Looking Ahead: Selecting Membranes With Water Quality Degradation in Mind

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Increased salinity in groundwater is of growing concern to utilities aiming to maximize the value of the drinking water treatment process, while ensuring longevity for future operation. Increased salinity can occur through the migration of higher-salinity groundwater within the aquifer or from hydraulically connected aquifers. Salinity increases will impart challenges on utilities to treat the high levels of total dissolved solids (TDS) in the water supply with membranes that will physically outlast their current treatment capabilities. Identifying membrane elements that can serve their useful life for both current and future water quality can allow the Palm Beach County Water Utilities Department (PBCWUD) to get the maximum value of its investment, despite a water quality downturn.

The PBCWUD is currently experiencing this rise in salinity in the raw water at Water Treatment Plant No. 11 (WTP 11). To circumvent the current and projected rising salinity level, PBCWUD sought to select the best possible membrane elements and develop a pilot to test the current and future performance.

This article presents the methodology in comparing different criteria of the selection process, as well as the steps to develop a multicriteria membrane element selection tool leading up to the pilot.

Background

The WTP 11 has been in operation since 2007 and has experienced significant raw water quality changes since its original start-up. The WTP 11 utilizes reverse osmosis (RO) membranes to treat brackish water from the Floridan aquifer. Normally, this aquifer is typically a reliable water source with minimal variations in water quality, such that the raw water for WTP 11 has been historically high in TDS, which mainly consists of sodium, sulfate, and chloride. Since the facility's start-up in 2007, the raw water quality has rapidly degraded. An example of this degradation is seen with one of the facility's recently installed wells, PW-9. As shown in Figure 1, the TDS concentration of PW-9 has increased from approximately 4,800 mg/L in 2015 to nearly 8,000 mg/L in 2018. The overall raw water TDS concentration for WTP 11, however, represents the blended water quality of various combinations of the 10 wells that currently supply the facility. The current blended raw water TDS levels for the facility have risen to approximately 7,300 mg/L. Raw water TDS increase has led to several operating challenges, including elimination of raw water blend, increased feed pressures, and reduction in recovery.

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A combined raw water quality trend for the entire wellfield is shown in Figure 2, which includes all 10 wells in production at the time of this study.

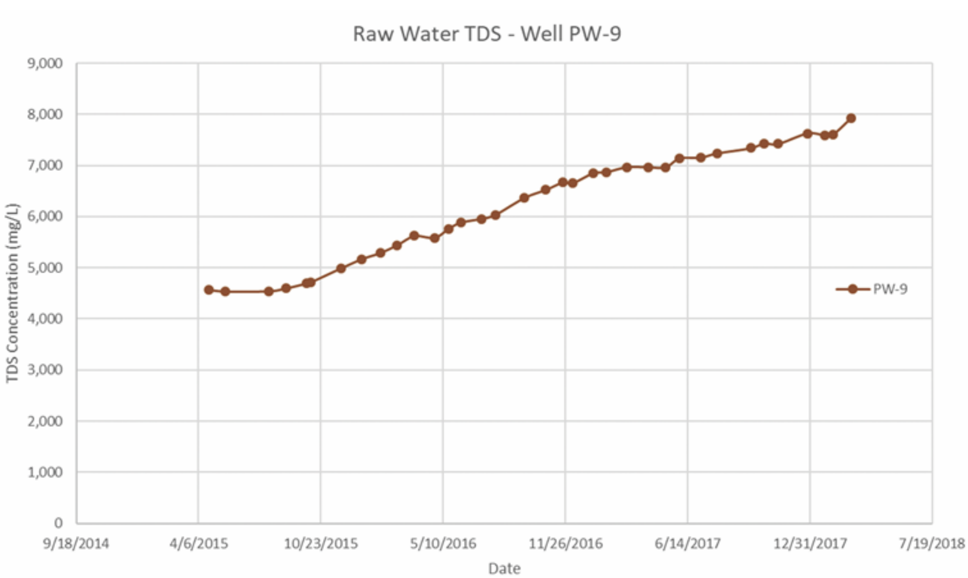

Figure 1. Well PW-9 Total Dissolve Solids Increase

Restoration

With the increased salinity characteristic of brackish water, WTP 11 began to experience operational challenges, with the pumps reaching maximum capacity, which led to lowered recovery rates. These challenges have led PBCWUD to implement an interstage boost at WTP 11 to maintain recovery. The interstage boost was achieved by retrofitting the existing RO train with energy recovery devices. Installation of these devices produced an interstage boost that restored the recovery rate back to 80 percent and allowed for increased capacity, while reducing first-stage feed pressures. As water quality continues to decline, PBCWUD has identified the need to seek out alternate solutions and carefully select membrane elements for the upcoming replacement.

While the current membranes and retrofit efforts have mitigated short-term challenges and performed successfully at current water quality levels, the membranes are nearing the end of their useful service life and are due for replacement. Furthermore, water quality from the WTP 11 wellfields is anticipated to continue to degrade in the future. Based on historical water quality trends and future groundwater modeling, projected water quality values were developed in partnership with JLA Geosciences Inc. and PBCWUD. As shown in Table 1, the raw water TDS is expected to increase by 30 percent over the next 10 years. Waters with TDS concentrations over 10,000 mg/L are considered saline and push the upper limit of traditional brackish water membrane elements. The 10-year (2028) predicted TDS concentration of 10,385 mg/L exceeds this range, presenting a unique challenge for the selection of membranes over the physical element's anticipated 10-year life cycle. Establishment of projected raw water quality values was the first step in planning for the future and served as a foundation for selection of replacement membranes.

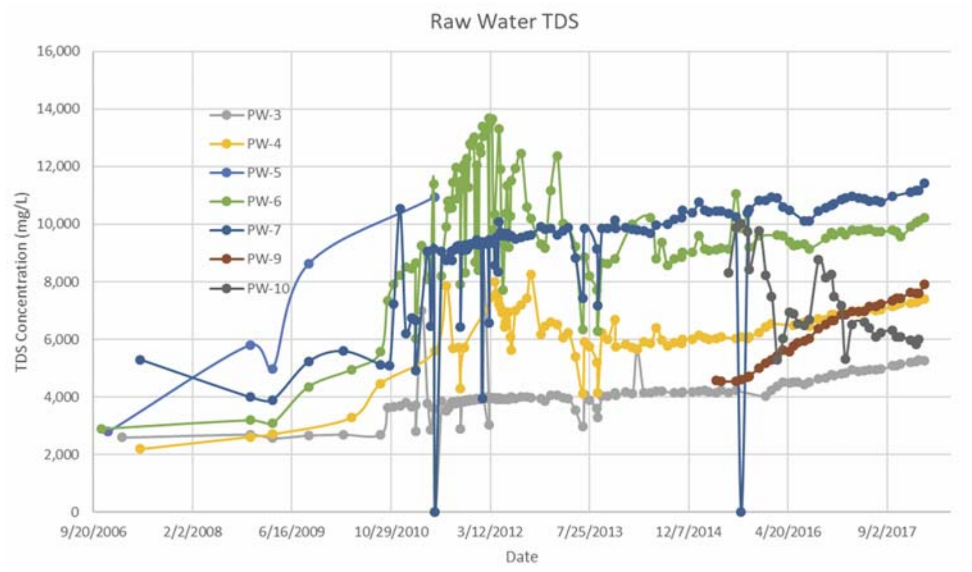

Figure 2. Cumulative Wells Total Dissolve Solids Incline

Membrane Selection Criteria

The membrane selection criteria were developed with the goal to identify all the parameters that PBCWUD considers important in its membrane selection and simplify the selection process for assessing each parameter. The selection criteria also offered the flexibility to manufacturers by providing the criteria prior to projecting their element array for piloting and ultimate bidding and selection. This allowed the manufacturers to understand the drivers for selection as they prepared their best possible element selection. The PBCWUD staff and engineers developed the criteria based on qualitative and quantitative parameters. All qualitative data would be ranked on impact to cost and thus provide a numerical value of performance for each manufacturer. By setting these goals prior to piloting, PBCWUD could expect that the best-performing membrane element will be the most cost-effective solution throughout the membrane life.

The criteria developed would need to incorporate the potential upgrades necessary to the plant for each membrane tested based on a minimum 77 percent recovery rate. The current pilot will allow PBCWUD to plan aggressively, while predicting and preparing for future water quality degradation.

Table 1. 5-Year and 10-Year Predicted Water Quality Parameters

Ion	Current Design 2018 (mg/L)	Predicted 2023 (mg/L)	Predicted 2028 (mg/L)
Designated TDS	7,332.00	9,376.00	10,385.00
NH4	0.73	0.93	1.03
K	26.76	34.21	37.90
Na	2,402.87	3,072.73	3,403.41
Mg	126.96	162.35	179.83
Ca	213.96	211.96	234.77
Sr	18.61	23.80	26.36
Ba	0.04	0.05	0.05
CO3	0.07	0.09	0.10
HCO3	88.98	113.78	126.03
NO3	0.04	0.05	0.05
Cl	4,001.37	5,116.86	5,667.51
F	0.75	0.96	1.07
SO4	480.88	614.93	681.11
SiO2	17.16	21.95	24.31
Boron	0.00	0.00	0.00
CO2	24.15	30.88	34.20
pH	7.6	7.6	7.6
Cations	126.79	159.06	176.18
Anions	124.41	159.1	176.23
Projected TDS	7,380.00	9,376.00	10,385.00

Selection Parameters

The selection parameters were discussed with PBCWUD staff members and ranking was determined in collaboration with them based on the impacts to the system during the short- and long-term water quality of the system. First, parameters specific to performance were considered, followed by criteria specific to cost.

Water Quality Performance

The parameters for water quality performance were based on the membrane performance meeting the anticipated water quality goals. These goals included lowering sodium and chloride, which are secondary contaminants as regulated by the U.S. Environmental Protection Agency (EPA), to 42 and 175 mg/L, respectively. Additional water quality parameters included in the performance criteria are HS^- ion rejection, pH in the permeate and concentrate, and cal-

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cium hardness. These levels will determine the impacts to post-treatment stabilization and concentrate disposal.

The pH level of the concentrate was used to evaluate disposal feasibility to determine if the concentrate can be blended with bioscrubber waste and injected into the onsite deep well. When considering disposal, the water quality would need to be evaluated to consider blending and pH impacts to the deep well. For calcium hardness, a higher level is preferred in the permeate, as it will require less post-treatment stabilization.

Production Capabilities

When PBCWUD evaluated the performance of the membranes, the potential for flexible capacity capabilities was considered and incorporated into the membrane criteria. The membrane production goals were determined to be 2 mil gal per day (mgd) at low flow, up to a maximum capacity of 2.5 mgd at high flow, and at 80 percent recovery. The production goals will be measured at both the current raw water quality TDS and simulated future increased TDS levels representing end-of-life water quality. The membrane pilot was constructed to allow for internal recycle of concentrate to the feed water to simulate increased TDS and is described in the Membrane Pilot heading that follows. The production goal for the selected membrane is to maximize recovery, while meeting water quality parameters.

Fouling Performance and Membrane Autopsies

Another important membrane performance criterion is fouling, and its performance will be analyzed for each membrane option through continuous monitoring of pilot performance data, including pressure differential and conductivity. Fouling is identified when the values begin to deviate from the normalized data established at pilot start-up. Furthermore, through autopsies conducted on each membrane at the end of the pilot, the fouling on each membrane would be observed and ranked from "good," "better," and "best," based on quantity of foulant compared to other manufacturers' elements. Irreversible fouling, meaning noncleanable or permanent damage to the membrane elements, will be ranked as either "pass" or "fail," as it's anticipated that no element should show signs of irreversible fouling at the end of the pilot.

Procurement

It's important for PBCWUD to select the most cost-feasible membrane, in addition to meeting performance criteria. The estimated membrane capital costs will be compared for each manufacturer, and the cost analysis will incorporate several additional annual expenses to understand long-term financial impacts. Operational expenses will be based on net present value over a 10-year operational period and this parameter would be ranked based on lowest cost. Additional parameters evaluated included any equipment upgrades required to meet the

Table 2. Performance Selection Criteria

Description			Current TDS Values (2018)				Projected TDS Values (2028)				Performance Criteria Description
	Units	Goal	Value	Score	Weighing Factor	Component Score	Value	Score	Weighing Factor	Component Score	
Water Quality Performance (Pass/Fail)											
pH											Identify impacts to post treatment
Permeate	S.U.										Identify impacts to post treatment
Concentrate	S.U.										Identify impacts to concentrate disposal
Sodium (30-60 mg/L HAL for aesthetic taste)	mg/L	42									Aesthetic taste component (30-60 mg/L HAL by EPA)
Chloride	mg/L	175									EPA secondary contaminant (70%)
Calcium/Hardness	mg/L	Highest									Water quality impacts to post treatment
TDS	mg/L	350									EPA secondary contaminant (70%)
HS^- Ion Rejection	mg/L	Highest									Water quality impacts to post treatment
Production Capabilities (Pass/Fail)											
Recovery Rate (77% Minimum prior to capital upgrades)	%	80%									Maximize production performance
Capacity Capabilities											Ability to achieve high (2.5 MGD) and low (2.0 MGD) flow capacity
Current WQ - Low Flow Rate (2.0 MGD per Train)	Pass/Fail	Pass									Ability to achieve low (2.0 MGD) flow capacity
Current WQ - High Flow Rate (2.5 MGD per Train)	Pass/Fail	Pass									Ability to achieve high (2.5 MGD) flow capacity
Flux Balancing (Noted - No Scoring)											
Stage 1	gfd	<18									Sustainable/maximum flux rate
Stage 2	gfd	>5									Sustainable/minimum flux rate
System Flux	gfd	<15									Average system pass flux
Membrane Array (Noted - No Scoring)											
Stage 1 Membrane Type	model										Hybrid load or same membranes
Stage 2 Membrane Type	model										Hybrid load or same membranes
Fouling Performance											
Foulant Observed (Noted - No Scoring)	Noted										Relative quantity of foulant compared to other manufacturer's elements
Predicted Frequency (Pass/Fail: Maximum 2/Year)	Pass/Fail	Pass									Anticipated cleaning cycles
Membrane Autopsies											
Irreversible Fouling	Pass/Fail	Pass									Non-cleanable or permanent damage to the membrane element
Bid Pricing											
Capital Expense											
Membrane Element Cost	$	Lowest									Cost per element
Ancillary Fittings and Labor	$	Lowest									Cost for ancillary equipment and labor
Cleaning Frequency											
Predicted Frequency ($40,000 per event)	#/Year	Lowest									Anticipated cleaning cycles
Operational Expense											
Power Use (Calculated from pressure required)	$/kgal	Lowest									Calculated power use based on actual pump and projected train performance
Operational Expense (10-year NPV)	$	Lowest									Calculated NPV over 10-year operational period
Pressure and Energy Consumption											
Feed Pressure (340 psi Max Allowable)	psi	Lowest									Energy consumption and impact to operating expenses
Interstage Boost (80 ERD Max Boost)	psi	Lowest									Equipment upgrades, energy consumption and impact to operating expenses
2nd Stage Feed Pressure	psi	Lowest									Equipment upgrades
Specific Energy Projections (Informational Only)	kWh/kgal	Lowest									Projected energy usage by membrane manufacturers
Feed Pump Upgrades	Yes/No	No									Equipment upgrades necessary
First Stage Train Upgrades	Yes/No	No									Equipment upgrades necessary
Second Stage Train Upgrades	Yes/No	No									Equipment upgrades necessary
Second Stage Vessel Upgrades	Yes/No	No									Equipment upgrades necessary
Boost Upgrades Required	Yes/No	No									Equipment upgrades necessary
Permeate Back Pressure Required	psi	Lowest									Equipment upgrades necessary
TOTAL SELECTION SCORE				0		0		0		0	

Figure 3. Pilot Unit Instrumentation

Figure 4. Pilot Unit Pumping and Power

feed pressure and the interstage boost pressure needed for each membrane evaluated.

Anticipated cleaning cycles were also incorporated into evaluation of cost, as the predicted frequency of cleaning has a direct impact to PBCWUD at approximately $40,000 per event. Each manufacturer's projected energy and power use based on actual pump and projected train performance data were also incorporated into the membrane criteria evaluation. Table 2 shows the membrane performance selection criteria used for the membrane selection. The rows in gray are related to membrane performance, while the parameters in white are related to cost evaluation.

Membrane Pilot

After developing the selection criteria, membranes from three different manufacturers will be compared side by side in a pilot study for a duration of 10 weeks. The pilot study has been started and is in progress at the time of this article's writing. The first phase of the pilot study will evaluate the three membrane options against the selection criteria. The three manufacturers were provided with the current and predicted raw water quality shown in Table 1, as well as the selection criteria table. The pilot will use raw feed water prior to acid injection, since PBCWUD is interested in eliminating acid injection at this facility. The raw water will be dosed with the existing scale inhibitor prior to the pilot unit's cartridge filter.

For the first eight weeks of the pilot, the membranes will be operated using the current feed water to the plant. For weeks nine and 10, a portion of the membrane concentrate will be recycled back to the raw water stream to simulate the 2028-projected TDS concentration of approximately 10,385 mg/L. The physical pilot unit consists of three parallel trains, as shown in Figure 3 and Figure 4, while the process flow diagram for the pilot is shown in Figure 5.

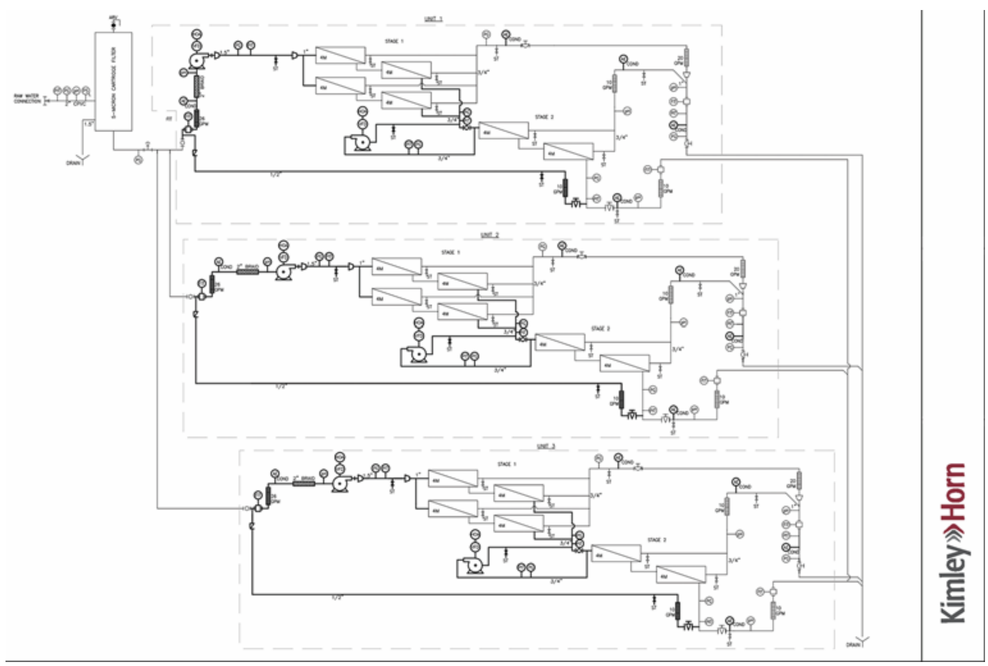

Figure 5. Pilot Process Flow Diagram

A key component of the pilot's success is obtaining and analyzing membrane performance and water quality data. During the pilot, PBCWUD staff will be recording data twice per day in a daily monitoring log. The pilot skid is also equipped with data loggers that continuously record several important parameters, such as feed pressures, permeate pressures, pH levels, flows, and conductivities at several points within the treatment process. The data will be used to develop "normalized" data values of the clean membranes during start-up. Operational data will be compared using normalized data to track membrane performance.

The important parameters to be normalized and monitored include salt passage, permeate flow, and feed-to-concentrate differential pressure. If the pilot operational data for the selected parameters deviate more than 10 percent from the normalized start-up values, this indicates membrane fouling, which will be confirmed through the membrane autopsies for each element manufacturer's lead and lag elements. Furthermore, several water quality

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parameters will be tested in a laboratory for the raw water feed and pilot skid permeate during the second half of the pilot. The laboratory analysis will address specific water quality performance criteria, including TDS, sodium, chloride, calcium hardness, and hydrogen sulfide ion removal.

Following the completion of the first phase, a sample of each of the manufacturer's membranes will be autopsied to further identify any fouling. The data from the first phase of the pilot will be analyzed to determine the membrane or membranes that best met the performance criteria by taking the life cycle costs and operational impacts into consideration. One of the three membrane manufacturer options will then be selected for performance testing of scale inhibitors in phase 2 of the pilot project.

Conclusion and Next Steps

The daily data collected from the membrane pilot study will be analyzed to track and compare membrane performance against the identified parameters. The membrane performance data, as well as the life cycle costs, will help PBCWUD make a decision that will best prepare it to meet future water quality challenges.

Development of the selection criteria prior to the pilot testing made the piloting process more efficient because it established clear goals and provided the manufacturers a level playing field to offer their best option for testing. The cost criteria are beneficial because they include operational expenses, such as cleaning and energy consumption, and also anticipate future upgrades at increased TDS levels, such as interstate boost, vessel upgrades, and feed pressure increases. This allows PBCWUD to plan for future cost expenditures and actively implement phased improvements as raw TDS levels increase. The deliberate development of selection criteria will provide a clear path for selection of a membrane system that will continue to provide high-quality potable water to PBCWUD customers.

For utilities facing deteriorating raw water quality in their membrane water supply, a similar pilot testing analysis can offer solace in selecting membrane elements for replacement of aged units. The performance criteria can and should be used to provide an open and transparent membrane selection process for membrane replacement. Moreover, pushing the membrane performance during the pilot testing to the future TDS limits will demonstrate the stepwise improvements necessary to sustain production capacity for the utility under the raw water quality conditions.

Finally, budgetary capital improvement planning based on TDS degradation allows utilities to accurately predict and continually evaluate budget expenditures using real-time data, rather than a rough time estimate derived from the linear digression of water quality. Proper planning with science-based decision trees will help ensure long-term operation of membrane treatment facilities anticipating a decline in water quality.

Acknowledgments

Special thanks to those who made this project possible: Palm Beach County Water Utilities Department leadership for its forethought to plan for deteriorating water quality rather than react to the consequences; and the PBCWUD operations team members who supported the day-to-day operations of the pilot testing, including extensive hands-on monitoring and data collection for the study.