Replacing Membranes To Save Energy at City Of Vero Beach Reverse Osmosis Water Treatment Facility

C. Robert Reiss, Christophe Robert, and Robert J. Bolton

The City of Vero Beach (City) currently owns and operates a 3.3-mil-gal-per-day (mgd) reverse osmosis water treatment facility (ROWTF) that was constructed in the early 1990s using 8.5-in. diameter pressure vessels. The facility currently operates a single 2-mgd reverse osmosis (RO) skid containing 8.5-in. membrane elements that were installed in August 2003. The City contracted with Reiss Engineering Inc. to assist with the replacement of the 10-year-old membranes as recent improvements in membrane technology have resulted in more efficient membranes requiring less pressure for the same rejection performance. However, with the industry now standardized on the 8-in. diameter element, locating manufacturers willing to fabricate lower pressure, 8.5-in. diameter membrane elements was uncertain. This article presents the steps taken to evaluate and select a replacement membrane for the ROWTF and the associated benefits to the City of Vero Beach.

Membrane Availability

Seven membrane element manufacturers/ suppliers in the United States were contacted to determine whether 8.5-in. diameter membranes were available. Out of the seven manufacturers/ suppliers, only three indicated that they could supply the membrane elements: Hydranautics, Trisep, and CSM.

In addition to being able to provide 8.5-in. membrane elements, it was necessary to have NSF 61 certification from the National Sanitation Foundation (per 62.555-320(3)(b)1.a. Florida Administrative Code *(F.A.C.)*, any equipment, chemicals, and materials, such as RO membrane elements that are in contact with drinking water, must be NSF 61-certified). Of the three manufacturers that confirmed the ability to provide the needed elements, most of their membrane elements that would be appropriate for this brackish water application were not yet NSF 61-certified; only a few membranes from Hydranautics are NSF 61-certified, while the majority of the membranes from Hydranautics and the other manufacturers are not (See Table 1 for summary).

The representative from Hydranautics stated that the NSF certification could be attained, but would take four to six weeks; the representative of CSM stated that the NSF certification may take three months. In addition, the CSM membranes would not be wet tested prior to shipping, which would lead to testing the membranes after they were installed in the full-scale skid. In the event that the replaced membrane elements do not meet membrane performance requirements, CSM would have to replace the noncompliant membranes.

Table 1. Membrane Availability and NSF 61 Certification

Manufacturer	8.5-inch Membrane Availability	NSF Certified
Hydranautics	Yes	Depends on membrane model Takes 1-1.5 months for certification
Trisep	Yes	Currently Not Takes 1-3 months for certification
CSM	Yes	Currently Not Takes 3 months for certification
Koch (& Fluid Systems)	No	N/A
Osmonics	No	N/A
Filmtec	No	N/A
Toray	No	N/A

C. Robert Reiss, Ph.D., P.E., is president and client services manager, and Christophe Robert, Ph.D., P.E., is project manager with Reiss Engineering Inc. in Winter Springs. Robert J. Bolton, P.E., is water and sewer administration division director with City of Vero Beach.

Membrane Projections

From the three membrane manufacturers/suppliers in the U.S. that have capabilities to provide the membrane elements, several membranes were evaluated through a desktop analysis. Membrane projections utilizing manufacturer's software were completed to predict the water quality and pressure requirements for each selected membrane model and identified configuration. The projections were based on a 2-mgd skid (36x15 array configuration) using the worst raw water quality, which is total dissolved solids (TDS) of approximately 1,500 mg/L. For the membrane projections, the raw water pH was adjusted to 6.0 standardized units (SU) by the addition of sulfuric acid, as currently practiced at the plant. In addition, the projections were made without applying permeate back pressure on the first stage, as there are no capabilities to do so on the existing skid. Only low-pressure RO membranes that reject enough chloride were selected, since the chloride concentration goal in the permeate was established at 60 mg/L or less (year 0). The results are presented in Table 2.

Trisep Membrane Projections

Out of the five Trisep membrane configurations that were evaluated, the ACM4 configuration and the hybrid ACM2/ACM4 membrane configuration were viable options to meet the water quality goals with relatively low pressure requirements. The advantage of the hybrid system is that the flux is better balanced between both stages compared to the use of ACM4 membrane in both stages; however, the hybrid system requires approximately 20 more pounds per sq in. (psi) of feed pressure. The ACM2 and SB20 membranes were not further evaluated as these membranes would reject too much hardness and alkalinity and exceed the feed pressures of the ACM2/ACM4 membrane configuration. The ACM5 membrane would meet the water quality goals; however, the flux is significantly unbalanced between stages one and two.

In order to balance the production between stage one and two, a piping/valve modification would be required to apply a permeate back pressure of approximately 50 psi in the first stage of the membrane configuration. Another option to balance the fluxes included installing an energy recovery device (ERD) to lower the feed pressure (eliminate the first-stage back pressure) and recover the energy of the concentrate to boost the feed pressure to the second stage. The City is not intending to modify the skid and, therefore, the ACM5 membrane was not recommended. As such, only the ACM4 and hybrid ACM2/ACM4 membrane configurations from Trisep were considered for further evaluation.

CSM Membrane Projections

Three membrane configurations from CSM were evaluated, and the hybrid BLR/BLF configuration was the most viable option that met the water quality goals and pressure requirements. The projections evaluating the BLR membranes alone had higher pressure requirements compared to the hybrid system and rejected too much calcium hardness and alkalinity; therefore, they were not evaluated further within this study. The BLF membrane met the water quality goals, but without back pressure in the first stage, the flows

Continued on page 28

Table 2. Membrane Projections

	Trisep ACM4				Trisep ACM2/ACM4			
Stage-One Membrane	ACM4	ACM4	ACM4	ACM4	ACM2	ACM2	ACM2	ACM2
Stage-Two Membrane	ACM4	ACM4	ACM4	ACM4	ACM4	ACM4	ACM4	ACM4
Membrane Age	0	3	5	7	0	3	5	7
Membrane Configuration	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15
Recovery (%)	85	85	85	85	85	85	85	85
Feed Pressure (psi)	121	131	132	133	143	158	158	159
Concentrate Pressure (psi)	94	102	103	104	110	123	122	123
Average Stage One Flux (gfd)	16.4	15.7	15.6	15.8	14	14	14	13.5
Average Stage Two Flux (gfd)	3.9	5.6	5.7	5.8	10	11	11	11
Stage One Back Pressure (psi)	0	0	0	0	0	0	0	0
Feed TDS (mg/L)	1,531	1,531	1,531	1,531	1,531	1,531	1,531	1,531
Acid Dose (mg/L)	109	109	109	109	109	109	109	109
Permeate TDS (mg/L)	109	131	155	183	64	79	91	108
Permeate Chloride (mg/L)	59	71	84	99	35	43	49	58
Permeate Calcium (mg/L as $CaCO_3$)	5	6	7	8	3	3.5	4	5
Permeate Alkalinity (mg/L as $CaCO_3$)	5	6	7	8	3	3.5	4	5
Permeate Sodium (mg/L)	39	43	51	60	21	26	30	35
Permeate pH	5.0	5.0	5.1	5.2	4.7	4.8	4.9	5.0

	Hydranautics ESPA2/ESPA1				CSM BLR/BLF			
Stage-One Membrane	ESPA2	ESPA2	ESPA2	ESPA2	BLR	BLR	BLR	BLR
Stage-Two Membrane	ESPA1	ESPA1	ESPA1	ESPA1	BLF	BLF	BLF	BLF
Membrane Age	0	3	5	7	0	3	5	7
Membrane Configuration	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15	36 x 15
Recovery (%)	85	85	85	85	85	85	85	85
Feed Pressure (psi)	123	137	150	164	128	139	149	161
Concentrate Pressure (psi)	98	110	120	134	98	106	114	125
Average Stage One Flux (gfd)	17.2	16.3	15.8	15.4	16.8	15.6	15	14.5
Average Stage Two Flux (gfd)	6.4	8.5	9.6	10.5	7.3	10.1	11..5	12.7
Stage One Back Pressure (psi)	0	0	0	0	0	0	0	0
Feed TDS (mg/L)	1,531	1,531	1,531	1,531	1,535	1,535	1,535	1,535
Acid Dose (mg/L)	115	115	115	115	109	109	109	109
Permeate TDS (mg/L)	96	113	123	133	42	52	61	71
Permeate Chloride (mg/L)	42	49	54	58	19	23	27	31
Permeate Calcium (mg/L as $CaCO_3$)	4	5	5.5	6	3	4	5	6
Permeate Alkalinity (mg/L as $CaCO_3$)	11	13	14	15	3	3.7	4.3	5
Permeate Sodium (mg/L)	30	35	38	41	14	17	19	22
Permeate pH	5.3	5.4	5.4	5.4	4.7	4.8	4.9	5

Continued from page 27

are significantly unbalanced between the two membrane stages. Therefore, the BLF membrane was also not considered for further evaluation.

Hydranautics Membrane Projections

Three membrane configurations from Hydranautics were evaluated, and similar to the CSM membranes, this hybrid configuration was the most viable option compared to the ESPA1 or ESPA2 configurations. Out of the three options, the hybrid ESPA2/ESPA1 system resulted in a better flux balance.

Desktop Summary

Based on the computer projections of performance, the following membrane configurations were deemed feasible for further evaluation at bench scale (single-element testing):

- Trisep ACM4
- Trisep ACM2/ACM4
- CSM BLR/BLF
- Hydranautics ESPA2/ESPA1

For each configuration, the projected feed pressure requirement is within the existing high-pressure pump capacity (445 ft TDH–192 psi), as the maximum projected feed pressure for the selected membrane configurations would be 165 psi after seven years. In addition, the estimated pressure requirements are for the worst expected raw water quality; therefore, it is anticipated that the feed pressure would be lower under normal operation of the ROWTF when using average water quality. The high-pressure pumps are equipped with variable frequency drives (VFDs), and consequently, the City has the capability to adjust the feed pressure, ultimately reducing electrical consumption upon installation of the new membranes.

Blended Water Quality Projections

For the four membrane configurations selected, a desktop blending analysis was performed to evaluate the water quality of the finished water after blending the ROWTF permeate with the lime-softened water treatment facility (LSWTF) filtrate. The following criteria were used:

- A blend ratio of 2:1 for RO permeate to LSWTF filtrate. This ratio would be used when the ROWTF is expanded (as part of a separate project). Currently, the ratio of RO permeate to LS filtrate is 1:2.
- An estimated 80 percent removal of carbonic acid from the permeate stream through the degasification process (degasification is used to remove the sulfide in the permeate but will also remove carbonic acid). This removal of carbonic acid resulted in an increase of pH of 0.7-0.9 SU in the permeate.

Table 3 presents the projected blended finished water quality, as well as the existing finished water quality and the finished water quality goals. As expected, the TDS and chloride concentrations in the finished water would be lower than the concentrations currently observed, while the blended alkalinity would be similar. The main difference in the projected versus the current water quality would be the calcium concentration, as it is projected to be significantly lower than the current concentration. As previously evaluated, a recommended option to increase the calcium concentration in the finished water includes decreasing the lime dose at the LSWTF in order to increase the calcium concentration in the LSWTF finished water.

It is important to note that these calculations were made at a 2:1 ratio for RO/LS, which would correspond to the ratio that will be used once the ROWTF is expanded. Until expansion of the ROWTF, the finished water quality would be similar to the existing finished water quality.

Continued on page 30

Table 3. Projected Finished Water Quality (After Caustic Addition)

Parameter	Units	Existing LS Finished Water Quality	Hydranautics Hybrid System Year 0	Hydranautics Hybrid System Year 7	Trisep ACM4 Year 0	Trisep ACM4 Year 7	Trisep Hybrid System Year 0	Trisep Hybrid System Year 7	CSM Hybrid System Year 0	CSM Hybrid System Year 7	Existing Average Finished Water Quality	Goals
pH	SU	8.7	8.7	8.6	8.7	8.7	8.7	8.7	8.7	8.6	8.4	8.0-8.5
TDS	mg/L	355	190	220	200	245	170	200	155	175	277	<500
Chloride	mg/L	109	65	76	76	102	61	77	50	58	86	<100
Calcium Hardness	mg/L as $CaCO_3$	100	36	37	37	39	35	37	36	37	73	40-80
Alkalinity	mg/L as $CaCO_3$	42	38	41	33	34	33	34	32	34	36	30-50
LSI	---	0.64	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.0-0.3
CCPP	mg/L	2.9	0.6	0.4	0.4	0.4	0.3	0.3	0.2	0.3	0.4	> 0
AI	---	12.3	11.8	10.8	11.8	11.8	11.8	11.8	11.8	10.8	11.8	> 10

LSI: Langelier Saturation Index
CCPP: Calcium Carbonate Precipitation Potential
AI: Aggressiveness Index ($AI = pH + \log(Alk \times Ca)$)

Continued from page 28

Single-Element Testing

Based on the desktop evaluation, the four selected membrane configurations for single-element testing were:

- Hydranautics hybrid system ESPA2/ESPA1
- Trisep ACM4
- Trisep hybrid system ACM2/ACM4
- CSM hybrid system BLR/BLF

The six membranes were tested in a single-element unit to confirm the relative pressure requirements and the rejection capabilities. For each test, the pressure was recorded and permeate samples were collected to analyze specific parameters in order to evaluate the membrane performance.

Each membrane was tested at multiple different recoveries, and recoveries from 15 to 85 percent were selected in order to simulate the water quality of the front end and the back end of the full-scale plant, respectively. In each set of conditions, recycling of the concentrate was required to maintain minimum flow across the membrane (Figure 1). The operating conditions for the tests described are presented in Table 4. Samples of the permeate stream were collected for laboratory analysis of membrane water quality.

For each test, feed pressure, as well as permeate, feed, and concentrate conductivities, were regularly monitored to determine whether the system reached steady state, which is when the permeate conductivity reading is within 5 percent of the previous conductivity reading. Pressure was also monitored and stayed consistent during the whole specific test.

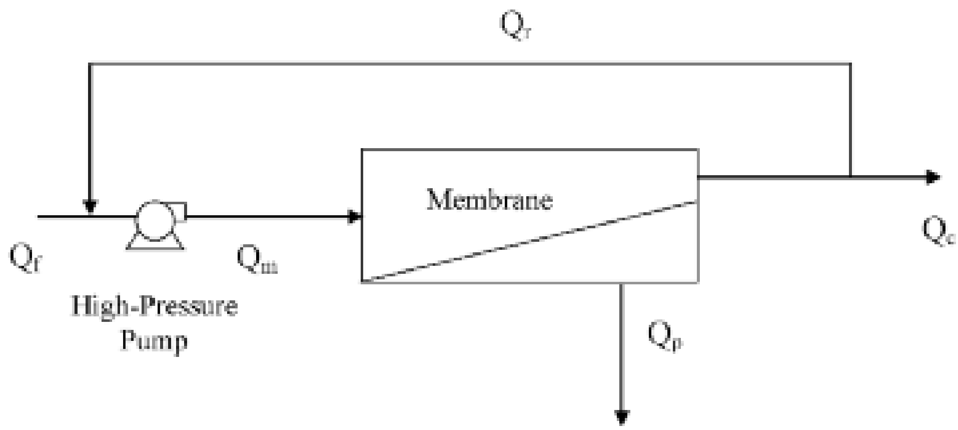

Figure 1. Single-Element Unit Flow Diagram

Table 4. Bench-Scale Study Operation Settings

		Recovery (15%)	Recovery (65%)	Recovery (85%)
Permeate Flow (Q_p)	gpm	0.75	0.75	0.75
Concentrate Flow (Q_c)	gpm	4.25	0.40	0.15
Recycle Flow (Q_r)	gpm	0.00	3.80	4.10
Feed Flow (Q_f)	gpm	5.00	1.15	0.90
Membrane Feed Flow (Q_m)	gpm	5.00	4.95	5.00

Table 5. Bench-Scale Study Results

		Test 1 (15%)		Test 2 (65%)		Test 3 (85%)	
		Feed Pressure (psi)	Permeate TDS (mg/L)	Feed Pressure (psi)	Permeate TDS (mg/L)	Feed Pressure (psi)	Permeate TDS (mg/L)
First-stage membranes							
Trisep	ACM4	N/A	N/A	81	115	103	202
Hydranautics	ESPA2	80	34	94	58	N/A	N/A
Trisep	ACM2	89	31	101	60	N/A	N/A
CSM	BLR	90	80	101	150	N/A	N/A
Second-stage membrane							
Hydranautics	ESPA1	N/A	N/A	80	102	96	218
Trisep	ACM4	N/A	N/A	81	115	103	202
CSM	BLF	N/A	N/A	61	262	70	422

Single-Element Testing Results

This section presents the results obtained during the single-element testing and assesses the performance of the membranes in terms of pressure requirement and water quality. As described earlier, the feed pressure and conductivities were monitored for each test until steady state was achieved. The final feed pressure and TDS, calculated based on field conductivity measurements, are presented in Table 5. Note that the feed pressure values are not representative of the expected full-scale pressure since the test was performed on a single element. However, because each membrane was tested under the same operating conditions, the relative differences in pressure and water quality are the basis of membrane selection for bidding.

Pressure Requirements

For each of the three manufacturers considered for this installation (supplying 8.5-in. membrane elements), a hybrid system was the recommended alternative, with a tighter membrane in the first stage and a looser membrane in the second stage. In addition, Trisep provided a fourth alternative, consisting of ACM4 membrane in both stages. For the four first-stage membranes (ACM4, ESPA2, ACM2, and BLR) two recoveries (15 percent and 65 percent) were tested. The pressure requirements for each membrane at each recovery are presented in Figure 2; the Trisep ACM4 requires 14 to 20 less psi than the other three membranes at 65 percent recovery.

For the three stage-two membranes (ACM4, ESPA1, and BLF) two recoveries (65 percent and 85 percent) were tested. The pressure requirements for each membrane at each recovery are presented in Figure 3, which shows that the CSM BLF requires approximately 20 percent less psi than the other two membranes at both recoveries tested. The Hydranautics ESPA1 and the Trisep ACM4 had similar pressure requirements.

The stage-one membrane pressure requirement will drive the overall pressure requirement of the system for the selected configurations in this analysis. Therefore, based on the stage-one pressure results, a system using only the ACM4 membranes would require the lowest feed pressure, and the Hydranautics membrane configuration would result in the lowest feed pressure among the three hybrid systems.

Continued on page 32

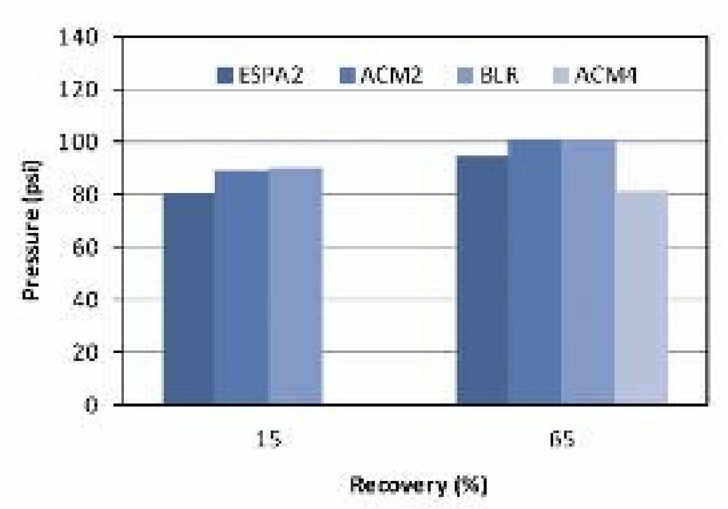

Figure 2. Stage-One Membrane Pressure Requirements

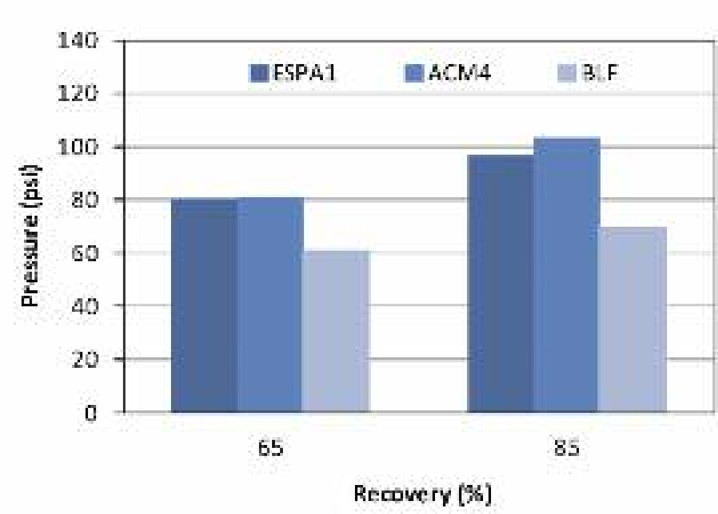

Figure 3. Stage-Two Membrane Pressure Requirements

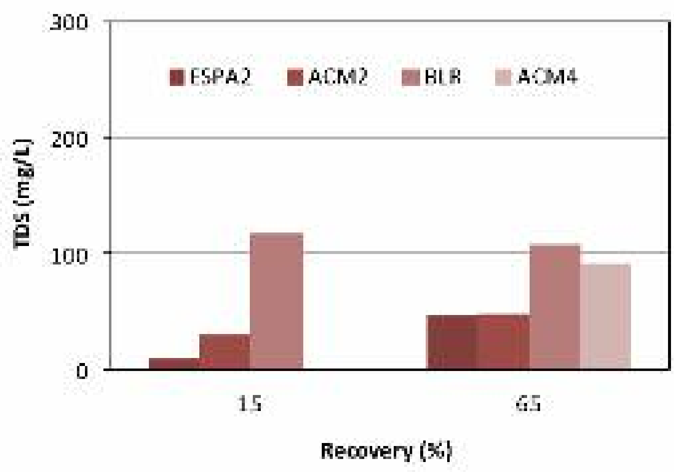

Figure 4. Stage-One Membrane TDS

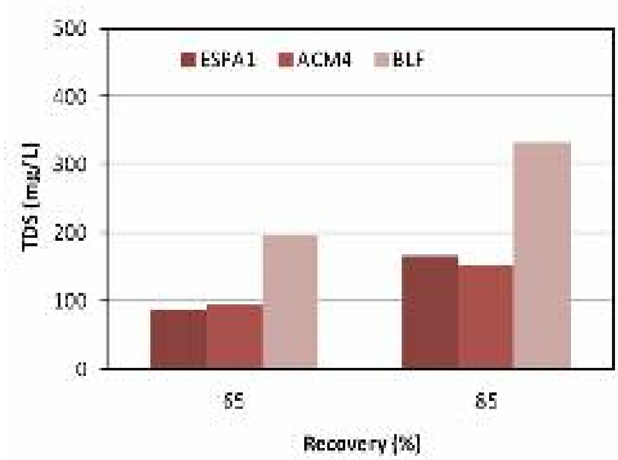

Figure 5. Stage-Two Membrane TDS

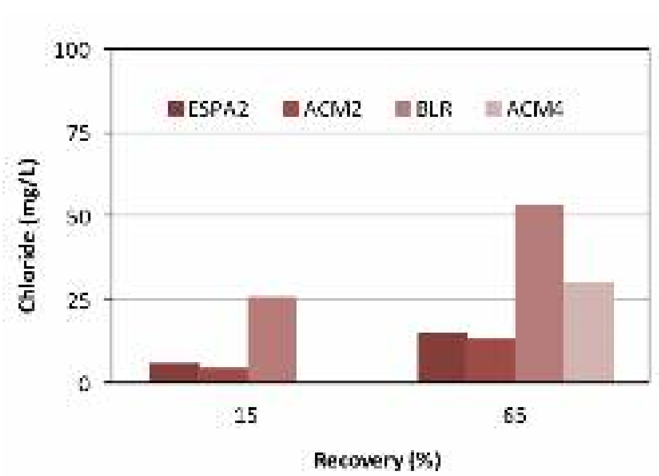

Figure 6. Stage-One Membrane Chloride

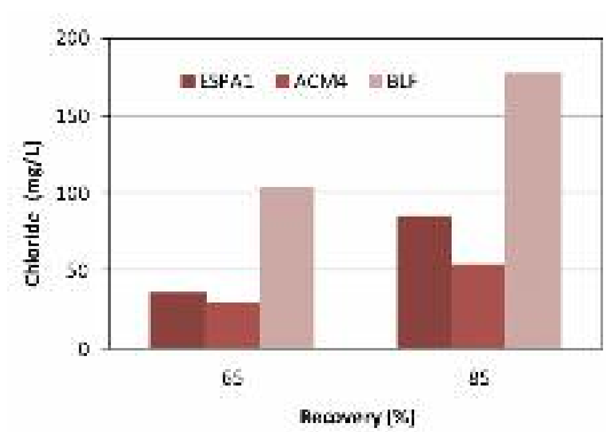

Figure 7. Stage-Two Membrane Chloride

Continued from page 30

Based solely on pressure requirements from the single-element unit testing, the membrane configurations are ranked as follows:

1. Trisep ACM4 in both stages one and two
2. Hydranautics ESPA2 in stage one and Hydranautics ESPA1 in stage two
3. Trisep ACM2 in stage one and Trisep ACM4 in stage two
4. CSM BLR in stage one and CSM BLF in stage two

Water Quality

The water quality of the permeate produced from the tested membranes was evaluated and then compared to the projected water quality from the membrane projections.

The permeate TDS for each membrane at each recovery is shown in Figures 4 and 5. As seen in both figures, the stage-one ESPA2 and ACM2 membranes and the stage-two ESPA1 and ACM4 membranes show similar performance in terms of TDS. The CSM BLR/BLF membranes have the lowest TDS rejection. The permeate chloride is shown in Figures 6 and 7. The same observations made for performance in terms of TDS rejection are also valid for chloride rejection.

The water quality from each single-element test was compiled to predict the water quality of the full-scale system. The water quality was calculated using a weighted average of the water quality from both stages. The predicted water quality from the testing was then compared to the projected water quality from the membrane projections. The results are presented in Table 6.

From Table 6, the predicted water quality from the projections and the observed water quality from the testing are relatively close, with the exception of chloride for both Trisep membrane configurations. Both Trisep configurations revealed that calculated chloride rejections (calculations based on water quality results from tests at different recoveries) were better than predicted from the software. For the Hydranautics system, the observed water quality from the testing was better than expected from the projections. However, for the CSM system, the opposite was observed: the predicted water quality from the membrane projection was better than the calculated water quality observed during testing.

The discrepancy between water quality predicted from the membrane projection and from the actual testing could be explained by the fact that the one membrane tested may not be a representative average of the associated membrane model. Past experience with the CSM membranes showed that calculated water quality had been relatively close to the projections. A recent pilot study using CSM membranes (BLR/BLF hybrid configuration) performed in south Florida is an example where the actual water quality observed was very close to the projections.

From the water quality results, the CSM BLR membrane has the lowest salt rejection, and as shown in the previous subsection, has the highest pressure requirement. Therefore, the CSM membrane configuration was not recommended for bidding. Single-element testing results are summarized as follows:

- All four membrane configurations tested met the water quality goals.
- The Trisep ACM4 membrane configuration requires less pressure than the other membrane configurations.
- The CSM BLR/BLF membrane configuration produced the worst water quality at the highest pressure among the four membrane configurations tested.
- The hybrid membrane configurations from Trisep (ACM2/ACM4) and Hydranautics (ESPA2/ESPA1) resulted in similar results in terms of water quality and pressure requirements.

Based on the pilot study analysis, it was recommended that the City pre-approve the following membrane configurations for bidding on the membrane replacement project:

- Trisep
  - ACM4 in both stages
  - ACM2 in stage one and ACM4 in stage two
- Hydranautics
  - ESPA 2 in stage one and ESPA1 in stage two

Energy and Cost Savings

A return on investment for the existing train, when using new membrane elements, was also performed prior to actual bidding. The energy savings were estimated to be approximately $76,600 per year (Table 7) in operating the existing train after replacing the existing membranes. Assuming a cost of $540 per membrane, and therefore, a total of $193,000 to replace the membranes in the existing skid, the payback period for the membrane replacement investment would be approximately 2.5 years. The payback period is significantly sooner than the life expectancy of the membrane elements of seven to 10 years.

Table 6. Predicted Water Quality From Membrane Projections and From Testing

	ACM4		ACM2 ACM4		ESPA2 ESPA1		BLR BLF	
	Proj.	Tested	Proj.	Tested	Proj.	Tested	Proj.	Tested
TDS	112	144	65	71	96	61	42	149
Chloride	60	42	37	17	42	17	18	55
Calcium Hardness	5	6	2.5	2.5	4	1	3	2.5
Magnesium Hardness	6	8	3.5	3.5	4.5	1	4	2.5
Total Hardness	11	14	6	6	8.5	2	7	5

Table 7. Energy and Financial Evaluation for the Existing Train

Existing Membranes at 2 mgd	180	kW/h
New Membranes at 2 mgd	104	kW/h
Energy Savings	76	kW/h
Energy Savings	1,824	kW/day
Financial Savings		
Electrical Purchase Rate	$ 0.115	$/kWh
Total Savings	$ 209.8	$/day
	$ 76,600	$/year

Summary

The City has bid the membrane replacement project, with bids received from both Hydranautics and Trisep. Based on an analysis of the capital costs and operating costs, Trisep ACM4 membranes were selected. The membrane replacement project was completed in August 2015. The detailed assessment of options for replacing the City's 8.5-in. elements has assured continued life for the existing RO skid, while providing significant cost savings to the City.