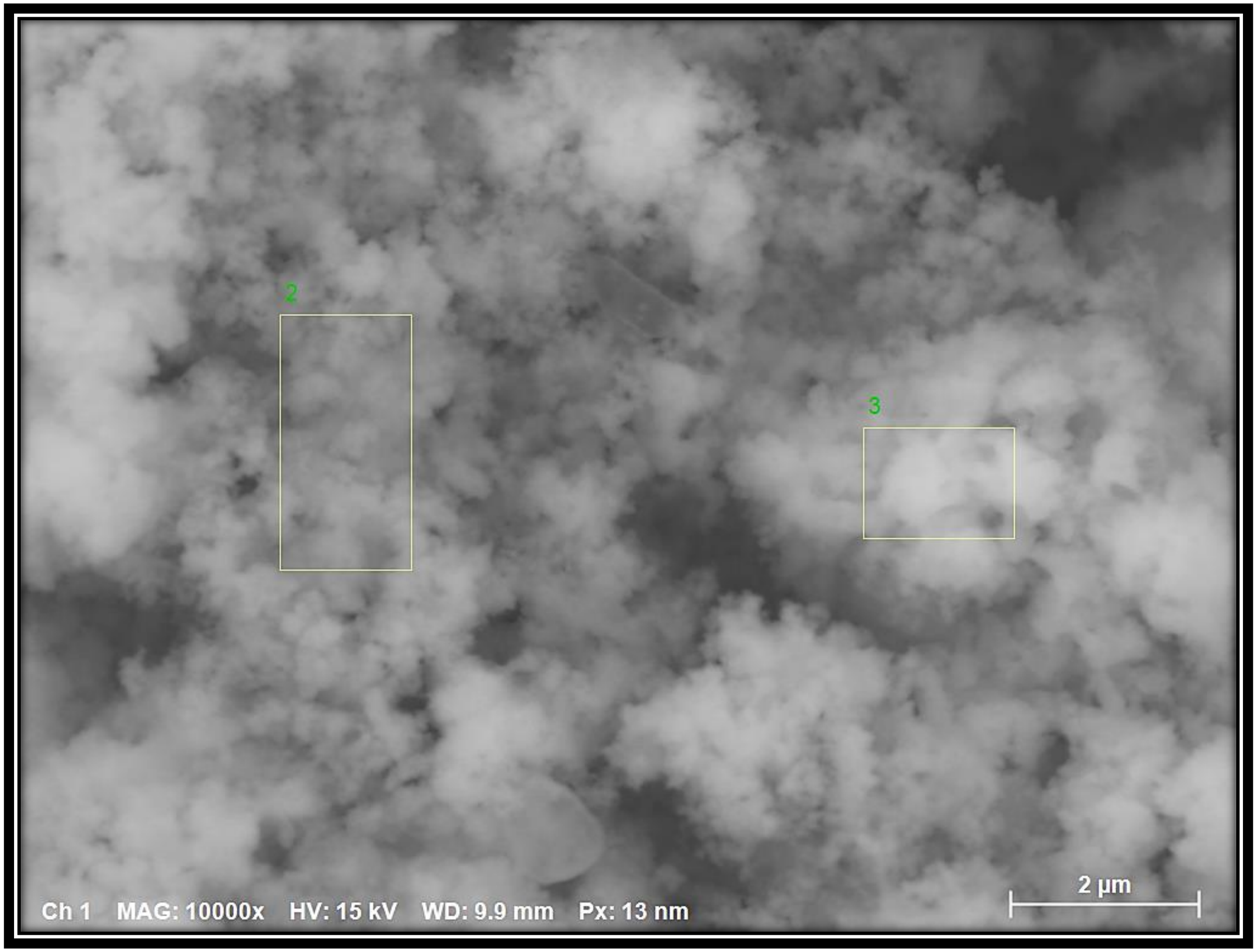


Figure 51: Electron micrograph of the deposit at 10000X magnification (Spectrum 2 & Spectrum 3).

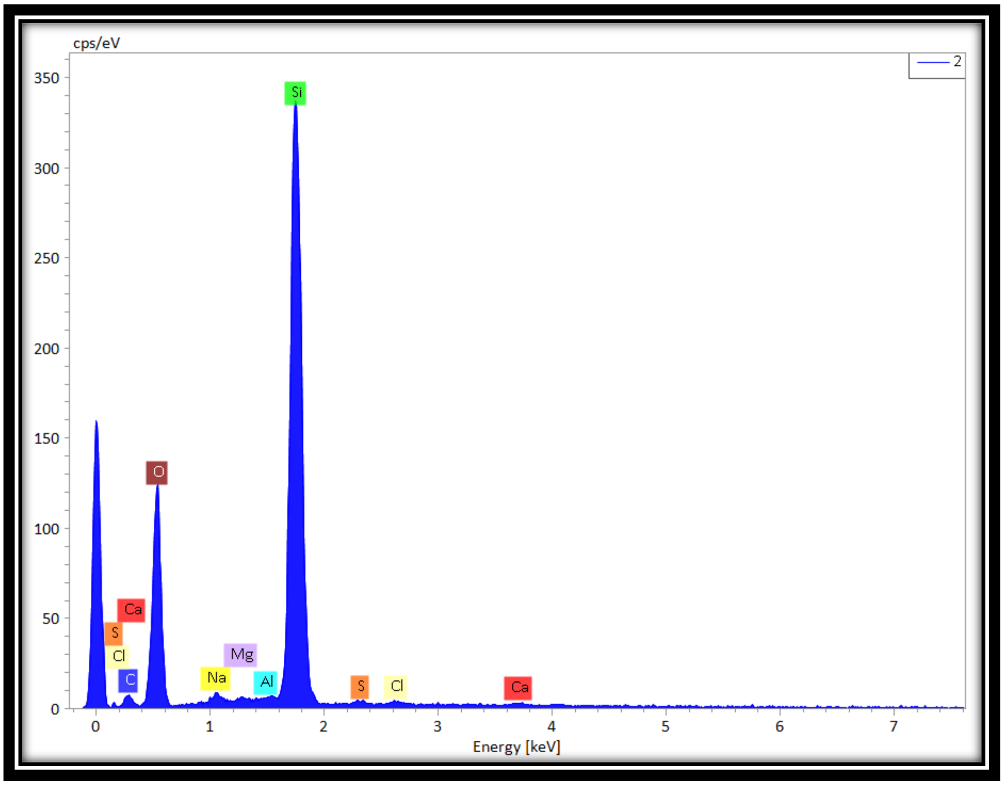


Figure 52: EDS and composition bar graph analysis of the deposit from Spectrum 2.

2

Element	Atom [%]
Carbon	14.60
Oxygen	55.89
Sodium	0.56
Silicon	28.53
Aluminium	0.10
Chlorine	0.15
Sulfur	0.16
	100.00

Carbon and Oxygen Ignored

2

Element	Atom [%]
Sodium	1.89
Silicon	96.72
Aluminium	0.33
Chlorine	0.52
Sulfur	0.54
	100.00

Table 6: Composition table from the EDS spectrum of localized deposit from Spectrum 2.

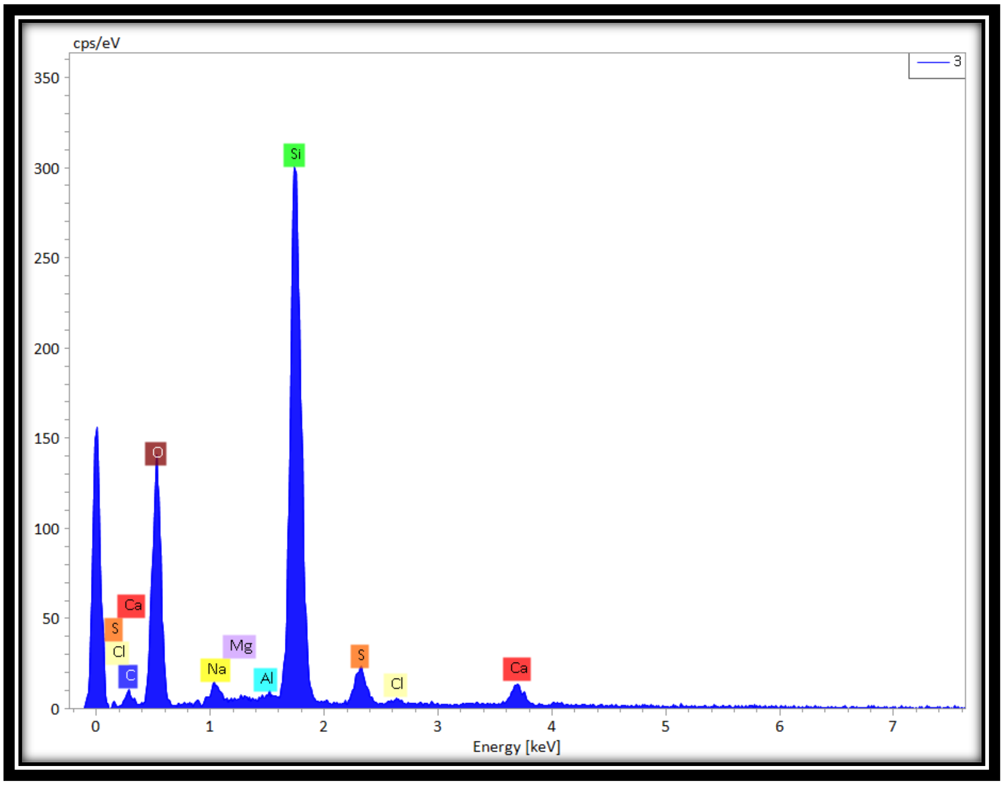


Figure 53: EDS and composition bar graph analysis of the deposit from Spectrum 3.

3

Element	Atom [%]
Carbon	12.98
Oxygen	58.99
Sodium	1.49
Silicon	22.76
Calcium	1.33
Sulfur	2.45
	100.00

Carbon and Oxygen Ignored 3

Element	Atom [%]
Sodium	5.29
Silicon	81.15
Calcium	4.80
Sulfur	8.76
	100.00

Table 7: Composition table from the EDS spectrum of localized deposit from Spectrum 3.

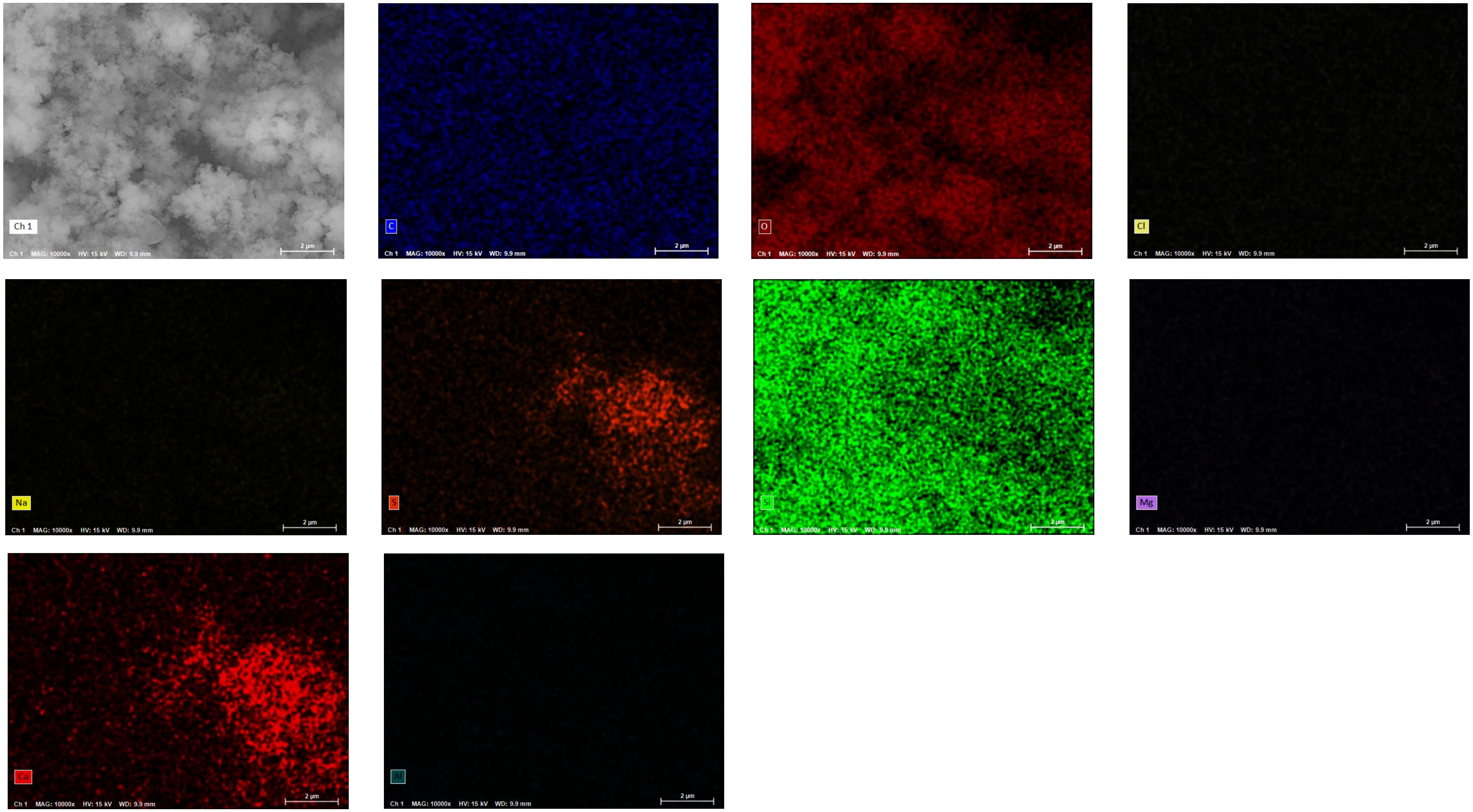


Figure 54: Prismatic Elemental Delineation (PED®) of the deposit at 10000X magnification. Deposits found: Silicate-based material with some calcium sulfate inclusions.

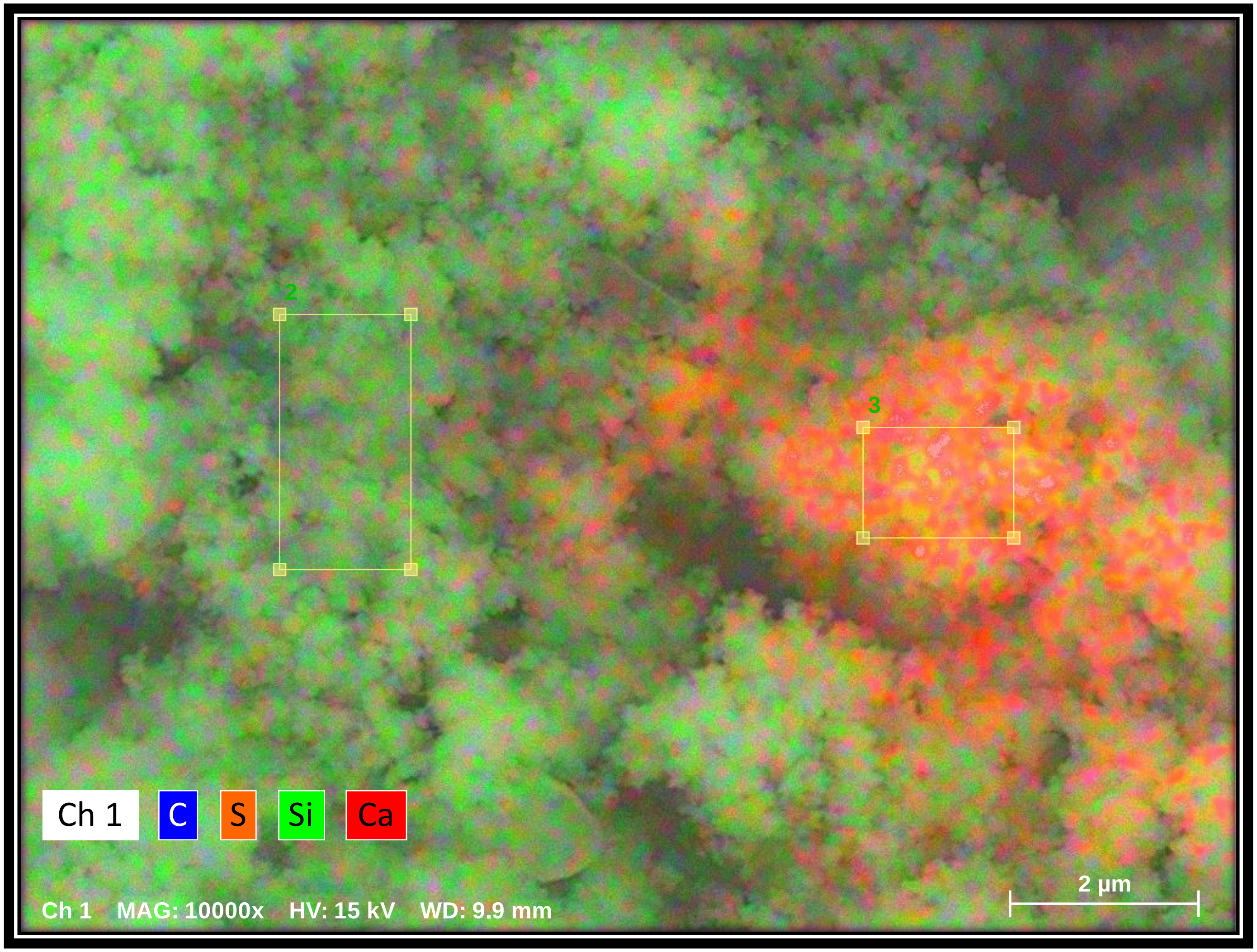


Figure 55: Superimposed Elemental Imaging (SEI®): Silicate-based material with some calcium sulfate inclusions.

FTIR analysis

Fourier Transform Infrared spectrometer (FTIR) is a powerful tool for identifying types of chemical bonds (functional groups). The wavelength of light absorbed is characteristic to the chemical bond. The tested material can be identified by comparing its spectrum to the spectra of documented compounds in the database.

The following samples were analyzed with FTIR:

- The scale sample (see Figure 56).

Results: White Material from the Pressure Vessel.

The spectrum of the sample had peaks associated with silica. A library search found that the material correlated well with silica gel.

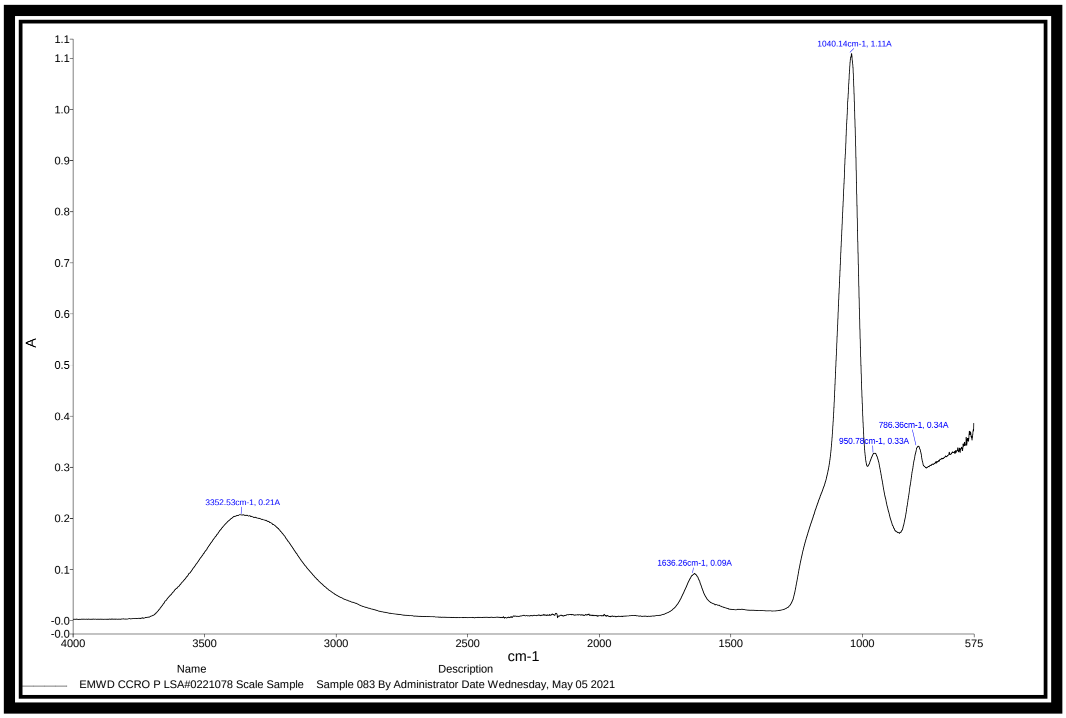


Figure 56:FTIR spectrum of the scale sample.

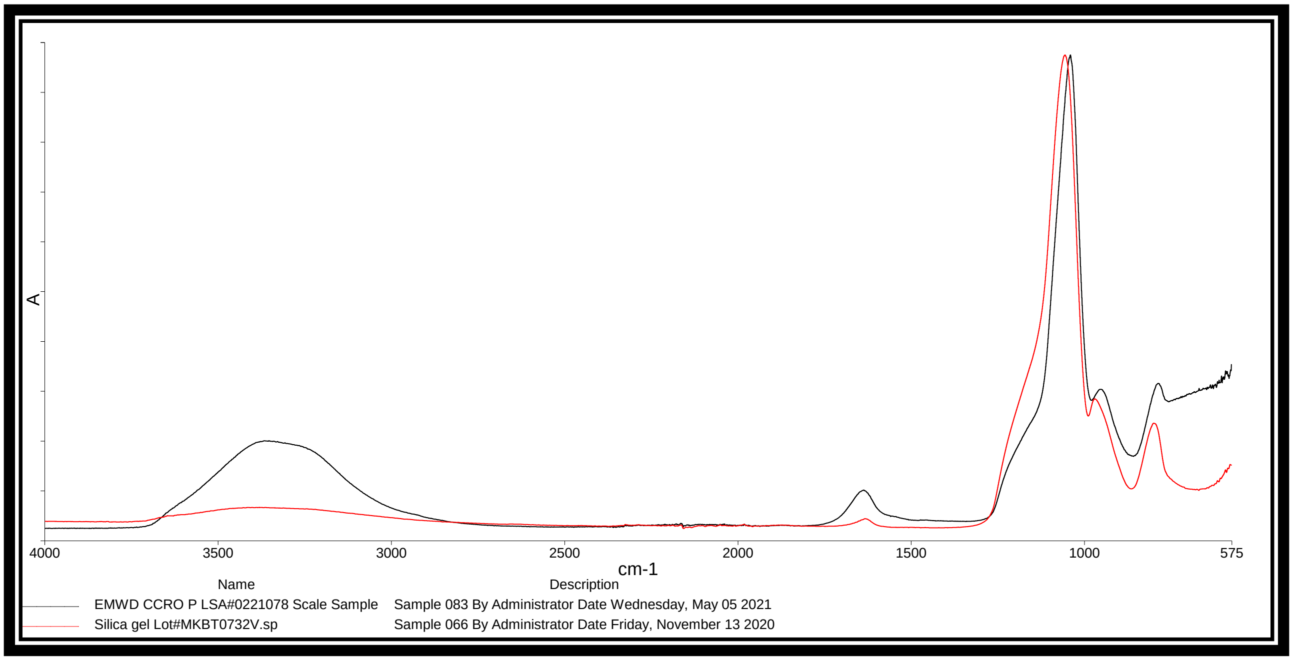


Figure 57:FTIR spectrum of the scale sample had a ~88% correlation to silica.

Release of Liability

The Membrane Autopsy Service (The Service) was performed in accordance with the standards of care, skill, and diligence normally provided by a professional in the performance of similar services. American Water Chemicals, Inc. makes no warranty of any kind with the respect to The Service and will not be liable for any damages resulting from the use or misuse of The Service. In no event shall American Water Chemicals, Inc. have any liability for The Service, including, but not limited to, special, indirect, incidental, consequential, or other direct damages whether such liability arises in contract, negligence, strict liability, or otherwise, and the Client hereby agrees to release and indemnify American Water Chemicals, Inc. against same.

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