Operation and Maintenance Comparative Assessment of Colocated Nanofiltration, Lime Softening, and Low-Pressure Reverse Osmosis Systems at the Norwood Water Treatment Plant

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The Norwood Water Treatment Plant (WTP), owned by NMB Water, is located in southeast Florida and provides potable water service to more than 180,000 residents. The plant has a permitted capacity of 32 mil gal per day (mgd), which includes a 15-mgd lime softening system, a 10.5-mgd nanofiltration (NF) system, and a 6.5-mgd low-pressure reverse osmosis (RO) system. All three treatment processes are simultaneously operated at various production flow rates, including variations to their integral bypass/blend systems, in order to meet water demands of approximately 20 mgd average daily demand (ADD). Production rates also must comply with the South Florida Water Management District consumptive use permit, which requires a minimum utilization of the RO system.

The WTP currently uses the following chemicals as part of the treatment process:

- Sulfuric acid, for NF and RO pretreatment.
- Scale inhibitor, for RO pretreatment.
- Sodium hypochlorite, for disinfection of treated water and also for the scrubber.
- Ammonia, to form chloramines for disinfection.
- Polymer, a flocculant aid for lime softening.
- Lime, for softening.
- Carbon dioxide, for pH adjustment on the lime softening system.
- Ortho/polyphosphate blend, a sequestrant for filter media protection and a corrosion inhibitor.
- Fluoride, for dental health.
- Sodium hydroxide, for pH adjustment of the NF and RO degasified water and also for the scrubber.

The membrane process building, which contains both NF and RO, completed an expansion in early 2020, increasing its capacity by 9 mgd and resulting in the plant's total capacity increase from 32 to 41 mgd.

The scope of the work included the addition of the following components:

- Interstage booster pump and expansion of three existing NF skids from 3 to 3.5 mgd.
- A fourth 3.5-mgd NF membrane skid within the existing building.
- One new NF feed pump and sand separator for increased redundancy.
- 18 new pressure vessels on each existing RO skid and upgrades to the existing turbochargers to expand permeate production capacity from 2 to 3 mgd for each skid.

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- Replacement of all NF and RO membrane elements.
- Flow meters and interconnection between the NF and RO blends to the degasifiers for increased degasifier system flexibility.
- The RO and NF membrane bypass-rated capacity increased accordingly with the permeate production increase.

Due to this expansion project and historical cost increases to the various components of the water treatment plant operations, a comparative study on cost, efficiency, maintenance, and water quality was carried out. Results from this study will help the utility in identifying best operation and maintenance (O&M) practices and plantwide system operation strategy optimization. This study will also help facilitate in projecting O&M budgets, recognizing plantwide process cost differentiators, and prioritizing capital improvement projects.

Cost Comparison Methodology

The method used to assess economic and operational feasibility focused on chemical use, energy consumption, cost of expendables, and disposal of waste streams, such as wet lime sludge, evaluation of operator personnel utilization, and maintenance efforts. The study focused on a nine-month evaluation of economic, operational, and water quality impact trends—from December 2018 to August 2019. Maintenance and personnel work efforts were quantified by analyzing work order requests for various treatment processes within the plant and comparing corrective and preventative maintenance work schedules at each treatment unit system. Water quality parameters were also monitored, and any treatment process flow anomaly events were documented.

Chemical cost was determined twofold: the chemical used during each month was calculated by tank fill levels and deliveries, as well as calculated pounds used per month based on average monthly dose and flow per the monthly operational reports (MORs), as viewed in Equation 1. Chemical cost was expressed either by total cost per chemical per month, and by chemical cost per 1,000 gal, normalized by production flow, for all three treatment systems (NF, RO, and lime softening).

Equation 1:

$$\frac{Average\ Dose\left(\frac{mg}{L}\right) * Flow(MGD) * 8.345}{Active\ Chemical\ Concentration\ (\%, decimal)}$$

$$= Daily\ Usage\ (ppd)$$

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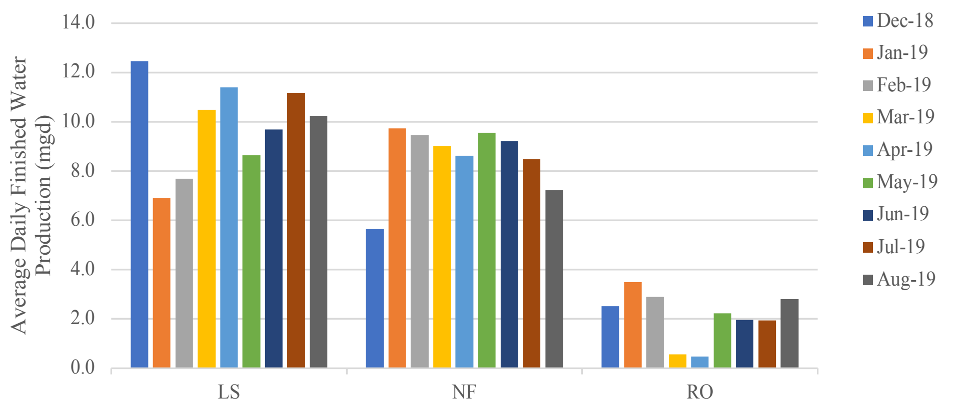

Figure 1. Average Daily Finished Water Production per Treatment System

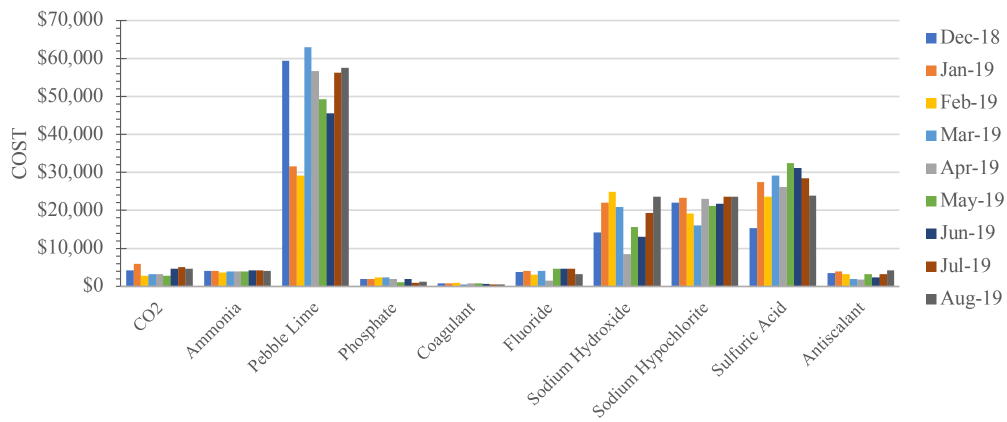

Figure 2. Cost per Chemical

Table 1. Chemical Cost per Treatment Unit			
Treatment Units	NF	RO	Lime
$/1000 gal (avg)	$0.19	$0.17	$0.23

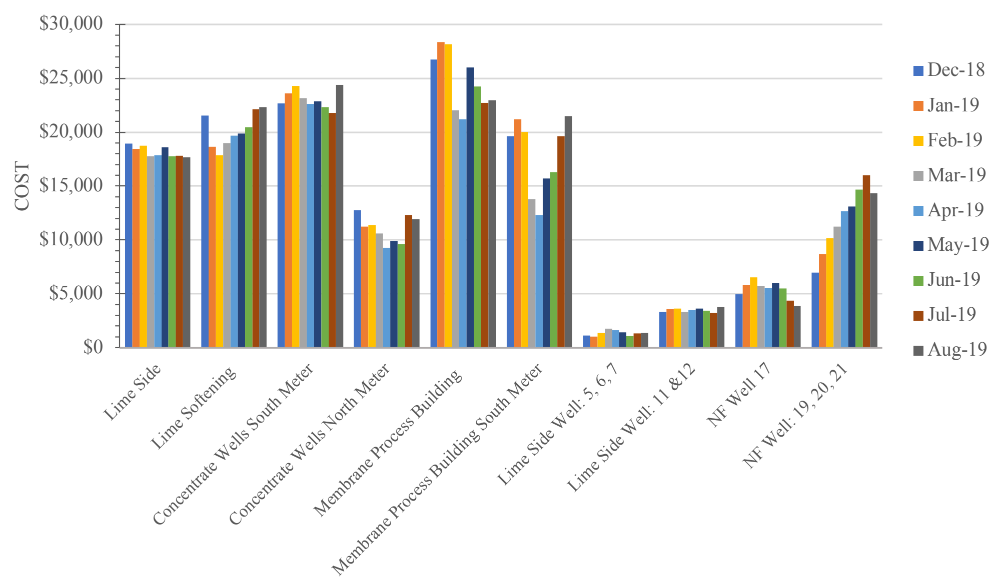

Figure 3. Cost per Power Meter

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Energy cost was calculated by analyzing the power load of water pumps and air blowers associated with each treatment system. This analysis excluded power loads that were assumed to be applied equally to all three treatment systems, including power use associated with air conditioning/ventilation, chemical pumps, lighting, and other miscellaneous smaller loads.

Equation 2 illustrates how the power load was calculated. Furthermore, the monthly electrical bill for the plant was used for comparison and confirmation of calculation results. Any monthly operational variations that contributed to energy fluxes were documented.

Equation 2:

$$\frac{0.7457 * \ Flow\ (MGD) * Dynamic\ Head(ft)}{3960 * Efficiency\ (\%, decimal)}$$

$$= \ Power\ Load\ (kW - h)$$

Preventative and corrective maintenance efforts of the lime treatment system and membrane treatment systems (NF and RO combined) were evaluated. A maintenance management software (Maintenance Connection, utilized at the WTP) tracks and schedules regular plant maintenance, equipment failures, allocated personnel, and financial resources. Finished water quality parameters were also tracked to ensure ongoing compliance and to identify any improvements due to system utilization variations.

Results and Discussion

Average daily finished water production for each treatment system during each month of this study is presented in Figure 1 and monthly total cost for each chemical is presented in Figure 2. As expected, pebble lime for the softening process in clarifiers contributed to an average of 37 percent of the total chemical budget cost due to large quantities needed to maintain a pH of 10.2 in the clarifiers. Pebble lime cost consumption is responsible for the high operation cost in the lime side.

Sulfuric acid use in both NF and RO pretreatment was the second most costly chemical, making up 20 percent of the total cost, on average, followed by sodium hypochlorite (16 percent) and hydroxide (14 percent). Polymer and phosphate had insignificant cost impact to the total chemical expenses of the plant.

Cost deviations contributed to flow fluctuations between treatment unit processes; for example, the RO treatment unit was out of service for a month during the trial, or lime flow production was reduced and NF flow increased from historical operations practices. Additionally, equipment failure or malfunctions also supported monthly cost differences. These events provided useful insight in comparing membrane technology cost versus conventional lime treatment cost.

When comparing normalized chemical cost between treatment systems, as displayed in Table 1, it was concluded that the RO had the least chemical expenses, followed by NF. A key differentiator between NF and RO chemical use is the amount of sulfuric acid added as pretreatment for both, with RO requiring a significantly lower dosage. As previously mentioned, due to the high cost of the pebble lime required, the lime softening treatment system had the highest chemical cost per 1,000 gal.

The WTP has several electrical power meters that monitor power use for different sections of the plant. The monthly cost per each power meter provided by the electrical bill is presented in Figure 3. Both Figure 3 and the calculated individual pump/blower power use by the system show the membrane-related items yielding the highest energy cost. The difference can be attributed to the relatively higher pressure boost required to feed the membranes. Furthermore, membrane wells also had a higher power requirement than the lime side wells due to their higher discharge head.

Table 2 concludes that, with respect to energy consumption and cost, the lime softening treatment system is the most economical, with 0.116 cent per 1,000 gal. As predicted, RO had the highest energy cost due to its higher feed pressure of approximately 200 pounds per sq in. (psi), as compared to about 110 psi for NF. It's important to highlight that only the power load of water pumps and air blowers associated with each treatment system were considered. This analysis excluded power loads that were assumed to be applied equally to all three treatment systems, including power use associated with air conditioning/ventilation, chemical pumps, lighting, and other miscellaneous smaller loads.

Table 3 presents a comparison of the overall production cost of the treatment systems, including the sum of chemical, energy (with exclusions previously noted), and expendables, and waste disposal costs. Results indicate that the water production costs associated with the NF and lime softening systems are the lowest, with insignificant differences between them. The cost for disposal of wet sludge associated with the lime softening system had a significant impact in the results of this analysis.

Norwood currently has a contractor that hauls wet sludge (total suspended solids [TSS] of approximately 20 to 25 percent). The costs for sludge disposal are projected to continue to rise for this utility. Some chemical and energy cost reductions are anticipated after completion of the membrane expansion and improvement project.

Preventative and corrective maintenance are essential to the effective operation of the plant.

Table 2. Energy Cost per Treatment Unit

Treatment Units	NF	RO	Lime
$/1,000 gal (avg)	$0.208	$0.296	$0.116

Table 3. Total Cost per Treatment Unit

Treatment Units	NF	RO	Lime
$/1,000 gal (avg)	$0.400	$0.467	$0.413

Note: Wet lime sludge disposal and diesel are accounted in the total cost.

Table 4. Average Finished Water Quality

Finish Water	Average	STD
pH	9.16	0.07
Turbidity	0.16	0.03
Color	8	0.71
Fluoride	0.61	0.12
Alkalinity	56	2.42
Hardness	64	2.29
CL_2 Residual – Norwood	3.9	0.05
CL_2 Residual – Golden Beach	3.2	0.22

When comparing the daily efforts and personnel utilization on the membrane systems versus the lime system, Norwood maintenance staff spent 10 percent more labor and material cost on servicing the lime system. The highest contributors on the lime side include gravity filters, lime slaker and clarifiers pumps, and motors failure and/or routine maintenance. It's important to point out that the lime side was constructed during the 1960s, while the membrane systems were constructed in 2008 and are currently being upgraded.

No significant water quality variation was noted from varying production flow rates in all three treatment processes, as shown in Table 4.

Conclusion and Recommendations

This article presents results on the treatment process and production costs, focusing on chemical use, energy consumption, cost of expendables, labor, and material maintenance efforts. Furthermore, the information presented aims at providing further insight to the industry's debate over the performance and cost of lime softening compared to NF and low-pressure RO technologies.

Overall, at the WTP, NF and lime softening production costs were about the same, and low-pressure RO was approximately 17 percent more expensive to operate. During the nine months of this study, the water marginal production cost—including chemicals, energy, and expendables—was estimated and ranked as follows:

1. NF: $0.40 per 1000 gal
2. Lime softening: $0.41 per 1000 gal
3. Low-pressure RO: $0.47 per 1000 gal

The results obtained from this study will give NMB Water a better understanding of how to optimize utilization of its treatment systems. A few areas of improvement that have been identified due to the evaluation are the potential reduction/optimization of sodium hydroxide and sulfuric acids doses, thus reducing the chemical cost of the membranes. Additionally, some reduction of sludge disposal cost may be obtained by further increasing the efficiency of the sludge thickener.

This study provided other benefits, such as identifying ways to reduce O&M costs and accurately predict O&M plant budgets. This information will also aid in decision making for resource allocation and for future capital expenditures, such as whether to further invest in lime softening compared to expanding membrane systems within the plant.

The WTP plans to continue tracking and evaluating comparative assessment of all three treatment systems, especially considering the recent expansion of the membrane systems and planned rehabilitation of the lime softening system.