Using Concentrate as a Feed Water to Clearwater's New Reverse Osmosis Water Treatment Plant

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The City of Clearwater (City) provides approximately 11 mil gal per day (mgd) of potable water to over 120,000 customers within the City's distribution system. The City treats approximately 4.95 mgd of Floridan Aquifer groundwater and bulk-purchases approximately 6.37 mgd of water provided by the regional water supply system through seven interconnections.

In order to increase local water production to better control quality and cost of water, the City intends to improve and expand its existing potable water system with a drought-resistant water supply. Current plans include the expansion of the reverse osmosis (RO) water treatment plant 1 (WTP 1) and upgrading the existing reverse osmosis water treatment plant 2 (WTP 2) with a brackish reverse osmosis plant. The WTP 1 is supplied by brackish groundwater wells, while WTP 2 treats fresh groundwater blended with potable water from Pinellas County. Additionally, the City is exploring the feasibility of indirect potable reuse for groundwater replenishment.

The WTP 1 currently produces approximately 3 mgd of potable water, resulting in 0.5 mgd of concentrate. The RO system treats slightly brackish water with total dissolved solids (TDS) of around 700 mg/L. The concentrate has approximately 3,000 mg/L TDS and is discharged into the City's sanitary sewer. The design of the WTP 1 expansion is underway to increase its capacity to around 4.5 mgd (3.0 of RO capacity). The capacity increase will result in a concentrate flow of 0.75 mgd; however, limits set by the City's industrial pretreatment program, which regulates pollutants discharged into the municipal sewer system, will require that the concentrate be disposed of by another means due to the increase in flow.

The City also plans on substantially expanding the treatment capabilities of WTP 2. The upgraded plant will produce 6.25 mgd of finished water by blending 1 mgd of treated fresh groundwater and 5.25 mgd of RO treated brackish water. Air and chlorine will be added to the fresh water to oxidize iron present in the freshwater, and the aerated/chlorinated water will be filtered via multimedia pressure filters. The filtrate from these filters will be mixed with 5.25 mgd of RO permeate from a new membrane system that will be fed by 12 new brackish wells distributed throughout the City. With an expected 80 percent recovery rate, this will result in 1.3 mgd of concentrate, which will be disposed of via a new deep injection well.

Figure 1. Reverse Osmosis Pilot Skid

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Since WTP 1 will no longer be able to discharge its concentrate flow to the sanitary sewer, other disposal means were evaluated. Options considered included construction of a deep injection well at WTP 1, piping the concentrate through 3.5 mi of transmission mains to the WTP 2 deep injection well, or piping the concentrate to WTP 2, blending it with raw brackish water and treating the blended stream through the RO system.

The third option has the added benefit of reducing the demand on the brackish wells, conserving limited groundwater resources as well as reducing the amount of byproduct water. This is also an innovative application, as no other RO plant in Florida currently treats the concentrate produced at another membrane facility blended with a raw water source.

Due to the innovative approach being considered, the Florida Department of Environmental Protection (FDEP) was approached with the concept of treating the RO concentrate from one plant at another RO facility. The FDEP was presented with the projected flow and basic water quality data and was open to the treatment concept, as long as the technical feasibility for RO membrane treatment of

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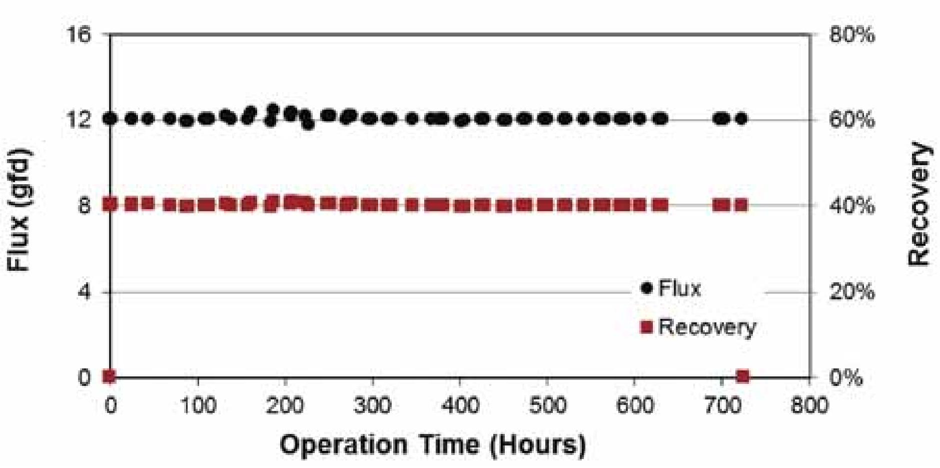

Figure 2. Pilot Flux and Recovery Over Time

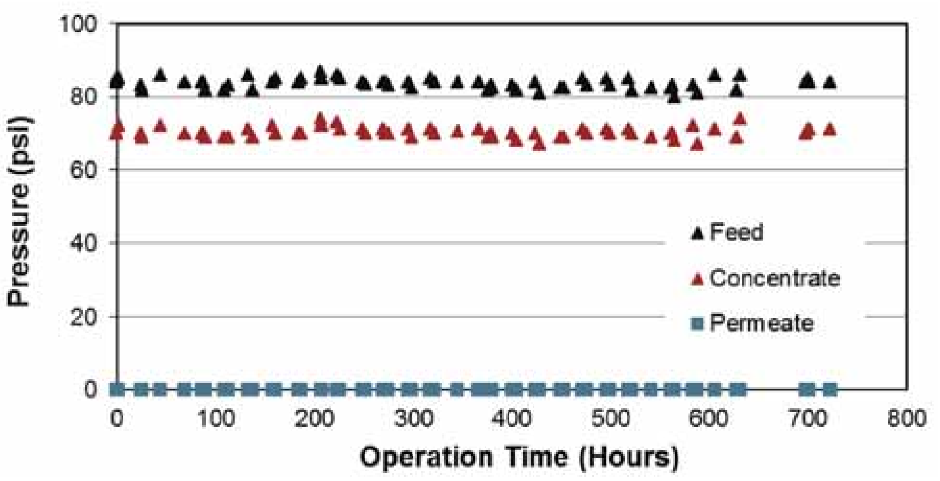

Figure 3. Pilot Feed, Concentrate, and Permeate Pressures Over Time

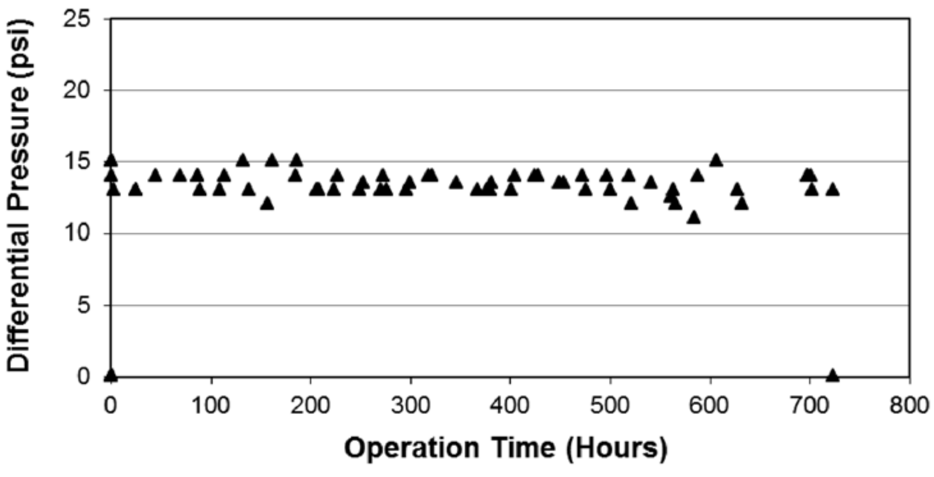

Figure 4. Pilot Feed-Side Pressure Differential Over Time

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WTP 1 concentrate was evaluated through a pilot study. While testing the blended water would be preferred, the more conservative approach of piloting just the WTP 1 concentrate was selected, as the new brackish well field transmission piping was not completed. It is important to note that a pilot study cannot mimic the exact reality and operating conditions of a full-size plant, but can be a useful resource for determining the technical possibility and design characteristics for treating a new water source.

Pilot Study

Methods and Results

The concentrate pilot study equipment consisted of a skid-mounted membrane unit (Figure 1) located at WTP 1 near the RO facilities. The unit was operated in a single-stage configuration with two vessels in parallel, each containing seven membrane elements, to treat the concentrate from the plant. The elements tested were Toray TMG10, which are each 4 in. in diameter and 40 in. long. Three cartridge filters capable of removing 5 µm or larger particles were used to protect the membranes from unexpected turbidity spikes. A high pressure feed pump and control valves were used to maintain the flows and pressure needed for consistent operation. The unit was also equipped with an instrumentation package and sample taps that allowed for detailed on-site measurement of the flow, pressure, conductivity, temperature, and turbidity for the feed, permeate, and concentrate streams. Samples for additional critical parameters in a RO system, such as alkalinity, chloride, hardness, silica dioxide, and total organic carbon were collected and analyzed by a local laboratory.

The pilot was operated 24 hours a day for approximately 30 days (724 hours), with intermittent outages due to power loss or maintenance on WTP 1. No additional antiscalant or acid was added to the concentrate from WTP 1, as there was an adequate residual of antiscalant in the concentrate. Operating conditions for the skid included a system flux of 12.1 gfd and a recovery of 40 percent, both of which remained constant through the study, as shown in Figure 2. The recovery of 40 percent was the highest recovery possible due to elevated levels of silica in the concentrate, which has a high potential of fouling or damaging the membranes. The feed flow of 21.9 gpm was split between the permeate at 8.8 gpm and the concentrate at 13.1 gpm, with an average feed pressure of 84 psi (Figure 3).

Productivity Performance

A membrane system may experience a decline in productivity over time due to the deposition of foulants, such as particles, precipitates, or biological material onto the membrane surface. Productivity is defined as the amount of treated water produced at a given pressure, and can be presented as a normalized permeate flow or water mass transfer coefficient (MTC). Fouling is evidenced by a decline in the MTC or an increase in pressure differential along the feed side of the membrane at constant recovery and flow rates. A decline in productivity indicates fouling has occurred, and requires a chemical cleaning to restore membrane performance. A chemical cleaning is typically performed following a 15 to 20 percent decline in the MTC, or a 25 percent increase in feed-side pressure differential. The chemical cleaning frequency goal for a groundwater source is typically once every six months. Therefore, MTC, differential pressure, and water quality were evaluated to determine if fouling would be an issue.

Feed-Side Pressure Differential

The feed-side pressure differential did not increase during the entire testing period, as shown in Figure 4. These results show that particle plugging or precipitation did not occur while treating the raw concentrate.

Normalized Mass Transfer Coefficient

The normalized MTC was also constant over the entire testing period, as shown in Figure 5. This constant value means that no fouling occurred and further supports that treatment of the concentrate is feasible without pH adjustment or the addition of more antiscalant.

Water Quality

Water quality samples were taken on a daily, weekly, and monthly basis, depending on the constituents being measured. Conductivity, pH, and turbidity were monitored daily on the pilot feed, permeate, and concentrate waters. Feed conductivity was consistently between 3,900 and 4,280 µS, which equates to 2,460 to 2,700 mg/L TDS. Permeate and concentrate conductivities were also consistent, with averages of 64 µS (40 mg/L TDS) and 6,508 µS (4,100 mg/L TDS), respectively. Figure 6 shows the TDS concentrations of the flows over the testing period. The pilot feed, permeate, and concentrate flows maintained consistent pH values of around 7.5, 5.7, and 7.7, respectively. Turbidity was relatively consistent as well, with av-

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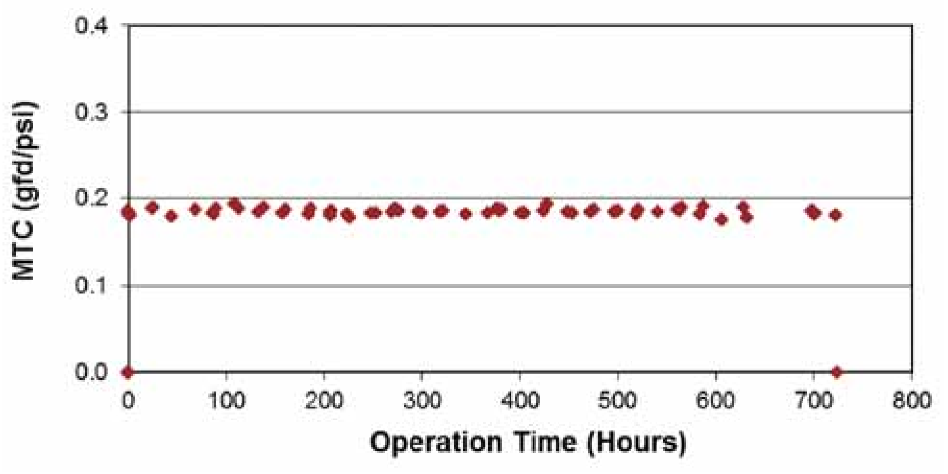

Figure 5. Pilot Normalized Mass Transfer Coefficient Over Time

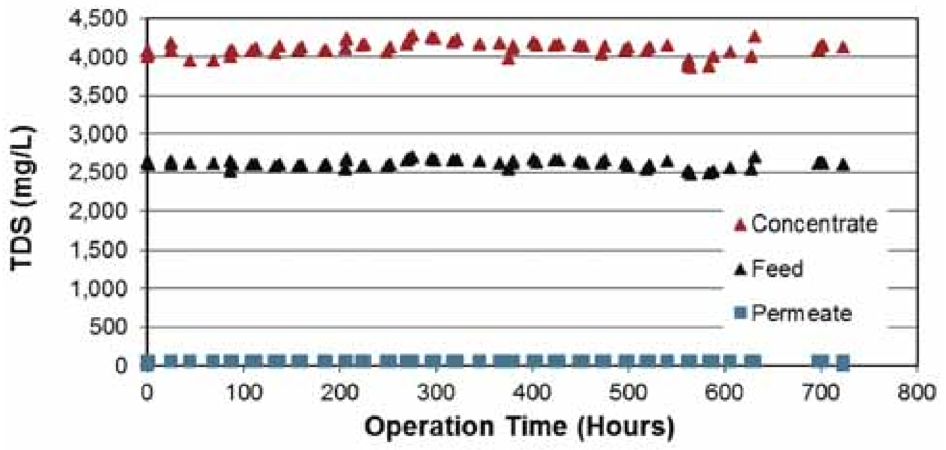

Figure 6. Pilot Feed, Permeate, and Concentrate Total Dissolved Solids Over Time

Table 1. Pilot Average Water Quality

Constituent	Unit	Pilot Feed (RO WTP 1 Concentrate)	Pilot Permeate	Pilot Concentrate
Total Dissolved Solids	mg/L	2,600	40	4,100
pH	Units	7.5	5.7	7.7
Turbidity	NTU	0.18	0.11	0.24
Alkalinity, total	mg/L as $CaCO_3$	845	10	1,400
Hardness, total	mg/L as $CaCO_3$	1,372	1.14	2,417
Chloride	mg/L	850	10.5	1,300
Iron, total	mg/L	0.055	0.027	0.085
Silica Dioxide	mg/L	160	0.34	310
Total Organic Carbon	mg/L	10	< 0.5	17

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erages of 0.18 NTU, 0.11 NTU, and 0.24 NTU, respectively.

Samples were also collected on a regular basis from the pilot feed, permeate, and concentrate, and brought to a local laboratory for measure of several constituents, including alkalinity, hardness, chloride, silica dioxide, iron, and total organic carbon. Table 1 summarizes average results from these tests. These water quality results, combined with the fact that the membranes did not foul, indicate that additional recovery of the WTP 1 concentrate is technically feasible.

Full-Scale Plant

At the full-scale WTP 2 plant, the feed water for the RO facilities will consist of approximately 88 percent (5.80 mgd) new brackish groundwater and 12 percent (0.76 mgd) concentrate from WTP 1. The blended feed water quality was projected by using the weighted average of the pilot feed water quality and the concentrations measured during core hole drilling for the new well field. The results of this projection are shown in Table 2 and were assessed for fouling potential using antiscalant modeling programs.

Table 2. Water Treatment Plant 2 Blended Feed Water Quality

Constituent	Unit	Blended Feed Water
Total Dissolved Solids	mg/L	976
Alkalinity, total	mg/L as $CaCO_3$	213
Hardness, total	mg/L as $CaCO_3$	410
Chloride	mg/L	371
Iron, total	mg/L	0.12
Silica Dioxide	mg/L	39
Total Organic Carbon	mg/L	2.26

After running the projected water quality through antiscalant modeling programs, it was determined that the maximum recovery was 83 percent, due to the high silica dioxide concentration. A second pilot used to test the raw groundwater found that treating the raw water at 80 percent was feasible. Therefore, it is reasonable to conclude that the treatment of the raw brackish water and concentrate blend is feasible at 80 percent recovery, as long as silica fouling is controlled with proper antiscalant dosing.

Since the pilot concluded that the treatment of the WTP 1 concentrate was technically feasible, the blend and treatment option was compared to other options available for the disposal of the concentrate. The options evaluated were constructing a new deep injection at WTP 1, piping the concentrate to the WTP 2 deep injection well, and piping the concentrate to WTP 2 and treating it through the RO facilities blended with the raw brackish water, with final disposal of the remaining concentrate into the WTP 2 deep injection well. Table 3 summarizes the advantages and disadvantage of these options.

Table 3. Comparison of Water Treatment Plant 1 Concentrate Disposal Options

New Deep Injection Well at Water Treatment Plant 1	
Advantages • Reduced piping and less construction • Dedicated disposal well • WTP 2 operation does not rely on WTP 1 operation	Disadvantages • Deep well cost • Complicated and extension permitting process • More waste (0.76 + 1.3 = 2.06 mgd total) • More demand on groundwater resources for WTP 2 feed supply
Piping Concentrate to Deep Injection Well at Water Treatment Plant 2	
Advantages • No need for second disposal well • Less cost than new disposal well at WTP 1	Disadvantages • Concentrate pipeline cost (3.5 mi of piping) • More waste (0.76 + 1.3 = 2.06 mgd total) • More demand on groundwater resources for WTP 2 feed supply • WTP 2 operation reliance on WTP 1 operation
Piping Concentrate to RO Facilities at Water Treatment Plant 2	
Advantages • Resource conservation • Reduced waste (0.76 mgd) • Less demand on groundwater resources for WTP 2 feed supply • No need for second disposal well	Disadvantages • Concentrate pipeline cost (3.5 mi of piping) • Slightly increased operational/energy costs due to higher feed TDS at WTP 2 • Silica fouling needs to be controlled and monitored closely • WTP 2 operation reliance on WTP 1 operation

The final decision was made to blend the full concentrate flow with raw brackish water for further treatment in the WTP 2 reverse osmosis facilities. Under the circumstances, where WTP 2 was offline or the concentrate flow or water quality characteristics change, the concentrate from WTP 1 can be sent directly to the deep injection well for disposal.

Conclusions

The pilot test of the WTP 1 concentrate found that it could be further treated without significant fouling of the membranes. When blended with raw brackish groundwater, the projected water quality was found to be acceptable for reverse osmosis treatment at 80 percent recovery. Using the concentrate as part of the feed for the RO facilities reduces the amount of concentrate sent to the deep injection well and the amount of groundwater needed to run WTP 2, thus conserving the limited groundwater sources of the area. This innovative treatment concept also eliminates the need for a new deep injection well at WTP 1. These benefits were found to outweigh the drawback of slightly increased operational costs at the new RO plan, and a system is being designed that will allow for treatment of the concentrate blend, while also maintaining the option for direct disposal.