How the Sawgrass Water Treatment Plant Gained Five Benefits With One Project

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The Sawgrass Water Treatment Plant (WTP) in the City of Sunrise (city) is a 24-mil-gal-per-day (mgd) nanofiltration (NF) facility. It was originally constructed in 2000 to treat Biscayne surficial aquifer water and was expanded in 2003 with the addition of two membrane trains. The water from the WTP blends in the distribution system with water from the city's other two lime softening plants. This creates a need to increase the pH of the finished water from the WTP so that the water is consistent with the other two plants. An existing facilities overall process flow diagram of the WTP is presented in Figure 1.

As a result of treating the water with NF membrane technology, the product water meets all regulatory requirements, but has less minerals and alkalinity than currently desired. Higher mineral content in the finished water will result in more-stable distribution system conditions in terms of minimizing red water occurrences, corrosion, nitrification potential, and associated system flushing. It would also be expected to improve overall aesthetics, such as taste. Adding minerals, referred to as remineralization, would allow for certain treatment process modifications, such as those associated with the elimination or reduction of sodium hydroxide (NaOH) use.

Membrane Element Replacement Evaluation

The type of municipal drinking water membranes utilized at the WTP have a typical useful life span of five to 10 years, depending on the type of service (i.e., source water treated, etc.) and their maintenance program. Due to the fact that both sets of membranes (those from the original construction, as well as those from the expansion) are older than the upper end of the typical life span, and as operations staff has reported some membrane performance degradation, it was prudent that a replacement program be developed and initiated.

Except for the parameters of iron and color, all reported raw water quality parameters meet primary and secondary drinking water standards, other than disinfection considerations and pH adjustment in the raw source water. The total hardness of the raw water averages 265 mg/L as calcium carbonate, which is considered "very hard" for human use and consumption. The total organic content of the water is also considered very high, averaging approximately 18 mg/L. It's this organic content that results in the color level, which exceeds secondary standards. The NF process was chosen for the effective removal of both the hardness and organics.

The other parameter not meeting standards in the raw water is iron, and although the NF process effectively removes iron to a level below the regulatory standard, it remains a concern to operations staff due to its potential to stain at levels well below the maximum contaminant level (MCL). Because of this concern, the proposed replacement membranes were evaluated to remove iron to levels below that currently being achieved. Table 1 summarizes the raw water quality from both the Arena and Flamingo park wellfields, which represent the source water to the WTP.

Table 2 summarizes the finished water quality goals identified for the membrane replacement activity. These goals were developed in meetings with city staff to achieve a finished water quality that would address challenges that had resulted in prior flushing activities and/or complaints.

Software packages from the different membrane manufacturers are available for simulation of the operating characteristics of membrane elements. Input information, such as raw water chemistry, infrastructure characteristics, and system design parameters, allows for simulations of available elements to be developed to project performance conditions. Due to the advent of new and improved materials and advanced manufacturing technologies, membranes have evolved to the extent that they

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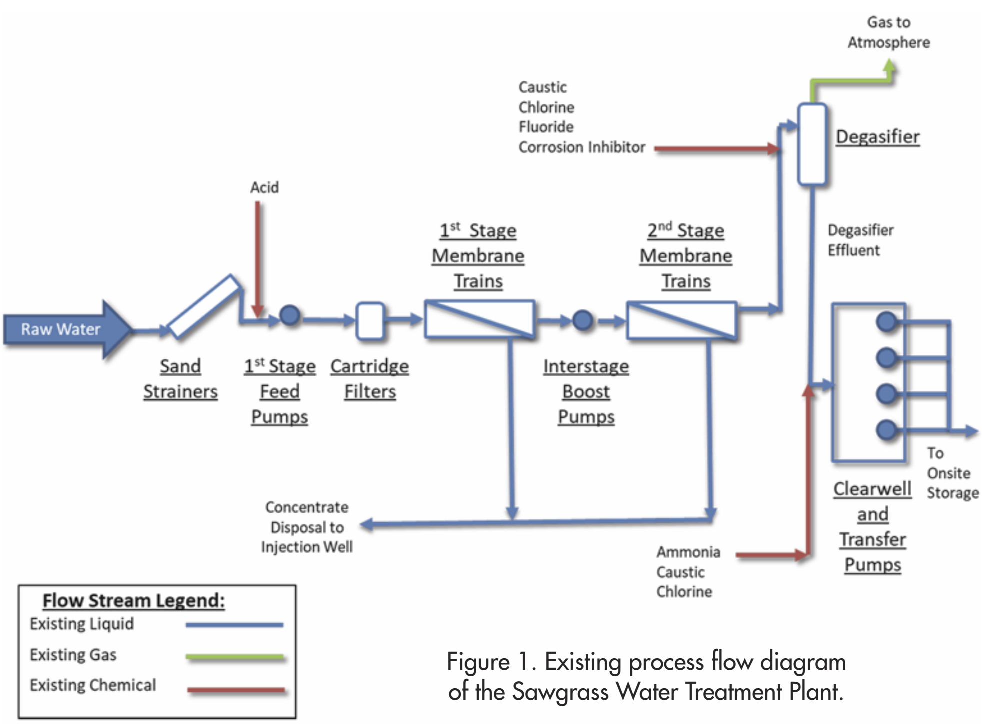

Figure 1. Existing process flow diagram of the Sawgrass Water Treatment Plant.

Table 1. Raw Water Quality Analysis

Parameter	Raw Water Analysis (mg/L as ion unless noted otherwise)
Calcium	97.92[2]
Magnesium	4.98[2]
Sodium	51.20[1]
Potassium	3.80[3]
Barium	0.021[1]
Strontium	0.80[3]
Ammonia	0.00[2]
Iron	1.49[1][2]
Bicarbonate	181.6[3]
Carbonate	0.36[4]
Carbon Dioxide	0.019[3]
Chloride	84[1][2][5]
Sulfate	0.86[1]-10[3]
Nitrate	0.05[1]
Fluoride	0.35[1]-1.10[3]
Bromide	0[3]
Phosphate	0[3]
Silica	8.0[3]
Boron	0[3]
Copper	0.51[1]
Manganese	0.014[1]
pH, unitless	7.3[2]-7.4[1]
TDS	385.33[1]
Specific Conductance	539 µS[1]
Temperature	24.5 °C[5]
Color	60.2[2]-113[1] CU
Turbidity	0.36[1]-0.42[2] NTU

Notes:
(1) From wellfield water analysis.
(2) From MORs.
(3) From Dow-FilmTec archives.
(4) Calculated.
(5) Provided by plant superintendent.

Table 2. Proposed Finished Water Quality Goals

Parameter	Units	Recommended Range
Hardness	mg/L as $CaCO_3$	[1]
Iron Concentration	mg/L	≤ 0.15[2]
Alkalinity	mg/L as $CaCO_3$	[1]

Notes:
(1) As high as possible, while achieving Iron removal goal.
(2) Established below the MCL to minimize staining and metallic taste of potable water. Refer to *Water Treatment Principles and Design*, MWH, Second Edition, 2005.

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can remove a wider range of contaminants (at varying rates) with less fouling, and require less energy. The latest NF and low-energy reverse osmosis (RO) technologies were investigated from the available manufacturers.

Due to the nature of NF membrane elements to reject divalent cations (such as calcium), the evaluation became a balancing act. Because the raw water iron from the raw water wells is relatively high, hybrid membrane arrangements became less attractive to consider. Hybrid arrays were found to be less attractive because, when lower rejection membranes were considered in the tail end of the second stage, it had the effect of increasing permeate hardness and alkalinity, while having the side effect of increasing the iron concentrations as well. It was soon decided to select membrane elements for the replacement effort that met the iron rejection goal, while considering additional treatment to meet the desired hardness and alkalinity goals.

Remineralization Cost Evaluation

Since the finished water alkalinity and hardness goals were not able to be met with membrane treatment alone, the city considered additional treatment options. A remineralization cost evaluation was performed to determine the present worth of two potential remineralization options. These options included the addition of carbon dioxide and liquid lime (hydrated calcium hydroxide solution) feed systems, and the blending of water treated with the processes of oxidation, filtration, and ion exchange (IX).

The finished water goals were further refined from the membrane element replacement evaluation in terms of alkalinity, hardness, and iron. The values identified were consistent with recommendations by industry-recognized sources, such as the American Water Works Association (AWWA) and the Water Research Foundation. The goals that were set are summarized in Table 3.

The resulting lowest-net and present-worth cost of remineralization, when considering both capital costs and operational and maintenance costs, was the alternative to implement a sidestream treatment process of oxidation, prefiltration, and IX. This treatment system was selected for full-scale implementation by the city.

Design of Oxidation, Prefiltration, and Ion Exchange Treatment as a Sidestream Process

The selected treatment system at the WTP to complement the existing NF treatment system consists of oxidation, prefiltration, and IX. The proposed facilities overall process flow diagram is presented in Figure 2.

The primary mechanism desired for iron control is oxidation of dissolved iron to form filterable particulate iron. It was determined through bench-scale testing that oxidation with sodium permanganate yielded effective results and relatively low residuals production, while operating at a cost deemed to be reasonable. The prefiltration system removes particulates, such as oxidized iron and turbidity, from the raw water flow stream to prevent excessive downstream IX fouling. A conservative loading rate was utilized to maximize iron and other particulate removal efficiency.

Filtered water will be conveyed to the IX system under pressure without the need for additional pumping. The IX process is to be operated in a continuous mode where water passes through pressure vessels containing anion resin in a plug flow manner. This process is used to selectively remove anions, such as organics that are negatively charged, while allowing most of the alkalinity and hardness to be conserved, in accordance with the treatment goals. Treated water from the IX process will be blended with the degasified NF permeate at the inlet to the chlorine contact tank. Four-log inactivation of viruses is then achieved in the contact tank, followed by transfer pumping, finished water storage, and high-service pumping into the distribution system.

Implementation of Selected Alternative

The process that was evaluated in the remineralization cost evaluation included consideration of accommodating the rated treatment plant capacity with a combination of IX and NF treatment. Table 4 summarizes the blended water characteristics of these two flow streams with varying amounts of IX treatment. Projections of the resulting blended finished water quality to meet the goals resulted in 18.5-mgd treatment through the existing NF process and blended with 5.5 mgd of the IX process. Each of the blending ratios met the desired water quality goals, but had increasing capital costs associated with new IX infrastructure.

Following review of the results of the remineralization cost evaluation, the city was eager to implement the selected process. Since the WTP is one of three treatment plants within the city's service area, there was a desire to implement this treatment scheme, while managing capital expenditures. As a result, the

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Table 3. Finished Water (Post-Treatment) Goals

Parameter	Units	Recommended Range
pH	[-]	8.0-8.5
Alkalinity	mg/L as $CaCO_3$	80-120
Hardness	mg/L as $CaCO_3$	75-120
Calcium Hardness	mg/L as $CaCO_3$	60-120
Iron Concentration	mg/L	≤ 0.15[(1)]

Notes:
(1) Established below the MCL to minimize staining and metallic taste of potable water. Refer to *Water Treatment Principles and Design*, MWH, Second Edition, 2005.

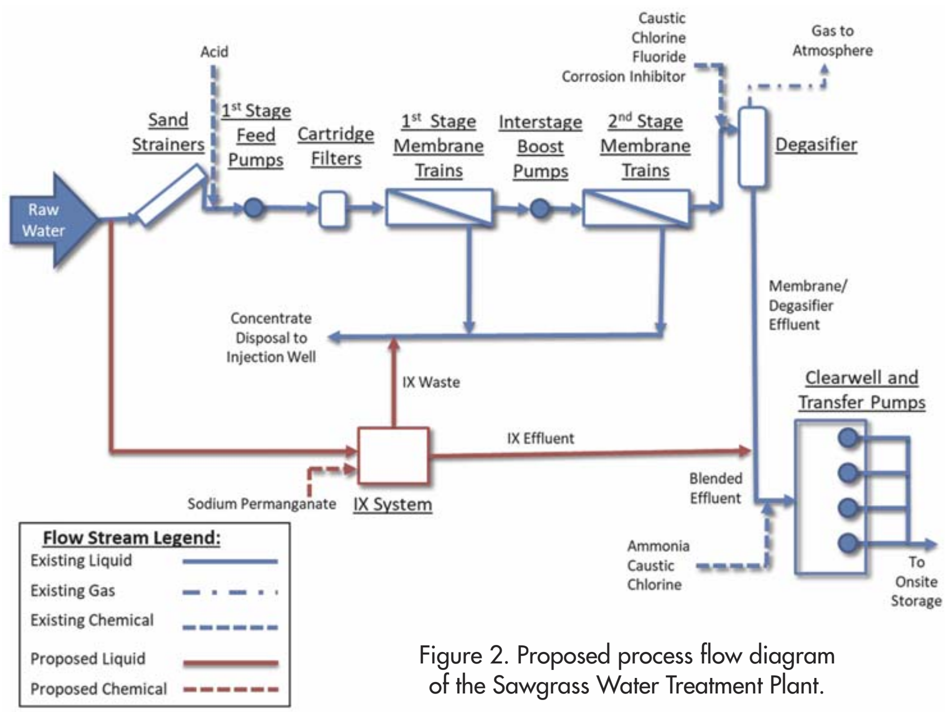

Figure 2. Proposed process flow diagram of the Sawgrass Water Treatment Plant.

Table 4. Projected Blend Characteristics of Nanofiltration- and Ion Exchange-Treated Finished Water

Parameter	Units	Parallel Treatment Streams: New NF Membrane Permeate[(1)]	Parallel Treatment Streams: IX Effluent[(2)]	Finished Water Blend: 5.5[(3)] mgd IX & 18.5 mgd NF Permeate	Finished Water Blend: 7.5[(3)] mgd IX & 16.5 mgd NF Permeate	Finished Water Blend: 9 mgd IX & 15 mgd NF Permeate
pH	SU	7.0	7.45	8.23	8.26	8.26
Alkalinity	mg/L	13	278	80	103	121
Calcium Hardness	mg/L	14	264	71	92	108
Iron	mg/L	0.05	0	0.039	0.034	0.03
NaOH Addition	mg/L	0	0	4.7	5.7	6.5

Notes:
(1) Water quality after degasification, from projections performed as part of the Sawgrass WTP membrane replacement evaluation (Carollo Engineers, October 2013).
(2) From previous bench-scale treatability study (Carollo Engineers, 2011).
(3) Operational flow rate.

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city elected to proceed with the first half of the established capacity in Phase I. Then, as the water production rates increase at the WTP, which at the time averaged 12 mgd, the city would implement Phase II of the project and construct the additional identified IX treatment features.

During the design process for Phase I, the capacity of the system was optimized, and updated blended water projections were performed. Based on maximizing the availability of existing treatment systems, the capacity for Phase I was increased to 3 mgd. Table 5 summarizes the updated water blend characteristics. These projects compared the 3-mgd IX system to the amount of NF treatment to achieve the average treated water flow, as well as the total rated plant capacity flow rate.

Waste Disposal Considerations

Waste from the prefilter and IX system is received in the waste equalization tanks from the prefilter backwashes and IX regenerations. An air gap is provided for all streams entering the waste equalization tank to ensure that there is no cross connection. Waste will be disposed via waste equalization pumps and directed into the existing deep industrial injection well. The availability of an existing onsite industrial injection well facilitated waste disposal, while minimizing capital costs.

Project Benefits

As a result of implementing the oxidation, prefiltration, and IX system in parallel with the existing NF treatment system, the city is anticipating five primary benefits:

Benefit 1

Water quality will be improved. This is realized through the increase in hardness and alkalinity in the finished water, with iron levels within the established goal (in which iron will be less than the preproject values, and at a level that is projected to not cause red water events in the distribution system).

Benefit 2

The cost of operation will be lower than with NF treatment alone. The only pumps necessary to convey water through the prefilter and IX treatment system is the existing well pumps. This saves the pumping energy by not sending the water through feed pumps, interstage boost pumps, and concentrate disposal pumps, as is necessary with the NF system. Further, the only chemicals utilized in IX treatment is 1 to 2 mg/L of sodium permanganate and salt for IX resin regeneration. A significant amount of sulfuric acid and NaOH are saved by not treating the water through NF. A cost evaluation performed in 2015 estimated the savings, based on the nominal 3-mgd IX system operating in parallel to the NF system, to be approximately $600,000 per year.

Benefit 3

There will be less water loss. For every gal of water that is treated through the IX system, it represents a savings in water usage. Of the total raw water conveyed to the existing NF system, 15 percent is disposed to the deep injection well as a concentrate byproduct. Only 1 to 3 percent of the water will be lost through the IX treatment system. This represents a significant water savings.

Benefit 4

Distribution system maintenance will be reduced. Sending water into the distribution system with higher alkalinity will result in a more-buffered and stable water. This water will resist pH change that may be present due to biofilm bacteria. This resistance to pH change will minimize distribution system corrosion, as well as help minimize the potential for nitrification, and both conditions typically trigger required maintenance flushing activities. Since these two conditions will be reduced, so will the maintenance associated with flushing, as will the corresponding loss of product water.

Benefit 5

Customer experience will be improved. Water that is balanced with calcium hardness and alkalinity, as well as low in other ions, such as iron, tastes better to customers. The reduction in staining due to iron levels below 0.15 mg/L will also contribute to an improved customer experience, as clothes will come out cleaner from the laundry and there will be less staining at homes that irrigate with potable water.

Table 5. Projected Water Blend Characteristics

		Parallel Treatment Streams		Finished Water Blend	
Parameter	Units	NF Membrane Permeate	IX Effluent(2)	3 mgd(3) IX & 9 mgd NF Permeate	3 mgd(3) IX & 21 mgd NF Permeate
pH	SU	6.4(1)	7.45	8.45(4)	8.48(4)
Alkalinity	mg/L	40(5)	250	91	67
Calcium Hardness	mg/L	14(5)	239	65	41
Iron	mg/L	0.06(5)	<0.02	0.05	0.06
TDS	mg/L	48(1)	530	168	108

Notes:
(1) Actual water quality after degasification based on measurements reported in the MORs from December 2007 to September 2009 and all of 2015.
(2) From previous bench-scale treatability study (Carollo Engineers, 2011).
(3) Operational flow rate for proposed IX system.
(4) Following post-treatment with NaOH addition.
(5) From operational data from Train 1 following membrane replacement in early 2016.

Conclusions

The city undertook a membrane element replacement project concurrently with a water quality optimization upgrade, which included implementation of an oxidation, prefiltration, and IX system. These projects were implemented to provide improvements to maintain current satisfactory operations, improve treatment reliability and water quality, and lower water production and system flushing/maintenance costs. At the present time, the membrane element replacement effort has been successfully completed and is in operation. The prefiltration, oxidation, and IX system construction is complete, with commissioning and closeout activities occurring at the time this article was written.

Once placed into service, the city can begin realizing the benefits of this new treatment system. The total cost for the membrane element replacement project was approximately $1,600,000, which included removal and disposal of the existing elements, vessel cleaning, disinfection, new element loading, and start-up and testing. The total construction cost for the prefiltration, oxidation, and IX system is $6,696,000.

The city looks forward to the successful completion of the project so that the benefits and savings may be realized by both the city and its customers.