Blending Floridan & Surficial Groundwater in Reponse to Drought at Palm Beach County's Membrane Softening WTP No. 3

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The Palm Beach County Water Utilities Department serves a population of 440,000 over a service area of 1,178 square miles. As a result of the water shortage of 2006, the department became interested in increasing its alternative water supply options.

The water shortage is inextricably linked to Lake Okeechobee—the lifeblood of South Florida's freshwater supply—which fell to a nine-foot water level in July 2007, three feet below its historical average one year prior and within one inch of its lowest recorded level. Because of the direct impact on water resources, the lake's low water level and ongoing rainfall deficit have emphasized the need to augment Southeast Florida's water resources with alternative supplies.

Blending groundwater from the deeper, brackish Floridan Aquifer with the existing surficial groundwater source at Palm Beach County's membrane softening water treatment facilities was identified as a way to quickly implement an alternative water supply source. The county's membrane softening water treatment plants each have aquifer storage and recovery (ASR) wells that could be used to supply brackish water and offset freshwater withdrawals during drought.

This article offers results from a multiphase pilot study conducted at the county's Water Treatment Plant No. 3. An existing ASR well that has not yet begun cycle testing provided a non-degraded Floridan Aquifer supply for testing. The tests confirmed chemical pretreatment, feed pressure, and permeate water quality when blending 10, 15, and 20 percent brackish water with the existing surficial supply.

These tests followed a desktop study that found drinking water standards could be maintained with up to a 20 percent Floridan blend. The preliminary evaluations also concluded that blending ahead of the membrane process allowed higher utilization of the Floridan water when compared to post-treatment blending brackish water into the membrane permeate.

Water Treatment Plant No. 3 is a 30-MGD facility with 25.5 MGD of nanofiltration and 4.5 MGD of surficial bypass and blend. It is located west of Delray Beach. Water Treatment Plant No. 9 is a 26.9-MGD treatment facility with 23.0 MGD of nanofiltration and 3.88 MGD of surficial bypass and blend. Both of these facilities use Koch nanofilitration softening type membranes.

Table 1 shows the Floridan alternative water supply quantities that can be achieved at various blend ratios. The total alternate water supply at 20 percent Floridan blend is 11.38 MGD. Blending Floridan water is a cost-effective alternate water supply alternative if water quality goals can be achieved within the pressure limitations of the membrane trains.

Objectives

A test program was designed to assess feasibility and operational constraints and requirements associated with blending fresh groundwater from the Lower Surficial Aquifer (LSA) and brackish groundwater from the Upper Floridan Aquifer (UFA). More specifically, the tests were used to:

- Assess membrane performance at different LSA:UFA blend ratios
- Simulate conditions representative of full-scale operations
- Determine chemical pretreatment requirements (three different scale inhibitors were tested)
- Characterize raw, pretreated, permeate and concentrate water quality

Table 2 highlights the basis and method behind these project objectives.

Table 1: Membrane Feedwater Requirements at 85% Recovery

% Brackish Feed Water Blend	WTP No. 3 25.5 MGD Membrane Capacity		WTP No. 9 22.9 MGD Membrane Capacity	
	Surficial (MGD)	Floridan (MGD)	Surficial (MGD)	Floridan (MGD)
0	30	0	26.9	0
5	28.5	1.5	25.6	1.4
10	27	3	24.2	2.7
15	25.5	4.5	22.9	4
20	24	6	21.5	5.4

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Methods & Materials

Test Conditions

The experimental test matrix evaluated the effects of blending ratio, pretreated pH level, and scale inhibitor type on membrane performance. Each test simulated full-scale operating conditions for system hydraulics, membrane type and configuration, as listed:

- Single pass two-stage 2:1 array
- Koch TFC-S thin-film composite membranes
- 85 percent system recovery rate
- 15 gsfd system permeate flux rate
- Seven membrane elements per pressure vessel
- Cartridge filter pretreatment

A total of four blending and pretreatment combinations were tested. Table 3 summarizes the LSA:UFA blend ratios, pretreatment conditions and status for each test. Test 1 established

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Objective	Basis	Methods
Assess effects of blending ratios	Brackish water from Upper Floridian Aquifer was blended with existing groundwater in order to lower the withdrawal from the Lower Surficial Aquifer.	1. Vary the blending ratio between 10%, 15%, and 20% brackish water. 2. Maintain recovery rate of 85%. 3. Monitor ratio's effect on feed pressure, scaling potential and water quality.
Simulate full-scale operating conditions	Pilot results were representative of full-scale operations by operating the pilot unit with the same raw water supply, system hydraulics, membrane type, and train configuration was used at full-scale.	1. Utilize the county's existing three-parallel train membrane pilot unit. 2. Operate the pilot unit at 85% recovery and 15 gsfd water flux rate with cartridge filter pretreatment, two-stage 2:1 configuration, and Koch TFC-S membranes.
Assess membrane performance under each test condition	Monitoring normalized membrane performance parameters was used to determine if blending is feasible for sustained periods of time.	1. Monitor membrane productivity, feed channel pressure drop, and salt passage. 2. Conduct sampling and analysis for inorganic, organic, particulate, and biological foulants. 3. Perform forensic membrane autopsies to characterize the physical and chemical nature of foulants accumulated within the membrane elements.
Characterize raw, pretreated, permeate and concentrate water quality	Water quality monitoring was used to document pretreatment conditions, effects on membrane performance, and possible secondary impacts on permeate post-treatment requirements, and concentrate disposal.	1. Sample and analyze process streams throughout the pilot study. 2. Routinely monitor scaling potential of the raw, pretreated, and concentrate water. 3. Perform mass balances for sparingly soluble salts.

Table 2: Pilot Study Objectives, Basis of Selection, and Methods Used

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baseline conditions at WTP design conditions using 100 percent LSA groundwater for comparison, with performance in Tests 2, 3, and 4 at LSA:UFA blend ratios of 90:10, 85:15 and 80:20. Tests 1, 2, 3 and 4 are also referenced as "Baseline," "10-percent Blend," "15-percent Blend," and "20-percent Blend," respectively.

Target pretreated feed pH was 5.8 for Test 1 and 6.65 for Tests 2 and 3. Operations were continuous, seven days per week, 24 hours per day, barring downtime for troubleshooting, equipment repair or routine maintenance.

Source Water

Raw water was pumped and blended from the LSA and UFA supplies. LSA water was supplied from the onsite WTP raw water transmission line. UFA water was pumped from the ASR wellhead and blended with LSA water in a common line feeding the pilot trains. The WTP 3 ASR had not yet begun cycle testing and was used as a source of Floridan water for the pilot. Flow meters and control valves enabled blended feed water control and adjustment for each test.

Pretreatment

Blended feed water was conditioned with sulfuric acid to lower pH for calcium carbonate scaling control, followed by cartridge filtration for suspended solids removal. A feed water manifold then split the acidified and cartridge filtered water into three separate feed lines. Each feed line was then dosed with scale inhibitor to control scaling of sparingly soluble salts in each train.

Multi-Train Membrane Pilot Unit

The county provided a multi-train membrane pilot unit comprising three parallel two-stage arrays for testing four-inch diameter spiral wound membranes. Each train was equipped with a raw water feed pump, pressure gauges, flow meters, sampling ports, flow control valves, pressure vessels, and instruments for monitoring conductivity and pH. Half-length pressure vessels (sized for up to four 40-inch length membranes) were arranged in a 2:2:1:1 wrap-around configuration.

Results

The pilot tests demonstrated that blending brackish and surficial groundwater is feasible with the existing plant, but secondary impacts were identified that require additional planning and consideration prior to full-scale implementation. The following sections highlight the comparison between existing plant operating conditions (100 percent surficial groundwater, sulfuric acid pretreatment to pH 5.8, and no scale inhibitor addition) with raw water blending, reduced acid feed (pH 6.65), and scale inhibitor addition.

Target Operating Conditions

Process operating data, collected once per shift, is shown in Figures 1 through 7. The vertical bars delineate the start of each test and changes in operating conditions. Target blend ratios, pretreated feed pH, flux, and recovery were well maintained for each test as shown in Figures 1 through 4. The pilot trains

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Test	Pretreated Feed Water pH	Raw Water Blend Ratio	Comment
1	5.8	"Baseline" 100:0 LSA:UFA	100% groundwater, simulated existing WTP operating conditions, completed 4/12/07
2	6.65	"10% Blend" 90:10 LSA:UFA	Completed 8/9/07
3	6.65	"15% Blend" 85:15 LSA:UFA	Completed 9/14/07
4	6.65	"20% Blend" 80:20 LSA:UFA	Completed 11/1/07

Table 3: Raw Water Blending Pilot Test Matrix

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experienced relatively minimal variation and required only minor periodic adjustments for flow or chemical pretreatment.

Membrane Fouling & Salt Passage

Foulant accumulation within the membranes was gauged using feed channel pressure drop, and normalized parameters for membrane productivity, and salt passage. Data normalization helped to identify changes in permeate flow and salt passage caused by membrane fouling or scaling by correcting for variation in system flows, pressure, temperature, and feed water quality.

Figure 5 shows that pressure drop was consistent for the first two tests showing comparable performances between the existing plant operating condition (Test 1) and the use of a 10 percent UFA blend in Test 2; however, pressure drop trended upward in the latter stages of Tests 3 and Test 4, suggesting some foulant accumulation within the feed channel spacer material at the 15- and 20-percent UFA blends. Projected cleaning frequencies suggest performance differed by train. Ranking by ability to sustain performance and minimize chemical cleaning was Train 2 > Train 1 > Train 3.

The water mass transfer coefficient (MTC_w) was used to monitor membrane productivity. Productivity refers to the amount of water flux (flow per membrane area, corrected to 25 degrees centigrade) per net available pressure across the membrane (net feed minus net osmotic pressure). Figure 6 shows that the systems experienced some productivity decline.

Projected run times between chemical cleaning for Trains 1 and 2 were similar and no less than 110 days. Train 3 consistently experi-

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Figure 1: Feed Water Blend Percentages

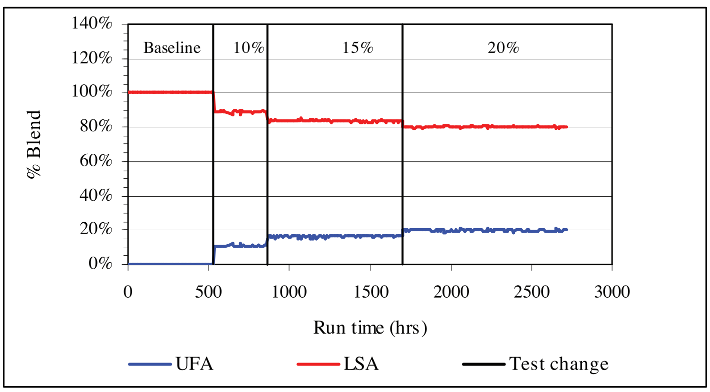


Figure 2: Pretreated Feedwater pH

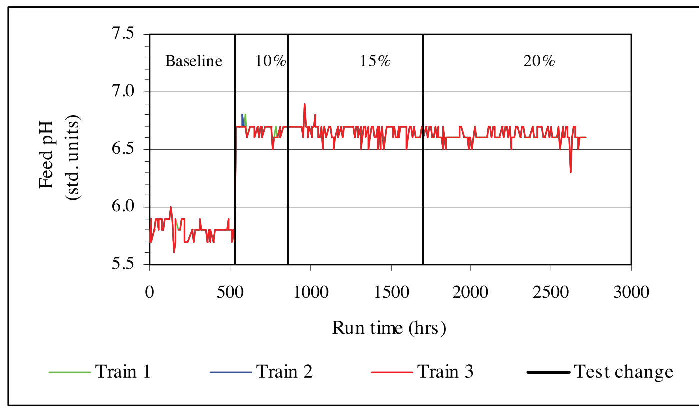


Figure 3: Water Recovery Rate

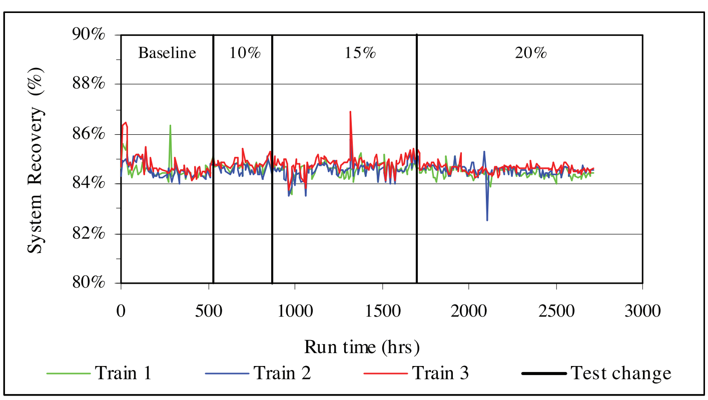


Figure 4: Water Flux Rate

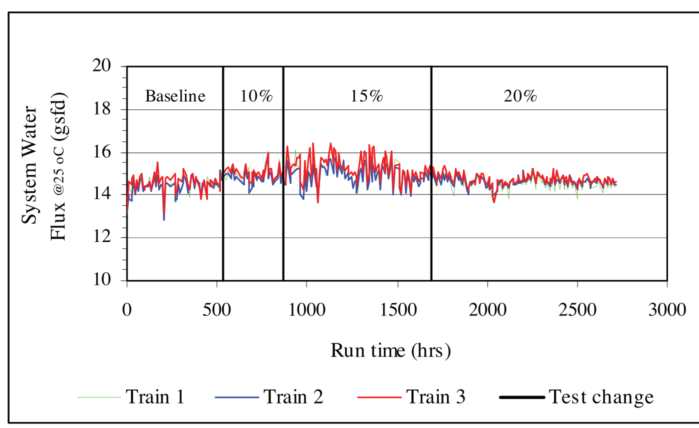


Figure 5: Feed Channel Pressure Drop

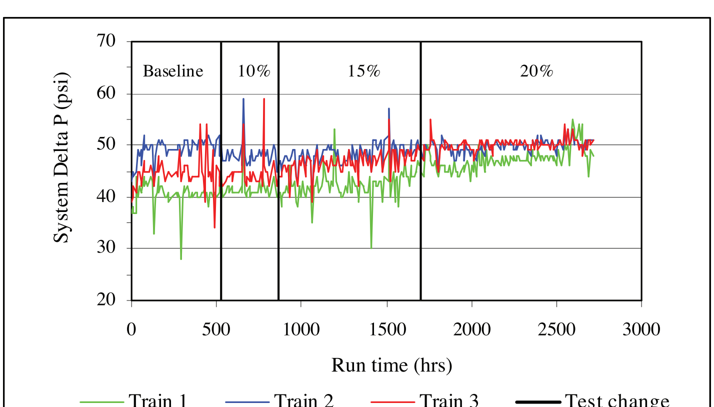


Figure 6: Membrane Productivity

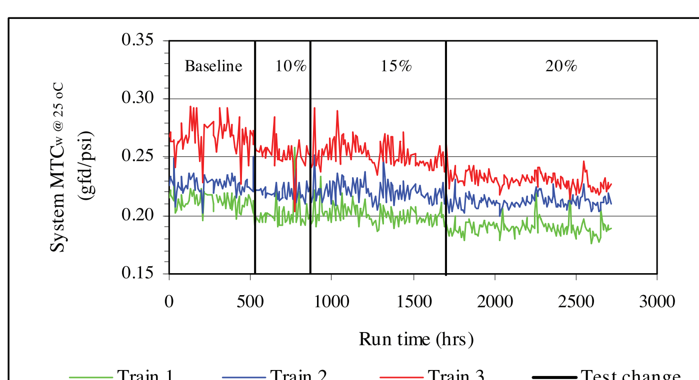
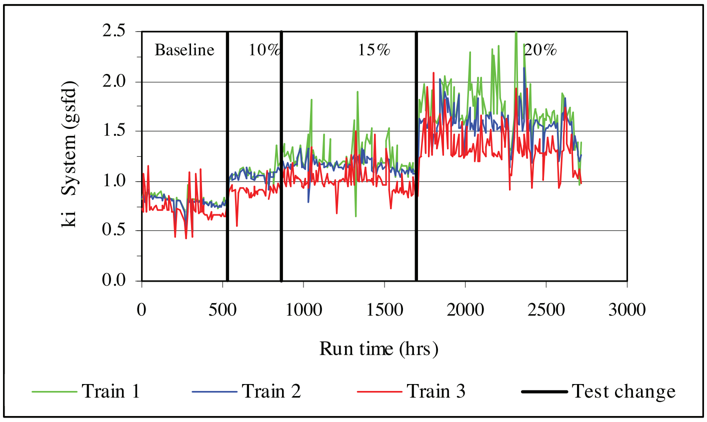


Figure 7: Salt Mass Transfer



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enced higher rates of productivity decline with run times as low as 33 days. Performance ranking, based on productivity decline, was consistent with the projected cleaning frequencies to control excessive feed channel pressure drop, with Train 2 > Train 1 > Train 3.

Salt mass transfer is shown in Figure 7. Test 1 data shows slightly increasing salt rejection over time. This is attributed to membrane start-up and the effects of membrane film compression caused by initial exposure to hydraulic pressure. Stable conditions were reached after 400 hours. Tests 2 and 3 showed a stepwise increase in salt passage with increasing UFA blend, but trends were relatively steady with relatively minor changes in salt passage over time.

Water Quality

The existing process uses relatively tight softening membranes for removing hardness, natural organics (color and total organic carbon), and TDS. A desktop evaluation showed that the existing process could handle up to a 20 percent UFA blend before exceeding operational and functional constraints for permeate water quality and feed pump pressure limitations.

As mentioned, the county currently utilizes surficial wells as its source of supply. Table 4 summarizes average water quality for both the lower surficial and upper Floridan supplies.

The surficial water has low salinity, with an average TDS of 398 mg/L, and is well buffered and mineralized, with alkalinity and calcium hardness of 245 and 262 mg/L as $CaCO_3$, respectively. The surficial water also contains low to moderate amounts of total sulfide at 0.6 mg/L S. In contrast, the upper Floridan water is brackish with TDS, chloride and sodium levels of 3,200, 1,700, and 960 mg/L, respectively, and total sulfides at 1.6 mg/L.

Table 5 shows permeate water quality for each test. As expected, TDS, conductivity, and most other parameters increased in proportion to the percent UFA blend, but rejection of divalent ions such as calcium and magnesium remained high, with increasing blend causing only minor increases in permeate concentration. Parameters increasing with increasing blend were mainly the monovalent ions such as chloride and sodium.

While the 20 percent blend increased permeate chloride and sodium levels, Table 5 shows the permeate was well within regulatory limits for TDS, chloride, and sodium.

Table 4: Raw Water Quality

Parameter	Units	Average Raw Water Quality	
		Upper Floridan Aquifer (UFA)	Lower Surficial Aquifer (LSA)
Alkalinity	mg/L as $CaCO_3$	198	247
Barium	mg/L	0.02	0.04
Bromide	mg/L	2.80	1.54
Calcium Hardness	mg/L as $CaCO_3$	295	262
Chloride	mg/L	1,254	40
Color	PCU	8	41
Conductivity (field)	umhos/cm	918	581
Fluoride	mg/L	1.51	0.24
Iron, Total	mg/L	0.04	0.07
Magnesium Hardness	mg/L $CaCO_3$	370	16
pH (field)	Std. units	7.57	7.16
Potassium	mg/L	29.2	2.0
Sodium	mg/L	826.3	25.3
Strontium	mg/L	8.7	1.1
Sulfate	mg/L	352	18
Silica, Total	mg/L	14.6	14.9
Temperature (field)	°C	26.2	26
Total Dissolved Solids	mg/L	2,478	389
Total Hardness	mg/L as $CaCO_3$	728	297
Total Organic Carbon	mg/L	5.20	11.60
Total Sulfide	mg/L	1.83	0.64
UV-254 - Unfiltered	cm^{-1}	0.16	0.47

Comparison of Pilot & Predicted Membrane Performance

The pilot performance data was compared to vendor-based membrane modeling software (Koch Membrane Systems ROPRO V7.0). Table 6 summarizes the model inputs and results for the 85:15 LSA:UFA blend. The data shows that the model over-predicted salt passage by 120 percent and under-predicted operating feed pressure by 6 percent.

While vendor-based models are good tools for screening alternative treatment scenarios, the difference between actual and predicted results highlights the importance and benefit of pilot testing for site-specific field verification. An important outcome is that much higher UFA blends appear feasible than predicted by vendor-based software.

Secondary Impacts

When implementing an alternative feed water with an existing membrane process, secondary impacts on membrane operations and maintenance (O&M), post-treatment, and finished and concentrate water quality must be considered. Noted impacts with raw water blending for this study include:

- Increased feed water pressure
- Increased permeate salinity, pH, and total sulfide concentrations
- Increased concentrate salinity, particularly sodium and chlorides
- Slightly increased sulfide loading to post-treatment processes (chlorine oxidation, aeration and off-gas odor control)
- Changes in finished water taste
- Water-quality changes in membrane concentrate

These impacts can be mitigated rela-

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Table 5: Permeate Water Quality

Parameter	Units	Average Permeate Water Quality			
		Test 1 100:0 LSA:UFA pH = 5.8	Test 2 90:10 LSA:UFA pH = 6.65	Test 3 85:15 LSA:UFA pH = 6.65	Test 4 80:20 LSA:UFA pH 6.65
Alkalinity	mg/L as $CaCO_3$	26	30	31	33
Barium	mg/L	0.003	0.005	0.005	0.01
Bromide	mg/L	0.56	0.16	0.13	0.22
Calcium Hardness	mg/L as $CaCO_3$	17	18	17	18
Chloride	mg/L	7.9	32.0	36.3	50
Color	PCU	5	5	5	5
Conductivity (field)	umhos/cm	108	171	210	273
Fluoride	mg/L	0.14	0.08	0.09	0.09
Iron, Total	mg/L	0.08	0.02	0.02	0.02
Magnesium Hardness	mg/L as $CaCO_3$	1.3	2.8	3.3	4.4
pH (field)	Std. units	6.59	5.96	5.81	5.9
Potassium	mg/L	0.5	1.1	1.3	1.7
Sodium	mg/L	8.8	23.0	28.0	36
Strontium	mg/L	0.1	0.1	0.1	0.14
Sulfate	mg/L	2.1	2.7	2.3	2.5
Silica, Total	mg/L	2.0	3.6	3.6	3.8
Temperature (field)	°C	25.8	25.8	26.4	26.5
Total Dissolved Solids	mg/L	70	88	91	130
Total Hardness	mg/L as $CaCO_3$	22	21	20	21
Total Organic Carbon	mg/L	0.9	0.7	1.0	0.9
Total Sulfide	mg/L	0.8	0.7	0.6	0.7
UV-254 (Unfiltered)	cm^{-1}	0.001	0.004	0.003	0.004

Table Notes: LSA = Lower Surficial Aquifer. UFA = Upper Floridan Aquifer. Blend ratios expressed in percent as $\%_{LSA}:\%_{UFA}$, e.g. 85:15 represents 85% LSA blended with 15% UFA.

Table 6: Actual & Predicted Membrane Performance for 85:15 LSA:UFA Blending

Parameter	Pilot Performance Test No. 2	Projected Full-Scale Performance (KMS ROPRO V7.0)
Permeate Flow	21.3 GPM Per Train	2.5-MGD Per Train
Percent Recovery	85 %	85 %
Train Configuration:		
Manufacturer	KOCH Membrane Systems, Inc.	KOCH Membrane Systems, Inc.
Model	TFC 4920S	TFC 8239S-400
# Stages per Train	2	2
# Stage 1 Pressure Vessels	2	40
# Stage 2 Pressure Vessels	1	21
No. Elements per Pressure Vessel	7	7
Area per Membrane Element	85 ft^2	400 ft^2
Performance:		
Average System Permeate Flux	14 – 16 gsfd	14.4 gsfd
Feed Pressure	122 psi	115 psi
Permeate TDS	88 mg/L	194 mg/L
Permeate Chloride	32 mg/L	82 mg/L

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tively easily, provided the brackish water blend remains below 20 percent. As with any project of this nature, each impact is being carefully reviewed to identify operating constraints and any necessary system improvements.

Summary

The pilot study indicated that the full-scale plant can be operated successfully with blended surficial and upper Floridan groundwater, giving the county added flexibility for managing water resources by relaxing surficial withdrawals during drought.

The data showed stable membrane productivity (MTC_w - water mass transfer coefficient) and consistent permeate water quality for the 10- to 20-percent LSA blends, but blending may require more frequent chemical cleanings to extract foulants from the system. Performance tended to be scale inhibitor specific, with one product consistently outperforming the other two.

Anticipated benefits for blending, reducing acid feed, and use of scale inhibitor pretreatment include:

- Flexibility during drought
- Reduced sulfuric acid consumption and chemical costs
- Reduced caustic soda dosages for off-gas odor control resulting from lower carbon dioxide emissions from the forced-draft aerator
- Reduction in occupational hazards associated with sulfuric acid handling and feed system operation and maintenance

It should also be noted that full-scale evaluations should consider the salinity degradation of the Floridan Aquifer. While this evaluation utilized a newly constructed ASR prior to cycle testing, blending can also be used for ASR wells in which the fresh water "bubble" has been fully recovered and the well quality has returned to the Floridan state.

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