Shifting Paradigms for Water Supply in Northeast Florida

Lisa Sterling, Cecile Toupiol, Bill Mendez, Martha Campbell, and John Regan

As we enter the twentieth century, water is quickly becoming recognized as a scarce and valuable commodity. Growth projections for Florida's rapidly expanding population predict that some large municipalities will not be able to meet the water demand of their populations by the year 2020.

Florida's Lower Surficial Aquifer (LSA), the longtime source of drinking water in Northeast Florida, will not be able to support this growing demand for water without consequence. The St. Johns River Water Management District has led the charge to decrease demand pressures on the LSA.

The district began its Water Protection and Sustainability Program in 2006 to provide cost-share funding for construction of alternative water supply projects in northeast Florida. The program emphasizes multi-jurisdictional, regional projects including projects that focus on reclaimed water, surface water augmentation, and new sources of public water supply. Since its inception, the program has jointly funded the construction of 55 projects totaling more than $411 million and resulting in over 178 million gallons per day in projected production.

Many municipal water plants have responded to the district's initiative by planning projects that utilize drinking water from the Upper Floridan Aquifer (UFA). Traditionally, the UFA has been characterized by water quality higher in chlorides, sulfate, total dissolved solids, and hydrogen sulfide than its LSA counterpart. This change in water quality has prompted municipalities to change their treatment technologies and operating paradigms.

The old treatment processes focusing on aeration, disinfection, and sometimes lime softening are not appropriate to treat the water quality of the UFA. The cities of Ormond Beach, Palm Coast, and St. Augustine, as well as St. Johns County, recently completed plant upgrades to low-pressure reverse osmosis (LPRO) systems to utilize UFA source water. The LPRO system, combined with a degasification/odor control system, addresses the water quality issues associated with the UFA.

Aside from the changes to water quality, the UFA provides some unique challenges for those wishing to shift their drinking water supply. This article will focus on the advantages and disadvantages of alternative water supply for the St. Augustine Water Treatment Plant.

New Technology

The city of St. Augustine currently operates a lime-softening water treatment plant that originally was placed in service in the 1920s and last modified in 1987. Like many municipal water treatment plants in Northeast Florida, the city's plant utilizes a blend of 60 percent LSA and 40 percent UFA for drinking water supply.

The plant is served by 14 groundwater wells—10 into the local LSA and four into the UFA. Twelve of these wells were installed in 1982 and two were installed in 2004.

The raw water supply is conveyed to the treatment plant through a 20-inch diameter raw water transmission main. The existing composite raw water is characterized as a relatively hard, high-color, high total organic carbon water.

An aerial photograph of the current water treatment plant is provided on Figure 1. The 1987 modifications to the original plant include the addition of the lime feed system, modifications to the sedimentation tank and reactor clarifier, modifications to the filter building, installation of an emergency power generator, installation of an ammonia feed system, and installation of a chlorine feed system.

The treatment process train includes a reactor clarifier for lime softening, a sedimentation basin for solids settlement and

Continued on page 18

Lisa Sterling, P.E., is an assistant project manager with the Jacksonville office of the engineering firm CDM. Cecile Toupiol, P.E., is a project manager with the firm's Jacksonville office. Bill Mendez, P.E., is the engineering manager for the city of St Augustine, Martha Campbell, P.E., is the public works director for the city of St. Augustine. John Regan, P.E., is the chief operations officer for the city of St. Augustine.

Figure 1: Aerial Photograph of the city of St. Augustine's Water Treatment Plant

Continued from page 17

recarbonation, dual media rapid sand filtration for solids removal, and a gravity sludge thickener for sludge treatment. Chemical feeds include the addition of chlorine and lime in the softening unit, carbon dioxide (recarbonation) in the sedimentation basin, chlorine followed by ammonia in the clearwell, and a sedimentation aid polymer in the gravity sludge thickener.

At 20 years, most of the current lime-softening process equipment is nearing the end of its service life. The increasing maintenance burden associated the aging lime-softening process represents both a financial and a reliability risk for the city. Accordingly, St. Augustine's aging infrastructure necessitated updating the treatment equipment at the plant.

In evaluating potential options, the city decided to participate in the water management district's Water Protection and Sustainability Program and initiate a transition from the LSA to the UFA for water supply.

By utilizing the UFA, St. Augustine will be able to transition to a much higher-yielding alternative water supply. To make this transition, the city evaluated the expected water quality from both the LSA and UFA to determine the treatment technology that would be most effective.

Raw water from the LSA is obtained from both low-yield and high-yield wells. A raw water quality sampling study was conducted in August 2000. The LSA low-yield well raw water quality is characterized, on average, by a relatively high total hardness of 307 milligrams per liter as calcium carbonate (mg/L as $CaCO_3$), high TOC (6 mg/L), high carbonate alkalinity (257 mg/L as $CaCO_3$), moderate TDS (392 mg/L), high iron content (1.4 mg/L), low sulfate (21.8 mg/L), and low chloride content (23 mg/L).

Raw water from the UFA is obtained from three wells. A raw water quality sampling study was conducted in August 2000. The UFA water is characterized by a relatively high total hardness (370 mg/L as $CaCO_3$), low TOC (1.4 mg/L), high TDS (643 mg/L), high carbonate alkalinity (153 mg/L as $CaCO_3$), low iron content (below detection limit), high sulfate (223 mg/L), and moderate chloride content (54 mg/L). Examination of the deep-well water quality data shows that most of the measured water quality parameters such as conductivity, hardness, alkalinity, TOC, pH, chloride and sulfate are similar in the three UFA wells.

Table 1: Summary of LSA and UFA Water Quality Data

Parameter	Unit	LSA – Low Yield Wells	LSA-High Yield Wells	UFA Wells
Color	cu [1]	28	67	BDL[4]
Specific Conductance	umhos/cm[2]	623	699	813
Total Hardness	mg/L as $CaCO_3$	307	353	373
pH	Units	7.22	7.12	7.57
TDS	mg/L	392	423	643
Turbidity	NTU[3]	6.82	0.17	0.42
Calcium Hardness	mg/L as $CaCO_3$	297	340	200
Magnesium Hardness	mg/L as $CaCO_3$	8.0	9.7	173.3
Bicarbonate Alkalinity	mg/L as $CaCO_3$	257	238	153
Carbonate Alkalinity	mg/L as $CaCO_3$	BDL[4]	BDL[4]	BDL[4]
Chloride	mg/L	23	24	54
TKN	mg/L as N	0.6	1.4	BDL[4]
Ammonia Nitrogen	mg/L as N	0.15	0.76	0.19
TOC	mg/L	6	19	1.4
Nitrate Nitrogen	mg/L as N	BDL[4]	BDL[4]	BDL[4]
Sulfate	mg/L	21.8	12.8	223.3
Iron	mg/L	1.4	0.33	<0.050
Potassium	mg/L	0.69	0.80	3.83
Sodium	mg/L	15	17	34
TTHM[5]	mg/L	0.28	0.15	0.07

Notes: 1. cu = color units
2. umhos/cm – micromhos per centimeter
3. NTU = nephlometric turbidity units
4. BDL = below detection limit
5. TTHM = Total Trihalomethanes

Table 2: Summary of NF and LPRO Permeate Water Quality Data

Parameter and Units	NF Membrane Value or Range	LPRO Membrane Value or Range
TDS (mg/L)	87[1] -175	18[1]-100
Calcium Hardness (mg/L as $CaCO_3$)	33[1]-40	6[1]-24
Total Hardness (mg/L as $CaCO_3$)	43[1]-53	8[1]-32
Alkalinity (mg/L as $CaCO_3$)	50-58[1]	12[1]-50
Chloride (mg/L)	12[1]-17	1.3[1]-2.9
Sodium (mg/L)	16[1]-18	3.2[1]-12
Sulfate (mg/L)	4.8[1]-19	2.1[1]-6.2
pH (units)	5.90[1]	5.90[1]

Notes: 1. This value is for the membranes as supplied by Koch Fluid Systems

Projected water quality for each water supply option is presented in Table 1. The UFA water quality projections exhibit a slight increase in chloride concentration, a significant increase in sulfate concentration, a significant decrease in alkalinity, a slight decrease in total hardness, and a very significant decrease in color, dissolved organic carbon, and total organic carbon.

Two treatment options were considered: LPRO and nanofiltration (NF). Using these water quality analyses and desired finished water production needs, membrane performance simulations were run using appropriate computer software programs from various membrane manufacturers.

The NF membranes used in the analysis were considered typical membrane softening membranes. The LPRO membranes used in this analysis were considered "low pressure brackish water membranes." Both LPRO and NF have a nominal chloride rejection value of 98.5 percent. Given the overlap in permeate water parameter values between the NF and the LPRO membranes for the source water, clear-cut differences between membrane processes were difficult to ascertain.

The results of water quality projections for the two membrane technologies are summarized in Table 2. Generally, The LPRO permeate water was a low-TDS, low-hardness, low-alkalinity water when compared to the NF permeate water. The LPRO permeate total hardness value was approximately one-fifth the NF permeate water value. Alkalinity values for the LPRO permeate were also approximately one-fifth the NF permeate water value. The LPRO permeate also provided distinctly lower sodium and chloride values.

Figure 2, top left, shows the raw water booster pumps that increase pressure on the raw water line to the LPRO membranes as it enters the plant.

Figure 3, above, shows the sand filter that is used for rough screening and capture of TSS in the raw water. As new UFA wells are brought online, the sand filter will help capture the sand and other solids that could clog the downstream cartridge filter.

Figure 4, left, shows the cartridge filters upstream of the LPRO membranes. The 5-μm cartridge filters represent the last screening step before water reaches the membranes.

Both the NF and LPRO processes provided significantly lower total hardness values when compared to lime-softened water at the St. Augustine plant. The alkalinity values for both membrane processes were above the average value for alkalinity in finished water at the plant.

When considering the choice between LPRO and NF treatment technologies, the city also evaluated their ability to treat future water quality. Modeling for the St. Johns County Upper Floridan Aquifer wellfield indicates moderate water quality degradation relating to chloride concentration with long-term pumpage in the same area as the city wellfield.

Such degradation in raw water quality is essentially unavoidable, even given the best designed wellfields and well pumping protocols, because of the cumulative impacts of regional aquifer pumping to serve expanding residential, commercial, and agricultural needs. If raw water degraded as it relates to chloride, sodium, sulfate, or TDS in general, the LPRO process had a significantly greater ability to treat a degrading water supply successfully. In fact, this advantage grew even stronger when evaluated with respect to the greater reliance on the UFA as an alternative water supply in the near future.

It should also be noted that raw water quality could degrade to a point that the NF process would not be capable of meeting regulatory standards or allow any possible raw water blending. The LPRO membranes allow the city to utilize the more brackish UFA and begin to phase out aging infrastructure within the plant.

The city selected the LPRO membrane treatment process consisting of pretreatment using sand straining, acidification with sulfuric acid, scale inhibitor addition, and cartridge filtration; membrane process including feed pumping and membrane treatment; and post-treatment including degasification, off-gas odor control, clearwell storage, and transfer pumping. Disinfection was assumed to occur in the existing chlorine contact area with an equal sodium hypochlorite dose and ammonia dose, since the lime-softened water would exert the greatest chlorine demand by far. The pH adjustment would occur after blending the permeate with the lime-softened water.

A membrane pilot study was conducted to determine treatment efficiencies and

Continued on page 20

Continued from page 19
design parameters. The pilot demonstrated that the LPRO treatment was able to treat the raw water successfully, and the pilot study findings were used in the LPRO final design.

A portion of the composite raw water entering the site is pretreated via acidification with sulfuric acid, scale inhibitor, and cartridge filtration. The sulfuric acid is added upstream of the membranes to maintain a permeate water pH at 5.9 or below to achieve adequate removal of hydrogen sulfide in the degasification process. Mixing the sulfuric acid is accomplished by the use of an in-line static mixer, as well as turbulence imparted to the water stream by flow through the downstream cartridge filters.

Following sulfuric acid addition, the chemically adjusted raw water is filtered using 5- micron (µm) cartridge filters. This cartridge filtration step is designed to remove sand, silt, clay, and corrosion debris particles produced from the supply wells. The cartridge filters serve to reduce the Silt Density Index of the feedwater to a value of 3.0 or less. Scale inhibitor addition following the cartridge filters assists in preventing mineral scaling from sulfate salts of calcium, barium, and strontium, as well as calcium carbonate on the membranes.

After pretreatment, the membrane feed pumps pressurize the feedwater and route it to two membrane skids, each with a permeate production capacity of 1.0 million gallons per day. Each skid has a dedicated feed pump and is configured to operate in a two-stage array using seven elements per pressure vessel configuration. Each skid is designed to operate at a permeate water recovery rate of 85 percent.

The permeate stream is degasified for the reduction of hydrogen sulfide with a counter-current removal of excess carbon dioxide. The degasified permeate water, as well as the lime-softened water, is collected in a clearwell for disinfection and pH adjustment. Three transfer pumps, each with a capacity of 1.0 million gallons per day, transfer the blended lime-softening and permeate water to the plant's existing storage tank. Concentrate water is disposed of through the existing sewer collection system to the city's wastewater treatment plant.

Figures 2 through 6 show the LPRO treatment process being constructed at the plant, which came on line in 2008. The project will provide significant benefits to the city and its customers by facilitating the implementation of a long-term water supply and resource management strategy that ensures the conservation of freshwater supplies in the area.

Figure 5 shows the LPRO membranes on the assembly room floor. Each skid will be able to process 1 million gallons of raw water per day at the plant.

Figure 6 shows the bulk chemical storage area. Chemical additions will be used for pH adjustment, disinfection, odor control, and corrosion inhibition throughout the membrane facility.

New Challenges

Along with the exciting possibilities of new technology and improved plant reliability comes the potential for new challenges the city will have to face. *Thiothrix spp* is a sulfur-reducing type of bacteria that occurs naturally in UFA and LSA source water. A distinguishing characteristic of *thiothrix* is its tendency to form long, gelatinous strings when exposed to air and a sulfur source.

While both UFA and LSA water have been used at the St. Augustine plant for years, the lime-softening process was able to remove any bacterial growth through settling. The new LPRO process employed to treat the UFA water to drinking water standards is more susceptible to bacterial growth in pre-filtration equipment and the membranes themselves.

The results of the original LPRO membrane pilot study revealed excessive fouling of the 5-µm cartridge filter located upstream of the membrane. No fouling of the membrane was observed, but the cartridge filters had to be replaced frequently. Based on these find-

Continued on page 22

Continued from page 20
ings, a second pilot study was initiated to test and identify the equipment required to achieve pretreatment water quality levels for the LPRO membranes.

The pilot plant included sand straining and a two-step filtration consisting of a 5-µm cartridge filter followed by a 1-µm cartridge filter. During testing, the pilot equipment consistently experienced plugging of the sand strainer and 5-µm cartridge filter. No plugging of the 1-µm cartridge filter was observed.

Testing of the feed water revealed that the plugging was due to bacteria in the feed water, rather than inorganic material. Operator observation described white stringy masses of bacteria, indicative of the sulfide oxidizing filamentous bacteria *Thiothrix spp*, commonly found in source waters that exhibit elevated levels of sulfide, and experienced increased growth near air-water interfaces.

To determine disinfection removal efficiency, a tap was installed from the nearest available chlorine solution line to the suction side of the pilot booster pump. Also, the sand strainer was cleansed with sodium hypochlorite for several hours and the sand-strained media was replaced with fresh material. The cartridge filter was also replaced to remove any bacteria able to break through the sand strainer.

The pilot study continued to experience plugging, which resulted in abnormally frequent backwashing of the sand strainer and reduced water pressure to the remainder of the treatment process. Physical observation again indicated bacterial matter in the feed water to the pilot plant. As previously indicated, the source of the bacteria at this point is unknown but could be related to elevated sulfide concentrations in the wellfield source water, air-water interfaces in the raw water transmission main, or possible contamination and sediment build-up in the main.

St. Augustine has begun a disinfection pilot study to determine the best means to protect the newly installed plant from this new challenge. Because of the physical constraints of the raw water main, as well as the financial constraints inherent in a project of its size, the city is considering implementation of a field-scale disinfection project to develop a disinfection protocol for the maintenance of the city raw water main.

Techniques in long-term planning have recently been adjusted to incorporate the uncertainty inherent in systems that deal with the natural environment. The development of large-scale pilot programs or demonstration projects is one of the state-of-the-art approaches being embraced by the planning community to move forward with complicated projects in the face of uncertainty. St. Augustine has the opportunity to embark on a field-scale demonstration project to answer key questions regarding raw water quality while taking the necessary steps to protect the new LPRO membrane facility addition at the city water plant.

The proposed demonstration project will determine the factors contributing to biogrowth in the raw water main and identify the potential avenues to control that growth. The basis of the protocol will be collecting sufficient information to answer key uncertainties to develop the full-scale disinfection program. The design will include a recommendation for disinfection technology, dosing, necessary equipment, permit requirements, disposition of test water, and alternative water supply for the plant.

Conclusion

While the recent change in source water from the LSA to the UFA in Northeast Florida represents an exciting shift in the traditional water supply paradigm, municipal water treatment plants will have to address the implementation of new technology as well as the threat of new challenges to make the adjustment a success.