Pall Water Processing

City of Ashland

Ashland, OR

Microfiltration Demonstration Pilot Study Treating Surface Water sources from the Talent Irrigation District (TID) and Reeder Reservoir

March 2018

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FIGURES

TABLES

ACRONYMS

AS	Air Scrub
CIP	Clean In Place
DIT	Direct Integrity Test
EFM	Enhanced Flux Maintenance
EPA	Environmental Protection Agency
FF	Feed Flush
GFD	Gallons per square Foot per Day
GPM	Gallons per Minute
IT	Integrity Test
LRV	Log Removal Value
MF	Microfiltration
MFGM	Membrane Filtration Guidance Manual
µg/L	Micrograms per Liter
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
NLT	Next Level of Treatment
NTU	Nephelometric Turbidity Unit
PDR	Pressure Decay Rate
ppm	Parts per million
ppb	Parts per billion
PSID	Pound per Square Inch Differential
PVDF	Polyvinylidene Fluoride
RF	Reverse Flush
SASRF	Simultaneous Air Scrub and Reverse Flush
SBW	Strainer Backwash
SCFM	Standard Cubic Feet per Minute
TCEQ	Texas Commission on Environmental Quality
TCF	Temperature Correction Factor
TID	Talent Irrigation District
TMDL	Total Maximum Daily Limits
TMP	Transmembrane Pressure
UCL	Upper Control Limit
USEPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive
WTP	Water Treatment Plant
XR	Excess Recirculation

GLOSSARY

Absolute Pore Size All particles with diameters exceeding this pore size will be retained during filtration with 100% efficiency under test conditions

Air Scrub (AS) On Pall systems an air scrub entails flushing water in the reverse direction through a membrane while simultaneously injecting air on the opposite side to gently vibrate fibers and direct foulant from the membrane surface to drain

Breach A hole or leak in a membrane system that is capable of contaminating produced water

Clean In Place (CIP) A membrane cleaning procedure where the membrane is cleaned without removing it from its rack; cleaning is performed by circulating chemical solution on the surface or through the membrane

Direct Coagulation The addition of a coagulant in the absence of flocculation and settling; the significant majority of pin floc formed during the coagulation reaction will not pass through a microfiltration membrane

Direct Integrity Test (DIT) (synonymous to integrity test) A physical test applied to a membrane to detect the presence of breaches; on Pall systems an integrity test is a pressure based test where the pressure decay is measured on a drained but wetted membrane surface and is compared to a standard to identify or isolate membrane breaches

Dead End Filtration A hydraulic configuration of membrane filtration systems where contaminants accumulate on the membrane surface and are removed through mechanical and chemical cleaning processes; all of the feed water is processed and waste streams only consist of filtered water used for cleaning and maintenance

Enhanced Flux Maintenance (EFM) A short-term relatively low strength microfiltration chemical cleaning whose interval can range from daily to an as-needed basis

Excess Recirculation (XR) On Pall systems excess recirculation refers to a mode of operation where a small portion of the feed water is diverted back to the feed tank to promote the suspension of solids and impede rapid accumulation on the membrane surface; however, excess recirculation does not change the characteristics of the filtration flow regime

Feed Flush (FF) A system flush on the feed side (only) of the membrane

Feed Water The influent stream to the microfiltration process

Filtrate The produced fluid from the microfiltration process

Flux The throughput of a membrane system measured in flow per unit area

Foulant Any substance that accumulates on the membrane surface

Fouling The accumulation of substances over time on a membrane which decreases membrane porosity resulting in higher driving pressures to produce filtrate

Hollow Fiber A configuration where membranes are constructed in hose-like fibers and bundled in a pressure vessel or submerged in a basin

Integrity Test (IT) (synonymous to Direct integrity test) A physical test applied to a membrane to detect the presence of breaches; on Pall systems an integrity test is a pressure based test where the pressure decay is measured on a drained but wetted membrane surface and is compared to a standard to identify or isolate membrane breaches

Log Removal Value (LRV) The removal efficiency of a target contaminant expressed using: $Log_{10}(feed\ concentration) - Log_{10}(filtrate\ concentration)$

LRV_{DIT} Log removal value with respect to direct integrity test sensitivity

Microfiltration A membrane filtration process that primarily utilizes physical separation to remove contaminants from process fluid

Module the encasement containing a membrane unit

Nominal Pore Size The significant majority of particles with diameters exceeding this pore size will be retained during filtration under test conditions

Particle Counter An instrument used to count the number of particles in a fluid and classify them according to size

Permeability (synonymous to specific flux) Susceptibility of membrane permeation by the process fluid; specific to microfiltration, permeability is calculated by dividing the flux by the transmembrane pressure

Pretreatment As referred to in this report, pretreatment is any water treatment or chemical addition prior to microfiltration

Recovery The ratio of net filtrate produced to net feed

Reverse Flush (RF) On Pall systems a reverse flush entails pumping filtrate in the reverse direction through the membrane and is directed to drain

Simultaneous Air Scrub and Reverse Flush (SASRF) (synonymous to Air Scrub) Entails flushing water in the reverse direction through a membrane while simultaneously injecting air on the opposite side to gently vibrate fibers and direct foulant from the membrane surface to drain

Specific Flux (synonymous to permeability) Susceptibility of membrane permeation by the process fluid; specific flux is calculated by dividing the flux by the transmembrane pressure

Temperature Corrected Flux Flux normalized to a standard temperature

Temperature Corrected Specific Flux Specific flux normalized to a standard temperature

Temperature Corrected Transmembrane Pressure Transmembrane pressure normalized to a standard temperature

Temperature Correction Factor (TCF) A factor used to adjust transmembrane pressure, flux, and specific flux to a target temperature (commonly 20°C)

Transmembrane Pressure (TMP) The pressure differential between the feed and filtrate side of a membrane

PURPOSE

The purpose of this demonstration pilot was to evaluate the performance of the Pall 0.1 μm microfiltration (MF) system treatment of the pretreated surface stream from the Talent Irrigation District and Reed Reservoir located in Ashland, OR. The pretreatment process included direct coagulation using aluminum chlorohydrate (ACH). The membrane treatment process will produce filtrate which will be used as a potable water source for the City of Ashland. This report summarizes the findings of the pilot test. Specific objectives of the pilot test included:

- Demonstration of the design criteria and operating parameters to be used in the full-scale 10 MGD system
- Demonstration of particulate and microbial removal capability via on-line turbidity
- Confirmation of on-line integrity test procedures
- Evaluation of membrane flux and recovery
- Evaluation of membrane fouling, CIP intervals, and effectiveness

SUMMARY

Pall Water was invited to participate in the pilot trials conducted at the City of Ashland WTP. Testing included three 28 day design runs, with each preceded with a brief optimization period on the surface stream to be treated. Evaluations would also consider the feasibility of two different surface streams, Talent Irrigation District (TID) and Reeder Reservoir. Design run 1 would treat the TID surface stream with the MF pilot operated at 55 gfd, 96.4% recovery with daily EFMs. Design run 2 would treat the Reeder Reservoir surface stream with the MF pilot operated at 70 gfd, 96.4% recovery with daily EFMs. Design run 2 would provide a glimpse of a very stable performance with operations treating the raw stream with and without direct coagulation. Performance essentially flattens with the implementation of direct coagulation using ACH. Design run 3 would also treat the Reeder Reservoir surface stream. Design run 3 allowed the Pall Water team to operate more aggressively highlighting the robustness of the Pall MF membranes. With the coagulated surface stream fed to the pilot, operations were at 85 gfd, 96.4% recovery, and EFM regimes triggered at 5 day intervals. A loss of the coagulant injection created an upset where minimal intervention was needed to continue stable operations for the remainder of the design run.

There were minimal interruptions to operations during the pilot trials. Occasionally, the site would have a power outage or the air compressor circuit breaker tipped and needed to be reset however, for the most part the pilot equipment operated reliably for the duration of the trials. The average feed water temperature measured during the pilot was 52.13°F (11.18°C). Throughout the pilot test, the Pall membrane demonstrated regenerative ability using EFM and CIP procedures. The cleaning parameters and the chemical concentrations implemented during this pilot test were determined to be appropriate. There was no irreversible fouling detected during the pilot trials. Membrane integrity was verified throughout the pilot with daily pressure hold tests.

TEST METHODS & EQUIPMENT

Membrane Module

The system was equipped with a new UNA-620A (S/N 905140317) hollow-fiber MF module. The module contains 538 square feet of active membrane surface area and operates in an outside-to-inside filtration mode. The membrane is a polyvinylidene fluoride (PVDF) hollow fiber type with a nominal pore size of 0.1 µm. PVDF fibers have excellent mechanical and chemical resistance. The physical characteristics of the membrane are described below in *Table 1*.

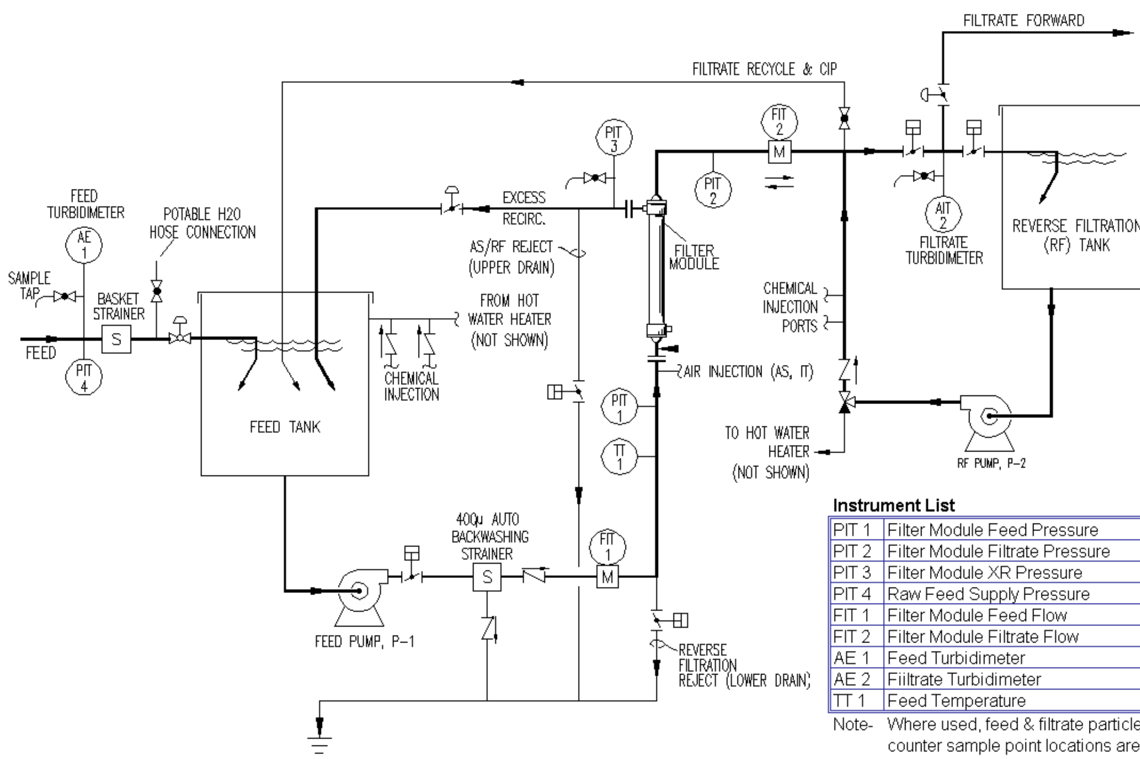
TABLE 1: MEMBRANE CHARACTERISTICS

Module Type	UNA-620A
Membrane Material	PVDF
Housing Material	ABS
Membrane Area (Outer Surface)	538 ft^2/50 m^2
Module Length	2 m
Module Diameter	15.24 cm
Nominal Membrane Pore Diameter	0.1µm
Number of Fibers per Module	6400
Fiber Diameter (ID/OD)	0.7mm/1.3mm
Filtration Mode	Outside-In, Dead End
Maximum Permeation Transmembrane Pressure	43.5 psid
Typical Operating Transmembrane Pressure	5-43.5 psid
Maximum Air Pressure for Integrity Test	>30 PSI
Maximum Operating Temperature	40°C
Maximum Cleaning Temperature	40°C
Operating pH Range	1-10
Cleaning pH Range	1-13
Maximum OCl- Exposure (Lifetime Contact Time)	>7,200,000 ppm-hr
Maximum Concentration for OCl- Cleaning	10,000 ppm

Pall MF Pilot System

The Pall MF pilot system is a fully automated membrane system designed with a range of capacity and capability intending to be applied to a wide range of process conditions. An industrial computer and a PLC controlled the operation of the system during this pilot study. The system was also monitored and controlled remotely through a wireless cellular router and remote access software. Critical operational parameters were logged continuously at 10 minute intervals and recorded automatically on the system computer hard drive. A schematic of the Pall MF system is show below in *Figure 1*. Included on the Pall MF pilot skid is a 400 micron auto backwashing strainer to protect the membrane from any foreign debris. The pilot unit also included a hot water heater and chemical pumps for EFM process.

FIGURE 1: PILOT PROCESS FLOW DIAGRAM



Instrument List

PIT 1	Filter Module Feed Pressure
PIT 2	Filter Module Filtrate Pressure
PIT 3	Filter Module XR Pressure
PIT 4	Raw Feed Supply Pressure
FIT 1	Filter Module Feed Flow
FIT 2	Filter Module Filtrate Flow
AE 1	Feed Turbidimeter
AE 2	Fiiltrate Turbidimeter
TT 1	Feed Temperature

Note- Where used, feed & filtrate particle counter sample point locations are same as AE 1 & AE 2 respectively.

There are five basic modes of operation for the MF membrane unit:

1. Forward Filtration

The feed pump draws water from the feed tank and pumps it into the feed port at the bottom of the module and through the membrane filter. Filtrate comes out of the vertical filtrate port at the top of the module. Excess recirculation (XR) entails circulating a small fraction of the feed water back to the feed tank to retain particulate suspension. This is performed by allowing a fraction of the feed flow to return to the feed tank through the horizontal XR port at the top of the module. The pilot unit is capable of operating with or without excess recirculation.

2. Reverse Filtration (RF)

The RF pump draws filtrate stored in the RF tank and pumps it through the membrane filter in the opposite direction as that during forward filtration. RF is used as a form of hydraulic cleaning for the membrane and is discharged through both the upper and lower discharge ports to drain. Chemicals such as chlorine or acid can be injected in the RF flow if necessary to keep the membrane clean. The frequency and duration of the RF is user defined.

3. Simultaneous Air Scrub/RF (AS)

AS (or sometimes termed SASRF) is another way to clean the membrane hydraulically. During an AS, air is injected into the module on the feed side of the fibers while filtrate is pumped in the reverse direction through the module. All discharge during the AS is sent to drain. The combined water-air flow creates turbulent flow generating a shearing force to dislodge foulant that has deposited on the membrane surface. The frequency and duration of an AS is dependent on feed water quality and is user defined.

4. Feed Flush (FF)

The feed pump is used to pump feed water into the module and out the upper drain/XR port. This process is used following an AS to flush waste out of the module. Flushed waste is directed to drain. The FF frequency and duration is also user defined.

5. Enhanced Flux Maintenance (EFM)

EFM is a short cleaning of membranes to maintain optimal performance. Called by various names, including chemical washes, mini-cleans, and relaxation, the basic process involves circulation of a chemical cleaning solution on the feed side of the membrane at an elevated temperature for 30 minutes before returning the unit back to normal operation.

TEST RESULTS & DISCUSSION

DESIGN RUN 1

Design run 1 began operations on Wednesday, August 30th to evaluate the Pall MF membrane performance on the surface feed from the Talent Irrigation District (TID). *Table 2* provides a summary of operating conditions utilized in design run 1.

TABLE 2: DESIGN RUN 1 OPERATING PARAMETERS

Filtrate Flux		55 GFD (20.5 gpm)
Recovery		96.4%
ASRF	Interval (gallons)	400 gallons
	Interval (minutes)	21.22 Minutes
	Filtration Duration	19.47 Minutes
	Duration	60 Seconds
	Air Flow (SCFM)	3 SCFM
	RF Flow (GPM)	8 GPM
FF	Interval (gallons)	400 gallons
	Interval (minutes)	21.22 Minutes
	Filtration Duration	19.47 Minutes
	Duration	20 Seconds
	Water Flow (GPM)	18 GPM
EFM	Frequency	Daily
	Duration	30 Minutes
	Chemical	500 ppm NaOCl
	Temperature	90-100°F
Cycle Length		28.1 Days
Excess Recirculation (XR)		2.0 gpm
Raw Water Pretreatment		8 ppm ACH Direct Coagulation

The MF pilot operated at 55 gfd. The ASRF was set to perform every 400 gallons with a recovery 96.4%. Daily EFMs were implemented into the process at a concentration of 500 mg/L NaOCl. Excess recirculation (XR) was implemented with the direct coagulation process at 2.0 gpm. The raw water pretreatment intended to inject ACH at a rate of 8 ppm. Previous jar testing by the plant staff would suggest this to be the optimum rate to achieve the reduction in the targeted constituents. It would be discovered and discussed by all parties involved that it is very likely that coagulant was not injected into the raw stream. The average feed water temperature was 63.3°F (17.4°C).

During the first two weeks of operation, the process trend would show a TMP growth rate that was higher than expected. While not concerning, there was an expectation to see a greater recovery in the TMP from the EFM regime than what was observed. On Tuesday, 9/5/17, with the assistance of the operations staff, chemical was manually added to the EFM process resulting in an effective EFM event where the TMP recovered from 24 psi to 13 psi. This manual chemical addition to the EFM process was repeated on

Monday 9/11/17 and produced similar results. Pall staff was on site Thursday 9/14/17 to troubleshoot and resolve the fact that there was no chlorine delivered during the EFM process. The chemical dispense system was found to not be functioning and was replaced. This would confirm previous suspicions that the EFM process has been operating without the proper chemical dose added to the EFM process. During the daily EFM, samples were collected at several points for analysis to insure that there was sufficient active chlorine residual.

As shown on *Figure 2*, the MF performance would operate with stability with the TMP trending in a range of 6.4 – 24 PSI. The average TMP for this test cycle was 15.01 PSI. The graph from *Figure 2* would also show that the daily EFM was effective in controlling the TMP growth. When the EFM process was functioning properly, the trend would show a predictable pattern of recovery before and after the completion of the EFM process each day. A similar observation can be seen in *Figure 3*, highlighting the permeability data. There was an interruption in the pilot operation on 9/20-9/21. There was a power outage. The rig remained offline until the details of the power outage were confirmed. A CIP was performed on Wednesday 9/27/17 in completion of this test period.

FIGURE 2: DESIGN RUN 1 PROCESS DATA

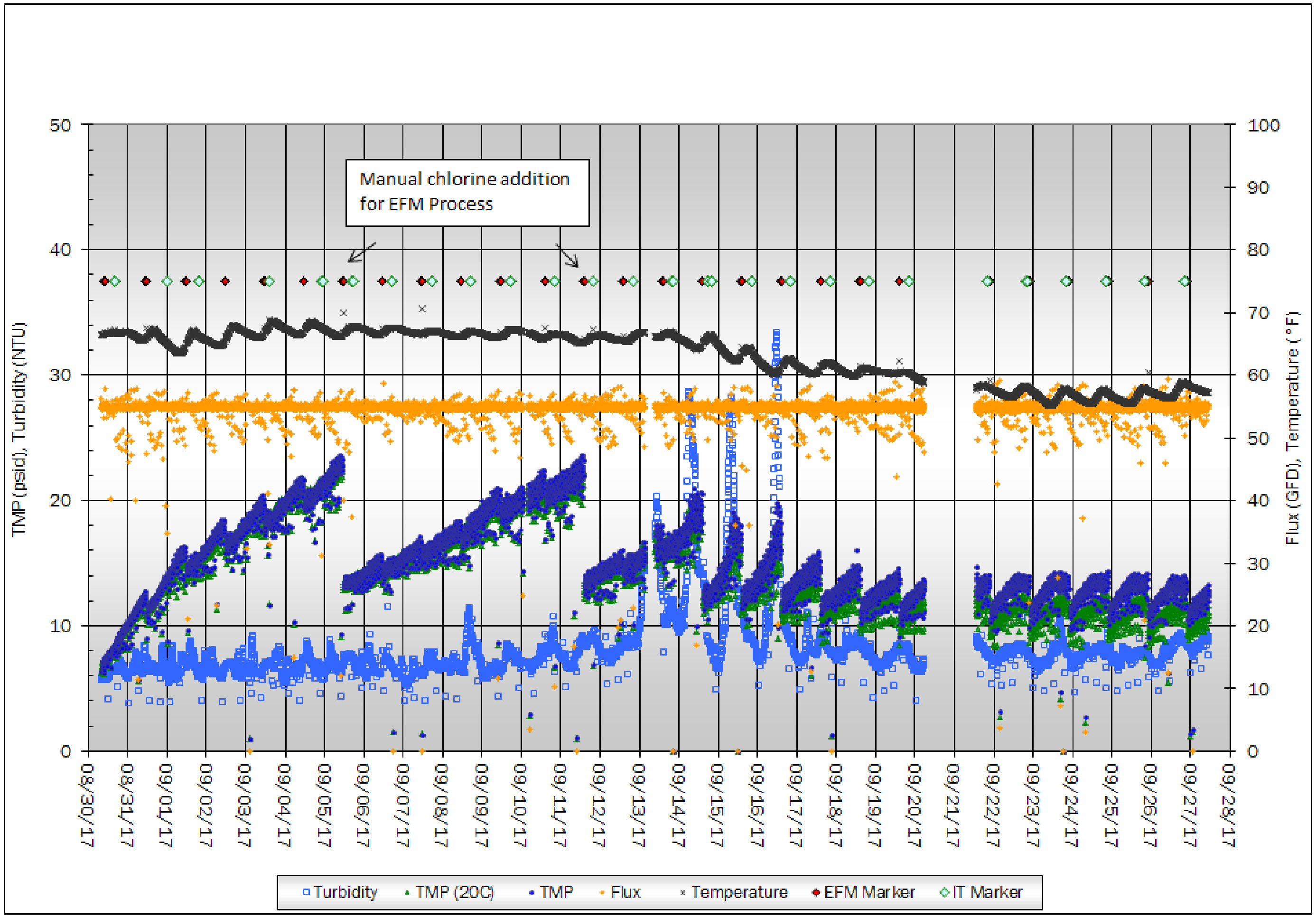


FIGURE 3: DESIGN RUN 1 SPECIFIC FLUX DATA

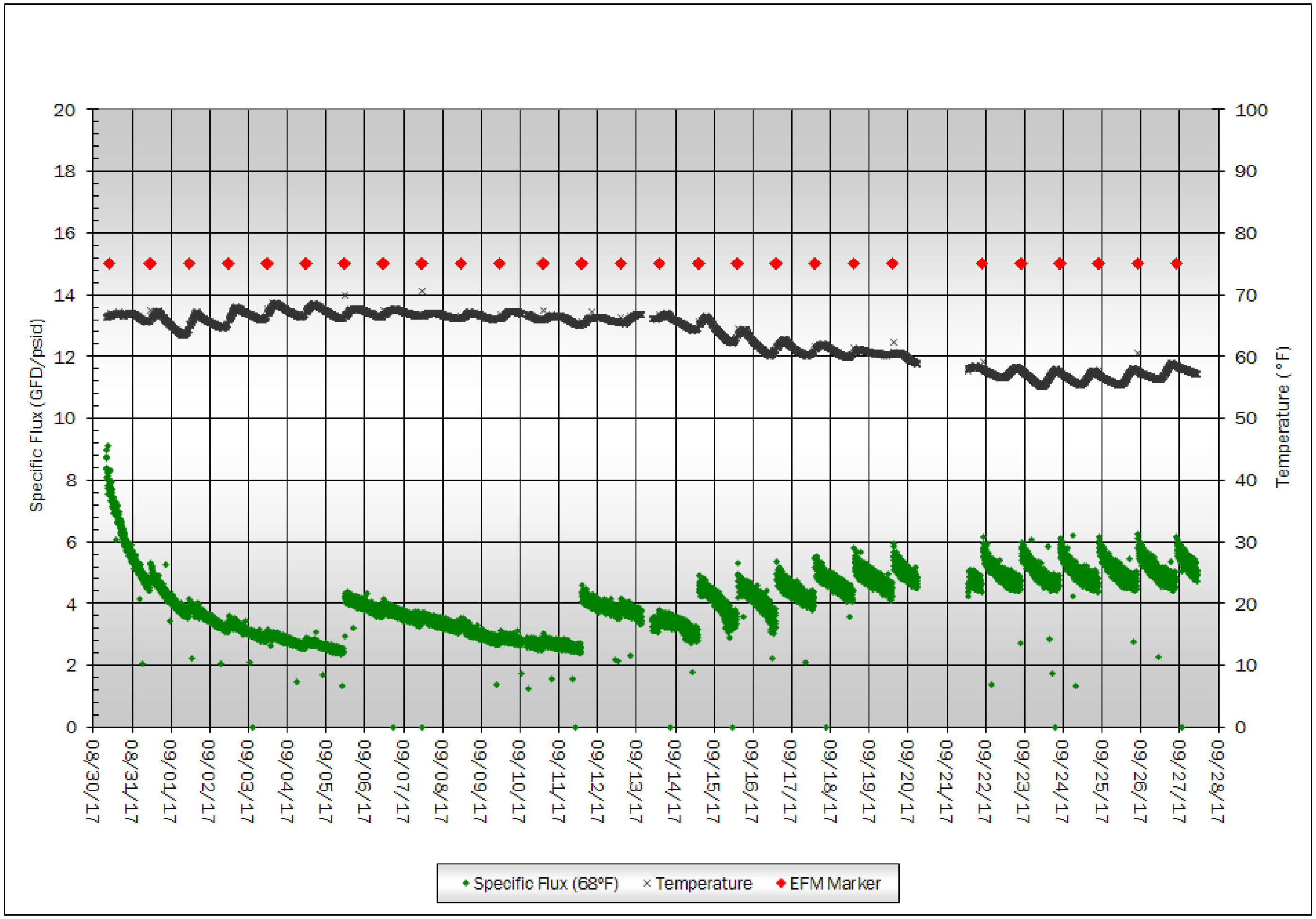
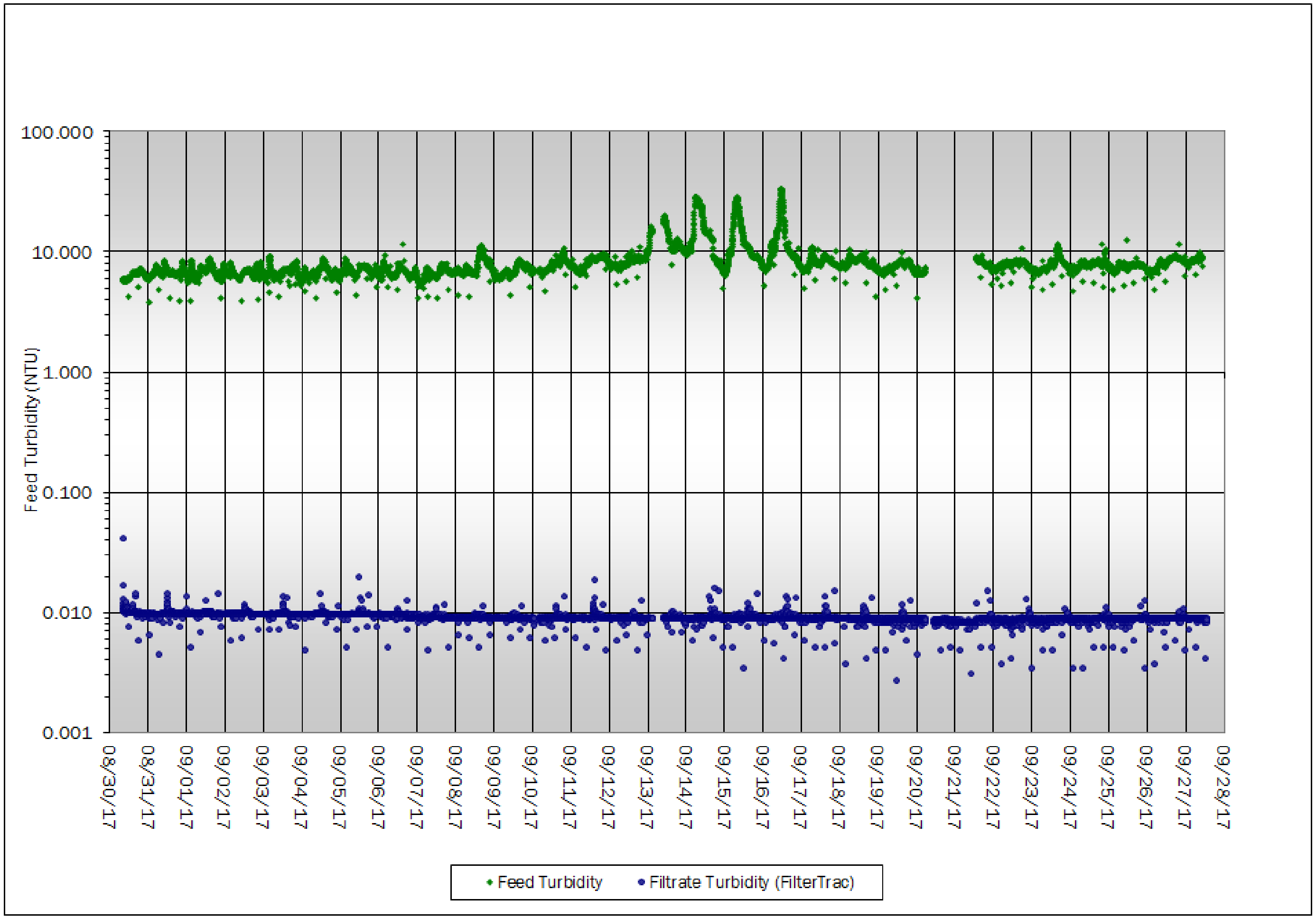


FIGURE 4: DESIGN RUN 1 TURBIDITY DATA



DESIGN RUN 2

Pilot testing began on Tuesday, October 3rd to evaluate the Pall MF membrane performance on the surface feed from the Reeder Reservoir. *Table 3* provides a summary of operating conditions utilized in design run 2.

TABLE 3: DESIGN RUN 2 OPERATING PARAMETERS

Filtrate Flux		70 GFD (26.2 gpm)
Recovery		96.4%
ASRF	Interval (gallons)	400 gallons
	Interval (minutes)	17.04 Minutes
	Filtration Duration	15.29 Minutes
	Duration	60 Seconds
	Air Flow (SCFM)	3 SCFM
	RF Flow (GPM)	8 GPM
FF	Interval (gallons)	400 gallons
	Interval (minutes)	17.04 Minutes
	Filtration Duration	15.29 Minutes
	Duration	20 Seconds
	Water Flow (GPM)	18 GPM
EFM	Frequency	1 – 3 days
	Duration	30 Minutes
	Chemical	500 ppm NaOCl
	Temperature	90-100°F
Cycle Length		30.2 Days
Excess Recirculation		1.0 gpm
Raw Water Pretreatment		8 ppm ACH Direct Coagulation

The MF pilot operated at 70 gfd. The ASRF was set to perform every 400 gallons with a recovery 96.4%. Daily EFMs were implemented into the process at a concentration of 500 mg/L NaOCl. After 13 days of very stable operation, the EFM interval was increased to 3 days. Excess recirculation (XR) was implemented with the direct coagulation process at 1.0 gpm. The raw water pretreatment intended to inject ACH at a rate of 8 ppm. Previous jar testing by the plant staff would again suggest this to be the optimum rate to achieve the reduction in the targeted constituents. During this run, it was discovered that the coagulant pump was not delivering the intended dose of ACH into the raw stream. On 10/12/17, the coagulant pump was properly started and began to feed the targeted injection rate of coagulant into the feed stream. The MF performance becomes noticeably flat. The average feed water temperature was 50.66°F (10.36°C)

As shown on *Figure 5*, the MF performance would operate with stability with the TMP trending in a range of 8.7 – 18.4 PSI. The average TMP for this test cycle was 15.9 PSI. The graph from *Figure 5* would also show that the daily EFM was effective in controlling the TMP growth. The trend would show a predictable pattern of recovery before and after the completion of the EFM process each day. A similar observation can be seen in *Figure 6*, highlighting the permeability data. During this design run, the specific flux trended within a range 5.1 - 10.3 gfd/psi at 20°C. The specific flux trend highlights the benefit of the EFM process. With coagulant injection functioning properly, the specific flux holds close to 5.3 gfd/psi at 20 °C. A CIP was performed on Thursday 11/9/17 in completion of this test period.

FIGURE 5: DESIGN RUN 2 PROCESS DATA

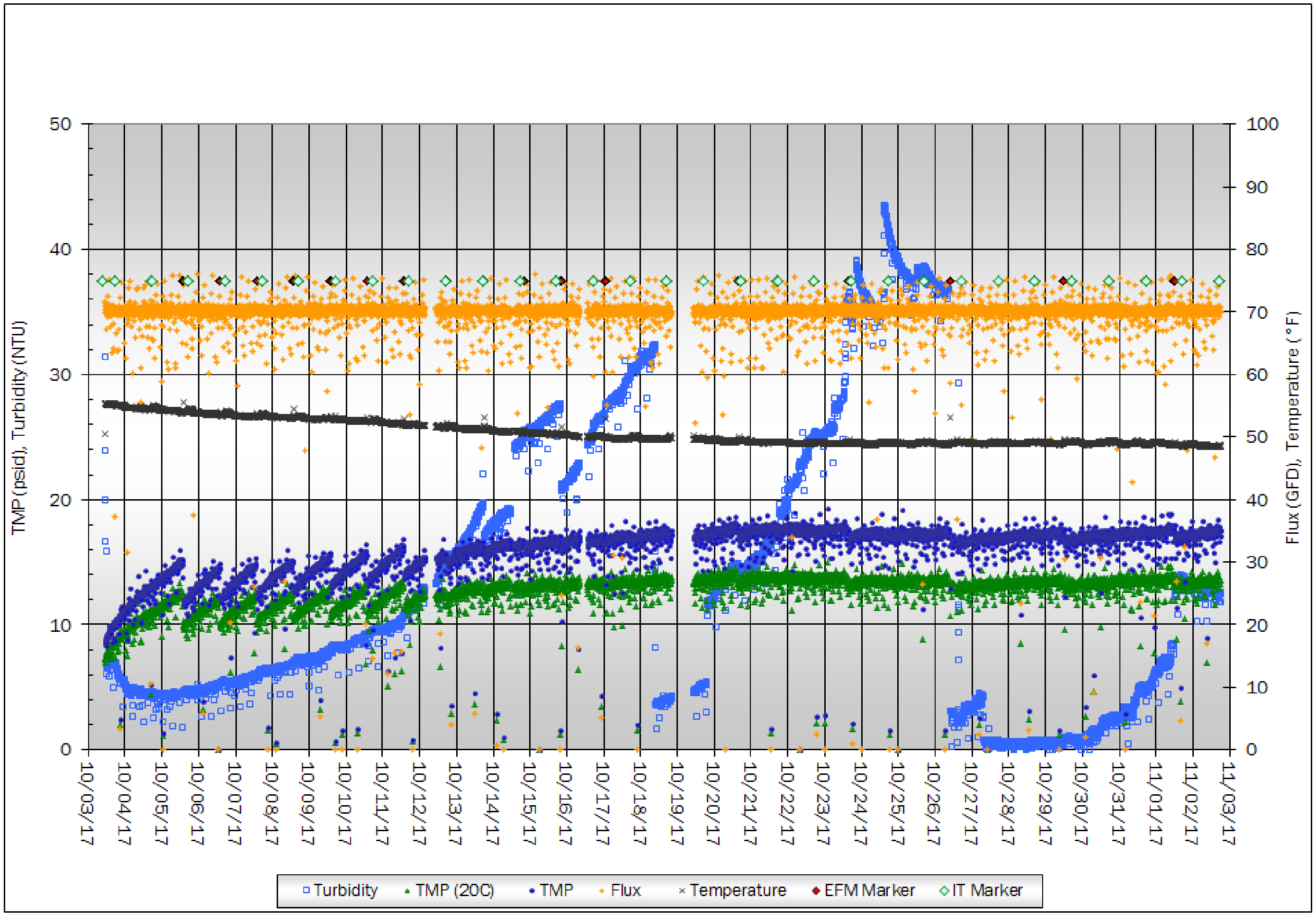


FIGURE 6: DESIGN RUN 2 SPECIFIC FLUX DATA

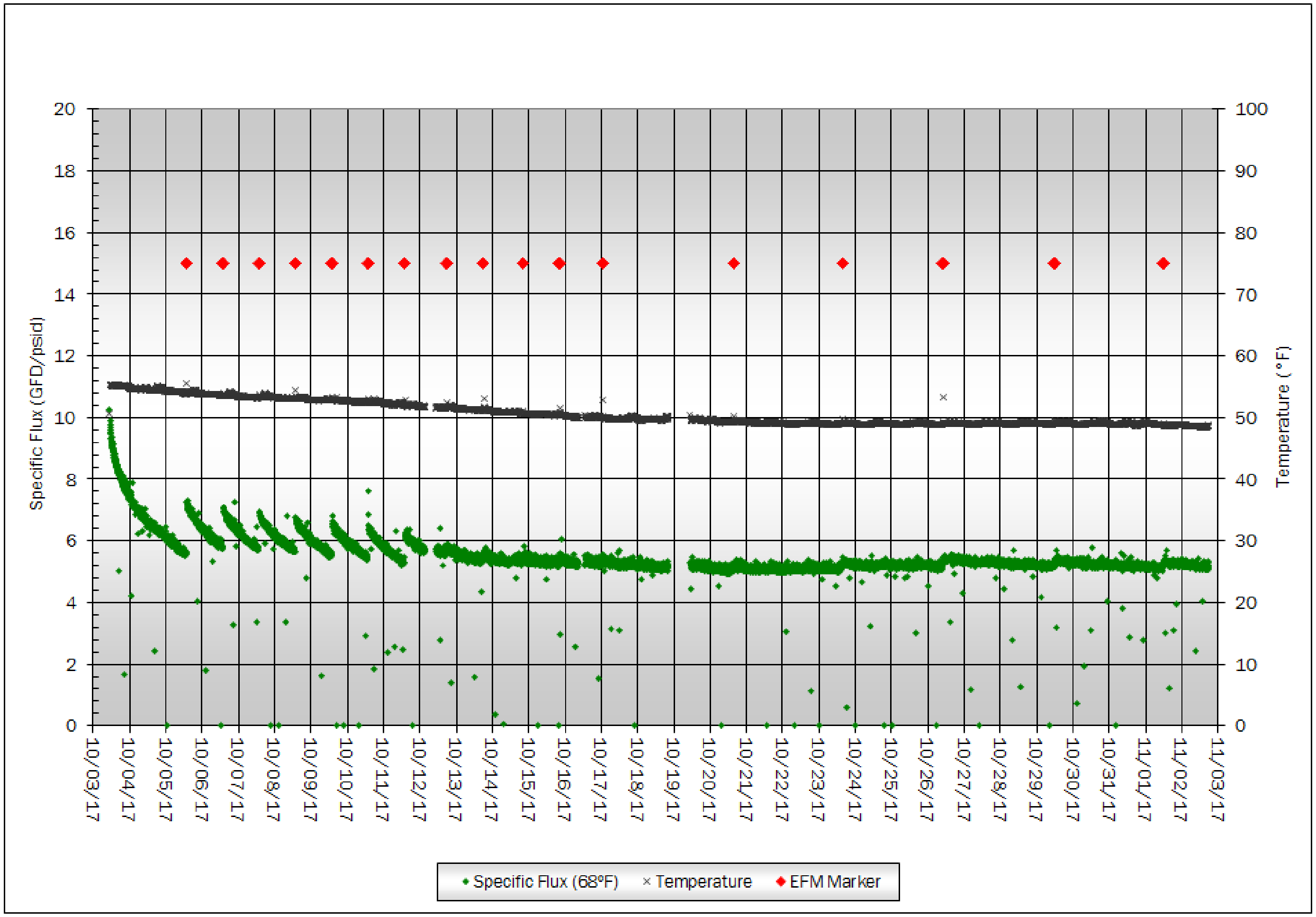
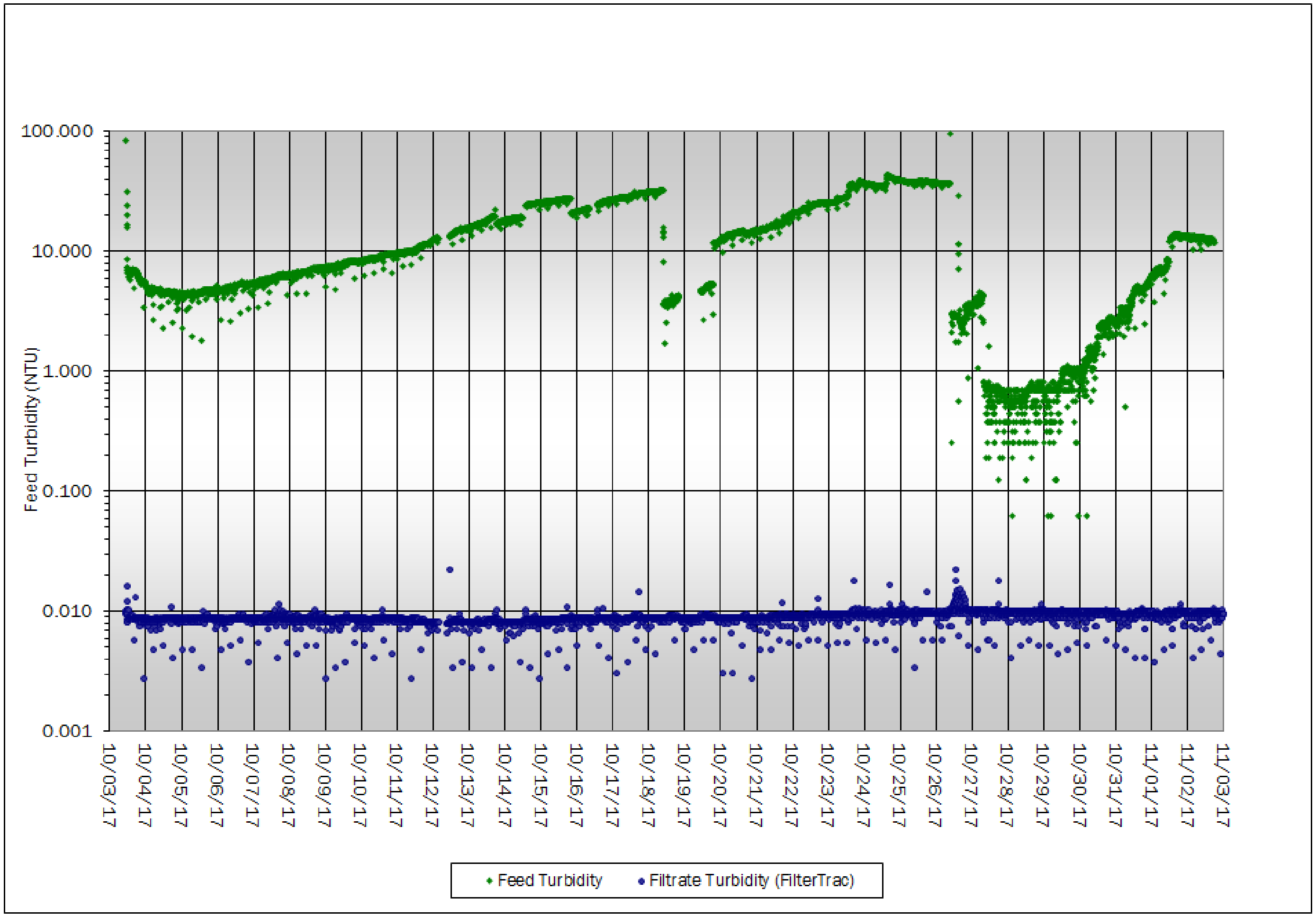


FIGURE 7: DESIGN RUN 2 TURBIDITY DATA



DESIGN RUN 3

Pilot testing began on Tuesday, November 14th to evaluate the Pall MF membrane performance on the surface feed from Reeder Reservoir. *Table 4* provides a summary of operating conditions utilized in design run 3.

TABLE 4: DESIGN RUN 3 OPERATING PARAMETERS

Filtrate Flux		85 GFD (31.8 gpm)
Recovery		96.4%
ASRF	Interval (gallons)	400 gallons
	Interval (minutes)	14.35 Minutes
	Filtration Duration	12.60 Minutes
	Duration	60 Seconds
	Air Flow (SCFM)	3 SCFM
	RF Flow (GPM)	8 GPM
FF	Interval (gallons)	400 gallons
	Interval (minutes)	14.35 Minutes
	Filtration Duration	12.60 Minutes
	Duration	20 Seconds
	Water Flow (GPM)	18 GPM
EFM	Frequency	Every 5 days
	Duration	30 Minutes
	Chemical	500 ppm NaOCl
	Temperature	90-100°F
Cycle Length		28.4 Days
Excess Recirculation		1.0 gpm
Raw Water Pretreatment		8 ppm ACH Direct Coagulation

The MF pilot will begin operating with an instantaneous flux of 85 gfd. The airscrub interval is currently set at 400 gallons per module with the typical flux maintenance parameters. An airscub occurs approximately every 14.3 minutes. The EFM is set to trigger every 5 days. The EFM process uses MF filtrate source as the makeup solution. The excess recirculation process will be set at 1.0 gpm. The overall recovery is calculated at 96.4%. The average feed water temperature was 42.4°F (5.8°C)

For the first 10 days of operation during this design run, the performance was very stable with a fairly aggressive flux rate. The coagulation process really helps to flatten the TMP trends. This is highlighted in *figure 8*. On Friday, November 24th, the trends begin to show a decline in performance with a rapidly increasing TMP. The feed turbidity also increased. Later discussions would confirm the loss of the coagulant feed. It would become necessary to intervene to prevent the MF process reaching terminal TMP limits. As the TMP climbed over 30 psi in the early morning hours on Saturday, a chlorine EFM was initiated. This provided minimal benefit. The performance was closely watched on Sunday. As the TMP climbed over 35 psi, a citric acid efm was initiated less than 24 hours from the previous EFM. Shortly afterwards, the compressor faulted out. The circuit breaker was reset and the system was brought back online early Monday morning. The coagulant feed was also restored. While the performance does not recover to the previously stable levels, the rapid climb in the TMP stopped. As shown on *Figure 8,* the average TMP for this design run was 26.9 PSI.

FIGURE 8: DESIGN RUN 3 PROCESS DATA

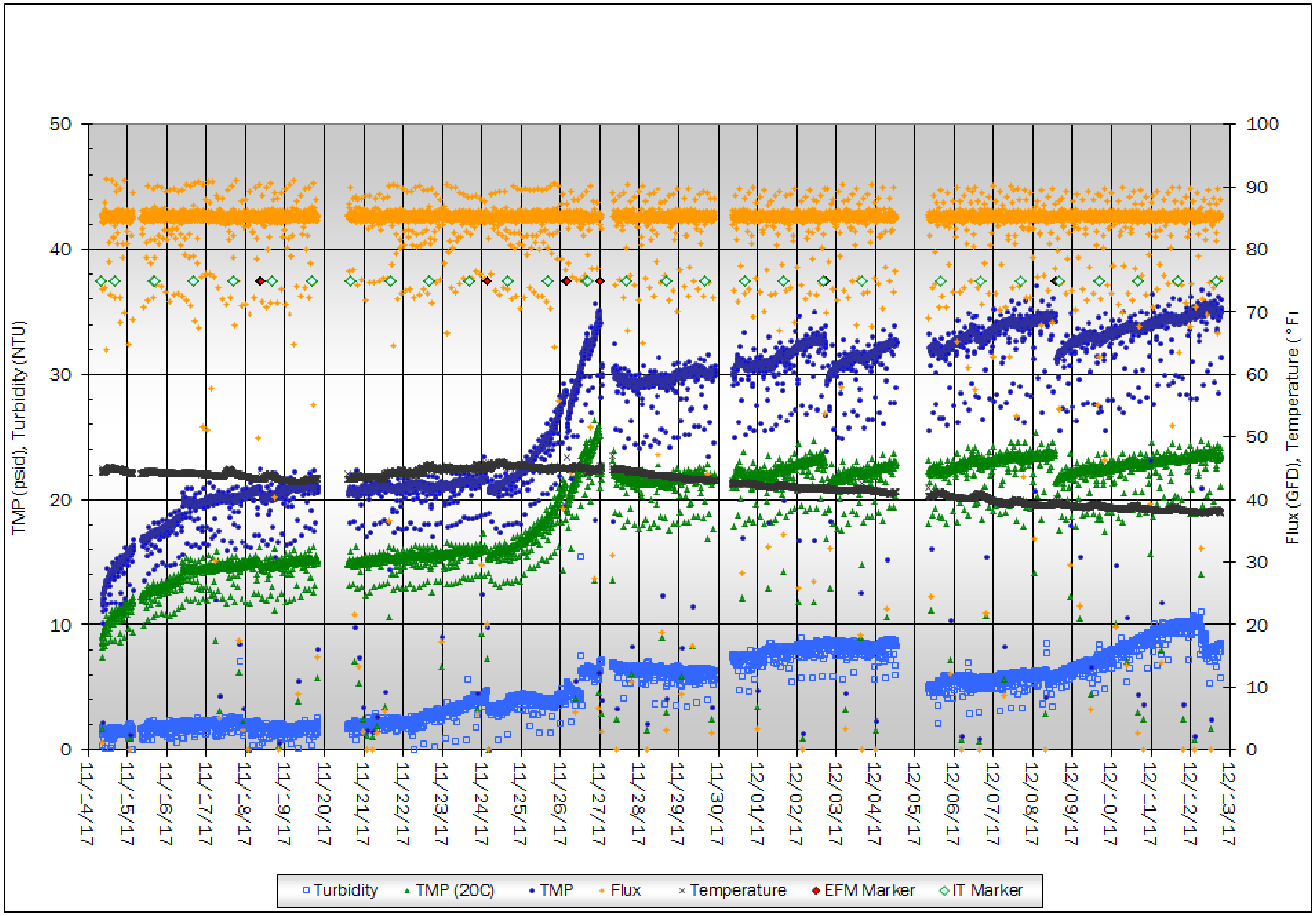


FIGURE 9: DESIGN RUN 3 SPECIFIC FLUX DATA

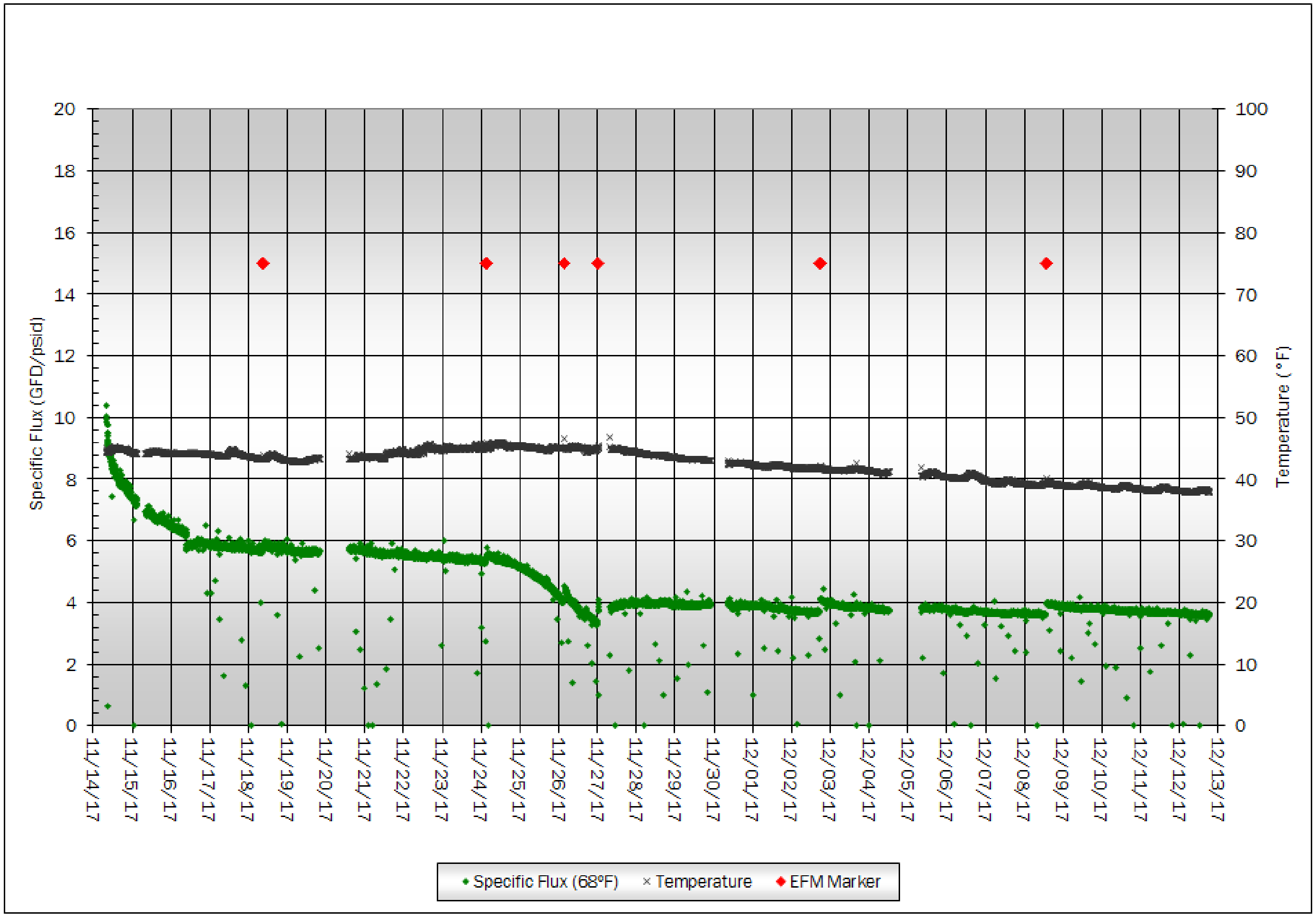
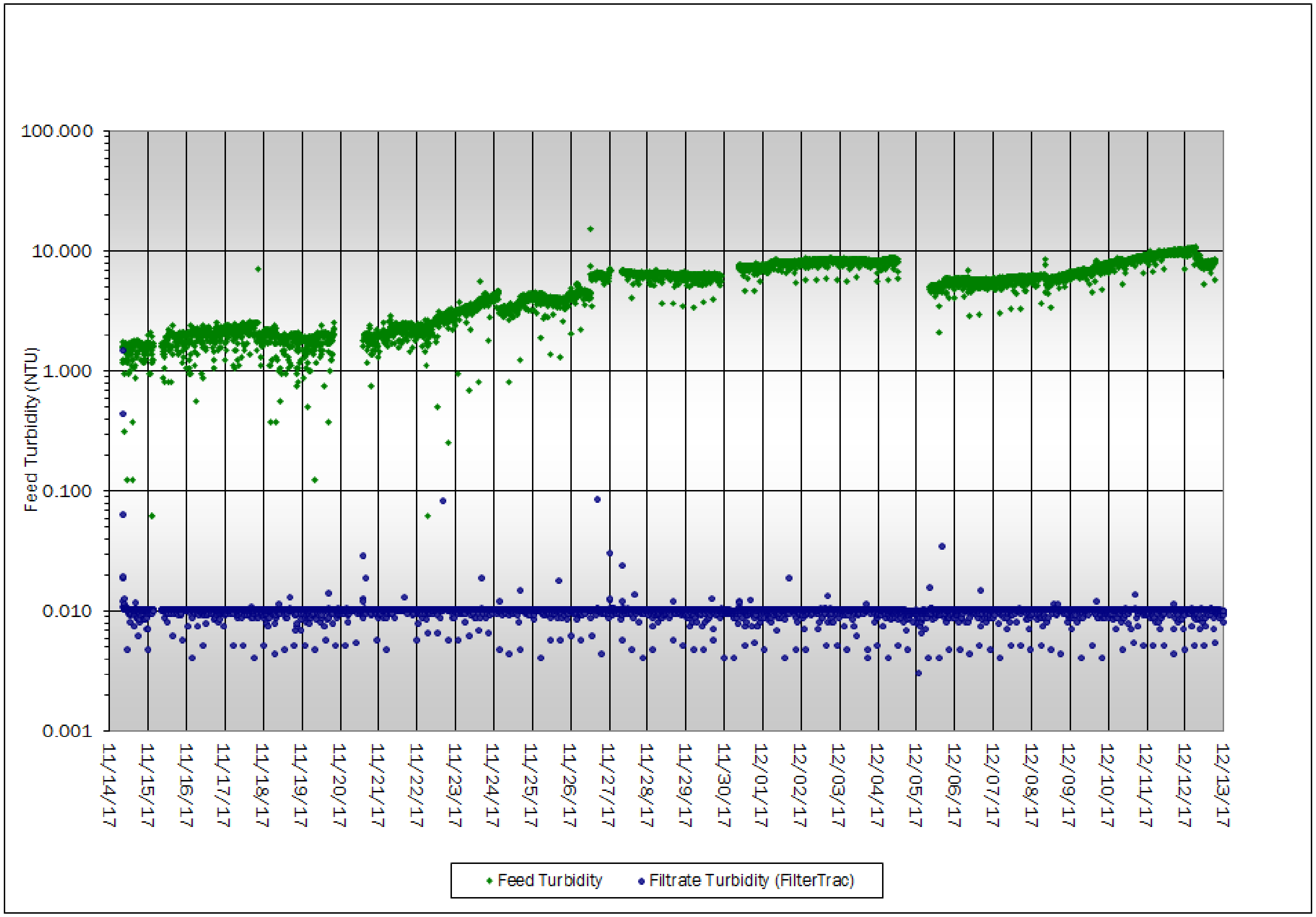


FIGURE 10: DESIGN RUN 3 TURBIDITY DATA



TURBIDITY

The Pall MF pilot rig is equipped with turbidity meters for continuous online monitoring on both the feed and filtrate streams. The feed and filtrate turbidity recorded data for the demonstration pilot is highlighted below in *Table 5*. The MF feed turbiditimeter detected turbidity in a general range of 1 – 12 NTU. The MF filtrate turbidimeter detected turbidity in a general range of 0.009 – 0.011 NTU. For both instruments, the maximum values listed in *Table 5* appear to be high and not in the expected range of detection. This is not an uncommon to experience. During airscrubs, integrity tests, EFMs, flow to these instruments is stopped. After these processes are completed and the system is brought back into production, there is often air trapped in the system. This notably causes variations in what is detected by both turbidimeters. Additionally, during the second design run, the feed turbidity data was trending higher in comparison with other units sampling at the same stream. Field service staff arrived on site to investigate any discrepancies in the data. The instrument was cleaned and recalibrated.

TABLE 5: TURBIDITY SUMMARY

	Feed Turbidity (NTU)						Filtrate Turbidity (NTU)					
	Min	**Max**	**5th**	**50th**	**95th**	**Avg**	**Min**	**Max**	**5th**	**50th**	**95th**	**Avg**
Design Run 1	3.83	196.0	6.10	7.54	12.64	8.21	0.002	0.042	0.008	0.009	0.010	0.009
Design Run 2	-2.0	94.80	0.69	9.81	37.28	13.89	0.000	0.022	0.008	0.009	0.010	0.009
Design Run 3	-1.1	15.40	1.63	5.78	9.18	5.23	0.004	1.495	0.009	0.010	0.010	0.011

CIP EFFECTIVENESS

A full CIP procedure was performed at the end of each design run using the protocol outlined in Appendix A. The standard CIP recipe entails two steps: circulation of a 2,000 ppm NaOCl with 1% NaOH for 2 hours, followed by circulation of 2% citric acid for one hour. The pilot was successful at demonstrating the ability to regenerate the membrane's permeability after each CIP. The cleaning parameters highlighted in Appendix A have proven to be appropriate and effective in restoring membrane permeability.

A typical measure of CIP effectiveness is the specific flux or permeability, reported gfd/psi. After each CIP step, clean water is circulated through the membrane in order to measure permeability at various flow rates. Baseline data for a conditioned module is measured after a full cycle of operation. For this test, the baseline data for a conditioned module is marked on the CIP performed 10/3/17. A summary of these values is given in *Table 6* below. A sufficient post CIP specific flux at 20 C is generally in the range of 9-10 gfd/psi. A result in specific flux greater than 10 gfd/psi is considered excellent for the UNA-620A filter module.

TABLE 6: CIP RESULTS SUMMARY

Date	Pre CIP Specific Flux at 20C (gfd/psi)	Post CIP Specific Flux at 20C (gfd/psi)	% Recovery of Specific Flux
8/17/2017	13.72	n/a	n/a
8/30/2017	3.90	9.42	n/a
10/3/2017	6.50	9.84	n/a
11/9/2017	4.30	10.30	104.7%
12/13/2017	4.70	11.68	118.7%

INTEGRITY TESTING

In order for a membrane treatment system to be an effective barrier against pathogens and particulate matter it must be free of breaches. The presence or breaches, or membrane integrity, can be demonstrated on an ongoing basis during system operation using pressure based tests. A pressure hold test was performed at the start of the pilot, daily during the pilot, and after each CIP. The procedure is outlined in Appendix B, and consists of pressurizing the wetted filtrate side of the membrane while exposing the feed side to atmosphere. The pressure decay rate is then monitored and compared to a standard to ensure breaches are not present. Each integrity test performed during piloting passed with an average pressure decay rate of 0.2 psi/min. Complete IT data is provided in Appendix D, and also is summarized in *Table 7*.

The upper control limit (UCL) of the PDR for a Pall pilot system is 0.2 psi/min or 1 psi per 5 minute direct integrity test (DIT). This UCL is based on empirical data from previous Pall fiber cuts and integrity tests. Experience has dictated that minor air leaks are inevitable in pilot systems, and this actuality needs to be considered when determining the PDR UCL. Transportation of piloting equipment can often contribute to air breaches in piping and instrument connections. Air leaks are less likely with a full scale plant that does not move once installed. Additionally, full scale plants have larger air hold up volumes than pilot units. The PDR of a larger volume of air has substantially less sensitivity from a single air leak, thus full scale systems are less sensitive to each individual air breach. The PDR of 0.2 psi/min is conservative enough to account for air leaks, but is still capable of verifying membrane integrity (based on previous Pall testing).

Under the Long-Term Stage 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), a direct integrity test must meet a resolution criterion (for the purpose of granting removal credit for *Cryptosporidium* from regulatory agencies). A direct integrity test is required to have sufficient resolution to detect an integrity breach of 3 μm or less. The resolution computation below shows that a minimum test pressure of 17.5 psi is required to meet this criterion. The pressure-hold procedure used by Pall for full scale systems typically applies testing pressures as high as 20 to 30 psi. All IT's performed during the pilot trial exceeded 20 psi. This high testing pressure not only ensures the resolution criterion specified in LT2ESWTR can be met, but also considerably increases the sensitivity of the test.

The minimum testing pressure required in order to achieve a resolution of 3µm (P_{test}) with the Pall pilot is calculated below using equation 4.1 from the US EPA's Membrane Filtration Guidance Manual (MFGM).

$$P_{test} = (0.193 \bullet \kappa \bullet \sigma \bullet \cos\theta) + BP_{\max} \quad \text{(MFGM Equation 4.1)}$$

κ	=	pore shape correction factor (κ = 1)
σ	=	surface tension at the air-liquid interface (σ = 74.9 dynes/cm @5^{o}C)
θ	=	liquid-membrane contact angle (θ = 0°)
BP_{max}	=	the sum of back pressure and static head (BP_{max} = 3.0 psid[1])

[1] BPmax is calculated by adding the back pressure (0 psi during an IT) and the static head pressure (module height is 2 meter resulting in 3 psi of hydrostatic head).

Therefore, P_{test} = 14.5 + 3 = 17.5 psi

The pilot's integrity test data is summarized in *Table 7* below. All integrity tests performed during the pilot had pressure decays less than 0.2 psi/min, implying the absence of membrane breaches and ensuring membrane integrity.

TABLE 7: INTEGRITY TEST DATA SUMMARY

	Minimum Value	Maximum Value	Average Value
Beginning Pressure, P_{test} (psi)	21.60	25.27	23.80
Ending Pressure (psi)	21.10	24.62	23.18
Change in Pressure (psi)	0.43	0.76	0.62
Change in Pressure (psi/min)	0.09	0.15	0.12

This section verifies that the sensitivity of the direct integrity tests (DIT) conducted on the Pall pilot during this study was equal to or greater than the currently required 4.0-log removal credit for Cryptosporidium cysts. The values shown below were used to calculate the sensitivity (LRV_{dit}), which is 4.31.

Determination of the lowest potential LRV_{DIT} using equations from the US EPA's MFGM is as follows:

$$LRV_{DIT} = \log\left(\frac{Q_p \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right) \qquad \text{(MFGM Equation 4.9)}$$

Q_p = pilot plant (design) flow, 28.1 gpm (106.3 L/min)
VCF = volume concentration factor (VCF = 1.0)
P_{atm} = atmosphere pressure (P_{atm} = 14.7 psia)
ΔP_{test} = the minimum verifiable pressure decay rate (0.2 psi/min).
V_{sys} = the hold-up volume during the test, 0.3 ft^3 (8.5 L)
$ALCR$ = air-to-liquid-conversion ratio (22.1, dimensionless, see below)

In the absence of excess recirculation (unfiltered feed water circulated back into the pilot influent) the VCF is equal to 1 (VCF = MF feed suspended solids/system influent suspended solids). When 10% excess recirculation is utilized a VCF of 1.08 is assumed, which is based on data from an actual microbial challenge test performed by a third party on a Pall MF system (Sethi et al. 2004). Calculation of the ALCR is shown below using methods outlined in Appendix C of the US EPA's MFGM.

Because the flow regime in a membrane system is turbulent, the Darcy pipe flow model was used to calculate the ALCR. The Darcy pipe flow model assumes that both air and liquid flow regimes persist through the membrane breach. The worst case scenario for the calculation is where the membrane breach is assumed to occur at the interface of potting, separating the feed side and filtrate side in the module (the shortest potential flow path for Q_{breach}). Under this scenario, the flows are in turbulent regime for the fiber lumen inner diameter (ID, 0.64 mm) and pressure differentials used in the pilot tests (P_{test} – BP > 14 psid), which is confirmed by calculating Reynold's Number under those conditions.

$$ALCR = 170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP)(P_{test} + P_{atm})}{(460 + T) \bullet TMP}} \quad \text{(MFGM Equation C.4)}$$

Y	=	net expansion factor (dimensionless) (0.627, see below)
P_{test}	=	direct integrity test pressure (25 psi[1])
BP	=	minimum back pressure plus static head (0 psi[2])
P_{atm}	=	atmospheric pressure (14.7 psia)
T	=	water temperature (72.7 ^{o}F[3])
TMP	=	TMP during normal operation (43.5 psi[4])

[1] Minimum test pressure expected during piloting
[2] Worst case value assumes breach is at the top of the module
[3] Highest water temperature recorded during piloting
[4] Terminal TMP during filtration

To calculate Y:

$$Y \propto \left[\frac{1}{\frac{(P_{test} - BP)}{(P_{test} + P_{atm})}}, K \right] \quad \text{(MFGM Equation C.5)}$$

K	=	flow resistant coefficient (dimensionless)

To calculate *K*:

$$K = f \bullet \frac{L}{d_{fiber}} \quad \text{(MFGM Equation C.6)}$$

F	=	friction factor (f = 0.025)
L	=	length of defect, or potting length (L = 60 mm)
d_{fiber}	=	lumen diameter of the fiber (d_{fiber} = 0.64 mm)

Thus, K = 2.34

The most conservative value of the defect length, L is 60 mm, which is the length of the potting at the top of the module (shortest potential flow path). The lumen diameter, d_{fiber}

of a hollow fiber is 0.64 mm. Thus using the steps outlined in section C.2 of the US EPA's MFGM grants a conservative net expansion factor (Y) of 0.63.

Using all of the above, LRV_{DIT} = 4.31

A value of 4.61 verifies that the sensitivity of the direct integrity tests (DIT) conducted on the Pall pilot during this study was greater than the currently required 4.0-log removal credit for Cryptosporidium cysts.

LRV calculated based on the IT data recorded during the pilot is summarized in *Table 8* below. LRV values displayed in the table were calculated the same as in the above section with the exception of using actual pilot data. All of the results can be viewed in Appendix C.

TABLE 8: CALCULATED LRVDIT SUMMARY (USING US EPA METHOD)

Number of Data Points	Minimum Value	Maximum Value	Average Value	95th Percentile
83	4.56	4.79	4.66	4.73

It should be noted that LRV is system-and-site-specific. LRV calculated from pilot tests are not necessarily representative for those of production systems. There are a few factors affecting the results of LRV calculation:

- The filtrate flow for the production system is larger, which dilutes the by-pass flow from the membrane breach more, thus resulting in higher LRV.

- The hold-up volume (i.e.,V_{system}) for the pilot and production systems are different, which in turn results in difference in pressure decay rate.

- The most profound impact is on the differences in pressure decay rate. The LRV calculation in the US EPA's MFGM assumes that there is no air leak except from the membrane breach. In reality, a pilot system is likely to have air leaks from piping as the result of transporting and loading/unloading. Also, a pilot unit has a smaller hold-up volume, which makes it more sensitive to the minor air leaks from piping. In contrast, a production system is erected on-site and stays stationary. It has less probability of air leaks from piping. In addition, the impact of minor air leaks is also smaller due to a larger hold-up volume.

In summary, the LRV calculated based on pilot integrity data may not be "scalable" due to multiple factors discussed above.

CONCLUSIONS & RECOMMENDATIONS

The conclusions of this pilot study proved to be valid under raw water quality conditions tested and within the test parameters utilized. The results of the pilot study indicated the following:

- The Pall MF system can operate with stability, treating the TID and Reeder Reservoir sources at flux rates in the range of 55-85 gfd, with 96.4% recovery, and daily Sodium Hypochlorite EFM procedures.
- The Pall Microfiltration membrane system produced excellent finished water quality, averaging 0.010 NTU.
- The pilot confirmed that a CIP interval greater than 28 days could be achieved under design conditions.
- The chemical cleaning processes (EFM & CIP) effectively restored membrane permeability, indicating that the specified cleaning regime (chemical, duration, and frequency) is appropriate for this feed water source.
- Membrane integrity was successfully verified on a daily basis during the pilot study using a pressure-hold test.

Pall Water appreciates the opportunity to work with Keller Associates and the City of Ashcroft operations staff on this project. We will be happy to assist in the future implementation of the Pall MF technology.

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Pilot Project Manager
Water Processing
Pall Water

REFERENCES

Membrane Filtration Guidance Manual, USEPA, Office of Water, EPA-815-R-06-009, November, 2005.

Sethi et al., (2004); Assessment and Development of Low-Pressure Membrane Integrity Testing Tools. AwwaRF Report 91032, Denver, CO. AwwaRF

APPENDIX A: MF STANDARD CIP PROTOCOL

1. **System Preparation:**
   - 1.0 Initiate appropriate AS/RF sequence.
   - 1.1 Close Feed valve to unit after ensuring that all secondary feed pumps to system is shut off.
   - 1.2 Close valves to turbidimeters, particle counters and other instruments, as required.
   - 1.3 Drain feed tank: Wipe sides and bottom of feed tank, floater valve, inside of cover, etc. Rinse and drain feed tank so it is clean.
   - 1.4 Drain module and any prefilters.

2. **Softened (Potable) Water Flushing:**
   - 2.0 Fill feed and filtrate tanks with softened water to 15 gal level
   - 2.1 Recirculate feed through XR valve at 8 gpm for 5-10 minutes
   - 2.2 Flush the feed to drain
   - 2.3 Perform a RF with filtrate at 15 gpm for one minute
   - 2.4 Drain feed and filtrate tanks.

3. **1% Caustic/2000 (ppm) Chlorine Cleaning:**
   - 3.0 Switch filtrate valve to tank (recirculation mode)
   - 3.1 Fill feed and filtrate tanks with softened heated (90-100° F) water to 15 gal
   - 3.2 Add 25% NaOH (1500 ml in 15 gal) and 12.5% NaOCl (760 ml in 15 gal)
   - 3.3 Recirculate with 3-4 gpm forward flow for 2 hrs
   - 3.4 Stop the system and AS the chemical solution to drain
   - 3.5 Perform a RF with filtrate at 15 gpm for one minute
   - 3.6 Drain feed and filtrate tanks.

4. **Softened (Potable) Water Flushing:** see section 3 above
   - 4.0 Fill feed and filtrate tanks with softened water to 15 gal level
   - 4.1 Recirculate feed through XR valve at 8 gpm for 5-10 minutes
   - 4.2 Flush the feed to drain
   - 4.3 Perform a RF with filtrate at 15 gpm for one minute
   - 4.4 Drain feed and filtrate tanks.

5. **2% Citric Acid Cleaning**
   - 5.0 Switch filtrate valve to tank (recirculation mode)
   - 5.1 Fill feed and filtrate tanks with softened heated (90-100° F) water to 15 gal
   - 5.2 Add 50% citric acid (1830 ml in 15 gal)
   - 5.3 Recirculate with 3-4 gpm forward flow for 1 hour
   - 5.4 Stop the system and AS the chemical solution to drain
   - 5.5 Perform a RF with filtrate at 15 gpm for one minute
   - 5.6 Drain feed and filtrate tanks.

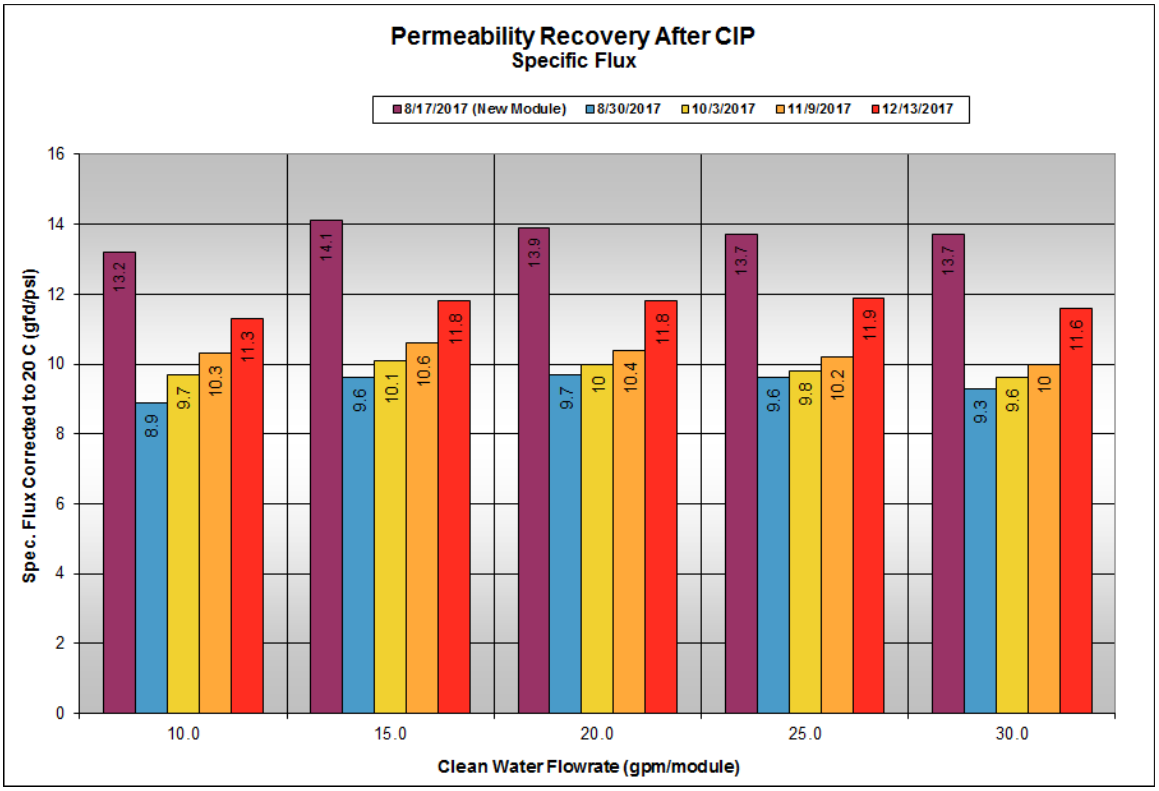
6. **Softened (Potable) Water Flushing:** see section 4 above

APPENDIX B: INTEGRITY TEST PROTOCOL

1. **In Automatic Mode**
   1.1 Open the *Mode* view in the HMI
   1.2 Select *Integrity Test* tab from the view. The integrity test sequence is automatically executed and the test data is logged into data file. If the pressure decay rate exceeds the set point (typically 0.2 psid/min.), an alarm is activated. If the system passes the integrity test, the system will return to the normal operation after integrity test.

2. **In Manual Mode**
   2.1 Open the *Process* view in the HMI
   2.2 Set the system in *Manua*l mode by clicking *Auto/Manual* button
   2.3 Close valves on feed and excess recirc line and open the valve on the filtrate line by clicking valves on process flow diagram. The color Red indicates "Close" and Green indicates, "Open"
   2.4 Open the air valve to pressurize the module to the set point (typically 25 – 30 psi).
   2.5 Wait until pressure stabilizes and record the pressure reading on the feed pressure transmitter tag as initial pressure; close the air valve start the timer.
   2.6 Record pressure reading every 30 seconds for 5 minutes.
   2.7 If the pressure reading at the end of 5 minutes exceeds the set point (typically 1.0 psi), the module fails the test. Check for leaks from piping and valves and look at the clear plastic coupling at the top of the module for air bubbles. If a continuous stream of air bubbles is visible, then the module failure is positively confirmed.
   2.8 If the pressure loss at the end of 5 minutes is within or less than the set point (typically 1.0 psi), the module passes the test. Proceed to the next step.

APPENDIX C: CIP PERMEABILITY



APPENDIX D: INTEGRITY TEST RESULTS

	Intial Test (PSI)	Final Test P (PSI)	ΔPressure (PSI)	ΔP/min (PSI/min)	Filtrate flow (GPM)	Temperature (°F)	TMP at Start (psi)	LRV_{DIT}
8/30/17	22.11	21.35	0.76	0.15	20.5	66.9	8.49	4.61
8/31/17	21.60	21.10	0.50	0.10	20.5	65.11	13.96	4.68
9/1/17	22.05	21.61	0.44	0.09	20.3	66.287	14.81	4.73
9/3/17	22.36	21.93	0.43	0.09	20.6	67.825	18.28	4.70
9/4/17	21.88	21.38	0.50	0.10	20.5	67.568	21.38	4.59
9/5/17	22.04	21.59	0.45	0.09	20.5	67.656	13.73	4.73
9/6/17	21.93	21.45	0.48	0.10	20.5	67.46	14.84	4.69
9/7/17	21.76	21.29	0.48	0.10	20.5	67.05	15.91	4.67
9/8/17	22.05	21.59	0.46	0.09	20.4	67.08	17.67	4.67
9/9/17	22.05	21.55	0.50	0.10	20.4	67.31	18.94	4.61
9/10/17	21.99	21.51	0.48	0.10	20.5	66.55	20.12	4.62
9/11/17	22.10	21.62	0.48	0.10	20.4	66.19	13.04	4.71
9/12/17	21.85	21.38	0.48	0.10	19.7	66.05	13.67	4.69
9/13/17	22.03	21.56	0.47	0.09	20.5	66.7	17.10	4.67
9/14/17	23.46	22.96	0.49	0.10	20.5	65.94	13.27	4.72
9/15/17	22.88	22.29	0.59	0.12	20.4	64.056	12.52	4.64
9/16/17	23.05	22.49	0.56	0.11	20.5	62.69	12.38	4.67
9/17/17	23.23	22.64	0.59	0.12	20.9	61.91	12.02	4.66
9/18/17	23.38	22.76	0.62	0.12	20.6	60.95	11.50	4.65
9/19/17	23.58	22.98	0.60	0.12	19.4	60.368	10.60	4.66
9/21/17	23.42	22.77	0.65	0.13	20.4	58.1	13.04	4.60
9/22/17	23.33	22.75	0.58	0.12	20.5	58.25	13.17	4.65
9/23/17	23.31	22.66	0.66	0.13	20.7	57.818	13.15	4.60
9/24/17	23.56	22.91	0.64	0.13	20.4	57.43	13.02	4.61
9/25/17	23.63	23.01	0.62	0.12	20.7	57.93	13.05	4.63
9/26/17	23.48	22.91	0.58	0.12	20.0	58.78	12.18	4.66
10/3/17	25.27	24.62	0.65	0.13	26.4	55.62	10.19	4.79
10/4/17	24.93	24.24	0.68	0.14	26.3	54.481	13.20	4.70
10/5/17	25.14	24.48	0.67	0.13	26.4	54.03	12.30	4.73
10/6/17	24.99	24.34	0.65	0.13	26.2	53.57	12.50	4.74
10/7/17	25.02	24.43	0.59	0.12	26.2	53.656	12.94	4.77
10/8/17	24.98	24.31	0.67	0.13	26.3	53.218	13.39	4.71
10/9/17	25.03	24.38	0.64	0.13	26.1	52.73	13.51	4.72
10/10/17	25.01	24.36	0.65	0.13	26.3	52.46	13.99	4.72
10/11/17	25.09	24.42	0.67	0.13	26.4	51.993	14.13	4.70
10/12/17	25.12	24.43	0.69	0.14	26.1	51.52	15.25	4.67
10/13/17	25.09	24.39	0.70	0.14	26.4	51.231	16.68	4.65
10/14/17	24.91	24.24	0.68	0.14	26.0	50.875	16.32	4.66
10/15/17	24.95	24.30	0.65	0.13	26.3	50.3	16.61	4.68
10/16/17	24.91	24.33	0.58	0.12	26.3	49.981	17.11	4.72
10/17/17	24.76	24.07	0.69	0.14	25.3	49.737	16.29	4.64
10/18/17	24.94	24.31	0.63	0.13	26.7	49.625	17.49	4.69
10/19/17	24.91	24.29	0.63	0.13	26.0	49.681	17.18	4.68
10/20/17	25.04	24.35	0.69	0.14	26.3	49.412	16.85	4.65

	Intial Test (PSI)	Final Test P (PSI)	ΔPressure (PSI)	ΔP/min (PSI/min)	Filtrate flow (GPM)	Temperature (°F)	TMP at Start (psi)	LRV_{DIT}
10/21/17	24.91	24.26	0.65	0.13	25.9	49.237	16.97	4.67
10/22/17	25.16	24.51	0.65	0.13	26.1	49.037	17.58	4.67
10/23/17	24.91	24.25	0.66	0.13	26.2	48.987	16.70	4.67
10/24/17	24.95	24.29	0.66	0.13	26.1	49.068	17.10	4.66
10/25/17	24.82	24.10	0.72	0.14	26.3	49.1	16.83	4.63
10/26/17	24.84	24.17	0.66	0.13	26.3	49.1	16.76	4.67
10/27/17	24.90	24.26	0.64	0.13	26.0	49.1	16.98	4.67
10/28/17	24.81	24.18	0.64	0.13	26.3	49.09	17.50	4.67
10/29/17	24.88	24.21	0.67	0.13	26.3	49.1	17.08	4.66
10/30/17	24.81	24.14	0.67	0.13	26.2	49.09	17.09	4.66
10/31/17	24.79	24.13	0.66	0.13	26.3	48.68	17.79	4.65
11/14/17	25.04	24.32	0.71	0.14	32.0	44.93	14.59	4.75
11/15/17	24.94	24.21	0.73	0.15	31.7	44.38	17.50	4.70
11/16/17	24.94	24.24	0.70	0.14	31.8	44.125	19.95	4.69
11/17/17	24.83	24.10	0.73	0.15	31.8	44.275	20.30	4.67
11/18/17	24.81	24.11	0.71	0.14	31.9	43.813	20.38	4.68
11/19/17	24.86	24.14	0.71	0.14	32.1	43.137	21.32	4.67
11/20/17	24.94	24.26	0.68	0.14	31.7	43.181	20.72	4.69
11/21/17	24.88	24.22	0.66	0.13	32.0	44.21	21.17	4.71
11/22/17	24.90	24.27	0.63	0.13	31.8	45.618	20.75	4.73
11/23/17	24.91	24.26	0.64	0.13	31.6	45.006	21.64	4.71
11/24/17	24.64	23.99	0.65	0.13	31.9	45.51	21.70	4.70
11/25/17	24.79	24.17	0.63	0.13	31.9	44.875	25.31	4.69
11/26/17	24.51	23.88	0.63	0.13	31.9	45.006	32.49	4.63
11/27/17	23.34	22.74	0.61	0.12	31.8	44.67	29.43	4.65
11/28/17	23.65	22.96	0.69	0.14	31.7	43.78	29.43	4.60
11/29/17	23.39	22.79	0.60	0.12	31.8	43.17	30.12	4.65
11/30/17	23.35	22.71	0.64	0.13	32.1	42.6	30.94	4.62
12/1/17	23.03	22.37	0.66	0.13	31.9	42.29	32.02	4.59
12/2/17	22.78	22.09	0.69	0.14	30.8	41.86	31.59	4.56
12/3/17	22.84	22.24	0.61	0.12	31.7	41.75	31.35	4.63
12/5/17	22.42	21.75	0.67	0.13	31.8	41.09	32.15	4.58
12/6/17	22.29	21.68	0.61	0.12	31.8	40.8	33.25	4.61
12/7/17	22.38	21.71	0.67	0.13	32.9	39.71	34.88	4.58
12/8/17	22.20	21.56	0.64	0.13	31.8	39.36	31.71	4.60
12/9/17	22.28	21.64	0.63	0.13	31.8	39.13	33.02	4.60
12/10/17	22.25	21.65	0.60	0.12	31.9	38.76	34.06	4.61
12/11/17	22.33	21.71	0.62	0.12	31.8	38.6	34.27	4.60
12/12/17	21.78	21.16	0.63	0.13	31.8	38.22	35.12	4.58

Water Processing

APPENDIX E: MF LIFE CYCLE COST RUN #2

PALL Water Processing

Plant Life (years)	30
Membrane Life (years)	10
MARR	6%
Module Replacement Price	2700

MF Life Cycle Cost Run #2

Flux	EFM Interval days	CIP Interval days	Ave TMP	Racks (incl red.)	Modules per rack	Yearly O&M Electrical	Total modules	Membrane Replacement	Evaluated O&M Electrical	Total Evaluation
70	1	30	14	5	66	$ 37,458	330	$497,530	$515,603	$1,013,133

Electricity:	Cost Per KWH	$0.10

Costing Totals

Yearly Operating Cost Breakdown	Electrical	Chemical	Total
Main System Operation	$10,915	$0	**$10,915**
CIP	$575	$8,667	**$9,242**
EFM	$8,222	$9,078	**$17,300**
Total	$19,712	$17,745	**$37,458**

System Electrical Usage

Pump	Flow (gpm)	Pressure (psi)	Pump Eff.	Mtr/VFD Eff.	hp	Hours Per Day	kWh/day	kWh/ Year	$/day	$/year
Feed	7,201.43	0.00	90.0%	100.0%	0.00	24.00	0.0	0	$0.00	$0
XR	354.75	0.00	78.0%	95.0%	0.00	24.00	0.0	0	$0.00	$0
AS-RF	528.00	14.00	78.0%	95.0%	5.82	6.45	28.0	10,211	$2.80	$1,021
AS-Feed Flush	0.00	0.00	80.0%	95.0%	0.00	6.45	0.0	0	$0.00	$0
RF	0.00	0.00	75.0%	95.0%	0.00	2.15	0.0	0	$0.00	$0
Forward Flush	1,188.00	14.00	80.0%	95.0%	12.76	2.15	20.5	7,467	$2.05	$747
Enhanced RF										
Forward Flush	0.00	14.00	80.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
FF-AS	0.00	14.00	80.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
Alt. AS-RF	0.00	14.00	75.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
RF Rinse	0.00	14.00	75.0%	95.0%	0.00	25.45	0.0	0	$0.00	$0
Alt. RF	0.00	20.31	78.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
Total						**90.7**	**48.4**	**17,678**	**$4.84**	**$1,768**

Compressed Air	AS Time Per Day (min./mod.)	scfm Per Module	scfm Per hp	AS Volume Per Day (ft3)	Average cfm	KWh Per Day	KWh Per Year	$/day	$/year
AS	77	3.00	3.8	76,626	53.2	251	91,474	$25.06	$9,147
Continuous Air	0	9.00	9.0	0	0.0	0	0	$0.00	$0

Pall Water Processing

APPENDIX F: MF LIFE CYCLE COST RUN #3

PALL Water Processing

MF Life Cycle Cost Run #3

Plant Life (years)	30
Membrane Life (years)	10
MARR	6%
Module Replacement Price	2700

Flux	EFM Interval days	CIP Interval days	Ave TMP	Racks (incl red.)	Modules per rack	Yearly O&M Electrical	Total modules	Membrane Replacement	Evaluated O&M Electrical	Total Evaluation
80	1	30	14	5	60	$ 35,740	300	$452,300	$491,955	$944,255

Electricity:	Cost Per KWH	$0.10

Costing Totals

Yearly Operating Cost Breakdown	Electrical	Chemical	Total
Main System Operation	$10,914	$0	**$10,914**
CIP	$537	$8,109	**$8,646**
EFM	$7,685	$8,494	**$16,180**
Total	$19,136	$16,604	**$35,740**

Totals	Electrical	Chemical	Total
Average KWh Per Day	524		
KWh Per Year	191,363		
Average Cost Per Day	$52	$45	**$98**
Cost Per Year	$19,136	$16,604	**$35,740**
Cost Per 1,000 Gallons	$0.0052	$0.0045	**$0.010**

System Electrical Usage

Pump	Flow (gpm)	Pressure (psi)	Pump Eff.	Mtr/VFD Eff.	hp	Hours Per Day	kWh/day	kWh/ Year	$/day	$/year
Feed	7,200.85	0.00	90.0%	100.0%	0.00	24.00	0.0	0	$0.00	$0
XR	354.72	0.00	78.0%	95.0%	0.00	24.00	0.0	0	$0.00	$0
AS-RF	480.00	14.00	78.0%	95.0%	5.29	7.09	28.0	10,211	$2.80	$1,021
AS-Feed Flush	0.00	0.00	80.0%	95.0%	0.00	7.09	0.0	0	$0.00	$0
RF	0.00	0.00	75.0%	95.0%	0.00	2.36	0.0	0	$0.00	$0
Forward Flush	1,080.00	14.00	80.0%	95.0%	11.60	2.36	20.5	7,466	$2.05	$747
Enhanced RF										
Forward Flush	0.00	14.00	80.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
FF-AS	0.00	14.00	80.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
Alt. AS-RF	0.00	14.00	75.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
RF Rinse	0.00	14.00	75.0%	95.0%	0.00	23.14	0.0	0	$0.00	$0
Alt. RF	0.00	20.31	78.0%	95.0%	0.00	0.00	0.0	0	$0.00	$0
Total						90.1	48.4	17,677	$4.84	$1,768

Compressed Air	AS Time Per Day (min./mod.)	scfm Per Module	scfm Per hp	AS Volume Per Day (ft3)	Average cfm	KWh Per Day	KWh Per Year	$/day	$/year
AS	85	3.00	3.8	76,620	53.2	251	91,467	$25.06	$9,147
Continuous Air	0	9.00	9.0	0	0.0	0	0	$0.00	$0

APPENDIX G: PLAN LEVEL DESIGN AND BUDGETARY PROPOSAL

Budgetary Proposal for a Pall ARIA™ Membrane Filtration System

Ashland, OR

7/7/2017
Proposal #: 184874-0-B

Submitted to:

The City of Ashland20 East Main StreetAshland, OR

and

Bryan Phinney, Keller Associates, 305 N 3rd Avenue, Suite A, Pocatello, Idaho 83201

Submitted by:

Lance Gannon
Regional Sales Manager
607.591.0077
lance_gannon@pall.com

PROPRIETARY & CONFIDENTIAL
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- to avoid publication or other disclosure of this document or the information it contains to any third party without the prior approval of Pall Corporation.

- to make only those copies needed for recipient's internal review, and

- to return this document and any copies thereof when they are no longer needed for the purpose for which furnished or upon the request of Pall Corporation.

Table of Contents

The following information can be provided upon request

- Warranty
- Overview of Pall Corporation
- Hollow Fiber Membrane System Overview
- Pall Standard Terms and Conditions

1 Pall Offering

1.1 Project Summary

Pall Water is pleased to present The City of Ashland and Keller Associates with the enclosed budgetary solution to supply the City with a new water treatment plant.
The goal of the Pall Membrane Filtration system is to meet or exceed the existing water treatment plant performance.
Pall is proposing the following system offering featuring our Aria Flex Hollow Fiber Membrane System solution:

• Five (5) Pall Aria Flex 8" Transverse Membrane units
• Four (4) Feed Strainers
• Two (2) Reverse Filtration Pumps
• CIP System with one (1) Acid Tank, one (1) Caustic/EFM Tank, two (2) Circulation/ Drain Pumps and chemical transfer pumps
•Air System with two (2) compressors and one (1) Air Receiver
•MCP
• System Commissioning and Operator Training
• Optional Adder: Integrated Waste Water Neutralization System

Although design aspects surrounding this project have not been fully defined, Pall looks forward to partnering up to support this objective. We acknowledge there are areas to value engineer this plan level design, improve operational efficiencies, and build in expansion capabilities all of which will be addressed as formal spec's are developed.

For over 20 years, Pall has provided municipalities and industries with reliable water treatment solutions to meet their most complex water challenges many of which focus specifically on potable supply and waste water treatment for alternative uses.
Once you have had sufficient time to review our offering, please direct any questions you may have to our team members. We appreciate the interaction with your team to explore the advantages of the Pall Membrane Filtration System.

1.2 Pricing Summary

Item	**Description**	**Sale Price (US)**
1	Aria™ Membrane Filtration System (Details Per Section 2)	$3,200,000
2	Neutralization System Adder	$50,000
	Total	$3,250,000

1.3 Delivery Schedule

The schedule provided is Pall's standard and reflects typical project execution. If requested, we would be happy to review customer schedule requirements and adjust where possible to accommodate project specific needs.

	Milestone	Typical Schedule
1	Acknowledgement of Purchase Order	Typically 1 to 2 weeks after Receipt of Purchase Order
2	First Submittals/Shop Drawings	Typically 6 weeks after Acknowledgement of Purchase Order
3	Second Submittals/Shop Drawings	Typically 4 weeks after Submittals/Shop Drawings submitted
4	Commence Manufacturing1	Typically 1 - 2 weeks after Final Submittals/Shop Drawings submitted
5	Equipment Ready to Ship and Preliminary O&M Manual	Typically 14 -18 weeks after Commence Manufacturing
6	Installation Completed (by Others)	Variable
7	Commissioning Complete/Final Acceptance	Approximately 11 weeks after Installation Completed

Note 1: For standard equipment, manufacturing may commence order acknowledgement. The schedule above assumes standard equipment and standard submittals.

1.4 Terms and Conditions

All sales made by Pall are subject to the terms contained within this Section 1.4 and *Additional Terms and Conditions of Sale of Systems and Made to Order Goods – The Americas* (Available upon request).

Price Validity	This proposal is for discussion purposes only, does not constitute a binding agreement on either party, and remains subject to corporate approval by both parties. The information contained herein is deemed confidential and is not to be shared with any third party.
Shipping Terms	The price does not include shipping costs. Delivery shall be FCA Seller's Shipping Point, INCOTERMS® 2010.
Payment Terms	Payment of invoiced amounts due to Seller shall be paid Net 30 days and as further defined in *Additional Terms and Conditions of Sale Systems and Made to Order Goods – The Americas*.
Bonds	No bonds of any type are included with this proposal.
Taxes	No taxes are included in the pricing. Payment of all Taxes related to the Goods and Services proposed shall be the exclusive responsibility of the Buyer as further defined in *Additional Terms and Conditions of Sale Systems and Made to Order Goods – The Americas*.

2 Scope of Supply

2.1 Scope Summary Table

Item Description	By PALL	By OTHERS
(1) Master Control Panel with Allen Bradley Logix PLC, or equal	X	
Design and supply of systems prior to membrane filtration system.		X
Feed Tank, Valves and Instrumentation by Others		X
Feed Pumps by Others, VFDs by others		X
4 (3 + 1) Automatic Backwashing Strainers	X	
5 (4 + 1) 8" Transverse Valve Racks, each factory assembled and tested valve rack with valves, intruments and I/O required for operation (some B&B valves are shipped loose for field installation).	X	
Each Valve Rack will include a membrane module rack for on-site assembly and (112) hollow fiber membrane modules	X	
RF Tank, Valves and Instrmentation by Others	X	
2 (1 + 1) Close-Coupled End Suction Centrifugal Reverse Filtration (RF) Pumps	X	
(1) 3000 gallon CIP System:	X	
(1) 12,500 Gallon Automated Neutralization System	Adder	
(2) Air Compressors (1) Air Receiver	X	
Chemical Storage Equipment		X
Supply of any required chemicals		X
Design and supply of anchor bolts for Pall supplied Equipment		X
Receiving, unloading and safe storage of equipment until ready for installation		X
Installation of all equipment		X
Design and supply of interconnecting pipe, inclusive of pipe supports and flexible connectors		X
Motor Control Center (MCC)		X
All wiring, cabling, and tubing for power supply, signals, communications, and to connections on Pall supplied equipment		X
Design, supply, and installation of all civil infrastructure inclusive of buildings, fire and safety protection, HVAC, walkways, platforms, etc.		X
All Permits		X

2.3 Submittal Description

The project schedule is based on submittals/shop drawings provided in electronic format via a secure FTP site for information only. This allows work to proceed on the project without a document approval process.

First Submittal
P&ID
Membrane Filter Skid/Rack Assembly Drawing
Power Single-Line Diagram/Network Diagram/System Interconnection Details Drawing
Second Submittal
System Functional Description (SFD)
CIP/EFM Solution Tank Drawing(s)
Skidded Equipment Drawings (where applicable)
Main Control Panel
Valve Rack Panel
CIP Panel
Instrument List and Supporting Vendor Information (catalog cut sheets)
Equipment List and Supporting Vendor Information (catalog cut sheets)
Valve List and Supporting Vendor Information (catalog cut sheets)
Recommended Spare Parts List
Third Submittal (provided at completion of comissioning)
Final Operation and Maintenance Manual
Software License Transfer Documentation

2.4 Services and Labor

Commissioning & Training time is estimated to be 10 man-weeks. Training activities occur during the commissioning process.

Commissioning

Each day shall be considered 8 hours on site. Commissioning will begin once the system is fully installed. A commissioning Checklist is prepared specifically for each project during project execution. Commissioning shall consist of the activities outlined in the project specific Commissioning Checklist. Commissioning activities include:

- Confirmation of network communications
- Confirmation that I/O is connected to the control system
- Confirmation of MF System functionality (components are functioning and control system sequences are functional)
- Startup and tuning of Pall controls

Operator Training

Operator training is estimated to take 1 to 3 days depending on system complexity. Training is provided on-site by a Pall Field Service Engineer. The estimated time assumes that all staff are trained at the same time. Training time will be split between a classroom presentation and hands-on training with the equipment.

3 Technical Summary

3.1 Process Summary

Source Description:

Ashland Creek/Reeder Reservoir

Treatment processes prior to Membrane Filtration System

Treatment prior to membrane filtration would include:

1) Pre-oxidation with sodium permanganate along with pH increase with sodium hydroxide to precipitate iron and / or manganese, if present;

2) direct in-line coagulation with ACH; along with pH reduction using carbon dioxide, to remove naturally occurring organic matter.

Membrane System Feed Water Characteristics

Quality of the water entering the Pall Membrane Filtration System as summarized in table below forms the basis of design for this proposal. In the event that the feed water to the membrane filtration system is outside these parameters the system performance, cleaning protocol, operating parameters, and/or warranties may be affected.

Parameter	Units	Range
Turbidity	NTU	5-50
TOC	ppm	3-6
Hardness	ppm	50-350
Alkalinity	ppm	60-320
TSS	ppm	10-100
Fe	ppm	<2.0
Mn	ppm	<1.0

Notes:

1 – Assumed Water Quality is based on typical water quality for similar source waters. The design parameters may change after review of actual source water quality data.

3.2 Treated Water Objectives

The proposed membrane system is designed to achieve the following results given the feed fluid conditions described in Section 3.1 of this proposal and operation of the system in accordance with the operation and maintenance manual.

Net Filtrate Capacity of 10 MGD

Turbidity less than 0.10 NTU 95% of the time, below 0.20 NTU at all times.

The membrane system shall produce effluent with Silt Density Index (SDI) value of 2.5 or less in 95% of samples using ASTM 4189-95 and a Pall nylon test membrane.

3.3 Operational Parameters

Hollow Fiber Membrane System operational parameters at design flow		
Net Filtrate Capacity	10.000	MGD
Recovery	95.8%	%
Instantaneous Flux	50	GFD
FM (Backwash) Interval	26	Minutes
EFM Interval	1	Day(s)
CIP Interval	30	Days

3.4 Acceptance Criteria

The system shall be accepted by the end user upon completion of the following:

1) Completed system commissioning per section 2.4
2) Production of 1st useable effluent

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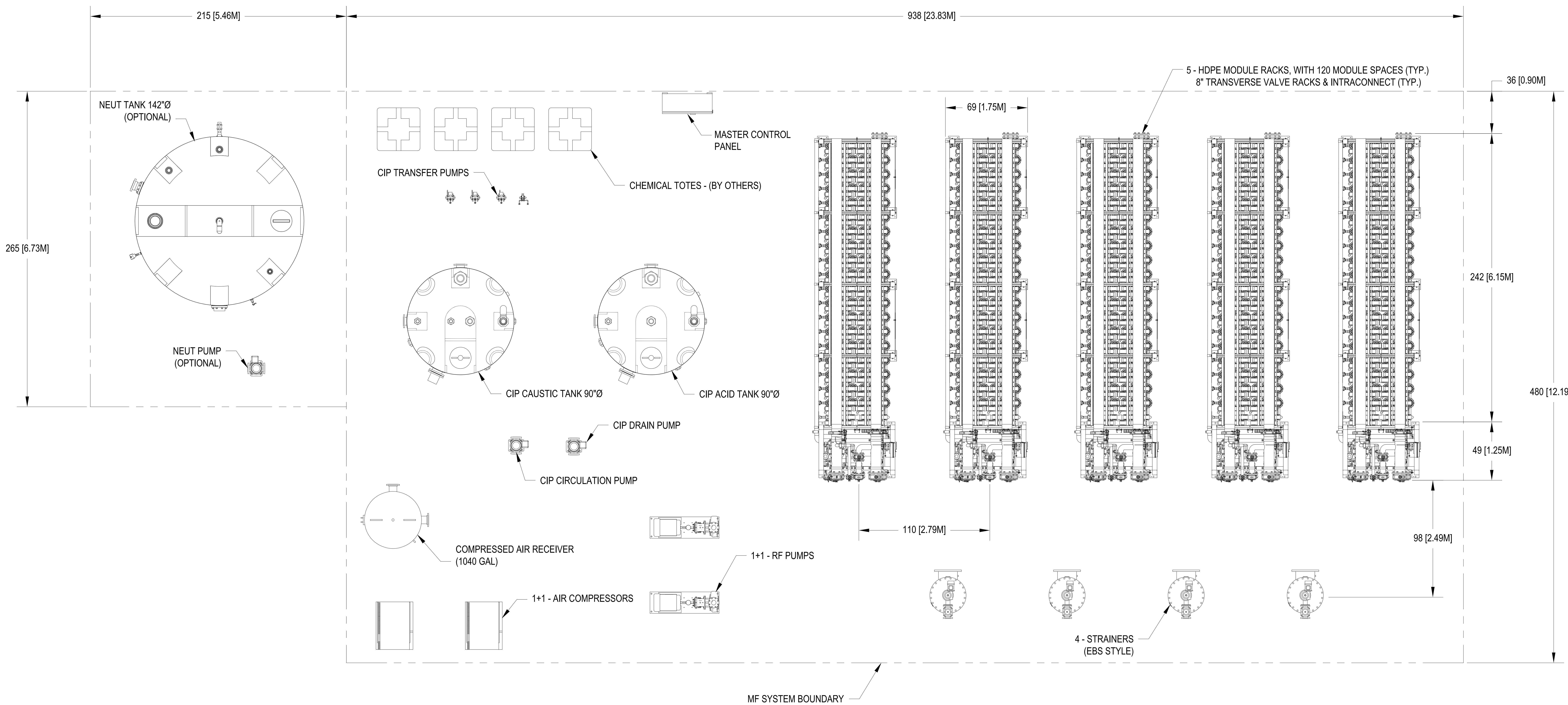

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DIMENSIONS ARE IN: ☐ INCHES ONLY ☐ MILLIMETER ONLY ☒ IN [mm] ☐ mm [IN]

TOLERANCE	
FRACTION ±	1/8
ANGLE ±	2 DEG
.XXXX ±	
.XXX ±	
.XX ±	
.X ±	
X. ±	

ALL FINISHED SURFACES √ μIN √ μm

SCALE 1/4"=1'-0" DO NOT SCALE FROM DRAWING

THIRD ANGLE PROJECTION

	NAME	DATE
DRAWN BY	B. HARRIS	05JUL2017
PROJECT ENGINEER	Z. HOWARD	05JUL2017
ENGINEER	---	---
ENGINEER	---	---
ENGINEER	---	---
CHECKER	----	----

CODE INDENTIFICATION NO. 17238

PROJECT ID W-21966

PALL Corporation
Pall Advanced Separation Systems
Industrial, Cortland NY

DRAWING NAME
ASSY,MF,ASHLAND OR
TRANSVERSE SYSTEM DESIGN - LAYOUT

IMPORTANT: *BEFORE ATTEMPTING TO OPERATE OR INSTALL THIS SYSTEM, IT IS ESSENTIAL TO READ AND UNDERSTAND THIS PRODUCT'S OPERATION AND MAINTENANCE MANUAL (SHIPPED UNDER SEPARATE COVER). FAILURE TO READ THE OPERATION AND MAINTENANCE MANUAL BEFORE ATTEMPTING TO OPERATE ANY PALL CORPORATION EQUIPMENT MAY RESULT IN SERIOUS PERSONAL INJURY AND/OR PRODUCT DAMAGE, AND VOID ANY AND/OR ALL WARRANTIES*

DRAWING NUMBER **NYCS000010007** REVISION 00

MATERIAL MASTER ---- DWG SIZE D SHEET 1 OF 1

TEMPLATE REV: R2013.3

PRELIMINARY
NOT FOR CONSTRUCTION

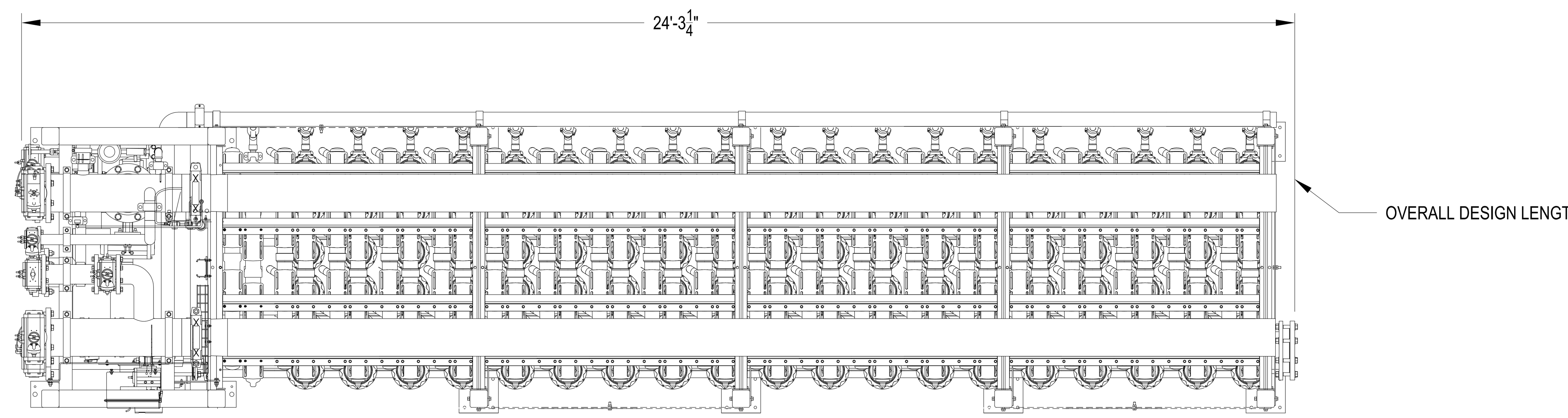
LOCATIONS AND DIMENSIONS ARE FOR REFERENCE ONLY AND MUST BE VERIFIED BEFORE FINAL CONSTRUCTION

NOTES:
1. FRAMES ARE CONSTRUCTED OF CARBON STEEL STRUCTURAL MEMBERS.
2. ALL WETTED PIPING IS HDPE EXCEPT AS NOTED.
3. VALVE RACK IS FACTORY ASSEMBLED AND TESTED BY PALL. THE VALVE RACK IS SHIPPED FULLY ASSEMBLED AND WIRED, WITH THE EXCEPTION OF THE PRESSURE TRANSMITTERS, WHICH ARE SHIPPED LOOSE FOR FIELD ASSEMBLY BY OTHERS.
4. EACH MODULE RACK IS SHIPPED WITHOUT MODULES, PARTIALLY ASSEMBLED. SEE SEPARATE INSTALLATION INSTRUCTIONS.
5. DO NOT DRILL OR OTHERWISE MODIFY PAINTED FRAME MEMBERS.
6. THE MINIMUM PAD HEIGHT SUGGESTED IS ONLY FOR HOUSEKEEPING PURPOSES; ACTUAL PAD REQUIREMENT FOR STRUCTURAL OR OTHER PURPOSES IS TO BE DETERMINED BY OTHERS.
7. ALL STUB ENDS AND VALVE FACES (A,A1,A2,C1,C2,C3,D1,D2,F1,F2,R1) EXTEND 3in OFF FRONT EDGE OF VALVE RACK FRAME.
8. FRAME PAINT APPLIED PER MANUFACTURER'S GUIDELINES AND JOB SPECIFICATION.

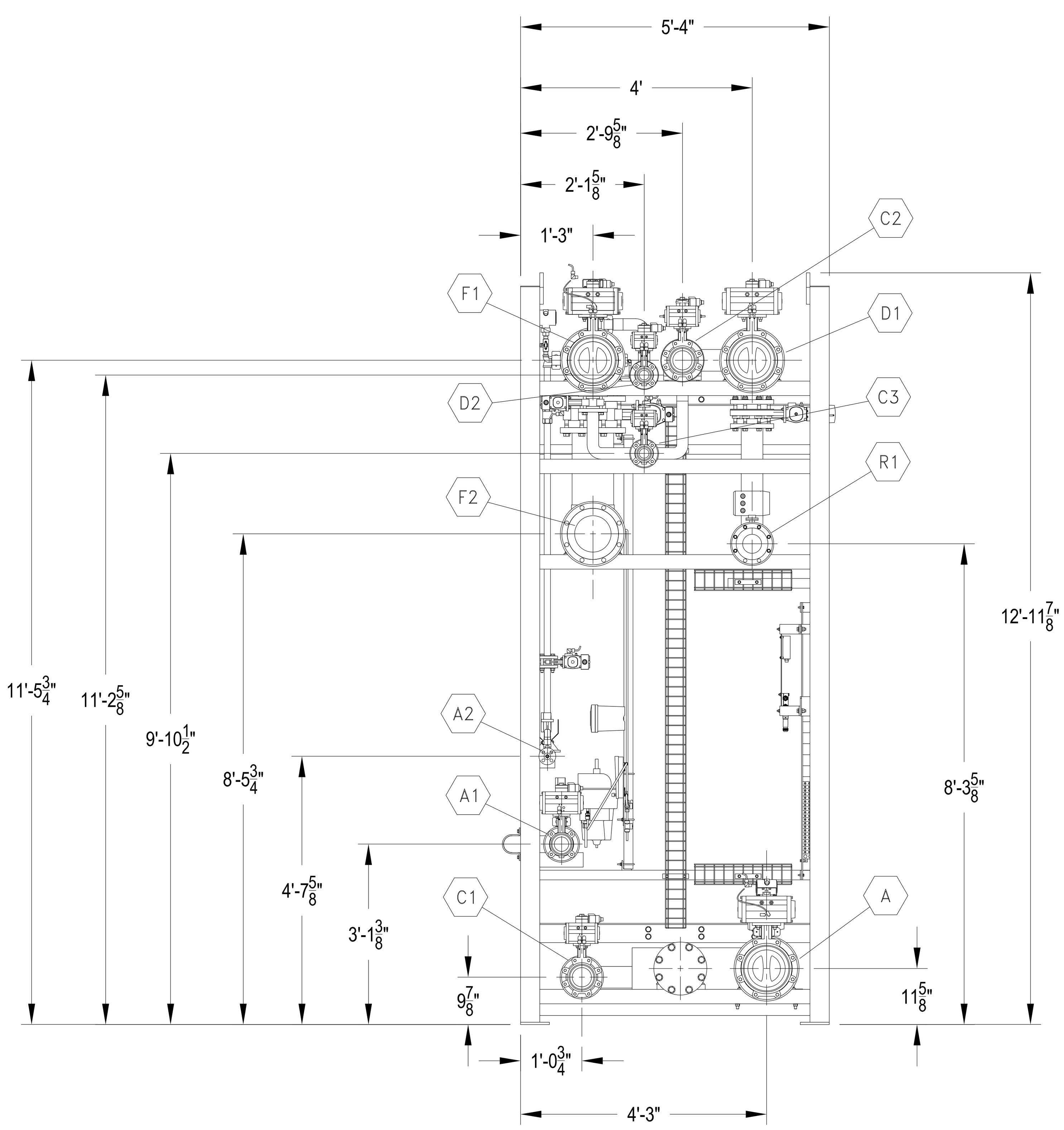
ESTIMATED WEIGHTS:

VALVE RACK: 3500 LBS [1588 KG] (DRY); 4200 LBS [1905 KG]
MODULE RACK: ____ LBS [____ KG] (DRY); ____ LBS [____ KG]

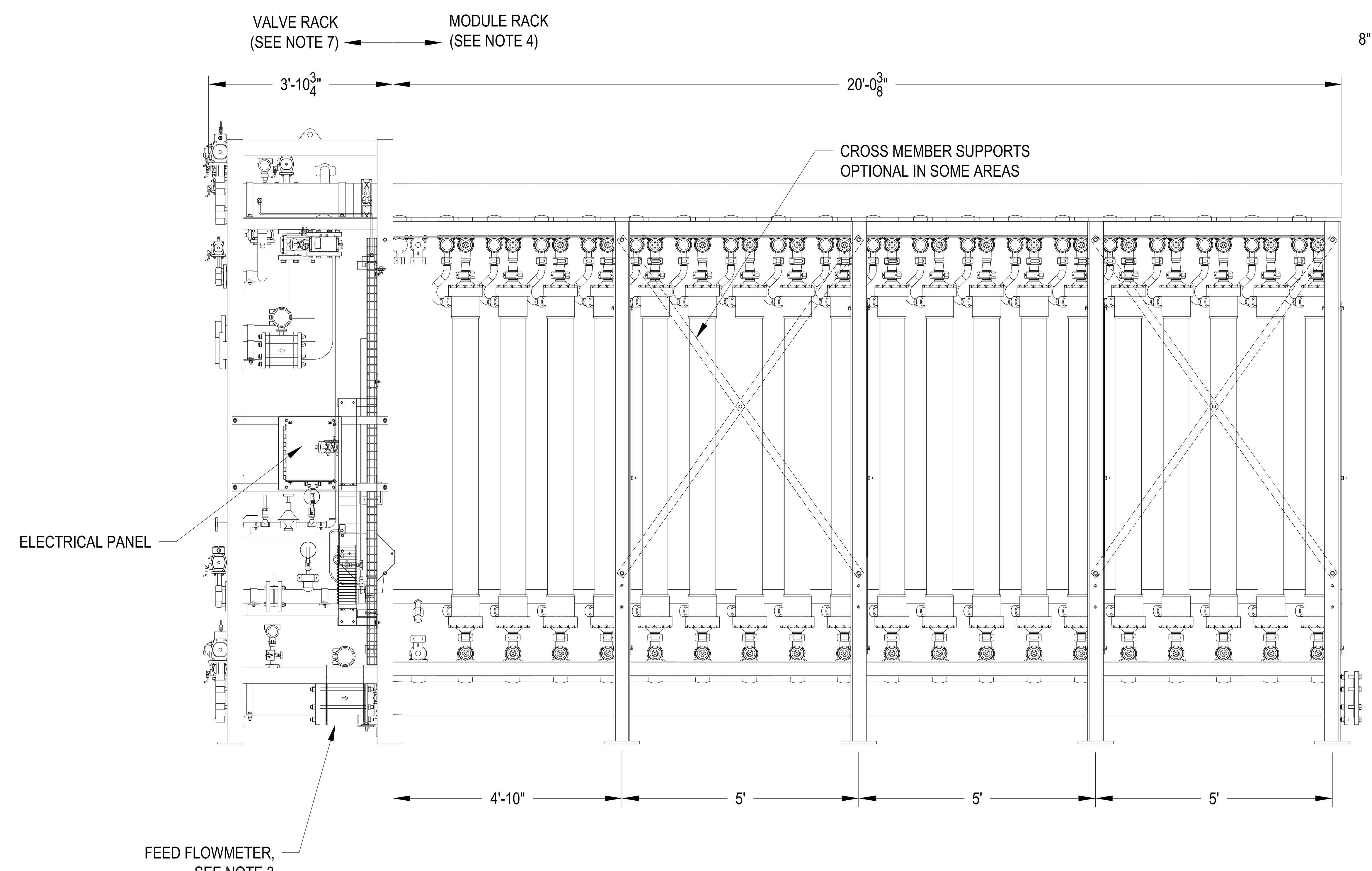
MODULE RACK CALCULATIONS:
4 ROW MOD RACK = 3300 lbs [1497 kg] DRY; 5300 lbs [2404 kg] WET
5 ROW MOD RACK = 3850 lbs [1746 kg] DRY; 6300 lbs [2858 kg] WET
6 ROW MOD RACK = 4400 lbs [1996 kg] DRY; 7300 lbs [1311 kg] WET
HEADER WEIGHT = 6 lbs x (# of pulls) x 3 headers DRY
HEADER WEIGHT = 27 lbs x (# of pulls) x 3 headers WET



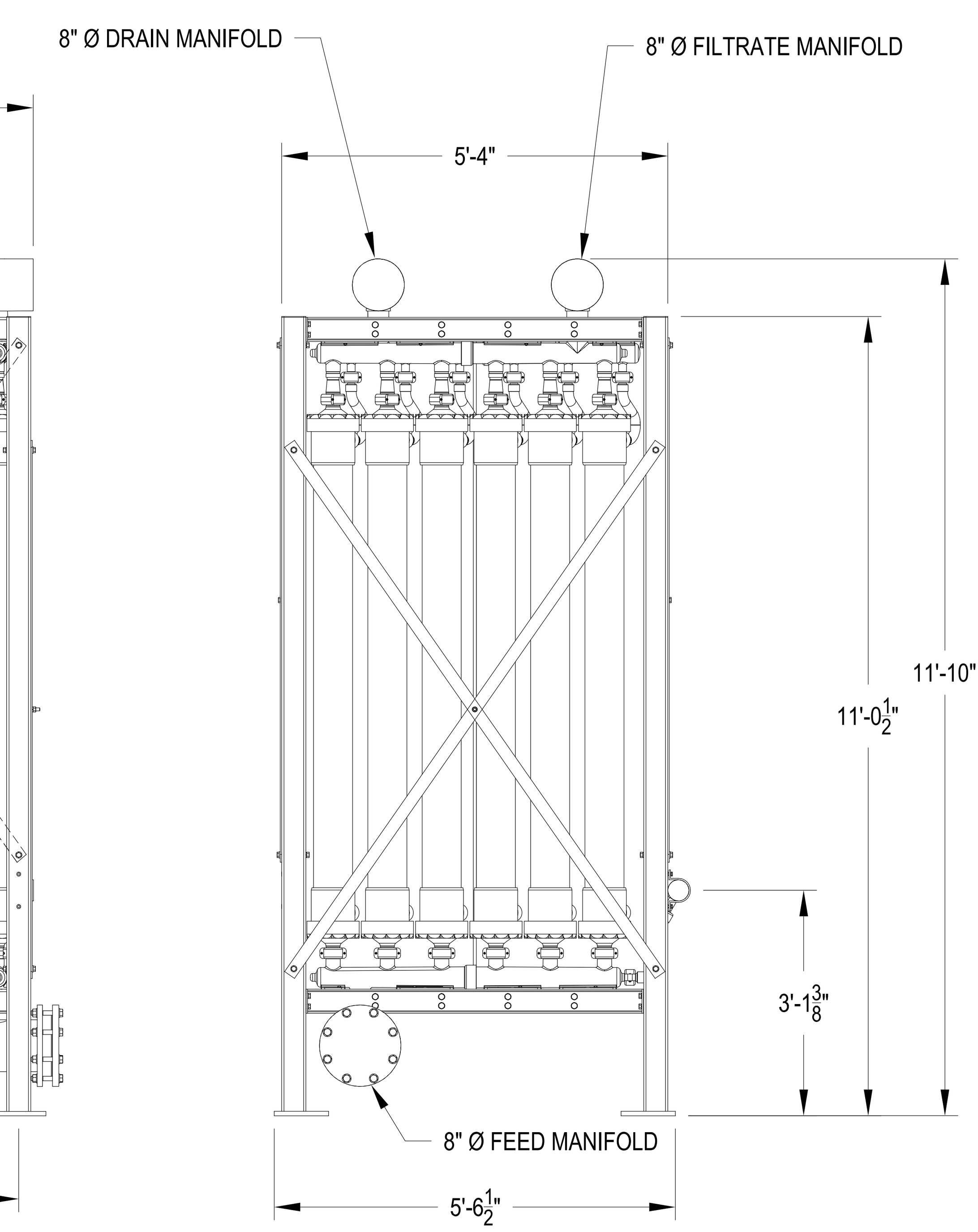
-PLAN VIEW-
(120 MODULE FILTER RACK ASSEMBLY)



-FRONT ELEVATION-
(MODULE RACK REMOVED FOR CLARITY)



-RIGHT SIDE ELEVATION-
(SOME MODULES REMOVED FOR CLARITY)



-REAR ELEVATION-
(VALVE RACK REMOVED FOR CLARITY)

ITEM	DESCRIPTION	CONN. SIZE
A	FEED CONNECTION	8in
A1	AIR SCRUB SUPPLY	3in
A2	INSTRUMENT AIR	1/2in
C1	CIP FEED	4in
C2	CIP/EFM RETURN	4in
C3	CIP RETURN BLEED	2in
D1	AS/RF (UPPER) DRAIN	8in
D2	FILTRATE VENT	2in
F1	FILTRATE/RF	8in
F2	REVERSE FILTRATION SUPPLY	8in
R1	EXCESS RECIRC, XR	4in

-COMPLETED INSTALLATION-

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ALL FINISHED SURFACES √ μIN √ μm

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DRAWING NUMBER NYCS000010008 | REVISION 00
MATERIAL MASTER ---- | DWG SIZE D | SHEET 1 OF 1

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