Innovative Disposal of Reverse Osmosis Concentrate in Central Florida

Michael L. Weatherby, Deborah Beatty, Mark B. McNeal, and Jon Fox

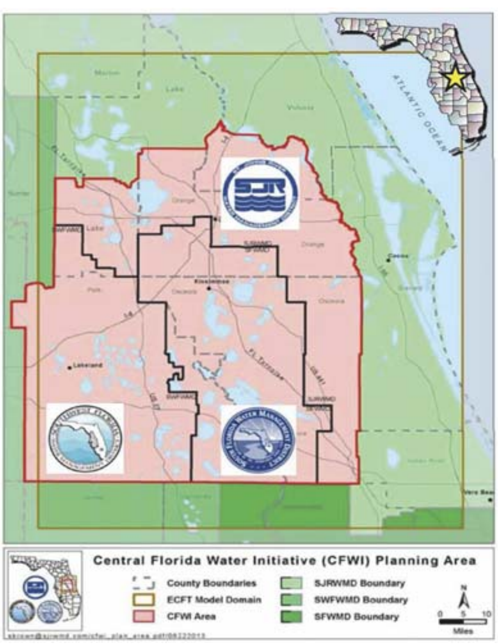
The Central Florida Water Initiative (CFWI) has identified that fresh groundwater supplies in central Florida are not sustainable at the current withdrawal rates and are inadequate to meet the growing demands over the next decade. Figure 1 illustrates the area of the CFWI with partnering water management districts (Southwest, South, and St. Johns River) and the cover of the CFWI regional water supply plan that outlines potential water supply projects to meet future demands.

Water utilities in the CFWI area are identifying future alternative water supplies, including sources such as brackish groundwater, surface water, reclaimed water, and stormwater, and implementing conservation measures to ensure that current and future supplies last longer. The Water Cooperative of Central Florida (cooperative) was formed as a regional effort to develop a long-term, sustainable water supply approach on which its utility members can rely. The cooperative members consist of the City of St. Cloud, Toho Water Authority, Orange County Utilities, and Polk County Utilities. The cooperative, together with the Reedy Creek Improvement District (collectively referred to as "utility partners"), have identified brackish groundwater from the Lower Floridan aquifer (LFA) as a viable, sustainable alternative water supply source in central Florida.

Florida Reverse Osmosis Concentrate Disposal History

The challenge to the development of a brackish water source is the limited options available to dispose of the reject, or concentrate, stream from the reverse osmosis (RO) treatment process. The RO treatment of brackish groundwater is a commonly utilized treatment process and concentrate disposal via injection wells. It's the widely utilized disposal option in Florida coastal communities or areas due to the prolific Oldsmar Formation "Boulder Zone" and its ability to readily accept RO reject flows. Unfortunately, the known unlimited capacity of the Boulder Zone in south Florida is unavailable, for the most part, in central Florida. The seeming lack of an injection zone for disposal, coupled with the deep occurrence of fresh groundwater in central Florida, made brackish water development in the CFWI area an infeasible water supply option in the past.

Michael L. Weatherby, P.G., is president of HydroGeo Consulting LLC in Tampa. Deborah Beatty, P.E., is project manager and senior engineer with Toho Water Authority in Kissimmee. Mark B. McNeal, P.G., is chief executive officer of ASRus LLC in Tampa. Jon Fox, P.E., is vice president and project manager with Tetra Tech Inc. in Orlando.



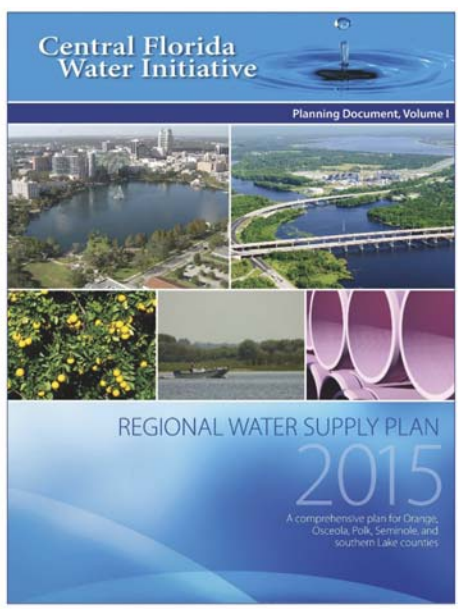


Figure 1. Central Florida Water Initiative study area and the cover of the final regional water supply plan. *(source: https://cfwiwater.com)*

Central Florida Concentrate Disposal Options Evaluated

To meet future water supply demands in the CFWI area, the utility partners evaluated the most feasible and cost-effective RO concentrate disposal options available to the central Florida region. Without an affordable disposal option, the development of a large-scale brackish water supply in central Florida would be cost prohibitive. The disposal options study included managing the concentrate through surface water discharge, agricultural reuse blending, wastewater reuse blending, zero liquid discharge, RO concentrate reduction processes called enhanced recovery, and deep injection wells. The study detailed advantages, disadvantages, challenges, and planning-level costing of each option. The evaluation made clear that even the most cost-effective disposal option is still too expensive to develop for the utility partners. The following six concentrate disposal options were evaluated.

Option 1: Surface Water Discharge

The impact of discharging RO concentrate to a surface water body can vary, depending on the surface water body's volume, flow, depth, temperature, and surface water chemistry, in addition to the volume, flow, temperature, chemistry, and specifically salinity of the RO concentrate. Identifying whether a target surface water body is considered as impacted by specific water quality conditions (i.e., nutrients, salinity, etc.) is critical to determining if a surface water disposal option is feasible. The advantages and disadvantages for disposal to a surface water body are as follows:

Advantages
- Cost-efficient operation.
- Can provide additional flows needed to water-level-impacted waterbodies.

Disadvantages
- Permitting is challenging for discharge of more-saline RO concentrate to fresh surface water and to identified impaired waterbodies.
- Long pipelines likely needed to transport concentrate.
- Blending facility may be needed.
- Toxicity caused by total dissolved solids (TDS), ion imbalances, and pH may occur.
- Potential flood control may be challenging during above average rainfall.

Option 2: Agricultural Reuse

The impact of using RO concentrate for agriculture irrigation purposes can vary, depending on the level of salinity tolerance that specific crops can tolerate, soil percolation rates, irrigation demands, and water quality regulatory standards of surface waters and subsurface groundwater, as well as the volume, flow, temperature, and chemistry of the RO concentrate. The advantages and disadvantages for disposal via agriculture irrigation are as follows:

Advantages
- Spray irrigation is a proven concentrate management option.
- Reduces groundwater reliance as an irrigation source.

Disadvantages
- Salinity could impact quality of crop yield, soil, nearby waterbodies, and groundwater.
- Large blending facilities are needed.
- Large-scale storage during periods of above average rainfall or post-harvest periods.
- Cooperation and agreements from local agricultural community to use a blended resource.
- Binding legal agreements tied to land sales.

Option 3: Wastewater Reuse

The RO concentrate may be disposed at water reclamation facilities (WRFs) that will treat the concentrate and become a part of reclaimed water from the facility. The addition of RO concentrate to a WRF is specific to the volume, flow, and chemistry (primarily salinity) of the RO concentrate and the inflow to the specific WRF. If the RO concentrate is too saline for a specific WRF to adequately absorb and treat the RO concentrate without causing harm to the biological treatment process, this option cannot be feasible. It's a delicate balance between the quality of the RO concentrate and the ability of the specific WRF to treat the additional flow.

Due to the location of the potential reverse osmosis water treatment plant (ROWTP) at the Cypress Lake site, nine WRFs are considered viable options; eight of these are owned and operated by the Toho Water Authority (TWA) and the remaining WRF is owned and operated by the City of St. Cloud. The advantages and disadvantages for disposal into a WRF are as follows:

Advantages
- The WRFs could have sufficient hydraulic capacity for proper blending.
- Existing permits could provide flexibility to operate at permitted levels.
- Could blend concentrate with raw wastewater or finished reclaimed water.

Disadvantages
- The WRFs could be located far away from the RO concentrate source.
- Concrete structures can be attacked by high chloride and sulfate.
- Delivery of the concentrate must mimic the diurnal wastewater flow patterns to avoid high-salinity slugs entering the system.
- Discharging directly to rapid infiltration basins (RIBs) could potentially impact groundwater quality.

Option 4: Zero Liquid Discharge

The term zero liquid discharge (ZLD) is used to describe the various technologies that are employed to produce a solid waste stream from a liquid process stream. The various categories of ZLD options can be classified as:
- Evaporation ponds
- Thermal-based technologies (brine crystallizers)

Most of these technologies are in conceptual development or are only available for small-scale application and are energy-intensive. The ZLD technologies are not commonly used in Florida, mainly due to the availability of injection zones for RO concentrate in coastal Florida where desalination of brackish groundwater is common. Additionally, evaporation ponds have significant operational limitations in states such as Florida that have annual average precipitation rates of 50 in.; they are much more effective in arid areas, such as the southwest United States. The advantages and disadvantages for ZLD technologies are as follows:

Advantages
- Creates a solid to be safely disposed or recovered as a byproduct for beneficial use.

Disadvantages
- High capital costs (brine crystallizers).
- Very high energy consumption (brine crystallizers).
- Evaporation ponds will have limited performance during wet weather periods.

Option 5: Concentrate Reduction/Enhanced Recovery

Concentrate reduction and enhanced recovery are terms used to describe the various technologies that are employed to reduce RO concentrate flow. A significant reduction of RO concentrate flows does make concentrate disposal easier; however, a liquid disposal option is still needed in concert with this option. The various categories of enhanced recovery options can be classified as:
- Intermediate treatment (chemical softening)
- Thermal-based technologies (brine concentrators)
- Additional membrane stages
- Electric potential driven membrane technologies such as electrodialysis (ED) and/or electrodialysis reversal (EDR)

These concentrate reduction and enhanced recovery options are energy-intensive. The advantages and disadvantages for concentrate reduction and enhanced recovery technologies are as follows:

Advantages
- Concentrate TDS up to 20,000 mg/L (additional-stage membranes, ED, and EDR).
- Concentrate TDS as high as 250,000 mg/L (brine concentrator).
- Additional high-quality product water produced (additional stage membranes and brine concentrator).

Disadvantages
- Energy cost increases with TDS of water (ED and EDR).
- Still requires a liquid disposal option.
- Membranes need to be periodically cleaned (ED and EDR).
- High capital costs (brine concentrator).
- High energy consumption (brine concentrator).

Option 6: Injection Wells

The injection zone evaluation was initially based on the ability of a selected injection zone to accept up to 2 mil gal per day (mgd) of concentrate from the Cypress Lake ROWTP and the hydrogeological characteristics needed to meet regulatory requirements of an industrial injection well for disposal.

In Florida, the historical and current common method of RO concentrate disposal using injection wells follows a design and permitting mechanism for Class I industrial injection wells. These Class I wells must dispose of fluids into an injection zone that is not an underground source of drinking water (USDW), which has an adequate thickness of overlying low-permeability rock to confine the injected water to prevent it from migrating upward into a USDW that could be used as

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a drinking water supply in the future. An USDW in Florida is defined as water having a TDS water quality concentration of less than 10,000 mg/L. The federal definition of a USDW includes additional criteria, including that the formation is capable of producing a sufficient amount of water for public supply.

There are two types of Class I injection well designs: municipal and industrial. Municipal injection wells dispose of treated domestic wastewater and today can only dispose of wet weather excess reclaimed water, or water that has undergone the high-level disinfection (HLD) process. Since the injectate is generally fresh water, the wells can be designed with a carbon steel final casing. The industrial injection well design requires a corrosion-resistant injection tubing inside the final carbon steel casing. This final tubing is either left with a fluid-filled annulus (sealed at the bottom with a packer) or is cemented from top to bottom.

The disposal of RO concentrate using an injection well requires the wells to be designed to Class I industrial standards. These Class I injection well designs also include a dual-zone monitoring well to monitor for impacts to the base of the locally identified USDW. Based on the Florida Department of Environmental Protection (FDEP) underground injection control (UIC) rules (Chapter 62-528, Florida Administrative Code [FAC]), the Class I industrial injection well regulations prohibit adverse injectate impacts to a USDW, and if impacts are discovered, they constitute a serious violation that can shut down the Class I industrial injection system.

Evaluation of central Florida hydrogeology indicated that the base of the lowermost USDW (waters with less than 10,000 mg/L TDS concentrations) existed into the top half of the LFA permeable zones of the Oldsmar Formation, which is commonly used for RO concentration disposal in coastal Florida and is far below the base of the identified USDW in the area. In central Florida, however, since the lowermost permeable unit of the LFA intersects the base of the USDW, the upper half of the lowermost potential injection zone (Oldsmar Formation) is considered by FDEP as a USDW, while the lower half of the fractured zone is non-USDW or greater than 10,000 mg/L TDS concentration. With this general information, the LFA cannot be considered for RO concentrate disposal through traditional Class I industrial injection well criteria.

Figure 2 provides a hydrogeologic section developed for the project showing the approximate depth of the base of the lowermost USDW, which is protected by FDEP and the U.S. Environmental Protection Agency (USEPA). The local hydrogeologic and water quality information was provided from the test wells constructed at the site. Due to Class I industrial injection well rules, the only available injection zone that will avoid impacting a FDEP-defined USDW was the Upper Cretaceous formation permeable zone below the Floridan Aquifer System (FAS). The previous study identified the potential Upper Cretaceous formation injection zone between approximately 3,600 and 5,000 ft below land surface (bls), which is shown in light blue in the figure.

The Upper Cretaceous formations are not commonly used for injection in Florida. Currently, only three injection wells in southwest Polk County are constructed in the Upper Cretaceous formations, along with one well in the Florida Panhandle. The corresponding deeper well design makes these injection wells much more expensive

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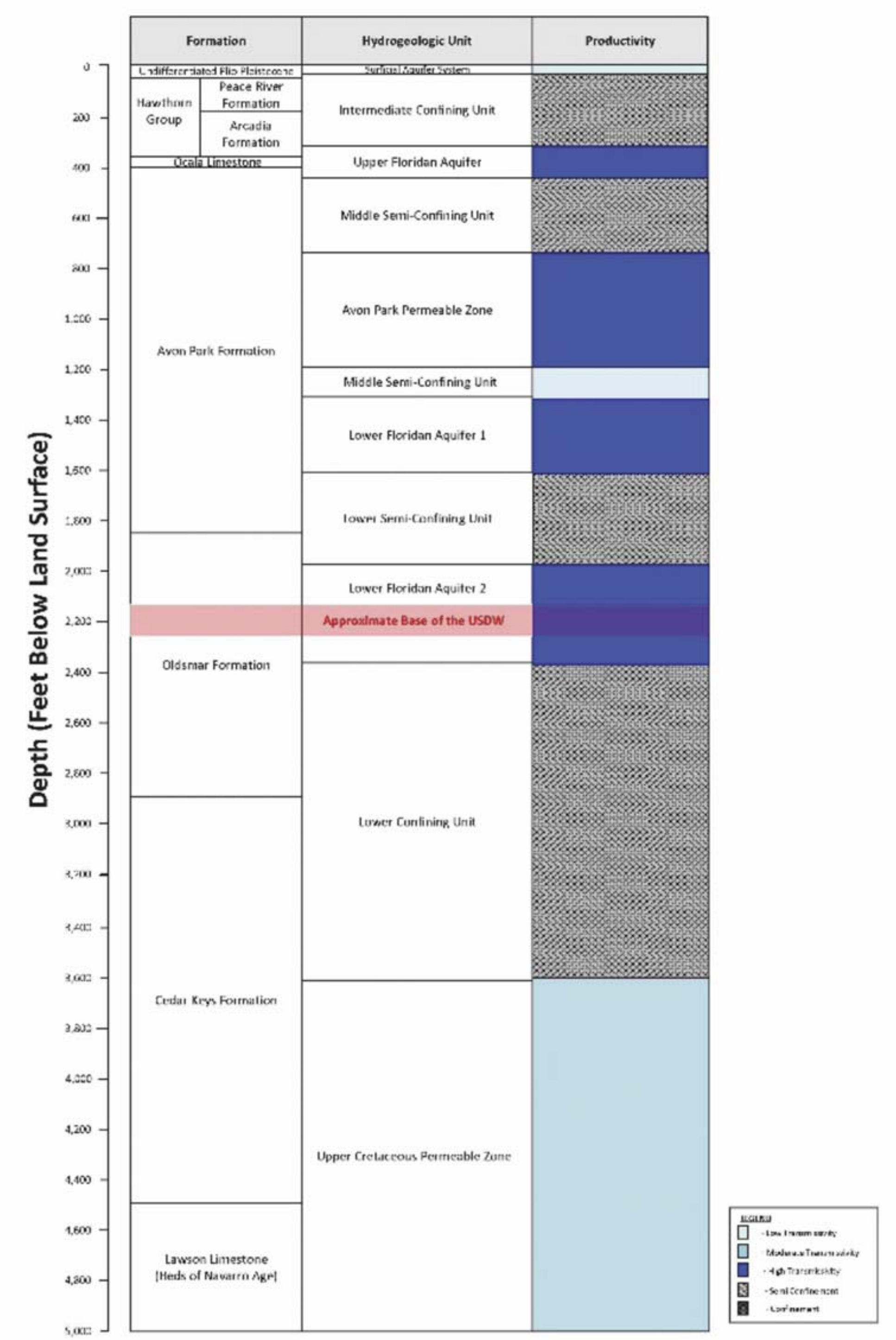

Figure 2. Hydrogeological section showing the estimated depth of the base of the underground source of drinking water.

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to construct than typical FAS injection wells and results in higher injection pressures, which increases operation and maintenance costs.

Even with these limitations, such as lower formation permeability and higher construction and operational costs, this RO concentrate disposal option was the least costly option evaluated in this study. The advantages and disadvantages for injection well disposal are as follows:

Advantages

- Proven technology with minimal maintenance.
- Provide continuous flow capacity regardless of the season.
- Minimal to no additional land.
- Splitting the flow among multiple wells can save energy costs.
- Variable or increasing injectate salinity does not affect injection.
- No third-party involvement or contractual agreements needed.

Disadvantages

- Not commonly considered for injection. Only four injection wells currently exist in Florida in the Upper Cretaceous permeable zone.
- Upper Cretaceous formations will cause elevated wellhead pressures at 2 mgd (potentially >200 pounds per sq in. [psi]).
- Must be monitored for potential plugging effects due to low permeability of the injection zone.

Selected Disposal Option

The disposal option evaluation highlighted complications and limitations of all other disposal options to permit, implement, and operate. For example, changes in water quality of the RO concentrate will not affect the disposal process using injection wells when a slight change in the concentrate water quality would render other evaluated disposal options unusable. Ultimately, the other disposal options were deemed not feasible or had significantly higher costs when compared to the injection well option. For the 10-mgd initial phase of the ROWTP, the next viable option of EDR was 50 percent more expensive than utilizing Upper Cretaceous formation injection wells; for the final 30-mgd ROWTP phase, EDR was 30 percent more expensive than utilizing multiple injection wells. The recommended injection well option is easily expandable to provide additional system redundancy or injection capacity if needed. Even though the study recommended the injection well option because of less limitations and lower cost of all the options evaluated, a more detailed evaluation would be needed to move toward the permitting phase.

Concerns among the utility partners regarding the cost of constructing these Upper Cretaceous formation injection wells to depths up to 5,000 ft bls prompted the pursuit of an alternative approach to permit an injection well in the LFA for the disposal of RO concentrate. To develop an injection well disposal option that is more affordable and is permittable in central Florida, a creative well design and permitting approach was developed not previously presented to the UIC department at FDEP for RO concentrate disposal. Instead of a Class I industrial injection well that's constructed into the Upper Cretaceous formations, a Class V Group 4 injection well approach was utilized. This approach will allow a shallower injection well to be developed into the LFA (which is not available for the Class I injection well option) to depths up to 2,400 ft bls, reducing the injection well costs up to 60 percent.

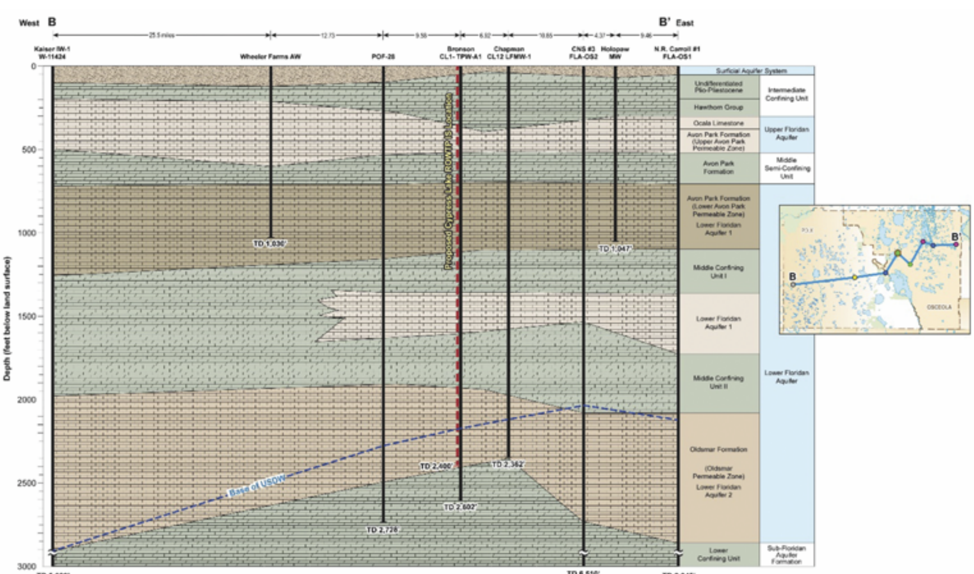

Figure 3. East-west cross section showing the estimated base of the underground source of drinking wate and the ultimately proposed injection well.

Class V Injection Well Design and Permitting Strategy

Brackish groundwater RO concentrate is developed when brackish groundwater is forced under pressure into a membrane that divides the brackish water into two streams. The fresh permeate (water that goes through the membrane) is the portion that becomes drinking water and the reject, or concentrate, is a waste byproduct that needs disposal. The RO concentrate is saline because it is a concentration of all the impurities in the brackish groundwater, predominantly salts.

Understanding the injectate water quality, regional hydrogeology, and target injection zone is important to meet the regulatory requirements to properly design and permit this injection well. Since the source of the concentrate is natural groundwater, FDEP UIC rules allow for a Class V Group 4 injection option for nonhazardous industrial and commercial disposal wells for disposal of desalination process concentrate (Chapter 62-528.600(2)(d), FAC) provided the concentrations of the waste do not exceed drinking water standards contained in Chapter 62-550, FAC. This rule has not been used in Florida for the disposal of RO concentrate since injection wells are commonly constructed in south Florida in the Lower Floridan aquifer Oldsmar Formation below the identified base of the lowermost USDW, or along the Florida Gulf Coast in the Avon Park High Permeability Zone of the Upper Floridan aquifer (UFA).

Having local subsurface hydrogeologic and water quality information was critical in developing a permitting strategy for this project. During the brackish water supply evaluation, the utility partners had constructed multiple test wells at and near the proposed ROWTP site. A test well was constructed to a depth of 2,600 ft at the ROWTP site, which provided much-needed hydrogeological and ambient water quality information. Figure 3 shows the east-west hydrogeological cross section of the area surrounding the injection well site. The Oldsmar Formation is the target formation for injection of RO concentrate. This figure also shows the approximate location of the base of the USDW (where aquifer water exceeds 10,000 mg/L TDS concentrations).

The previous hydrogeologic data identified the base of the USDW and the LFA permeable zone, which was valuable information to present to FDEP's UIC department. The permitting of the first Class V injection well for disposal of 2 mgd and possibly up to 6 mgd of RO concentrate in Florida was significant for FDEP to consider and will set a new precedent in the state.

The added significance for this unique Class V permitting option surrounded the criticality of water supply issues in central Florida as a whole. Without this Class V permitting concept to dispose of RO concentrate in the LFA and approval to impact a small portion of the USDW (that has TDS concentrations over 8,000 mg/L) in the injection zone, the future option of using brackish groundwater may have been removed from the water supply options for an entire region. This Class V injection well option is less costly to construct, will operate with less wellhead pressure (which lowers operation costs), eliminates plugging potential issues that can shorten the injection well life, and may reduce the number of injection wells needed for this facility.

The TDS concentration of the produced RO concentrate is estimated to be approximately 16,000 mg/L; therefore, the Class V well design does not change from a Class I industrial injection well design because the RO concentrate remains corrosive to steel. To meet the Class I industrial injection well design requirements, a fiberglass reinforced plastic (FRP) injection tubing is designed to be cemented inside the final steel casing to protect it from salt corrosion. Class I injection wells typically require a dual-zone monitoring well to be constructed within 150 ft of the Class I injection well to monitor for impacts to shallower aquifers. An added benefit of the Class V injection system is the lower-cost requirement of a single-zone monitoring well instead of the dual-zone monitoring well required for Class I injection wells. Figure 4 provides the construction details of the Class V Group 4 injection well system at the Cypress Lake ROWTP location.

Class V Injection Well Florida Department of Environmental Protection Permitting

The Class V Group 4 well construction and testing permit application was prepared and submitted on behalf of the utility partners to the FDEP UIC department in June 2016. The application included the local hydrogeological information obtained from the existing onsite monitoring wells constructed at the proposed ROWTP site, an area of review documenting the existing wells in the area, injection well design, drilling and testing plan, and plugging and abandonment plan, among other required information. The Class V Group 4 well construction and testing permit was received on Jan. 30, 2017, allowing the utility partners to begin construction of the injection well.

Since the RO concentrate water quality will contain specific constituents that exceed the upper portion of the Oldsmar Formation that contains groundwater with less than 10,000 mg/L TDS concentration, regulatory relief will be needed to allow for injection of RO concentrate into the Oldsmar Formation and impact the upper portion of this permeable zone. A water quality criteria exemption (WQCE) will be prepared for parameters, such as chloride, sodium, TDS, and radionuclides, that will exceed the water quality in the upper portion of the Oldsmar Formation. This regulatory relief, expected to be approved by FDEP, changes the water quality standards of specific parameters to a new standard that must be met in the receiving aquifer zone.

Exploratory Well Construction

This FDEP Class V Group 4 well construction and testing permit is a critical component of the Cypress Lake ROWTP project for it to move forward for the utility partners. The next phase of the project is to drill the first well as an exploratory well to gather subsurface information, such as ambient aquifer water quality profile data, formation lithology, injection zone productivity, and injection capacity, which will help the utility partners better understand the capacity of each injection well and determine how many injection wells will be needed to meet the disposal capacity of each phase of the ROWTP system design and construction. The exploratory well will be completed as a Class V injection well.

Conclusion

This new disposal option, successfully permitted, is the first Class V injection well permit to be issued in Florida for the disposal of RO concentrate. The permit allows for the construction and testing of the shallower injection well and associated monitoring well. Additional permitting, after testing and prior to placing the well into service, will be necessary. The permitting of this disposal option is the first step toward the development of the first brackish water supply in central Florida. Without this FDEP permitting approach, the development of brackish groundwater would not be economically feasible in this area, which is experiencing limits on potable groundwater development.

Once feasibility is demonstrated, this Class V injection well option can be used throughout the CFWI area, making brackish groundwater development a cost-effective alternative water supply in an area not previously considered to be viable. ◊

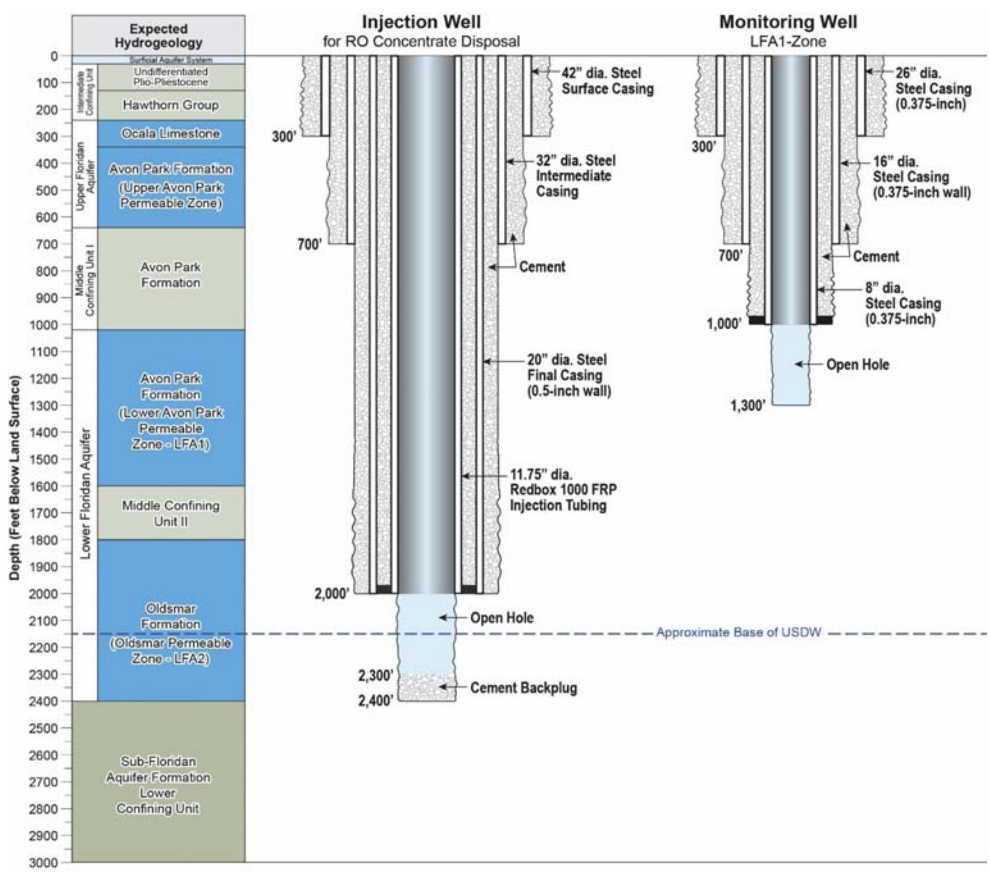

Figure 4. Permitted injection well and associated monitoring well construction details.