Hybrid NF-RO Sodium Chloride Removal Process Pilot Study

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Abstract and Benefits

Abstract:
Concentrate disposal is a major cost for desalting operations, particularly for inland sites. For many water-recycling applications, only partial desalting is needed, with sodium chloride the most common target for removal. A process to preferentially remove sodium chloride could result in significant savings for concentrate treatment and disposal.

A pilot study was conducted to demonstrate the viability of one such approach. This pilot study examined the salt passage characteristics of several nanofiltration (NF) membranes to segregate sodium chloride from other dissolved ions. The pilot study testing unit used a two-pass system, combining an NF pass with a second reverse osmosis (RO) pass. In this approach, unlike typical two-pass systems, the concentrate from the first NF pass is blended with the permeate from the second RO pass. Since the NF effectively retains total organic carbon (TOC), chemicals of emerging concern (CECs), and any pathogens, these contaminants are blended into the product water. Thus, further treatment may be necessary for potable reuse applications.

The pilot study consisted of a scalable two-pass NF-RO membrane system operated in parallel with full-scale RO units. Water quality, power consumption, and chemical consumption were tracked for 6 months at varying system conditions. Findings indicate that sodium chloride can be preferentially removed from the reclaimed water, chemical and power consumption can be reduced when operated at system recoveries comparable to typical RO systems, and much higher recoveries are achievable with modest increases in power and chemical usage.

Benefits:

- The NF-RO process selectively removes sodium chloride from reclaimed water where the use of water softeners is widespread.
- The selective separation of monovalent and divalent ions reduced concentrate management and disposal costs by reducing the mass of salts disposed in the concentrate and minimizing the quantity of concentrate for disposal.
- The NF pass retains minerals that contribute to water stability that would typically be discarded with the concentrate in a conventional RO process operated at the same hydraulic recovery.
- Chemical consumption for the NF-RO process is less than that for a conventional RO process.
- Blended-product water from the NF-RO process is well-suited for reclaimed water applications and could be adapted in a non-RO based potable reuse flow scheme.

Keywords: concentrate management, sodium chloride reduction, water softening, nanofiltration, reverse osmosis, salt passage, high recovery system, selective ion rejection.

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Acronyms and Abbreviations

AWC	American Water Chemicals
BC	Brown and Caldwell
BOD	biochemical oxygen demand
$CaCO_3$	calcium carbonate
CAP	Central Arizona Project
CCPP	calcium carbonate precipitation potential
CCRO™	closed-circuit reverse osmosis
CECs	chemicals of emerging concern
CIP	clean-in-place
ECw	electrical conductivity of irrigation water
EDC	endocrine disruptor
gfd	gallons per square foot per day
gpm	gallon(s) per minute
IEBL	Inland Empire Brine Line
KMS	Koch Membrane Systems
LSI	Langelier Saturation Index
mgd	million gallons per day
mg/L	milligram(s) per liter
NF	nanofiltration
ng/L	nanogram(s) per liter
PLC	programmable logic controller
PPCPs	pharmaceuticals and personal care products
psi	pounds per square inch
psig	pounds per square inch gauge
RO	reverse osmosis
SAR	sodium adsorption ratio
TDS	total dissolved solids
TOC	total organic carbon
TOrC	trace organic compound
TSS	total suspended solids
WTP	water treatment plant
ZLD	zero liquid discharge

Executive Summary

A common issue with reclaimed water, particularly in arid regions, is its elevated salt content. In the City of Phoenix and City of Scottsdale, where the drinking water source is from the Central Arizona Project (CAP) (Colorado River), the reclaimed water has been documented to be 400 to 600 milligrams per liter (mg/L) greater than the drinking water source. This phenomenon is not believed to be isolated to these two areas. While total dissolved solids (TDS) reduction can easily be accomplished with conventional reverse osmosis (RO) facilities, these systems are more energy-intensive than conventional drinking water treatment systems. A more efficient process that could remove problematic sodium chloride, while retaining the “good” ions such as calcium, magnesium, and sulfate, would improve the quality of the reclaimed water. This improvement in economics would allow more water agencies to consider membranes for reducing the TDS in their reclaimed water sources and promote greater use and acceptance of reclaimed water.

The two-pass membrane system described herein uses a novel approach with conventional treatment components: a nanofiltration (NF) system with concentrate recycle in the first pass followed by RO in the second pass. In a previous study, the concentrate recycle was found to enhance the passage of monovalent ions when NF membranes are used (McCandless, 2015). The process flow schematic provided in Figure ES-1 provides an overview of the treatment concept. Multivalent ions in the concentrate stream of the first pass are retained and blended with permeate from the second pass. Because the feed to the second pass is softened, very high overall recoveries are possible with minimal pretreatment.

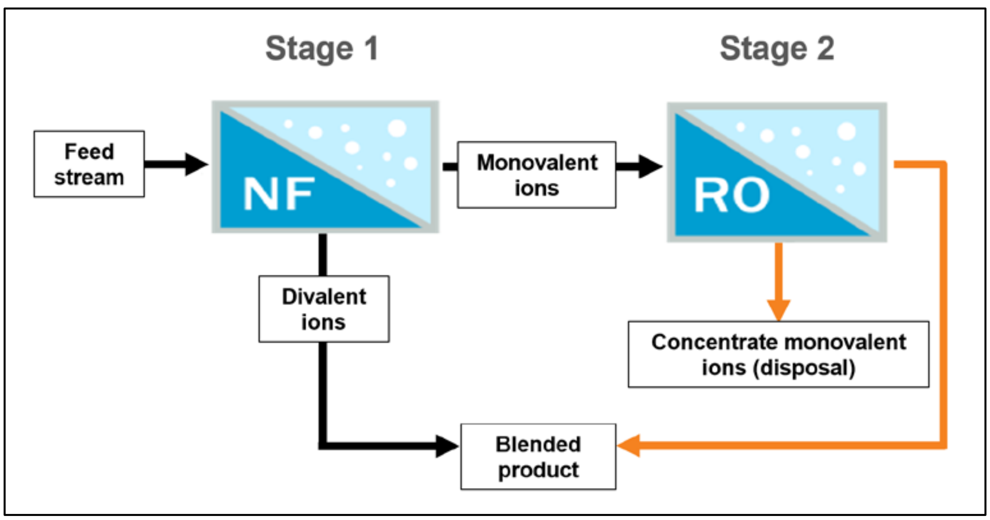

Figure ES-1. NF-RO Hybrid Membrane System Process Schematic.

This study included two parts: (1) testing to evaluate NF membranes for use in the NF-RO treatment scheme, and (2) operation of the two-pass system to evaluate membrane system performance and gather data for evaluating full-scale operation. Based on the data from the testing, the life-cycle cost of the NF-RO system and cost savings for concentrate management and disposal were evaluated.

The NF membrane selection portion is a rapid field test of 4 to 5 days duration per membrane. The membrane performance was compared based on the following four criteria:

- Sodium passage relative to calcium passage: This parameter is an indicator of the ability of the NF membrane to retain hardness ions which, in turn, promotes higher recovery potential of the second-pass RO process.

- Overall TDS removal: Predicted values from the laboratory values for NF permeate and desktop RO projection software evaluated in conjunction with the sodium passage/calcium passage gives an indication of how much of the feed water sodium chloride is removed. Given the same sodium and calcium passage values of the NF membrane, a higher value is more desirable.
- Percentage of sodium chloride in the RO concentrate as predicted from the NF permeate: This is a measure of the relative purity of the RO concentrate with respect to sodium chloride and an indicator of the recovery potential for concentrate treatment processes. A higher percentage is desirable.
- Predicted maximum RO recovery: This relates directly to the overall recovery of the NF-RO process. A higher value is desirable.

These values are summarized in Table ES-1.

Table ES-1. Summary of NF Membrane Performance

	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Sodium Passage	88.5%	90.9%	87.0%	82.1%
Calcium Passage	64.0%	54.1%	60.3%	26.2%
Predicted Reduction of TDS	45.0%	41.0%	46.0%	38.0%
Predicted Sodium Chloride in RO	79.2%	81.5%	79.1%	83.2%
Predicted Maximum RO Recovery	92.7%	93.0%	93.3%	93.7%

All membranes exhibited excellent ability to improve the maximum RO recovery by removing scale-forming minerals and total organic carbon (TOC). The Koch Membrane Systems (KMS) product was selected as most appropriate for the second part of testing.

The second part of the study included operation at overall recoveries of 86.0 percent and 92.5 percent. Normalized specific flux and normalized permeate conductivities were tracked for both the NF and RO passes. Samples were gathered weekly for laboratory analysis to evaluate system performance with respect to TDS reduction, product water quality improvement, and sodium chloride removal. Monthly samples included TOC and trace organic compounds (TOrCs) to determine the fate of these compounds.

Using data from the pilot test, several evaluations were conducted to demonstrate the costs and benefits of the NF-RO process for reducing concentrate management and disposal costs. These evaluations concluded that the NF-RO process has a somewhat higher capital and operating cost than an RO system of the same capacity, but these additional costs are recovered very quickly when concentrate management and disposal costs are included.

Water quality improvements by the NF-RO process were also evaluated. The evaluation included a comparison of the Langelier Saturation Index (LSI) and calcium carbonate precipitation potential (CCPP) of the feed, concentrate, and blended-product; a comparison of sodium adsorption ratio (SAR) for the feed, concentrate, and blended-product; and overall TDS reduction. The product water from the NF-RO process had a nearly neutral LSI and low CCPP. The SAR was notably reduced (an improvement) from the feed to blended-product, as was the chloride content. TDS reduction for this particular combination of NF and RO membranes and recovery was approximately 32 percent, which could be improved using a lower flux, using an alternative NF membrane, or by increasing RO recovery.

CHAPTER 1

Introduction

1.1 Project Need

In arid climates, reclaimed water is a key component of many water resource portfolios. Reclaimed water often has a total dissolved solids (TDS) content 400 to 600 milligrams per liter (mg/L), greater than the drinking water source. In some instances, TDS increases nearly 100 percent from what enters the system from the source water, and nearly all the increase is from sodium chloride due to widespread water softener usage. Figure 1-1 provides an example of major ion compositions for drinking water and reclaimed water for the City of Scottsdale, Arizona. Most constituents other than sodium and chloride in the reclaimed water are not detrimental for irrigation of plants or harmful to aquatic organisms, at least not at the concentrations found in the wastewater.

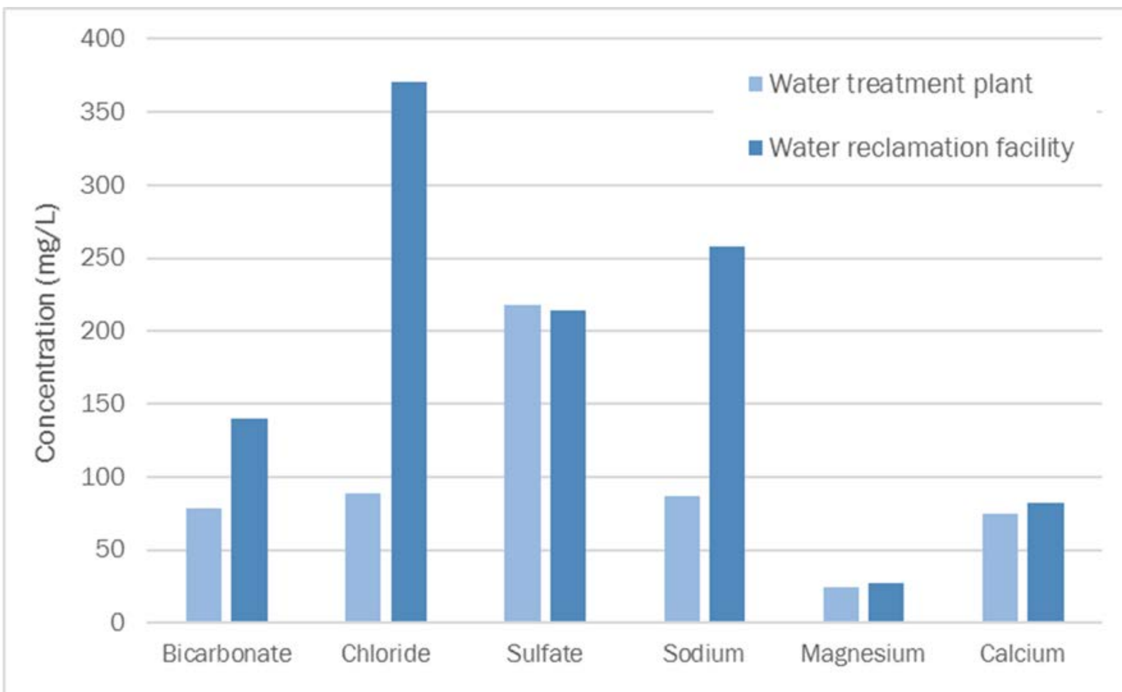

Figure 1-1. Drinking and Reclaimed Water Quality Comparison.

High levels of sodium chloride in reclaimed water have impacted utilities and their reclaimed-water customers. In some cases, the elevated TDS has harmful effects on crops or landscape vegetation. These negative effects most commonly relate to the reclaimed water’s high composition of sodium chloride relative to the original drinking water source. Source-control measures often achieve limited success, and in extreme cases, utilities have resorted to desalting reclaimed water. Desalting reclaimed water is costly and generates a concentrate stream that can be difficult and expensive to manage, particularly for inland utilities, where disposal options are limited.

To combat this growing water reclamation issue, Brown and Caldwell (BC) requested in-kind assistance and participation of the City of Scottsdale to investigate the viability of an innovative nanofiltration/reverse osmosis (NF-RO) membrane system in April 2014. The configuration of the innovative membrane system targeted the desalting of reclaimed water that is impacted by high levels of sodium chloride. High sodium chloride levels are increasingly common in wastewater systems, particularly in newly developed communities where the market penetration of water softeners is highest. During the 2014 study, testing of several NF membranes in a single-stage unit with concentrate recycle demonstrated that a high degree of separation of sodium chloride could be achieved. Desktop analyses also suggested that the process could be operated at higher recoveries and with similar energy and chemical usage to conventional RO. Subsequently, the team assembled a research project to demonstrate the complete two-pass hybrid system operating in parallel with full-scale RO units at the Scottsdale Water Campus. Research with the full-scale pilot unit was conducted from October 2017 through April 2018.

1.2 Conventional RO Treatment

The traditional approach to desalting brackish waters is to use RO, with a partial bypass to blend the finished product water to the desired target water quality. The traditional RO process is displayed schematically on Figure 1-2. Depending on the feed stream water quality, chemical addition is required to reduce the scaling potential of the feed water and to stabilize the product water.

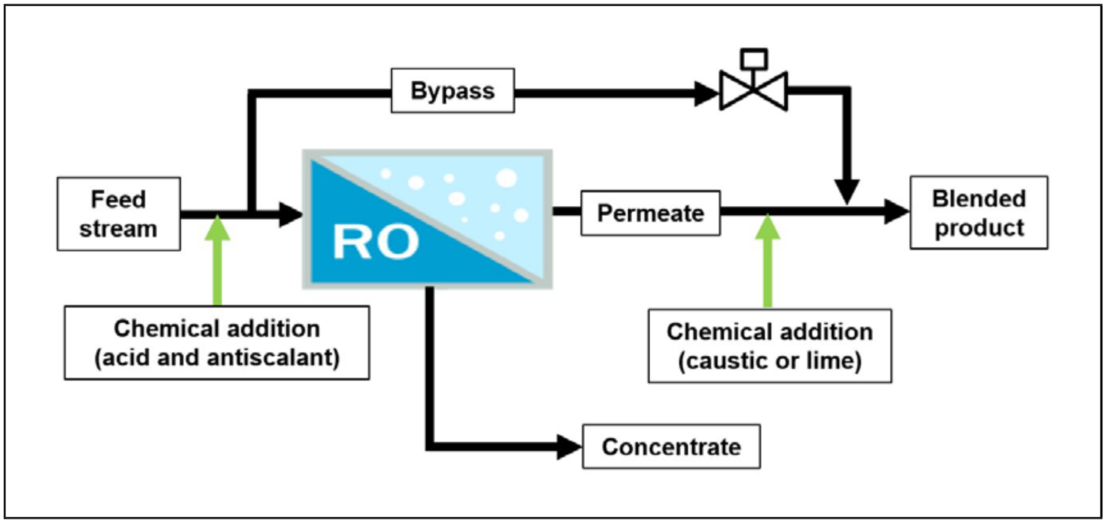

Figure 1-2. Conventional Reverse Osmosis Treatment Schematic.

The RO process rejects all dissolved ions very effectively compared to NF. Therefore, many of the salts that contribute to water stability and low sodium adsorption ratio are conveyed to the concentrate stream. To control scale formation on the membranes at such high concentrations, scale inhibitors and sulfuric acid are added to the feed water. This further contributes to the salinity of the concentrate. Chemical addition to the product water using caustic or lime may be necessary to increase the pH and produce stable, non-aggressive water.

Recognizing that the traditional RO membrane treatment approach requires the addition of calcium hardness for stabilization of the blended product, the common approach is to first discard a resource only to later incur the expense by adding it back to the process stream. If elevated sodium chloride alone impairs reclaimed water quality and inhibits beneficial use, then the treatment objective should focus solely on the removal of sodium chloride.

1.3 Proposed NF/RO Process

A membrane process that could selectively remove sodium chloride, while retaining the ions beneficial to maintaining water stability, such as calcium, magnesium, and sulfate, would improve the quality of the reclaimed water and promote greater use and acceptance. A flow scheme that involves a two-pass NF-RO membrane system, as shown on Figure 1-3 below, could achieve this objective. The flow scheme uses an NF system in the first treatment stage followed by RO. The second-stage RO serves to remove monovalent ions, predominantly sodium and chloride.

Multivalent ions and total organic carbon (TOC) in the first stage are retained in the NF concentrate stream and blended with permeate from the RO stage to achieve a more stable product water, with minimal post-treatment chemical addition. Because the feed to the second stage is softened, higher recoveries than conventional RO treatment are possible with reduced chemical pretreatment.

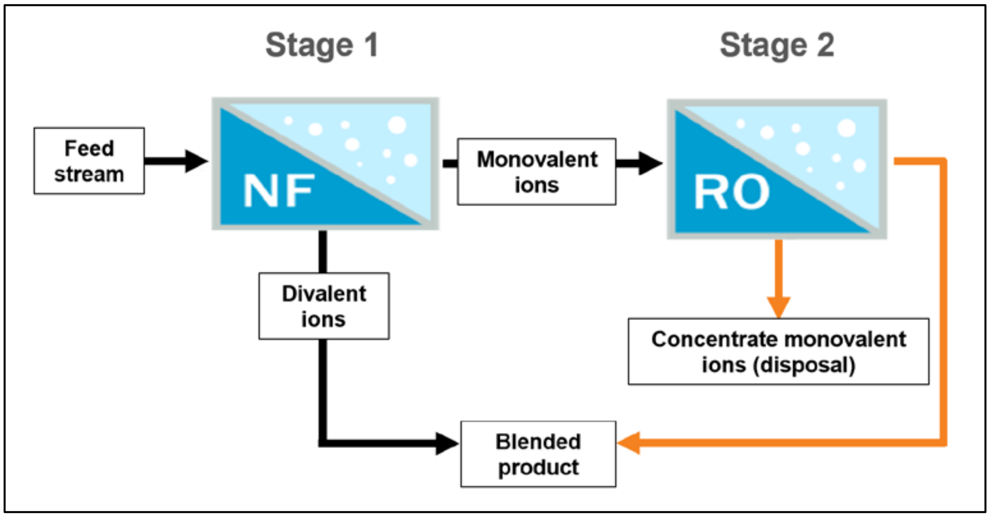

Figure 1-3. NF-RO Hybrid Membrane System Process Schematic.

The goals for the NF-RO membrane system and associated treatment process are to reduce reclaimed water salinity to levels close to the potable water supply or raw water source, and to reduce the cost of brine management, treatment, and disposal. The process may benefit the City of Scottsdale and similar utilities by reducing chemical consumption and reducing the costs for brine disposal from desalting operations. For this approach to succeed, the first NF pass of the hybrid membrane system would ideally exhibit low rejection of monovalent ions and high rejection of multivalent ions. Also, minimizing the recovery in the NF stage helps to reduce the required capacity of the second stage. The fate of TOC, nutrients, and measured trace organic compounds (TOrCs), including pharmaceuticals and personal care products (PPCPs), is also of interest for water quality management and concentrate disposal. If the reclaimed water is to be used for irrigation, then there is little need for further treatment to remove TOC, TOrCs, pathogens and nutrients. If the water is to be used for potable reuse by direct or indirect means, then an additional treatment steps, such as ozonation or other advanced oxidation processes, might be required. The key to the success of this process scheme is managing salt passage through the NF membrane stage.

An initial pilot study was conducted in 2014 to gather data and understand the factors affecting passage (or rejection) of various dissolved ions, particularly sodium chloride, using NF membranes. Using data from the 2014 NF membrane study, further projections were performed for the RO component and concentrate management. These results were compared with a traditional approach to desalting using RO with a blend of the feed water to achieve comparable water quality objectives.

Projections and desktop analyses from the 2014 study governed the design objectives and criteria for a second pilot study, which was conducted from October 2017 through April 2018 and will be the focus of this report. The 2017-18 study focused on the daily operation of a pilot skid that combined both NF and RO stages into a single unit to allow for observation and recording of key water quality and systems operation data. Testing was conducted at the City of Scottsdale Water Campus, which allowed for a direct comparison between the hybrid NF-RO process and the conventional RO treatment process currently used at the Water Campus. Comparison metrics focused on key differences between system operational parameters, energy usage, chemical consumption, and product and concentrate water quality.

1.3.1 Salt Passage

Typical NF and RO membrane systems use a plug flow regime, which provides good salt rejection (low salt passage) at a fixed or narrow range of operating recoveries. In contrast, systems with concentrate recirculation allow for operation over a wider range of recoveries and variable feed water quality.

Systems with concentrate recirculation require higher pumping energy than plug flow systems. Several factors contribute to passage (or conversely, rejection) of salts. Salt passage increases with increasing concentration on the feed side of the membrane, with increasing temperature and at reduced flux. Salt passage also increases with increasing system recovery. In plug flow systems, the salt passage increases linearly with respect to system recovery. Salt passage using internal concentrate recirculation increases at an exponential rate with respect to system recovery.

Different dissolved ion species exhibit different rates of salt passage. NF membranes allow lower molecular weight, lower ion charge species to pass more readily than higher molecular weight and higher charge species. It may be possible to use a combination of the right membrane, recovery, and recirculation fraction to optimize the separation of multivalent ions (e.g., calcium, magnesium, and sulfate) from monovalent ions (e.g., sodium and chloride). The combination of these variables was explored in the 2014 pilot study.

Results of the 2014 study showed selective passage of key monovalent and divalent ions. The hybrid system first explored during 2014 and later continued during this 2017-18 study capitalized on the advantage of the selective passage of different ions through the first NF pass. The study focused on the passage of six key ions as shown below; parentheses indicate whether the NF membrane was more likely to allow the desired rejection or passage of each ion:

- Bicarbonate
- Calcium
- Chloride
- Magnesium
- Sodium
- Sulfate

The passage or rejection of key ions varied in response to both the selected recovery percentage and recycle flow rate for each portion of the test. Figure 1-4 shows an example of passage between a monovalent ion, sodium, and a divalent ion, calcium. Both system recovery and recycle flow rate contribute significantly to salt passage for the monovalent ions. The selected recovery and recycle flow rate did not make a significant difference on the larger divalent ions that were rejected by the NF membrane. Ions that were rejected at low recovery and recycle rates were rejected similarly at higher recovery and recycle rates.

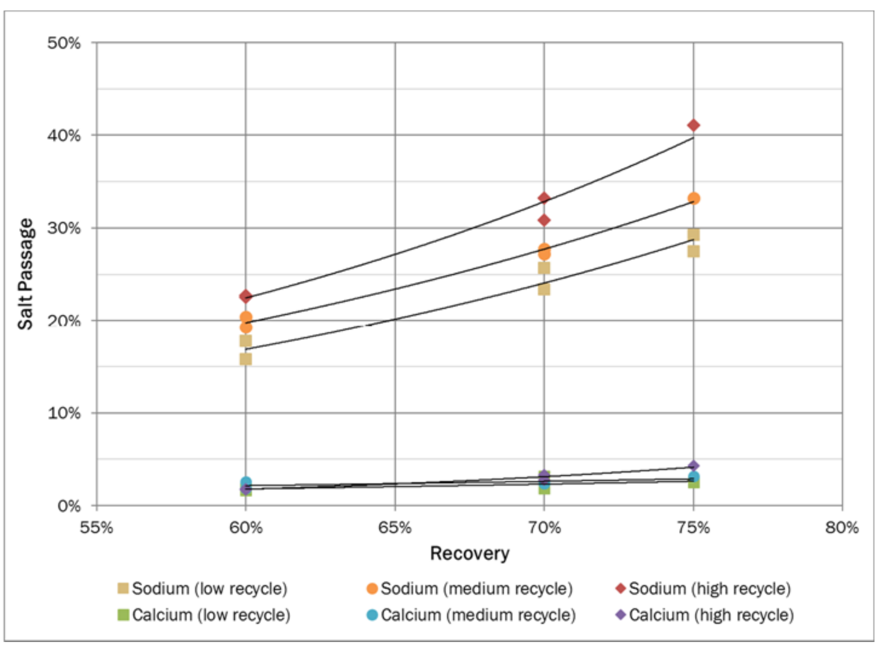

Figure 1-4. NF Membrane Salt Passage Characteristics.

(McCandless, 2015)

Salt passage is also affected by flux. Salt passage is greater at lower flux and lower as the flux is increased. A series of projections were prepared to examine the sensitivity of salt passage over a range of flux values. The results of projections for two NF membranes, the Dow NF270 product and a Hydranautics NF membrane, are shown on Figure 1-5.

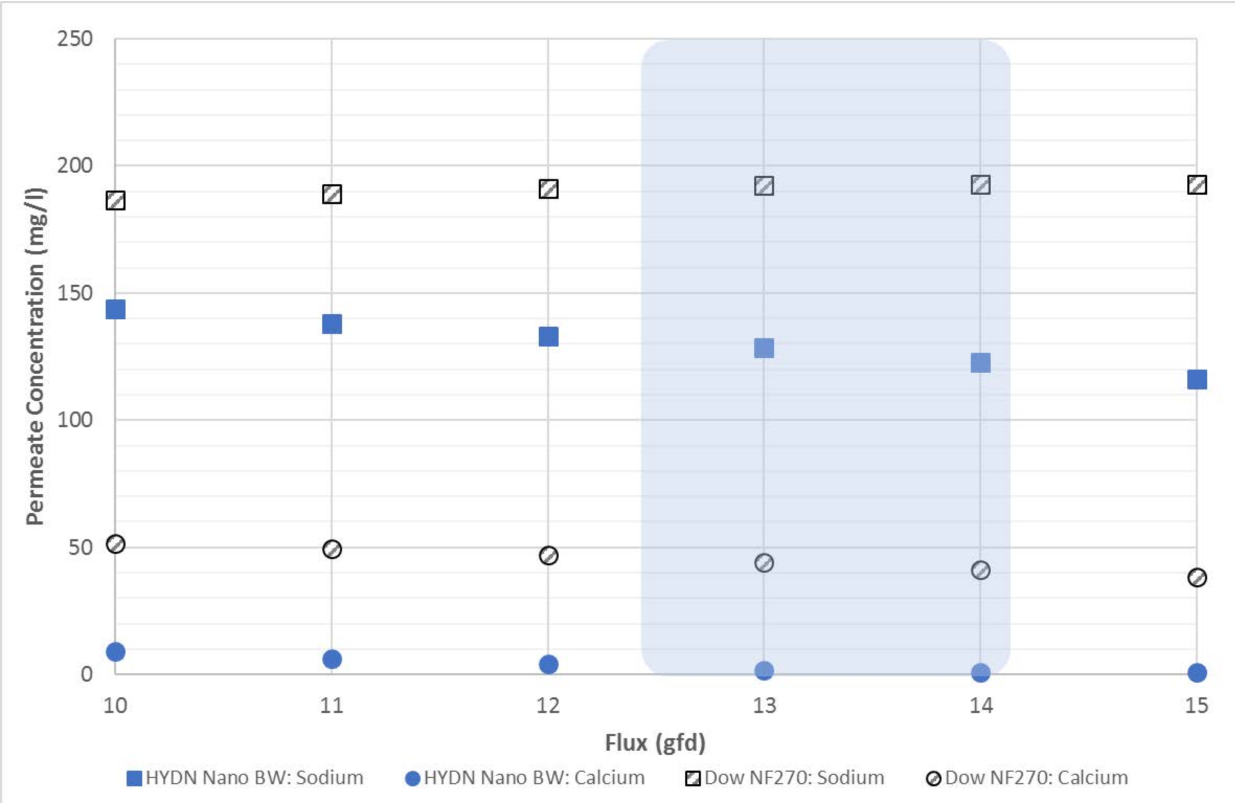

Figure 1-5. NF Permeate Concentrations and Flux.

This figure shows that salt passage does decrease with increasing flux. For both membranes, the change in calcium passage over the range of flux covered in this study (indicated in blue shaded area), is very low (less than 10 mg/L). The change in sodium passage for the Dow NF270 membrane, considered a 'looser' NF membrane, is also very low. The change in sodium passage for the Hydranautics membrane was approximately 7-8 percent between 12.5 and 14 gallons per square foot per day (gfd).

Salt passage also increases with increasing water temperature. A demonstration of this phenomenon is shown in Figure 1-6. The software projections gave very mixed results as to the magnitude of change in salt passage for each membrane and each solute. Sodium passage through the Hydranautics membrane was most affected by temperature, while the calcium passage was less affected. The opposite was observed for the Dow NF270 membrane. The shaded are represents the range of temperature of the water during the pilot test. The implications are that for water sources with wide variations in temperature, the effects of temperature on salt passage should be considered in design. However, for the conditions encountered in this study, the differences are not of significant concern.

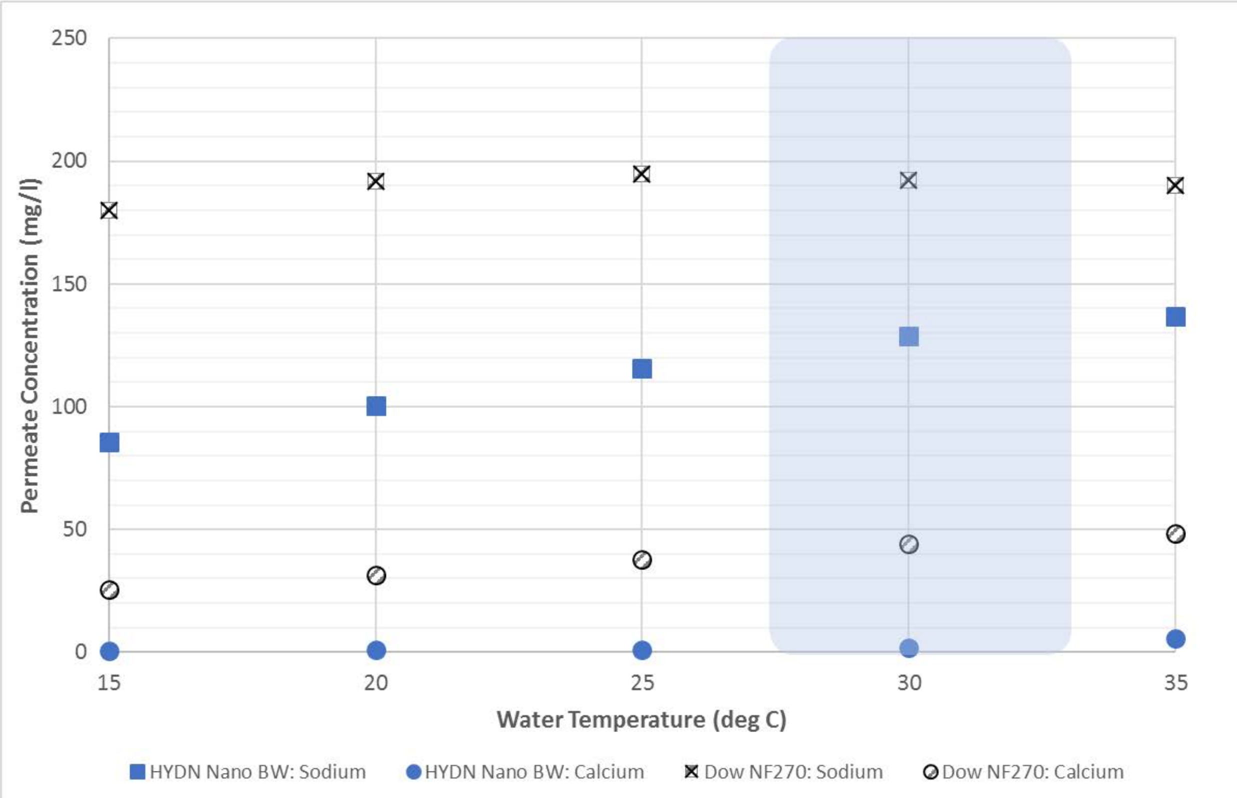

Figure 1-6. NF Permeate Concentrations and Temperature.

1.3.2 Prior Study Guidance

The 2014 study results formed the basis for a desktop comparison of the proposed NF-RO process and a conventional RO system with feed-water blending. The pilot study results and desktop study demonstrated good removal of sodium chloride while retaining dissolved ions beneficial for water stability. The results indicated that the NF-RO system may have a higher capital cost and would use slightly more energy than the conventional system but would reduce chemical consumption considerably. Initial projections were explored in detail during the subsequent pilot study performed from October 2017 to April 2018.

1.4 Pilot Study Objectives

The pilot study conducted from October 2017 to April 2018 built upon the 2014 pilot study, with the objective of verifying the long-term operational viability and further substantiating the significant cost and water savings the hybrid NF-RO approach can provide over conventional single-pass RO. Specific objectives of the recent study were as follows:

- Demonstrate that the combined NF and RO operation is a scalable system for the selective removal of sodium chloride.
- Demonstrate the reduced cost of concentrate disposal and examine applications of the process for varying concentrate disposal strategies.
- Refine membrane selection criteria to optimize product selection.
- Investigate energy-savings potential of a hydraulic energy recovery device on the internal concentrate recycle stream.
- Gather long-term operating data to predict long-term membrane performance and operational stability (minimum 6-month operation).
- Establish the performance envelope.
- Investigate the fate of organic contaminants and develop strategies to incorporate this process into potable reuse flow schemes.

- Develop capital and operations and maintenance cost estimates for comparison with conventional RO desalting approaches to potable and reuse water treatment.

This research aimed to demonstrate that this configuration can sustainably operate at large pilot scale and provide the following four clear benefits:

- Improvement of water quality impaired by widespread water softener usage. This is achieved through selective removal of sodium chloride without removing less detrimental materials. The 2014 study demonstrated the potential of restoration of the water quality to the raw water source ion profile.
- Improved concentrate management by reducing the mass of salts disposed in the concentrate. This results in a lower concentration or a lower volume of brine.
- Lower cost of chemical consumption for both pretreatment and post-treatment.
- Significantly lower concentrate treatment and disposal costs due to the lower mass of salts and lower concentration of limiting scale-forming compounds.

If successful, the findings of this pilot study may be used for full-scale deployment of the process for interested utilities.

CHAPTER 2

Study Plan

The 2017-18 pilot study built upon initial recommendations from the 2014 investigation on NF technology to selectively remove monovalent ions from the membrane feed stream. The pilot study that is presented in this report had two parts: Part 1 and Part 2. Part 1 examined the advantages between NF technologies currently available on the market to select the best membrane for application in the two-pass pilot system. Part 2 employed the membrane selection for pilot operation and evaluated two differing objectives: matching the existing recovery of the RO process at Scottsdale Water Campus (Phase A) and maximizing recovery for the total hybrid system (Phase B). Phase A system recovery (the amount of blended product relative to the reclaimed water [NF feed] process stream) averaged 86 percent. The system recovery for Phase B was 92 percent.

2.1 Part 1: NF Membrane Selection

The purpose of the NF membrane selection testing was to select one NF product for use in the two-pass NF-RO pilot. NF membrane elements (4-inch diameter) were obtained from four manufacturers. The following membrane manufacturers and models were chosen for this test:

- Membrane A: DOW FILMTEC NF270-4040
- Membrane B: CSM NE4040-40
- Membrane C: Hydranautics NANO-BW-4040
- Membrane D: Koch Membrane Systems (KMS) 4040-SR200

Manufacturer data sheets and specifications for each nanofiltration product are included in Appendix F. Criteria for evaluation were based on the overall ability of the NF membranes to separate monovalent ions from multivalent ions. All pilot study testing for Parts 1 and 2 was performed at the City of Scottsdale's Water Campus. Sampling and monitoring activities were performed by both BC and City of Scottsdale employees. The sampling protocol was kept consistent for all pilot testing.

2.1.1 Testing Methods and Materials

The NF membrane selection test was performed using a two-element membrane unit. The water supply was obtained from the Water Campus's RO transfer pump discharge. The water supply was treated secondary effluent that has undergone nitrification/denitrification, filtration, disinfection with chloramination, and ultrafiltration. The tertiary effluent is classified as Class A+ reclaimed water in the state of Arizona. Adequate feed flow rate was achieved at a minimum pressure of approximately 20 pounds per square inch (psi). Figure 2-1 below depicts a schematic of the Part 1 test system, which included a cartridge filter, high-pressure feed pump, and concentrate recycle loop.

The test unit included pressure gauges for feed and concentrate streams and rotameters to measure permeate, recycle, and concentrate flows. An image of the Part 1 testing unit is provided as Figure 2-2 below. The feed flow rate was adjusted manually using the needle valve on the discharge of the high-pressure feed pump. Concentrate recycle and concentrate discharge were adjusted using the needle valve adjustment knobs (associated with the rotameters) on the front of the unit. Adjusting one knob affects the other flow rates, and thus, fine-tuned adjustments are necessary to reach the target permeate flux, recovery, and recycle settings. The accuracy of flow readings obtained from the rotameters limited flow-control precision and resulted in slightly different flux and recovery values. Specifically, the measurement increments on the rotameters were 0.2, 0.1, and 0.2 gallons per minute (gpm) for permeate, concentrate, and recycle streams, respectively. Readings between the increments were reported based on visual field observations, with maximum error estimated to be 0.05 gpm.

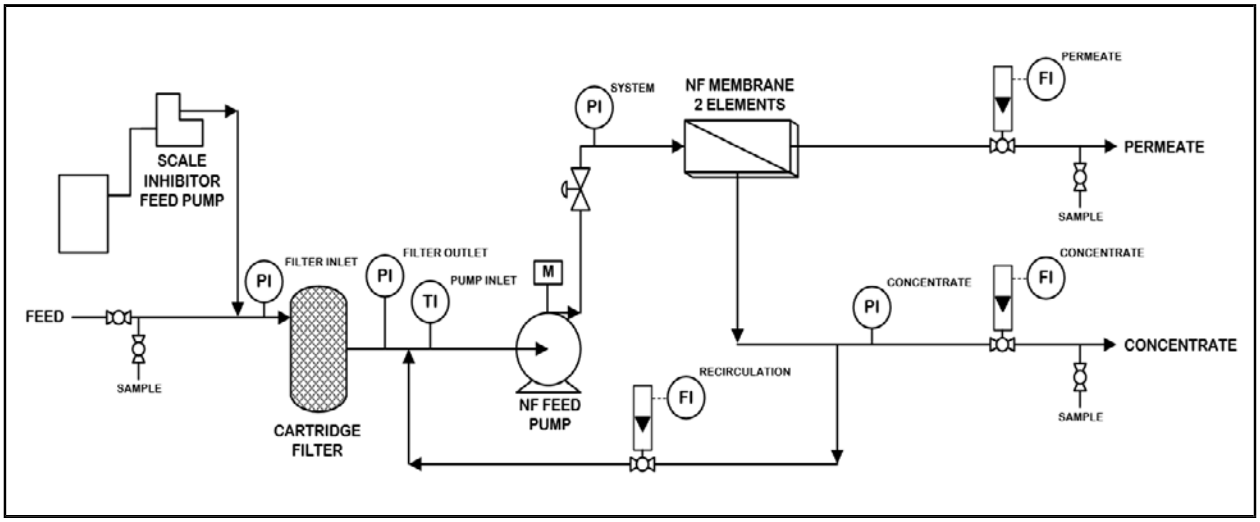

Figure 2-1. Part 1: Test Unit Schematic.

Figure 2-2. Part 1: Test Unit for NF Membrane Selection.

Test parameters for each NF membrane are shown in Table 2-1 below. The system recovery between all membranes varied within a tight range of 71 percent to 73 percent. Although the operational characteristics of the individual membranes varied little, the KMS NF membrane provided the highest flux for Phase A. The equipment used for the test presented challenges in setting consistent flows for consecutive membrane tests. Consequently, the team was unable to reproduce identical flux for all tests. Operational considerations must be coupled with water quality considerations, especially the passage of individual key ions. Water quality is discussed in detail in Chapter 3.

Table 2-1. Part 1: NF Membrane Summary

Parameter	Unit	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Membrane Area per Module	ft^2	82	85	75	85
System Membrane Area	ft^2	164	170	150	170
Feed Water Temperature	°F	85–86	86	85-86	88
Permeate Flow	gpm	1.55	1.5	1.35	1.65
Concentrate Flow	gpm	0.60	0.65	0.60	0.60
Recycle Flow	gpm	0.60	0.65	0.67	0.60
Feed Pressure	psi	35	40	58	73
Concentrate Pressure	psi	33	35	55	70
System Recovery	Percent	72	71	73	73
Array Recovery	Percent	57	54	51	58
Flux	gfd	13.6	12.7	12.5	14.0

The antiscalant, King Lee Pre-Treat Y2K, was diluted at a 10:1 ratio using RO permeate. There was no means of pacing the dose in response to flow variations; therefore, the dosing pump was checked and adjusted daily. The target dose was 5 mg/L.

Flux and system recoveries were reasonably consistent during the test. A bypass valve on the discharge of the antiscalant metering pump was open during testing of the first three membranes, and the dosing rate was nearly zero. After the fourth membrane was installed and operational, the technician noticed the open bypass valve and closed it. Antiscalant consumption increased and dosing was much greater than the target dose. Two samples were taken for the fourth membrane (KMS SR200) operating with the antiscalant. To be consistent with the data from the first three membranes, the investigation team decided to take a third sample without antiscalant. The antiscalant pump was disengaged and the test unit was allowed to run for 24 hours before taking a grab sample for metals and anions. The overdose of antiscalant did appear to affect rejection for the KMS SR200 membrane; the rejection (without scalant) was somewhat higher for all major ions. It is unclear if the overdose of antiscalant resulted in permanent fouling of the membrane. The operating pressure did decrease once the antiscalant dose was turned off and there was some increase in permeate TDS, which indicates that the antiscalant did affect the first two results. As a result, the sample taken without antiscalant was used for comparison of salt passage and concentrate quality.

2.1.2 Sample and Data Collection

Data collection consisted of visual readings, handheld analytical measurements, and laboratory analysis of grab samples. Water quality grab samples were obtained daily from the feed, concentrate, and permeate streams. A summary of recorded visual readings, handheld analytical measurements, and laboratory sample data are included in Appendix A.

The following visual readings were recorded from the instrumentation on the test unit:

- Water temperature
- Permeate, concentrate, and recycle flows
- Feed pressure
- Concentrate pressure
- Stroke length (percent), and stroke speed (percent) of the scale inhibitor metering pump
- Level of scale inhibitor tank

A handheld analyzer was used to determine the following:

- Conductivity readings for feed, permeate, and concentrate
- pH readings for feed, permeate, and concentrate

The membrane pilot unit was run for three days to allow performance to stabilize prior to taking grab samples for analysis at the City of Scottsdale Water Campus's onsite laboratory. Samples were taken from each of the feed, permeate, and concentrate flow streams. A comprehensive set of samples was gathered on the first day, followed by a shortened set of samples on the next day. Only the data from the six major ions (short set) were needed for the evaluation; the additional data from the comprehensive set were provided to each membrane manufacturer for its own research purposes. The second shortened data set was gathered to provide some redundancy. In the case of the KMS membrane, a third sample for metals and anions analysis was collected as described previously. The recorded measurements and laboratory analytical results are provided in Appendix A.

2.2 Part 2: Pilot Operation

Operation of the pilot unit from October 2017 to April 2018 was divided into two distinct phases of operation, with a different core objective governing each phase. Phase A focused on matching the recovery of RO systems operating at the Scottsdale Water Campus, while Phase B sought to maximize recovery of the NF-RO system. Phase B resulted in a higher percentage of water produced and, accordingly, a reduction in RO concentrate. A photograph of the pilot unit is displayed on Figure 2-3. The unit included feed and blend product water tanks, membrane skid to house both NF and RO membranes, clean-in-place (CIP) system, analog and digital instrumentation, and programmable logic controller (PLC).

Figure 2-3. Test Pilot Unit.

2.2.1 Testing Methods and Materials

The pilot system was manufactured by Wigen Technologies, LLC and consisted of a 500-gallon feed tank to receive ultrafiltered effluent, a two-pass membrane system, and a product water tank. The first pass was a single-stage array with recycle. The second pass was a two-stage array. All membrane elements were 4-inch diameter. Pressure vessels were sized for three elements each and each stage included two vessels in series. This allowed the pilot to perform like a system with six elements per pressure vessel. Each manufacturer evaluated offers a low-pressure RO product that is suitable to meet the process goals of the pilot study. As part of the agreement for participation in the test, the manufacturers whose NF membranes were not selected were offered the opportunity to provide the RO elements for the second pass. Hydranautics accepted the opportunity and provided their EPSA4LD product. A summary of the system arrangement is given in Table 2-2 below.

Table 2-2. Hybrid Two-Pass NF-RO Pilot Membrane Array

Parameter	Nanofiltration Membranes (First Pass)	Reverse Osmosis Membranes (Second Pass)
Stage 1 Vessels in Series	2	2
Stage 1 Vessels in Parallel	4	2
Elements Per Vessel	3	3
Stage 2 Vessels in Series	--	2
Stage 2 Vessels in Parallel	--	1
Elements per Vessel	--	3
Membrane Elements	KMS SR200-4040	Hydranautics ESPA4LD-4040

Figures 2-4 and 2-5 below show the process flow diagram, sample locations, instruments, and analyzers for the two-pass system. The NF concentrate was blended with the RO permeate at the product water tank.

Process Flow Summary

Flow ID	Description
1	Raw Water Feed
2	NF Feed
3	NF Permeate
4	Internal Recycle
5	Blend Stream
6	RO Feed
7	RO Permeate
8	RO Concentrate
9	Blended Product

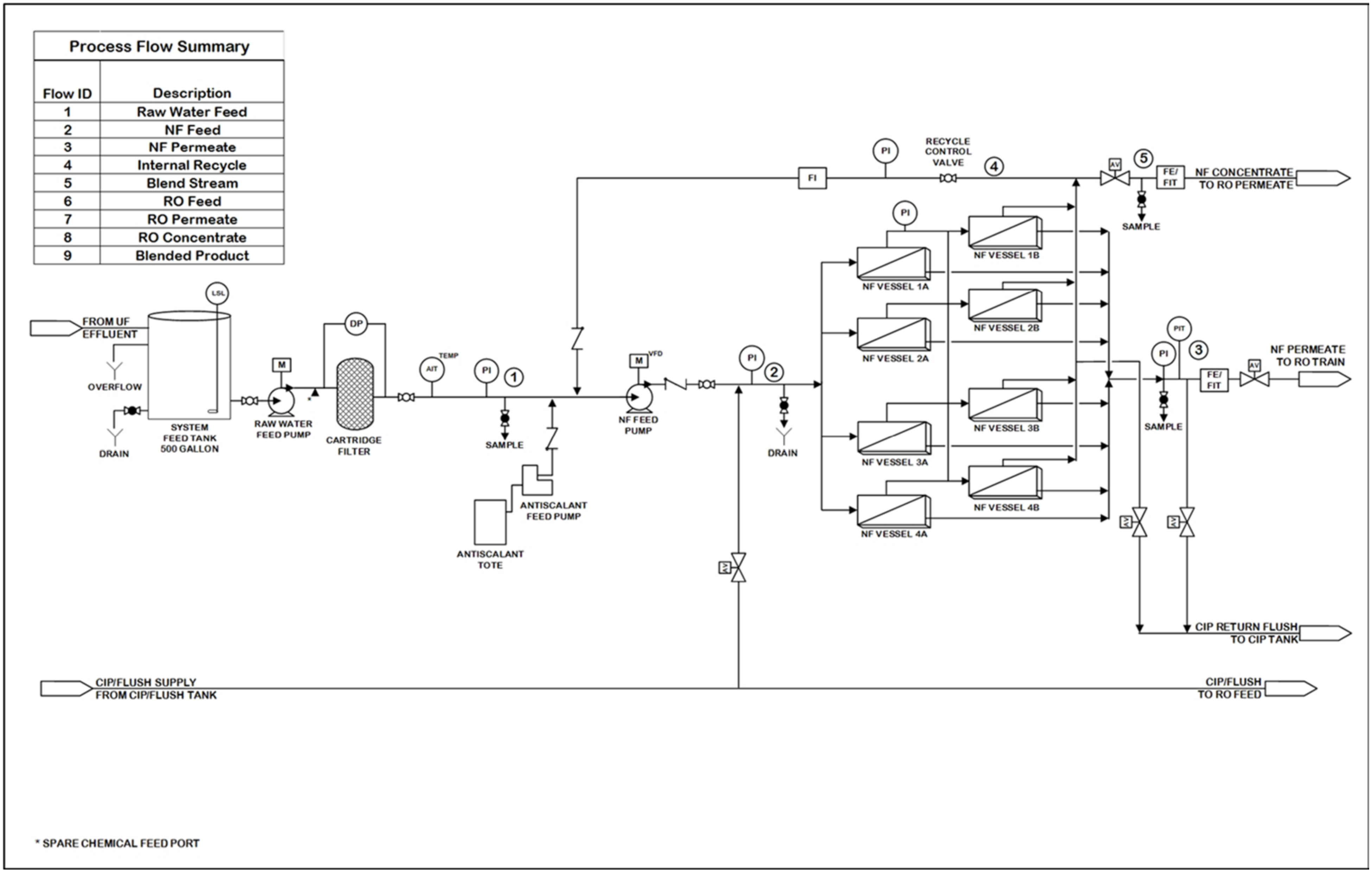

Figure 2-4. NF System Schematic.

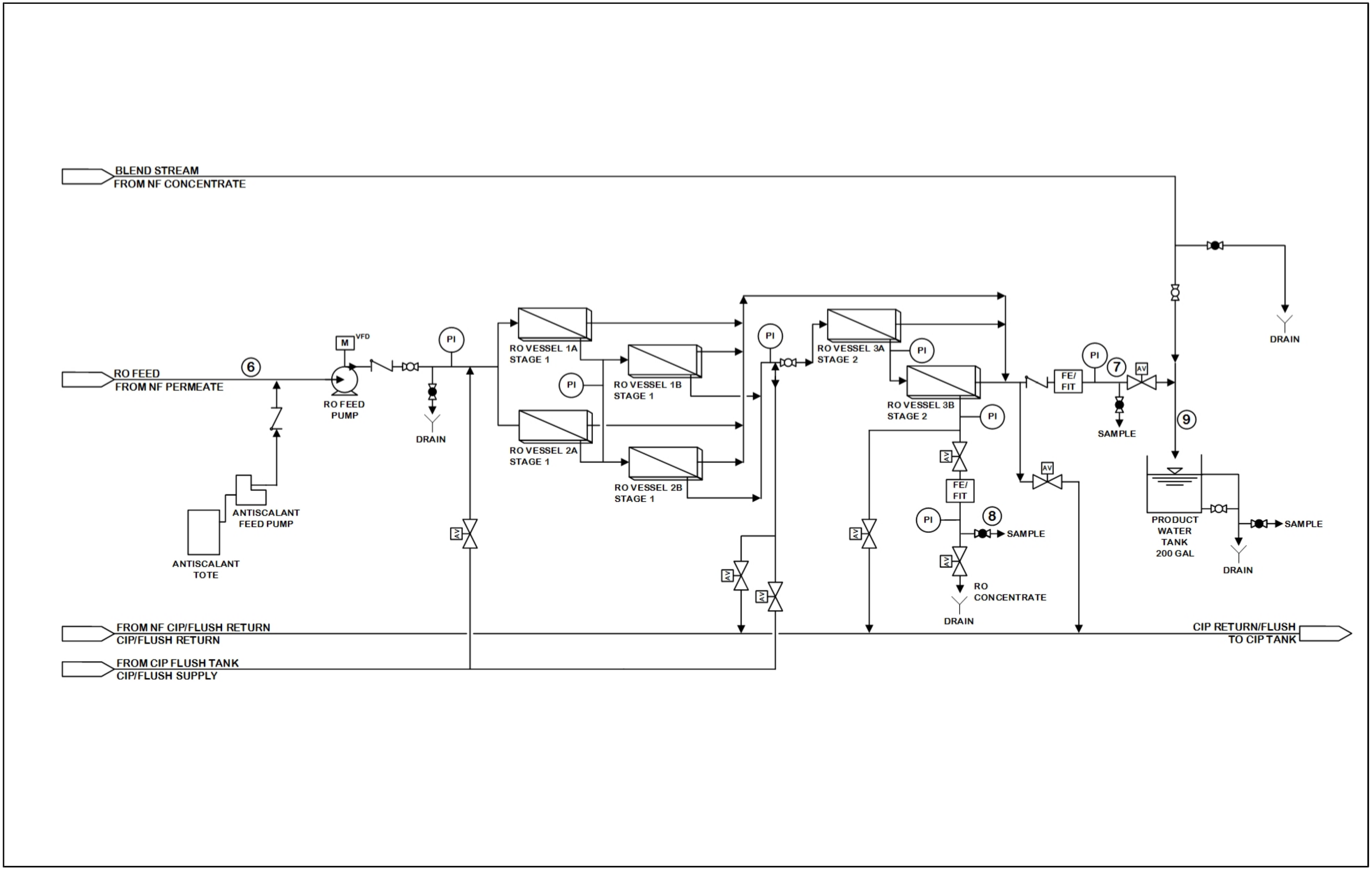

Figure 2-5. RO System Schematic.

2.2.2 Sample and Data Collection

To meet project budget requirements, the system was specified without certain common online instruments and analyzers. The necessary data were gathered with visual readings and the use of a handheld conductivity and pH analyzer (Myron L Ultrameter). Flow, temperature, and some pressure measurements were recorded by the pilot unit PLC. Water quality grab samples were obtained weekly from one of the six sample locations for the various pilot process streams:

- NF feed (reclaimed water from the City of Scottsdale Water Campus, Class A+)
- NF concentrate
- NF permeate (RO feed)
- RO concentrate
- RO permeate
- Blend (combination of NF concentrate and RO permeate)

Weekly samples were limited to the analysis of major water quality constituents, which included bicarbonate ion, calcium, chloride, sodium, silica, and sulfate. Monthly samples provided a more comprehensive analysis of the water quality. Graphical data for NF and RO flows and recovery, as obtained from the pilot unit PLC, are included in Appendix C. PLC records were taken at 5-minute intervals and visual readings were recorded three times daily, approximately once every 8-hour shift. Samples from each of the six process streams were taken once daily, and the conductivity and pH were also recorded. The antiscalant tank level was also recorded daily. The monochloramine concentration in the ultrafiltered effluent is continuously monitored at the Water Campus, and this value was recorded daily. The monochloramine residual was maintained between 1 and 2 mg/L. Table 2-3 provides a summary of data recorded for analysis, while Table 2-4 provides laboratory analytes measured either on a weekly or monthly period.

Table 2-3. Recorded Data.

Visual Readings		PLC Recorded Data Fields
Pressure (raw water booster pump discharge)	Pressure (RO interstage)	Temperature (NF feed)*
Pressure (NF feed)	Pressure (RO permeate)	Pressure (NF permeate/RO feed)*
Pressure (NF interstage)	Pressure (RO concentrate)	Flow Rate (NF permeate)*
Pressure (NF recycle)	RO Feed Pump Voltage	Flow Rate (NF concentrate)*
Flow rate (NF recycle)	RO Feed Pump Current	Flow Rate (RO permeate)*
Pressure (NF concentrate)	--	Flow Rate (RO concentrate)*
NF Feed Pump Voltage	--	--
NF Feed Pump Current	--	--

*Also recorded from visual observation.

Table 2-4. Laboratory Analytes and Testing Frequency.

Analysis	Analytical Method	Testing Frequency
Metals (cations)	EPA 200.7	Weekly
Anions	EPA 300.0	Weekly
Alkalinity	Standard Methods, 22nd Ed., 2320 B	Monthly
TDS	Standard Methods, 22nd Ed., 2540 C	Monthly
TOC	Standard Methods, 22nd Ed., 5310 C	Monthly
Total Kjeldahl Nitrogen and Ammonia	Standard Methods, 22nd Ed., 4500 NH3 D	Monthly
Endocrine Disruptors	LC-MS-MS*	Monthly
Compounds of Potential Concern	LC-MS-MS*	Monthly
Hormone Panel	LC-MS-MS*	Monthly

*In-house method of liquid chromatography tandem mass spectrometry.

2.2.3 Phase A Operations

Phase A testing was conducted to operate the NF-RO pilot system at the recovery of the Water Campus's full-scale RO units, to demonstrate performance with reduced chemical feed, and similar power requirements. The test ran for 74 days. Table 2-5 lists the target settings for recovery, flux, antiscalant dosage, and concentrate recycle. The NF concentrate recycle flow rate target is approximately equal to the NF concentrate flow rate.

However, the recycle rate was not constant throughout the study, as it was manually adjusted to maintain a setpoint. In general, the target settings were maintained, except for the antiscalant dose. During the first part of the study, the NF antiscalant dosing rate was set at a low dose calculated from projection software and was judged insufficient based upon the rate of decline of specific flux in the NF pass. Therefore, the NF feed antiscalant dose was adjusted upward on Day 39 of operation. While the decline in specific flux slowed, it had reached more than 15 percent from above the starting value. On Day 58, a low pH CIP of the NF and RO was conducted. Upon system startup after the clean, the NF feed antiscalant dose was increased again for the remainder of Phase A operation.

The NF pass provided excellent pretreatment for the RO. Consequently, the RO pass flux is much higher than would be possible if the feed water was ultrafiltered tertiary effluent. The flux used for the RO is on the low end of manufacturer's recommendations for second-pass RO systems; it is very likely that the RO flux could have been increased further.

Table 2-5. Phase A Test Parameters

Parameter	Unit	Target	Actual
NF Recovery	Percent	70.0	69.5
NF Flux	gfd	14.9	14.4
NF Concentrate Recycle	gpm	9.0	7.5–11.0
NF Antiscalant Dose	mg/L	0.60	0.64–1.28
RO Recovery	Percent	80.0	80.3
RO Flux	gfd	16.0	15.5
RO Antiscalant Dose	mg/L	0.80	1.09
System Recovery	Percent	86.0	86.3

2.2.4 Phase B Operations

Phase B targeted a system recovery of 92.5 percent, which would result in a 50 percent reduction in the flow rate of concentrate compared to the conventional RO units operating at the Scottsdale Water Campus. Additional Phase B test parameters are presented in Table 2-6 below. The NF concentrate recycle flow rate target is approximately equal to the NF concentrate flow rate, but varied considerably at times, as there was no automated control to maintain a setpoint flow.

Pilot study operation closely matched targeted values. The NF flux was adjusted downward very early to reduce the rate of specific flux decline. Antiscalant was dosed to control scale formation of multiple salts of sulfate, carbonates, and silica. Antiscalant dosing started at 6.4 mg/L and was reduced on Day 22 after an error was discovered in the calculation for dilution of antiscalant. The target dose was intended to be approximately 3.2 mg/L. Heavy fouling of the cartridge filter was observed and, on Day 27, a high-pH detergent CIP was conducted. Specific flux recovered and exceeded the initial specific flux. This was likely due to the membranes not being given a chemical cleaning when first installed (as recommended by the manufacturer); they were only flushed, as is common practice for most membrane elements. The system ran continuously until Day 76, when both a high-pH detergent and a low-pH CIP were conducted on the NF only. After the CIP, the antiscalant dose was adjusted downward again and the unit ran continuously until the end of the run on Day 108. After Day 108, the unit operated, but samples were not collected.

Table 2-6. Phase B Test Parameters

Parameter	Unit	Target	Actual
NF Recovery	Percent	75.0	73.8
NF Flux	gfd	14.0	12.6
NF Concentrate Recycle	gpm	6	7–12
NF Antiscalant Dose	mg/L	5.0	1.7–7.7
RO Recovery	Percent	90.0	89.1
RO Flux	gfd	16.0	15.1
RO Antiscalant Dose	mg/L	2.5	4.1–4.9
System Recovery	Percent	92.5	92.0

CHAPTER 3

Results and Discussion

This chapter presents results of field testing conducted during this study. The field testing included a preliminary set of tests to select a NF product for the pilot test of the NF-RO process. The pilot test included two operational modes over the course of 6 months.

3.1 Nanofiltration Membrane Selection

Selection of the most appropriate NF membrane for the pilot study required evaluation of performance for passage (or rejection) of specific ions, as well as the predicted performance in tandem with the second-pass RO. The following four criteria were considered in the evaluation:

- Selective ion passage: This refers specifically to the passage of sodium and calcium (see Table 3-1). Higher NF passage is preferred.
- Predicted product water TDS (blend of RO permeate and NF concentrate): A lower TDS blended product water is preferred.
- Percentage of sodium chloride in the second-pass RO concentrate: This is based on modeled projections using the water quality data of the NF permeate. A higher fraction of sodium chloride represents better separation of multivalent and monovalent ions and is preferred.
- Maximum predicted recovery. The highest value achievable without pH adjustment is preferred. Calcium carbonate precipitation governed this value in all cases, with silica being the next limiting parameter.

The determination and significance of each of these criteria are discussed in the following sections.

3.1.1 Results and Discussion

The NF membrane selection testing was based on a series of short duration tests designed to provide insight into the capabilities of several NF membrane products for selective separation of monovalent and multivalent ions.

Selective Ion Passage

Selection of the most appropriate NF membrane for the pilot study requires evaluation of performance for passage (or rejection) of specific ions, as well as the predicted performance in tandem with the second-pass RO.

The determination and significance of each of these criteria are discussed in the following sections.

Table 3-1. NF Membrane Selection Ion Passage

Parameter	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Sodium Passage	88.5%	90.9%	87.0%	82.1%
Calcium Passage	64.0%	54.1%	60.3%	26.2%
Predicted Reduction of TDS	45%	41%	46%	38%
Predicted Sodium Chloride in RO Concentrate	79.2%	81.5%	79.1%	83.2%
Predicted Maximum RO Recovery	92.7%	93.0%	93.3%	93.7%

Tables 3-2 through 3-4 below present detailed results of the laboratory analyses of inorganic compounds for each membrane tested. The following analytes were not detected in any samples: aluminum, arsenic, beryllium, cadmium, lead, nickel, vanadium, and nitrite; therefore, the results for these constituents are not shown. Figure 3-1 below provides the passage of both sodium and chloride ions for each day of testing for all four membranes. Passage calculations used average permeate concentration values for each NF membrane, except for the KMS membrane. For the KMS membrane, only the data taken on the third day was used for evaluation of sodium, calcium, silica, sulfate, chloride and bicarbonate passage due to the high dose of antiscalant during the first two days. The passage percentages are calculated using the method described in the Technical Manual excerpt *Filmtec Membranes System Design: Plug Flow Versus Concentrate Recirculation*, by Dow Chemical Company.

Table 3-2. Summary of NF Membrane Permeate Water Quality

Parameter	NF Feed	Dow NF 270		CSM NE		Hydranautics Nano BW		KMS SR200	
	Average (mg/L)	Permeate (mg/L)	Passage	Permeate (mg/L)	Passage	Permeate (mg/L)	Passage	Permeate (mg/L)	Passage
Salinity, Bicarbonate (as $CaCo_3$)	168	107	82%	93	74%	94	75%	48	48%
Calcium	78.6	34.3	64%	28.0	54%	30.4	60%	10.4	26%
Chloride	385	379	98%	351	97%	331	95%	272	85%
Magnesium	30.8	11.1	58%	5.2	30%	10.9	57%	1.7	12%
Nitrate	4.0	5.0	100%	4.5	100%	3.7	100%	3.8	100%
Potassium	24.4	18.2	86%	19.5	89%	17.0	86%	14.5	81%
Silica	10.0	7.2	95%	9.1	98%	9.9	96%	9.7	93%
Sodium	244	161	88%	210	91%	185	87%	167	82%
Sulfate	250	BDL	0%	BDL	0%	BDL	0%	BDL	0%
Sum of Ions	1,194	722	--	720	--	681	--	527	--
TDS, Residue	1,217	752	--	724	--	700	--	516	--

Table 3-3. Summary of NF Membrane Ion Passage Estimates

Parameter	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Sodium	85.7%–91.3%	90.4%–91.4%	86.5%–87.6%	81.0%–84.1%
Calcium	62.1%–66.0%	53.6%–54.5%	58.9%–61.7%	23.6%–31.2%
Chloride	97.5%–97.6%	97.0%–97.4%	95.0%–95.3%	83.8%–86.8%
Bicarbonate	81.1%–82.7%	72.8%–75.2%	73.0%–76.5%	45.4%–50.5%
Sulfate	0.0%	0.0%	0.0%	0.0%

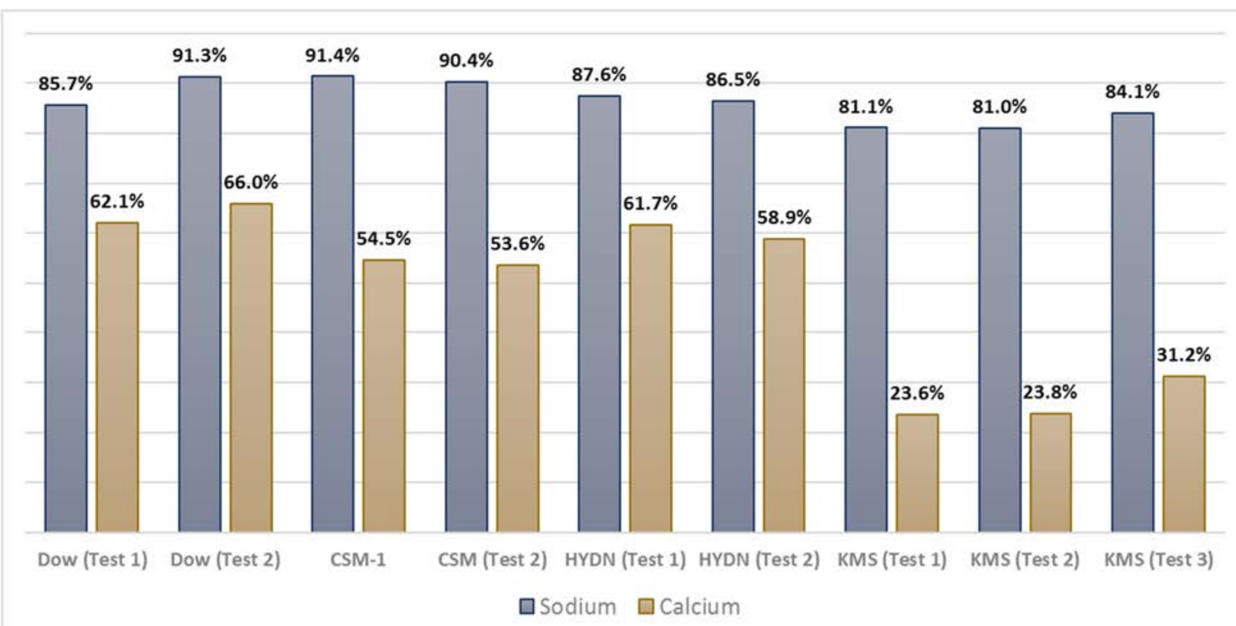

Figure 3-1. Passage of Sodium and Calcium by NF Membrane.

All four membranes exhibited no measurable passage of sulfate. Three of the four membranes had high passage rates for sodium and chloride. The fourth, KMS SR200, had slightly lower passage rates for sodium and chloride, but had a much lower passage rate for calcium (and magnesium). Both nitrate and silica had high passage rates for all four membranes, indicating that these constituents would need to be removed by the second-pass RO. Figure 3-1 depicts the difference in passage of sodium and calcium for each sampling event of each membrane. Despite a slightly lower passage of sodium and chloride, the KMS SR200 is preferred because of a much lower passage of calcium and bicarbonate alkalinity. This implies that less chemical would be necessary to re-stabilize the blended-product water using the KMS membrane. The role that the excess antiscalant played on the broad difference of sodium and calcium passage is not known, but it does not appear that the large difference can be explained solely by possible antiscalant fouling. The NF permeate quality in Part 2 of the pilot study was similar to Part 1, particularly the last sample, taken when antiscalant was not being used.

Predicted Product Water TDS

Reducing TDS is a goal for the quality of the blended-product. In the case of the City of Scottsdale, the water sent to golf course irrigation must not exceed 125 mg/L of sodium. To predict the quality of the blended-product, the data for the NF permeate have been used in a desktop projection model of the second-pass RO, and the resulting RO permeate is blended with the NF concentrate (in proportions matching the recovery of the pilot system design).

The second-pass RO was modeled using American Water Chemicals' (AWC's) Proton™ projection software. For low-pressure RO applications, the AWC software produces results that are reasonably similar to the membrane manufacturer's projection software. The NF permeate values were input to the water quality analysis fields and balanced with the addition of sodium ions. The net effect of adding sodium to balance the ions on the permeate water quality was negligible. Sulfate and phosphate, both non-detect in the laboratory analyses, were input as one-half the method detection limit. The system configuration is a 2:1 array with six 4-inch elements per tube. A Dow BW30LE element was selected for the projection. Recovery was set at 80 percent, the flux at 16.4 gfd, and no pH adjustment was applied. Printed outputs for each projection are included in Appendix B.

The values for the resulting RO permeate were then input into a mass-balance spreadsheet, applying the NF system recovery values and using NF concentrate values. The mass balance includes the following major ions that compose more than 95 percent of the TDS: calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, silica, and nitrate.

The mass-balance equation is as follows:

$$C_{bpw} = \frac{C_{nfc}\left(1 - R_{nf}\right) + C_{rop}\left(R_{nf} \times R_{ro}\right)}{1 - R_{nf} + R_{nf} \ \times (R_{ro}} \qquad \text{(Equation 3 } - \text{ 1)}$$

Where:

C_{bpw} = concentration in blended-product water, calculated C_{nfc} = concentration in NF concentrate per lab analysis

C_{rop} = concentration in RO permeate per projection model R_{nf} = system recovery of NF from test

R_{ro} = system recovery of RO from projection model

The RO system recovery and flux were constant for all four sets of projections, and the resulting RO permeate TDS concentrations were within 20 mg/L for all four cases. The values for the predicted blended-product concentrations are shown in Table 3-4 below.

Table 3-4. Summary of Blended-Product Water Concentrations

Parameter	Unit	Range of NF Feed Streams	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Calcium	mg/L	75.8–82.6	53.6	60.9	47.6	61.5
Magnesium	mg/L	30.1–32.1	20.5	26.7	19.2	26.5
Sodium	mg/L	249–271	97	121	117	130
Potassium	mg/L	23.0–26.0	13.2	12.0	12.0	13.4
Bicarbonate (as ion)	mg/L	100.0–104.9	54.4	61.5	57.0	57.7
Carbonate (as ion)	mg/L	0.0–4.8	0.0	0.0	0.0	0.0
Sulfate	mg/L	238–272	256	235	193	218
Phosphate	mg/L	0.9–2.2	0.8	2.0	0.9	1.3
Chloride	mg/L	362–411	161	145	145	203
Silica	mg/L	8.3–11.9	3.4	3.7	4.2	4.9
Nitrate	mg/L	3.3–4.6	0.0	0.0	0.0	1.2
Sum of Ions	mg/L	1,100–1,206	660	689	597	719
Percent Reduction of TDS			45%	41%	46%	38%

Because the feed stream quality varies slightly from day to day, it is not possible to look solely at the blended-product concentration of any one component. However, the overall percent reduction does provide some insight. The Hydranautics Nano-BW exhibited the highest percent reduction in overall TDS, with the KMS SR200 exhibiting the lowest percentage. However, a desirable characteristic is the ability to retain hardness ions such as calcium and magnesium. In this instance, the KMS SR200 had the lowest removal of calcium, meaning that a higher fraction is retained for blending in the finished water product. All membranes show good retention of sulfate and phosphate, two anions responsible for high fouling potential. The best membrane per this criterion is very dependent on the overall process objectives.

Percentage of Sodium Chloride in Second-Pass RO Concentrate

Using the AWC Proton™ model, the relative purity of RO concentrate for each membrane was evaluated. Concentrations of the major ions are plotted as a percent of the TDS of the concentrate. The goal of the process is to remove sodium chloride from the water. Therefore, the concentrate with the highest percentage of sodium chloride and lowest percentage of multivalent ions is the most desirable. This should result in a concentrate that is the least expensive to further process to zero liquid discharge (ZLD) or near ZLD conditions and provides the greatest opportunity to recover sodium chloride for beneficial use. Table 3-5 and Figure 3-2 below depict the results of the analysis.

Table 3-5. Summary of Second-Pass RO Concentrate Quality

Parameter	Unit	Dow NF 270	CSM NE	HYDN Nano BW	KMS SR200
Calcium	mg/L	183.0	138.9	146.4	60.1
Magnesium	mg/L	58.7	25.3	53.1	10.4
Sodium	mg/L	1,057.6	1,039.6	896.4	917.2
Potassium	mg/L	91.6	95.8	81.2	72.2
Bicarbonate (as ion)	mg/L	315.1	267.6	280.3	238.9
Carbonate (as ion)	mg/L	3.9	5.0	3.1	4.3
Sulfate	mg/L	24.8	24.8	24.8	24.8
Chloride	mg/L	1,833	1,689	1,530	1,441
Silica	mg/L	37.6	42.4	46.8	49.7
Nitrate	mg/L	5.4	4.9	4.0	3.8
TDS, sum of ions	mg/L	3,648	3,346	3,069	2,833
Sodium and Chloride as Percent of TDS		79.2%	81.5%	79.1%	83.2%

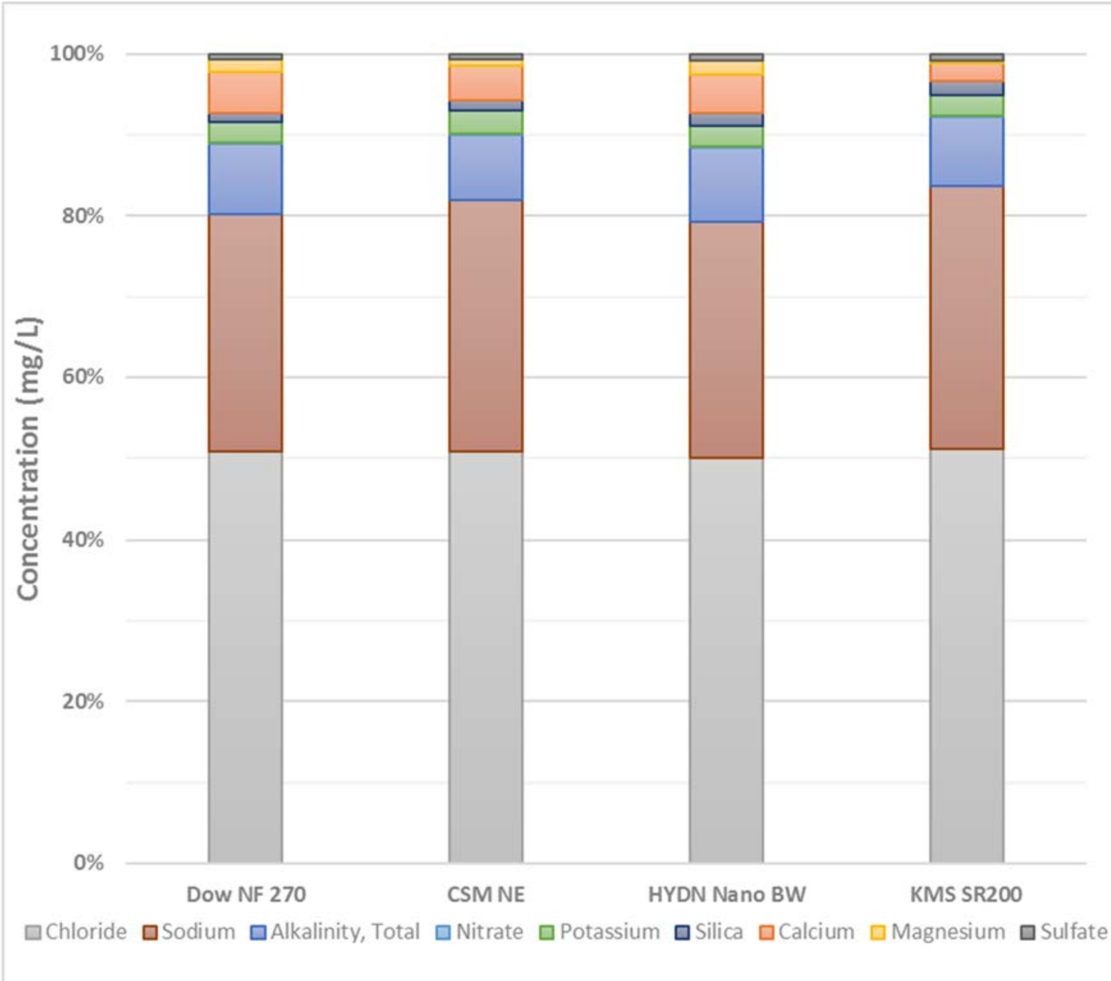

Figure 3-2. Predicted Second-Pass RO Concentrate Quality Based on NF Membrane Permeate.

As noted in Table 3-5, there is variability in the TDS concentration and makeup among the membranes. The quality of the concentrate predicted for the second-pass RO using the KMS SR200 membrane in the first pass has the highest fraction of sodium chloride and the lowest-percentage concentrations of calcium and magnesium, thus reducing its potential for calcium-carbonate scaling. With the reduced potential for calcium-carbonate scaling, silica-scaling potential limits the recovery. This is the opposite of the other three membranes, for which calcium-carbonate scale potential was limiting.

Because of the high percentage of sodium chloride and low percentage of calcium and magnesium, the KMS membrane was preferred.

Predicted Maximum Recovery

The maximum theoretical recovery of the second-pass RO was predicted using the AWC Proton™ software; projections from the software are included in Appendix B. Proton™ offers a feature that maximizes recovery for a given water quality and system design. In the case of this analysis, the pH was not adjusted and hydraulic limitations such as low permeate production, low concentrate flow per vessel, and high beta values were ignored. The limitations on recovery were determined primarily by calcium carbonate ($CaCO_3$) and silica saturation limits. These maximum recovery estimates are given in Table 3-1 above.

All membranes exhibited the potential for extremely high recoveries of the second-pass RO. Because the KMS SR200 rejected a higher fraction of calcium and carbonate alkalinity species than the other membranes, this membrane exhibited the highest recovery potential (by a very small margin).

3.1.2 Nanofiltration Membrane Selection Recommendation

All four membranes rejected sulfate and phosphate to a very high degree. This is significant because these anions are associated with several scale-forming compounds that reduce the efficiency of high-recovery or ZLD processes. But each membrane has limitations. The Dow, CSM, and Hydranautics membrane allow a significant fraction of hardness and carbonate alkalinity to pass to the RO. This will result in $CaCO_3$ being the limiting factor for the second-pass RO recovery. All four membranes allow a high percentage of silica to pass, which also ultimately would limit the recovery of the second-pass RO. The KMS SR200 membrane, while removing the lowest overall TDS, would provide the highest-quality brine in terms of low percentages of hardness and carbonate alkalinity and, therefore, the highest recovery potential.

In practical applications, other factors would weigh into membrane selection. A track record of successful municipal applications is a common requirement for selection on full-scale projects. The Dow NF270 membrane has perhaps the longest track record and is widely known. At the other end of the spectrum is the KMS SR200 membrane, which was originally developed for use in the food and beverage industry and would rank lower based on municipal experience. In the case of the City of Scottsdale, the water delivered to golf courses must have a sodium content less than 125 mg/L. If this selection process were to include this specification, the KMS SR200 membrane would not have met the requirement.

The purpose of this project was research to find more cost-effective solutions for salinity control and concentrate management and, therefore, our selection criteria did not need to rely solely on commercial experience or the irrigation water quality requirements. For this reason, the KMS SR200 was selected for Part 2 of the full-scale pilot study.

3.2 Pilot Operation

The next phase of the pilot study involved operation of the two-pass NF-RO system with the purpose of monitoring performance and gathering data for comparison with the full-scale RO units operating at the Scottsdale Water Campus. Two operating modes, Phase A and Phase B, were conducted. The purpose of Phase A was to operate the NF-RO system at a similar recovery to the full-scale RO units (85 percent). The expectation was that the NF-RO system would operate with nearly the same unit energy requirement as the full-scale RO unit and require less chemical dosing to manage scaling. Phase B was to operate the NF-RO system at a higher recovery than the full-scale RO unit such that the reject flow percentage would be one-half that of the full-scale RO unit.

The data recorded were evaluated to determine normalized specific flux and normalized permeate conductivity for both the NF and RO passes for each phase. Normalized specific flux and permeate conductivity allow for tracking of membrane performance, fouling, and timing of membrane cleaning cycles. Field and laboratory analyses were prepared at each of six process sample locations to determine the treatment performance of the process and provide data for determining the mass balances and fate of certain chemicals.

3.2.1 Phase A Results and Discussion

This section presents results from Phase A of the pilot test. The results include membrane performance parameters (normalized specific flux and normalized permeate conductivity) and water quality data.

Phase A Normalized NF Specific Flux and Normalized Permeate Conductivity

Figure 3-3 depicts the specific flux for the NF pass. With the lower antiscalant dose in the first month, specific flux declined steadily. After the dose was increased to the target dose, specific flux appeared to stabilize somewhat but, by this time, the specific flux had declined more than 20 percent from the start of operations and it was decided that a chemical clean was necessary. Normalized permeate conductivity (see Figure 3-4 below) also showed an increase during this period, likely indicative of inorganic fouling due to the low antiscalant dose. The normalized permeate conductivity trend after adjustment of the scale inhibitor dose is difficult to follow and it is difficult to determine whether permeate conductivity held relatively steady or continued to increase. The unit was offline for three days while programming issues were resolved, and a low-pH CIP was conducted on Day 55. After the CIP, the specific flux ran at 0.20 gallon per square foot per day (gfd) per 1 psi until the end of Phase A testing on December 27, 2017.

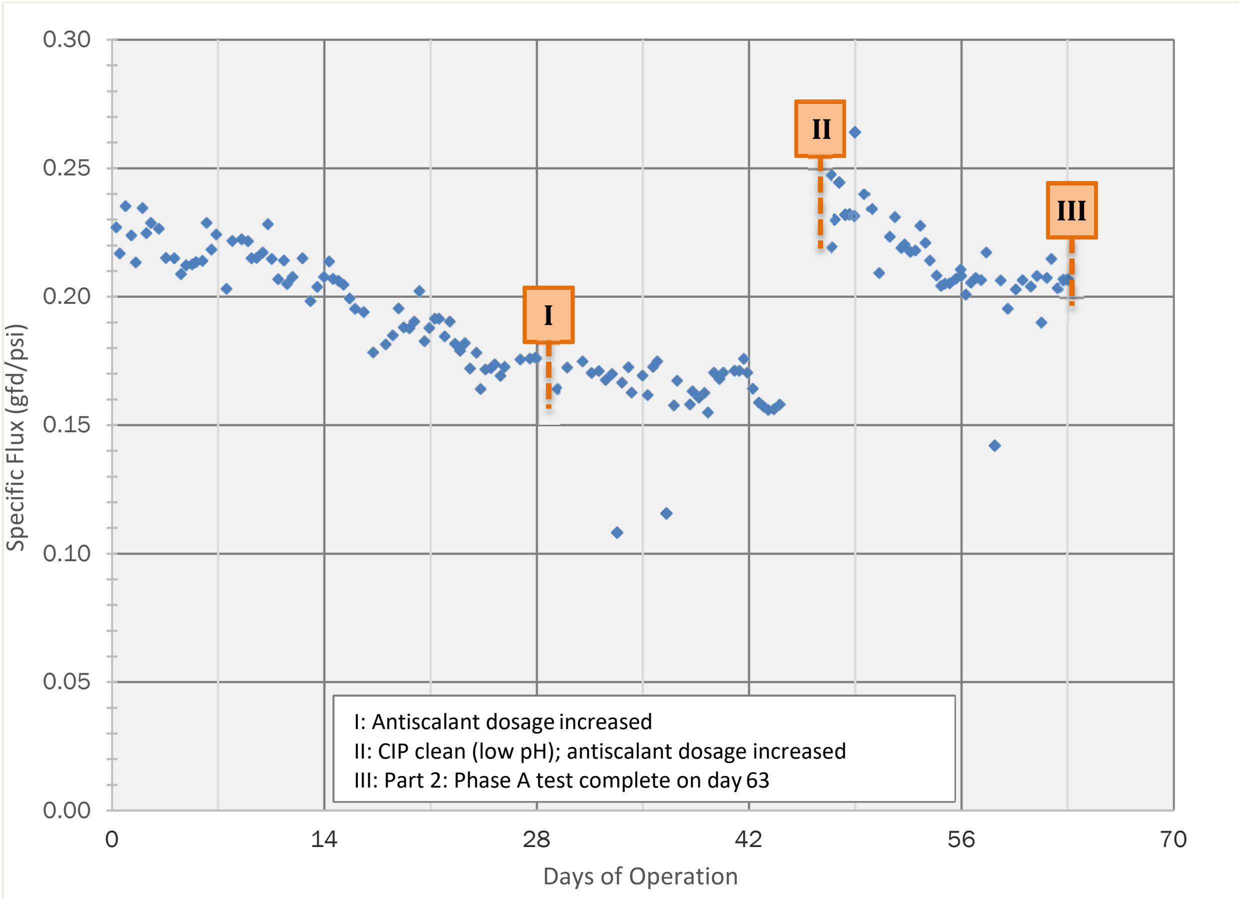

Figure 3-3. Phase A NF Normalized Specific Flux.

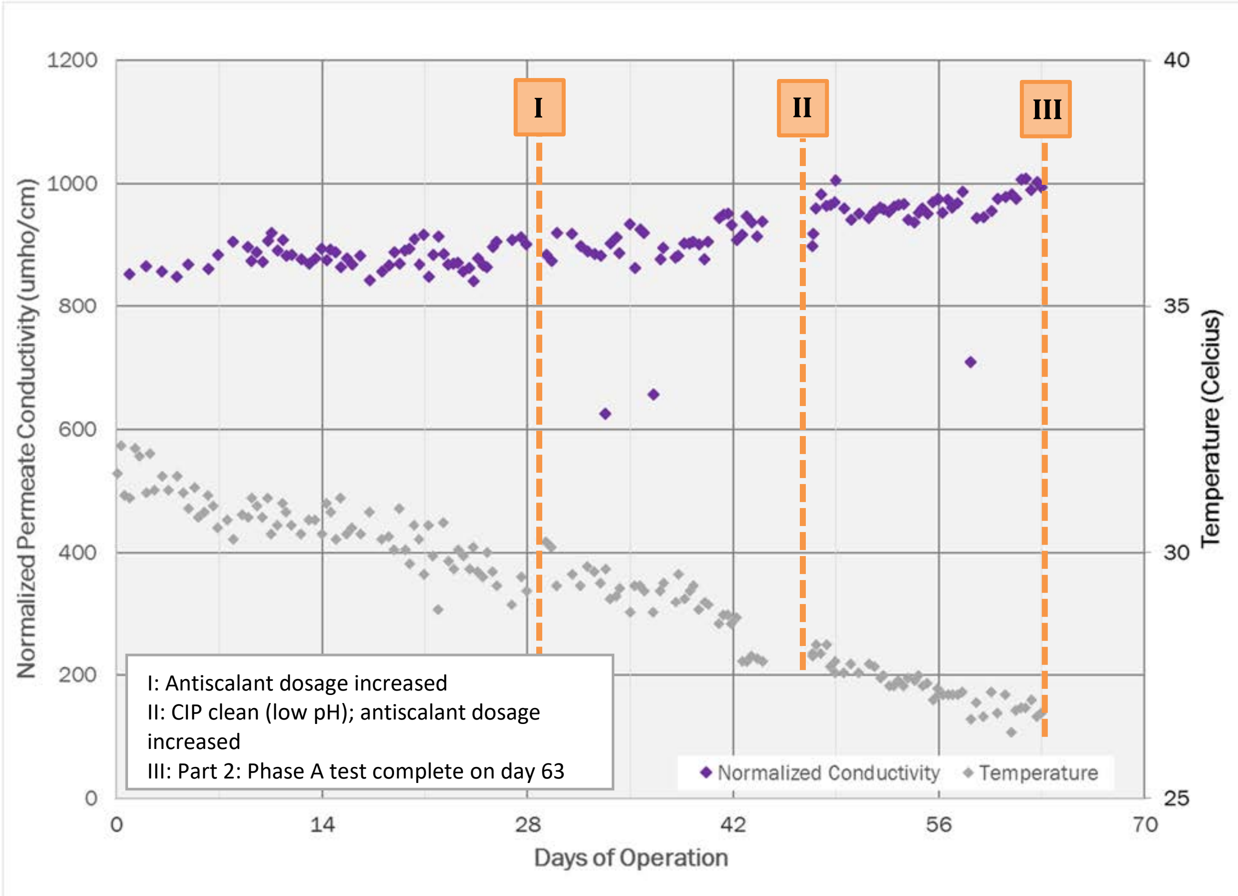

Figure 3-4. Phase A NF Normalized Permeate Conductivity.

Phase A Normalized RO Specific Flux and Normalized Permeate Conductivity

Figure 3-5 below depicts the specific flux for the RO pass. The RO operation was stable and ran without difficulty throughout the test. Permeate conductivity (see Figure 3-6 below) readings were erratic early in the test period, but this was attributed to sampling procedures and higher error of readings at low conductivity levels.

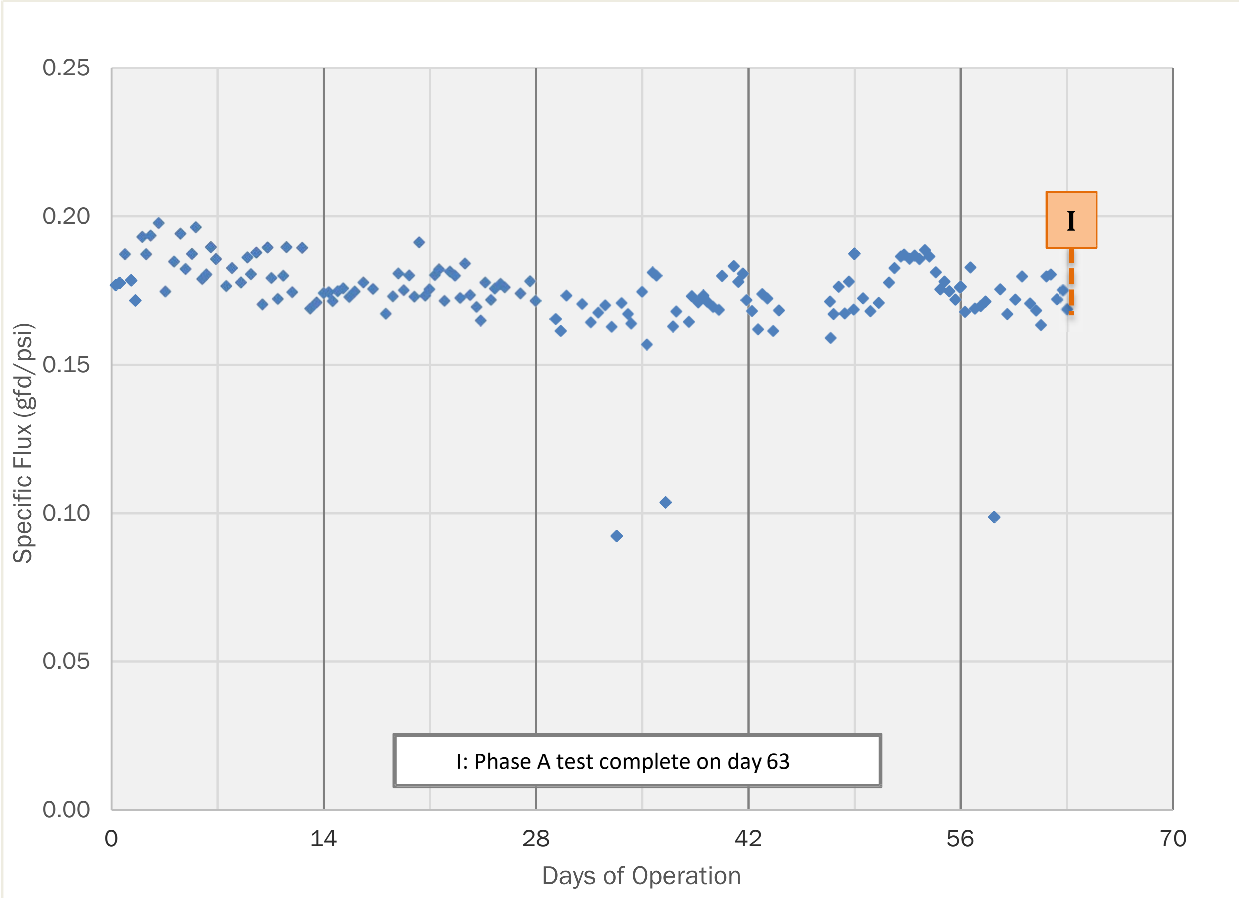

Figure 3-5. Phase A RO Normalized Specific Flux.

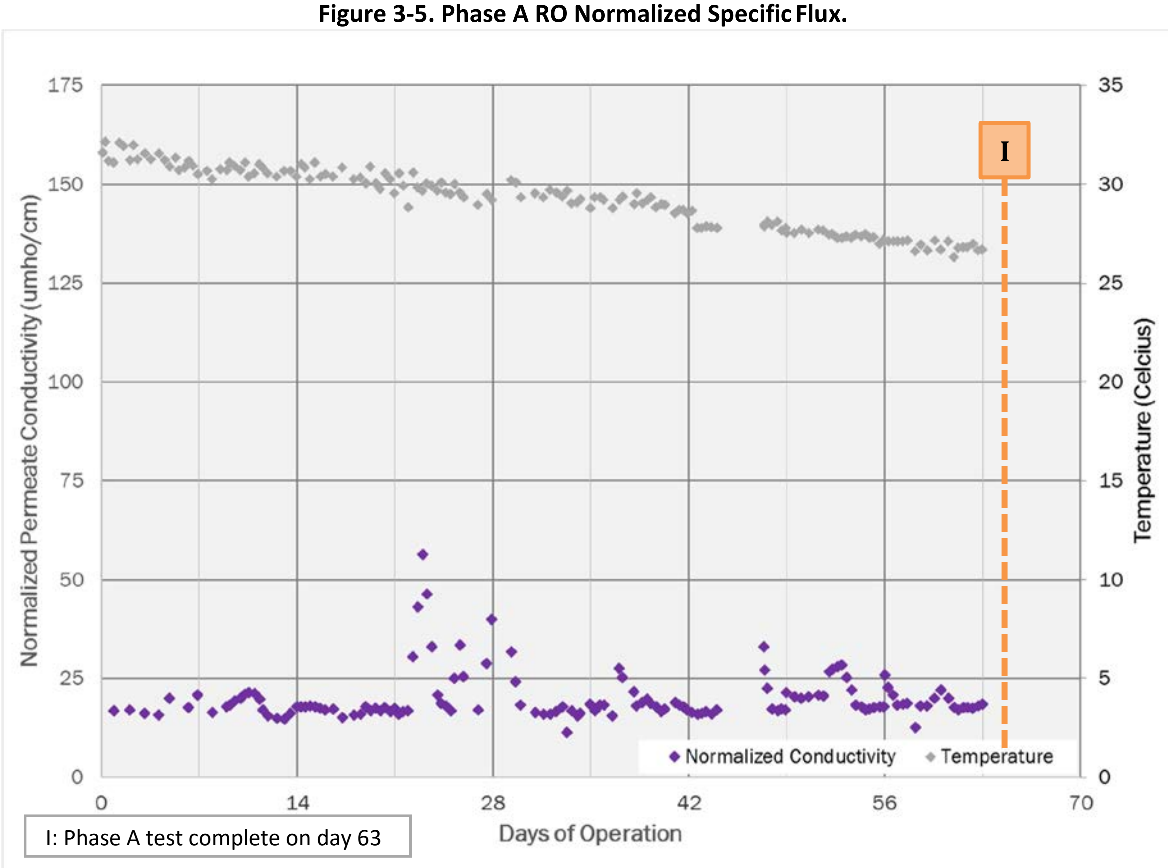

Figure 3-6. Phase A RO Normalized Permeate Conductivity.

Phase A Water Quality

Six dissolved ion species make up approximately 90 percent of the TDS in the reclaimed water. Figure 3-7 below shows the distribution of these six ion species across six sample locations in the process.

Conservation of calcium, sulfate, and alkalinity was good, with the blended-product concentrations remaining close to the feed concentrations. Sodium and chloride in the RO concentrate were very high relative to other species. The average NF feed TDS during Phase A was 1,163 mg/L, and the average blended-product TDS was 950 mg/L, for an overall 20 percent reduction in TDS. With a higher RO recovery, more low-TDS water would be available for the blended-product and overall TDS reduction would be greater. Alternately, a different NF membrane with lower rejection would reduce overall TDS in the blended-product water. The average RO concentrate TDS was 2,635 mg/L, of which 2,165 mg/L were sodium and chloride. Table 3-6 and Appendix D provide summaries of water quality for Phase A.

Table 3-6. Phase A Water Quality

Parameter	Unit	Tertiary	NF Concentrate	NF Permeate (RO Feed)	RO Concentrate	RO Permeate	Blend
Alkalinity, bicarbonate	mg/L	153	369	45	204	BDL	159
Calcium	mg/L	80	223	12	59	BDL	84
Chloride	mg/L	375	475	268	1,350	BDL	227
Magnesium	mg/L	28	80	2	10	BDL	32
Nitrate	mg/L	5	4	5	19	BDL	2
Potassium	mg/L	25	44	16	76	BDL	16
Silica	mg/L	12	16	10	48	BDL	6
Sodium	mg/L	251	476	158	814	4	160
Sulfate	mg/L	239	577	4	50	BDL	275
TDS	mg/L	1,163	2,601	543	2,683	BDL	932

Figures 3-7 and 3-8 below depict the relative quality of the tertiary treated wastewater (NF feed) and RO concentrate. The sodium chloride content of the tertiary effluent (NF feed) is approximately 53 percent of the TDS. Sulfate also makes up a large fraction of the overall TDS. The RO concentrate has 82 percent sodium chloride and very low sulfate. Monovalent ions make up more than 90 percent of the RO concentrate compared to approximately 70 percent in the NF feed. This demonstrates the ability of the process to separate monovalent and multivalent salts. These results are comparable to the NF membrane selection test for the KMS membrane, which yielded 83 percent sodium chloride and nearly 95 percent monovalent ions in the RO concentrate. This lessens concerns about the impact of the antiscalant on the KMS membrane during the NF membrane selection test.

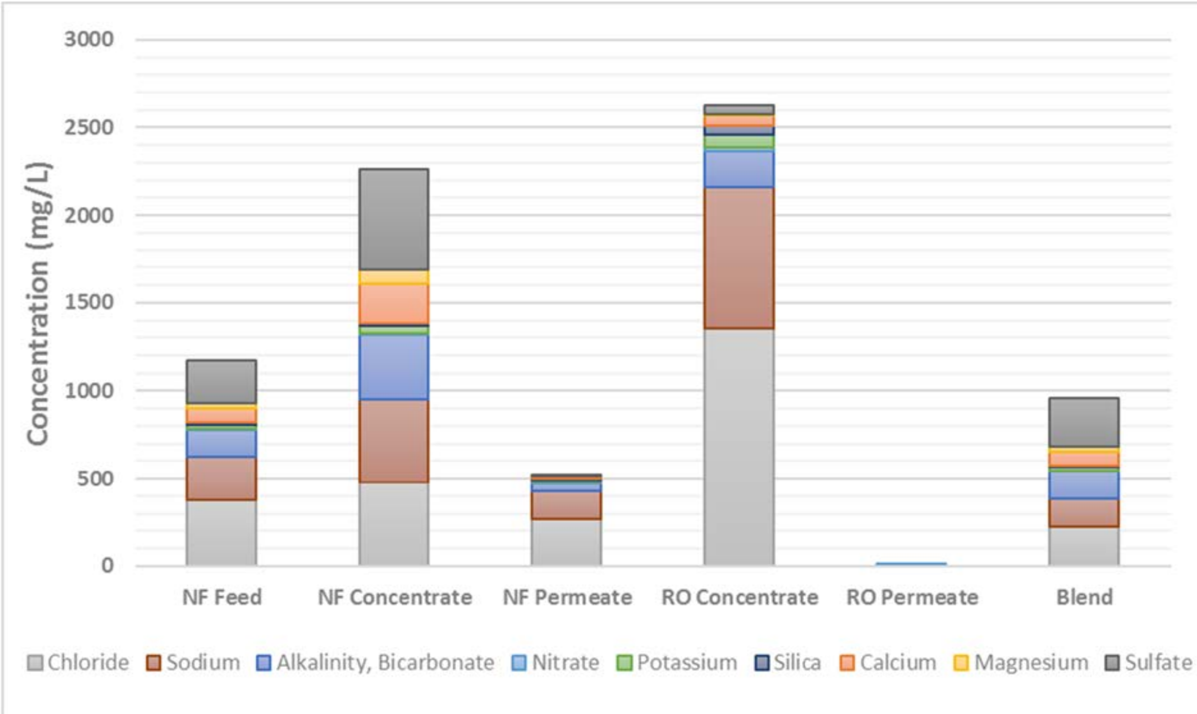

Figure 3-7. Phase A Major Dissolved Ion Concentrations.

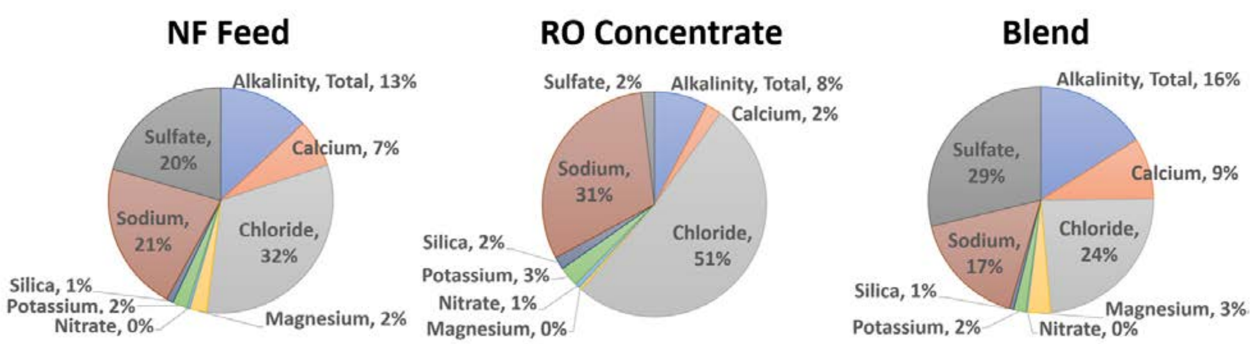

Figure 3-8. Phase A Water Quality Composition Percentages.

3.2.2 Phase B Results and Discussion

This section presents results from Phase B of the pilot test. The results include membrane performance parameters (normalized specific flux and normalized permeate conductivity) and water quality data.

Phase B Normalized NF Specific Flux and Normalized Permeate Conductivity

Figure 3-9 shows the specific flux of the NF system for the Phase B test. Specific flux started at approximately 0.20 gfd/psi and began to quickly decline. There was some indication from the pressure drop across the first bank of vessels and the permeate quality that this might be particulate or organic fouling. Permeate quality remained consistent through this period. A high-pH detergent clean was performed on Day 27 and, during the cleaning exercise, the cartridge filter was changed. The old cartridge filter appeared to be heavily fouled, furthering our suspicion that particulate fouling was occurring. The new cartridge filter had a 1-micron rating versus the original 5-micron rating in an attempt to reduce particulate fouling.

Specific flux rebounded to well above the initial specific flux (a high-pH detergent clean had not been performed previously and perhaps should have been). The specific flux after the first clean started at approximately 0.28 gfd/psi and gradually declined to approximately 0.24 gfd/psi before a full CIP (high pH and low pH) was done on Day 77. For the remainder of the test, the specific flux stayed within 0.25 to 0.29 gfd/psi until the end of the test on Day 107.

Figure 3-10 depicts the normalized permeate conductivity for the Phase B NF operation. Normalized permeate conductivity remained very stable throughout Phase B testing. There was a slight increase after the CIP on Day 77, and a declining trend in the two weeks of operation. This decline seemed to occur as the water temperature began to increase. It is possible that some scaling began to occur as the temperature increased.

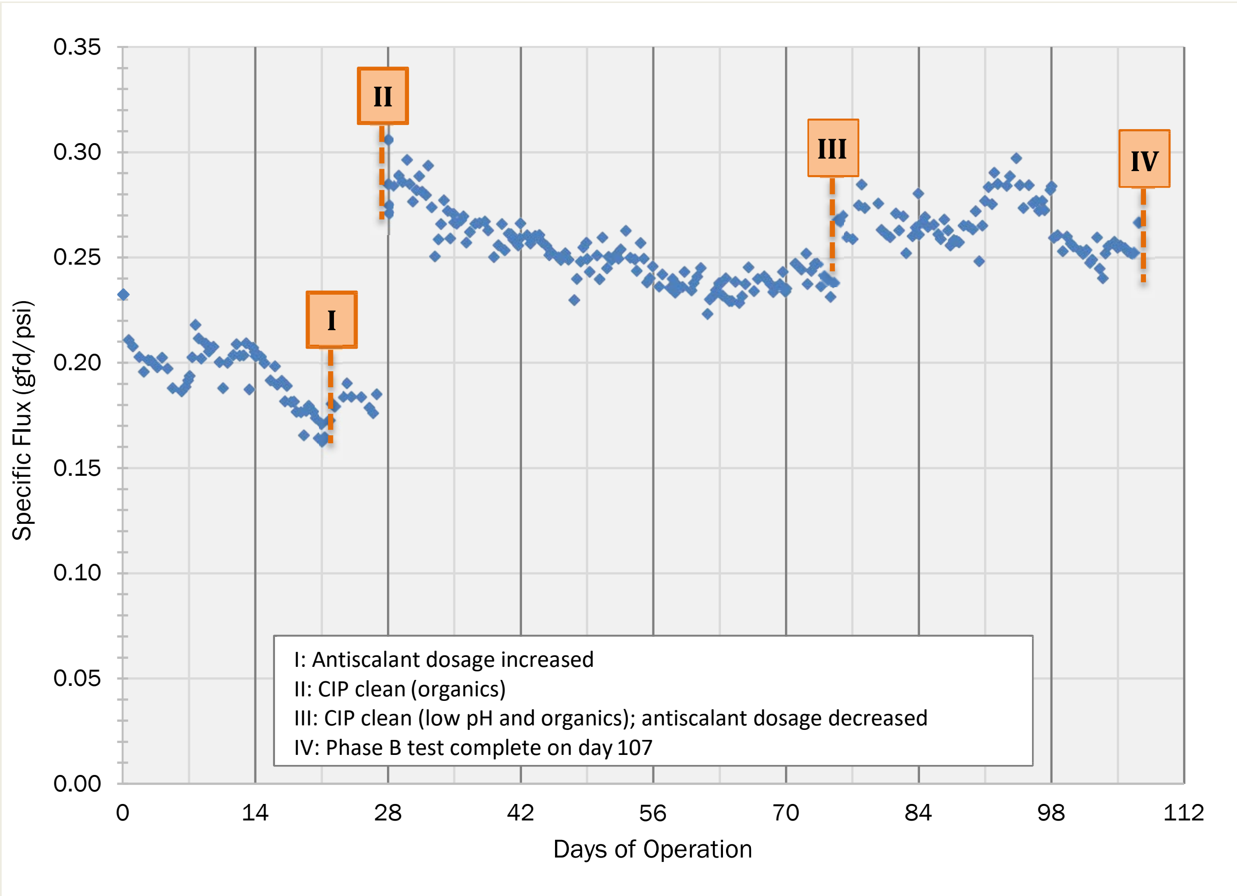

Figure 3-9. Phase B NF Normalized Specific Flux.

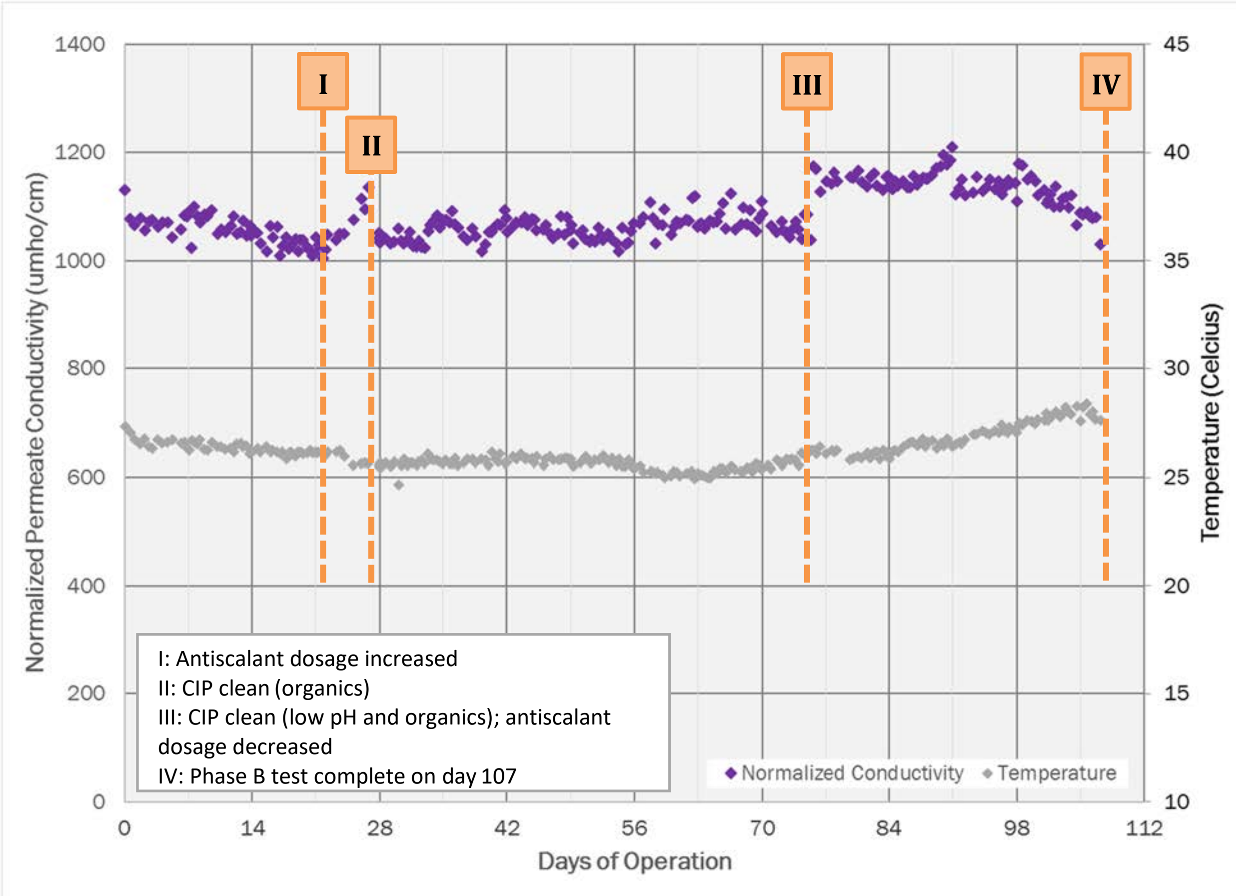

Figure 3-10. Phase B NF Normalized Permeate Conductivity.

Phase B Normalized RO Specific Flux and Normalized Permeate Conductivity

Figure 3-11 below depicts the specific flux for the RO unit during Phase B, when performance remained stable with only a slight decline. CIP was performed on Day 77 and moderate flux recovery was observed. RO specific flux ranged from approximately 0.14 to 0.17 gfd/psi throughout the entire duration of the Phase B testing. It should also be noted that the RO system recovery was 90 percent and, to achieve this, the concentrate flow was reduced below recommended minimum rates for an array of this design.

Figure 3-12 below depicts normalized permeate conductivity for the Phase B RO operation. Normalized permeate conductivity remained within 25 to 50 micromhos per centimeter (cm). The conductivity was much more variable than during Phase A, when the recovery was 80 percent. However, there did seem to be an upward trend toward the end of the study. Operating the array at such a high recovery may have played a role in the normalized permeate conductivity variability and upward trend. Further discussion on this is found in Section 3.3.

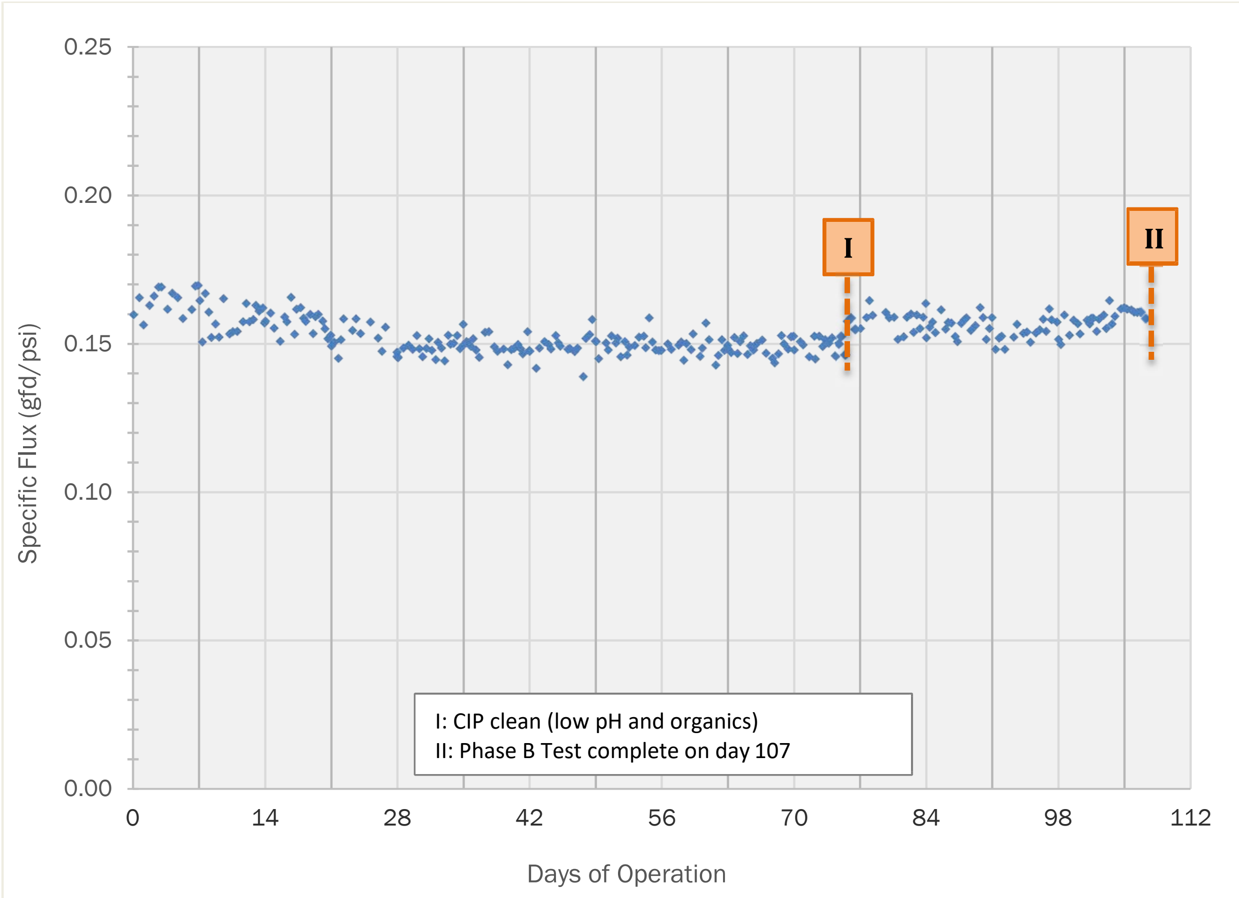

Figure 3-11. Phase B RO Normalized Specific Flux.

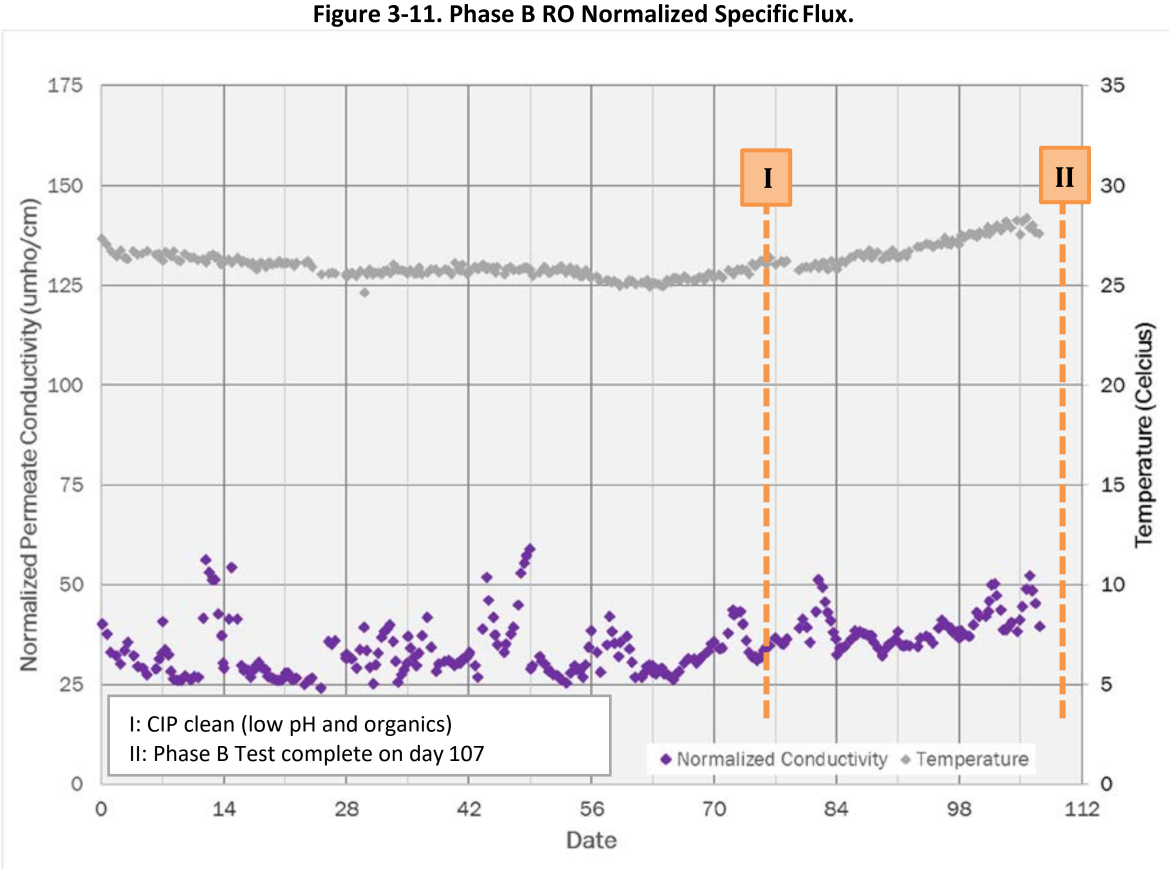

Figure 3-12. Phase B RO Normalized Permeate Conductivity.

Impacts of Phase B NF Recycle Flow Rate

Some of the variability in specific flux appeared to be due to changing concentrate recycle rates as shown on Figure 3-13. The concentrate recycle rate was set by manually adjusting the control valve and reading a rotameter. Without continuous adjustment, the concentrate recycle rate varied from 7 to 14 gpm. As the concentrate recycle increases, the feed pressure increases and as the concentrate recycle decreases, so does the feed pressure. This directly affects the net driving pressure used in calculating specific flux. As the concentrate recycle increases, the specific flux decreases and vice versa. This makes prediction of membrane performance over a short period challenging.

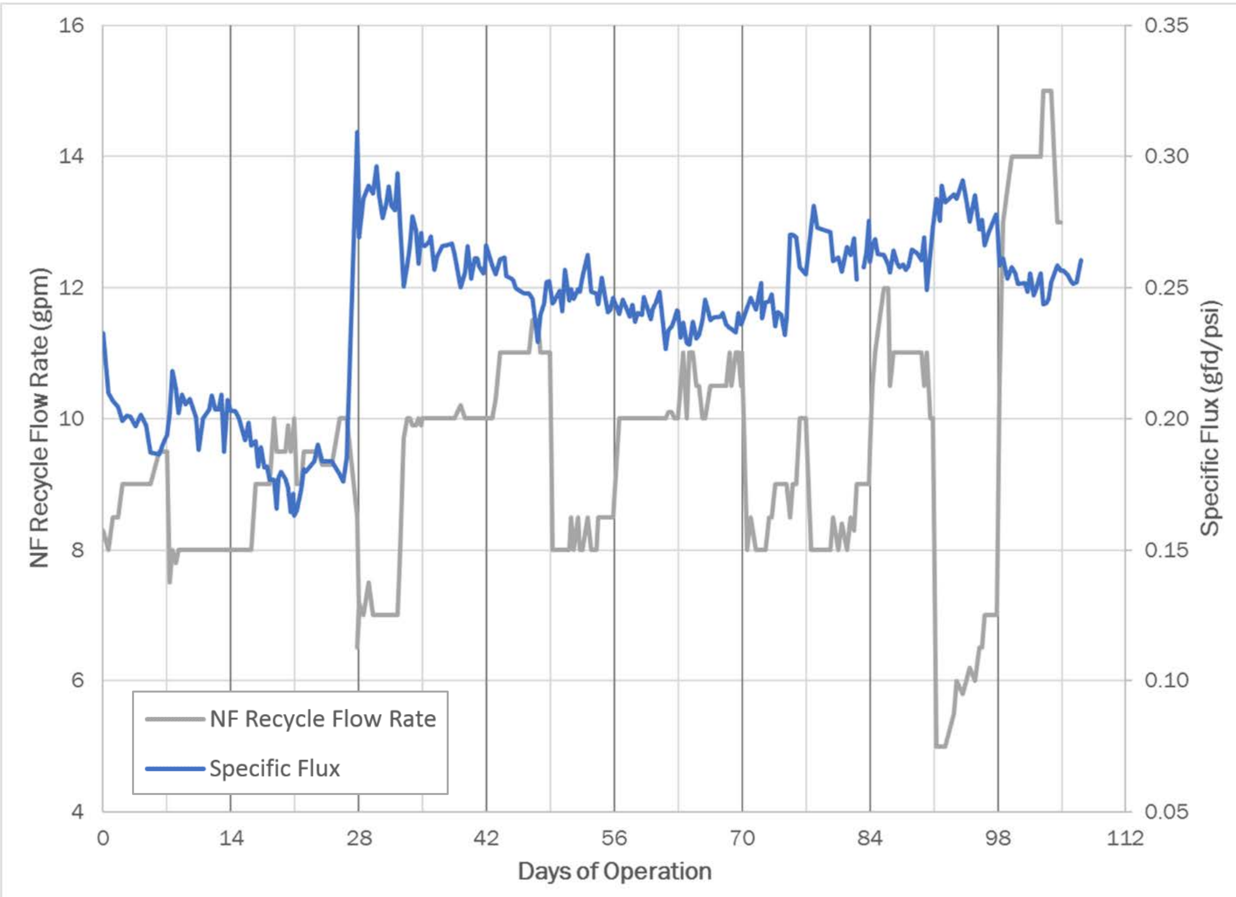

Figure 3-13. Phase B Impact of NF Recycle Flow on Specific Flux.

Phase B Water Quality

Table 3-8 and Appendix D provide a summary of water quality for Phase B. Six dissolved ion species make up approximately 97 percent of the TDS in the reclaimed water. Figure 3-14 below shows the distribution of these six ion species across six sample locations in the process. Conservation of calcium, sulfate, and alkalinity was good, with the blended-product concentrations remaining close to the feed concentrations. The concentration of sodium and chloride was very high in the RO concentrate relative to other species. The average NF feed TDS during Phase B was 1,189 mg/L, and the average blended product TDS was 806 mg/L, for a 32 percent overall reduction in TDS. As stated in the Phase A discussion, the higher RO recovery resulted in greater overall TDS reduction. Alternately, a different NF membrane with lower rejection would reduce overall TDS.

The average RO concentrate TDS was 5,900 mg/L, of which 4,519 mg/L are sodium and chloride. Table 3-7 below and Appendix D provide summaries of water quality for Phase B.

Table 3-7. Phase B Water Quality

Parameter	Unit	NF Feed	NF Concentrate	NF Permeate (RO Feed)	RO Concentrate	RO Permeate	Blend
Alkalinity, bicarbonate	mg/L	161	445	61	520	BDL	131
Calcium	mg/L	82	252	18	166	BDL	74
Chloride	mg/L	393	602	317	2,827	1	180
Magnesium	mg/L	29	94	3	26	BDL	29
Nitrate	mg/L	6	6	6	47	1	2
Potassium	mg/L	25	45	18	160	BDL	13
Silica	mg/L	10	14	9	81	BDL	4
Sodium	mg/L	261	478	190	1,692	7	138
Sulfate	mg/L	241	881	7	90	0	252
TDS by Residue	mg/L	1,189	2,856	628	5,900	19	806

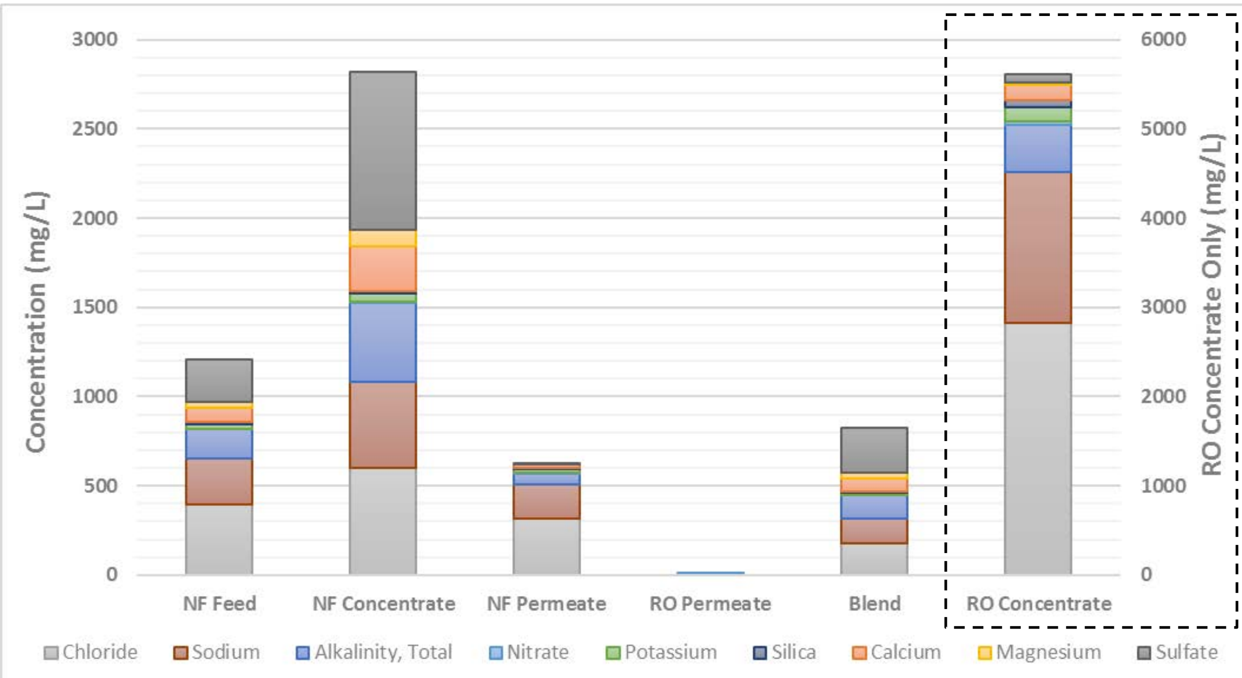

Figure 3-14. Phase B Water Quality Concentrations.

Figures 3-14 and 3-15 depict the relative quality of the tertiary treated wastewater (feed) and of the RO concentrate. The RO concentrate has approximately 72 percent sodium chloride and low sulfate. Monovalent ions make up 87 percent of the RO concentrate compared to approximately 70 percent in the feed.

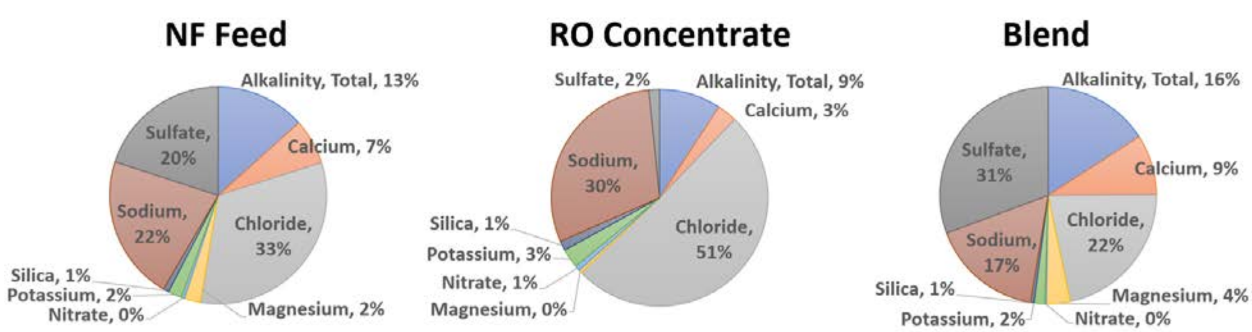

Figure 3-15. Phase B Water Quality Composition.

Given the conditioning provided by the NF pass, the scale-formation potential of the RO concentrate is very low. The laboratory analyses values were input to Alkema Proton™ to determine critical water quality indices. The LSI for the RO concentrate is estimated to be 0.66 and the CCPP is 25.75 mg/L, as $CaCO_3$. No other critical-scale indices were reported. The results indicate that further volume reduction of the RO concentrate could be readily achieved with less concern over scale-forming minerals and foulants.

3.3 Membrane Element Analysis

During the last six weeks of operation, the NF pass was operated with half of the antiscalant dose as the rest of Stage B and no changes were made to RO operations. No additional water quality samples were collected, and only operating parameters were recorded during this period.

Membrane element analyses were provided by Avista Technologies. A total of 18 membrane elements were shipped to Avista's testing facilities in San Marcos, California, on May 24, 2018, immediately following decommissioning of the pilot. A copy of the test results is included in Appendix E.

3.3.1 Membrane Element Flow Testing

Membrane elements from each pass were collected for profile testing. One membrane element from each location along the process flow was saved and the serial number was recorded such that the order of membranes could be recreated in the testing laboratory.

The NF membranes exhibited about a 20 percent decline of the manufacturer's specified flow rate before cleaning. After cleaning, the NF membranes were close to the full specified flow rate. The tests were originally set up with an earlier version of the membrane specification and as a result, the test pressure for the flow test was 80 pounds per square inch gauge (psig), while the manufacturer's current test specification was 90 psig. The rejection remained slightly above the manufacturer's specified rejection rate.

The RO membranes also exhibited about a 20 percent decline in the manufacturer's specified flow rate before cleaning, which was recovered after cleaning. Rejection values were well below manufacturer's specification on most of the elements before and after cleaning.

3.3.2 Element Autopsy

The last element from the NF pass and the last element from the RO pass were reserved for membrane autopsy to determine the nature of foulants.

Over the course of the last 6 weeks of operation, normalized specific flux of the NF membrane showed approximately 20 percent decline over this period and normalized permeate conductivity declined as well. The NF membranes were found to have some organic and calcium phosphate fouling which was readily removed by cleaning.

The RO performance remained steady through March 12, when a CIP was conducted. From March 13 through de-commissioning on May 24, there was an increase in normalized permeate conductivity and the rate increased over time. Autopsy of the membrane element found no decline in rejection, leading to the conclusion that there was some mechanical failure, likely at one or more O-rings, that led to the increased permeate conductivity. The autopsy of the RO membranes also found no signs of fouling or scale accumulation, which supported the premise that the NF pass provided excellent protection of the RO membranes by removing TOC and scale-forming minerals. This was observed despite the damage to the NF membranes.

CHAPTER 4

Discussion

For the purposes of this report, the scope of research has been completed. The NF membrane provided excellent pretreatment for the RO membrane, allowing the RO to operate at very high recovery with no adverse impacts for over four months. However, the NF membrane performance was challenging and required more frequent cleanings than desired.

Overall TDS removal in the Phase A test was less than would be useful for a full-scale operation, but the quality of RO concentrate was high, demonstrating good selective removal of monovalent ions. TDS removal in the data yielded by Phase B is very much in agreement with predicted results from testing of the NF membrane. This is significant because it suggests that overall process performance can be predicted using less expensive and less time-consuming methods. The NF membrane selection test was performed with equipment that cost less than $10,000 and required only 5 to 6 days of operation per membrane. If the process objective were greater overall removal of TDS with some sacrifice to the final RO concentrate quality and slight reduction in the system recovery, then other NF membranes might be more suitable.

Perhaps the greatest benefit of the process is its ability to achieve high recoveries without additional processing, high chemical doses, or high energy inputs. For those applications where removal of monovalent ions can achieve water quality goals and disposal of concentrate is a significant cost and concern, this process may provide a workable solution.

4.1 Water Quality

This section presents a discussion on water quality. The discussion includes comparison of the major process streams (pilot feed, RO concentrate, blended-product) to the potable water supply from where the reclaimed water was derived. Parameters analyzed include a comparison of the distribution of major dissolved minerals and salts, fate of trace organic chemicals, and irrigation water quality metrics.

4.1.1 Mass Balance of Dissolved Solids and Significant Ions

Mass flow rate will vary in response to concentrations in the NF feed process stream. Based on a simple mass balance, the mass flow rate of the NF feed must be equivalent to the outflow mass, which is the sum of the RO concentrate and the blended-product stream. Figure 4-1 below shows the NF feed stream to be approximately equal to this sum (RO concentrate and blended product) for most key ions and further validates process and laboratory data. Several ions, such as chloride and sodium, show a difference between the NF feed and summation of RO concentrate and blended-product flow rate. Mass flow rate was calculated from a single grab sample and an average daily flow rate on the day of sampling. Differences can be attributed to the daily fluctuations in both process flow and water quality.

Pilot operations for Phase B provided increased NF and total system recovery in comparison to Phase A. Increases in recoveries typically resulted in a higher fraction of sodium and chloride mass in the RO concentrate relative to the blended product for Phase B. Figure 4-1 below shows the mass flow rate of seven key water quality constituents for both phases. Excluding alkalinity and sulfate, all other ions shown on Table 4-1 and Figure 4-1 below shows exhibited an approximately 10 percent increase in the mass of the RO concentrate (comparing Phase B performance to Phase A) as a percentage of the total system outflow mass (RO concentrate plus blended-product). For example, chloride composed 54.7 percent of the system outflow mass in Phase A, and 66.6 percent of outflow mass in Phase B.

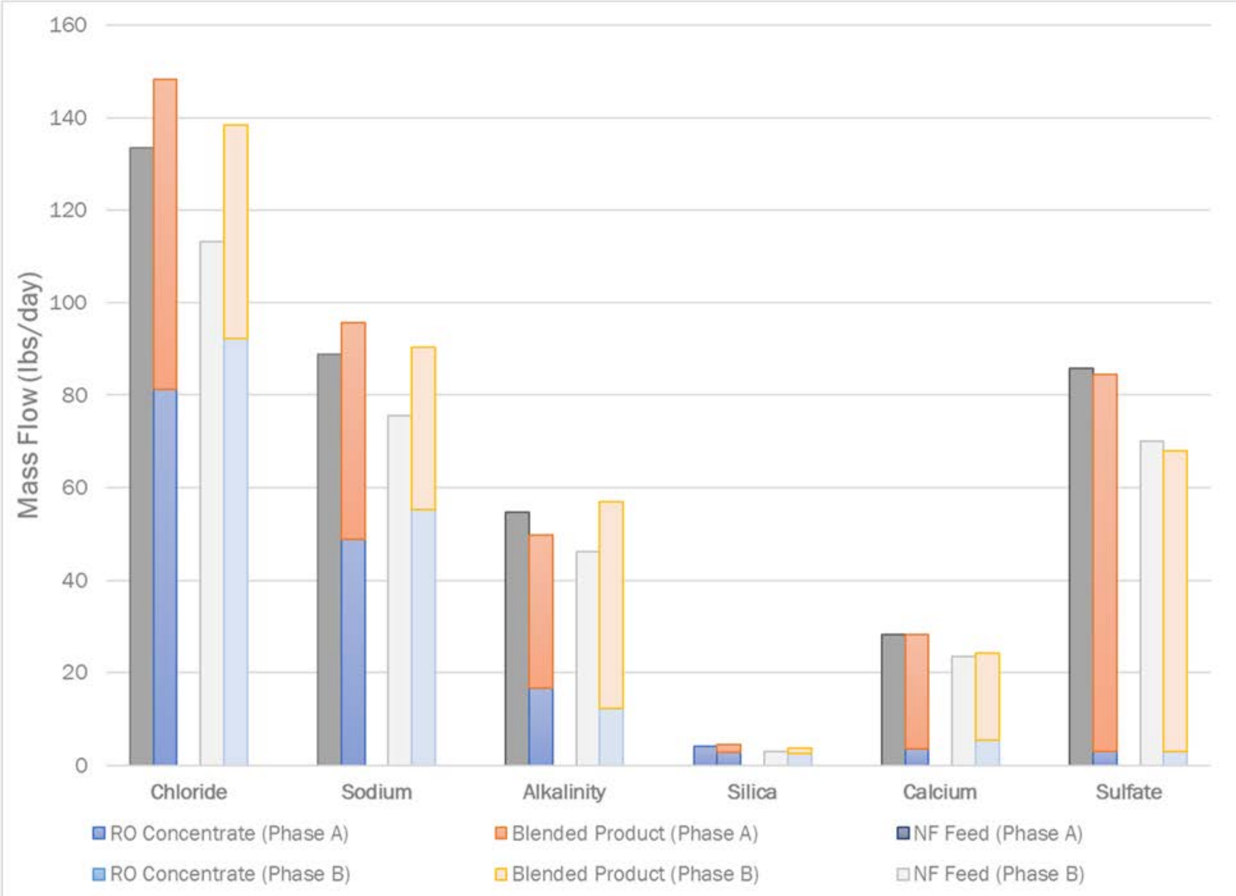

Figure 4-1. Mass Balance Check of Dissolved Ions.

Because the NF recovery of Phase B was higher than Phase A, more flow and monovalent ions passed through the NF membrane. The additional monovalent ions present in the NF permeate stream were then rejected by the RO membrane. Accordingly, the RO concentrate contained more sodium and chloride on a mass basis than Phase A. Table 4-1 summarizes the mass ratio of several key ions by comparing the mass flow rate of the RO concentrate stream to the blended product. An increase in the mass ratio between Phase A and Phase B indicates that additional amounts of the ion are being removed from the process. The lower NF flux and higher NF recovery likely contributed to greater passage of salts to the RO where they are subsequently removed from the system. It is very possible that the observed damage to the NF membrane also resulted in more TDS passing to the RO and being subsequently removed.

Table 4-1. Ratio of Mass Rate in RO Concentrate to Blended Product

Parameter	Phase A Ratio	Phase B Ratio
Chloride	1.21	1.99
Sodium	1.04	1.57
Alkalinity, total	0.50	0.28
Silica	1.67	2.46
Calcium	0.15	0.29
Sulfate	0.04	0.05

4.1.2 Product Water Comparison

The objective for final blended-product water was to significantly reduce the concentration of sodium chloride relative to the NF feed stream, while retaining other key ions. The average NF feed chloride concentration was 386 mg/L, over 4.1 times higher than Scottsdale's drinking water from the Central Arizona Project (CAP). Sodium concentrations were similarly high at 257 mg/L, exceeding the drinking water concentration by a multiple of 2.7. Table 4-2 and Figure 4-2 display average concentrations for major ions for Phases A and B compared to the NF feed and CAP drinking water.

Table 4-2. Part 2: Blended-Water Quality Comparison

Parameter	Unit	CAP Water	NF Feed	Phase A Blend	Phase B Blend
Alkalinity, total	mg/L	126	157	151	129
Calcium	mg/L	68	81	84	74.1
Chloride	mg/L	93	386	227	180
Magnesium	mg/L	26	29	32	30
Nitrate	mg/L	0.3	5.2	2.0	1.8
Potassium	mg/L	4.9	25	16	13
Silica	mg/L	11	11	5.8	4.2
Sodium	mg/L	95	257	160	138
Sulfate	mg/L	225	240	275	252
TDS, residual	mg/L	603	1,183	932	806

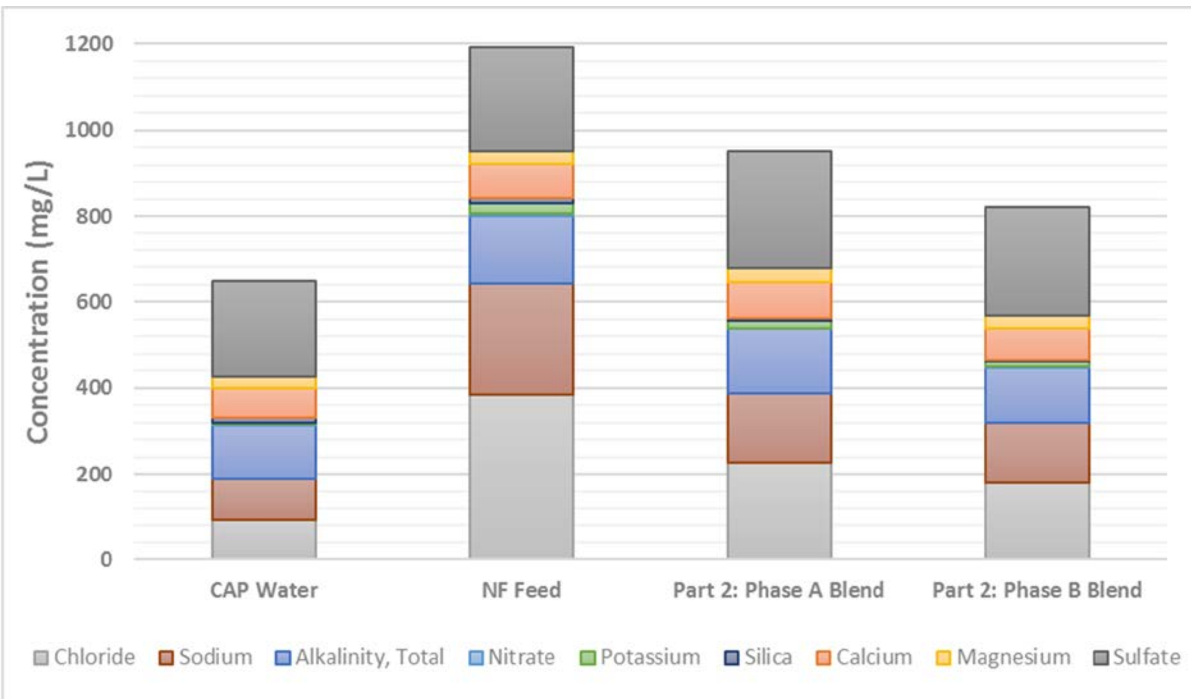

Figure 4-2. Blended-Water Quality Comparison.

Both phases within Part 2 of the pilot study were successful in reducing sodium chloride concentrations. Chloride concentrations were reduced by 41 percent and 53 percent for Phases A and B, respectively. Sodium concentrations were likewise reduced by 38 percent in Phase A and by 46 percent in Phase B. The NF feed TDS concentration was reduced by 250 mg/L (21 percent) for Phase A and 376 mg/L (32 percent) for Phase B. The majority of TDS reduction between the NF feed water and blended product is due to sodium chloride reduction.

No significant reduction in calcium, magnesium, or sulfate occurred. A minor reduction of 18 percent in alkalinity was observed for Phase B. Although TDS for both Phases A and B proves higher than CAP drinking water, TDS is substantially reduced in comparison to the NF feed, as shown in Figure 4-3 below[1]. The

[1] Figure 4-2 is the sum of all the ions that compose TDS. This value is averaged for all sampling events. Figure 4-3 is the laboratory-attained TDS value, averaged for all sampling events. There is a slight difference due to expected laboratory tolerances for the attained values and the effect of averaging the different components of TDS versus TDS as a whole.

reduction in sodium chloride assists in broadening the range of reclaimed-water applications as discussed in Sections 4.1.3 and 4.1.4.

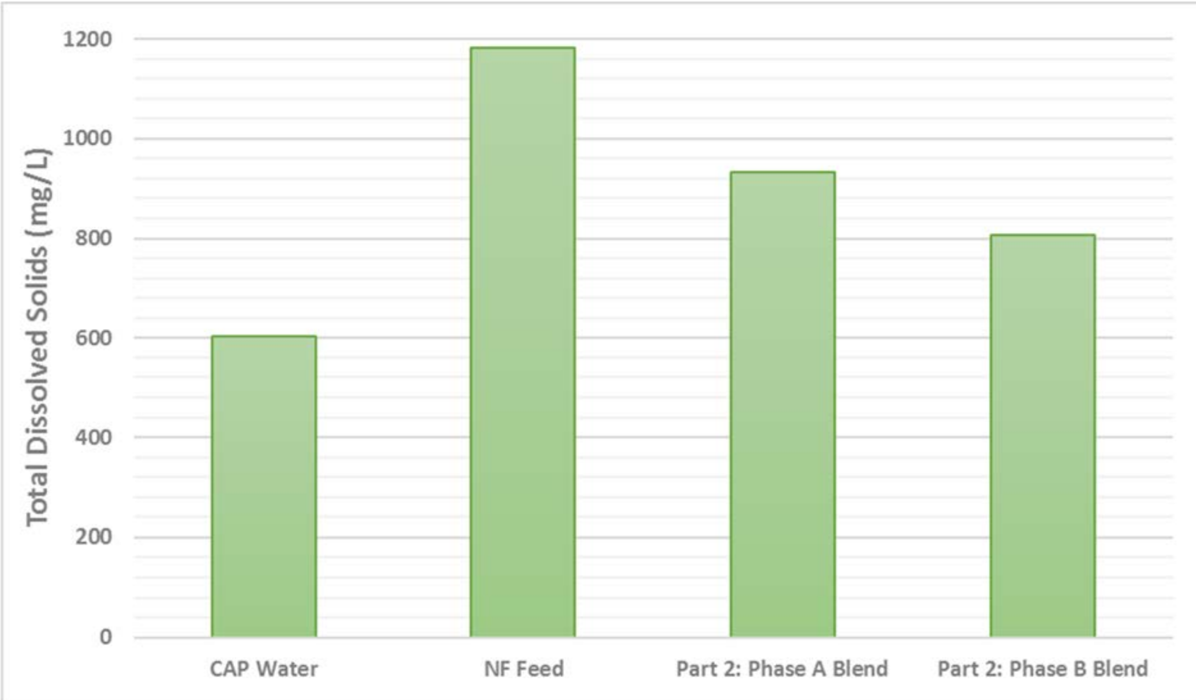

Figure 4-3. Part 2: Total Dissolved Solids Comparison.

4.1.3 Irrigation Water Quality

In general, increasing salinity of irrigation water has harmful effects on turf, crops, and other plants. Salinity can also affect the soil structure, reducing permeability of the soil. The NF-RO process improves the quality of recycled water used for irrigation purposes. The SAR is one measure used to determine the potential impact an irrigation water source may have on water infiltration rates and soil aeration. Excess sodium can result in breakdown of soil structure by dispersion of aggregates, resulting in loss of soil permeability and aeration capacity. SAR is calculated using the following equation:

$$SAR = \frac{Na}{f1/2(Ca + Mg)} \text{ where NA, CA, and Mg are expressed in me/L} \qquad \text{(Equation } 4-1\text{)}$$

A higher SAR generally is worse for soil infiltration; the effects are also related to the electrical conductivity of the irrigation water (ECw). Increasing ECw improves infiltration. Table 4-3 below (University of California Committee of Consultants, 1974) shows the range of effects of SAR for given ranges of ECw.

Table 4-3. Irrigation Water SAR and ECw Impacts on Soil Infiltration

SAR	Reduction in Infiltration at ECw (dS/m)		
	None	Slight to Moderate	Severe
0–3	>0.7	0.7–0.2	<0.2
3–6	>1.2	1.2–0.3	<0.3
6–12	>1.9	1.9–0.5	<0.5
12–20	>2.9	2.9–1.3	<1.3
20–40	>5.0	5.0–2.9	<2.9

dS/m is deci-Siemens per meter. 1 dS/m is equivalent to 1,000 micromhos/cm.

Table 4-4 summarizes the average SAR and ECw values for the City of Scottsdale's finished drinking water from the CAP Water Treatment Plant (WTP), the reclaimed water (pilot unit NF feed), blended product, and RO concentrate. These values are from data taken during Phase B of the study, from December 27, 2017, to April 13, 2018.

Table 4-4. Summary of SAR and ECw Values from Pilot Study

Water Source	Average SAR	Average ECw (dS/m)	Reduction in Infiltration
CAP WTP finished water	3.6	0.97	Slight to moderate
Reclaimed water (NF Feed)	8.9	2.1	None
Blended-product	4.9	1.3	None
RO concentrate	45.8	9.9	Out of range

Excess chloride can be detrimental to a wide variety of plants. Chloride can become toxic as it accumulates in leaves but also causes leaf burn with sprinkler irrigation. Table 4-5 lists the acceptable limits for chloride concentration for selected crops and plants.

Table 4-5. Effect of Chloride Concentrations on Select Crops

Crop	Chloride Concentration Limit to Avoid Foliar Injury, mg/L	Reference
Tomato	<175	1
Corn	175–350	1
Citrus (S. tangelo)	355	2
Avocado	117–178	2

References:

1. Mass (1990) Crop Salt Tolerance. Agricultural Salinity Assessment and Management Manual, K.K. Tanji (ed.). ASCE, New York, pp 262–304.
2. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/003/t0234e/t0234e05.htm.

Because turf grasses are generally mowed regularly, there is little opportunity for accumulation of chloride in the leaf. Some turf varieties are more salt-sensitive than others. However, toxicity can occur with chloride levels more than 355 mg/L. Table 4-6 summarizes the chloride content of the four water sources described above.

Table 4-6. Chloride Concentrations

Water Source	Average Chloride Concentration, mg/L
CAP WTP finished water	95
Reclaimed water (NF feed)	392
Blended-product	180
RO concentrate	2,820

The CAP WTP finished water is satisfactory for most uses, including the four crops listed in Table 4-5. The NF feed exceeds recommended limits for most uses, including chloride-tolerant plants and turf. The blended-product is suitable for many uses, but levels are still somewhat high for the more sensitive crops, including avocados and tomatoes. The blended-product chloride concentration is well below the 355 mg/L threshold for chloride uptake toxicity. The RO concentrate is not suitable for irrigation of most crops and plants.

Boron was present in the reclaimed water at low levels. There was no discernable rejection of boron by the NF membranes and only a modest rejection by the RO membranes. As a result, the overall removal of boron was minimal. Table 4-7 summarizes the boron concentrations for each process stream and each stage of operation.

Table 4-7. Boron Concentrations

Water Source	Average Boron Concentration, mg/L	
	Stage A	Stage B
Reclaimed water (NF feed)	0.34	0.36
NF Concentrate	0.35	0.37
NF Permeate/RO Feed	0.33	0.34
RO Permeate	0.25	0.28
Blended-product	0.29	0.31
RO concentrate	0.62	0.86

4.1.4 Langelier Saturation Index and Calcium Carbonate Precipitation Potential

The LSI is a common measure of water corrosivity or scale formation based on $CaCO_3$ saturation levels. The LSI is a function of calcium concentration, alkalinity, pH, temperature, and TDS. The LSI is the difference between the measured pH and the calculated pH at which $CaCO_3$ is in equilibrium. An LSI of 0 means the water is in equilibrium and does not have tendency toward corrosion or scale formation. An LSI value greater than 0 has a tendency toward $CaCO_3$ scale formation, and an LSI value less than 0 will tend to be corrosive. Other water-chemistry parameters such as chloride and sulfate ratios, play a role in corrosivity or scale formation, but the LSI is widely used in evaluating RO water chemistry.

In practice, the product water should have an LSI that is slightly positive, between 0.0 and 0.3. This slightly favors scale formation, which can help to maintain a protective layer on pipe surfaces. For operation of NF and RO processes where antiscalant chemicals are used, the upper limit of LSI for RO concentrate is typically 2.0, unless field testing proves a higher concentrate LSI tolerable to operations. CCPP is a measure of the amount of $CaCO_3$ that can precipitate. CCPP is often used in conjunction with LSI to determine not just whether a water has potential to precipitate, but to what magnitude. For finished water systems, a CCPP of 4 to 10 mg/L provides adequate protection against corrosion without excessive scaling of piping and plumbing fixtures. In RO and NF operation with scale inhibitors, the CCPP may be up to 1,000 mg/L.

Table 4-8 summarizes the LSI values for the City of Scottsdale's finished drinking water from the CAP WTP, the reclaimed water (pilot unit NF feed), blended product, and RO concentrate. These LSI values were calculated using the corrosion model developed by Tetra Tech (Tetra Tech (RTW) Model for Water Process & Corrosion Chemistry, AWWA).

Table 4-8. Average pH and LSI Values

Water Source	Number of Samples	Average pH	Average LSI	Average CCPP
CAP WTP Finished Water	2	7.95	0.28	4.8
Reclaimed Water (NF Feed)				
Phase A (80% RO recovery)	2	7.15	-0.25	-11.3
Phase B (90% RO recovery)	6	7.21	-0.21	-10.7
RO Permeate				
Phase A (80% RO recovery)	2	6.04	-5.59	-16.0
Phase B (90% RO recovery)	5	6.16	-5.58	-13.15
Blended Product				
Phase A (80% RO recovery)	2	7.40	0.08	2.9
Phase B (90% RO recovery)	5	7.33	-0.21	-7.3
RO Concentrate				
Phase A (80% RO recovery)	2	7.43	-0.01	-0.5
Phase B (90% RO recovery)	5	7.50	0.75	93.1

The CAP WTP finished water had an LSI that is slightly positive and is in a suitable range. The CCPP is 4.8 mg/L, which is within the recommended range for water distribution. Note that the reclaimed water (NF feed) had a slightly negative LSI and the pH was lower than the finished-water pH. This is likely due at least in part to the biological nitrification process, which consumes alkalinity. Though some of the alkalinity was recovered during biological denitrification, there was a net loss of alkalinity and a decrease in pH. There was no pH adjustment of the NF feed or in the upstream processes. The CCPP was also negative, indicating that this water is mildly corrosive.

The blended-product pH is slightly higher than the NF feed but still less than the CAP WTP finished water. For the Phase A results where the blended-product contained less RO permeate, the LSI is slightly positive; for Phase B where there was more RO permeate in the blended product, the LSI is slightly negative and equal to the NF feed water. The CCPP under Phase A (80 percent RO recovery) operating conditions was also negative. However, both values are considerably less negative than the RO permeate values. This implies that there is a suitable conservation of alkalinity and calcium hardness with the NF-RO process that greatly reduces the chemical demand for product water stabilization.

Based on the results of the model, the RO concentrate LSI for Phase A was nearly zero; for the Phase B condition it was 0.75. The CCPP for Phase A was slightly negative; for Phase B, it was 93.1 mg/L, well below the recommended limit of 1,000 mg/L. While this was a scale-forming condition, the magnitude was not as great as would be found in most RO systems.

For comparison, a projection was prepared using a three-stage RO array with the NF feed water quality profile, 85 percent recovery, and acid addition of 18 mg/L to obtain an LSI of 1.91 and a CCPP of 557 mg/L in the concentrate. The implication is that even at higher recovery, the concentrate waste stream from the NF-RO process has less potential for scale formation and, therefore, lower operating and maintenance costs for concentrate disposal.

4.1.5 Trace Organic Compound Analysis

Monthly laboratory samples measured TOrCs and TOC in each of the six process streams. A summary of maximum, minimum, and average TOrCs concentrations for both Phases A and B is provided in Appendix D. The passage of TOrCs through the hybrid NF-RO system can be generalized: the NF membrane rejects the majority of TOrCs because of their high molecular weight. The small percentage of these compounds in the NF permeate stream are almost completely rejected by the RO membranes. Accordingly, most TOrCs are transferred to either the product blend or RO concentrate streams. Table 4-9 and Figure 4-4 below give an example of five specific TOrCs; trends in passage percentage and the ratio of blend concentration to NF feed concentration are similar for each. These TOrCs are unregulated compounds and as such do not present a regulatory compliance issue at the current time.

Table 4-9. Part 2: Trace Organic Compounds

Trace Organic Compound	Unit	NF Feed	NF Concentrate	NF Permeate (RO Feed)	RO Concentrate	RO Permeate	Blend
Carbamazepine	ng/L	114.9	351.3	14.0	115.1	2.1	107.4
DEET	ng/L	150.7	434.8	28.4	189.8	11.7	152.0
Diuron	ng/L	20.2	35.6	19.0	126.5	1.4	6.7
Naproxen	ng/L	162.7	486.2	6.9	53.6	0.7	165.3
Oxybenzone	ng/L	29.7	191.7	22.0	164.1	12.2	28.7

ng/L = nanograms per liter

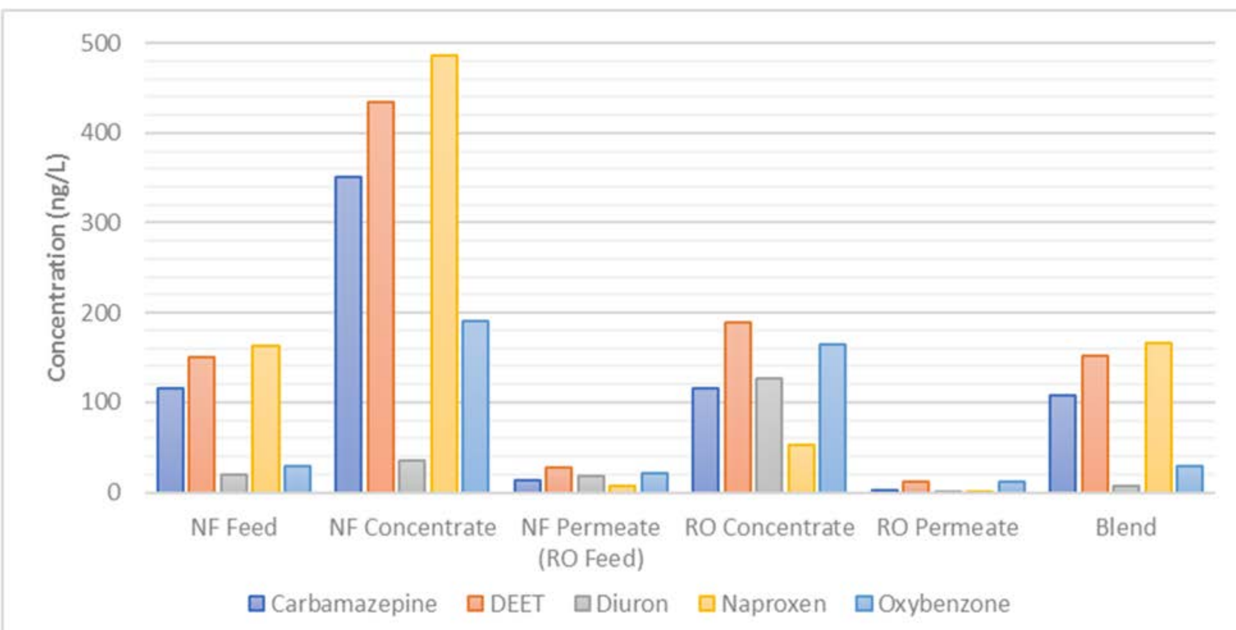

Figure 4-4. Part 2: Trace Organic Compounds.

The passage of TOC behaves in a manner like the TOrCs; the NF stage rejects most of the TOC as shown in Table 4-10 and Figure 4-5. TOC is largely bypassed to the final blend product, with a small percentage by mass ending up in the RO concentrate process stream. The quantity of TOC from antiscalant addition was determined to be negligible; laboratory analyses determined that the TOC content of the antiscalant was 2.1 percent by weight. The rejection of TOC has important implications for reclaimed use applications. TOC may need to be removed depending on the end use of the reclaimed water.

Table 4-10. Part 2: Total Organic Carbon

Sampling Phase	Unit	NF Feed	NF Concentrate	NF Permeate (RO Feed)	RO Concentrate	RO Permeate	Blend
Part 2: Phase A	mg/L	2.46	5.49	0.26	0.95	ND	3.43
Part 2: Phase B	mg/L	3.60	12.29	0.27	2.45	0.11	5.84

ND = Not detected

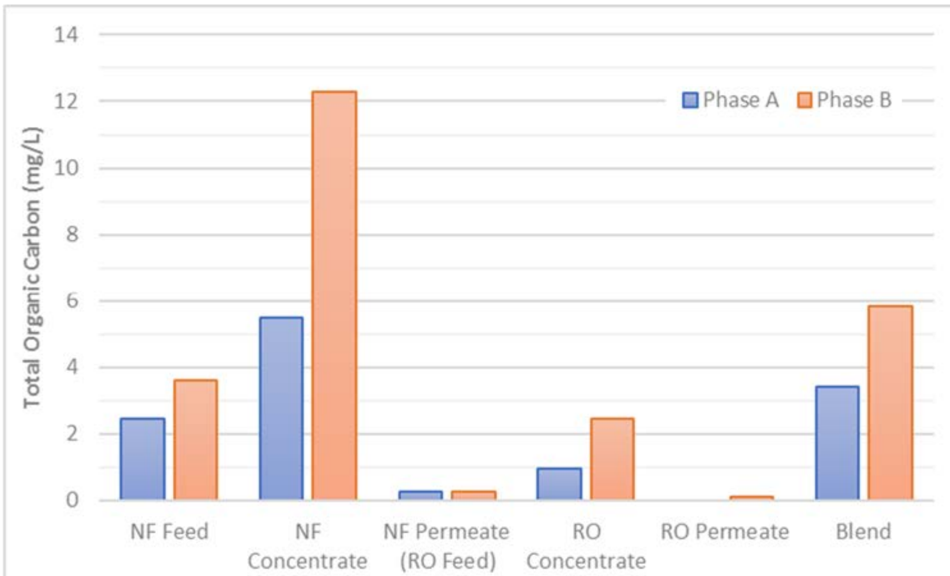

Figure 4-5. Part 2: Total Organic Carbon.

4.2 Cost Comparison of NF-RO to Conventional RO

A cost analysis was prepared to compare the NF-RO process to a conventional RO process similar to that currently in use at the City of Scottsdale. The cost analysis was prepared based on treating 700-gpm, or approximately 1 million gallons per day (mgd) and includes the cost of one unit or skid.

4.2.1 Capital Costs

Capital costs were prepared based on budgetary quotes prepared by Wigen Technologies, with escalation for installation, engineering, bonds, insurance, and taxes. Costs reflect only the individual membrane unit and not common piping, chemical feed systems, cartridge filters, or CIP systems. Also not included in the pricing are structural, architectural, electrical power distribution, and supervisory control and data acquisition.

The basis for estimating the cost of the NF-RO unit is summarized in Table 4-11 below.

Table 4-11. NF-RO Equipment Design Summary

Item	Unit	Value
Feed Capacity	gpm	700
Pass 1		
Configuration		Single-stage with concentrate recycle
Pressure Vessels	ea	23
Elements per Pressure Vessel	ea	7
Membrane Elements		Dow NF 270
Pass Recovery		70%–75%
Concentrate Recycle	gpm	175–215
High-pressure Pump Capacity	gpm	915
Pass 2		
Configuration		Two-stage
Pressure vessels	ea	9:5
Item	**Unit**	**Value**
Elements per Pressure Vessel	ea	7
Membrane Elements		Hydranautics ESPA2-LD-Max
Pass Recovery		87%–90%
High-pressure Pump Capacity	gpm	490–525

The basis for estimating the cost of the conventional RO unit is summarized in Table 4-12.

Table 4-12. RO Equipment Design Summary

Item	Unit	Value
Feed Capacity	gpm	700
Configuration		Two-stage
Pressure Vessels	ea	18:8
Elements Per Pressure Vessel	ea	7
Membrane Elements		Hydranautics ESPA2-LD-Max
Pass Recovery		85%
High-Pressure Pump Capacity	gpm	700

The capital costs for each system are summarized in Table 4-13. Capital costs are indexed to an *Engineering News-Record* construction cost index of 10972.

Table 4-13. Membrane System Capital Cost Comparison

Item	Factor	RO	NF-RO
Equipment Price		$656,000	$982,000
Installation and Startup		$38,000	$46,000
Contractor Markups	15%	$104,000	$154,000
General Conditions	15%	$104,000	$154,000
Bonds, Insurance	3.5%	$32,000	$47,000
Total Construction Cost		$934,000	$1,383,000
Engineering	8%	$75,000	$111,000
Construction Administration	8%	$75,000	$111,000
Contingency	10%	$93,000	$138,000
Total Capital Budget		$1,177,000	$1,743,000

The NF-RO skid requires more membrane per unit of flow treated than the conventional RO, and consequently has a higher capital cost. However, as is demonstrated in subsequent sections, the benefits of reduced concentrate volume and improved concentrate treatability greatly outweigh the additional capital cost.

4.2.2 Operating Costs

Operating costs for each design were developed for comparison. Operating costs include electrical power, chemical costs, equipment maintenance, and membrane element replacement. It is assumed that labor costs would be essentially equal for both systems, so staffing is not included in the analysis.

Power

Electrical power costs include all motor-driven equipment associated with the membrane system. This includes the booster pumps, high-pressure pumps, CIP pumps and heater, decarbonation fans, and lime slaker. Miscellaneous facility loads such as lighting and heating, ventilation, and air conditioning are not included. For the NF-RO system, power consumption was calculated from the average feed pressure for the NF and RO passes minus the suction pressure from the booster pumps and NF permeate. The unit price for electrical power at the Scottsdale Water Campus is $0.089 per kilowatt-hour.

The NF-RO has somewhat higher power consumption than the RO due primarily to the added power for the concentrate recycle flow.

Chemical and Membrane Cleaning

Chemical needs for the hybrid NF-RO system and conventional RO system include pre- and post-treatment chemicals used on a continuous basis and chemicals needed periodically for the CIP system. CIP frequency is assumed to be five times per year for both the NF-RO and RO systems. Scale inhibitor and lime will be required for both systems. Actual dosage rates from the Phase B pilot test were used for the NF-RO scale-inhibitor consumptions. Recent historical dosage rates from the Water Campus were used for the RO scale-inhibitor consumption. Only the RO system would require sulfuric acid for the system feed stream; the dose is based on recent historical usage at the Water Campus. Lime dosage was calculated using the Tetra Tech/RTW Excel model for the NF-RO blended-product water quality and for RO permeate water quality from projections. Chemical costs were based on historical rates paid by the City of Scottsdale.

Membrane Replacement

Membrane life will vary in response to specific system feed water quality and operation of an individual system. NF and RO membranes are assumed to have expected lives of 5 years and 7 years, respectively, for the NF-RO system. These assumptions are based on the pilot study operation and the apparent frequency of CIP cleaning for the NF membrane. The NF pass provides excellent pretreatment of the RO membranes and prolongs the life of these membranes. The expected life of RO membranes of the conventional system is assumed to be 5 years.

Other Consumables and Maintenance Costs

Consumables and maintenance costs include cartridge filter replacement and regular equipment maintenance. It is expected that cartridge filters upstream of the NF membranes will require replacement every 4 months. To account for regular equipment maintenance costs, an annual cost of 2 percent of total equipment cost (excluding membrane elements) was assumed for each system. Table 4-14 provides these costs in addition to the costs summarized in the preceding sections. Operating costs are marginally higher for the NF-RO in comparison to the conventional RO system.

Table 4-14. Operating Cost Comparison

Item	Frequency	RO	NF-RO
Power	Annual	$61,000	$68,000
Chemical	Annual	$19,000	$16,000
Equipment Maintenance and Consumables	Annual	$13,000	$19,000
Membrane Replacement NF Elements RO Elements	Periodic	 $68,000	 $60,000 $37,000

4.2.3 Present-Value Analysis

A present-value analysis was prepared to compare the NF-RO and RO system (primary membrane systems) economics.

The analysis assumes a project life cycle of 20 years. The discount rate is 2.75 percent as published by the U.S. Bureau of Reclamation in the Federal Register, January 10, 2018, for water resources planning projects. The inflation rate is 2.06 percent per the Bureau of Labor Statistics online calculator for the period of April 2017 through April 2018.

As shown in Table 4-15, the total present value is then amortized and expressed as $/1,000 gallons of water produced. Note that while the total present value of the NF-RO is approximately 29 percent higher than the RO system, the cost per 1,000 gallons produced is only 7 percent greater because of the increased recovery.

Table 4-15. Present-Value Analysis

Item	RO	NF-RO
Capital Cost	$1,177,000	$1,743,000
Present-Value O&M Cost	$1,983,000	$2,231,000
Total Present Value	$3,160,000	$3,974,000
Water Recovery	85%	92.5%
Gallons of Water Produced per Day	850,000	925,000
$/1,000 Gallons of Water Produced	$0.71	$0.76

4.3 Benefits to Concentrate Management

The benefits of the NF-RO process are fully realized when concentrate management costs are included in the analysis. The cost reductions are due to the higher recovery achievable with NF-RO, lower TDS of the brine generated by NF-RO, and reduction of foulants and scale-forming minerals in the brine. A summary of benefits for an array of concentrate management approaches is given in Table4-16.

Table 4-16. NF-RO Process Benefits to Concentrate ManagementStrategies

Item	Reduced Salt Load	Reduced Volume	Reduced Chemical Consumptions	Reduced Energy	Reduced Maintenance
Disposal to Sewer or Interceptor	✓	✓			
Evaporation Ponds		✓			
Thermal/Mechanical Evaporation		✓		✓	✓
High Recovery Membrane Process		✓	✓	✓	✓
Brine Concentrator/Crystallizer		✓		✓	✓
Salt Recovery		✓	✓	✓	✓

The following examples demonstrate the magnitude of cost savings achievable through use of the NF-RO approach. The basis of sizing is for the brine from a process treating 700-gpm.

4.3.1 Closed-Circuit Reverse Osmosis™

Closed-circuit reverse osmosis (CCRO™) is a unique membrane process that has been tested for high-recovery applications and concentrate volume reduction. The process is a semi-batch process where the water being treated is fed at a constant rate, but concentrate is recirculated and periodically purged from the system. The process can successfully operate with scale-forming minerals above typical recommended limits. This is made possible primarily by taking advantage of the kinetics of scale formation and purging the concentrate before scale has had time to attach and form crystals on the membrane surface. The high rate of concentrate recirculation also helps to maintain turbulence and minimize concentration polarization along the full length of the membrane surface.

Table 4-17 summarizes the design-sizing criteria for CCRO™ systems for the RO process and the NF-RO process. In this example, CCRO™ systems were sized for two scenarios: treatment of concentrate from the conventional RO process and treatment of concentrate from the NF-RO process. The system for the NF-RO is smaller because it treats only half the volume. Furthermore, the concentrate from NF-RO has fewer scale-forming minerals and can be operated with more cycle of concentration and a higher recovery.

Table 4-17. Closed-Circuit Reverse Osmosis™ Design Criteria

Item	Unit	From RO	From NF-RO
Brine Feed Flow	gpm	105	52
Brine Feed TDS	mg/L	8,759	5,604
CCRO™ Recovery		70%	80%
Concentrated Brine Flow	gpm	30	10
Number of Pressure Vessels	ea	8	5
Membrane Elements Per Vessel	ea	5	5
Average Feed Pressure	psi	212	200
CCRO™ Cycles	ea	5	8
Antiscalant Dose	mg/L	28	3.2
Sulfuric Acid Dose	mg/L	336	13

Desalitech provided budgetary pricing for each CCRO™ equipment package. Table 4-18 summarizes the capital costs for each CCRO™ concentrate volume-reduction system.

Table 4-18. Closed-Circuit Reverse Osmosis™ Capital Costs

Item	Factor	RO	NF-RO
Equipment Price		$220,000	$170,000
Installation and Startup		$36,000	$36,000
Contractor Markups	15%	$38,000	$31,000
General Conditions	15%	$38,000	$31,000
Bonds, Insurance	3.5%	$12,000	$9,000
Total Construction Cost		$344,000	$277,000
Engineering	8%	$28,000	$22,000
Construction Administration	8%	$28,000	$22,000
Contingency	10%	$34,000	$28,000
Total Capital Budget		$434,000	$349,000

Table 4-19 below summarizes the operations and maintenance costs for each CCRO™ system. The power consumption difference is primarily due to the difference in the volume of concentrate treated.

Chemical costs are drastically different. Chemical dose requirements for each were predicted using AWC Proton™ software (American Water Chemicals, Inc.). Sulfuric acid doses were 336 mg/L and 13 mg/L for the RO and NF-RO concentrates, respectively. Antiscalant doses were 28.0 and 3.2 mg/L for the RO and NF-RO concentrates, respectively. This large difference in chemical need is due to the higher concentration of scale-forming minerals in the RO concentrate as compared to the concentrate from the NF-RO. Membrane replacement was assumed to be every 2 years for both systems, though with less scale-forming potential, the system treating NF-RO concentrate may not require membrane replacement as frequently as the RO unit.

Table 4-19. Closed-Circuit Reverse Osmosis™ Operating Costs

Item	Frequency	RO	NF-RO
Power	Annual	$12,000	$6,000
Chemical	Annual	$35,000	$1,000
Equipment Maintenance and Consumables	Annual	$5,000	$4,000
Membrane Replacement	Every 2 years	$15,000	$9,000
Total		$67,000	$20,000

Table 4-20 summarizes the present-value analyses for the two CCRO™ concentrate volume reduction systems. The primary membrane system present value costs are included to demonstrate that despite the added cost of NF-RO versus RO, the overall cost still demonstrates cost savings.

Table 4-20. Closed-Circuit Reverse Osmosis™ Present-Value Analysis

Item	From RO	From NF-RO
Total Capital Cost	$434,000	$349,000
Present Value of Operation and Maintenance Cost	$1,096,000	$281,000
CCRO™ Present Value	$1,530,000	$630,000
Primary Membrane + CCRO™ Present Value	$4,690,000	$4,604,000

While the present value for the CCRO™ system from the NF-RO concentrate is 2.5 times less than that for the RO concentrate, the combined cost with the primary system is nearly equal. However, it is important to note that there is still 43,200 gallons per day (30 gpm) of concentrate from the RO process versus 14,400 gallons per day (10 gpm) of concentrate from the NF-RO. As is demonstrated in the following examples, final disposal costs can be quite different for the two approaches.

4.3.2 Inland Empire Brine Line

Brine disposal to an interceptor for ocean outfall or for processing at a regional wastewater treatment plant is often a low-cost solution, if available. Costs for disposal to the Inland Empire Brine Line (IEBL) include capacity (capital) charges and usage charges. Capacity charges are based strictly on volume of flow, while usage charges include monthly capital improvement plan charges, volumetric charges, and strength charges for biochemical oxygen demand (BOD) and total suspended solids (TSS). In this case, it is assumed that the TSS and BOD concentrations are negligible. In the case of IEBL, there are no charges for TDS. The calculation of charges is based on the framework defined in Resolution 2017-6-4 adopted by the Inland Empire Utilities Agency Board of Directors for fiscal year 2017/2018. Table 4-21 summarizes the costs for capacity and usage of the IEBL for the RO and NF-RO conditions.

Table 4-21. Comparison of Brine Interceptor Costs

Item	From RO	From NF-RO
Agency Capacity Rights Charge	$1,505,000	$753,000
Annual Capacity, CIP, Volumetric, and Strength Charges	$90,000	$45,000
Present Value of Annual Cost	$1,678,000	$839,000
IEBL Present Value	$3,183,000	$1,592,000
Primary Membrane + IEBL Present Value	$6,343,000	$5,566,000

The IEBL costs are proportional to the volume of brine. Therefore, the NF-RO approach results in greater cost savings for brine disposal. When coupled with the present-value cost of the NF-RO and RO systems, there is still a significant cost savings. The payback for the NF-RO approach is immediate and the savings extend the full life cycle. This particular example does not include charges for mass of salts discharged to the brine interceptor. When the cost for disposal salts is included, as would be necessary for an inland facility, the cost savings are even greater.

4.3.3 Evaporation Ponds

Evaporation pond costs are driven primarily by the volume to be evaporated and, to a lesser extent, the salinity maintained in the pond. For this example, net evaporation rates are based on historical pan evaporation data and precipitation date for the Phoenix metropolitan area. As the brine salinity increases, evaporation rates decline and factors for increasing salinity are included in the evaporation pond sizing calculations. Pond design includes a primary pond where the bulk of evaporation takes place, followed by a secondary pond where brine is allowed to crystallize and accumulate for eventual removal. The ponds are assumed to be 4 feet deep. Pond construction includes dual high-density polyethylene liners with a leak-detection system for aquifer protection.

Dried residual salts are assumed to be hauled to a non-municipal landfill for disposal. Budgetary pricing for a 75-mile haul and tipping fees by the ton form the basis of annual operating costs.

Table 4-22 summarizes the sizing criteria for the evaporation ponds and landfill disposal of salts.

Table 4-22. Evaporation Pond Size and Annual Mass of Salt

Item	Unit	From RO	From NF-RO
Brine Flow	gpm	105	52
Annual Mass of Dried Solids	Tons	1,935	675
Total Evaporation Pond Area	Acres	37	17

Table 4-23 summarizes the capital, annual operating, and present-value cost for each alternative. The present value of the primary membrane process is added to the present value of the evaporation ponds to demonstrate cost savings with the added cost of the NF-RO process.

Table 4-23. Cost Comparison of Evaporation Ponds

Item	Factor	From RO	From NF-RO
Construction Cost		$27,340,000	$12,560,000
Engineering Design	8%	$2,187,000	$1,005,000
Construction Administration	8%	$2,187,000	$1,005,000
Contingency	10%	$2,734,000	$1,256,000
Total Capital Cost		$34,448,000	$15,826,000
Annual Residuals Hauling and Disposal		$142,000	$50,000
Present Value of Annual Cost		$2,648,000	$932,000
Evaporation Pond Present Value		$37,096,000	$16,758,000
Primary Membrane + Evaporation Pond Present Value		$40,256,000	$20,732,000

The demonstrated cost savings are substantial, even when the added cost of the NF-RO system is included.

4.3.4 CCRO™ with Evaporation Ponds

Combining CCRO™ with evaporation ponds is a cost-effective means of reducing the capital cost and large land area requirements of evaporation ponds. Using the data from the CCRO™ analysis, the ponds were resized. Since the CCRO™ for the NF-RO concentrate can operate at 80 percent recovery versus 70 percent for the CCRO™ using RO concentrate, the reduction is pond size is even greater. This results in even larger cost savings for the NF-RO option.

Table 4-24 summarizes the sizing criteria for the evaporation ponds and landfill disposal of salts when CCRO™ is used for concentration of the brine.

Table 4-24. Evaporation Pond Size and Annual Mass of Salt

Item	Unit	From RO-CCRO	From NF-RO-CCRO
Brine Flow	gpm	32	11
Annual Mass of Dried Solids	Tons	1,955	602
Total Evaporation Pond Area	Acres	12.4	4.9

Table 4-25 below summarizes the capital, annual operating, and present-value cost for each alternative. The present value of the primary membrane process is added to the present value of the CCRO and evaporation ponds to demonstrate cost savings with the added cost of the NF-RO process.

Table 4-25. Cost Comparison of Closed-Circuit Reverse Osmosis™ with Evaporation Ponds

Item	Factor	From RO	From NF-RO
Construction Cost		$9,504,000	$12,560,000
Engineering Design	8%	$760,000	$312,000
Construction Administration	8%	$733,000	$290,000
Contingency	10%	$916,000	$362,000
Total Capital Cost		$21,417,000	$8,758,000
Annual Operating, Hauling and Disposal Cost		$143,000	$44,000
Present Value of Annual Cost		$2,667,000	$821,000
CCRO + Evaporation Pond Present Value		$24,084,000	$9,579,000
Primary Membrane + Evaporation Pond Present Value		$27,244,000	$13,553,000

This approach results in more than 50 percent cost savings for concentrate disposal. Also note that the costs for evaporation ponds using NF-RO concentrate (without CCRO™) is less expensive than the RO-CCRO™ evaporation pond option in terms of capital and lifecycle cost.

4.4 Future Research

A number of topics for future research stem from this pilot study. Among these topics are the optimization of product water quality to further reduce sodium chloride content and TDS, recovery of sodium chloride for beneficial use, and requirements for potable reuse applications.

4.4.1 Optimizing Product Water Quality

The difference in blended-product water quality between Phase A and Phase B can be used to estimate water quality at other RO recoveries. Table 4-26 summarizes the blended-product TDS for multiple RO recoveries assuming a consistent RO permeate water quality and the NF concentrate TDS from Phase B operation. The NF recovery in this example is 74 percent. For this comparison, the flux is held constant.

Table 4-26. Blended-Product TDS at Various RO Recoveries

RO Recovery	Fraction of RO Permeate in Total	RO Permeate TDS, mg/L	NF Concentrate TDS, mg/L	Blended-Product TDS
80%	70%			870
85%	71%			842
90%	72%	19	2,856	813
95%	73%			785
98%	74%			757

With no other changes, an increase in RO recovery can further improve the blended-product water quality. In practice, the RO permeate TDS would increase with increasing RO recovery, which would lessen some of the TDS reduction.

Another approach to tailoring product water quality would be to use different NF membranes. From the NF membrane selection test, other membranes allow more passage of dissolved matter, while still achieving high rejection of major foulants and scale-forming minerals (especially TOC, sulfate, phosphates).

4.4.2 Resource Recovery

Average percentages for Phases A and B samples are illustrated on Figure 4-6 below; average RO concentrate sodium chloride concentrations amounted to 80.6 percent and 76.6 percent of TDS for Phases A and B, respectively. The ratio of sodium chloride in the RO concentrate provides a significant advantage over traditional RO for salt recovery. For the Scottsdale Water Campus's RO process, sodium chloride constitutes only 51.2 percent of TDS in the concentrate. Average concentrations from the pilot study and RO treatment train laboratory samples are provided in Table 4-27 below.

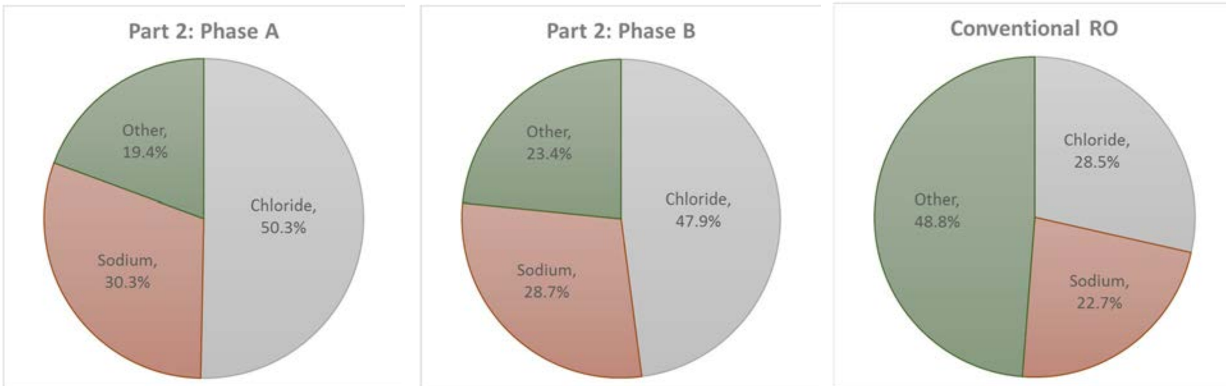

Figure 4-6. RO Concentrate Sodium Chloride Percentage.

Table 4-27. RO Concentrate Sodium Chloride Composition of TDS

Parameter	Phase A RO Concentrate		Phase B RO Concentrate		Conventional RO Process	
	Concentration (mg/L)	Percentage of TDS	Concentration (mg/L)	Percentage of TDS	Concentration (mg/L)	Percentage of TDS
Chloride	1,350	50.3%	2,827	47.9%	2,500	28.5%
Sodium	814	30.3%	1,692	28.7%	1,989	22.7%
TDS	2,683	--	5,900	--	8,759	--

Considering that most of the hybrid NF-RO pilot system's RO concentrate is composed of sodium and chloride ions, there is potential for beneficial reuse of the RO concentrate stream. The Phase B waste stream is especially concentrated with sodium chloride at an average concentration of 4,519 mg/L, or approximately 76 percent of TDS. Beneficial-use options for the RO concentrate include further concentration to create a marketable brine solution or electrolytic generation to produce sodium hypochlorite solution. Both beneficial-use strategies would transform a waste product into a net-cost benefit.

Potential for beneficial reuse is unique to the feed-water quality of a specific NF-RO system. For the pilot unit study conducted at the City of Scottsdale Water Campus, supplemental salt was necessary to generate a sodium hypochlorite solution. The quality of brine will also vary in accordance with system feed-water quality and desired end use. However, the increased percentage of sodium chloride relative to TDS increases the viability of these two options.

Although the beneficial reuse scenarios will be dependent on specific water composition, the quantity of sodium and chloride produced will be much greater than can be used at an individual plant. For Phase B, pilot system feed flows averaged 24-gpm, with a sodium chloride mass flow rate of 200 pounds per day. For a larger 1-mgd system, this equates to daily sodium chloride passage of almost 3 tons. Ample salt exists for beneficial reuse, whether through sodium hypochlorite generation or the selective recovery of commercial-grade salts from RO concentrate. Depending on the quality of salt generated and selected combination of reuse and disposal strategies, utilities will also have the option to market additional salt products as a net-cost benefit.

4.4.3 Needs for Potable Reuse Applications

While the NF-RO process offers unique benefits for salinity management and concentrate disposal, issues need to be addressed for potable reuse applications. The issues include microbiological contaminant removal, TOC (and by corollary disinfection by-products), and TOrCs, including PPCPs, and residual-scale inhibitor.

RO can remove microbial contaminants, and some regulatory agencies grant some log removal credit for RO. When a measurable indicator is added to the feed stream, it is possible to demonstrate 4-log removal of viruses with RO. All the microbial contaminants are disposed of with the concentrate. The NF-RO process is not intended to remove microbial contaminants and, therefore, no log-removal credits can be granted.

As demonstrated in this pilot study, most of the TOC and TOrCs will be captured in the NF concentrate and blended with the product water. Therefore, unlike RO, the NF-RO process should not be relied upon for removal of TOC or TOrCs, or mitigation of disinfection by-products. An advanced treatment process that incorporates ozone and biologically active filtration could remove TOrCs and a large fraction of the TOC. Because ozone breaks down larger organic molecules into smaller molecules, it is possible that these might pass through the NF membrane and be removed by the RO pass. This is a topic of interest for future research.

The antiscalant dosed to the NF pass ultimately finds its way to the blended-product. Early expectations were that the lower recovery of the NF would allow for a lower dose of antiscalant. In Phase A, the antiscalant dose was set at a low level that proved to be unsustainable. In Phase B, the scale-inhibitor dose for the NF membranes was slightly higher than for the conventional RO process. However, the dose was never fully optimized.

Even with operation at high recovery as in Phase B, the antiscalant concentration in the blended product will be slightly higher than the dose. Many antiscalant products, including the product used during the pilot study, are National Sanitation Foundation 60 certified as additives for drinking water treatment. At the concentrations that would occur in the blended concentrate, these products do not pose a health risk, though their presence may be undesirable. Further research to remove antiscalant, reduce the dose, or substitute with a chemical that can be easily removed by a non-membrane process could prove beneficial.

CHAPTER 5

Summary and Conclusions

This study presents a novel approach to salinity control of reclaimed water that can yield substantially reduced costs for membrane concentrate disposal. The process includes a two-pass system where the concentrate from the first pass (NF) is blended with permeate from the second pass (RO). The process is particularly suited to reclaimed water that is heavily impacted by water softener discharges, a phenomenon that has been demonstrated repeatedly in the desert Southwest, particularly in communities using Colorado River water as a primary drinking water supply.

All pilot testing was conducted at the City of Scottsdale's Water Campus using ultra-filtered tertiary effluent as the feed stream. The study consisted of two parts: (1) testing of various NF membranes and (2) operation of a scalable, 30-gpm two-pass system consisting of NF followed by RO. Four NF membranes were tested in two element membrane units under operating conditions like the full 30-gpm pilot. By comparing the rejection performance and projecting performance of the second-pass RO, one NF product was selected for the 30-gpm pilot. The 30-gpm pilot was operated in two different phases to observe membrane performance and water quality data. The first phase ran for 74 days and the second phase ran for 107 days.

The NF membranes required some adjustments to antiscalant dose and flux through the test. Cleaning frequency was somewhat more than expected and, despite using ultra-filtered water, colloidal and microbiological fouling appeared to be occurring. The RO system, on the other hand, ran trouble-free for the entire test, even at 90 percent recovery.

During Phase A, the system was operated with 70 percent NF recovery and 80 percent RO recovery for a combined system recovery of 86 percent. The TDS reduction in the blended-product compared to the ultra-filtered effluent (NF feed) was modest and probably not useful for a practical application.

However, the process demonstrated good selective removal of sodium chloride based on the high fraction of sodium chloride in the RO concentrate and low fraction of hardness and sulfate. Phase B was operated at 75 percent NF recovery and 90 percent RO recovery for a combined system recovery of 92.5 percent. In addition, the NF was operated at slightly lower flux in Phase B than in Phase A. This change, combined with some apparent damage to the NF membrane, resulted in higher passage of dissolved ions through the NF membrane. Therefore, more TDS was removed by the RO membrane. The TDS reduction in the blended product was greater than Phase A and the selective removal of sodium chloride remained high. For future consideration, optimization of flux, operation of the RO at higher recovery, and careful selection of NF membranes would improve TDS reduction.

The performance was compared to the performance of the RO units at the Water Campus, which ran at 85 percent recovery. Phase A had a very similar recovery and Phase B had a higher recovery that reduced brine flow by 50 percent. The operating conditions and data from Phase B were used to evaluate savings by several concentrate management and disposal approaches. The low concentrate flow, lower TDS of the concentrate, and low fouling potential of the concentrate of the NF-RO process yield substantial savings for concentrate management and disposal. These cost savings outweigh the higher capital and operating costs for the NF-RO process.

There are multiple variables that contribute to the separation of monovalent and multivalent salts. The NF concentrate recycle rate, NF recovery, flux and membrane selection all play an important part. Membrane selection plays the greatest role in determining the monovalent and multivalent mineral passage characteristics. Constituent passage increases with recovery and increasing the concentrate recycle flow further enhances the separation characteristics. Operating at a lower recovery rate results in lower scaling and fouling potential and actually adds an incremental percentage to the overall system recovery. Operating at a higher concentrate recycle rate provides greater separation but with some cost penalty for increased energy consumption. Flux also affect salt passage, though the degree to which flux affect the monovalent and multivalent passage characteristics can vary considerably with the membrane selection. In one sense, operating at a higher flux is desirable to reduce the membrane area and, therefore, the cost of the NF portion of the process. The additional benefits that might be gained by operating at a lower flux need to be balanced with the added costs.

This process offers substantial benefits for utilities with brackish reclaimed water, particularly those utilities that are: (1) inland with no inexpensive means of concentrate disposal, and (2) restricted use of reclaimed water due to high sodium chloride levels. The separation of sulfates, phosphates, organic carbon, and minerals such as calcium, magnesium, barium, strontium and others in the first pass greatly improves the recovery potential of the second pass. This conclusion would apply to any of the four nanofiltration membranes tested, which are representative of a broad array of commercially available NF products. The process has applications where the end use of the water is for irrigation purposes. It can also be incorporated into a potable reuse scheme. The process does not effectively remove organic carbon, CECs, and cannot provide log reduction credits for microbial contaminants. However, in most applications, RO itself is not granted very high log reduction credits. Other processes are very effective at removal of these contaminants and could compliment this process in potable reuse applications.

References

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APPENDIX A

Part 1: Data-Recorded Measurements and Laboratory Sampling

Summary of Inorganic Analyses – Dow NF270.

Analyte	Units	Feed	Permeate	Concentrate
pH, field	standard units	7.35	7.16	7.59
Conductivity, field	micromho/cm	2083	1452	3063
Total Dissolved Solids	mg/l	1216	752	2162
Metals, Cations				
Aluminum	mg/l	ND	ND	ND
Ammonia	mg/l	2.24	2.03	3.30
Barium	mg/l	0.07	0.03	0.14
Beryllium	mg/l	ND	ND	ND
Cadmium	mg/l	ND	ND	ND
Calcium	mg/l	79.95	34.30	153.50
Chromium	mg/l	ND	ND	ND
Copper	mg/l	0.01	0.16	0.02
Iron	mg/l	0.05	ND	0.13
Lead	mg/l	ND	0.06	ND
Magnesium	mg/l	29.75	11.05	59.25
Manganese	mg/l	0.03	0.01	0.06
Molybdenum	mg/l	ND	ND	0.02
Nickel	Mg/l	ND	ND	0.023
Potassium	mg/l	25.50	18.21	36.50
Sodium	mg/l	211.50	161.02	257.50
Strontium	mg/l	1.15	0.47	2.28
Vanadium	mg/l	ND	ND	ND
Zinc	mg/l	0.06	0.14	0.07
Anions				
Alkalinity, bicarbonate	mg/l as $CaCO_3$	164	107	266
Alkalinity, total	mg/l as $CaCO_3$	168	108	262
Arsenic	mg/l	ND	ND	ND
Chloride	mg/l	402	378.50	442.50
Nitrate	mg/l as N	4.5	5	ND*
Nitrite	mg/l as N	ND	ND	ND
Orthophosphate	mg/l as P	0.86	ND	2.43
Silica	mg/l	8.10	7.23	8.90
Sulfate	mg/l	266.50	ND	752

micromho/cm = micromho per centimeter
mg/l = milligrams per liter
$CaCO_3$ = milligrams as calcium carbonate
N = nitrate
P = phosphorus
ND = not detected
*MDL of 4 mg/l on concentrate samples

Handheld Analytical Measurements/Readings

Part 1 (June 2017)

Date	6/1/2017	6/2/2017	6/2/2017	6/2/2017	6/3/2017	6/3/2017	6/4/2017	6/4/2017	6/5/2017	6/5/2017	6/6/2017	6/6/2017	6/6/2017
Membrane	**Dow NF270**												
Feed Temp, degF	85	85	85	85	85	86	85	86	85	85	86	85	86
Pressure, psi													
Pumped Feed	35	35	35	30	37		30		30	36	35	30	35
Recycle/Concentrate	30	30	30	30	33		25		30	32	35	30	33
Flow, gpm													
Permeate	1.65	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.57	1.5	1.6	1.55
Concentrate	0.6	0.6	0.6	0.5	0.6	0.5	0.6	0.4	0.6	0.6	0.6	0.6	0.6
Recycle	0.6	0.6	0.6	0.65	0.6	0.6	0.65	0.65	0.6	0.62	0.6	0.6	0.6
Conductivity, uhmo/cm													
Feed			2138		2067		30	1600		2060		2058	2083
Permeate			1469		1422					1488		1445	1452
Concentrate			3225		3131					3094		3082	3063
pH													
Feed			7.41		7.41					7.33		7.36	7.35
Permeate			7.16		7.28					7.15		7.05	7.16
Concentrate			7.56		7.58					7.48		7.52	7.59
Metering Pump													
Stroke Speed %	55	55	55	55	25	26	26	26	30	30	35	30	25
Stroke Length %	50	49	49	48	25	26	26	26	30	30	32	30	70
Tank Level	20	20	20	20	20	20	20	20	20	20	20	20	20
Run Hours	**2214**	**2229**	**2229**	**2250**	**2254**	**2263**	**2279**	**2288**	**2300**	**2308**	**2325**	**2300**	**2332**
Calculations													
Membrane area	82	82	82	82	82	82	82	82	82	82	82	82	82
Calculate system recovery	73%	73%	73%	76%	73%	76%	73%	80%	73%	72%	71%	73%	72%
Calculate arraye recovery	58%	57%	57%	58%	57%	59%	56%	60%	57%	56%	56%	57%	56%
Calculate Flux, gfd	14.5	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.8	13.2	14.0	13.6

Summary of Inorganic Analyses – CSM NE.

Analyte	Units	Feed	Permeate	Concentrate
pH, field	standard units	7.48	7.35	7.85
Conductivity, field	micromho/cm	2059	1402	3113
Total Dissolved Solids	mg/l	1254	724	2054
Metals, Cations				
Aluminum	mg/l	ND	ND	ND
Ammonia	mg/l as N	2.35	2.08	3.01
Barium	mg/l	0.09	0.02	0.20
Beryllium	mg/l	ND	ND	ND
Cadmium	mg/l	ND	ND	ND
Calcium	mg/l	81.4	28	174.50
Chromium	mg/l	ND	ND	ND
Copper	mg/l	0.02	0.06	0.04
Iron	mg/l	0.05	ND	0.12
Lead	mg/l	ND	ND	ND
Magnesium	mg/l	31.75	5.20	76.75
Manganese	mg/l	0.02	ND	0.06
Molybdenum	mg/l	ND	ND	ND
Nickel	mg/l	ND	0.06	ND
Potassium	mg/l	25	19.50	34
Sodium	mg/l	257.50	209.50	340.50
Strontium	mg/l	1.20	0.31	2.73
Vanadium	mg/l	ND	ND	ND
Zinc	mg/l	0.09	0.07	0.10
Anions				
Alkalinity, bicarbonate	mg/l as $CaCO_3$	167	93	297
Alkalinity, total	mg/l as $CaCO_3$	164	92	294
Arsenic	mg/l	ND	ND	ND
Chloride	mg/l	374.5	351	408
Nitrate	mg/l as N	4.20	4.50	ND*
Nitrite	mg/l as N	ND	ND	ND
Orthophosphate	mg/l as P	2.22	ND	5.92
Silica	mg/l	9.50	9.10	10.50
Sulfate	mg/l	251.5	ND	685.5

micromho/cm = micromho per centimeter
mg/l = milligrams per liter
$CaCO_3$ = milligrams as calcium carbonate
N = nitrate

P = phosphorus
ND = not detected
*MDL of 4 mg/l on concentrate samples

Handheld Analytical Measurements/Readings

Part 1 (June 2017)

Date	6/6/2017	6/7/2017	6/7/2017	6/8/2017	6/8/2017	6/9/2017	6/9/2017	6/10/2017	6/11/2017
Membrane	CSM NE								
Feed Temp, degF	86	86	86	86	86	86	86	86	86
Pressure, psi									
Pumped Feed	35	37		40		40	40	40	40+
Recycle/Concentrate	33	33		35		36	35	35	39
Flow, gpm									
Permeate	1.65	1.65	1.7	1.6	1.6	1.6	1.6	1.5	1.5
Concentrate	0.63	0.67	0.8	0.63	0.6	0.63	0.6	0.6	0.65
Recycle	0.63	0.63	0.6	0.6	0.62	0.63	0.6	0.7	0.65
Conductivity, uhmo/cm									
Feed		2114	1610	2094			2059		
Permeate		1430		1403			1402		
Concentrate		3226		3183			3113		
pH									
Feed		7.75		7.22			7.48		
Permeate		7.8		7.03			7.35		
Concentrate		7.9		7.43			7.85		
Metering Pump									
Stroke Speed %	25	25	30	25	30	25	30	30	30
Stroke Length %	70	70	70	70	70	70	70	70	70
Tank Level	20	20	20	20	20	20	20	19	19
Run Hours	**2333**	**2352**	**2359**	**2375**	**2388**	**2396**			
Calculations									
Membrane area	85	85	85	85	85	85	85	85	85
Calculate system recovery	72%	71%	68%	72%	73%	72%	73%	71%	70%
Calculate arraye recovery	57%	56%	55%	57%	57%	56%	57%	54%	54%
Calculate Flux, gfd	14.0	14.0	14.4	13.6	13.6	13.6	13.6	12.7	12.7

Summary of Inorganic Analyses – Hydranautics Nano BW.

Analyte	Units	Feed	Permeate	Concentrate
pH, field	Standard units	7.54	7.18	7.61
Conductivity, field	micromho/cm	2085	1361	3030
Total Dissolved Solids	mg/l	1194	700	1956
Metals, Cations				
Aluminum	mg/l	ND	ND	ND
Ammonia	mg/l as N	1.85	1.33	2.10
Barium	mg/l	0.09	0.03	0.17
Beryllium	mg/l	ND	ND	ND
Cadmium	mg/l	ND	ND	ND
Calcium	mg/l	77.90	30.35	151
Chromium	mg/l	ND	ND	ND
Copper	mg/l	0.02	0.05	0.02
Iron	mg/l	0.05	ND	0.12
Lead	mg/l	ND	ND	ND
Magnesium	mg/l	30.65	10.85	60.60
Manganese	mg/l	0.023	ND	0.05
Molybdenum	mg/l	ND	ND	0.02
Nickel	mg/l	ND	ND	ND
Potassium	mg/l	24	17	35.5
Sodium	mg/l	251.50	185	348
Strontium	mg/l	1.15	0.43	2.24
Vanadium	mg/l	ND	ND	ND
Zinc	mg/l	0.04	0.06	0.07
Anions				
Alkalinity, bicarbonate	mg/l as $CaCO_3$	170	94	278
Alkalinity, total	mg/l as $CaCO_3$	172	96	286
Arsenic	mg/l	ND	ND	ND
Chloride	mg/l	371.5	330.5	453
Nitrate	mg/l as N	3.3	3.7	ND*
Nitrite	mg/l as N	ND	ND	ND
Orthophosphate	mg/l as P	1.19	ND	2.97
Silica	mg/l	10.85	9.85	12.55
Sulfate	mg/l	238.5	ND	620.5

micromho/cm = micromho per centimeter
mg/l = milligrams per liter
$CaCO_3$ = milligrams as calcium carbonate
N = nitrate
P = phosphorus
ND = not detected
*MDL of 4 mg/l on concentrate samples

Handheld Analytical Measurements/Readings

Part 1 (June 2017)

Date	6/11/2017	6/12/2017	6/13/2017	6/14/2017	6/14/2017
Membrane	**Hydranautics Nano BW**				
Feed Temp, degF	86	85	85	85	86
Pressure, psi					
Pumped Feed	58	55	57	55	58
Recycle/Concentrate	53±	51±	55	51	55
Flow, gpm					
Permeate	1.45±	1.4±	1.35	1.35	1.3
Concentrate	0.65	0.8±	0.6	0.5	0.6
Recycle	0.63±	0.75±	0.7	0.75	0.67
Conductivity, uhmo/cm					
Feed		2030	1999	2075	2085
Permeate		1300	1290	1363	1361
Concentrate		3015	3003	3044	3030
pH					
Feed		7.51	7.31	7.28	7.54
Permeate		7.42	7.12	6.91	7.18
Concentrate		7.31	7.51	7.29	7.61
Metering Pump					
Stroke Speed %	70	80	75	75	75
Stroke Length %	30	30	30	30	30
Tank Level	19	20	20	20	20
Run Hours		**2468**	2488	**2514**	**2521**
Calculations					
Membrane area	75	75	75	75	75
Calculate system recovery	69%	64%	69%	73%	68%
Calculate arraye recovery	53%	47%	51%	52%	51%
Calculate Flux, gfd	13.9	13.9	13.0	13.0	12.5

Summary of Inorganic Analyses – Koch Membrane Systems SR200.

Analyte	Units	Feed	Permeate	Concentrate
pH, field	standard units	7.59	7.14	7.88
Conductivity, field	micromho/cm	2108	1129	3721
Total Dissolved Solids	mg/l	1204	516	2408
Metals, Cations				
Aluminum	mg/l	ND	ND	ND
Ammonia	mg/l as N	2.00	1.57	2.4
Barium	mg/l	0.09	ND	0.23
Beryllium	mg/l	ND	ND	ND
Cadmium	mg/l	ND	ND	ND
Calcium	mg/l	75	10.40	193.33
Chromium	mg/l	ND	ND	ND
Copper	mg/l	0.02	0.04	0.02
Iron	mg/l	0.05	ND	0.12
Lead	mg/l	ND	ND	ND
Magnesium	mg/l	30.87	1.67	82.67
Manganese	mg/l	0.02	ND	0.06
Molybdenum	mg/l	ND	ND	0.02
Nickel	mg/l	ND	ND	ND
Potassium	mg/l	23	14.50	40.33
Sodium	mg/l	255.67	166.67	390
Strontium	mg/l	1.15	0.10	3.07
Vanadium	mg/l	ND	ND	ND
Zinc	mg/l	0.04	0.03	0.07
Anions				
Alkalinity, bicarbonate	mg/l as $CaCO_3$	172.7	48	362
Alkalinity, total	mg/l as $CaCO_3$	174	48	394
Arsenic	mg/l	ND	ND	ND
Chloride	mg/l	390.33	272.33	614
Nitrate	mg/l as N	3.60	3.80	3.30
Nitrite	mg/l as N	ND	ND	ND
Orthophosphate	mg/l as P	1.57	ND	4.05
Silica	mg/l	11.53	9.67	14.70
Sulfate	mg/l	242	ND	687.67

micromho/cm = micromho per centimeter
mg/l = milligrams per liter
$CaCO_3$ = milligrams as calcium carbonate
N = nitrate

P = phosphorus
ND = not detected
*MDL of 4 mg/l on concentrate samples

Handheld Analytical Measurements/Readings

Part 1 (June 2017)

Date	6/14/2017	6/15/2017	6/15/2017	6/16/2017	6/17/2017	6/17/2017	6/18/2017	6/18/2017	6/30/2017
Membrane	**Koch Membrane Systems SR200**								
Feed Temp, degF	86	86	86	86	86	86	86	86	88
Pressure, psi									
Pumped Feed	35	70	76		85	88	93	98	73
Recycle/Concentrate	30	68	73		80	85	90	95	70
Flow, gpm									
Permeate	1.65	1.65	1.65	1.6	1.6	1.6	1.65	1.65	1.65
Concentrate	0.62	0.65	0.62	0.62	0.6	0.6	0.6	0.62	0.6
Recycle	0.62	0.62	0.62	0.62	0.62	0.6	0.65	0.6	0.6
Conductivity, uhmo/cm									
Feed		2091	2075		2033	2032	2028	2034	2108
Permeate		1107	1047		1000	1000	971	995	1129
Concentrate		3627	2560		3640	3748	3830	3779	3721
pH									
Feed		7.33	7.53		5.92	7.34	5.96	7.11	7.59
Permeate		6.7	6.76		5.92	6.59	5.96	7	7.14
Concentrate		7.5	7.41		5.92	7.53	5.96	7.59	7.88
Metering Pump									
Stroke Speed %	75	75	75	80	80	80	50	50	0
Stroke Length %	30	30	30	30	30	30	30	30	0
Tank Level	20	18	16	14	13.8	13.8	28	28	
Run Hours		**2534**	**2560**	**2571**	**2584**	**2586**	**2612**	**2629**	
Calculations									
Membrane area	85	85	85	85	85	85	85	85	85
Calculate system recovery	73%	72%	73%	72%	73%	73%	73%	73%	73%
Calculate arraye recovery	57%	57%	57%	56%	57%	57%	57%	57%	58%
Calculate Flux, gfd	14.0	14.0	14.0	13.6	13.6	13.6	14.0	14.0	14.0

APPENDIX B

Part 1: Reverse Osmosis Projections

Projections with DOW FILMTEC NF270-4040 for 80% Recovery

Projection by:	**Robert McCandless**		
Client name:	BC		
Project:	DWPR / Pass2RO DownNF270 80pct		
Location:	United States / Arizona / Scottsdale		

AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	80.000
Internal Recovery:	%	80.000
Temperature:	°F	86.000
Total permeate:	gal/min	14.400
Average Flux:	gfd	14.050

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	79.582
Total Δ P Elements:	psi	10.046
Brine Pressure:	psi	69.533

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	36.88	36.88	36.88	182.99	0.35
Mg^{2+}	11.82	11.82	11.82	58.65	0.11
Ba^{2+}	0.03	0.03	0.03	0.15	0.00
Sr^{2+}	0.51	0.51	0.51	2.53	0.00
Na^{+}	221.51	221.51	221.51	1057.57	12.50
K^{+}	19.18	19.18	19.18	91.57	1.08
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.01	0.01	0.01	0.05	0.00
NH3/NH4(as N)	2.03	2.03	2.03	9.61	0.13

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	108.00	107.90	107.90	516.55	5.08
CO_3^{2-} Alk($CaCO_3$)	0.00	0.23	0.23	6.53	0.00
Total Alk ($CaCO_3$)	108.00	108.13	108.13	523.08	5.08
Ortho-PO_4^3	0.10	0.10	0.10	0.49	0.00
SO_4^{2-}	5.00	5.00	5.00	24.81	0.05
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	381.00	381.00	381.00	1833.25	17.94
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	7.80	7.80	7.80	37.59	0.35
NO_3^--N	1.13	1.13	1.13	5.43	0.05
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.35	0.35	0.35	0.68	0.27
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	821.300	821.300	821.300	3949.640	39.230
Conductivity (µs/cm):	1452.000	1309.468	1309.467	6302.278	61.234
pH:	7.160	7.160	7.160	7.780	5.880
Flow:	gal/min	18.000	0.000	3.600	14.400

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	0.600 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO DowNF270 80pct
Location:	United States / Arizona / Scottsdale

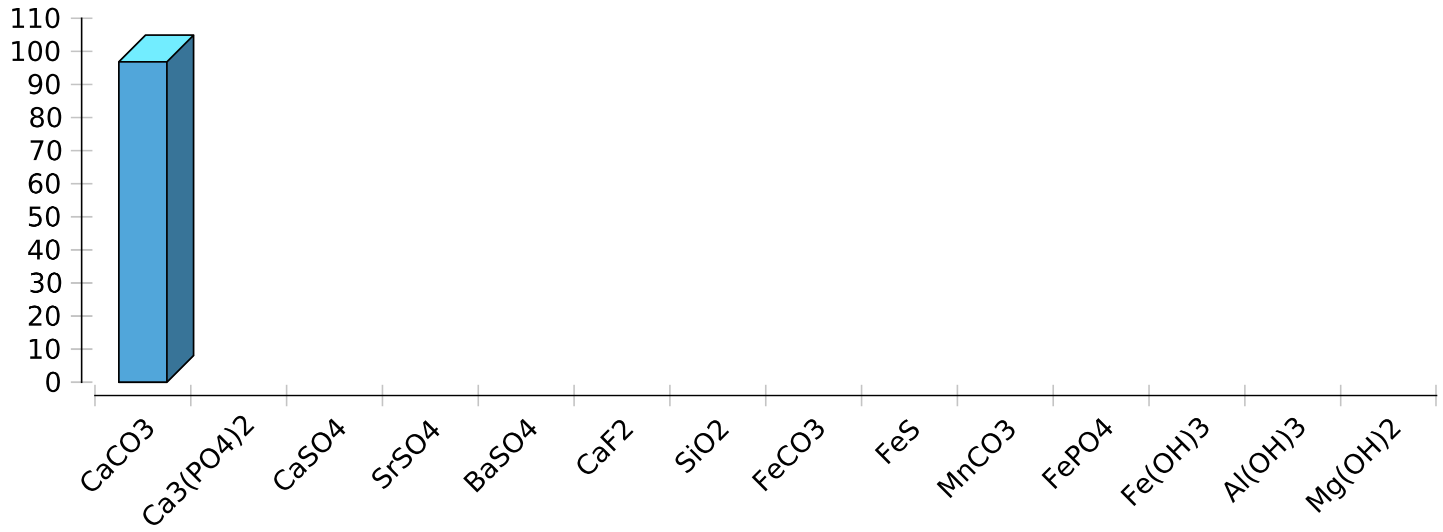
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	21.485	39.430
Net Driving Pressure:	psi	57.650	49.002
Req'd P/Stage:	psi	76.289	73.839
Feed P:	psi	79.582	73.839
Permeate Throttle/P:	psi	3.292	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	73.839	69.533

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		10.667	15.610	59.259	1.101	9.000	3.667	5.743	21.483	57.650
1	BW30LE-4040	1.003	17.620	11.149	1.102	9.000	7.997	1.602	10.414	65.075
2	BW30LE-4040	0.961	16.869	12.013	1.102	7.997	7.036	1.292	11.741	62.301
3	BW30LE-4040	0.917	16.112	13.040	1.101	7.036	6.119	1.023	13.381	59.503
4	BW30LE-4040	0.872	15.308	14.246	1.101	6.119	5.247	0.792	15.444	56.533
5	BW30LE-4040	0.820	14.406	15.635	1.100	5.247	4.427	0.597	18.078	53.204
6	BW30LE-4040	0.760	13.344	17.166	1.097	4.427	3.667	0.437	21.483	49.282
Stage2		3.733	10.927	50.909	1.113	7.333	3.600	4.306	39.414	49.002
1	BW30LE-4040	0.768	13.488	10.474	1.081	7.333	6.565	1.126	23.460	49.815
2	BW30LE-4040	0.713	12.525	10.863	1.078	6.565	5.852	0.925	25.995	46.255
3	BW30LE-4040	0.656	11.520	11.209	1.074	5.852	5.196	0.754	28.867	42.544
4	BW30LE-4040	0.596	10.464	11.467	1.069	5.196	4.600	0.611	32.085	38.644
5	BW30LE-4040	0.533	9.356	11.581	1.063	4.600	4.067	0.493	35.625	34.552
6	BW30LE-4040	0.467	8.209	11.493	1.057	4.067	3.600	0.398	39.414	30.318

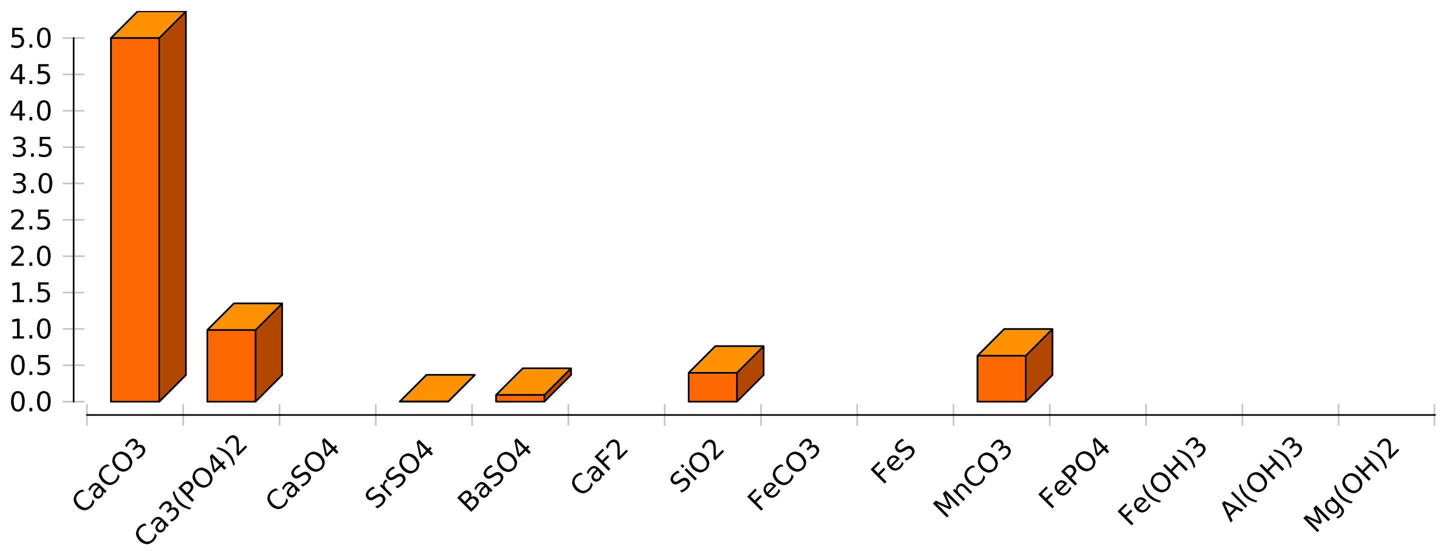
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
96.821	0	0	0	0	0	0	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
9.705	0.984	0	0.001	0.092	0	0.396	0	0	0.631	0	0	0	0

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO DowNF270 80pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	96.821	9.705	0.987
$MgCO_3$	0.000	3.167	0.501
$SrCO_3$	0.000	0.527	-0.278
$BaCO_3$	0.000	0.004	-2.423
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.631	-0.200

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	0.000	0.984	-0.007
$Mg_3(PO4)_2$	0.000	0.000	-5.620
$Sr_3(PO4)_2$	0.000	0.000	-8.618
$Ba_3(PO4)_2$	0.000	0.000	-17.520
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	-17.413
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.485

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.000	-3.532
$SrSO_4$	0.000	0.001	-3.143
$BaSO_4$	0.000	0.092	-1.034

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-4.290
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	-6.088
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-9.628

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Projection by:	**Robert McCandless**	AWC Proton 3.031.03
Client name:	BC	(release date: June 25, 2017)
Project:	DWPR / Pass2RO DownNF270 80pct	
Location:	United States / Arizona / Scottsdale	

Silicate Scales	**Precipitation Potential**	**X Saturation**	**Saturation Index**
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.037	-1.428
$Mg_3Si_2O_5(OH)_4$	0.000	0.001	-2.871
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	0.000	0.396	-0.402

Scales above 100% saturation	
$CaCO_3$	Saturation is 9.71 X; [Saturation Index is 0.99]
$MgCO_3$	Saturation is 3.17 X; [Saturation Index is 0.50]

Critical Indices		**Guideline**	**Status**
CaCO3 SI (CCNI)	0.987	< 2.300	OK
Mg(OH)2 SI	-4.290	< 9.200	OK
SiO2 (MSI)	0.000	< 10.000	OK
Antiscalant Precipitation Index (API)	8.161	< 9.900	OK
Ca3(PO4)2 SI (MPI)	-0.007	< 4.200	OK
CaSO4 SI	-3.532	< 0.500	OK
BaSO4 SI	-1.034	< 3.000	OK
SrSO4 SI	-3.143	< 1.000	OK
LSI	1.387		OK
Stiff&Davis Index	1.581		OK

Chemical dosing:	**AWC A-102 Ultra**	**HCL**
Calculated Dosage:	0.600 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.600 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.037 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.130 lbs	0.000 lbs
Week	0.909 lbs	0.000 lbs
4 Weeks	3.634 lbs	0.000 lbs
Year	47.372 lbs	0.000 lbs
5 Years	236.862 lbs	0.000 lbs

Insert your additional comments below:

Comments...

Projections with DOW FILMTEC NF270-4040 for Maximum Recovery

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO DowNF270 92.7pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	92.657
Internal Recovery:	%	92.657
Temperature:	°F	86.000
Total permeate:	gal/min	16.678
Average Flux:	gfd	16.270

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	121.679
Total Δ P Elements:	psi	6.737
Brine Pressure:	psi	114.903

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	36.88	36.88	36.88	520.02	0.00
Mg^{2+}	11.82	11.82	11.82	166.67	0.00
Ba^{2+}	0.03	0.03	0.03	0.42	0.00
Sr^{2+}	0.51	0.51	0.51	7.19	0.00
Na^{+}	221.51	221.51	221.51	2937.45	6.29
K^{+}	19.18	19.18	19.18	254.35	0.54
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.01	0.01	0.01	0.14	0.00
NH3/NH4(as N)	2.03	2.03	2.03	26.67	0.08

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	108.00	107.90	107.90	1419.65	1.67
CO_3^{2-} Alk($CaCO_3$)	0.00	0.23	0.23	61.38	0.00
Total Alk ($CaCO_3$)	108.00	108.13	108.13	1481.03	1.67
Ortho-$PO4^3$	0.10	0.10	0.10	1.39	0.00
SO_4^{2-}	5.00	5.00	5.00	70.50	0.00
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	381.00	381.00	381.00	5114.56	5.89
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	7.80	7.80	7.80	104.97	0.10
NO_3^--N	1.13	1.13	1.13	15.16	0.02
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.35	0.35	0.35	1.10	0.29
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	821.300	821.300	821.300	11016.710	15.480
Conductivity (µs/cm):	1452.000	1309.468	1309.467	17585.449	20.089
pH:	7.160	7.160	7.160	8.150	5.400
Flow:	gal/min	18.000	0.000	1.320	16.680

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	1.545 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO DowNF270 92.7pct
Location:	United States / Arizona / Scottsdale

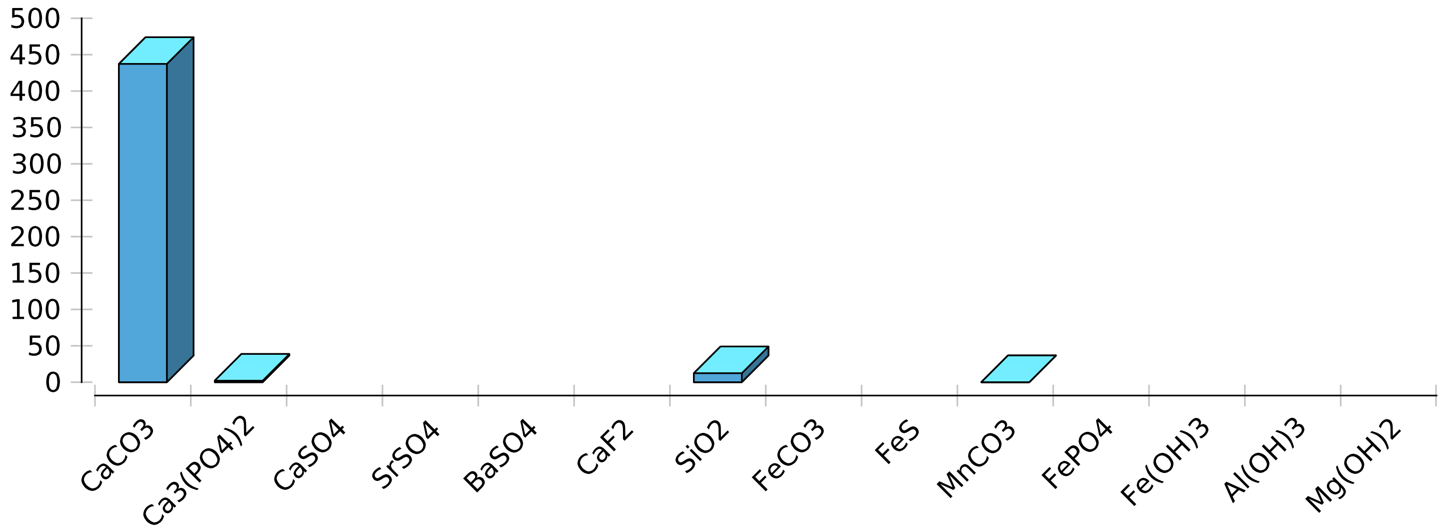
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	28.278	97.795
Net Driving Pressure:	psi	66.771	56.755
Req'd P/Stage:	psi	87.854	116.568
Feed P:	psi	121.679	116.568
Permeate Throttle/P:	psi	33.826	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	116.568	114.903

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		12.354	18.080	68.635	1.123	9.000	2.823	5.111	28.269	66.771
1	BW30LE-4040	1.175	20.641	13.060	1.123	9.000	7.825	1.573	10.838	76.229
2	BW30LE-4040	1.127	19.793	14.405	1.123	7.825	6.698	1.216	12.572	73.100
3	BW30LE-4040	1.076	18.887	16.059	1.124	6.698	5.622	0.912	14.854	69.754
4	BW30LE-4040	1.016	17.839	18.069	1.124	5.622	4.606	0.659	17.941	65.882
5	BW30LE-4040	0.941	16.527	20.432	1.123	4.606	3.665	0.454	22.229	61.038
6	BW30LE-4040	0.842	14.790	22.979	1.118	3.665	2.823	0.297	28.269	54.622
Stage2		4.324	12.656	76.590	1.254	5.646	1.322	1.665	101.758	56.755
1	BW30LE-4040	1.197	21.023	21.205	1.150	5.646	4.449	0.644	36.524	77.643
2	BW30LE-4040	1.026	18.017	23.237	1.139	4.449	3.423	0.416	46.455	66.541
3	BW30LE-4040	0.806	14.160	24.074	1.117	3.423	2.616	0.262	58.937	52.294
4	BW30LE-4040	0.566	9.945	22.756	1.086	2.616	2.050	0.167	72.432	36.728
5	BW30LE-4040	0.508	8.928	27.178	1.082	2.050	1.542	0.105	95.924	32.971
6	BW30LE-4040	0.220	3.861	13.534	1.030	1.542	1.322	0.071	101.758	14.261

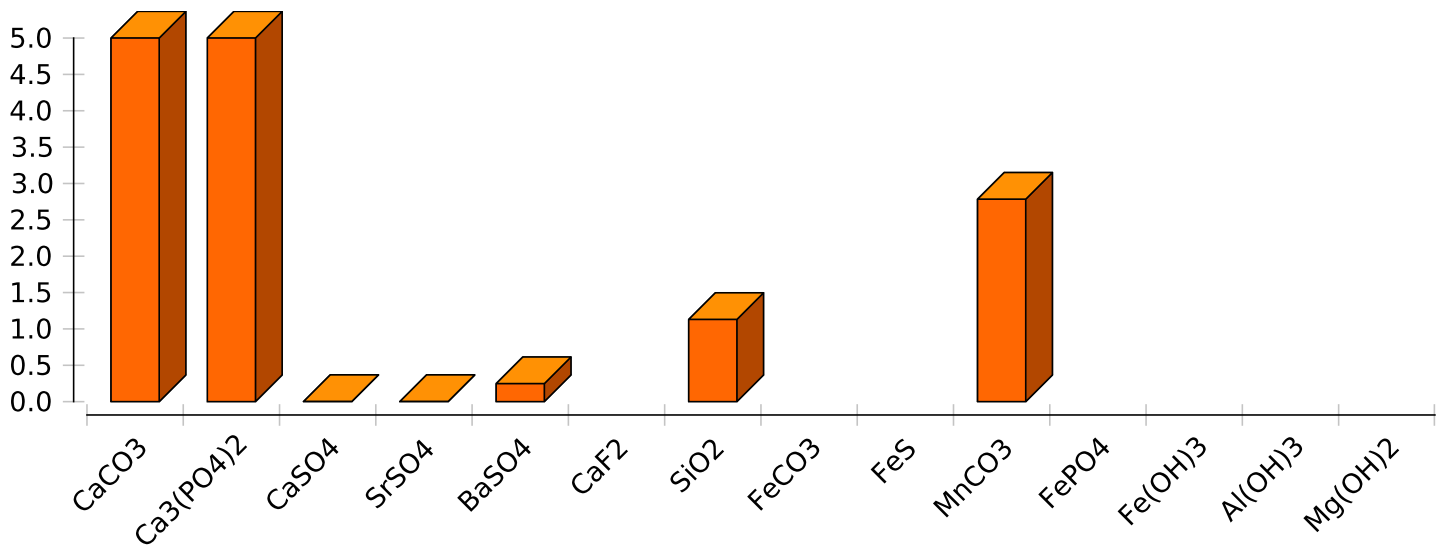
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
437.23	2.079	0	0	0	0	12.327	0	0	0.031	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
87.458	78.452	0.001	0.001	0.247	0	1.13	0	0	2.784	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	437.230	87.458	1.942
$MgCO_3$	7.862	30.498	1.484
$SrCO_3$	7.218	4.702	0.672
$BaCO_3$	0.000	0.034	-1.471
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.031	2.784	0.445

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	2.079	78.452	1.895
$Mg_3(PO4)_2$	0.000	0.000	-5.644
$Sr_3(PO4)_2$	0.000	0.000	-8.628
$Ba_3(PO4)_2$	0.000	0.000	-17.522
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	-19.671
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.001	-3.252

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.001	-3.251
$SrSO_4$	0.000	0.001	-3.062
$BaSO_4$	0.000	0.247	-0.607

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-3.302
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	-5.856
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-8.670

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Silicate Scales	**Precipitation Potential**	**X Saturation**	**Saturation Index**
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.305	-0.516
$Mg_3Si_2O_5(OH)_4$	0.000	0.866	-0.062
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	12.327	1.130	0.053

Scales above 100% saturation	
$CaCO_3$	Saturation is 87.46 X; [Saturation Index is 1.94]
$MgCO_3$	Saturation is 30.50 X; [Saturation Index is 1.48]
$SrCO_3$	Saturation is 4.70 X; [Saturation Index is 0.67]
$MnCO_3$	Saturation is 2.78 X; [Saturation Index is 0.44]
$Ca_3(PO4)_2$	Saturation is 78.45 X; [Saturation Index is 1.89]
SiO_2	Saturation is 1.13 X; [Saturation Index is 0.05]

Critical Indices		**Guideline**	**Status**
CaCO3 SI (CCNI)	1.942	< 2.300	OK
Mg(OH)2 SI	-3.302	< 9.200	OK
SiO2 (MSI)	6.934	< 10.000	OK
Antiscalant Precipitation Index (API)	9.688	< 9.900	OK
Ca3(PO4)2 SI (MPI)	1.895	< 4.200	OK
CaSO4 SI	-3.251	< 0.500	OK
BaSO4 SI	-0.607	< 3.000	OK
SrSO4 SI	-3.062	< 1.000	OK
LSI	2.606		OK
Stiff&Davis Index	2.426		OK

Chemical dosing:	**AWC A-102 Ultra**	**HCL**
Calculated Dosage:	1.545 mg/L	0.000 mg/L
Total Dosage (modified by user):	1.545 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.094 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.334 lbs	0.000 lbs
Week	2.340 lbs	0.000 lbs
4 Weeks	9.358 lbs	0.000 lbs
Year	121.992 lbs	0.000 lbs
5 Years	609.958 lbs	0.000 lbs

Insert your additional comments below:

Comments...

obtained or damages incurred from the application of this information. Because use conditions and applicable laws may differ from one location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. American Water Chemicals assumes no liability, if, as a result of customer's use of the Proton membrane aqueous chemistry calculator, the customer should be sued for alleged infringement of any patent not owned or controlled by American Water Chemicals Inc.

Projections with CSM NE4040-40 for 80% Recovery

Projection by:	**Robert McCandless**	AWC Proton	3.031.03
Client name:	BC	(release date: June 25, 2017)	
Project:	DWPR / Pass2RO CSMpermeate 80pct		
Location:	United States / Arizona / Scottsdale		

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	80.000
Internal Recovery:	%	80.000
Temperature:	°F	86.000
Total permeate:	gal/min	14.400
Average Flux:	gfd	14.050

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	77.161
Total Δ P Elements:	psi	10.073
Brine Pressure:	psi	67.086

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	28.00	28.00	28.00	138.93	0.27
Mg^{2+}	5.10	5.10	5.10	25.31	0.05
Ba^{2+}	0.02	0.02	0.02	0.12	0.00
Sr^{2+}	0.31	0.31	0.31	1.54	0.00
Na^{+}	217.02	217.02	217.02	1039.62	11.37
K^{+}	20.00	20.00	20.00	95.81	1.05
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	2.08	2.08	2.08	9.84	0.14

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	92.00	91.86	91.86	438.67	4.31
CO_3^{2-} Alk($CaCO_3$)	0.00	0.30	0.30	8.34	0.00
Total Alk ($CaCO_3$)	92.00	92.16	92.16	447.02	4.31
Ortho-$PO4^3$	0.10	0.10	0.10	0.49	0.00
SO_4^{2-}	5.00	5.00	5.00	24.81	0.05
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	351.00	351.00	351.00	1689.02	16.49
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	8.80	8.80	8.80	42.41	0.40
NO_3^--N	1.02	1.02	1.02	4.89	0.05
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.33	0.33	0.33	0.65	0.25
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	753.160	753.160	753.150	3623.330	35.630
Conductivity (µs/cm):	1402.000	1192.203	1192.202	5738.396	55.607
pH:	7.350	7.350	7.350	7.970	6.060
Flow:	gal/min	18.000	0.000	3.600	14.400

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	0.600 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO CSMpermeate 80pct
Location:	United States / Arizona / Scottsdale

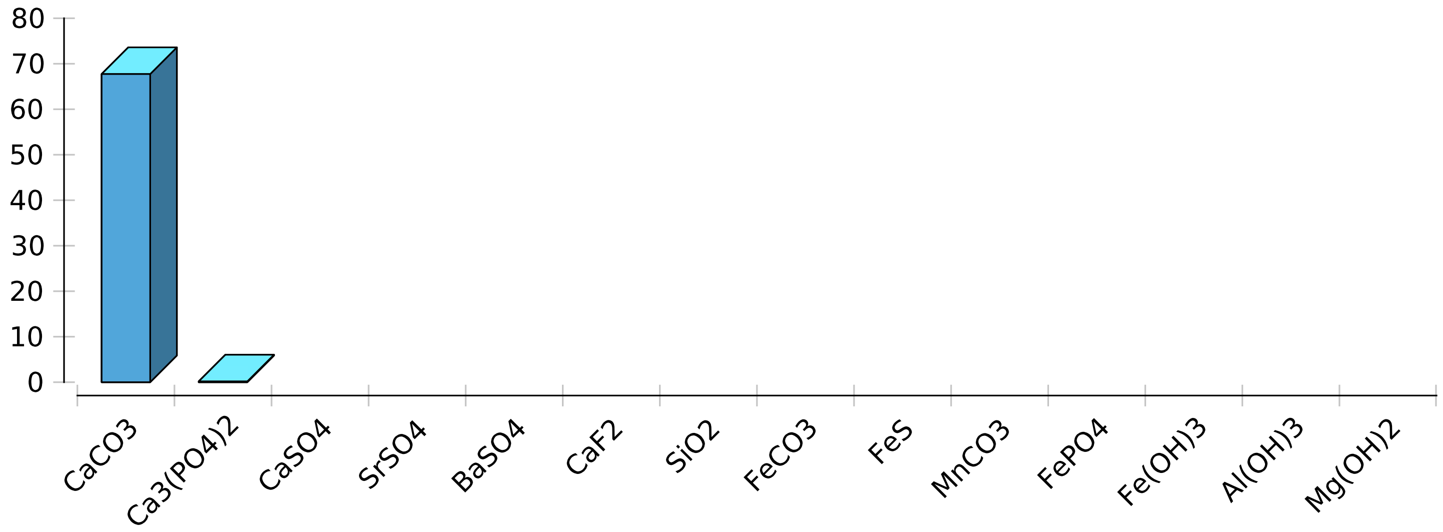
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	19.873	36.388
Net Driving Pressure:	psi	57.650	49.002
Req'd P/Stage:	psi	75.148	71.407
Feed P:	psi	77.161	71.407
Permeate Throttle/P:	psi	2.013	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	71.407	67.086

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		10.667	15.610	59.259	1.100	9.000	3.667	5.754	19.871	57.650
1	BW30LE-4040	0.998	17.523	11.087	1.102	9.000	8.002	1.603	9.630	64.717
2	BW30LE-4040	0.957	16.801	11.956	1.101	8.002	7.045	1.294	10.849	62.049
3	BW30LE-4040	0.916	16.079	12.996	1.101	7.045	6.130	1.026	12.357	59.382
4	BW30LE-4040	0.872	15.318	14.230	1.101	6.130	5.258	0.795	14.257	56.572
5	BW30LE-4040	0.824	14.469	15.671	1.100	5.258	4.434	0.599	16.695	53.437
6	BW30LE-4040	0.767	13.468	17.299	1.098	4.434	3.667	0.438	19.871	49.742
Stage2		3.733	10.927	50.909	1.113	7.333	3.600	4.321	36.376	49.002
1	BW30LE-4040	0.759	13.328	10.349	1.080	7.333	6.574	1.128	21.622	49.221
2	BW30LE-4040	0.708	12.424	10.762	1.077	6.574	5.867	0.928	23.929	45.886
3	BW30LE-4040	0.654	11.485	11.148	1.073	5.867	5.213	0.757	26.555	42.417
4	BW30LE-4040	0.598	10.498	11.467	1.069	5.213	4.615	0.614	29.517	38.770
5	BW30LE-4040	0.539	9.457	11.668	1.064	4.615	4.077	0.495	32.807	34.925
6	BW30LE-4040	0.477	8.369	11.691	1.058	4.077	3.600	0.399	36.376	30.909

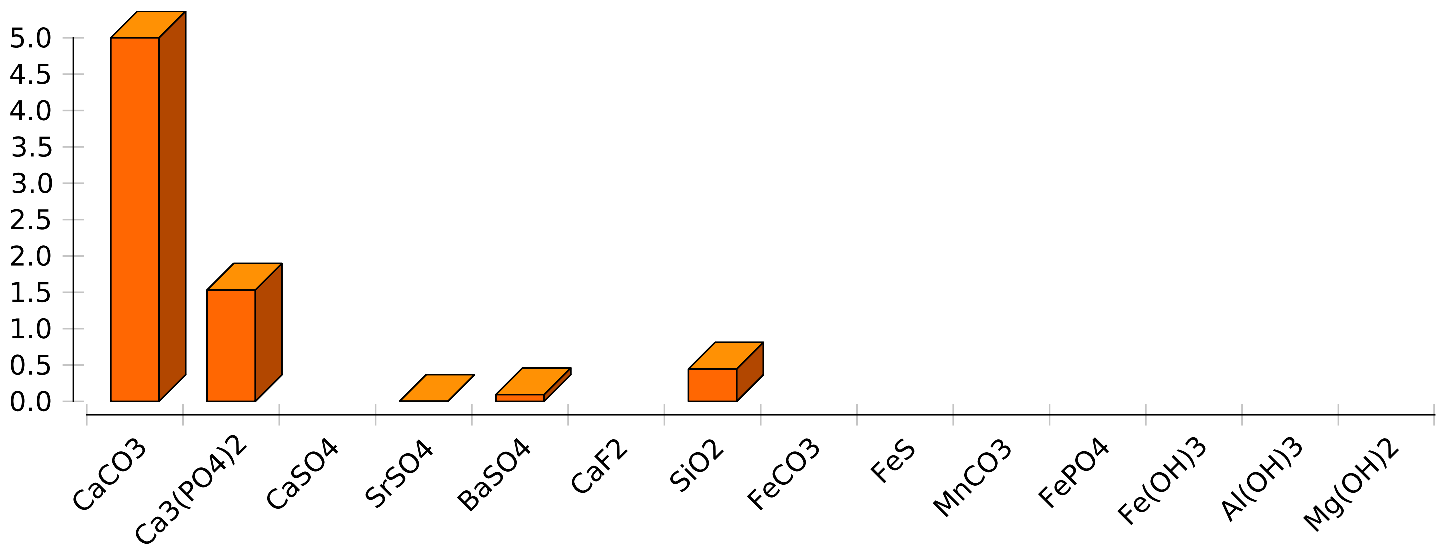
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
67.736	0.163	0	0	0	0	0	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
9.91	1.53	0	0.001	0.093	0	0.445	0	0	0	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	67.736	9.910	0.996
$MgCO_3$	0.000	1.939	0.288
$SrCO_3$	0.000	0.451	-0.346
$BaCO_3$	0.000	0.004	-2.372
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	0.163	1.530	0.185
$Mg_3(PO4)_2$	0.000	0.000	-6.295
$Sr_3(PO4)_2$	0.000	0.000	-8.842
$Ba_3(PO4)_2$	0.000	0.000	-17.387
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.647

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.000	-3.501
$SrSO_4$	0.000	0.001	-3.264
$BaSO_4$	0.000	0.093	-1.031

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-4.253
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-9.338

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO CSMpermeate 80pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.038	-1.419
$Mg_3Si_2O_5(OH)_4$	0.000	0.002	-2.817
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	0.000	0.445	-0.352

Scales above 100% saturation	
$CaCO_3$	Saturation is 9.91 X; [Saturation Index is 1.00]
$MgCO_3$	Saturation is 1.94 X; [Saturation Index is 0.29]
$Ca_3(PO4)_2$	Saturation is 1.53 X; [Saturation Index is 0.18]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	0.996	< 2.300	OK
Mg(OH)2 SI	-4.253	< 9.200	OK
SiO2 (MSI)	0.000	< 10.000	OK
Antiscalant Precipitation Index (API)	8.063	< 9.900	OK
Ca3(PO4)2 SI (MPI)	0.185	< 4.200	OK
CaSO4 SI	-3.501	< 0.500	OK
BaSO4 SI	-1.031	< 3.000	OK
SrSO4 SI	-3.264	< 1.000	OK
LSI	1.394		OK
Stiff&Davis Index	1.613		OK

Chemical dosing:	AWC A-102 Ultra	HCL
Calculated Dosage:	0.600 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.600 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.037 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.130 lbs	0.000 lbs
Week	0.909 lbs	0.000 lbs
4 Weeks	3.634 lbs	0.000 lbs
Year	47.372 lbs	0.000 lbs
5 Years	236.862 lbs	0.000 lbs

Insert your additional comments below:

Comments...

Projections with CSM NE4040-40 for Maximum Recovery

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO CSMpermeate 93.0pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	93.030
Internal Recovery:	%	93.030
Temperature:	°F	86.000
Total permeate:	gal/min	16.745
Average Flux:	gfd	16.340

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	118.935
Total Δ P Elements:	psi	6.688
Brine Pressure:	psi	112.216

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	28.00	28.00	28.00	410.66	0.00
Mg^{2+}	5.10	5.10	5.10	74.80	0.00
Ba^{2+}	0.02	0.02	0.02	0.35	0.00
Sr^{2+}	0.31	0.31	0.31	4.55	0.00
Na^{+}	217.02	217.02	217.02	3008.13	7.90
K^{+}	20.00	20.00	20.00	277.22	0.73
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	2.08	2.08	2.08	28.41	0.11

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	92.00	91.86	91.86	1242.48	2.69
CO_3^{2-} Alk($CaCO_3$)	0.00	0.30	0.30	83.82	0.00
Total Alk ($CaCO_3$)	92.00	92.16	92.16	1326.29	2.69
Ortho-$PO4^3$	0.10	0.10	0.10	1.45	0.00
SO_4^{2-}	5.00	5.00	5.00	73.33	0.00
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	351.00	351.00	351.00	4898.25	10.30
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	8.80	8.80	8.80	123.12	0.24
NO_3^--N	1.02	1.02	1.02	14.19	0.03
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.33	0.33	0.33	1.08	0.27
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00

TDS:	753.160	753.160	753.150	10507.990	23.220
Conductivity (µs/cm):	1402.000	1192.203	1192.202	16644.728	34.655
pH:	7.350	7.350	7.350	8.350	5.860
Flow:	gal/min	18.000	0.000	1.250	16.750

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-108	0.350 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO CSMpermeate 93.0pct
Location:	United States / Arizona / Scottsdale

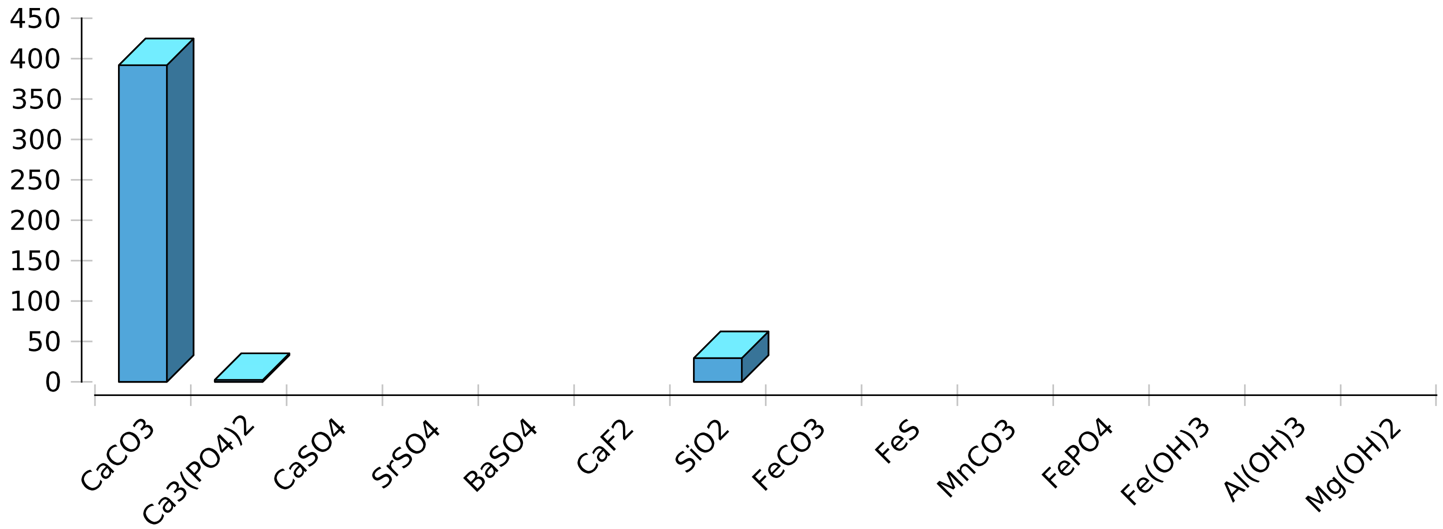
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	**Stage 1**	**Stage 2**
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	26.408	95.666
Net Driving Pressure:	psi	67.039	56.983
Req'd P/Stage:	psi	86.848	113.826
Feed P:	psi	118.935	113.826
Permeate Throttle/P:	psi	32.087	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	113.826	112.216

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		12.404	18.152	68.911	1.123	9.000	2.798	5.109	26.401	67.039
1	BW30LE-4040	1.172	20.587	13.026	1.122	9.000	7.828	1.574	10.028	76.033
2	BW30LE-4040	1.126	19.776	14.387	1.123	7.828	6.702	1.217	11.629	73.036
3	BW30LE-4040	1.077	18.916	16.073	1.124	6.702	5.624	0.913	13.741	69.860
4	BW30LE-4040	1.021	17.925	18.149	1.125	5.624	4.604	0.659	16.613	66.202
5	BW30LE-4040	0.950	16.685	20.638	1.124	4.604	3.654	0.453	20.640	61.620
6	BW30LE-4040	0.856	15.023	23.416	1.120	3.654	2.798	0.294	26.401	55.484
Stage2		4.341	12.707	77.580	1.258	5.596	1.255	1.610	96.159	56.983
1	BW30LE-4040	1.193	20.955	21.323	1.150	5.596	4.403	0.633	34.072	77.389
2	BW30LE-4040	1.031	18.100	23.575	1.140	4.403	3.372	0.408	43.549	66.848
3	BW30LE-4040	0.819	14.388	24.780	1.119	3.372	2.553	0.253	55.789	53.139
4	BW30LE-4040	0.590	10.366	24.155	1.091	2.553	1.962	0.157	69.861	38.285
5	BW30LE-4040	0.537	9.429	29.286	1.088	1.962	1.425	0.095	95.190	34.825
6	BW30LE-4040	0.171	3.000	10.704	1.021	1.425	1.255	0.063	96.159	11.078

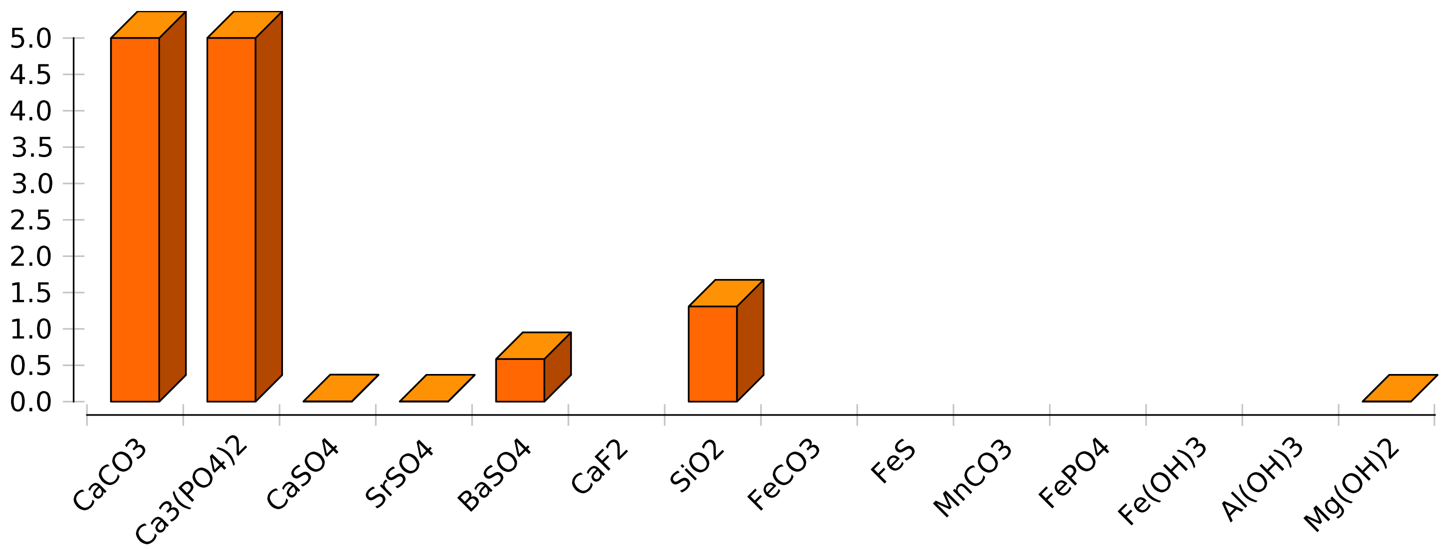
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
391.824	2.288	0	0	0	0	29.272	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
117.133	331.284	0.004	0.002	0.585	0	1.308	0	0	0	0	0	0	0.001

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	391.824	117.133	2.069
$MgCO_3$	0.000	19.653	1.293
$SrCO_3$	4.453	4.299	0.633
$BaCO_3$	0.000	0.041	-1.391
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	2.288	331.284	2.520
$Mg_3(PO4)_2$	0.000	0.000	-6.598
$Sr_3(PO4)_2$	0.000	0.000	-9.126
$Ba_3(PO4)_2$	0.000	0.000	-17.663
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.563

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.004	-2.437
$SrSO_4$	0.000	0.002	-2.797
$BaSO_4$	0.000	0.585	-0.232

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.001	-3.227
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-8.384

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO CSMpermeate 93.0pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03

(release date: June 25, 2017)

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.282	-0.550
$Mg_3Si_2O_5(OH)_4$	0.000	0.868	-0.061
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	29.272	1.308	0.117

Scales above 100% saturation	
$CaCO_3$	Saturation is 117.13 X; [Saturation Index is 2.07]
$MgCO_3$	Saturation is 19.65 X; [Saturation Index is 1.29]
$SrCO_3$	Saturation is 4.30 X; [Saturation Index is 0.63]
$Ca_3(PO_4)_2$	Saturation is 331.28 X; [Saturation Index is 2.52]
SiO_2	Saturation is 1.31 X; [Saturation Index is 0.12]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	2.069	< 2.300	OK
Mg(OH)2 SI	-3.227	< 9.200	OK
SiO2 (MSI)	8.618	< 10.000	OK
Antiscalant Precipitation Index (API)	8.725	< 9.900	OK
Ca3(PO4)2 SI (MPI)	2.520	< 4.200	OK
CaSO4 SI	-2.437	< 0.500	OK
BaSO4 SI	-0.232	< 3.000	OK
SrSO4 SI	-2.797	< 1.000	OK
LSI	2.661		OK
Stiff&Davis Index	2.537		OK

Chemical dosing:	AWC A-108	HCL
Calculated Dosage:	0.350 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.350 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.280 g/cm3	1.184 g/cm3
Dosing Pump:	0.019 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.076 lbs	0.000 lbs
Week	0.530 lbs	0.000 lbs
4 Weeks	2.120 lbs	0.000 lbs
Year	27.634 lbs	0.000 lbs
5 Years	138.170 lbs	0.000 lbs

Insert your additional comments below:

Comments...

location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. American Water Chemicals assumes no liability, if, as a result of customer's use of the Proton membrane aqueous chemistry calculator, the customer should be sued for alleged infringement of any patent not owned or controlled by American Water Chemicals Inc.

Projections with Hydranautics NANO-BW-4040 for 80% Recovery

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2 RO NanoBWpermeate 80pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	80.000
Internal Recovery:	%	80.000
Temperature:	°F	86.000
Total permeate:	gal/min	14.400
Average Flux:	gfd	14.050

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	74.783
Total Δ P Elements:	psi	10.098
Brine Pressure:	psi	64.683

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	29.50	29.50	29.50	146.38	0.28
Mg^{2+}	10.70	10.70	10.70	53.09	0.10
Ba^{2+}	0.03	0.03	0.03	0.15	0.00
Sr^{2+}	0.42	0.42	0.42	2.08	0.00
Na^{+}	187.71	187.71	187.71	896.35	10.55
K^{+}	17.00	17.00	17.00	81.18	0.96
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	1.33	1.33	1.33	6.30	0.09

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	96.00	95.92	95.92	459.57	4.50
CO_3^{2-} Alk($CaCO_3$)	0.00	0.18	0.18	5.10	0.00
Total Alk ($CaCO_3$)	96.00	96.10	96.10	464.66	4.50
Ortho-$PO4^3$	0.10	0.10	0.10	0.49	0.00
SO_4^{2-}	5.00	5.00	5.00	24.81	0.05
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	318.00	318.00	318.00	1530.33	14.92
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	9.70	9.70	9.70	46.75	0.44
NO_3^--N	0.84	0.84	0.84	4.02	0.04
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.36	0.36	0.36	0.70	0.27
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	699.050	699.050	699.040	3362.090	33.300
Conductivity (µs/cm):	1290.000	1105.636	1105.635	5322.223	51.461
pH:	7.120	7.120	7.120	7.750	5.830
Flow:	gal/min	18.000	0.000	3.600	14.400

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	0.600 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2 RO NanoBWpermeate 80pct
Location:	United States / Arizona / Scottsdale

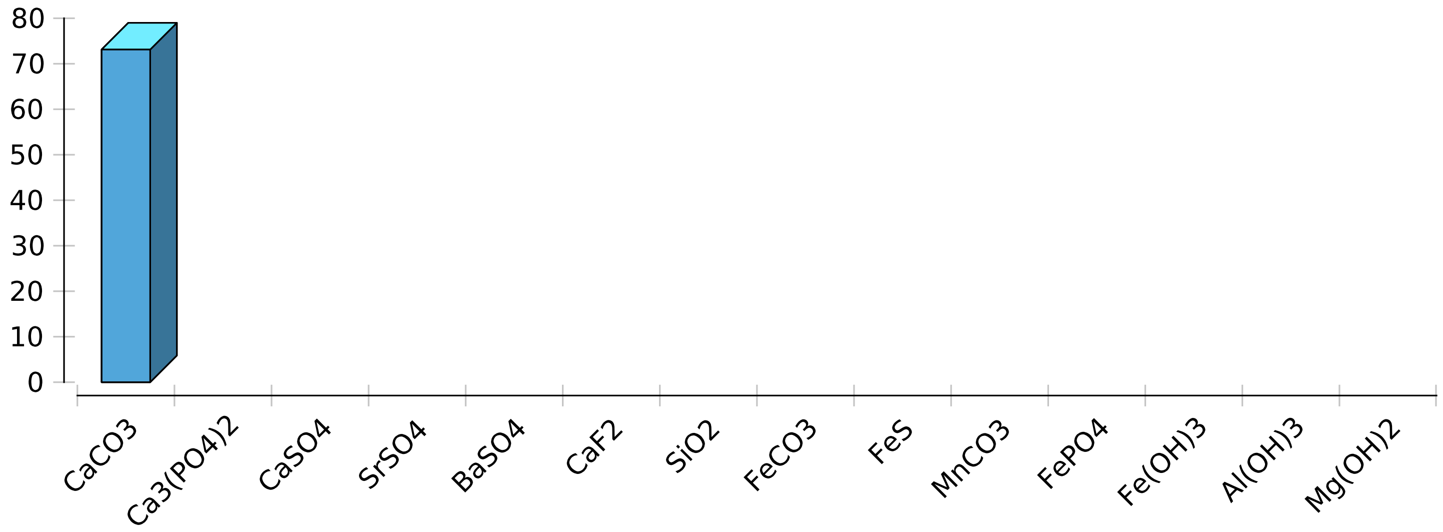
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	18.222	33.451
Net Driving Pressure:	psi	57.650	49.002
Req'd P/Stage:	psi	73.960	69.018
Feed P:	psi	74.783	69.018
Permeate Throttle/P:	psi	0.823	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	69.018	64.683

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		10.667	15.610	59.259	1.101	9.000	3.667	5.765	18.221	57.650
1	BW30LE-4040	0.992	17.428	11.027	1.101	9.000	8.008	1.604	8.795	64.363
2	BW30LE-4040	0.953	16.734	11.900	1.101	8.008	7.055	1.296	9.906	61.803
3	BW30LE-4040	0.914	16.047	12.953	1.101	7.055	6.141	1.028	11.283	59.263
4	BW30LE-4040	0.873	15.328	14.214	1.101	6.141	5.268	0.797	13.023	56.610
5	BW30LE-4040	0.827	14.531	15.707	1.100	5.268	4.441	0.601	15.269	53.665
6	BW30LE-4040	0.774	13.591	17.428	1.099	4.441	3.667	0.439	18.221	50.193
Stage2		3.733	10.927	50.909	1.113	7.333	3.600	4.334	33.441	49.002
1	BW30LE-4040	0.751	13.182	10.236	1.079	7.333	6.583	1.129	19.770	48.684
2	BW30LE-4040	0.702	12.334	10.670	1.076	6.583	5.880	0.931	21.871	45.553
3	BW30LE-4040	0.652	11.455	11.093	1.073	5.880	5.228	0.761	24.274	42.304
4	BW30LE-4040	0.600	10.529	11.468	1.069	5.228	4.628	0.617	27.004	38.884
5	BW30LE-4040	0.544	9.548	11.747	1.065	4.628	4.085	0.497	30.069	35.262
6	BW30LE-4040	0.485	8.513	11.868	1.059	4.085	3.600	0.399	33.441	31.442

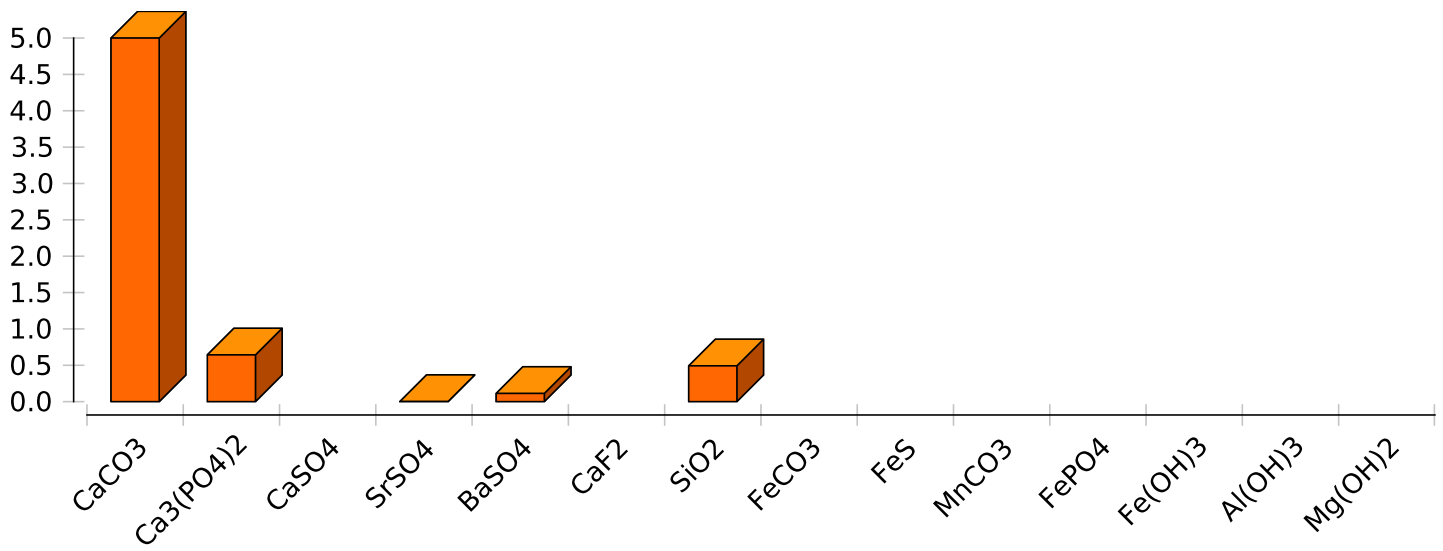
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
73.123	0	0	0	0	0	0	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
7.086	0.643	0	0.001	0.113	0	0.492	0	0	0	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	73.123	7.086	0.850
$MgCO_3$	0.000	2.577	0.411
$SrCO_3$	0.000	0.390	-0.409
$BaCO_3$	0.000	0.003	-2.470
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	0.000	0.643	-0.192
$Mg_3(PO4)_2$	0.000	0.000	-5.662
$Sr_3(PO4)_2$	0.000	0.000	-8.786
$Ba_3(PO4)_2$	0.000	0.000	-17.435
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.673

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.000	-3.502
$SrSO_4$	0.000	0.001	-3.149
$BaSO_4$	0.000	0.113	-0.948

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-4.376
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-9.767

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.039	-1.410
$Mg_3Si_2O_5(OH)_4$	0.000	0.001	-2.922
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	0.000	0.492	-0.308

Scales above 100% saturation	
$CaCO_3$	Saturation is 7.09 X; [Saturation Index is 0.85]
$MgCO_3$	Saturation is 2.58 X; [Saturation Index is 0.41]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	0.850	< 2.300	OK
Mg(OH)2 SI	-4.376	< 9.200	OK
SiO2 (MSI)	0.000	< 10.000	OK
Antiscalant Precipitation Index (API)	8.017	< 9.900	OK
Ca3(PO4)2 SI (MPI)	-0.192	< 4.200	OK
CaSO4 SI	-3.502	< 0.500	OK
BaSO4 SI	-0.948	< 3.000	OK
SrSO4 SI	-3.149	< 1.000	OK
LSI	1.210		OK
Stiff&Davis Index	1.435		OK

Chemical dosing:	AWC A-102 Ultra	HCL
Calculated Dosage:	0.600 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.600 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.037 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.130 lbs	0.000 lbs
Week	0.909 lbs	0.000 lbs
4 Weeks	3.634 lbs	0.000 lbs
Year	47.372 lbs	0.000 lbs
5 Years	236.862 lbs	0.000 lbs

Insert your additional comments below:

Comments...

Projections with Hydranautics NANO-BW-4040 for Maximum Recovery

Projection by:	**Robert McCandless**		AWC Proton 3.031.03
Client name:	BC		(release date: June 25, 2017)
Project:	DWPR / Pass2 RO NanoBWpermeate 93.3pct		
Location:	United States / Arizona / Scottsdale		

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	93.335
Internal Recovery:	%	93.335
Temperature:	°F	86.000
Total permeate:	gal/min	16.800
Average Flux:	gfd	16.390

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	115.721
Total Δ P Elements:	psi	6.652
Brine Pressure:	psi	109.079

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	29.50	29.50	29.50	424.06	1.32
Mg^{2+}	10.70	10.70	10.70	153.81	0.48
Ba^{2+}	0.03	0.03	0.03	0.43	0.00
Sr^{2+}	0.42	0.42	0.42	6.04	0.02
Na^{+}	187.71	187.71	187.71	2536.09	20.01
K^{+}	17.00	17.00	17.00	229.68	1.81
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	1.33	1.33	1.33	17.81	0.15

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	96.00	95.92	95.92	1288.99	9.05
CO_3^{2-} Alk($CaCO_3$)	0.00	0.18	0.18	49.39	0.00
Total Alk ($CaCO_3$)	96.00	96.10	96.10	1338.38	9.05
Ortho-$PO4^3$	0.10	0.10	0.10	1.42	0.01
SO_4^{2-}	5.00	5.00	5.00	71.88	0.22
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	318.00	318.00	318.00	4350.03	30.07
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	9.70	9.70	9.70	133.03	0.89
NO_3^--N	0.84	0.84	0.84	11.43	0.08
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.36	0.36	0.36	1.15	0.30
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00

TDS:	699.050	699.050	699.040	9554.730	66.650
Conductivity (µs/cm):	1290.000	1105.636	1105.635	15131.650	104.017
pH:	7.120	7.120	7.120	8.120	6.130
Flow:	gal/min	18.000	0.000	1.200	16.800

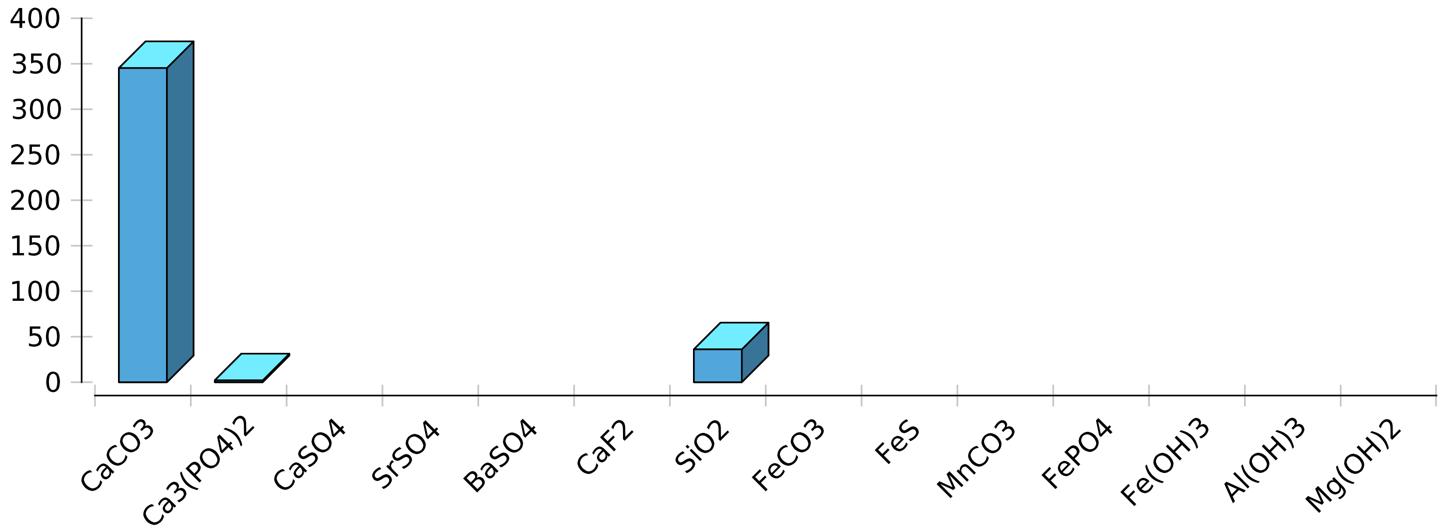
Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	1.080 mg/L

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	24.423	94.560
Net Driving Pressure:	psi	67.259	57.170
Req'd P/Stage:	psi	85.718	110.610
Feed P:	psi	115.721	110.610
Permeate Throttle/P:	psi	30.003	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	110.610	109.079

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		12.445	18.212	69.137	1.124	9.000	2.778	5.111	24.418	67.259
1	BW30LE-4040	1.168	20.516	12.981	1.122	9.000	7.832	1.575	9.162	75.769
2	BW30LE-4040	1.124	19.741	14.354	1.123	7.832	6.708	1.219	10.625	72.909
3	BW30LE-4040	1.078	18.928	16.069	1.124	6.708	5.630	0.914	12.562	69.906
4	BW30LE-4040	1.025	17.998	18.205	1.125	5.630	4.605	0.659	15.210	66.471
5	BW30LE-4040	0.959	16.832	20.815	1.126	4.605	3.646	0.452	18.960	62.165
6	BW30LE-4040	0.869	15.254	23.822	1.123	3.646	2.778	0.292	24.418	56.335
Stage2		4.356	12.748	78.404	1.256	5.555	1.200	1.531	93.375	57.170
1	BW30LE-4040	1.203	21.131	21.660	1.152	5.555	4.352	0.623	31.639	78.042
2	BW30LE-4040	1.053	18.498	24.206	1.144	4.352	3.299	0.396	40.862	68.317
3	BW30LE-4040	0.858	15.067	26.001	1.126	3.299	2.441	0.240	53.377	55.646
4	BW30LE-4040	0.655	11.507	26.728	1.102	2.441	1.785	0.140	69.570	42.498
5	BW30LE-4040	0.540	9.481	28.794	1.088	1.785	1.246	0.078	93.375	35.015
6	BW30LE-4040	0.046	0.804	2.885	1.000	1.246	1.200	0.054	85.809	2.970

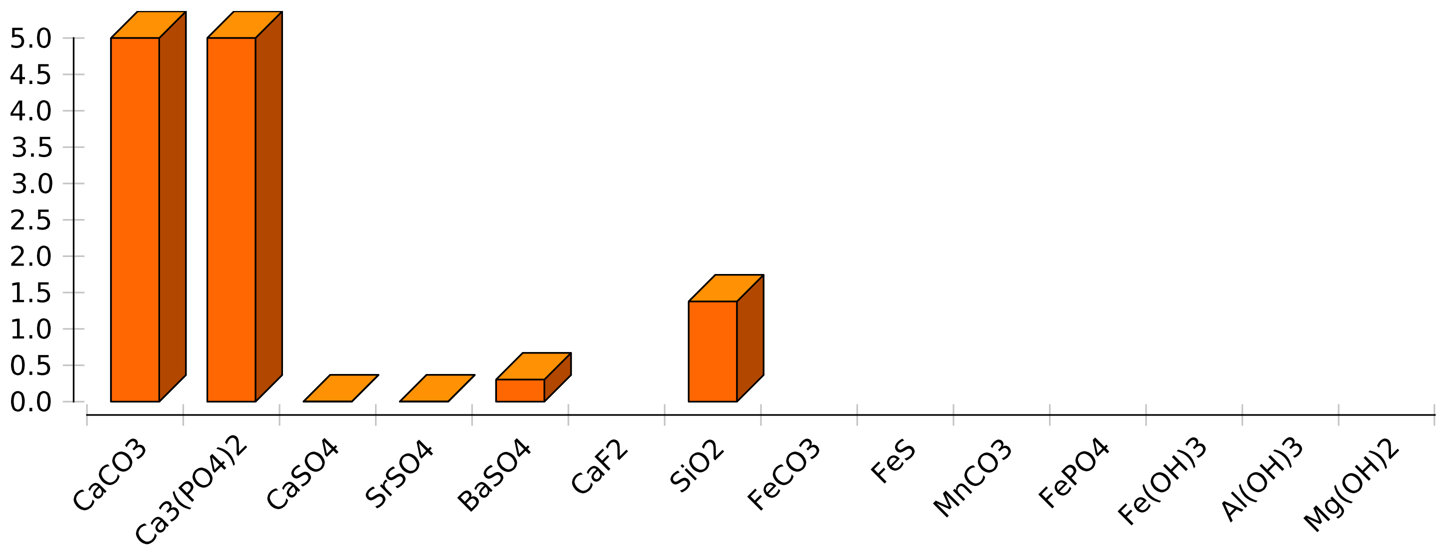
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO_4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
345.257	1.999	0	0	0	0	36.087	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO_4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
64.24	53.096	0.001	0.001	0.303	0	1.377	0	0	0	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	345.257	64.240	1.808
$MgCO_3$	17.953	25.509	1.407
$SrCO_3$	5.453	3.578	0.554
$BaCO_3$	0.000	0.031	-1.505
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	1.999	53.096	1.725
$Mg_3(PO4)_2$	0.000	0.000	-5.470
$Sr_3(PO4)_2$	0.000	0.000	-8.582
$Ba_3(PO4)_2$	0.000	0.000	-17.222
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.336

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.001	-3.236
$SrSO_4$	0.000	0.001	-3.019
$BaSO_4$	0.000	0.303	-0.519

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-3.349
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-8.792

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2 RO NanoBWpermeate 93.3pct
Location:	United States / Arizona / Scottsdale

AWC Proton 3.031.03
(release date: June 25, 2017)

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.333	-0.477
$Mg_3Si_2O_5(OH)_4$	0.000	0.895	-0.048
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	36.087	1.377	0.139

Scales above 100% saturation	
$CaCO_3$	Saturation is 64.24 X; [Saturation Index is 1.81]
$MgCO_3$	Saturation is 25.51 X; [Saturation Index is 1.41]
$SrCO_3$	Saturation is 3.58 X; [Saturation Index is 0.55]
$Ca_3(PO_4)_2$	Saturation is 53.10 X; [Saturation Index is 1.73]
SiO_2	Saturation is 1.38 X; [Saturation Index is 0.14]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	1.808	< 2.300	OK
Mg(OH)2 SI	-3.349	< 9.200	OK
SiO2 (MSI)	8.782	< 10.000	OK
Antiscalant Precipitation Index (API)	9.493	< 9.900	OK
Ca3(PO4)2 SI (MPI)	1.725	< 4.200	OK
CaSO4 SI	-3.236	< 0.500	OK
BaSO4 SI	-0.519	< 3.000	OK
SrSO4 SI	-3.019	< 1.000	OK
LSI	2.460		OK
Stiff&Davis Index	2.365		OK

Chemical dosing:	AWC A-102 Ultra	HCL
Calculated Dosage:	1.080 mg/L	0.000 mg/L
Total Dosage (modified by user):	1.080 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.066 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.234 lbs	0.000 lbs
Week	1.635 lbs	0.000 lbs
4 Weeks	6.539 lbs	0.000 lbs
Year	85.246 lbs	0.000 lbs
5 Years	426.231 lbs	0.000 lbs

Insert your additional comments below:

Comments...

location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. American Water Chemicals assumes no liability, if, as a result of customer's use of the Proton membrane aqueous chemistry calculator, the customer should be sued for alleged infringement of any patent not owned or controlled by American Water Chemicals Inc.

Projections with KMS 4040-SR200 for 80% Recovery

Projection by:	**Robert McCandless**	AWC Proton 3.031.03
Client name:	BC	(release date: June 25, 2017)
Project:	DWPR / Pass2RO KMS SR200 Permeate 80pct	
Location:	United States / Arizona / Scottsdale	

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	80.000
Internal Recovery:	%	80.000
Temperature:	°F	86.000
Total permeate:	gal/min	14.400
Average Flux:	gfd	14.050

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	78.066
Total Δ P Elements:	psi	10.752
Brine Pressure:	psi	67.312

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	12.10	12.10	12.10	60.06	0.11
Mg^{2+}	2.10	2.10	2.10	10.42	0.02
Ba^{2+}	0.00	0.00	0.00	0.00	0.00
Sr^{2+}	0.13	0.13	0.13	0.64	0.00
Na^{+}	190.56	190.56	190.56	917.18	8.91
K^{+}	15.00	15.00	15.00	72.19	0.70
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	2.08	2.08	2.08	9.88	0.13

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	50.00	49.93	49.93	238.88	2.25
CO_3^{2-} Alk($CaCO_3$)	0.00	0.16	0.16	4.33	0.00
Total Alk ($CaCO_3$)	50.00	50.09	50.09	243.21	2.25
Ortho-PO_4^3	0.10	0.10	0.10	0.49	0.00
SO_4^{2-}	5.00	5.00	5.00	24.82	0.05
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	299.00	299.00	299.00	1441.03	13.49
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	10.30	10.30	10.30	49.71	0.45
NO_3^--N	0.79	0.79	0.79	3.81	0.04
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.30	0.30	0.30	0.59	0.23
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	600.690	600.690	600.690	2895.010	27.120
Conductivity (µs/cm):	1100.000	959.840	959.839	4627.315	42.924
pH:	7.350	7.350	7.350	7.980	6.040
Flow:	gal/min	18.000	0.000	3.600	14.400

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	0.600 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO KMS SR200 Permeate 80pct
Location:	United States / Arizona / Scottsdale

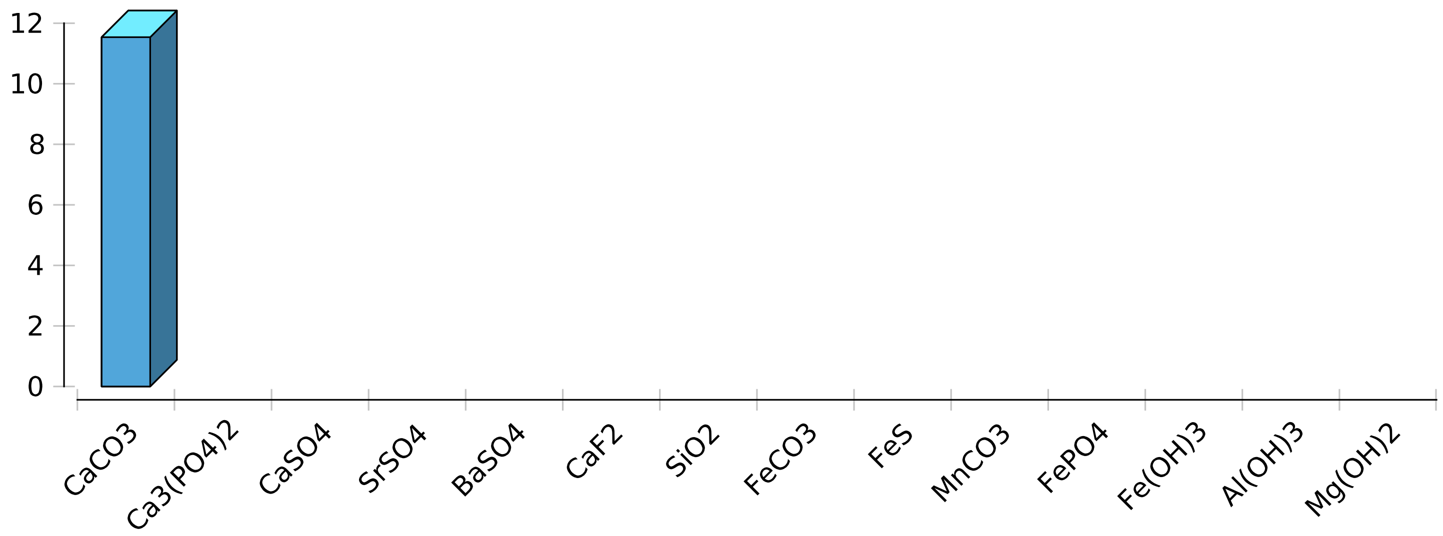
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	**Stage 1**	**Stage 2**
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	15.085	30.281
Net Driving Pressure:	psi	54.615	50.519
Req'd P/Stage:	psi	69.165	72.077
Feed P:	psi	78.066	72.077
Permeate Throttle/P:	psi	8.901	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	72.077	67.312

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		10.105	14.788	56.140	1.093	9.000	3.947	5.990	15.085	54.615
1	BW30LE-4040	0.934	16.398	10.375	1.094	9.000	8.066	1.613	7.797	60.562
2	BW30LE-4040	0.897	15.757	11.124	1.093	8.066	7.169	1.323	8.698	58.192
3	BW30LE-4040	0.862	15.136	12.023	1.093	7.169	6.307	1.067	9.796	55.900
4	BW30LE-4040	0.826	14.509	13.100	1.093	6.307	5.481	0.844	11.156	53.584
5	BW30LE-4040	0.788	13.841	14.381	1.093	5.481	4.693	0.652	12.874	51.118
6	BW30LE-4040	0.745	13.088	15.882	1.092	4.693	3.947	0.490	15.085	48.336
Stage2		4.295	12.570	54.400	1.127	7.895	3.600	4.764	30.274	50.519
1	BW30LE-4040	0.844	14.826	10.694	1.088	7.895	7.051	1.279	16.684	54.753
2	BW30LE-4040	0.797	13.992	11.301	1.086	7.051	6.254	1.043	18.600	51.676
3	BW30LE-4040	0.747	13.126	11.952	1.083	6.254	5.506	0.841	20.858	48.476
4	BW30LE-4040	0.695	12.200	12.617	1.080	5.506	4.812	0.669	23.521	45.058
5	BW30LE-4040	0.637	11.192	13.245	1.076	4.812	4.174	0.525	26.649	41.333
6	BW30LE-4040	0.574	10.084	13.756	1.071	4.174	3.600	0.407	30.274	37.242

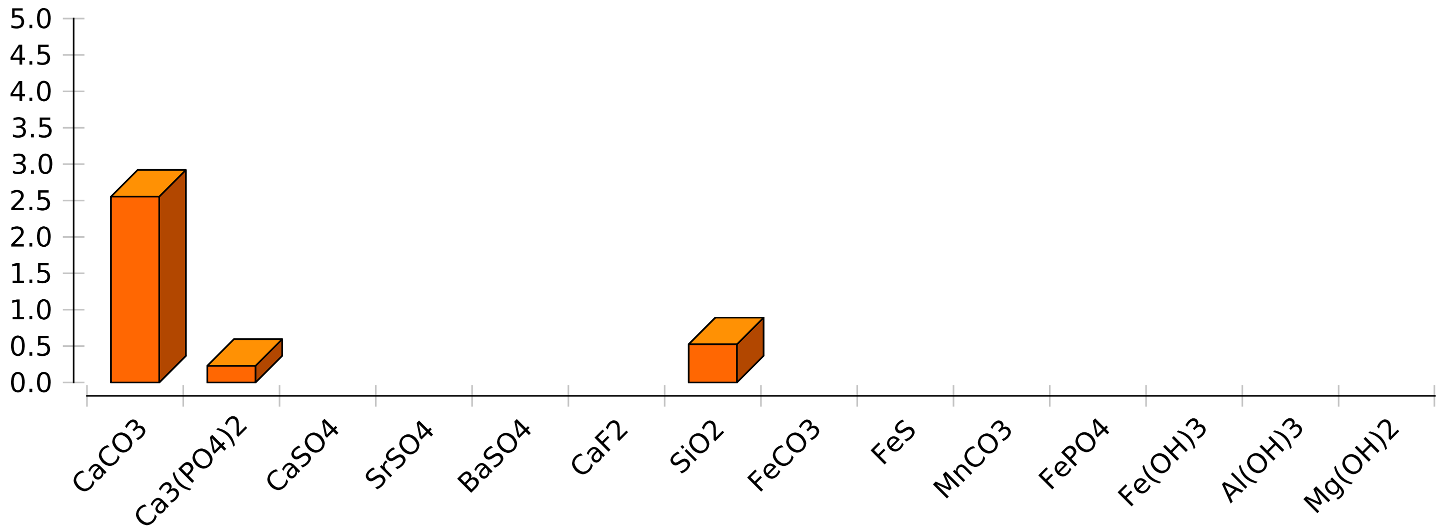
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
11.538	0	0	0	0	0	0	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
2.554	0.228	0	0	0	0	0.524	0	0	0	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	11.538	2.554	0.407
$MgCO_3$	0.000	0.527	-0.278
$SrCO_3$	0.000	0.120	-0.919
$BaCO_3$	0.000	0.000	0.000
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	0.000	0.228	-0.643
$Mg_3(PO4)_2$	0.000	0.000	-6.903
$Sr_3(PO4)_2$	0.000	0.000	-9.437
$Ba_3(PO4)_2$	0.000	0.000	0.000
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.000	-3.767

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.000	-3.417
$SrSO_4$	0.000	0.000	-3.401
$BaSO_4$	0.000	0.000	0.000

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-4.587
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-9.600

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Projection by:	**Robert McCandless**		AWC Proton 3.031.03
Client name:	BC		(release date: June 25, 2017)
Project:	DWPR / Pass2RO KMS SR200 Permeate 80pct		
Location:	United States / Arizona / Scottsdale		

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.025	-1.606
$Mg_3Si_2O_5(OH)_4$	0.000	0.000	-3.521
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	0.000	0.524	-0.281

Scales above 100% saturation	
$CaCO_3$	Saturation is 2.55 X; [Saturation Index is 0.41]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	0.407	< 2.300	OK
Mg(OH)2 SI	-4.587	< 9.200	OK
SiO2 (MSI)	0.000	< 10.000	OK
Antiscalant Precipitation Index (API)	7.321	< 9.900	OK
Ca3(PO4)2 SI (MPI)	-0.643	< 4.200	OK
CaSO4 SI	-3.417	< 0.500	OK
BaSO4 SI	0.000	< 3.000	OK
SrSO4 SI	-3.401	< 1.000	OK
LSI	0.782		OK
Stiff&Davis Index	1.031		OK

Chemical dosing:	AWC A-102 Ultra	HCL
Calculated Dosage:	0.600 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.600 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.037 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.130 lbs	0.000 lbs
Week	0.909 lbs	0.000 lbs
4 Weeks	3.634 lbs	0.000 lbs
Year	47.372 lbs	0.000 lbs
5 Years	236.862 lbs	0.000 lbs

Insert your additional comments below:

Comments...

Projections with KMS 4040-SR200 for Maximum Recovery

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO KMS SR200 Permeate 93.7pct
Location:	United States / Arizona / Scottsdale

AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Overall
Source:		Well Water (Brackish)
System Recovery:	%	93.744
Internal Recovery:	%	93.744
Temperature:	°F	86.000
Total permeate:	gal/min	16.874
Average Flux:	gfd	16.460

	Unit	Overall
Recycling flow:	gal/min	0.000
Fouling Factor:		1.000
Feed Pressure:	psi	108.571
Total Δ P Elements:	psi	6.606
Brine Pressure:	psi	101.975

Cations	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
Ca^{2+}	12.10	12.10	12.10	172.64	1.39
Mg^{2+}	2.10	2.10	2.10	29.96	0.24
Ba^{2+}	0.00	0.00	0.00	0.00	0.00
Sr^{2+}	0.13	0.13	0.13	1.83	0.01
Na^{+}	190.56	190.56	190.56	2582.15	30.96
K^{+}	15.00	15.00	15.00	203.25	2.44
Fe^{2+}	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00
Al^{3+}	0.00	0.00	0.00	0.00	0.00
Mn^{2+}	0.00	0.00	0.00	0.00	0.00
NH3/NH4(as N)	2.08	2.08	2.08	27.77	0.37

Anions	Raw water (mg/L)	Balanced Feed (mg/L)	Recycling + Feed (mg/L)	Reject (mg/L)	Permeate (mg/L)
HCO_3^- Alk($CaCO_3$)	50.00	49.93	49.93	658.83	7.98
CO_3^{2-} Alk($CaCO_3$)	0.00	0.16	0.16	40.15	0.00
Total Alk ($CaCO_3$)	50.00	50.09	50.09	698.98	7.98
Ortho-$PO4^3$	0.10	0.10	0.10	1.41	0.01
SO_4^{2-}	5.00	5.00	5.00	71.34	0.57
F^-	0.00	0.00	0.00	0.00	0.00
Cl^-	299.00	299.00	299.00	4058.30	48.12
Br^-	0.00	0.00	0.00	0.00	0.00
SiO_2	10.30	10.30	10.30	140.16	1.63
NO_3^--N	0.79	0.79	0.79	10.73	0.13
NO_2^--N	0.00	0.00	0.00	0.00	0.00
Sulfides (as S^2)	0.00	0.00	0.00	0.00	0.00
B	0.30	0.30	0.30	0.97	0.26
AS (III)	0.00	0.00	0.00	0.00	0.00
AS (V)	0.00	0.00	0.00	0.00	0.00
TDS:	600.690	600.690	600.690	8154.840	96.500
Conductivity (µs/cm):	1100.000	959.840	959.839	13034.855	153.965
pH:	7.350	7.350	7.350	8.360	6.580
Flow:	gal/min	18.000	0.000	1.130	16.870

Summary	Product:	Dosage:
pH adjusted using:	HCL	0.000 mg/L
Selected product:	AWC A-102 Ultra	0.600 mg/L

Projection by:	**Robert McCandless**
Client name:	BC
Project:	DWPR / Pass2RO KMS SR200 Permeate 93.7pct
Location:	United States / Arizona / Scottsdale

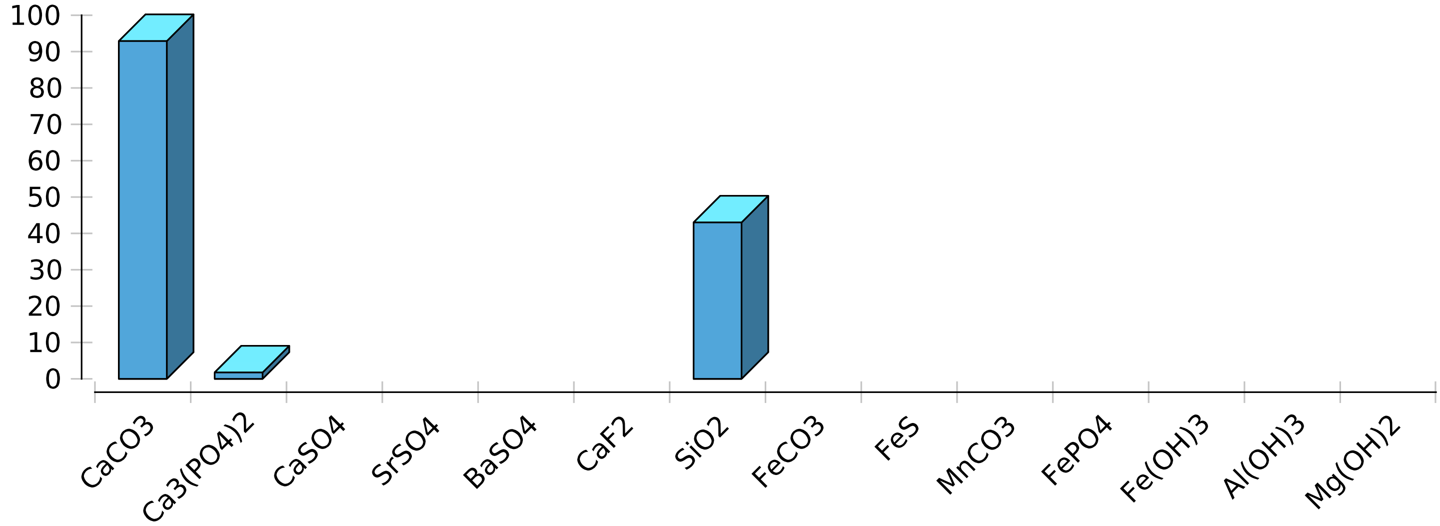
AWC Proton | 3.031.03
(release date: June 25, 2017)

	Unit	Stage 1	Stage 2
Total Elements:		12	6
Total Vessels:		2	1
Elements / Vessels:		6	6
Net Osmotic Pressure:	psi	22.114	93.175
Net Driving Pressure:	psi	67.554	57.421
Req'd P/Stage:	psi	84.496	103.460
Feed P:	psi	108.571	103.460
Permeate Throttle/P:	psi	24.075	0.000
Boost P:	psi	0.000	0.000
Concentrate P:	psi	103.460	101.975

Stages output

	Membrane Model:	Permeate Flow: gal/min	Average Flux: gfd	System Recovery: %	β	Feed Flow / PV: gal/min	Concentrate Flow / PV: gal/min	Δ P: psi	Osmotic P: psi	Net Driving P: psi
Stage1		12.499	18.291	69.440	1.124	9.000	2.750	5.111	22.110	67.554
1	BW30LE-4040	1.164	20.439	12.932	1.121	9.000	7.836	1.575	8.223	75.485
2	BW30LE-4040	1.122	19.707	14.321	1.122	7.836	6.714	1.220	9.529	72.781
3	BW30LE-4040	1.079	18.949	16.071	1.124	6.714	5.635	0.916	11.262	69.981
4	BW30LE-4040	1.030	18.090	18.281	1.126	5.635	4.605	0.660	13.644	66.810
5	BW30LE-4040	0.969	17.017	21.044	1.127	4.605	3.636	0.451	17.053	62.846
6	BW30LE-4040	0.885	15.547	24.351	1.125	3.636	2.750	0.289	22.110	57.419
Stage2		4.375	12.804	79.529	1.248	5.501	1.126	1.485	76.654	57.421
1	BW30LE-4040	1.186	20.830	21.563	1.149	5.501	4.315	0.613	28.460	76.929
2	BW30LE-4040	1.058	18.576	24.302	1.143	4.315	3.257	0.389	36.842	68.605
3	BW30LE-4040	0.891	15.641	26.650	1.130	3.257	2.366	0.231	48.672	57.764
4	BW30LE-4040	0.706	12.406	28.048	1.109	2.366	1.660	0.129	64.725	45.816
5	BW30LE-4040	0.420	7.374	21.657	1.065	1.660	1.240	0.073	76.654	27.234
6	BW30LE-4040	0.114	1.998	7.730	1.010	1.240	1.126	0.051	75.296	7.378

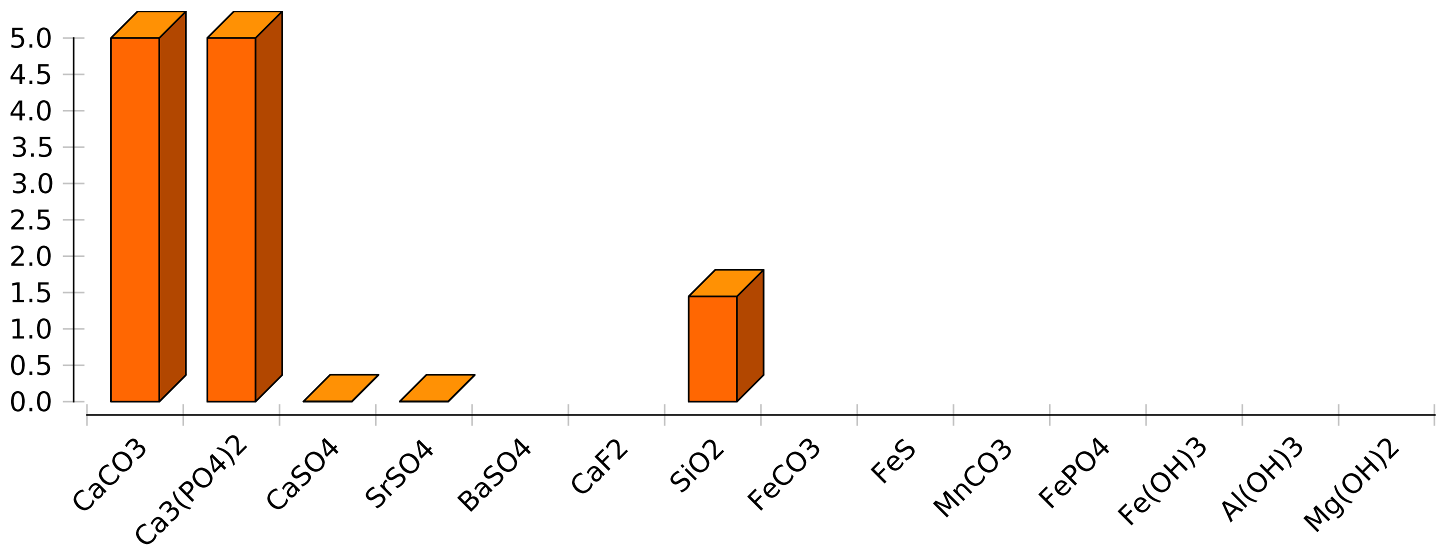
Summary Scale - Precipitation Potentials (mg/L)



Summary Scale - Precipitation Potentials (mg/L)

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
92.889	1.744	0	0	0	0	43.011	0	0	0	0	0	0	0

Summary Scale - X Saturation



Summary Scale - X Saturation

$CaCO_3$	$Ca_3(PO4)_2$	$CaSO_4$	$SrSO_4$	$BaSO_4$	CaF_2	SiO_2	$FeCO_3$	FeS	$MnCO_3$	$FePO_4$	$Fe(OH)_3$	$Al(OH)_3$	$Mg(OH)_2$
21.092	15.856	0.003	0.002	0	0	1.446	0	0	0	0	0	0	0

Carbonate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaCO_3$	92.889	21.092	1.324
$MgCO_3$	0.000	5.309	0.725
$SrCO_3$	0.266	1.125	0.051
$BaCO_3$	0.000	0.000	0.000
$FeCO_3$	0.000	0.000	0.000
$MnCO_3$	0.000	0.000	0.000

Phosphate Scales	Precipitation Potential	X Saturation	Saturation Index
$Ca_3(PO4)_2$	1.744	15.856	1.200
$Mg_3(PO4)_2$	0.000	0.000	-6.130
$Sr_3(PO4)_2$	0.000	0.000	-8.640
$Ba_3(PO4)_2$	0.000	0.000	0.000
$FeHPO_4$	0.000	0.000	0.000
$Fe_3(PO_4)_2$	0.000	0.000	0.000
$Mn_3(PO_4)_2$	0.000	0.000	0.000
$FePO_4$	0.000	0.000	0.000
$AlPO_4$	0.000	0.000	0.000
$MgNH_4PO_4.6H_2O$	0.000	0.001	-3.164

Sulfate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSO_4$	0.000	0.003	-2.462
$SrSO_4$	0.000	0.002	-2.604
$BaSO_4$	0.000	0.000	0.000

Fluoride Scales	Precipitation Potential	X Saturation	Saturation Index
CaF_2	0.000	0.000	0.000
MgF_2	0.000	0.000	0.000
SrF_2	0.000	0.000	0.000
BaF_2	0.000	0.000	0.000
FeF_2	0.000	0.000	0.000

Metal Hydroxide and Oxide Scales	Precipitation Potential	X Saturation	Saturation Index
$Mg(OH)_2$	0.000	0.000	-3.552
$Fe(OH)_2$	0.000	0.000	0.000
$Mn(OH)_2$	0.000	0.000	0.000
$Fe(OH)_3$	0.000	0.000	0.000
MnO_2	0.000	0.000	0.000
$Al(OH)_3$	0.000	0.000	0.000
$Ca(OH)_2$	0.000	0.000	-8.614

Sulfide Scales	Precipitation Potential	X Saturation	Saturation Index
FeS	0.000	0.000	0.000
MnS	0.000	0.000	0.000

Silicate Scales	Precipitation Potential	X Saturation	Saturation Index
$CaSiO_3.H_2O$	0.000	0.000	0.000
$MgSiO_3.H_2O$	0.000	0.200	-0.700
$Mg_3Si_2O_5(OH)_4$	0.000	0.203	-0.692
$Al_2Si_2O_5(OH)_4$	0.000	0.000	0.000
Na_2F_6Si	0.000	0.000	0.000
SiO_2	43.011	1.446	0.160

Scales above 100% saturation	
$CaCO_3$	Saturation is 21.09 X; [Saturation Index is 1.32]
$MgCO_3$	Saturation is 5.31 X; [Saturation Index is 0.73]
$SrCO_3$	Saturation is 1.12 X; [Saturation Index is 0.05]
$Ca_3(PO_4)_2$	Saturation is 15.86 X; [Saturation Index is 1.20]
SiO_2	Saturation is 1.45 X; [Saturation Index is 0.16]

Critical Indices		Guideline	Status
CaCO3 SI (CCNI)	1.324	< 2.300	OK
Mg(OH)2 SI	-3.552	< 9.200	OK
SiO2 (MSI)	9.293	< 10.000	OK
Antiscalant Precipitation Index (API)	8.515	< 9.900	OK
Ca3(PO4)2 SI (MPI)	1.200	< 4.200	OK
CaSO4 SI	-2.462	< 0.500	OK
BaSO4 SI	0.000	< 3.000	OK
SrSO4 SI	-2.604	< 1.000	OK
LSI	2.027		OK
Stiff&Davis Index	2.032		OK

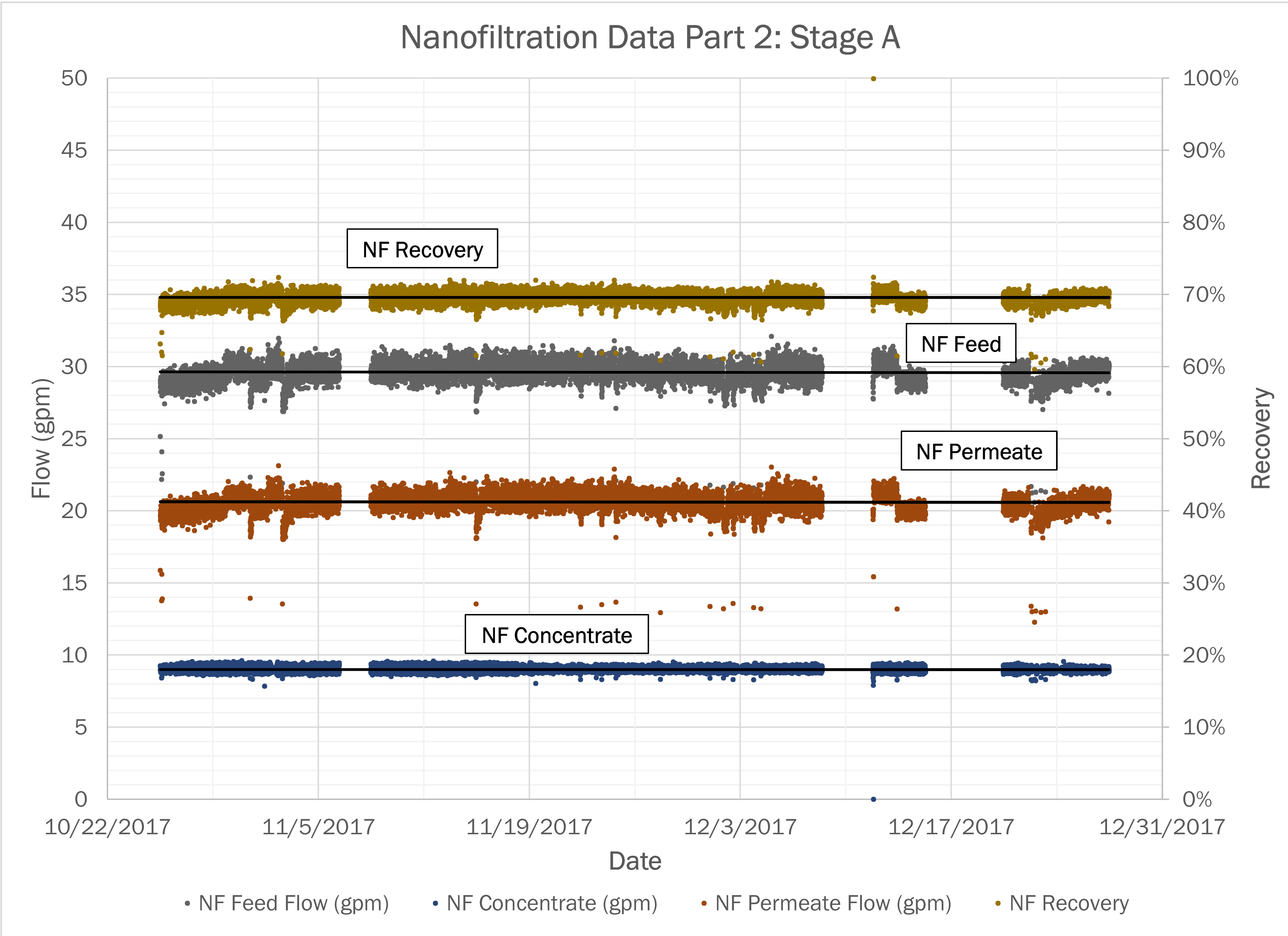
Chemical dosing:	AWC A-102 Ultra	HCL
Calculated Dosage:	0.600 mg/L	0.000 mg/L
Total Dosage (modified by user):	0.600 mg/L	N/A
% Concentration:	N/A	37.000%
Density:	1.120 g/cm3	1.184 g/cm3
Dosing Pump:	0.037 ml/min	0.000 ml/min
Hours of Operation/Day:	24 hour(s)	24 hour(s)
Consumption per:		
Day	0.130 lbs	0.000 lbs
Week	0.909 lbs	0.000 lbs
4 Weeks	3.634 lbs	0.000 lbs
Year	47.372 lbs	0.000 lbs
5 Years	236.862 lbs	0.000 lbs

Insert your additional comments below:

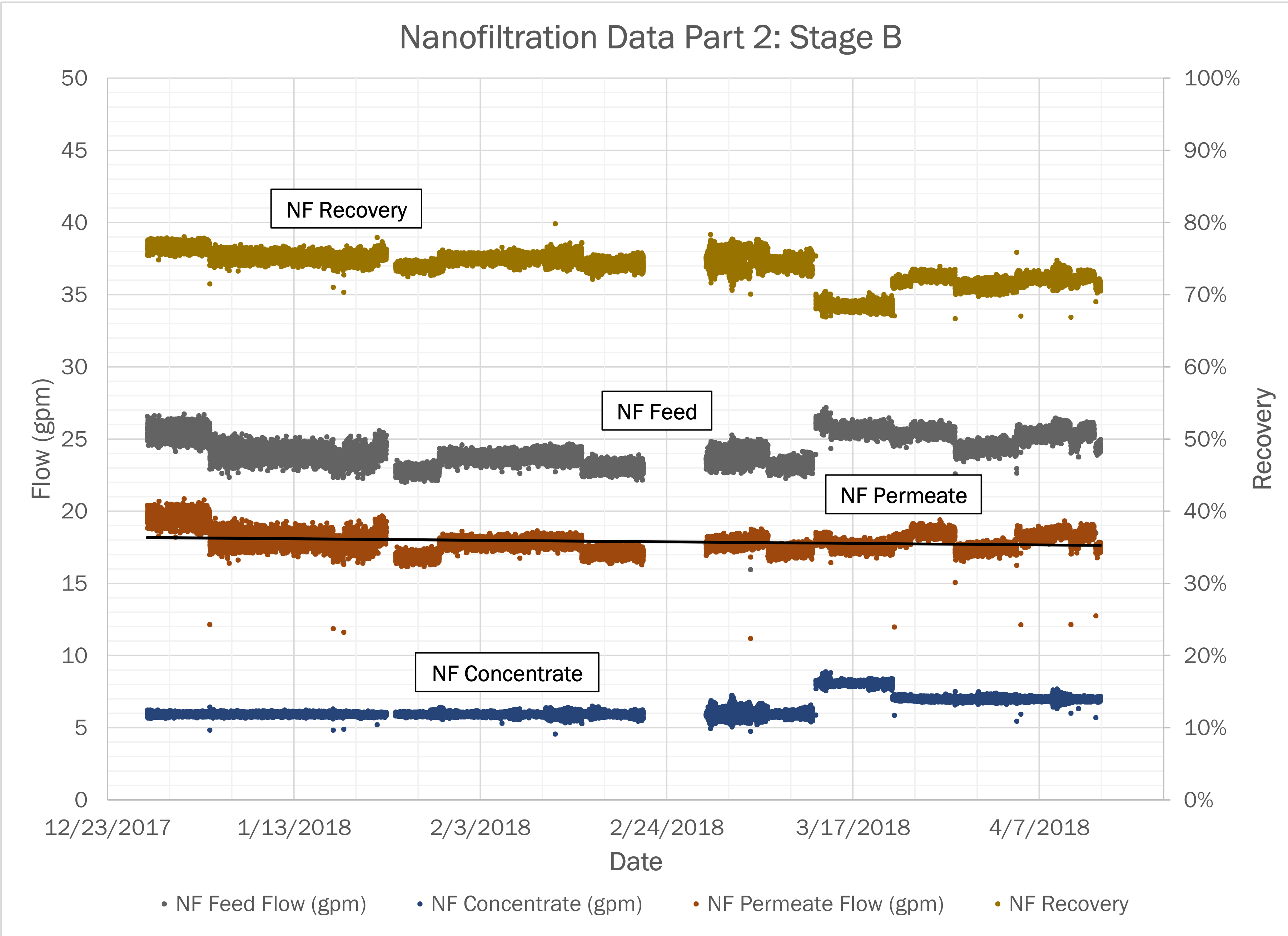
Comments...

APPENDIX C

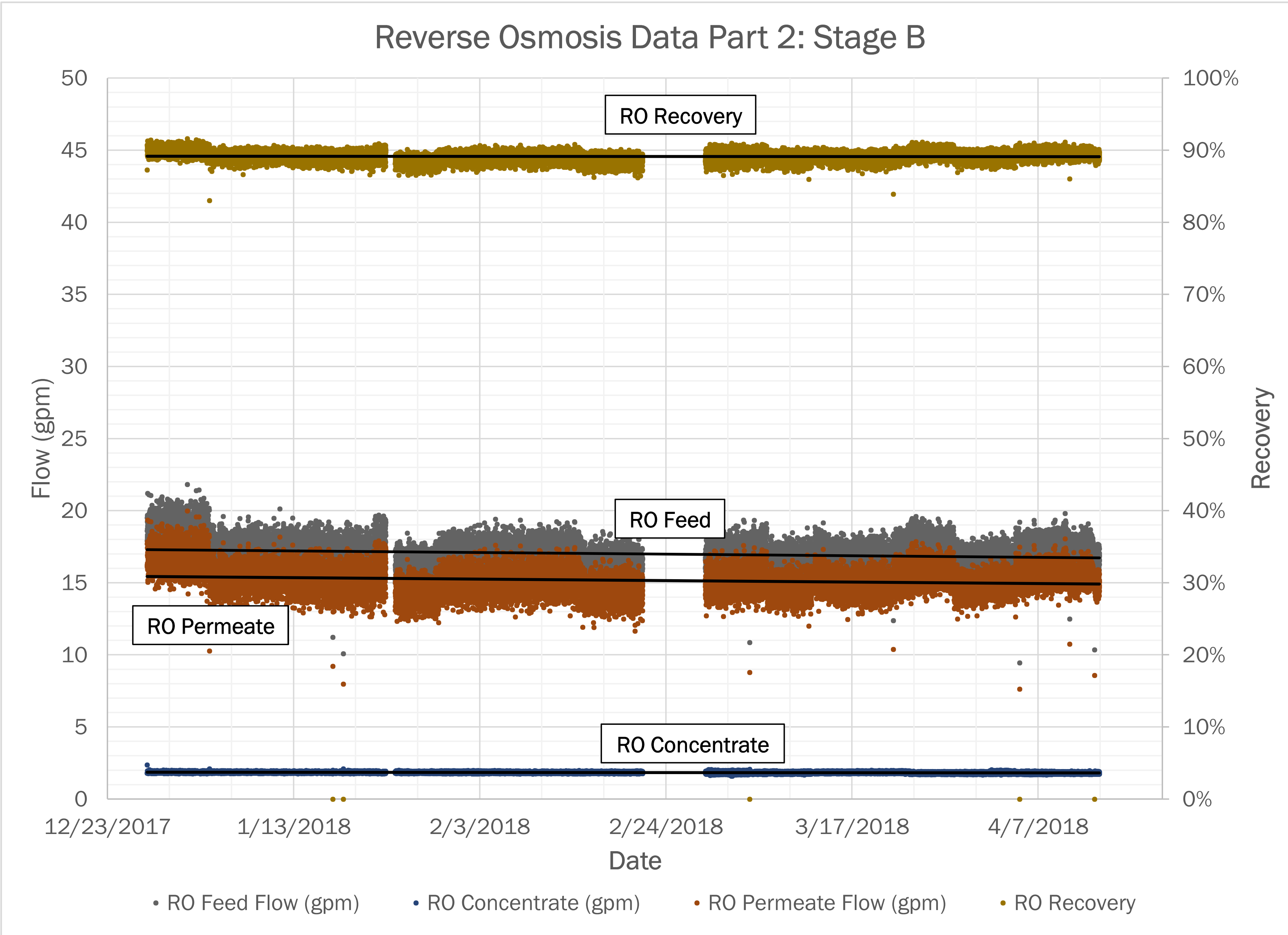
Part 2: Phases A and B Pilot Operational Data



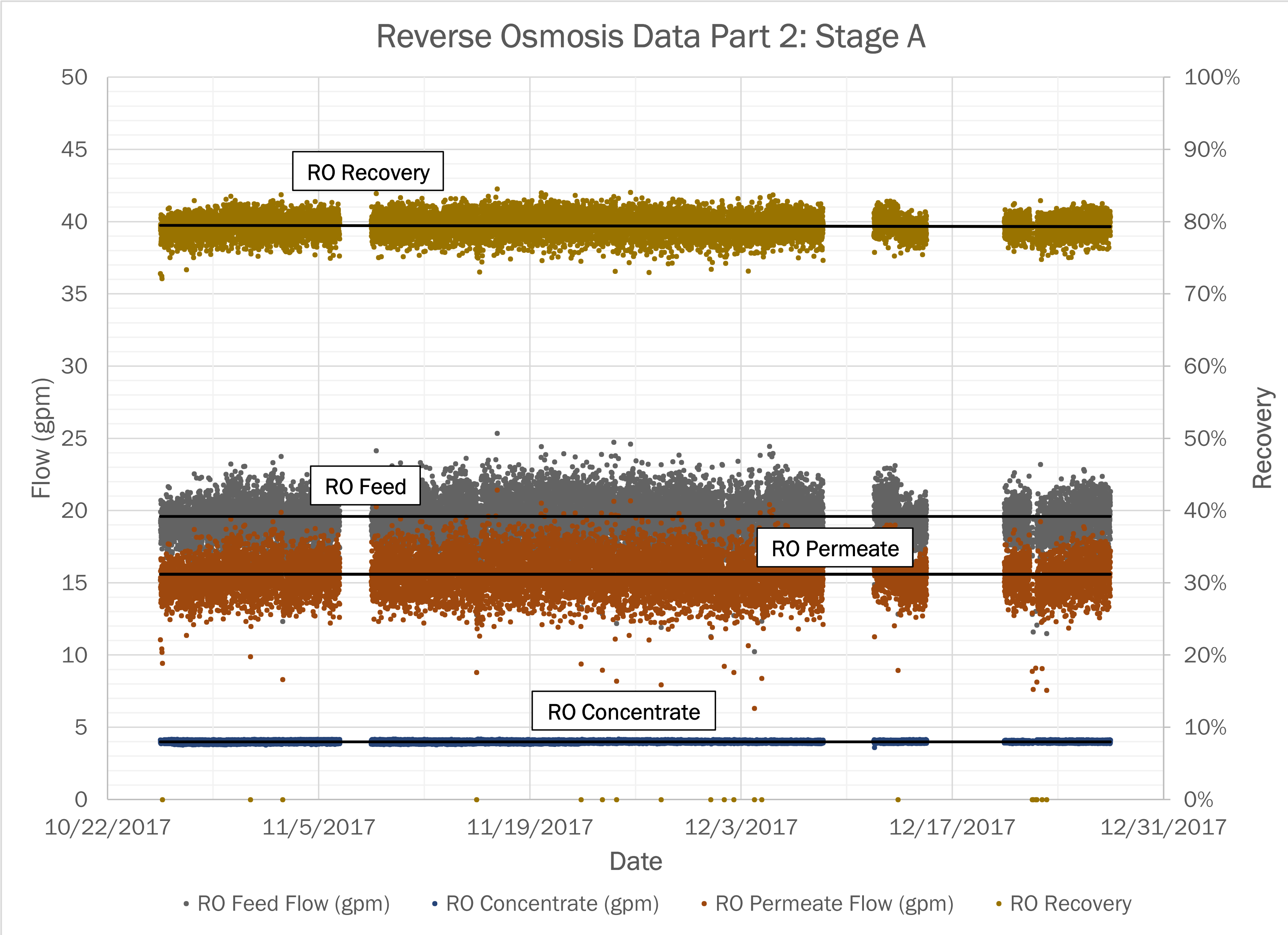
Nanofiltration Data Part 2: Stage A
NF Recovery
NF Feed
NF Permeate
NF Concentrate
Flow (gpm)
Recovery
Date
50
45
40
35
30
25
20
15
10
5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10/22/2017
11/5/2017
11/19/2017
12/3/2017
12/17/2017
12/31/2017
NF Feed Flow (gpm)
NF Concentrate (gpm)
NF Permeate Flow (gpm)
NF Recovery



Nanofiltration Data Part 2: Stage B
NF Recovery
NF Feed
NF Permeate
NF Concentrate
Flow (gpm)
Recovery
Date
50
45
40
35
30
25
20
15
10
5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
12/23/2017
1/13/2018
2/3/2018
2/24/2018
3/17/2018
4/7/2018
NF Feed Flow (gpm)
NF Concentrate (gpm)
NF Permeate Flow (gpm)
NF Recovery



Reverse Osmosis Data Part 2: Stage B
RO Recovery
RO Feed
RO Permeate
RO Concentrate
Flow (gpm)
Recovery
Date
0
5
10
15
20
25
30
35
40
45
50
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
12/23/2017
1/13/2018
2/3/2018
2/24/2018
3/17/2018
4/7/2018
RO Feed Flow (gpm)
RO Concentrate (gpm)
RO Permeate Flow (gpm)
RO Recovery


Reverse Osmosis Data Part 2: Stage A
RO Recovery
RO Feed
RO Permeate
RO Concentrate
Flow (gpm)
Recovery
Date
50
45
40
35
30
25
20
15
10
5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10/22/2017
11/5/2017
11/19/2017
12/3/2017
12/17/2017
12/31/2017
RO Feed Flow (gpm)
RO Concentrate (gpm)
RO Permeate Flow (gpm)
RO Recovery

APPENDIX D

Part 2: Phases A and B Water Quality Summary

Laboratory Sample Data Summary

Part 2: Stage A (October 18, 2017 to December 20, 2017)

		Sample Count						Average						Maximum						Minimum					
Analyte Name	Units	Total	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend
Acetaminophen	ng/L	6	1	1	1	1	1	1.8	0.0	4.4	0.0	1.4	2.4	1.8	0.0	4.4	0.0	1.4	2.4	1.8	0.0	4.4	0.0	1.4	2.4
Alkalinity, Bicarbonate	mg/L	18	3	3	3	3	3	152.7	44.7	368.7	0.0	204.0	159.3	158.0	46.0	386.0	0.0	210.0	174.0	148.0	44.0	352.0	0.0	196.0	148.0
Alkalinity, Total	mg/L	60	10	10	10	10	10	153.8	44.8	386.6	0.0	202.2	150.8	162.0	48.0	412.0	0.0	212.0	174.0	136.0	42.0	348.0	0.0	182.0	128.0
Atrazine	ng/L	6	1	1	1	1	1	0.0	4.0	1.2	0.0	0.0	0.0	0.0	4.0	1.2	0.0	0.0	0.0	0.0	4.0	1.2	0.0	0.0	0.0
Barium, Ba	mg/L	54	9	9	9	9	9	0.1	0.0	0.3	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.1	0.1	0.1	0.0	0.3	0.0	0.0	0.1
Boron, B	mg/L	54	9	9	9	9	9	0.3	0.3	0.4	0.2	0.6	0.3	0.4	0.3	0.4	0.3	0.7	0.3	0.3	0.3	0.3	0.2	0.5	0.3
Caffeine	ng/L	6	1	1	1	1	1	7.9	7.1	13.2	6.4	7.6	7.7	7.9	7.1	13.2	6.4	7.6	7.7	7.9	7.1	13.2	6.4	7.6	7.7
Calcium, Ca	mg/L	54	9	9	9	9	9	79.6	12.1	223.0	0.0	59.1	83.7	81.8	13.7	236.0	0.0	67.3	87.6	76.2	10.7	214.0	0.0	53.2	79.6
Carbamazepine	ng/L	6	1	1	1	1	1	2.8	0.0	12.4	10.4	1.5	4.1	2.8	0.0	12.4	10.4	1.5	4.1	2.8	0.0	12.4	10.4	1.5	4.1
Carbon, Total Organic, TOC	mg/L	12	2	2	2	2	2	2.5	0.3	5.5	0.0	0.9	3.4	2.6	0.5	5.8	0.0	1.1	3.6	2.3	0.0	5.1	0.0	0.8	3.2
Chloride, Cl	mg/L	57	10	10	9	9	9	375.1	267.8	475.2	0.0	1238.7	226.9	415.0	297.0	674.0	0.0	1490.0	248.0	344.0	245.0	13.0	0.0	498.0	214.0
Cotinine	ng/L	6	1	1	1	1	1	39.8	4.4	174.0	4.6	19.7	45.4	39.8	4.4	174.0	4.6	19.7	45.4	39.8	4.4	174.0	4.6	19.7	45.4
DEET	ng/L	6	1	1	1	1	1	71.4	19.0	222.0	27.8	59.8	72.1	71.4	19.0	222.0	27.8	59.8	72.1	71.4	19.0	222.0	27.8	59.8	72.1
Diazepam	ng/L	6	1	1	1	1	1	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0
Diclofenac	ng/L	6	1	1	1	1	1	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Dilantin	ng/L	6	1	1	1	1	1	21.1	2.3	89.8	6.5	9.2	20.6	21.1	2.3	89.8	6.5	9.2	20.6	21.1	2.3	89.8	6.5	9.2	20.6
Diuron	ng/L	6	1	1	1	1	1	3.8	3.3	7.9	0.0	13.6	3.0	3.8	3.3	7.9	0.0	13.6	3.0	3.8	3.3	7.9	0.0	13.6	3.0
Estradiol	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Estrone	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethinylestradiol	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluoxetine	ng/L	6	1	1	1	1	1	18.2	3.0	73.8	8.2	8.1	20.8	18.2	3.0	73.8	8.2	8.1	20.8	18.2	3.0	73.8	8.2	8.1	20.8
Gemfibrozil	ng/L	6	1	1	1	1	1	0.0	0.0	2.2	1.8	0.0	0.0	0.0	0.0	2.2	1.8	0.0	0.0	0.0	0.0	2.2	1.8	0.0	0.0
Hydrocodone	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ibuprofen	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iron, Fe	mg/L	54	9	9	9	9	9	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Magnesium, Mg	mg/L	54	9	9	9	9	9	28.2	2.0	80.2	0.0	9.8	31.7	29.3	2.5	84.5	0.0	12.8	33.3	27.0	1.7	77.8	0.0	8.5	29.7
Manganese, Mn	mg/L	54	9	9	9	9	9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Meprobamate	ng/L	6	1	1	1	1	1	137.0	14.3	456.0	20.3	68.1	147.0	137.0	14.3	456.0	20.3	68.1	147.0	137.0	14.3	456.0	20.3	68.1	147.0
Naproxen	ng/L	6	1	1	1	1	1	5.4	1.0	6.1	3.4	6.1	5.2	5.4	1.0	6.1	3.4	6.1	5.2	5.4	1.0	6.1	3.4	6.1	5.2
Nitrate, NO3	mg/L	45	8	8	7	7	7	4.9	5.0	3.8	0.3	18.6	2.0	8.2	8.3	8.2	0.5	36.5	3.1	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen, Ammonia, N	mg/L	12	2	2	2	2	2	1.1	1.0	1.5	0.1	3.2	1.0	1.3	1.2	1.8	0.3	4.0	1.3	1.0	0.8	1.2	0.0	2.4	0.7
Nitrogen, Total Kjeldahl, TKN	mg/L	6	1	1	1	1	1	1.8	1.0	4.0	0.6	3.1	1.5	1.8	1.0	4.0	0.6	3.1	1.5	1.8	1.0	4.0	0.6	3.1	1.5
Orthophosphate as P	mg/L	12	2	2	2	2	2	2.1	0.0	6.9	0.0	1.7	2.5	2.4	0.0	8.2	0.0	2.2	2.6	1.7	0.0	5.7	0.0	1.2	2.3
Oxybenzone	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potassium, K	mg/L	54	9	9	9	9	9	24.8	15.9	44.0	0.0	76.0	16.4	26.0	16.0	47.0	0.0	78.0	18.0	24.0	15.0	42.0	0.0	74.0	16.0
Primidone	ng/L	6	1	1	1	1	1	111.0	7.5	346.0	21.8	33.0	126.0	111.0	7.5	346.0	21.8	33.0	126.0	111.0	7.5	346.0	21.8	33.0	126.0
Progesterone	ng/L	6	1	1	1	1	1	0.0	0.0	1.2	1.2	0.0	0.0	0.0	0.0	1.2	1.2	0.0	0.0	0.0	0.0	1.2	1.2	0.0	0.0
Residue, Total Dissolved	mg/L	12	2	2	2	2	2	1163.0	543.0	2601.0	0.0	2683.0	932.0	1206.0	598.0	2674.0	0.0	2974.0	992.0	1120.0	488.0	2528.0	0.0	2392.0	872.0
Silica, as SiO2	mg/L	54	9	9	9	9	9	11.7	9.9	15.5	0.0	48.1	5.8	13.1	10.8	17.6	0.0	55.0	6.9	11.0	9.5	14.5	0.0	44.9	5.3
Sodium, Na	mg/L	60	10	10	10	10	10	250.9	158.0	475.5	3.9	813.6	159.5	265.0	168.0	499.0	5.0	850.0	168.0	241.0	150.0	446.0	3.0	768.0	149.0
Strontium, Sr	mg/L	54	9	9	9	9	9	1.1	0.1	3.3	0.0	0.6	1.2	1.2	0.1	3.5	0.0	0.7	1.3	1.1	0.1	3.2	0.0	0.5	1.2
Sucralose	ng/L	6	1	1	1	1	1	20800.0	2370.0	65700.0	4880.0	9670.0	25300.0	20800.0	2370.0	65700.0	4880.0	9670.0	25300.0	20800.0	2370.0	65700.0	4880.0	9670.0	25300.0
Sulfamethoxazole	ng/L	6	1	1	1	1	1	7.3	2.7	30.5	3.0	2.6	8.5	7.3	2.7	30.5	3.0	2.6	8.5	7.3	2.7	30.5	3.0	2.6	8.5
Sulfate, SO4	mg/L	57	10	10	9	9	9	239.2	3.5	576.7	0.0	49.9	274.7	261.0	13.0	814.0	0.0	71.0	295.0	223.0	0.0	17.0	0.0	21.0	249.0
Testosterone	ng/L	6	1	1	1	1	1	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0
Triclosan	ng/L	6	1	1	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trimethoprim	ng/L	6	1	1	1	1	1	0.0	0.0	4.2	0.0	0.0	1.3	0.0	0.0	4.2	0.0	0.0	1.3	0.0	0.0	4.2	0.0	0.0	1.3

Laboratory Sample Data Summary

Part 2: Stage B (December 27, 2017 to April 11, 2018)

		Count						Average						Maximum						Minimum					
Analyte Name	Units	Total	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend	NF Feed	NF Perm	NF Conc	RO Perm	RO Conc	Blend
Acetaminophen	ng/L	24	4	4	4	4	4	0.3	0.7	4.6	0.0	3.2	1.4	1.2	1.7	15.5	0.0	12.7	4.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity, Bicarbonate	mg/L	36	6	6	6	6	6	161.3	61.0	445.0	0.0	520.0	130.7	182.0	68.0	480.0	0.0	600.0	154.0	148.0	58.0	392.0	0.0	464.0	114.0
Alkalinity, Total	mg/L	90	15	15	15	15	15	159.3	60.4	435.3	0.0	508.8	128.5	196.0	70.0	512.0	0.0	600.0	166.0	144.0	54.0	390.0	0.0	462.0	110.0
Atrazine	ng/L	24	4	4	4	4	4	4.7	0.0	0.0	0.0	0.0	0.0	18.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barium, Ba	mg/L	81	14	13	13	14	13	0.1	0.0	0.3	0.0	0.1	0.1	0.1	0.0	0.4	0.0	0.2	0.1	0.1	0.0	0.2	0.0	0.1	0.1
Boron, B	mg/L	79	14	13	13	14	13	0.4	0.3	0.4	0.3	0.9	0.3	0.4	0.4	0.4	0.3	1.0	0.3	0.3	0.3	0.3	0.3	0.8	0.3
Caffeine	ng/L	24	4	4	4	4	4	82.6	19.6	230.2	7.5	170.1	79.0	236.0	53.0	663.0	21.4	505.0	223.0	24.7	5.8	58.0	1.4	49.8	22.8
Calcium, Ca	mg/L	81	14	13	13	14	13	81.8	18.4	252.2	0.0	165.5	74.1	87.6	21.0	286.0	0.0	186.0	80.5	72.9	14.8	187.0	0.0	147.0	64.2
Carbamazepine	ng/L	23	4	4	4	4	4	142.9	17.5	436.0	0.0	143.5	141.8	221.0	25.1	615.0	0.0	220.0	205.0	39.5	4.6	119.0	0.0	42.8	33.4
Carbon, Total Organic, TOC	mg/L	23	4	4	4	4	4	3.6	0.3	12.3	0.1	2.4	5.8	6.0	1.1	26.5	0.4	6.8	8.8	2.7	0.0	7.0	0.0	0.9	4.2
Chloride, Cl	mg/L	91	15	15	15	16	15	392.6	316.6	601.8	0.7	2827.3	179.9	464.0	377.0	677.0	6.1	3370.0	226.0	352.0	276.0	539.0	0.0	2500.0	157.0
Cotinine	ng/L	24	4	4	4	4	4	68.4	7.9	269.5	0.0	73.1	66.2	85.7	10.4	379.0	0.0	116.0	74.6	54.4	5.3	199.0	0.0	43.7	55.9
DEET	ng/L	23	4	4	4	4	4	170.5	30.7	488.0	7.7	222.3	178.7	234.0	39.4	686.0	10.0	326.0	279.0	137.0	21.8	382.0	5.6	174.0	118.0
Diazepam	ng/L	24	4	4	4	4	4	3.0	0.0	8.0	0.0	0.8	2.6	5.9	0.0	14.7	0.0	1.8	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Diclofenac	ng/L	23	4	4	4	4	4	1.6	0.9	4.6	0.0	11.1	45.3	4.6	3.6	15.2	0.0	41.3	131.0	0.0	0.0	0.0	0.0	0.0	0.0
Dilantin	ng/L	24	4	4	4	4	4	54.6	5.6	183.8	0.0	49.0	51.1	74.4	6.6	309.0	0.0	64.5	84.1	42.4	5.0	130.0	0.0	32.4	35.9
Diuron	ng/L	23	4	4	4	4	4	24.3	22.9	42.6	1.8	154.8	8.0	26.3	27.6	56.9	2.7	190.0	12.7	22.1	18.8	26.7	1.4	124.0	0.0
Estradiol	ng/L	24	4	4	4	4	4	0.5	0.0	3.0	0.0	0.0	0.5	1.9	0.0	8.2	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Estrone	ng/L	24	4	4	4	4	4	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethinylestradiol	ng/L	24	4	4	4	4	4	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluoxetine	ng/L	24	4	4	4	4	4	50.3	3.5	145.4	0.3	29.7	45.2	67.7	6.0	200.0	1.3	47.6	56.7	27.0	2.5	91.5	0.0	20.6	22.3
Gemfibrozil	ng/L	24	4	4	4	4	4	101.1	3.1	320.7	0.0	31.4	82.7	288.0	6.4	879.0	0.0	62.2	216.0	20.2	0.0	74.9	0.0	5.6	21.5
Hydrocodone	ng/L	24	4	4	4	4	4	6.8	0.0	22.8	0.0	0.4	8.0	23.8	0.0	79.2	0.0	1.7	25.6	0.0	0.0	0.0	0.0	0.0	0.0
Ibuprofen	ng/L	24	4	4	4	4	4	9.4	1.0	30.3	0.0	2.3	10.8	17.0	3.9	48.7	0.0	9.1	20.6	3.7	0.0	16.1	0.0	0.0	0.0
Iron, Fe	mg/L	81	14	13	13	14	13	0.1	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0
Magnesium, Mg	mg/L	81	14	13	13	14	13	29.0	2.8	93.7	0.0	25.6	29.2	30.5	3.6	102.0	0.0	33.1	31.1	27.0	2.4	77.5	0.0	20.8	27.2
Manganese, Mn	mg/L	81	14	13	13	14	13	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Meprobamate	ng/L	24	4	4	4	4	4	190.8	20.3	580.5	0.0	172.5	189.8	199.0	22.4	679.0	0.0	178.0	206.0	170.0	17.7	474.0	0.0	169.0	181.0
Naproxen	ng/L	24	4	4	4	4	4	202.0	8.4	606.2	0.0	65.5	205.3	746.0	26.8	2380.0	0.0	248.0	793.0	1.0	0.0	0.0	0.0	0.0	0.0
Nitrate, NO3	mg/L	30	5	5	5	5	5	5.8	6.0	6.0	0.6	46.5	1.8	9.5	9.7	8.6	0.9	73.4	2.8	2.9	3.1	4.4	0.4	23.6	1.1
Nitrogen, Ammonia, N	mg/L	24	4	4	4	4	4	3.1	2.4	4.2	0.5	19.4	1.4	5.4	4.0	8.5	1.0	38.3	2.6	1.1	0.9	1.4	0.2	6.5	0.6
Nitrogen, Total Kjeldahl, TKN	mg/L	24	4	4	4	4	4	3.6	2.0	6.9	0.0	18.4	2.4	6.5	4.2	12.6	0.0	39.6	4.2	2.1	0.9	4.5	0.0	6.2	1.4
Orthophosphate as P	mg/L	24	4	4	4	4	4	1.5	0.0	6.7	0.0	2.5	1.6	2.4	0.0	10.3	0.0	3.7	2.5	0.2	0.0	0.0	0.0	0.0	0.2
Oxybenzone	ng/L	24	4	4	4	4	4	37.2	27.5	239.6	15.3	205.2	35.9	68.0	72.1	686.0	48.2	416.0	74.2	0.0	0.0	14.3	0.0	18.1	0.0
Potassium, K	mg/L	81	14	13	13	14	13	24.9	17.8	44.8	0.0	160.0	13.1	27.0	19.0	49.0	0.0	169.0	14.0	24.0	16.0	39.0	0.0	140.0	12.0
Primidone	ng/L	24	4	4	4	4	4	266.3	13.1	894.0	0.0	110.0	262.0	307.0	17.7	994.0	0.0	147.0	310.0	236.0	10.5	754.0	0.0	89.9	207.0
Progesterone	ng/L	24	4	4	4	4	4	0.3	0.0	1.3	0.0	0.3	0.3	1.0	0.0	3.3	0.0	1.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Residue, Total Dissolved	mg/L	35	6	6	6	6	6	1189.0	628.3	2855.8	18.7	5900.0	806.4	1226.0	662.0	2980.0	32.0	6230.0	844.0	1152.0	572.0	2755.0	0.0	5644.0	750.0
Silica, as SiO2	mg/L	81	14	13	13	14	13	10.3	9.1	13.6	0.0	81.4	4.2	13.8	12.0	17.5	0.0	106.0	6.1	8.0	6.8	10.7	0.0	63.7	3.2
Sodium, Na	mg/L	81	14	13	13	14	13	261.0	189.9	478.4	6.6	1691.5	138.0	291.0	229.0	531.0	9.0	1930.0	163.0	238.0	156.0	406.0	5.0	1320.0	125.0
Strontium, Sr	mg/L	81	14	13	13	14	13	1.1	0.2	3.8	0.0	1.7	1.1	1.3	0.2	4.4	0.0	1.9	1.2	1.0	0.2	2.7	0.0	1.5	0.9
Sucralose	ng/L	24	4	4	4	4	4	35150.0	2105.0	109675.0	22.2	14100.0	40600.0	44400.0	3480.0	137000.0	37.6	17700.0	54500.0	23100.0	1160.0	55700.0	0.0	10200.0	23500.0
Sulfamethoxazole	ng/L	24	4	4	4	4	4	315.4	16.7	1013.0	0.0	150.9	302.7	1030.0	50.0	3260.0	0.0	449.0	983.0	44.0	2.3	113.0	0.0	18.4	45.8
Sulfate, SO4	mg/L	91	15	16	15	15	15	241.3	6.6	880.8	0.0	90.4	252.3	291.0	22.0	1040.0	0.0	223.0	320.0	184.0	0.0	570.0	0.0	16.0	196.0
Testosterone	ng/L	24	4	4	4	4	4	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	10.9	0.0	0.0	0.0	0.0	0.0	0.0
Triclosan	ng/L	24	4	4	4	4	4	3.0	0.0	6.5	0.0	0.0	0.0	12.1	0.0	25.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trimethoprim	ng/L	24	4	4	4	4	4	128.6	9.1	413.6	0.0	79.7	129.3	438.0	31.2	1410.0	0.0	259.0	445.0	14.2	0.0	39.4	0.0	7.6	12.1

APPENDIX E

Part 2: Membrane Autopsy Report

Membrane Autopsy Report

Completed for:

Brown & Caldwell

Scottsdale Water Campus

Serial Number C7520230

P2-S2-5

06/25/2018 WO#053018-5

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Table of Contents

Executive Summary

Background

Brown & Caldwell provided 6 Koch SR200-4040 nanofiltration (NF) and 12 Hydranautics ESPA4-LD-4040 reverse osmosis (RO) membrane elements from Scottsdale Water Campus to Avista Technologies wet testing. Element Serial Number (SN) KM8048229-7015 (Koch SR200-4040) and SN C7520230 (Hydranautics ESPA4-LD-4040) were selected for dissection and analysis to identify foulant constituents, as well as other causes for loss of performance. SN KM8048229-7015 was noted as position “P1-6” while SN C7520230 came from position “P2-S2-5”. The remainder of this report pertains to SN C7520230 (P2-S2-5).

Initial Element Testing

The element produced lower than normal flow (90% of normal), lower than normal rejection (91.0%) and a differential pressure of 4 psi. The element passed integrity testing, indicating the absence of damage to the internal components of the spiral wound element.

External Inspection

The fiberglass casing, brine seal and permeate tube displayed no visible damages. The feed (brine seal end) and concentrate (opposite brine seal) ATDs were in good condition.

Internal Inspection

The feed scroll end had uneven discoloration along the glue line of one leaf and possessed brown-colored, granular particles deposited on the surface. A piece of thin, flaky plastic was blocking part of the feed channels. The concentrate scroll end also possessed brown-colored granular material in the flow channels. The exposed membrane surfaces were virtually free of any visible or removable foulant material. Obvious signs of physical damage (e.g. abrasion, delamination) were not present. The feed spacers were in good condition and clear of foulant material. The glue lines possessed discoloration (as observed on the feed scroll end) but displayed no clear signs of performance-affecting defects or damages. Visible foulant was not observed on the permeate spacers or membrane backings.

Cell Testing Results

Flat sheet samples harvested from the full element produced 96% of normal water passage and normal salt passage upon baseline cell testing.

Foulant Analysis

As there was no removable foulant material on the membrane surface, foulant density determination and loss on ignition testing to determine organic content were non-applicable. Acid testing performed on the membrane surface was negative for the presence of carbonates and no visible color change - which is associated with the presence of metals - occurred. Microscope imaging could not be performed due to the absence of foulant. Fourier-Transform Infrared (FT-IR) spectroscopy performed directly on a sample of the membrane detected only peaks representative of the membrane structure components (e.g. polysulfone).

The Energy Dispersive Spectroscopy (EDS) analysis performed on the membrane surface detected only carbon, oxygen and sulfur. Carbon can be contributed by the presence of foreign organics but is also a component of the membrane materials. The sulfur weight percentage (5.60 wt%) is associated with the membrane support layer (polysulfone) and suggests no masking of the membrane surface as analysis of new membranes usually detects between 5.00 and 7.00 weight percent of sulfur. Foreign inorganic elements were not present. Scanning Electron Microscope (SEM) imaging (500x) revealed that the membrane surface was predominantly free of foulant material. Only traces of particulate materials were observed. Close-up (1000x) imaging displayed topography representative of the membrane surface itself. Chromatic Elemental Imaging^{SM} (CEI^{SM}) identified only an alternating pattern of carbon and sulfur, which is representative of the membrane surface and backing materials. Foreign elements were not identified. A small patch of material was observed; however, the layer was very thin and only the elements associated with the membrane materials were detected.

Based on the analysis it was determined that the membrane was predominantly clear of foulant.

Cleaning Study

As the membrane possessed no foulant and performed closely to the manufacturer's specification, a cleaning study is not required at this time.

Testing for Flat Sheet Damage

Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure.

Full Element Wet Testing

A discrepancy between the full element and flat sheet performance of SN C7520230 was observed - the full element displayed relatively low rejection (91%) while the flat sheet samples performed with normal salt passage. Internal and external inspection of the element showed no clear signs of damage. Due to this discrepancy, one of the remaining elements which performed most similarly to SN C7520230, SN C7520228 (P2-S1-4), was retested. Element performance was analyzed after the first five minutes of rinse-up, then once more after 20 minutes. The wet test trial revealed that the membrane rejection was fully recovered after the extended rinse-up time. This is an indication that contamination of the permeate side of the membrane occurred.

Initial Element Test Results

Element Weight

All elements are weighed prior to autopsy as weight is often indicative of the degree of fouling. New eight-inch elements weigh approximately 30 to 35 pounds. Additionally, elements in excess of 50 pounds cannot be wet tested.

SN C7520230 weighed 8 pounds.

Wet Test

The element was wet tested using dechlorinated City of San Marcos, CA water. Wet test results were normalized to the manufacturer's published test conditions.

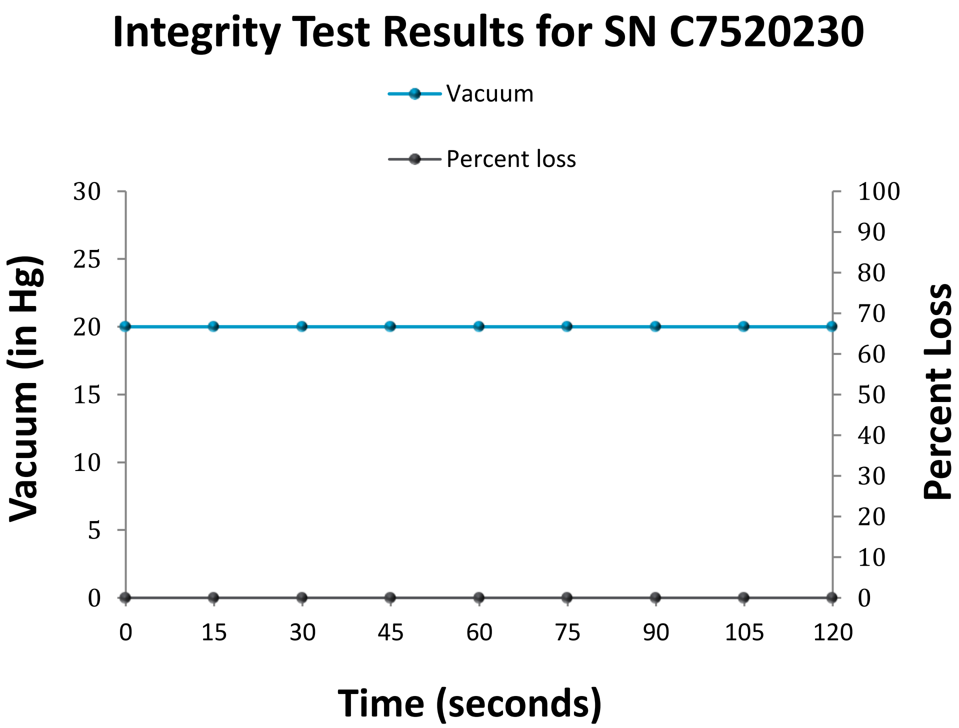
Hydranautics ESPA4-LD-4040	**Flow (gpm)**	**Rejection (%)**	**Pressure Drop (psi)**
SN C7520230	1.24	91.0	4
Manufacturer's Specifications	1.39 to 1.88	99.0 to 99.2	≤15

Element wet testing

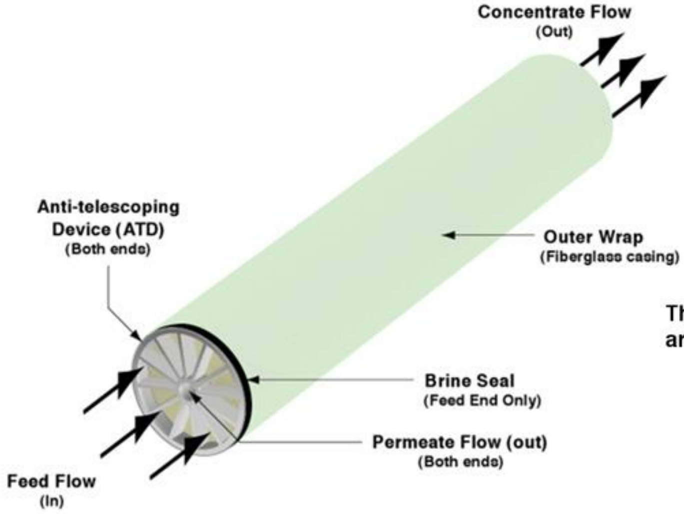
Integrity Test

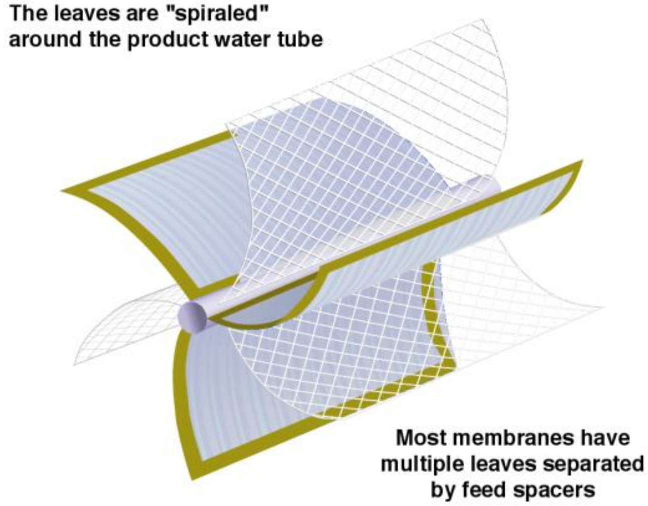
Integrity testing is performed to identify mechanical damage to the internal components of the spiral wound element. In this test, a vacuum of approximately 22 inches Mercury (in. Hg) is applied to the permeate side of the membrane and the membrane is then sealed. The vacuum is monitored for a duration of 120 seconds. Any loss of vacuum indicates the presence of damage; however, membranes that lose over 35% of the vacuum within the 120 second period have severe physical damage.

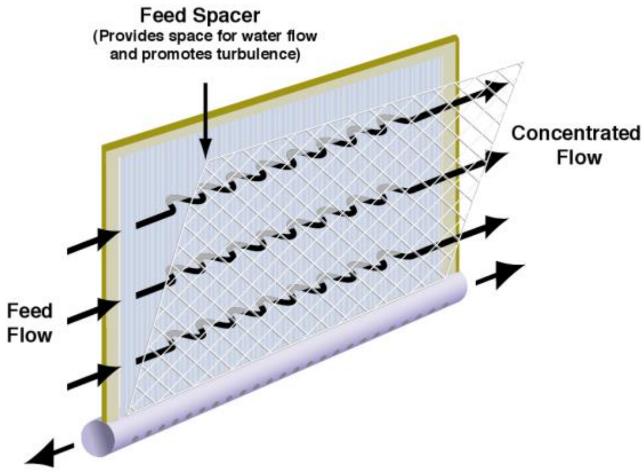
The element maintained stable vacuum pressure, passing the integrity test.

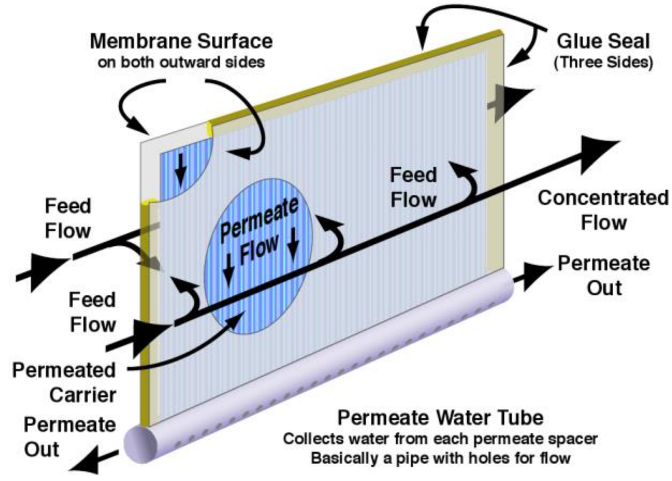


Membrane Construction Diagrams







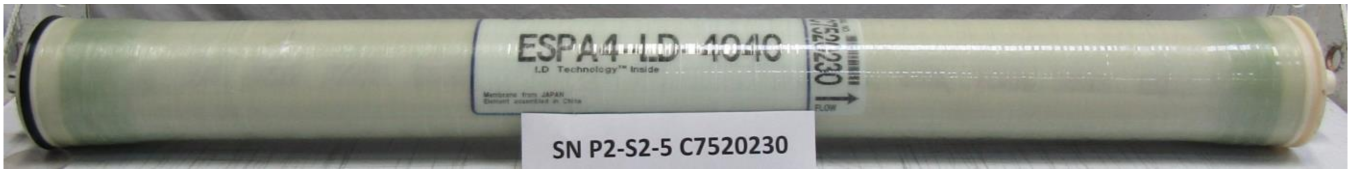


External Inspection

Fiberglass Casing

The purpose of the fiberglass casing is to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the casing can be an indication of rough handling or damage from excessive differential pressure across the element.

The fiberglass casing was free of damage and foulant.



Fiberglass casing of SN C7520230

Brine Seal

The brine seal is used to seal against the inside diameter of the pressure vessels and the outside diameter of the membrane to ensure that all the feed water passes through the element. Feed water passing on the exterior of the element can result in higher pressures, which can cause cracking of the fiberglass casing.

The brine seal was in good condition.

Permeate Tube

The permeate tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf allowing permeate water to travel from the leaves into the permeate tube to be collected. Damage to the ends of the permeate tube can lead to o-ring failures, causing bypass of feed or concentrate water into the permeate stream. Cracking of the permeate tube can also result in permeate contamination.

The permeate tube displayed no visible damages.

Anti-Telescoping Devices (ATDs)

The function of the ATDs are to stabilize the components of the element. This helps to prevent shifting of the internal mechanical components under pressure, also known as telescoping. Telescoping may still occur if pressures exceed the manufacturer's specifications.

The feed and concentrate ATDs possessed no damages or foulant.

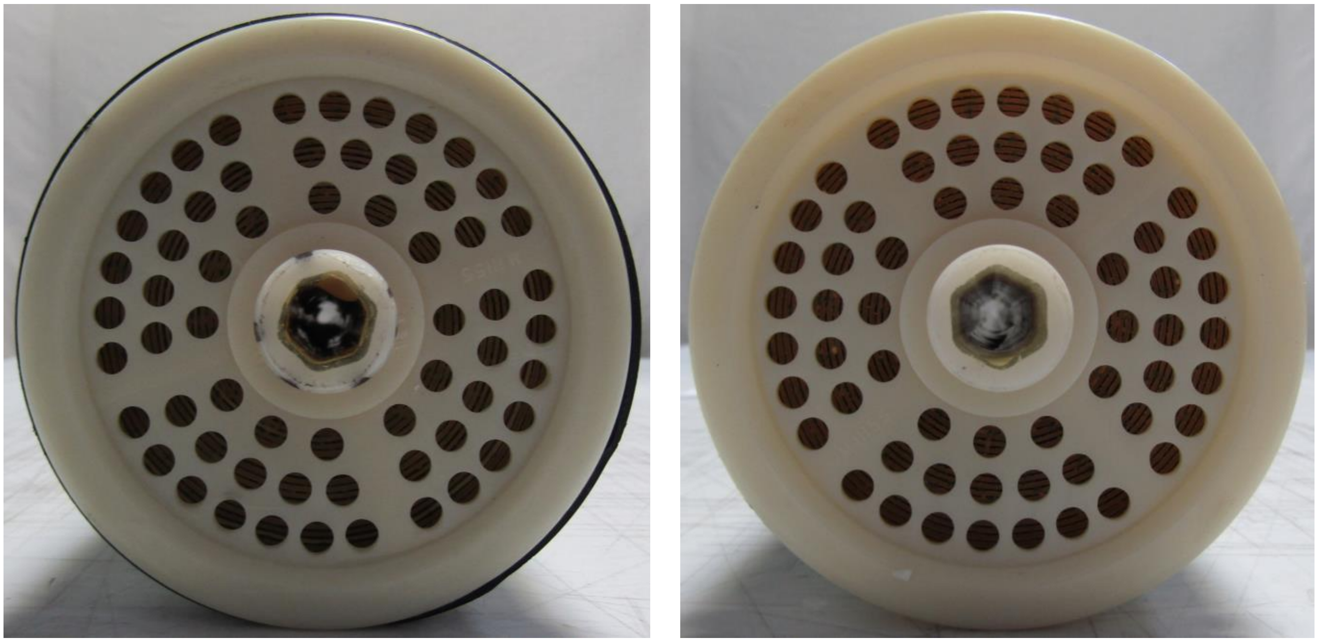


Image of the feed (left) and concentrate (right) ATD of SN C7520230

Internal Inspection

Scroll Ends

The ends of the element are called scroll ends. They are examined for the presence of foulant debris and mechanical damage (e.g. gapping, feed spacer extrusion). The presence of foulant on the scroll ends can cause elevated delta pressures while gapping and feed spacer extrusion indicate uneven hydraulics (high flow/low flow regions). In addition, each scroll end is examined for telescoping, the gradual axial shift of the membrane leaves from the outer diameter of the element towards the permeate tube. Telescoping is often caused by the development of high differential pressure (greater than the manufacturer's specification) across the element or when pressure is applied too quickly, causing a water hammer effect.

The feed scroll end had uneven discoloration along the glue line of one leaf and possessed brown-colored, granular particles deposited on the surface. A piece of thin, flaky plastic was blocking part of the feed channels. The concentrate scroll end also possessed brown-colored granular material in the flow channels.

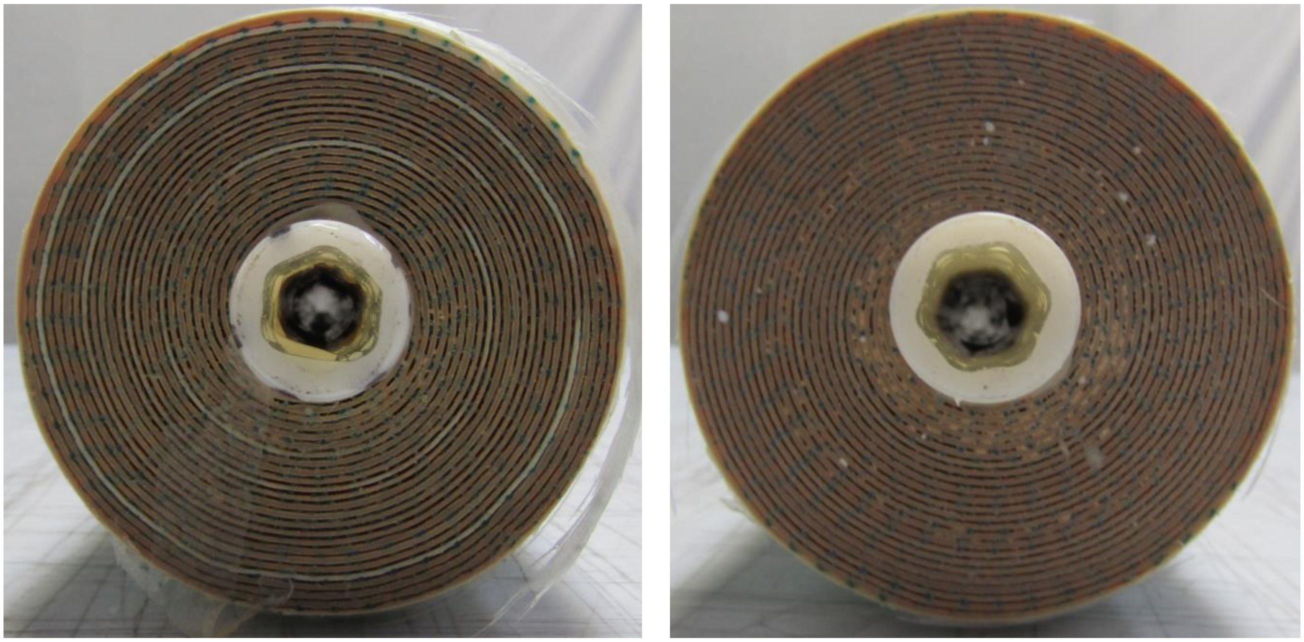
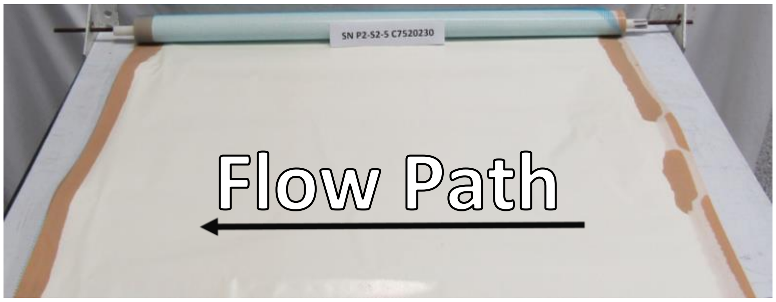


Image of feed scroll end (left) and concentrate scroll end (right) of SN C7520230

Membrane Surface

New membrane surfaces are uniform and shiny. Foulant can often be detected through visual examination; however, membrane appearance can be misleading as some foulants are not visible. The presence of foulant on the membrane surface can cause elevated delta pressure, loss in flow and damage if the foulant is abrasive. Additionally, the membrane surface is inspected for damage such as delamination. Delamination is the lifting of the thin-film membrane from the support layer and often occurs due to a positive pressure on the permeate side of the element.

The exposed membrane surfaces were virtually free of any visible or removable foulant material. Obvious signs of physical damage (e.g. abrasion, delamination) were not present.



Exposed membrane surface of SN C7520230

Exposed membrane surface from feed end of SN C7520230

Feed Spacers

The feed spacer is a plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. Foulant blocking the feed channels causes more resistance for the feed water flowing through the element and results in higher than normal delta pressures.

The feed spacers were in good condition and clear of foulant material.

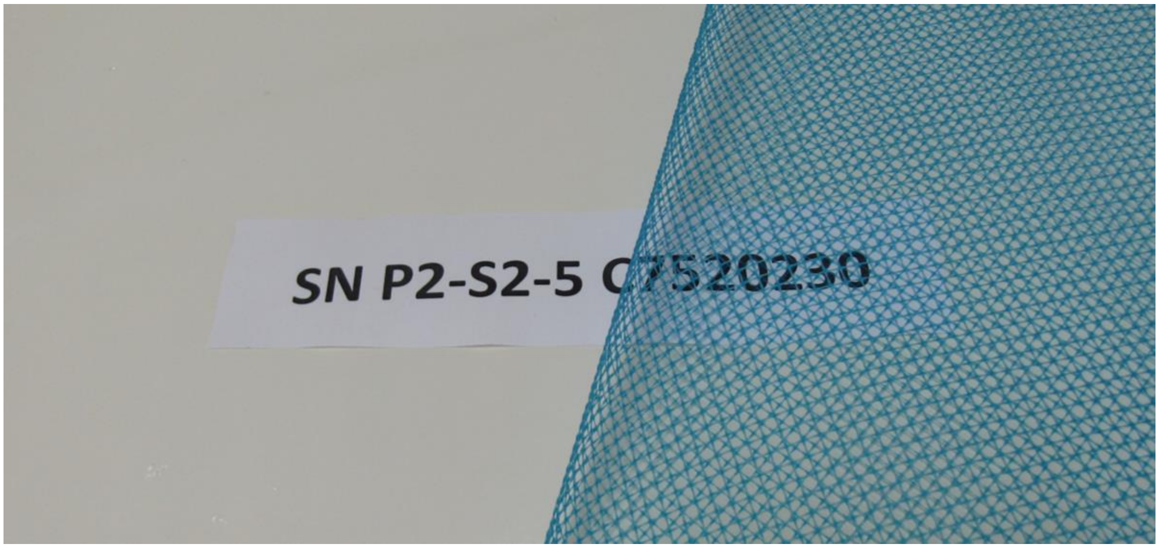


Image of feed spacer

Glue Lines

Membrane leaves are glued on three sides to separate the feed and permeate streams. The glue lines are inspected for specific damage, including glue flaps and pouching. Glue flaps refer to excess inactive membrane material located closest to the ends of the element. Flaps found on the feed end of the element can flair during operation, blocking the feed channels on the scroll end, potentially causing increased differential pressure. Pouching of the glue line, which is often a result of delamination, allows feed water to pass through the inactive membrane at the glue line, contaminating the permeate stream.

The glue lines possessed discoloration (as observed on the feed scroll end) but displayed no clear signs of performance-affecting defects or damages.

Permeate Spacers and Membrane Backing

The permeate spacers provide a path for permeate water to flow towards the permeate tube, which minimizes permeate-side pressure losses. New permeate spacers and membrane backing are uniform in color. Foulant found on the permeate side of the membrane leaves indicates contamination of the permeate stream.

Visible foulant material was not observed on the permeate spacers or membrane backings.

Cell Test for Permeate Water & Salt Passage

To determine membrane performance characteristics, membrane samples are tested in a cell test apparatus. The water passage constant is expressed as the “A” value, and the salt passage constant is expressed as the “B” value. Both constants are functions of the chemical-physical properties of the membrane and any fouling layer present.

“A” and “B” value constants are also independent of operating parameters such as pressure, temperature and salt content of the feed stream. “A” value units are cm/sec/atm. “B” value units are cm/sec.

The flat sheet performance is normalized to the manufacturer’s specifications so the flat sheet performance can be compared to that of the full element. The results are shown in the table below.

SN C7520230	Water Passage Constant “A” Value	Salt Passage Constant “B” Value
Flat Sheet Membrane	1.96E-04 96% of Normal	1.37E-05 Normal
Manufacturer’s Specifications	2.06 to 2.79E-04 Normal Range	1.33 to 1.67E-06 Normal Range

Note: testing conducted using dechlorinated city water from San Marcos, CA

Water Passage (% of Normal)

Salt Passage (% of Normal)

Foulant Analysis

Organic Content Testing

Loss on ignition (LOI) testing gives an approximation of the organic content of the foulant. Values higher than 65% represent notable organic fouling.

Loss on ignition testing was unnecessary due to the absence of foulant on the membrane surface.

Foulant Density Measurement

The foulant density is the weight of dry foulant per area of membrane surface. The foulant densities determined from past autopsies at Avista Technologies range from 0.02 to 5.23 mg/cm^2 with an average of 0.45 mg/cm^2.

Since there was no foulant on the membrane surface, foulant density measurement was non-applicable.

Acid Testing

Acid testing is used to determine the presence of carbonates and metals on the membrane surface. In this test, several drops of dilute hydrochloric acid were placed on the foulant surfaces. Effervescing indicates the presence of carbonates while a color change is associated with the presence of metals.

Acid testing was negative for the presence of carbonates and no visible color change occurred.

Microbiological Analysis

This analysis is performed to identify the biological activity of foulant removed from the membrane surface. Foulant samples are stained and examined with a light microscope at 1000x using an oil immersion lens. Gram positive bacteria are stained purple while Gram negative bacteria are stained pink.

Microscope analysis could not be performed due to the absence of removable foulant.

Zeta Potential Testing

The zeta potential is the charge that resides at the double layer boundary of colloids. Most naturally occurring colloids are negatively charged. A goal of coagulation is to neutralize the colloids to form floc prior to filtration. If an excess of coagulant is present, the charge of the colloids switches from negative to positive.

The zeta potential of the foulant present on the membrane surface is measured to determine if coagulant is being overfed. Two grams of wet foulant is required for this test.

Zeta potential testing could not be performed due to the absence of foulant material.

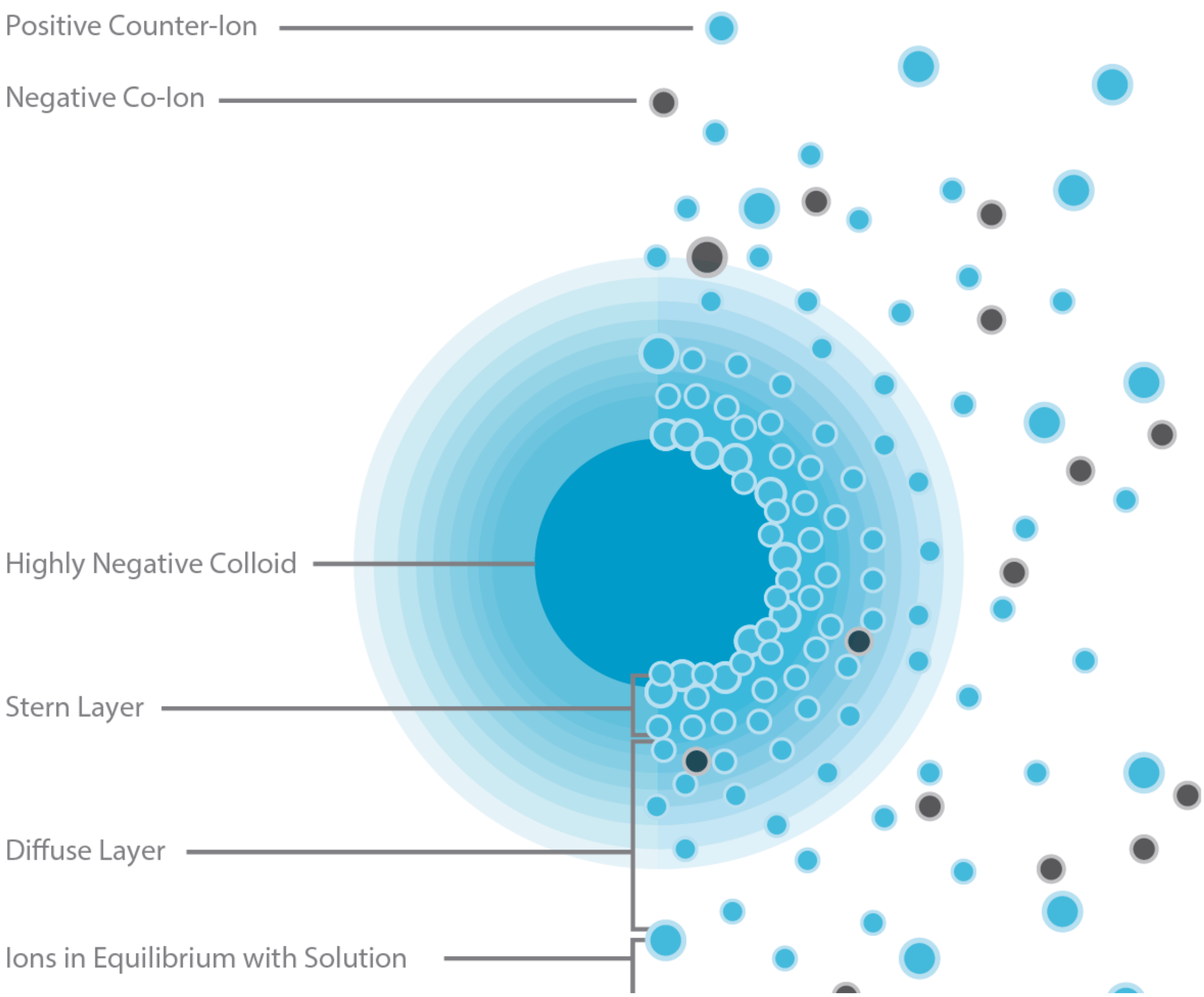
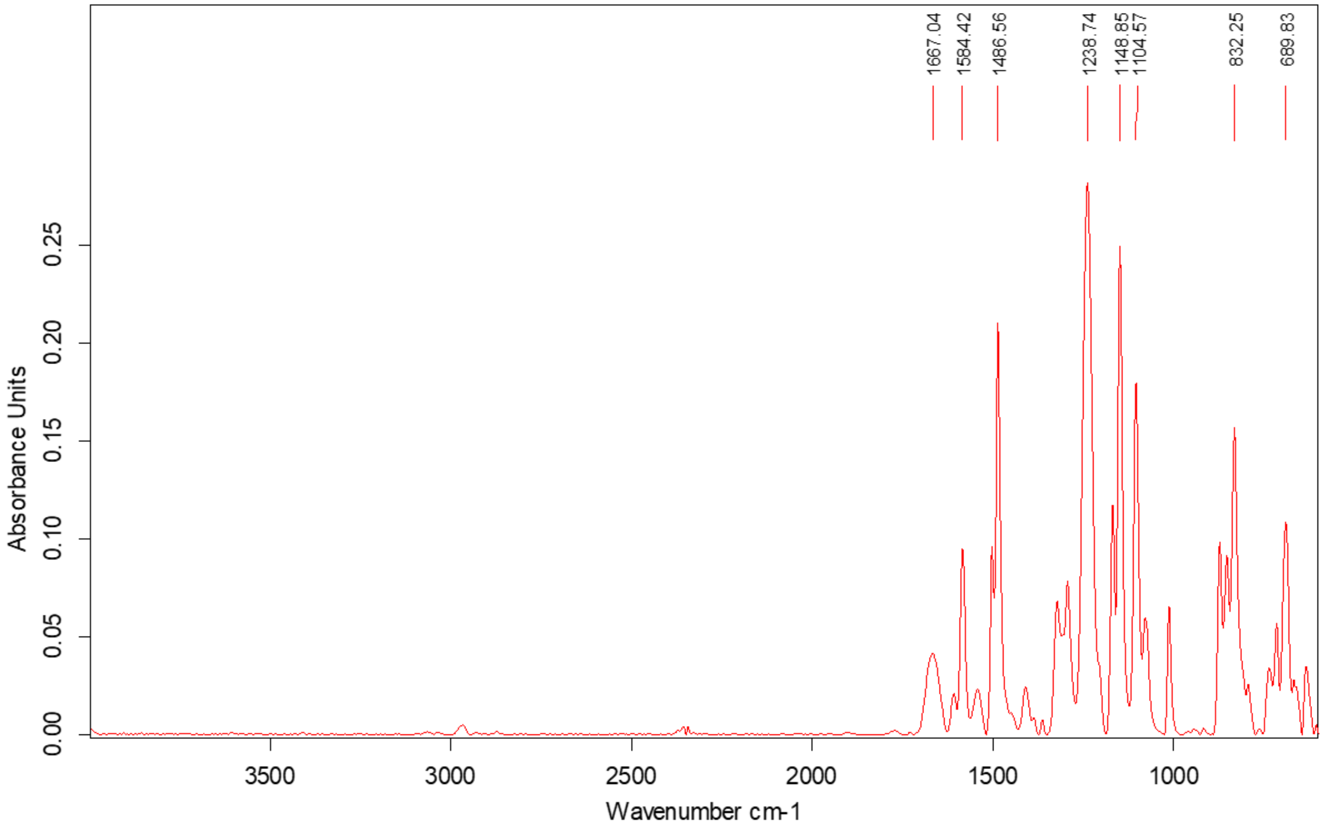


Image based on diagram from Particle Characterization Laboratories, Inc.

Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) is an analytical technique used to identify functional groups (specific groups of atoms or bonds within molecules). Infrared radiation passes through a sample, with some of the radiation absorbed and some transmitted. A measurement and interpretation of this data produces a spectrum which can then be compared and matched to the known spectra for functional groups based on the wavenumber at which bands appear and their respective shapes (e.g. sharp, broad, strong, weak).

FT-IR spectroscopy performed directly on a sample of the membrane detected only peaks representative of the membrane structure components (e.g. polysulfone).



FT-IR spectral image of the membrane surface of SN C7520230

Energy Dispersive Spectroscopy (EDS) Analysis

Energy Dispersive Spectroscopy analysis is used to determine the relative concentration of elements present in a sample. EDS analysis is performed on a dry membrane sample. The element sulfur is at least in part associated with the membrane support material (polysulfone) rather than a foulant layer. Avista's analysis of new membranes typically detects between 5.00 and 7.00 weight percentage. Relative concentrations below 5.00 percent indicate the presence of a foulant layer masking the membrane surface.

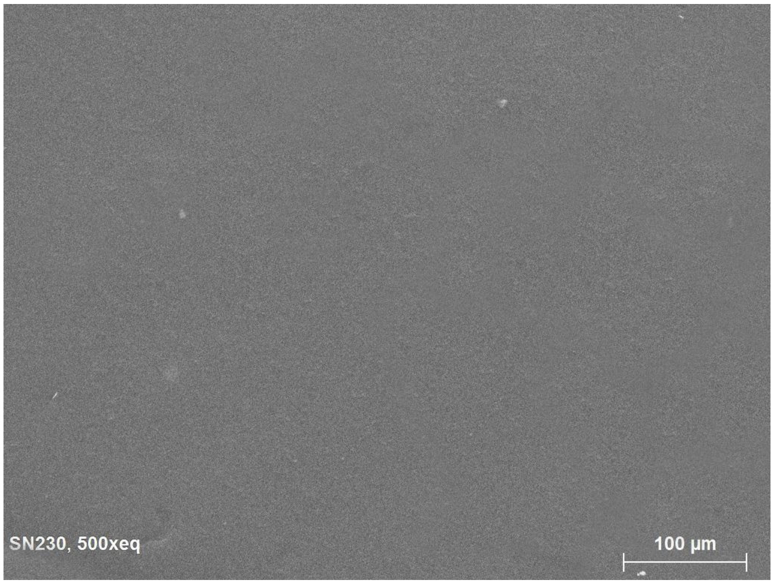
EDS analysis performed on the membrane surface detected only carbon, oxygen and sulfur. Foreign inorganic elements were not present. The element carbon can be contributed by the presence of foreign organics but is also a component of the membrane materials. The sulfur weight percentage (5.60 wt%) suggests no masking of the membrane surface.

Elements	**SN C7520230 Weight Percent (wt%)**
Carbon	82.37
Oxygen	12.03
Sulfur	5.60

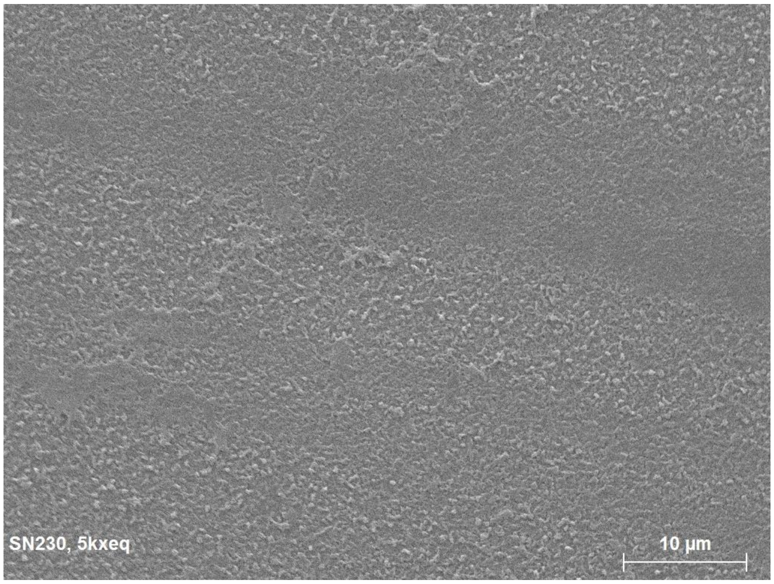
Scanning Electron Microscope (SEM) Imaging

SEM imaging is performed on the membrane surface to observe the topography of the foulant material. Foulant morphology can be an indicator of the type of foulant.

SEM imaging (500x) revealed that the membrane surface was predominantly free of foulant material. Only traces of particulate material were observed. Close-up (1000x) imaging displayed topography representative of the membrane surface itself.



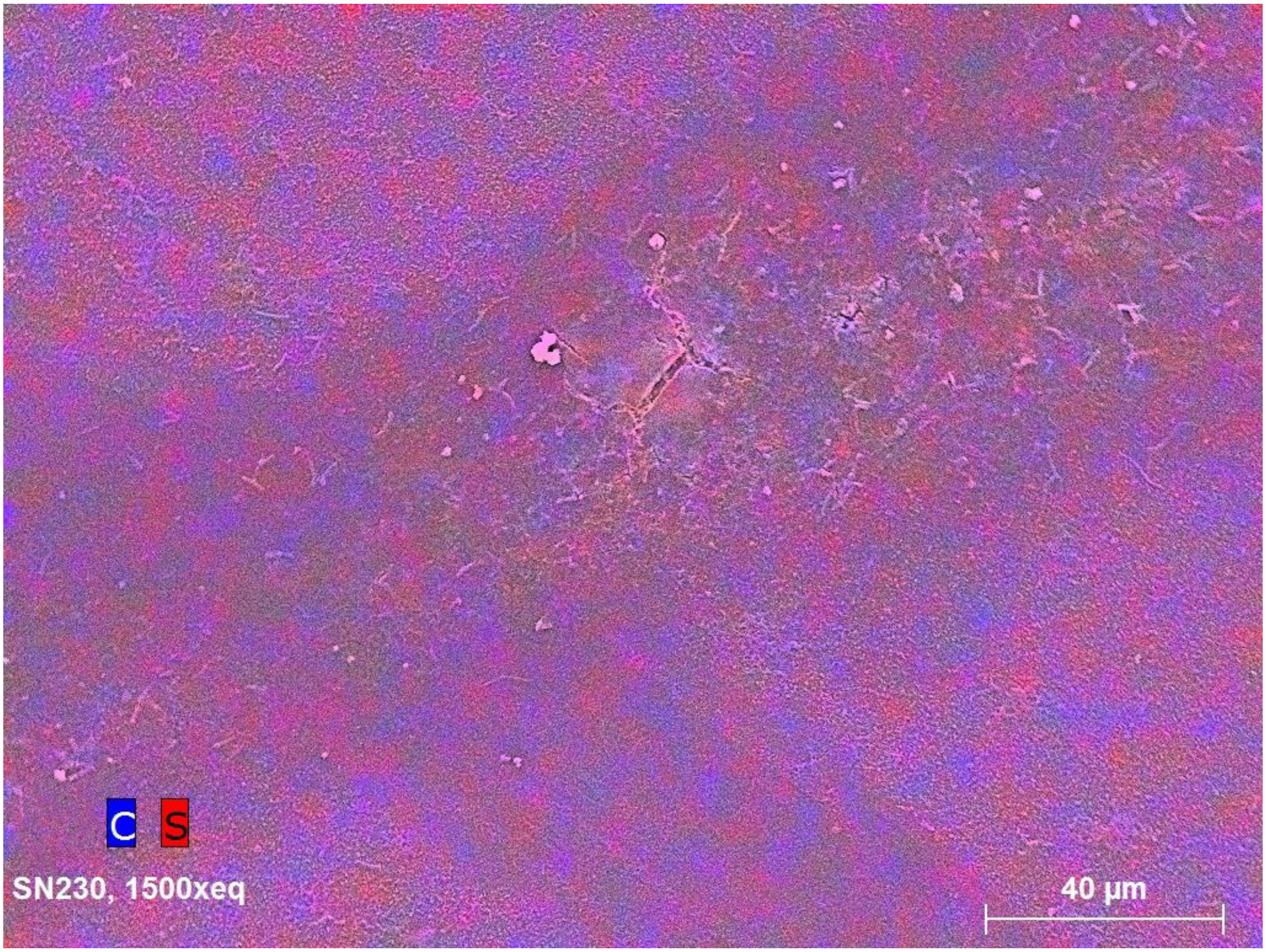
SEM image (500x) of the membrane surface of SN C7520230



Close-up SEM image (5000x) of the membrane surface of SN C7520230

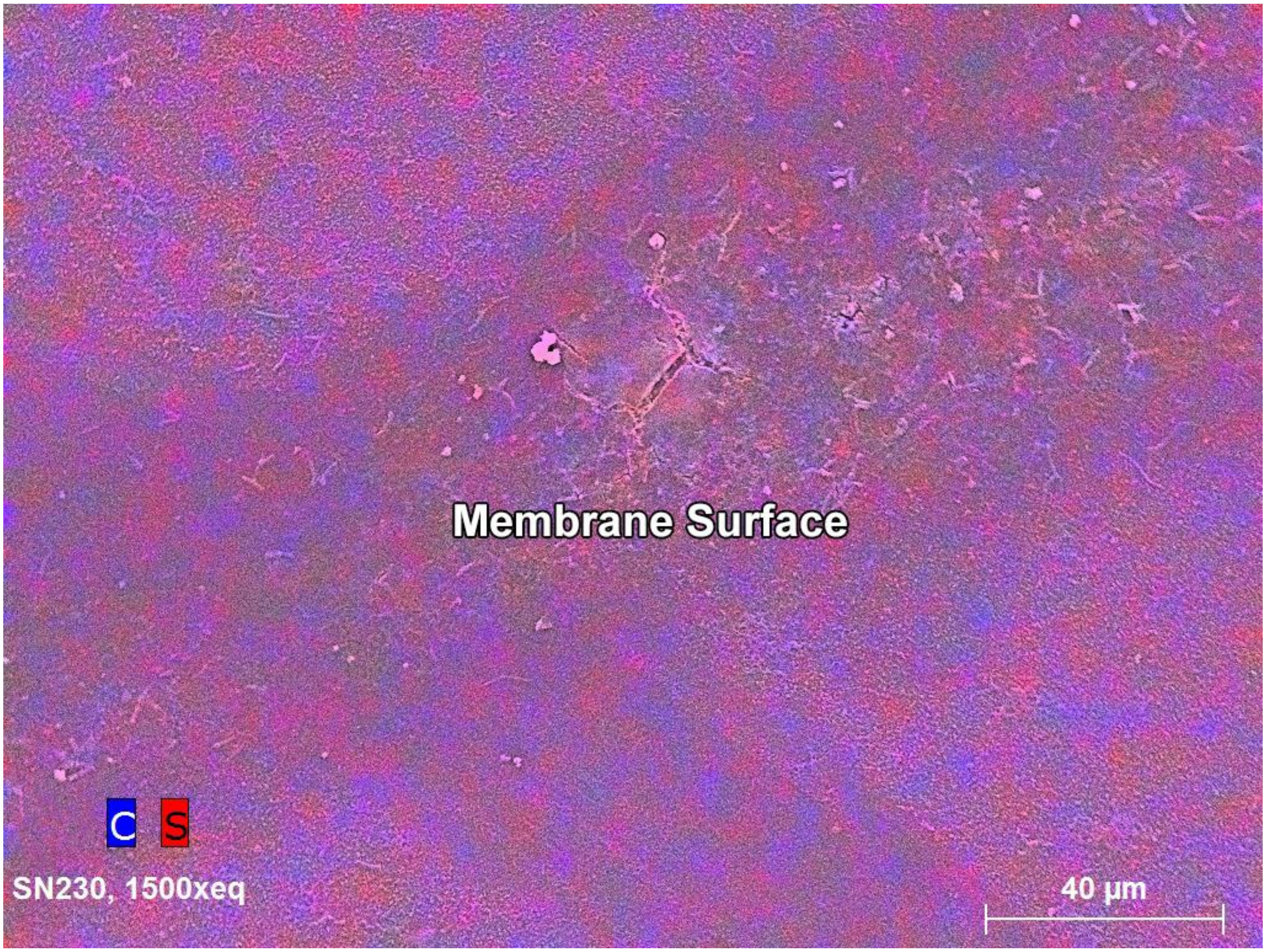
Chromatic Elemental Imaging^{SM} (CEI^{SM})

CEI is an analytical technique used to determine the spatial distribution of elements in a foulant sample. In this technique, a beam of focused electrons is accelerated across the surface of a foulant sample and interacts with the sample's inorganic elements by causing the elements to emit electrons. An element's electron emission from its atomic shell generates a characteristic X-ray spectrum that allows for its identification. CEI assigns each element a color (colors for each element are shown in a legend on the bottom left corner of the CEI image) and provides a high-resolution image where the colors correspond to the exact location of the elements in the sample. An element's color intensity in a CEI is largely influenced by its concentration in the foulant sample; i.e. elements present with higher relative concentrations are displayed with greater color intensity in the image. CEI can uniquely identify the distinct elements in a mixed foulant sample.



CEI image (1500x) of the membrane surface

CEI[SM] identified only an alternating pattern of carbon (blue) and sulfur (red), which is representative of the membrane surface and backing materials. Foreign elements were not identified. A small patch of material was observed; however, the layer was very thin and only the elements associated with the membrane materials were detected.



CEI image (1500x) of the membrane surface with labels

Cell Test & Laboratory Clean-in-Place Study

Flat sheet membrane samples harvested from the full element are placed in a cell test apparatus and cleaned with various Avista chemicals to determine the most effective cleaner combinations and contact times. The most effective cleaner is chosen based on overall improvement in water and salt passage and visual foulant removal.

Since the membrane surface was clear of foulant and the flat sheet samples flowed only slightly below normal, a cleaning study was not required at this time.

Testing to Determine Damage to Flat Sheet Samples

Fujiwara Testing

Fujiwara testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. If the solution changes color to pink or red, the element is declared positive for the presence of oxidizing halogens. A color change does not occur if the membranes has not been exposed to halogens. Common symptoms of halogen oxidation include increased flow and loss in permeate quality.

Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure.

Example of negative (left) and positive (right) Fujiwara color change

Full Element Wet Testing

Additional full element wet testing was performed on element SN C7520228 (P2-S1-4), which performed most similarly to SN C7520230 during the initial wet test performed upon arrival. The purpose of the additional testing was to investigate element performance following extended rinse-up time. Element performance was analyzed after the first five minutes of rinse-up, then once more after 20 minutes.

SN C7520228	**Flow (gpm)**	**Rejection (%)**	**Pressure Drop (psi)**
Initial Wet Test	1.20	88.8	4
5 Minutes Rinse-Up	1.20	94.5	4
20 Minutes Rinse-Up	**1.20**	**99.3**	**4**
Manufacturer's Specifications	1.39 to 1.88	99.0 to 99.2	≤15

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#053018-5	Standard Spiral Autopsy	KM8048229-7015 **C7520230**	June 25, 2018

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

Date: 06/25/2018

Signed:

Megan Lee
Laboratory Services Manager

Arnell Abad
Laboratory Services Chemist

Membrane Autopsy Report

Completed for:

Brown & Caldwell

Scottsdale Water Campus

SN KM8048229-7015

P1-6

06/25/2018 WO#053018-5

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Table of Contents

Executive Summary

Background

Brown & Caldwell provided 6 Koch SR200-4040 nanofiltration (NF) and 12 Hydranautics ESPA4-LD-4040 reverse osmosis (RO) membrane elements from Scottsdale Water Campus to Avista Technologies for wet testing. Element Serial Number (SN) KM8048229-7015 (Koch SR200-4040) and SN C7520230 (Hydranautics ESPA4-LD-4040) were selected for dissection and analysis to identify foulant constituents, as well as other causes for loss of performance. SN KM8048229-7015 was noted as position “P1-6” while SN C7520230 was from position “P2-S2-5”. The remainder of this report pertains to SN KM8048229-7015 (P1-6).

Initial Element Testing

The element produced lower than normal flow (81% of normal), lower than normal rejection (97.6%) and a differential pressure of 6 psi. Testing was conducted using an aqueous solution containing 2,000 ppm $MgSO_4$. The element passed integrity testing, indicating the absence of damage to the internal components of the spiral wound element.

External Inspection

The fiberglass casing was in good mechanical condition and the brine seal was intact. Damages to the permeate tube ends and interior were not observed. The feed (brine seal end) and concentrate (opposite brine seal) ATDs were clear of visible damages and foulant.

Internal Inspection

The feed scroll end had light deposits of brown-colored foulant material while the concentrate scroll end was more heavily fouled, containing a higher density of the foulant. The exposed membrane surfaces were coated with a layer of smooth, brown-colored foulant. The foulant layer was evenly unevenly distributed and followed a gradient pattern which increased in prevalence from the feed to the concentrate end of the membrane. Physical damages (e.g. abrasion, delamination) to the membrane surface were not immediately apparent. The feed spacers contained a light, uneven coating of the brown-colored foulant. Granular material was present on the feed end glue lines, breaching partially into the active membrane surface. The permeate spacers and membrane backing were uniform in color and no foulant was present on the interior surfaces.

Cell Testing Results

Flat sheet samples harvested from the full element produced 82% of normal water passage and lower than normal $MgSO_4$ rejection (97.5%) upon baseline cell testing. Testing was conducted using an aqueous solution containing 2,000 ppm $MgSO_4$.

Foulant Analysis

The loss on ignition (organic content) for the foulant material removed from the membrane surface was 81.7%, which indicates the foulant contained primarily organic material. Foulant density on the membrane surface could not be determined due to the uneven distribution of the material. Acid testing was negative for the presence of carbonates; however, a slight yellow color change was observed which indicates the presence of metals (e.g. iron). Microscope imaging displayed amorphous organic material (e.g. bio-slime) containing an abundance of Gram-negative bacteria. Also present were algae and various particulate materials, as well as a lesser amount of Gram-negative bacteria. Fourier-Transform Infrared (FT-IR) spectroscopy performed on foulant removed from the membrane surfaces resulted in a broad peak at the 1000 cm^{-1} range, which is characteristic of the presence of both organic material (e.g. carbohydrates – polysaccharides) and phosphate compounds (e.g. calcium phosphate). A smaller double peak at the 1650-1500 cm^{-1} range was also present, which is associated with the presence of proteins (e.g. amino acids from microorganisms).

The Energy Dispersive Spectroscopy (EDS) analysis detected calcium and phosphorus as the primary inorganic constituents of the foulant material. Lesser amounts of magnesium, iron and aluminum were also detected. The sulfur weight percentage (4.86 wt%) indicates that the foulant layer did not contribute to notable masking of the membrane surface as Avista's analysis of new polyamide membranes typically detects between 5.00 and 7.00 wt% sulfur. Scanning Electron Microscope (SEM) imaging (150x) displayed a cracked layer of smooth foulant containing fine-granular deposits. Close-up imaging (5000x) provided a clearer representation of the amorphous topography of the foulant layer. Chromatic Elemental Imaging^{SM} (CEI^{SM}) identified the bulk of the foulant layer to be comprised of organic material (represented by the element carbon) and calcium phosphate. Separate deposits of calcium were also present. The membrane surface is depicted by the element sulfur and was visible through cracks in the foulant layer.

Based on the analysis, it was determined that the foulant present on the membrane surface was primarily a combination of organics and calcium phosphate.

Cleaning Study

Flat sheet samples were cleaned with RoClean P111 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours. Complete visual foulant removal was achieved and flow was restored to the manufacturer's specification.

Testing for Flat Sheet Damage

The full element and flat sheet samples produced lower than normal $MgSO_4$ rejection. Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure. Dye testing revealed pinhole-sized areas of heavy dye uptake on the membrane surface. The pinholes maintained a symmetrical, rounded shape which can indicate chemical damage caused by foulant. A pattern of lesser dye uptake was displayed in the areas corresponding to the feed spacer contact points, representing some degree of physical abrasion. Additionally, the dye appeared to penetrate through the pinholes to the membrane backing, signifying that the damage was severe.

Initial Element Test Results

Element Weight

All elements are weighed prior to autopsy as weight is often indicative of the degree of fouling. New eight-inch elements weigh approximately 30 to 35 pounds. Additionally, elements in excess of 50 pounds cannot be wet tested.

SN KM8048229-7015 weighed 10 pounds.

Wet Test

The element was wet tested using an aqueous solution containing 2,000 ppm $MgSO_4$. Wet test results were normalized to the manufacturer's published test conditions.

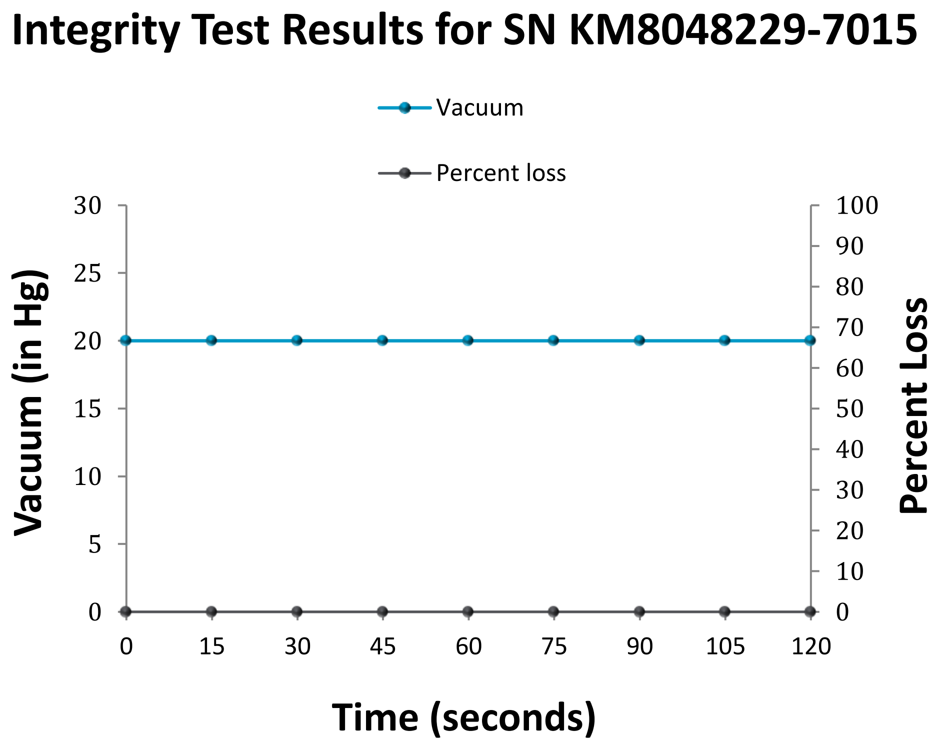
Koch 4040-SR200	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN KM8048229-7015	0.61	97.6	6
Manufacturer's Specifications	0.75 to 1.06	99.0 to 99.4	≤10

Element wet testing

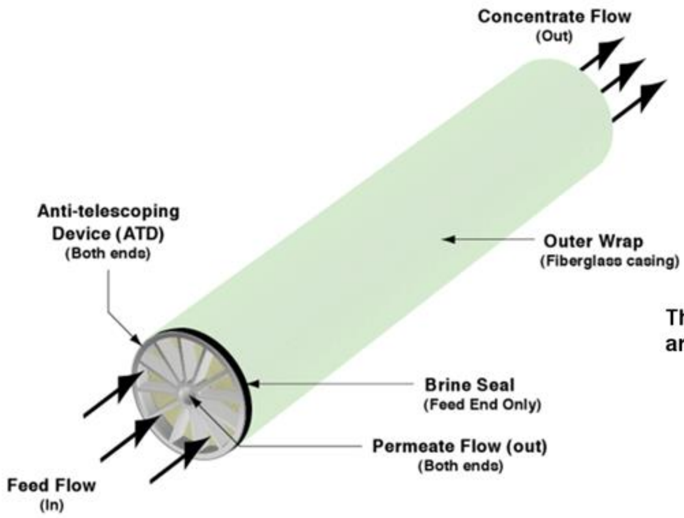
Integrity Test

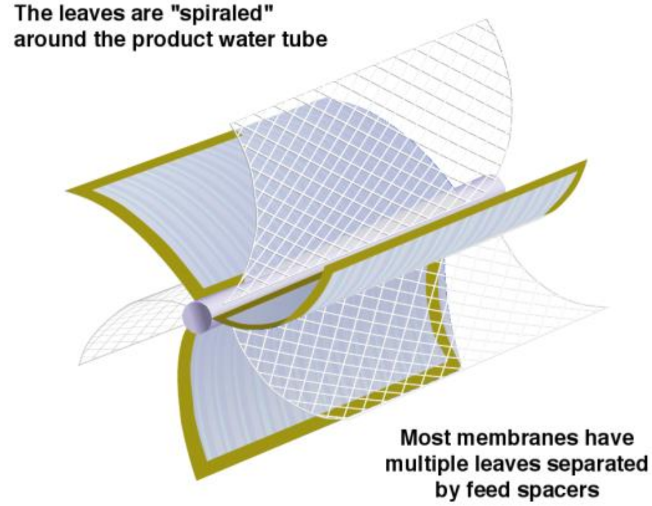
Integrity testing is performed to identify mechanical damage to the internal components of the spiral wound element. In this test, a vacuum of approximately 22 inches Mercury (in. Hg) is applied to the permeate side of the membrane and the membrane is then sealed. The vacuum is monitored for a duration of 120 seconds. Any loss of vacuum indicates the presence of damage; however, membranes that lose over 35% of the vacuum within the 120 second period have severe physical damage.

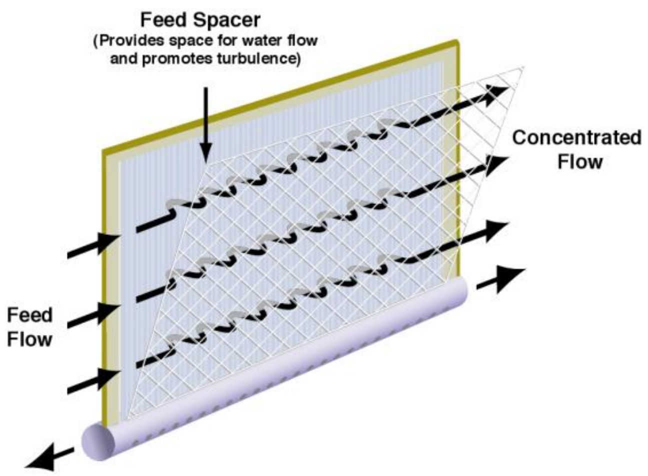
The element maintained stable vacuum pressure, passing the integrity test.

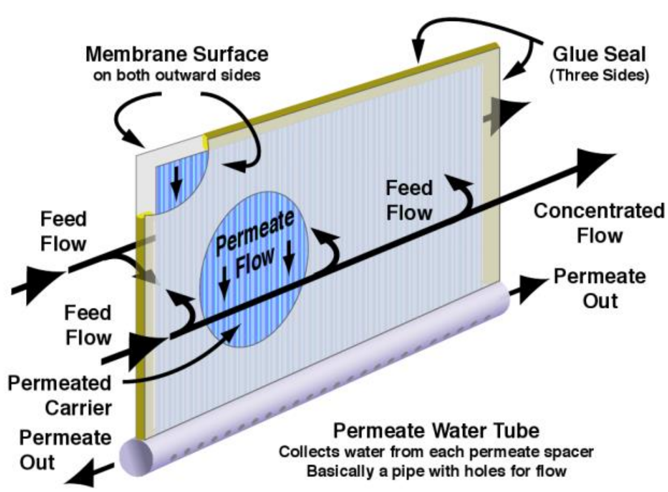


Membrane Construction Diagrams







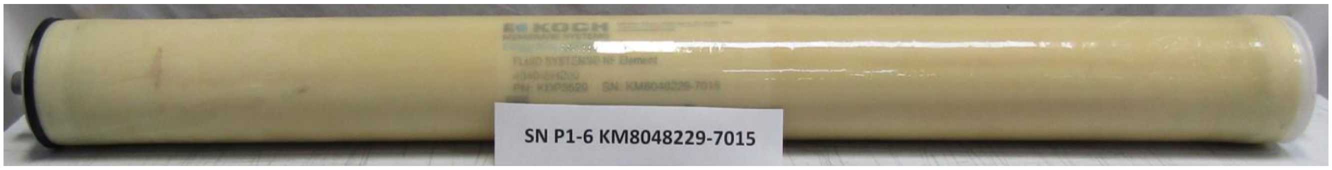


External Inspection

Fiberglass Casing

The purpose of the fiberglass casing is to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the casing can be an indication of rough handling or damage from excessive differential pressure across the element.

The fiberglass casing was in good mechanical condition.



Fiberglass casing of SN KM8048229-7015

Brine Seal

The brine seal is used to seal against the inside diameter of the pressure vessels and the outside diameter of the membrane to ensure that all the feed water passes through the element. Feed water passing on the exterior of the element can result in higher pressures, which can cause cracking of the fiberglass casing.

The brine seal was intact.

Permeate Tube

The permeate tube is a pipe that is located at the center of the element. It contains lines of holes and is bonded to each membrane leaf allowing permeate water to travel from the leaves into the permeate tube to be collected. Damage to the ends of the permeate tube can lead to o-ring failures, causing bypass of feed or concentrate water into the permeate stream. Cracking of the permeate tube can also result in permeate contamination.

Damages to the permeate tube ends and interior were not observed.

Anti-Telescoping Devices (ATDs)

The function of the ATDs are to stabilize the components of the element. This helps to prevent shifting of the internal mechanical components under pressure, also known as telescoping. Telescoping may still occur if pressures exceed the manufacturer's specifications.

The feed and concentrate ATDs were clear of visible damages and foulant.

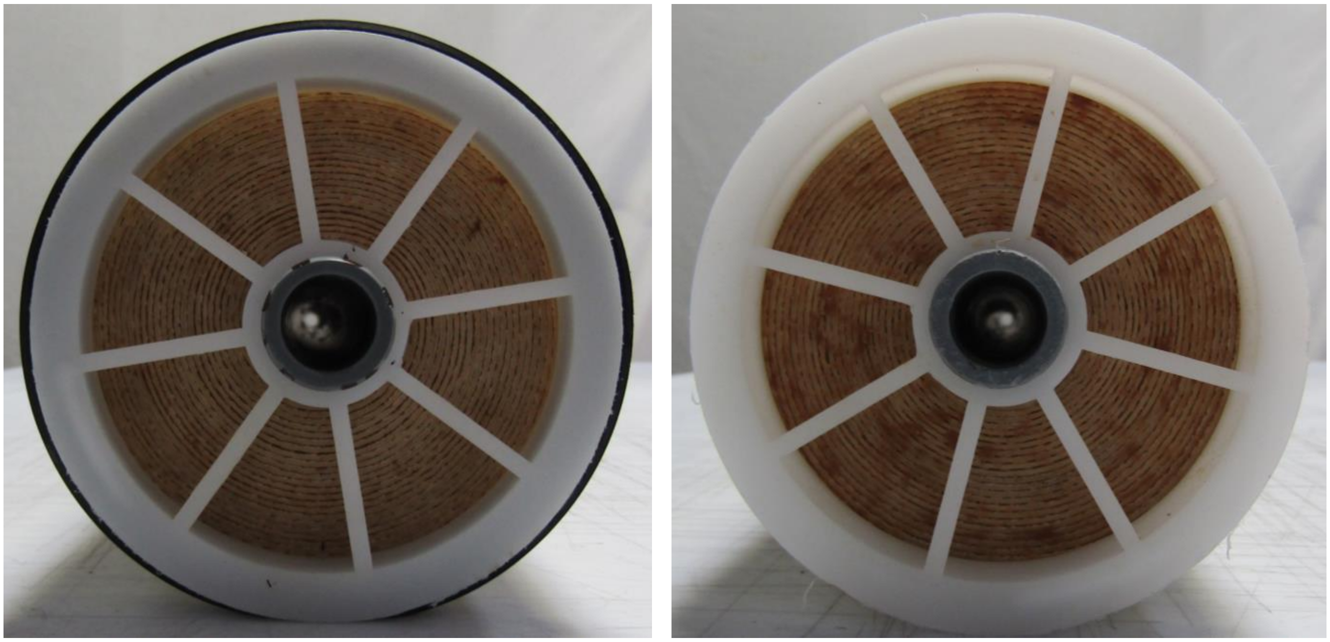


Image of the feed (left) and concentrate (right) ATD of SN KM8048229-7015

Internal Inspection

Scroll Ends

The ends of the element are called scroll ends. They are examined for the presence of foulant debris and mechanical damage (e.g. gapping, feed spacer extrusion). The presence of foulant on the scroll ends can cause elevated delta pressures while gapping and feed spacer extrusion indicate uneven hydraulics (high flow/low flow regions). In addition, each scroll end is examined for telescoping, the gradual axial shift of the membrane leaves from the outer diameter of the element towards the permeate tube. Telescoping is often caused by the development of high differential pressure (greater than the manufacturer's specification) across the element or when pressure is applied too quickly, causing a water hammer effect.

The feed scroll end had light deposits of brown-colored foulant material. The concentrate scroll end was more heavily fouled, containing a higher density of the brown-colored foulant.


Image of feed scroll end (left) and concentrate scroll end (right) of SN KM8048229-7015

Membrane Surface

New membrane surfaces are uniform and shiny. Foulant can often be detected through visual examination; however, membrane appearance can be misleading as some foulants are not visible. The presence of foulant on the membrane surface can cause elevated delta pressure, loss in flow and damage if the foulant is abrasive. Additionally, the membrane surface is inspected for damage such as delamination. Delamination is the lifting of the thin-film membrane from the support layer and often occurs due to a positive pressure on the permeate side of the element.

The exposed membrane surfaces were coated with a layer of smooth, brown-colored foulant. The foulant layer was evenly unevenly distributed and followed a gradient pattern which increased in prevalence from the feed to the concentrate end of the membrane. Physical damages (e.g. abrasion, delamination) to the membrane surface were not immediately apparent.

Exposed membrane surface of SN KM8048229-7015

Exposed membrane surface from feed end of SN KM8048229-7015

Feed Spacers

The feed spacer is a plastic net material designed to separate the membrane leaves, forming a flow path, and to promote turbulence within the feed water channels. Foulant blocking the feed channels causes more resistance for the feed water flowing through the element and results in higher than normal delta pressures.

The feed spacers contained a light, uneven coating of the brown-colored foulant.

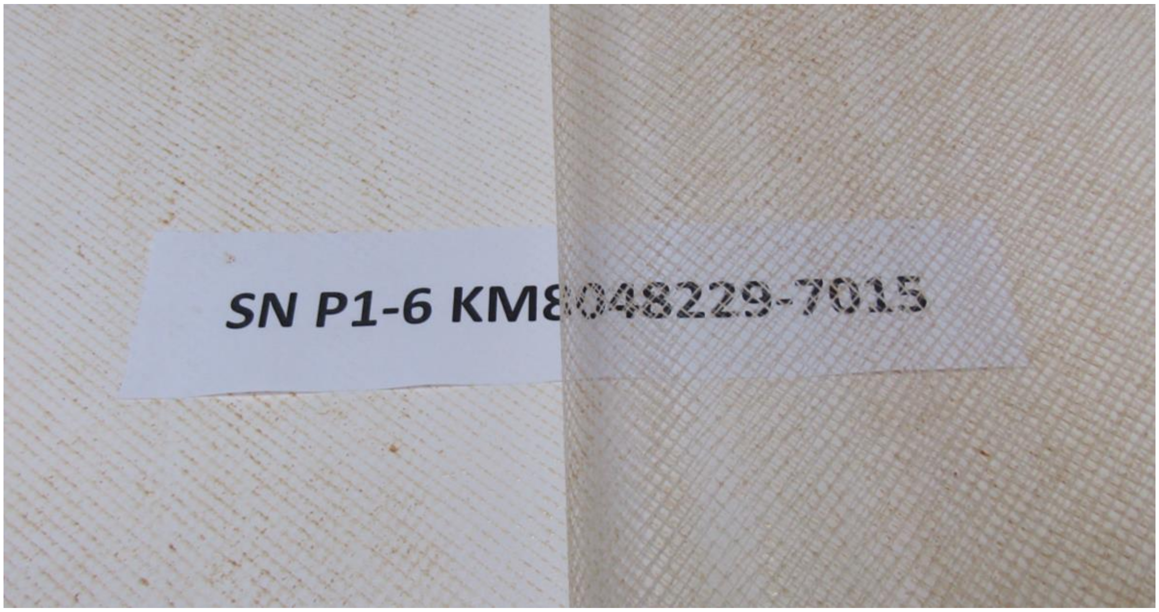


Image of feed spacer

Glue Lines

Membrane leaves are glued on three sides to separate the feed and permeate streams. The glue lines are inspected for specific damage, including glue flaps and pouching. Glue flaps refer to excess inactive membrane material located closest to the ends of the element. Flaps found on the feed end of the element can flair during operation, blocking the feed channels on the scroll end, potentially causing increased differential pressure. Pouching of the glue line, which is often a result of delamination, allows feed water to pass through the inactive membrane at the glue line, contaminating the permeate stream.

Granular material was present on the feed end glue lines, breaching partially onto the active membrane surface.

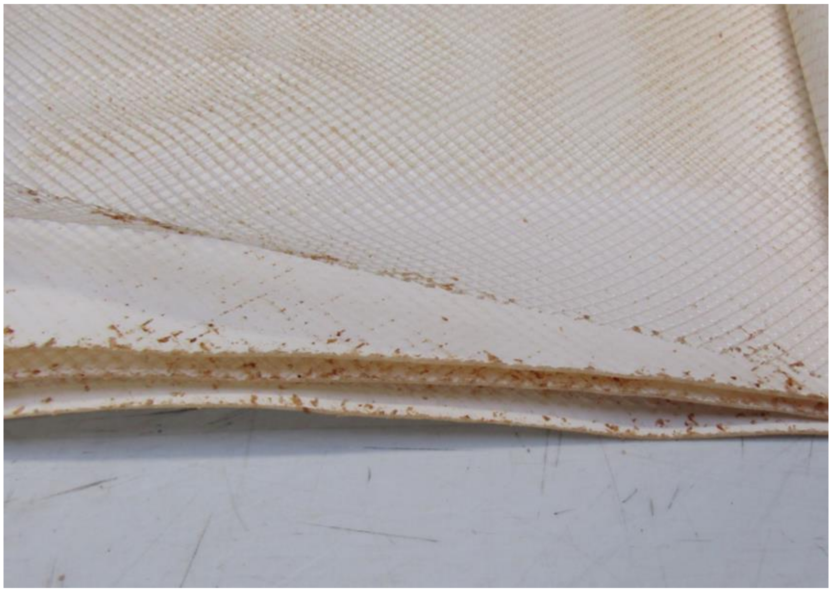


Image of the granular material present on the feed end glue lines

Permeate Spacers and Membrane Backing

The permeate spacers provide a path for permeate water to flow towards the permeate tube, which minimizes permeate-side pressure losses. New permeate spacers and membrane backing are uniform in color. Foulant found on the permeate side of the membrane leaves indicates contamination of the permeate stream.

The permeate spacers and membrane backing were uniform in color and no foulant was present on the interior surfaces.

Cell Test for Permeate Water & Salt Passage

To determine membrane performance characteristics, membrane samples are tested in a cell test apparatus. The water passage constant is expressed as the “A” value, and the salt passage constant is expressed as the “B” value. Both constants are functions of the chemical-physical properties of the membrane and any fouling layer present.

“A” and “B” value constants are also independent of operating parameters such as pressure, temperature and salt content of the feed stream. “A” value units are cm/sec/atm. “B” value units are cm/sec.

The flat sheet performance is normalized to the manufacturer’s specifications so the flat sheet performance can be compared to that of the full element. The results are shown in the table below.

SN KM8048229-7015	Water Passage Constant “A” Value	$MgSO_4$ Rejection (%)
Flat Sheet Membrane	0.91E-04 82% of Normal	97.5
Manufacturer’s Specifications	1.11 to 1.57E-04 Normal Range	99.0 to 99.4

Note: testing conducted using an aqueous solution containing 2,000 ppm MgSO4.

Water Passage (% of Normal)

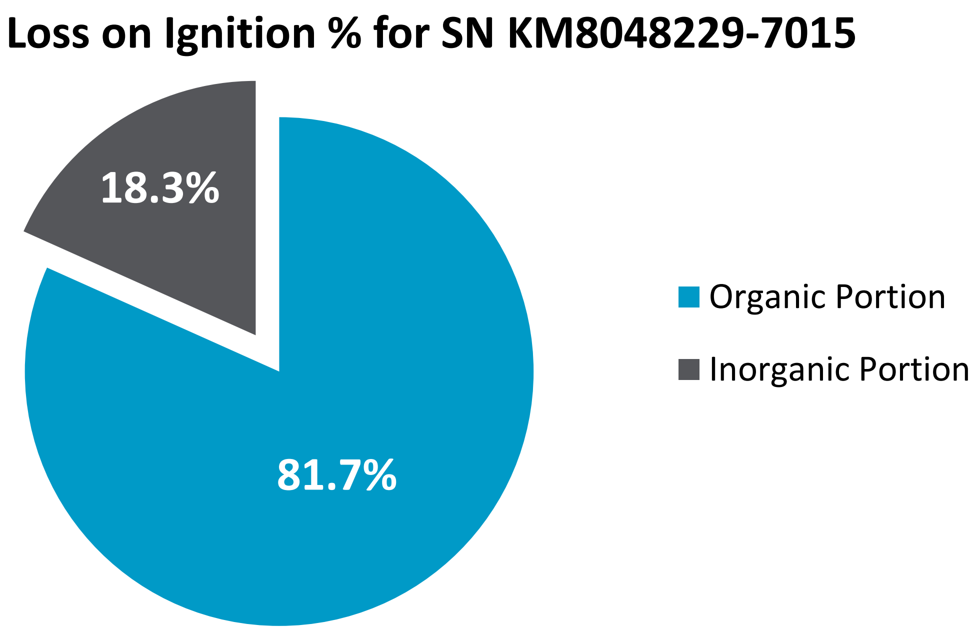
Rejection (%)

Foulant Analysis

Organic Content Testing

Loss on ignition (LOI) testing gives an approximation of the organic content of the foulant. Values higher than 65% represent notable organic fouling.

Organic content for SN KM8048229-7015 is shown in the graph below.



Foulant Density Measurement

The foulant density is the weight of dry foulant per area of membrane surface. The foulant densities determined from past autopsies at Avista Technologies range from 0.02 to 5.23 mg/cm^2 with an average of 0.45 mg/cm^2.

Foulant density could not be calculated due to the uneven distribution of the foulant material.

Acid Testing

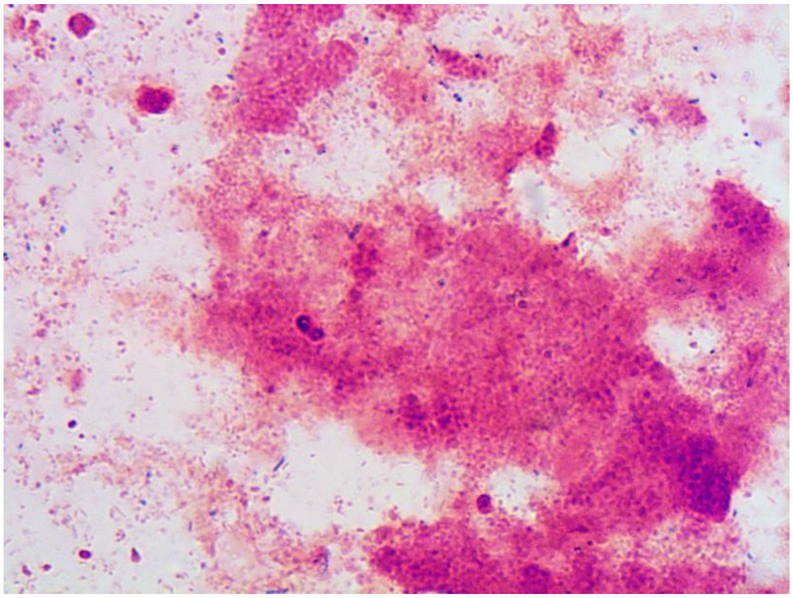
Acid testing is used to determine the presence of carbonates and metals on the membrane surface. In this test, several drops of dilute hydrochloric acid were placed on the foulant surfaces. Effervescing indicates the presence of carbonates while a color change is associated with the presence of metals.

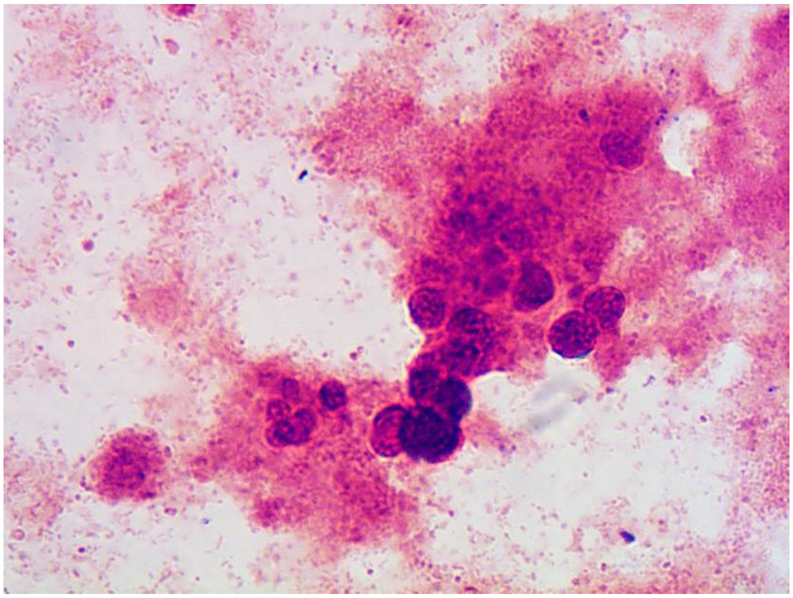
Acid testing was negative for the presence of carbonates; a yellow color change occurred which is indicative of the presence of metals.

Microbiological Analysis

This analysis is performed to identify the biological activity of foulant removed from the membrane surface. Foulant samples are stained and examined with a light microscope at 1000x using an oil immersion lens. Gram positive bacteria are stained purple while Gram negative bacteria are stained pink.

Microscope imaging displayed amorphous organic material (e.g. bio-slime) containing an abundance of Gram-negative bacteria. Also present were algae and various particulate materials, as well as a lesser amount of Gram-negative bacteria.





Light microscope images (1000x) of foulant scraped from SN KM8048229-7015

Zeta Potential Testing

The zeta potential is the charge that resides at the double layer boundary of colloids. Most naturally occurring colloids are negatively charged. A goal of coagulation is to neutralize the colloids to form floc prior to filtration. If an excess of coagulant is present, the charge of the colloids switches from negative to positive.

The zeta potential of the foulant present on the membrane surface is measured to determine if coagulant is being overfed. Two grams of wet foulant is required for this test.

The foulant material of SN KM8048229-7015 had a zeta potential of -23.4 mV indicating there was no coagulant on the membrane surface.

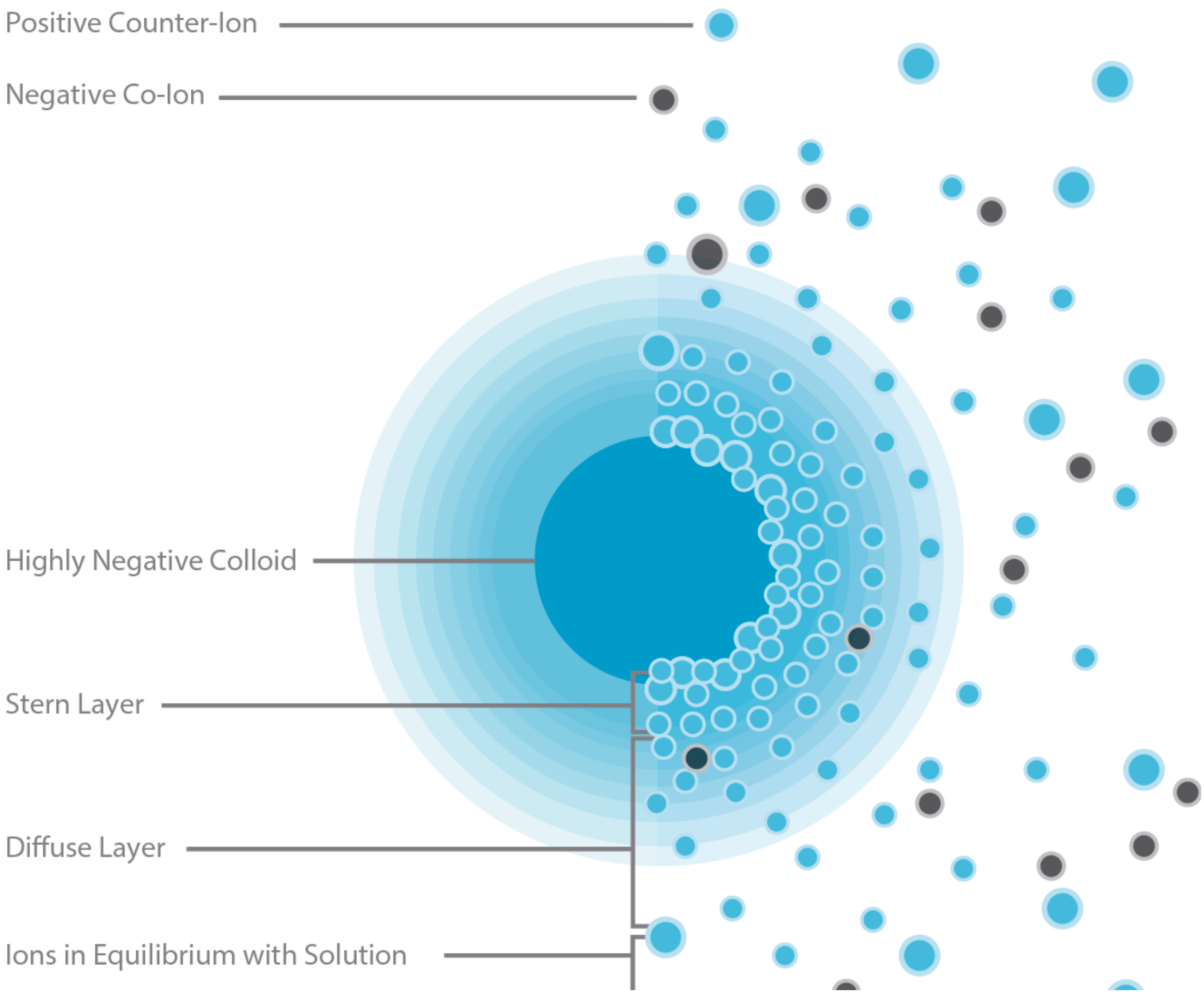
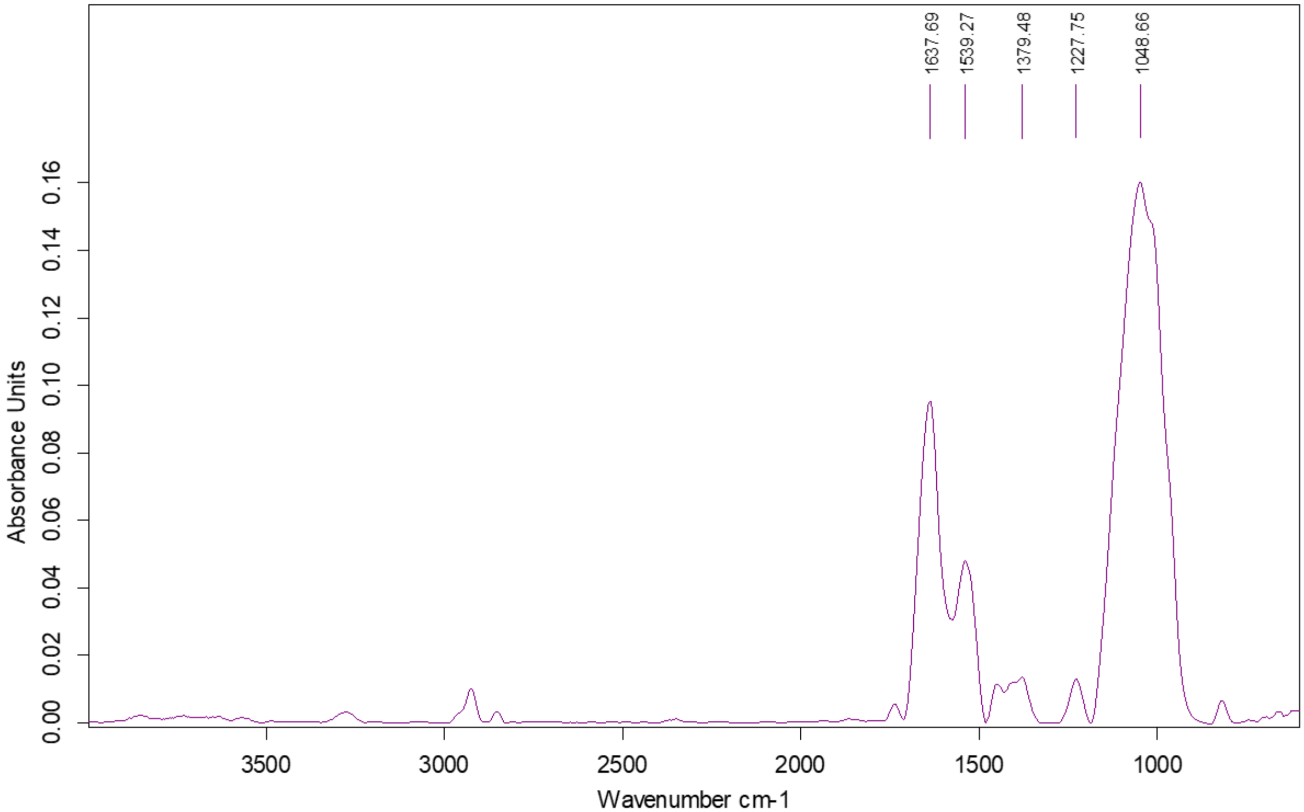


Image based on diagram from Particle Characterization Laboratories, Inc.

Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FT-IR) is an analytical technique used to identify functional groups (specific groups of atoms or bonds within molecules). Infrared radiation passes through a sample, with some of the radiation absorbed and some transmitted. A measurement and interpretation of this data produces a spectrum which can then be compared and matched to the known spectra for functional groups based on the wavenumber at which bands appear and their respective shapes (e.g. sharp, broad, strong, weak).

FT-IR spectroscopy performed on foulant removed from the membrane surfaces resulted in a broad peak at the 1000 cm^{-1} range, which is characteristic of the presence of both organic material (e.g. carbohydrates – polysaccharides) and phosphate compounds (e.g. calcium phosphate). A smaller double peak at the 1650-1500 cm^{-1} range was also present, which is associated with the presence of proteins (e.g. amino acids from microorganisms).



FT-IR spectral image of foulant removed from the membrane surface of SN KM8048229-7015

Energy Dispersive Spectroscopy (EDS) Analysis

Energy Dispersive Spectroscopy analysis is used to determine the relative concentration of elements present in a sample. EDS analysis is performed on a dry membrane sample. The element sulfur is at least in part associated with the membrane support material (polysulfone) rather than a foulant layer. Avista's analysis of new membranes typically detects between 5.00 and 7.00 weight percentage. Relative concentrations below 5.00 percent indicate the presence of a foulant layer masking the membrane surface.

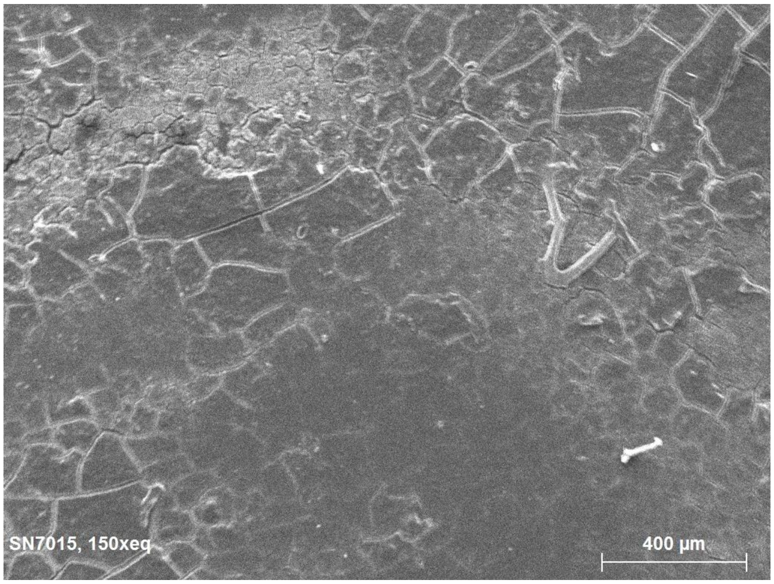
EDS analysis detected calcium and phosphorus as the primary inorganic constituents of the foulant material. Lesser amounts of magnesium, iron and aluminum were also detected. The sulfur weight percentage (5.86 wt%) indicates that the foulant layer did not contribute to notable masking of the membrane surface.

Elements	SN KM8048229-7015 Weight Percent (wt%)
Carbon	65.22
Oxygen	17.96
Sulfur	5.86
Calcium	4.97
Phosphorus	4.04
Magnesium	0.80
Iron	0.70
Aluminum	0.45

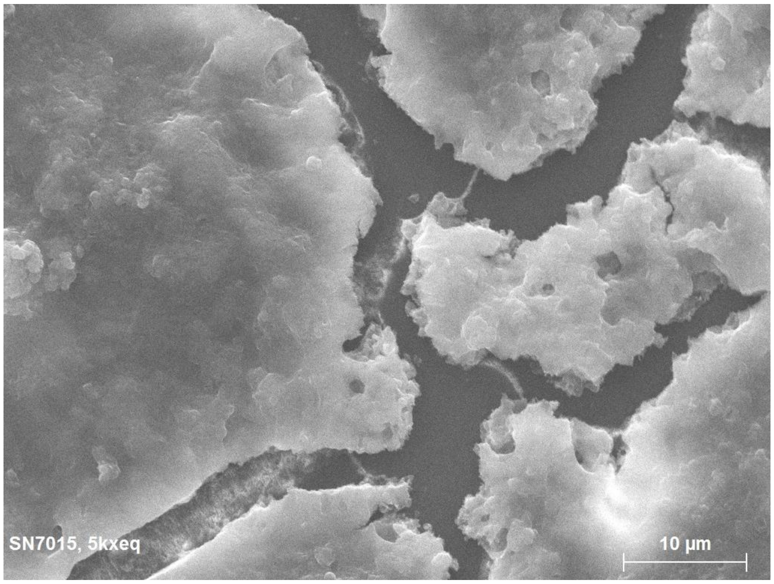
Scanning Electron Microscope (SEM) Imaging

SEM imaging is performed on the membrane surface to observe the topography of the foulant material. Foulant morphology can be an indicator of the type of foulant.

SEM imaging (150x) displayed a cracked layer of smooth foulant containing fine-granular deposits. Close-up imaging (5000x) provided a clearer representation of the amorphous topography of the foulant layer.



SEM image (150x) of the membrane surface of SN KM8048229-7015



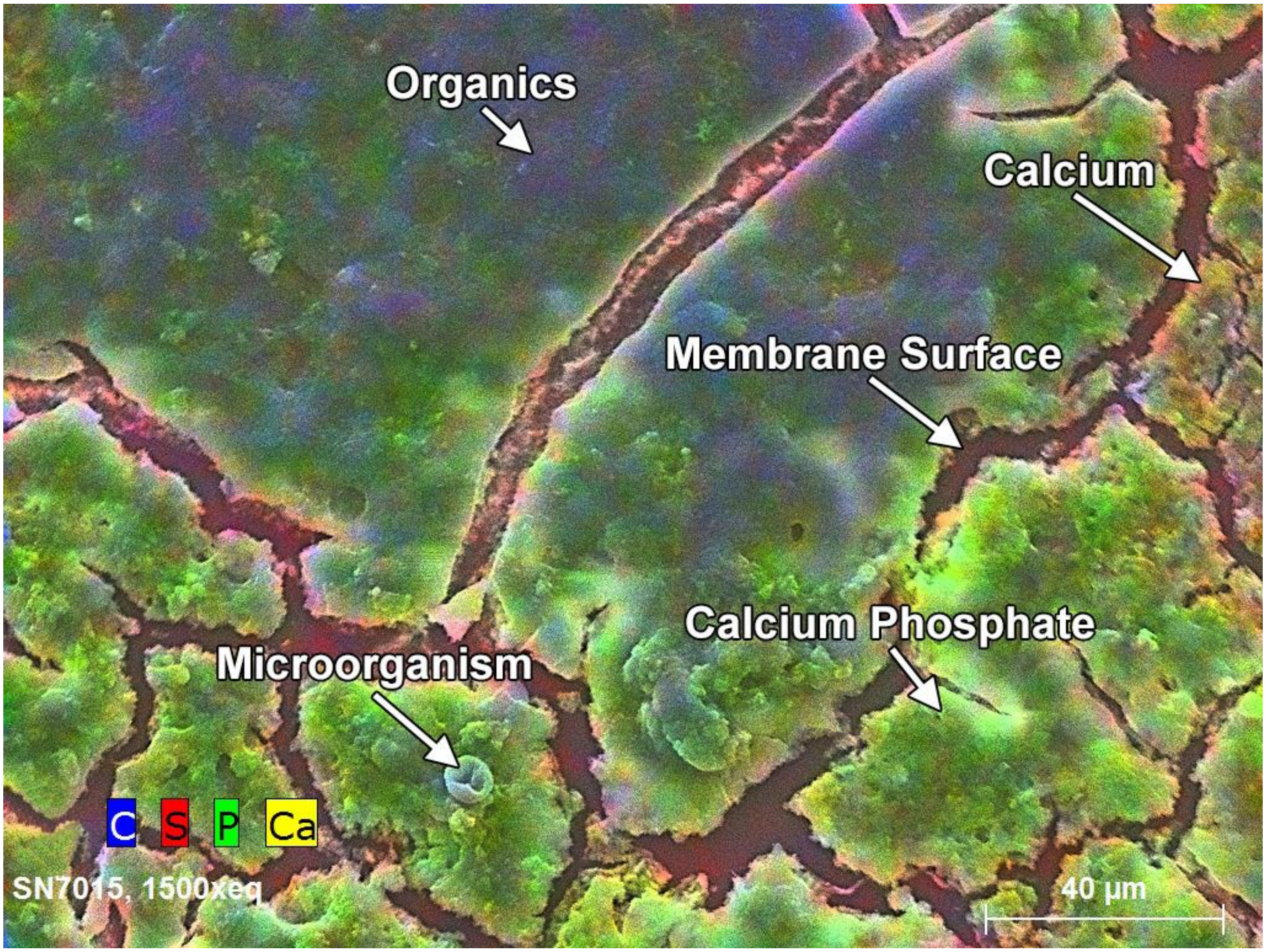
Close-up SEM image (5000x) of the membrane surface of SN KM8048229-7015

Chromatic Elemental Imaging^{SM} (CEI^{SM})

CEI is an analytical technique used to determine the spatial distribution of elements in a foulant sample. In this technique, a beam of focused electrons is accelerated across the surface of a foulant sample and interacts with the sample's inorganic elements by causing the elements to emit electrons. An element's electron emission from its atomic shell generates a characteristic X-ray spectrum that allows for its identification. CEI assigns each element a color (colors for each element are shown in a legend on the bottom left corner of the CEI image) and provides a high-resolution image where the colors correspond to the exact location of the elements in the sample. An element's color intensity in a CEI is largely influenced by its concentration in the foulant sample; i.e. elements present with higher relative concentrations are displayed with greater color intensity in the image. CEI can uniquely identify the distinct elements in a mixed foulant sample.

CEI image (1500x) of the membrane surface

CEI℠ identified the bulk of the foulant layer to be comprised of organic material (represented by the element carbon – dark blue) and calcium phosphate (combination of yellow and green). Separate deposits of calcium (yellow) were also present. The membrane surface is depicted by the element sulfur (red) and was visible through cracks in the foulant layer.



CEI image (1500x) of the membrane surface with labels

Cell Test & Laboratory Clean-in-Place Study

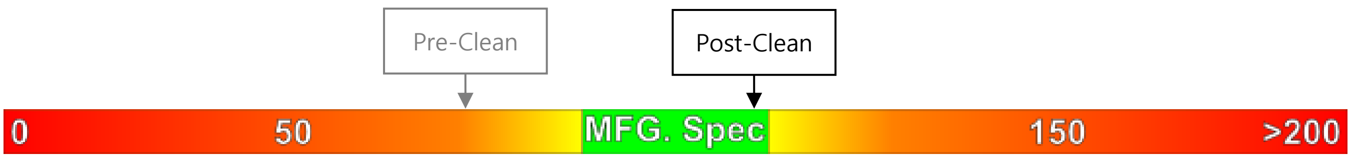
Flat sheet membrane samples harvested from the full element are placed in a cell test apparatus and cleaned with various Avista chemicals to determine the most effective cleaner combinations and contact times. The most effective cleaner is chosen based on overall improvement in water and salt passage and visual foulant removal.

The table below shows performance data for the optimum cleaning. Flat sheet samples were cleaned with RoClean P111 (2% by weight in RO/DI water, heated to approximately 35 degrees Celsius and circulated) for 2 hours. Complete visual foulant removal was achieved and flow was restored to the manufacturer's specification.

SN KM8048229-7015	Water Passage Constant "A" Value	$MgSO_4$ Rejection (%)
Pre-Clean	0.91E-04 82% of Normal	97.5
Post-Clean	**1.55E-04** **Normal**	**97.3**
Manufacturer's Specifications	1.11 to 1.57E-04 Normal Range	99.0 to 99.4

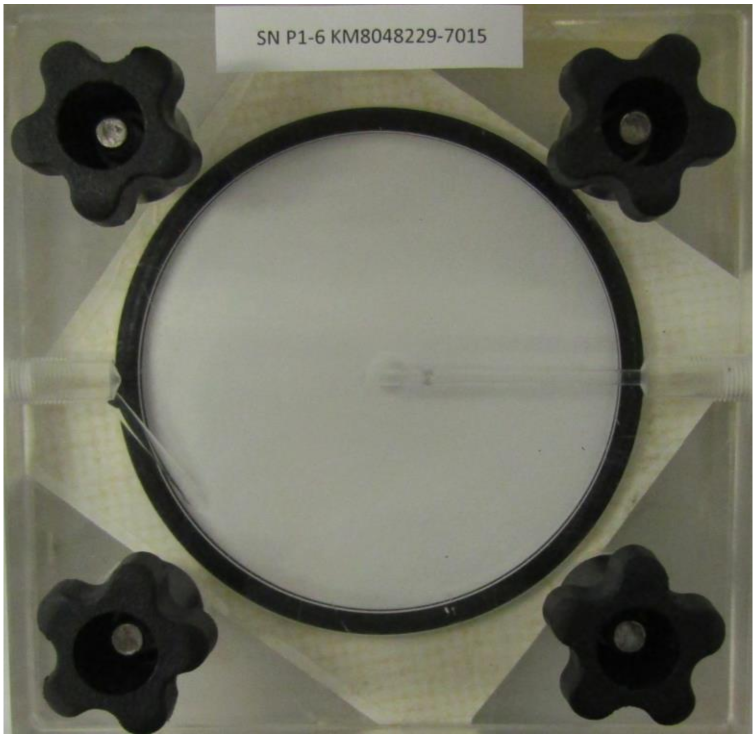
Note: testing conducted using an aqueous solution containing 2,000 ppm MgSO4.

Water Passage (% of Normal)



Rejection (%)

Pre-Clean



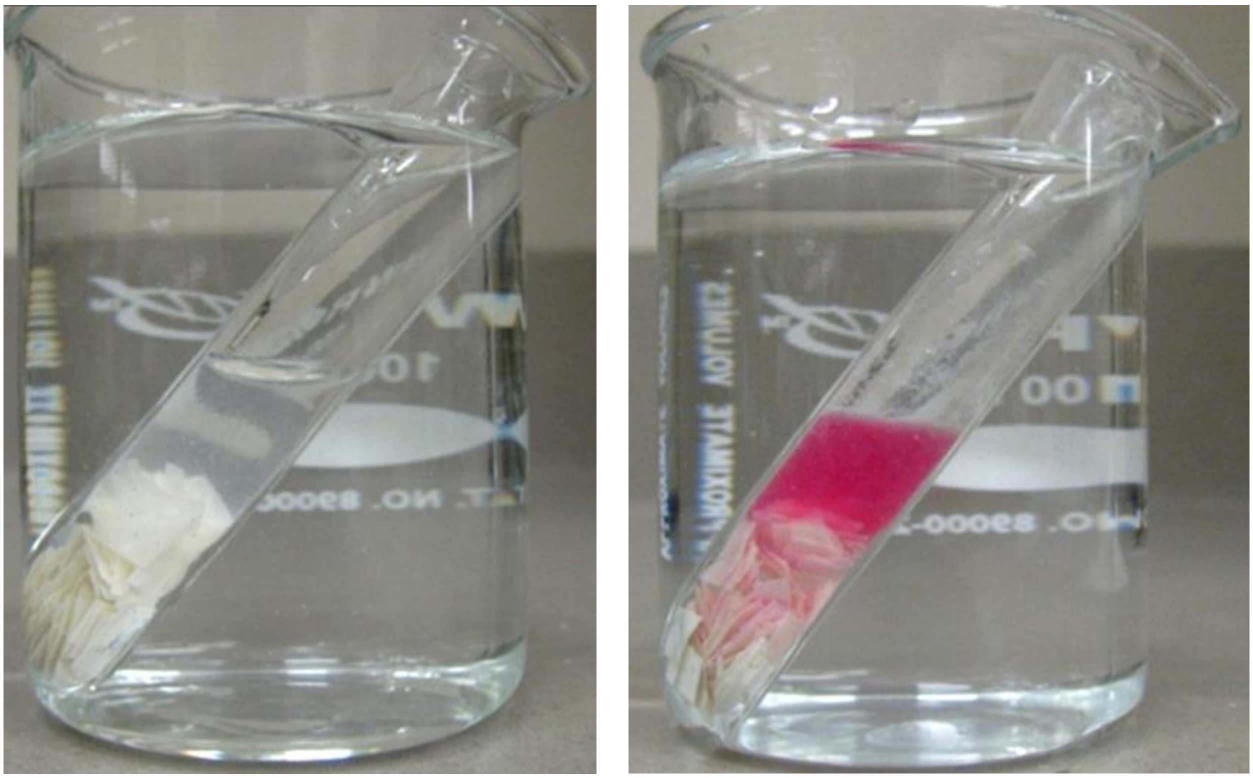
Post-Clean

Testing to Determine Damage to Flat Sheet Samples

Fujiwara Testing

Fujiwara testing is a qualitative analysis which determines if a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. If the solution changes color to pink or red, the element is declared positive for the presence of oxidizing halogens. A color change does not occur if the membranes has not been exposed to halogens. Common symptoms of halogen oxidation include increased flow and loss in permeate quality.

Fujiwara testing was negative for the presence of halogens (e.g. chlorine) in the membrane structure.



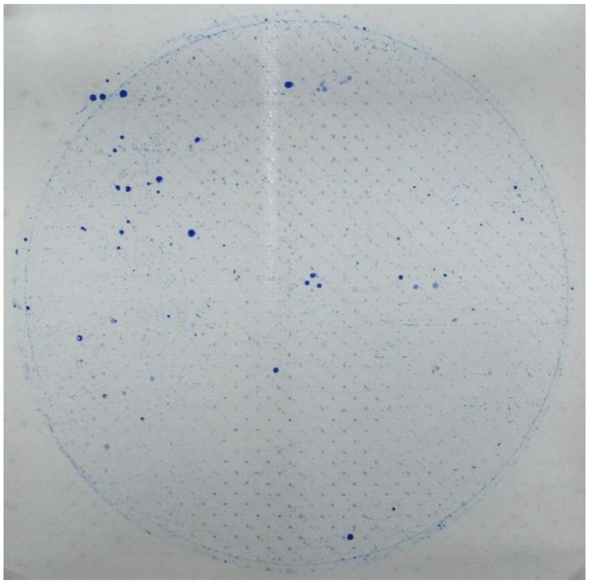
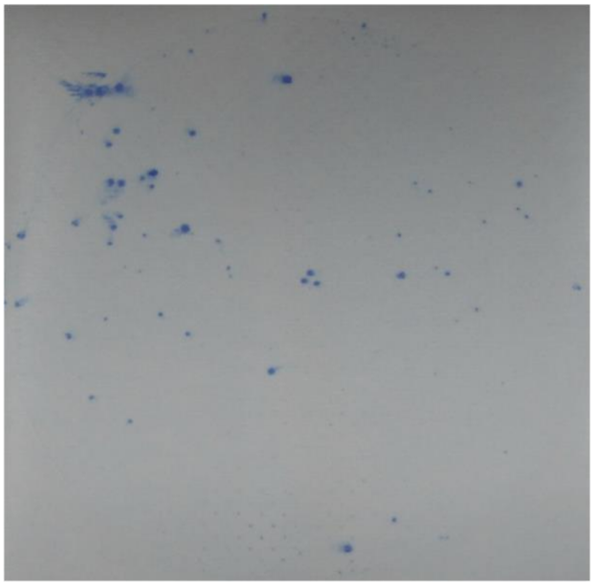
Example of negative (left) and positive (right) Fujiwara color change

Testing to Determine Physical Damage to Flat Sheet Samples

Dye Test

Cleaned flat sheet samples were exposed to dye in a cell test apparatus at 100 psi for 15 minutes. Physically and/or chemically damaged membranes will absorb the dye on the membrane surface. Dye penetration through the membrane backing indicates severe physical and/or chemical damage.

Dye testing revealed pinhole-sized areas of heavy dye uptake on the membrane surface. The pinholes maintained a symmetrical, rounded shape which can indicate chemical damage caused by foulant. A pattern of lesser dye uptake was displayed in the areas corresponding to the feed spacer contact points, representing some degree of physical abrasion. Additionally, the dye appeared to penetrate through the pinholes to the membrane backing, signifying that the damage was severe.

Example of dye uptake on the membrane surface (left) and penetration to the membrane backing (right)

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#053018-5	Standard Spiral Autopsy	**KM8048229-7015** C7520230	June 25, 2018

We the undersigned being the technical specialists in membrane autopsy and related testing procedures and protocol for Avista Technologies certify to the best of our knowledge and belief that the tests listed in this report have been conducted following Avista's standard testing practices and that the results are accurate and complete.

By signing this certificate neither the laboratory employees nor their employer makes any warranty, expressed or implied, concerning the cleaning study results.

Date: 06/25/2018

Signed:

Megan Lee
Laboratory Services Manager

Arnell Abad
Laboratory Services Chemist

APPENDIX F

Nanofiltration Membrane Element Data Sheets

FILMTEC™ Membranes

FILMTEC NF270 Nanofiltration Elements for Commercial Systems

Features

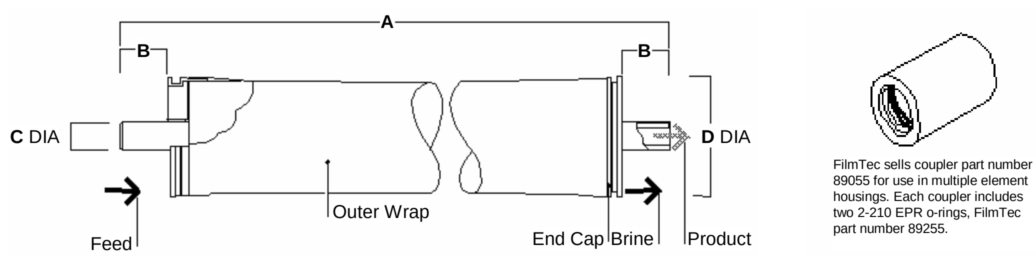
The FILMTEC™ NF270 membrane elements are ideal for removing a high percentage of TOC and THM precursors with medium to high salt passage and medium hardness passage. The FILMTEC NF270 membrane is an ideal choice for surface water and ground water where good organic removal is desired with partial softening.

Product Specifications

Product	Part Number	Active Area ft^2 (m^2)	Applied Pressure psig (bar)	Permeate Flow Rate gpd (m^3/d)	Stabilized Salt Rejection (%)
NF270-2540	149986	28 (2.6)	70 (4.8)	850 (3.2)	>97.0
NF270-4040	149987	82 (7.6)	70 (4.8)	2,500 (9.5)	>97.0

1. Permeate flow and salt rejection based on the following test conditions: 2,000 ppm $MgSO_4$, 77°F (25°C) and 15% recovery at the pressure specified above.
2. Permeate flows for individual NF270-2540 elements may vary by -20% / +30%. NF270-4040 individual elements may vary -15% / +50%.
3. Developmental products available for sale.

Figure 1



Product	Dimensions – Inches (mm) A	B	C	D
NF270-2540	40.0 (1,016)	1.19 (30)	0.75 (19)	2.4 (61)
NF270-4040	40.0 (1,016)	1.05 (27)	0.75 (19)	3.9 (99)

1. Refer to FilmTec Design Guidelines for multiple-element systems. 1 inch = 25.4 mm
2. NF270-2540 has a tape outer wrap. NF270-4040 has a fiberglass outer wrap.

Operating Limits

- Membrane Type — Polyamide Thin-Film Composite
- Maximum Operating Temperature — 113°F (45°C)
- Maximum Operating Pressure — 600 psi (41 bar)
- Maximum Feed Flow Rate - 4040 elements — 16 gpm (3.6 m^3/hr)
  - 2540 elements — 6 gpm (1.4 m^3/hr)
- Maximum Pressure Drop - tape wrapped — 13 psig (0.9 bar)
  - fiberglassed — 15 psig (1.0 bar)
- pH Range, Continuous Operation[a] — 2 - 11
- pH Range, Short-Term Cleaning (30 min.)[b] — 1 - 12
- Maximum Feed Silt Density Index — 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 Cleaning Guidelines in specification sheet 609-23010 for NF90.
[c] Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

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. 609-02077) 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.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 30 psi (2.1 bar).
- Avoid static permeate-side backpressure at all times.

FILMTEC™ Membranes
For more information about FILMTEC membranes, call the Dow Liquid Separations business:

North America:	1-800-447-4369
Latin America:	(+55) 11-5188-9222
Europe:	(+32) 3-450-2240
Pacific:	+60 3 7958 3392
Japan:	+813 5460 2100
China:	+86 21 2301 9000

http://www.filmtec.com

NE4040-40

High productivity NF element

SPECIFICATIONS:

General Features

Permeate flow rate[1]:	2,100 GPD (7.9 m^3/day)
Monovalent ion rejection (NaCl) :	20 –40%
Effective membrane area:	85 ft^2 (7.9 m^2)

1. The stated product performance is based on data taken after 30 minutes of operation at the following monovalent test conditions:

   - **2,000 mg/L NaCl solution at 75 psig (0.5 MPa) applied pressure**
   - **15% recovery**
   - **77 °F (25 °C)**
   - **pH 6.5–7.0**

2. Permeate flow rate for each element may vary but will be no more than 15%.
3. All elements are vacuum sealed in a polyethylene bag containing 1.0% SBS (sodium bisulfite) solution and individually packaged in a cardboard box.

Membrane type:	Thin-Film Composite
Membrane material:	Polyamide (PA)
Element configuration:	Spiral-Wound, FRP Wrapping

Dimensions

Model Name	A	B	C	D	E
NE4040-40	40.0 inch (1,016.0 mm)	4.0 inch (101.6 mm)	0.75 inch (19.1 mm)	1.61 inch (40.9 mm)	1.61 inch (40.9 mm)

1. Each membrane element supplied with one brine seal, one interconnector (coupler) and four o-rings.
2. All NE4040 elements fit nominal 4.0 inch (101.6 mm) I.D. pressure vessels.

NE4040-40

High productivity NF element

CSM

APPLICATION DATA:

Operating Limits	· Max. Pressure Drop / Element	15 psi (0.1 MPa)
	· Max. Pressure Drop / 240" Vessel	60 psi (0.41 Mpa)
	· Max. Operating Pressure	600 psi (4.14 MPa)
	· Max. Feed Flow Rate	18 gpm (4.09 m^3/hr)
	· Min. Concentrate Flow Rate	4 gpm (0.91 m^3/hr)
	· Max. Operating Temperature	113 °F (45 °C)
	· Operating pH Range	2.0–11.0
	· CIP pH Range	1.0–13.0
	· Max. Turbidity	1.0 NTU
	· Max. SDI (15 min)	5.0
	· Max. Chlorine Concentration	< 0.1 mg/L
Design Guidelines for Various Water Sources	· Wastewater Conventional (SDI < 5)	8–12 gfd
	· Wastewater Pretreated by UF/MF (SDI < 3)	10–14 gfd
	· Seawater, Open Intake (SDI < 5)	7–10 gfd
	· Seawater, Beach Well (SDI < 3)	8–12 gfd
	· Surface Water (SDI < 5)	12–16 gfd
	· Surface Water (SDI < 3)	13–17 gfd
	· Well water (SDI < 3)	13–17 gfd
	· RO permeate (SDI < 1)	21–30 gfd
Saturation Limits (Using Antiscalants)†	· Langlier Saturation Index (LSI)	<+1.5
	· Stiff and Davis Saturation Index (SDSI)	<+0.5
	· $CaSO_4$	230% saturation
	· $SrSO_4$	800% saturation
	· $BaSO_4$	6,000% saturation
	· SiO_2	100% saturation

†The above saturation limits are typically accepted by proprietary antiscalant manufacturers. It is the user's responsibility to ensure proper chemical(s) and concentration are dosed ahead of the membrane system to prevent scale formation anywhere within the membrane system. Membrane elements fouled or damaged due to scale formation are not covered by the limited warranty.

GENERAL HANDLING PROCEDURES

- Elements contained in the boxes must be kept dry at room temperature (7–32°C; 40–95°F) and should not be stored in direct sunlight. If the polyethylene bag is damaged, a new preservative solution (sodium bisulfite) must be added and air-tight sealed to prevent drying and biological growth.
- Permeate from the first hour of operation should be discarded to flush out the preservative solution.
- Elements should be immersed in a preservative solution during storage, shipping and system shutdowns to prevent biological growth and freezing. The standard storage solution contains 1% by weight sodium bisulfite or sodium metabisulfite (food grade). For short term storage (i.e. one week or less) 1% by weight sodium metabisulfite solution is adequate for preventing biological growth.
- Keep elements moist at all times after initial wetting.
- Avoid excessive pressure and flow spikes.
- Only use chemicals compatible with the membrane elements and components. Use of such chemicals may void the element limited warranty.
- Permeate pressure must always be equal or less than the feed/concentrate pressure. Damage caused by permeate back pressure voids the element limited warranty.

Nitto

HYDRANAUTICS
Nitto Group Company

Membrane Element NANO-BW-4040

Performance:	**$MgSO_4$**	
	Permeate Flow (Nominal):	2,000 gpd (7.6 m^3/d)
	$MgSO_4$ Rejection (Nominal):	99.7% (99.5% minimum)

Type	Configuration:	Spiral Wound
	Membrane Polymer:	Composite Polyamide
	Nominal Membrane Area:	75 ft^2 (7 m^2)
	Feed/Brine Spacer Thickness:	34 mil (0.87 mm) with HYDRAblock ™ Technology

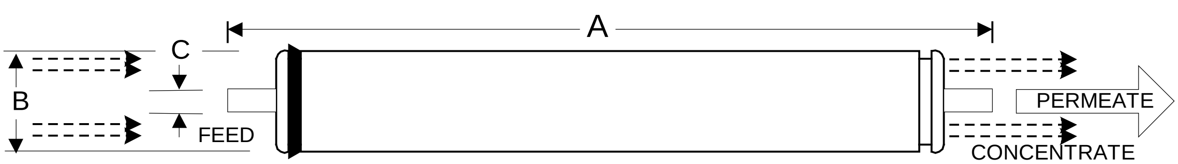
Application Data*	Maximum Applied Pressure:	600 psig (4.14 MPa)
	Maximum Chlorine Concentration:	< 0.1 PPM
	Maximum Operating Temperature:	113 °F (45 °C)
	pH Range, Operation (Cleaning):	3.0 - 9.0 (1.0 – 11.5) *
	Maximum Feedwater Turbidity:	1.0 NTU
	Maximum Feedwater SDI (15 mins):	5.0
	Maximum Feed Flow:	16 GPM (3.6 m^3/h)
	Minimum Ratio of Concentrate to Permeate Flow for any Element:	5:1
	Maximum Pressure Drop for Each Element:	15 psi

***** The limitations shown here are for general use. For specific projects, operating at more conservative values may ensure the best performance and longest life of the membranes. See Hydranautics Technical Bulletins for more detail on operation limits, cleaning pH, and cleaning temperatures.

Test Conditions

The stated performance is based on the following test conditions:

2000 ppm $MgSO_4$
130 psi (0.9 MPa) Applied Pressure
77 °F (25 °C) Operating Temperature
15% Permeate Recovery
6.5 – 7.0 Feed pH



A, inches (mm)	B, inches (mm)	C, inches (mm)	Weight, lbs. (kg)
40.00 (1016)	3.95 (100.3)	0.75 (19.1)	8 (3.6)

Notice: Permeate flow for individual elements may vary + or - 20 percent. All membrane elements are supplied with a brine seal, interconnector, and o-rings. All membrane elements are supplied with a brine seal, interconnector, and o-rings. Elements are enclosed in a sealed polyethylene bag and then packaged in a cardboard box.

3/06/15

Hydranautics Corporate: 401 Jones Road, Oceanside, CA 92058
1-800-CPA-PURE Phone: 760-901-2500 Fax: 760-901-2578 info@Hydranautics.com

SR200 4” NANOFILTRATION ELEMENTS

Hard Overwrap Low Pressure, Selective Rejection Elements

PRODUCT DESCRIPTION

Membrane Chemistry:	Proprietary TFC® polyamide chemistry
Membrane Type:	SR200 - selective rejection nanofiltration
Molecular weight cut-off:	200 Daltons
Construction:	Spiral wound with fiberglass outerwrap
Applications:	Separation of higher molecular weight components (>200 Dalton) and multivalent ions from various feed solutions, hardness and sulfate removal from seawater and chloralkali process stream

SPECIFICATIONS

Part Number	Model	Nominal Permeate Flow gpd (m^3/d)	Nominal Rejection	Active Membrane Area ft² (m^2)	Feed Spacer mil (mm)
KDP3529	4040-SR200	1,275 (4.8)	99.4%	85 (7.9)	28 (0.7)

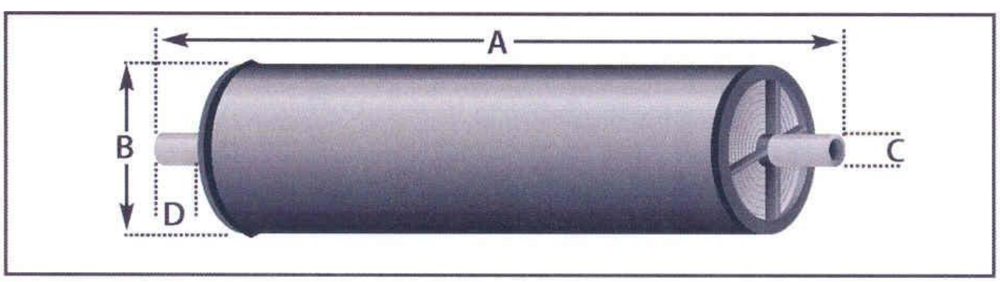
Test Conditions: 5,000 mg/l $MgSO_4$ in deionized water at 95 psi (655 kPa) applied pressure, 15% recovery, 77°F (25°C), pH 7.5

OPERATING AND DESIGN INFORMATION*

Typical Operating Pressure:	200 - 600 psi (1,380 - 4,140 kPa)
Maximum Operating Pressure:	600 psi (4,140 kPa)
Maximum Operating Temperature:	122°F (50°C)
Maximum Cleaning Temperature:	113°F (45°C)
Maximum Continuous Free Chlorine:	< 0.1 mg/l
Allowable pH – Continuous Operation:	4 - 10
Allowable pH – Short Term Cleaning:	1.7 – 11.5
Maximum Differential Pressure Per Element:	10 psi (69 kPa)
Maximum Differential Pressure Per Vessel:	60 psi (414 kPa)
Maximum Feed Turbidity:	1 NTU
Maximum Feed SDI (15 minute test):	5

* Consult Process Engineering Group for specific information.

NOMINAL DIMENSIONS*



Model	A inches (mm)	B inches (mm)	C inches (mm)	D inches (mm)	Part Numbers Interconnector	O-ring	Brine Seal
4040-SR200	40 (1,016)	4 (101.6)	0.75 (19.0)	1.0 (25.4)	0035267	0035458	0035702

* Dimensions are provided for reference only and should not be interpreted as accurate specifications.

Performance:
Performance specifications shown on the front side of this document are nominal values. Individual element permeate flows may vary +20/-15% from the values shown. Minimum magnesium sulfate rejection is 99.0% at the conditions shown.

Selective Rejection (SR200) nanofiltration membrane performance is highly dependent on feed chemistry, temperature, pH, and solution concentration. Performance can only be accurately known through pilot study. KMS strongly recommends that the appropriate pilot studies be conducted to determine suitability for a given application.

Operating Limits:

- **Operating Pressure:** Maximum operating pressure is 600 psi (4,140 kPa). Typical operating pressure for SR200 systems is in the range of 150 psi (1,035 kPa) to 250 psi (1,725 kPa). Actual operating pressure is dependent upon system flux rate (appropriate for feed source) as well as feed salinity, recovery and temperature conditions.
- **Permeate Pressure:** Permeate pressure should not exceed feed-concentrate pressure by more than 5 psi (34 kPa) at any time (on-line, off-line and during transition).
- **Differential Pressure**: Maximum differential pressure limits are 10 psi (69 kPa) per element. Maximum differential pressure for pressure vessel is 60 psi (414 kPa).
- **Temperature**: Maximum operating temperature is 122°F (50°C). Maximum cleaning temperature is 113°F (45°C).
- **pH:** Allowable range for continuous operation is pH 4-10. Allowable range for short term cleaning is pH 1.7-11.5. It is recommended to limit the exposure of the SR200 membrane to the extended pH range to 4 hours, once per month.
- **Turbidity and SDI:** Maximum feed turbidity is 1 NTU. Maximum feed Silt Density Index (SDI) is 5.0 (15 minute test) while recommended SDI_{15} of feed is 3 or less. Experience has shown that feedwater with turbidity greater than 0.2 NTU generally results in frequent cleanings.
- **Recovery**: Maximum recovery is site and application specific. In general, single element recovery is approximately 15% per element.

Chemical Tolerance:

- **Chlorine:** Exposure of SR200 membrane to free chlorine or other oxidizing agents such as permanganate, ozone, bromine and iodine is not recommended. SR200 membrane has a free chlorine tolerance of approximately 2,000 ppm-hours based on testing at 77°F (25°C), pH 8. This tolerance may be significantly reduced if catalyzing metals such as iron are present or if the pH and/or temperature are different. Sodium metabisulfite (without catalysts such as cobalt) is the preferred reducing agent. SR200 membrane has a chloramine tolerance of approximately 60,000 ppm-hours in the absence of free chlorine based on testing at 77°F (25°C), pH 8.
- **Cationic (Positively Charged) Polymers and Surfactants:** SR200 membrane may be irreversibly fouled if exposed to cationic (positively charged) polymers or surfactants. Exposure to these chemicals during operation or cleaning is not recommended.

Lubricants:
For element loading, use only the recommended silicone lubricant (or approved equivalent), water or glycerin to lubricate O-rings and brine seals. The use of petroleum based lubricants or vegetable based oils may damage the element and void the warranty.

Service and Ongoing Technical Support:
KMS has an experienced staff of professionals available to assist end users and OEM's for optimization of existing systems and support with the development of new applications. Along with the availability of supplemental technical bulletins, KMS also offers a complete line of KOCHKLEEN® membrane cleaners, RO pretreatment and maintenance chemicals.

Koch Membrane Systems, Inc., www.kochmembrane.com
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