Direct Potable Reuse as a Tool for Revitalizing Brackish Groundwater Desalination Facilities: Water Quality and Operations

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Florida is a global leader for brackish groundwater desalination, with more than 70 major (i.e., capacity over 1 mil gal per day [mgd]) municipal brackish groundwater reverse osmosis (RO) water treatment plants (WTPs) online as of 2019. Brackish groundwater desalination has proven its value as a critical alternative water supply, meeting pressing water supply needs; however, many utilities have experienced challenges from wells with declining groundwater quality in the form of increasing salinity, measured as total dissolved solids (TDS). Rising groundwater salinity can be a costly problem for municipal utilities with RO WTPs, resulting in the following negative consequences:

- Increased feed pump pressures resulting in higher power costs.
- Decreased water production capacity.
- Increased water purchases from neighboring utilities.
- Stranded assets when the TDS exceeds safe limits of equipment, resulting in need of equipment repair or replacement.
- Additional post-treatment chemical costs when bypass blending becomes unfeasible due to high chlorides.
- Overdesign costs when RO WTPs are designed conservatively with high-pressure rated equipment due to uncertainty about future increases in groundwater salinity.
- Subsequent changes to blending ratios and corrosion chemistry in distribution systems.

Besides brackish groundwater desalination, Florida has also been a leader in potable reuse, with at least 12 utilities conducting pilots or demonstrations since 2000. While many of these projects focused on indirect potable reuse (IPR), utilities are increasingly viewing direct potable reuse (DPR) as a potentially viable alternative water supply. While stable, low-salinity, and permittable brackish groundwater supplies are increasingly challenging to find, many parts of the state have excess reclaimed water that is not being utilized (FDEP, 2015). Reclaimed water is a "drought-proof" water supply, with TDS typically less than 1,000 mg/L. In contrast, the TDS of brackish groundwater wells frequently ranges from about 2,000 to 10,000 mg/L.

This article includes a review of municipal brackish desalination in Florida and a discussion of the impacts that declining groundwater quality can have on water production. It discusses a concept of blending highly treated reclaimed water directly into the feed of an existing brackish groundwater RO WTP.

It also includes an assessment of operating costs and capital improvements required for two approaches to maintain plant production in the face of increasing groundwater salinity. The first approach to maintain plant production is to retrofit the RO WTP to handle the higher salinity and corresponding increases in feed pressure. The alternative approach is to retrofit the facility to process lower-salinity reclaimed water.

Increasing groundwater salinity is a common challenge for many facilities, but it has varying consequences depending on the change in salinity and how drastically the changes happen. Figure 1 shows data from different utilities in Florida and how their groundwater salinity has changed over time. The typical TDS of reclaimed water (usually below 1,000 mg/L)

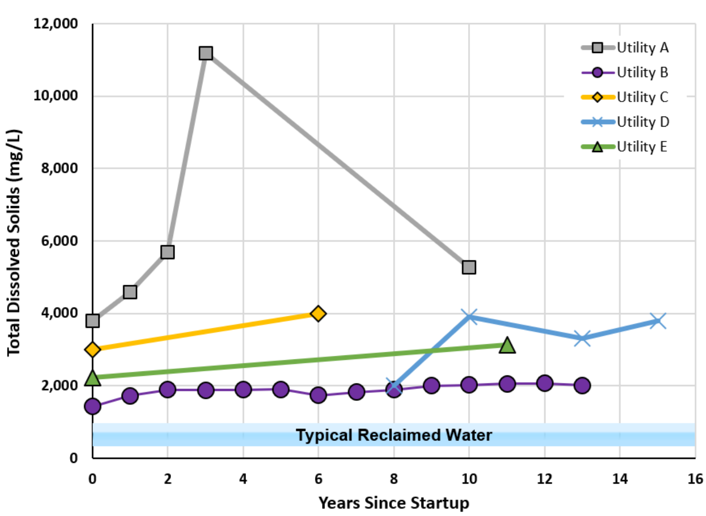

Figure 1. Changes in groundwater salinity over time for several desalinization facilities, compared with the typical total dissolved solids of reclaimed water.

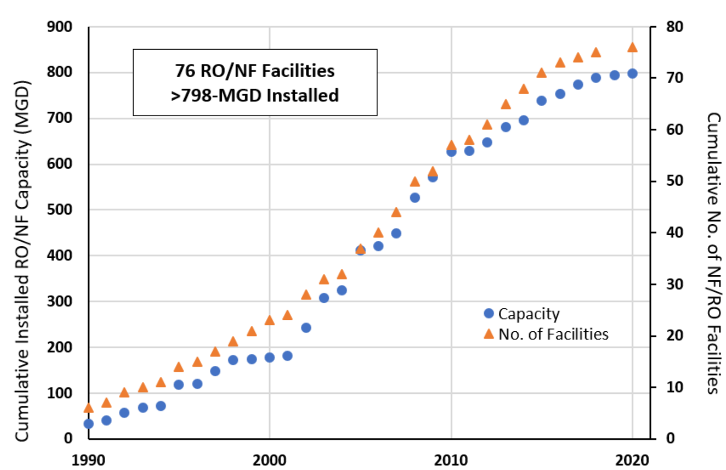

Figure 2. The application of reverse osmosis in Florida for municipal water treatment has increased rapidly.

is also shown on Figure 1. While most brackish groundwater desalination facilities in Florida have performed well, a number of utilities have observed that their desalination facilities have experienced rapid increases in source water salinity. For those utilities, and others contemplating their alternative water supply options, adapting brackish water RO WTPs for DPR could be a cost-effective solution for communities looking to get the most from past investments in alternative water supplies.

With the adoption of Florida Senate Bill 712 in 2020, the Florida Department of Environmental Protection (FDEP) is mandated to begin the development of regulations allowing DPR in Florida. When this rule is finalized, DPR will be an allowable alternative water supply.

Under what conditions might a utility decide to consider DPR as an alternative water supply? Two reasons stand out that suggest DPR at existing brackish groundwater desalination plants may be one of the first approaches for DPR implementation in Florida: water quality and economics.

For water quality, with high-rejection RO membranes, brackish RO facilities are already well-equipped to remove contaminants of emerging concern (CECs) from reclaimed water, safeguarding confidence in treatment and protecting public health. With respect to economics, alternative water supplies represent a major financial investment for a municipality. Where particular brackish RO facilities are constricted by increasingly saline groundwater, use of low-salinity reclaimed water as a supply can increase water supply certainty over the long term, while avoiding the risk and expense of new well construction and high-pressure treatment retrofits.

Brackish Water Desalination in Florida

The past several decades have led to extraordinary progress and innovation in the RO membrane technology market. As such, membrane-based technology has transitioned from being thought of as an emerging technology to mainstream technology, and the cost of membrane elements has steadily declined. A 2010 paper on brackish RO in Florida (Robert, 2010) showed that membrane costs had steadily declined since 1980. As of 2019, the authors found that this trend has continued, with the real unit price of membrane elements decreasing steadily by nearly 50 percent every seven years, with a current unit price of about $1.00 per sq ft of active membrane area. At a typical flux of 15 gal per sq ft per day (gfd), the unit cost of membrane elements for treatment is only about $0.07 per gal per day (gpd) of treatment capacity.

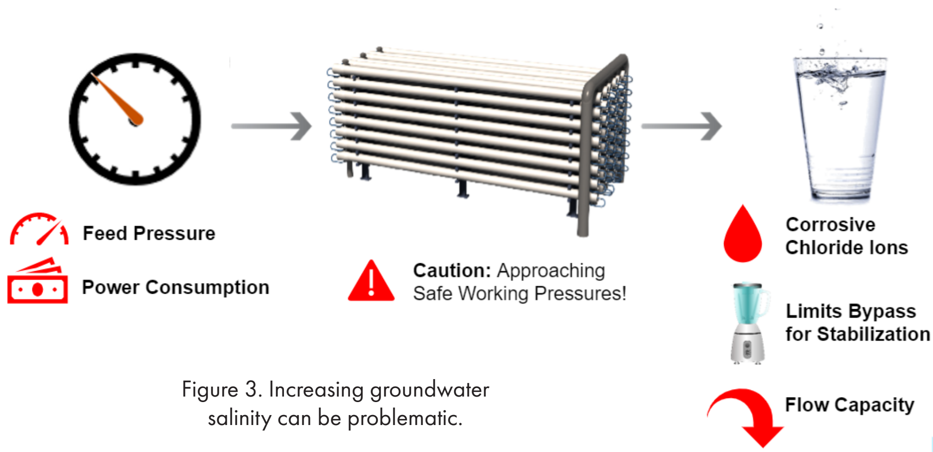

Figure 3. Increasing groundwater salinity can be problematic.

This is meaningful to many utilities that utilize brackish water membranes for drinking water treatment and may present opportunities for utilities that wish to replace existing membranes to utilize the latest, more-energy-efficient membrane products. The increase in production of membrane elements, coupled with improvements in technology and manufacturing automation, have all driven the prices of membranes lower; however, the overall cost of membrane treatment systems (i.e., pumps, piping, electrical, etc.) has not necessarily declined.

The application of membrane-based treatment in Florida has grown steadily over the past 30 years, as shown in Figure 2. Currently, Florida has 76 membrane-based drinking water facilities with a capacity greater than 1 mgd (FDEP Monthly Operating Report Database). In total, these facilities have an installed drinking water production capacity of nearly 800 mgd.

Challenges in Water Supply and Water Availability

While most brackish groundwater supplies in Florida have held steady over time, several facilities in the state have observed increases in groundwater salinity. Typically, increases in groundwater salinity occur due to landward intrusion of seawater, or upconing of water from underlying, more-saline aquifer layers. When groundwater salinity increases, the most significant consequence for RO WTPs is an increase in osmotic pressure of the groundwater that makes it more costly to treat. If feed pressures are maintained, production will decline; if water production is maintained, then feed pressures must be increased. The rate of increase in groundwater salinity is highly dependent on local hydrogeologic conditions.

Rising groundwater salinity can be a costly problem for RO WTPs in several forms, as summarized in Figure 3. Higher salinity can lead to increased feed pump pressures (higher power consumption), additional post-treatment chemical costs (when bypass blending becomes unfeasible), stranded assets when production capacity is decreased to stay within safe pressure limits, and overdesign costs when RO WTPs are designed conservatively with high-pressure rated equipment due to uncertainty about future increases in groundwater salinity.

When groundwater salinity increases, the practical production capacity of the RO WTP may decrease due to limitations in feed pumping pressure. Retrofitting the RO WTP with new, higher-pressure feed pumps may be required. Furthermore, several other areas of the plant may also be impacted as a result of treating higher-salinity water. For example, installing larger feed pumps may require upgrades to motors, variable frequency drives, and associated electrical equipment. Pump materials, fittings, and associated piping may need to be upgraded to withstand the high corrosivity of increasingly saline groundwater. The pressure rating of the membrane housings (typically fiberglass reinforced) would need to be checked against the higher feed pumping pressure. If new membrane housings are required to withstand the pressure, the membrane support rack may also require structural upgrades.

A common practice for RO WTPs is to bypass a portion of the raw or pretreated water around the RO system and blend it with permeate, thus improving finished water stability and minimizing operating costs; however, increasing salinity in brackish groundwater typically corresponds with increased chlorides. This can necessitate additional post-treatment stabilization and

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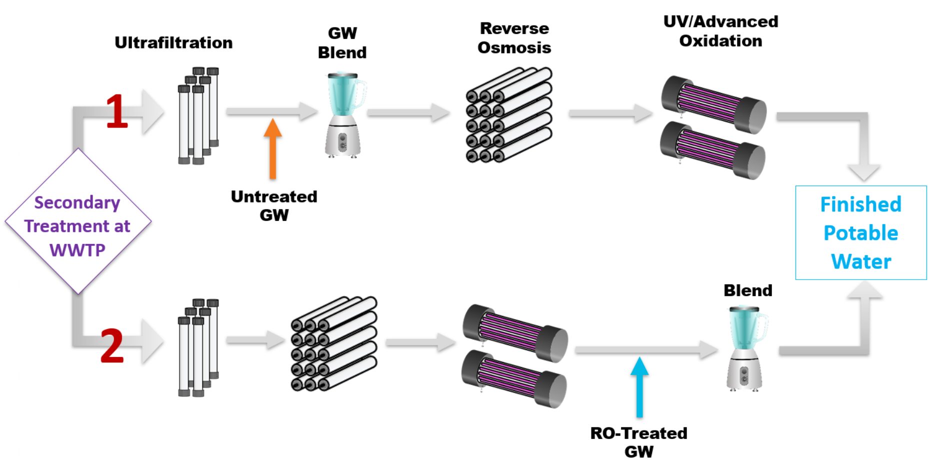
limit opportunities for bypass blending. Without post-treatment stabilization through calcium addition and pH adjustment, elevated chlorides can result in more-corrosive water, with potential impacts to lead and copper corrosion compliance and aesthetic effects from water discoloration caused by iron pipe corrosion.

Benefits of Source Water Augmentation With Reclaimed Water

Instead of expending time and capital to retrofit an existing RO facility or construct new brackish supply wells with uncertain water quality and production capacity, source water augmentation with reclaimed water can allow a utility to restore underperforming RO skids to beneficial use. As mentioned, reclaimed water is a reliable, "drought-proof" water supply. Many utilities have excess reclaimed water supply that is currently not being utilized for irrigation or other beneficial purposes.

For existing RO WTPs dealing with increasing groundwater salinity, blending reclaimed water into the RO feed could provide several benefits. Most notably, a WTP may be able to recover lost production capacity by treating water with a lower salinity and lower required feed pressure. Reclaimed water is a secure and stable water source and less prone to increases in salinity over time.

While the TDS of reclaimed water is relatively stable and low, one limitation of reclaimed water is the day-to-day variation in reclaimed flows that, absent storage, require immediate use or disposal. A key consideration to identifying the quantity of available water, and associated capacity of RO treatment that can be supported, is to review historical daily reclaimed water flows to identify a reliable yield from reclaimed water.



	Advantages	Disadvantages
Option 1 Blending Reclaimed Water and Groundwater Before RO Train	• Maximum operational flexibility • Groundwater can compensate for variable reclaimed water availability • Operators run "one" treatment train • Avoids potential cross-connection issue with CIP system	• Blending ratio management to control TDS and membrane fouling • Larger UV-AOP process to treat entire flow
Option 2 Dedicated RO Train for Reclaimed Water Only	• Smaller UV-AOP process to treat RO permeate from reclaimed water train only • Reduced need to track blending ratios	• Less operational flexibility • Potentially offline on days reclaimed water flows are low • Operators run "two" treatment trains, with very different water chemistries • Potential cross connection issues with CIP system

Figure 4. Advantages and disadvantages of groundwater blending location.

Annual electricity costs of potable reuse to brackish groundwater desalination are comparable because the lower feed pressure savings of treating reclaimed water by RO would be offset by additional advanced treatment processes, including ultrafiltration (UF) and ultraviolet advanced oxidation process (UV-AOP), that are required for treatment of reclaimed water, as discussed in the next section.

Treatment Process Considerations

When blending highly treated reclaimed water directly into the feed of an existing brackish RO WTP, several potential operational impacts should be considered. Changes in feed water chemistry may require sulfuric acid addition or a change in antiscalant dose to control membrane scaling. Also, if an existing brackish groundwater source is anaerobic, with high concentrations of dissolved iron or hydrogen sulfide, mixing with an aerobic reclaimed water may lead to iron precipitation or the formation of sulfur turbidity. In such cases, it may be better to treat reclaimed water and groundwater separately. The introduction of nutrient-rich reclaimed water may also present new challenges with membrane fouling. Nitrogen can promote growth of biological foulants, and phosphorus can contribute to calcium phosphate scaling.

The RO is extremely effective at removing inorganics, nutrients, and most CECs. The CECs are unregulated compounds and substances, such as per- and polyfluoroalkyl substances (PFAS), pharmaceuticals and personal care products (PPCPs), endocrine-disrupting compounds (EDCs), and antibiotic resistance genes (ARGs). The RO membrane elements with a high salt rejection (greater than 99.5 percent NaCl removal) are best suited to DPR because they have been shown to most effectively remove CECs (Howe et al., 2019). Pretreatment by membrane filtration (whether as microfiltration/UF or membrane bioreactors) is necessary for suspended solids removal before RO to meet silt density index (SDI) feed water goals. The most common approach that has been pilot-tested several times in Florida, and implemented elsewhere at full scale is to utilize UF with chloramination to control biological fouling. After RO treatment, UV-AOP is commonly used as an added barrier to CECs and an added disinfection step for pathogens.

Several considerations should be evaluated when deciding where to blend the reclaimed water source with the brackish groundwater. The options include:

- Option 1 - Blending reclaimed water after UF treatment and before RO trains.

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- Option 2 - Having one dedicated UF-RO-AOP train for reclaimed water, then blending with treated groundwater.

Advantages and disadvantages are associated with each approach, as presented in Figure 4. While UF is only needed for the reclaimed water, RO cannot be bypassed when relied upon as a pathogen removal barrier. Blending reclaimed water after UF treatment and upstream of the RO system (Option 1) provides the most treatment flexibility and simplifies operations because staff must only worry about operating one RO treatment train; however, this approach requires a larger UV-AOP system sized to accommodate the entire plant flow, not just reclaimed water. Also, the total flow of reclaimed water can vary from day to day, with potential shortfalls in flow, limiting the ability to keep the RO skids running. If a utility wishes to maximize capture of available reclaimed water, groundwater pumping can vary day to day, compensating for varying reclaimed water availability.

Alternatively, a dedicated UF-RO-UV-AOP treatment train for reclaimed water (Option 2) reduces the need to closely track feed water blend ratios and requires a smaller UV-AOP system; however, plant staff must operate two different RO trains with very different water chemistries at the same time. There may also be concerns with cross-contamination if the same clean-in-place (CIP) system for both the brackish water and reclaimed water trains is used.

Economic Considerations

Given the widespread adoption of brackish RO and associated concerns with groundwater quality, this approach of augmenting brackish groundwater supplies with reclaimed water could be a timely solution for many utilities. Table 1 presents an example case study for an existing brackish RO WTP experiencing increased salinity in its groundwater.

With the facility operating at only half its design capacity, the utility is faced with two alternatives to recover the full design flow: either retrofit the existing facility to accommodate brackish water with a higher TDS, or retrofit the facility to treat blended reclaimed water. To retrofit an existing plant for higher salinity may require new feed pumps, new electrical equipment, replacing pressure vessels, and installing corrosion-resistant piping, valves, and other improvements. The major benefit of augmenting a brackish water supply with reclaimed water is having a more secure and stable water source that is less prone to variations in source water quality and increases in salinity.

Path Forward

Brackish water desalination has proven its value as a critical alternative water supply over the past 30 years; however, many Florida facilities face challenges with increased salinity in brackish groundwater, leading to loss of production capacity or the need for costly retrofits. The authors considered an approach to restore production capacity of brackish water RO facilities facing these challenges.

Augmenting groundwater supplies with reclaimed water can provide a stable, low-TDS feed water to support long-term operations of the RO WTP facility. While it's necessary to demonstrate protection of public health through removal of pathogens and CECs, capital and operation and maintenance (O&M) costs of the potable reuse approach can be competitive with upgrading a brackish facility for higher salinities, while providing the additional benefit of stable source quality for the future.

Utilities interested in pursuing this approach typically would conduct a feasibility study or benchtop/pilot evaluation to help characterize site-specific reclaimed water quality and availability, determine potential operational benefits, study blending in the distribution system, characterize membrane fluxes and fouling rates, and develop planning-level capital and O&M cost estimates.

In June 2020, Florida Gov. Ron DeSantis signed Senate Bill 712, which deemed reclaimed water as a water source for public water systems. The bill required FDEP to initiate rule revisions for potable reuse based on the recommendations of the Potable Reuse Commission's Framework Report (Florida Potable Reuse Commission, 2020). The rules must address CECs, and this is an important step forward toward the safe, regulated availability of DPR as a water supply option in Florida.

With proper regulations in place, this approach may help Florida continue to provide a reliable and sustainable water supply for years to come.

Table 1. Potential Retrofit Requirements for an Example Florida Brackish RO Facility Showing Higher Salinity Retrofit Versus Retrofit for Source Water Augmentation with Reclaimed Water.

Alternative A	Alternative B
Retrofit for Higher Salinity	**Retrofit for Reclaimed Augmentation**
• 300 psi Limit at 5,000 mg/L TDS • Retrofit With Super Alloys • New Feed Pumps, Booster Pumps, Energy Recovery Device • Motors and Drives • Redo Header Pipework • Valves, Actuators, Instrumentation • Replace Pressure Vessels • New Membrane Elements	• Leave Existing RO System Intact • Ultrafiltration • UV Advanced Oxidation • Chemical Storage and Feed • Online Integrity Monitoring • Yard Piping • Equipment Buildings
Risk of Further Increases in TDS	**Secure Control of TDS**

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