Groundwater Nanofiltration Plant Addresses Color and Disinfection Byproducts for Flagler County

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Flagler County (county) owns and operates the Plantation Bay Water Treatment Plant (PBWTP), which was constructed in the 1980s. The PBWTP has a design capacity of 756,000 gal per day (gpd) and utilizes four groundwater wells to produce average day and maximum day flows of 232,000 gpd and 377,000 gpd, respectively. While all of the wells are moderately high in total hardness (~325 mg/L as calcium carbonate [$CaCO_3$]), two of the wells also yield water with high color that frequently approaches 90 color units. The lime softening treatment process utilized at the PBWTP is ineffective in removing the color, and this condition has resulted in frequent complaints from customers and the inability to use these wells. Additionally, the PBWTP has had past exceedances of the U.S. Environmental Protection Agency (EPA) disinfection byproduct (DBP) maximum contaminant levels (MCL) of 80 µg/L for total trihalomethanes (TTHMs). Both the color and DBP formation issues stem from natural organic matter (NOM) in the wells, resulting in total organic carbon (TOC) levels as high as 25 mg/L.

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An alternatives evaluation was performed to determine the best treatment solution to address the water quality issues. A weighted treatment (1 = lowest ranking, 5 = highest ranking) decision matrix was developed for these potential alternatives, as shown in Table 1.

Based on results from the evaluation, nanofiltration (NF) was selected for implementation to remove organics, color, and hardness, and to reduce DBP formation potential. Concurrent with preliminary and final design, a pilot test was conducted using the well with the highest organics and color.

The county is moving forward with replacing the current treatment process with a low-pressure NF treatment system, as NF is ideally suited for the removal of dissolved constituents, such as TOC and hardness. This article presents the findings from the pilot test and discusses the design of the new NF treatment system.

Table 1. Weighted Treatment Decision Matrix

Primary Criteria	Weight	Treatment Process					
		Lime Softening		Ion Exchange		Nanofiltration	
		Score	WGPS	Score	WGPS	Score	WGPS
Costs							
Capital Costs	15%	4	0.6	3	0.45	3	0.45
Operation and Maintenance Costs	15%	3	0.45	3	0.45	2	0.3
Technical Feasibility							
Overall Water Quality	25%	2	0.5	3	0.75	5	1.25
Proven Technology	10%	3	0.3	3	0.30	5	0.5
Treatment Waste/Disposal Requirements	3%	2	0.06	4	0.12	4	0.12
Footprint	3%	3	0.09	3	0.09	2	0.06
Operation and Maintenance							
Operator Training	4%	3	0.12	3	0.12	2	0.08
Maintenance	5%	1	0.05	3	0.15	3	0.15
Schedule							
Construction Period	15%	4	0.6	3	0.45	2	0.3
Permitting	5%	4	0.2	4	0.20	2	0.1
Total	**100%**		**2.97**		**3.08**		**3.31**

WGPS = weighted grade point score

Pilot Study

The PBWTP has four production wells that have varying high levels of iron, ammonia, sulfides, color, TOC, and hardness. Groundwater quality data from the wells is shown in Table 2.

Pilot testing was performed to confirm that the proposed treatment process will produce a quality effluent that meets or surpasses treatment goals of the new water treatment project. Based on the groundwater quality presented in Table 2, the pilot study aimed to reduce the following groundwater constituents:

- *Iron* – High levels of iron in the source water

Continued on page 6

Continued from page 4

contribute to color within the water and are likely the source of the majority of customer complaints received by the county.

- *Hardness* – With an average hardness of 338 mg/L as $CaCO_3$, the PBWTP source water is considered very hard (>180 mg/L as $CaCO_3$), according to the U.S. Geological Survey (USGS) hardness classification.
- *Color* – In groundwater, color may be attributed to a variety of sources, including metallic ions, organic acids, or dissolved plant materials. Color in the water has been the most common complaint from customers.
- *TOC* – This is a measure of organic matter in water and becomes a major concern when the source water is chlorinated, potentially forming DBPs such as trihalomethanes (THM) and haloacetic acids (HAA5).

A pilot unit was designed to address these constituents and produce high-quality potable water. The pilot study simulated the performance of the components of a full-scale system. The primary objectives of the pilot study were to:

1. Demonstrate the filter media operating parameters, including:
   a. Iron removal efficiency
   b. Filter head loss as a function of run time
   c. Approximate filter run length
2. Determine the chemical feed rates to meet the water's oxidant demand to the extent possible.
3. Evaluate membrane nanofiltration operating parameters, including:
   a. Ability to remove TOC with a goal less than 1 mg/L
   b. Hardness removal efficiency
   c. Comparison of NF membrane performance with Dow® ROSA NF membrane model simulation
   d. Transmembrane pressure as a function of run time
   e. Confirm that antiscalants chemical feed rates recommended by manufacturer avoid fouling the membrane
   f. Approximate run length before clean-in-place (CIP) is required
4. Demonstrate that the proposed equipment can meet the following water quality objectives:
   a. TOC below 1 mg/L and near detection limit
   b. Filter effluent iron below MCL and NF permeate iron near detection limit
   c. Manganese <0.05 mg/L
   d. Total Hardness < 150 mg/L
   e. Total Sulfides < 0.01 mg/L
   f. Ammonia, nitrogen converted to monochloramine

It was determined that the well with the highest color and organics (Well No. 4) would be used for pilot testing. This well was selected to ensure a conservative design approach. Additionally, due to the high levels of color and organics, Well No. 4 was not being used for production purposes and, therefore, provided access for the pilot trailer. A blend of the various wells was considered; however, the existing piping and valving infrastructure limited the blending opportunities. The pilot unit consisted of the following treatment schemes:

Filtration

A 3-ft-diameter by approximately 7-ft-tall filter column was utilized. Its main purpose was to remove iron and other suspended solids. To aid in the removal of iron, an injection point was included upstream of the filter. Prior to filtration, a small dosage of sodium hypochlorite was added to precipitate iron for downstream filtration. It should be noted the low dosage was used to form monochloramines and to limit the formation of DBPs. The filter was set up to monitor differential pressure across the filter, and valves were provided so that filter backwash could be performed at predetermined differentials.

Nanofiltration System

The NF was the main treatment process used to decrease the concentration of iron, organics (DBP precursors), color, and hardness in the filter effluent. Upstream of the NF system, sodium metabisulfite was added for dechlorination, and antiscalant was added to reduce the potential for scaling, especially at the tail end of the second-stage membrane elements. The NF system also included a 5-micron cartridge filter for filtering out any particulates in the filter effluent. The system also utilized a high-pressure pump to push water through the NF membranes. A two-stage configuration was utilized with a 2/1 array. The first stage incorporated Dow NF90-4040 membrane elements, while the second stage utilized the "more open" Dow NF270-4040 membrane elements.

ChemScan®

A Chemscan spectroscopic analyzer was also utilized with this pilot to provide online testing of color, TOC, and iron levels in the raw water and permeate water.

Pilot Study Performance

Iron Removal

Based on laboratory results, the iron in the filter effluent averaged approximately Fe = 0.25 mg/L entering the NF membrane system, while the NF permeate iron was below the detection limit of approximately Fe < 0.03 mg/L. Thus, the NF average approximate removal of the NF influent iron was at least 88 and 89 percent, based on the laboratory and field results, respectively.

Total Organic Carbon Removal

The NF membrane skid provided excellent removal of organics based on laboratory results, lowering the approximate concentration of TOC = 22 mg/L in the raw water and filter effluent to below the detection limit of approximately TOC < 0.57 mg/L in the NF permeate.

Calcium, Magnesium, and Hardness Treatment

The raw water hardness (avg = 310 mg/L as $CaCO_3$) was effectively decreased with the two-stage NF membrane system to an average permeate of 105 mg/L as $CaCO_3$. The hardness of 105 mg/L as $CaCO_3$ is classified as a moderately

Continued on page 8

Table 2. Groundwater Quality Data (May 2012)

Parameter	Units	Well No. 1	Well No. 2	Well No. 3	Well No. 4
Calcium	mg/L	126	130	125	122
Iron	mg/L	0.18	0.18	0.63	0.82
Magnesium	mg/L	6.3	6.1	5.6	5.6
Potassium	mg/L	1.3	1.3	1.1	1.2
Sodium	mg/L	21.9	17.8	17.7	18.5
Total Hardness	mg/L as $CaCO_3$	341	351	332	328
True Color	mgPt/L	25	35	90	90
Total Alkalinity	mg/L as $CaCo_3$	334	328	317	312
Specific Conductance	umhos/cm	704	671	665	656
Total Dissolved Solids	mg/L	427	413	406	414
Chlorides	mg/L	30.7	23.3	24.2	23.8
Sulfate	mg/L	<0.25	<0.25	<0.25	<0.25

Continued on page 8

hard water by USGS; thus, the hardness was reduced by approximately 66 percent.

Totally Dissolved Solids

The two-stage NF membrane was demonstrated to effectively decrease the totally dissolved solids (TDS). The raw water averaged TDS of approximately TDS = 390 mg/L, while the TDS in the NF permeate averaged approximately TDS = 160 mg/L. The TDS was lowered by approximately 61 percent.

Conductivity

The raw water conductivity, which as measured by the laboratory averaged approximately 600 mho/cm, was lowered by the two-stage NF system to an average in the NF permeate of approximately 260 mho/cm; thus, the NF membranes decreased the conductivity by approximately 57 percent.

Color

The average raw water color based on the Chemscan was approximately 33.9 = Platinum-Cobalt (Pt-Co) color units, whereas the color wheel produced raw water readings of approximately 30 color units. Because all of the color wheel readings for the NF permeate were "0" color units, the Chemscan unit, with its multi-wavelength analyzer, could discern minor differences in color for the NF permeate effluent. The average, including these points, was approximately 1.1 Pt-Co color units with a range of approximately <1.0 – 1.8 Pt-Co color units.

Pilot Study Summary

The pilot study demonstrated that a two-stage NF membrane system provided excellent organic removal, while decreasing the hardness to acceptable levels. The organics removal from the NF process lowered the Well No. 4 TOC from approximately 22 mg/L to below detectable limits. The DBP formation potential testing was performed on the NF permeate and indicates that the county will now be able to consistently meet DBP regulations. The results of the pilot study are included in Table 3.

It is noted that toward the end of pilot testing, permeate flow from the second stage was significantly reduced and scaling was indicated. Both an alkaline and acid CIP were performed to restore membrane performance; however, the membranes never fully recovered. It appears that the reduced performance after the cleaning in place (CIP) was the result of iron fouling (not targeted with the CIP) that occurred throughout the pilot operation. The iron fouling likely occurred due to inconsistent operation resulting from Hurricane Irma. Additionally, it's noted that, in order to facilitate daily pilot operation, county staff was utilized to start/stop the unit. Several instances occurred in which chemical levels were not checked prior to starting the system, resulting in a chemical running out while the rest of the system ran. This likely contributed to iron fouling.

Design Considerations

Based on the pilot testing and the design team's experience with other facilities having similar water quality, the treatment processes will include oxidation, pressurized multimedia filtration, dechlorination, pH adjustment, antiscalant, cartridge filtration, membrane softening, permeate stabilization, and disinfection. The system will include a two-stage NF system with an overall recovery of approximately 80 percent. A partial NF bypass stream is planned and will be used to add pH and alkalinity to the permeate water, resulting in lower chemical usage and operational costs.

Since the chloride levels of the water supply are so low (~25 mg/L), the concentrate from the NF system will be beneficially used for reuse water irrigation with no damage to plants, grass, and other landscaping. The concentrate will be blended with the reclaimed water to supplement the county's reclaimed water system that is used to irrigate the Plantation Bay Country Club. This approach to concentrate reuse also provides the benefit of eliminating the need for deep well injection or surface water discharge.

The new treatment facility will include a membrane softening treatment process designed to improve water quality by removing hardness, organics, color, and other contaminants. The NF process will include three skids capable of producing a combined 756,000 gpd of finished water. The process will be expandable to 1 mil gal per day (mgd) as demands increase. A brief description of the major components of the reverse osmosis (RO) process is provided.

Booster Pump Station

An inline booster pump station will be constructed and will include three pumps to provide ample feed pressure to the pressurized filters so that a minimum of 20 pounds per sq in. (psi) is available at the suction side of the NF feed pumps.

Filtration

Three vertical pressure filters will be installed upstream of the RO skids as a means of pretreating the raw water. The filters will mainly serve to remove iron so as to mitigate iron fouling, which typically occurs on the lead elements of the first NF stage. Sodium hypochlorite will be used as an oxidant to aid in iron removal.

Softening and Color Removal

Via a membrane separation process, the NF membranes will treat the filtered water to meet all drinking water standards. The NF will remove the color and will allow some hardness and alkalinity to pass through the process, thereby reducing costs associated with post-treatment stabilization. The NF skids will include 5-micron cartridge filters to further protect the membranes, and high-pressure feed pumps provide approximately 90 psi at the membrane inlet. A CIP skid will provide for periodic cleaning using high-pH solutions for biofouling and lowering pH solutions to remove scaling.

Chemical Treatment

As previously mentioned, chemicals will be added throughout the treatment process as a means of enhancing the overall treatment and end-water quality. The chemicals that were used for the new treatment process include the following:

- *Oxidant* – Sodium hypochlorite will be added to the raw water line prior to the vertical pressure filters to aid in iron removal.
- *Dechlorination* –The filtered effluent will be dechlorinated, using sodium metabisulfite prior to introduction into the NF membranes.
- *Antiscalant* – To protect the membranes from scaling, an antiscalant will be added to the filtered effluent ahead of the RO treatment process.
- *Caustic* – Sodium hydroxide will be added to the RO permeate stream to increase the pH and alkalinity.
- Additional space will be provided for a future chemical as needed.

The project also includes a new prefabricated metal building, replacement of the existing filter backwash pumps, yard piping modifications, site improvements, and instrumentation and electrical improvements. Construction and commissioning are scheduled for completion by mid-2020.

Table 3. Pilot Study Results

TOC	**22 mg/L**	**0.57 mg/L**
Color	**34 NTU**	**< 1.0 NTU**
Hardness	**300 mg/L**	**100 mg/L**