TIME TO CLEAN AGAIN? CHANGES IN CLEANING FREQUENCY AND EFFECTIVENESS AT THE RICHARD A. REYOLDS GROUNDWATER DESALINATION FACILITY

Gabriela J. Handley, Separation Processes, Inc. 3156 Lionshead Ave. Ste. 2 Carlsbad, CA 92010
Email: ghandley@spi-engineering.com Phone: 760-400-3660

Introduction

Sweetwater Authority (SWA) owns and operates the Richard A. Reynolds Groundwater Desalination Facility (RAR) in Chula Vista, CA. The facility has a maximum daily production of 4 MGD sourced from six brackish groundwater wells that draw from the San Diego Formation. The facility consists of three Reverse Osmosis (RO) trains in a 20:10 array operating at an 81% recovery. Due to high manganese concentrations in the groundwater, the bypass (blend) water is treated through an iron and manganese removal system. During the dry season the facility maintains a flux of 9.5 gfd, increasing to 12-14 gfd in the wet season when more wells are available. In 2016, the plant will be expanded to a 10 MGD facility with the addition of three new RO trains and 5 new groundwater wells requiring a six to eight month shutdown during construction.

SWA has hired Separation Processes Inc. (SPI) to conduct a performance audit that reviews current and historical performance of the facility along with a discussion of the RO cleaning effectiveness. Operational data is collected daily by water treatment plant operators and entered into a normalization software database. The data is then analyzed for several parameters including; feed water characteristics, recovery, flux, specific flux, normalized differential pressure, normalized permeate conductivity, and normalized conductivity rejection. Once the data is compiled and normalized an assessment of the membrane performance and condition is made. Then, potential areas for optimization are identified including, an evaluation of the CIP process for the effectiveness of the current RO cleaner, recommendations for new RO cleaners, and procedural improvements.

The current RO elements were installed in January 2010 and have historically been cleaned annually. However, in 2014 the fouling rate began to increase and a second cleaning was performed within the same calendar year. In only 7 months specific flux and normalized differential pressure values had already reached values which historically had taken 12 months to achieve. The fouling rate continued to increase in early 2015 prompting another cleaning in June/July. This paper will look at past and present operational data and discuss changes observed in cleaning frequency and effectiveness.

Agency and Facility Background

SWA was formed in 1977 and provides water to approximately 186,000 in a service area that covers about 32 square miles of southern San Diego County including residents in National City, Bonita, as well as parts of Chula Vista. SWA was originally established to enable public acquisition of the water system which was previously owned by a private water firm.

Since 1999, the Richard A. Reynolds Groundwater Desalination Facility has been used to treat brackish groundwater for public distribution. R.A.R. extracts and treats approximately 4 mgd. Groundwater is extracted from six wells which pull water from the San Diego Formation. Well 5 has be put offline permanently and as a result currently only five wells contribute to the feed of the plant. Three of these wells operate year round while the remaining two are operated during the "wet season" which is considered to be December 1st- May 1st. During the wet season, the brine discharge permit increases to 1 mgd based on a monthly average. These two wells can only be operated during the wet season if the brine discharge permit increases to 1 mgd and also only if the TDS concentration in the riverbed is below 4000 mg/L.

Table 1: Average Well Flows for Reynolds Desalination Facility

Individual Wells	**Flow (GPM)**
Well 1	875
Well 2	400
Well 3	600
Well 4	700
Well 6	1350
Combined Wells	**Flow (GPM)**
Wet season with wells 2,3,4,6	3050
Wet season with wells 2,3,4,6 (including well 1)	3925
Dry season with wells 1,2,6	2625

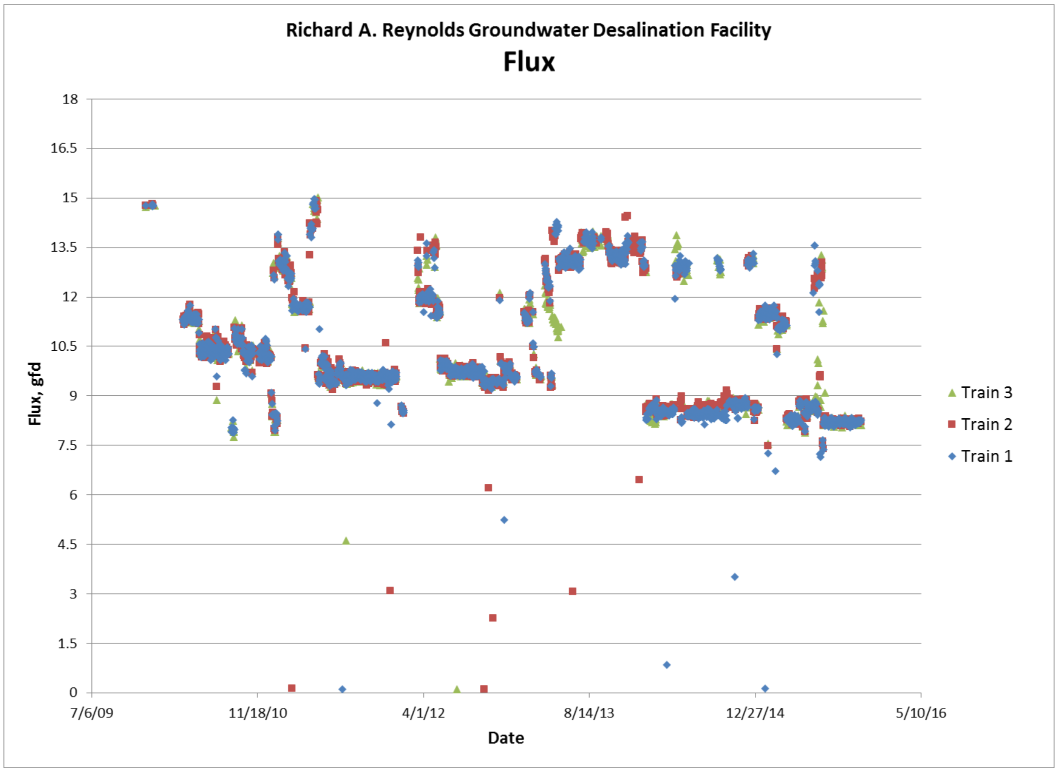
The upcoming expansion of the facility will add three additional RO trains as well as five new groundwater wells. Due to high levels of iron and manganese, a percentage of the plant feed water is bypassed through an iron and manganese removal system. The iron and manganese removal system has 8 units with a 1 mgd (694 gpm) capacity.

Historical Operating Data

RO Train Operating Conditions

Historically, during the dry season the Reynolds Desalination Facility would maintain a flux of approximately 9.5 gfd. During the wet season when additional wells were brought online, the flux became more variable between 12-14 gfd based on availability. Due to reduced production from the wells and permit limitations, since February 2014 the average flux during dry season has decreased to approximately 8.5 gfd. During the wet season of 2015, the average flux was approximately 11.3 gfd which is significantly lower than historical wet season fluxes. Not only were flux values lower during the most recent wet season but also the trains were only operated at this flux for a period of 3 months, (January-March 2015) due to limited production from those wells. **Figure *1*** below shows historical flux data for these membranes.

Figure 1: R.A.R. Historical Flux



Normalized Trends

The three main normalized parameters used as performance indicators are specific flux, normalized differential pressure, and normalized permeate conductivity. Specific flux is a temperature corrected ratio of permeate flux and the applied pressure necessary to achieve that permeate flux. This can be an indicator of fouling on the membrane's surface, causing a restriction of flow through the membrane. At the Reynolds Desalination Facility, a steady fouling rate has been observed since the startup in 2010. During the wet season, the rate of fouling increases due to the increased flux and possibly to some extent a change in feedwater quality due to new wells being brought online.

Another key normalized parameter is normalized differential pressure which indicates the pressure drop across the feed/brine channel within the RO element. This is an indication of the buildup of foulant restricting flow through the RO element's feed/brine channel. An increase in this value could indicate a blockage of the channel, due to deposition of particulate matter, biological growth and/or precipitants. Historically, the Reynolds Desalination Facility has experienced significant increases in normalized differential pressure and most times has been the main cause for cleaning. Increases in normalized differential pressure have also been localized to the first stage for this plant with hardly any visible increase in second stage values.

The last key normalized parameter is normalized permeate conductivity. This value takes the raw permeate conductivity values and adjusts for changes in operating temperature, flux and feed concentration to illustrate what permeate conductivity values would be if the system were running at the standard design conditions. An increase in this value could indicate deterioration of the membrane or mechanical leaks. Typically, normalized permeate conductivity values also experience an increase following cleanings. In the case of the Reynolds Desalination Facility, normalized permeate conductivity values have actually decreased over time. TDS, sulfate, and chloride concentrations in the permeate have also decreased over time. Since water quality has not been negatively impacted by fouling, increases in normalized differential pressure and losses in specific flux have been the main factors prompting cleanings

Cleaning History

The membranes currently in use were installed in January 2010 and for the first three years of operation cleanings were performed annually. The first two cleanings in May of 2011 and 2012 were performed on the first stage of each train with the Avista P303 cleaner. For the May 2013 cleaning of Train 1, both stages were cleaned in an effort to try and restore permeability lost in the first two cleanings. Following this cleaning a series of element cleaning trials were performed by Avista and a new cleaning chemical, P130, was chosen to clean the remaining two trains. Both stages of Train 2 were cleaned using the P130 cleaner in May 2013 and shortly after Train 3 stage 1 was also cleaned. Only the first stage of Train 3 was cleaned in 2013 in order to determine the impact if there were significant cost savings associated with cleaning only the first stage.

The next cleaning occurred in May 2014 and both stages of all three trains were cleaned using the Avista P130 cleaner. For this cleaning a new procedure was used where the first stage was separated into two sections and each section was cleaned twice. Since the vast majority of the fouling is localized to the lead elements of the first stage, the second stage was only cleaned once using chemicals left over from the cleaning of the second section of stage 1. This cleaning was successful in restoring permeability and reducing differential pressure values however following this cleaning the fouling rate began to increase. Normalized differential pressure values were rising rapidly despite operating at a low flux of approximately 8.5 gfd. This prompted another cleaning for all three trains in December 2014 and was the first time the system was unable to achieve an annual cleaning interval. This cleaning yielded similar results to the May 2014 cleaning however following the cleaning the fouling rate remained high prompting another cleaning in June and July 2015 for all three trains. The cleanings performed in June and July 2015 were performed on both stages of all three trains using a slightly modified procedure which increased the recirculation time of the chemical in the first stage in an effort to remove more of the foulant. **Table 2** below summarizes all of the cleanings performed at the Reynolds Desalination Facility to date.

Table 2:*R.A.R. Cleaning History*

	Train 1	Train 2	Train 3
May 2011	1st stage only Avista P303	1st stage only Avista P303	1st stage only Avista P303
May 2012	1st stage only Avista P303	1st stage only Avista P303	1st stage only Avista P303
May 2013	1st and 2nd stage Avista P303	1st and 2nd stage Avista P130	1st stage only Avista P130
May 2014	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130
December 2014	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130
June/July 2015	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130	1st stage twice 2nd stage once Avista P130

Cleaning Effectiveness

The three key normalized parameters discussed previously, specific flux, normalized differential pressure, and normalized permeate conductivity are the main indicators used to determine the effectiveness of a cleaning. An effective cleaning should improve specific flux values, decrease differential pressure values, and improve normalized permeate conductivity.

Specific Flux

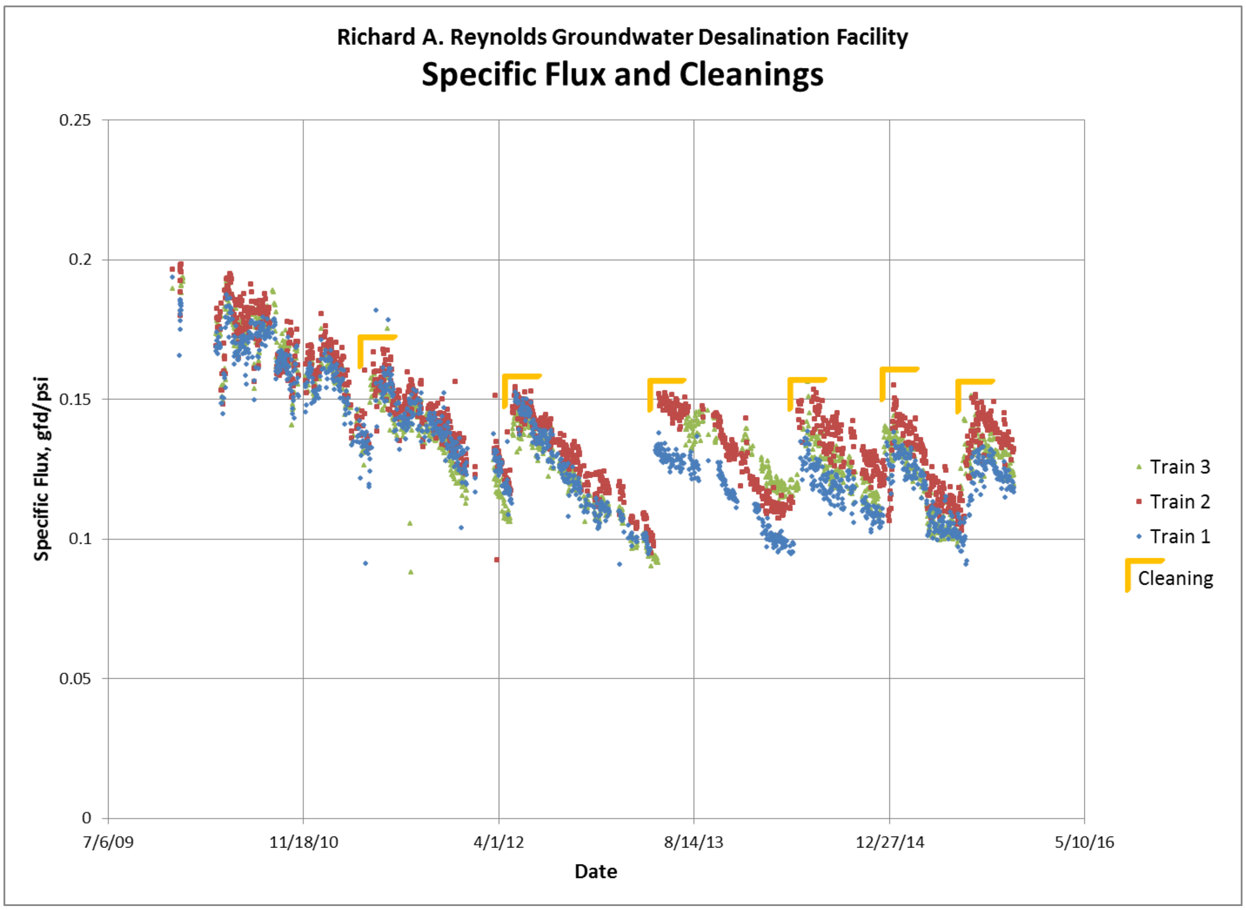
The specific flux trends for the Reynolds Desalination Facility indicate a steady fouling rate since startup in 2010. During the wet season, the rate of fouling increases due to the increased flux, and perhaps changes in feedwater chemistry from the contribution of wells 3 and 4. The cleanings performed in May 2011 with Avista P303 cleaner showed consistent results for all three trains. The cleanings resulted in a step up in specific flux, but startup values were not achieved. The first set of cleaning increased specific flux values back up to 85-90% of startup for all three trains. The second set of cleanings in May 2012 also exhibited consistent results between the three trains, but the 2012 cleanings were only able to recover membrane permeability to 75-80% of startup performance.

In May 2013, train 1 was cleaned with Avista P303 again and lost a considerable amount of flux only being able to achieve 70-75% of the startup value. Consequently, trains 2 and 3 were cleaned with Avista P130 which yielded better results with specific flux values returning to 78% of startup values. In May 2014 all three trains were cleaned with Avista P130 with trains 2 and 3 able to achieve similar results to the last cleaning with specific flux values returning to 79% of the original startup values. Train 1 was able to achieve post-clean specific flux values of 70% of original startup values which is consistent with the results seen with the last cleaning performed with Avista P130.

The cleaning performed on the trains in December 2014 yielded similar results to the May 2014 cleaning. Trains 2 and 3 post-clean values were slightly lower than the previous cleaning at 78% of startup values and Train 1 post-clean values were once again around 70% of startup values. In the two weeks following this cleaning, specific flux values for Train 2 began low and gradually increased. After taking a closer look at the data it appeared that this may have been a result of incorrect pressure readings during this period. During this time, pressures decreased by 10-15 psi while flow and feed conductivity remained relatively consistent.

In the months following this cleaning, specific flux values continued to decline at a faster rate. In July 2015 specific flux values had already reached historically low values once again after only 7 months of operation in between cleanings. **Figure 2** below illustrates the specific flux trends over the lifetime of these membranes so far.

Figure 2: R.A.R. Specific Flux Trends



Normalized Differential Pressure

The cleaning effectiveness with the P303 cleanings prior to 2013 was apparent in the differential pressure data (Figure 9). After all cleanings with P303, including the 2013 cleaning of Train 1, the train normalized differential pressure values were returned to approximately 40 psi. The increase in differential pressure was localized in the first stage of the trains, as shown in Figure 10.

The May 2013 cleaning of Train 2 with Avista 130 product also returned the train to approximately 40 psi. The July 2013 Train 3 cleaning resulted in a significant drop in normalized differential pressure (85 psi to 40-50 psi). The fourth cleaning performed May 2014 was able to bring normalized dP values back to the baseline of 40 psi for all trains. The December 2014 cleaning was not as effective at restoring dP values to the baseline of 40 psi. Furthermore, in just 3 weeks dP values are already creeping up towards 50 psi with Train 3 being closer to 60 psi.

When the trains were cleaned again in July 2015, post clean overall normalized differential pressure values came back down closer to 40 psi. This cleaning appeared to be more effective in terms of reducing differential pressure however once again it not entirely successful in completely removing the foulant from the membrane surface. As mentioned previously, fouling remains localized to the first stage which is evident in

Figure 3 below which shows individual stage normalized differential pressure values. **Figure 4** illustrates the overall train normalized differential pressure trends.

Figure 3: RA.R. Stage Normalized Differential Pressure Trends

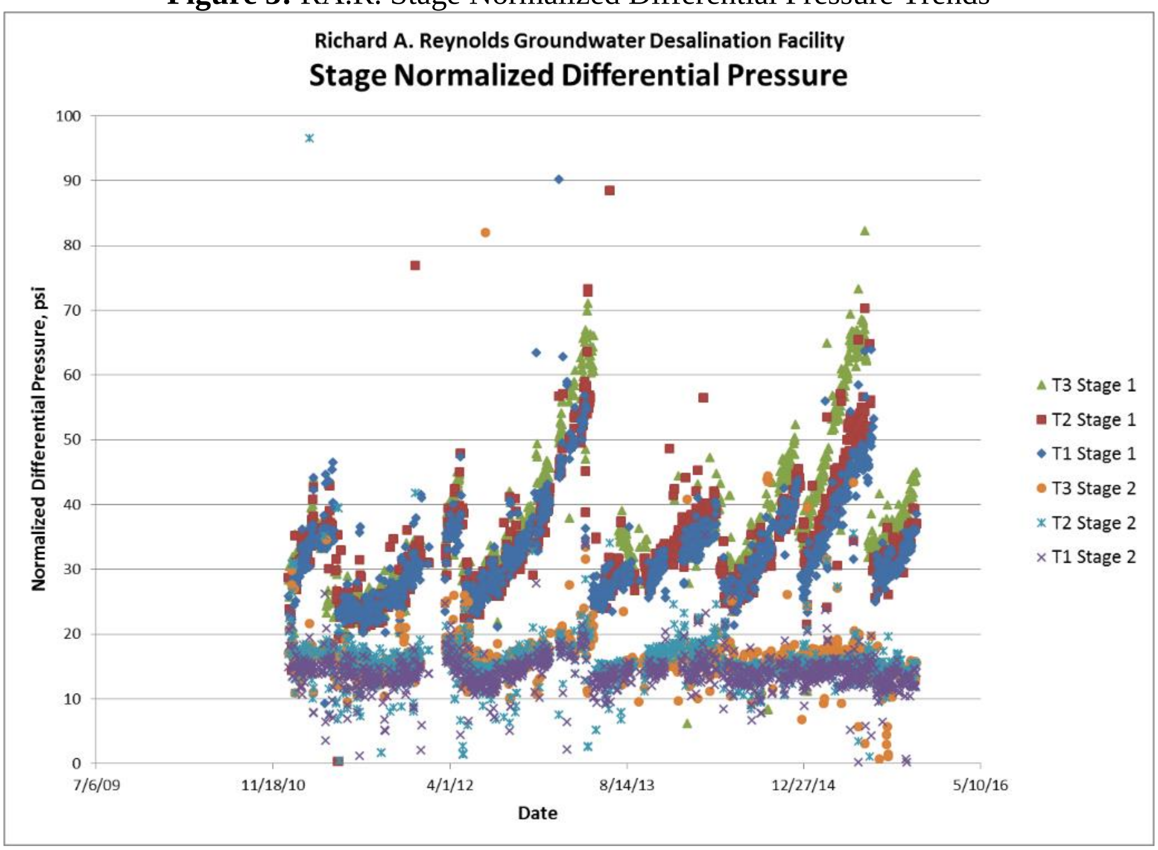
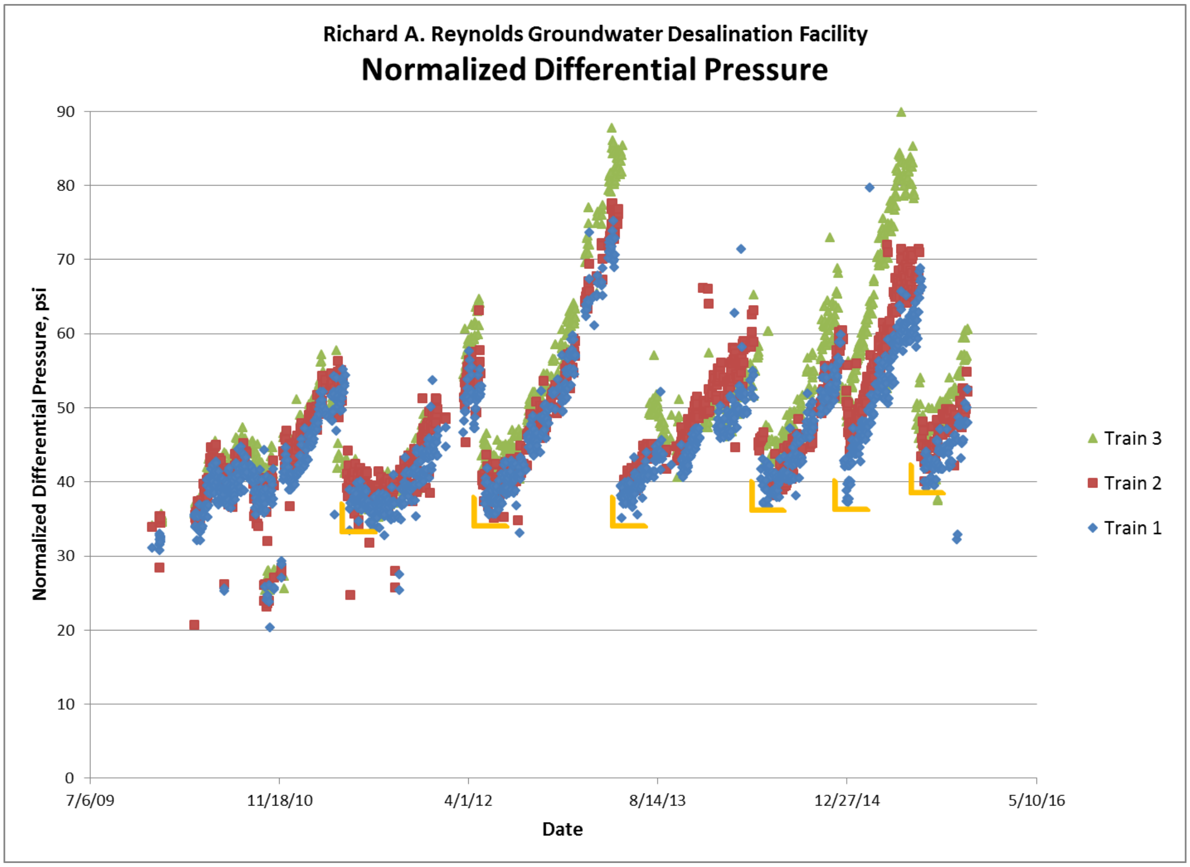


Figure 4:*R.A.R. Normalized Differential Pressure Trends*



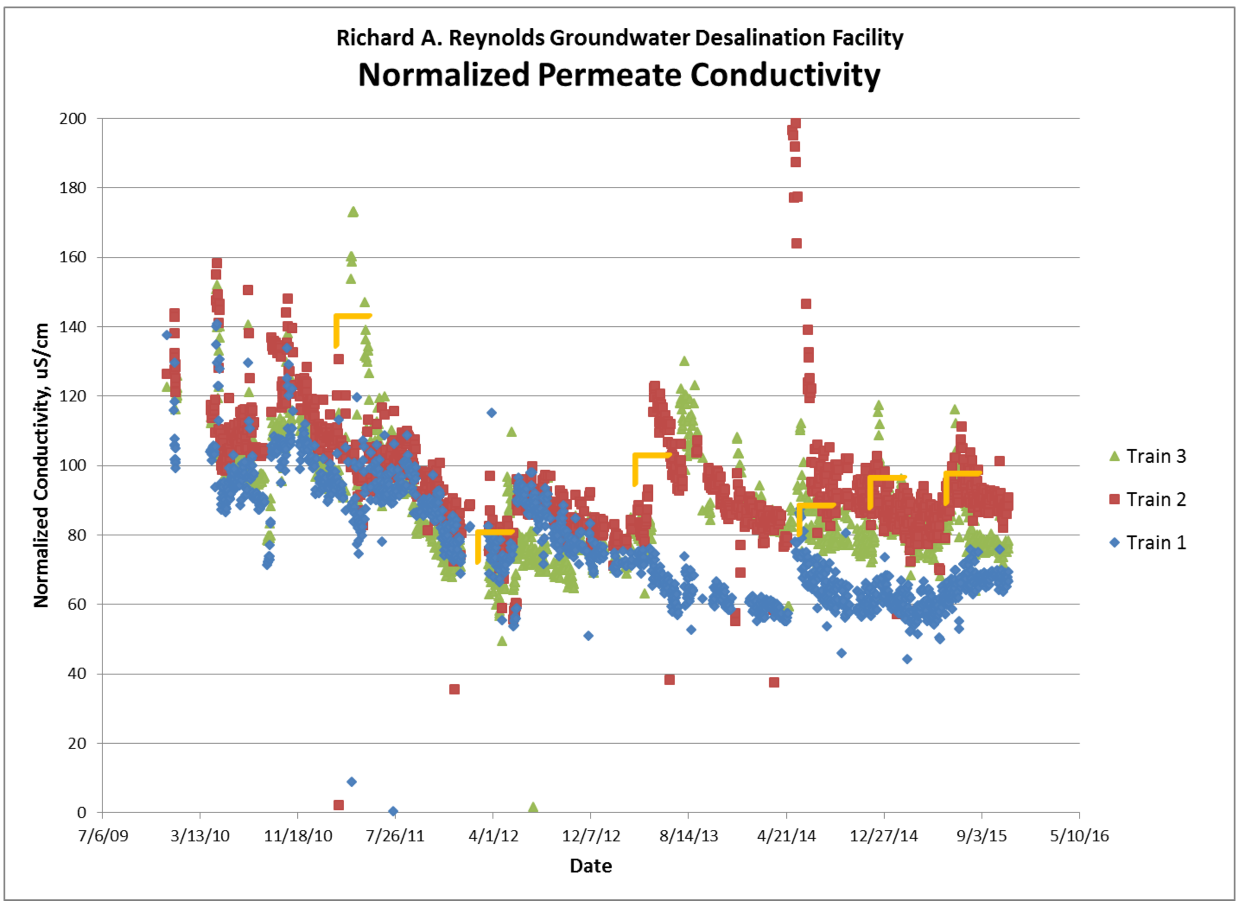
Normalized Permeate Conductivity

Despite annual cleanings, which can often lead to increases in permeate conductivity, the Reynolds Desalination Facility permeate conductivity has improved since startup. The fact that the normalized permeate conductivity has not returned to startup conditions following previous cleanings (2011, 2012) supports the observation that the cleanings have not been completely effective in removing the foulant from the membrane surface. This observation is also true for the 2013 cleaning of Train 1 using P303, which has offered the least effective cleaning to date and also failed to impact the normalized permeate conductivity as well.

The May 2012 Avista 130 cleanings on Trains 2 and 3 caused a jump in permeate conductivity from 85 µS/cm to 120 µS/cm, which is approximately the same as the startup conductivity of the Toray membrane. This increase, in combination with the improved specific flux value, strongly suggests that the fouling layer was more successfully removed. The increase could also be a consequence of the cleanings unmasking physical damage on the membrane (seen in previous autopsies), however the increase in conductivity did not increase beyond startup values. When the trains were cleaned again in May 2014, Train 2 saw a large increase in permeate conductivity from around 80 µS/cm to 220 µS/cm which is higher than startup conductivity values. It is believed that this was the result of delamination of some second stage membranes. These membranes were replaced with new elements and overall permeate conductivity returned to values consistent with what they were previous to the cleaning. Train 1 conductivities increased from 55 µS/cm to 80 µS/cm following the May 2014 cleaning then settled around 60 µS/cm until the next cleaning. Train 3 experienced an increase from 80 µS/cm to 110 µS/cm immediately following the cleaning and within about 2-3 weeks values had settled back down around 75 µS/cm.

The December 2014 cleaning caused a similar increase in conductivity as the previous cleaning for train 3 however trains 1 and 2 saw virtually no change in permeate conductivity and stabilized at about 60 µS/cm and 90 µS/cm respectively. In the months following the cleaning normalized permeate conductivity values continued to improve slightly as Trains 2 and 3 stabilized at approximately 85 µS/cm and Train 1 values at 55-60 µS/cm. In terms of normalized permeate conductivity, the most recent cleaning performed in 2015 appear to have been slightly more effective with a larger increase in values observed immediately following the cleaning. Shortly after, normalized permeate conductivity values decreased and stabilized at approximately 65 µS/cm for Train 1, 85 µS/cm for Train 2 and 75 µS/cm for Train 3 which was the largest improvement of the three trains. Historical normalized permeate conductivity trends are shown below in **Figure 5**.

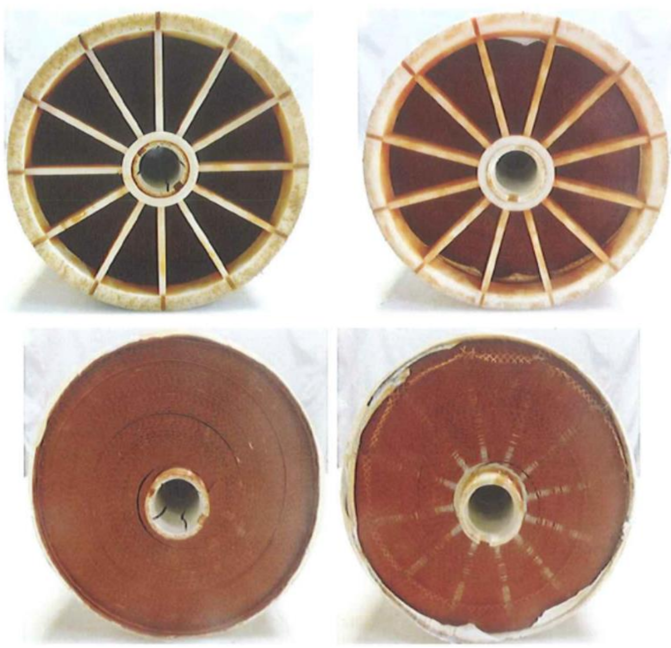
Figure 5: *R.A.R. Normalized Permeate Conductivity Trends*



Cleaning Trials, Investigation, and Optimization

In early 2013 when normalized differential pressure values began to rise at an increased rate together Sweetwater, SPI, and Avista began to investigate the cause and find possible solutions. In April 2013, an element autopsy was performed by Avista Technologies on one first stage and one second stage element from Train 1. The first stage element was heavily fouled and physically damaged. Telescoping, membrane tears, and delamination of the membrane leaves and glue lines were observed. The foulant was found to be 43% inorganic and 57% organic material based on a loss on ignition test. The inorganic foulant was comprised of iron, silicon, calcium, and aluminum. This is consistent with silts and clays with some iron and calcium oxides. Some colloidal silica was also observed. **Figure 6** below shows the extent of fouling and mechanical damage to the first stage elements observed.

Figure 6: First Stage Element Fouling Evidence



The second stage element was observed to have no oxidative or physical damage. A slight greenish foulant layer was observed, but was not substantial enough to determine the percentage of organic vs non organic matter present. EDX/SEM analysis found some patches of clay, silica, and iron oxide foulants, but the membrane was relatively clean. Following these autopsies, several lead elements which had extensive damage from the first stage of each train were replaced. The replacement of these elements together with the cleaning performed in May 2013 were able to improve performance. **Figure 7** below compares the membrane surface of the heavily fouled first stage element and the relatively clean second stage element.

Figure 7: Comparison of Stage 1 and Stage 2 Element Membrane Surfaces

Exposed membrane surface for SN#091012439

Exposed membrane surface for SN#090910283

Performance was stable again until 2014 when the fouling rate of all three trains began to increase. The increase in the fouling rate was observed in late 2014 after the fourth annual cleaning of all three trains. Initially, operating data following the cleaning in May indicated that it had been effective at restoring permeability and reducing differential pressure values. However after three months it was clear that the fouling rate had increased and a cleaning would be necessary before the end of the year. During this time period the operating data was monitored closely to ensure raw differential pressure values did not exceed the recommended maximum per element and cause mechanical damage similar to what was discovered in the autopsies performed two years earlier.

In December 2014 another cleaning was performed on all three trains, marking the first time the system had not been able to achieve an annual cleaning interval. Operating data following the cleaning indicated that not only was the cleaning not as effective as previous cleanings but also the rate of fouling had continued to increase. Water quality data from the wells was analyzed however there were no apparent changes in the feedwater quality to explain the increase in fouling rate. Another cleaning was scheduled for June 2015 and Train 3 was selected to be cleaned first since it had the highest differential pressure values of the three trains. Prior to cleaning this train all the elements of one first stage vessel and one second stage vessel were removed from the system and were weighed and wet tested by Avista. These elements were then placed back in the system and the full train was cleaned. The procedure for this cleaning was modified slightly to increase the recirculation time of the cleaning solution from 2.5 to 3 hours for each section. Following the cleaning, the same elements were removed and wet tested once again in order to determine the effectiveness of the cleaning. **Table 3** and

Table *4* below contain the results from the pre and post clean wet tests for each membrane.

Table 3: First Stage Wet Test Data (Train 3 Vessel 14)

Position	Serial #	Test	Delta psi	Normalized Flow	Normalized Reject %	Weight lbs.	Notes
1	101011381	Pre-Clean	25	3.06	98.3	43	Iron/Separated Vexar
		Post-Clean	6	5.73	98.4		Iron/Separated Vexar
2	091032348	Pre-Clean	13	3.61	95.7	40	Iron/Separated Vexar
		Post-Clean	5	5.67	97.0		Iron/Separated Vexar
3	091012480	Pre-Clean	10	3.26	98.9	36	
		Post-Clean	5	6.20	99.1		Iron
4	091021639	Pre-Clean	14	3.95	99.2	37	
		Post-Clean	5	5.50	99.2		Iron
5	091012472	Pre-Clean	6	4.83	99.0	35	
		Post-Clean	3	5.97	99.2		
6	091032345	Pre-Clean	7	5.04	98.9	35	
		Post-Clean	5	6.07	99.1		
7	091032337	Pre-Clean	7	5.07	98.6	35	Fouling/Organic
		Post-Clean	4	5.93	99.0		Fouling/Organic

Table 4: Second Stage Wet Test Data (Train 3 Vessel 29)

Position	Serial #	Test	Delta psi	Normalized Flow	Normalized Reject %	Notes
1	090910267	Pre-Clean	7	5.08	98.2	
		Post-Clean	3	6.06	99.0	
2	091011539	Pre-Clean	7	5.19	98.7	
		Post-Clean	3	6.05	99.0	
3	091021614	Pre-Clean	7	5.19	98.6	
		Post-Clean	3	6.02	99.1	
4	091011465	Pre-Clean	7	5.27	99.2	
		Post-Clean	3	6.00	99.2	
5	091021598	Pre-Clean	7	5.60	99.1	
		Post-Clean	3	6.30	99.1	
6	091021566	Pre-Clean	7	5.60	99.0	
		Post-Clean	3	6.06	99.1	
7	091021634	Pre-Clean	6	5.04	98.6	
		Post-Clean	5	6.00	98.0	Fouling/Organics

Wet test data confirmed the conclusions that had been drawn from reviewing the operating data which is that the majority of the fouling is occurring in the lead elements of the first stage. Flow and rejection values for the first four elements of the first stage elements were significantly lower than the remaining elements in that vessel. Furthermore, flow and rejection values for the last two elements of the first stage vessel were in line with the results from the second stage elements.

Shortly after the post clean wet test was performed on these elements, two lead elements from the first stage and one tail element from the second stage were sent to Avista to perform a high pH clean on a small test unit. The purpose of the high pH clean was to see if a dual clean would improve permeability and remove the remaining foulant from the membrane surface. The results of the high pH cleaning test are listed below in **Table 5** and reveal no significant improvement in flow or rejection. As a result, a dual cleaning was deemed to not enough improvement in performance to warrant the cost associated with purchasing additional chemicals and performing the cleaning so it was not implemented full scale.

Table 5: High pH OSCAR Test Results

Position	Serial #	Test	Delta psi	Normalized Flow (gpm)	Normalized Reject %	Notes
1	091021585	Pre-Clean	5	5.08	97.4	Extruding Vexar
		Post-Clean	5	6.19	92.4	
1	101011381	Pre-Clean	5	5.06	98.4	
		Post-Clean	5	6.07	98.5	
14*	90910267	Pre-Clean	6	6.05	99.0	
		Post-Clean	6	6.33	99.1	

The remaining two trains were cleaned in early July 2015 with Avista P130 using the same modified procedure used for the cleaning of Train 3 where the recirculation time period was increased from 2.5 to 3 hours. Initially, post-clean operating data indicated that the cleaning was less effective than the previous cleaning in December. However in the four weeks after the cleaning, performance improved and stabilized at conditions similar to the December 2014 cleaning. This gradual improvement was most likely due to the large variance in operating conditions during this time. Recovery rates for all three trains were lowered from 81% to 75% for approximately 24 hours each in order to obtain samples required for the plants discharge permit.

Additionally, when elements were removed from Train 3 for wet testing, the remaining trains were operated at a higher flux with the feed flow being divided between the two trains. Although the flux during this period did not exceed the traditional wet season flux, historically the fouling rate has increased during periods where the trains are operating at a higher flux. As of November 2015 it appears that the increase in the fouling rate of these trains has subsided and a cleaning will likely not be necessary until June/July 2016.

Summary

Changes in the fouling behavior and the diminishing effectiveness of the Avista P303 cleaner at the Reynolds Desalination facility suggested that the nature of the foulant had changed over the first three years of operation of the facility. The diminishing effectiveness of the P303 cleaner and development of an organic foulant prompted a switch to the Avista P130 cleaner. After three cleanings on trains 2 and 3 and two cleanings of train 1, this product had been able to consistently return post-clean specific flux values to around 79% and 70% (of initial values) for these trains. The May 2013 cleaning of train 2 using Avista P130 was cleaned back to the same specific flux as the 2012 cleaning with the P303. These results were then duplicated on the two subsequent cleanings not only for Train 2 but also for train 3. Train 1 had also been able to consistently reach the same post-clean values following cleanings, however, specific flux values for this train were lower than the others.

In 2014 the trains began to foul at an increased rate than previously observed despite operating at or below the dry season flux of 9.5 gfd for the majority of that year. Post clean operating data suggested that even though permeability was being restored with these cleanings, they were not removing the foulant entirely from the membrane surface. In 2015 elements were removed from the system to perform pre and post clean wet tests to determine the effectiveness of the cleaning and decide whether a new cleaning chemical should be considered. Test data revealed that the cleanings were effective however the membranes continued to show visible signs of fouling and some mechanical damage.

Three elements were taken out of the system and cleaned with a high pH cleaner offsite at Avista in order to determine if a dual cleaning would yield better results and improve flow and rejection. Data from the high pH cleaning revealed minimal improvements and therefore the option of performing a high pH cleaning full scale was ruled out. The cleaning procedure was modified to increase the recirculation period from 2.5 hours to 3 hours. This modified cleaning procedure was implemented in the July 2015 cleanings and post clean operating data indicates that not only was this cleaning more effective than the previous cleaning but also the fouling rate has somewhat stabilized and the Reynolds Desalination Facility will likely be able to operate until June/July 2016 before another cleaning is necessary.