# Assessment of Water Levels and Water Quality of the Floridan Aquifer System at Intercession City, Florida

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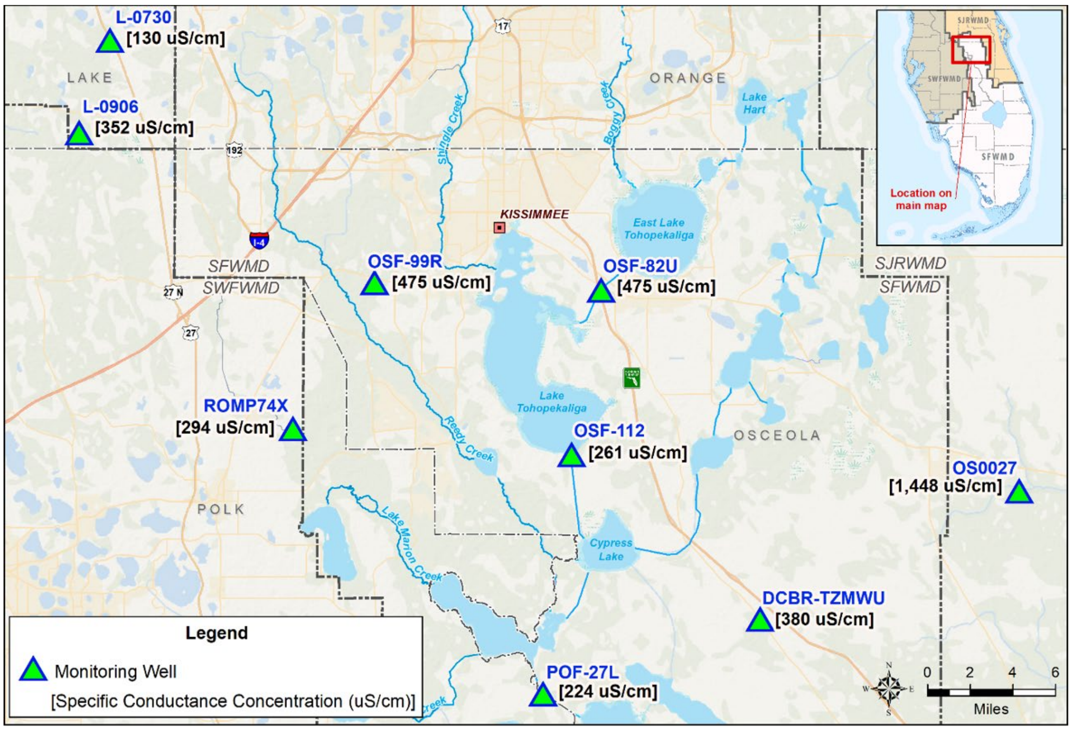



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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| APPZ | Avon Park permeable zone |
| bls | below land surface |
| CFWI | Central Florida Water Initiative |
| FAS | Floridan aquifer system |
| FRP | fiber-reinforced plastic |
| ft | feet |
| GMWL | global meteoric water line |
| GPS | Global Positioning System |
| IC-TPW | Intercession City test production well |
| IC-TW | Intercession City tri-zone well |
| LFA | Lower Floridan aquifer |
| meq/L | milliequivalents per liter |
| mg/L | milligrams per liter |
| psi | pounds per square inch |
| PVC | polyvinyl chloride |
| SC | specific conductance |
| SCADA | supervisory control and data acquisition |
| SFWMD | South Florida Water Management District |
| TDS | total dissolved solids |
| μS/cm | microsiemens per centimeter |

# INTRODUCTION

The South Florida Water Management District (SFWMD) constructed the OSF-99R monitor well as part of the Central Florida Water Initiative (CFWI; https://www.cfwiwater.com/), a cooperative effort among the SFWMD, Southwest Florida Water Management District, St. Johns River Water Management District, Florida Department of Environmental Protection, Florida Department of Agriculture and Consumer Services, and local stakeholders. As part of the CFWI, the data monitoring and investigations team identified regions in Central Florida that were lacking adequate monitoring and information on hydraulic properties in the Floridan aquifer system (FAS). OSF-99R was built as a replacement for OSF-99 at the Intercession City site in Osceola County, Florida, to address anomalous water quality data and to verify and provide hydraulic and water quality information for the Avon Park permeable zone (APPZ; **Figure 1**). The Intercession City site was originally constructed as a tri-zone well (Intercession City tri-zone well [IC-TW]; OSF-97, OSF-98, OSF-99 in order from deepest to shallowest zone) in 2002 by Diversified Drilling Corporation as part of the *2000 Kissimmee Basin Water Supply Plan* (SFWMD 2000). In 2002, Diversified Drilling Corporation also constructed the Intercession City test production well (IC-TPW).

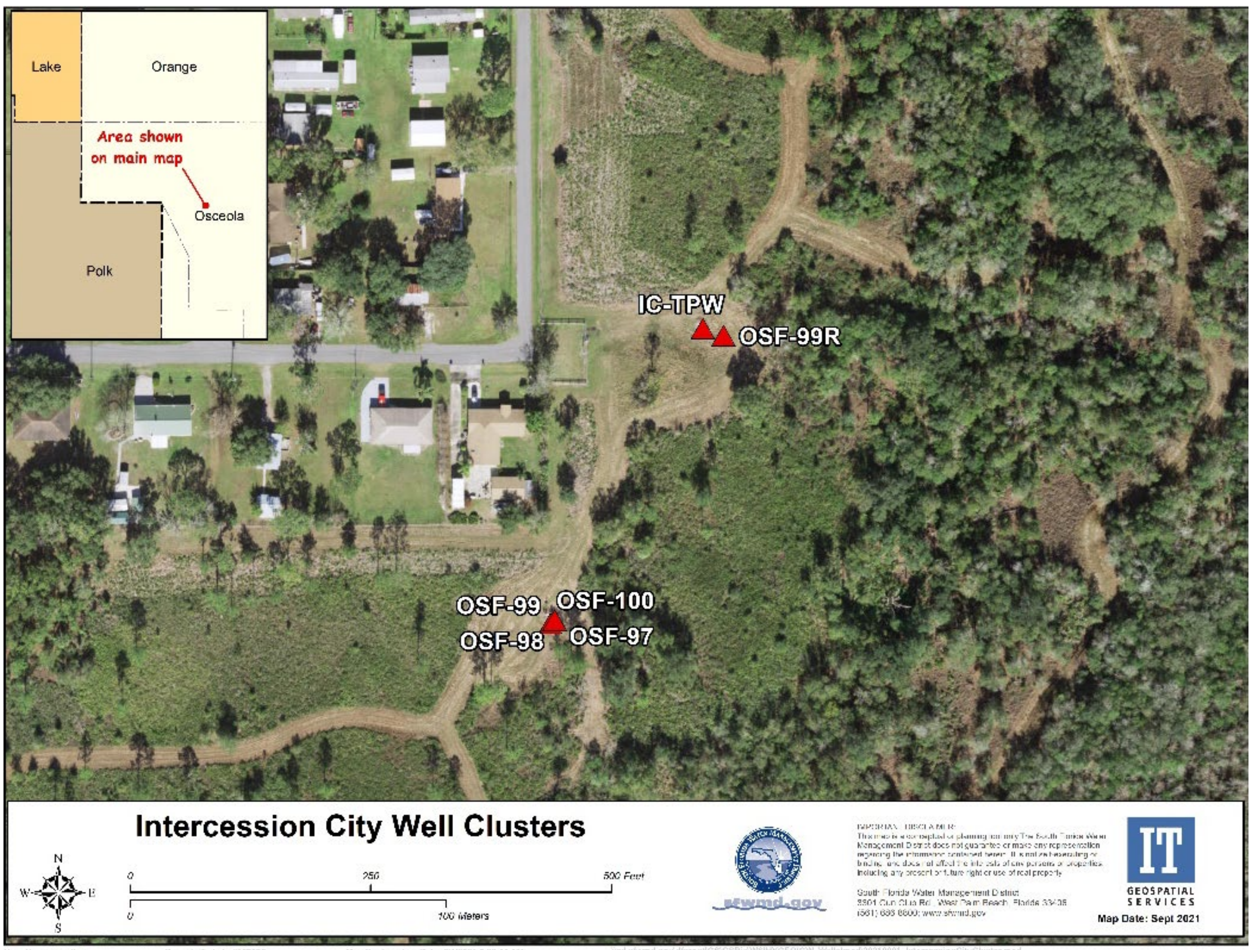


Figure 1. Aerial map of OSF-99R and surrounding wells.

Construction of OSF-99R began on January 21, 2020 when Huss Drilling, Inc. mobilized a Versadrill 2000 rig to the site and set up for mud rotary drilling. From January 27, 2020 to January 31, 2020, 40 feet (ft) of 16-inch surface casing was installed, and a 15-inch mud-rotary drilled borehole was drilled to 110 ft below land surface (bls) of depth. During this time frame, a 10-inch conductor casing was installed to the top of the FAS. From February 3, 2020 to February 13, 2020, a 10-inch reverse-air drilled borehole was advanced from 110 ft to a total depth of 500 ft bls. From February 17, 2020 to February 26, 2020, the 4-inch fiber-reinforced plastic (FRP) final casing was installed to 355 ft bls with a back-off. A back-off is utilized when casing annular space is not large enough to support a larger submersible pump. The resulting well has the casing cemented in place below the back-off area. The casing above the cemented area is unscrewed and removed allowing a large annular space for the placement of a submersible pump at a later time. Bentonite grout (2%) was used to seal the formation to the base of the back-off (60 ft bls). The final wellhead configuration is shown in **Figure 2**, and a cross section illustrating the completed intervals of the wells at the Intercession City site is shown in **Figure 3**. A survey to determine ground elevation, measuring point, and GPS coordinates was conducted by the SFWMD on June 11, 2020.

Figure 2. Wellhead configuration of OSF-99R.

The primary objectives of the well replacement were to (1) provide for reliable long-term water level and water quality monitoring of the APPZ at the Intercession City location, (2) evaluate data from the new well compared to historical water level and water quality data observed in the OSF-99 well to assess the reliability of that dataset, and (3) assist in water supply efforts and regional modeling.

OSF-99 is the shallowest monitoring interval of the IC-TW. It is completed in the APPZ with steel casing. Water quality sampling results from OSF-99 have been anomalous in certain respects over its period of record. This is illustrated in **Table 1**, with the record of specific conductance (SC) from historical sampling events.

Water quality sampling of OSF-99 commenced in December 2002, and various issues arose concerning the validity of water quality sampling results. OSF-99 water quality results, particularly sulfate, calcium ion concentrations, and SC, which is impacted especially by the sulfate ionic concentrations, were found to be anomalously high when compared with ionic concentrations in surrounding wells completed in the APPZ. The ionic concentration values and thus SC for OSF-99 seemed more reflective of the Lower Floridan aquifer – upper permeable zone (LFA-upper) of OSF-98.

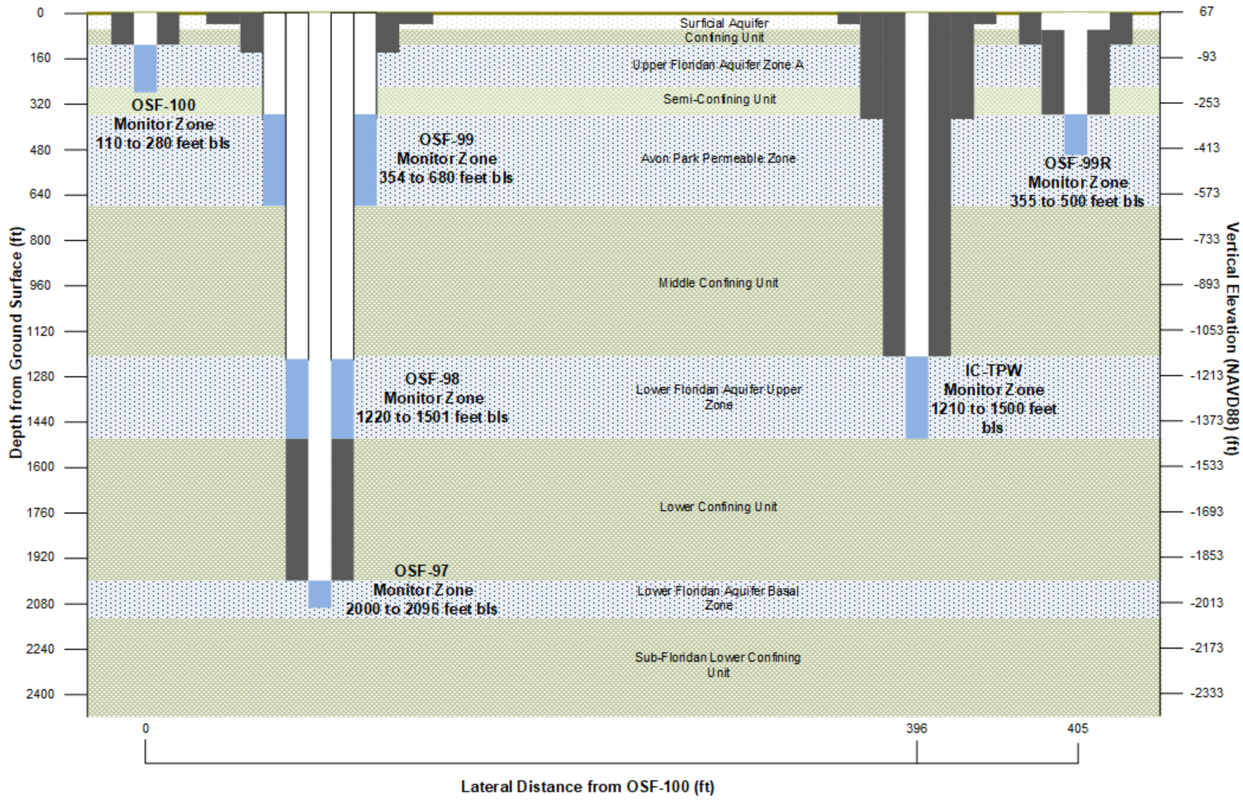


Figure 3. Cross section of wells at the Intercession City site.

Throughout the early years of operation (2002–2009), two specific issues plagued the IC-TW. First, the wells completed in the three monitoring intervals were inadequately labeled, and many of the initial water quality samples were taken prior to sufficient purging. Second, the access ports for water quality sampling of the two annular-zone monitor intervals (OSF-98 and OSF-99) are only 3 inches in diameter, but the purge volumes are large. Because of the small diameter, there was considerable difficulty in fitting pumps and associated sampling equipment into the wells. By 2009, the labeling issue had been resolved and sampling procedures for this site were modified to ensure sufficient purging prior to sampling. After this point, the water quality data were assumed to be indicative of formational water and observed increases in SC in OSF-99 immediately prior to sampling were thought to indicate sufficient purging of the monitoring zone, inspiring confidence that the issues were resolved.

Despite these corrective actions, it was discovered during a 2019 review of the APPZ of the CFWI region that the SC in the OSF-99 zone of the IC-TW was higher than surrounding wells, by up to an order of magnitude (**Table 1, Figure 4**). Of the APPZ wells plotted, only ROMP74X is closer to the expected recharge location; the other wells are farther away and thus would be expected to have higher salt content. While the SC at OSF-99 is mostly impacted by sulfate, the anomalous SC still raised flags that the water quality data may have been erroneous. It was also noted that although the median SC concentrations in each Intercession City monitoring zone increased with depth as expected, considerable overlap existed in the range of SC values in IC-TW (**Table 2**). This was true both before and after the initial well mislabeling and purging issues were resolved. Thus, it was suspected that the source of the water quality anomaly associated with the OSF-99 monitoring zone went beyond mislabeling or inadequate purging.

Table 1. Specific conductance concentrations (µS/cm) in OSF-99 and surrounding APPZ wells.

| Date (Month-Year) | OSF-99 | OSF-82U | OSF-112 | ROMP74X |
|---|---|---|---|---|
| Apr-11 | 249 | - | - | - |
| Mar-12 | 274 | 509 | - | - |
| May-12 | - | - | - | 276 |
| Feb-13 | - | - | - | 274 |
| Oct-13 | - | - | - | 294 |
| Feb-15 | 1,105 | - | - | - |
| Feb-18 | - | - | 278 | - |
| Jan-19 | - | 422 | - | - |
| Apr-19 | 1,200 | - | - | - |
| Jul-19 | - | - | 266 | - |
| Jan-20 | - | 475 | - | - |
| Mar-20 | - | - | 261 | - |
| Feb-21 | 1,074 | - | - | - |
| Range | 951 | 87 | 17 | 20 |

APPZ = Avon Park permeable zone; µS/cm = microsiemens per centimeter.
"-" = no sample taken on date.

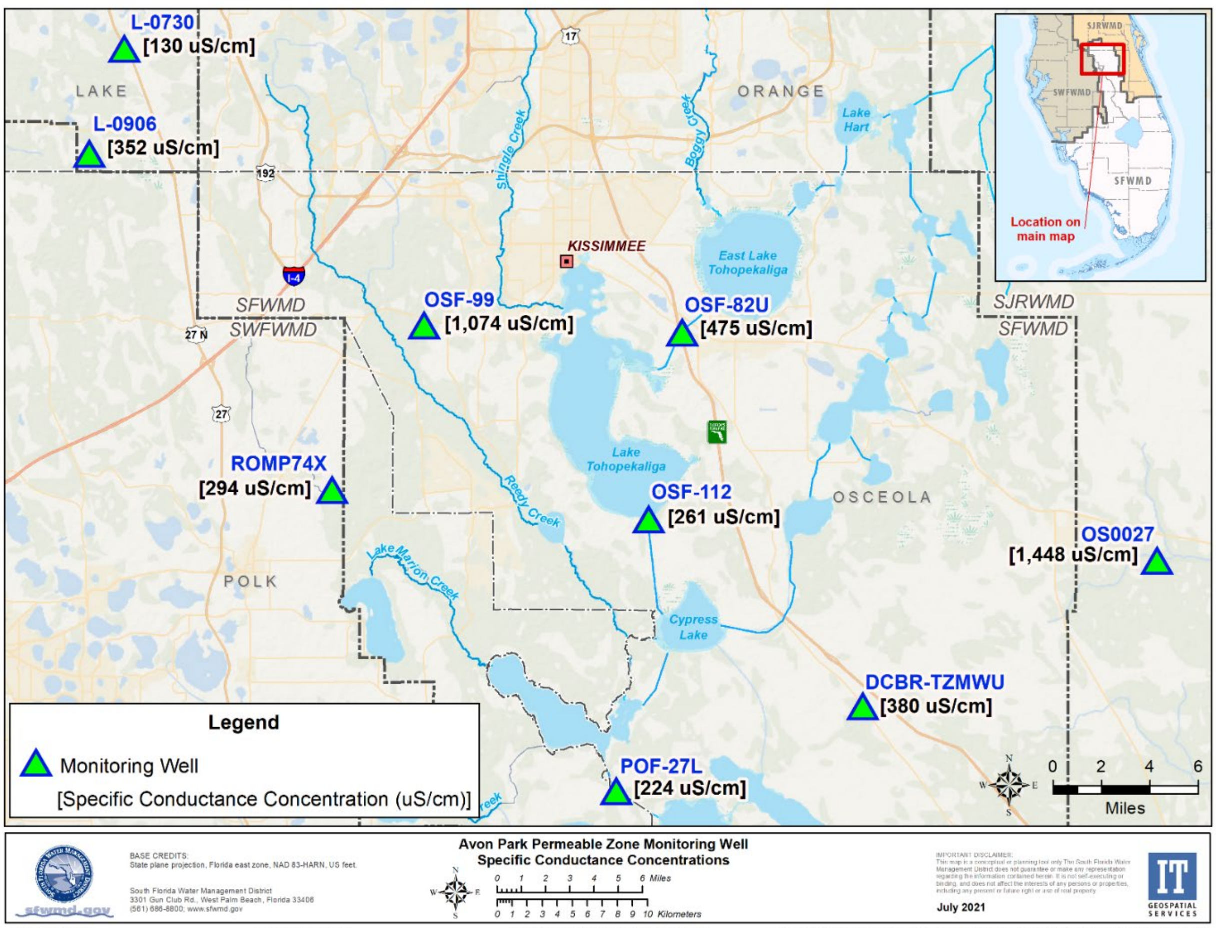


Figure 4. Specific conductance concentrations (µS/cm) in OSF-99 and surrounding APPZ wells prior to the drilling of OSF-99R.

Various hypotheses for the anomalous water quality data were considered as follows: (1) The SC in the APPZ at the site was naturally high. While this was somewhat corroborated by the geophysical logs, which indicated significant decrease in fluid resistivity between 570 and 640 ft bls, this hypothesis was not supported by drill-stem water quality data, which did not exceed an SC concentration of 520 microsiemens per centimeter (µS/cm) during pilot-hole drilling. Furthermore, the interval of decreased resistivity was more confined and less productive than the upper APPZ (360 to 425 ft bls), which was responsible for most of the flow in the APPZ at the site (Bennett and Rectenwald 2003). (2) Vertical gradient was analyzed as a potential cause for mixing of the natural waters. This hypothesis was rejected as vertical gradient is downward, so natural migration of LFA-upper waters is not possible. (3) Pumping-induced upconing was also considered and rejected, as there is over 500 ft of confinement between the APPZ and the LFA-upper at the Intercession City site. Thus, the SC of native groundwater within the lower section of the APPZ was rejected as a determinant factor to the anomalous SC data for OSF-99.

Currently, the leading hypothesis for the anomalous water quality is considered to be an issue with the well construction of the OSF-99 zone of the IC-TW. Sulfide concentrations are elevated in all zones in the IC-TW, and the steel casing may have corroded due to the high sulfides. If the steel casing has in fact corroded over time, it is likely that there is mixing of waters between the two wells during pumping and sampling. Both OSF-99 and OSF-98 are typically purged and sampled at the same time. It is also possible the suspected mixing of formation water was caused by an inadequate grout seal between OSF-99 and OSF-98.

Table 2. Specific conductance concentrations (µS/cm) in OSF-99, OSF-99R, OSF-98, and IC-TPW.

| Date (Month-Year) | OSF-99 | OSF-99R | OSF-98 | IC-TPW |
|---|---|---|---|---|
| Dec-02 | 975 | - | 1,136 | - |
| Sep-06 | 1,120 | - | 1,080 | - |
| Feb-07 | 1,150 | - | 959 | - |
| Jun-08 | 909 | - | 1,133 | - |
| Sep-08 | 454 | - | 908 | - |
| May-09 | 799 | - | 1,149 | - |
| May-10 | - | - | 1,295 | - |
| Apr-11 | 249 | - | 984 | - |
| Mar-12 | 274 | - | 897 | - |
| Mar-13 | - | - | 1,211 | - |
| Feb-15 | 1,105 | - | 894 | - |
| May-16 | - | - | 1,180 | - |
| Apr-19 | 1,200 | - | 1,259 | - |
| Feb-21 | 1,074 | 477 | 1,635 | 1,403 |
| Feb-21 | - | 475 | - | - |

µS/cm = microsiemens per centimeter.
"-" = no sample taken on date.

# METHODS

## Construction

OSF-99R was constructed with the objective of facilitating its use for long-term water quality sampling. It was built with a 10-inch polyvinyl chloride (PVC) casing from ground surface to a depth of 110 ft bls, and 4-inch FRP casing from 60 to 355 ft bls. The narrower-diameter FRP casing was set at 60 ft bls in order to allow for insertion of large diameter submersible pumps for sample purging. PVC and fiberglass were chosen for casing material to avoid any potential casing deterioration issues from the high sulfur content in the FAS.

OSF-99R was cased to the same depth as OSF-99 to facilitate comparisons between the two wells, but the monitoring interval for OSF-99R is 355 to 500 ft bls, which corresponds only with the upper half of the APPZ at the site. This differs from the monitoring interval at OSF-99, which is from 354 to 680 ft bls, corresponding to the entire APPZ at the site. The shallower monitoring interval in OSF-99R was chosen because the deeper APPZ is less productive and more confined than the shallower depths. Additionally, the shallower monitoring interval helps facilitate water quality sampling by reducing the purge volume requirement for the well.

## Instrumentation

At completion of the OSF-99R well construction, an In-Situ Level TROLL 500 data logger was installed in April 2020 to collect water level data. After installation of the data logger in April 2020, groundwater level data have been continuously recorded at both OSF-99 and OSF-99R and are available in 15-minute increments, allowing direct comparisons of water level data. In February 2021, OSF-99R was switched from the SFWMD Hydrogeology Unit control to a supervisory control and data acquisition (SCADA) system.

## Water Quality Sampling

This investigation analyzed water quality data collected by the SFWMD between 2002 and 2021. Sampling events followed the *Florida Department of Environmental Protection Standard Operating Procedures for Field Activities DEP-SOP-001/01* and Section 2200, Florida Statutes. It is suspected that the initial sampling events (pre-2009) may have had insufficient purge volumes and may have been sampled based on the pump volume rather than the well volume. OSF-99/OSF-99R (APPZ) and OSF-98/IC-TPW (LFA-upper) were sampled to compare water quality data and to help determine if any contamination of LFA-basal was occurring while sampling OSF-99. Collected samples were acidified (as appropriate) and chilled until delivery to the SFWMD laboratory. At the laboratory, samples were analyzed for major ion composition (**Table 3**). Alkalinity was measured as calcium carbonate concentration and converted to bicarbonate concentration. Deuterium and oxygen-18 samples were sent to the University of Arizona Environmental Isotope Laboratory for analyses. Ionic data from the February 2021 sampling events were imported into Grapher (Golden Software 2020) for analyses and generation of stiff plots and trilinear diagrams. Charge balance errors were verified and found to be less than 5% on analyzed OSF-99, OSF-99R, OSF-98, OSF-97, and IC-TPW samples.

Table 3. List of water quality parameters.

| Cations (mg/L) | Anions (mg/L) | Field Parameters |
|---|---|---|
| Sodium ($Na^+$) | Chloride ($Cl^-$) | pH (Dimensionless) |
| Potassium ($K^+$) | Sulfate ($SO_4^{2-}$) | Temperature (°C) |
| Calcium ($Ca^{2+}$) | Bicarbonate ($HCO_3^-$)* | Specific Conductance (µS/cm) |
| Magnesium ($Mg^{2+}$) | | |

°C = degrees Celsius; µS/cm = microsiemens per centimeter; mg/L = milligrams per liter.
* Derived from alkalinity.

Hydrochemical facies were identified using the classification system developed by Back (1960, 1961). This classification system is based on cation and anion percentages. The hydrochemical facies are reflective of differences in groundwater, host rock, and flow path framework of the samples. **Table 4** provides the classification of water types based on major ion contents as described by Back (1961). **Figure 5** illustrates the divisions of the hydrochemical facies presented on a trilinear diagram (Back, 1960).

Table 4. Classification of groundwater hydrochemical facies (Modified from Back 1961).

| Hydrochemical Facies | Percentage of Constituents (meq/L) | | | |
|---|---|---|---|---|
| | Ca + Mg | Na + K | $HCO_3 + CO_3$ | $Cl + SO_4$ |
| Cation Facies | | | | |
| Ca–Mg | 90 – 100 | 0 < 10 | - | - |
| Ca–Na | 50 – 90 | 10 < 50 | - | - |
| Na–Ca | 10 – 50 | 50 < 90 | - | - |
| Na–K | 0 – 10 | 90 - 100 | - | - |
| Anion Facies | | | | |
| $HCO_3$ | - | - | 90 – 100 | 0 < 10 |
| $HCO_3$–Cl–$SO_4$ | - | - | 50 – 90 | 10 < 50 |
| Cl–$SO_4$–$HCO_3$ | - | - | 10 – 50 | 50 < 90 |
| Cl–$SO_4$ | - | - | 0 – 10 | 90 – 100 |

Ca = calcium; Cl = chloride; $CO_3$ = carbonate; $HCO_3$ = bicarbonate; K = potassium; meq/L = milliequivalents per liter; Mg = magnesium; Na = sodium; $SO_4$ = sulfate.

Stiff plots were generated for the February 2021 samples from OSF-99 and OSF-99R. These are generated by plotting cation concentrations on the left and anion concentrations on the right to generate a polygon shape, which allows for quick visual comparison between water types. If axes are the same scale, greater concentrations produce wider polygon shapes (Fetter 2001). For this study, sodium (Na), calcium (Ca), and magnesium (Mg) were plotted on the left side of the graph as the major cations; chloride (Cl), bicarbonate ($HCO_3$), and sulfate ($SO_4$) were plotted on the right side of the graph as the major anions.

Oxygen-18 and deuterium isotope data were plotted relative to the global meteoric water line (GMWL) using Grapher (Golden Software 2020). By plotting oxygen-18 and deuterium isotope ratios on the GMWL, it is possible to determine whether different samples of groundwater have similar sources based on evaporation and precipitation effects on the sampled water. Water impacted by evaporation tends to plot beneath the GMWL due to the selective evaporation of deuterium isotopes compared to oxygen-18 isotopes, while water impacted by recent precipitation will plot above the GMWL due to enrichment of deuterium isotopes compared to oxygen-18 isotopes from meteoric waters (Zhang et al. 2012).

All samples collected post-2009 adhered to the SFWMD *Field Sampling Quality Manual*, and recent samples adhered to the 2017 revision (SFWMD 2017). The SFWMD laboratory is certified by the National Environmental Laboratory Accreditation Program. Field data and records are stored and maintained in accordance with the SFWMD *Policies and Procedures* (SFWMD 2021). Analytical data are stored in the SFWMD's DBHYDRO database and are available to the public for retrieval at https://www.sfwmd.gov/science-data/dbhydro.

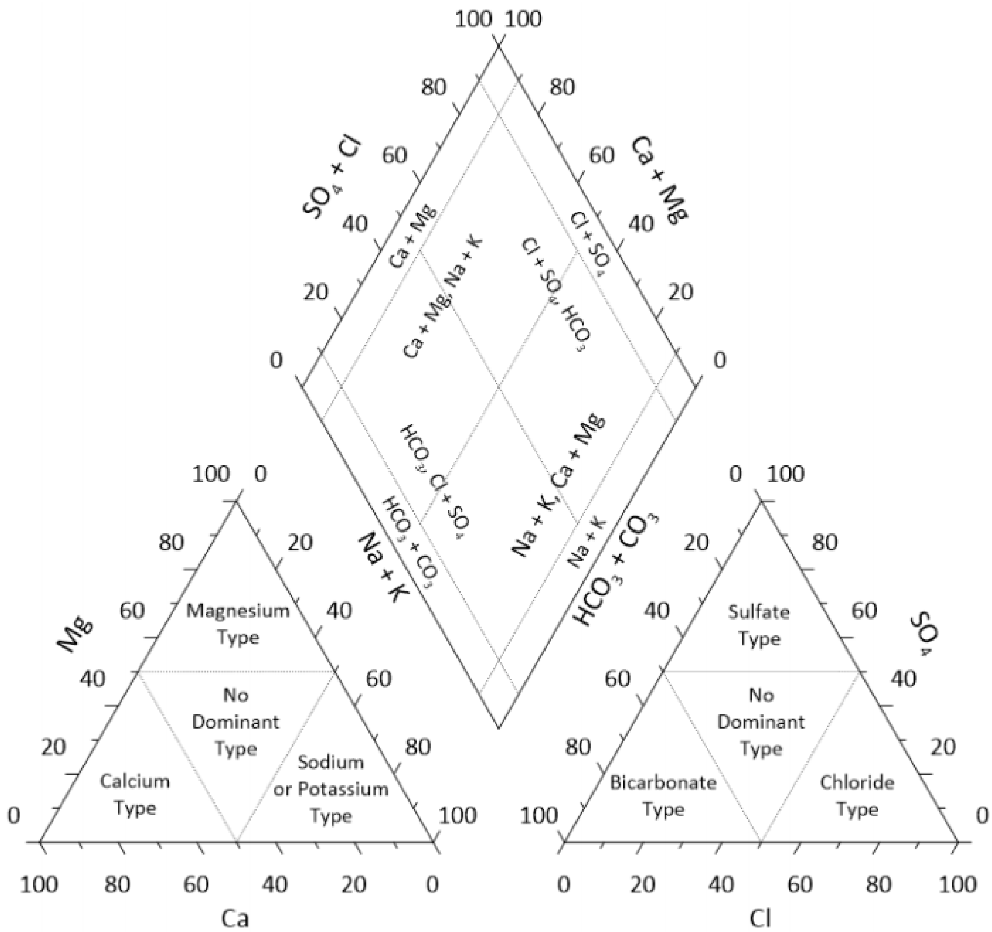


Figure 5. Classification of groundwater types (From Back 1960).

## Geophysical Logging

Geophysical logs for OSF-99R were collected by RM Baker LLC on February 13, 2020. This included caliper, sonic, induction (medium/deep), and resistivity. WellCAD (Advanced Logic Technology 2021) was utilized to plot and analyze geophysical log data. The data were compared with the same suite of logs collected from OSF-99 between November 19, 2001 and February 21, 2002.

# RESULTS AND ANALYSES

## Water Level Results

This section presents comparative hydrographs for the SFWMD Intercession City wells. **Figure 6** is a hydrograph of OSF-99 and OSF-99R monitoring wells and shows APPZ groundwater levels from April 2020 through December 2021. **Figure 7** is a hydrograph of OSF-98 and IC-TPW LFA-upper monitoring wells. **Figure 8** shows both APPZ and LFA-upper monitoring wells to demonstrate the difference in groundwater levels. Results indicate that both APPZ monitoring wells (OSF-99 and OSF-99R) and both LFA-upper monitoring wells (OSF-98 and IC-TPW) had almost identical groundwater levels. The hydraulic gradient at the Intercession City location is downward with the APPZ groundwater levels being approximately 10 ft higher than LFA-upper groundwater levels.

Both the OSF-99R and IC-TPW exhibited the same general pattern in changes to monthly water levels and daily water levels when compared to OSF-99 and OSF-98, respectively. Average and median monthly groundwater elevations for the two APPZ wells are similar, with OSF-99R being slightly higher with a maximum of ~0.3 ft difference across the compared period from April 2020 through August 2021 (**Table 5**). OSF-99 and OSF-99R featured a groundwater elevation difference of 0.12 ft on average prior to the OSF-99R pressure transducers being switched from SFWMD Hydrogeology Unit control to SCADA control in February 2021, and 0.15 ft of groundwater elevation difference on average after being switched to SCADA control. OSF-98 and IC-TPW featured a groundwater elevation difference of 0.05 ft on average prior to the IC-TPW pressure transducers being switched from SFWMD Hydrogeology Unit control to SCADA control in February 2021, and 0.20 ft of groundwater elevation difference on average after being switched to SCADA control.

Various possibilities were investigated for the source of the variations in water levels between the wells. Sensor calibration from when SCADA switched to managing OSF-99R may account for some of the groundwater elevation differences, as a jump in elevation differences is observed when the sensors were switched in February 2021 (e.g., 0.12 ft difference in average before SCADA took over to 0.15 ft difference after SCADA sensors were installed). The water elevation differences between the OSF-99 and OSF-99R before and after SCADA management may be explained by survey error range (0.02 ft) or sensor error range (0.01%). Density differences were further calculated between OSF-99 and OSF-99R to determine if density may have impacted water levels. It was found that there was a density difference of 0.03% (62.25 lb/ft$^3$ versus 62.23 lb/ft$^3$ for OSF-99 and OSF-99R, respectively), resulting in a difference in water head of 0.01 ft, another possible contributing factor to the observed elevation differences. Another potential source of the observed differences in water level before and after SCADA management of well data collection at OSF-99R and IC-TPW is the pounds per square inch (psi) ratings of the pressure transducers. The SFWMD Hydrogeology Unit used In-Situ Level TROLL 500 transducers with pressure ratings of 15 psi for OSF-99R and IC-TPW until February 2021, whereas SCADA switched to CR1000X sensors with less-accurate 30 psi sensors after February 2021.

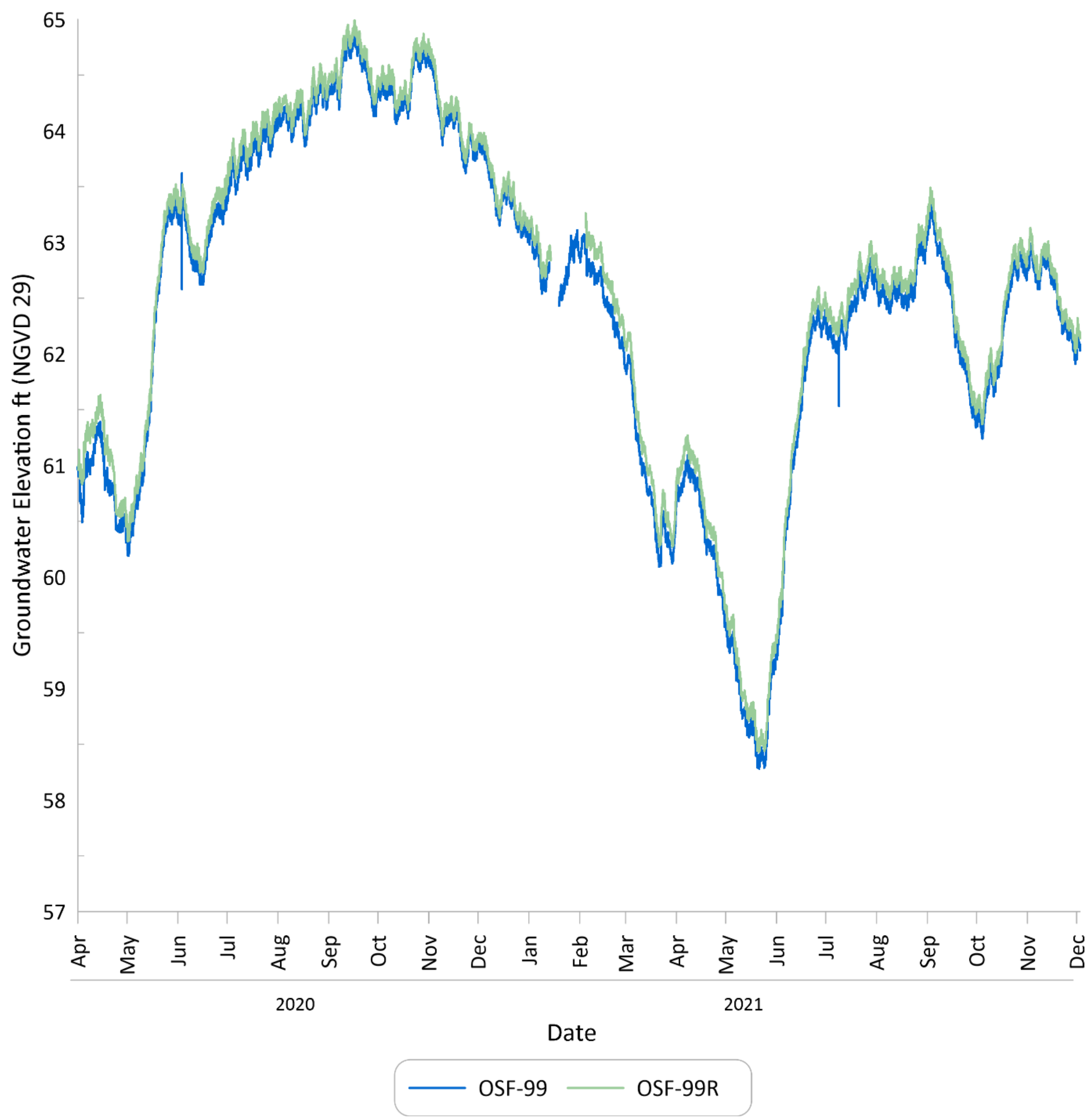


Figure 6. Hydrograph of OSF-99 and OSF-99R monitoring wells.

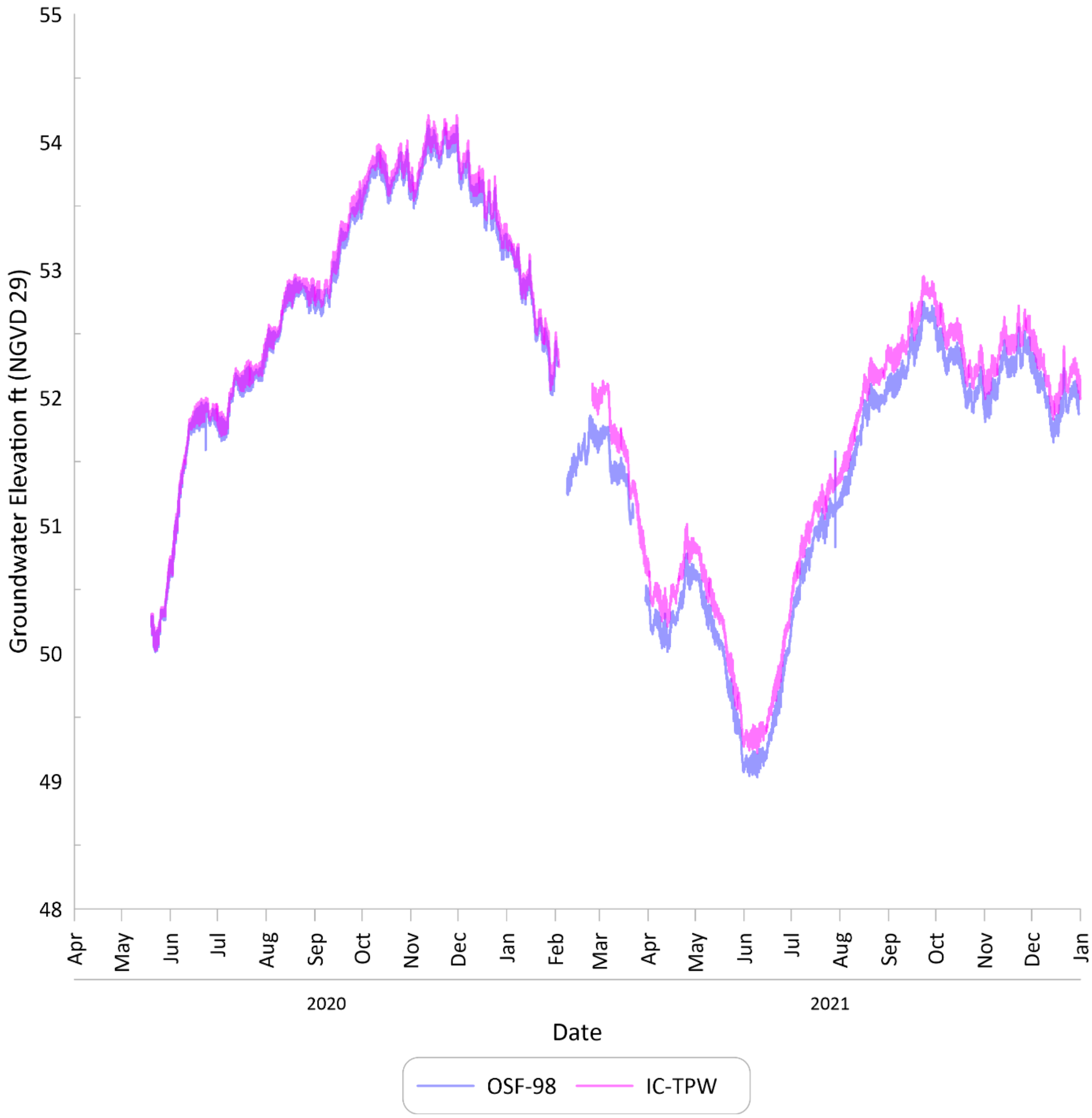


Figure 7. Hydrograph of OSF-98 and IC-TPW monitoring wells.

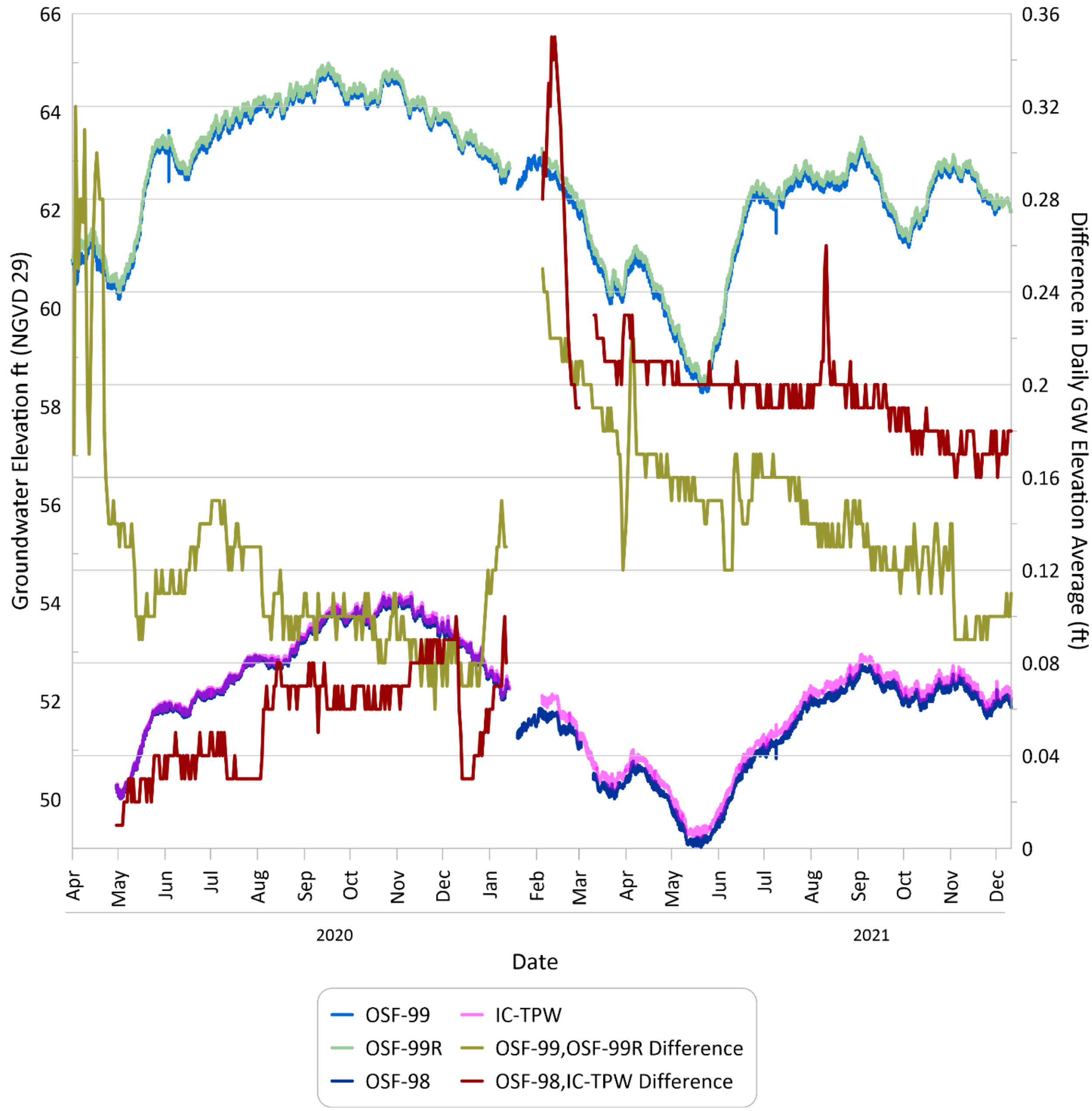


Figure 8. Hydrograph of APPZ and LFA-upper monitoring wells (OSF-99, OSF-99R, OSF-98, IC-TPW) at the Intercession City site.

Table 5. Monthly median and mean groundwater levels and differences between OSF-99 and OSF-99R.

| Date (Month-Year) | OSF-99R Median (ft) | OSF-99 Median (ft) | Median Difference (ft) | OSF-99R Mean (ft) | OSF-99 Mean (ft) | Mean Difference (ft) |
|---|---|---|---|---|---|---|
| Apr-20 | 61.24 | 60.97 | 0.27 | 61.17 | 60.91 | 0.27 |
| May-20 | 60.88 | 60.75 | 0.13 | 60.93 | 60.75 | 0.18 |
| Jun-20 | 63.15 | 63.04 | 0.10 | 62.87 | 62.76 | 0.11 |
| Jul-20 | 63.42 | 63.28 | 0.14 | 63.38 | 63.25 | 0.13 |
| Aug-20 | 64.10 | 63.98 | 0.12 | 64.07 | 63.95 | 0.12 |
| Sep-20 | 64.40 | 64.31 | 0.09 | 64.39 | 64.29 | 0.10 |
| Oct-20 | 64.51 | 64.41 | 0.10 | 64.60 | 64.50 | 0.10 |
| Nov-20 | 64.51 | 64.41 | 0.09 | 64.49 | 64.40 | 0.09 |
| Dec-20 | 63.93 | 63.85 | 0.08 | 63.94 | 63.86 | 0.08 |
| Jan-21 | 63.22 | 63.13 | 0.09 | 63.21 | 63.11 | 0.10 |
| Feb-21 | 63.00 | 62.81 | 0.19 | 62.98 | 62.83 | 0.15 |
| Mar-21 | 62.39 | 62.18 | 0.21 | 62.28 | 62.07 | 0.21 |
| Apr-21 | 60.88 | 60.70 | 0.18 | 60.79 | 60.61 | 0.18 |
| May-21 | 60.07 | 59.91 | 0.16 | 60.08 | 59.91 | 0.16 |
| Jun-21 | 58.97 | 58.82 | 0.16 | 59.32 | 59.17 | 0.14 |
| Jul-21 | 62.30 | 62.14 | 0.16 | 62.15 | 61.99 | 0.16 |
| Aug-21 | 62.67 | 62.51 | 0.16 | 62.66 | 62.52 | 0.15 |
| Sep-21 | 63.00 | 62.85 | 0.15 | 62.93 | 62.79 | 0.14 |
| Oct-21 | 61.93 | 61.80 | 0.13 | 62.02 | 61.89 | 0.12 |
| Nov-21 | 62.83 | 62.72 | 0.11 | 62.68 | 62.56 | 0.12 |
| Dec-21 | 62.27 | 62.17 | 0.10 | 62.38 | 62.28 | 0.10 |

## Water Quality Results

Descriptive statistics for major ion concentrations and field parameters for five sampling events at OSF-99 are presented in **Table 6**. OSF-99R sampling results for February 2021 are shown in **Table 7**, in comparison with results from OSF-99. **Table 8** presents the statistics for six sampling events at OSF-98. The 25th and 75th percentiles in **Tables 6** and **8** illustrate the tighter grouping of data at OSF-98 compared to OSF-99.

Table 6. Major ion concentrations and field parameter data for OSF-99 (2008 – 2021).

| Analyte | Minimum | 25th Percentile | Mean | Median | 75th Percentile | Maximum | Range |
|---|---|---|---|---|---|---|---|
| Calcium (mg/L) | 23.6 | 33.1 | 96.4 | 92.3 | 161.9 | 164.0 | 140.4 |
| Magnesium (mg/L) | 12.6 | 18.9 | 36.3 | 44.4 | 49.7 | 50.1 | 37.5 |
| Potassium (mg/L) | 0.8 | 0.9 | 1.3 | 1.5 | 1.6 | 1.6 | 0.8 |
| Sodium (mg/L) | 3.3 | 3.4 | 4.2 | 3.8 | 5.3 | 6.7 | 3.4 |
| Chloride (mg/L) | 4.4 | 4.4 | 5.4 | 5.1 | 6.7 | 8.0 | 3.6 |
| Sulfate (mg/L) | 68.8 | 127.4 | 328.4 | 367.0 | 510.0 | 512.0 | 443.2 |
| Alkalinity (mg/L) | 7.0 | 12.0 | 52.4 | 39.0 | 99.5 | 100.0 | 93.0 |
| Bicarbonate (mg/L) | 8.5 | 14.6 | 63.9 | 47.5 | 121.3 | 121.9 | 113.4 |
| TDS (mg/L) | 100.0 | 220.0 | 570.0 | 580.0 | 915.0 | 940.0 | 840.0 |
| pH | 7.6 | 7.7 | 8.5 | 9.0 | 9.2 | 9.2 | 1.6 |
| SC (µS/cm) | 249.0 | 351.5 | 736.2 | 799.0 | 1089.5 | 1105.0 | 856.0 |

µS/cm = microsiemens per centimeter; mg/L = milligrams per liter; SC = specific conductance; TDS = total dissolved solids.

Table 7. Major ion concentrations and field parameter data for OSF-99 and OSF-99R (February 2021 sampling events).

| Analyte | OSF-99 | OSF-99R |
|---|---|---|
| Calcium (mg/L) | 159.8 | 64.3 |
| Magnesium (mg/L) | 49.2 | 17.3 |
| Potassium (mg/L) | 1.6 | 0.8 |
| Sodium (mg/L) | 3.8 | 3.2 |
| Chloride (mg/L) | 5.3 | 4.5 |
| Sulfate (mg/L) | 508 | 147 |
| Alkalinity (mg/L) | 100 | 88 |
| Bicarbonate (mg/L) | 121.9 | 107.3 |
| TDS (mg/L) | 890 | 330 |
| pH | 7.7 | 8.2 |
| SC (µS/cm) | 1074 | 475 |
| Temperature (°C) | 25.7 | 24.9 |

°C = degrees Celsius; µS/cm = microsiemens per centimeter; mg/L = milligrams per liter; SC = specific conductance; TDS = total dissolved solids.

Table 8. Major ion concentrations and field parameter data for OSF-98 (2008 – 2021).

| Analyte | Minimum | 25th Percentile | Mean | Median | 75th Percentile | Maximum | Range |
|---|---|---|---|---|---|---|---|
| Calcium (mg/L) | 111.2 | 122.7 | 175.6 | 172.5 | 216.7 | 273.0 | 161.8 |
| Magnesium (mg/L) | 49.9 | 52.3 | 58.9 | 55.3 | 65.6 | 78.9 | 29.0 |
| Potassium (mg/L) | 1.6 | 1.6 | 1.7 | 1.6 | 1.7 | 1.8 | 0.2 |
| Sodium (mg/L) | 4.0 | 4.1 | 6.5 | 7.4 | 8.1 | 8.4 | 4.4 |
| Chloride (mg/L) | 6.0 | 6.0 | 8.0 | 8.8 | 9.2 | 9.4 | 3.4 |
| Sulfate (mg/L) | 480.0 | 489.0 | 586.7 | 533.0 | 677.0 | 869.0 | 389.0 |
| Alkalinity (mg/L) | 7.0 | 19.0 | 72.8 | 98.0 | 103.8 | 109.0 | 102.0 |
| Bicarbonate (mg/L) | 8.5 | 23.2 | 88.8 | 119.5 | 126.5 | 132.9 | 124.4 |
| Hardness (mg/L) | 483.0 | 521.3 | 682.5 | 658.0 | 813.0 | 1017.0 | 534.0 |
| TDS (mg/L) | 680.0 | 770.0 | 973.3 | 940.0 | 1130.0 | 1460.0 | 780.0 |
| pH | 7.6 | 7.6 | 8.2 | 7.8 | 8.9 | 9.6 | 2.0 |
| SC (µS/cm) | 908.0 | 965.0 | 1184.0 | 1141.0 | 1380.0 | 1635.0 | 727.0 |

µS/cm = microsiemens per centimeter; mg/L = milligrams per liter; SC = specific conductance; TDS = total dissolved solids.

Major cations and anions from the February 2021 sampling event were plotted on a trilinear diagram (**Figure 9**) to determine water type. While all wells plotted as calcium-sulfate type, OSF-99R had a lower sulfate concentration than the other wells which all cluster together.

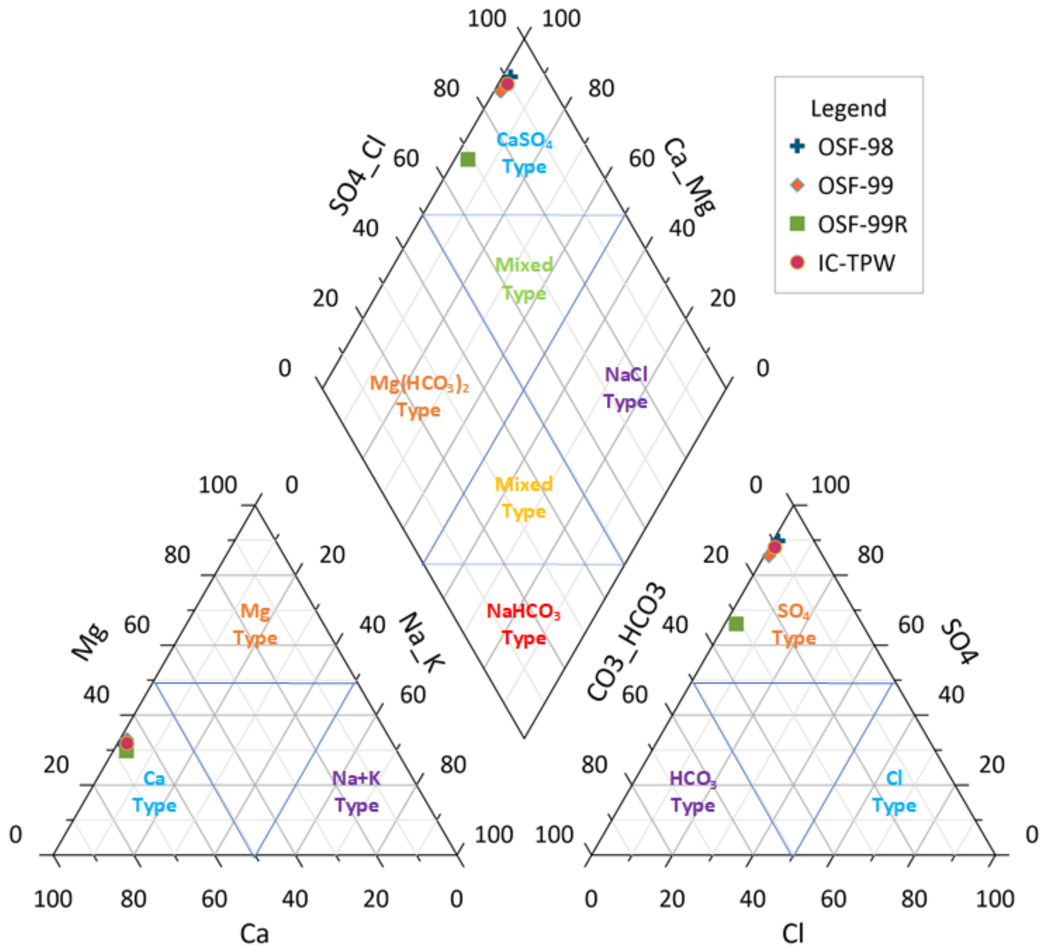


Figure 9. Trilinear diagram of Intercession City wells.

Stiff plots were generated for OSF-99 and OSF-99R (**Figure 10**) and for OSF-98 and IC-TPW (**Figure 11**). While OSF-99 and OSF-99R have similar shapes, the stiff plots indicate the latter shows slightly fresher groundwater. OSF-98 and IC-TPW stiff plots indicate the groundwater has similar ionic concentrations.

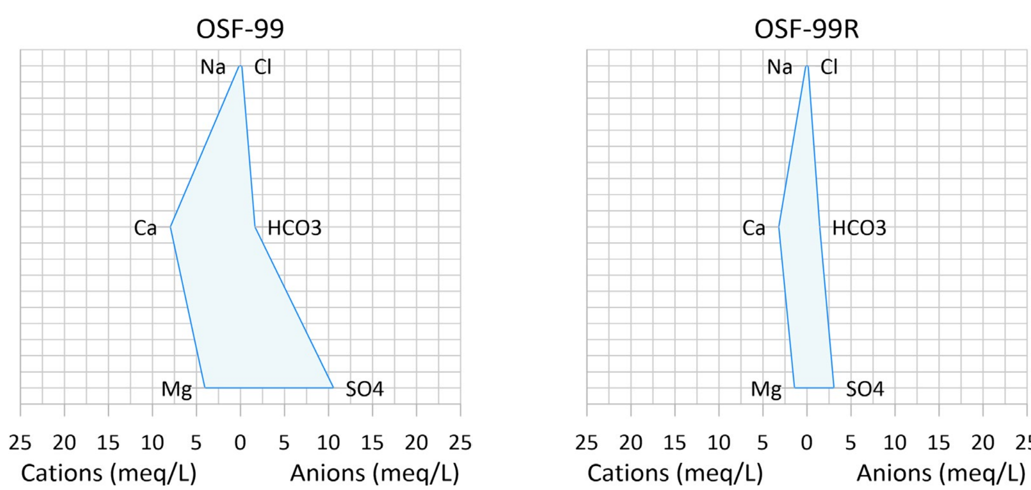


Figure 10. Stiff plots of OSF-99 and OSF-99R in milliequivalents per liter.

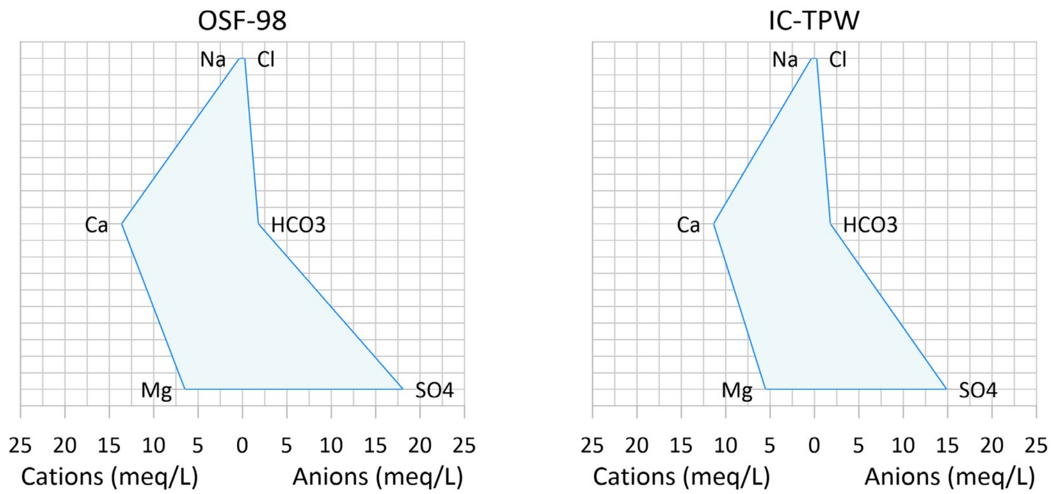


Figure 11. Stiff plots of OSF-98 and IC-TPW in milliequivalents per liter.

Oxygen-18 and deuterium isotope data are presented in **Figure 12**. OSF-99, OSF-99R, OSF-98, and IC-TPW all plot beneath the GMWL, indicating they are more influenced by evaporation than precipitation. OSF-98 and IC-TPW feature tighter clumping of data than OSF-99 and OSF-99R. OSF-99 plots approximately in between OSF-98/IC-TPW and OSF-99R.

Water quality data collected in February 2021 for OSF-99 and OSF-99R showed contrasting ionic concentrations, pH, and SC between the two APPZ wells (**Table 7**). Calcium, magnesium, sulfate, hardness, and total dissolved solids (TDS) were all more than twice the concentrations in OSF-99 compared to OSF-99R. In particular, the SC observed at OSF-99 (1,074 µS/cm) was an anomaly in the regional APPZ values (driven by anomalous sulfate values found in OSF-99 water quality samples), which ranged between 224-475 µS/cm in the surrounding APPZ wells (**Figure 4**). In contrast, the SC observed at OSF-99R (475 µS/cm) was consistent with other observed SC values in surrounding wells. The anomalous SC observed in OSF-99 during the February 2021 sampling event is consistent with previous sampling events (**Table 2**), so it is unlikely that the observed SC value is an outlier. The SC anomaly observed in OSF-99 in the regional APPZ framework paired with hydrogeochemical parameters that plot in-line with OSF-98 and IC-TPW seem to indicate a well construction issue with the OSF-99 zone in the IC-TW that results in the mixing of water from OSF-98 into OSF-99 during sampling events. Unlike the two APPZ wells, the LFA-upper wells both feature very similar water quality results from the February 2021 sampling event, indicating that the past and present data from OSF-98 are representative of formation water.

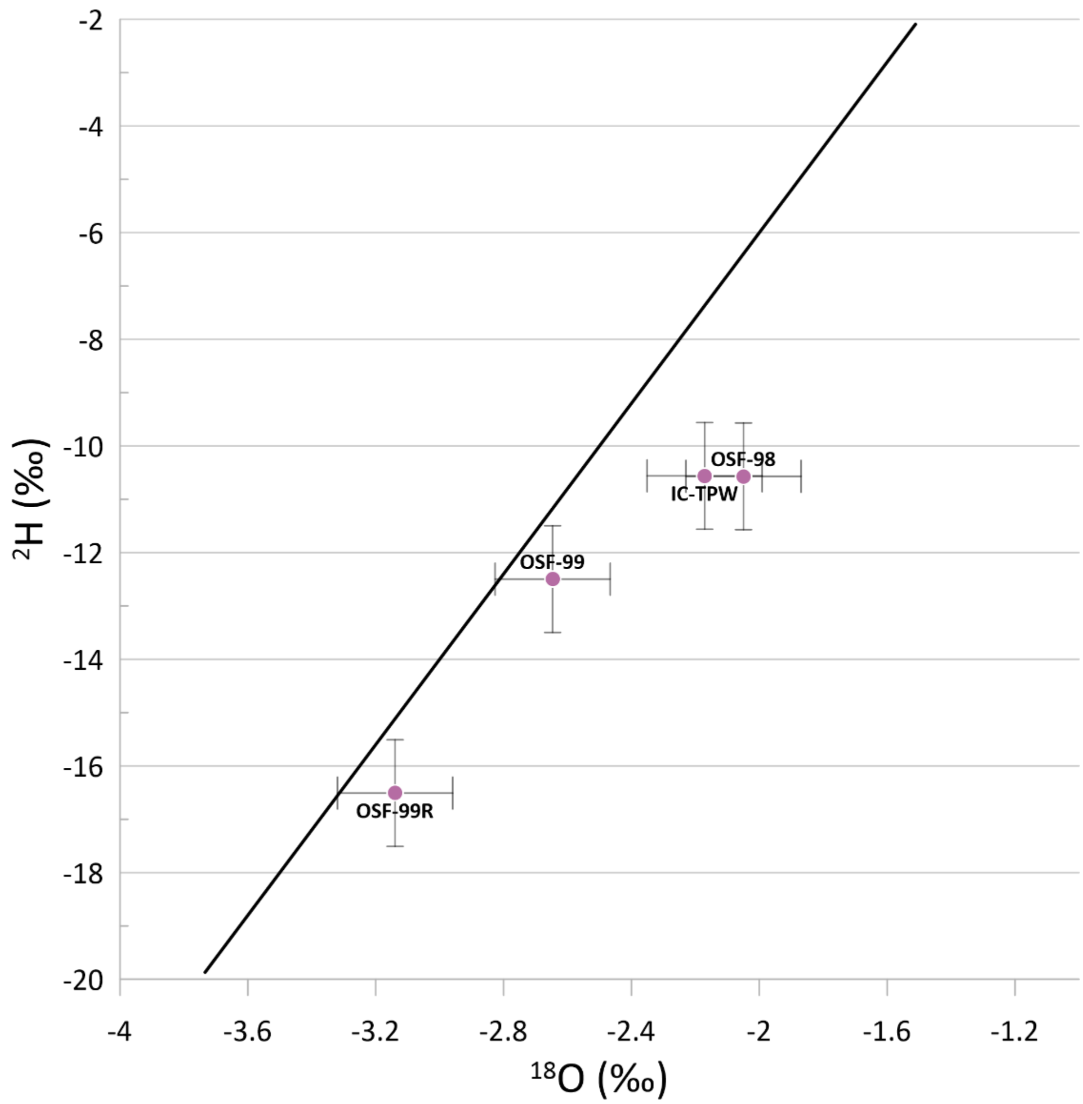


Figure 12. Oxygen-18 and deuterium isotope results.

## Geophysical Logging Results

Gamma, caliper, and resistivity logs for OSF-99 and OSF-99R were plotted for comparison (**Figure 13**). Results indicate that while minor differences exist between the logs, overall, they are nearly identical. The wells are approximately 340 ft apart, and logging was completed by two different geophysical logging firms several years apart, which also contributes to small variations seen on the logs. Due to the similarity in the geophysical logs and close proximity between the two wells, it is unlikely that minor differences between the two wells would be a contributing factor to the differences in groundwater levels and water quality.

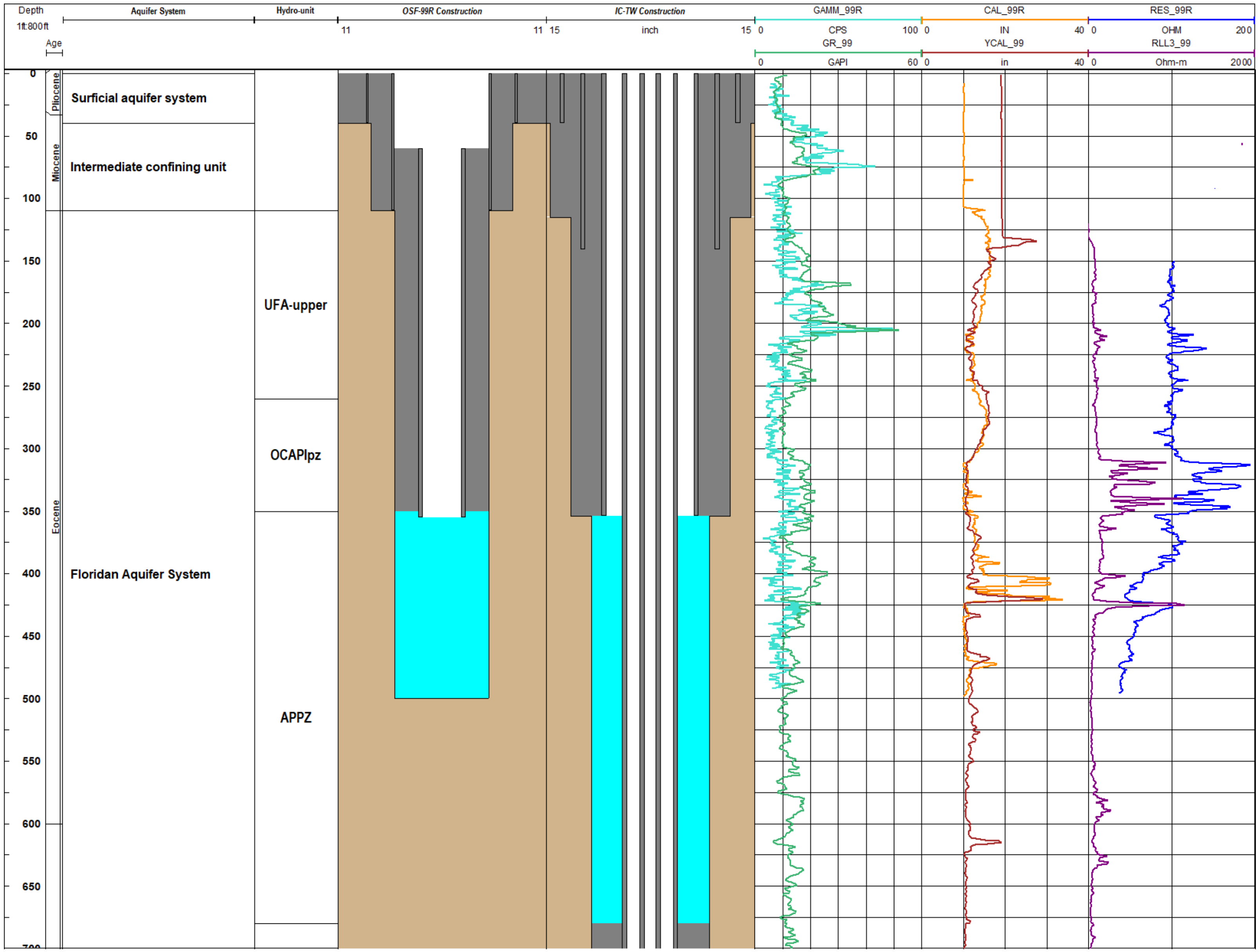


Figure 13. Geophysical logs of OSF-99 and OSF-99R.

# DISCUSSION AND RECOMMENDATIONS

Prior SFWMD efforts to ensure proper well identification and sufficient purging for representative samples have not been sufficient to resolve the anomalous water quality data observed at OSF-99. With the exception of two sampling events between 2011 and 2012, all SC values collected at OSF-99 have been analogous to what is observed in the LFA-upper at the site, rather than conforming to the expected SC values observed during the initial exploratory drilling of the IC-TW and at other APPZ wells surrounding the Intercession City site. A comparison of February 2021 water quality results from OSF-99 to the replacement APPZ well OSF-99R confirms the suspicion that OSF-99 water is not a valid reflection of formation water within the APPZ. OSF-99 features elevated SC and elevated ionic balances (particularly sulfate and calcium), showing more similarities with LFA-upper wells OSF-98 and IC-TPW than the APPZ replacement well OSF-99R. Furthermore, the oxygen-18 and deuterium results indicate that OSF-98 and IC-TPW have matching groundwater signatures, while OSF-99 and OSF-99R have dissimilar groundwater signatures, with OSF-99 data being consistent with a mix of water between the APPZ (OSF-99R) and the LFA-upper (OSF-98/IC-TPW). The anomalous water quality parameters observed over the period of record at OSF-99 indicate there is a fundamental issue with the OSF-99 data set.

Due to the downward hydraulic gradient observed between OSF-99 and OSF-98 and the 500 ft confining unit separating the APPZ from the LFA-upper, natural migration of LFA-upper formation groundwater into the APPZ is not possible. Pumping-induced upconing can also be rejected as a hypothesis due to the presence of the confining unit. Consequently, the issue with the OSF-99 zone is believed to be due to a loss of structural integrity within the well. This could have been caused by a weak grout seal between the casing components or by corrosion of the steel casing that separates OSF-99 and OSF-98 by prolonged contact with the caustic, sulfate-rich water of the LFA. During sampling events, LFA-upper formation water from OSF-98 appears to leak and mix with APPZ water from OSF-99. As OSF-99 has always been purged and sampled concurrently with OSF-98, the likelihood of such mixing to occur is high if there is a casing leak between the two zones. There is no indication that OSF-98 water quality or water level data are negatively affected based on comparisons with IC-TPW. Groundwater level data appear to be unaffected by questionable water quality results at OSF-99. The average deviation between OSF-99 and OSF-99R was 0.14 ft between 2020 and 2021, an average of 0.2% of deviation, which could be due to sensor error range or survey differences. Thus, historical water level data from OSF-99 can be assumed to be accurate.

The construction of OSF-99 as a small diameter monitoring annular zone makes it difficult to diagnose potential construction issues, but the anomalous data compared to surrounding APPZ wells combined with diverging water quality data compared to OSF-99R show that OSF-99 data are suspect. Based on the likely leakage between OSF-99 and OSF-98, it is recommended that the OSF-99 zone of the IC-TW well be abandoned, and all historical water quality results from OSF-99 be discarded as the data are not representative of formation groundwater. Historical groundwater levels from OSF-99 appear to be unaffected by the potential casing leakage and are considered appropriate for groundwater modeling and monitoring purposes. The OSF-98 and OSF-97 zones of the IC-TW may remain in operation for both water quality and water level data; however, careful observation must be kept to ensure no casing problems arise with those zones, as both feature steel casing that is susceptible to corrosion from the elevated sulfate content found in the LFA. IC-TPW can be utilized as an LFA-upper replacement well for OSF-98 should issues arise with the zone in the future. Only the OSF-97 (LFA-basal) zone of the IC-TW well currently has no analogue at the Intercession City site. It is recommended that data from OSF-97 be closely monitored and compared with other LFA-basal wells in the region to avoid water quality issues from affecting data gathered at the site. Any projects and models requiring APPZ water level data or water quality data at the Intercession City site should utilize OSF-99R, though water level data from OSF-99 continues to be representative of the APPZ in the region.

Several suggestions are offered to minimize the potential for future problems of this type. In the future, data from separate zones in multi-zone steel wells located in regions where deterioration of the casing is likely due to corrosive components in the groundwater should be monitored in order to ensure there are no water quality impacts due to casing degradation. Standard steel casings should be avoided for construction of future monitor wells where corrosion has a high probability of occurring. The narrow sampling ports at the zones of the IC-TW have made it logistically difficult and time intensive to purge and sample the wells and significantly delayed the discovery of the problem with OSF-99. Future monitor wells should have back-offs and/or wider casing diameters to facilitate efficient and accurate sampling.

Furthermore, it is recommended that regional aquifer-specific water chemistry maps be created every 5 years in order to ensure that water quality results remain representative of formation groundwater. These maps should include wells from the SFWMD's Regional Floridan Groundwater (RFGW) network of wells and any surrounding wells from the St. Johns River Water Management District and the Southwest Florida Water Management District. Doing so will help identify anomalous data trends in a timely manner and ensure that resource evaluations do not utilize erroneous data for modeling purposes.

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