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Managing Water in the West

Desalination and Water Purification Research and Development Program Report No. 199

Maximizing Product Water through Brine Minimization: Innovative Recovery RO Testing

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Eileen Y. Idica, Ph.D., P.E., Brett W. Faulkner, P.E., and R. Shane Trussell, Ph.D., P.E. BCEE Trussell Technologies, Inc., 32 North Lake Avenue, Suite 300, Pasadena, CA 91101 Tel: (626) 486-0560 Seval Sen, P.E. Padre Dam Municipal Water District	5e. TASK NUMBER 5f. WORK UNIT NUMBER

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14. ABSTRACT
Cost effective and innovative approaches are needed to reduce brine flows and enable discharge with low economic and environmental impact. Trussell Technologies and the Padre Dam Municipal Water District (Padre Dam) investigated methods to maximize the product water produced from the RO system that is part of the East County Advanced Water Purification (AWP) Program. This study compared the recoveries that can be achieved with conventional RO brine minimization technologies and with closed circuit desalination at Padre Dam's AWP Demonstration Facility, and evaluated their performance with respect to operability, energy efficiency, and water quality. First a closed circuit desalination (CCD) pilot plant was installed in early 2016 at Padre Dam's AWP Demonstration Facility and tested for 8 months. Then the CCD pilot system was replaced with a conventional recovery RO system (CRRO), which was tested for 4 months. The CCD pilot system used more energy than the CRRO system, when comparing both systems operations at 95% overall recovery. The CCD system used an equalization tank between the primary RO system and the CCD pilot system as the semi-batch nature of the CCD process results in non-constant feed flow rates, thus using more energy. Special water quality sampling, particularly on the CCD permeate, demonstrated that the CCD permeate exhibited much of the same water quality characteristics as other RO systems operating in potable reuse applications, thereby suggesting that using the CCD process within the existing and planned regulations is feasible.

15. SUBJECT TERMS
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by
Eileen Y. Idica, Ph.D., P.E.
Brett W. Faulkner, P.E.
R. Shane Trussell, Ph.D., P.E. BCEE
Trussell Technologies, Inc.

Seval Sen, P.E.
Padre Dam Municipal Water District

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Acronyms and Abbreviations

AOP	advanced oxidation process
AWP	Advanced Water Purification
BNR	Biological Nutrient Removal
CCD	closed circuit desalination
CEC	contaminant of emerging concern
CIP	clean-in-place
CRRO	conventional recovery reverse osmosis
DPB	disinfection byproduct
DWPR	Desalination and Water Purification Research Program
EPA	U.S. Environmental Protection Agency
HAA5	total haloacetic acids
HMI	human machine interface
HRT	hydraulic retention time
LACSD	Los Angeles County Sanitation District
LRV	log removal values
LVL	Leo J. Vander Lans Water Treatment Facility
MDL	method detection limit
MF	microfiltration
MRL	method reporting limit
N	nitrogen
NaOH	sodium hydroxide
NDMA	*N*-Nitrosodimethylamine
ORP	oxidation reduction potential
P	phosphorus
Padre Dam	Padre Dam Municipal Water District
PLC	programmable logic controller
Program	East County Advanced Water Purification Program
RO	reverse osmosis
RRO	recovery reverse osmosis
TDS	total dissolved solids
TMDL	total maximum daily load
TOC	total organic carbon
TTHM	total trihalomethanes
UF	ultrafiltration
UV	ultraviolet
UVA	UV absorbance
UVT	UV transmittance
VFD	variable frequency drive
WRD	Water Replenishment District of Southern California
WRF	Water Reclamation Facility

Measurements

ºC	degrees Celsius
ºF	degrees Fahrenheit
gfd	gallon per square of membrane area per day
gpd	gallon per day
gpm	gallon per minute
kgal	thousand gallons
km	kilometer
kWh	kilowatt hour
lmh	liter per square meter per hour
lpm	liter per minute
m^3	cubic meter
mm	millimeter
MGD	million gallons per day
mg/L	milligram per liter
mJ/cm^2	millijoule per square centimeter
Ng/L	nanogram per liter
nm	nanometer
ppm	parts per million
psi	pounds per square inch
sf	square foot
μg/L	microgram per liter

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Executive Summary

Inland water districts often lack economical options for disposal of brine from a reverse osmosis (RO) treatment system. Therefore, it is important to maximize the product water produced by RO systems. A new closed circuit desalination (CCD) technology presents a potential opportunity to achieve these higher recoveries compared to what can be achieved with traditional RO systems.

For this reason, Padre Dam Municipal Water District (Padre Dam) is interested in maximizing the product water produced from the RO system that is part of their pursuit of potable reuse through the East County Advanced Water Purification (AWP) Program. This study sought to:

A. Compare the recoveries that can be achieved with conventional RO brine minimization technologies and with closed circuit desalination at Padre Dam's AWP Demonstration Facility

B. Evaluate their performance with respect to operability, energy efficiency, and water quality

Two systems were installed at Padre Dam's AWP Demonstration Facility and tested in series. Each system was fed concentrate from the existing primary RO system, and run to increase the overall recovery of the entire RO system. First, a closed circuit desalination (CCD) pilot plant was installed in early 2016 and tested for 8 months. Then the CCD pilot system was replaced with a conventional recovery RO system (CRRO), which was tested for 4 months. Water quality in the feed, permeate, and concentrate of these systems was sampled and analyzed at regular frequencies to track performance. Specific flux, membrane feed pressures, and other parameters were also regularly assessed to determine cleaning frequencies for each set of conditions. Energy use was monitored using power meters on each system.

The CCD pilot system demonstrated sustainable operation at 95% and 96% overall recoveries with clean-in-place (CIP) intervals of 40 to 50 days, above the 30-day minimum CIP interval criterion The CRRO system demonstrated runtimes at 22 days, which was less than the 30-day criterion, but it was run during a period of increased feed silica. Silica was identified for as the primary scalant for both systems. The project team recommends that the CRRO system be further tested for several months to verify if the CRRO system can achieve 95% overall recovery under water quality conditions similar to that during the CCD testing, particularly with respect to silica.

The CCD pilot system exhibited greater energy use than the CRRO system, when comparing both systems operations at 95% overall recovery. Using an equalization tank between the primary RO system and the CCD pilot system was the main reason for increased energy use for the CCD pilot system. The

equalization tank was needed as the semi-batch nature of the CCD process results in non-constant feed flow rates. The CRRO system did not have an upstream equalization tank, as is consistent with industry standards. Further investigation is necessary to identify the engineering design that would allow the CCD system to act as a recovery RO unit, but that would not have an equalization tank and the corresponding loss of pressure on the CCD system feed stream.

Special water quality sampling, particularly on the CCD permeate, demonstrated that the CCD permeate exhibited much of the same water quality characteristics as other RO systems operating in potable reuse applications, thereby suggesting that using the CCD process within the existing and planned regulations is feasible.

1. Introduction

Droughts, water shortages, population growth: these factors have driven water reuse and desalination to the forefront of our search for new potable water supplies. Reverse osmosis (RO) is the most widely used technology for both seawater and brackish water desalination, and is the "workhorse" process underlying most potable reuse treatment trains (CDPH 2013 and Gerrity et al. 2013). While the technology is well understood and cost-effective, its Achilles heel remains unsolved: what to do with the concentrated brine stream resulting from the purification process? These large flows—typically 15-25% of the influent volume—present a major disposal problem, both economically and environmentally (Bond and Veerapaneni 2007, Fox et al. 2009, and Mickley, 2005).

One common brine disposal option is ocean discharge, but there is an important caveat: this solution is only realistically open to coastal utilities. Inland communities must turn to alternative brine disposal methods, such as discharge to surface waters or deep well injection (Sethi et al. 2009). Both of these options, however, are also fraught with problems: increasing the salinity of surface and groundwaters is problematic if these waters are also used as drinking water sources. Land disposal and evaporation are other options, but are associated with significant costs and accessibility constraints (Mohamed et al. 2005 and Sethi et al. 2009). In short, the lack of brine disposal options makes RO treatment a non-starter for many inland utilities (Fox et al. 2009).

While facing fewer constraints, coastal utilities must also navigate brine issues. Facilities seeking to expand must deal with economic and regulatory issues related to brine discharge. Sewer discharge has been one of the traditional discharge options for recycling facilities. However, as the number of utilities using wastewater for potable reuse increases, disposing concentrated brines into sewer lines becomes increasingly restrictive. For utilities across the country—both inland and coastal—the challenge is clear: cost effective and innovative approaches are needed to reduce brine flows and enable discharge with low economic and environmental impact.

Located in eastern San Diego County, Padre Dam Municipal Water District (Padre Dam) and its partner agencies (Helix Water District, County of San Diego, and City of El Cajon) are pursuing potable reuse as part of the East County Advanced Water Purification Program (Program). This Program aims to diversify the current water supply portfolio with local recycled water to reduce dependence on imported water, and meet 25 to 30 percent of East County's drinking water supply. Two options of potable reuse are being considered: surface water augmentation via a local reservoir, Lake Jennings, and groundwater recharge via the Santee Basin (Figure 1).

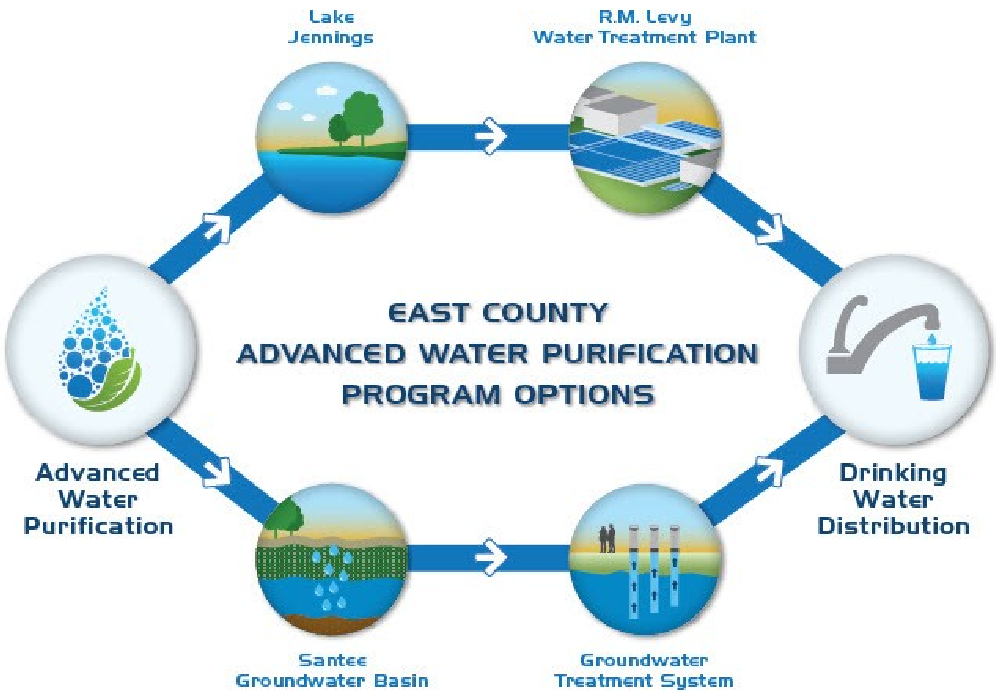


Figure 1. East County Advanced Water Purification Program options.

At conventional RO recovery rates for potable reuse (75 to 85%), it is expected that this program will generate a significant and continuous stream of brine. Due to disposal costs through San Diego's Metropolitan Sewerage System (Metro), Padre Dam has a strong incentive to develop local reliable alternatives for brine disposal. To achieve this, Padre Dam is targeting a drastic reduction of brine generation by increasing RO recovery to 95%.

The method typically used to decrease brine production or increase the recovery of RO systems is to "bolt" an additional RO system onto the end of a standard RO treatment train to further reduce the brine flow (e.g., Fu 2014). This configuration is termed recovery RO (RRO) in this project and is being considered separate from the primary (or main) RO system. Recent designs of reuse facilities aiming for higher RO recoveries have entailed separating out the primary RO system (as that produces most of the RO permeate) while operating at stable recoveries with longer intervals between cleaning (i.e., fewer operational and maintenance needs). The RRO portion of the design then functions to squeeze as much of the remaining permeate out of the primary RO as possible, while also having the ability to be isolated from the primary RO system for additional cleanings and membrane replacements. Therefore, operations and maintenance efforts can be concentrated on a smaller portion of the overall system. Figure 2 provides a schematic for positioning an RRO in relation to a primary RO unit.

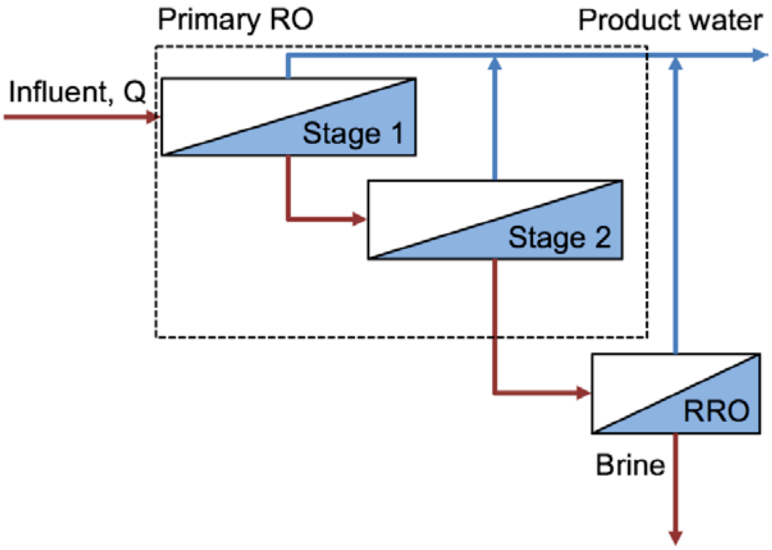


Figure 2. Schematic of a RRO in relation to a primary RO unit.

The RRO unit could be an additional stage of an RO system, using another set of pressure vessels to treat the concentrate from the previous stage. For a standard two-stage brackish water RO system, the RRO unit could be another one or two stages, thereby creating a three- or four-stage system as a whole. Inter-stage booster pumps can be used to help balance the hydraulics between stages and allowing each stage of membranes to operate under more optimal conditions, such as adequate cross-flow velocity to prevent scaling or fouling. In this project, this type of system is the baseline system and is termed a conventional recovery RO system (CRRO). The configuration for a CRRO system, with typical flows, is presented in Figure 3, with Stage 1 and Stage 2 representing the primary RO system.

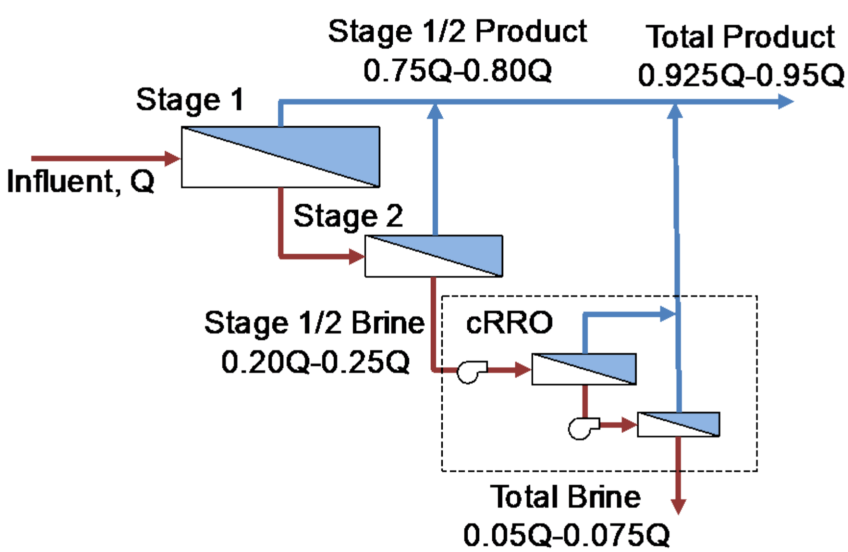


Figure 3. Configuration for the CRRO pilot system.

In comparison, Desalitech, a private company, has developed a proprietary operational mode for RO known as closed circuit desalination (CCD). One of the main differences between the CCD system and standard RO systems is that the CCD system recirculates the feed-concentrate across the membranes rather than continually feeding influent flow across the membranes in a plug-flow manner. As a result, the CCD is sometimes termed a "semi-batch" process, since the system processes most of the influent water in "batches." Once the batch of feed-concentrate water has been processed to a certain salt concentration (or produces a certain volume of permeate), this batch is flushed out in a few minutes and another "fresh" batch of feed water is recirculated through the system for treatment. The configuration for the CCD system is presented in Figure 4, with Stage 1 and Stage 2 representing the primary RO system.

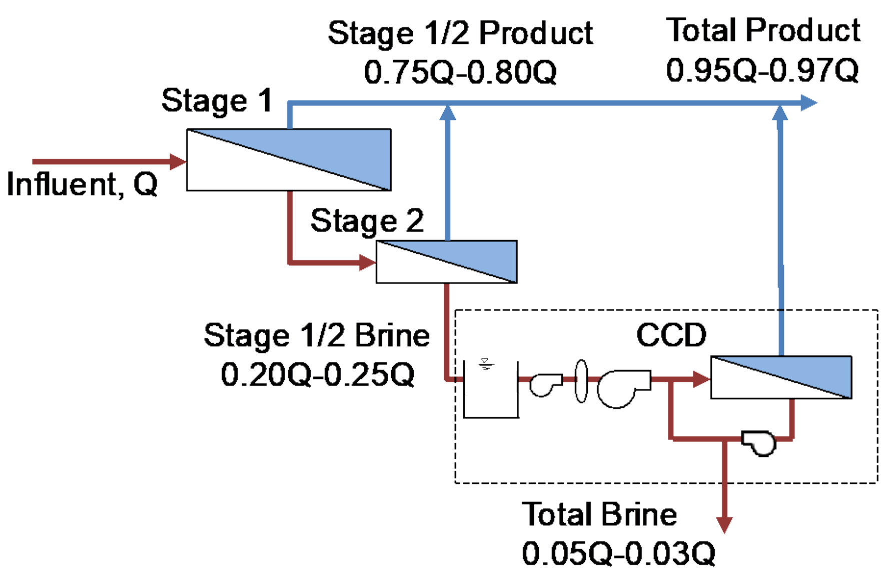


Figure 4. Configuration for CCD system.

This project compares using the CCD system to operate as an RRO unit to adding conventional stages to a primary RO system, as described above. The CCD system has been shown in other pilot work on municipal wastewater effluent to have the potential to significantly increase recoveries. This project builds from that work to compare the conventional brine minimization method to the newer CCD system.

To benefit the implementation of potable reuse for Padre Dam and its partner agencies, as well as other water suppliers in similar situations, this study aims to maximize RO recovery at Padre Dam by:

A. Comparing the recoveries that can be achieved with conventional brine minimization technologies and with closed circuit desalination at Padre Dam's Advanced Water Purification Demonstration Facility

B. Evaluating their performance with respect to operability, energy efficiency, and water quality.

2. Background

2.1. Padre Dam Municipal Water District

Padre Dam is in the eastern portion of San Diego County, California, approximately 20 miles (32 kilmeters [km]) from the coast. Padre Dam provides water, wastewater, recycled water, and recreation services to 100,000 residents of the communities of Santee, El Cajon, Lakeside, Flinn Springs, Harbison Canyon, Blossom Valley, Alpine, Dehesa and Crest (Figure 5). Padre Dam imports 100% of its treated water supply from the Metropolitan Water District of Southern California and the San Diego County Water Authority, which comes from the Colorado River, California State Water Project, ocean, and local watersheds.

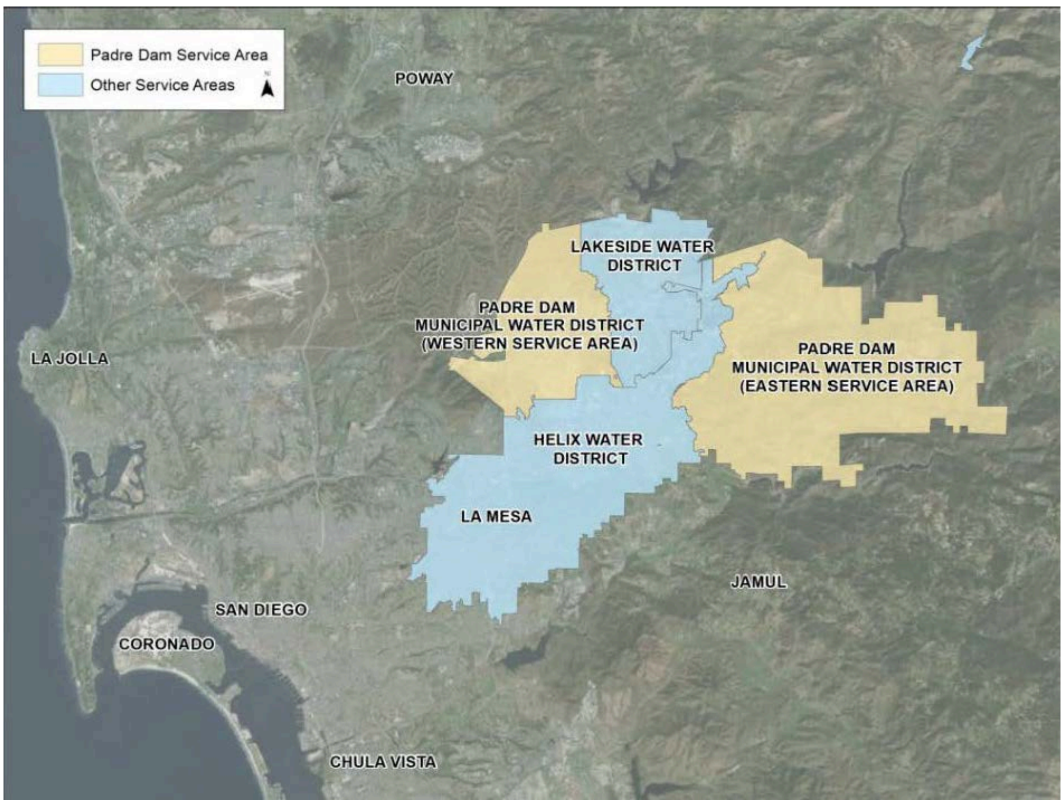


Figure 5. Padre Dam Service District.

2.1.1. Ray Stoyer Water Reclamation Plant

Padre Dam currently treats 2 million gallons per day (MGD) (7,571 cubic meters [m^3] per day) of wastewater at the Ray Stoyer Water Recycling Facility (WRF). Built in 1962, and last upgraded in 1997, the Ray Stoyer WRF is a state-of-the-art facility capable of producing 2 MGD (7,571 m^3/day) of recycled water for nonpotable reuse and recreational reuse at the Santee Lakes. The WRF is a scalping facility receiving a constant 2 MGD (7,571 m^3/day) inflow at all times. Due to decreased wastewater flows in the Padre Dam service area at night, the WRF is supplemented with up to 0.8 MGD (3,028 m^3/day) of wastewater from the County of San Diego sewer line during the night time. Wastewater not captured by the WRF flows to the Point Loma Wastewater Treatment Plant in San Diego, along with return flows from solids handling processes. The 1997 upgrade expanded the WRF's tertiary capacity, allowing it to achieve its strict nutrient discharge limitations (approximately 1 and 0.1 milligram per liter [mg/L] for total nitrogen and total phosphorous, respectively, based on a 2 MGD (7,751 m^3/day) flow). The superior water quality allows Padre Dam to engage in inland live-stream discharge, the only remaining utility permitted for such purposes in San Diego County.

Figure 6 shows an aerial layout and Figure 7 shows a process flow diagram for the WRF treatment processes. Treatment at the WRF includes primary sedimentation, secondary treatment (activated sludge and secondary clarification), denitrifying tertiary filtration, and chlorine disinfection.

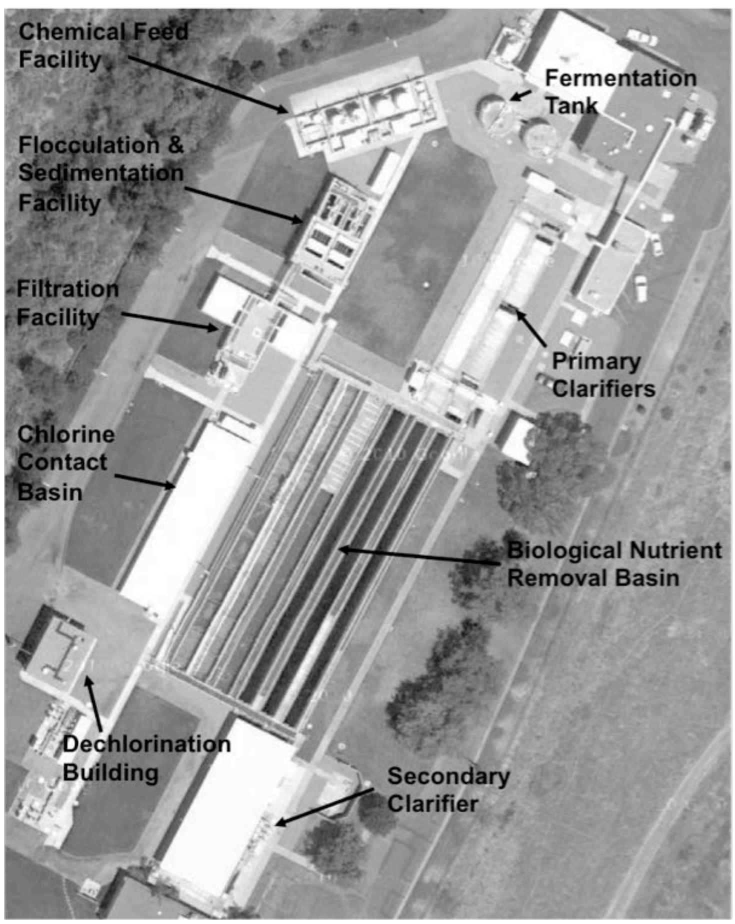


Figure 6. Aerial View of Padre Dam Ray Stoyer WRF.

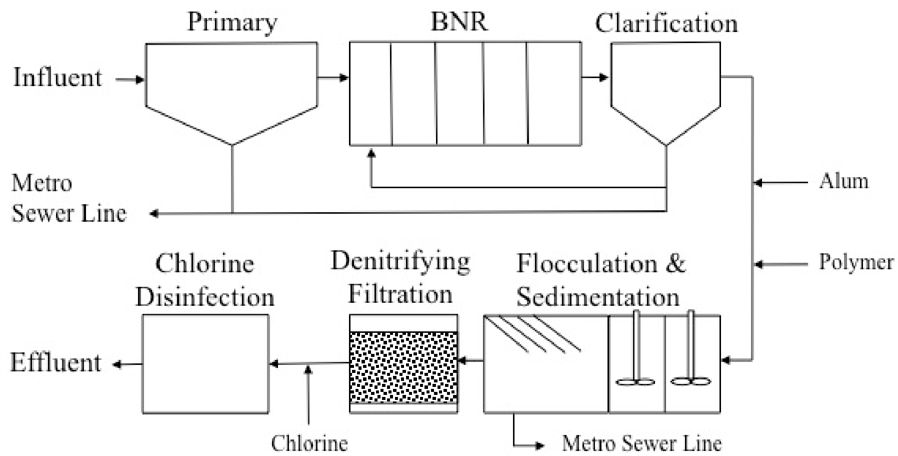


Figure 7. Ray Stoyer WRF Treatment Train with Biological Nutrient Removal (BNR).

The secondary treatment uses one of the more sophisticated activated sludge processes in the industry today, the modified Bardenpho® process, that is can reduce the total carbon, nitrogen, and phosphorus concentrations. The modified Bardenpho® process is followed by secondary clarification in rectangular secondary clarifiers.

Secondary effluent undergoes further treatment through coagulation (alum and polymer), flocculation, and sedimentation with lamella plate settlers. The tertiary filtration process also removes any phosphorus particulates that were not settled through the clarification process. After chlorine disinfection, a fraction of the flow undergoes dechlorination with sulfur dioxide. Sludge and scum from the primary clarifier, waste activated sludge and scum from the secondary clarifier, and sludge from the sedimentation basins are all discharged to the Metro sewer line for treatment at the Point Loma Wastewater Treatment Plant in San Diego.

2.1.2. Advanced Water Purification Demonstration Facility

In 2015, Padre Dam completed construction and began operating the Advanced Water Purification (AWP) Demonstration Facility (Figure 8), to evaluate the performance of advanced treatment unit operations in achieving pathogen control and removal of a suite of regulated and other chemicals of concern to meet California potable reuse requirements. The AWP Demonstration Facility consists of free chlorine disinfection, ultrafiltration (UF), reverse osmosis (RO), and ultraviolet/advanced oxidation process (UV/AOP) (Figure 9). The AWP Demonstration Facility produces 100,000 gallons per day (gpd) (378 m^3/day) or 70 gallons per minute (gpm) (265 liters per minute [lpm]) of treated effluent through the RO process with a minimum of 10 gpm (38 lpm) treated through UV/AOP.

Figure 8. AWP Demonstration Facility.

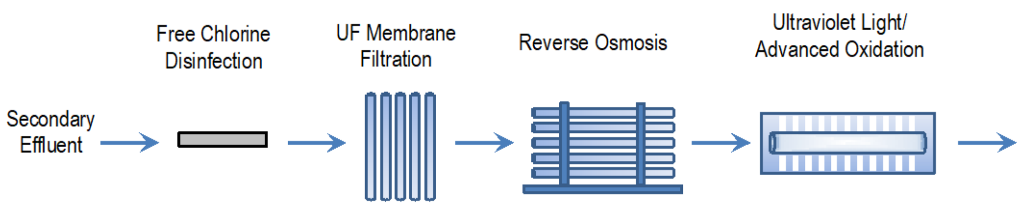


Figure 9. AWP Demonstration Facility treatment train.

2.1.2.1. Free Chlorine Disinfection

The free chlorine system consists of a pipeline contactor and instrumentation to control and measure the chlorine residual at various locations during the process. Free chlorine disinfection ensures adequate pathogen removal (mainly for viruses) for potable reuse applications. At the end of the pipeline contactor, ammonia is added to convert the free chlorine to a chloramine residual. The chloramine residual (>2 parts per million [ppm]) is carried through the UF and RO processes to help control biofouling, which is current industry practice for membrane treatment of wastewater.

2.1.2.2. Ultrafiltration System

The UF system consists of one rack with five hollow fiber polyvinylidine fluoride membrane modules manufactured by Toray (model no. HFU-2020N). The design flux is 37 gallons per square foot of membrane area per day (gfd) (63 liters per square meter per hour [lmh]) and the system has a minium recovery of 95%.

2.1.2.3. Primary Reverse Osmosis System

The primary RO system at the AWP Demonstration Facility is a conventional two-stage system with design recoveries of 75 to 81% and an average flux rate of 12 gfd (20.4 lmh). The system consists of 21 total membrane elements, manufactured by CSM (model no. RE8040-FLR), in a 2:1 pressure vessel array, with 7 elements per pressure vessel. Concentrate from the primary RO system was used as source water for the two brine minimization technologies investigated in this study. Further design and process details of the primary RO can be found in Section 6.1.

2.1.2.4. Ultraviolet/Advanced Oxidation Process

The UV/AOP reactor at the AWP Demonstration Facility is the NeoTech D438™ provided by NeoTech Aqua of San Diego, California. The reactor employs patented high-efficiency concepts in which UV light is reflected multiple times with a specialized coating that allows light to be reflected back through the water sample. The reactor contains two low pressure UV lamps that emit light with a 254 nanometer (nm) wavelength and delivers a UV dose of approximately 1,000 millijoule per square centimeter (mJ/cm^2) (Pecson et al. 2016). The UV/AOP reactor offers 6 logs of virus, *Giardia*, and *Cryptosporidium* inactivation. The treated water from the AWP Demonstration Facility is returned to, and blended with, the WRF process water. The point of blending is upstream of the tertiary filtration process, and downstream of the AWP Demonstration Facility intake. RO brine and other waste streams (e.g., UF backwash water) are sent to the sewer system. During this study, the product and waste of the recovery RO pilot systems was sent to the sewer as well.

3. Literature Review

One common method used to decrease brine production or increase the recovery of RO systems is to attach an additional RO system onto the end of standard RO treatment train to further concentrate and reduce the brine flow. Further information on brine minimization can be found in Subramani and Jacangelo (2014). Generally, most current RRO applications use a conventional RO skid (i.e., single- or two-stage plug flow treatment) that is directly plumbed onto the end of the existing RO system. Thus, the RRO skid is essentially adding a stage to the existing RO unit. This kind of setup is referred to as conventional RRO (CRRO).

Over the past several years, novel ideas to improve RO recoveries have been studied in research and development. These include using magnetic fields to control scale deposition (Salman et al. 2015), and reversing the flow in the membrane modules periodically to disturb deposition (Shamsuddin 1999). One of the more promising ideas to reach commercial scale is the Desalitech CCD process. Papers published in recent years, demonstrated the potential that CCD holds in terms of energy efficiency (e.g., Lin and Elimelech 2015). It was estimated that a CCD system can reduce the specific energy of sea water desalination by 22% when targeting an overall recovery of 50%. Another study (Stover 2016) found the CCD system to operate at high concentrations of silica in groundwater and still achieve 93.5% recovery.

To provide the most meaningful comparison of the technologies, we began by reviewing the state of the science for CRRO and CCD in municipal reuse applications (i.e., advanced treated wastewater). Presented below are summaries of the findings from two utilities that have tested using RRO systems for municipal reuse.

3.1. Water Replenishment District of Southern California

One location where a CRRO system has been considered for use in municipal reuse is at the Leo J. Vander Lans Water Treatment Facility (LVL), which is part of the Water Replenishment District of Southern California (WRD). WRD uses recycled water as part of its seawater intrusion barriers in two groundwater basins. Maximizing production of recycled water is extremely beneficial due to rising costs of imported water. One way to do this is through maximizing RO recovery; because of limitations in the current RO system design, the only way to increase the recovery in the current configuration is by using an RRO unit.

WRD performed modeling as well as lab-scale and pilot-scale testing to determine the potential benefits of implementing a CRRO unit. Their primary RO system is a two-stage system operating with a recovery of 85%; modeling indicated that using an RRO unit operating with a flux of 7 gfd (12 lmh) with 50% recovery could increase the overall system recovery to 92.5% (Yu et al. 2011). Lab testing of the conventional RRO membrane showed high rejection of total organic carbon (TOC), nitrate, and total dissolved solids (TDS), such that the effluent quality was able to meet regulatory limits. This finding was confirmed by pilot testing, where TOC rejection was observed to be 98.4% and rejection of all trace organic contaminants was greater than 90%. In addition to recovery and water quality performance, LVL's testing also revealed information about operational considerations. Modeling revealed that calcium carbonate and barium sulfate scaling could be problematic. However, by adding sulfuric acid to lower the pH below 6.3, inorganic scaling was controlled such that the estimated number of down days per year for the CRRO system is the same as for the primary RO. Relatively large volumes of acid would be required for the operation of a full-scale facility, and more optimization is required to balance the added cost of acid with the reduced cost of fewer CIPs. Inorganic scaling resulted in a decline of specific flux over the course of the testing, resulting in an increased feed pressure to maintain a constant permeate flux. Altogether, the power costs (at 0.15 kilowatt hours [kWh]) of the CRRO unit represented a significant addition (approximately 25%) to the overall RO system electricity costs (Yu et al. 2011).

3.2. Los Angeles County Sanitation District

Los Angeles County Sanitation District (LACSD) operates two water reclamation plants that are producing tertiary recycled water that is ultimately destined for irrigation of several salt-sensitive crops in the Santa Clara River basin. Because of these crops, a chloride management system is needed to meet the total maximum daily load (TMDL) for chloride. After evaluating several alternatives, an advanced water treatment facility with membrane filtration and RO was chosen as the most viable option for meeting the TMDL. The facility treats a portion of the tertiary effluent, which is later blended back into the rest of the flow. Currently, the RO brine is disposed of via deep-well injection, a highly costly method, which is why LACSD is pursuing brine reduction strategies. Their goal is to use an RRO system to increase their recovery to 92.5%, which would halve their concentrate disposal requirements. LACSD used a pilot CCD unit to investigate the potential increase in overall RO system recovery. LACSD also tested a CRRO system to facilitate direct comparison of CRRO and CCD. Both systems were operated close to 92% recovery (Table 1), with a flux of about 9 gfd (15.3 lmh) and a feed water pH adjusted with acid to 6.5. Note that the CCD system was also tested at higher fluxes of 13 and 11 gfd (22.1 and 18.7 lmh), which both resulted in a CIP required after about 30 days of testing. The flux was lowered to 9 gfd (15.3 lmh) to increase the run time before a CIP was required.

In both cases, antiscalant was added to the feed of the primary RO and, because the antiscalant is fully rejected by the RO membrane, was also present in the feed to the RRO.

Table 1. Operating Recoveries for LACSD RRO Systems (Mansell et al. 2015)

Parameter	Primary RO recovery	RRO recovery	Overall recovery
CCD	74%	72%	92.7%
CRRO	85%	48%	91.2%

In terms of water quality performance, both systems achieved high rejection of chloride—to levels that would enable compliance with the chloride TMDL. The key difference between the two systems is operational: the conventional RRO requires much more frequent cleanings than the CCD. During the 30-day test period of the CCD at flux of 9 gfd (15.3 lmh), the specific flux declined only 15%—typically a clean-in-place (CIP) is performed after 30% decline. The initial run of the CRRO was 21 days before a CIP was required, but after that the duration shortened to 4-7 days between CIPs, which is an impractical cleaning frequency (Mansell et al. 2015).

4. Study Goals and Strategies

The goal of this study was to maximize RO recovery at Padre Dam by comparing the recoveries that can be achieved with CRRO and CCD at Padre Dam's currently operating AWP Demonstration Facility, and evaluating their performance with respect to water quality, operability, and energy efficiency.

Based on the literature review and past industry experience, the CCD unit was expected to enable the overall RO system to achieve a recovery of 90 to 95%, and the CRRO was expected to allow for an overall RO system recovery of 85% or less. Therefore, the general strategy of this study was to first run the CCD and assess the maximum sustainable recovery possible, and then test the CRRO at the same recovery rate to enable comparison of performance. Subsequently, the CRRO maximum sustainable recovery was determined. For this study, sustainable recovery was defined as 30 days of total runtime without performing a CIP, or a drop of up to 15% in the specific flux. The system average flux was kept constant for both technologies, as well as the acid and antiscalant dosing.

To determine the maximum sustainable recovery of the CCD unit, the project team consulted with both the provider of the skid (Desalitech), and the demonstration facility's antiscalant provider (Avista Technologies). Based on their input, the project team selected an initial target of 95% overall recovery. Once the CCD skid demonstrated sustainable operation at this recovery, a second run at the same conditions was performed to indicate repeatability. After that, the project team periodically increased the recovery to define a maximum recovery for the technology with the AWP water. After verifying the CCD skid's capabilities, the CRRO skid was initially tested at the same overall recovery at which the CCD exhibited sustainable operations, and using the same acid and antiscalant dosing.

During the testing of both the CCD and CRRO technologies, data was gathered that allowed evaluation of each technology's performance with respect to water quality, operability, and energy efficiency. Specifically, weekly sampling and water quality analyses of the RRO feed and permeate was performed as well as monthly monitoring of the RRO brine. These data allowed a quantitative comparison between the water quality produced by both technologies. Operability was measured by tracking the occurrence of CIPs, along with standard RO monitoring parameters, for both systems. Energy usage was tracked directly using a power monitor and logging of system pressures, which often serve as an indirect measure of power. These data contributed to a comparison of the energy efficiency of the two technologies.

On a qualitative level, these data can provide a basis for future designs to meet relevant regulations and project-specific drivers. The focus of this study was to directly compare the performance of the CCD and CRRO pilot units, as tested at the AWP Demonstration Facility.

5. Methods

5.1. Chemical Dosing

The same antiscalant and pH set points were used throughout the testing period. The antiscalant (Vitec 1400 from Avista Technologies) was dosed at a rate of 2.0 mg/L in the primary RO feed. Sulfuric acid was also dosed in the primary RO feed, to maintain a primary RO concentrate (RRO feed) pH of 6.5.

A constant chloramines residual existed in the RO feed to prevent biofouling, as is industry standard for membrane systems treating wastewater. Chloramines residual was 3-4 mg/L during this study. The dose was verified by the Padre Dam operators using online free chlorine, total chlorine, oxidation reduction potential (ORP), and ammonia analyzers.

Padre Dam operators verified chemical feed rates through physical draw-downs, as well as checking doses with online and handheld analyzers.

5.2. Water Quality Sampling

Water quality was monitored frequently throughout this project, from March 2016 to March 2017. The feed and permeate of each RRO skid were sampled weekly, and the concentrate was sampled monthly. The project team also performed select water quality sampling of the CCD permeate and concentrate over the course of one CCD cycle, and termed these events as CCD cycle assessments. Furthermore, the project team undertook special sampling of the CCD permeate which covered disinfection byproducts, certain trace organics and priority pollutants. For the CCD, feed water was sampled between the booster pump and the high-pressure pump. Permeate water was sampled from the permeate tank. This tank had a hydraulic retention time (HRT) of about 1 hour, meaning the sample was an indicator of the average permeate produced (since CCD cycles investigated during this project were 13 to 23 minutes in length). Brine was sampled at the start of the flush cycle since the system wastes no brine during the CCD cycle. A sample port located just upstream of the waste valve was used to collect the brine samples.

Water quality parameters measured and associated analysis methods are summarized in Table 2. Alkalinity, ammonia, nitrate, orthophosphate, total Kjehldahl nitrogen, and biochemical oxygen demand were analyzed by lab at Padre Dam's Ray Stoyer WRF. All other parameters were analyzed by Eurofins Eaton Analytical, Inc., a certified laboratory (ELAP #2813) located in Monrovia, California.

Table 2. Water Quality Parameters and Analytical Method

Parameter	Method	MRL
Alkalinity	SM 2320B	2 mg/L
Aluminum	EPA 200.8	20 µg/L
Ammonia	SM4500-NH3	0.2 mg/L as P
Barium	EPA 200.8	2 µg/L
Calcium	EPA 200.7	1 mg/L
Chloride	EPA 300.0	1 mg/L
Iron	EPA 200.7	0.02 mg/L
Magnesium	EPA 200.7	0.1 mg/L
Nitrate	SM4500-NO3	0.2 mg/L as P
Orthophosphate	EPA 365.1/SM 4500-P E	0.01 mg/L as P
Potassium	EPA 200.7	1 mg/L
Silica	EPA 200.7	0.43 mg/L
Sodium	EPA 200.7	1 mg/L
Strontium	EPA 200.7, UCMR 200.8 [A]	0.01 mg/L, 0.3 µg/L
Sulfate	EPA 300.0	0.5 mg/L
TDS	E160.1 / SM2540C	10 mg/L
Total Hardness	SM 2340B	3 mg/L
TOC	SM5310 / E415.3	0.3 mg/L
UV Absorbance at 254 nm	SM 5910	0.009 cm^{-1}
Total Kjehldahl nitrogen (TKN)	EPA 351.2	0.5 mg/L as N
Biochemical Oxygen Demand (BOD)	SM 5210	2.0 mg/L

MRL = method reporting limit
P = phosphorus
[A] For strontium, UCMR 200.8 was used after April 7, 2016
N = nitrogen

UV transmittance (UVT) was also calculated from UV absorbance (UVA) at 254 nm using the following formula:

UVT = 10^(2-UVA)

On-site pH and conductivity measurements were made using field equipment, as necessary and part of daily rounds.

Actual sampling dates throughout the testing periods are illustrated in Figure 10 for CCD and Figure 11 for CRRO. Further discussion of results from these water quality measurements are described in Section 7.

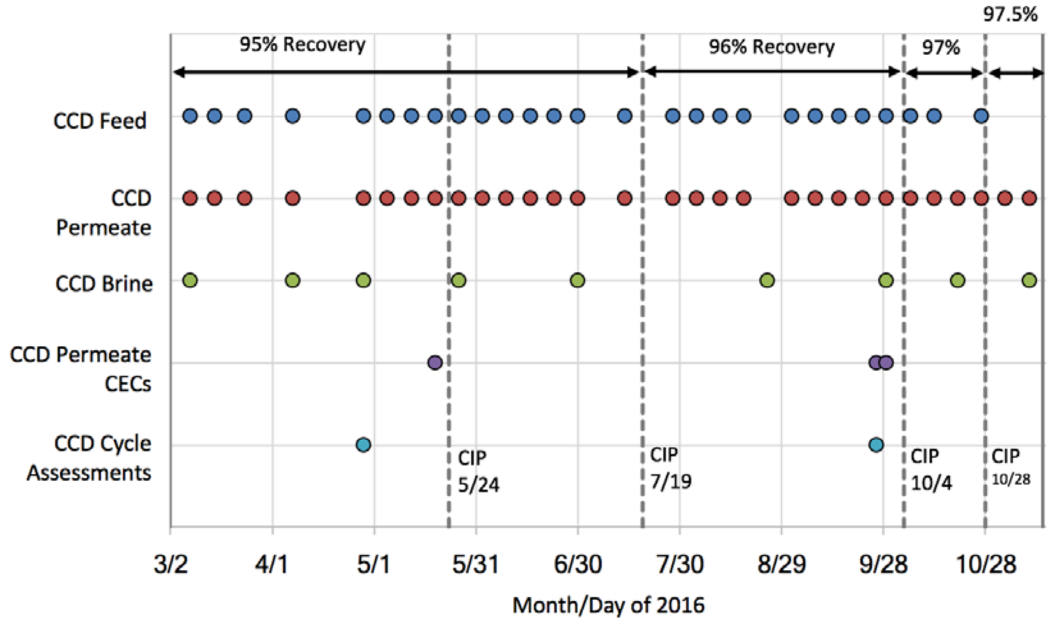


Figure 10. CCD sample dates.

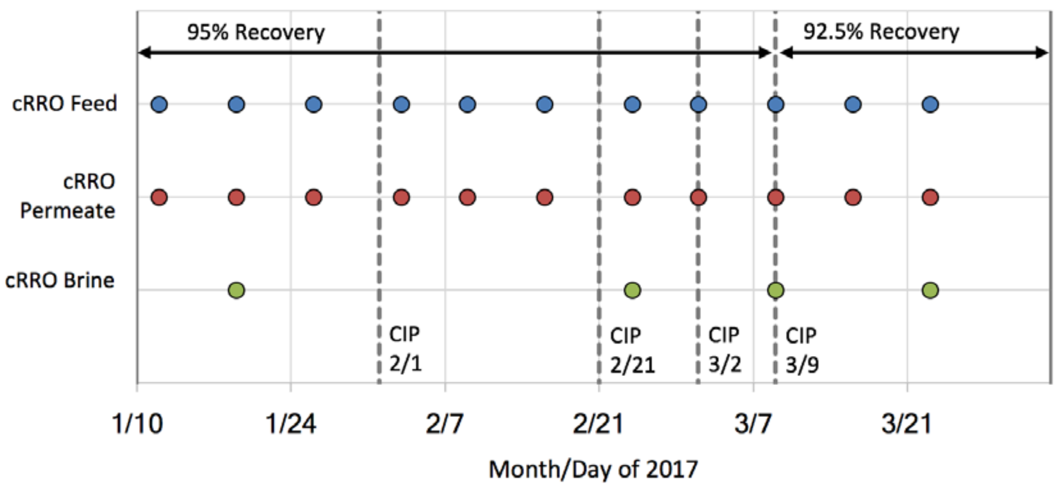


Figure 11. CRRO sample dates.

5.3. Performance Monitoring

Operating system data (e.g., pressure, flow, conductivity, temperature, and pH) was collected primarily automatically for the CCD pilot system, using an SD card that recorded a set of parameters every 20 seconds from the CCD programmable logic controller (PLC). Operating system data for the CRRO pilot was collected manually by Padre Dam operators twice a day. Turbidity and ammonia readings were not collected specifically for this study. However, both turbidity and ammonia are monitored continuously by online meters in the AWP feed and readings are recorded daily by a Padre Dam operator since they are crucial elements in the free chlorine disinfection process of the AWP. During plant upsets or challenging water upstream of the AWP, the primary RO will shut down. During primary RO shutdowns, there is no feed water available for the RRO test pilots; this linkage ensures that the RRO test pilots are tested during acceptable operating conditions as far as turbidity and ammonia levels are concerned.

The overall performance of the RRO was monitored using recovery and specific flux. Recovery and specific flux were calculated using the collected performance data: temperature, conductivity, flow, and pressure. Complete rounds and operational data of both RRO systems can be found in Appendices A and B. For comparison purposes, it is important to correct the flux for temperature since RO performance is impacted by the temperature of the water. Specific flux is also an important value for evaluating RO performance because this value is normalized against pressure.

5.4. Membrane Cleanings

For on-site chemical cleans (CIPs), both the CCD and CRRO were cleaned using high and low pH CIP solutions. Typically, a CIP is performed when specific flux declines by 15%. A 0.1% by weight sodium hydroxide (NaOH) solution was used for the high pH and a 2% by weight citric acid solution was used for the low pH solution.

The CCD CIP system did not include a heater, so the CIPs were conducted at ambient temperature. The CRRO CIP system did include a heater and the cleaning solution was heated and maintained at 100 degrees Fahrenheit (°F) (37.7 degrees Celsius [°C]). One CIP for the CCD system was conducted off-site at Avista Technologies facilities in San Marcos, California. Warm CIP solutions are known to be more effective at stripping scale than ambient temperature solutions.

6. Testing Equipment

6.1. Primary Reverse Osmosis System

This RRO project was integrated into Padre Dam's existing AWP demonstration testing. The AWP Demonstration Facility (Figure 12) has been operating since March 2015 and receives a high quality nitrified secondary effluent from the Ray Stoyer WRF. The AWP train consists of free chlorine disinfection, ultrafiltration, conventional two-stage RO, and an UV/AOP process. The AWP Demonstration Facility receives 90 gpm (341 lpm) of secondary effluent, leading to the production of 21 gpm (79.5 lpm) of brine, assuming recoveries of 95% and 75% through MF and RO, respectively.

Figure 12. AWP Demonstration Facility primary RO system.

The AWP Demo RO served as the primary RO during this study. The primary RO system consists of skid-mounted equipment designed to produce 100,000 gpd (378 m^3/day) of RO permeate. The system is a conventional two-stage system, operating at either 75 or 80% recovery with a design flux rate of 12 gfd (20.4 lmh). Feed water to the primary RO is treated with free chlorine for disinfection, and ultrafiltration process. The first stage consists of two 8-inch

(203-mm) vessels containing 7 pressure elements each. The second stage is one 8-inch (203-mm) vessel containing 7 pressure elements as well. The design criteria for the primary RO system are summarized in Table 3.

Table 3. Primary RO System Design Criteria

Parameter	Unit	Value
Design Capacity (Total Product Flow)	gpd	100,000
System Recovery	%	81
Feed Flow	gpd	123,457
Number of Stages	no.	2
Pressure Vessel Configuration	-	2:1
Pressure Vessel Diameter	inch	8
Elements per Pressure Vessel	no.	7
Total Number of Elements	no.	21
Membrane Area per Element	sq. ft.	400
Element Manufacturer and Type	-	CSM RE8040-FLR
Membrane Type	-	Polyamide thin-film composite
Maximum Average Flux	gfd	12

6.2. Recovery Reverse Osmosis System

Each RRO system, CCD and CRRO, was tested separately, since not enough brine was produced by the primary RO to run them both in parallel.

Table 4 provides the design criteria for each pilot system, as well as operating ranges for flows.

Table 4. RRO Pilot System Design Criteria and Operated Ranges

Parameter	CCD	CRRO
Element Manufacturer	Hydranautics	Hydranautics
Element Model	ESPA2-LD	ESPA2-LD4040
No. of Stages	1	2
Number of Pressure Vessels	1	3
Elements per Pressure Vessel	3	7
Pressure Vessel Diameter	8 inch	4 inch
Total Membrane Area	1,200 sf	1,680 sf
Average Flux	9 gfd	9 gfd
Feed Flow	8-17 gpm	14-15 gpm
Brine Flow	0-15 gpm	3.5-4.5 gpm
Permeate Flow	2-8 gpm	10.5 gpm
Concentrate Recirculation Flow	24 gpm	-

sf = square foot

Sulfuric acid was used for pH adjustment, and an antiscalant was selected and used for both RRO pilot skids. Sulfuric acid addition took place at the primary RO system as there was existing injection port at this location. The RRO testing equipment lacked a proper chemical injection system that met the Padre Dam Municipal Water District's Health and Safety requirements. The doses and ranges were calculated based on the manufacturers' recommendations, as well as hydraulic and scaling modeling provided by the antiscalant manufacturer. These models take into consideration the feed water quality, type of membrane, recovery, and other parameters, and produce a chemical dose and pH recommendation. The pH target for acid dosing was 6.5, and antiscalant dose of 2 mg/L.

6.2.1. CCD System

6.2.1.1. Components and Configuration of the CCD System

The CCD system is shown in Figure 13 and the configuration is presented in Figure 14, with Stage 1 and Stage 2 representing the primary RO system. For the CCD system, a break tank existed upstream of the CCD booster pump, as flow equalization is necessary to accommodate the semi-batch nature of the CCD system operation.

A process flow diagram of the unit provided by Desalitech may be found in Appendix J. The main components of the prefabricated Desalitech container and skid were:

- **Booster pump** delivered the water from the break head tank to the high pressure pump, and to push the water through a micron filter. The booster pump also served to recirculate the CIP solution.

- **High pressure pump** provided the driving force for the cycle.

- One, 8 inch (203 millimeter [mm]) **pressure vessel** contained 3 membrane elements.

- **Circulation pump** circulated the concentrate back into the feed during the CCD cycle.

- Each pump had its own dedicated **variable frequency drive** (VFD).

- The container had a built-in **control panel** with a PLC and a human machine interface (HMI) screen. The HMI enabled real-time operator monitoring and control of the system and its performance.

- The 130 gallon (492 liter) **permeate tank** stored permeate for shut down flushes and for CIP.

Figure 13. CCD prefabricated container skid by Desalitech.

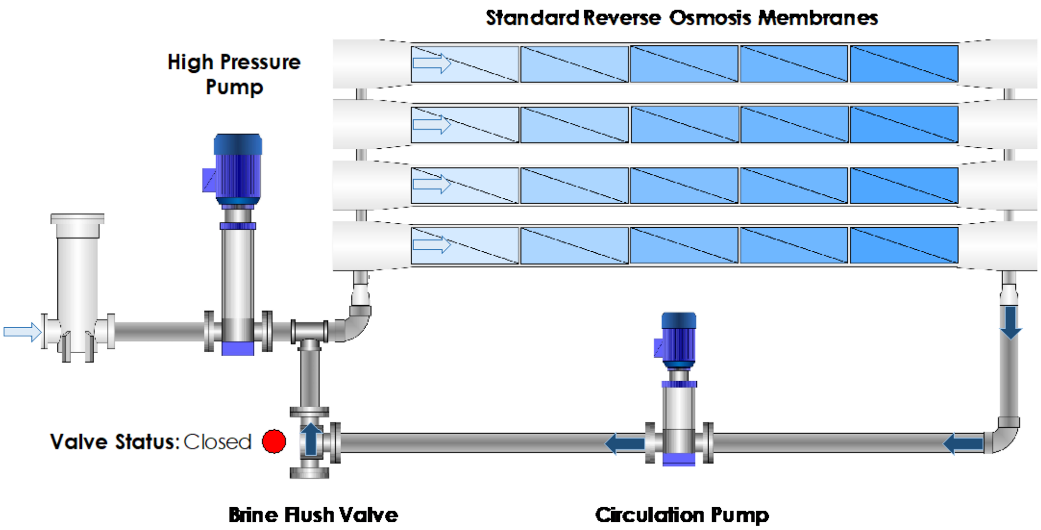


Figure 14. Conceptual sketch of a typical CCD system during the CCD cycle (courtesy of Desalitech).

6.2.1.2. Process of the CCD System

The innovation behind the CCD technology is a recirculation loop that decouples cross-flow velocity from the flow rate through the system. In a recirculation loop, feed water enters the system in the first cycle, producing permeate and recycling brine. As more product water is produced and brine is recycled, the brine concentration increases. When the system achieves its recovery set point, the brine is purged from the system and the cycle begins again.

As indicated in Table 4, the CCD pilot system had an average flux of about 9 gfd (15.3 lmh), which corresponds to the average permeate production divided by the membrane area.

The CCD system cycles between two main modes:

- **Mode 1.** The first is a closed circuit mode in which the feed and permeate flows are the same, the concentrate flow out of the vessel is zero, and the pressure gradually increases as the salt concentration of the feed-concentrate increases over the length of the cycle. This cycle lasted between 13 and 23 minutes in the scenarios tested during this study (Figure 15 shows a conceptual sketch and Figure 16 is an example of a screenshot).

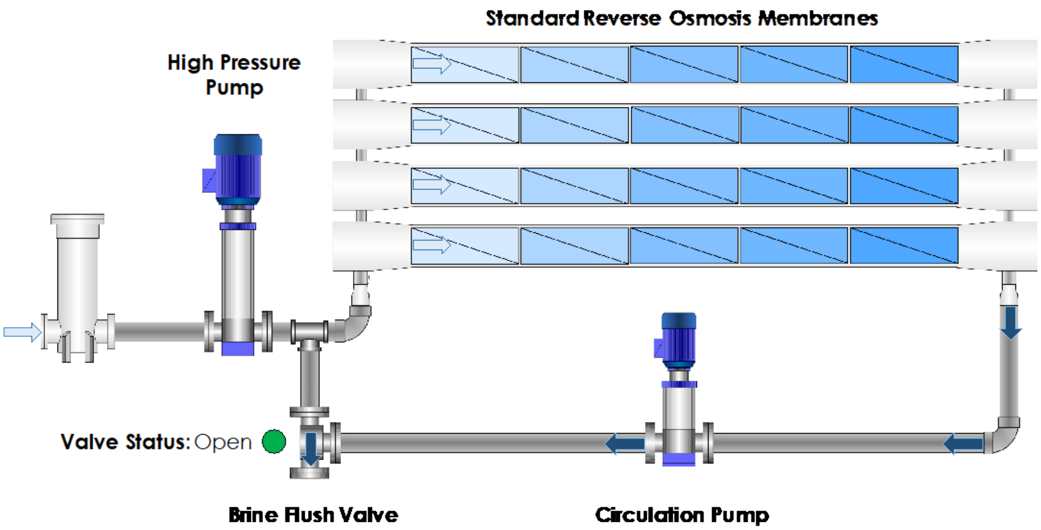


Figure 15. Conceptual sketch of a typical CCD system during the brine flush cycle (courtesy of Desalitech).

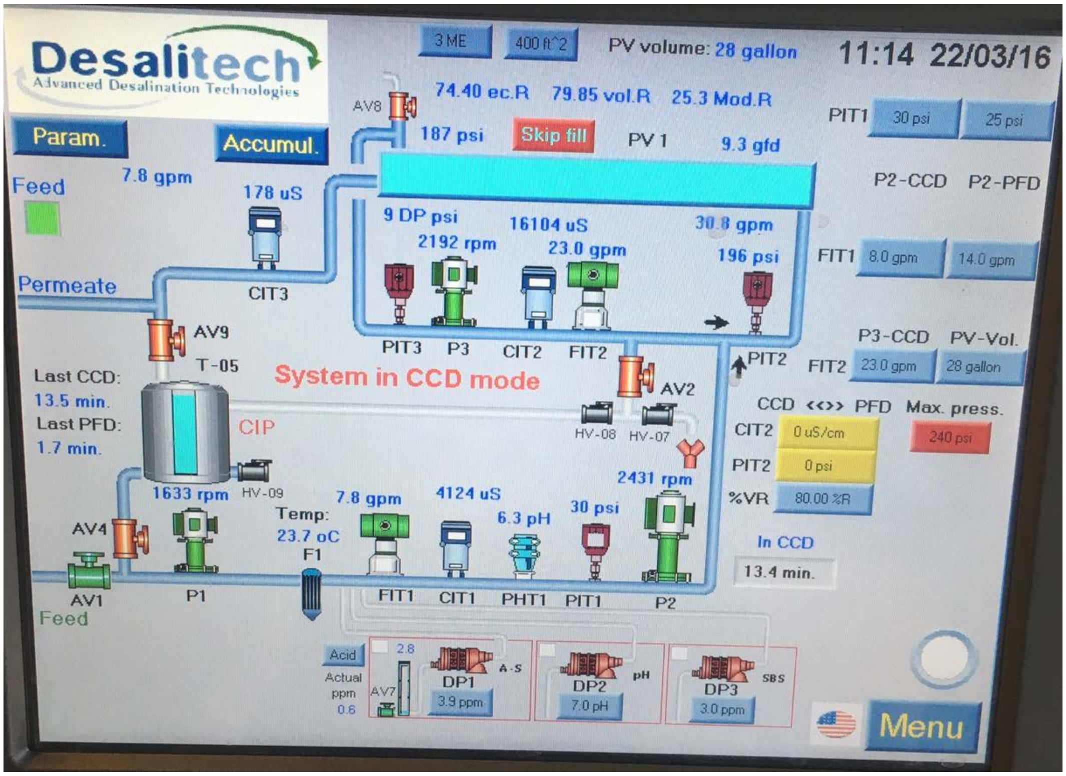


Figure 16. Screen shot of the HMI during a CCD cycle.

- **Mode 2.** The second mode is a flushing mode in which the concentrate valve is opened to allow the high salinity water inside the vessel flush out with a higher rate pulse of feed flow. During this mode, the recirculation pump stops and the brine flush valve opens. A check valve between the brine flush valve and the feed line results in a plug flow flush in which the feed flow displaces the concentrated brine in the system. A manual valve on the flush line is pinched to create back pressure on the system and maintain some flow through the membranes (i.e., permeate flow) during the flush cycle. This mode lasted about 2 to 3 minutes for the scenarios tested during this study.

Figure 17 through Figure 20 show various CCD operating parameters over two typical cycles. The system was operated using a volumetric recovery setpoint (Figure 17), which meant that the closed circuit mode continued until the total volume of permeate divided by the feed flow reached the recovery setpoint, after which the system would automatically move to the flushing mode. Because the primary RO and the CCD were decoupled by a break tank, each system was run independently.

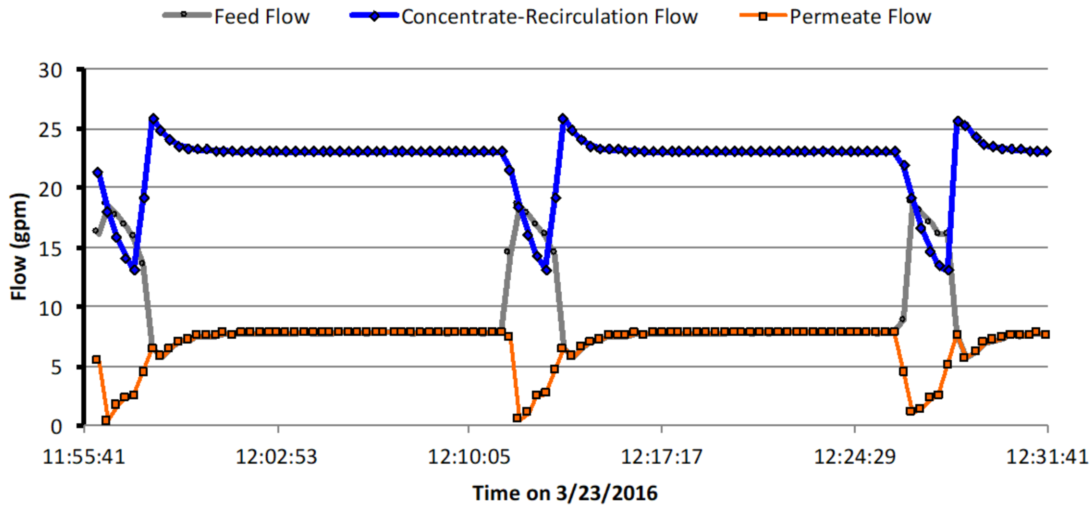


Figure 17. Flows during two cycles of the CCD system.

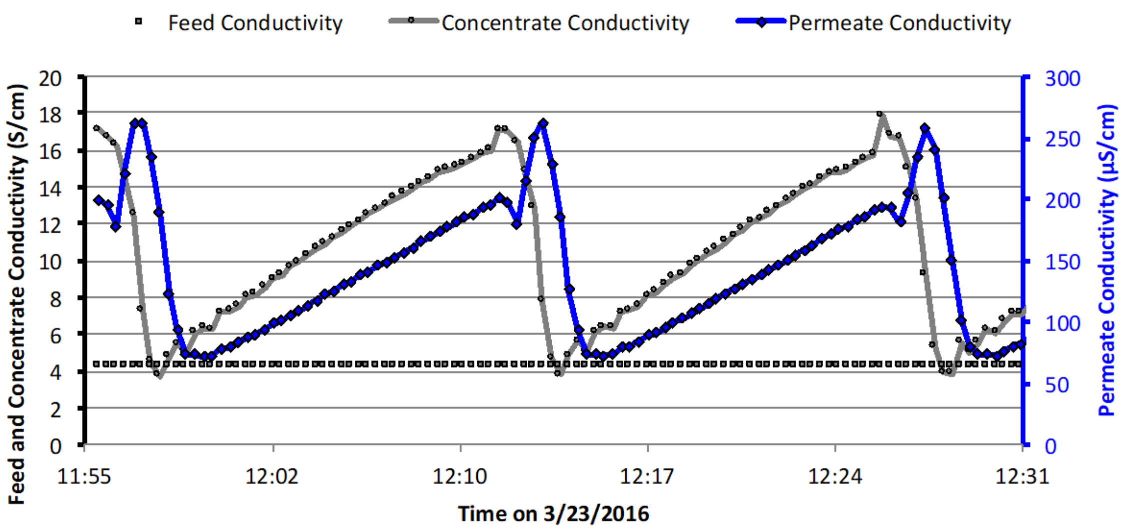


Figure 18. Feed, brine and permeate conductivities during the two cycles of the CCD system.

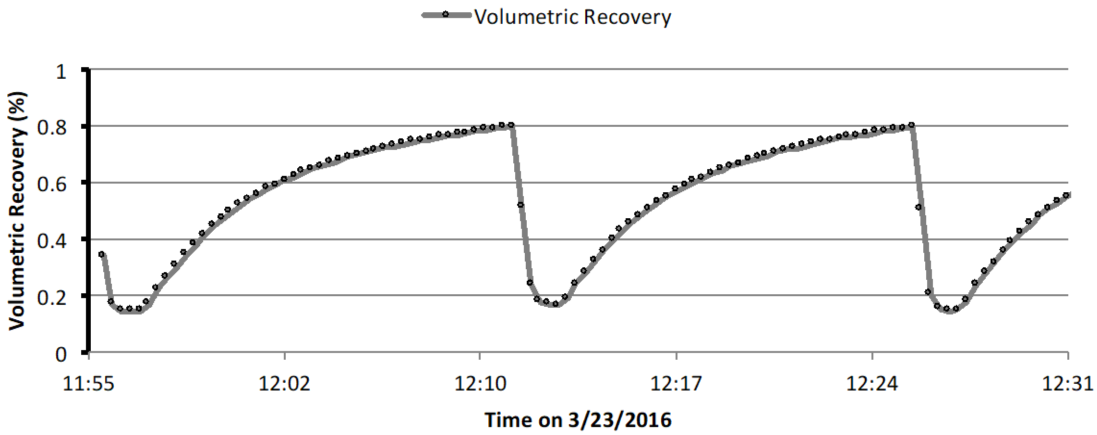


Figure 19. Volumetric recovery over two cycles of the CCD system.

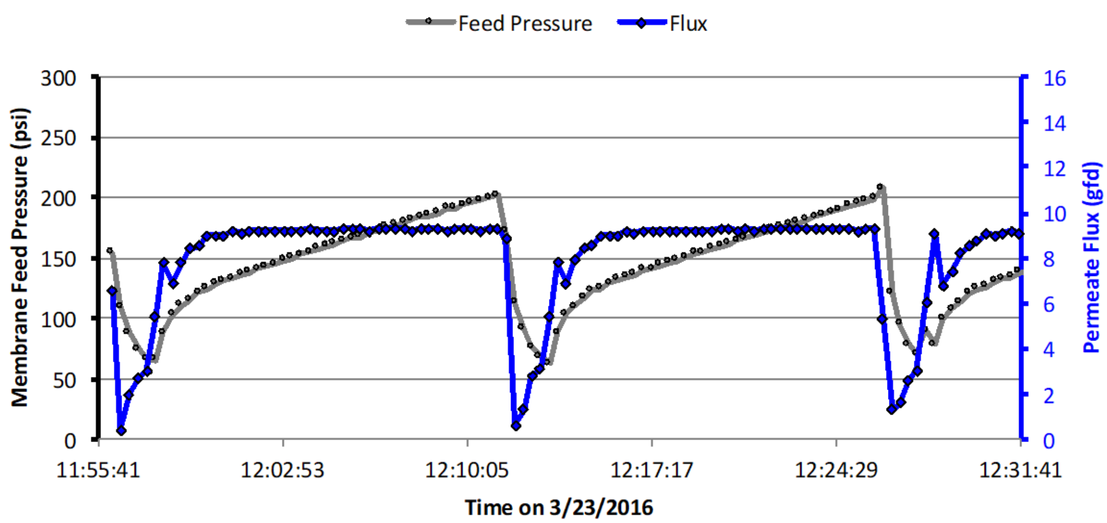


Figure 20. Feed pressure and permeate flux over two cycles of the CCD system

6.2.2. CRRO System

6.2.2.1. Components and Configuration of the CRRO System

The configuration for the CRRO system is presented in Figure 3, with Stage 1 and Stage 2 representing the primary RO system. It is worth noting that the test plan included a break tank for the CRRO skid as well, the manufacturer of the skid suggested to forego the tank in order to improve performance, and so it was plumbed directly onto the primary RO concentrate line.

A process flow diagram for the CRRO system is provided in Appendix K. The main components of the CRRO system were:

- Feed pump with a dedicated VFD.

- Second stage booster pump with a dedicated VFD.
- CIP skid. The CIP skid was purchased separately from the CRRO skid and consisted of: 110 gallon (416 liter) CIP tank filled with primary RO permeate, 1.5 horsepower (1120 Watts) recirculation pump, 7.5 kW water heater, and a 5 micron cartridge filter. The CIP skid was operated manually by the operators.
- Pressure switches.
- Mechanical valves.

6.2.2.2. Process Description of the CRRO System

When in operation, the CRRO is essentially a third and fourth stage for the primary RO system with third and fourth stage interstage booster pumps. Hydraulics for operating the CRRO system as shown require adjusting the hydraulics of the primary RO system. However, unlike a true 4-stage system (i.e., RO system design to operate with all four stages at all times), the primary RO can be decoupled from the CRRO system for separate maintenance.

The CRRO was maintained at a constant flux of 9 gfd (15.3 lmh) throughout testing. However, the primary RO flux was adjusted for each operating recovery to produce the appropriate concentrate flow to feed the CRRO. The CRRO was hard plumbed to the primary RO and, therefore, could use the primary RO concentrate pressure. Two booster pumps to maintain flow set points for each stage.

The CRRO feed booster pump was controlled with a VFD that was programmed to maintain a combined permeate flow rate of 10.5 gpm (40 lpm). The feed booster pump's VFD was interlocked with a feed pressure switch set to 45pounds per square inch (psi) (3.1 bar) The VFD only started the pump once the feed pressure (primary RO concentrate pressure) reached above that setpoint. The inter-stage booster pump also used a VFD that was programmed to maintain an inter-stage flow rate of 6.5 gpm (24.6 gpm). The membrane manufacturer's software was used to ensure the hydraulic requirements were met with these flow set points. This was the only form of process control available. The operator conducting the test used the concentrate hand valve to set the desired concentrate flow, and the two VFDs the each adjusted their pump output accordingly to meet their programmed setpoints. In the case of a primary RO shutdown, the feed pressure dropped below the setpoint and the VFDs turned off the pumps. Simultaneously, a concentrate valve bypass line opened up and the primary RO brine flushed the skid. The primary RO was programmed to perform a 10 minute flush with feed water. Therefore, the CRRO was flushed for ~10 minutes as well. If the CRRO was shut down independently of the primary RO, the concentrate valve bypass line also opened and primary RO brine simply flowed through the system to drain. A picture of the CRRO system is shown in Figure 21.

Figure 21. CRRO treatment skid.

6.3. Operability

For this project, operability is primarily measured by the length of time between CIPs, and system parameters before and after each CIP are compared. The length of time between CIPs is termed “runtime” in this report, and covers the time during which the system was running, as opposed to calendar time, which includes times when the system was offline. Generally, offline times during this study have corresponded to RRO pilot equipment issues or issues with upstream facilities. These offline times are not being considered in the analysis because pilot equipment issues were not representative of full scale situations, and/or issues with upstream facilities were unrelated to the performance of the RRO pilot skids.

The CCD pilot system was operated for five distinct runs at four different overall recoveries, combined. The CRRO pilot system was operated for five distinct runs at two different recoveries, combined. Additional details about these runs and conditions, along with the runtimes and CIP types, are presented in Table 5.

Table 5. Operating Conditions and Runtimes for Each Scenario Tested

Date(s)	Runtime (days)	Primary RO Recovery	Secondary RO Recovery	Overall RO Recovery
CCD Pilot Testing				
3/2/16 – 5/22/16	49	75%	80%	95%
5/23/16	CIP (on site, no heat)			
5/24/16 – 7/18/16	43	75%	80%	95%
7/19/16 – 7/25/16	CIP (off site)			
7/26/16 – 10/3/16	58	80%	80%	96%
10/4/16	CIP (on site, no heat)			
10/5/16-10/27/16	20	80%	85%	97%
10/28/16	CIP (on site, no heat)			
10/29/16 – 11/14/16	15	80%	87.5%	97.5%
CRRO Pilot Testing				
1/10/17 – 2/1/17	22	80%	75%	95%
2/1/17 – 2/2/17	CIP (on site, with heat)			
2/2/17 – 2/21/17	15	80%	75%	95%
2/21/17 – 2/22/17	CIP (on site, with heat)			
2/23/17 – 3/2/17	5	80%	75%	95%
3/2/17 – 3/3/17	CIP (on site, with heat)			
3/3/17 – 3/9/17	6	80%	75%	95%
3/9/17	CIP (on site, with heat)			
3/9/17 – 4/3/17	22	75%	70%	92.5%

The CCD pilot system was run at 95% overall recovery twice, with a goal of achieving greater than 30 days of runtime without a CIP. Specific flux (temperature corrected to 25°C) and membrane feed pressures, as calculated at the end of each closed circuit cycle and binned into daily median values, are shown in Figure 22. Specific flux did not show significant decrease during the first 95% run, but as runtime exceeded 30 days, a CIP was performed on-site, and then another run at 95% overall recovery was performed to confirm repeatability. Towards the end of the second 95% run, about 3 days of data exhibited unusually high specific flux values, apparently due to lower pressure values. It is believed that these values are due either to errors in data recording or potentially unintended improper operations after a week-long shut down due to equipment issues. The values were not removed, however, as the exact reason cannot be confirmed. Pressure returned to normal values, and a CIP was performed as the system had exceeded 30 days of runtime

As seen in Figure 22, at the beginning of the second run, the system appeared to have recovered most of its performance. This second run at 95% overall recovery was maintained for 43 days of runtime.

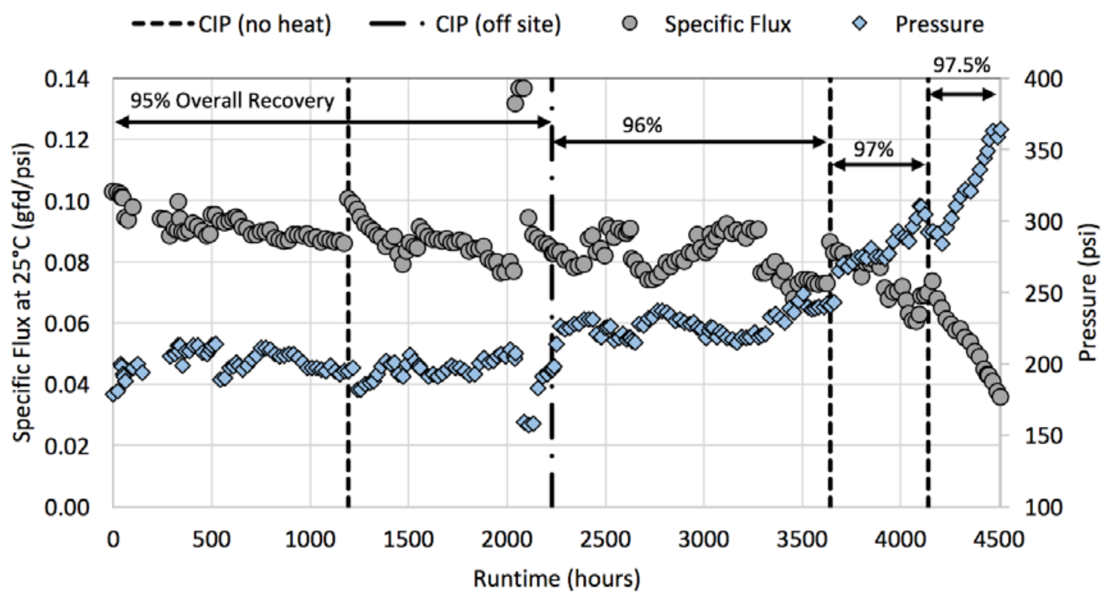


Figure 22. Performance of CCD pilot system in terms of specific flux (normalized to 25°C) and membrane feed pressure.

Having exhibited sustainable, repeatable, operations at 95% overall recovery with a minimum CIP interval of 30 days, the study achieved its objective for the CCD system. However, to increase the applicability of the results at 95% to full-scale design, the CCD system testing was extended to demonstrate performance at 96% recovery. The Bureau of Reclamation approved additional funds and an extended schedule to perform these runs for the CCD system to support the separate pre-design work being performed by Padre Dam. Corresponding runs were not performed for the CRRO, and as a result, the overall testing period of the CCD system was longer than that of the CRRO.

Performance was stable at 96% overall recovery with a runtime of 58 days. This result allows 95% overall recovery to be a reasonably conservative design target for the preliminary full-scale design efforts. The CCD system was then tested at 97% overall recovery for 20 days of runtime and then cleaned and increased to 97.5% overall recovery for 15 days of runtime to establish the CCD system maximum unsustainable recovery in the time allotted by the project.

Four CRRO runs were executed at an overall recovery of 95%. Figure 23 presents the performance of the CRRO pilot system in terms of specific flux and the feed pressures for the first and second stages. CIPs were performed when a 15% decrease in the overall specific flux was observed. The decrease in specific flux and increases in the second stage feed pressure, as shown in Figure 23, indicated scaling of the second stage elements at 95%. The third and fourth runs at 95% indicated rapid decline in performance (i.e., decrease in specific flux) resulting in runs of only 5 and 6 days respectively. Based on this performance the overall recovery was reduced to 92.5%. The 92.5% recovery resulted in a lower second stage flux rate, lower second stage feed pressure, and higher second stage crossflow velocity while maintaining an overall flux rate of 9 gfd (15.3 lmh). The rate of fouling/scaling was lower at 92.5% but still required a CIP after 22 days of runtime. The CRRO did not produce runs of substantial length (i.e., > 30 day runtime) at both 92.5% and 95% recovery.

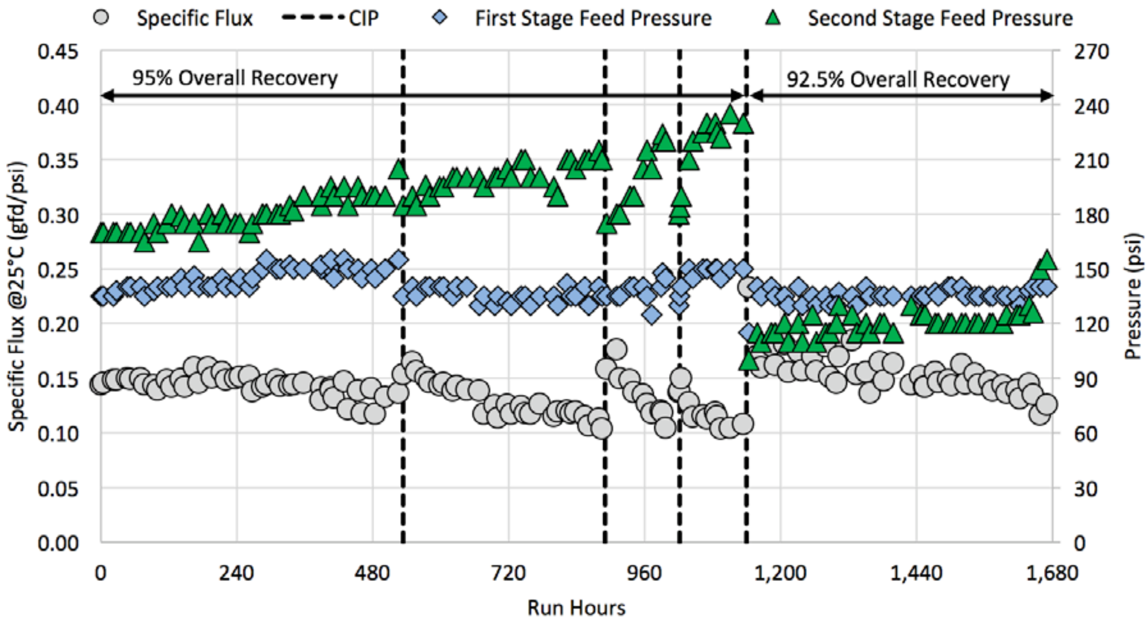


Figure 23. Performance of CRRO pilot system in terms of specific flux (normalized to 25°C), first stage feed pressure, and second stage feed pressure.

Figure 24 shows the CRRO recovery rates based on the permeate and concentrate flow rates. At the 95% overall recovery the primary RO maintained at 80% and the CRRO targeted a 75% recovery. The recovery of the CRRO was controlled manually with a concentrate control valve. At a 95% recovery rate, the concentrate flow rate was 3.5 gpm (13.2 lpm) and the flow would typically fluctuate by ±0.1 gpm (0.4 lpm)—resulting in ±2% recovery. At a 92.5% overall recovery rate, the primary RO recovery was lowered to 75%, and the CRRO recovery target was lowered to 70%.

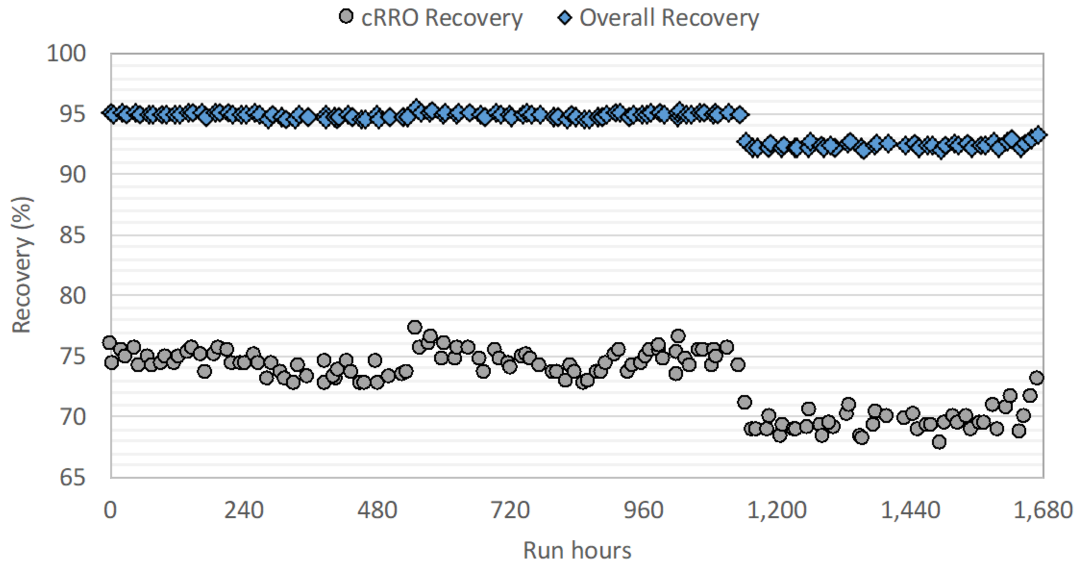


Figure 24. CRRO pilot system recovery rate.

During the CRRO testing, the project team noticed that feed silica concentrations were higher than concentrations during the CCD testing. Figure 25 indicates that, even accounting for differences in the primary RO recovery rate, silica concentrations into the CRRO system were significantly higher than into the CCD system. Further disucssion of the feed silica's potential effect is addressed in Section 7.1.1.

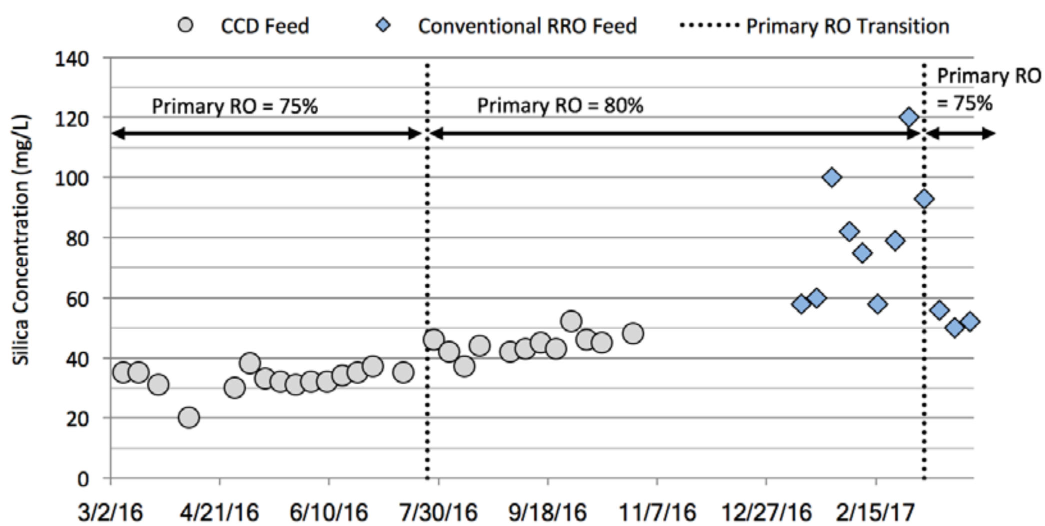
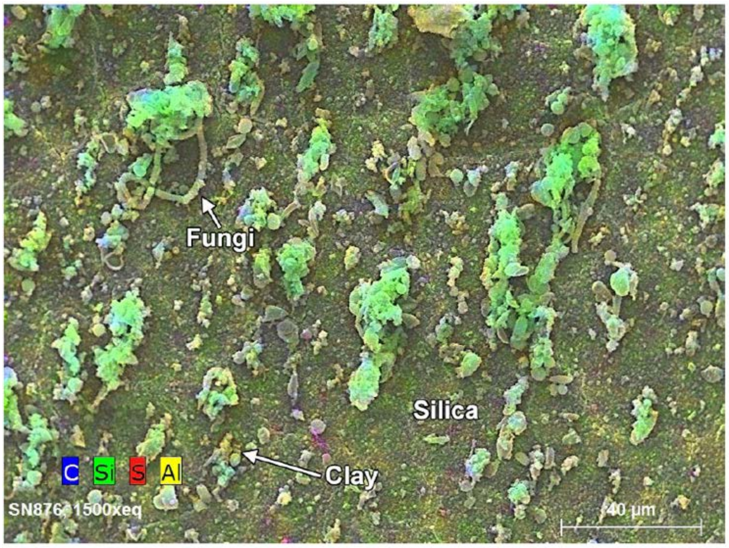


Figure 25. RRO feed silica concentrations.

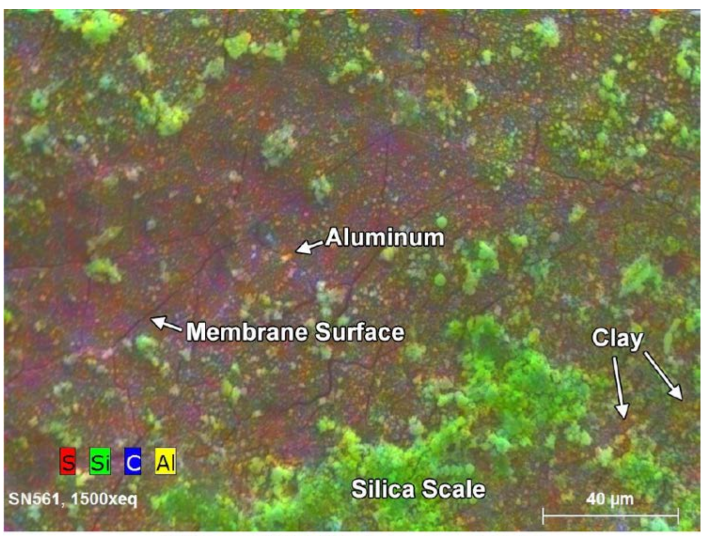
6.3.1. Scaling and Saturation Analysis

Autopsies were performed by Avista Technologies on the tail membrane elements of the CCD and CRRO systems. The tail element from the CCD unit was removed at the end of the 97.5% recovery run on 11/14/16—prior to any chemical cleaning when a significant decrease in specific flux was observed. The tail element from the CRRO was removed at the end of the 92.5% recovery run on 4/5/17 when moderate loss of specific flux was observed. Both autopsies revealed that the primary scale was silica, with some aluminum silicate present, common results for high recovery water reuse systems (Abbas and Malki 2013). Chromatic elemental imaging results from the two autopsies show scalants on the membrane surface as different colors Figure 26 shows the CCD autopsy and Figure 27 shows the CRRO autopsy. Figure 28 shows a picture of the CRRO tail element after being removed, where white scale can be seen on the element's fiberglass casing. The full autopsy reports can be found in Appendices M and N.



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

Figure 26. Chromatic elemental imaging results from of the CCD membrane autopsy.



CEI^{SM} image (1500x) of the image above with labels

Figure 27. Chromatic elemental imaging results from of the CRRO membrane autopsy.

Figure 28. Observed scaling on outside of CRRO tail element prior to autopsy.

In addition to the autopsies, samples of the high and low pH CIP solutions were analyzed for potential scalants following the CRRO's fourth run at the 95% overall recovery rate. Samples were taken from the CIP solution before and after the CIP process to determine what dissolved and was removed during the chemical clean. Aluminum and silica were sampled for the alkaline CIP solution, and calcium, iron, and phosphorus were sampled for the acidic CIP solution. These inorganics were chosen because they can identify the presence of most of the common inorganic scalants (i.e., silica, aluminum silicate, calcium carbonate, calcium sulfate, calcium phosphate, and iron). Table 6presents the results of the CIP solution sampling. A slight increase in aluminum, calcium, and iron was observed. However, a significant increase in silica concentration was measured in the post CIP solution. These results coincide with the autopsy results and suggest that CIP solutions can be analyzed to determine scalants without having to sacrifice and replace membranes to perform autopsies. Qin et al. (2009) also conducted CIP solution sampling and found that total phosphate and calcium concentrations were much higher than other constituents, indicating that calcium phosphate scalant had dissolved in the acid CIP solution.

Table 6. CIP Solution Sample Results for Scalant Identification

Parameter	Caustic CIP Solution		Acid CIP Solution	
	Before CIP	After CIP	Before CIP	After CIP
Aluminum (mg/L)	ND	0.58	-	-
Silica (mg/L)	0.72	13.0	-	-
Calcium (mg/L)	-	-	1.3	3
Iron (mg/L)	-	-	0.014	0.086
Total Phosphorus (mg/L-P)	-	-	ND	ND

ND = not detected

To better understand the decline in CCD and CRRO performance (i.e., lower specific flux), a water quality analysis was conducted to determine scalant saturations. Inorganics were measured weekly in the CCD and CRRO feed water (presented in Appendices C and F) and input into Hydranautic's Integrated Membrane Solutions Design software to estimate the saturations of potential scalants in the concentrate. Temperature and pH values were input from corresponding primary RO data since temperature and pH affect saturations. Figure 29 presents the estimated silica saturations in the CCD brine. The saturations increased when the recovery was increased. Sustainable operation was observed at 95% and 96% recovery, which experienced silica saturations between 100 and 200%. At 97% recovery silica saturation were greater than 200% and resulted in fouling rates that required CIPs more frequently than 30 days.

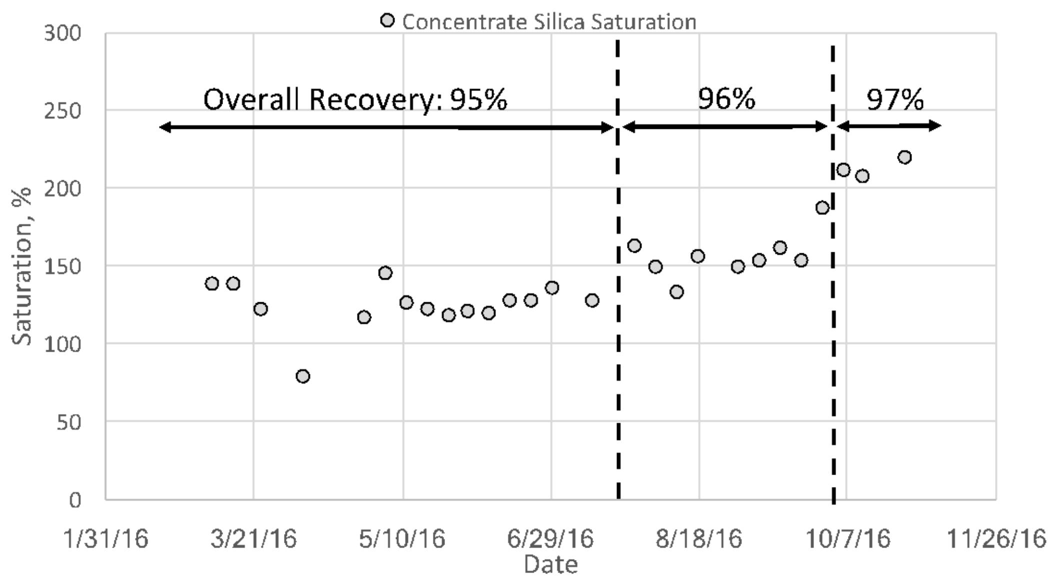


Figure 29. Estimated silica saturations in CCD concentrate.

Figure 30 presents the estimated concentrate silica saturations observed during the CRRO operation based on the routine water quality sampling of the CRRO influent (i.e., the primary RO concentrate). Higher and less consistent silica saturations were observed during the CRRO operation than during the CCD operation at 95% overall recovery. The higher silica saturations likely attributed to the CRRO's unsustainable operation at 95% recovery. When the overall recovery was reduced to 92.5%, the silica saturations were reduced, varying between 1.3 and 1.7, which is analogous to the silica saturations observed at the 96% overall recovery rate during the CCD operation. The increase in silica concentrations and saturations of the feed water is thought to be associated with rain events that occurred during the CRRO operation between January and March 2017. It is possible that infiltration during the storm events elevated silica concentrations in the collection system upstream of the AWP Demonstration Facility, as increased silica in wastewater influents due to storm runoff has been seen elsewhere (Maguire and Fulweiler 2016). Based on these results, additional operation of the CRRO unit is expected during dry weather to better compare fouling rates to the CCD given comparable water quality and concentrate silica saturations.

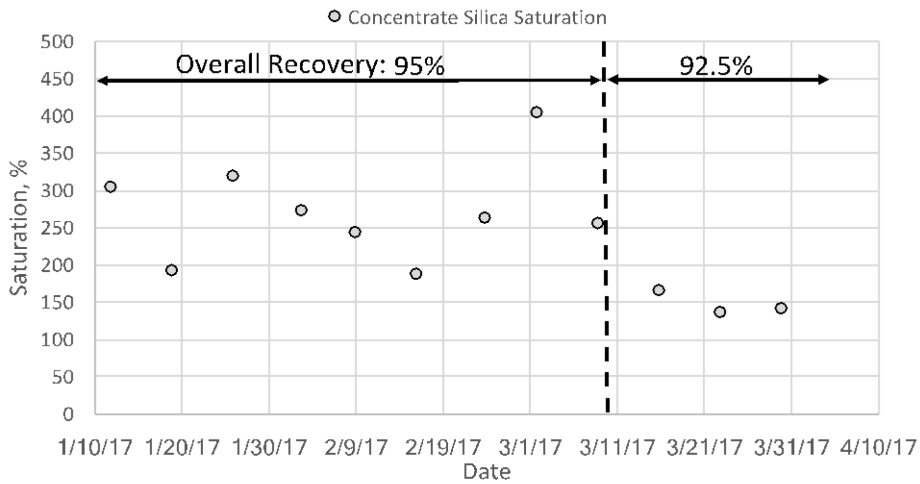


Figure 30. Estimated silica saturations in CRRO concentrate.

Silica was the limiting scalant, based on both autopsy results and the CIP solution analysis. Therefore, the saturations are of particular interest. Since other scalants were not observed, it is thought that the estimated saturations for these other scalants (presented in Appendix O) did not result in significant membrane fouling/scaling with the antiscalant, pH, temperatures, and recoveries tested.

6.4. Energy Efficiency

Generally, reverse osmosis is a process that exerts higher, or often the highest, energy demand on a facility. Increasing the recovery from the more typical values of 75% or 85% to 95% will correspond to an increased energy usage in conventional RO systems. The project team investigated the energy usage for each pilot system by estimating the power as kWh used to produce a volume of permeate as thousand gallons (kgal). For the CCD system, we had both a separate power meter on the influent power supply, and the pilot unit itself also had the ability to measure energy used and report the value in real time on its HMI display. For this project, the CCD system's energy measurements that the Padre

Dam operators recorded daily were used. The cumulative flow was calculated using the SD card data from the system, which recorded the average permeate flow at 20-second intervals. For the CRRO system, the energy was measured using a power meter placed on the influent power supply to the skid. The cumulative flow was estimated using permeate flow values recorded twice a day by the Padre Dam operators and online runtime. Energy usage calculations do not include the energy used by CIPs.

The results of these calculations are shown in Table 7, in kWh/kgal, separated by the target overall RO recovery. For the CCD, the energy use was calculated for 95%, 96%, 97% and 97.5% overall recoveries. The length of runs did vary among the runs at different recoveries, with that of the 97.5% being less than half than that of the 95% runs. Similarly, for the CRRO, the energy use was calculated for 92.5% and 95% overall recoveries and the length of each run varied at the 95% overall recovery. For both systems, the energy use increased as the overall recovery increased. This result is expected, as greater energy is necessary to overcome the higher osmotic pressure of the more concentrated water on the feed side of the RO membranes.

Table 7. Energy Use Comparison for CCD and CRRO

	CCD		**CRRO**	
Recovery Rate	**Energy Use (kWh/kgal)**	**Length of Run(s) (days)**	**Energy Use (kWh/kgal)**	**Length of Run(s) (days)**
92.5%	N/A	N/A	1.75	22
95.0%	4.87	49, 43	2.32	22, 15, 5, 6
96.0%	5.69	58	N/A	N/A
97.0%	5.82	20	N/A	N/A
97.5%	6.98	15	N/A	N/A

N/A = not applicable because a test was not run at that recovery rate.

At 95% overall recovery, the CCD and the CRRO energy use numbers can be compared. The CRRO exhibited nearly half the energy use of the of the CCD system, mostly due to the difference in the hydraulics of the pilot system setups. As described in Section 6.2, the CCD pilot system had an equalization tank for concentrate from the primary RO system. The CCD pilot system then used a booster pump, cartridge filter, and high pressure membrane feed pump to feed water from that equalization tank. The main reason for the CCD equalization tank was to fit this existing pilot system within the confines of this study, which sought to have a recovery RO unit treating the concentrate from the primary RO system. An equalization tank between the two units provided the most operational ease without modifying the primary RO system. It allowed the CCD to operate with flows on a semi-batch schedule while the primary RO system produced a constant flow of concentrate. Another reason is that the CCD pilot system was designed and intended to be used as the whole RO system. An equalization tank on the front end is often standard practice, and this tank would not impart additional energy usage over another alternative, as shown in this study.

The CRRO pilot system was configured to use residual pressure from the primary RO concentrate line and had only one booster pump ahead of each CRRO stage to increase and balance the pressure as needed. The CRRO pilot system configuration is the generally more practiced method for recovery RO in municipal reuse. For the CRRO portion of this study, a small equalization tank in front of the CRRO pilot system was originally intended for operational ease, but further evaluation with the skid manufacturer resulted in a design that would be more applicable to full-scale. As a result, the energy use values for each pilot system are reported for somewhat different hydraulic conditions. This should be taken into account when selecting a system for further design and implementation.

Additionally, a full-scale CCD system may have the option of removing the CCD feed equalization tank when operating as a recovery RO. This has not yet been demonstrated in municipal applications, but is a topic that Padre Dam is further investigating as they evaluate the two types of recovery RO technologies for implementation at the full-scale facility.

6.5. Water Quality

6.5.1. Inorganics and Bulk Organic Water Quality Parameters

Water quality parameters in the RRO feed, permeate, and concentrate were sampled frequently throughout the project, as described in Section 5.2. Generally, except for silica as discussed in Section 7.1, RRO water quality was consistent through the CCD and CRRO testing periods. Concentrations of RRO feed constituents trended well with adjustments to the recovery of the primary RO system. For example, TDS in the RRO feed increased when the primary RO system recovery was increased from 75% to 80% between the first two runs (at 95% overall recovery) and the third run (at 96% overall recovery) (Figure 31). Similarly, concentrations in RRO permeate and concentrate adjusted as RRO recoveries were changed. Table 8.provides the average TDS for each stream for each overall recovery condition. RRO permeate TDS ranged from 81 mg/L at 95% overall recovery for both CCD and CRRO systems to 165 mg/L at 97% overall recovery with the CCD system.

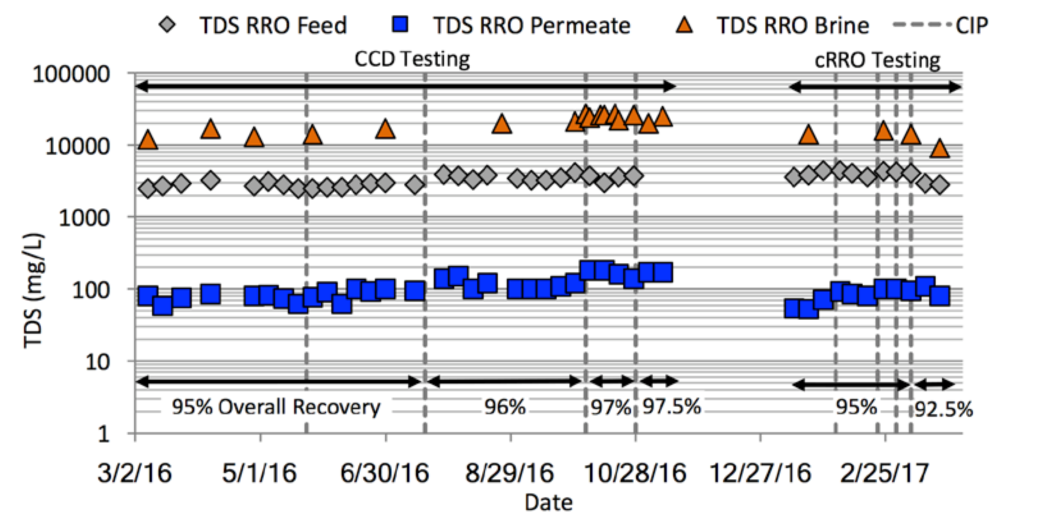


Figure 31. TDS for RRO feed, permeate, and concentrate.

TOC concentrations throughout the study are presented in Figure 32. RRO permeate TOC remained below 1 mg/L most of the time, with many values below the method reporting limit of 0.3 mg/L, but still within the method detection limit (MDL) of 0.042 mg/L, for the lower recoveries tested. RRO feed TOC values, like TDS, also increased as the primary RO system recoveries were adjusted. RRO brine TOC concentrations increased with increasing recovery, as expected.

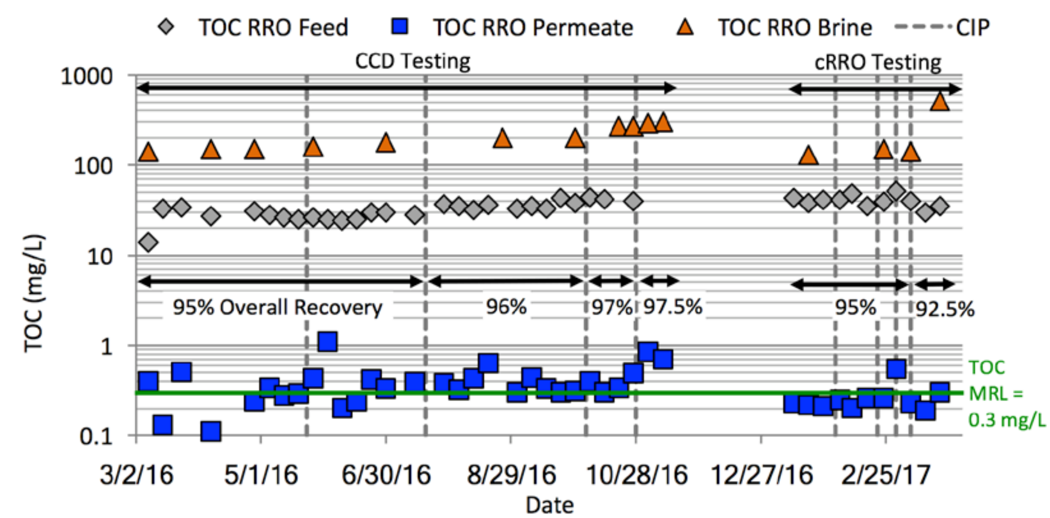


Figure 32. TOC for RRO feed, permeate, and concentrate.

RRO permeate UVT data is presented in Figure 33, and generally remained above 95%. RO permeate UVT for potable reuse is a key design criteria for UV/AOP. In this configuration, where the RRO permeate would be blended with the primary RO permeate, the decrease in UVT may be mitigated by combining the two streams, and significant changes in the downstream UV/AOP design would not be necessary.

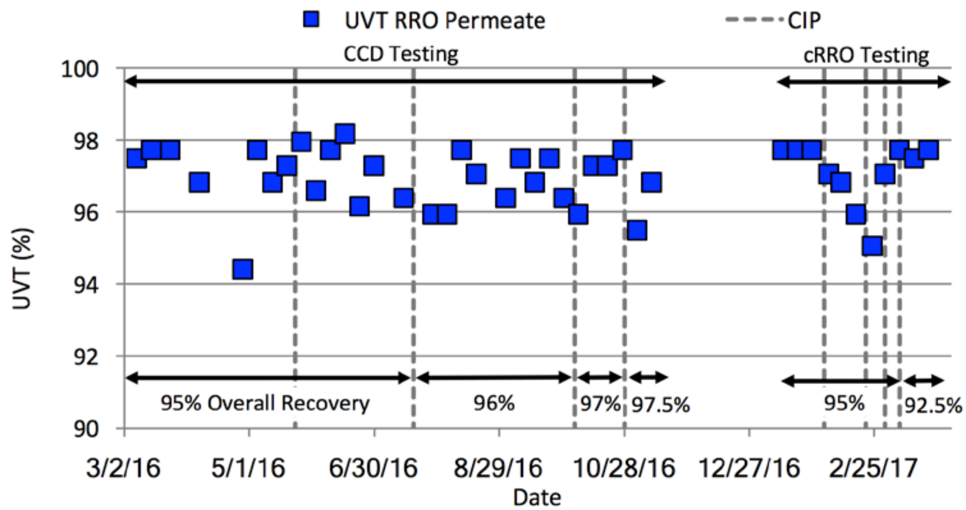


Figure 33. UVT for RRO permeate.

Average water quality during the runs for overall recovery at 92.5%, 95%, 96% and 97% are presented in Table 8. The 97% recovery rate is shown as a reference, although this rate did not have stable runs at that time period. The 97.5% recovery rate is not shown in summary table, but data for the short run may be found in Appendices C through E, along with individual water quality sampling results for the entire testing period. Water quality is along the lines expected of an RO system running at these recoveries. Significant water quality differences for these parameters were not seen between the CCD and the CRRO pilot system testing.

Table 8. Average Inorganic and Bulk Organic Water Quality by Overall RO Recovery

Parameter	CCD 95%			CCD 96%			CCD 97%			CRRO 95%			CRRO 92.5%		
	Feed	Perm	Brine	Feed	Perm	Brine	Feed	Perm	Brine	Feed	Perm	Brine	Feed	Perm	Brine
Aluminum (µg/L)	68.6	4.16	322	98.7	1.22	585	77.7	1.25	480	63.7	1.41	266. 7	54.5	ND (20)	170
Barium (µg/L)	207.3	0.43	1,118	251.1	0.30	1,850	250.0	0.23	1,950	275.6	0.37	1,300	175.0	ND (2)	470
Calcium (mg/L)	224.7	0.21	1,156.7	272.2	0.20	1,450	280.0	0.16	1,300	327.8	0.16	1,266.7	220.0	0.16	670
Iron (mg/L)	0.163	0.003	0.796	0.231	ND (0.02)	1.2	0.242	ND (0.02)	1.95	0.142	ND (0.02)	0.567	0.105	ND (0.02)	0.38
Magnesium (mg/L)	78.6	0.030	412	97.2	0.033	560	94.7	0.030	725	136.3	0.023	560	87.5	0.032	260
Potassium (mg/L)	63.2	2.50	312	80.7	3.71	395	82.0	5.30	595	67.4	1.84	273.3	58.5	2.40	190
Silica (mg/L)	32.7	0.56	138	43.8	0.97	240	46.3	1.35	300	80.6	1.01	253.3	53.0	1.40	150
Sodium (mg/L)	533.3	22.8	2,600	681	33.2	3,350	690	46.3	5,200	758.9	22.4	2,966.7	590.0	26.0	1,800
Strontium (mg/L)	2.41	0.0016	12.76	3.10	0.0017	20.5	3.17	0.0018	20.5	3.37	0.0009	13	1.65	0.0010	4.6
TOC (mg/L)	27.1	0.36	156	35.8	0.38	200	42.0	0.38	270	41.9	0.27	140	32.5	0.25	510
Dissolved UVA at 254 nm (cm^{-1})	0.507	0.0128	2.964	0.652	0.0141	3.750	0.653	0.0130	4.900	0.741	0.0133	2.767	0.510	0.0105	1.700
UV Transmittance (%)	31.1	97.1	0.167	22.1	96.8	0.018	22.2	97.1	0.0013	18.9	97.0	0.172	30.9	97.6	2.00
Total Hardness (mg/L as $CaCO_3$)	886	ND (3)	4,560	1,067	ND (3)	5,900	1,100	ND (3)	7,300	1,378	ND (3)	5,466.7	910	ND (3)	3,000
Chloride (mg/L)	688	17.1	3,400	828	25.0	4,850	897	34.8	6,200	978	16.0	3,400	830	20.5	2,500
Sulfate (mg/L)	926	0.62	4,860	1,211	0.84	7,550	1,200	0.67	8,800	1,367	0.48	5,067	840	0.37	2,500

Recovery RO Testing

Parameter	CCD 95%			CCD 96%			CCD 97%			CRRO 95%			CRRO 92.5%		
	Feed	**Perm**	**Brine**	**Feed**	**Perm**	**Brine**	**Feed**	**Perm**	**Brine**	**Feed**	**Perm**	**Brine**	**Feed**	**Perm**	**Brine**
TDS (mg/L)	2,773	80.9	14,600	3,567	115.6	20,500	3,500	165.0	25,167	4,033	81.1	14,667	2,850	95.0	9,100
Alkalinity (mg/L as $CaCO_3$)	143.0	9.8	854.5	109.4	11.1	569.5	125.0	10.3	897.5	202.9	8.6	746	184.7	8.0	420
Ammonia (mg-N/L)	2.5	0.55	10.6	3.2	0.69	15.3	2.9	0.83	16.8	2.1	0.48	6.5	2.0	0.50	5.5
Nitrate (mg-N/L)	40.1	5.9	209.2	55.9	8.6	282	59.5	13.9	378.3	57.9	6.4	317.8	45.2	5.7	143
Ortho Phosphate (mg-P/L)	0.16	ND (0.01)	0.84	0.25	0.013	1.12	0.40	0.013	2.78	1.75	0.066	10.82	0.24	0.015	0.46

Note: "ND" refers to non-detected values, with the method reporting limit in parentheses. The method reporting limit assumes no dilutions, although dilutions were performed in a few analyses. Averages are calculated without taking into account non-detected values. Aluminum and barium permeate samples were sometimes quantified at values below the method reporting limit; these values are presented in this table when possible.

6.5.2. Log Removal Values for Naturally Occurring Constituents to Monitor Integrity

Membrane filtration processes, including RO systems, rely on ongoing monitoring strategies to demonstrate system integrity and confirm its effectiveness on barring pathogens (U.S. Environmental Protection Agency [EPA] 2005). Of the methods available, online TOC and conductivity monitoring are commonly employed for full-scale RO systems (DDB Engineering 2014, WRD 2016, Kumar et al. 2007, and Adham et al., 1998). Other methods, such as monitoring the rejection of naturally occurring sulfate (Kruithof et al., 2001) and strontium (Trussell et al. 2017) have also been proposed. These later methods are attractive since they provide higher log removals (up to 3.5 logs) relative to conductivity and TOC, and are closer to RO’s potential in terms of actual virus removal (up to 7 logs for MS2 phage from Lozier et al. 2003 as cited in and discussed by Pype et al., 2016). Should these RRO systems be used at full-scale for potable reuse, monitoring integrity would be a requirement.

Figure 34 provides log-based removal for four naturally occurring constituents (strontium, sulfate, TOC, and TDS) measured across the CCD and CRRO systems at different conditions. Averaged log removal values (LRV) were plotted using water quality data from Table 8, which included composite permeate samples for the CCD system and grab sample for the CRRO system. Overall, the extent of constituent removal was comparable for the two systems tested at these conditions.

A noteworthy difference was observed for TOC removal. TOC removal was 1.8-logs for the CCD system operated at 95% overall recovery in comparison to 2.2-logs of removal for the CRRO system operated at 92.5% overall recovery. This is directly related to the RRO feed concentration of TOC, which was lower for the CCD system’s 95% overall recovery run due to the primary RO system recovery operating at 75% recovery, whereas the CRRO system at 92.5% overall recovery used the primary RO system recovery at 80%. Also, averaged TDS rejection for both systems was no less than 1.3-logs (95.0%). The levels of removal observed for the CCD and CRRO are comparable to conventional RO systems (Pype et al. 2016), suggesting that these naturally occurring constituents can also be used to monitor integrity of the evaluated brine minimization systems. Up to 3 logs of removal can be demonstrated using strontium and/or sulfate assuming there is sufficient concentration in the feed water to measure detectable concentration in the permeate.

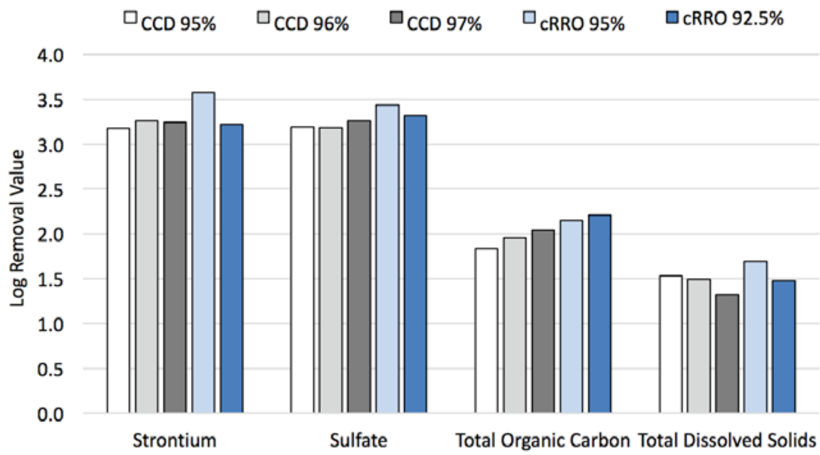


Figure 34. Log removal value for naturally occurring constituents for the CCD and CRRO systems for the various conditions tested.

6.5.3. CCD Permeate Special Sampling for Disinfection Byproducts, Trace Organics, and Contaminants of Emerging Concern

To better understand how a CCD system would fit into a full-scale design at Padre Dam, which included various uses of the permeate, the project team undertook special sampling of the CCD permeate. A sampling event in May 2016 included disinfection byproducts and certain trace organics and priority pollutants, for the CCD permeate at 95% overall recovery. Two sampling events took place in September 2016 and together covered disinfection byproducts (DPB), certain trace organics, and contaminants of emerging concern (CEC) in the CCD permeate at 96% overall recovery.

The results from these three sampling events are summarized in Table 9, with full results presented in Appendix I. For disinfection byproducts, total trihalomethanes (TTHM) were notably 33 and 67 µg/L for two sampling events, whereas total haloacetic acids (HAA5) were non-detected in the September 2016 sampling event. HAA5s are typically better rejected by RO than TTHMs. The increase in TTHMs in the second sampling event is due to increased chloroform concentrations. These TTHM values may be related to the upstream free chlorine disinfection system that operates upstream of the microfiltration (MF) system. TTHMs values, however, are still below the potable water primary maximum contaminant level of 80 µg/L. Chlorate was also sampled once and detected at 98 micrograms per liter (µg/L), below the California notification level of 800 µg/L and the 2002 proposed action level of 200 µg/L by the California Office of Environmental Health Hazard Assessment. Values for *N*-Nitrosodimethylamine (NDMA) concentrations were 17 and 22 Ng/L for the two sampling events, and were similar to previous measurements of the primary RO permeate during a separate 2015-2016 study at the Padre Dam AWP demo. This information helps to confirm that addition of the CCD permeate would not significantly alter the design of treatment processes after the RO system, such as UV/AOP.

Table 9 presents 11 trace organics and CECs that were detected and/or quantified but below the method reporting limit, out of over 200 parameters measured. Advanced water treatment, including RO, has been shown to generally remove many trace organics and CECs, and the limited sampling performed on the CCD permeate is consistent with this trend. Sampling was not undertaken of the CRRO system permeate as it was expected that the conventional RO system would have similar water quality characteristics as the primary RO system. The primary RO system permeate was sampled and analyzed for these various constituents as part of an earlier and separate study by Padre Dam during 2015 and 2016.

Table 9. CCD Permeate DBPs, Detected Organics, and CECs

Parameter	Unit	Ray Stoyer WRF secondary effluent[A]	Sampling Date and Overall Recovery		
			5/19/16 or 5/26/16 at 95%	9/26/16 at 96%	9/29/16 at 96%
Disinfection byproducts					
Total Trihalomethanes (TTHMs)	µg/L	ND (0.5)	33.8	67	NS
Haloacetic Acids (HAA5)	µg/L	5.6	NS	ND (2)	NS
Bromodichloromethane	µg/L	ND (0.5)	10.98	21	NS
Bromoform	µg/L	ND (0.5)	0.44	ND (0.5)	NS
Chlorate by IC	µg/L	86	NS	98	NS
Chlorodibromomethane	µg/L	ND (0.5)	4.11	5.6	NS
Chloroform	µg/L	0.25	13.95	40	NS
N-Nitrosodimethylamine (NDMA)	Ng/L	8.7	ND (2000[B])	17	22
Detected Organics and CECs					
1,4-Dioxane	µg/L	0.74	NS	ND (0.085)	ND (0.085)
Acetaldehyde	µg/L	NS	NS	5.9	NS
Atenolol	Ng/L	350	NS	10	54
Caffeine	µg/L	ND (0.005)	NS	ND (0.020)	0.065
Di-n-butylphthalate	µg/L	ND (1)	1.30[C]	ND (1)	ND (1)
Formaldehyde	µg/L	11	NS	27	NS
Iohexal	Ng/L	NS	NS	14	20
Propylparaben	Ng/L	NS	NS	6.3	ND (5)
Sucralose	Ng/L	37750	NS	ND (100)	120
Triclocarban	Ng/L	NS	NS	ND (5)	5.3
Triclosan	Ng/L	32	NS	38	36

Note: "ND" refers to non-detected values, with the method reporting limit in parentheses. The method reporting limit assumes no dilutions, although dilutions were performed in a few analyses. Averages are calculated without taking into account non-detected values.
NS = not sampled
[A] Pecson et al. (2016), average concentration of sampling from February 2015 to February 2016
[B] May 2016 NDMA detection limit was 2 µg/L for EPA 625
[C] Two samples were taken on 5/19/2017. One was quantified at 1.30 µg/L and one was not detected, and both analyses had a method reporting limit of 2 µg/L.

6.5.4. CCD Cycle Assessments

One of the ways in which the CCD process differs from conventional RO is the semi-batch nature of the process, as described in Section 6.2. As such, the project team performed cycle assessments by collecting select water quality of the CCD permeate and concentrate over the course of one CCD cycle. The collected data is provided in Table 10 for 95% overall recovery and in Table 11 for 96% overall recovery. Figure 35 and Figure 36 also show visually how the CCD concentrate changed color through the CCD cycle.

The objective of the cycle assessments was to sample at the beginning, middle, and end of the CCD cycle, during which the concentrate valve was closed and the solution on the feed side of the RO membranes was increasing in concentration. For both events, the CCD cycle time was approximately 13.1 to 13.2 minutes, and the PFD cycle was about 1.6 minutes. Due to sampling logistics, the permeate samples were collected during a separate cycle than the collection of the concentrate samples. The project team selected parameters to measure that would be representative of the overall water quality changes throughout the cycle.

Generally, the CCD permeate showed increasing concentrations of inorganics (sodium, strontium, TDS, and conductivity) as the CCD cycle progressed. This trend is reasonable as the concentrate concentrations also increase during the CCD cycle. No change in CCD permeate UVA was observed over the cycle for the 95% overall recovery condition but an increase was observed over the cycle for the 96% overall recovery condition. CCD permeate TOC for both conditions appeared to stay stable over the CCD cycle, although this trend may be an artifact of the concentrations being around the method reporting limit. The TOC of the CCD concentrate did increase as expected over the CCD cycle for both events.

Routine CCD permeate values, as described in Section 5.2, were sampled from the CCD permeate tank and thus represent a composite value of many CCD and PFD cycles. Composite values may be more representative of full-scale conditions as flow equalization on the CCD permeate may be desired to allow for a constant flow for downstream processes, such as UV/AOP in many potable reuse scenarios. However, this data provides values for the bounding conditions on the CCD permeate water quality for downstream processes, if no flow equalization is present. Also of note is that, as a RRO system, the permeate from the CCD system would be blended with the primary RO, which would smooth out the water quality variations over the CCD and PFD cycles, depending on the relative flow contribution of the CCD permeate to the combined permeate flow.

Table 10. CCD Cycle Assessment Data at 95% Overall Recovery from April 28, 2016

CCD Stream	CCD Cycle Time (min)	UVA (cm^{-1})	UVT (%)	Sodium (mg/L)	Strontium (µg/L)	TOC (mg/L)	TDS (mg/L)	pH	Conductivity (µS/cm)
Permeate	2.2	0.012	97.3	10	0.36	0.29 [A]	44	5.4	60.5
	6.0	0.012	97.3	16	0.56	0.23 [A]	48	5.35	98.3
	11.4	0.012	97.3	26	4.8	0.4	96	5.34	161.7
Concentrate	2.0	1.05	8.9	980	4,600	52	5,700	6.66	7,750
	6.0	1.68	2.1	1,600	7,200	83	9,100	6.83	11,900
	13.0	2.83	0.1	2,600	12,000	140	13,000	6.98	18,620

[A] TOC measurements quantified but below method reporting limit of 0.3 mg/L

Table 11. Table 11. CCD Cycle Assessment Data at 96% Overall Recovery from September 26, 2016

CCD Stream	CCD Cycle Time (min)	UVA (cm^{-1})	UVT (%)	Sodium (mg/L)	Strontium (µg/L)	TOC (mg/L)	TDS (mg/L)	pH	Conductivity (µS/cm)
Permeate	1.3-2.4	0.009	97.9	16	0.98	0.3	60	5.88	95.0
	7.0-7.9	0.011	97.5	27	1.0	0.27 [A]	110	5.63	167.6
	12.2-13.0	0.014	96.8	41	1.9	0.3	160	5.66	251
Concentrate	1.5-2.3	1.3	5.0	1,300	7,700	73	7,300	6.80	9,570
	7.2-8.7	2.7	0.2	2,700	16,000	160	15,000	6.99	18,010
	during PFD start [B]	3.8	0.0	4,000	18,000	220	22,000	7.13	23,300

[A] TOC measurements quantified but below method reporting limit of 0.3 mg/L
[B] CCD cycle time was approximately 13.2 minutes and the PFD cycle time was 1.6 minutes.

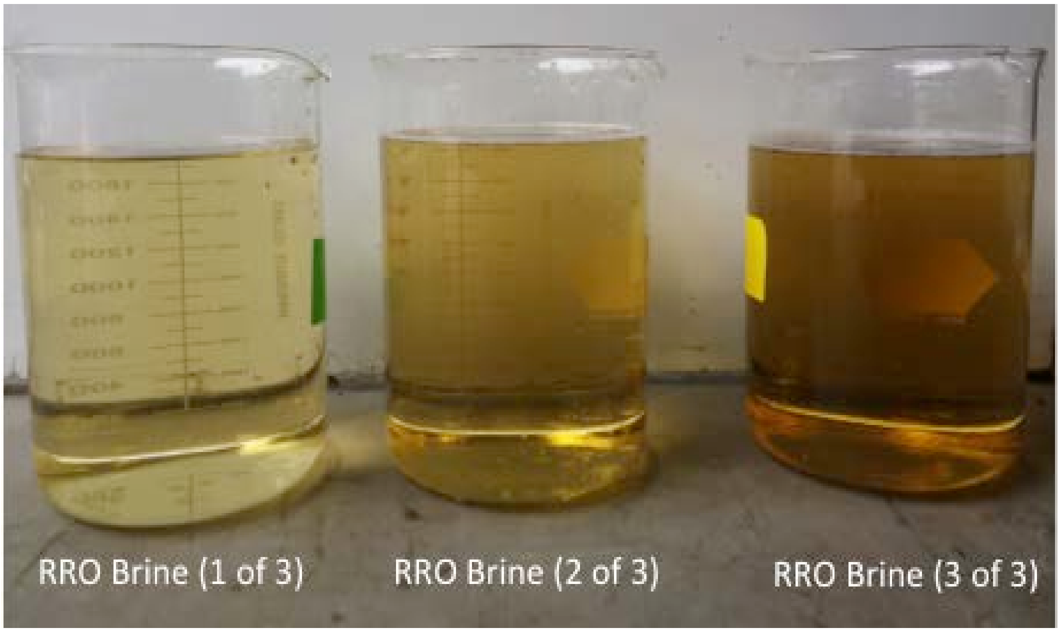


Figure 35. CCD brine during the April 2016 cycle assessment.

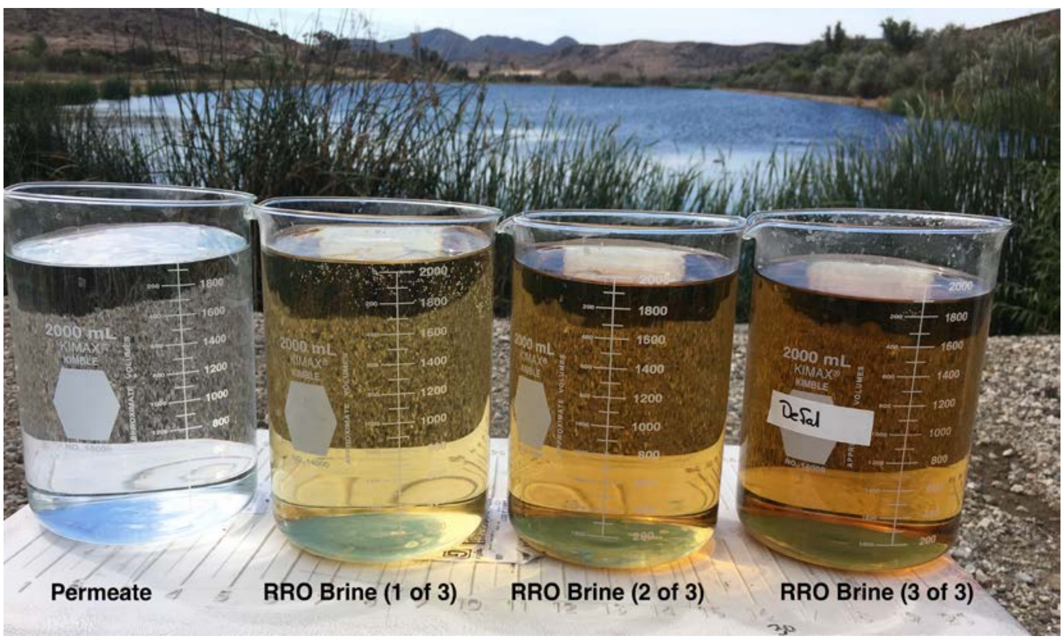


Figure 36. CCD brine during the September 2016 cycle assessment.

7. Conclusions and Recommendations

This study had several goals related to maximizing RO recovery at Padre Dam using innovative technologies and evaluating their performance for potential full-scale design. Conclusions and recommendations are summarized as follows:

- The CCD system, as a recovery RO system, demonstrated sustainable operations at 95% and 96% overall recoveries with runtimes around 40 to 50 days, above the 30 day minimum CIP interval set by the project team.

- The CRRO system demonstrated runtimes less than the 30 day minimum CIP interval at 95% and 92.5% overall recoveries. Increased silica concentrations in the feed and corresponding increased silica saturation in the CRRO concentrate, as compared to those during the CCD testing may have contributed to this difference in performance.

- Silica appeared to be the main scalant of concern for both RRO systems, based on water quality analyses and membrane autopsies.

The CCD system permeate exhibited similar water quality characteristics to conventional RO permeate for potable reuse, as proven by special sampling for disinfection byproducts, bulk organics, trace organics, contaminants of emerging concern, and during assessments of the semi-batch cycle.

- To compare CRRO operability to the CCD system, further testing is recommended when feed silica concentrations have decreased to their usual dry-weather levels.

- Energy use was greater for the CCD pilot system (at 4.87 kWh/kgal) than the CRRO pilot system (2.32 kWh/kgal), although system configurations differed once installed. The CCD system, due to the batch nature of its flows, included an upstream equalization tank for the primary RO system concentrate, whereas the CRRO system did not include an equalization tank.

- To compare energy use of the CCD system to the CRRO system, further investigation should be undertaken to eliminate the equalization tank on the feed side of the CCD system, when acting as a RRO unit. Retaining the pressure from the primary RO system concentrate would save a significant amount of energy in terms of RRO membrane feed pressure.

These items should be taken into account when considering which technology should be pursued for a full-scale design. This study focused on the pilot-scale testing of these two technologies to identify reasonable recovery values, and further work would be necessary to translate these results to full-scale applications. Considerations for an economic analysis to determine which technology would work best for a particular application include costs for brine disposal, costs of energy, available space, as well as ease of operation and tolerance for membrane replacement.

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SI Metric Conversion Table

US Customary Unit Used in Document	Multiply by	To Get SI Unit
Miles	1.61	Kilometer (km)
Million gallons/day (MGD)	3785.4	Cubic meters/day (m^3/day)
Gallons/day (gpd)	0.003785	Cubic meters/day (m^3/day)
Gallons/minute (gpm)	3.7854	Liters/ minute (lpm)
Gallons/square foot/day (gfd)	1.69	Liters/square meter/hour (lmh)
Degrees Fahrenheit (˚F)	([˚F]-32)*5/9	Degrees Celsius (˚C)
Inch	25.4	Millimeters (mm)
Square feet (sq. ft.) / (ft^2)	0.093	Square meters (m^2)
Gallons (gal)	3.7854	Liters (l)
Horsepower (hp)	745.7	Watts (W)
Pounds force/square inch (psi)	0.069	Bars (bar)
gfd/psi	24.6	lmh/bar
Kilowatt•hour/kilogallon (kWh/kgal)	0.264	kiloWatt•hour/cubic meter (kWh/m^3)

Appendix A – CCD Daily Operating Parameters

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
2/29/16	21875	21875			9	8.7	7.6	1.7	23.2	8.7	30	179	4736	6.7	14807
3/1/16	74085	74085			9	8.7	7.7	1.65	22.7	8.7	30	181	4664.5	6.6	15044.5
3/2/16	154737	154737	0	0	9	7.8	13.6	1.7	22.7	7.8	30	200	4499.5	6.6	19994
3/3/16	240455	240455	24	1.0	9	7.8	13.6	1.7	23	7.8	30	198	4400	6.5	18663
3/4/16	290226	290226	38	1.6	9	7.8	13.5	1.7	23.2	7.8	30	193	4213	6.7	18617
3/7/16	305234	305234	42	1.7	8	7.8	13.5	1.7	22.2	7.8	30	191	3947.5	6.4	19863
3/8/16	328046	328046	48	2.0	9	7.8	13.5	1.7	23	7.8	30	188	3830.5	6.8	15483
3/10/16	340012	340012	51	2.1	3	5.7	0.9	1.7	23.5	5.7	30		4130	6.3	573
3/15/16	368033	368033	59	2.5	9	7.8	13.6	1.7	23.7	7.8	30	197	4060	6.5	16477
3/16/16	436378	436378	78	3.3	9	7.8	13.6	1.7	23.5	7.8	30	200	4104.5	6.6	16253.5
3/17/16	522063	522063	102	4.3	9	7.8	13.6	1.7	23.6	7.8	30	194	4130.5	6.7	17658
3/18/16	607326	607326	126	5.2	9	7.9	13.4	1.8	23.7	7.9	30		4130	6.8	8584
3/19/16	690175	690175	149	6.2	9	8	12.9	1.8	23.5	8	30		4141.5	6.7	6986
3/20/16	773023	773023	172	7.2	9	8	12.9	1.8	23.2	8	30		4113	7	6892
3/21/16	859971	859971	196	8.2	9	8	13.3	1.8	23.7	8	30		4011.5	6.6	6752
3/22/16	944084	944084	219	9.1	9	7.8	13.5	1.7	23.2	7.8	30		4140	6.4	16030
3/23/16	1027873	1027873	243	10.1	9	7.8	13.6	1.65	23	7.8	30	205	4360.5	6.3	15922.5
3/24/16	1114758	1114758	267	11.1	9	7.8	13.2	1.6	23	7.8	30	207	4428	6.3	16570.5
3/25/16	1198890	1198890	290	12.1	9	7.8	13.6	1.6	23	7.8	30	213	4440	6.6	19456
3/26/16	1280053	1280053	313	13.0	9	7.8	13.6	1.6	23.7	7.8	30	209	4431.5	6.9	18395
3/27/16	1328975	1328975	326	13.6	8	7.8	13.2	1.6	23.2	7.8	30	213	4517.5	7.1	16609.5
3/28/16	1341889	1341889	330	13.7	8	7.75	12.55	1.6	23.5	7.75	30	198.5	4645.5	7.2	21998
3/29/16	1370202	1370202	338	14.1	9	7.8	13.1	1.6	23.2	7.8	30	209	4541.5	6.4	23044
3/30/16	1424366	1424366	353	14.7	8	7.8	13.1	1.6	23	7.8	31	209	4337.5	6.5	15955
4/5/16	1480175	1480175	368	15.3	9	7.8	13.1	1.6	24.4	7.8	30	213	4683	6.1	16705
4/6/16	1543409	1543409	386	16.1	9	7.8	13.2	1.6	24.2	7.8	30	213	4690	6.3	18601.5
4/7/16	1621596	1621596	407	17.0	9	7.8	13.2	1.6	24.2	7.8	30	208	4506.5	6.3	16544.5
4/8/16	1705528	1705528	431	17.9	9	7.8	13.6	1.6	24.2	7.8	30	207	4427	5.8	15830
4/9/16	1788257	1788257	454	18.9	9	7.8	13.2	1.6	24	7.8	30	210	4482.5	6	15862.5
4/10/16	1873230	1873230	477	19.9	9	7.8	13.2	1.6	23.7	7.8	30	213	4485	6.1	15516
4/11/16	1923967	1923967	491	20.5	8	7.8	13.2	1.6	23.2	7.8	30	214	4515	6	17503
4/22/16	1958607	1958607	501	20.9	9	7.8	13.1	1.6	24.9	7.8	30	189	3839	5.7	20042
4/23/16	2025741	2025741	520	21.7	9	7.8	13.1	1.6	24.7	7.8	30	190	3914	5.9	15426
4/24/16	2110857	2110857	543	22.6	9	7.8	13.15	1.6	24.7	7.8	30	197	4076	6.3	15807

DRAFT

Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
2/29/16	121	170	24	10.4	1651	2315	2159	4736	80	
3/1/16	116	172	24	10.4	1655	2335.5	2154	4664.5	80	
3/2/16	187.5	191	23	9.3	1634	2462.5	2072	4499.5	80	0.102966181
3/3/16	180	189	23	9.3	1632	2445.5	2073	4400	80	0.102586591
3/4/16	178	184	23	9.3	1628	2414	2075.5	4213	80	0.102145625
3/7/16	129.5	183	23	9.3	1635.5	2401	2075	3974	80	0.10103432
3/8/16	163	178	23	9.3	1626.5	2374	2105	3830.5	80	0.100750549
3/10/16	61	89	0.7	6.8	1602	1482	3500	4130	80	
3/15/16	191	188	23	9.3	1629	2436	2198	4060	80	0.09426227
3/16/16	191	191	23	9.3	1633.5	2458.5	2195	4104.5	80	0.093628916
3/17/16	186	185	23	9.3	1632	2423.5	2193.5	4130.5	80	0.097947911
3/18/16	119	101	23	9.4	1632	1704	2177	4130	80	
3/19/16	114	101	23	9.6	1633	1692	2175	4141.5	80	
3/20/16	106	101	23	9.6	1634	1697	2174	4113	80	
3/21/16	99	100	23	9.6	1633	1681.5	2173	4011.5	80	
3/22/16	180	188	23	9.3	1634	2445	2189	4140	80	
3/23/16	198	196	23	9.3	1632	2499	2189.5	4360.5	80	0.094134124
3/24/16	194	199.5	23	9.3	1631.5	2517.5	2191	4428	80	0.093876262
3/25/16	189	204	23	9.3	1631	2550	2193	4440	80	0.088460952
3/26/16	189.5	200	23	9.3	1629	2527.5	2191	4431.5	80	0.090863337
3/27/16	186	204	23	9.3	1631	2554	2191	4517.5	80	0.090278993
3/28/16	164.5	190	23	9.25	1629.5	2455	2192.5	4645.5	80	0.099671077
3/29/16	208.5	200	23	9.3	1632	2527	2190	4541.5	80	0.093982358
3/30/16	183	200	23	9.3	1633	2524.5	2189	4337.5	80	0.08978558
4/5/16	206	204	23	9.3	1629	2548	2190	4683	80	0.089529586
4/6/16	191	205	23	9.3	1629.5	2558	2188	4690	80	0.090321918
4/7/16	201	200	23	9.3	1627	2523	2187	4506.5	80	0.092400024
4/8/16	200	198	23	9.3	1626	2513	2187	4427	80	0.091564467
4/9/16	196.5	201	23	9.3	1626	2534	2186	4482.5	80	0.089999685
4/10/16	199	204	23	9.3	1627	2554	2188	4485	80	0.088438061
4/11/16	201	205	23	9.3	1632	2562	2190	4515	80	0.089055766
4/22/16	166	180	23	9.3	1626	2381	2187	3971	80	0.095234365
4/23/16	153	181	23	9.3	1629	2394	2185	3914	80	0.095295299
4/24/16	149.5	188	23	9.3	1630	2440	2185	4100	80	0.093371418

Date	Comments
2/29/16	
3/1/16	
3/2/16	choosing to start plots at 3/2/16
3/3/16	
3/4/16	
3/7/16	
3/8/16	
3/10/16	System likely off this day
3/15/16	
3/16/16	
3/17/16	
3/18/16	Avista black box was negatively affecting operation of CCD pilot
3/19/16	
3/20/16	
3/21/16	
3/22/16	
3/23/16	
3/24/16	
3/25/16	
3/26/16	
3/27/16	
3/28/16	
3/29/16	
3/30/16	
4/5/16	
4/6/16	
4/7/16	
4/8/16	
4/9/16	
4/10/16	
4/11/16	
4/22/16	
4/23/16	
4/24/16	

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
4/25/16	2197193	2197193	567	23.6	9	7.8	13.2	1.6	24.4	7.8	30	198	4151	6.3	15765
4/26/16	2282985	2282985	591	24.6	9	7.8	13.1	1.6	24.4	7.8	30	201	4273	6.3	16046
4/27/16	2351293	2351293	610	25.4	9	7.8	13.1	1.6	24.2	7.8	30	199	4235	6.4	14856
4/28/16	2399239	2399239	623	26.0	9	7.8	13.1	1.6	24.7	7.8	30	196	4161	6.4	15346
4/29/16	2448752	2448752	637	26.6	9	7.8	13.1	1.6	24.7	7.8	30	199	4276	6.4	14906
4/30/16	2520948	2520948	657	27.4	9	7.8	13.1	1.6	24.7	7.8	30	203	4327	6.6	15322
5/1/16	2604388	2604388	680	28.4	9	7.8	13.2	1.6	24.4	7.8	30	206	4441	6.7	15855
5/2/16	2688207	2688207	704	29.3	9	7.8	13.2	1.6	25.2	7.8	30	211	4573	6.7	17041
5/3/16	2775507	2775507	728	30.3	9	7.8	13.1	1.6	25.2	7.8	30	211	4700.5	6.7	18562.5
5/4/16	2859757	2859757	751	31.3	9	7.8	13.1	1.6	25.2	7.8	30	210	4662	6.6	17318
5/5/16	2944519	2944519	775	32.3	9	7.8	13.1	1.6	25.2	7.8	30	207	4489.5	6.6	15843.5
5/6/16	3028397	3028397	798	33.3	9	7.8	13.1	1.6	24.7	7.8	30	205	4365	6.4	15691
5/7/16	3112486	3112486	822	34.2	8	7.8	13.1	1.6	24.7	7.8	30	206	4259.5	6.2	15477
5/8/16	3197055	3197055	845	35.2	9	7.8	13.1	1.6	24.9	7.8	30	207	4308.5	6.6	15672.5
5/9/16	3282146	3282146	869	36.2	9	7.8	13.1	1.6	24.9	7.8	30	207	4241	6.6	14847
5/10/16	3366767	3366767	892	37.2	9	7.8	13.1	1.6	25.2	7.8	30	204	4274.5	6.55	14866
5/11/16	3450007	3450007	915	38.1	8	7.8	13.1	1.6	25.2	7.8	28	201	4149	6.3	14912
5/12/16	3534445	3534445	939	39.1	9	7.8	13.1	1.6	25.4	7.8	30	197	4040	6.3	15103
5/13/16	3620345	3620345	963	40.1	9	7.8	13.1	1.6	25.4	7.8	30	197	4062	6.3	15104.5
5/14/16	3704336	3704336	986	41.1	8	7.8	13.1	1.6	25.4	7.8	28	197	4016	6.5	15297
5/15/16	3790009	3790009	1010	42.1	8	7.8	13.1	1.6	25.2	7.8	30	196	3967	6.5	15248
5/16/16	3876704	3876704	1034	43.1	9	7.8	13.1	1.6	25.2	7.8	30	195	3913	6.7	15149
5/17/16	3963091	3963091	1058	44.1	9	7.8	13.1	1.6	25.2	7.8	30	199	3931	6.5	15913
5/18/16	4045975	4045975	1081	45.0	9	7.8	13.1	1.6	25.7	7.8	30	195	3890	6.15	15924
5/19/16	4128647	4128647	1104	46.0	9	7.8	13.1	1.6	25.7	7.8	30	193	3802	6.2	14835
5/20/16	4214591	4214591	1128	47.0	9	7.8	13.1	1.6	25.4	7.8	30	195	3834	6.3	14944.5
5/21/16	4301445	4301445	1152	48.0	9	7.8	13.1	1.6	25.2	7.8	30	195	3792.5	6.4	14322
5/22/16	4385725	4385725	1175	49.0	9	7.8	13.1	1.6	25.2	7.8	30	197	3791	6.5	14678
5/23/16	29838	4456858	1195	49.8	9	7.8	13.1	1.6	25.2	7.8	30	182	3883	6.4	13562
5/24/16	105496	4532516	1216	50.7	8	7.8	13.5	1.7	25.2	7.8	30	182	3838	6.5	12019
5/25/16	187453	4614473	1239	51.6	8	7.8	13.6	1.7	25.2	7.8	30	186	3905	6.7	12620
5/26/16	255927	4682947	1258	52.4	8	7.8	13.5	1.7	25.4	7.8	30	187	3847	6.7	12469
5/27/16	329444	4756464	1278	53.3	8	7.8	13.5	1.7	25.4	7.8	30	188	3868	6.5	12561
5/28/16	413335	4840355	1302	54.2	8	7.8	13.5	1.7	25.4	7.8	30	193	4006.5	6.7	12740

Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
4/25/16	141	189	23	9.3	1630	2452	2185	4151	80	0.092881279
4/26/16	151	193	23	9.3	1631	2470	2185	4273	80	0.093398745
4/27/16	156	191	23	9.3	1632	2458	2184	4235	80	0.093965635
4/28/16	168	188	23	9.3	1633	2435	2186	4161	80	0.094664286
4/29/16	176	189	23	9.3	1629	2454	2184	4276	80	0.093700523
4/30/16	172	194	23	9.3	1629	2487	2183	4327	80	0.091335029
5/1/16	168	197	23	9.3	1629	2505	2186	4441	80	0.09073405
5/2/16	168	202	23	9.3	1629	2538	2185	4573	80	0.088623601
5/3/16	175	202	23	9.3	1630	2540	2184	4700.5	80	0.088817234
5/4/16	189	201	23	9.3	1633	2532	2184	4662	80	0.089623868
5/5/16	182.5	199	23	9.3	1635	2509.5	2185	4489.5	80	0.089747314
5/6/16	181	196	23	9.3	1635	2493	2186	4365	80	0.09034874
5/7/16	156.5	198	23	9.3	1632	2507.5	2186	4259.5	80	0.08763162
5/8/16	158	199	23	9.3	1630	2517	2185	4308.5	80	0.087176682
5/9/16	157	197	23	9.3	1629	2508	2185	4241	80	0.086711417
5/10/16	163.5	195	23	9.3	1628	2490	2184	4274.5	80	0.087023075
5/11/16	174	191	23	9.3	1633	2461	2184	4149	80	0.088744518
5/12/16	173	188	23	9.3	1627	2442	2184	4040	80	0.088643805
5/13/16	172	188	23	9.3	1629	2442	2184	4066	80	0.088590362
5/14/16	163	188	23	9.3	1627	2443	2183	4016	80	0.088905179
5/15/16	154	188	23	9.3	1629	2442	2184	3967	80	0.087537938
5/16/16	141	187	23	9.3	1607	2432	2183	3913	80	0.088021631
5/17/16	152	189	23	9.3	1624	2438	2183	3931	80	0.086456344
5/18/16	163.5	186	23	9.3	1625	2425	2184.5	3894.5	80	0.087586611
5/19/16	151	184	23	9.3	1626	2414	2185	3802	80	0.087019572
5/20/16	146	186	23	9.3	1628	2426	2183.5	3846.5	80	0.086539365
5/21/16	145	186	23	9.3	1631	2425.5	2186	3792.5	80	0.086649958
5/22/16	142	188	23	9.3	1634	2439	2186	3791	80	0.086010367
5/23/16	154	174	23	9.3	1618	2332	2187	3887	80	0.100631728
5/24/16	241	174	23	9.3	1615	2330	2186	3838	80	0.099085773
5/25/16	245	177	23	9.3	1617	2359	2186	3905	80	0.097102063
5/26/16	242	178	23	9.3	1618	2368	2188	3873	80	0.094621607
5/27/16	235	182	23	9.3	1618	2378	2186	3868	80	0.092300394
5/28/16	227	185	23	9.3	1617	2414	2185	4006.5	80	0.090920584

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Date	Comments
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5/8/16	
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5/10/16	
5/11/16	
5/12/16	
5/13/16	pulled out negative values of s. flux for daily avg
5/14/16	
5/15/16	
5/16/16	
5/17/16	
5/18/16	
5/19/16	
5/20/16	
5/21/16	
5/22/16	
5/23/16	CIP No heat
5/24/16	
5/25/16	
5/26/16	
5/27/16	
5/28/16	

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
5/29/16	483588	4910608	1321	55.0	8	7.8	13.6	1.7	25.7	7.8	30	198	4185	7	13574.5
5/30/16	556985	4984005	1341	55.9	9	7.8	13.6	1.7	25.4	7.8	30	202	4250	7	13978
5/31/16	632386	5059406	1362	56.8	9	7.8	13.6	1.7	25.9	7.8	30	200	4153.5	7.1	13360.5
6/1/16	708306	5135326	1383	57.6	8	7.7	13.5	1.7	25.9	7.8	30	201	4108	7	12761
6/2/16	794122	5221142	1407	58.6	9	7.8	13.5	1.7	26.4	7.8	30	193	3887	7.2	12333
6/3/16	867872	5294892	1428	59.5	9	7.8	13.5	1.7	26.9	7.8	30	191	3950	6.9	12130
6/4/16	942116	5369136	1448	60.4	8	7.8	13.5	1.7	26.7	7.8	24.5	200	3965.5	7.5	11860
6/5/16	1028675	5455695	1472	61.4	9	7.8	13.6	1.7	26.4	7.8	34.5	206.5	4037	7.7	13191
6/6/16	1091971	5518991	1490	62.1	9	7.8	13.5	1.7	26.7	7.8	30	202	4149	6.7	13288
6/7/16	1156093	5583113	1508	62.8	8	7.8	13.5	1.7	26.4	7.8	34	198	4055	6.8	11150
6/8/16	1232058	5659078	1529	63.7	9	7.8	13.6	1.7	26.4	7.8	30	199	4044.5	6.6	11556.5
6/9/16	1294482	5721502	1546	64.4	9	7.8	13.5	1.7	26.7	7.8	30	197	3968	6.7	10525
6/10/16	1322327	5749347	1554	64.8	4	6	12.9	1.2	24.4	6	35		3714	6.4	1993
6/10/16	1340796	5767816	1559	65.0	8	7.8	13.6	1.7	26.9	7.8	30	191	4088	6.8	17586
6/11/16	1401665	5828685	1576	65.7	8.5	7.8	13.5	1.7	26.4	7.8	30	193	3994.5	6.8	11988
6/12/16	1488151	5915171	1600	66.7	8	7.8	13.5	1.7	26.4	7.8	30	191	3874	6.9	11840
6/13/16	1574395	6001415	1624	67.7	9	7.8	13.5	1.7	26.4	7.8	30	193.5	3904.5	7	11519.5
6/14/16	1660169	6087189	1648	68.7	9	7.8	13.5	1.7	26.7	7.8	30	196	4022	6.6	12546
6/15/16	1746994	6174014	1672	69.7	8.5	7.8	13.6	1.7	26.7	7.8	30	199	4153	6.4	13117
6/16/16	1833727	6260747	1696	70.7	8	7.8	13.5	1.7	26.7	7.8	30	197	4101	6.1	11965
6/17/16	1909587	6336607	1717	71.5	9	7.8	13.5	1.7	26.9	7.8	30	197	4081	6.1	11652
6/18/16	1985307	6412327	1738	72.4	9	7.8	13.5	1.7	26.9	7.8	30	195	3984	6.2	10725
6/19/16	2072201	6499221	1762	73.4	9	7.8	13.5	1.7	27.4	7.8	30	192	3955	6.5	13079
6/20/16	2158397	6585417	1786	74.4	9	7.8	13.5	1.7	27.6	7.8	30	193	3942	6.9	11843
6/21/16	2244510	6671530	1810	75.4	9	7.8	13.5	1.7	27.4	7.8	30	200.5	4188.5	7.05	11580
6/22/16	2330743	6757763	1834	76.4	9	7.8	13.5	1.7	27.6	7.8	30	204	4279	6.8	16452
6/23/16	2417450	6844470	1858	77.4	9	7.8	13.5	1.7	27.6	7.8	30	201	4239	6.8	12225
6/24/16	2503854	6930874	1882	78.4	9	7.9	13.5	1.6	27.4	7.9	30	202	4272	6.8	11378
6/25/16	2590367	7017387	1906	79.4	9	7.8	13.5	1.6	27.4	7.8	30.5	205	8.5	6.8	11995.5
6/26/16	2671809	7098829	1929	80.4	9	7.8	13.5	1.6	27.6	7.8	26	207	4260	6.9	11658
6/27/16	2741872	7168892	1948	81.2	9	7.9	13.1	1.6	28.4	7.9	23	205	4349	7	11760
6/28/16	2817370	7244390	1969	82.1	9	7.9	13.5	1.6	28.1	7.9	37	210	4.5	6.8	11633.5
6/29/16	2902531	7329551	1993	83.0	9	7.7	13.5	1.6	27.9	7.7	32	205	5	6.7	11587
6/30/16	2988422	7415442	2017	84.0	9	7.8	13.5	1.7	27.9	7.8	30	203.5	26	6.7	11680

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Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25°C (gfd/psi)
5/29/16	226	189.5	23	9.3	1625.5	2455	2182	4185	80	0.089897818
5/30/16	232	194	23	9.3	1617	2473	2183	4250	80	0.088358738
5/31/16	209	191	23	9.3	1616.5	2459.5	2184	4153.5	80	0.087882487
6/1/16	222	192	23	9.2	1610	2462	2184	4108	80	0.084852682
6/2/16	209	183	23	9.3	1609	2418	2184	3887	80	0.086645086
6/3/16	213	183	23	9.3	1609	2400	2186	3951	80	0.088273373
6/4/16	207	191	23	9.3	1629	2474	2184.5	3965.5	80	0.082439883
6/5/16	226	199	23	9.3	1633.5	2504.5	2184	4037	80	0.079185258
6/6/16	232	194	23	9.3	1612	2467	2187	4149	80	0.083505479
6/7/16	215	192	23	9.3	1560	2461	2186	4055	80	0.08615152
6/8/16	231	189	23	9.3	1611.5	2452.5	2185	4045	80	0.084898137
6/9/16	216	189	23	9.3	1612	2438	2186	3975	80	0.084532796
6/10/16	61	104	0.1	7.2	1629	1597	3500	3714	80	
6/10/16	237	182	23	9.3	1618	2396	2186	4088	80	0.091315781
6/11/16	210	184	23	9.3	1618	2408.5	2184.5	3994.5	80	0.08963306
6/12/16	194	182	23	9.3	1618	2396	2184	3874	80	0.088270425
6/13/16	181	185	23	9.3	1619	2412.5	2184	3904.5	80	0.087220418
6/14/16	206.5	189	23	9.3	1618.5	2439	2185	4022	80	0.087305132
6/15/16	208	190	23	9.3	1615	2453.5	2184	4153	80	0.086654914
6/16/16	216	188	23	9.3	1612	2432.5	2185	4101	80	0.087599056
6/17/16	214	188	23	9.3	1614	2435	2186	4083	80	0.086132756
6/18/16	184	187	23	9.3	1618	2431	2186	4002	80	0.086176395
6/19/16	188	183	23	9.3	1611	2414	2186	3965	80	0.086971507
6/20/16	164	183.5	23	9.3	1612	2408.5	2185	3984.5	80	0.086425303
6/21/16	189	191.5	23	9.3	1609	2459	2184	4188.5	80	0.083505348
6/22/16	210	193	23	9.3	1588	2467	2184	4279	80	0.084088625
6/23/16	213	193	23	9.3	1613	2458	2184	4239	80	0.084221882
6/24/16	213	193	23	9.4	1605	2467	2184	4272	80	0.084834934
6/25/16	212	195.5	23	9.3	1598	2490	2185	4100	80	0.080882984
6/26/16	194	199	23	9.3	1646	2526	2185	4260	80	0.079839781
6/27/16	223	196	23	9.4	1633	2508	2188	4349	80	0.079806253
6/28/16	240	201	23	9.4	1572	2519.5	2186	4100	80	0.076428759
6/29/16	260	197	23	9.2	1641	2515	2187	4100	80	0.076564494
6/30/16	257	196	23	9.3	1605.5	2483.5	2186	4100	80	0.079942135

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Date	Comments
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6/28/16	System was off this day
6/29/16	
6/30/16	

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
7/1/16	3051089	7478109	2034	84.8	7.5	7.7	13.6	1.7	27.6	7.7	36	207.5	5	6.7	11165.5
7/8/16	3072942	7499962	2040	85.0	6	5.5	1	1.7	28.6	15.8	16		3832	6.6	5928
7/10/16	3090279	7517299	2045	85.2	9	7.9	13.4	1.7	28.9	7.9	30	159	3947.5	6.65	18564
7/11/16	3150652	7577672	2062	85.9	9	7.9	13.4	1.7	28.1	7.9	30	157	4039	6.8	18252
7/12/16	3237434	7664454	2086	86.9	9	7.9	13.5	1.7	28.1	7.9	30	158	3449.5	6.8	18353.5
7/13/16	3321212	7748232	2109	87.9	9	7.8	13.5	1.7	28.1	7.8	30	183	3	6.8	19820
7/14/16	3404387	7831407	2132	88.9	9	7.8	13.6	1.7	28.1	7.8	30	191	4	6.8	15164
7/15/16	3488427	7915447	2156	89.8	9	7.8	13.6	1.7	28.1	7.8	30	193	4051.5	6.7	15811.5
7/16/16	3574408	8001428	2180	90.8	9	7.8	13.6	1.7	28.4	7.8	30	196	4227	6.7	18510
7/17/16	3661090	8088110	2204	91.8	9	7.8	13.6	1.7	28.4	7.8	30	196	4153	6.7	17534
7/18/16	3721731	8148751	2221	92.5	9	7.8	13.6	1.7	27.9	7.8	30	198	4124.5	6.8	18264
7/26/16	19408	8186603	2231	93.0	9	7.8	13.1	1.6	29.8	7.8	30	214	5000	5	27544
7/27/16	53728	8220923	2241	93.4	9	7.8	13.1	1.6	28.9	7.8	30	226.5	5000	6.05	20802.5
7/28/16	94627	8261822	2252	93.8	9	7.75	13.1	1.6	29.7	7.75	30	224	5000	6.25	499
7/29/16	162845	8330040	2271	94.6	9	7.8	13.1	1.6	29.1	7.8	30	225	5000	6.1	598
7/30/16	248785	8415980	2295	95.6	9	7.8	13.1	1.6	29.3	7.8	30	228	5000	6	471
7/31/16	335287	8502482	2319	96.6	9	7.7	13.1	1.6	29.3	7.7	30	228	5000	6.1	385
8/1/16	422186	8589381	2343	97.6	9	7.7	13.1	1.6	29.3	7.7	30	231	5000	6.2	422
8/2/16	507678	8674873	2367	98.6	9	7.8	13.1	1.6	29.3	7.8	30	231	5000	6	246
8/3/16	593023	8760218	2390	99.6	9	7.8	13.1	1.6	29.3	7.8	30	231	5000	6	339
8/4/16	679589	8846784	2414	100.6	9	7.8	13.1	1.6	29.3	7.8	25	221	4970	6.4	24574
8/5/16	753115	8920310	2435	101.5	9	7.8	13.1	1.6	29.3	7.8	25	219	4962	6.3	1519
8/6/16	826331	8993526	2455	102.3	9	7.8	13.1	1.6	29.3	7.8	25	225	4833	6.2	382
8/7/16	912845	9080040	2479	103.3	9	7.8	13.1	1.6	29.1	7.8	25	226	4796	6.4	234
8/8/16	976449	9143644	2497	104.0	8	7.8	13.1	1.6	29.1	7.8	24	226.5	4784	6.6	282
8/8/16	1020235	9187430	2509	104.5	8.5	7.8	13.1	1.6	29.6	7.8	20	216.5	4888	6.3	24691
8/9/16	1076188	9243383	2525	105.2	8	7.8	13.1	1.6	28.9	7.8	20	218	4818.5	6.1	19365
8/10/16	1151184	9318379	2545	106.1	9	7.8	13.2	1.6	29.1	7.8	20	221	3520	6.1	1226
8/11/16	1227815	9395010	2567	106.9	9	7.8	13.2	1.6	29.3	7.8	20	217	3792	6.15	628.5
8/12/16	1304235	9471430	2588	107.8	9	7.8	13.2	1.6	29.3	7.8	20	218	3333	6.4	588
8/13/16	1377383	9544578	2608	108.7	9	7.8	13.6	1.6	29.6	7.8	20	218	3526	6.6	595
8/14/16	1423771	9590966	2621	109.2	9	7.8	13.6	1.6	30.1	7.8	20	216	4590.5	6.55	369.5
8/15/16	1451574	9618769	2629	109.5	9	7.8	13.6	1.6	30.7	7.8	20	215	4770	6.6	510
8/16/16	1480652	9647847	2637	109.9	9	7.8	13.2	1.6	30.1	7.8	20	228	5084.5	6.5	605.5

Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
7/1/16	252	199	23	9.2	1483.5	2488.5	2186	4100	80	0.076942044
7/8/16	73	57	12.5	6.6	1500	1500	3500	3836	80	
7/10/16	218.5	151	23	9.4	1617	2153.5	2123.5	4100	80	0.131754291
7/11/16	190	149	23	9.4	1616	2136	2120	4095	80	0.136758761
7/12/16	193	149	23	9.4	1612	2143.5	2117	4100	80	0.136659614
7/13/16	234	175	23	9.3	1612	2340	2117	4100	80	0.094323298
7/14/16	231.5	183	23	9.3	1612	2402	2119	4100	80	0.088776984
7/15/16	247	184	23	9.3	1612	2413.5	2119	4100	80	0.087612553
7/16/16	233	187	23	9.3	1610	2434	2119	4227	80	0.086054769
7/17/16	249	186	23	9.3	1611	2429	2118	4153	80	0.085591007
7/18/16	218	189	23	9.3	1613	2446	2119.5	4124.5	80	0.084640718
7/26/16	542	204	23	9.3	1612	2560	2124	5000	80	0.082750416
7/27/16	355	218	23	9.3	1611.5	2650.5	2117	5500	80	0.082648027
7/28/16	383.5	215	23	9.25	1611	2626	2121	5500	80	0.083427611
7/29/16	361.5	217	23	9.3	1611	2639	2117	5500	80	0.083064205
7/30/16	361	219	23	9.3	1610	2657	2115	5500	80	0.080771204
7/31/16	344	219	23	9.2	1609	2655	2115	5500	80	0.080925548
8/1/16	326	222	23	9.2	1611	2674	2115	5500	80	0.078182209
8/2/16	341	222	23	9.3	1614	2673	2116	5500	80	0.078573189
8/3/16	336	222	23	9.3	1618	2668	2116	5500	80	0.079238871
8/4/16	325	213	23	9.3	1491	2623	2115	5500	80	0.087442567
8/5/16	338	211	23	9.3	1490	2629	2116	5500	80	0.088400657
8/6/16	333	216	23	9.3	1489	2668	2115	5500	80	0.083066738
8/7/16	306	217	23	9.3	1464	2666	2115	5500	80	0.084137872
8/8/16	267	218	23	9.3	1487.5	2672	2115	5500	80	0.081887773
8/8/16	287	208	23	9.3	1354	2644	2115	5500	80	0.091669812
8/9/16	314	210	23	9.3	1356	2653	2115	5500	80	0.090751785
8/10/16	275	212	23	9.3	1357	2671	2115	5500	80	0.088092265
8/11/16	285	208.5	23	9.3	1357	2650	2115	5500	80	0.090705967
8/12/16	278	210	23	9.3	1357	2657	2115	5500	80	0.089660403
8/13/16	276	210	23	9.3	1355	2655	2115	5500	80	0.089169565
8/14/16	271.5	207	23	9.3	1352.5	2637.5	2117	5500	80	0.090357012
8/15/16	273.5	205.5	23	9.3	1354	2628	2120	5500	80	0.090812483
8/16/16	304	219	23	9.3	1354	2716	2119	5500	80	0.080796158

Date	Comments
7/1/16	
7/8/16	negative value
7/10/16	
7/11/16	
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7/14/16	
7/15/16	96% run started, all EC feed data not valid, using 5500 for conduc
7/16/16	
7/17/16	
7/18/16	
7/26/16	CIP off site
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7/30/16	
7/31/16	
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8/15/16	
8/16/16	

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
8/17/16	1527282	9694477	2650	110.4	9	7.8	13.2	1.6	30.1	7.8	20	227	5140	6.2	607
8/18/16	1599348	9766543	2670	111.2	9	7.8	13.2	1.6	29.3	7.8	20	232	5270	6.4	595
8/19/16	1685610	9852805	2694	112.2	9	7.8	13.2	1.6	29.3	7.8	20	233	5297	6.4	592
8/20/16	1772505	9939700	2718	113.3	9	7.8	13.2	1.6	29.3	7.8	20	237	5435	6.4	595
8/21/16	1858929	10026124	2742	114.3	9	7.8	13.2	1.6	29.3	7.8	20	237	5415	6.5	369.5
8/22/16	1945082	10112277	2766	115.2	9	7.8	13.2	1.6	29.3	7.8	20	236	5292	6.5	598
8/23/16	2031146	10198341	2790	116.2	8	7.8	13.2	1.6	29.3	7.8	20	234	5212	6.4	592
8/24/16	2106225	10273420	2811	117.1	8	7.8	13.2	1.6	29.3	7.8	20	230	5070	6.1	582
8/25/16	2180543	10347738	2831	118.0	8	7.8	13.2	1.6	29.3	7.8	20	231	5109	6.1	588
8/26/16	2267210	10434405	2855	119.0	8	7.8	13.2	1.6	29.1	7.8	20	229	4980.5	6.05	592
8/27/16	2353905	10521100	2880	120.0	8	7.8	13.2	1.6	29.1	7.8	20	228	4879	5.9	588
8/28/16	2440219	10607414	2904	121.0	8	7.8	13.2	1.6	29.3	7.8	20	229	4898	6.1	373
8/29/16	2526333	10693528	2927	122.0	8	7.8	13.2	1.6	29.6	7.8	20	225.5	4807.5	6.3	370
8/30/16	2602175	10769370	2949	122.9	8	7.8	13.6	1.6	29.8	7.8	20	224	4845	6.1	364
8/31/16	2667839	10835034	2967	123.6	9	7.8	13.6	1.6	29.8	7.8	20	218	3793	5.8	463.5
9/1/16	2744171	10911366	2988	124.5	9	7.8	13.6	1.6	29.3	7.8	20	223	3957	6	336
9/2/16	2830392	10997587	3012	125.5	8	7.8	13.6	1.6	29.3	7.8	20	226	4213	6.5	287
9/3/16	2886223	11053418	3027	126.1	8	7.8	13.7	1.6	29.1	7.8	20.5	225.5	4381	6.5	593.5
9/4/16	2914190	11081385	3035	126.5	9	7.7	13.6	1.6	29.1	7.7	20	219	3409	6.4	397
9/5/16	2954540	11121735	3046	126.9	9	7.8	13.1	1.6	29.1	7.8	20	222.5	3615	6.5	303.5
9/6/16	3020447	11187642	3065	127.7	8	7.8	13.6	1.6	29.1	7.8	20	221	3675	6.7	259
9/7/16	3088625	11255820	3084	128.5	8	7.8	13.6	1.6	28.9	7.8	20	218	3501	6.65	383.5
9/8/16	3144477	11311672	3099	129.1	8	7.8	13.6	1.6	29.1	7.8	20	217	3408	6.4	391
9/9/16	3215827	11383022	3119	130.0	8	7.8	13.6	1.6	29.1	7.8	20	215	2634	6.2	305
9/10/16	3303263	11470458	3143	131.0	8	7.8	13.6	1.6	29.1	7.8	20	219	2632.5	6.2	209.5
9/11/16	3388474	11555669	3167	132.0	8	7.8	13.6	1.6	29.1	7.8	20	218	3604	6.4	345
9/12/16	3475109	11642304	3191	133.0	8	7.8	13.6	1.6	29.1	7.8	20	219	1972	6.6	176
9/13/16	3559202	11726397	3214	133.9	8	7.8	13.6	1.6	28.6	7.8	20	222	1934	6.5	225
9/14/16	3638626	11805821	3236	134.9	8	7.8	13.6	1.6	28.4	7.8	20	219	3059	6.2	259
9/15/16	3721476	11888671	3259	135.8	8	7.8	13.6	1.6	28.4	7.8	20	220	3521	6.3	169
9/16/16	3794032	11961227	3280	136.6	8	7.8	13.6	1.6	27.9	7.8	20	221	2976.5	6.4	291.5
9/18/16	3849351	12016546	3295	137.3	9	7.8	13.7	1.6	29.3	7.8	20	233	4557	5.25	228
9/19/16	3919028	12086223	3314	138.1	8	7.8	13.2	1.6	29.1	7.8	20	235	3934	6.3	111
9/20/16	4005512	12172707	3338	139.1	8	7.8	13.6	1.6	29.1	7.8	20	232	4862	6.5	142

Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
8/17/16	340.5	218	23	9.3	1354	2709	2120	5500	80	0.080184125
8/18/16	309.5	224	23	9.3	1355	2748.5	2116	5500	80	0.077266821
8/19/16	308	224	23	9.3	1355	2751	2115	5500	80	0.077001339
8/20/16	313	229	23	9.3	1354	2777	2114	5500	80	0.074160004
8/21/16	300.5	229	23	9.3	1354	2778	2114	5500	80	0.074183702
8/22/16	283	227	23	9.3	1354.5	2770	2114	5500	80	0.074878313
8/23/16	294.5	226	23	9.3	1356	2759	2114	5500	80	0.076515045
8/24/16	310	222	23	9.3	1357	2732	2115	5500	80	0.079608603
8/25/16	300	223	23	9.3	1357	2741	2115	5500	80	0.078361092
8/26/16	272	221	23	9.3	1357	2727.5	2115	5500	80	0.080278445
8/27/16	247.5	220	23	9.3	1358	2721	2116	5500	80	0.081011233
8/28/16	228	221	23	9.3	1357	2728	2115	5500	80	0.080058669
8/29/16	238	218	23	9.3	1357	2704	2115	5500	80	0.083034318
8/30/16	257	215	23	9.3	1356	2695	2116	5500	80	0.082659195
8/31/16	257	210	23	9.3	1356	2650.5	2118.5	5500	80	0.088748942
9/1/16	235	215	23	9.3	1357	2688	2117	5500	80	0.084562932
9/2/16	254.5	218	23	9.3	1356	2702	2117	5500	80	0.082842612
9/3/16	259.5	218	23	9.3	1357.5	2708	2116	5500	80	0.083944649
9/4/16	267.5	211	23	9.2	1357	2670	2123	5500	80	0.088903626
9/5/16	284.5	213.5	23	9.3	1357.5	2685	2123	5500	80	0.08676534
9/6/16	243.5	212.5	23	9.3	1357	2672.5	2121	5500	80	0.08821542
9/7/16	208	211	23	9.3	1359	2664	2121	5500	80	0.090455334
9/8/16	304	209	23	9.3	1358	2653	2124	5500	80	0.090296579
9/9/16	293	207	23	9.3	1358	2639	2122	5500	80	0.092305057
9/10/16	165	210.5	23	9.3	1358	2660	2120.5	5500	80	0.089326792
9/11/16	282	210	23	9.3	1357	2650	2120	5500	80	0.090296579
9/12/16	333	210	23	9.3	1358	2659	2119	5500	80	0.089357939
9/13/16	304	213	23	9.3	1360	2678	2120	5500	80	0.087640241
9/14/16	298	211	23	9.3	1358	2657	2121	5500	80	0.090656397
9/15/16	289.5	211	23	9.3	1360	2668	2121	5500	80	0.089951126
9/16/16	263	213	23	9.3	1360	2678	2121	5500	80	0.090620442
9/18/16	319	225	23	9.3	1354.5	2750.5	2125	5500	80	0.076481384
9/19/16	272	227	23	9.3	1354	2761.5	2119	5500	80	0.076260743
9/20/16	379	224	23	9.3	1357	2747	2118	5500	80	0.078361092

Date	Comments
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Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
9/21/16	4091337	12258532	3362	140.1	8	7.8	13.6	1.6	29.3	7.8	20	229	3879.5	6.1	97.5
9/22/16	4177830	12345025	3386	141.1	8	7.7	13.2	1.6	28.9	7.7	20	239	2752	6.1	120
9/23/16	4263912	12431107	3410	142.1	8	7.8	13.7	1.6	28.6	7.8	20	236	4765	6.1	99
9/24/16	4350275	12517470	3434	143.1	8.5	7.8	13.2	1.6	28.4	7.8	20	244	1528	6	177.5
9/25/16	4436858	12604053	3458	144.1	8	7.8	13.2	1.6	28.5	7.8	20	249	686	6.3	265
9/26/16	4522334	12689529	3482	145.1	9	7.8	13.2	1.6	29.1	7.8	17	240	1165	6.5	625
9/27/16	4608485	12775680	3506	146.1	9	7.8	13.2	1.6	29.1	7.8	17	238	5125.5	6.5	2047
9/28/16	4694805	12862000	3530	147.1	9	7.8	13.2	1.6	28.9	7.8	17	239	5157	6.4	585
9/29/16	4765288	12932483	3549	147.9	8	7.8	13.7	1.6	28.6	7.8	17	240	89	6.5	582
9/30/16	4822341	12989536	3565	148.6	9	7.8	13.2	1.6	29.3	7.8	17	240	24	6.4	299
10/1/16	4893659	13060854	3585	149.4	8	7.8	13.2	1.6	28.6	7.8	17	242	127	6.5	573
10/2/16	4979439	13146634	3609	150.4	8	7.8	13.2	1.6	28.4	7.8	17	241	7.5	6.6	462
10/3/16	19966	13210263	3627	151.1	8	7.8	13.2	1.6	27.9	7.8	17	243	8	6.7	585
10/4/16	72347	13262644	3641	151.7	8	7.8	19.2	1.7	28.1	7.8	17	265	5235	5.5	13473
10/5/16	141515	13331812	3660	152.5	8	7.8	19.2	1.7	27.9	7.8	17	270	5192	5.7	746
10/6/16	228791	13419088	3685	153.5	8	7.8	19.2	1.7	27.9	7.8	17	268	5002	5.65	337.5
10/7/16	314279	13504576	3708	154.5	8	7.8	19.2	1.7	27.9	7.8	17	271	4762	5.9	280
10/8/16	400331	13590628	3732	155.5	8	7.8	19.2	1.7	27.6	7.8	17	274.5	5234.5	6.1	174
10/9/16	486608	13676905	3756	156.5	8	7.8	19.2	1.7	27.9	7.8	17	275	5170	6.2	373
10/10/16	572662	13762959	3780	157.5	8	7.8	19.2	1.7	27.9	7.8	17	274	5092	6.3	414.5
10/11/16	657420	13847717	3804	158.5	8	7.8	19.2	1.6	27.9	7.8	17	281	5207	6.4	339
10/12/16	739089	13929386	3826	159.4	8	7.8	19.2	1.7	27.6	7.8	17	275	5086	6.1	311
10/13/16	823964	14014261	3850	160.4	8	7.8	19.2	1.7	27.6	7.8	17	275	4950	6.1	243
10/14/16	910679	14100976	3874	161.4	8	7.8	19.2	1.7	27.6	7.8	17	274	4963	6.2	323
10/15/16	996743	14187040	3898	162.4	8	7.8	19.2	1.7	27.6	7.8	17	277	5117.5	6.2	285
10/16/16	1083417	14273714	3922	163.4	8	7.8	19.2	1.6	27.9	7.8	17	286	5142.5	6.5	303.5
10/17/16	1154210	14344507	3942	164.2	8	7.8	19.3	1.6	27.9	7.8	17	293	5414.5	6.5	599.5
10/18/16	1225966	14416263	3962	165.1	8	7.8	19.3	1.6	27.6	7.8	17	289	5474.5	6.5	291.5
10/19/16	1312280	14502577	3986	166.1	8	7.8	19.3	1.6	27.4	7.8	17	288	5179	6.4	305
10/20/16	1398493	14588790	4009	167.1	8	7.8	19.2	1.7	27.4	7.8	17	286	5024.5	6.25	429.5
10/21/16	1465869	14656166	4028	167.8	8	7.8	19.3	1.6	27.1	7.8	17	296	8	6.3	582
10/22/16	1515288	14705585	4042	168.4	8	7.8	19.3	1.6	27.75	7.8	17	302	4	3.2	359
10/23/16	1583198	14773495	4061	169.2	8	7.8	19.3	1.6	27.1	7.8	17	310.5	8	3.4	188
10/24/16	1660960	14851257	4082	170.1	8	7.8	19.3	1.6	27.1	7.8	17	310	1124	6.2	194

Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
9/21/16	333.5	221	23	9.3	1358	2729.5	2119	5500	80	0.079968486
9/22/16	300	230	23	9.2	1358	2790	2118	5500	80	0.073884224
9/23/16	302.5	227	23	9.3	1356	2767	2121	5500	80	0.076886355
9/24/16	262.5	235	23	9.3	1357.5	2816.5	2120	5500	80	0.071373466
9/25/16	275	241	23	9.3	1352.5	2852	2119	5500	80	0.067754506
9/26/16	293.5	231	23	9.3	1270	2807.5	2119	5500	80	0.072857985
9/27/16	322	229	23	9.3	1269	2799	2119	5500	80	0.074105452
9/28/16	284.5	230	23	9.3	1270	2808	2123	5500	80	0.074109894
9/29/16	277	231	23	9.3	1271	2814	2120	5500	80	0.073868843
9/30/16	0	230	23	9.3	1269	2808	2123	5500	80	0.072885109
10/1/16	272.5	233	23	9.3	1270	2829	2120	5500	80	0.07267473
10/2/16	283	233	23	9.3	1271	2823	2120	5500	80	0.072742914
10/3/16	0	235	23	9.3	1273	2834	2122	5500	80	0.072772969
10/4/16	513	257	23	9.3	1270	2970	2117	5500	85	0.086410368
10/5/16	488	262	23	9.3	1270	2996	2113	5500	85	0.083026035
10/6/16	473	260	23	9.3	1270	2985	2113	5500	85	0.083460319
10/7/16	465	263	23	9.3	1270	3006	2113	5500	85	0.082594529
10/8/16	466	267	23	9.3	1269	3027	2113	5500	85	0.079346714
10/9/16	434	267	23	9.3	1271	3026	2118	5500	85	0.079736393
10/10/16	420	266	23	9.3	1270	3024	2115	5500	85	0.080035857
10/11/16	437	273	23	9.3	1270	3062	2114	5500	85	0.075201163
10/12/16	450.5	267	23	9.3	1270.5	3029	2115	5500	85	0.079595836
10/13/16	428	268	23	9.3	1271	3033	2115	5500	85	0.079493755
10/14/16	420	266	23	9.3	1270	3024	2115	5500	85	0.080333381
10/15/16	418	269	23	9.3	1270	3038.5	2116	5500	85	0.078094854
10/16/16	396	278	23	9.3	1270	3090	2116	5500	85	0.071311034
10/17/16	435	285	23	9.3	1270	3131.5	2118.5	5500	85	0.06791301
10/18/16	397	281	23	9.3	1270	3109.5	2118	5500	85	0.070003705
10/19/16	399	280	23	9.3	1270	3100	2120	5500	85	0.070259807
10/20/16	412	279	23	9.3	1269	3095.5	2122	5500	85	0.071805939
10/21/16	413	287	23	9.3	1271	3146	2122	5500	85	0.067333771
10/22/16	464	293.5	23	9.3	1267	3176	2125	5500	85	0.0630854
10/23/16	395	303	23	9.3	1269	3227	2121	5500	85	0.060715953
10/24/16	385.5	302.5	23	9.3	1269	3224	2120	5500	85	0.060508372

Date	Comments
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9/28/16	
9/29/16	
9/30/16	
10/1/16	
10/2/16	
10/3/16	
10/4/16	CIP no heat
10/5/16	
10/6/16	
10/7/16	
10/8/16	
10/9/16	
10/10/16	
10/11/16	
10/12/16	
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10/23/16	
10/24/16	

Date	Runtime	Runtime total (Sec)	Runtime corrected (Hrs)	Runtime Corrected (Days)	Differential Pressure (psi)	Permeate Flow Rate (gpm)	CCD Cycle Length (min)	PFD Cycle Length (min)	Temp. (˚C)	Feed Flow Rate (gpm)	Inlet Pressure (psi)	Membrane Feed Pressure (psi)	Electrical Conductivity Feed µS/cm	Feed pH	Electrical Conductivity Concentrate µS/cm
10/25/16	1705253	14895550	4095	170.6	7	7.8	19.3	1.6	27.1	7.8	17	305	5068	3.1	598
10/26/16	1743489	14933786	4105	171.1	8	7.8	19.25	1.6	27.6	7.8	17	292.5	5147.5	2.8	23912.5
10/27/16	1805539	14995836	4123	171.8	8	7.8	19.3	1.6	27.1	7.8	17	293	5183	2.6	593.5
10/28/16	1866020	15056317	4139	172.5	8	7.8	19.3	1.6	27.1	7.8	17	291	5086.5	2.8	592
10/29/16	1945020	15135317	4161	173.4	8	7.8	22.9	1.5	27.6	7.8	17	284	4860	3.2	2305
10/30/16	2030423	15220720	4185	174.4	8	7.9	22.9	1.5	27.4	7.9	17	295.5	4965.5	3.1	456
10/31/16	2116904	15307201	4209	175.4	8	7.8	23	1.5	27.1	7.8	17	302	4961	3	77
11/1/16	2203578	15393875	4233	176.4	8	7.85	23	1.5	26.9	7.85	17	310.5	197	2.8	142
11/2/16	2289246	15479543	4257	177.4	8	7.9	23	1.5	26.7	7.9	17	317	235	3.1	194
11/3/16	2375929	15566226	4281	178.4	7	7.8	23	1.5	26.7	7.8	17	322	14	3.1	176
11/4/16	2462698	15652995	4305	179.4	7	7.8	23	1.5	26.7	7.8	17	321	7	2.8	145
11/5/16	2549432	15739729	4329	180.4	7	7.9	23	1.5	26.7	7.9	18	329	7	3.5	10475
11/6/16	2639354	15829651	4354	181.4	7	7.9	23	1.5	26.4	7.9	20	336	7	3.5	10475
11/7/16	2726769	15917066	4378	182.4	7	7.9	23	1.5	26.4	7.9	22	344	7	3.5	10475
11/8/16	2812182	16002479	4402	183.4	8	7.9	23	1.5	26.7	7.9	23	349	1501	3.5	10475
11/9/16	2893815	16084112	4425	184.4	8	7.5	22.3	1.4	26.7	7.5	28	357	14	3.5	10475
11/10/16	2952653	16142950	4441	185.0	7	7.2	22.3	1.4	26.2	7.2	30	363	4709	3.5	10475
11/11/16	2986701	16176998	4451	185.4	7	7.25	22.3	1.4	26.7	7.25	30	359	7	3.5	10475
11/12/16	3046101	16236398	4467	186.1	6.5	7.05	22.6	1.4	26.4	7.05	34	364	5.5	3.5	10475
11/13/16	3130944	16321241	4491	187.1	10	6.6	22.9	1.4	26.4	6.6	38	365	6	3.5	10475
11/14/16	3195099	16385396	4509	187.9	7	6.3	23.6	1.4	25.9	6.3	41	374	7	3.5	10475

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Date	Electrical Conductivity Permeate µS/cm	Concentrate Pressure (psi)	Concentrate Flow Rate (gpm)	Membrane Flux (gfd)	Pump 1 Speed (rpm)	Pump 2 Speed (rpm)	Pump 3 Speed (rpm)	Corrected Electrical Conductivity Feed (µS/cm	Recovery Setpoint (%)	Specific Flux at 25˚C (gfd/psi)
10/25/16	417	296	23	9.3	1270	3195	2126	5500	85	0.062769685
10/26/16	401	284	23	9.3	1268	3126.5	2126	5500	85	0.068725359
10/27/16	415	285	23	9.3	1269	3131.5	2122.5	5500	85	0.069129688
10/28/16	401	283	23	9.3	1271	3117	2125	5500	85	0.069842377
10/29/16	577	276	23	9.3	1269	3083	2119	5500	85	0.073710436
10/30/16	527	287	23	9.4	1270	3142.5	2115.5	5500	85	0.067750516
10/31/16	489	294	23	9.3	1270	3185	2114	5500	85	0.064724101
11/1/16	508	303	23	9.35	1270	3227.5	2114	5500	85	0.061261892
11/2/16	487	310	23	9.4	1272	3269	2114	5500	85	0.059380236
11/3/16	485	314	23	9.3	1271	3290	2114	5500	85	0.057487009
11/4/16	461	314	23	9.3	1271	3283	2114	5500	85	0.057911159
11/5/16	468	322	23	9.4	1307	3323	2114	5500	85	0.055263029
11/6/16	442	328	23	9.4	1351	3349	2113	5500	85	0.053687656
11/7/16	412	337	23	9.4	1403	3376	2113	5500	85	0.050516664
11/8/16	435	342	23	9.4	1467	3411	2113	5500	85	0.048777796
11/9/16	481	350	23	9	1495	3500	2112	5500	85	0.044907475
11/10/16	463	352	23	8.6	1562	3500	2109	5500	85	0.042952067
11/11/16	542	352	23	8.65	1622	3500	2114.5	5500	85	0.042840396
11/12/16	486.5	357.5	23	8.45	1688	3500	2112	5500	85	0.040806998
11/13/16	542	361	23	7.9	1861.5	3500	2105	5500	85	0.037605767
11/14/16	579.5	366	23	7.5	1934	3500	2102	5500	85	0.035735383

Date	Comments
10/25/16	
10/26/16	
10/27/16	
10/28/16	CIP no heat
10/29/16	
10/30/16	
10/31/16	
11/1/16	
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11/3/16	
11/4/16	
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Appendix B – cRRO Daily Operating Parameters

Date	Time	RRO Feed Flow (gpm)	RRO Feed pH	Pre-Feed Pump Pressure PI-401 (psi)	Feed Pressure (psi)	Conc. Pressure PI407 (psi)	Feed Pump P401 (Amps)	Conc. Flow, FIT-403 (gpm)	Permeate Flow, FIT-401 (gpm)	Interstage Flow, FIT-402 (gpm)	Pre-Boost Pressure, PI-405 (psi)	Post-Boost Pressure, PI-406 (psi)	Interstage Booster Pump P402 (Amps)
1/10/17	10:40	14.1		46	135	160	48.9	3.49	10.7	8.8	127	170	32.1
1/10/17	15:00	14.4	6.79	46	135	160	50.06	3.62	10.7	6.9	130	170	32.41
1/11/17	8:30	14.2	6.47	45	135	160	48.88	3.59	10.7	7	127	170	32.54
1/11/17	14:40	14.3	6.5	45	138	160	49.1	3.6	10.7	6.8	126	170	32.4
1/12/17	9:11	14.3	6.6	50	140	160	49	3.6	10.8	6.9	130	170	32.5
1/12/17	15:30	14.3	6.4	46	140	160	49.2	3.6	10.6	6.7	130	170	32.3
1/13/17	8:45	14.3	6.76	50	140	160	49.8	3.6	10.7	6.9	130	170	32.6
1/13/17	15:29	14.3	6.47	47	135	155	47.9	3.5	10.6	6.8	125	165	32.1
1/14/17	8:32	14.4	6.51	50	138	160	48.5	3.6	10.7	6.9	130	175	32.1
1/14/17	15:25	14.3	6.77	45	140	155	44.1	3.6	10.7	6.9	125	170	32.4
1/15/17	8:25	14.4	6.49	50	140	165	50.8	3.6	10.7	6.6	135	175	32.4
1/15/17	15:26	14.3	6.8	48	140	165	49.6	3.6	10.7	6.7	130	180	32.2
1/16/17	8:30	14.5	6.9	49	145	165	51..0	3.6	10.9	6.9	130	179	32.4
1/16/17	15:28	14.3	6.88	46	140	165	50.36	3.6	10.8	6.8	130	175	32.35
1/17/17	8:05	14.4	6.7	49	146	160	50.3	3.7	10.8	6.9	132	175	32.3
1/17/17	15:20	14.4	6.71	46	140	160	49.5	3.6	10.6	6.9	130	165	32.4
1/18/17	8:21	14.4	6.6	50	140	165	49.7	3.6	10.8	6.9	133	180	32.4
1/18/17	15:30	14.3	6.6	50	140	165	49.4	3.6	10.8	6.7	130	175	32.3
1/19/17	8:45	14.2	6.4	50	145	162	49.9	3.6	10.7	6.9	130	180	32.1
1/19/17	15:30	14.4	6.5	48	140	160	48.7	3.6	10.7	6.8	130	175	32.3
1/20/17	8:30	14.4	6.6	51	140	165	49.16	3.6	10.7	6.8	130	175	32.4
1/20/17	16:30	14.4	6.6	52	145	160	49.5	3.7	10.7	6.8	125	175	32.5
1/21/17	8:39	14.4	6.54	54	140	160	48.59	3.7	10.8	6.9	130	170	32.6
1/21/17	15:13	14.4	6.6	54	145	160	48.85	3.7	10.7	6.8	135	175	32.31
1/22/17	8:21	14.5	6.86	55	150	170	50.47	3.7	10.6	7	140	180	32.43
1/22/17	15:24	14.4	6.74	55	155	170	50.04	3.8	10.7	6.8	140	180	32.33
1/23/17	8:30	14.6	6.97	55	150	170	50.85	3.81	10.75	6.94	140	180	32.3
1/23/17	15:30	14.5	6.38	54	150	170	49.92	3.81	10.6	6.9	135	180	32.34
1/24/17	8:15	14.6	6.46	55	152	172	51.16	3.83	10.61	6.85	140	185	32.46
1/24/17	15:30	14.5	6.51	55	150	175	50.08	3.83	10.76	6.82	138	182	32.31
1/25/17	8:30	14.6	6.49	57	150	180	51.37	3.89	10.7	6.8	140	190	32.33
1/26/17	16:00	14.5	6.5	52	150	175	51.1	3.8	10.8	6.8	140	185	32.3
1/27/17	9:15	14.5	6.45	55	150	180	51.18	3.9	10.6	6.5	140	190	32.41
1/26/17	15:25	14.6	6.46	55	152	180	50.9	3.8	10.6	6.8	143	190	32.3
1/27/17	8:20	14.6	6.2	56	155	180	51	3.9	10.7	6.8	140	195	32.4
1/27/17	14:00	14.5	6.2	55	145	175	51.06	3.8	10.7	6.8	140	190	32.36
1/28/17	8:29	14.5	6.56	52	155	180	52.4	3.9	10.8	6.7	145	195	32.34

Date	S2 Perm Pressure, PI-404 (psi)	S1 Perm Pressure, PI-403 (psi)	Feed Cond, AE-401 (uS/cm)	Feed Temp (˚C)	Conc. Cond. AE-404 (mS/cm)	Conc. Temp. (˚C)	S1 Perm Cond. AE-402 (uS/cm)	S1 Perm Temp. (˚C)	S2 Perm Cond. AE-403 (uS/cm)	S2 Perm Temp. (˚C)	Power (kWh)
1/10/17	0	2	5880	23.4	18.98	22.4	66.13	21.4	101.6	22.7	391.9
1/10/17	0	2	5985	23.3	19.09	22.2	65.13	20.3	95.15	20.9	402.2
1/11/17	0	1.5	5848	23	19.24	21.9	66.27	19.6	102	19.1	429.7
1/11/17	1	2	5850	23	19.2	21.7	62.7	19.6	101.4	19	441.6
1/12/17	1	2	5830	22.6	19.4	21.4	66	19.1	99.8	18.3	477.8
1/12/17	1	2	5918	22.3	19.5	20.8	66.6	18.3	99.7	17.6	489.8
1/13/17	1	2	5816	22.1	19.4	21	65.38	18.1	101.5	17.6	523.3
1/13/17	1	2	5493	22.7	18.8	21.5	60.7	19.4	81.3	19	535.8
1/14/17	1	3	5559	21.7	19	20.6	60.8	18	95.8	17	567.7
1/14/17	0.5	2	5666	22.9	19.2	22.2	60.8	21.4	106.8	21.6	580.8
1/15/17	1	3	5930	21.5	20	20.2	64.5	17.6	116.1	16.9	614.5
1/15/17	0.5	2	5993	22.3	20.1	21.2	64.7	19.6	103.9	19.6	628.2
1/16/17	1	3	6065	22.1	20.3	21.1	67.6	18.8	112.4	18.4	662.4
1/16/17	0	2	6096	23.3	20.4	22.5	66.1	21.4	100.3	22.2	675.7
1/17/17	1	1.5	6124	21.3	20.5	20	67.7	16.5	112.14	15.3	705.1
1/17/17	1	2	6082	23	20.4	22.2	67.5	20.9	84.8	21.1	718.9
1/18/17	2	4	6162	21.4	20.7	20.2	74.2	17.1	109.6	16	743.2
1/18/17	1	3	6138	22.8	20.5	21.8	71.7	20.1	100	20.2	755.4
1/19/17	1	2	6162	21.4	20.6	19.6	73.5	17.6	117.89	17.1	779.3
1/19/17	1	3	6075	22.6	20.4	21.5	71.7	19.4	94.8	19.9	788.5
1/20/17	1	2	5856	21.1	19.7	19.5	67.78	17	135.3	16.5	811.5
1/20/17	1	2	5822	21	19.3	19.7	60.1	17.3	86.6	16.9	822
1/21/17	1	2	5573	20.4	18.6	19.2	55.7	17.2	81.9	16.7	844.9
1/21/17	0.5	2	5686	21	18.8	20.2	52.8	19.1	70.1	18.8	857
1/22/17	1	3	6180	20.5	20.1	19.4	61.4	17.1	89.8	16.3	886.1
1/22/17	1	3	6334	20.8	20.4	19.6	64.3	17.9	92.7	17.6	900.3
1/23/17	1	3	6284	20.6	20.13	19.4	67.45	16.8	82.9	16.1	935
1/23/17	1	2	6107	20.4	19.63	19.3	62.12	16.8	81.39	16.1	948.6
1/24/17	1	2	6235	19.7	19.76	18.6	63.9	15.6	85.8	14.6	982.7
1/24/17	1	2	6243	20.5	19.7	19.4	65.5	17.3	83.6	16.8	998.1
1/25/17	1	2	6452	19.6	20.2	18.3	69.1	16	80.1	14.8	26.9
1/26/17	1	3	6449	21	20.2	20.2	71.9	18.3	80.9	20.7	41.6
1/27/17	1	2	6629	20.4	20.6	19.3	77.3	17.6	112.2	16.6	69.9
1/26/17	1	3	6591	21.2	20.5	20.5	76.4	19.2	106.2	20.6	82.4
1/27/17	1	2	6534	20.1	20.3	19	78	16.6	93.8	16	110.4
1/27/17	0.5	1	6392	21.5	20	20.7	74.2	19.6	109.5	20.9	121.9
1/28/17	1	2	6467	19.5	20.1	18.1	76	14.7	93.7	13.5	152

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Date	Time	RRO Feed Flow (gpm)	RRO Feed pH	Pre-Feed Pump Pressure PI-401 (psi)	Feed Pressure (psi)	Conc. Pressure PI407 (psi)	Feed Pump P401 (Amps)	Conc. Flow, FIT-403 (gpm)	Permeate Flow, FIT-401 (gpm)	Interstage Flow, FIT-402 (gpm)	Pre-Boost Pressure, PI-405 (psi)	Post-Boost Pressure, PI-406 (psi)	Interstage Booster Pump P402 (Amps)
1/28/17	15:25	14.4	6.48	48	150	175	50.9	3.8	10.6	6.8	135	185	32.24
1/29/17	8:22	14.6	6.61	50	150	180	51.19	3.9	10.6	6.8	140	195	32.19
1/29/17	15:21	14.6	6.42	47	145	175	51.97	3.8	10.6	6.9	135	190	32.54
1/30/17	8:45	14.5	6.46	51	150	180	52	3.92	10.8	6.5	140	190	32.34
1/30/17	15:45	14.6	6.46	47	145	180	51.8	3.8	10.6	6.8	135	190	32.3
1/31/17	9:10	14.6	6.49	50	150	185	52.34	3.97	10.7	6.9	140	190	32.46
2/1/17	8:30	14.7	6.3	51	155	195	52.4	4	10.8	6.8	145	205	32.4
2/2/17	16:15	14.4	6.61	81	135	175	39.7	3.4	10.6	6.8	125	185	32.5
2/3/17	8:31	14.1	6.47	83	140	180	39.4	3.5	10.9	6.8	130	190	32.76
2/3/17	16:05	14.3	6.58	80	135	180	40.69	3.5	10.8	6.8	125	185	32.43
2/4/17	8:28	14.1	6.56	82	140	180	40.06	3.5	10.7	6.9	130	196	32.41
2/4/17	15:21	14.1	6.43	80	140	180	40.3	3.5	10.8	6.8	130	190	32.41
2/5/17	8:26	14.2	6.69	82	140	185	40.71	3.5	10.6	6.9	130	195	32.78
2/5/17	15:14	14.1	6.52	81	140	185	39.51	3.5	10.7	6.9	130	195	32.31
2/6/17	8:23	14.2	6.7	80	135	190	40.8	3.5	10.6	6.8	130	200	32.3
2/6/17	15:20	14.3	6.55	81	140	190	40.4	3.5	10.8	6.8	130	200	32.4
2/7/17	8:25	14.3		81	140	190	41.13	3.56	10.8	6.82	130	200	32.34
2/8/17	7:14	14.2	6.45	80	130	190	40	3.5	10.6	6.8	125	200	32.3
2/8/17	15:25	14.4	6.61	78	135	190	40.3	3.5	10.6	6.8	130	195	32.4
2/9/17	9:50	14.2	6.5	79	130	190	40	3.5	10.7	6.8	125	200	32.3
2/9/17	15:34	14.2	6.6	77	135	190	39.6	3.5	10.6	6.8	125	200	32.3
2/10/17	8:37	14.4	6.46	80	132	195	39.63	3.5	10.7	6.8	125	205	32.21
2/10/17	15:14	14.2	6.57	64	130	190	44.25	3.5	10.5	6.8	125	200	32.28
2/11/17	8:23	14.3	6.54	65	135	195	44.73	3.6	10.7	6.7	125	210	32.13
2/11/17	15:24	14.4	6.52	76	135	205	40.97	3.5	10.8	6.7	125	210	32.39
2/12/17	8:34	shut down											
2/12/17	15:30	shut down											
2/13/17		shut down											
2/14/17	AM	shut down											
2/14/17	15:20	14.2	6.68	78	130	185	39.7	3.5	10.6	6.8	120	200	32.3
2/15/17	8:15	14.3	6.3	82	135	200	40	3.6	10.6	6.8	130	200	32.4
2/16/17	9:00	14.4	6.44	80	135	185	40.48	3.8	10.6	6.8	125	195	32.39
2/16/17	16:00	14.4	6.47	80	130	180	40.68	3.79	10.6	6.6	125	190	32.38
2/17/17	8:20	14.7	6.5	81	142	182	41.3	3.6	10.7	6.9	130	210	32.2
2/17/17	15:28	14.3	6.4	82	135	200	34.69	3.6	10.6	6.8	130	210	32.38
2/18/17		Shut down											
2/19/17	AM	Shut down	WRF Secondary issues										

Date	S2 Perm Pressure, PI-404 (psi)	S1 Perm Pressure, PI-403 (psi)	Feed Cond, AE-401 (uS/cm)	Feed Temp (˚C)	Conc. Cond. AE-404 (mS/cm)	Conc. Temp. (˚C)	S1 Perm Cond. AE-402 (uS/cm)	S1 Perm Temp. (˚C)	S2 Perm Cond. AE-403 (uS/cm)	S2 Perm Temp. (˚C)	Power (kWh)
1/28/17	0	0.5	6332	22.7	19.8	22.4	75.1	22.5	112.1	24.2	165.9
1/29/17	1	2	6378	20.1	19.8	18.8	72.3	15.6	105.4	14.5	192
1/29/17	0	1	6330	23.3	19.8	23	74.5	23.1	93.6	24.6	202.9
1/30/17	1	2	6404	20.9	19.86	19.8	68.3	17.9	80.1	17	230.3
1/30/17	0	1	6414	23.2	20	22.8	71	22.6	91.1	25.6	241.5
1/31/17	1	1	6582	21.4	20.4	20.4	74.1	19.4	93.7	18.3	269.1
2/1/17	1	2	6829	20.4	20.8	19.3	78.8	16.2	89.5	14.9	306.8
2/2/17	1	3	6729	22.3	22.9	21.3	106.1	20.1	185.1	20.4	333.8
2/3/17	1	2	6704	21.4	22.4	20.3	108.9	18	188.4	17.5	351.6
2/3/17	1	2	6669	22.4	22.2	21.5	106.8	20.1	172.3	20.2	360.3
2/4/17	1	2	6722	22	22	20.9	105.8	18.8	162.4	18.5	378.8
2/4/17	0.5	1	6710	22.9	21.9	22.2	104.4	20.9	154	22.1	386.8
2/5/17	1	2	6615	21.8	21.6	20.6	94.5	18.2	169.4	17.9	406.6
2/5/17	1	2	6642	22.2	21.6	21.2	95.9	19.2	133.1	19	414.4
2/6/17	1	3	6547	22.1	21.1	21	95.9	18.8	156.1	18.3	434.8
2/6/17	1	3	6576	21.9	21.2	20.6	94.7	18.8	110.3	18.5	443.1
2/7/17	1	2	6468	21.9	20.8	20.6	101.6	18.7	131.2	18.4	464.2
2/8/17	1	3	6338	22	20.4	20.9	116.7	18.4	130.1	18.4	491.9
2/8/17	1	1	6257	23.7	20.4	23.2	97.9	22.4	130	24	501.9
2/9/17	1	2	6132	23.7	20.1	22.6	100.2	21.8	132.2	21.8	524.3
2/9/17	0	1	6201	24.3	20.1	23.9	101.3	23.2	126.5	26.2	531.1
2/10/17	0.5	1	6225	22.5	20.3	21.6	104.7	19.5	118.6	19.6	552.1
2/10/17	0	1	6155	23.7	20	23.1	99.2	21.8	162.7	22.8	556.9
2/11/17	1	2	6107	22.5	19.9	21.4	97.1	19.3	127.6	18.8	580.3
2/11/17	1	2	6187	23	22.1	22.2	99.5	20	143.6	22.1	588.4
2/12/17											
2/12/17											
2/13/17											
2/14/17											
2/14/17	0	0	5943	23.7	19.6	23.2	94.7	22.3	146	24.3	599.1
2/15/17	1	2	6090	21.6	19.9	20.3	100	17.7	161	16.9	619
2/16/17	0	1	5761	23.3	18.4	22.2	90.4	22.2	111.9	21.6	645.7
2/16/17	1	1	5884	23.7	18.6	23	93.3	22.4	136.2	24.2	652.7
2/17/17	1	1	6069	22.2	19.2	21	104.4	19	172	18.7	671.6
2/17/17	0.5	1	6181	22.4	19.8	21.3	99.7	19.6	108	19.3	680.1
2/18/17											
2/19/17											

Date	Time	RRO Feed Flow (gpm)	RRO Feed pH	Pre-Feed Pump Pressure PI-401 (psi)	Feed Pressure (psi)	Conc. Pressure PI407 (psi)	Feed Pump P401 (Amps)	Conc. Flow, FIT-403 (gpm)	Permeate Flow, FIT-401 (gpm)	Interstage Flow, FIT-402 (gpm)	Pre-Boost Pressure, PI-405 (psi)	Post-Boost Pressure, PI-406 (psi)	Interstage Booster Pump P402 (Amps)
2/19/17	15:31	14.4	6.64	86	135	195	40.31	3.7	10.6	6.8	130	205	32.44
2/20/17	8:25	14.6	6.57	84	140	200	39.77	3.7	10.6	6.8	125	210	32.24
2/20/17	15:23	14.4	6.49	80	130	200	40.68	3.6	10.5	6.7	125	210	32.38
2/21/17	8:45	14.4	6.6	82	140	205	40	3.6	10.6	6.7	130	215	31.8
2/21/17	15:20	14.4	6.78	81	135	205	40	3.6	10.6	6.7	125	210	31.9
2/22/17	8:00	Shut down	WRF Secondary issues										
2/22/17	15:00	Shut down	WRF Secondary issues										
2/23/17	8:00	Shut down	WRF Secondary issues										
2/23/17	15:30	14.4	6.5	82	135	165	40.2	3.6	10.7	6.8	125	175	32.4
2/24/17	9:06	14.4	6.58	85	135	165	39.56	3.6	10.8	6.9	125	180	32.71
2/24/17	15:24	14.2	6.5	84	135	170	40.07	3.6	10.7	6.7	125	180	32.76
2/25/17	8:36	14.4	6.58	86	140	180	40.95	3.7	10.6	6.6	130	190	32.48
2/25/17	15:24	14.3	6.53	84	140	180	40.22	3.7	10.6	6.8	130	190	32.24
2/26/17	8:28	14.4	6.61	85	140	190	41.29	3.8	10.7	6.7	130	205	32.29
2/26/17	15:32	14.3	6.61	85	135	205	39.52	3.6	10.7	6.7	130	215	32.29
2/28/17	15:30	14.2	6.82	86	125	195	36.6	3.5	10.7	6.8	120	205	32.4
3/1/17	8:15	14.2	6.85	89	140	210	40.23	3.6	10.7	6.7	130	220	31.3
3/2/17	8:45	14	6.5	88	148	215	42.1	3.44	10.6	6.8	135	224	27.9
3/2/17	14:45	14.2	6.89	86	145	210	42	3.4	10.6	6.2	135	220	29.5
3/3/17	14:21	14.3	6.52	85	130	170	40.6	3.5	10.5	6.8	125	180	32.39
3/3/17	15:00	14.1		86	135	174	39	3.53	10.6	6.7	124	184	
3/3/17	17:40	14.1		86	140	181	40	3.57	10.8	6.9	130	190	32
3/4/17	8:29	14.2	6.52	86	150	200	42.92	3.6	10.6	6.8	135	210	32.26
3/4/17	15:28	14.3	6.6	85	145	210	43.65	3.5	10.6	6.6	135	220	31.35
3/5/17	8:25	14.2	6	86	150	220	45.04	3.6	10.7	6.3	140	225	30.38
3/5/17	15:21	14.2	6.57	86	150	220	45.32	3.6	10.7	6.3	145	230	30.13
3/6/17	7:15	14.3	6.72	88	150	220	45.72	3.64	10.6	6.5	145	230	29.81
3/7/17	9:05	14.2	6.43	85	150	215	45.5	3.5	10.7	6.3	140	225	30
3/7/17	15:50	14.3	6.47	83	145	215	44.4	3.5	10.7	6.3	135	222	30
3/8/17	8:35	14.1	6.3	86	150	220	45.75	3.44	10.67	6.11	145	235	28.99
3/9/17	7:35	14.3	6.55	88	150	220	44.79	3.5	10.6	6.7	140	230	29.48
3/9/17	16:30	15.1	6.6	49	115	85	47.2	4.6	10.72	7.3	115	100	32.5
3/10/17	8:15	15.4	6.45	55	140	100	50.5	4.8	10.6	6.9	128	115	32.5
3/10/17	15:33	15.4	6.54	54	135	100	50.62	4.7	10.6	6.7	125	110	32.5
3/11/17	8:23	15.4	6.42	5.5	140	100	50.75	4.8	10.6	6.6	125	115	32.5
3/11/17	15:32	15.3	6.53	53	135	100	50.65	4.7	10.7	6.7	125	115	32.58
3/12/17	8:23	15.5	6.4	55	135	100	51.04	4.8	10.6	6.8	130	120	32.5

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Date	S2 Perm Pressure, PI-404 (psi)	S1 Perm Pressure, PI-403 (psi)	Feed Cond, AE-401 (uS/cm)	Feed Temp (˚C)	Conc. Cond. AE-404 (mS/cm)	Conc. Temp. (˚C)	S1 Perm Cond. AE-402 (uS/cm)	S1 Perm Temp. (˚C)	S2 Perm Cond. AE-403 (uS/cm)	S2 Perm Temp. (˚C)	Power (kWh)
2/19/17	1	2	5767	21.4	18.4	20.4	87.9	18.2	127.7	17.9	707
2/20/17	1	2	5782	21.5	18.3	20.4	87.8	18.2	87.1	17.6	727.9
2/20/17	0	0.5	5916	23.1	18.9	22.7	96.8	21.5	97.5	22.6	737.1
2/21/17	1	3	6003	22	19.2	21.2	87	19.1	84.1	18.8	760.2
2/21/17	0	1	6005	23.8	19.2	23.5	88.8	22.6	84.9	25.1	769.1
2/22/17											
2/22/17											
2/23/17											
2/23/17	1	2	6410	22.2	20.3	21.2	112.2	19.2	167	20.9	824.3
2/24/17	1	2	6466	21.1	20.6	18.9	122.6	16.5	243.8	14.9	826.6
2/24/17	0.5	1	6430	22.6	20.5	21.9	118.7	20.3	180.7	22.5	831.2
2/25/17	1	2	6472	21	20.3	19.6	113.1	16.7	152.6	15.9	849
2/25/17	1	2	6487	22.4	20.2	21.5	113.7	19.9	129.8	20.5	856.6
2/26/17	1	2	6426	21.6	19.8	20.3	106.8	17.8	130.7	17	875.7
2/26/17	1	2	6534	21.9	20.8	20.8	108.5	18.8	114.3	18.7	884.8
2/28/17	1	3	5059	20.8	16.4	20	70.8	18.4	76.1	19	912.4
3/1/17	1	2	5815	19.8	18.5	18.8	90.7	16.1	122.1	15.6	932.3
3/2/17	1	1	6493	20.5	21.1	19.7	120.14	17.3	134.15	17.1	942.3
3/2/17	0	1	6447	23	21.2	22.6	117.7	22.4	127	23	951
3/3/17	0	0.5	6444	23.6	20.9	20.8	150.8	23.6	204.1	24.6	966.4
3/3/17	0	0	6570	23.3	21.3	22.7	151	22.7	253	24.3	968
3/3/17	0	0	6740	22.2	21.75	21.3	121	19.9	183	20	975
3/4/17	1	2	6633	21	20.9	19.8	117.7	17.3	207.4	17.2	992.4
3/4/17	0.5	2	6697	22.1	21.4	21.4	116	20.1	165.3	20.3	1.3
3/5/17	1	2	6666	21.5	21.3	20.5	116.5	18	134.9	17.4	23.4
3/5/17	1	2	6727	21.5	21.3	20.4	115.6	18.3	129.5	18.1	33
3/6/17	1	1	6700	20.3	21.1	19	115	15.2	122	14	54.5
3/7/17	1	3	6585	21.6	21	20.5	122.1	18.4	144.5	18.1	59.6
3/7/17	0	2	6561	23.4	21	23.2	120.3	22.3	117.8	24.4	68.8
3/8/17	1	3	6551	22.4	21.5	21.7	122.9	19.6	126.6	20.1	91.6
3/9/17	1	1	6496	21.7	21	20.8	119	18	143	17.1	99.1
3/9/17	0	0	5200	24.2	14	23.6	114.9	23.9	175.1	25.5	111.3
3/10/17	0	0	5115	22.5	14	21.6	119.2	20.3	168.6	20.4	128.7
3/10/17	0	0.5	5038	24.6	13.9	23.7	113.7	24.3	144.1	26.2	136.3
3/11/17	0.5	2	5115	22.3	13.9	21.3	114.9	19.8	150.2	19.3	154.2
3/11/17	0	0.5	5063	24.5	14	23.7	114.1	24.1	137.1	25.7	161.9
3/12/17	1	2	5042	21.9	13.8	20.6	111.8	17.9	150.3	16.6	178.4

Date	Time	RRO Feed Flow (gpm)	RRO Feed pH	Pre-Feed Pump Pressure PI-401 (psi)	Feed Pressure (psi)	Conc. Pressure PI407 (psi)	Feed Pump P401 (Amps)	Conc. Flow, FIT-403 (gpm)	Permeate Flow, FIT-401 (gpm)	Interstage Flow, FIT-402 (gpm)	Pre-Boost Pressure, PI-405 (psi)	Post-Boost Pressure, PI-406 (psi)	Interstage Booster Pump P402 (Amps)
3/12/17	15:19	15.3	6.52	53	130	100	49.31	4.7	10.6	6.8	120	110	32.5
3/13/17	8:20	15.4	6.43	55	140	100	50.76	4.78	10.6	6.7	125	120	32.5
3/13/17	15:28	15.4	6.55	54	130	95	49.33	4.7	10.6	6.8	120	110	32.5
3/14/17	9:15	15.5	6.26	56	135	100	49.8	4.78	10.7	6.8	115	125	32.5
3/14/17	15:50	15.3	6.47	53	130	100	49.7	4.7	10.8	6.9	120	110	32.5
3/15/17	8:15	15.3	6.15	56	135	100	49.9	4.7	10.6	6.8	125	115	32.5
3/15/17	15:45	15.5	6.4	55	130	100	48.21	4.7	10.6	6.7	120	115	32.58
3/16/17	8:20	15.5	6.43	56	137	110	50.8	4.8	10.7	6.8	115	130	32.5
3/16/17	3:30	15.4	6.7	55	130	104	50	4.6	10.7	6.6	125	120	32.5
3/17/17	7:50	15.4	6.4	56	135	105	50	4.7	10.8	6.9	115	125	32.5
3/17/17	15:30	15.1	6.63	55	130	100	48.66	4.6	10.7	6.8	125	115	32.5
3/18/17	8:31	15.5	5.98	56	140	105	50.77	4.7	10.6	6.8	130	120	32.5
3/18/17	15:31	15.4	6.68	55	135	105	50.28	4.7	10.5	6.7	125	115	32.58
3/19/17	8:26	15.3	6.38	58	135	110	50.35	4.6	10.6	6.7	125	120	32.5
3/19/17	15:30	15.2	6.59	56	135	110	48.87	4.6	10.7	6.7	125	120	32.57
3/20/17	8:27	15.3	6.53	57	135	105	49.65	4.7	10.7	6.8	130	115	32.5
3/21/17	15:30	15.2	6.73	56	135	110	50.3	4.4	10.6	6.8	125	130	32.5
3/22/17	8:22	15.1	6.5	56	135	115	50	4.4	10.6	6.8	125	125	32.5
3/22/17	15:30	15.4	6.64	58	135	110	50.15	4.7	10.6	6.8	125	125	32.68
3/22/17	15:48	15.4	6.64	58	135	110	50.15	4.7	10.6	6.8	125	125	32.68
3/23/17	9:40	15.3	6.46	58	137	105	50.8	4.68	10.6	6.8	130	120	32.5
3/23/17	15:48	15.3	6.5	57	135	103	49.2	4.7	10.6	6.9	130	120	32.5
3/24/17	8:50	15.5	6.2	59	140	105	49.29	4.6	10.5	6.8	130	120	32.5
3/24/17	15:30	15.4	6.66	57	140	105	49.68	4.6	10.7	6.7	125	120	32.5
3/25/17	8:24	15.3	6.49	58	140	105	48.79	4.7	10.7	6.7	125	120	32.5
3/25/17	15:28	15.4	6.7	58	135	105	49.72	4.6	10.7	6.7	130	120	32.5
3/26/17	8:31	15.3	6.61	60	135	110	49.58	4.6	10.7	6.8	130	120	32.5
3/26/17	15:22	15.4	6.71	58	135	105	51.02	4.7	10.6	6.7	125	120	32.5
3/27/17	9:45	15.4	6.71	59	135	105	49.81	4.6	10.7	6.8	125	120	32.5
3/27/17	15:26	15.4	6.73	56	135	115	49.76	4.6	10.7	6.8	130	120	32.5
3/28/17	9:50	15.1	6.93	58	135	105	50.22	4.6	10.7	6.8	130	120	32.5
3/28/17	15:50	15.4	6.8	57	135	105	50.3	4.7	10.6	6.9	125	125	32.5
3/29/17	9:30	15	6.8	56	135	112	48.8	4.5	10.6	6.8	125	125	32.5
3/29/17	15:15	15.1	6.8	56	130	115	48.3	4.5	10.8	6.7	125	125	32.5
3/30/17	8:00	15.3	6.9	58	138	115	50.6	4.6	10.5	6.7	125	130	32.5
3/30/17	15:00	15.3	6.8	57	140	120	50	4.6	10.7	6.7	126	126	32.5
4/1/17	14:25	15.1	6.9	55	140	135	52.8	4.7	10.8	6.8	130	150	32.5

DRAFT

Date	S2 Perm Pressure, PI-404 (psi)	S1 Perm Pressure, PI-403 (psi)	Feed Cond, AE-401 (uS/cm)	Feed Temp (˚C)	Conc. Cond. AE-404 (mS/cm)	Conc. Temp. (˚C)	S1 Perm Cond. AE-402 (uS/cm)	S1 Perm Temp. (˚C)	S2 Perm Cond. AE-403 (uS/cm)	S2 Perm Temp. (˚C)	Power (kWh)
3/12/17	0	0	4875	25.4	13.6	24.5	109.9	26	147.8	27.8	185.7
3/13/17	1	1	4900	22.2	13.5	20.9	105	18.4	144	17	203.1
3/13/17	0	0.5	4762	25.3	13.3	24.4	97.6	25.4	145.7	26.8	210.2
3/14/17	1	2	4856	23	13.3	22.1	105	21.2	132	21.6	228.5
3/14/17	0	0	4762	25.8	13.3	24.9	101.2	26.2	142.5	28	235.1
3/15/17	1	4	4875	22.9	13.4	21.7	112.9	19.7	126	18.7	251.8
3/15/17	0	0	4788	25.4	13.4	24.4	102.2	24.8	145.3	25.9	259.6
3/16/17	1	2	4907	22.6	13.5	21.3	114	18.8	178	17.6	276.4
3/16/17	0	0	4829	25.5	13.6	24.5	105.85	25.1	147.9	26.7	283.2
3/17/17	1	2	4864	22.3	13.6	21	110	18.1	137	16.6	299.8
3/17/17	0	0.5	4701	25.1	13.3	24.1	97.8	24.6	123.2	26.4	307.3
3/18/17	0.5	1	4712	23	13.2	21.8	83.4	19.5	95.3	18.6	324.7
3/18/17	0	0.5	4692	25.6	13.3	24.6	81.6	25.4	102.3	27.5	332.1
3/19/17	1	2	4709	22.6	13.4	21.3	84.4	18.7	120.4	17.5	348.2
3/19/17	0	1	4726	24.7	13.5	23.5	84.1	23.1	96.3	24	355.3
3/20/17	0.5	2	4642	23.2	13	21.9	78.8	19.9	163.4	19	372.4
3/21/17	0	1	4787	24.3	13.8	23.3	81.5	22.7	124.8	22.7	386.2
3/22/17	0	1	4689	23.3	13.5	21.8	91.4	20.1	136.8	19.1	403.9
3/22/17	0	0	4727	24.5	13.38	23.2	86.5	22.5	116.5	22.9	410.9
3/22/17	0	0	4727	24.5	13.38	23.2	86.5	22.5	116.5	22.9	410.9
3/23/17	1	1	4652	23.3	13.1	21.8	91.2	19.9	198.5	19	429.3
3/23/17	0	0	4690	24.4	13.3	22.4	85.1	22.4	191.6	23.3	435.7
3/24/17	0	1	4593	22.6	12.9	21.3	88	20.4	110.6	19.1	453
3/24/17	0	1	4586	24.4	13	23.2	81.9	22.6	118	24.1	459
3/25/17	0.5	2	4588	22.7	12.9	21.3	84.6	19.1	128.6	17.7	477
3/25/17	0	1	4511	24	12	22.8	80.5	22	116.5	22.3	484
3/26/17	0.5	2	4536	23.1	12.7	22	77.8	19.8	115.9	19	501.3
3/26/17	0.5	1	4580	24.5	12.9	23.3	77	22.8	110.2	24.1	508.5
3/27/17	0	0	4387	23.8	12.4	22.6	67.6	21.3	84.7	21.1	527.3
3/27/17	0	1	4540	24.3	12.7	23.1	71.6	22.3	160.58	23.3	532.9
3/28/17	0	1	4318	24.3	12.3	22.8	70.8	21.1	94.9	22	551.6
3/28/17	1	1	4467	24.9	12.7	23.8	77.3	23.7	100.7	24.3	557.8
3/29/17	1	2	4286	24	12.5	22.5	77.2	21.5	88.8	22.8	575.5
3/29/17	0	0	4418	25.6	12.78	24.7	75.3	25.1	106.7	27.2	581
3/30/17	1	2	4469	22.7	12.6	21.4	81.8	18.6	107	17.9	598.8
3/30/17	1	1	4515	24.2	12.8	23.1	78.1	22.3	113.8	22.7	606
4/1/17	0	0	4669	24.8	16	23.7	101.6	23.6	158.4	25.4	645

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Date	Time	RRO Feed Flow (gpm)	RRO Feed pH	Pre-Feed Pump Pressure PI-401 (psi)	Feed Pressure (psi)	Conc. Pressure PI407 (psi)	Feed Pump P401 (Amps)	Conc. Flow, FIT-403 (gpm)	Permeate Flow, FIT-401 (gpm)	Interstage Flow, FIT-402 (gpm)	Pre-Boost Pressure, PI-405 (psi)	Post-Boost Pressure, PI-406 (psi)	Interstage Booster Pump P402 (Amps)
4/3/17	14:20	14.8	7.1	55	140	130	49.4	4.3	10.8	7	120	155	32.5

DRAFT

Date	S2 Perm Pressure, PI-404 (psi)	S1 Perm Pressure, PI-403 (psi)	Feed Cond, AE-401 (uS/cm)	Feed Temp (˚C)	Conc. Cond. AE-404 (mS/cm)	Conc. Temp. (˚C)	S1 Perm Cond. AE-402 (uS/cm)	S1 Perm Temp. (˚C)	S2 Perm Cond. AE-403 (uS/cm)	S2 Perm Temp. (˚C)	Power (kWh)
4/3/17	0	0	4548	24.1	13.2	23.1	78.9	22.4	115.1	21.9	665.8

Appendix C – CCD Feed Water Quality Data

DRAFT

Parameter	Units	Method	MRL	MDL	Average	STDEV	3/8/16	3/15/16	3/24/16	4/7/16
Aluminum Total ICAP/MS*	µg/L	EPA 200.8	20	0.78	***80.6***	20.06	63 [6]	70 [6]	66	61
Barium Total ICAP/MS*	µg/L	EPA 200.8	2	0.17	***226.7***	42.15	160	190	220	270
Calcium Total ICAP*	mg/L	EPA 200.7	1	0.12	***246.7***	32.46	200	210	240	260
Iron Total ICAP*	mg/L	EPA 200.7	0.02	0.0026	***0.19***	0.06	0.18	0.18	0.18	0.15
Magnesium Total ICAP*	mg/L	EPA 200.7	0.1	0.003	***86.6***	14.51	75	84	97	100
Potassium Total ICAP*	mg/L	EPA 200.7	1	0.13	***71.1***	9.41	58	62	64	66
Silica*	mg/L	EPA 200.7	0.43	0.1	***37.9***	7.11	35	35	31	20
Sodium Total ICAP*	mg/L	EPA 200.7	1	0.11	***600.0***	84.40	490	500	580	580
Strontium ICAP*	mg/L	EPA 200.7/UCMR 200.8	0.01	0.002	***2.7***	0.56	2	2.2	2.7	3.4
Total Organic Carbon*	mg/L	SM5310C/E415.3	0.3	0.042	***31.6***	6.79	14	33	34	27
Dissolved UV abs. at 254 nm*	cm^{-1}	SM 5910	0.009	0.002	***0.57***	0.08	0.53	0.55	0.5	0.52
UV Transmittance (by calc from UVA)*	%	*calc*			***27.1***	4.8	29.5	28.2	31.6	30.2
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	SM2340B	3	3	***970.0***	137.73	810	870	1000	1100
Chloride*	mg/L	EPA 300.0	1	0.025	***757.8***	132.57	670	690	740	680
Sulfate*	mg/L	EPA 300.0	0.5	0.06	***1051.5***	188.29	860	930	1000	1100
Total Dissolved Solids (TDS)*	mg/L	E160.1/SM2540C	10	4.2	***3132.1***	472.23	2500	2700	2900	3200
Alkalinity as CaCO3**	mg/L	SM2320B	2		***130.2***	57.11	66	190	111	90
Ammonia**	mg-N/L	EPA 350.1	0.2		***2.8***	0.58	3.74	2.6	2.13	2.14
Nitrate**	mg-N/L	EPA 353.2	0.2		***47.9***	10.79	35.1	33.5	53.3	53.4
Ortho Phosphate**	mg-P/L	EPA 365.1	0.01		***0.23***	0.12	0.161	0.107	0.132	0.168
* Performed by Eurofins Eaton Analytical										
** Performed by Ray Stoyer WRF lab										
[1] Analysis did not meet one or more of the QC criteria										
[2] Sample required dillution due to matrix										
[6] Too many dillutions. Sample removed from statistics										

Parameter	Units	4/28/16	5/5/16	5/12/16	5/19/16	5/26/16	6/2/16	6/9/16	6/16/16	6/23/16	6/30/16
Aluminum Total ICAP/MS*	µg/L	61	80	64	65	48	65	73	75	86	82
Barium Total ICAP/MS*	µg/L	220	280	190	170	190	210	180	190	210	240
Calcium Total ICAP*	mg/L	220	260	230	200	200	210	210	230	230	240
Iron Total ICAP*	mg/L	0.16	0.14	0.13	0.15	0.16	0.19	0.2	0.17	0.14	0.11
Magnesium Total ICAP*	mg/L	71	94	74	67	68	72	66	71	79	85
Potassium Total ICAP*	mg/L	62	66	64	62	61	62	62	65	63	66
Silica*	mg/L	30	38	33	32	31	32	32	34	35	37
Sodium Total ICAP*	mg/L	480	570	540	500	490	500	530	530	560	580
Strontium ICAP*	mg/L	2.2	3.1	2.1	2	2.2	2.2	2	2.2	2.6	2.8
Total Organic Carbon*	mg/L	31	28	26	25	26	25	24	25	30	30
Dissolved UV abs. at 254 nm*	cm^{-1}	0.53	0.51	0.49	0.47	0.49	0.48	0.49	0.5	0.53	0.52
UV Transmittance (by calc from UVA)*	%	29.5	30.9	32.4	33.9	32.4	33.1	32.4	31.6	29.5	30.2
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	840	1000	880	780	780	820	800	870	900	950
Chloride*	mg/L	670	700	660	600	650	650	690	700	720	730
Sulfate*	mg/L	970	1200	920	830	810	760	860	970	920	920
Total Dissolved Solids (TDS)*	mg/L	2700	3100	2800	2500	2500	2600	2600	2800	2900	3000
Alkalinity as CaCO3**	mg/L	120	162	112	84	158	322	122	88	234	
Ammonia**	mg-N/L	2.19	2.4	2.18	2.12	2.68	2.73	2.7	2.56	2.56	
Nitrate**	mg-N/L	45	37.9	44.0	37.4	46.3	29.1	34.2	40.4	31.5	
Ortho Phosphate**	mg-P/L	0.228	0.313		0.174	0.15	0.093	0.141	0.0968	0.127	
* Performed by Eurofins Eaton Analytical											
** Performed by Ray Stoyer WRF lab											
[1] Analysis did not meet one or more of the QC criter											
[2] Sample required dillution due to matrix											
[6] Too many dillutions. Sample removed from statist											

Parameter	Units	7/14/16	7/28/16	8/4/16	8/11/16	8/18/16	8/25/16	9/1/16	9/8/16	9/15/16	9/22/16	9/29/16
Aluminum Total ICAP/MS*	µg/L	66	99	86	130	120		87	87	92	99	88 [2]
Barium Total ICAP/MS*	µg/L	190	300	310	190	260		210	220	210	260	300
Calcium Total ICAP*	mg/L	230	300	280	240	290		250	250	260	270	310
Iron Total ICAP*	mg/L	0.2	0.2	0.22	0.4	0.3		0.23	0.24	0.15	0.12	0.22
Magnesium Total ICAP*	mg/L	76	120	99	86	100		87	84	90	89	120
Potassium Total ICAP*	mg/L	65	85	82	80	85		76	80	78	76	84
Silica*	mg/L	35	46	42	37	44		42	43	45	43	52
Sodium Total ICAP*	mg/L	570	710	720	640	750		630	660	640	690	690
Strontium ICAP*	mg/L	2.4	3.5	3	2.8	3.3		2.6	2.5	2.9	3.1	4.2
Total Organic Carbon*	mg/L	28	37	35	32	36		33	35	33	43	38
Dissolved UV abs. at 254 nm*	cm^{-1}	0.5	0.66	0.65	0.6	0.67		0.63	0.62	0.62	0.72	0.7
UV Transmittance (by calc from UVA)*	%	31.6	21.9	22.4	25.1	21.4		21.4	24.0	24.0	19.1	20.0
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	890	1200	1100	950	1100		980	970	1000	1000.0	1300
Chloride*	mg/L	770	940	920	780	1000		800	890	820	910	391
Sulfate*	mg/L	840	1400	1200	1100	1300		1100	1000	1100	1200	1500
Total Dissolved Solids (TDS)*	mg/L	2800	3900	3700	3300	3800		3400	3200	3200	3500	4100
Alkalinity as CaCO3**	mg/L						80	62	106	114	96	132
Ammonia**	mg-N/L						3.84	3	3.42	2.47	3.22	3.68
Nitrate**	mg-N/L						60.1	55.4	49.8	58.4	56.4	61.8
Ortho Phosphate**	mg-P/L						0.186	0.244	0.234	0.318	0.288	0.183
* Performed by Eurofins Eaton Analytical												
** Performed by Ray Stoyer WRF lab												
[1] Analysis did not meet one or more of the QC criter												
[2] Sample required dillution due to matrix												
[6] Too many dillutions. Sample removed from statist												

Parameter	Units	9/30/16	10/6/16	10/13/16	10/20/16	10/27/16
Aluminum Total ICAP/MS*	µg/L		88 [2]	80 [1]		65 [1]
Barium Total ICAP/MS*	µg/L		240	240		270
Calcium Total ICAP*	mg/L		270	270		300
Iron Total ICAP*	mg/L		0.24	0.26		0.225
Magnesium Total ICAP*	mg/L		92	94		98
Potassium Total ICAP*	mg/L		80	81		85
Silica*	mg/L		46	45		48
Sodium Total ICAP*	mg/L		680	670		720
Strontium ICAP*	mg/L		2.9	3.1		3.5
Total Organic Carbon*	mg/L		44	42		40
Dissolved UV abs. at 254 nm*	cm^{-1}		0.66	0.64		0.66
UV Transmittance (by calc from UVA)*	%		21.9	22.9		21.9
Total Hardness as CaCO3 by ICP (calc.)*	mg/L		1000	1100		1200
Chloride*	mg/L		890	870		930
Sulfate*	mg/L		1200	1200		1200
Total Dissolved Solids (TDS)*	mg/L		3700	3000	3600	3700
Alkalinity as CaCO3**	mg/L	176	120	122	122	136
Ammonia**	mg-N/L	3.05	3.16	2.75	1.99	3.81
Nitrate**	mg-N/L	49.4	56.3	59.1	62	60.6
Ortho Phosphate**	mg-P/L	0.292	0.208	0.508	0.534	0.336
* Performed by Eurofins Eaton Analytical						
** Performed by Ray Stoyer WRF lab						
[1] Analysis did not meet one or more of the QC criter						
[2] Sample required dillution due to matrix						
[6] Too many dillutions. Sample removed from statist						

Appendix D – CCD Permeate Water Quality Data

DRAFT

Parameter	Units	Method	MRL	MDL	Average	STDEV	3/8/16	3/15/16	3/24/16	4/7/16
Aluminum Total ICAP/MS*	µg/L	EPA 200.8	20	0.78	***2.9***	2.61	1.3	5.9	5.5	2.4
Barium Total ICAP/MS*	µg/L	EPA 200.8	2	0.17	***0.4***	0.22	0.18	ND	0.22	0.38
Calcium Total ICAP*	mg/L	EPA 200.7	1	0.12	***0.2***	0.12	0.2	ND	ND	0.16
Iron Total ICAP*	mg/L	EPA 200.7	0.02	0.0026	***0.0***	N/A	ND	ND	ND	ND
Magnesium Total ICAP*	mg/L	EPA 200.7	0.1	0.003	***0.0***	0.03	0.067	0.045	0.022	0.037
Potassium Total ICAP*	mg/L	EPA 200.7	1	0.13	***3.5***	1.30	2	1.9	2.3	2.4
Silica*	mg/L	EPA 200.7	0.43	0.1	***0.9***	0.43	0.5	0.43	0.34	0.23
Sodium Total ICAP*	mg/L	EPA 200.7	1	0.11	***31.2***	11.36	20	18	24	23
Strontium ICAP*	mg/L	EPA 200.7/UCMR 200.8	0.01	0.002	***0.0***	0.0014	0.0027	0.0021	ND	0.0019
Total Organic Carbon*	mg/L	SM5310C/E415.3	0.3	0.042	***0.4***	0.20	0.4	0.13	0.51	0.11
Dissolved UV abs. at 254 nm*	cm^{-1}	SM 5910	0.009	0.002	***0.014***	0.00	0.011	0.01	0.01	0.014
UV Transmittance (by calc from UVA)*	%	*calc*			***96.9***	0.8	97.5	97.7	97.7	96.8
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	SM2340B	3	3			ND	ND	ND	ND
Chloride*	mg/L	EPA 300.0	1	0.025	***23.8***	9.81	16	15	15	16
Sulfate*	mg/L	EPA 300.0	0.5	0.06	***0.7***	0.41	1.1	0.76	0.64	0.93
Total Dissolved Solids (TDS)*	mg/L	E160.1/SM2540C	10	4.2	***108.5***	36.46	80	58	76	86
Alkalinity as CaCO3**	mg/L	SM2320B	2		***10.3***	1.55	9	8	6	10
Ammonia**	mg-N/L	EPA 350.1	0.2		***0.65***	0.16	0.531	0.51	0.486	0.508
Nitrate**	mg-N/L	EPA 353.2	0.2		***8.5***	3.42	4.85	4.65	6.5	7.54
Ortho Phosphate**	mg-P/L	EPA 365.1	0.01		***0.0***	0.00	ND	ND	ND	ND
Total Kjehldahl nitrogen (TKN)**	mg-N/L	EPA 351.2	0.5							
Biochemical Oxygen Demand (BOD)**	mg-BOD/L	SM 5210	2.0							
Total Chlorine**	mg/L									
Dissolved Oxygen (DO)**	mg/L									
pH**										
* Performed by Eurofins Eaton Analytical										
** Performed by Ray Stoyer WRF lab										

Parameter	4/28/16	5/5/16	5/11/16	5/12/16	5/19/16	5/20/16	5/25/16	5/26/16	6/2/16	6/8/16
Aluminum Total ICAP/MS*	ND	5.5		ND	0.89			8.4	3.4	
Barium Total ICAP/MS*	ND	ND		ND	ND			1.0	0.39	
Calcium Total ICAP*	ND	ND		ND	ND			0.33	0.15	
Iron Total ICAP*	ND	ND		ND	ND			ND	0.0028	
Magnesium Total ICAP*	0.020	0.016		0.011	0.011			0.1	0.027	
Potassium Total ICAP*	2.4	2		2.1	2			2.1	3.4	
Silica*	0.43	0.48		0.45	0.36			0.47	0.77	
Sodium Total ICAP*	20	18		19	18			19	25	
Strontium ICAP*	0.00087	0.00081		0.00045	0.0026			0.0059	0.0011	
Total Organic Carbon*	0.24	0.34		0.28	0.29			0.43	1.1	
Dissolved UV abs. at 254 nm*	0.025	0.01		0.014	0.012			0.009	0.015	
UV Transmittance (by calc from UVA)*	94.4	97.7		96.8	97.3			97.9	96.6	
Total Hardness as CaCO3 by ICP (calc.)*	ND	ND		ND	ND			ND	ND	
Chloride*	15	15		13	11			13	20	
Sulfate*	0.76	0.70		0.46	0.56			0.60	0.53	
Total Dissolved Solids (TDS)*	80	82		74	62			78	90	
Alkalinity as CaCO3**	10	12		10	10			8	12	
Ammonia**	0.49	0.486		0.5	0.468			0.414	0.771	
Nitrate**	6.36	5.84		5.48	4.47			6.18	5.7	
Ortho Phosphate**	ND	ND		ND	ND			ND	ND	
Total Kjehldahl nitrogen (TKN)**						ND		ND	ND	
Biochemical Oxygen Demand (BOD)**			ND				ND			ND
Total Chlorine**										
Dissolved Oxygen (DO)**										
pH**										
* Performed by Eurofins Eaton Analytical										
** Performed by Ray Stoyer WRF lab										

Parameter	6/9/16	6/16/16	6/22/16	6/23/16	6/30/16	7/14/16	7/28/16	8/4/16	8/11/16	8/18/16
Aluminum Total ICAP/MS*	ND	ND		ND	ND	ND	1.6	0.9	ND	1.2
Barium Total ICAP/MS*	ND	ND		ND	ND	ND	0.40	0.39	ND	0.18
Calcium Total ICAP*	ND	ND		ND	ND	D	0.33	0.14	0.18	0.14
Iron Total ICAP*	ND	ND		ND	ND	ND	ND	ND	ND	ND
Magnesium Total ICAP*	0.018	ND		0.015	0.018	0.014	0.1	0.036	0.034	0.034
Potassium Total ICAP*	2.9	3.1		2.8	3.3	2.8	4.9	4.4	3.1	3.8
Silica*	0.7	0.73		0.82	0.89	0.83	1.5	1.1	0.62	1
Sodium Total ICAP*	25	27		27	32	27	45	40	26	36
Strontium ICAP*	0.00074	0.00075		0.001	0.00095	0.0008	0.0043	0.0016	0.002	0.0016
Total Organic Carbon*	0.2	0.24		0.42	0.33	0.39	0.38	0.32	0.43	0.64
Dissolved UV abs. at 254 nm*	0.01	0.008		0.017	0.012	0.016	0.018	0.018	0.01	0.013
UV Transmittance (by calc from UVA)*	97.7	98.2		96.2	97.3	96.4	95.9	95.9	97.7	97.1
Total Hardness as CaCO3 by ICP (calc.)*	ND	ND		ND	ND	ND	ND	ND	ND	ND
Chloride*	20	20		22	23	23	38	32	19	30
Sulfate*	0.49	0.50		0.45	0.39	0.41	2.00	1.00	0.56	0.92
Total Dissolved Solids (TDS)*	62	100		92	100	94	140	150	100	120
Alkalinity as CaCO3**	9	12		12						
Ammonia**	0.6	0.67		0.762						
Nitrate**	6.28	7.2		5.6						
Ortho Phosphate**	ND	ND		ND						
Total Kjehldahl nitrogen (TKN)**	ND									
Biochemical Oxygen Demand (BOD)**			ND							
Total Chlorine**										
Dissolved Oxygen (DO)**										
pH**										
* Performed by Eurofins Eaton Analytical										
** Performed by Ray Stoyer WRF lab										

Parameter	8/24/16	8/25/16	9/1/16	9/8/16
Aluminum Total ICAP/MS*			1.4	0.92
Barium Total ICAP/MS*			ND	0.28
Calcium Total ICAP*			ND	ND
Iron Total ICAP*			ND	ND
Magnesium Total ICAP*			0.017	0.023
Potassium Total ICAP*			3.4	3.4
Silica*			0.87	0.98
Sodium Total ICAP*			29	32
Strontium ICAP*			0.001	0.0011
Total Organic Carbon*			0.3	0.44
Dissolved UV abs. at 254 nm*			0.016	0.011
UV Transmittance (by calc from UVA)*			96.4	97.5
Total Hardness as CaCO3 by ICP (calc.)*			ND	ND
Chloride*			19	22
Sulfate*			0.54	0.62
Total Dissolved Solids (TDS)*			100	100
Alkalinity as CaCO3**		12	10	12
Ammonia**		0.678	0.894	0.724
Nitrate**		10.5	7.55	8.34
Ortho Phosphate**		0.0155	ND	0.0109
Total Kjehldahl nitrogen (TKN)**				
Biochemical Oxygen Demand (BOD)**	ND			
Total Chlorine**	2.8			
Dissolved Oxygen (DO)**				
pH**	5.51			
* Performed by Eurofins Eaton Analytical				
** Performed by Ray Stoyer WRF lab				

Parameter	9/9/16	9/15/16	9/21/16	9/22/16	9/29/16	9/30/16	10/5/16	10/6/16	10/13/16	10/19/16
Aluminum Total ICAP/MS*		1.1		ND	1.5			1.7	0.8	
Barium Total ICAP/MS*		ND		0.26	ND			0.23	ND	
Calcium Total ICAP*		ND		ND	ND			0.2	0.14	
Iron Total ICAP*		ND		ND	ND			ND	ND	
Magnesium Total ICAP*		0.0067		0.022	0.025			0.043	0.026	
Potassium Total ICAP*		3.4		3.1	3.9			6	4.7	
Silica*		0.88		0.81	1			1.6	1.2	
Sodium Total ICAP*		30		29	32			54	42	
Strontium ICAP*		0.001		0.0011	0.0014			0.0022	0.0021	
Total Organic Carbon*		0.33		0.3	0.31			0.4	0.3	
Dissolved UV abs. at 254 nm*		0.014		0.011	0.016			0.018	0.012	
UV Transmittance (by calc from UVA)*		96.8		97.5	96.4			95.9	97.3	
Total Hardness as CaCO3 by ICP (calc.)*		ND		ND	ND			ND	ND	
Chloride*		21		21	23			41	33	
Sulfate*		0.65		0.59	0.65			1.00	0.66	
Total Dissolved Solids (TDS)*		100		110	120			180	180	
Alkalinity as CaCO3**		10		10	12	12		11	10	
Ammonia**		0.538		0.643	0.686	0.657		0.882	0.884	
Nitrate**		8.94		7.64	9.96	7.2		13.8	14.6	
Ortho Phosphate**		ND		ND	ND	ND		ND	ND	
Total Kjehldahl nitrogen (TKN)**				ND				ND	ND	
Biochemical Oxygen Demand (BOD)**	ND		ND				ND			ND
Total Chlorine**	2.7		2.7				2.6			2.6
Dissolved Oxygen (DO)**	6.94		5.88				7.1			5.63
pH**	5.51		5.49				5.61			5.54
* Performed by Eurofins Eaton Analytical										
** Performed by Ray Stoyer WRF lab										

Parameter	10/20/16	10/27/16	11/2/16	11/3/16	11/10/16
Aluminum Total ICAP/MS*	ND	ND		ND	8.4
Barium Total ICAP/MS*	ND	ND		0.23	0.60
Calcium Total ICAP*	0.15	0.14		0.23	0.58
Iron Total ICAP*	ND	ND		ND	ND
Magnesium Total ICAP*	0.026	0.026		0.041	0.17
Potassium Total ICAP*	5.7	4.8		6.2	5.8
Silica*	1.4	1.2		1.9	1.7
Sodium Total ICAP*	46	43		57	52
Strontium ICAP*	0.0015	0.0014		0.0021	0.0058
Total Organic Carbon*	0.34	0.49		0.85	0.7
Dissolved UV abs. at 254 nm*	0.012	0.01		0.02	0.014
UV Transmittance (by calc from UVA)*	97.3	97.7		95.5	96.8
Total Hardness as CaCO3 by ICP (calc.)*	ND	ND		ND	ND
Chloride*	34	31		49	43
Sulfate*	0.54	0.46		0.81	2.2
Total Dissolved Solids (TDS)*	160	140		170	170
Alkalinity as CaCO3**	10	10		10	12
Ammonia**	0.554	0.986		0.687	0.794
Nitrate**	13	14		16	12.1
Ortho Phosphate**	0.0131	ND		0.0122	0.0124
Total Kjehldahl nitrogen (TKN)**	ND			ND	
Biochemical Oxygen Demand (BOD)**			ND		
Total Chlorine**			2.5		
Dissolved Oxygen (DO)**			6.46		
pH**			5.58		
* Performed by Eurofins Eaton Analytical					
** Performed by Ray Stoyer WRF lab					

Appendix E – CCD Brine Water Quality Data

Parameter	Units	Method	MRL	MDL	Average	STDEV	3/8/16	3/15/16	3/24/16	4/7/16	4/28/16	5/5/16
Aluminum dissolved ICAP/MS*	µg/L	EPA 200.8	20	0.78	***350.0***	72.11	30 [1]				36 [1]	
Aluminum Total ICAP/MS*	µg/L	EPA 200.8	20	0.78	***430.0***	121.04	300 [1]			350	380	
Barium dissolved ICAP/MS*	µg/L	EPA 200.8	2	0.17	***1184.0***	693.74	83 [1]				120	
Barium Total ICAP/MS*	µg/L	EPA 200.8	2	0.17	***1489.0***	452.02	740			1500	1400	
Calcium Dissolved ICAP*	mg/L	EPA 200.7	1	0.12	***1361.7***	494.39	870				1200	
Calcium Total ICAP*	mg/L	EPA 200.7	1	0.12	***1268.0***	215.03	880			1400	1400	
Iron Dissolved ICAP*	mg/L	EPA 200.7	0.02	0.0026	***0.88***	0.40	0.74				0.92	
Iron Total ICAP*	mg/L	EPA 200.7	0.02	0.0026	***1.23***	0.55	0.78			0.9	0.98	
Magnesium Dissolved ICAP*	mg/L	EPA 200.7	0.1	0.003	***478.3***	161.30	330				420	
Magnesium Total ICAP*	mg/L	EPA 200.7	0.1	0.003	***542.0***	166.25	330			540	440	
Potassium Dissolved ICAP*	mg/L	EPA 200.7	1	0.13	***370.0***	125.22	260				360	
Potassium Total ICAP*	mg/L	EPA 200.7	1	0.13	***418.0***	141.09	250			340	370	
Dissolved Silica*	mg/L	EPA 200.7	0.5	0.1	***210.0***	54.77						
Silica*	mg/L	EPA 200.7	0.43	0.1	***209.0***	82.79	140			90	150	
Sodium Dissolved ICAP*	mg/L	EPA 200.7	1	0.11	***3166.7***	1150.07	2100				2800	
Sodium Total ICAP*	mg/L	EPA 200.7	1	0.11	***3570.0***	1288.45	2100			2900	2900	
Strontium ICAP*	mg/L	EPA 200.7/UCMR 200.8	0.01	0.002	***16.3***	4.98	8.8			18	14	
Strontium Dissolved ICAP*	mg/L	EPA 200.7/UCMR 200.8	0.01	0.002	***15.2***	5.91	8.6					
Total Organic Carbon*	mg/L	SM5310C/E415.3	0.3	0.042	***202.0***	58.08	140			150	150	
Dissolved Organic Carbon*	mg/L	SM5310C	0.3	0.042	***205.0***	49.33	150					
Dissolved UV abs. at 254 nm*	cm^{-1}	SM 5910	0.009	0.002	***3.8***	1.03	2.4			3.02	2.7	
UV Transmittance (by calc from UVA)*	%	*calc*			***0.1***	0.13	0.4			0.1	0.2	
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	SM2340B	3	3	***5590.0***	1458.65	3500			5700	5300	
Chloride*	mg/L	EPA 300.0	1	0.025	***4550.0***	1356.67	2800			3600	3600	
Sulfate*	mg/L	EPA 300.0	0.5	0.06	***6570.0***	1976.56	3700			6100	5600	
Total Dissolved Solids (TDS)*	mg/L	E160.1/SM2540C	10	4.2	***21133.3***	5343.44	12000			17000	13000	
Alkalinity as CaCO3**	mg/L	SM2320B	2		***911.1***	506.76	930	1088	590	450	680	900
Ammonia**	mg-N/L	EPA 350.1	0.2		***12.8***	3.71	17.6	12.2	7.72	8.88	8.95	9.53
Nitrate**	mg-N/L	EPA 353.2	0.2		***265.3***	81.08	195	166	263	273	230	197
Ortho Phosphate**	mg-P/L	EPA 365.1	0.01		***1.28***	0.89	0.804	0.582	0.666	0.875	1.2	1.7
* Performed by Eurofins Eaton Analytical												
** Performed by Ray Stoyer WRF lab												
[1] Analysis did not meet one or more of the QC criteria												
[2] Sample required dillution due to matrix												
[3] Target analyte detected in blank at, or above, method acceptance criteria												

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Parameter	5/12/16	5/19/16	5/26/16	6/2/16	6/9/16	6/16/16	6/23/16	6/30/16
Aluminum dissolved ICAP/MS*								370
Aluminum Total ICAP/MS*			270					310
Barium dissolved ICAP/MS*								1100
Barium Total ICAP/MS*			1000					950
Calcium Dissolved ICAP*								1100
Calcium Total ICAP*			1000					1100
Iron Dissolved ICAP*								0.5
Iron Total ICAP*			0.81					0.51
Magnesium Dissolved ICAP*								360
Magnesium Total ICAP*			350					400
Potassium Dissolved ICAP*								260
Potassium Total ICAP*			300					300
Dissolved Silica*								170
Silica*			160					150
Sodium Dissolved ICAP*								2400
Sodium Total ICAP*			2400					2700
Strontium ICAP*			12					11
Strontium Dissolved ICAP*								
Total Organic Carbon*			160					180
Dissolved Organic Carbon*								170 [3]
Dissolved UV abs. at 254 nm*			2.9					3.8
UV Transmittance (by calc from UVA)*			0.1					0.0
Total Hardness as CaCO3 by ICP (calc.)*			3900					4400
Chloride*			3600					3400
Sulfate*			4600					4300
Total Dissolved Solids (TDS)*			14000					17000
Alkalinity as CaCO3**	640	500	500	1980	940	570	1340	
Ammonia**	9.13	9.74	9.54	9.96	13.2	11	10.9	
Nitrate**	272	202	222	154	172	220	154	
Ortho Phosphate**		0.932	0.686	0.542	0.764	0.615	0.716	
* Performed by Eurofins Eaton Analytical								
** Performed by Ray Stoyer WRF lab								
[1] Analysis did not meet one or more of the Q(								
[2] Sample required dillution due to matrix								
[3] Target analyte detected in blank at, or abov								

Parameter	8/25/16	9/1/16	9/29/16	9/30/16	10/4/16	10/6/16	10/11/16	10/13/16	10/18/16	10/20/16	10/27/16	11/3/16
Aluminum dissolved ICAP/MS*	410		120 [2]								270	
Aluminum Total ICAP/MS*	670		500							500	460	
Barium dissolved ICAP/MS*	1100		1700								1900	
Barium Total ICAP/MS*	1900		1800							2000	1900	
Calcium Dissolved ICAP*	1100		1700								2200	
Calcium Total ICAP*	1300		1600							1300	1300	
Iron Dissolved ICAP*	0.98		0.547								1.6	
Iron Total ICAP*	1.2		1.2							2	1.9	
Magnesium Dissolved ICAP*	400		640								720	
Magnesium Total ICAP*	500		620							720	730	
Potassium Dissolved ICAP*	310		450								580	
Potassium Total ICAP*	370		420							610	580	
Dissolved Silica*	180		200								290	
Silica*	210		270							280	320	
Sodium Dissolved ICAP*	2700		3800								5200	
Sodium Total ICAP*	3200		3500							4900	5500	
Strontium ICAP*	20		21							16	25	
Strontium Dissolved ICAP*			20								17	
Total Organic Carbon*	200		200							270	270	
Dissolved Organic Carbon*	200		200								270	
Dissolved UV abs. at 254 nm*	3.8		3.7							5	4.8	
UV Transmittance (by calc from UVA)*	0.0		0.0							0.0	0.0	
Total Hardness as CaCO3 by ICP (calc.)*	5300		6500							6200	8400	
Chloride*	5300		4400							6100	6300	
Sulfate*	7600		7500							9200	8400	
Total Dissolved Solids (TDS)*	20000		21000		27000	24000	26000	26000	27000	22000	26000	
Alkalinity as CaCO3**	418	340	720	800		840		920		900	930	2460
Ammonia**	16.8	14.4	16.9	13.1		17.9		16		11.5	21.8	15.9
Nitrate**	298	295	306	229		332		371		398	412	350
Ortho Phosphate**	0.975	1.16	1.1	1.26		1.4		3.54		3.93	2.26	1.29
* Performed by Eurofins Eaton Analytical												
** Performed by Ray Stoyer WRF lab												
[1] Analysis did not meet one or more of the Q												
[2] Sample required dillution due to matrix												
[3] Target analyte detected in blank at, or abov												

Parameter	11/10/16
Aluminum dissolved ICAP/MS*	
Aluminum Total ICAP/MS*	430
Barium dissolved ICAP/MS*	
Barium Total ICAP/MS*	1700
Calcium Dissolved ICAP*	
Calcium Total ICAP*	1400
Iron Dissolved ICAP*	
Iron Total ICAP*	2
Magnesium Dissolved ICAP*	
Magnesium Total ICAP*	790
Potassium Dissolved ICAP*	
Potassium Total ICAP*	640
Dissolved Silica*	
Silica*	320
Sodium Dissolved ICAP*	
Sodium Total ICAP*	5600
Strontium ICAP*	17
Strontium Dissolved ICAP*	
Total Organic Carbon*	300
Dissolved Organic Carbon*	
Dissolved UV abs. at 254 nm*	5.4
UV Transmittance (by calc from UVA)*	0.0
Total Hardness as CaCO3 by ICP (calc.)*	6700
Chloride*	6400
Sulfate*	8700
Total Dissolved Solids (TDS)*	25000
Alkalinity as CaCO3**	1520
Ammonia**	12.8
Nitrate**	390
Ortho Phosphate**	1.14
* Performed by Eurofins Eaton Analytical	
** Performed by Ray Stoyer WRF lab	
[1] Analysis did not meet one or more of the Q(	
[2] Sample required dillution due to matrix	
[3] Target analyte detected in blank at, or abov	

Appendix F – cRRO Feed Water Quality Data

Appendix F - cRRO Feed Water Quality

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Parameter	Units	MRL	MDL	Average	STDEV	1/12/17	1/19/17	1/26/17	2/3/17	2/9/17	2/16/17
Aluminum Total ICAP/MS*	µg/L	20	0.78	***110.6***	170.51	651	56	52 [2]	63 [1]	74 [1]	50
Barium Total ICAP/MS*	µg/L	2	0.17	***245.8***	64.87	260	280	240	320	320	240
Calcium Total ICAP*	mg/L	1	0.12	***299.2***	62.01	260	320	360	380	340	270
Iron Total ICAP*	mg/L	0.02	0.0026	***0.1***	0.03	0.2	0.19	0.14	0.13	0.16	0.14
Magnesium Total ICAP*	mg/L	0.1	0.003	***123.3***	31.04	97	130	160	160	140	100
Potassium Total ICAP*	mg/L	1	0.13	***65.8***	7.22	69	73	60	74	74	67
Silica*	mg/L	0.43	0.1	***73.6***	22.02	58	60	100	82	75	58
Sodium Total ICAP*	mg/L	1	0.11	***715.0***	96.53	640 [3]	750	850	780	780	700
Strontium ICAP*	mg/L	0.01	0.002	***2.9***	1.00	3	3.3	4.8	4.1	3.3	2.5
Total Organic Carbon*	mg/L	0.3	0.042	***39.3***	6.53	43	38	41	41	48	35
Dissolved Organic Carbon*	mg/L	0.3	0.02	***37.0***	N/A		37				
Dissolved UV abs. at 254 nm*	cm^{-1}	0.009	0.002	***0.7***	0.16	0.65	0.68	0.97	0.68	0.66	0.65
UV Transmittance (by calc from UVA)*	%			***21.7***	6.64	22.4	20.9	10.7	20.9	21.9	22.4
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	3	3	***1253.3***	288.99	1000	1300	1600	1600	1400	1100
Chloride*	mg/L	1	0.025	***936.7***	82.28	900	990	980	1000	1000	980
Sulfate*	mg/L	0.5	0.06	***1216.7***	307.85	1200	1400	1500	1600	1300	1100
Total Dissolved Solids (TDS)*	mg/L	10	4.2	***3700.0***	670.14	3600	3800	4400	4400	4000	3600
Alkalinity as CaCO3**	mg/L	2		***197.4***	45.37			166	180	168	176
Ammonia**	mg-N/L	0.2		***2.1***	0.33			2.14	2.27	2.3	2.45
Nitrate**	mg-N/L	0.2		***54.1***	7.20			61	62.7	58.1	50.9
Ortho Phosphate**	mg-P/L	0.01		***1.3***	3.41			11	0.218	0.22	0.116
* Performed by Eurofins Eaton											
** Performed by Ray Stoyer WRF lab											
[1] Analysis did not meet one or more of the QC criteria											
[2] Sample required dillution due to matrix											
[3] Target analyte detected in blank at, or above, method acceptance criteria											

Parameter	2/24/17	3/2/17	3/9/17	3/16/17	3/23/17	3/30/17
Aluminum Total ICAP/MS*	64	87	62	59	50	59 [1]
Barium Total ICAP/MS*	330	230	260	190	160	120
Calcium Total ICAP*	330	350	340	220	220	200
Iron Total ICAP*	0.11	0.1	0.11	0.099	0.11	0.14
Magnesium Total ICAP*	140	150	150	91	84	78
Potassium Total ICAP*	69	52	69	55	62	66
Silica*	79	120	93	56	50	52
Sodium Total ICAP*	720	800	810	600	580	570
Strontium ICAP*	3.5	2.9	2.9	1.8	1.5	1.5
Total Organic Carbon*	39	52	40	30	35	30
Dissolved Organic Carbon*						
Dissolved UV abs. at 254 nm*	0.69	1	0.69	0.5	0.52	0.54
UV Transmittance (by calc from UVA)*	20.4	10.0	20.4	31.6	30.2	28.8
Total Hardness as CaCO3 by ICP (calc.)*	1400	1500	1500	920	900	820
Chloride*	980	1000	980	840	820	770
Sulfate*	1400	1500	1300	850	830	620
Total Dissolved Solids (TDS)*	4300	4200	4000	2900	2800	2400
Alkalinity as CaCO3**	202	286	242	210	124	220
Ammonia**	1.72	2.1	1.88	2.48	2.09	1.45
Nitrate**	59	53.2	60.6	42.2	47.3	46.1
Ortho Phosphate**	0.194	0.193	0.284	0.259	0.179	0.285
* Performed by Eurofins Eaton						
** Performed by Ray Stoyer WRF lab						
[1] Analysis did not meet one or more of the QC crit						
[2] Sample required dillution due to matrix						
[3] Target analyte detected in blank at, or above, me						

Appendix G – cRRO Permeate Water Quality Data

Parameter	Units	MRL	MDL	Average	STDEV	1/12/17	1/19/17	1/25/17	1/26/17	2/3/17	2/8/17
Aluminum Total ICAP/MS*	µg/L	20	0.78	***1.4***	0.65	0.82	1.3		ND	ND	
Barium Total ICAP/MS*	µg/L	2	0.17	***0.4***	0.08	ND	ND		ND	ND	
Calcium Total ICAP*	mg/L	1	0.12	***0.1***	0.02	ND	ND		ND	ND	
Iron Total ICAP*	mg/L	0.02	0.0026	***N/A***	N/A	ND	ND		ND	ND	
Magnesium Total ICAP*	mg/L	0.1	0.003	***0.0***	0.01	0.021	0.31		0.016	0.024	
Potassium Total ICAP*	mg/L	1	0.13	***1.9***	0.42	1.5	1.4		1.3	2.2	
Silica*	mg/L	0.43	0.1	***1.1***	0.49	0.42	0.38		0.81	1	
Sodium Total ICAP*	mg/L	1	0.11	***23.1***	4.16	16	16		20	25	
Strontium ICAP*	mg/L	0.01	0.002	***0.0***	0.00	0.00072	ND		0.00077	0.001	
Total Organic Carbon*	mg/L	0.3	0.042	***0.3***	0.10	0.23	0.22		0.21	0.25	
Dissolved Organic Carbon*	mg/L	0.3	0.02	***0.4***	N/A		0.36[4]				
Dissolved UV abs. at 254 nm*	cm^{-1}	0.009	0.002	***0.0***	0.00	0.01	0.01		0.01	0.013	
UV Transmittance (by calc from UVA)*	%			***97.1***	0.88	97.7	97.7		97.7	97.1	
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	3	3	***N/A***	N/A	ND	ND		ND	ND	
Chloride*	mg/L	1	0.025	***16.8***	4.76	10	9.9		11	18	
Sulfate*	mg/L	0.5	0.06	***0.5***	0.14	0.49	0.42		0.35	0.69	
Total Dissolved Solids (TDS)*	mg/L	10	4.2	***83.6***	18.48	54	53		71	92	
Alkalinity as CaCO3**	mg/L	2		***8.4***	1.01				8	8	
Ammonia**	mg-N/L	0.2		***0.5***	0.05				0.465	0.398	
Nitrate**	mg-N/L	0.2		***6.3***	0.96				4.77	7.08	
Ortho Phosphate**	mg-P/L	0.01		***0.0***	0.07				0.0242	ND	
Total Kjehldahl nitrogen (TKN)**	mg-N/L	0.5		***N/A***	N/A				ND		
Biochemical Oxygen Demand (BOD)**	mg-BOD/L	2.0		***N/A***	N/A			ND			ND
Total Chlorine**	mg/L							3.1			1.4
Dissolved Oxygen (DO)**	mg/L							7.28			6.52
pH								5.32			5.26
* Performed by Eurofins Eaton											
** Performed by Ray Stoyer WRF lab											
[4] Sample analyzed after more than 48 hours											

Parameter	2/9/17	2/16/17	2/22/17	2/24/17	3/2/17	3/8/17	3/9/17	3/16/17	3/23/17
Aluminum Total ICAP/MS*	ND	ND		ND	2.1		ND	ND	ND
Barium Total ICAP/MS*	ND	ND		0.42	0.31		ND	ND	ND
Calcium Total ICAP*	ND	ND		0.14	0.12		0.13	0.16	ND
Iron Total ICAP*	ND	ND		ND	ND		ND	ND	ND
Magnesium Total ICAP*	0.016	0.014		0.035	0.030		0.036	0.041	0.022
Potassium Total ICAP*	2.1	2		2.3	1.6		2.2	2.5	2.3
Silica*	0.95	0.8		1.3	1.9		1.5	1.7	1.1
Sodium Total ICAP*	24	22		26	26		27	28	24
Strontium ICAP*	0.00087	0.00062		0.0014	0.0009		0.001	0.0013	0.00072
Total Organic Carbon*	0.2	0.26		0.26	0.55		0.23	0.19	0.3
Dissolved Organic Carbon*									
Dissolved UV abs. at 254 nm*	0.014	0.018		0.022	0.013		0.01	0.011	0.01
UV Transmittance (by calc from UVA)*	96.8	95.9		95.1	97.1		97.7	97.5	97.7
Total Hardness as CaCO3 by ICP (calc.)*	ND	ND		ND	ND		ND	ND	ND
Chloride*	17	16		21	21		20	24	17
Sulfate*	0.37	0.32		0.71	0.43		0.55	0.41	0.32
Total Dissolved Solids (TDS)*	86	80		100	100		94	110	80
Alkalinity as CaCO3**	8	7		10	10		9	8	8
Ammonia**	0.4	0.569		0.522	0.498		0.476	0.504	0.487
Nitrate**	6.14	5.61		8.04	6.54		6.91	5.75	5.92
Ortho Phosphate**	0.163	ND		0.0109	ND		ND	0.0117	0.0182
Total Kjehldahl nitrogen (TKN)**	ND			ND			ND		
Biochemical Oxygen Demand (BOD)**			ND			ND			ND
Total Chlorine**			2.8			2.7			2.7
Dissolved Oxygen (DO)**			5.62			5.5			5.44
pH			5.38			6.55			5.49
* Performed by Eurofins Eaton									
** Performed by Ray Stoyer WRF lab									
[4] Sample analyzed after more than 48 hours									

Appendix H – cRRO Brine Water Quality Data

Parameter	Units	MRL	MDL	Average	STDEV	1/19/17	1/26/17
Aluminum dissolved ICAP/MS*	µg/L	20	0.78	***132.5***	49.92	200	
Aluminum Total ICAP/MS*	µg/L	20	0.78	***242.5***	55.00	230	
Barium dissolved ICAP/MS*	µg/L	2	0.17	***915.0***	306.97	1000	
Barium Total ICAP/MS*	µg/L	2	0.17	***1092.5***	438.43	1100	
Calcium Dissolved ICAP*	mg/L	1	0.12	***1107.5***	256.04	1200	
Calcium Total ICAP*	mg/L	1	0.12	***1117.5***	302.03	1200	
Iron Dissolved ICAP*	mg/L	0.02	0.0026	***0.4***	0.20	0.71	
Iron Total ICAP*	mg/L	0.02	0.0026	***0.5***	0.13	0.7	
Magnesium Dissolved ICAP*	mg/L	0.1	0.003	***460.0***	123.56	490	
Magnesium Total ICAP*	mg/L	0.1	0.003	***485.0***	157.80	500	
Potassium Dissolved ICAP*	mg/L	1	0.13	***240.0***	32.66	280	
Potassium Total ICAP*	mg/L	1	0.13	***252.5***	41.93	280	
Dissolved Silica*	mg/L	0.5	0.1	***207.5***	37.75	220	
Silica*	mg/L	0.43	0.1	***227.5***	88.08	180	
Sodium Dissolved ICAP*	mg/L	1	0.11	***2525.0***	427.20	2800	
Sodium Total ICAP*	mg/L	1	0.11	***2675.0***	607.59	2800	
Strontium ICAP*	mg/L	0.01	0.002	***10.9***	4.28	13	
Strontium Dissolved ICAP*	mg/L	0.01	0.002	***9.4***	6.58		
Total Organic Carbon*	mg/L	0.3	0.042	***232.5***	185.18	130	
Dissolved Organic Carbon*	mg/L	0.3	0.042	***121.3***	24.19	130	
Dissolved UV abs. at 254 nm*	cm^{-1}	0.009	0.002	***2.5***	0.54	2.8	
UV Transmittance (by calc from UVA)*	%			***0.6***	0.91	0.2	
Total Hardness as CaCO3 by ICP (calc.)*	mg/L	3	3	***4850.0***	1279.32	5000	
Chloride*	mg/L	1	0.025	***3175.0***	478.71	3400	
Sulfate*	mg/L	0.5	0.06	***4425.0***	1289.38	5100	
Total Dissolved Solids (TDS)*	mg/L	10	4.2	***13275.0***	2938.68	14000	
Alkalinity as CaCO3**	mg/L	2		***680.8***	187.41		640
Ammonia**	mg-N/L	0.2		***6.3***	0.82		6.28
Nitrate**	mg-N/L	0.2		***282.8***	188.11		218
Ortho Phosphate**	mg-P/L	0.01		***8.7***	17.48		40
* Performed by Eurofins Eaton							
** Performed by Ray Stoyer WRF lab							
[1] Analysis did not meet one or more of the QC criteria							
[2] Sample required dillution due to matrix							

Parameter	2/3/17	2/9/17	2/24/17	3/9/17	3/23/17
Aluminum dissolved ICAP/MS*			90 [2]	140	100
Aluminum Total ICAP/MS*			280 [2]	290 [2]	170 [1]
Barium dissolved ICAP/MS*			1100	1100	460
Barium Total ICAP/MS*			1400	1400	470
Calcium Dissolved ICAP*			1200	1300	730
Calcium Total ICAP*			1300	1300	670
Iron Dissolved ICAP*			0.3 [2]	0.3	0.36 [1]
Iron Total ICAP*			0.48	0.52	0.38 [2]
Magnesium Dissolved ICAP*			510	560	280
Magnesium Total ICAP*			560	620	260
Potassium Dissolved ICAP*			240	240	200
Potassium Total ICAP*			270	270	190
Dissolved Silica*			200	250	160
Silica*			230	350	150
Sodium Dissolved ICAP*			2600	2800	1900
Sodium Total ICAP*			2900	3200	1800
Strontium ICAP*			14	12	4.6
Strontium Dissolved ICAP*			14		4.7
Total Organic Carbon*			150 [1]	140	510
Dissolved Organic Carbon*				140	94
Dissolved UV abs. at 254 nm*			2.8	2.7	1.7
UV Transmittance (by calc from UVA)*			0.2	0.2	2.0
Total Hardness as CaCO3 by ICP (calc.)*			5600	5800	3000
Chloride*			3200	3600	2500
Sulfate*			5200	4900	2500
Total Dissolved Solids (TDS)*			16000	14000	9100
Alkalinity as CaCO3**	720	680		944	420
Ammonia**	7.36	6.84		5.49	5.53
Nitrate**	226	213		614	143
Ortho Phosphate**	1.44	0.701		1.13	0.459
* Performed by Eurofins Eaton					
** Performed by Ray Stoyer WRF lab					
[1] Analysis did not meet one or more of the QC					
[2] Sample required dillution due to matrix					

Appendix I – CCD Permeate Special Sampling Water Quality Data

Category	Method	Units	Parameter	Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	MDL	5/19/16	5/19/16	5/19/16	5/19/16	5/19/16	5/26/16	5/26/16	
Total Metals by EPA 6000/7000	EPA 6010	mg/L	**Calcium**	0.5	0.1		**1.72**						
			Potassium	1	1		**1.92**						
			Magnesium	0.5	0.1		**0.1**						
			Sodium	0.5	0.04		**17.3**						
	EPA 7470	mg/L	**Mercury**	0.0001	0.00008	ND							
Total Metals by EPA 200	EPA 200.7	mg/L	**Silver**	0.1	0.01	ND							
			Aluminum	0.2	0.1	ND		ND					
			Arsenic	0.01	0.004	ND							
			Barium	0.01	0.004	ND							
			Beryllium	0.01	0.0002	ND							
			Cadmium	0.01	0.001	ND							
			Chromium	0.05	0.002	ND							
			Copper	0.05	0.009	ND							
			Nickel	0.05	0.004	ND							
			Lead	0.05	0.008	ND							
			Antimony	0.1	0.1	ND							
			Selenium	0.01	0.005	ND							
			Thallium	0.05	0.02	ND							
			Zinc	0.05	0.004	**0.004**	**0.028**						
			Iron	0.1	0.05		**0.093**						
			Manganese	0.03	0.03				ND				
			Boron	0.5	0.1					**0.68**			
Conventional Chemistry Parameters by Standard/EPA Methods	SM2320B	mg-$CaCO_3$/L	**Bicarbonate Alkalinity**	5	5		**10**						
	SM4500 Cl C	mg/L	**Chloride**	0.05	0.05		**20**						
	SM2120 B	Color Units	**Color**	1	1		ND						
	SM2510 B	umhos/cm	**Specific Conductance (EC)**	1	1		**117**						
	SM4500 F C	mg/L	**Fluoride**	0.1	0.031					**0.33**			
	EPA 200.7	mg-$CaCO_3$/L	**Hardness (Total)**	10	10					ND			
	SM5540 C	mg/L	**Methylene Blue Active Substances (MBAS)**	0.5	0.1					ND			
	SM4500 SO4 E	mg/L	**Sulfate as SO4**	5	1					**2.5**			
	EPA 1664 A	mg/L	**Oil & Grease**	5	1.56					ND			
	SM5310B	mg/L	**TOC**	0.3	0.15					ND			
			Aldrin	0.1	0.07	ND							
			alpha-BHC	0.05	0.04	ND							
			beta-BHC	0.05	0.05	ND							
			gamma-BHC (Lindane)	0.05	0.05	ND							
			delta-BHC	0.05	0.05	ND							

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Category	Method	Units	Parameter	Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	**MDL**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/26/16**	**5/26/16**	
Organochlorine Pesticides and PCBs by EPA 608	EPA 608	µg/L	**alpha-Chlordane**	0.1	0.04	ND							
			gamma-Chlordane	0.1	0.04	ND							
			Chlordane (Total)	0.1	0.04	ND							
			4,4'-DDD	0.1	0.04	ND							
			4,4'-DDE	0.1	0.04	ND							
			4,4'-DDT	0.1	0.08	ND							
			Dieldrin	0.1	0.04	ND							
			Endosulfan I	0.05	0.04	ND							
			Endosulfan II	0.1	0.05	ND							
			Endosulfan sulfate	0.1	0.06	ND							
			Endrin	0.1	0.05	ND							
			Endrin aldehyde	0.1	0.04	ND							
			Heptachlor	0.05	0.04	ND							
			Heptachlor epoxide	0.05	0.05	ND							
			Methoxyclor	0.5	0.13	ND							
			Toxaphene	1	1	ND							
			Arochlor-1016	0.5	0.34	ND							
			Arochlor-1221	0.5	0.34	ND							
			Arochlor-1232	0.5	0.34	ND							
			Arochlor-1242	0.5	0.34	ND							
			Arochlor-1248	0.5	0.34	ND							
			Arochlor-1254	0.5	0.34	ND							
			Arochlor-1260	0.5	0.34	ND							
			Arcolein	100	2.8	ND							
			Acrylonitrile	10	0.66	ND							
			Benzene	1	0.24	ND							
			Bromodichloromethane	1	0.17	**8.96**						**13**	10.98
			Bromoform	1	0.17	**0.40**						**0.48**	0.44
			Bromomethane	2	0.67	ND							
			Carbon tetrachloride	2	0.26	ND							
			Chlorobenzene	1	0.21	ND							
			Chlorodibromomethane	1	0.23	**3.12**						**5.1**	4.11
			Chloroethane	2	0.88	ND							
			2-Chloroethylvinyl ether	2	0.36	ND							
			Chloroform	1	0.28	**12.7**						**15.2**	13.95
			Chloromethane	2	0.76	ND							
			1,2-Dibromoethane (EDB)	1	0.26	ND							
			1,2-Dichlorobenzene	1	0.09	ND							

Category	Method	Units	Parameter										
				Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	**MDL**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/26/16**	**5/26/16**	
Purgeables by EPA Method 624	EPA 624	µg/L	**1,3-Dichlorobenzene**	1	0.15	ND							
			1,4-Dichlorobenzene	1	0.14	ND							
			1,1-Dichloroethane	1	0.31	ND							
			1,2-Dichloroethane	1	0.21	ND							
			1,1-Dichloroethane	1	0.31	ND							
			trans-1,2-Dichloroethene	1	0.19	ND							
			1,2-Dichloropropane	1	0.21	ND							
			cis-1,3-Dichloropropene	1	0.22	ND							
			trans-1,3-Dichloropropene	1	0.17	ND							
			Ethyl benzene	1	0.18	ND							
			Methylene chloride	5	0.35	ND							
			1,1,2,2-Tetrachloroethane	2	0.21	ND							
			Tetrachloroethene	1	0.66	ND							
			Toluene	1	0.21	ND							
			1,1,1-Trichloroethene	2	0.41	ND							
			1,1,2-Trichloroethene	1	0.22	ND							
			Trichloroethane	1	0.12	ND							
			Trichlorofluoromethane	2	0.36	ND							
			Vinyl chloride	2	0.43	ND							
			Methyl tert-butyl ether (MTBE)	1	0.47					ND			
			Total Trihalomethanes (TTHMs)	1	0.17							**33.8**	
			Acenaphthene	2	0.52	ND	ND						
			Acenaphthylene	2	0.87	ND	ND						
			Anthracene	2	0.63	ND	ND						
			Benzidine	50	0.18	ND	ND						
			Benzo (a) anthracene	2	0.65	ND	ND						
			Benzo (b) fluoranthene	2	1.8	ND	ND						
			Benzo (k) fluoranthene	2	1.39	ND	ND						
			Benzo (g,h,i) perylene	2	1.09	ND	ND						
			Benzo (a) pyrene	2	0.65	ND	ND						
			Bis(2-chloroethoxy)methane	2	0.49	ND	ND						
			Bis(2-chloroethyl)ether	2	0.66	ND	ND						
			Bis(2-chloroisopropyl)ether	2	0.66	ND	ND						
			Bis(2-ethylhexyl)phthalate	2	1.79	ND	ND						

Category	Method	Units	Parameter	Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	**MDL**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/19/16**	**5/26/16**	**5/26/16**	
Acid and Base/Neutral Extractables by EPA 625	EPA 625	µg/L	**4-Bromophenyl phenyl ether**	2	1.05	ND	ND						
			Butyl benzyl phthalate	2	0.91	ND	ND						
			4-Chloroaniline	10	2.86	ND	ND						
			4-Chloro-3-methylphenol	2	1.21	ND	ND						
			2-Chloronaphthalene	2	0.97	ND	ND						
			2-Chlorophenol	2	0.73	ND	ND						
			4-Chlorophenyl phenyl ether	2	0.44	ND	ND						
			Chrysene	2	0.5	ND	ND						
			Dibenz (a,h) anthracene	2	0.95	ND	ND						
			Dibenzofuran	2	0.89	ND	ND						
			Di-n-butylphthalate	2	0.52	**1.30**	**ND**						
			1,2-Dichlorobenzene	2	0.62	ND	ND						
			1,3-Dichlorobenzene	2	0.4	ND	ND						
			1,4-Dichlorobenzene	2	0.66	ND	ND						
			3,3'-Dichlorobenzidine	5	2.52	ND	ND						
			2,4-Dichlorophenol	2	0.75	ND	ND						
			Dimethyl phthalate	2	0.91	ND	ND						
			2,4-Dimethylphenol	2	1.64	ND	ND						
			Diethyl phthalate	2	0.66	ND	ND						
			4,6-Dinitro-2-methylphenol	2	0.78	ND	ND						
			2,4-Dinitrophenol	2	0.97	ND	ND						
			2,4-Dinitrotoluene	2	0.66	ND	ND						
			2,6-Dinitrotoluene	2	0.67	ND	ND						
			Di-n-octyl-phthalate	2	0.77	ND	ND						
			1,2-Diphenylhydrazine	2	0.79	ND	ND						
			Fluoranthene	2	0.6	ND	ND						
			Fluorene	2	0.55	ND	ND						
			Hexachlorobenzene	2	0.73	ND	ND						
			Hexachlorobutadiene	2	0.77	ND	ND						
			Hexachlorocyclopentadiene	2	1.17	ND	ND						
			Hexachloroethane	2	0.47	ND	ND						
			Indeno (1,2,3-cd)pyrene	2	0.99	ND	ND						
			Isophorone	2	0.57	ND	ND						
			2-Methylnaphthalene	2	1.18	ND	ND						
			2-Methylphenol	2	1.5	ND	ND						

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Category	Method	Units	Parameter	Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	MDL	5/19/16	5/19/16	5/19/16	5/19/16	5/19/16	5/26/16	5/26/16	
			4-Methylphenol	2	1.6	ND	ND						
			Naphthalene	2	0.36	ND	ND						
			2-Nitroaniline	5	2.26	ND	ND						
			3-Nitroanilini	5	2.84	ND	ND						
			4-Nitroaniline	5	1.89	ND	ND						
			Nitrobenzene	2	0.61	ND	ND						
			2-Nitrophenol	2	0.81	ND	ND						
			4-Nitrophenol	2	1.04	ND	ND						
			N-Nitrosodimethylamine (NDMA)	2	0.85	ND	ND						
			N-Nitrosodiphenylamine	2	0.96	ND	ND						
			N-Nitrosodi-n-propylamine	2	1.07	ND	ND						
			Pentachlorophenol	2	1.07	ND	ND						
			Phenanthrene	2	0.46	ND	ND						
			Phenol	2	1.08	ND	ND						
			Pyrene	2	1.15	ND	ND						
			Pyridine	2	1.46	ND	ND						
			1,2,4-Trichlorobenzene	2	0.53	ND	ND						
			2,4,5-Trichlorophenol	2	1.07	ND	ND						
			2,4,6-Trichlorophenol	2	1.19	ND	ND						
Polynuclear Aromatic Compounds by EPA Method 8270C	EPA 8270C	µg/L	Acenaphthene	2	0.77	ND					ND		
			Acenaphthylene	2	0.87	ND					ND		
			Anthracene	2	0.63	ND					ND		
			Benzo (a) pyrene	2	0.55	ND					ND		
			Benzo (b) fluoranthene	2	1.8	ND					ND		
			Benzo (k) fluoranthene	2	1.39	ND					ND		
			Benzo (g,h,i) perylene	2	1.09	ND					ND		
			Benzo (a) pyrene	2	0.65	ND					ND		
			Chrysene	2	0.5	ND					ND		
			Dibenz (a,h) anthracene	2	0.95	ND					ND		
			Fluoranthene	2	0.6	ND					ND		
			Fluorene	2	0.55	ND					ND		
			Indeno (1,2,3-cd)pyrene	2	0.99	ND					ND		
			Phenanthrene	2	0.46	ND					ND		
			Pyrene	2	1.15	ND					ND		
Transmission Electron	TEM	MF/L	Asbestos Conc (>10 µm)	0.18	0.18	ND							

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Category	Method	Units	Parameter	Sampling technique		Composite	24h Composite / Grab for Zinc and Bis-2-Ethylhexyl thalate	24h Composite	24h Composite	24h Composite / Grab for MTBE and Grease and Oil	Composite	Grab?	Average for Summary Table
				Sampling Group		Annual Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Monthly Sample Analysis	Quarterly Sample Analysis	Annual Sample Analysis	Monthly Sample Analysis	
				EnviroMatrix Analytical Log #		16E0673	16E0669	16E0670	16E0671	16E0672	16E0866	16E0865	
				MRL	MDL	5/19/16	5/19/16	5/19/16	5/19/16	5/19/16	5/26/16	5/26/16	
Microscopy (TEM) for Asbestos	TEM	MF/L	**Asbestos Conc (Total)**	0.18	0.18	ND							
Miscellaneous Physical/Conventional Chemistry Parameters	Suarez-1981	Ratio	**adj-Sodium Adsorption Ratio**	0.1	0.1		**1.00**						
	Calculation	%	**% Sodium of Irrigation Water**	0.5	0.5		**84**						

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
Haloacetic Acids	**SM 6251B**	µg/L	Bromochloroacetic acid	0.053	1	ND	-
			Dibromoacetic acid	0.054	1	ND	-
			Dichloroacetic acid	0.1	1	ND	-
			Monobromoacetic acid	0.055	1	ND	-
			Monochloroacetic acid	0.41	2	ND	-
			Total Haloacetic Acids (HAA5)	2	2	ND	-
			Trichloroacetic acid	0.1	1	ND	-
Trihalomethanes	**EPA 551.1**	µg/L	Bromodichloromethane	0.057	0.5	**21**	-
			Bromoform	0.045	0.5	**0.46**	-
			Chloroform	0.054	0.5	**40**	-
			Dibromochloromethane	0.027	0.5	**5.6**	-
			Total Trihalomethanes		0.5	**67**	-
EPA Method 556	**EPA 556**	µg/L	Acetaldehyde	0.19	1	**5.9**	-
			Formaldehyde	0.81	5	**27**	-
			2,4-DDD	0.044	0.1	ND	ND
			2,4-DDE	0.019	0.1	ND	ND
			2,4-DDT	0.014	0.1	ND	ND
			2,4-Dinitrotoluene	0.013	0.1	ND	ND
			2,6-Dinitrotoluene	0.036	0.1	ND	ND
			4,4-DDD	0.015	0.1	ND	ND
			4,4-DDE	0.018	0.1	ND	ND
			4,4-DDT	0.031	0.1	ND	ND
			Acenaphthene	0.016	0.1	ND	ND
			Acenaphthylene	0.014	0.1	**ND**	**ND**
			Acetochlor	0.009	0.1	ND	ND
			Alachlor	0.022	0.05	ND	ND
			Aldrin	0.042	0.05	**ND**	**ND**
			Alpha-BHC	0.018	0.1	ND	ND
			alpha-Chlordane ND	0.029	0.05	ND	ND
			Anthracene	0.019	0.02	ND	ND
			Atrazine	0.048	0.05	ND	ND
			Benz(a)Anthracene	0.011	0.05	ND	ND

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
Semivolatiles by GCMS	**EPA 525.2**	µg/L	Benzo(a)pyrene	0.011	0.02	ND	ND
			Benzo(b)Fluoranthene	0.011	0.02	ND	ND
			Benzo(g,h,i)Perylene	0.012	0.05	ND	ND
			Benzo(k)Fluoranthene	0.017	0.02	ND	ND
			Beta-BHC	0.02	0.1	ND	ND
			Bromacil	0.029	0.2	ND	ND
			Butachlor	0.033	0.05	ND	ND
			Butylbenzylphthalate	0.063	0.5	ND	ND
			Caffeine by method 525mod	0.02	0.05	ND	**0.065**
			Chlorobenzilate	0.019	0.1	ND	ND
			Chloroneb	0.016	0.1	ND	ND
			Chlorothalonil(Draconil,Bravo)	0.016	0.1	ND	ND
			Chlorpyrifos (Dursban)	0.019	0.05	ND	ND
			Chrysene	0.014	0.02	ND	ND
			Delta-BHC	0.033	0.1	ND	ND
			Di-(2-Ethylhexyl)adipate	0.063	0.6	ND	ND
			Di(2-Ethylhexyl)phthalate	0.15	0.6	ND	ND
			Diazinon (Qualitative)	0.025	0.1	ND	ND
			Dibenz(a,h)Anthracene	0.033	0.05	ND	ND
			Dichlorvos (DDVP)	0.022	0.05	ND	ND
			Dieldrin	0.017	0.2	ND	ND
			Diethylphthalate	0.051	0.5	ND	ND
			Dimethoate	0.033	0.1	ND	**ND**
			Dimethylphthalate	0.039	0.5	ND	ND
			Di-n-Butylphthalate	0.074	1	ND	ND
			Di-N-octylphthalate	0.027	0.1	ND	ND
			Endosulfan I (Alpha)	0.058	0.1	ND	ND
			Endosulfan II (Beta)	0.052	0.1	ND	ND
			Endosulfan Sulfate	0.04	0.1	ND	ND
			Endrin	0.038	0.2	ND	**ND**
			Endrin Aldehyde	0.084	0.1	ND	**ND**
			EPTC	0.013	0.1	ND	ND

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
			Fluoranthene	0.01	0.1	ND	ND
			Fluorene	0.014	0.05	ND	ND
			gamma-Chlordane	0.021	0.05	ND	ND
			Heptachlor	0.013	0.03	ND	ND
			Heptachlor Epoxide (isomer B)	0.023	0.05	ND	ND
			Hexachlorobenzene	0.041	0.05	ND	ND
			Hexachlorocyclopentadiene	0.038	0.05	ND	ND
			Indeno(1,2,3,c,d)Pyrene	0.027	0.05	ND	ND
			Isophorone	0.02	0.5	ND	ND
			Lindane	0.022	0.04	ND	ND
			Malathion	0.025	0.1	ND	ND
			Methoxychlor	0.032	0.1	ND	ND
			Metolachlor	0.016	0.05	ND	ND
			Metribuzin	0.016	0.05	ND	ND
			Molinate	0.015	0.1	ND	ND
			Naphthalene	0.014	0.3	ND	ND
			Parathion	0.037	0.1	ND	ND
			Pendimethalin	0.047	0.1	ND	ND
			Pentachlorophenol	0.32	1	**ND**	ND
			Permethrin (mixed isomers)	0.037	0.1	ND	ND
			Phenanthrene	0.008	0.04	ND	ND
			Propachlor	0.02	0.05	**ND**	ND
			Pyrene	0.008	0.05	ND	ND
			Simazine	0.028	0.05	ND	ND
			Terbacil	0.069	0.1	ND	ND
			Terbuthylazine	0.023	0.1	ND	ND
			Thiobencarb (ELAP)	0.017	0.2	ND	ND
			trans-Nonachlor	0.026	0.05	ND	ND
			Trifluralin	0.044	0.1	ND	ND
1,4-Dioxane	**EPA 522**	µg/L	1,4-Dioxane	0.085	1	**0.32**	**0.26**
Nitrosamines by GCMS	**EPA 521**	ng/L	N-Nitroso-dimethylamine (NDMA)	0.96	2	**17**	**22**

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
Bromate by UV/VIS 317	**EPA 317**	µg/L	Bromate by UV/VIS	0.2	1	ND	-
Disinfection ByProducts by 300.0	**EPA 300.0**	µg/L	Chlorate by IC	1.3	10	**98**	-
			1,7-Dimethylxanthine	3.4	10	ND	ND
			Acetaminophen	3.0	5	ND	ND
			Albuterol	2.4	5	ND	ND
			Amoxicillin (semi-quantitative)	6.4	20	ND	ND
			Andorostenedione	1.7	5	ND	ND
			Atenolol	3.9	5	**10**	**54**
			Atrazine	2.3	5	ND	ND
			Azithromycin	10	20	ND	ND
			Bezafibrate	3.5	5	ND	ND
			Bromacil	3.2	5	ND	ND
			Caffeine	4.3	5	ND	ND
			Carbadox	4.2	5	ND	ND
			Carbamazepine	1.2	5	ND	ND
			Carisoprodol	1.2	5	ND	ND
			Chloridazon	1.6	5	ND	ND
			Chlorotoluron	0.89	5	ND	ND
			Cimetidine	2.7	5	ND	ND
			Cotinine	4.8	10	**8.2**	ND
			Cyanazine	1.7	5	**2.9**	**3.4**
			DACT	3.9	5	ND	ND
			DEA	1.5	5	ND	ND
			DEET	1.1	10	**2.6**	ND
			Dehydronifedipine	1.4	5	ND	ND
			DIA	2.4	5	ND	ND
			Diazepam	1.1	5	ND	ND
			Dilantin	13	20	ND	ND
			Diltiazem	3.0	5	ND	ND

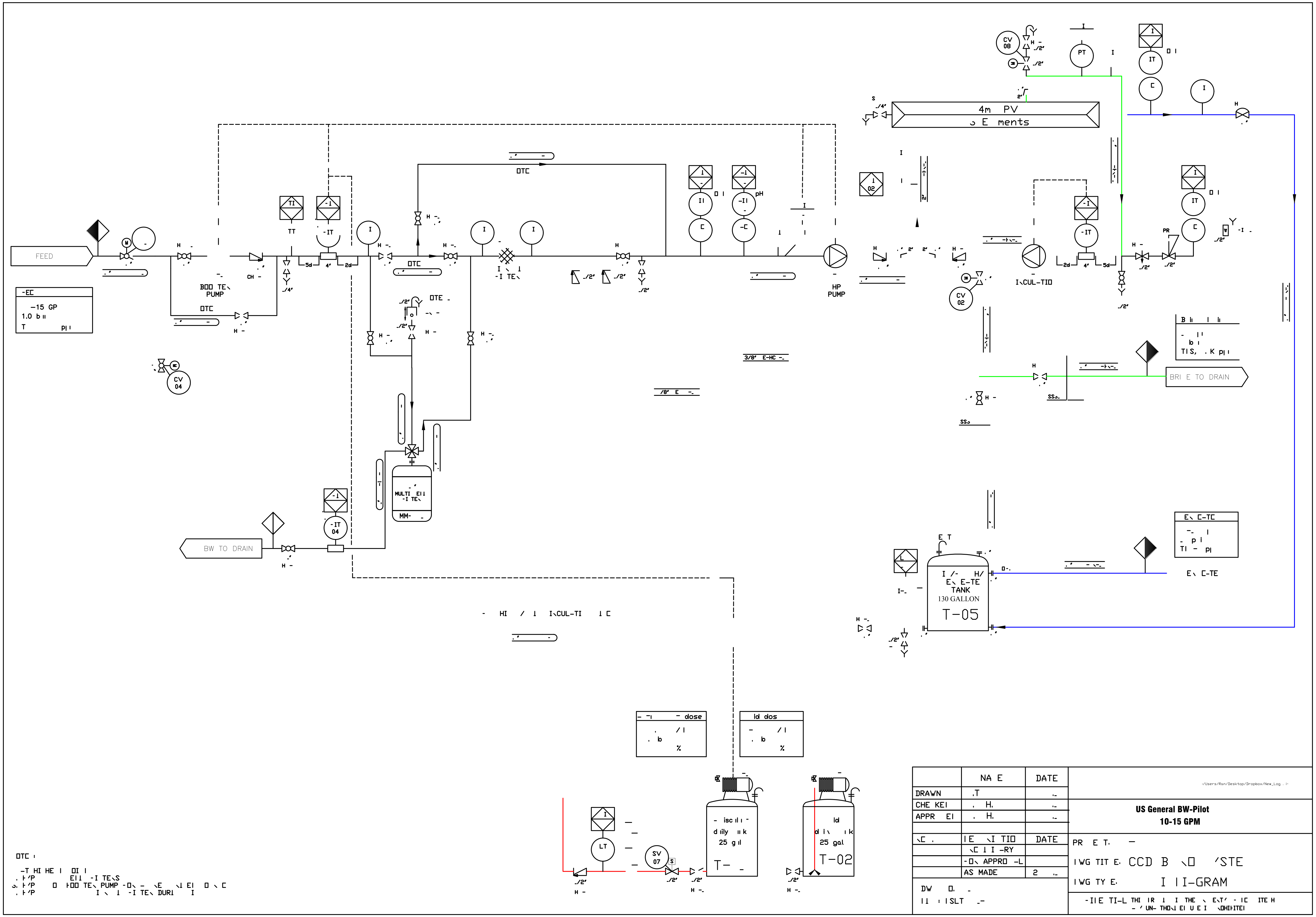
Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
Endocrine Disruptors Positive Mode	**LC/MS-MS SPE**	ng/L	Diuron	1.8	5	ND	ND
			Erythromycin	4.0	10	ND	ND
			Flumeqine	7.1	10	ND	ND
			Fluoxetine	10	10	ND	ND
			Isoproturon	12	100	ND	ND
			Ketoprofen	2.6	5	ND	ND
			Ketorolac	2.1	5	ND	ND
			Lidocaine	1.1	5	ND	ND
			Lincomycin	1.7	10	ND	ND
			Linuron	2.8	5	ND	ND
			Lopressor	5.1	20	**19**	ND
			Meclofenamic Acid	4.7	5	ND	ND
			Meprobamate	2.0	5	ND	ND
			Metazachlor	1.3	5	ND	ND
			Metolachlor		5	ND	ND
			Nifedipine	12	20	ND	ND
			Norethisterone	2.3	5	ND	ND
			OUST (Sulfameturon,methyl)	2.5	5	ND	ND
			Oxolinic acid	2.5	10	ND	ND
			Pentoxifylline	1.5	5	ND	ND
			Phenazone	5.0	5	ND	ND
			Primidone	4.8	5	ND	ND
			Progesterone	2.9	5	ND	ND
			Propazine	1.8	5	ND	ND
			Quinoline	2.5	5	ND	**3.6**
			Simazine	1.2	5	ND	ND
			Sulfachloropyridazine	2.1	5	ND	ND
			Sulfadiazine	3.9	5	ND	ND
			Sulfadimethoxine	1.6	5	ND	ND
			Sulfamerazine	4.6	5	ND	ND
			Sulfamethazine	1.5	5	ND	ND
			Sulfamethizole	3.2	5	ND	ND

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
			Sulfamethoxazole	2.8	5	ND	ND
			Sulfathiazole	2.4	5	ND	ND
			TCEP	3.2	10	ND	**4.4**
			TCPP	20	100	ND	ND
			TDCPP	20	100	ND	ND
			Testosterone	2.5	5	ND	ND
			Theobromine	3.2	10	ND	ND
			Theophylline	4.8	20	ND	ND
			Thiabendazole	2.4	5	ND	ND
			Trimethoprim	1.8	5	ND	ND
Endocrine Disruptors Negative Mode	**LC/MS-MS SPE**	ng/L	2,4-D	5.0	5	ND	ND
			4-nonylphenol (semi-quantitative)	50	100	ND	ND
			4-tert-Octylphenol	6.9	50	ND	ND
			Acesulfame-K	20	20	ND	ND
			Bendroflumethiazide	4.4	5	ND	ND
			BPA	7.2	10	ND	ND
			Butalbital	2.9	5	ND	ND
			Butylparaben	3.3	5	ND	ND
			Chloramphenicol	3.1	10	ND	ND
			Clofibric Acid	5.0	5	ND	ND
			Diclofenac	3.3	5	ND	ND
			Estradiol	4.4	5	ND	ND
			Estriol	4.0	5	ND	ND
			Estrone	3.9	5	ND	ND
			Ethinyl Estradiol - 17 alpha	3.3	5	ND	ND
			Ethylparaben	11	20	**13**	ND
			Gemfibrozil	2.5	5	ND	ND
			Ibuprofen	8.6	10	ND	ND
			Iohexal	7.7	10	**14**	**20**
			Iopromide	1.6	5	ND	ND
			Isobutylparaben	4.2	5	ND	ND
			Methylparaben	11	20	**11**	ND

Category	Method	Units	Parameter	MDL	MRL	9/26/16	9/29/16
			Naproxen	8.5	10	ND	ND
			Propylparaben	2.9	5	**6.3**	ND
			Salicylic Acid		100	ND	ND
			Sucralose	42	100	**92**	**120**
			Triclocarban		5	**38**	**5.3**
			Triclosan	6.3	10	ND	**36**
			Warfarin	4.1	5	ND	ND
Perfluorinated Alkyl Acids	**EPA 537**	µg/L	Perfluorooctanesulfonic acid	0.00020	0.0025	ND	-
			Perfluorooctanoic acid	0.00023	0.0025	ND	-
Perchlorate by EPA 331.0	**EPA 331.0**	µg/L	Perchlorate	0.086	2	ND	-

Appendix J – CCD Pilot System Process Flow Diagram

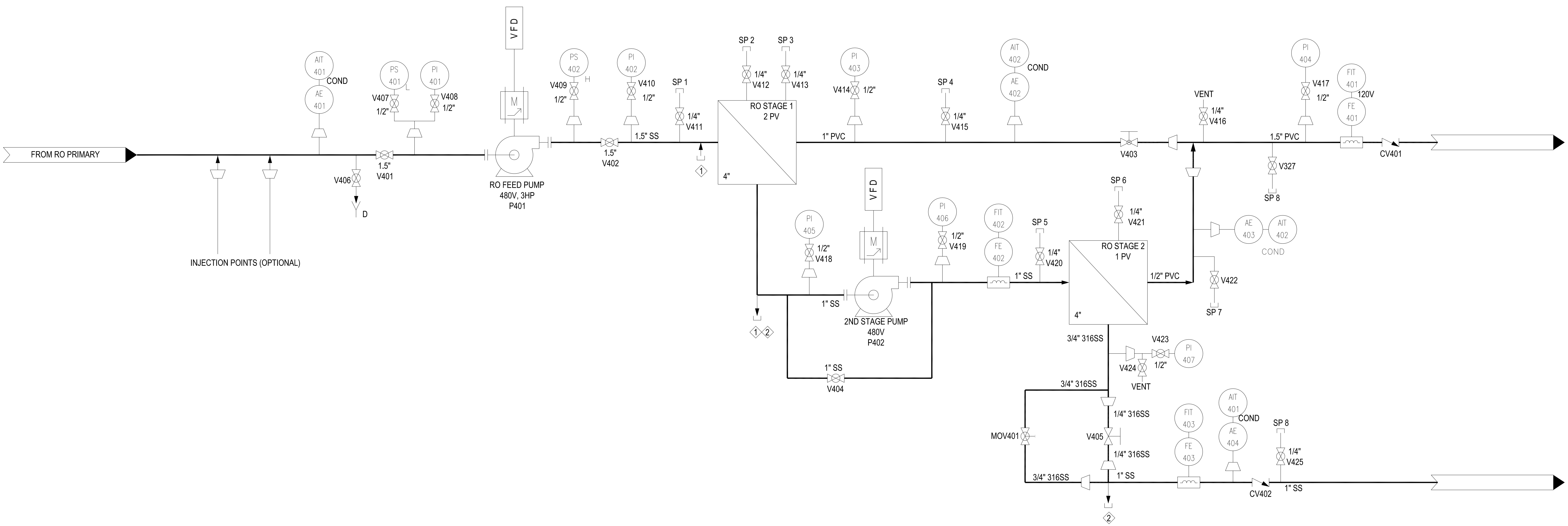
DRAFT



FEED
4m PV
HP PUMP
BW TO DRAIN
BRI E TO DRAIN
MULTI
MM-
TANK
130 GALLON
T-05
T-02
25 gal
PT
LT
SV 07
CV 08
CV 02
CV 04
pH
3/8"
NA E
DATE
DRAWN
AS MADE
US General BW-Pilot
10-15 GPM

Appendix K – cRRO Pilot System Process Flow Diagram

DRAFT



NOTES:

1. CIP CONNECTIONS USE FLEXIBLE HOSE CONNECTIONS
   - (1) CIP FEED QUICK CONNECT, 1-1/2" FLEXIBLE HOSE
   - (2) CIP RETURN QUICK CONNECT, 1" FLEXIBLE HOSE
   - (3) CIP RETURN (PERMEATE) QUICK CONNECT, 1/2" FLEXIBLE HOSE
   - (4) CIP FEED QUICK CONNECT, 1/2" FLEXIBLE HOSE

REV	DESCRIPTION	DATE	BY	APPD

REVISIONS TABLE

Biwater

BIWATER INC.
190 E. Arrow Hwy Ste F, San Dimas CA 91773 USA
Phone: (909) 599-4129 Fax: (909) 599-4017

DRAWN DP	DATE 09/16/2016	SUBMITTAL #		
CHECK RW	DATE 09/16/2016	SPECS. REF.#		
APPROVE JM	DATE 09/16/2016	PROJECT NO. 650		

TOLERANCE BLOCK : *INCH = +/- 1/32 (+/- 0.03)* *METRIC = +/- 1 mm*

DRAWING STATUS	FOR FABRICATION
ENGINEER	
CONTRACTOR	
PROJECT	PADRE DAM CONCENTRATOR RO PILOT SYSTEM
DWG TITLE	RO SYSTEM P&ID
DWG NO.	650-RO-001
SCALE	NTS
SHEET NO	1 OF 1
REV	A

Appendix L – cRRO Model Projections at 95% and 92.5% Overall Recovery

Booster Pump

Project name	Padre Secondary RO			Page : 1/4
Calculated by	Brett		Permeate flow/train	10.50 gpm
HP Pump flow		14.00 gpm	Raw water flow/train	14.00 gpm
Feed pressure		97.0 psi	Permeate recovery	75.00 %
Feed temperature		25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH		6.50	Flux decline %, first year	12.0
Chem dose, mg/l, 93 %		29.8 H2SO4	Fouling factor	1.00
Specific energy		1.49 kwh/kgal	SP increase, per year	10.0 %
Pass NDP		52.8 psi	Inter-stage pipe loss	3.0 psi
Average flux rate		9.00 gfd		
			Feed type	Waste MF/UF

Pass - Stage	Perm. Flow gpm	Flow / Vessel Feed gpm	Flow / Vessel Conc gpm	Flux gfd	DP psi	Flux Max gfd	Beta	Stagewise Pressure Perm. psi	Stagewise Pressure Boost psi	Stagewise Pressure Conc psi	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	7.5	7	3.3	9.6	9.7	13.2	1.11	0	0	87.3	104.2	ESPA2-LD4040	14	2 x 7M
1-2	3	6.5	3.5	7.7	9.1	12.6	1.11	0	45	120.1	306.7	ESPA2-LD4040	7	1 x 7M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	1081.40	1081.40	13.081	2318.3	4295.2
Ca	274.20	274.20	3.317	587.8	1089.1
Mg	96.60	96.60	1.168	207.1	383.7
Na	683.30	683.30	39.024	1442.3	2621.4
K	81.00	81.00	5.753	170.1	307.4
NH4	3.20	3.20	0.227	6.7	12.1
Ba	250.800	250.800	3.034	537.7	996.1
Sr	3.100	3.100	0.037	6.6	12.3
H	0.00	0.00	0.005	0.0	0.0
CO3	0.27	0.03	0.000	0.2	0.6
HCO3	115.10	80.40	5.089	170.9	307.8
SO4	1208.30	1235.44	11.080	2651.3	4918.6
Cl	845.10	845.10	30.025	1797.3	3297.0
F	0.00	0.00	0.000	0.0	0.0
NO3	253.30	253.30	62.149	497.9	828.3
PO4	0.80	0.80	0.007	1.7	3.2
OH	0.00	0.00	0.000	0.0	0.0
SiO2	44.40	44.40	1.301	94.6	174.1
B	0.00	0.00	0.000	0.0	0.0
CO2	7.40	32.60	32.60	32.60	32.60
TDS	**3859.47**	**3851.68**	**162.22**	**8172.32**	**14951.83**
pH	**7.30**	**6.50**	**5.38**	**6.80**	**7.03**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	31	32	181	400
SrSO4 / ksp * 100, %	23	23	129	1200
BaSO4 / ksp * 100, %	2833616	2888972	14113230	10000
SiO2 saturation, %	35	35	140	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.2	-1.0	0.5	2.4
CCPP, mg/l	7.05	-43.09	123.85	100000
Langelier saturation index	0.15	-0.81	0.84	2.5
Ionic strength	0.08	0.08	0.32	
Osmotic pressure, psi	27.6	27.4	105.6	

Booster Pump

Project name	Padre Secondary RO			Page : 2/4
Calculated by	Brett		Permeate flow/train	10.50 gpm
HP Pump flow		14.00 gpm	Raw water flow/train	14.00 gpm
Feed pressure		97.0 psi	Permeate recovery	75.00 %
Feed temperature		25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH		6.50	Flux decline %, first year	12.0
Chem dose, mg/l, 93 %		29.8 H2SO4	Fouling factor	1.00
Specific energy		1.49 kwh/kgal	SP increase, per year	10.0 %
Pass NDP		52.8 psi	Inter-stage pipe loss	3.0 psi
Average flux rate		9.00 gfd		
			Feed type	Waste MF/UF

Pass - Stage	Perm. Flow gpm	Flow / Vessel Feed gpm	Flow / Vessel Conc gpm	Flux gfd	DP psi	Flux Max gfd	Beta	Stagewise Pressure Perm. psi	Stagewise Pressure Boost psi	Stagewise Pressure Conc psi	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	7.5	7	3.3	9.6	9.7	13.2	1.11	0	0	87.3	104.2	ESPA2-LD4040	14	2 x 7M
1-2	3	6.5	3.5	7.7	9.1	12.6	1.11	0	45	120.1	306.7	ESPA2-LD4040	7	1 x 7M

Pass - Stage	Element no.	Feed Pressure psi	Pressure Drop psi	Conc Osmo. psi	NDP psi	Permeate Water Flow gpm	Permeate Water Flux gfd	Beta	Permeate (Passwise cumulative) TDS	Ca	Mg	Na	Cl	NO3
1-1	1	97	2.12	30.5	69.4	0.7	13.2	1.1	45.1	0.884	0.312	10.574	8.073	18.104
1-1	2	94.9	1.8	34	62.1	0.7	11.7	1.1	52.2	1.026	0.362	12.261	9.364	20.923
1-1	3	93.1	1.56	37.9	57	0.6	10.7	1.11	60.2	1.185	0.418	14.149	10.81	24.05
1-1	4	91.5	1.32	42.4	51.5	0.5	9.7	1.1	69.6	1.374	0.484	16.386	12.526	27.724
1-1	5	90.2	1.14	47.3	45.8	0.5	8.5	1.11	79.7	1.579	0.556	18.812	14.389	31.658
1-1	6	89.1	0.97	52.5	39.8	0.4	7.4	1.1	91.1	1.812	0.638	21.555	16.497	36.053
1-1	7	88.1	0.84	57.9	33.7	0.3	6.2	1.1	104.2	2.08	0.733	24.7	18.917	41.032
1-2	1	129.3	1.91	64.7	68.5	0.7	12.6	1.11	106.3	2.128	0.75	25.252	19.349	41.769
1-2	2	127.4	1.63	72.1	59.7	0.6	10.9	1.1	110.8	2.223	0.783	26.35	20.201	43.374
1-2	3	125.7	1.41	79.7	50.8	0.5	9.2	1.1	117.3	2.361	0.832	27.957	21.446	45.771
1-2	4	124.3	1.22	87.2	41.9	0.4	7.5	1.09	125.9	2.542	0.896	30.056	23.071	48.912
1-2	5	123.1	1.08	94.3	33.6	0.3	6	1.08	136.3	2.763	0.974	32.624	25.06	52.741
1-2	6	122	0.98	100.4	26	0.3	4.6	1.06	148.5	3.023	1.065	35.63	27.39	57.185
1-2	7	121	0.9	105.5	19.6	0.2	3.4	1.05	162.2	3.317	1.168	39.024	30.025	62.149

Booster Pump

Project name	Padre Secondary RO			Page : 3/4
Calculated by	Brett		Permeate flow/train	10.50 gpm
HP Pump flow		14.00 gpm	Raw water flow/train	14.00 gpm
Feed pressure		97.0 psi	Permeate recovery	75.00 %
Feed temperature		25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH		6.50	Flux decline %, first year	12.0
Chem dose, mg/l, 93 %		29.8 H_2SO_4	Fouling factor	1.00
Specific energy		1.49 kwh/kgal	SP increase, per year	10.0 %
Pass NDP		52.8 psi	Inter-stage pipe loss	3.0 psi
Average flux rate		9.00 gfd		
			Feed type	Waste MF/UF

THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS

Concentrate saturation of $BaSO_4$ (14113230.00 %) is higher than limit 10000 %.

Concentrate saturation of SiO_2 (140.06 %) is higher than limit 140 %.

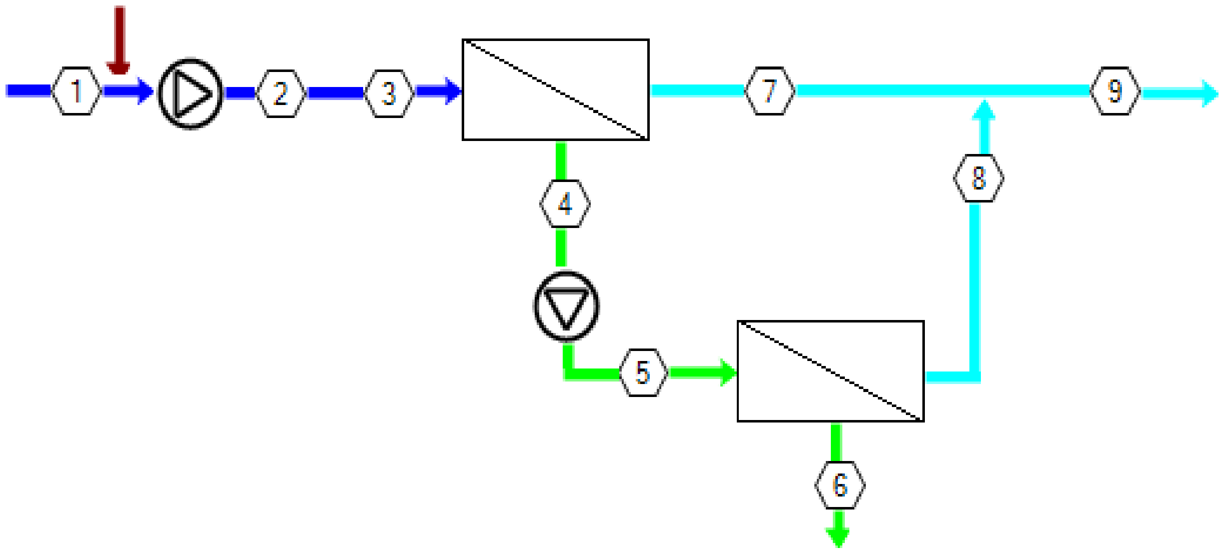
The above saturations limits only apply when using effective scale inhibitor or dispersant. Without scale inhibitor or dispersant, the saturation and precipitation limit of the contaminant should not exceed its solubility in solution.

Booster Pump

Project name Padre Secondary RO

Temperature : 77.0 °F

Element age, P1 : 0.0 years



Stream No.	Flow (gpm)	Pressure (psi)	TDS	pH	Econductivity
1	14.0	0	3859	7.30	6139
2	14.0	97.0	3852	6.50	6154
3	14.0	97.0	3852	6.50	6154
4	6.50	87.3	8172	6.80	12285
5	6.50	129	8172	6.80	12285
6	3.49	120	14952	7.03	21555
7	7.50	0	104	5.19	177
8	3.01	0	307	5.65	519
9	10.5	0	162	5.38	274

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Booster Pump

Project name Padre Secondary RO

Calculated by	Brett	Permeate flow/train	10.50 gpm
HP Pump flow	15.00 gpm	Raw water flow/train	15.00 gpm
Feed pressure	106.3 psi	Permeate recovery	70.00 %
Feed temperature	25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH	6.50	Flux decline %, first year	12.0
Chem dose, mg/l, -	None	Fouling factor	1.00
Specific energy	1.54 kwh/kgal	SP increase, per year	10.0 %
Pass NDP	55.9 psi	Inter-stage pipe loss	3.0 psi
Average flux rate	9.00 gfd		
		Feed type	

Pass - Stage	Perm. Flow gpm	Flow / Vessel Feed gpm	Conc gpm	Flux gfd	DP psi	Flux Max gfd	Beta	Stagewise Pressure Perm. psi	Boost psi	Conc psi	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	8.5	7.5	3.2	10.9	10.4	14.8	1.12	0	0	95.9	97.3	ESPA2-LD4040	14	2 x 7M
1-2	2	6.5	4.5	5.2	10.8	8.3	1.07	0	17	99.1	424.6	ESPA2-LD4040	7	1 x 7M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	1080.90	1080.90	12.791	2485.4	3578.1
Ca	274.00	274.00	3.242	630.0	907.0
Mg	96.60	96.60	1.143	222.1	319.8
Na	683.00	683.00	38.217	1546.7	2190.5
K	81.00	81.00	5.639	182.5	257.2
NH4	3.20	3.20	0.223	7.2	10.2
Ba	250.000	250.000	2.958	574.8	827.6
Sr	3.100	3.100	0.037	7.1	10.3
H	0.00	0.00	0.006	0.0	0.0
CO3	0.04	0.04	0.000	0.3	0.6
HCO3	115.00	115.00	7.012	261.7	370.5
SO4	1208.00	1208.00	10.414	2780.7	4007.9
Cl	845.00	845.00	28.887	1928.1	2753.0
F	0.00	0.00	0.000	0.0	0.0
NO3	253.00	253.00	60.236	534.9	703.7
PO4	0.80	0.80	0.007	1.8	2.7
OH	0.00	0.00	0.000	0.0	0.0
SiO2	60.00	60.00	1.704	137.2	196.3
B	0.00	0.00	0.000	0.0	0.0
CO2	46.62	46.62	46.62	46.62	46.62
TDS	**3872.74**	**3872.74**	**159.72**	**8815.19**	**12557.10**
pH	**6.50**	**6.50**	**5.36**	**6.82**	**6.96**

Booster Pump

Project name Padre Secondary RO

Saturations	Raw Water	Feed Water	Concentrate	Limits
CaSO4 / ksp * 100, %	31	31	141	400
SrSO4 / ksp * 100, %	23	23	100	1200
BaSO4 / ksp * 100, %	2821410	2821410	11185230	10000
SiO2 saturation, %	48	48	158	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	-1.0	-1.0	0.3	2.4
CCPP, mg/l	-48.33	-48.33	143.64	100000
Langelier saturation index	-0.65	-0.65	0.79	2.5
Ionic strength	0.08	0.08	0.27	
Osmotic pressure, psi	27.6	27.6	88.9	

Booster Pump

Project name Padre Secondary RO

Calculated by	Brett	Permeate flow/train	10.50 gpm
HP Pump flow	15.00 gpm	Raw water flow/train	15.00 gpm
Feed pressure	106.3 psi	Permeate recovery	70.00 %
Feed temperature	25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH	6.50	Flux decline %, first year	12.0
Chem dose, mg/l, -	None	Fouling factor	1.00
Specific energy	1.54 kwh/kgal	SP increase, per year	10.0 %
Pass NDP	55.9 psi	Inter-stage pipe loss	3.0 psi
Average flux rate	9.00 gfd		
		Feed type	Waste MF/UF

Pass - Stage	Perm. Flow gpm	Flow / Vessel Feed gpm	Flow / Vessel Conc gpm	Flux gfd	DP psi	Flux Max gfd	Beta	Stagewise Pressure Perm. psi	Stagewise Pressure Boost psi	Stagewise Pressure Conc psi	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	8.5	7.5	3.2	10.9	10.4	14.8	1.12	0	0	95.9	97.3	ESPA2-LD4040	14	2 x 7M
1-2	2	6.5	4.5	5.2	10.8	8.3	1.07	0	17	99.1	424.6	ESPA2-LD4040	7	1 x 7M

Pass - Stage	Element no.	Feed Pressure psi	Pressure Drop psi	Conc Osmo. psi	NDP psi	Permeate Water Flow gpm	Permeate Water Flux gfd	Beta	Permeate (Passwise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	106.3	2.33	30.9	78.1	0.8	14.8	1.11	40.8	0.798	0.281	9.546	7.164
1-1	2	104	1.98	34.7	70.5	0.7	13.3	1.11	47.3	0.927	0.327	11.084	8.321
1-1	3	102	1.67	39.1	64.8	0.7	12.2	1.12	54.8	1.077	0.38	12.864	9.661
1-1	4	100.4	1.41	44.1	58.8	0.6	11	1.12	63.6	1.252	0.442	14.941	11.226
1-1	5	99	1.17	49.8	52.2	0.5	9.7	1.1	73.2	1.447	0.51	17.24	12.962
1-1	6	97.8	1	56	45.3	0.5	8.4	1.11	84.3	1.672	0.59	19.898	14.969
1-1	7	96.8	0.85	62.5	38.2	0.4	7	1.11	97.3	1.937	0.683	23.008	17.323
1-2	1	109.9	1.96	67.2	45.4	0.5	8.3	1.07	103.3	2.06	0.726	24.449	18.416
1-2	2	108	1.77	71.7	39.1	0.4	7.1	1.06	110.3	2.206	0.778	26.157	19.712
1-2	3	106.2	1.62	76	33	0.3	6	1.06	118.4	2.374	0.837	28.12	21.203
1-2	4	104.6	1.5	80	27.4	0.3	4.9	1.05	127.5	2.563	0.904	30.325	22.879
1-2	5	103.1	1.4	83.5	22.4	0.2	4	1.04	137.4	2.772	0.977	32.757	24.728
1-2	6	101.7	1.32	86.4	17.9	0.2	3.2	1.03	148.2	2.999	1.057	35.396	26.737
1-2	7	100.4	1.26	88.8	14.1	0.1	2.5	1.03	159.7	3.242	1.143	38.217	28.887

Booster Pump

Project name Padre Secondary RO

Calculated by	Brett	Permeate flow/train	10.50 gpm
HP Pump flow	15.00 gpm	Raw water flow/train	15.00 gpm
Feed pressure	106.3 psi	Permeate recovery	70.00 %
Feed temperature	25.0 °C(77.0°F)	Element age	0.0 years
Feed water pH	6.50	Flux decline %, first year	12.0
Chem dose, mg/l, -	None	Fouling factor	1.00
Specific energy	1.54 kwh/kgal	SP increase, per year	10.0 %
Pass NDP	55.9 psi	Inter-stage pipe loss	3.0 psi
Average flux rate	9.00 gfd		
		Feed type	

THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS

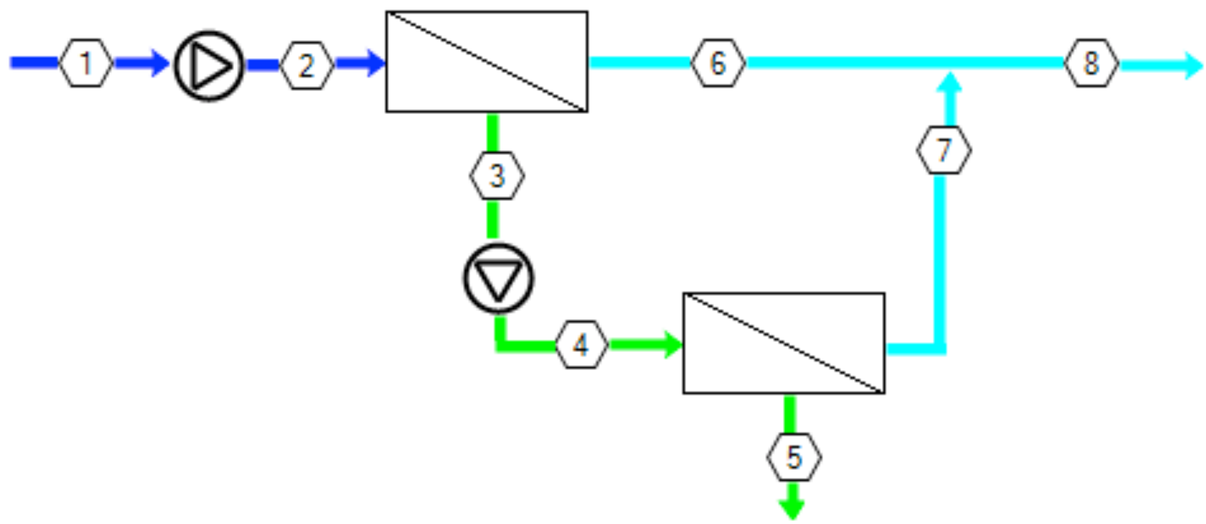
Concentrate saturation of $BaSO_4$ (11185230.00 %) is higher than limit 10000 %.
Concentrate saturation of SiO_2 (158.13 %) is higher than limit 140 %.

The above saturations limits only apply when using effective scale inhibitor or dispersant. Without scale inhibitor or dispersant, the saturation and precipitation limit of the contaminant should not exceed its solubility in solution.

Booster Pump

Project name Padre Secondary RO

Temperature : 77.0 °F Element age, P1 : 0.0 years



Stream No.	Flow (gpm)	Pressure (psi)	TDS	pH	Econductivity
1	15.0	0	3873	6.50	6137
2	15.0	106	3873	6.50	6137
3	6.50	95.9	8815	6.82	13070
4	6.50	110	8815	6.82	13070
5	4.49	99.1	12557	6.96	18171
6	8.50	0	97.3	5.15	164
7	2.00	0	425	5.78	711
8	10.5	0	160	5.36	268

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Appendix M – CCD Tail Element Membrane Autopsy

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1/3/2017

Eileen Y. Idica, Ph.D., P.E.
Trussell Technologies, Inc
380 Stevens Avenue, Suite 308
Solana Beach, CA 92075

Hello, Eileen,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached please find the autopsy report for the Hydranautics ESPA2-LD membrane serial number 11634876. This element was a tail end element taken from the Desalitech Closed Circuit Desalination (CCD) pilot at Padre Dam.

I have reviewed this report and have the following comments:

SN#11634876 Tail Element

- The full element produced less than 1 gpm flow during initial wet testing
- Flat sheet samples produced no water passage during baseline cell testing
- No mechanical damage was observed during the external and internal inspection
- The membrane surfaces were evenly coated in white colored, granular foulant material which adhered tightly to the membrane surfaces. The foulant was identified as silica scale.
- Flat sheet sample water passage was restored using RoClean P112 (2%, 3 hours)
- Fujiwara testing was positive for the presence of halogens in the membrane structure

Avista TECHNOLOGIES

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Discussion

The objective of the pilot was to determine the maximum recovery possible with the limiting salt being silica scale as determined by Avista's Antiscalant Software, AdvisorCi. AdvisorCi showed that the overall 97% recovery exceeded the silica saturation control using Vitec 1400. As predicted the element provided for autopsy which was in the system when the recovery reached 97% recovery was silica scaled.

Previous AdvisorCi projections showed the need of an additional antiscalant to achieve the higher recoveries (>95%). However, field testing showed that 2.0 ppm of Vitec 1400 dosed in the primary RO was sufficient to prevent scale formation, even at the higher recoveries. Avista Technologies believes the success of the Vitec 1400 was not only due to the chemistry of the product but also due to the innovative design of the Closed Circuit Desalination Process.

Thanks again for permitting our organization to evaluate your membrane. We appreciate your business.

Best regards,

Ray C Eaton

Ray Eaton
Applications and Sales
Avista Technologies, Inc.

140 Bosstick Boulevard
San Marcos, California 92069, United States

Tel. | +1.760.744.0536 www.avistatech.com

DRAFT

Membrane Autopsy Report

Completed for:

Trussell Technologies

Padre Dam

Tail Element

12/09/2016 WO#111616-5

CORPORATE OFFICES

Avista Technologies, Inc.
Global Headquarters
+1.760.744.0536
info@avistatech.com

Avista Technologies (UK) Ltd
+44 (0) 131 449 6677
info@avistatech.co.uk

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Table of Contents

Executive Summary

Background

Trussell Technologies provided one (1) Hydranautics ESPA2-LD reverse osmosis (RO) element to Avista Technologies for dissection and analysis. Element Serial Number (SN#) 11634876 was removed from the tail end of the RO system. The RO system was reportedly running at 97% recovery. Below is a summary of the findings of SN#11634876.

Initial Element Testing

Element SN#11634876 produced less than 1.00 gallon per minute (gpm) of flow during initial wet testing while new elements of this type typically produce between 5.90 and 7.90 gpm.

External Inspection

The external mechanical components (fiberglass casing, anti-telescoping devices (ATDs), brine seal, permeate tube) were in good mechanical condition. The element passed integrity testing, indicating an absence of damage to the internal mechanical components of the spiral-wound element.

Internal Inspection

Both scroll ends were in good condition and virtually free of visual foulant material. The exposed membrane surfaces were evenly coated with a layer of granular, white colored foulant material. The foulant adhered tightly and could not be scraped for further analysis. The remaining internal components (e.g. feed spacers, permeate spacers, membrane folds and glue lines) were in good mechanical condition.

Cell Testing Results

Flat sheet samples harvested from the full element produced no water passage during baseline cell testing.

Foulant Analysis

The loss on ignition (organic content), foulant density, and zeta potential could not be determined as the majority of the foulant adhered tightly to the membrane and could not be fully removed. Additionally, a microscope analysis could not be performed. Fourier Transform Infrared (FT-IR) spectroscopy of the membrane surfaces detected a strong band between 1100 and 900 cm^{-1}, which is indicative to the presence of Silicon – Oxygen (Si-O) bond stretching.

Foulant Analysis

The Energy Dispersive X-ray (EDX) analysis identified silicon as the dominant inorganic constituent of the foulant material. Lesser amounts of aluminum, calcium and trace amounts (0.50%) of salts (sodium, chlorine, magnesium, potassium) were also detected. The sulfur percentage is representative of the membrane support material itself, rather than the foulant layer and was relatively low (2.29%) which indicates masking of the membrane surface by foulant material. Avista EDX analysis of new polyamide membrane typically detects between 5.00 and 7.00% sulfur. The Scanning Electron Microscope (SEM) images showed a layer of granular foulant material coating the membrane surface. The foulant layer appeared to vary in thickness with randomly scattered granular particles and patches of foulant. Close-up imaging (5000x) showed that the foulant consisted of botryoidal material that completely coated the membrane surface. Chromatic Elemental Imaging (CEI) confirmed the foulant layer was composed of silica. The botryoidal shape of the deposits along with the intensity of the coloring indicates the presence of silica scale. The layer of material was thin but even. Fungi coated in silica and clay deposits (aluminum silicates) were also observed during CEI analysis. The membrane surface (represented by sulfur) was hardly visible.

Based on the foulant analysis, the foulant layer was identified as silica scale. Lesser amounts of clay and fungi were also identified.

Cleaning Study

Flat sheet samples were cleaned using RoClean P112 (2% by weight) heated and circulated for three hours. This regimen restored water passage to the manufacturer's specified range.

Determining Damage to Flat Sheet Samples

The flat sheet samples produced higher than normal salt passage after cleaning (The salt passage could not be determined prior to cleaning as samples produced no water passage). No mechanical damage was detected during the external or internal inspection of the element. Fujiwara testing was positive for the presence of halogens (e.g. chlorine) in the membrane structure. A common symptom of halogen oxidation is loss of rejection.

Initial Element Test Results

Element Weight

Because element weight is often indicative of the degree of fouling, elements are weighed prior to the autopsy.

SN# 11634876 weighed 36 pounds while new eight inch elements weigh approximately 30 to 35 pounds.

Wet Test

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

Hydranautics ESPA2-LD	**Flow (gpm)**	**Rejection (%)**	**Pressure Drop (psi)**
SN# 11634876		< 1.00 gpm flow	
Manufacturer's Specifications	5.60 to 7.90	99.5 to 99.6	≤15

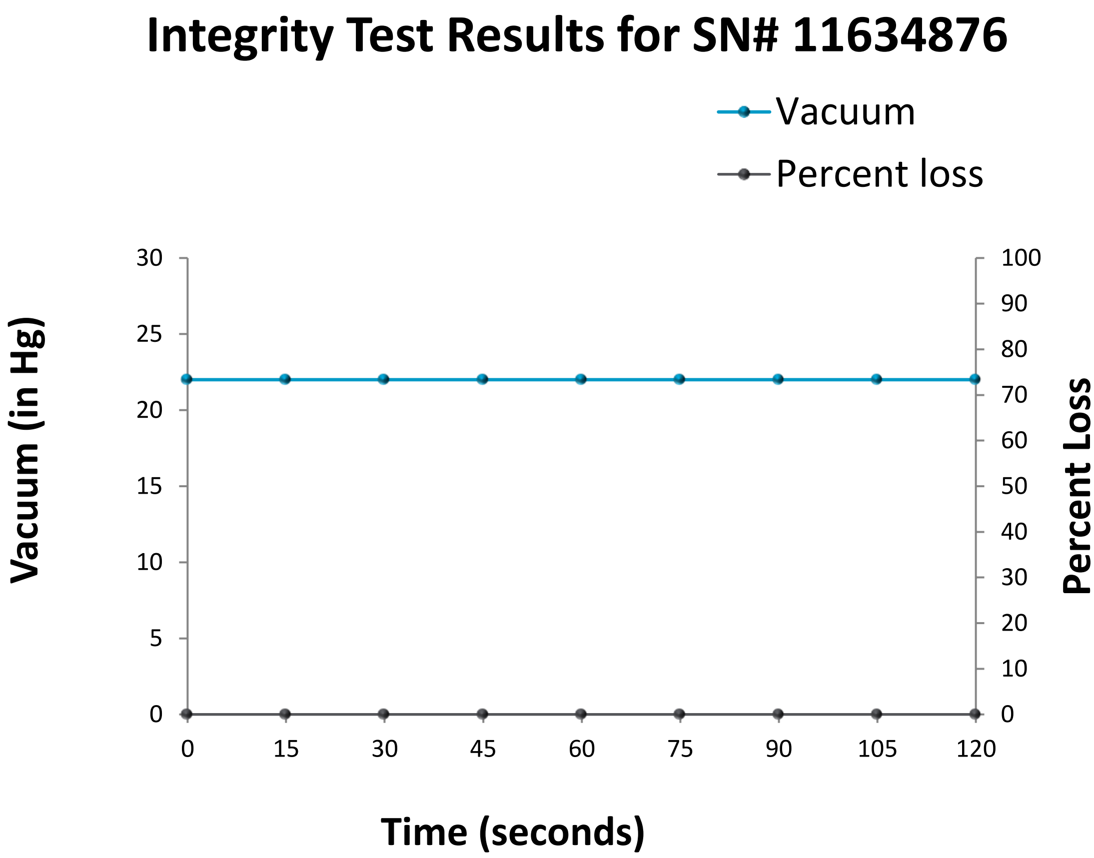
Element wet testing

Integrity Test

To determine if a membrane performance problem is possibly caused by mechanical damage, membranes are tested to check for vacuum decay that may indicate abnormal bypass.

In this test a vacuum of about 22 inches Mercury (in. Hg) is applied to the permeate side of the membrane for a duration of 120 seconds. If over 35% of the vacuum is lost within a 120 second period, then the membrane can be said to have severe physical damage.

The element passed integrity testing.

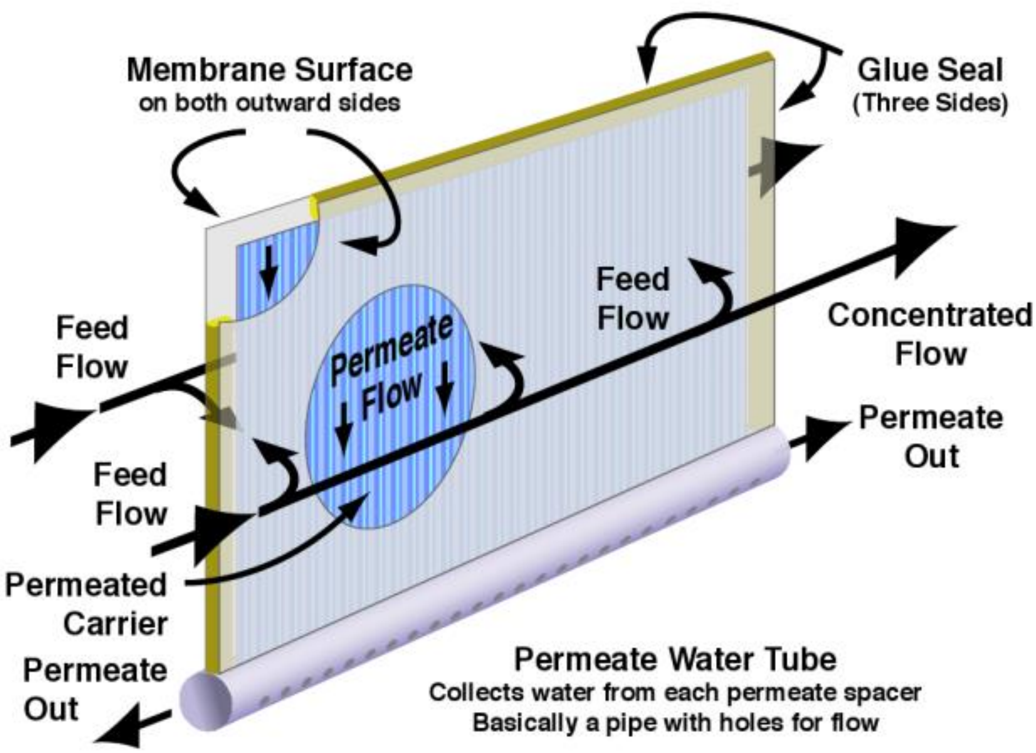


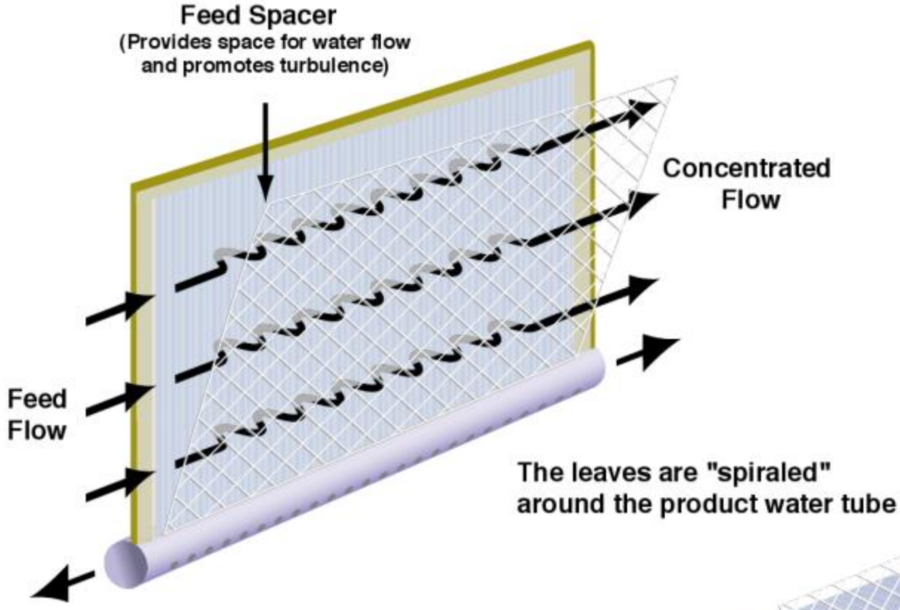
External Inspection

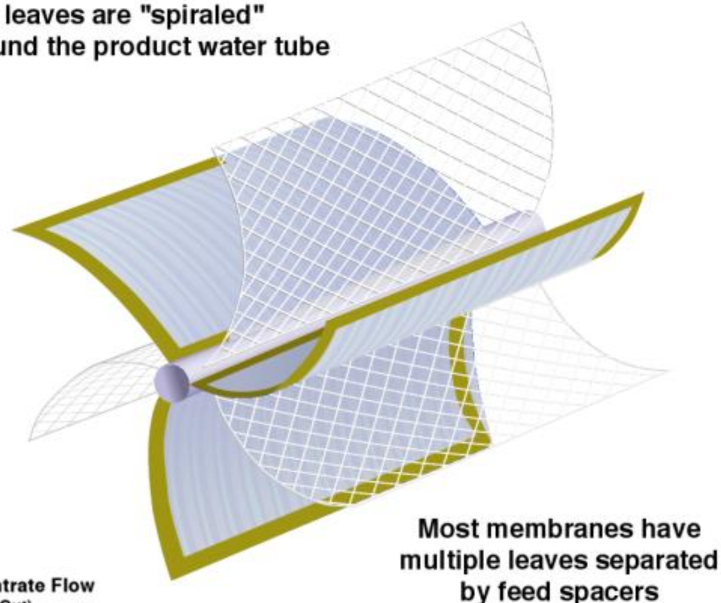
The external inspection of a membrane element is an important step in the autopsy process. Physical damage to the exterior components can contribute to performance issues in the element or may yield clues as to the operating conditions of the membrane system that led to poor membrane performance. As most of the external components are damaged during the autopsy process, documenting any significant finds before further work is completed is essential.

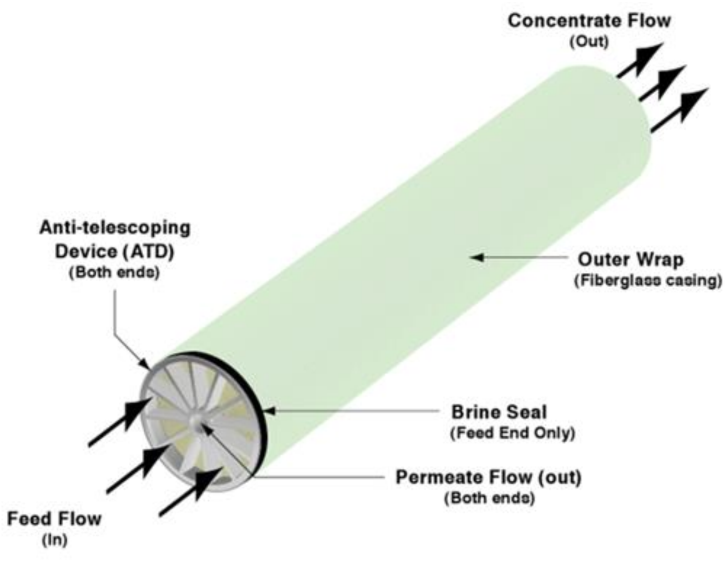
This section covers the fiberglass casing, anti-telescoping devices (ATDs), permeate tube, and brine seal. In addition, the scroll ends are also examined for any foulant/scale material that may be interfering with flow and for feed spacer extrusion also known as telescoping and gapping in the scroll end which may cause localized scaling (uneven hydraulics).

Spiral-Wound Membrane Element Construction




Feed Spacer
(Provides space for water flow and promotes turbulence)
Concentrated Flow
Feed Flow
The leaves are "spiraled" around the product water tube


Most membranes have multiple leaves separated by feed spacers


Concentrate Flow
(Out)
Anti-telescoping Device (ATD)
(Both ends)
Outer Wrap
(Fiberglass casing)
Brine Seal
(Feed End Only)
Permeate Flow (out)
(Both ends)
Feed Flow
(In)

Fiberglass Casing

The fiberglass casing is an integral part of each element. The purpose of this wrap is to protect the element from external differential pressure, provide compressive strength to prevent telescoping and to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the wrap can be an indication of rough handling or damage from excessive differential pressure across the membrane surface.

The fiberglass casing was in good mechanical condition and free from foulant material.

Fiberglass casing for SN# 11634876

Brine Seal

The purpose of the brine seal is 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 membrane element. Chevron type seals are used to aid in membrane loading and to seal to a variety of pressure vessel inside surfaces.

The brine seal was in good condition.

Permeate Tube

At the center of each membrane element is a round section of pipe that is called the permeate tube. Down the length of the tube, holes are drilled through the pipe wall to the tube center. This tube is bonded to the membrane leaves and permits water to flow from the leaves outward at each end of the full element and the through the holes for collection. To function properly, the permeate tube must be free from gouges or damage that can prevent proper O-ring sealing at each end. Poor sealing can result in bypass from the high-pressure feed/concentrate flow into the permeate stream.

The permeate tube was free of physical damage.

Anti-Telescoping Device (ATD)

When assembled at the factory, membrane elements are commonly fitted with Anti-Telescoping Devices (ATDs) at each end of the element. These devices are designed to prevent telescoping of the membrane leaves under normal operating conditions that can cause membrane damage.

The anti-telescoping devices (ATDs) were free of any damage that would be detrimental to operational functionality.

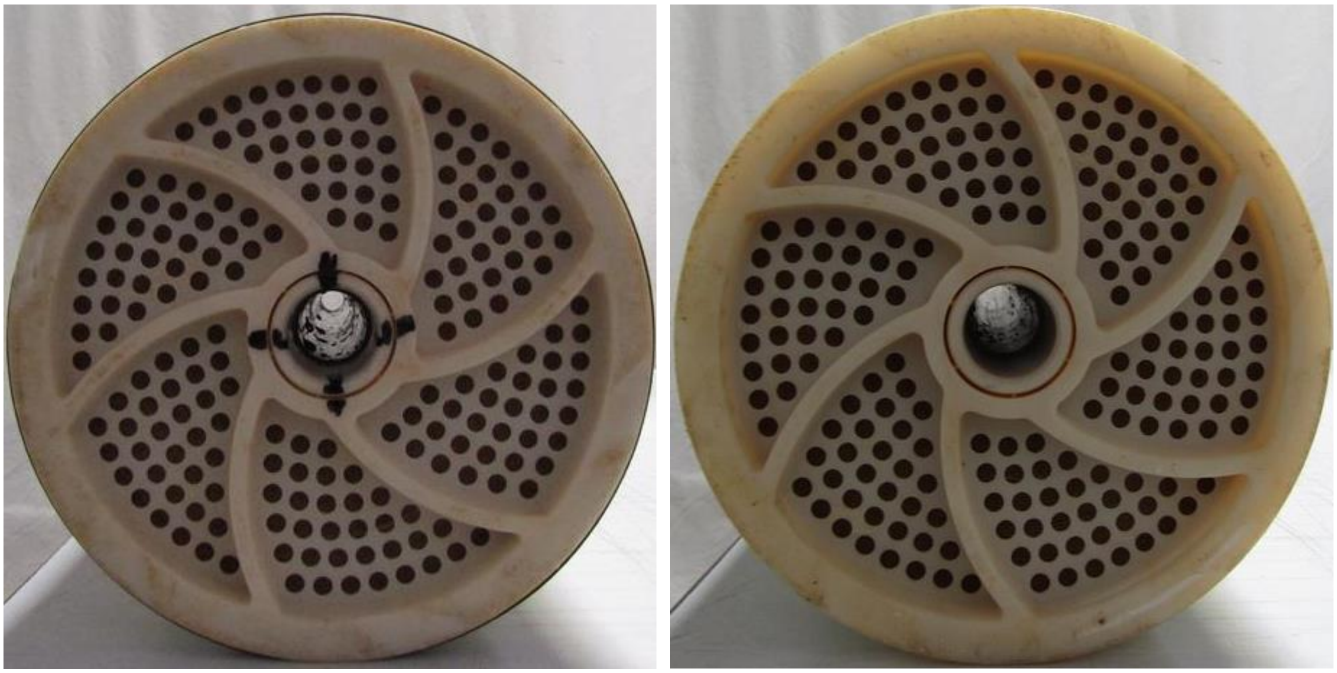


Image of feed ATD (left) and concentrate ATD (right) for SN# 11634876

Internal Inspection & Testing

Scroll End Examination

Once the anti-telescoping devices are removed, the scroll ends of the membrane leaves are examined for presence of colloidal particles, biofouling, feed spacer extrusion and membrane gapping. In addition, each scroll end is examined for the gradual axial shift of the element leaves from outer diameter of the element towards the permeate tube. This type of damage is termed "telescoping" and is caused by the development of high differential pressure (usually greater than 10 psi) across the element.

Both scroll ends were in good condition and free of foulant material.

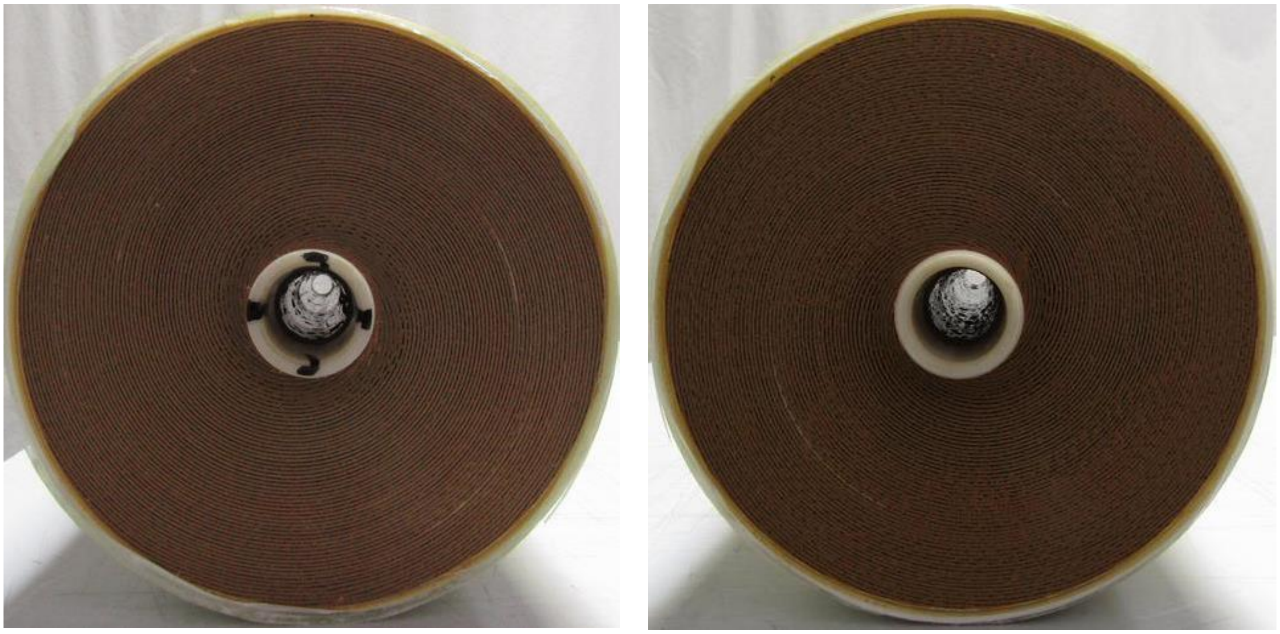
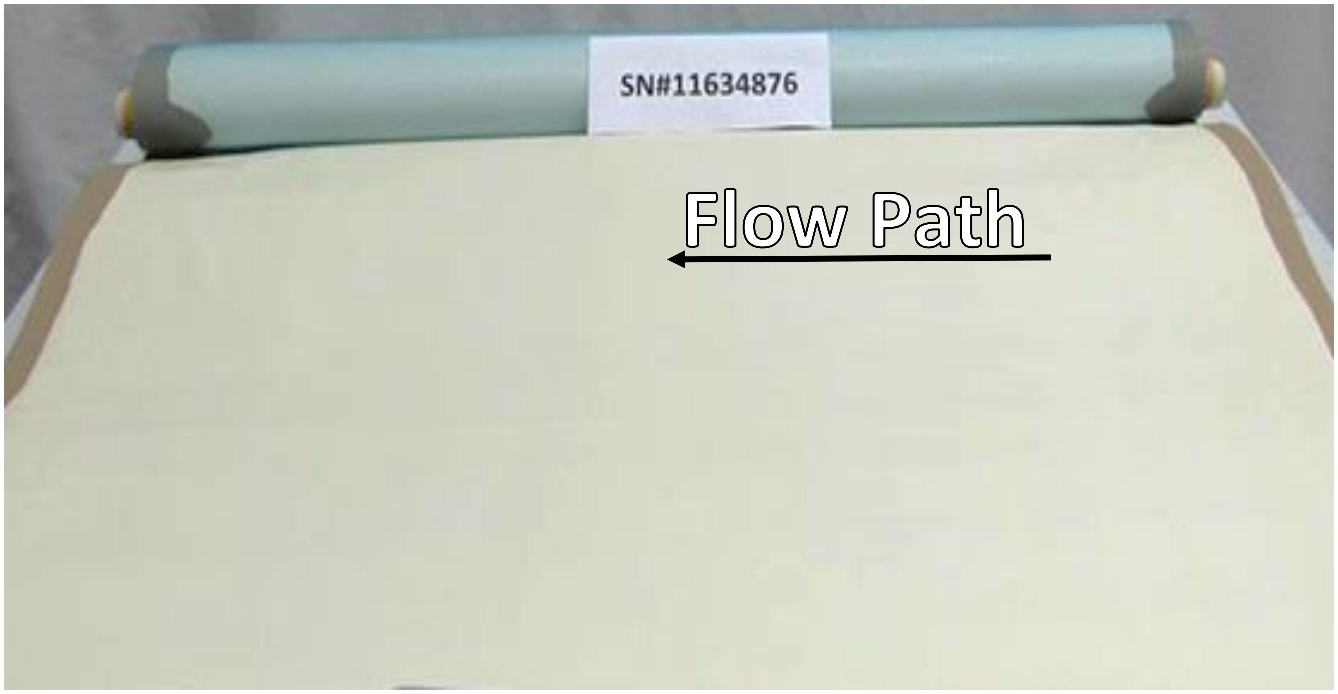


Image of feed scroll end (left) and concentrate scroll end (right) for SN# 11634876

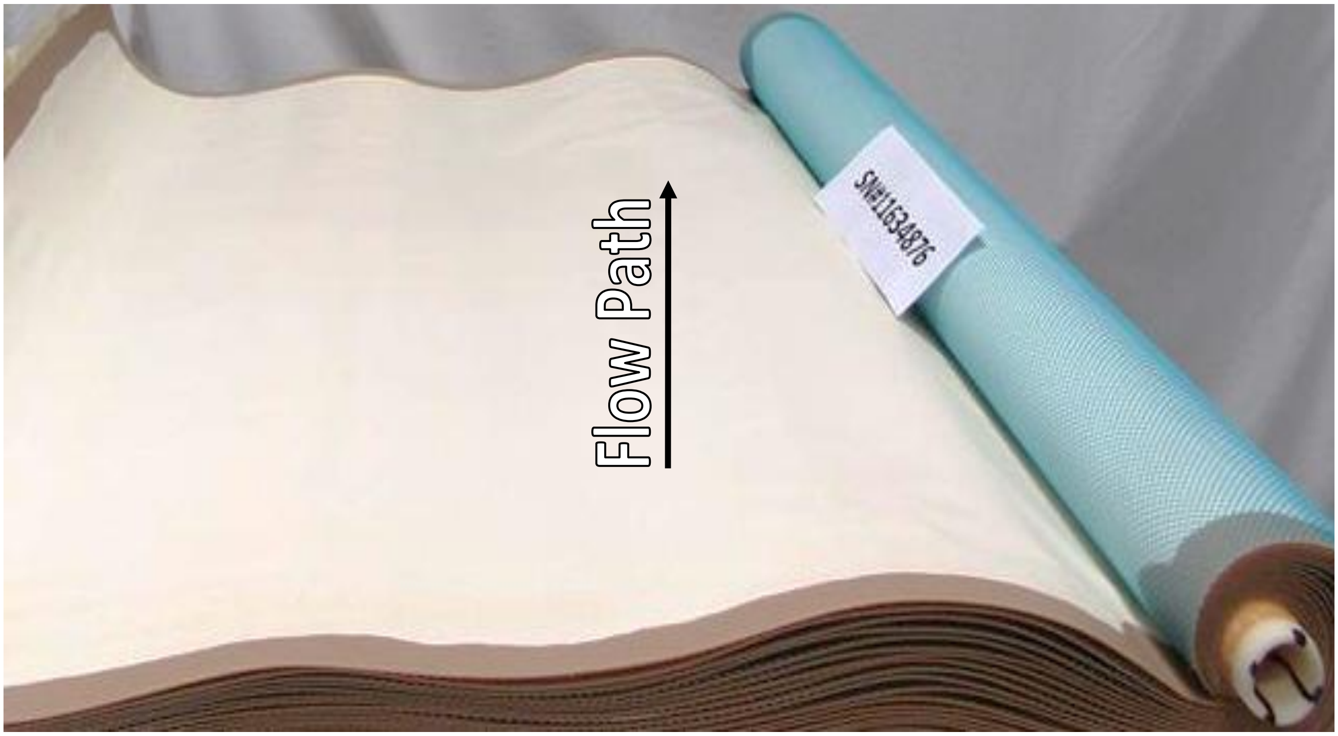
Membrane Surface Visual Examination

When assembled, the surface of the membrane is a uniform, shiny surface with no visual contamination or impurities. Although the membrane surface contamination can be sometimes hard to detect visually many times contamination is very visible and easy to detect with the naked eye.

The exposed membrane surfaces were evenly coated with a layer of granular, white colored foulant material. The foulant adhered tightly and could not be scraped for further analysis.



Exposed membrane surface for SN# 11634876



Exposed membrane surface from feed end for SN# 11634876

Feed Spacer Visual Examination

The feed spacer is a plastic net material designed to separate membrane surfaces to form a flow path and to promote turbulence within feed water channel.

The feed spacers were in good condition.

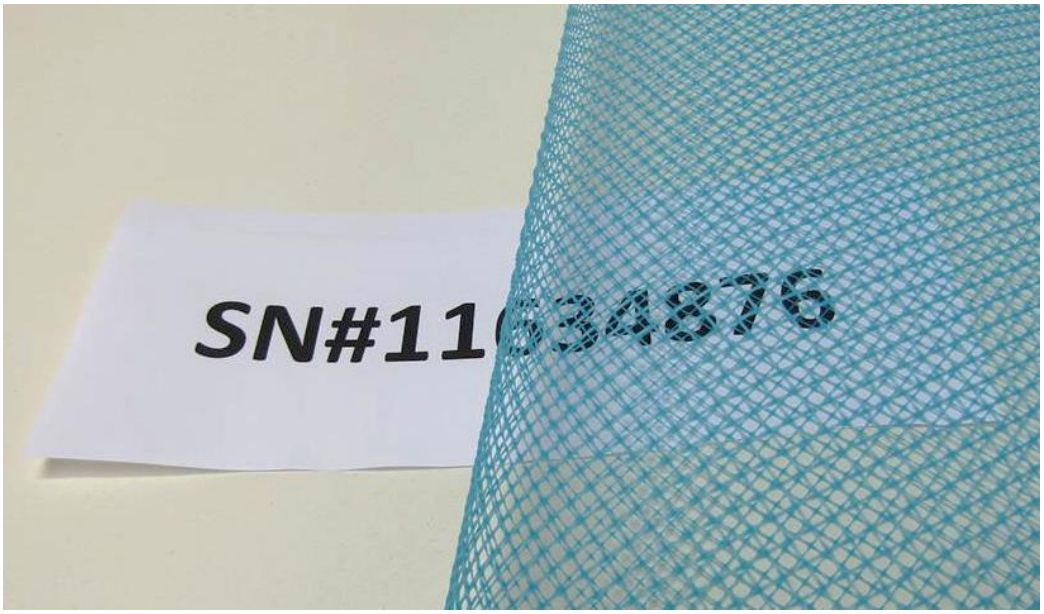


Image of feed spacer

Glue Line Integrity Examination

Membrane leaves are glued on three sides to separate feed and permeate streams. Glue lines are inspected to ensure that there are no sections of unbounded material referred to as glue flaps that may block the feed channel into the element module. In some worst case situations, glue lines may fail at the feed end of the membrane permitting contamination. The glue lines are also inspected for pouching and delamination which often occur on the concentrate end of last stage elements. This type of physical damage may indicate permeate backpressure caused by positive pressure on the permeate side of the membrane.

No damage to glue lines was noted.

Permeate Spacer and Membrane Backing Visual Examination

Permeate spacer provides a path for permeate flow to channel towards the central permeate tube which minimizes permeate-side pressure losses.

The permeate spacers of the element were free from foulant contamination.

Cell Test for Permeate Flow & Salt Passage

To determine membrane performance characteristics membrane samples are tested in a cell test apparatus (CTA). The water passage constant is expressed as the “A” value, and the salt passage constant is expressed by a “B” value. Both constants are functions of the chemical-physical properties of the membrane plus 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 table below shows baseline performance data before cleaning.

Comparing cell testing of the membrane material to the original specification for the full spiral membrane element is a useful comparison tool. This data is collected in order to factor out any additional mechanical aspects the element construction may have caused in the spiral configuration.

SN# 11634876	**Water Passage Constant “A” Value**	**Salt Passage Constant “B” Value**
Flat Sheet Results	No Water Passage	
Manufacturer’s Specifications	1.35 to 1.83E-04 Normal Range	5.64 to 7.06E-06 Normal Range

Note: Testing conducted with dechlorinated city water

Water 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.

Adequate foulant could not be collected to determine the organic content.

Foulant Density Measurement

Membrane foulant density is the weight of dry foulant per area of membrane surface. Foulant densities determined from past autopsies range from 0.02 to 1.84 mg/cm^2 and average 0.51 mg/cm^2.

Foulant could not be removed from the membrane surface to measure the foulant density.

Testing for the Presence of Carbonates

Acid testing is used to determine the presence of carbonates on the membrane surface. In this test, several drops of dilute hydrochloric acid were placed on the foulant surfaces. Effervescing indicates a positive test result.

Acid testing was negative for the presence of carbonates.

Testing for the Presence of Microbiological Organisms

Foulant samples were stained and examined with a light microscope at 1000x using an oil immersion lens. Gram positive bacteria are stained blue while Gram negative bacteria are stained red.

A microscope analysis could not be performed due to the scarcity of removable foulant present on the membrane surfaces.

Testing for the Presence of Coagulant

Zeta potential testing of the membrane surface foulant can determine the presence of excess coagulant by measuring the charge associated with the surface colloids. Most naturally occurring colloids are negatively charged and surrounded by a double layer of counter ions. Zeta potential is the charge that resides at the double layer boundary, which we can conveniently measure with a zeta potential meter.

Electrostatic repulsion becomes significant when two colloids approach each other and their charged double layers begin to interfere. Because of this mutual repulsion, coagulation and flocculation are difficult to accomplish and coagulants are often overfed into the RO system resulting in a positive zeta potential. Samples that show a near zero or neutral zeta potential represent the optimum coagulant dosage.

The requisite foulant sample (two grams of wet foulant) could not be collected in order to perform zeta potential testing.

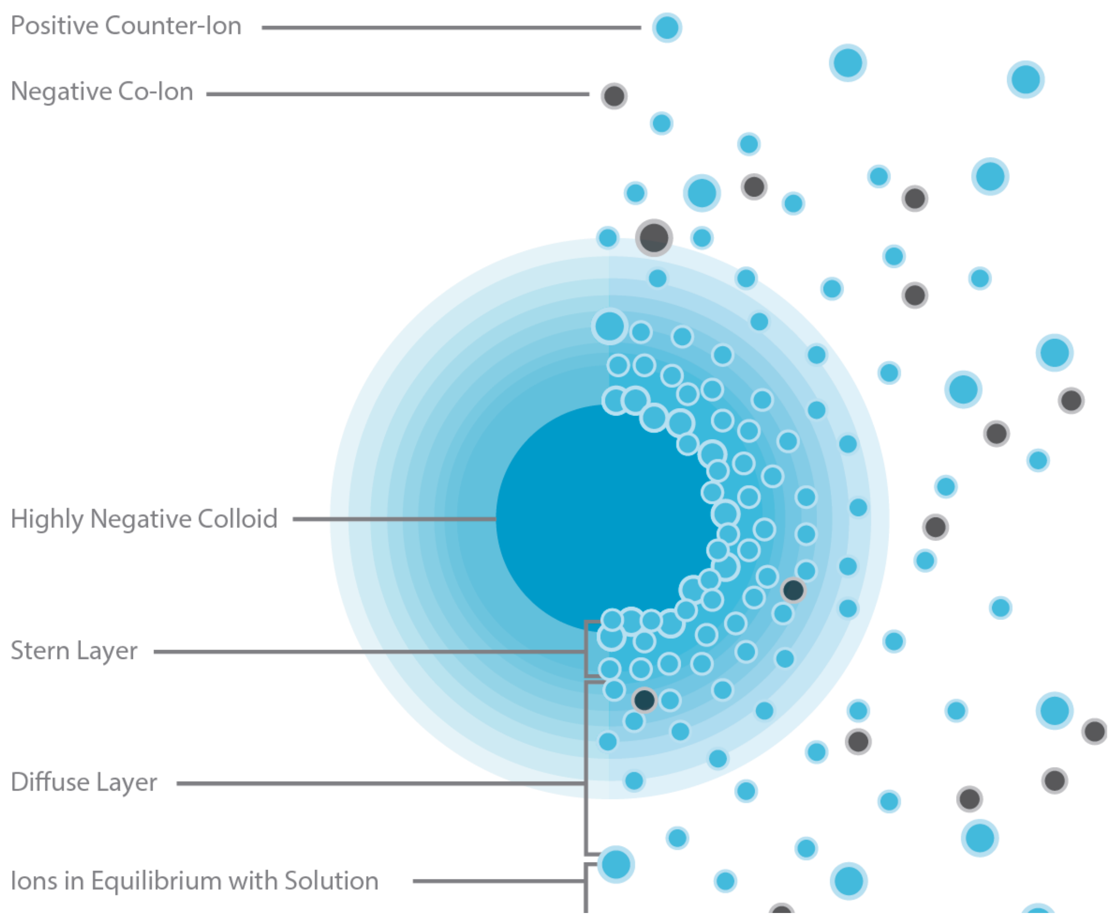
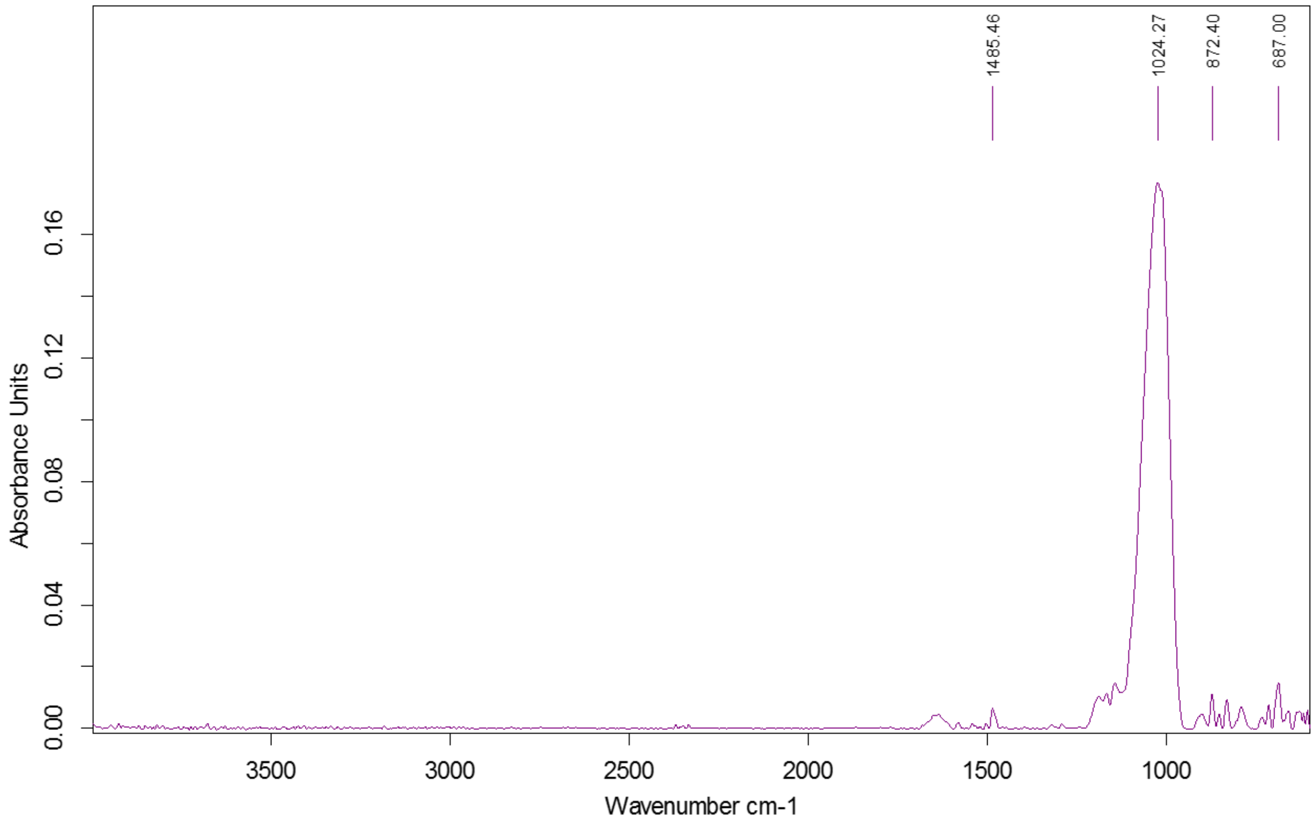


Image based on diagram from Particle Characterization Laboratories, Inc.

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 shape (e.g. sharp, broad, strong, weak).

FT-IR spectrum of the membrane surfaces detected a strong sharp band between 1100 and 900 cm^{-1}, which is indicative of the presence of Si-O bond stretching in the foulant sample.



FT-IR spectral image of the membrane surface

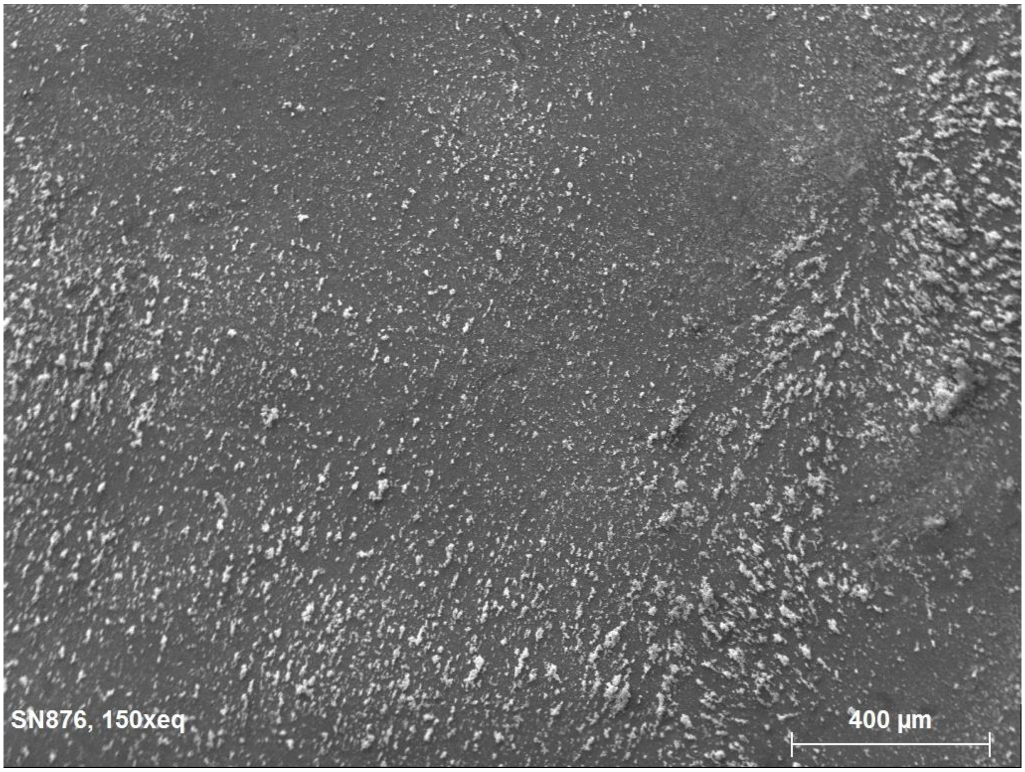
Testing to Identify Foulant Constituents

Energy Dispersive X-ray (EDX) analysis is conducted in conjunction with scanning electron microscopy (SEM) to identify inorganic foulant constituents. The electron beam in the microscope causes specimens to emit x-rays including those from the k, l and m atomic shells. Spectrometer counts of these x-rays, which are said to be "characteristic" of the elements present in the specimen, can be used to calculate composition for a full qualitative analysis.

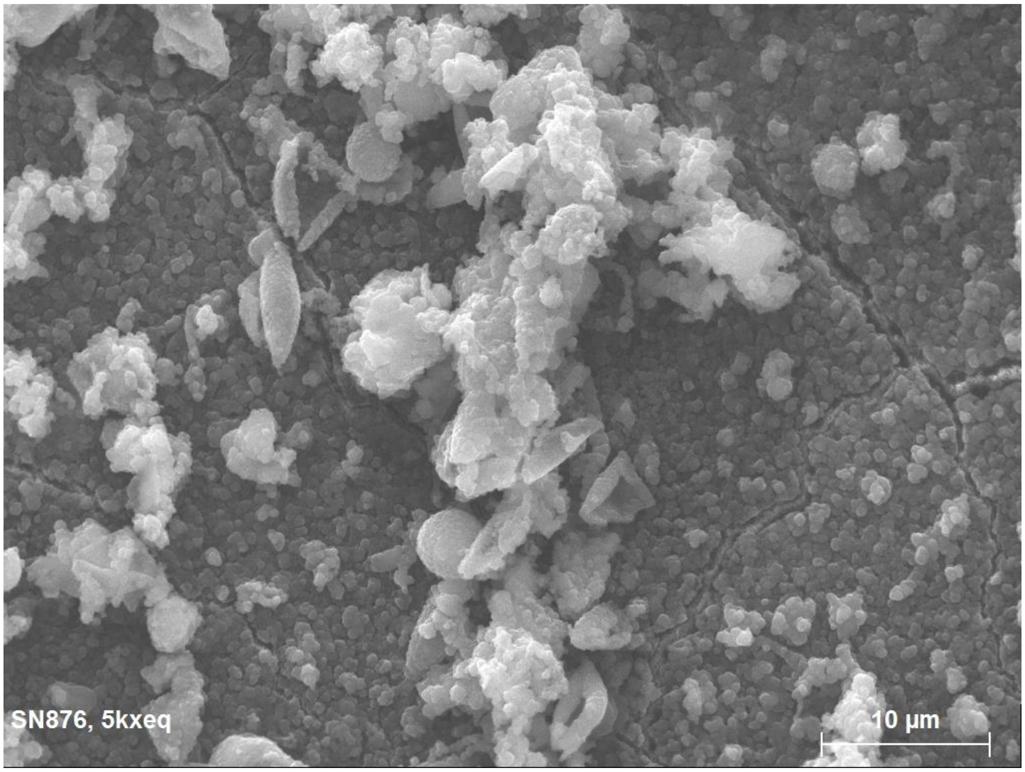
Chromatic Elemental Imaging (CEI) is an analytical technique used to resolve the spatial distribution of elements in a foulant sample. In this technique, a beam of focused electrons is accelerated across the surface of a foulant sample and interacts with the sample's inorganic elements by causing the elements to emit electrons. Since each element has its own unique atomic shell, 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 a 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 Chromatic Elemental Image is largely influenced by its concentration in the foulant sample; elements present in a higher percentage will be displayed with greater intensity in the image. CEI can uniquely identify the distinct elements in a mixed foulant sample containing several inorganic deposits. This technique also reveals the location and concentration of different elements relative to each other in a sample.

Inorganic Foulant Constituents Test Results

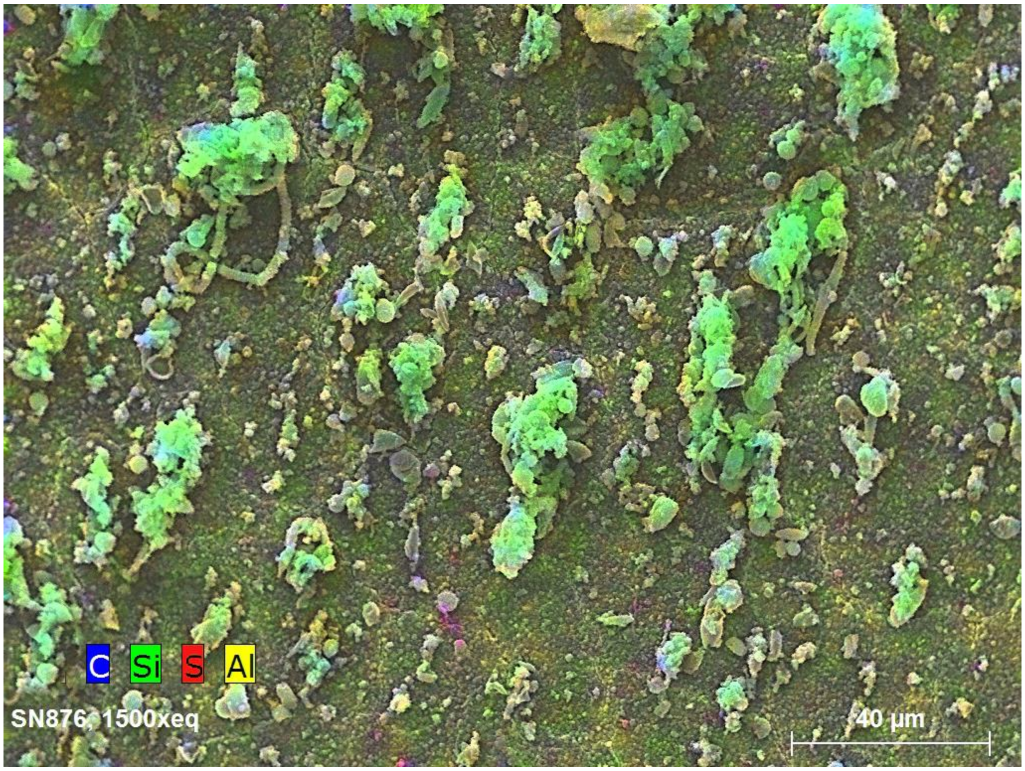
Elements	SN#11634876 Weight Percent
Oxygen	45.05
Carbon	37.56
Silicon	9.70
Sulfur	2.29
Aluminum	2.42
Calcium	1.13
Sodium	0.58
Chlorine	0.57
Magnesium	0.35
Potassium	0.35



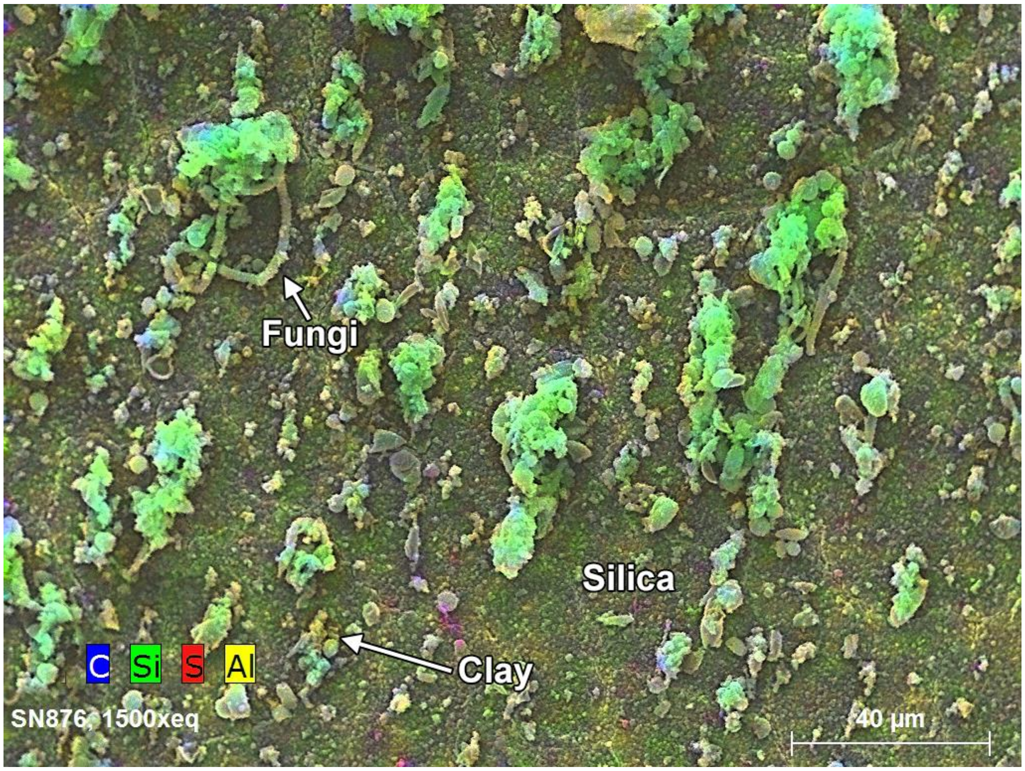
SEM image (150x) of the membrane surface of SN#11634876



Close up SEM image (5000x) of the membrane surface of SN#11634876



CEI image (1500x) of the membrane surface



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

Testing Comments and Interpretation

The Energy Dispersive X-ray (EDX) analysis identified silicon as the dominant inorganic constituent of the foulant material. Lesser amounts of aluminum, calcium and trace amounts (0.50%) of salts (sodium, chlorine, magnesium, potassium) were also detected. The sulfur percentage is representative of the membrane support material itself, rather than the foulant layer and was relatively low (2.29%) which indicates masking of the membrane surface by foulant material. Avista EDX analysis of new polyamide membrane typically detects between 5.00 and 7.00% sulfur.

The Scanning Electron Microscope (SEM) images showed a layer of granular foulant material coating the membrane surface. The foulant layer appeared to vary in thickness with randomly scattered granular particles and patches of foulant. Close-up imaging (5000x) showed that the foulant consisted of botryoidal material that completely coated the membrane surface.

Chromatic Elemental Imaging (CEI) confirmed the foulant layer was composed of silica (green). The botryoidal shape of the deposits along with the intensity of the coloring indicates the presence of silica scale. The layer of material was thin but even. Fungi coated in silica and clay deposits (aluminum silicates - combination of green and yellow) were also observed during CEI analysis. The membrane surface (represented by sulfur in red) was hardly visible.

Cell Test & Laboratory Clean-in-Place Study

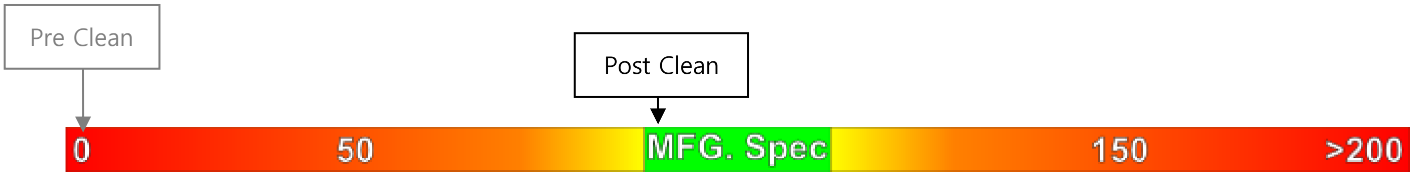
Flat sheet membrane samples harvested from the full element are placed in a cell test apparatus and cleaned with various Avista chemicals to determine the most effective cleaner combinations and the amount of time required for an effective cleaning.

Flat sheet water passage was restored using RoClean P112 (2% by weight, heated to 35°C and circulated) for three hours. Cleaning results are shown in the table below.

SN# 11634876	Water Passage Constant "A" Value	Salt Passage Constant "B" Value
Pre Clean	No Water Passage	
Post Clean	**1.36E-04** **Normal**	**41.5E-06** **248% of Normal**
Manufacturer's Specifications	1.35 to 1.83E-04 Normal Range	5.64 to 7.06E-06 Normal Range

Note: Testing Conducted with dechlorinated city water from San Marcos, CA

Water Passage (% of Normal)



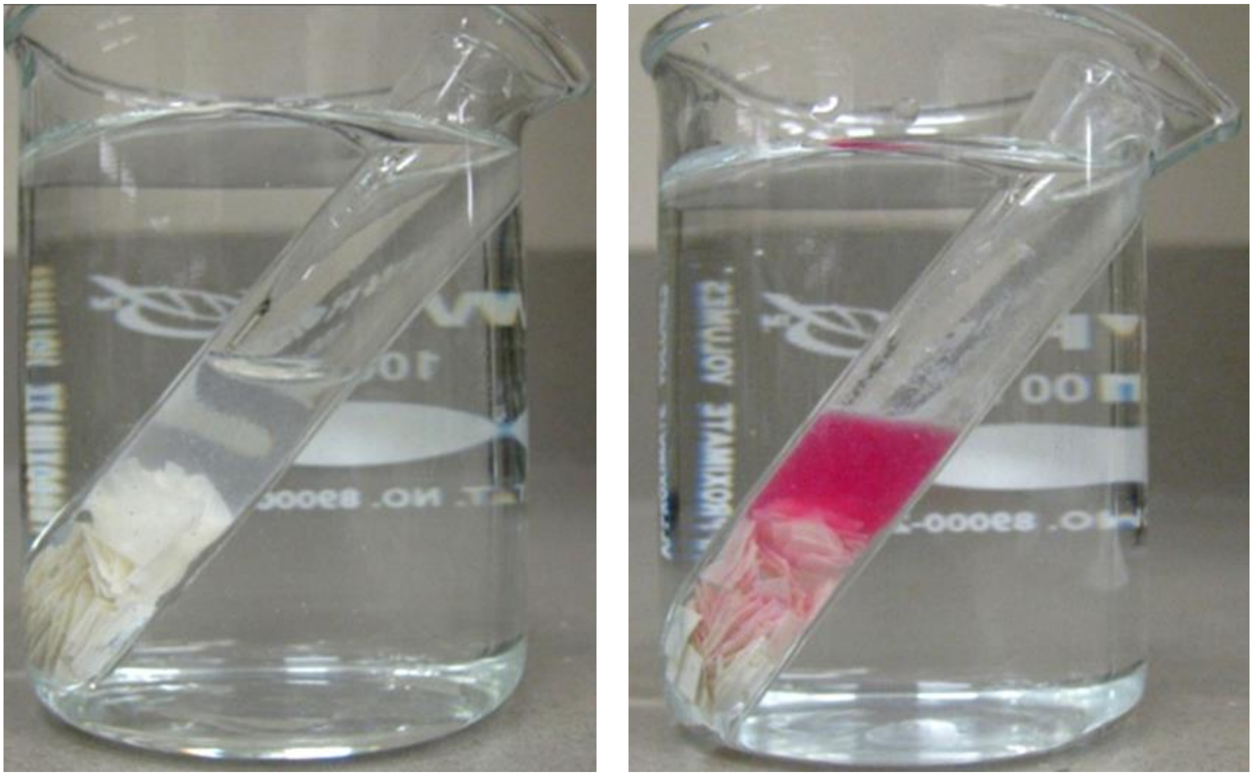
Salt Passage (% of Normal)

Testing to Determine Damage to Flat Sheet Samples

Testing for the Presence of Oxidizing Halogens

The Fujiwara test is used to confirm that a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. This test analyzes whether halogens have become part of the polymer structure through oxidative attack. Please note that the Fujiwara test is a qualitative test and that any color change indicates the presence of a halogen in the membrane structure. However, the test does not quantify the amount of exposure or which exact halogen is attached.

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



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

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#111616-5	Standard Spiral Autopsy	**11634876**	December 09, 2016

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 above have been conducted following Avista 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: 12/09/2016

Signed:

Sara Pietsch	Nagham Najeeb
Laboratory Services Manager	Laboratory Services Chemist

Appendix N – cRRO Tail Element Membrane Autopsy

Avista TECHNOLOGIES
Creative Chemistry. Smart Solutions.

4/19/2017

Eileen Y. Indica, Ph.D., P.E.
Trussell Technologies, Inc.
380 Stevens Avenue, Suite 308
Solana Beach, CA 92075

Hello Eileen,

Thank you for sending your membrane to Avista Technologies for evaluation. Attached please find the autopsy report for the Hydranautics ESPA2-LD-4040 reverse osmosis membrane serial number (SN#) 11518561. This element was a tail end element taken from a conventional reverse osmosis pilot system at Padre Dam Municipal Water District.

I have reviewed this report and have the following comments:

SN#11518561 3rd Stage Tail Membrane

- The full element produced less than 0.2 gpm during initial wet testing
- The external components were coated with white colored, powdery foulant material
- The membrane surfaces were evenly coated with white colored, granular foulant that adhered tightly to the membrane surfaces
- The foulant was identified as silica scale
- Flat sheet water passage was restored using RoClean P112 (2%, 2 hours)
- Fujiwara testing was positive, and dye testing revealed dye uptake suggestive of foulant abrasion (scale)

Avista TECHNOLOGIES

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Discussion

The objective of the pilot was to determine how well a conventional reverse osmosis 3rd stage would perform at high recovery rates. The limiting scale, based on previous analytical work, was determined to be silica scale. Feed water review determined that the silica concentration in the feed to the recovery RO unit had seen an increase. Smaller changes in the feed quality at the higher recoveries can put the system at a higher scaling risk.

Avista recommends determining the maximum recovery through the use of AdvisorCi and backing off a few percentage points to allow for any fluctuations in the feed stream and still remain within the antiscalant's limits.

Silica scale can be difficult to remove from a membrane surface. If this scale is not fully removed from the membrane surface it can become a nucleation site for future silica. I would be happy to review cleaning chemicals and procedures for cleaning silica scale.

Thanks again for permitting our organization to evaluate your membrane. We appreciate your business.

Kind regards,

Lee Durham
Technical Support Director
Avista Technologies, Inc.

DRAFT

Membrane Autopsy Report

04/19/2017 WO#033117-5

CORPORATE OFFICES

Avista Technologies, Inc.
Global Headquarters

+1.760.744.0536
info@avistatech.com

Avista Technologies (UK) Ltd

+44 (0) 131 449 6677
info@avistatech.co.uk

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Table of Contents

Executive Summary

Background

Trussell Technologies provided one (1) Hydranautics ESPA2-LD-4040 reverse osmosis (RO) element to Avista Technologies from the Padre Dam Municipal Water District for dissection and analysis. Element Serial Number (SN#) 11518561 was removed from the tail position of the third stage of the RO pilot system. The system was running at greater than 90% recovery. The results are provided below.

Initial Element Testing

The element weighed 11 pounds. New four inch elements typically weigh between 7 and 9 pounds. Element SN# 11518561 produced less than 0.20 gallons per minute (gpm) during initial wet testing. New elements of this type produce between 1.10 and 1.60 gpm.

External Inspection

The fiberglass casing had streaks of white colored, powdery foulant running from the feed (brine seal end) of the element to the concentrate (opposite brine seal end) but was otherwise in good mechanical condition. The anti-telescoping devices (ATDs) were in good condition, although they were coated in white colored foulant. The brine seal and permeate tube were in good condition and free of visual foulant material. Additionally, the element passed integrity testing, indicating the absence of mechanical damage (e.g. mechanical leaks) to the internal components of the spiral-wound element.

Internal Inspection and Testing

The scroll ends of the element were in good condition and were free of any visual foulant material. The exposed membrane surfaces were evenly coated with a layer of white colored, fine granular foulant material. The foulant adhered tightly to the membrane surfaces and could not be removed for further analysis. The remaining internal components (feed spacers, membrane folds and permeate spacers, membrane backing) were in good condition.

Cell Testing Results

Flat sheet samples harvested from the element produced no water passage upon baseline cell testing.

Foulant Analysis

Sufficient foulant material could not be scraped from the membrane surfaces to determine the loss on ignition, zeta potential or foulant density. Additionally, a microscope analysis could not be performed. Acid testing for the presence of carbonates was negative, indicating any carbonates present were below the visual detection limit. Fourier Transform Infrared (FT-IR) spectroscopy of the membrane surface identified a strong, sharp band around 1000 cm^{-1}, which is associated with the presence of Silicon – Oxygen (Si-O) bond stretching.

Foulant Analysis

The Energy Dispersive X-ray (EDX) analysis only identified silicon as the dominant foreign inorganic element present on the membrane surface. Lesser amounts of aluminum and trace amounts of salts (e.g. sodium, chlorine) were also detected. The sulfur weight percentage is associated with the membrane materials rather than foulant. The sulfur weight percentage (2.40%) indicates masking of the membrane surface by foulant as Avista's analysis of new membranes typically detects between 5.00 and 7.00%. The Scanning Electron Microscope (SEM) images at lower magnification showed a granular foulant scattered across the membrane. The foulant appeared to vary in thickness as portions of the membrane surface appeared to be visible the foulant layer had also cracked in some areas, likely due to the drying procedure involved with the analysis. The cracking observed is indicative of clay fouling. Close-up SEM imaging (5000x) showed a botryoidal geometry that is associated with silica scale. Chromatic Elemental Imaging^{SM} (CEI^{SM}) confirmed the granular foulant as silica scale. The layer was relatively thin in some areas, allowing the elements which represent the membrane material, alternating carbon and sulfur, to be displayed through the deposits. Thicker silica patches, shown by the intensity of the color, were also observed randomly across the membrane. Particles of aluminum and areas where clay (aluminum silicates) had deposited were also observed during CEI analysis.

Based on the results it was determined that there was a layer of silica scale on the membrane surface.

Cleaning Study

Flat sheet samples were cleaned using RoClean P112 (2% by weight, heated and circulated) for two hours. This cleaning regimen restored flat sheet water passage back to the manufacturer's specified range.

Testing for Flat Sheet Damage

Flat sheet samples produced higher than normal salt passage after cleaning. Fujiwara testing for halogen oxidation (e.g. chlorine damage) of the membrane surface was positive. Dye testing was performed to determine the cause/extent of damage to the membrane surfaces and revealed uneven dye uptake, with increased dye uptake consistent with the feed spacer contact points. Dye penetration through to the membrane backing was not observed. This type of damage is commonly attributed by physical damage to the membrane surface by the feed spacer material in the presence of an abrasive foulant. Based on these observations the higher than normal salt passage observed after cleaning is most likely due to a combination of halogen oxidation and scale abrasion.

Initial Element Test Results

Element Weight

Because element weight is often indicative of the degree of fouling, elements are weighed prior to the autopsy.

SN# 11518561 weighed 11 pounds; new four inch elements weigh approximately 7 to 9 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 ESPA2-LD-4040	Flow (gpm)	Rejection (%)	Pressure Drop (psi)
SN# 11518561	Less than 0.20 gallons per minute		
Manufacturer's Specifications	1.10 to 1.60	99.4 to 99.6	≤15

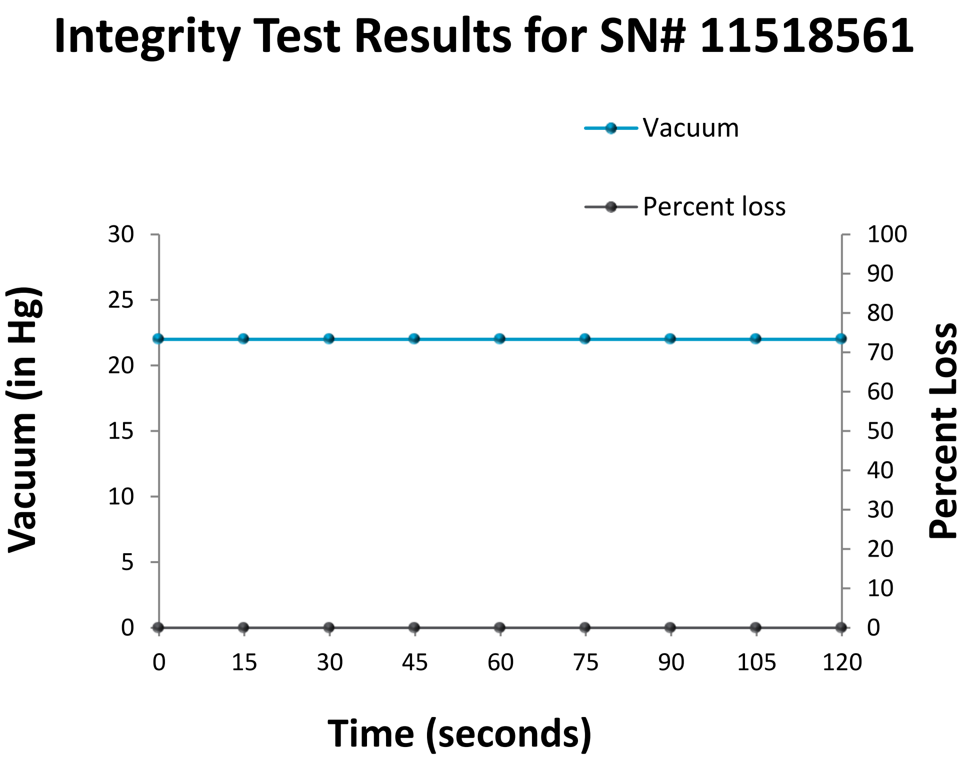
Element wet testing

Integrity Test

To determine if a membrane performance problem is possibly caused by mechanical damage, membranes are tested to check for vacuum decay that may indicate abnormal bypass.

In this test a vacuum of about 22 inches Mercury (in. Hg) is applied to the permeate side of the membrane for a duration of 120 seconds. If over 35% of the vacuum is lost within a 120 second period, then the membrane can be said to have severe physical damage.

Element SN#11518561 passed integrity testing.

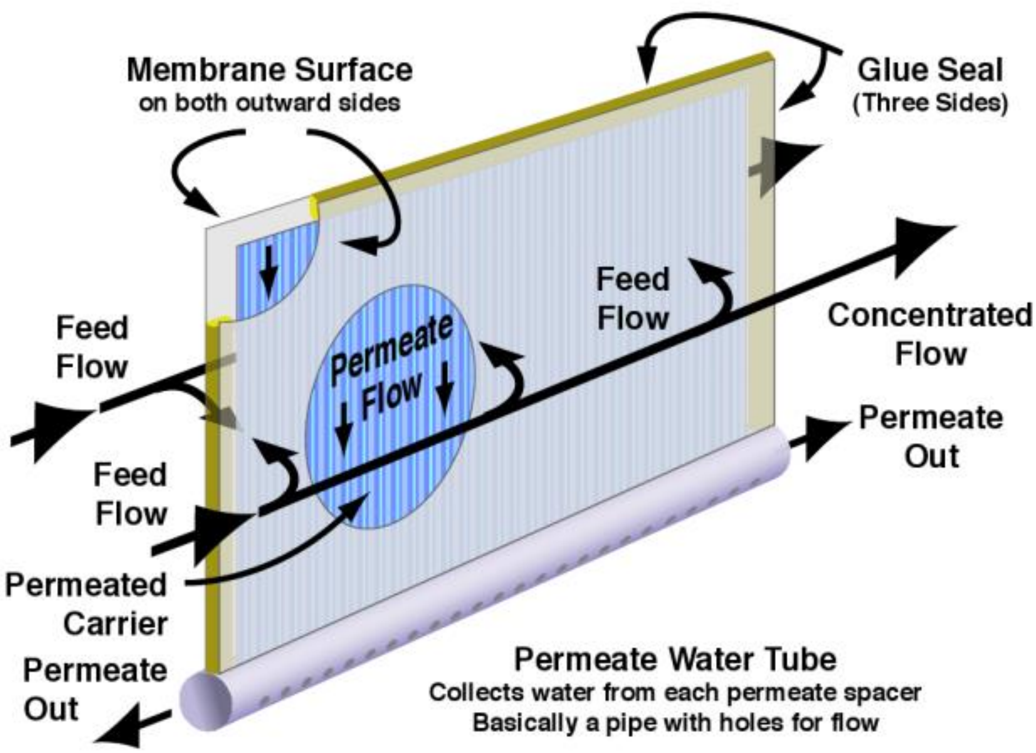


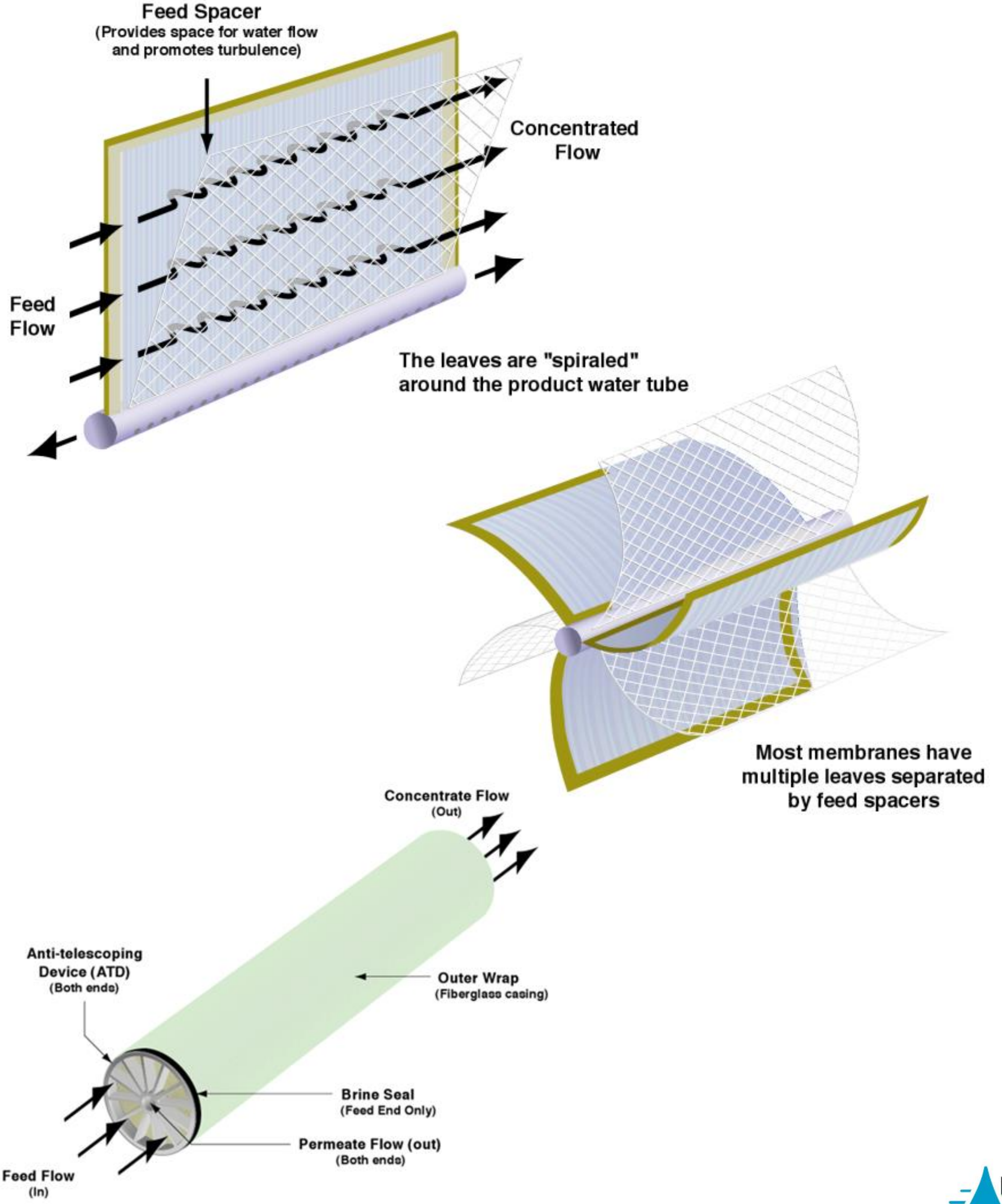
External Inspection

The external inspection of a membrane element is an important step in the autopsy process. Physical damage to the exterior components can contribute to performance issues in the element or may yield clues as to the operating conditions of the membrane system that led to poor membrane performance. As most of the external components are damaged during the autopsy process, documenting any significant finds before further work is completed is essential.

This section covers the fiberglass casing, anti-telescoping devices (ATDs), permeate tube, and brine seal. In addition, the scroll ends are also examined for any foulant/scale material that may be interfering with flow and for feed spacer extrusion also known as telescoping and gapping in the scroll end which may cause localized scaling (uneven hydraulics).

Spiral-Wound Membrane Element Construction

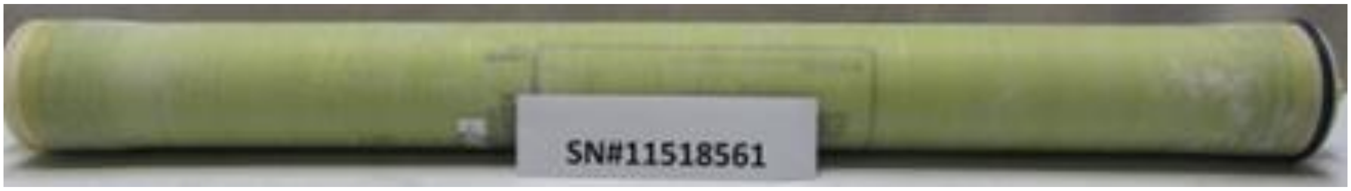



Feed Spacer
(Provides space for water flow
and promotes turbulence)
Concentrated
Flow
Feed
Flow
The leaves are "spiraled"
around the product water tube
Most membranes have
multiple leaves separated
by feed spacers
Concentrate Flow
(Out)
Anti-telescoping
Device (ATD)
(Both ends)
Outer Wrap
(Fiberglass casing)
Brine Seal
(Feed End Only)
Permeate Flow (out)
(Both ends)
Feed Flow
(In)

Fiberglass Casing

The fiberglass casing is an integral part of each element. The purpose of this wrap is to protect the element from external differential pressure, provide compressive strength to prevent telescoping and to ensure that the various membrane components are held in their correct position for optimum performance. Damage to the wrap can be an indication of rough handling or damage from excessive differential pressure across the membrane surface.

Although white colored foulant ran across the length of the casing, it was in good condition.



Fiberglass casing for SN# 11518561

Brine Seal

The purpose of the brine seal is 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 membrane element. Chevron type seals are used to aid in membrane loading and to seal to a variety of pressure vessel inside surfaces.

The brine seal was in good condition and free from damage.

Permeate Tube

At the center of each membrane element is a round section of pipe that is called the permeate tube. Down the length of the tube, holes are drilled through the pipe wall to the tube center. This tube is bonded to the membrane leaves and permits water to flow from the leaves outward at each end of the full element and the through the holes for collection. To function properly, the permeate tube must be free from gouges or damage that can prevent proper O-ring sealing at each end. Poor sealing can result in bypass from the high-pressure feed/concentrate flow into the permeate stream.

Damage which could allow for the bypass of feed water into the permeate stream, such as gouges or cracks, was not detected during the examination of the permeate tube.

Anti-Telescoping Device (ATD)

When assembled at the factory, membrane elements are commonly fitted with Anti-Telescoping Devices (ATDs) at each end of the element. These devices are designed to prevent telescoping of the membrane leaves under normal operating conditions that can cause membrane damage.

The anti-telescoping devices (ATDs) were in good condition; however, they were coated in white colored foulant.

Image of feed ATD (left) and concentrate ATD (right) for SN# 11518561

Internal Inspection & Testing

Scroll End Examination

Once the anti-telescoping devices are removed, the scroll ends of the membrane leaves are examined for presence of colloidal particles, biofouling, feed spacer extrusion and membrane gapping. In addition, each scroll end is examined for the gradual axial shift of the element leaves from outer diameter of the element towards the permeate tube. This type of damage is termed "telescoping" and is caused by the development of high differential pressure (usually greater than 10 psi) across the element.

The feed and concentrate scroll end were virtually free of visual foulant material.

Image of feed scroll end (left) and concentrate scroll end (right) for SN# 11518561

Membrane Surface Visual Examination

When assembled, the surface of the membrane is a uniform, shiny surface with no visual contamination or impurities. Although the membrane surface contamination can be sometimes hard to detect visually many times contamination is very visible and easy to detect with the naked eye.

The exposed membrane surfaces were evenly coated in a thin layer of white colored, fine granular foulant material. The foulant adhered tightly to the membrane surfaces and could not be removed for further analysis.

Exposed membrane surface for SN# 11518561

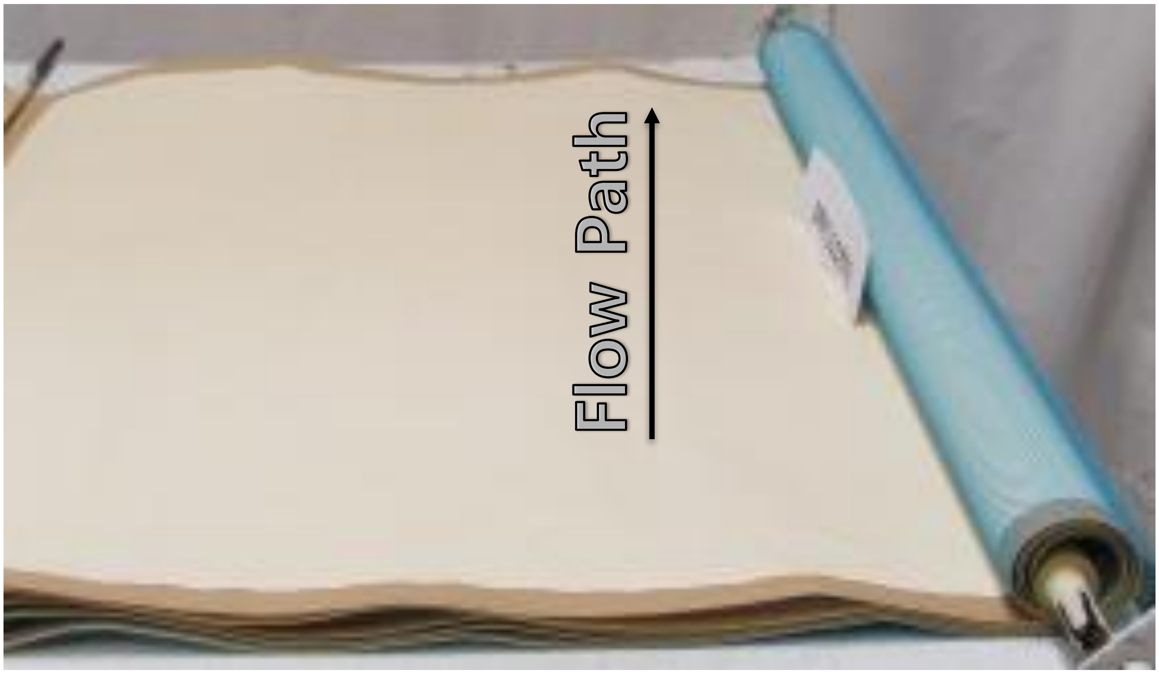


Image of membrane surface from feed end

Feed Spacer Visual Examination

The feed spacer is a plastic net material designed to separate membrane surfaces to form a flow path and to promote turbulence within feed water channel.

The feed spacers were free from visible foulant material.

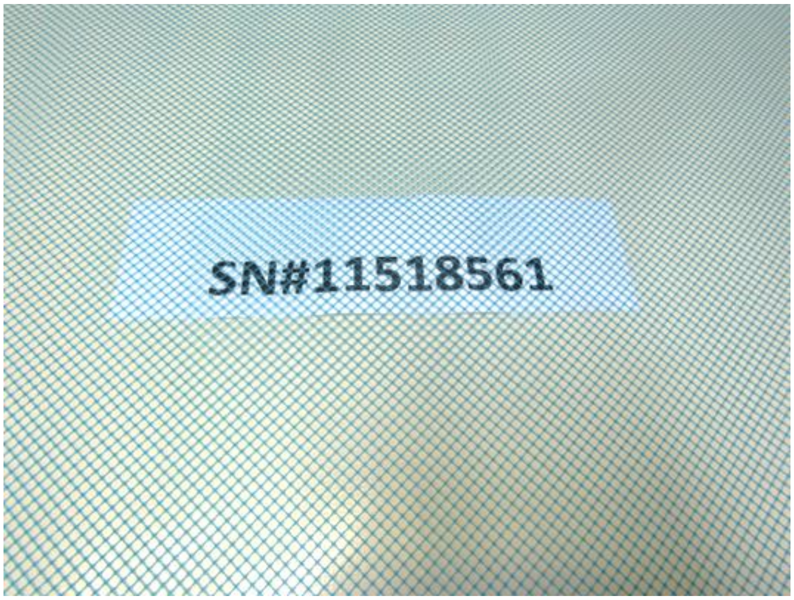


Image of feed spacer

Glue Line Integrity Examination

Membrane leaves are glued on three sides to separate feed and permeate streams. Glue lines are inspected to ensure that there are no sections of unbounded material referred to as glue flaps that may block the feed channel into the element module. In some worst-case situations, glue lines may fail at the feed end of the membrane permitting contamination. The glue lines are also inspected for pouching and delamination which often occur on the concentrate end of last stage elements. This type of physical damage may indicate permeate backpressure caused by positive pressure on the permeate side of the membrane.

The glue lines were in good condition; free of any pouching, delamination or glue flaps.

Permeate Spacer Visual Examination

Permeate spacer provides a path for permeate flow to channel towards the central permeate tube which minimizes permeate-side pressure losses.

No signs of contamination or damage were detected on the permeate spacers.

Cell Test for Permeate Flow & Salt Passage

To determine membrane performance characteristics membrane samples are tested in a cell test apparatus (CTA). The water passage constant is expressed as the “A” value, and the salt passage constant is expressed by a “B” value. Both constants are functions of the chemical-physical properties of the membrane plus 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 table below shows baseline performance data before cleaning.

Comparing cell testing of the membrane material to the original specification for the full spiral membrane element is a useful comparison tool. This data is collected in order to factor out any additional mechanical aspects the element construction may have caused in the spiral configuration.

SN# 11518561	**Water Passage Constant “A” Value**	**Salt Passage Constant “B” Value**
Flat Sheet Result	No water passage	
Manufacturer’s Specifications	1.27 to 1.91E-04 Normal Range	5.64 to 8.48E-06 Normal Range

Note: Testing conducted using dechlorinated city water

Water 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.

The organic content could not be determined due to the lack of foulant material on the membrane surfaces.

Foulant Density Measurement

Membrane foulant density is the weight of dry foulant per area of membrane surface. Foulant densities determined from past autopsies range from 0.02 to 1.84 mg/cm^2 and average 0.51 mg/cm^2.

The foulant density could not be measured as a sample could not be collected from the membrane surfaces.

Testing for the Presence of Carbonates

Acid testing is used to determine the presence of carbonates on the membrane surface. In this test, several drops of dilute hydrochloric acid were placed on the foulant surfaces. Effervescing indicates a positive test result.

No bubbling was observed as acid was applied to the active membrane surfaces.

Testing for the Presence of Coagulant

Zeta potential testing of the membrane surface foulant can determine the presence of excess coagulant by measuring the charge associated with the surface colloids. Most naturally occurring colloids are negatively charged and surrounded by a double layer of counter ions. Zeta potential is the charge that resides at the double layer boundary, which we can conveniently measure with a zeta potential meter.

Electrostatic repulsion becomes significant when two colloids approach each other and their charged double layers begin to interfere. Because of this mutual repulsion, coagulation and flocculation are difficult to accomplish and coagulants are often overfed into the RO system resulting in a positive zeta potential. Samples that show a near zero or neutral zeta potential represent the optimum coagulant dosage.

Two grams of wet foulant could not be collected in order to determine the zeta potential.

Testing for the Presence of Microbiological Organisms

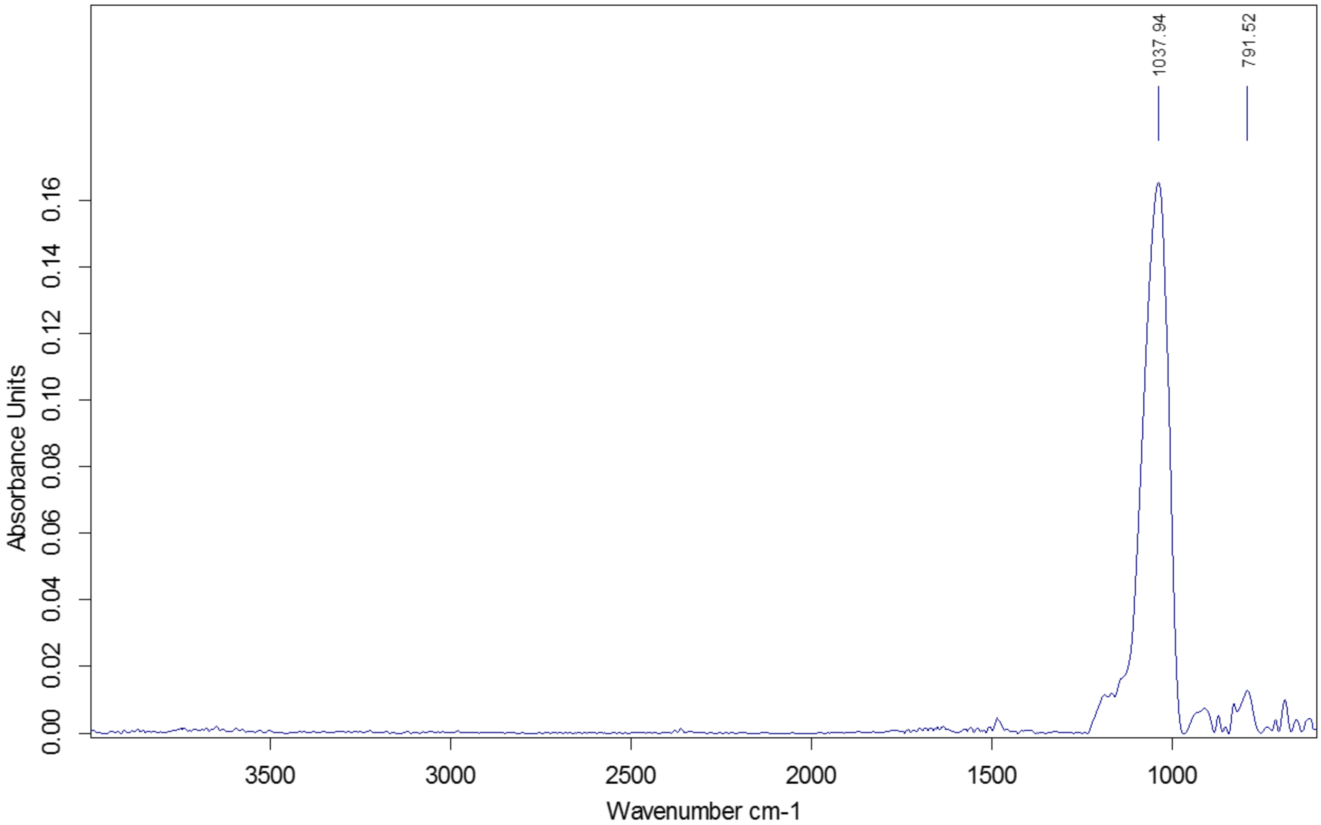
Foulant samples were stained and examined with a light microscope at 1000x using an oil immersion lens. Gram positive bacteria are stained blue while Gram negative bacteria are stained red.

A microbiological analysis could not be performed due to the lack of removable foulant on the membrane surfaces.

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 shape (e.g. sharp, broad, strong, weak).

FT-IR spectrum of the membrane surface identified a strong, sharp band around 1000 cm^{-1}, which is associated with the presence of Silicon – Oxygen (Si-O) bond stretching.



FT-IR spectral image of the membrane surface of SN#11518561

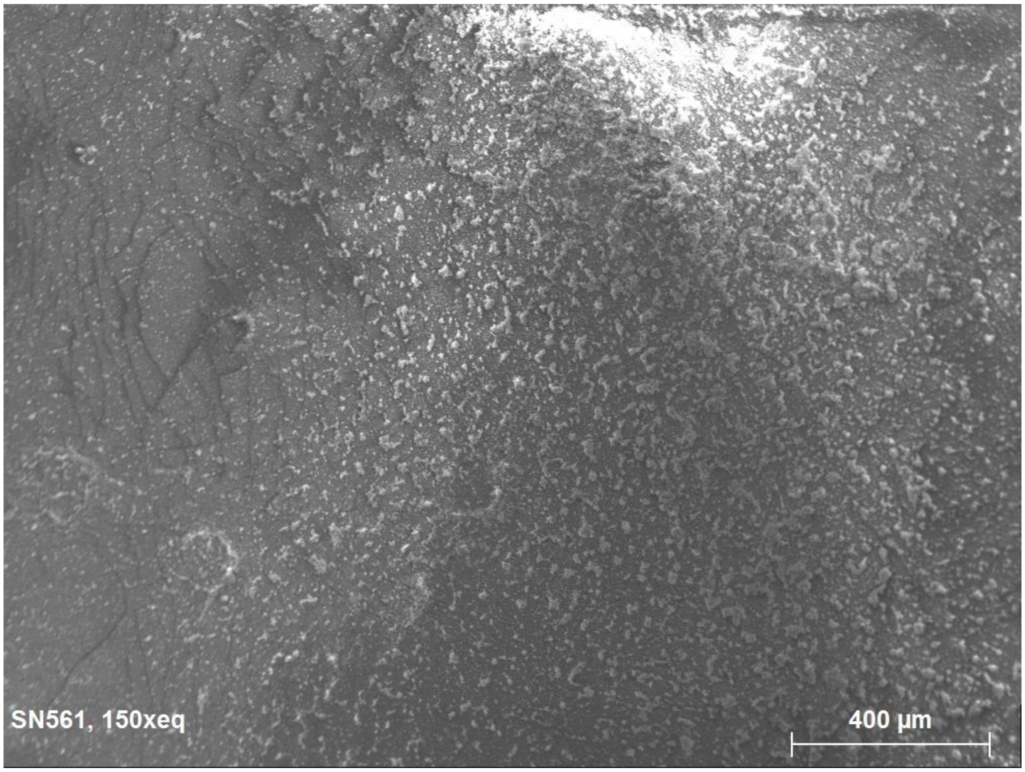
Testing to Identify Inorganic Foulant Constituents and Chromatic Elemental Imaging^{SM}

Energy Dispersive X-ray (EDX) analysis is conducted in conjunction with scanning electron microscopy (SEM) to identify inorganic foulant constituents. The electron beam in the microscope causes specimens to emit x-rays including those from the k, l and m atomic shells. Spectrometer counts of these x-rays, which are said to be "characteristic" of the elements present in the specimen, can be used to calculate composition for a full qualitative analysis.

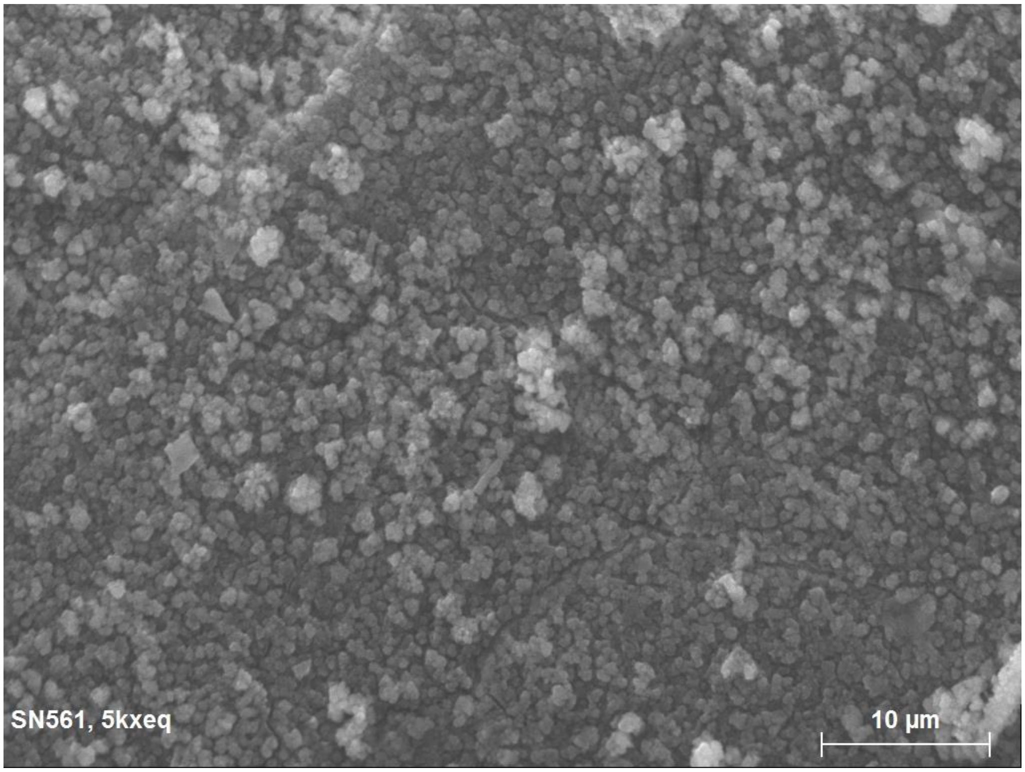
Chromatic Elemental Imaging^{SM} (CEI^{SM}) is an analytical technique used to resolve the spatial distribution of elements in a foulant sample. In this technique, a beam of focused electrons is accelerated across the surface of a foulant sample and interacts with the sample's inorganic elements by causing the elements to emit electrons. Since each element has its own unique atomic shell, a particular 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 a 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 Chromatic Elemental Image is largely influenced by its concentration in the foulant sample; elements present in a higher percentage will be displayed with greater intensity in the image. CEI can uniquely identify the distinct elements in a mixed foulant sample containing a number of inorganic deposits. This technique also reveals the location and concentration of different elements relative to each other in a sample.

Inorganic Foulant Constituents Test Results

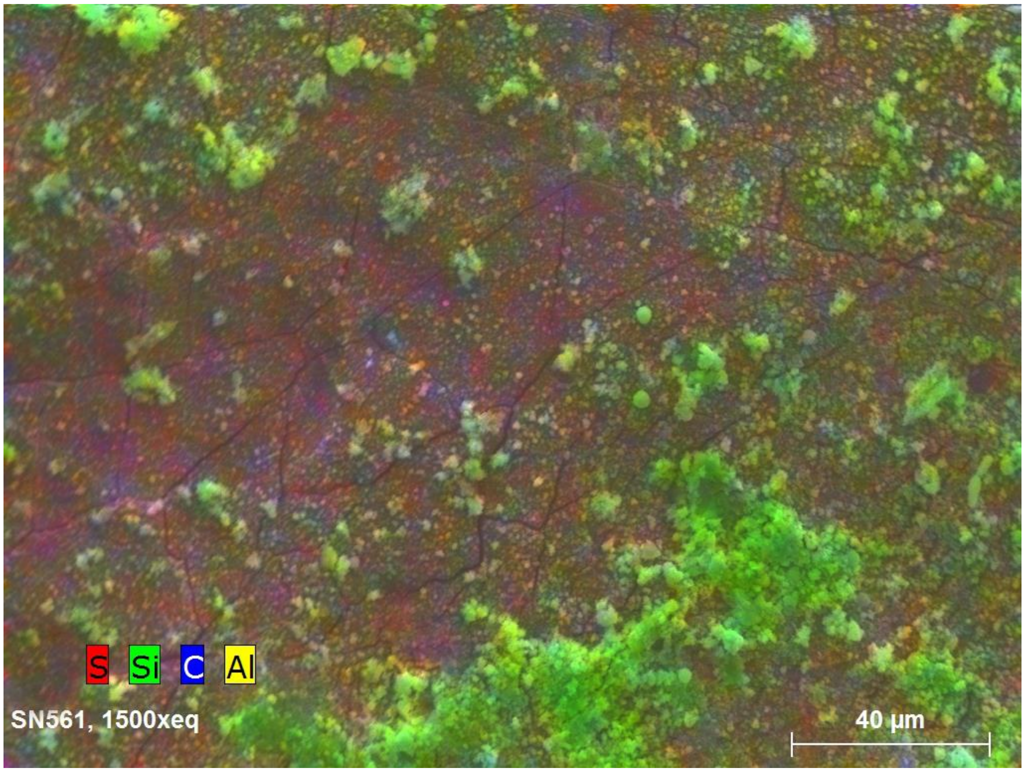
Elements	**SN#11518561** (Mag: 150x, weight percentage)
Oxygen	50.18
Carbon	29.93
Sulfur	2.40
Silicon	13.81
Aluminum	2.01
Sodium	0.57
Calcium	0.41
Chlorine	0.28
Magnesium	0.25
Potassium	0.16



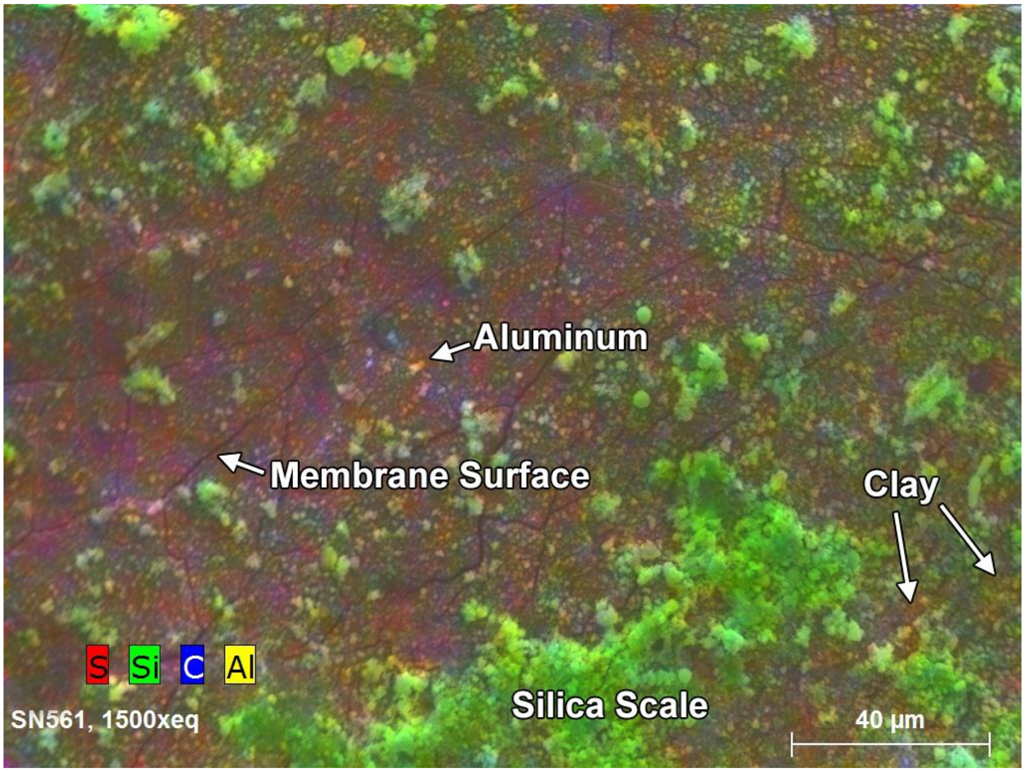
SEM image (150x) of the membrane surface of SN#11518561



Close-up SEM image (5000x) of a granular patch of foulant



CEI[SM] image (1500x) of the membrane surface



CEI[SM] image (1500x) of the image above with labels

Testing Comments and Interpretation

The Energy Dispersive X-ray (EDX) analysis only identified silicon as the dominant foreign inorganic element present on the membrane surface. Lesser amounts of aluminum and trace amounts of salts (e.g. sodium, chlorine) were also detected. The sulfur weight percentage is associated with the membrane materials rather than foulant. The sulfur weight percentage (2.40%) indicates masking of the membrane surface by foulant as Avista's analysis of new membranes typically detects between 5.00 and 7.00%.

The Scanning Electron Microscope (SEM) images at lower magnification showed a granular foulant scattered across the membrane. The foulant appeared to vary in thickness as portions of the membrane surface appeared to be visible the foulant layer had also cracked in some areas, likely due to the drying procedure involved with the analysis. The cracking observed is indicative of clay fouling. Close-up SEM imaging (5000x) showed a botryoidal geometry that is associated with silica scale.

Chromatic Elemental Imaging^{SM} (CEI^{SM}) confirmed the granular foulant as silica scale (green). The layer was relatively thin in some areas, allowing the elements which represent the membrane material, alternating carbon and sulfur (dark blue and red), to be displayed through the deposits. Thicker silica patches, shown by the intensity of the green color, were also observed randomly across the membrane. Particles of aluminum (yellow) and areas where clay (aluminum silicates – combination of green and yellow) had deposited were also observed during CEI analysis.

Cell Test & Laboratory Clean-in-Place Study

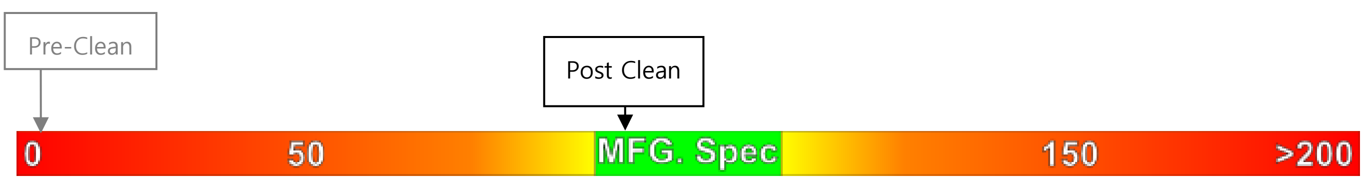
Flat sheet membrane samples harvested from the full element are placed in a cell test apparatus and cleaned with various Avista chemicals to determine the most effective cleaner combinations and the amount of time required for an effective cleaning.

The table below shows performance data before and after cleaning. Flat sheet samples were cleaned with RoClean P112 (2% by weight, heated and circulated) for two hours.

SN# 141142944	**Water Passage Constant "A" Value**	**Salt Passage Constant "B" Value**
Pre-Clean	No water passage	
Post Clean	**1.30E-05** **Normal**	**74.7E-06** **880% of Normal**
Manufacturer's Specifications	1.27 to 1.91E-04 Normal Range	5.64 to 8.48E-06 Normal Range

Note: Testing conducted with dechlorinated city water

Water Passage (% of Normal)



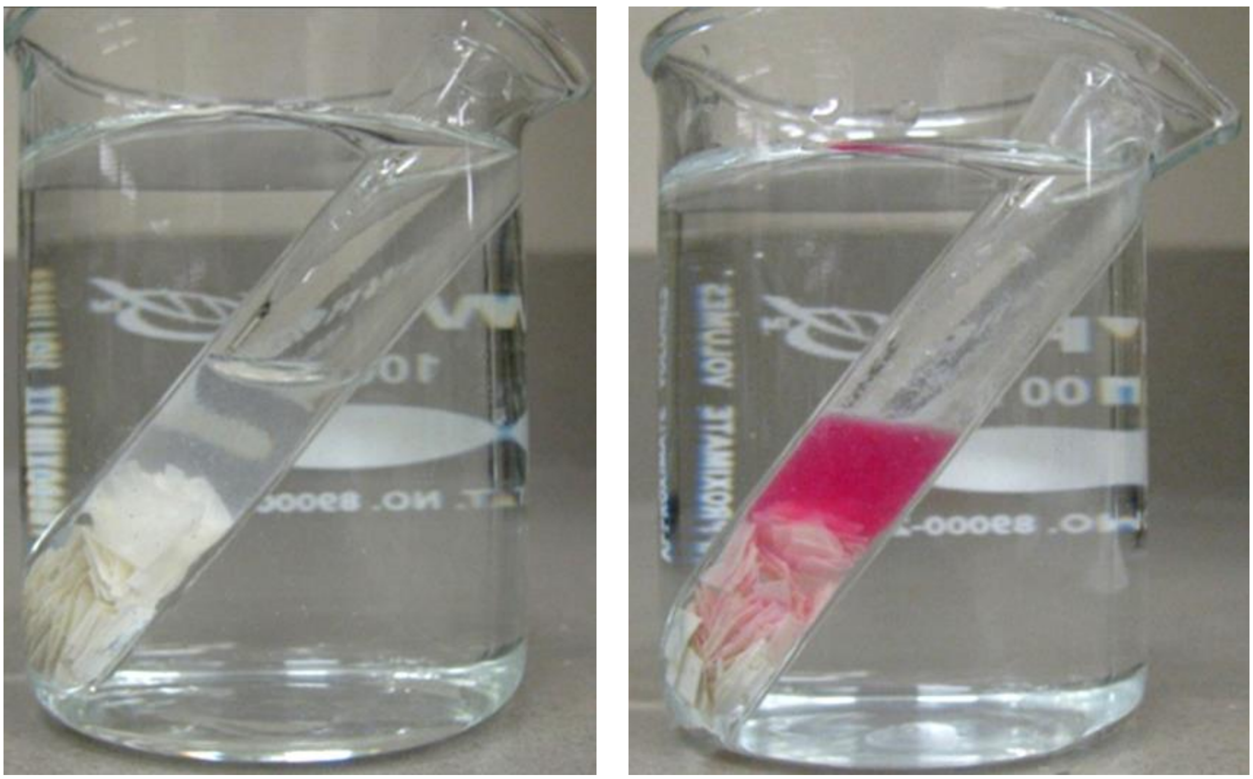
Salt Passage (% of Normal)

Testing to Determine Damage to Flat Sheet Samples

Testing for the Presence of Oxidizing Halogens

The Fujiwara test is used to confirm that a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. This test analyzes whether halogens have become part of the polymer structure through oxidative attack. Please note that the Fujiwara test is a qualitative test and that any color change indicates the presence of a halogen in the membrane structure. However, the test does not quantify the amount of exposure or which exact halogen is attached.

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



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

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.

Uneven dye uptake was observed on the membrane surface with increased dye uptake on the feed spacer contact points. Dye penetration through to the membrane backing material was not observed. This type of damage observed is commonly attributed by scale abrasion.

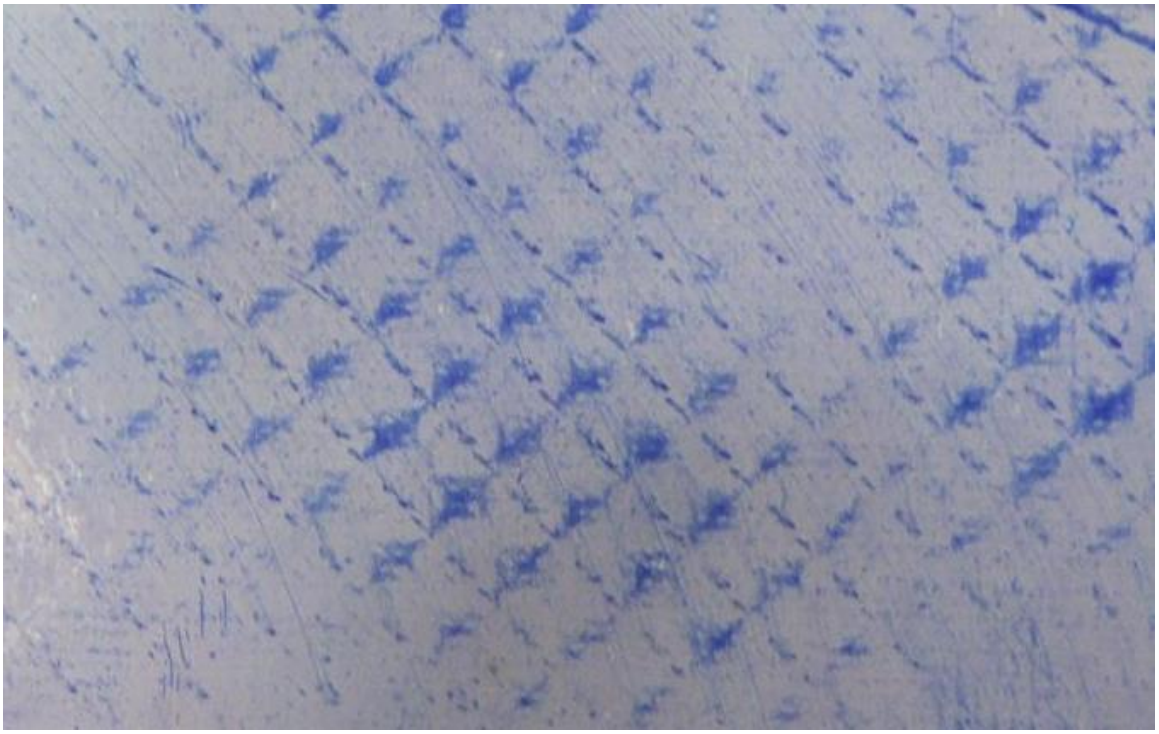


Image of dye uptake on membrane surfaces

Certification by Laboratory

Report Number	Report Content	Element Serial Number	Report Date
WO#033117-5	Standard Spiral Autopsy	**11518561**	April 18, 2017

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 above have been conducted following Avista 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: 04/19/2017

Signed:

Megan Lee
Laboratory Services Manager

Jared Furlong
Laboratory Services Chemist

Appendix O – Saturation Modeling

Parameter	Units	3/8/16	3/15/16	3/24/16	4/7/16	4/28/16	5/5/16
Calcium Total ICAP	mg/L	200	210	240	260	220	260
Magnesium Total ICAP	mg/L	75	84	97	100	71	94
Sodium Total ICAP	mg/L	490	500	580	580	480	570
Potassium Total ICAP	mg/L	58	62	64	66	62	66
Ammonia	mg-N/L	3.74	2.6	2.13	2.14	2.19	2.4
Barium Total ICAP/MS	µg/L	160	190	220	270	220	280
Strontium ICAP	mg/L	2	2.2	2.7	3.4	2.2	3.1
Alkalinity as CaCO3	mg/L	66	190	111	90	120	162
Sulfate	mg/L	860	930	1000	1100	970	1200
Chloride	mg/L	670	690	740	680	670	700
Nitrate	mg/L	***155.4***	***148.4***	***236.0***	***236.5***	***199.3***	***167.8***
Phosphate	mg/L	*0.5*	*0.3*	*0.4*	*0.5*	*0.7*	*1.0*
Silica	mg/L	35	35	31	20	30	38
RRO Recovery		80	80	80	80	80	80
Temp		75	76	76	76.2	76.8	78.7
CaSO4 Saturation		159	165	193	226	184	240
BaSO4		10975	13214	14974	19822	15846	21980
Ca3(PO4)2		0.54	0.33	0.47	0.59	0.66	0.75
SrSO4		100	112	136	186	116	180
SiO2 Saturation		138	137	121	78	116	144
LSI		0.9	1.41	1.49	1.25	1.19	1.31
Overall Recovery		95	95	95	95	95	95

Parameter	5/12/16	5/19/16	5/26/16	6/2/16	6/9/16	6/16/16	6/23/16
Calcium Total ICAP	230	200	200	210	210	230	230
Magnesium Total ICAP	74	67	68	72	66	71	79
Sodium Total ICAP	540	500	490	500	530	530	560
Potassium Total ICAP	64	62	61	62	62	65	63
Ammonia	2.18	2.12	2.68	2.73	2.7	2.56	2.56
Barium Total ICAP/MS	190	170	190	210	180	190	210
Strontium ICAP	2.1	2	2.2	2.2	2	2.2	2.6
Alkalinity as CaCO3	112	84	158	322	122	88	234
Sulfate	920	830	810	760	860	970	920
Chloride	660	600	650	650	690	700	720
Nitrate	***194.9***	***165.6***	***205.0***	***128.9***	***151.5***	***178.9***	***139.5***
Phosphate		*0.5*	*0.5*	*0.3*	*0.4*	*0.3*	*0.4*
Silica	33	32	31	32	32	34	35
RRO Recovery	80	80	80	80	80	80	80
Temp	79	79.6	78.4	80.6	80.8	80.9	83.3
CaSO4 Saturation	183	155	150	146	161	190	176
BaSO4	13092	11552	12423	12865	12098	13647	14027
Ca3(PO4)2	0.64	0.55	0.49	0.33	0.41	0.34	0.38
SrSO4	105	98	104	97	97	114	123
SiO2 Saturation	125	121	118	120	119	127	127
LSI	1.22	1.13	1.3	1.54	1.21	1.1	1.45
Overall Recovery	95	95	95	95	95	95	95

Parameter	6/30/16	7/14/16	7/28/16	8/4/16	8/11/16	8/18/16	9/1/16
Calcium Total ICAP	240	230	300	280	240	290	250
Magnesium Total ICAP	85	76	120	99	86	100	87
Sodium Total ICAP	580	570	710	720	640	750	630
Potassium Total ICAP	66	65	85	82	80	85	76
Ammonia							3
Barium Total ICAP/MS	240	190	300	310	190	260	210
Strontium ICAP	2.8	2.4	3.5	3	2.8	3.3	2.6
Alkalinity as CaCO3							62
Sulfate	920	840	1400	1200	1100	1300	1100
Chloride	730	770	940	920	780	1000	800
Nitrate							***245.3***
Phosphate							*0.7*
Silica	37	35	46	42	37	44	42
RRO Recovery	80	80	80	80	80	80	80
Temp	82.9	83.4	85.7	85.7	85.2	85.8	85.7
CaSO4 Saturation	182	164	275	234	202	253	208
BaSO4	15865	11893	23417	22322	13914	19380	15237
Ca3(PO4)2	0.41	0.4	0.36	0.58	0.36	0.36	0.54
SrSO4	134	108	201	158	148	181	136
SiO2 Saturation	135	127	162	148	132	155	149
LSI	1.21	1.19	1.21	1.41	1.18	1.2	0.97
Overall Recovery	95	95	96	96	96	96	96

Parameter	9/8/16	9/15/16	9/22/16	9/29/16	10/6/16	10/13/16	10/27/16
Calcium Total ICAP	250	260	270	310	270	270	300
Magnesium Total ICAP	84	90	89	120	92	94	98
Sodium Total ICAP	660	640	690	690	680	670	720
Potassium Total ICAP	80	78	76	84	80	81	85
Ammonia	3.42	2.47	3.22	3.68	3.16	2.75	3.81
Barium Total ICAP/MS	220	210	260	300	240	240	270
Strontium ICAP	2.5	2.9	3.1	4.2	2.9	3.1	3.5
Alkalinity as CaCO3	106	114	96	132	120	122	136
Sulfate	1000	1100	1200	1500	1200	1200	1200
Chloride	890	820	910	391	890	870	930
Nitrate	***220.5***	***258.6***	***249.8***	***273.7***	***249.3***	***261.7***	***268.4***
Phosphate	*0.7*	*1.0*	*0.9*	*0.6*	*0.6*	*1.6*	*1.0*
Silica	43	45	43	52	46	45	48
RRO Recovery	80	80	80	80	85	85	85
Temp	85.2	84.4	85	84.3	82.9	83.1	82
CaSO4 Saturation	190	213	231	310	330	328	353
BaSO4	14555	14921	19114	25513	24554	24361	26471
Ca3(PO4)2	0.57	0.68	0.65	0.56	0.81	1.32	1.21
SrSO4	120	150	166	264	222	236	258
SiO2 Saturation	153	161	153	186	211	206	219
LSI	1.19	1.18	1.14	1.3	1.5	1.68	1.78
Overall Recovery	96	96	96	96	97	97	97

Parameter	**1/12/17**	**1/19/17**	**1/26/17**	**2/3/17**	**2/9/17**	**2/16/17**	**2/24/17**
Calcium Total ICAP	260	320	360	380	340	270	330
Magnesium Total ICAP	97	130	160	160	140	100	140
Sodium Total ICAP	640	750	850	780	780	700	720
Potassium Total ICAP	69	73	60	74	74	67	69
Ammonia			2.14	2.27	2.3	2.45	1.72
Barium Total ICAP/MS	260	280	240	320	320	240	330
Strontium ICAP	3	3.3	4.8	4.1	3.3	2.5	3.5
Alkalinity as CaCO3			166	180	168	176	202
Sulfate	1200	1400	1500	1600	1300	1100	1400
Chloride	900	990	980	1000	1000	980	980
Nitrate			***270.1***	***277.7***	***257.3***	***225.4***	***261.3***
Phosphate			*33.7*	*0.7*	*0.7*	*0.4*	*0.6*
Silica	58	60	100	82	75	58	79
RRO Recovery	87.5	75	75	75	75	75	75
Temp	73.6	72.5	69.6	71.2	73.4	73.1	70.9
CaSO4 Saturation	388	221	245	279	218	151	230
BaSO4	32083	16223	3552	19150	17080	11214	1923
Ca3(PO4)2	1	0.58	1.76	0.59	0.54	0.19	0.49
SrSO4	280	143	205	189	133	88	153
SiO2 Saturation	304	191	317	270	242	187	261
LSI	1.55	1.21	1.31	1.43	1.34	1.21	1.42
Overall Recovery	95	95	95	95	95	95	95

Parameter	**3/2/17**	**3/9/17**	**3/16/17**	**3/23/17**	**3/30/17**
Calcium Total ICAP	350	340	220	220	200
Magnesium Total ICAP	150	150	91	84	78
Sodium Total ICAP	800	810	600	580	570
Potassium Total ICAP	52	69	55	62	66
Ammonia	2.1	1.88	2.48	2.09	1.45
Barium Total ICAP/MS	230	260	190	160	120
Strontium ICAP	2.9	2.9	1.8	1.5	1.5
Alkalinity as CaCO3	286	242	210	124	220
Sulfate	1500	1300	850	830	620
Chloride	1000	980	840	820	770
Nitrate	***235.6***	***268.4***	***186.9***	***209.5***	***204.2***
Phosphate	*0.6*	*0.9*	*0.8*	*0.5*	*0.9*
Silica	120	93	56	50	52
RRO Recovery	75	70	70	70	70
Temp	69	72	66	74.7	76
CaSO4 Saturation	249	172	98	95	69
BaSO4	13268	11061	7212	6123	3753
Ca3(PO4)2	0.5	0.35	0.14	0.1	0.31
SrSO4	129	92	50	41	33
SiO2 Saturation	403	255	164	135	139
LSI	1.59	1.21	0.91	0.82	0.94
Overall Recovery	95	92.5	92.5	92.5	92.5