Groundwater Chemistry of the Lower Floridan Aquifer – Upper Permeable Zone in Central and South Florida

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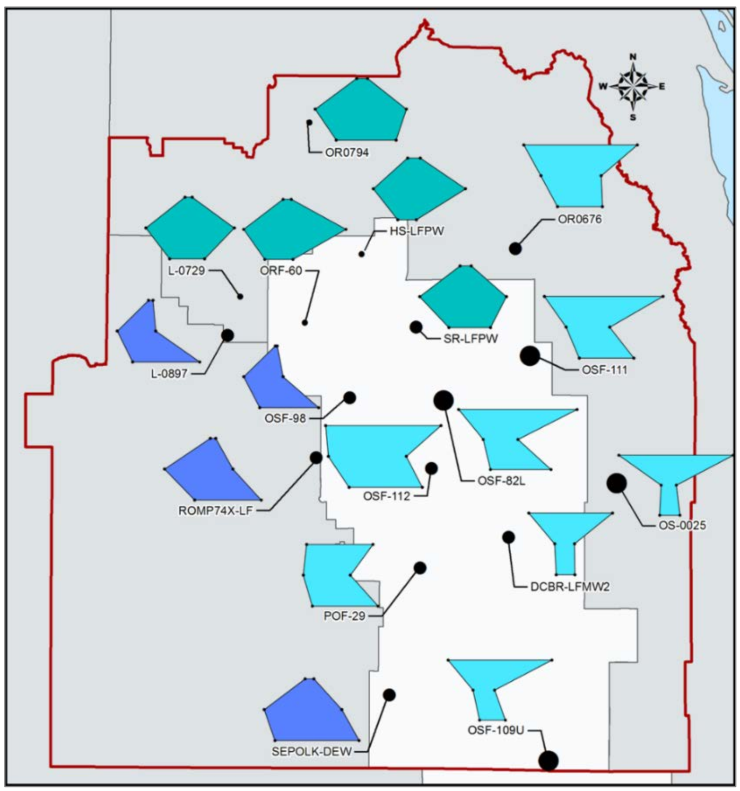

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ACRONYMS AND ABBREVIATIONS

CFWI	Central Florida Water Initiative
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
ft	foot
GMU	Glauconite Marker Unit
LEC	Lower East Coast
LFA	Lower Floridan aquifer
LFA-upper	Lower Floridan aquifer-upper permeable zone
LKB	Lower Kissimmee Basin
LWC	Lower West Coast
mg/L	milligrams per liter
MCU	middle confining unit
NAVD88	North American Vertical Datum of 1988
RFGW	Regional Floridan Groundwater (monitoring network)
SC	specific conductance
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SWFWMD	Southwest Florida Water Management District
TDS	total dissolved solids
UEC	Upper East Coast

INTRODUCTION

Overview

The South Florida Water Management District (SFWMD) samples Regional Floridan Groundwater (RFGW) monitoring network wells to evaluate groundwater quality status and trends in the Floridan aquifer system (FAS) within its boundaries. The RFGW network is composed of more than 100 monitor wells completed within the various zones of the FAS. Data from the RFGW network are incorporated into groundwater models used by water supply planners to determine long-term viability of the FAS as a water source (Geddes et al. 2018).

The water quality of the Lower Floridan aquifer – upper permeable zone (LFA-upper) is the primary subject of this investigation. There are 15 monitor wells in the RFGW network completed in the LFA-upper within the SFWMD. Water quality data from six additional monitor wells within the Southwest Florida Water Management District (SWFWMD) and St. Johns River Water Management District (SJRWMD) and four wells belonging to water supply utilities are included for completeness. This report summarizes and evaluates major ionic and physical parameter data. **Figure 1** shows the location of the 25 monitor wells used in this investigation along with the boundary of the Central Florida Water Initiative (CFWI) planning area, which includes portions of the SFWMD, SJRWMD, and SWFWMD. For the purposes of this investigation, the CFWI planning area is synonymous with Central Florida. The various planning areas within the SFWMD are shown in **Figure 1** and referred to throughout this report.

The CFWI is a collaborative effort to address water supply issues in Central Florida. The CFWI team includes the SFWMD, SJRWMD, SWFWMD, Florida Department of Environmental Protection (FDEP), Florida Department of Agriculture and Consumer Services, and local stakeholders. Observed and simulated effects on natural systems indicate the traditional groundwater source—the Upper Floridan aquifer—is at or approaching its safe, sustainable yield. Future water demands may need to rely on alternative water sources such as the LFA (CFWI 2015).

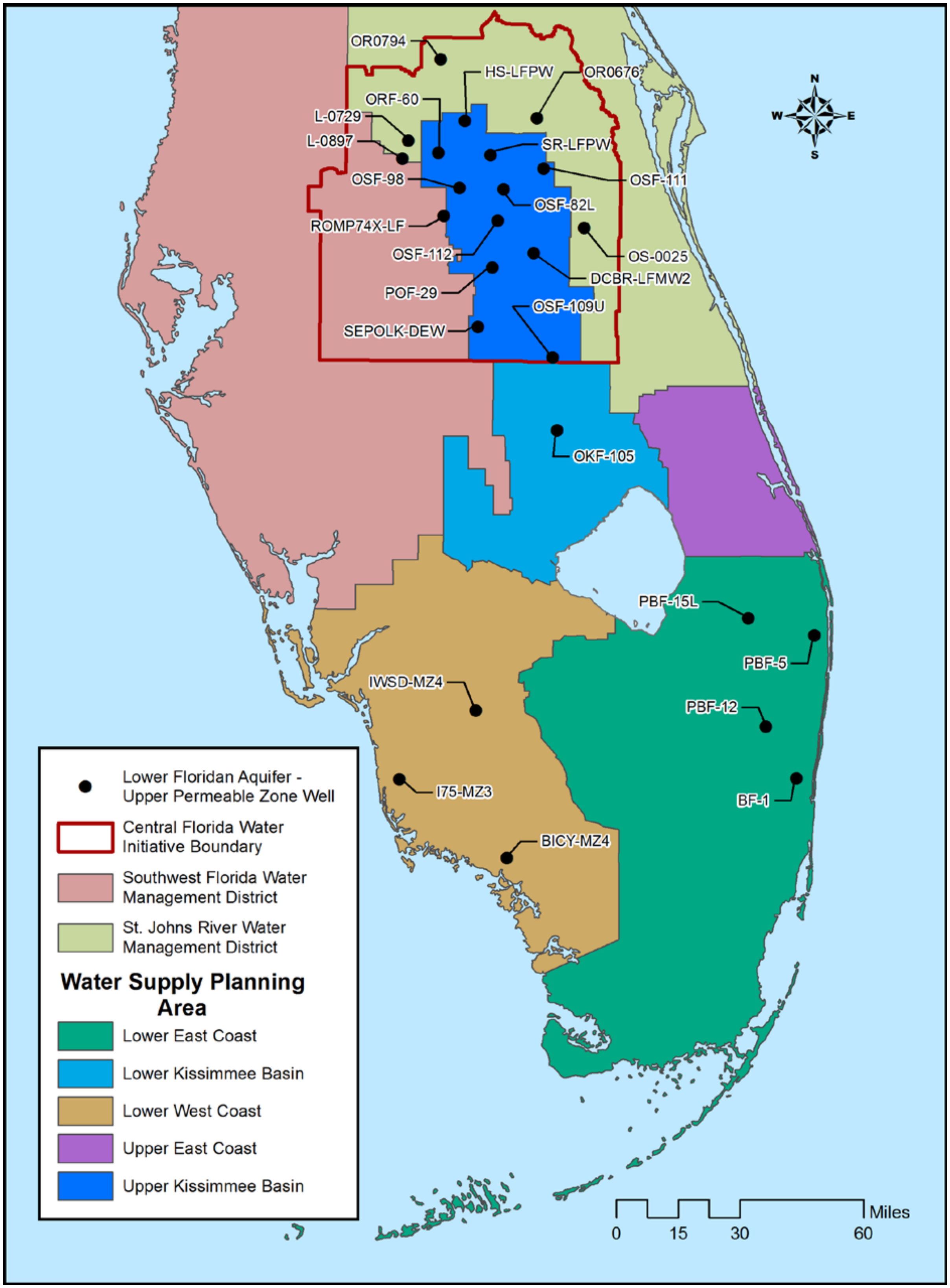

Figure 1. Location of wells completed in the Lower Floridan aquifer – upper permeable zone in Central and South Florida.

Regional Geology and Hydrogeology

The hydrogeologic framework of Central and South Florida has been described and refined over time by numerous investigators, including Miller (1986), Meyer (1989), Reese and Richardson (2008), and Williams and Kuniansky (2015). Present throughout the SFWMD, the FAS is composed of a series of permeable zones, semi-confining zones, and confining zones. The formations are Tertiary in age and range from Oligocene to Paleocene. The FAS is separated from the overlying surficial aquifer system by the intermediate confining unit. The thickness of the intermediate confining unit varies across the SFWMD and generally is thicker and deeper from north to south. The Upper Floridan aquifer of the FAS is separated from the LFA by the middle confining unit (MCU), which can be semi-confining to confining, depending on location within the SFWMD (Williams and Kuniansky 2015). The LFA is separated into two permeable zones by the Glauconite Marker Unit (GMU), which is near the top of the Oldsmar Formation. The GMU is based on the glauconite marker horizon of Reese and Richardson (2008), mapped by Williams and Kuniansky (2015), and is identified based on its distinct gamma-ray spike on geophysical logs. The two zones are the LFA-upper and the underlying basal permeable zone. The basal permeable zone is in the Oldsmar Formation and includes the Boulder Zone. The base of the LFA (and the FAS) is bounded by the underlying Sub-Floridan confining unit. **Figure 2** outlines the relationships between the hydrogeologic and lithostratigraphic units in the FAS. The position of the LFA-upper, which is the focus of this report, is outlined in red in **Figure 2**.

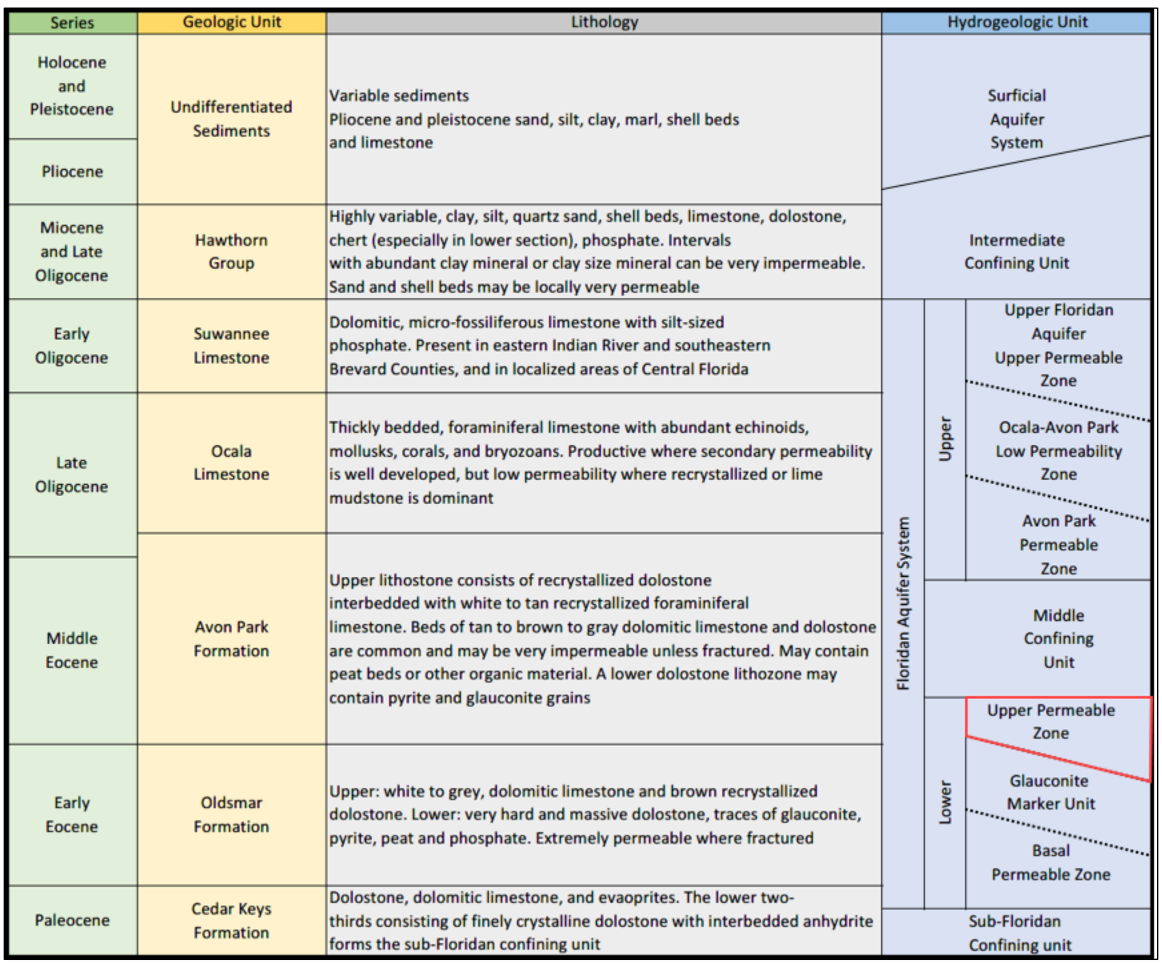

Figure 2. Hydrogeologic and lithostratigraphic units in Central and South Florida (Modified from: Sepulveda et al. 2012, Williams and Kuniansky 2015).

In Central Florida, the top of the LFA (and the LFA-upper) is at the base of the Avon Park Formation. This occurs at approximately -1,000 feet (ft) North American Vertical Datum of 1988 (NAVD88) and dips to approximately -2,600 ft NAVD88 in the southern end of the Florida peninsula (**Figure 3**). The GMU is the base of the LFA-upper (**Figure 4**). This marker unit may be absent in parts of southwestern Florida. The elevation of the GMU ranges from approximately -1,200 ft NAVD88 in Central Florida to more than -2,800 ft NAVD88 in South Florida (**Figure 5**). Nomenclature for the permeable zone between the top of the LFA and the GMU varies in the literature. This technical publication will follow the nomenclature established by the CFWI Hydrologic Assessment Team (2016), which refers to this production zone as the LFA-upper (**Figure 4**).

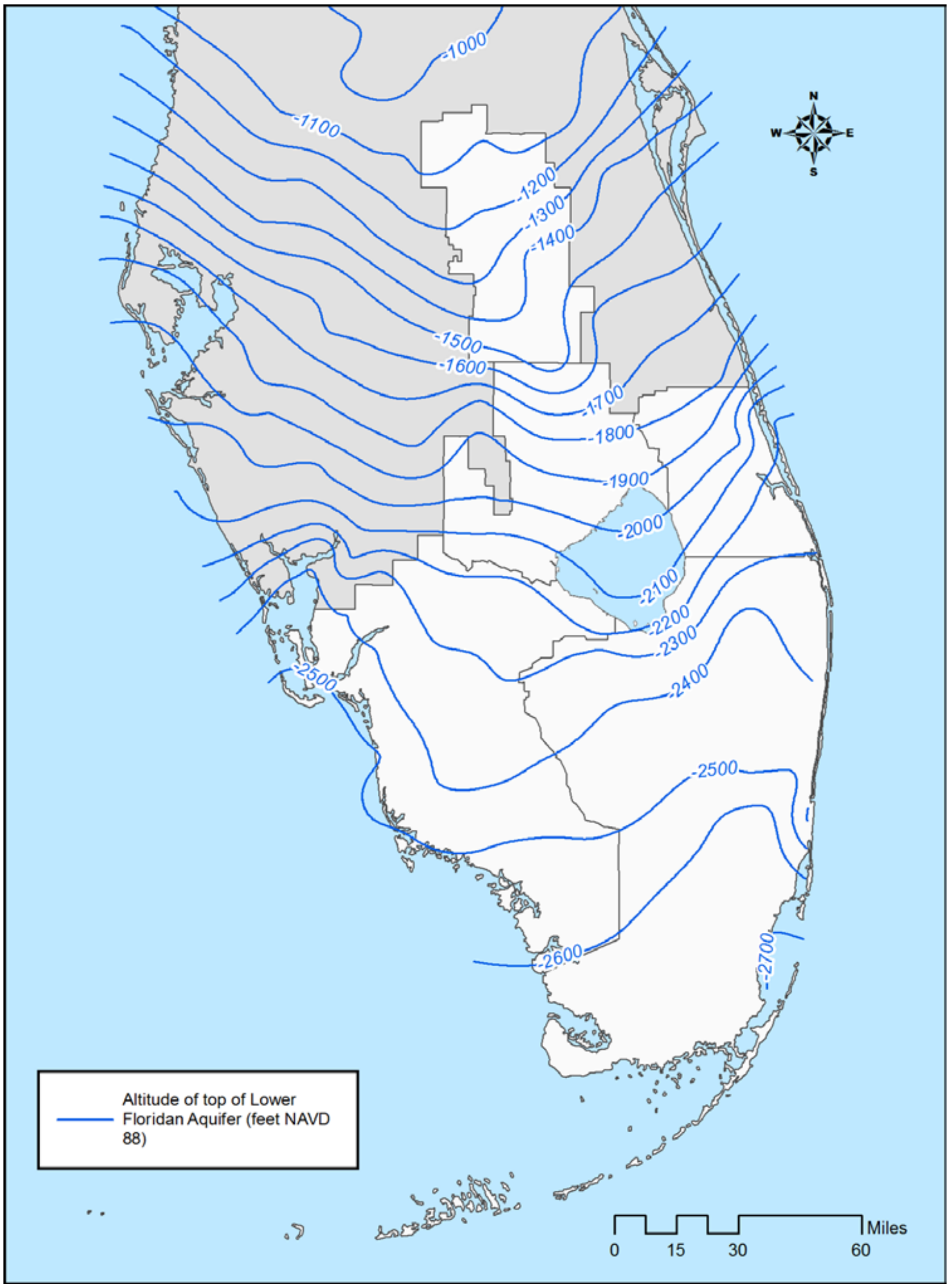

Figure 3. Altitude of the top of the Lower Floridan aquifer in Central and South Florida (Modified from: Williams and Kuniansky 2015).

<table>
<tr><th></th><th>Miller (1986)</th><th>Reese and Richardson (2008)</th><th colspan="2">Williams and Kuniansky (2015)</th><th>CFWI Hydrologic Assessment Team (2016)</th></tr>
<tr><td rowspan="7">Floridan Aquifer System</td><td rowspan="3">Upper Floridan Aquifer</td><td>Upper Floridan Aquifer</td><td rowspan="3">Upper Floridan Aquifer</td><td>Uppermost permeable zone (UPZ)</td><td>Upper permeable zone (UFA-upper)</td></tr>
<tr><td>Middle Confining/ Semi-Confining Unit 1</td><td>Ocala-Avon Park low permeability zone (OCAPlpz)</td><td>Ocala-Avon Park low permeability zone (OCAPlpz)</td></tr>
<tr><td>Avon Park Permeable Zone</td><td>Avon Park Permeable Zone (APPZ)</td><td>Avon Park Permeable Zone (APPZ)</td></tr>
<tr><td>Middle Confining Unit (I, II, or VI)</td><td>Middle Confining Unit 2</td><td colspan="2">Middle Avon Park confining & composite units (MAPCU)</td><td>Middle Confining Unit (I or II)</td></tr>
<tr><td rowspan="3">Lower Floridan Aquifer</td><td rowspan="3">Lower Floridan Aquifer</td><td rowspan="3">Lower Floridan Aquifer</td><td>Lower Avon Park permeable zone (LAPPZ)</td><td>Upper lower Floridan Aquifer (LFA-upper)</td></tr>
<tr><td>Glauconitic Marker Unit (GLAUCU)</td><td>Glauconitic Marker Unit (GLAUC-lpu)</td></tr>
<tr><td>Oldsmar permeable zone / Boulder zone (OLDSPZ)</td><td>Basal Lower Floridan Aquifer (LFA-basal)</td></tr>
</table>

Figure 4. Comparison of hydrogeologic nomenclature used in this study with previous studies.

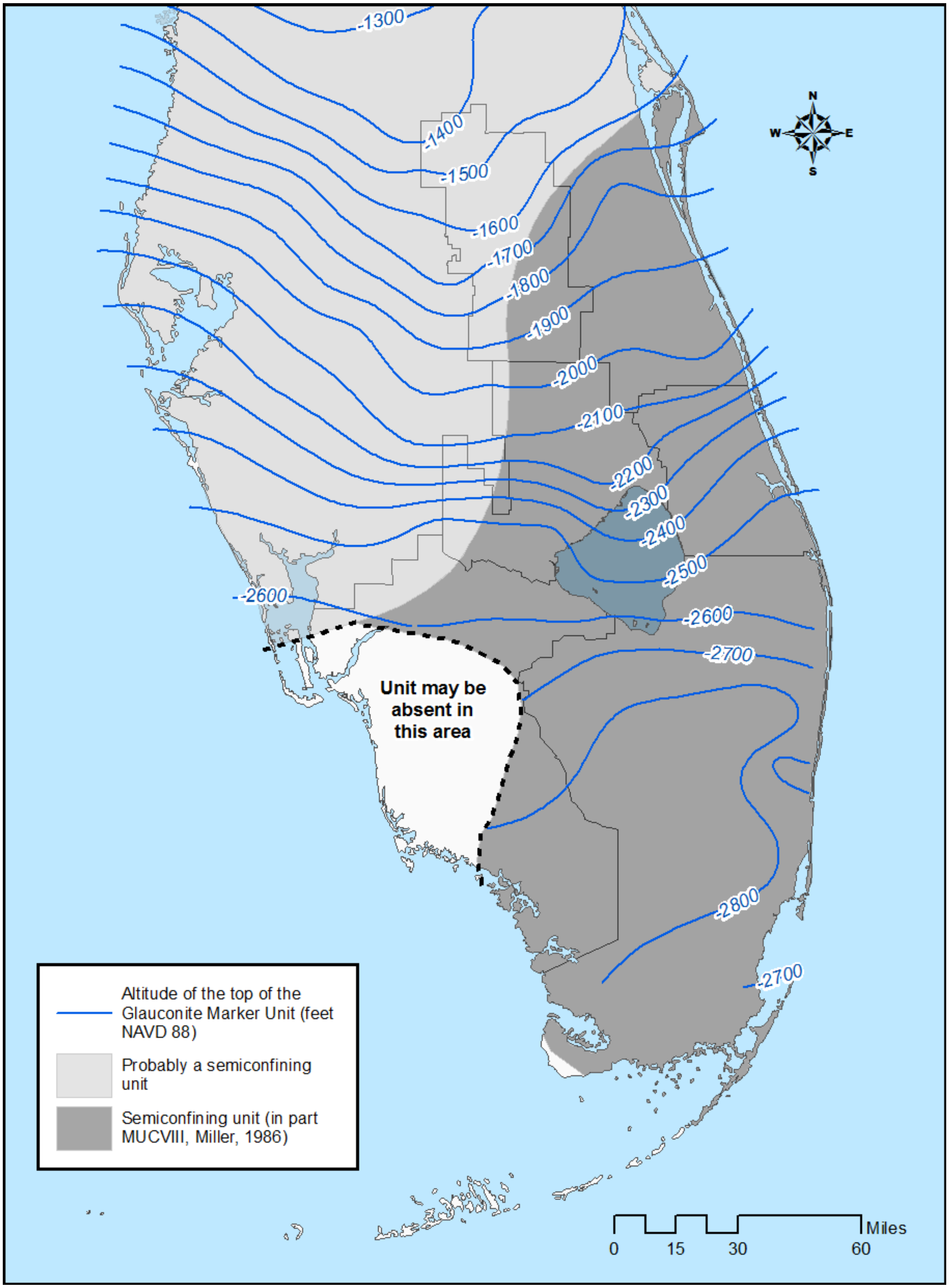

Figure 5. Altitude of the top of the Glauconite Marker Unit within the Lower Floridan aquifer in Central and South Florida (Modified from: Williams and Kuniansky 2015).

Limited hydraulic data are available due to sparse spatial coverage of wells completed in the LFA throughout much of Central and South Florida. Permeability varies spatially in the LFA-upper, with the highest transmissivity values observed in eastern Central Florida (in excess of 500,000 ft^2/day; O'Reilly et al. 2002) and low transmissivity values in southwestern Central Florida (less than 500 ft^2/day; CFWI Hydrologic Analysis Team 2016). Primary and secondary porosity influence transmissivity in the LFA, and spatial variability may be due to infilling of secondary porosity. Productivity of the LFA-upper decreases to the south. Due to the limited number of monitor wells in the study area, additional data points are needed to further characterize the LFA.

Water Quality

Water quality in the LFA varies across the study area, and salinity increases with depth. The data are evaluated in two regions: coastal and CFWI. Overall, water quality in the LFA-upper is fresher in the inland portions of Central Florida, with increasing salinity to the east, west, and south. Due to the lower concentrations of total dissolved solids (TDS) in Central Florida, water is withdrawn from the LFA for a variety of uses, including public water supply and agricultural irrigation (CFWI 2015).

Groundwater Chemistry

Factors affecting groundwater chemistry include the composition of recharge water, characteristics of the host rock, residence time, and distance traveled since infiltration. With increased residence and travel time within the subsurface, a general increase in TDS is observed. In addition to the above considerations, major ion composition can be affected by mixing with other groundwater types (Hem 1985).

The major cations of the LFA discussed in this investigation are sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg). Sodium originates from seawater and connate waters left behind from prior marine transgressions (Upchurch 1992). Potassium concentrations are very low compared to other major cations and typically come from saline water and the weathering of clays and potassium feldspar. The calcium ion is a product of the dissolution of dolomite, limestone, anhydrite, and gypsum. Magnesium originates from dolomite dissolution, magnesium-rich clays, and seawater transition zones (Hem 1985).

The major anions of the LFA discussed in this investigation are chloride (Cl), sulfate (SO_4), and bicarbonate (HCO_3). The chloride ion originates from seawater. Higher chloride concentrations often are found in deeper zones due to widespread saltwater intrusion during Plio-Pleistocene transgressions (Upchurch 1992). The sulfate ion may be sourced from gypsum, anhydrite, or pyrite (Freeze and Cherry 1979). For this study, alkalinity is converted to the equivalent value of bicarbonate (HCO_3). Alkalinity is derived from the dissolution of carbonate minerals and from carbon dioxide (CO_2) in the atmosphere (Hem 1985).

Few regional studies have been published regarding the water quality of the LFA in Central and South Florida. Much of the current understanding comes from site-specific investigations. For example, O'Reilly et al. (2002) summarized water quality results from 33 LFA wells with data ranging from 1996 through 2001 and focused on east-central Florida. That investigation included Orange, Brevard, and Seminole counties and parts of Lake, Osceola, Polk, Marion, Sumter, and Volusia counties. While the different zones of the LFA were noted, the results were not differentiated. The samples were analyzed for alkalinity, major ion composition, strontium, and field parameters.

METHODS

Water Quality Sampling

This investigation includes water quality data from the LFA-upper collected between 1993 and 2018 from sampling events conducted by the SFWMD, SWFWMD, and SJRWMD. Not all wells have a full period of record, and some wells only have one or two sampling events. According to the available records, groundwater sample collection followed FDEP Standard Operating Procedure 001/01 Section FS2200. All wells were sampled after water quality field parameters (pH, temperature, and specific conductance) had stabilized. Water samples were chilled, preserved in acid (as appropriate), and taken to state-certified laboratories for processing. Alkalinity was measured as calcium carbonate ($CaCO_3$) and afterwards converted to bicarbonate. The list of analyzed water quality parameters is provided in **Table 1**.

Table 1. List of water quality parameters.

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

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

Aquachem software (Schlumberger Water Services 2014) was used for ionic data analyses, and Grapher 13 (Golden Software LLC 2019) and R software (R Core Team 2019) were used to present data in graphical form. Sampling events with a charge balance error of more than 5% were excluded from the results. The charges of cations and anions must balance out or there is an error in the data. Charge balance error issues can arise due to missing ionic data, unfiltered samples, and laboratory errors (Fritz 1994). Any data flagged by the laboratories as questionable were excluded from further evaluation, as were samples with a pH greater than 8.5. A pH of 8.5 was chosen because the endpoint for the alkalinity titration is 8.3, and the YSI instrumentation for pH measurements allows ±0.2 range in calibration. Higher pH may indicate cement contamination that may have occurred during well construction. Sulfate and alkalinity results can be affected by changes in pressure and exposure to the atmosphere during groundwater sampling. Caution should be exercised when interpreting these results. The results for each major ion and field parameter were mapped using ArcMap (Esri, Inc. 2015). Averaged results were used for stations that had more than one sampling event available.

Grouping, Statistics, and Trends

Graphs were created comparing sodium to chloride and specific conductance (SC) to the sum of cations and anions to serve as additional data quality checks and to identify potential grouping by characteristics. **Figure 6** shows the SC values plotted against the sum of cations and anions. The graph shows two general clusters, one with low chloride concentrations and the other with high chloride concentrations. OKF-105 is a single data point from a packer test that plots at approximately 11,000 microsiemens per centimeter (µS/cm). This well is the only LFA-upper site located in the Lower Kissimmee Basin (LKB) planning area, and the lack of data does not allow for trend analysis.

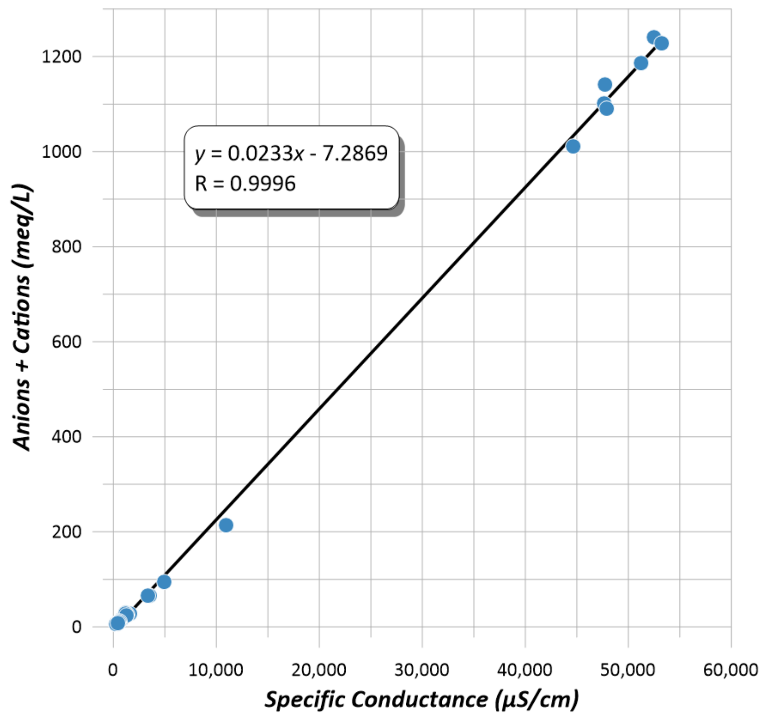

Figure 6. Correlation between specific conductance and the sum of cations and anions (in milliequivalents per liter).

The clustering in this preliminary graphing resulted in separating the results into two general regions: stations in the CFWI planning area and wells located elsewhere (i.e., the coastal group), as they are dominated by sodium and chloride ions. Further division of the CFWI stations into subgroups was done using Schoeller plots.

Schoeller (1962) developed plots that represent major ion concentrations on a semilogarithmic graph. The major ions are listed on the x-axis, and ionic concentrations are plotted on the y-axis. This approach allows multiple stations to be plotted together, and patterns readily emerge showing dominant cations and anions. One Schoeller plot was created for the average ionic concentrations at each station. Subgroups were visually determined from the clustering of the peaks and troughs, which suggest different ionic profiles. These visual subgroups were found to be regional similar and were grouped as follows:

1. Coastal group (all non-CFWI wells)
2. CFWI group
   a. Northern subgroup (HS-LFPW, L-0729, OR0794, ORF-60, and SR-LFPW)
   b. Western subgroup (L-0897, OSF-98, ROMP74X-LF, and SEPOLK-DEW)
   c. Eastern subgroup (DCBR-LFMW2, OR0676, OS-0025, OSF-82L, OSF-109U, OSF-111, OSF-112, and POF-29)

Schoeller plots were generated for the coastal group (**Figure 7**) and CFWI subgroups: northern (**Figure 8**), western (**Figure 9**), and eastern (**Figure 10**). The coastal group is dominated by sodium and chloride. OKF-105, which is farther from the coastline, has the same overall shape but lower concentrations. The northern subgroup is dominated by calcium and bicarbonate. The western subgroup has a similar profile to the northern subgroup but much higher sulfate and magnesium concentrations, resulting in a very mixed ionic profile. The eastern subgroup has two peaks in sodium and chloride concentrations, but the peaks are not as high as in the coastal group.

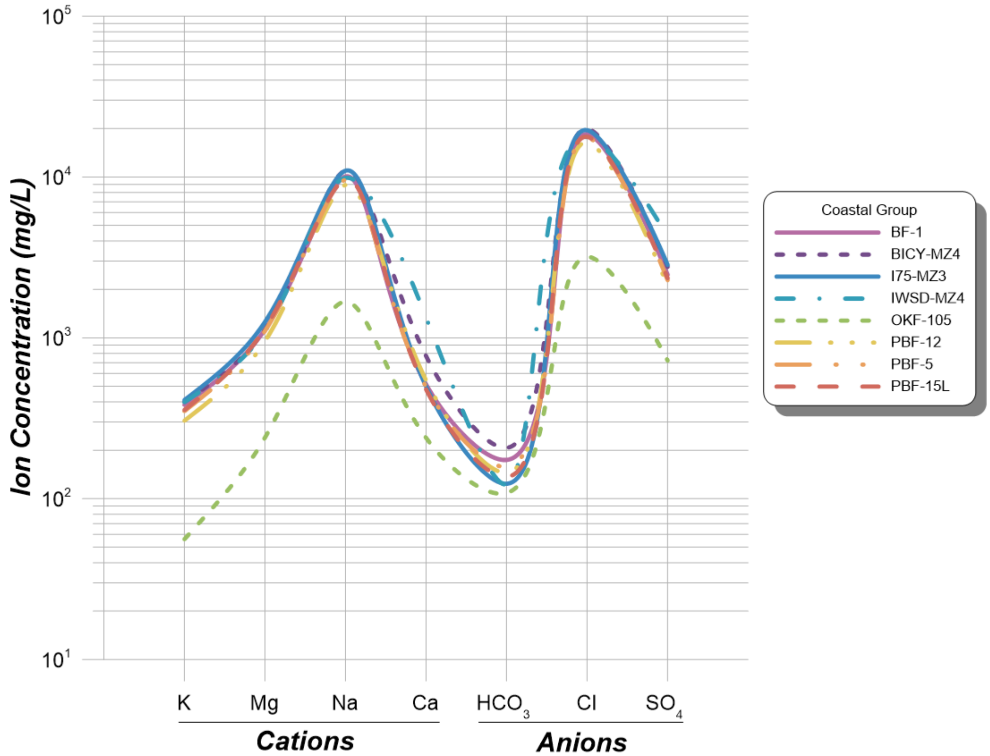

Figure 7. Schoeller plot of major ion concentrations (in milligrams per liter) at monitor wells in the coastal group.

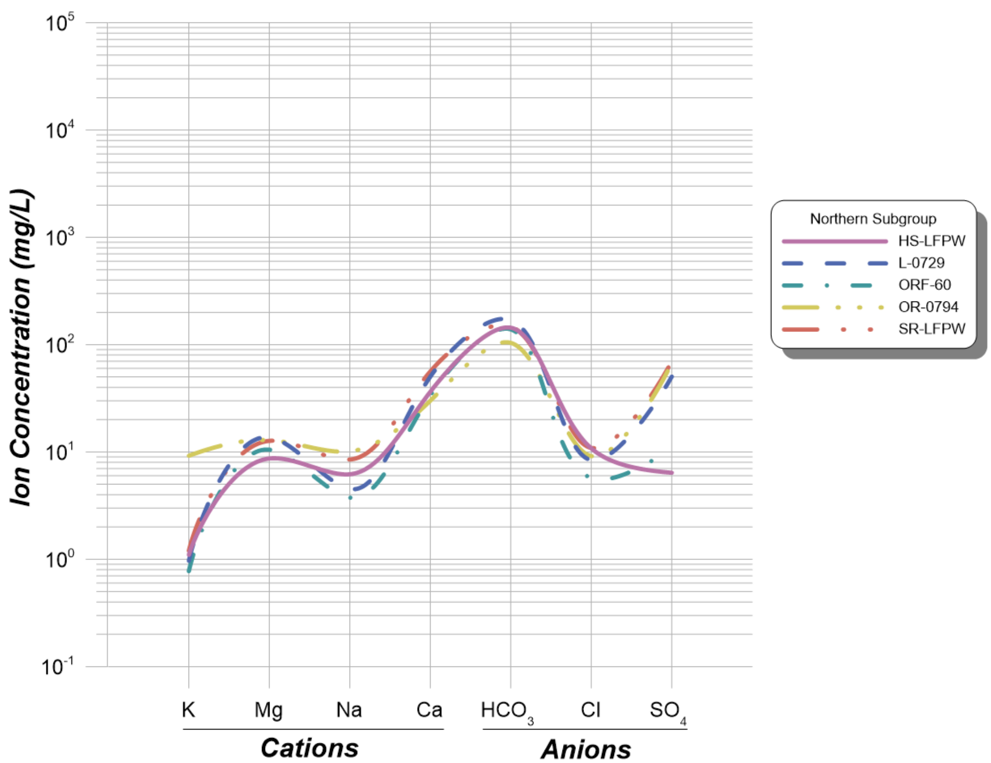

Figure 8. Schoeller plot of major ion concentrations (in milligrams per liter) at monitor wells in the Central Florida Water Initiative northern subgroup.

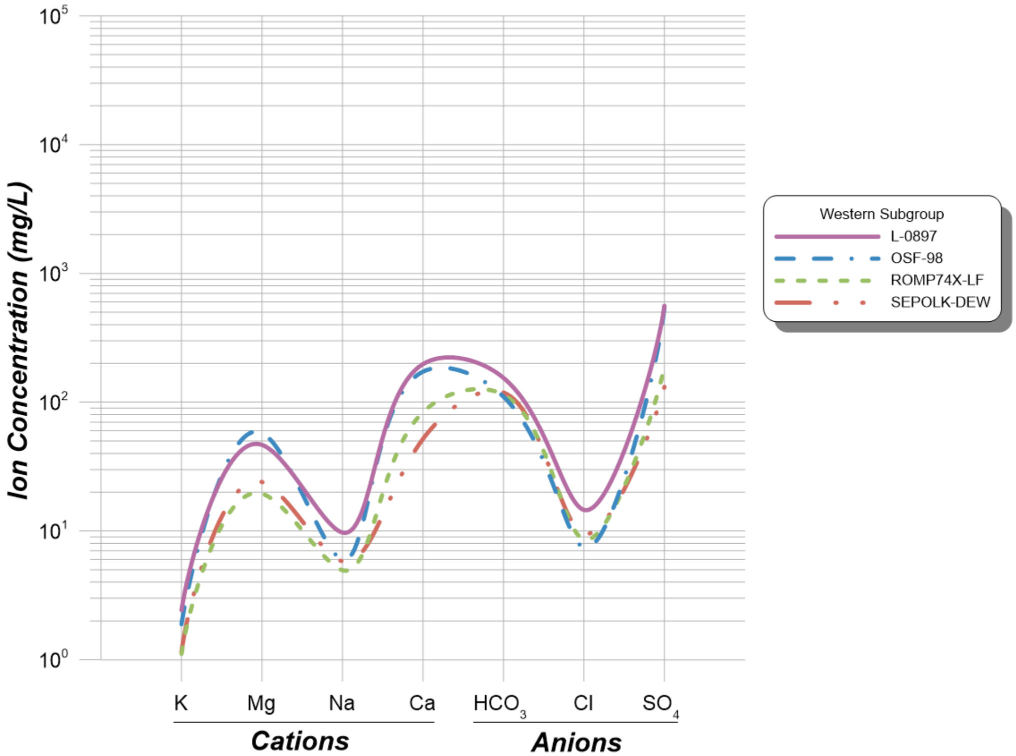

Figure 9. Schoeller plot of major ion concentrations (in milligrams per liter) at monitor wells in the Central Florida Water Initiative western subgroup.

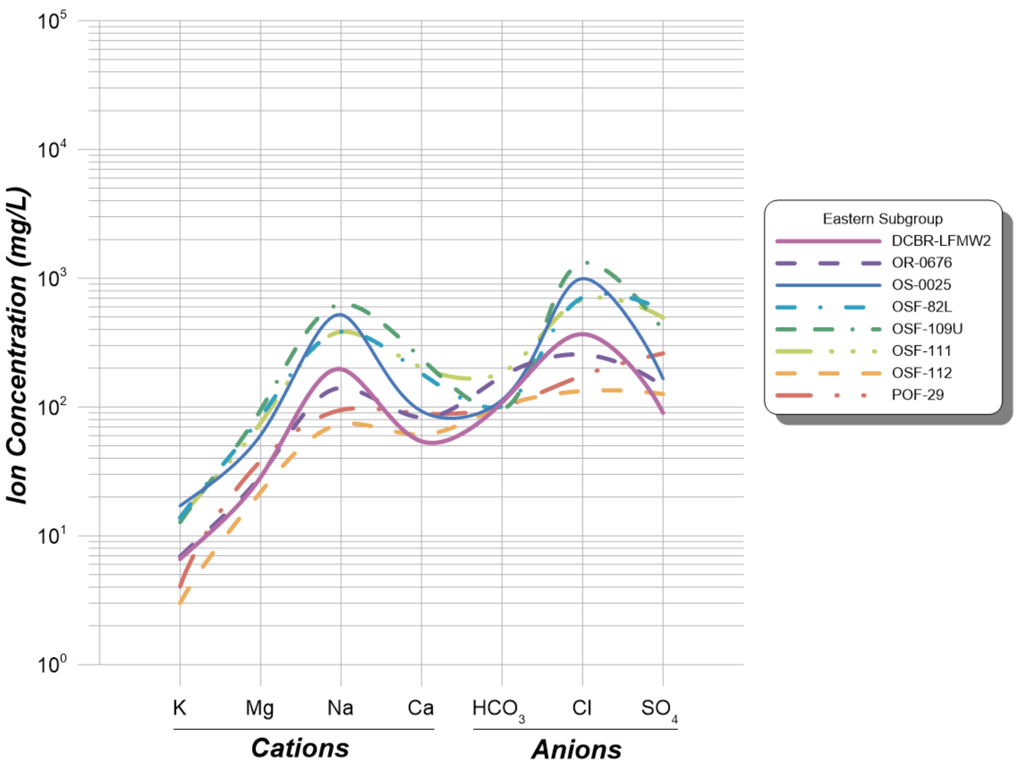

Figure 10. Schoeller plot of major ion concentrations (in milligrams per liter) at monitor wells in the Central Florida Water Initiative eastern subgroup.

Stiff diagrams were generated for the most recent sampling event at each well. These plots allow for quick visual comparison between water types. The polygon shapes are created by plotting the cations on the left and corresponding anions on the right, in milliequivalents per liter (meq/L). For this investigation, sodium and chloride are graphed on top, with calcium and bicarbonate in the middle, and magnesium and sulfate at the base of the diagram. Assuming the axes have the same scale, the greater concentrations produce a wider shape (Fetter 2001). **Figure 11** provides examples of typical stiff diagram shapes for sodium chloride dominant wells, in this case BF-1 (top left); mixed trend wells, OSF-98 (top right); and calcium carbonate dominant wells, L-0729 (bottom). BF-1 is part of the coastal group, and all coastal group stiff diagrams have the same shape but different concentrations. OSF-98 is in the western subgroup and gets its shape from the mixed dominance of sulfate, calcium, and magnesium. L-0729 is part of the northern subgroup and shares its shape with other stations from this subgroup. Overall, the ionic concentrations of wells closer to the coast will be much higher than water from wells in the CFWI planning area. Groundwater that has longer residence time and traveled greater distances tends to have a more mixed ionic composition and higher concentration.

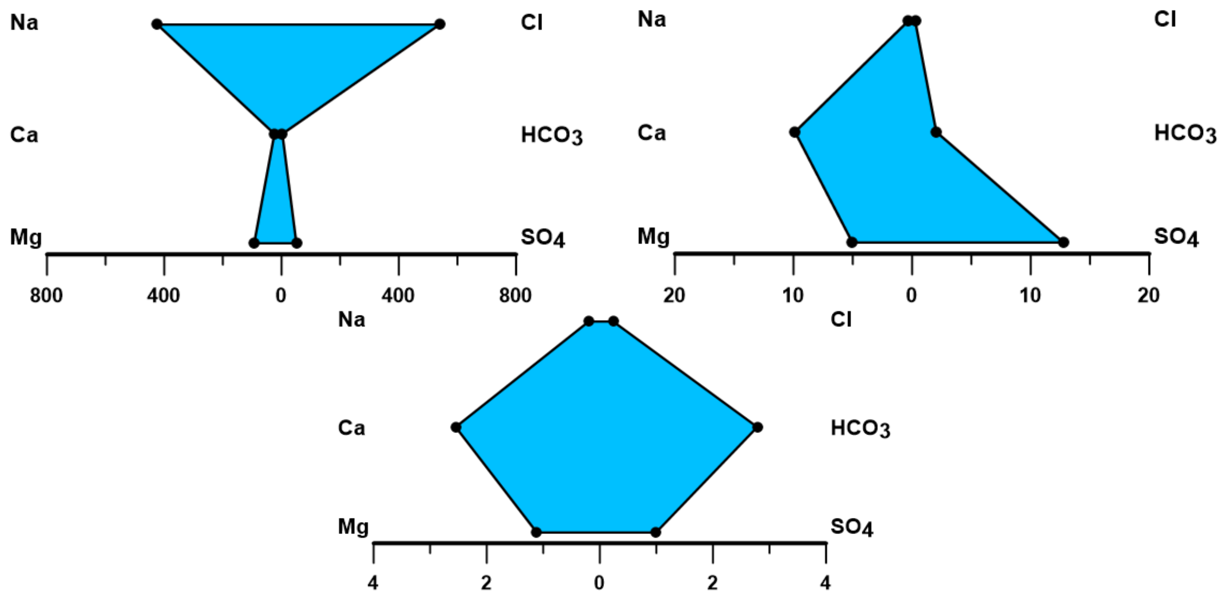

Figure 11. Stiff diagrams of BF-1 (top left), OSF-98 (top right), and L-0729 (bottom).

Groundwater quality data may exhibit a non-normal distribution and, in the presence of outliers, often has a positive skew. This is due to the data being constrained on the left by zero. Where there are only a few outliers, mean values generally are sufficient to use in data analysis. When the mean and median values of a skewed data set are not close in value, it is best to use the median as it is the central value of a data set and the 50^{th} percentile. With the exception of pH, all parameters use the mean value for plots and maps. For pH, the geometric mean is more appropriate due to it being on a logarithmic scale. Summary statistics include interquartile ranges of the 25^{th} and 75^{th} percentiles, minima and maxima, standard deviation (a measure of the variability or spread), and standard error. Standard error describes how far a given result is from the mean value and is always smaller than the standard deviation. Seasonal trends and auto-correlation also may be present, but these analyses are beyond the scope of this investigation with its limited data set (Helsel and Hirsch 2002). Summary statistics for each parameter are presented in the **Appendix**.

Spearman's rho (ρ) is a commonly used non-parametric test that measures the degree of association between variables and is based on ranks of data, not observations. It measures monotonic correlation. It does not require a normal distribution of the data and is not sensitive to outliers. Spearman's ρ values range from -1 to 1, with a positive value indicating an increasing trend and a negative value indicating a decreasing trend. The closer the value is to -1 or 1, the stronger the relationship. Analyses were run using SC for wells with five or more sampling events. The number of sampling events per well ranges from 1 to 18 for RFGW monitor wells. Statistical analyses were executed using R software (R Core Team 2019).

Hydrochemical Facies

Major cation and anion results are presented in the *Data Analyses* section. This investigation uses the classification system developed by Back (1960, 1961), which is based on numerical divisions of the cation and anion percentages of constituents. Back's scheme is based on approximately 3,000 analyses of groundwater samples and their associated lithology from the Atlantic coastal plain. The results reflect the constituents of groundwater, host rock, and flow path framework (Back 1961). **Table 2** provides information on percentage ranges and classification of water types assigned to hydrochemical facies. Hydrochemical facies provide a signature of the water sample's interactions while in residence within the subsurface. **Figure 12** demonstrates the hydrochemical facies divisions on a Piper diagram.

Table 2. Classification of groundwater hydrochemical facies (Modified from: Back 1961).

Hydrochemical Facies	Percentage of constituents (milliequivalents per liter)			
	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; Mg = magnesium; Na = sodium; SO_4 = sulfate.

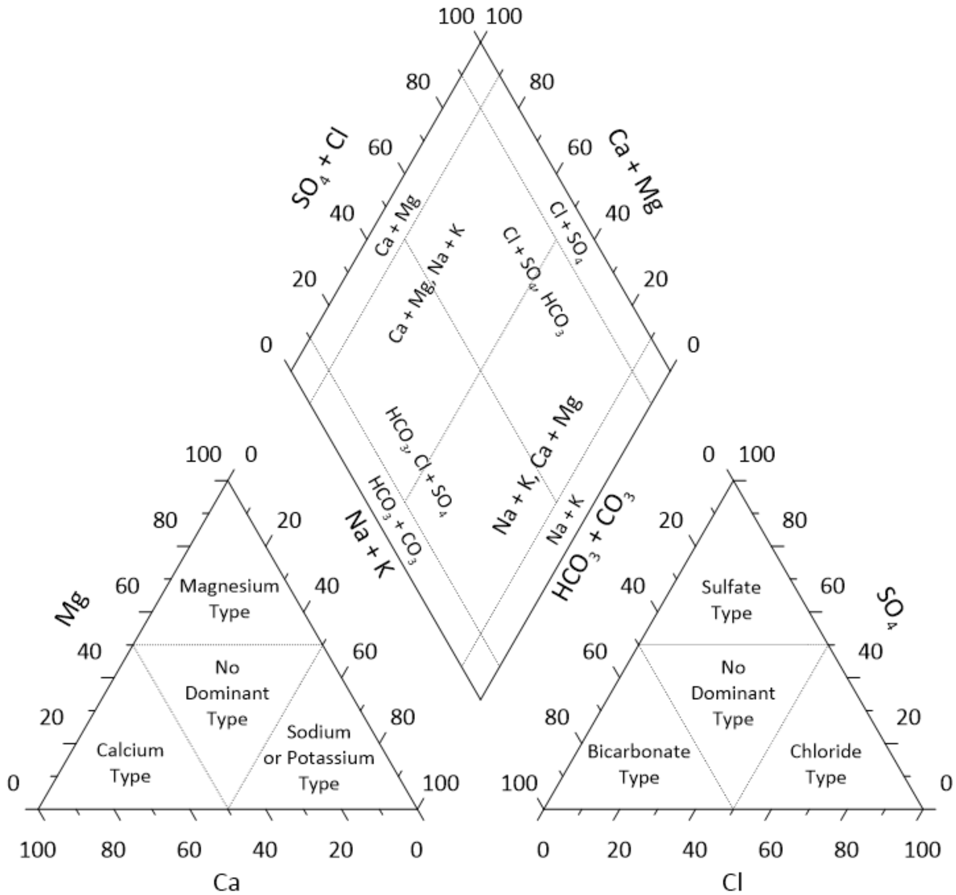

Figure 12. Classification of groundwater types (From: Back 1960).

WATER QUALITY RESULTS

This section includes summary tables, maps of parameter concentrations for all stations, and a map of stiff plots for wells within the CFWI planning area. **Table 3** summarizes the wells sampled, water types, date range, number of sampling events, and depth of monitoring intervals. **Table 4** lists the average values, by station, for LFA-upper water quality results within the RFGW monitoring network. **Figure 13** is a map showing the stiff diagram for each station in the CFWI planning area based on the most recent sampling results. Maps of major ion concentrations and parameters are presented in **Figures 14** to **24**. Temperature, pH, and SC were collected in the field. Alkalinity and sulfate concentrations are impacted by the groundwater sampling process, so caution is advised when interpreting these results.

Table 3. Summary of Lower Floridan aquifer-upper permeable zone monitoring well water types, sampling events, monitored intervals, and date ranges, by spatial group.

Well	Water Type	Date Range	Number of Sampling Events	Monitored Interval (ft bls)
Coastal				
BF-1	Na-Cl	1993 – 2014	6	2,080 – 2,280
BICY-MZ4	Na-Cl	2004 – 2015	15	2,260 – 2,505
I75-MZ3	Na-Cl	2004 – 2016	17	2,300 - 2,350
IWSD-MZ4[a,b]	Na-Cl	2000 – 2007	3	2,134 – 2,236
OKF-105[a,b]	Na-Cl	2009	1	1,614 – 1,674
PBF-12	Na-Cl	1999 – 2017	18	2,135 – 2,268
PBF-15L	Na-Cl	2008 – 2020	7	2,010 – 2,100
PBF-5	Na-Cl	1996 – 2010	17	2,340 – 2,490
Eastern				
DCBR-LFMW2[a]	Na-Cl	2013	1	1,350 – 1,560
OR-0676	Na-Ca-Cl-SO_4-HCO_3	2004 – 2018	20	1,269 – 1,300
OS-0025	Na-Cl	2002 – 2015	21	1,473 – 1,483
OSF-109U	Na-Ca-Cl	2012-2020	3	1,489 – 1,573
OSF-111	Na-Ca-Cl-SO_4	2018	1	1,145 – 1,653
OSF-112[a,b]	Na-Ca-Mg-Cl-SO_4	2018	1	1,310 – 1,340
OSF-82L	Na-Ca-Mg-Cl-SO_4	2007 – 2020	5	1,230 – 1,503
POF-29	Ca-Na-Mg-SO_4-Cl	2012 – 2015	3	1,350 – 1,685
Northern				
HS-LFPW[a]	Ca-Mg-HCO_3	2012	1	1,250 – 1,400
L-0729	Ca-Mg-HCO_3-SO_4	2007 – 2014	4	1,295 – 1,410
OR-0794	Ca-Mg-HCO_3-SO_4	2003 – 2013	9	1,050 – 1,140
ORF-60	Ca-Mg-HCO_3	2010 – 2020	4	1,170 – 1,280
SR-LFPW[a]	Ca-Mg-HCO_3-SO_4	2012	1	1,100 – 1,400
Western				
L-0897	Ca-Mg-SO_4-HCO_3	2007 – 2017	17	1,160 – 1,310
OSF-98	Ca-Mg-SO_4	2006 – 2010	4	1,220 – 1,501
ROMP74X-LF	Ca-Mg-SO_4-HCO_3	2011 – 2016	17	1,250 – 1,400
SEPOLK-DEW[a]	Ca-Mg-SO_4-HCO_3	2013	2	1,400 – 2,140

Ca = calcium; Cl = chloride; ft bls = feet below land surface; HCO_3 = bicarbonate; Mg = magnesium; Na = sodium; SO_4 = sulfate.

[a] Retired station.

[b] Packer test results.

Table 4. Average values, by Regional Florida Groundwater monitoring well, for Lower Floridan aquifer-upper permeable zone water quality results.

Well	Alkalinity	SO_4	Cl	Mg	Ca	K	Na	SC	TDS	pH	Temp.
BF-1	143	2,466	18,469	1,128	514	383	10,078	47,761	34,450	7.89	21.22
BICY-MZ4	170	2,761	19,926	1,129	771	400	10,933	52,522	36,250	6.98	27.54
I75-MZ3	102	2,838	19,536	1,257	499	411	10,944	53,267	34,849	7.42	29.01
IWSD-MZ4	101	4,259	17,685	1,100	1,340	398	9,873	51,248	34,300	7.12	28.29
OKF-105	89	722	3,193	240	239	56	1,681	10,931	6,681	6.38	29.99
PBF-12	119	2,086	16,413	952	544	305	8,923	44,637	28,094	7.32	24.77
PBF-15L	112	2,351	17,781	1,146	479	356	9,674	47,622	30,534	7.23	28.36
PBF-5	129	2,282	17,600	1,105	496	350	9,626	47,904	31,735	7.25	22.95
DCBR-LFMW2	89	90	368	29	54	7	197	1585	611	7.70	26.50
OR-0676	142	144	256	29	83	7	141	1,358	793	7.65	26.65
OS-0025	93	166	993	61	93	17	521	3,469	1,927	8.12	26.13
OSF-109U	79	395	1,313	95	238	13	628	4,958	2,843	7.7	27.03
OSF-111	152	495	679	75	203	14	383	3,530	2,148	7.30	26.70
OSF-112	83	126	133	22	61	3	74	882	563	8.00	23.00
OSF-82L	83	570	708	83	182	14	385	3,369	2,096	7.74	25.76
POF-29	83	261	176	38	89	4	95	1,256	780	7.57	26.80
HS-LFPW	118	6	11	9	36	1	6	285	134	7.90	26.40
L-0729	139	50	8	14	50	1	5	375	224	7.92	24.68
OR-0794	85	68	9	13	30	9	10	327	209	7.85	24.19
ORF-60	114	11	6	11	34	1	4	266	143	7.9	25.48
SR-LFPW	121	70	11	13	56	1	9	425	258	7.70	27.60
L-0897	127	560	15	47	198	2	10	1195	994	7.42	26.65
OSF-98	91	550	7	58	173	2	6	1164	945	7.83	25.33
ROMP74X-LF	94	190	9	19	84	1	5	598	-	7.70	27.46
SEPOLK-DEW	98	132	10	24	52	1	6	474	303	7.65	26.90

Ca = calcium; Cl = chloride; CO_3 = carbonate; HCO_3 = bicarbonate; K = potassium; Mg = magnesium; Na = sodium; SO_4 = sulfate; SC = specific conductance; TDS = total dissolved solids; Temp. = temperature.
Note: All concentration values are provided in milligrams per liter (mg/L); specific conductance is provided in microsiemens per centimeter (µS/cm); pH is unitless; and temperature is provided in degrees Celsius (°C).

Several factors play a role in spatial variation of water quality in the LFA-upper within Central and South Florida, including proximity to groundwater extraction, degree of confinement, host rock, upconing or mixing with seawater, and distance from the area of aquifer recharge. Upconing occurs when deeper, more saline water moves upward due to hydraulic stresses such as groundwater withdrawal. In general, TDS (**Figure 14**), SC (**Figure 15**), sodium (**Figure 16**), chloride (**Figure 17**), magnesium (**Figure 18**), potassium (**Figure 19**), and sulfate (**Figure 20**) have lower concentrations in inland Central Florida, while stations in southern and southwestern areas of the Florida peninsula have higher concentrations of these constituents. SC is highest in the Lower West Coast (LWC) planning area, possibly due to lower circulation within the LFA. Calcium concentrations (**Figure 21**) in Central Florida are lower than in the Lower East Coast (LEC) and LWC planning areas of the SFWMD. (Calcium levels are highest in well IWSD-MZ4 in southwestern Florida.) Alkalinity (**Figure 22**) varies greatly, with lower concentrations in Central Florida and higher concentrations in coastal areas and the LEC planning area. pH (**Figure 23**) has apparent variability, ranging from 6.38 to 8.12. Temperature was not mapped due to the potential error associated with weather conditions when a sample is taken. Recharge to the LFA-upper occurs outside of the SFWMD boundary, in northern Florida where the MCU is absent or leaky (Williams and Kuniansky 2015). Flow then continues down gradient. These flow paths run parallel to the peninsula and then towards the coastline.

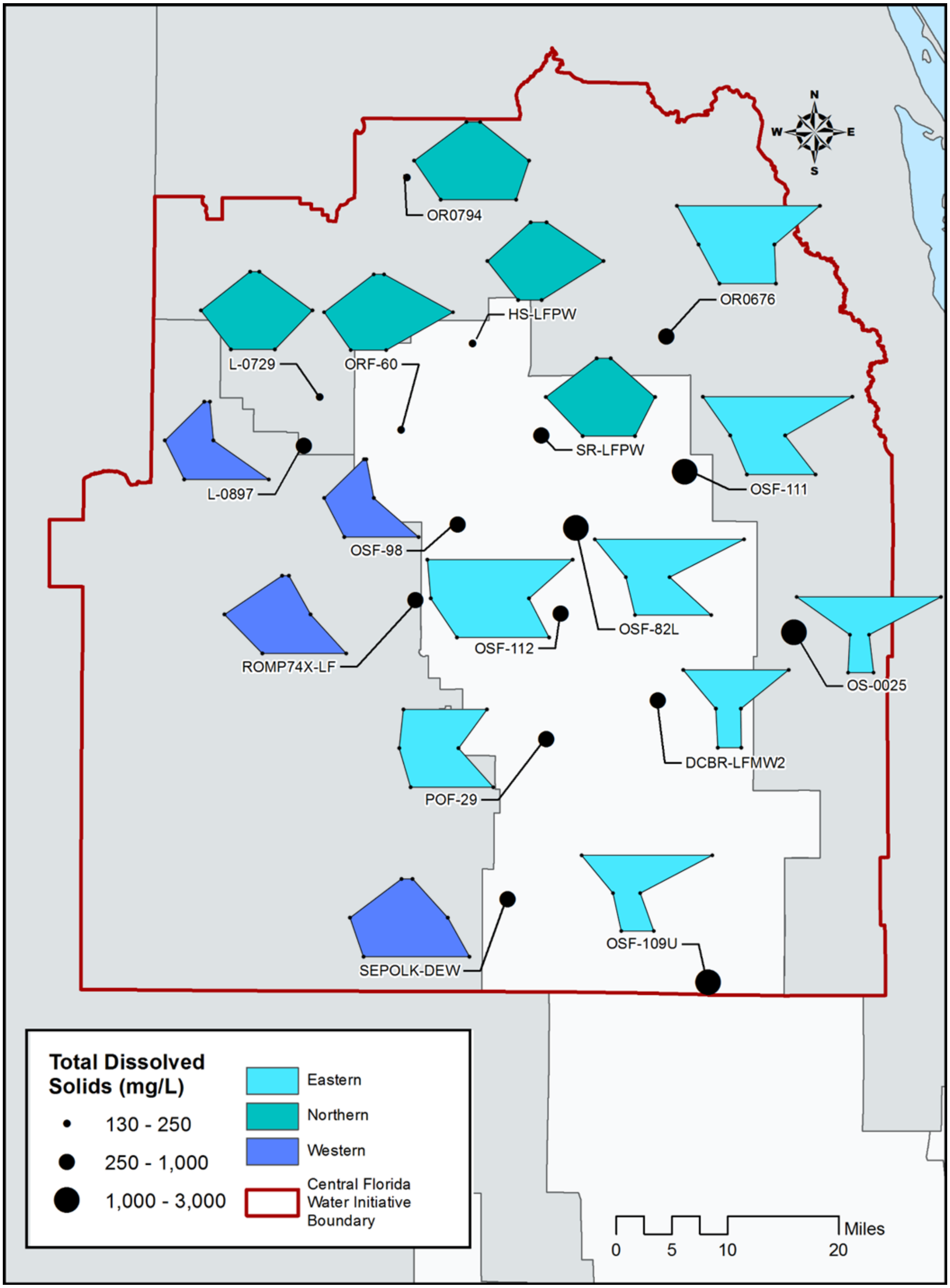

Figure 13. Map of stiff diagram results and total dissolved solids concentrations from wells completed in the Lower Floridan aquifer – upper permeable zone within the Central Florida Water Initiative planning area.

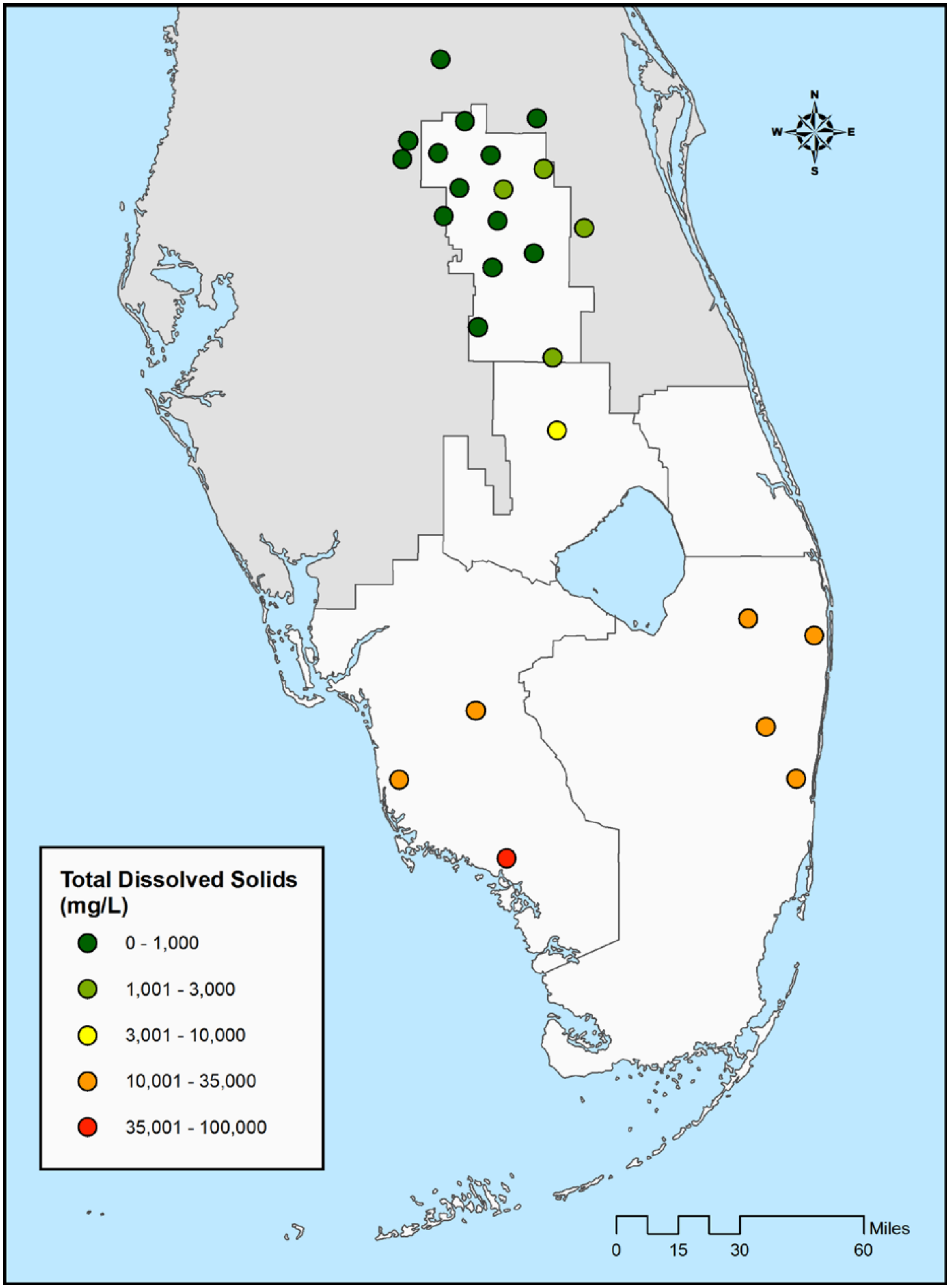

Figure 14. Map of total dissolved solids concentrations in the Lower Floridan aquifer-upper permeable zone.

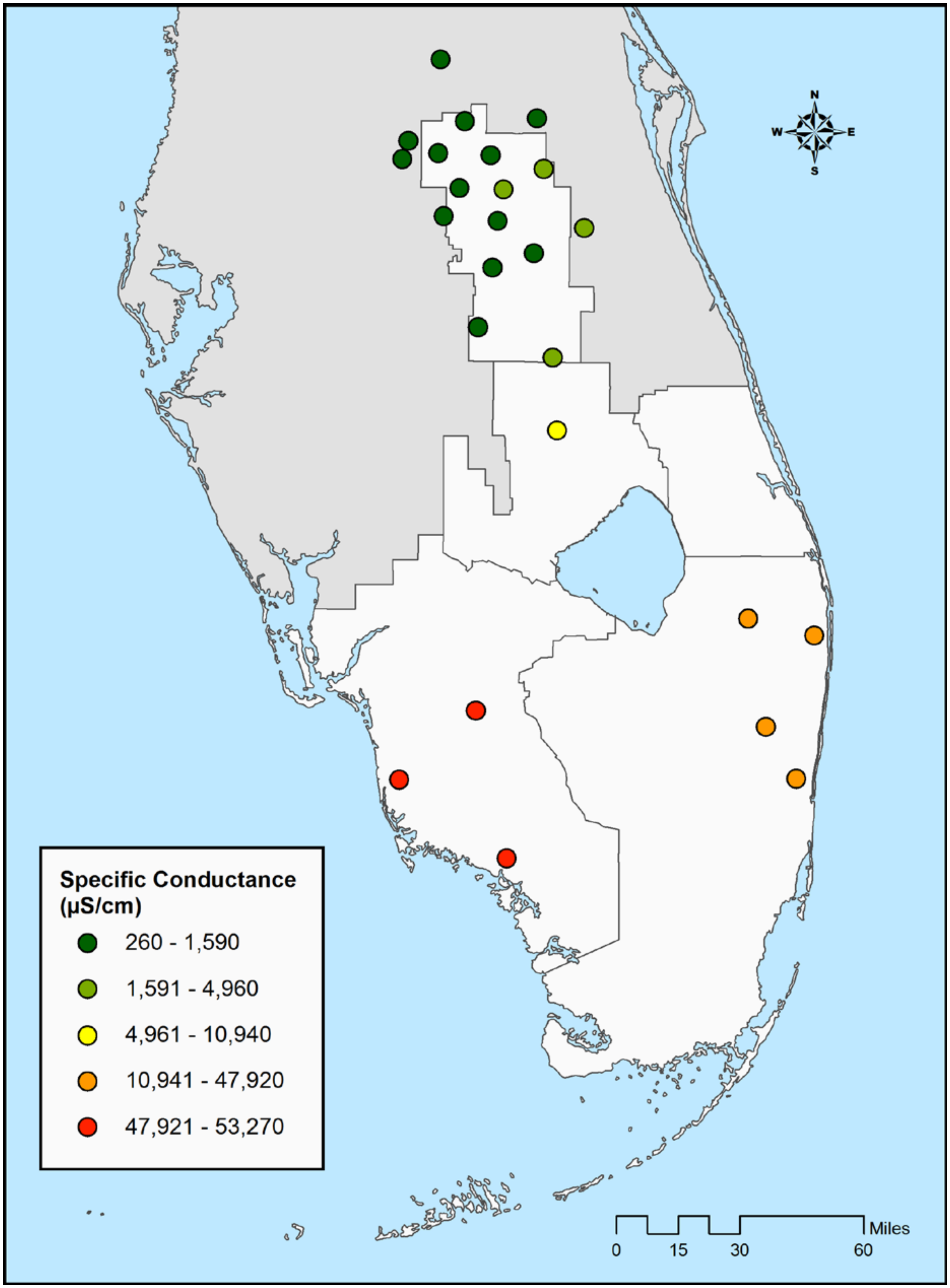

Figure 15. Map of specific conductance in the Lower Floridan aquifer-upper permeable zone.

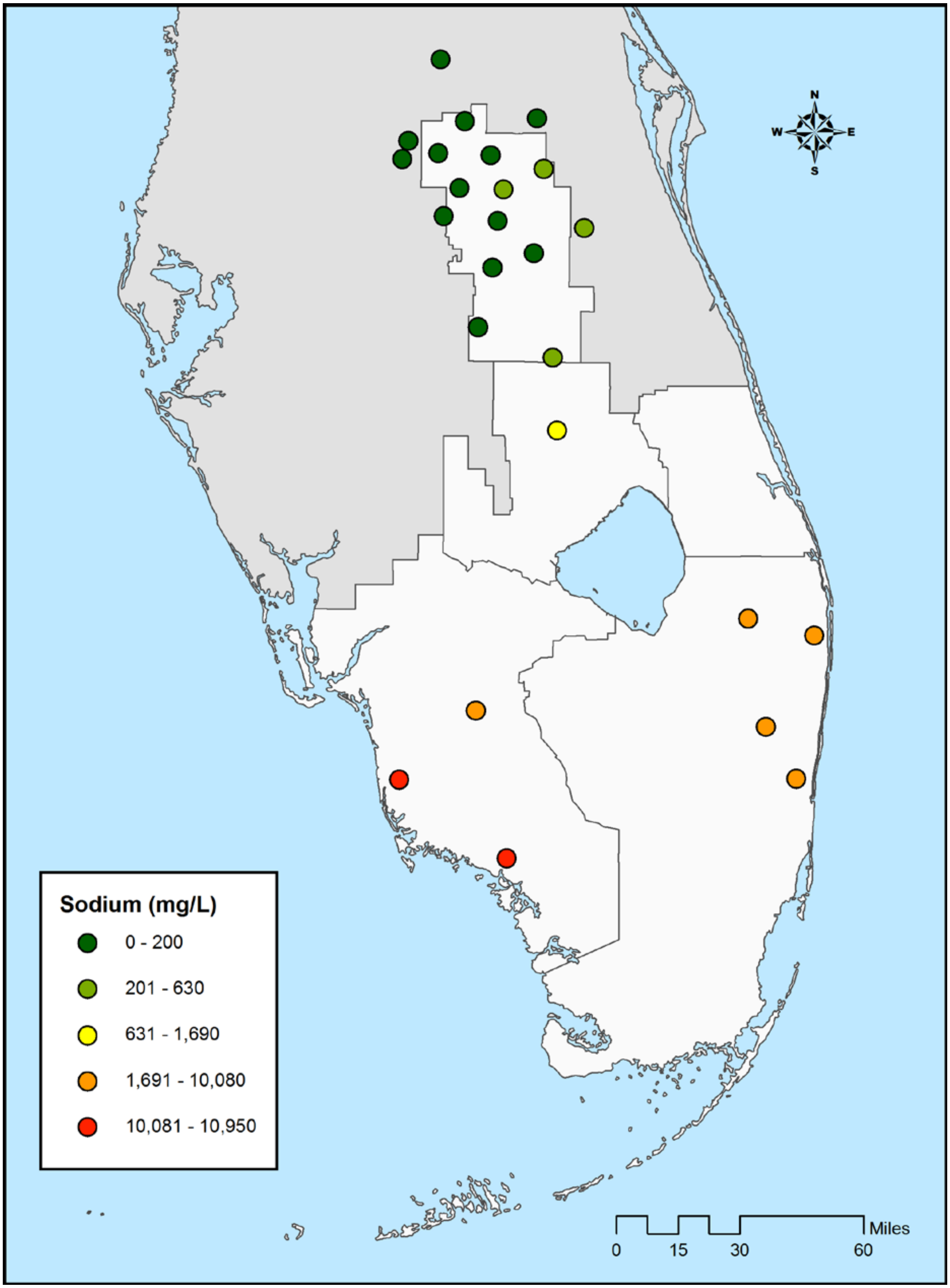

Figure 16. Map of sodium concentrations in the Lower Floridan aquifer-upper permeable zone.

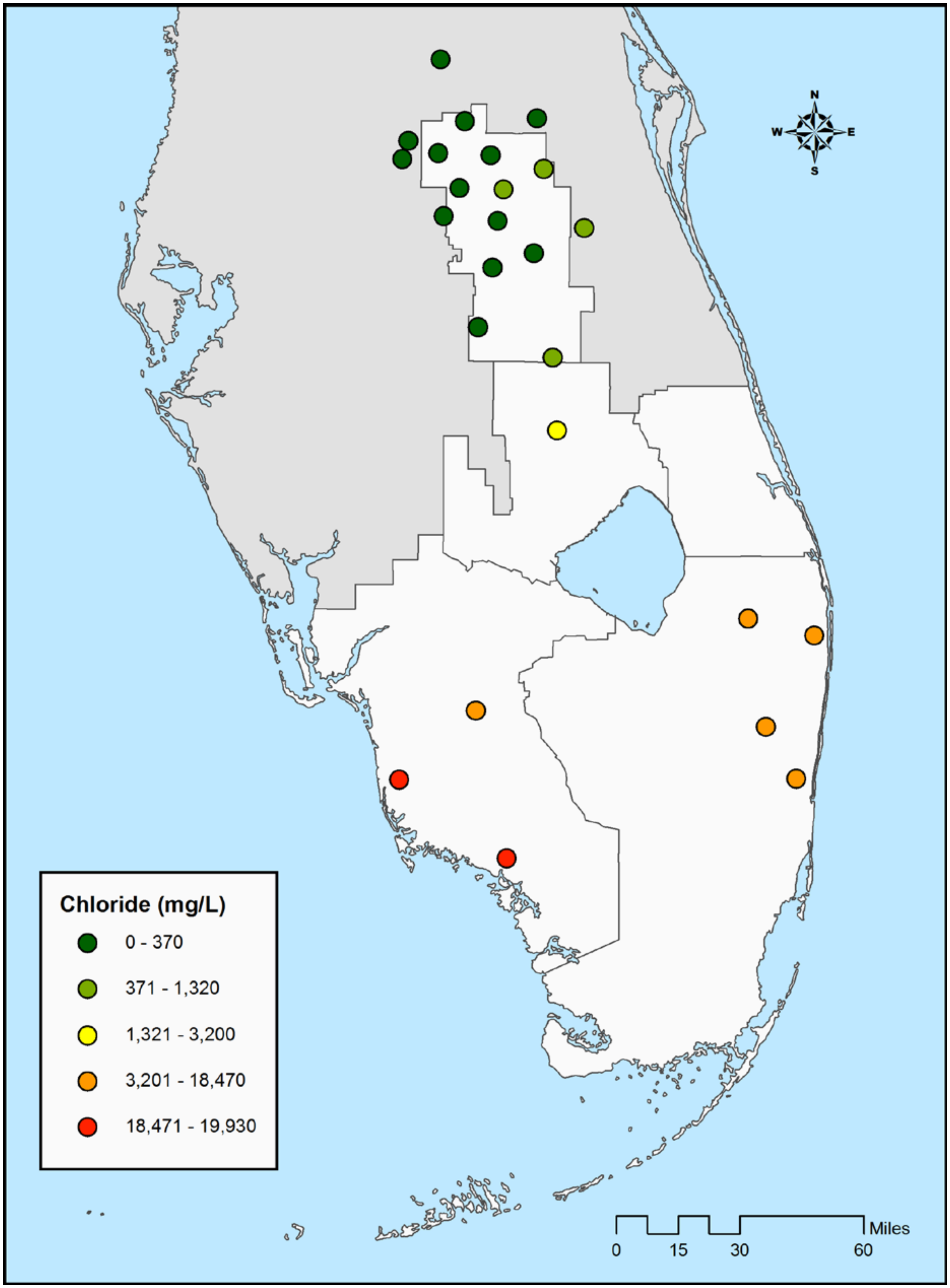

Figure 17. Map of chloride concentrations in the Lower Floridan aquifer-upper permeable zone.

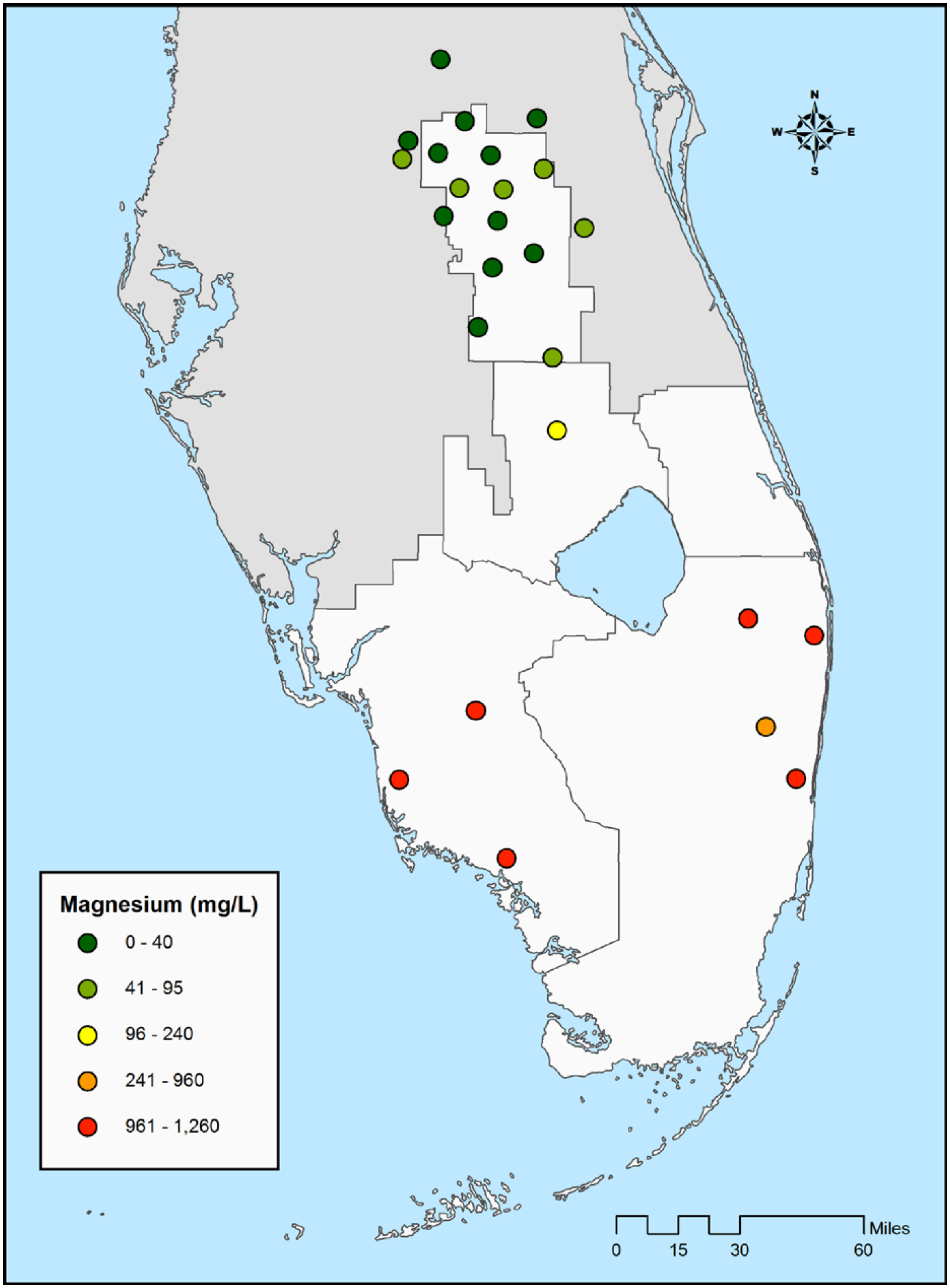

Figure 18. Map of magnesium concentrations in the Lower Floridan aquifer-upper permeable zone.

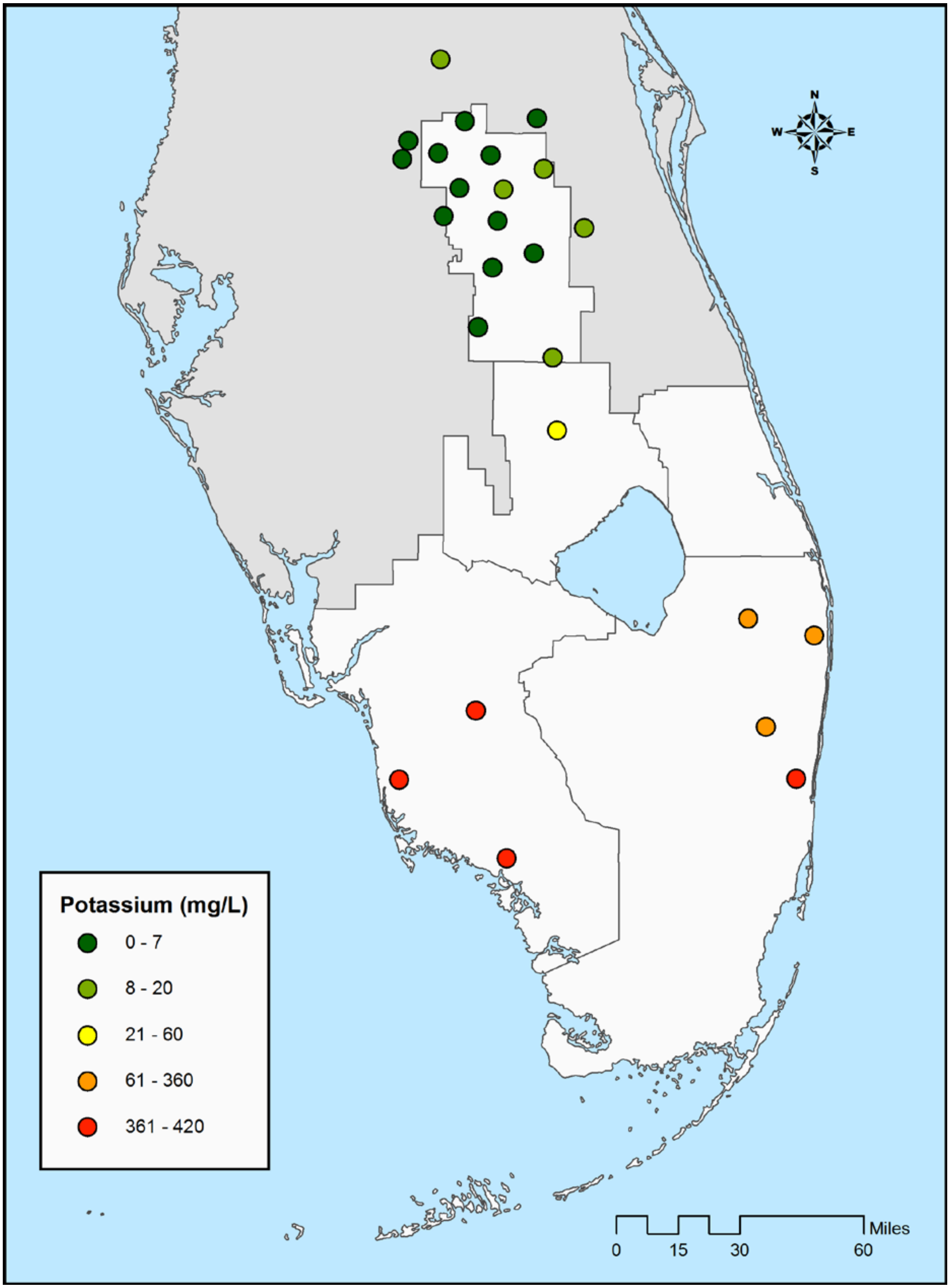

Figure 19. Map of potassium concentrations in the Lower Floridan aquifer-upper permeable zone.

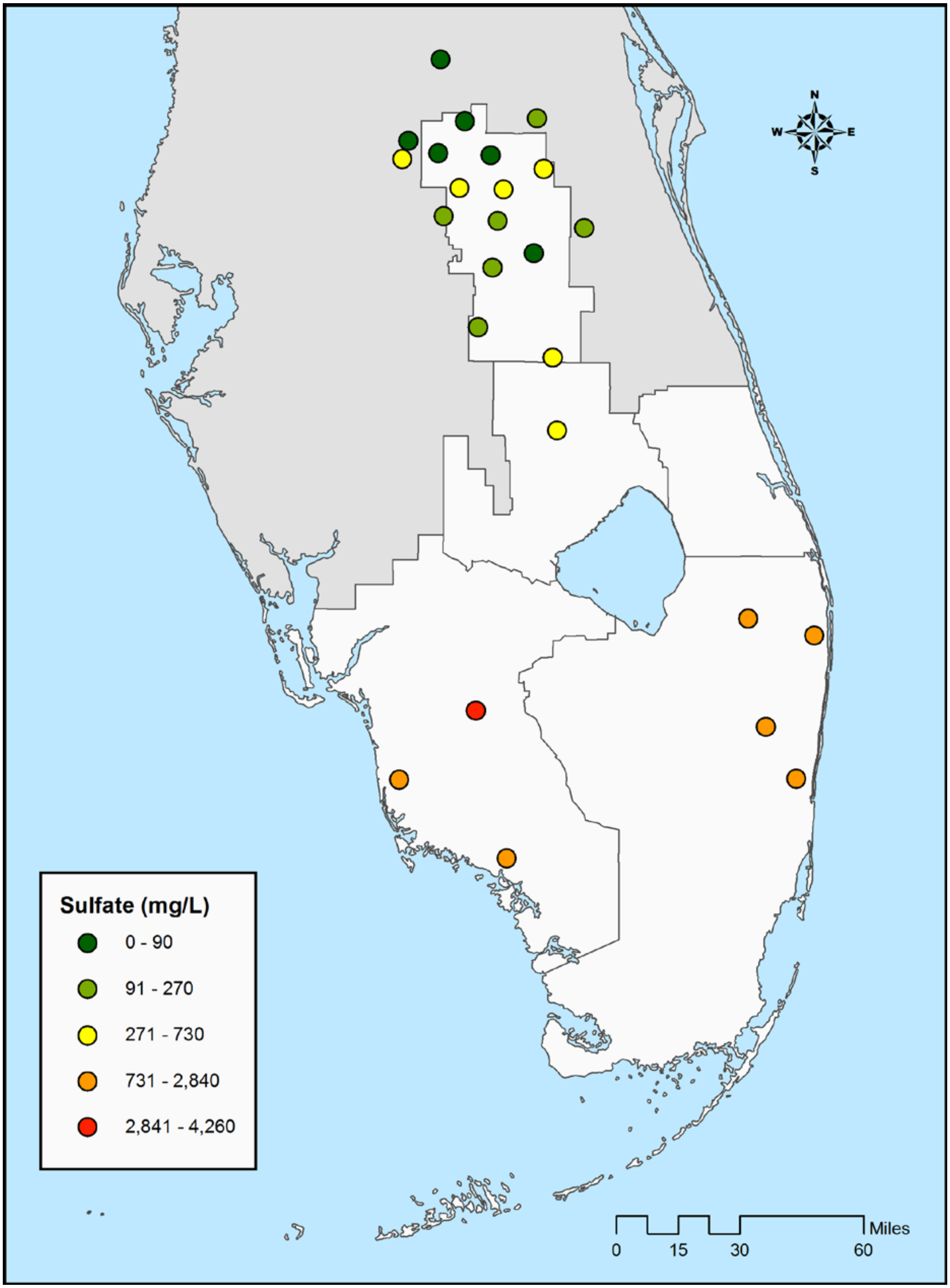

Figure 20. Map of sulfate concentrations in the Lower Floridan aquifer-upper permeable zone.

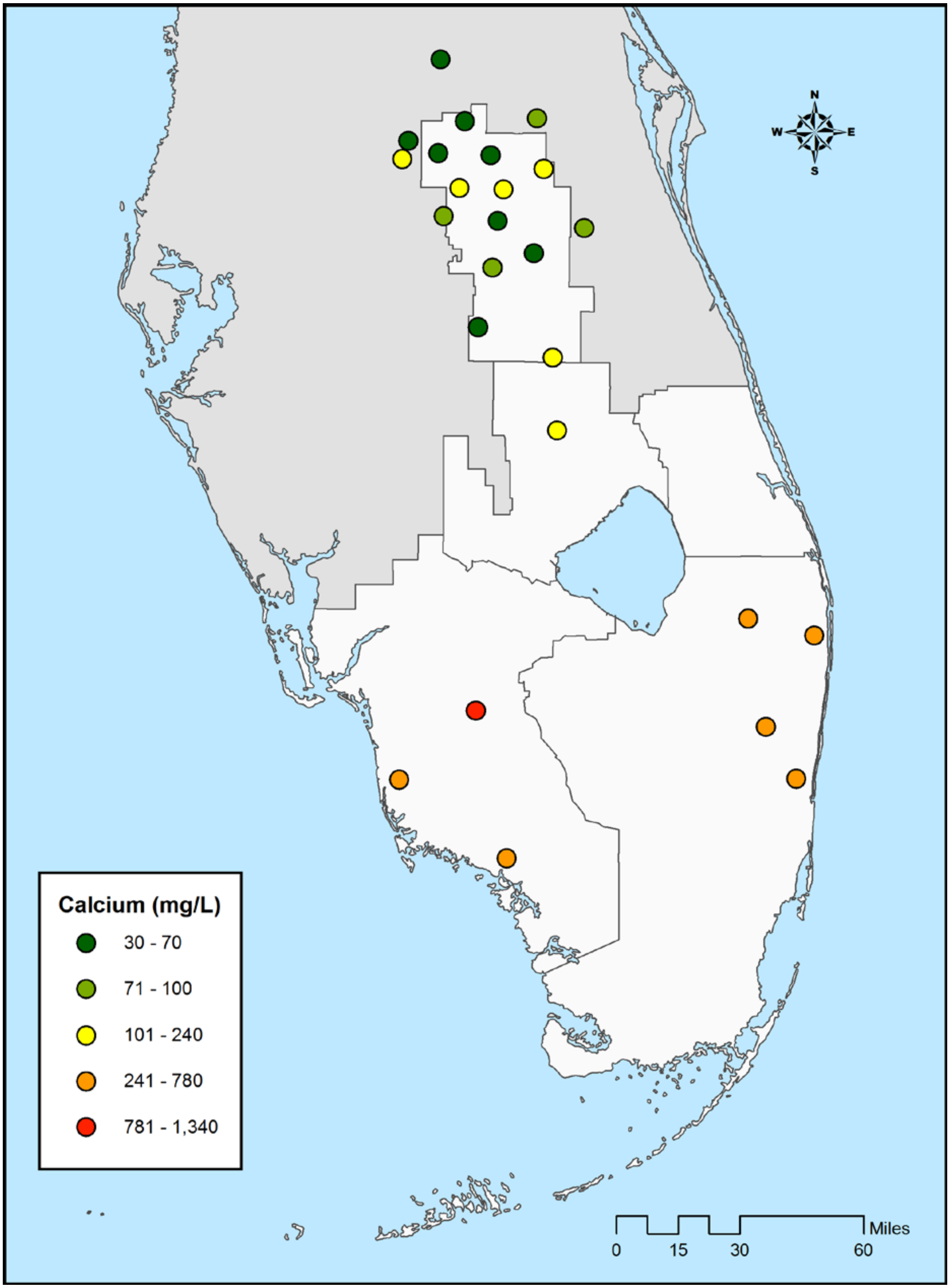

Figure 21. Map of calcium concentrations in the Lower Floridan aquifer-upper permeable zone.

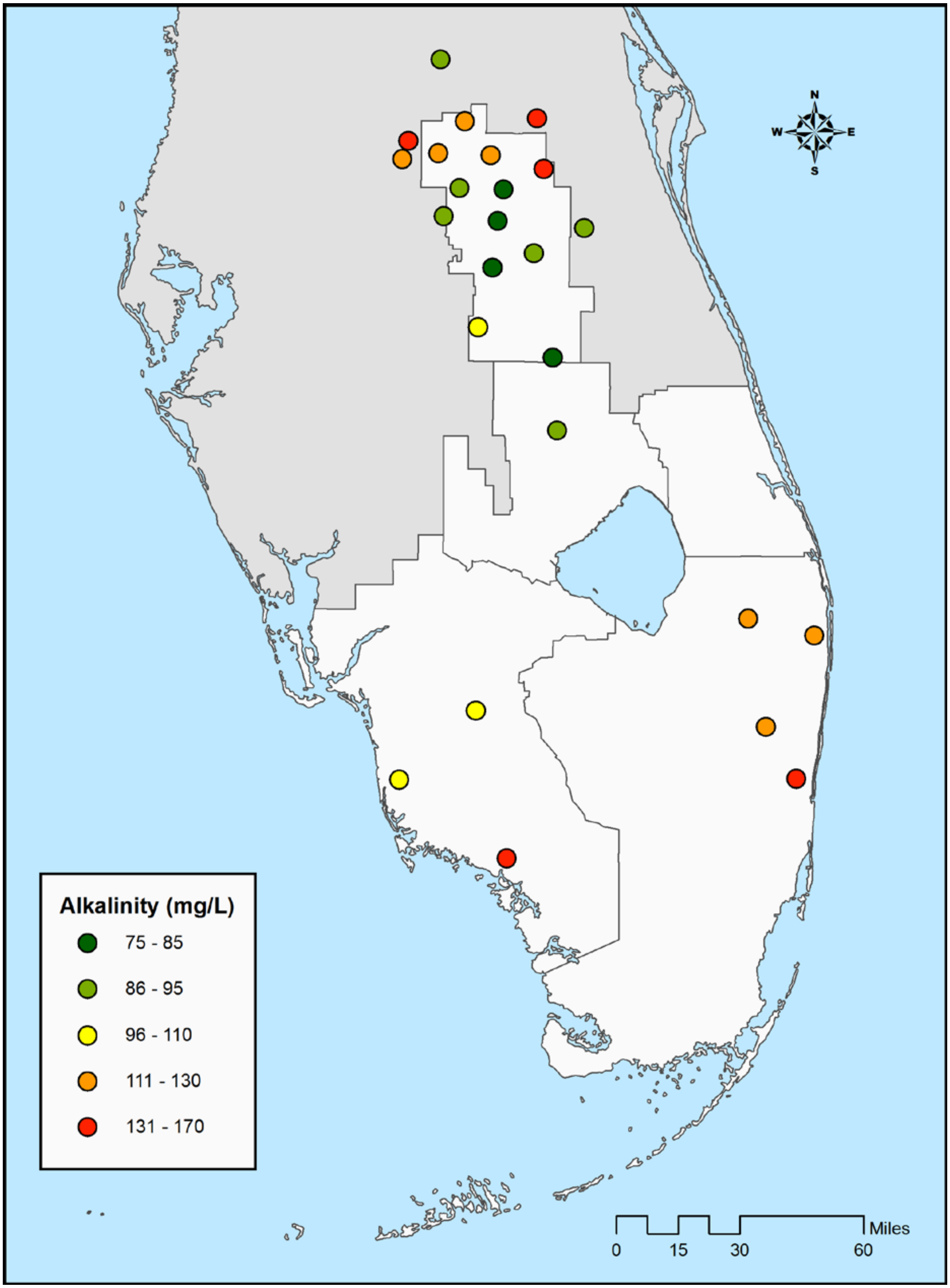

Figure 22. Map of alkalinity concentrations in the Lower Floridan aquifer-upper permeable zone.

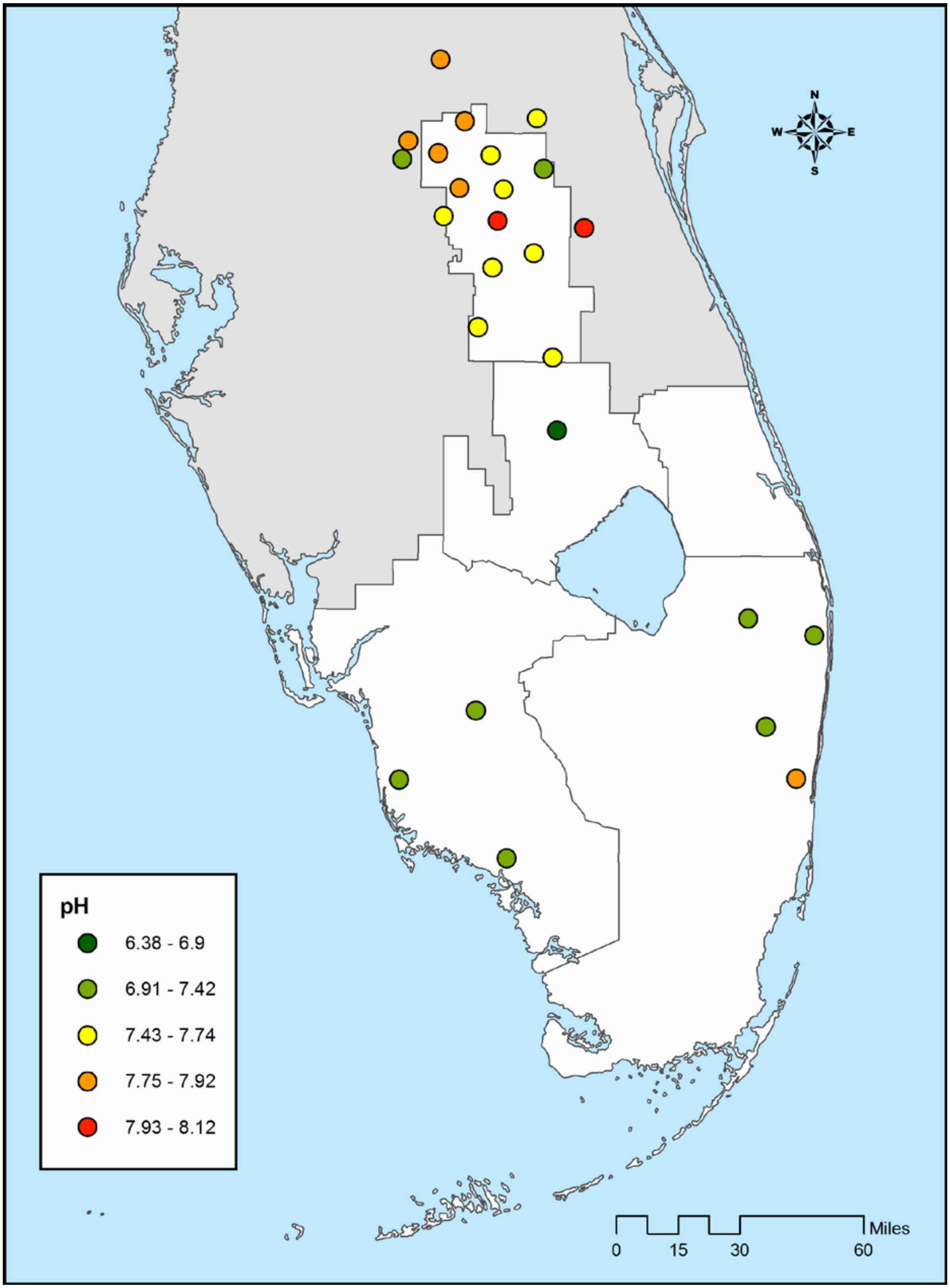

Figure 23. Map of pH in the Lower Floridan aquifer-upper permeable zone.

The different ionic profiles found in this technical publication reflect the different possible flow paths and/or water mixing that might occur. The northern subgroup has the lowest TDS concentrations and is calcium and bicarbonate dominant. This suggests recent recharge, lower residence time, and interaction primarily with limestone. Variations in sulfate concentrations could be from the overlying MCU, which contains anhydrite and gypsum, or from pyrite within the Avon Park Formation.

The western subgroup is slightly higher in overall ionic concentration with dominance in calcium, magnesium, bicarbonate, and sulfate. This suggests a longer residence time in dolomite and more interaction with the MCU than the northern group after initial recharge through limestone. The MCU is more prevalent in the western half of the CFWI planning area and likely the source of high sulfate concentrations (Williams and Kuniansky 2015).

Both the eastern subgroup and coastal group are sodium and chloride dominant and share similar shapes of the Schoeller plots, but the coastal group has a higher ionic concentration than the eastern subgroup. The sodium and chloride come from saltwater intrusion as a result of previous sea level highstands. The eastern subgroup results reflect groundwater that is relatively young and has mixed with connate water. It is still very dilute compared to the coastal group, which has TDS concentrations similar to seawater.

DATA ANALYSES

Statistical analyses, historical water quality sampling records, well completion reports, technical publications, well construction and modification reports, and FDEP records were used to assist in this investigation. Of the 27 LFA-upper wells analyzed, 17 were part of the RFGW monitoring network. Results from wells owned by other water management districts are used for mapping only; analysis of any water quality changes at these sites are beyond the scope of this investigation. Where changes are noted, additional checks were performed to locate potential influences of nearby wellfields. Any identified potential influences are mentioned in this section. Large data gaps between sampling events are likely due to staffing and budget constraints.

Spearman's ρ was calculated for all stations with five or more sampling events. For the purposes of this investigation, a significance value of 0.05 was used. **Table 5** shows the p-value results for Spearman's ρ for SC. While five data points are not ideal, it is a reasonable starting point. The data set will grow as additional sampling occurs. Wells L-0897, OS-0025, PBF-5, and ROMP74X-LF show statistically significant trends. However, wells L-0897, OS-0025, and ROMP74X-LF are not part of the RFGW monitoring network, and discussion of those results is beyond the scope of this investigation.

Table 5. Trend analysis results for specific conductance.

Well	p-value
BF-1	0.419
BICY-MZ4	0.893
I75-MZ3	0.981
L-0897	*<0.001*
OR-0676	0.092
OR-0794	0.521
OS-0025	*0.015*
PBF-12	0.556
PBF-15L	0.396
PBF-5	*0.012*
ROMP74X-LF	*<0.001*

Central Florida Water Initiative Group

Seven RFGW monitoring network wells are in the CFWI group (ORF-60, OSF-82L, OSF-98, OSF-109U, OSF-111, OSF-112, and POF-29). The dominant anion varied among wells, as seen in the stiff diagrams (**Figure 13**) and in **Table 3**. General trends indicate groundwater is fresher in much of the CFWI planning area compared to South Florida. Recharge water quality, distance and travel time in the aquifer, rock interaction, and possible upconing can affect ionic concentrations, with "younger" water typically having more variation and lower major ion concentrations. No RFGW stations showed statistically significant trends in chloride concentrations, or there were insufficient data to evaluate trends. Sulfate was the dominant anion at OSF-98 and POF-29.

Coastal Group

One monitor well, PBF-5, in the coastal group showed variability in water quality results. The trend in PBF-5 is statistically significant.

PBF-5

Station PBF-5 is part of a tri-zone monitor well located in West Palm Beach. The measuring point elevation at this well is 22.11 ft NAVD88, and the monitored interval is open from 2,340 to 2,490 ft below the measuring point. The period of record for water quality sampling is from 1996 to 2010. Groundwater quality has varied since sampling commenced in 1996. No large consumptive water use permits or injection wells are within 3 miles of PBF-5. The minimum chloride concentration at this location was 16,607 milligrams per liter (mg/L) in October 2000 and the maximum chloride concentration was 19,000 mg/L in March 2006 (**Figure 24**). Water quality results from the most recent seven samples are relatively constant. Results from 17 sampling events were included in the PBF-5 analysis; most stations had fewer samples. With additional sampling, more stations could show statistically significant trends. Alternatively, the level of significance (0.05) may not be ideal for these analyses.

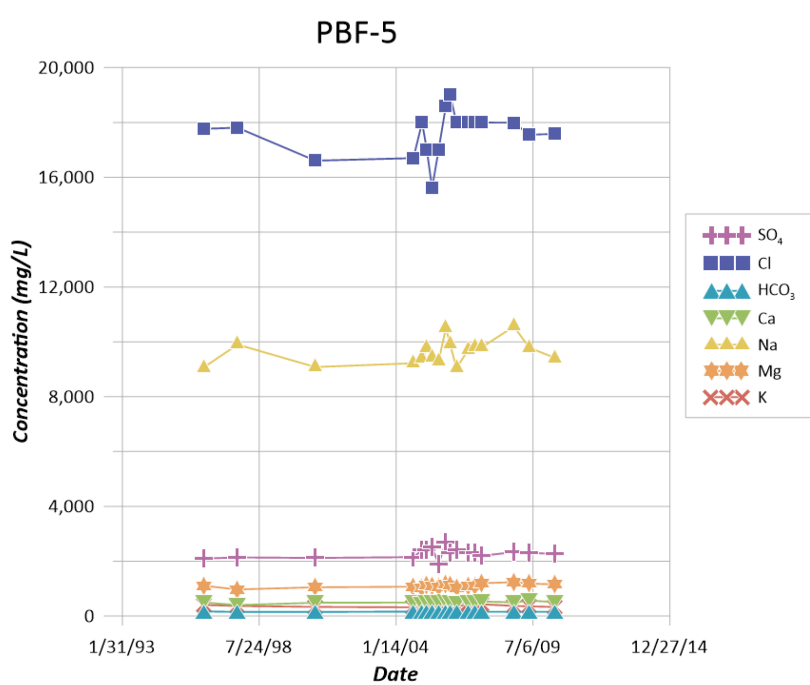

Figure 24. Major ion concentrations at station PBF-5 over the period of record.

Figure 25 shows the water types for the LFA-upper monitor stations. The coastal group is tightly clustered and has higher concentrations of sodium and chloride ions. In the CFWI planning area, overall major ion concentrations are lower and the water types more mixed. The northern subgroup is calcium and bicarbonate type, and the western subgroup shows a more mixed ionic makeup. The eastern subgroup results have a large spread and tend to be sodium and chloride dominated but at lower concentrations than its coastal counterparts.

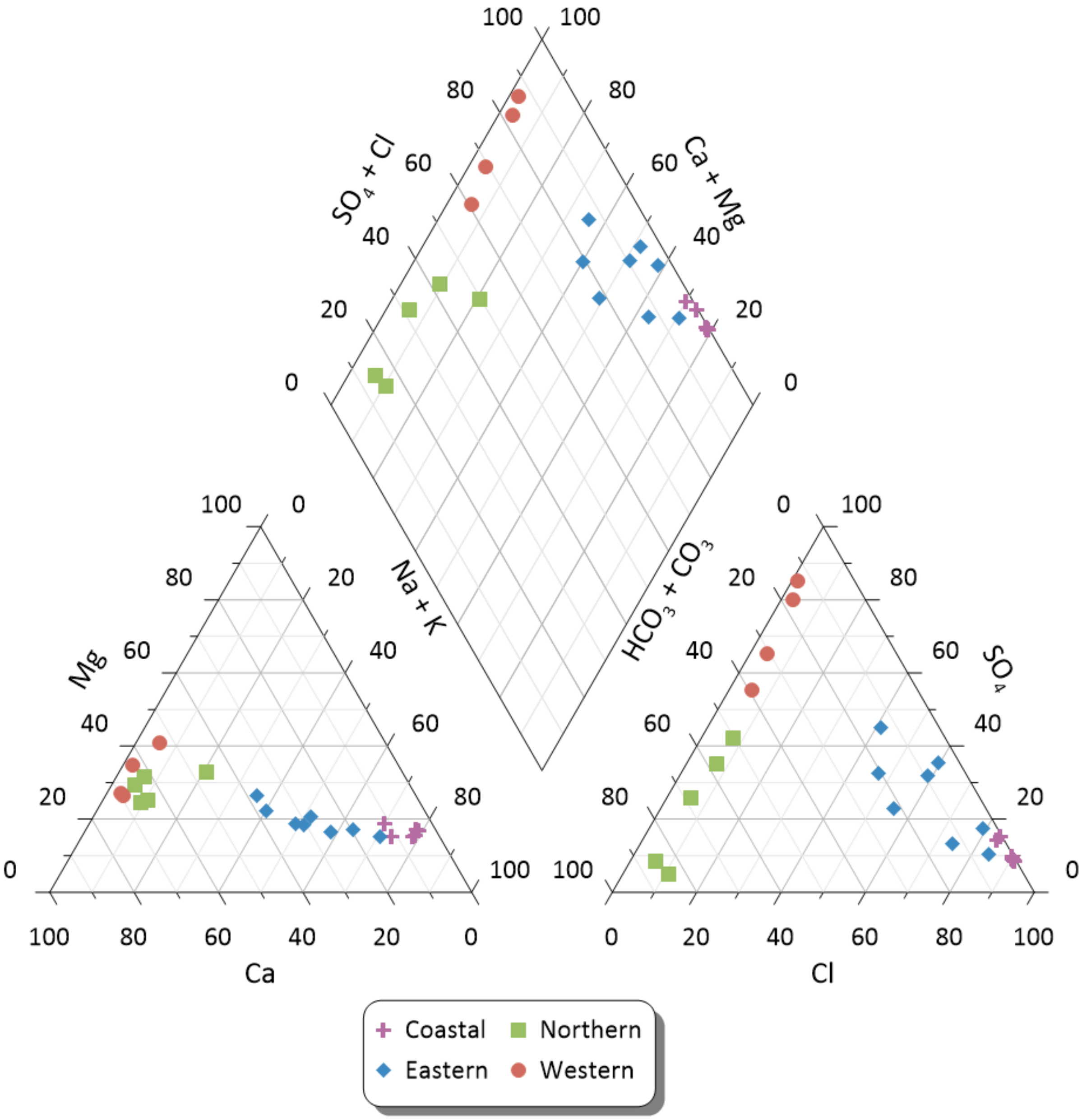

Figure 25. Piper diagram of water types from Lower Floridan aquifer-upper permeable zone water quality results.

DISCUSSION

Water quality data from 25 LFA-upper monitor wells were analyzed during this investigation. Of these, 15 wells were part of the RFGW monitoring network. Additional data from SJRWMD, SWFWMD, and public water supply utility wells were used for mapping purposes.

In the coastal group, station PBF-5 analyses indicated statistically significant trend; however, water quality results have been fairly steady since 2007. The selected p-value of 0.05 may not have been ideal for this data set. More sampling and data analyses are needed. The Upper East Coast (UEC) planning area lacks an LFA-upper monitor well. In the LKB planning area, the sole LFA-upper well had only one sampling event from a packer test. No further data were available at the time of publication. IWSD-MZ4 is a retired station in the LWC planning area, which opens up an additional spatial data gap. A suitable existing or new well should be located within the region to close this spatial data gap. The remaining stations in the coastal group showed some variation in groundwater quality over their respective periods of record, but changes were not statistically significant. These variations may reflect the dynamic nature of groundwater flow within the LFA or could be in response to distant pumping stresses. Trends in the LFA-upper across the SFWMD agree with the existing understanding that ionic concentrations in groundwater increase with distance from the recharge area. Wells in the coastal group are dominated by sodium and chloride. In the CFWI planning area, groundwater in the LFA-upper is notably fresher than the other SFWMD regions, and dominant ions vary. The eastern subgroup is similar to the coastal group, having sodium and chloride as dominant ions, but the eastern subgroup also has higher concentrations of sulfate, calcium, and magnesium. All wells in the northern subgroup have calcium and bicarbonate as dominant ions, with magnesium and/or sulfate also included. The western subgroup is dominated by calcium, magnesium, and sulfate. Bicarbonate is a dominant ion in all but one of the western wells. In the piper diagram, the separation between the northern and southern subgroups is in the anion trilinear diagram. If 50% or more is from sulfate, it is in the western subgroup. If 50% or more of the anion is from bicarbonate, then it is in the northern subgroup. Overall results agree with the fundamental concept that groundwaters with similar chemistry share a common heritage in terms of age and rock-water interactions (Upchurch et al. 2019).

The irregularity of the sampling events and, in some instances, a low number of sampling events introduce greater uncertainty. In order to effectively characterize baseline and temporal trends in water quality in the LFA-upper, a more robust data set is required. The additional wells planned and under construction throughout the CFWI planning area, along with more frequent sampling, will assist in building a better data set for future investigations of the LFA-upper.

CONCLUSIONS AND RECOMMENDATIONS

Consistent and increased frequency of sampling for stations in the LFA-upper are necessary to more accurately assess aquifer conditions in Central and South Florida. Of the 25 LFA-upper monitor wells, 56% have less than 5 water quality samples. Eight LFA wells within the CFWI planning area were constructed in Fiscal Year 2020, and an additional 13 LFA wells are planned in Fiscal Years 2021 through 2025 (CFWI Data, Monitoring and Investigations Team 2020). Spatial data gaps exist in the UEC, LKB and LWC planning areas. The UEC planning area has no LFA-upper monitor wells in the RFGW network, and one key monitoring well (IWSD-MZ4) has been retired in the LWC planning area. Additional LFA-upper wells should be planned for these areas to address spatial data gaps. Installing additional wells in these areas would allow for monitoring to capture upconing or locally degraded waters. Water quality results will assist in effective management practices of this limited groundwater resource. The CFWI Data, Monitoring and Investigations Team (2018) published a report outlining minimum standards for water resource data collection, recommending annual sample collection and testing of groundwater samples for anions and cations. Once this annual process is fully implemented, groundwater quality should be regularly reviewed, mapped, and made available online.

LITERATURE CITED

Back, W. 1960. Origin of hydrochemical facies of ground water in the Atlantic Coastal Plain. International Geological Congress, 21st Copenhagen. Part 1:87-95.

Back, W. 1961. Techniques for mapping of hydrochemical facies, pp. 380-382. U.S. Geological Survey Professional Paper 424-D. U.S. Geological Survey, Washington, D.C.

CFWI. 2015. Central Florida Water Initiative Regional Water Supply Plan, Planning Document, Volume I.

CFWI Data, Monitoring and Investigations Team. 2018. Minimum standards for water resource data collection, site establishment and field data collection protocols.

CFWI Data, Monitoring and Investigations Team. 2020. DMIT hydrogeologic annual workplan (FY2020 – FY2025).

CFWI Hydrologic Analysis Team. 2016. East-Central Florida Transient Expanded (ECFTX) model. Conceptual Model Report. Unpublished report. 78 pp.

Esri, Inc. 2015. ArcMap 10.3.1 for Desktop. Redlands, CA.

Fetter, C.W. 2001. Applied Hydrogeology. Prentice Hall, Upper Saddle River, NJ.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice Hall, Englewoods Hills, NJ.

Fritz, S.J. 1994. A survey of charge-balance errors on published analyses of potable ground and surface waters. Groundwater 32:539-546.

Geddes, E., B. Collins, E. Richardson, M. Laham-Pass, and S. Coonts. 2018. Operational project monitoring plan for Regional Floridan Groundwater (RFGW) network monitoring program. South Florida Water Management District, West Palm Beach, FL.

Golden Software LLC. 2019. Grapher 15.

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. Third Edition. U.S. Geological Survey Water-Supply Paper 2254. U.S. Geological Survey, Alexandria, VA.

Helsel, D.R. and R. M. Hirsch. 2002. Techniques of Water-Resources Investigations of the United States Geological Survey. In: Book 4 Hydrologic Analysis and Interpretation, Chapter A3, Statistical Methods in Water Resources. United States Geological Survey, Reston, VA.

Meyer, F.W. 1989. Hydrogeology, ground-water movement, and subsurface storage in the Floridan aquifer system in Southern Florida: U.S. Geological Survey Professional Paper 1403-G. 59 pp.

Miller, J.A. 1986. Ground Water Atlas of the United States. Segment 6, Alabama, Florida, Georgia, and South Carolina: U.S. Geological Survey Hydrologic Investigations Atlas 730-G. U.S. Geological Survey, Washington, D.C.

O'Reilly, A.M., R.M. Spechler, and B.E. McGurk. 2002. Hydrogeology and water-quality characteristics of the Lower Floridan aquifer in east-central Florida. U.S. Geological Survey Water-Resources Investigations Report 02-4193. U.S. Geological Survey, Tallahassee, FL.

R Core Team. 2019. The R Program. Version 3.5.3 (Great truth).

Reese, R.S. and E. Richardson. 2008. Synthesis of the hydrogeologic framework of the Floridan aquifer system and delineation of a major Avon Park Permeable Zone in Central and Southern Florida. U.S. Geological Survey Scientific Investigations Report 2007-5207. U.S. Geological Survey, Reston, VA.

Schlumberger Water Services. 2014. AquaChem V 2014.2. Kitchener, Ontario, Canada.

Sepulveda, N., C.R. Tiedeman, A.M. O'Reilly, J.B. Davis, and P. Burger. 2012. Groundwater flow and water budget in the surficial and Floridan aquifer systems in east-central Florida. U.S. Geological Survey Scientific Investigations Report 2012-5161. U.S. Geological Survey, Reston, VA.

Schoeller, H. 1962. Les Eaux Souterraines. Hydrologie dynamique et chimique, Recherche, Exploitation et Evaluation des Ressources. Massio et Cie, Editeurs. Paris, France.

Upchurch, S.B. 1992. Quality of water in Florida's Aquifer System. Florida Geological Survey Special Publication 34(4):13-56.

Upchurch, S.B., T.M. Scott, M.C. Alfieri, B. Fratesi, and T.L. Dobecki. 2019. The karst systems of Florida. Springer Nature, Cham, Switzerland.

Williams, L.J. and E.L. Kuniansky. 2015. Revised hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1807. U.S. Geological Survey, Reston, VA.

APPENDIX: SUMMARY STATISTICS

Table A-1. Descriptive statistics for bicarbonate (HCO_3; in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	174	133	54	25	134	149	164	424
BICY-MZ4	15	207	31	8	139	191	211	232	238
DCBR-LFMW2	1	109	-	-	109	109	109	109	109
HS-LFPW	1	144	-	-	144	144	144	144	144
I75-MZ3	17	124	13	3	95	119	126	134	146
IWSD-MZ4	3	123	23	14	99	111	122	134	146
L-0729	4	169	5	3	163	168	170	171	176
L-0897	17	155	42	10	34	161	169	171	182
OKF-105	1	109	-	-	109	109	109	109	109
OR-0676	20	173	8	2	154	168	174	181	183
OR-0794	9	104	13	4	82	99	101	114	124
ORF-60	4	139	3	1	135	138	139	140	143
OS-0025	21	113	31	7	23	119	124	129	132
OSF-82L	5	101	6	3	94	95	104	106	107
OSF-98	4	110	22	11	78	107	119	123	124
OSF-109U	3	96	5	3	90	94	98	99	100
OSF-111	1	185	-	-	185	185	185	185	185
OSF-112	1	101	-	-	101	101	101	101	101
PBF-12	18	145	15	4	117	138	146	157	171
PBF-15L	7	137	4	1	132	134	137	139	143
PBF-5	17	158	6	2	146	154	158	158	171
POF-29	3	101	5	3	95	99	104	104	104
ROMP74X-LF	18	114	3	1	108	113	115	116	118
SEPOLK-DEW	2	119	1	1	118	119	119	119	119
SR-LFPW	1	148	-	-	148	148	148	148	148

- not applicable.

Table A-2. Descriptive statistics for alkalinity (in milligrams calcium carbonate [$CaCO_3$] per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	143	109	44	21	110	122	135	348
BICY-MZ4	15	170	26	7	114	157	173	190	195
DCBR-LFMW2	1	89	-	-	89	89	89	89	89
HS-LFPW	1	118	-	-	118	118	118	118	118
I75-MZ3	17	102	10	3	78	98	103	110	120
IWSD-MZ4	3	101	19	11	82	91	100	110	120
L-0729	4	139	4	2	134	138	139	140	144
L-0897	17	127	34	8	28	132	138	140	149
OKF-105	1	89	-	-	89	89	89	89	89
OR-0676	20	142	7	2	126	138	143	148	150
OR-0794	9	85	11	4	67	81	83	93	101
ORF-60	4	114	2	1	111	113	114	115	117
OS-0025	21	93	25	5	18	98	102	106	108
OSF-82L	5	83	5	2	77	78	85	87	88
OSF-98	4	91	18	9	64	88	98	101	102
OSF-109U	3	79	4	2	74	77	80	81	82
OSF-111	1	152	-	-	152	152	152	152	152
OSF-112	1	83	-	-	83	83	83	83	83
PBF-12	18	119	12	3	96	113	120	129	140
PBF-15L	7	112	3	1	108	110	112	114	117
PBF-5	17	129	5	1	120	126	130	130	140
POF-29	3	83	4	2	78	82	85	85	85
ROMP74X-LF	18	94	2	1	89	92	95	96	97
SEPOLK-DEW	2	98	1	1	97	97	98	98	98
SR-LFPW	1	121	-	-	121	121	121	121	121

- not applicable.

Table A-3. Descriptive statistics for sulfate (SO_4; in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	2,466	138	56	2,240	2,436	2,470	2,519	2,659
BICY-MZ4	15	2,761	487	126	2,500	2,590	2,642	2,700	4,500
DCBR-LFMW2	1	90	-	-	90	90	90	90	90
HS-LFPW	1	6	-	-	6	6	6	6	6
I75-MZ3	17	2,838	485	118	2,320	2,674	2,700	2,800	4,600
IWSD-MZ4	3	4,259	319	184	3,900	4,133	4,366	4,438	4,510
L-0729	4	50	8	4	40	46	51	56	59
L-0897	17	560	123	30	411	442	604	673	768
OKF-105	1	722	-	-	722	722	722	722	722
OR-0676	20	144	6	1	134	139	146	148	154
OR-0794	9	68	4	1	65	65	67	73	73
ORF-60	4	11	1	1	10	10	11	12	13
OS-0025	21	166	27	6	86	166	171	182	191
OSF-82L	5	570	8	4	561	562	573	574	579
OSF-98	4	550	46	23	512	518	537	569	613
OSF-109U	3	395	27	16	366	383	400	410	419
OSF-111	1	495	-	-	495	495	495	495	495
OSF-112	1	126	-	-	126	126	126	126	126
PBF-12	18	2,086	1,109	261	1,570	1,739	1,853	1,900	6,500
PBF-15L	7	2,351	81	31	2,248	2,301	2,358	2,384	2,478
PBF-5	17	2,282	177	43	1,900	2,150	2,300	2,400	2,680
POF-29	3	261	74	43	198	220	242	293	343
ROMP74X-LF	18	190	10	2	172	183	190	198	210
SEPOLK-DEW	2	132	18	13	119	125	132	138	144
SR-LFPW	1	70	-	-	70	70	70	70	70

- not applicable.

Table A-4. Descriptive statistics for chloride (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	18,469	774	316	17,103	18,272	18,609	19,064	19,120
BICY-MZ4	15	19,926	691	179	19,000	19,263	20,000	20,175	21,000
DCBR-LFMW2	1	368	-	-	368	368	368	368	368
HS-LFPW	1	11	-	-	11	11	11	11	11
I75-MZ3	17	19,536	566	137	18,400	19,080	19,831	20,000	20,165
IWSD-MZ4	3	17,685	598	345	17,000	17,477	17,955	18,027	18,100
L-0729	4	8	2	1	7	7	8	9	12
L-0897	16	15	1	0	11	14	14	15	17
OKF-105	1	3,193	-	-	3,193	3,193	3,193	3,193	3,193
OR-0676	20	256	16	4	210	249	258	264	278
OR-0794	9	9	2	1	8	8	8	9	13
ORF-60	4	6	0	0	6	6	6	6	6
OS-0025	21	993	27	6	940	976	1,000	1,010	1,030
OSF-82L	5	708	3	1	705	707	708	708	712
OSF-98	4	7	2	1	6	6	7	9	9
OSF-109U	3	1,313	107	62	1,192	1,274	1,356	1,374	1,392
OSF-111	1	679	-	-	679	679	679	679	679
OSF-112	1	133	-	-	133	133	133	133	133
PBF-12	18	16,413	808	190	14,700	15,978	16,506	17,000	18,000
PBF-15L	7	17,781	820	310	16,501	17,303	18,010	18,222	18,908
PBF-5	17	17,600	810	196	15,600	17,000	17,808	18,000	19,000
POF-29	3	176	54	31	133	145	157	197	237
ROMP74X-LF	18	9	0	0	8	8	8	9	9
SEPOLK-DEW	2	10	0	0	10	10	10	10	10
SR-LFPW	1	11	-	-	11	11	11	11	11

- not applicable.

Table A-5. Descriptive statistics for magnesium (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	1,128	201	82	730	1,146	1,196	1,222	1,286
BICY-MZ4	15	1,129	47	12	1,070	1,095	1,120	1,154	1,235
DCBR-LFMW2	1	29	-	-	29	29	29	29	29
HS-LFPW	1	9	-	-	9	9	9	9	9
I75-MZ3	17	1,257	58	14	1,150	1,225	1,268	1,290	1,367
IWSD-MZ4	3	1,100	0	0	1,100	1,100	1,100	1,100	1,100
L-0729	4	14	1	0	13	13	14	14	14
L-0897	17	47	8	2	36	40	47	53	59
OKF-105	1	240	-	-	240	240	240	240	240
OR-0676	20	29	1	0	26	29	29	30	33
OR-0794	9	13	1	0	11	12	13	14	15
ORF-60	4	11	0	0	10	10	11	11	11
OS-0025	21	61	5	1	48	58	60	63	70
OSF-82L	5	83	2	1	81	83	84	85	85
OSF-98	4	58	3	2	55	56	58	60	61
OSF-109U	3	95	6	3	89	92	96	98	100
OSF-111	1	75	-	-	75	75	75	75	75
OSF-112	1	22	-	-	22	22	22	22	22
PBF-12	18	952	65	15	853	911	932	993	1,110
PBF-15L	7	1,146	42	16	1,072	1,130	1,150	1,167	1,203
PBF-5	17	1,105	68	16	970	1,060	1,100	1,150	1,236
POF-29	3	38	4	2	35	36	36	39	43
ROMP74X-LF	18	19	1	0	18	19	20	20	20
SEPOLK-DEW	2	24	2	1	23	23	24	25	25
SR-LFPW	1	13	-	-	13	13	13	13	13

- not applicable.

Table A-6. Descriptive statistics for calcium (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	514	56	23	465	472	492	558	590
BICY-MZ4	15	771	40	10	683	752	777	802	830
DCBR-LFMW2	1	54	-	-	54	54	54	54	54
HS-LFPW	1	36	-	-	36	36	36	36	36
I75-MZ3	17	499	37	9	414	481	505	517	560
IWSD-MZ4	3	1,340	35	20	1,300	1,330	1,360	1,360	1,360
L-0729	4	50	4	2	45	50	52	52	53
L-0897	17	198	42	10	121	176	198	231	261
OKF-105	1	239	-	-	239	239	239	239	239
OR-0676	20	83	4	1	75	81	83	86	90
OR-0794	9	30	11	4	17	19	30	42	44
ORF-60	4	34	1	0	33	33	34	34	35
OS-0025	21	93	15	3	52	93	97	99	110
OSF-82L	5	182	4	2	179	180	181	183	189
OSF-98	4	173	20	10	148	165	172	181	198
OSF-109U	3	238	2	1	236	237	238	239	240
OSF-111	1	203	-	-	203	203	203	203	203
OSF-112	1	61	-	-	61	61	61	61	61
PBF-12	18	544	60	14	440	511	539	573	667
PBF-15L	7	479	48	18	424	430	503	519	529
PBF-5	17	496	37	9	400	488	499	510	560
POF-29	3	89	25	14	70	75	80	99	117
ROMP74X-LF	18	84	3	1	77	82	84	85	89
SEPOLK-DEW	2	52	4	3	49	50	52	53	55
SR-LFPW	1	56	-	-	56	56	56	56	56

- not applicable.

Table A-7. Descriptive statistics for potassium (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	383	31	12	358	362	371	395	437
BICY-MZ4	15	400	42	11	375	380	382	402	540
DCBR-LFMW2	1	7	-	-	7	7	7	7	7
HS-LFPW	1	1	-	-	1	1	1	1	1
I75-MZ3	17	411	43	10	363	388	399	413	520
IWSD-MZ4	3	398	71	41	355	357	359	420	480
L-0729	4	1	0	0	1	1	1	1	1
L-0897	17	2	0	0	2	2	2	3	3
OKF-105	1	56	-	-	56	56	56	56	56
OR-0676	20	7	1	0	6	6	6	7	11
OR-0794	9	9	7	2	1	1	8	16	18
ORF-60	4	1	0	0	1	1	1	1	1
OS-0025	21	17	1	0	15	16	17	18	21
OSF-82L	5	14	0	0	14	14	14	14	14
OSF-98	4	2	1	0	2	2	2	2	3
OSF-109U	3	13	1	1	12	12	13	13	14
OSF-111	1	14	-	-	14	14	14	14	14
OSF-112	1	3	-	-	3	3	3	3	3
PBF-12	18	305	30	7	271	287	297	318	380
PBF-15L	7	356	12	5	341	347	358	363	376
PBF-5	17	350	38	9	305	319	340	370	430
POF-29	3	4	1	0	4	4	4	4	5
ROMP74X-LF	18	1	0	0	1	1	1	1	1
SEPOLK-DEW	2	1	0	0	1	1	1	1	1
SR-LFPW	1	1	-	-	1	1	1	1	1

- not applicable.

Table A-8. Descriptive statistics for sodium (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	10,078	303	124	9,733	9,906	9,991	10,233	10,560
BICY-MZ4	15	10,933	427	110	10,360	10,640	11,000	11,100	11,830
DCBR-LFMW2	1	197	-	-	197	197	197	197	197
HS-LFPW	1	6	-	-	6	6	6	6	6
I75-MZ3	17	10,944	379	92	10,390	10,800	10,910	11,200	11,880
IWSD-MZ4	3	9,873	155	90	9,700	9,810	9,920	9,960	10,000
L-0729	4	5	0	0	4	4	5	5	5
L-0897	17	10	0	0	9	9	10	10	11
OKF-105	1	1,681	-	-	1,681	1,681	1,681	1,681	1,681
OR-0676	20	141	6	1	133	136	140	147	155
OR-0794	9	10	4	1	6	6	9	14	16
ORF-60	4	4	0	0	4	4	4	4	4
OS-0025	21	521	30	7	471	499	511	537	587
OSF-82L	5	385	8	3	378	380	382	387	397
OSF-98	4	6	2	1	4	4	6	8	8
OSF-109U	3	628	41	24	583	611	640	651	661
OSF-111	1	383	-	-	383	383	383	383	383
OSF-112	1	74	-	-	74	74	74	74	74
PBF-12	18	8,923	436	103	7,908	8,648	8,909	9,183	9,900
PBF-15L	7	9,674	483	183	8,959	9,387	9,789	10,028	10,140
PBF-5	17	9,626	453	110	9,040	9,300	9,700	9,800	10,560
POF-29	3	95	28	16	75	79	83	105	127
ROMP74X-LF	18	5	0	0	5	5	5	5	5
SEPOLK-DEW	2	6	0	0	6	6	6	6	6
SR-LFPW	1	9	-	-	9	9	9	9	9

- not applicable.

Table A-9. Descriptive statistics for specific conductance (in microsiemens per centimeter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	47,761	5,311	2,168	40,479	43,646	50,770	51,340	51,748
BICY-MZ4	15	52,522	3,172	819	41,876	52,242	53,229	53,905	55,890
DCBR-LFMW2	1	1,585	-	-	1,585	1,585	1,585	1,585	1,585
HS-LFPW	1	285	-	-	285	285	285	285	285
I75-MZ3	17	53,267	1,004	244	50,988	52,827	53,194	53,900	55,139
IWSD-MZ4	3	51,248	1,130	652	50,361	50,612	50,863	51,692	52,520
L-0729	4	375	12	6	358	369	378	383	385
L-0897	17	1,195	192	46	866	1,036	1,180	1,410	1,470
OKF-105	1	10,931	-	-	10,931	10,931	10,931	10,931	10,931
OR-0676	20	1,358	34	8	1,280	1,340	1,374	1,380	1,403
OR-0794	9	327	13	4	307	316	331	334	346
ORF-60	4	266	3	1	263	265	267	268	269
OS-0025	21	3,469	123	27	3,230	3,400	3,500	3,560	3,680
OSF-82L	5	3,369	40	18	3,320	3,342	3,369	3,392	3,421
OSF-98	4	1,164	92	46	1,080	1,120	1,141	1,186	1,295
OSF-109U	3	4,958	293	169	4,624	4,854	5,083	5,126	5,168
OSF-111	1	3,530	-	-	3,530	3,530	3,530	3,530	3,530
OSF-112	1	882	-	-	882	882	882	882	882
PBF-12	18	44,637	1,662	392	39,489	44,630	44,936	45,355	47,760
PBF-15L	7	47,622	2,639	998	43,470	46,147	47,620	49,572	50,829
PBF-5	17	47,904	2,107	511	40,417	47,724	48,271	48,964	49,540
POF-29	3	1,256	91	53	1,152	1,223	1,293	1,308	1,322
ROMP74X-LF	17	598	12	3	574	592	598	607	616
SEPOLK-DEW	2	474	4	3	471	472	474	475	476
SR-LFPW	1	425	-	-	425	425	425	425	425

- not applicable.

Table A-10. Descriptive statistics for total dissolved solids (in milligrams per liter) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	34,450	2,091	853	31,900	32,685	34,638	36,187	36,785
BICY-MZ4	11	36,250	2,756	831	30,200	34,870	37,000	37,552	40,000
DCBR-LFMW2	1	611	-	-	611	611	611	611	611
HS-LFPW	1	134	-	-	134	134	134	134	134
I75-MZ3	15	34,849	2,306	595	28,000	34,000	35,793	36,200	37,000
IWSD-MZ4	2	34,300	2,404	1,700	32,600	33,450	34,300	35,150	36,000
L-0729	4	224	10	5	210	222	227	229	232
L-0897	17	994	213	52	689	826	1,060	1,150	1,310
OKF-105	1	6,681	-	-	6,681	6,681	6,681	6,681	6,681
OR-0676	19	793	29	7	734	775	790	808	853
OR-0794	9	209	25	8	187	190	202	211	259
ORF-60	4	143	17	9	124	132	143	155	162
OS-0025	20	1,927	283	63	915	1,899	1,978	2,083	2,236
OSF-82L	5	2,096	19	8	2,080	2,086	2,092	2,093	2,128
OSF-98	4	945	63	31	871	918	943	969	1,024
OSF-109U	3	2,843	129	75	2,722	2,776	2,829	2,904	2,979
OSF-111	1	2,148	-	-	2,148	2,148	2,148	2,148	2,148
OSF-112	1	563	-	-	563	563	563	563	563
PBF-12	16	28,094	4,156	1,039	14,000	27,900	29,000	30,300	31,153
PBF-15L	7	30,534	7,808	2,951	12,994	32,207	33,088	34,361	34,521
PBF-5	16	31,735	5,285	1,321	14,000	30,900	32,564	34,000	38,000
POF-29	3	780	54	31	722	756	790	809	828
ROMP74X-LF	3	379	27	16	354	365	376	392	408
SEPOLK-DEW	2	303	47	34	269	286	303	319	336
SR-LFPW	1	258	-	-	258	258	258	258	258

- not applicable.

Table A-11. Descriptive statistics for pH in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	7.9	0.5	0.2	6.9	7.9	8.0	8.1	8.4
BICY-MZ4	15	7.0	0.2	0.1	6.7	6.8	6.9	7.0	7.5
DCBR-LFMW2	1	7.7	-	-	7.7	7.7	7.7	7.7	7.7
HS-LFPW	1	7.9	-	-	7.9	7.9	7.9	7.9	7.9
I75-MZ3	17	7.4	0.1	0.0	7.2	7.3	7.4	7.5	7.8
IWSD-MZ4	3	7.1	0.3	0.2	6.9	6.9	7.0	7.2	7.5
L-0729	4	7.9	0.2	0.1	7.8	7.8	7.8	8.0	8.2
L-0897	16	7.4	0.3	0.1	7.0	7.2	7.4	7.5	8.4
OKF-105	1	6.4	-	-	6.4	6.4	6.4	6.4	6.4
OR-0676	13	7.6	0.2	0.1	7.4	7.5	7.6	7.8	8.0
OR-0794	5	7.9	0.2	0.1	7.5	7.8	7.8	8.0	8.1
ORF-60	4	7.9	0.1	0.1	7.8	7.8	7.9	8.0	8.1
OS-0025	19	8.1	0.4	0.1	7.8	7.9	7.9	8.1	9.2
OSF-82L	5	7.7	0.1	0.1	7.6	7.7	7.7	7.8	7.9
OSF-98	4	7.8	0.3	0.1	7.6	7.7	7.8	7.9	8.2
OSF-109U	3	7.7	0.1	0.1	7.6	7.7	7.7	7.8	7.8
OSF-111	1	7.3	-	-	7.3	7.3	7.3	7.3	7.3
OSF-112	1	8.0	-	-	8.0	8.0	8.0	8.0	8.0
PBF-12	18	7.3	0.2	0.1	6.7	7.2	7.4	7.5	7.6
PBF-15L	7	7.2	0.1	0.0	7.1	7.2	7.2	7.3	7.4
PBF-5	17	7.3	0.2	0.0	7.0	7.2	7.2	7.3	7.6
POF-29	3	7.6	0.1	0.1	7.5	7.5	7.5	7.6	7.7
ROMP74X-LF	17	7.7	0.1	0.0	7.5	7.7	7.7	7.8	7.8
SEPOLK-DEW	2	7.6	0.1	0.0	7.6	7.6	7.7	7.7	7.7
SR-LFPW	1	7.7	-	-	7.7	7.7	7.7	7.7	7.7

- not applicable.

Table A-12. Descriptive statistics for temperature (°C) in the Lower Floridan aquifer-upper permeable zone.

Monitoring Well	No. of Observations	Mean	Standard Deviation	Standard Error	Minimum	25th	50th	75th	Maximum
BF-1	6	21.2	1.7	0.7	19.7	20.1	20.5	22.6	23.4
BICY-MZ4	14	27.5	1.5	0.4	25.8	26.3	27.4	28.4	31.0
DCBR-LFMW2	1	26.5	-	-	26.5	26.5	26.5	26.5	26.5
HS-LFPW	1	26.4	-	-	26.4	26.4	26.4	26.4	26.4
I75-MZ3	17	29.0	1.4	0.3	26.3	28.0	29.3	29.9	31.4
IWSD-MZ4	3	28.3	1.3	0.7	26.9	27.7	28.6	29.0	29.4
L-0729	4	24.7	0.2	0.1	24.6	24.6	24.6	24.7	24.9
L-0897	17	26.6	0.7	0.2	25.0	26.5	26.7	27.0	27.7
OKF-105	1	30.0	-	-	30.0	30.0	30.0	30.0	30.0
OR-0676	13	26.6	0.7	0.2	24.7	26.7	26.9	27.0	27.1
OR-0794	7	24.2	1.3	0.5	22.6	23.1	24.5	25.2	25.8
ORF-60	4	25.5	0.2	0.1	25.2	25.4	25.5	25.6	25.7
OS-0025	21	26.1	0.9	0.2	23.6	25.8	26.4	26.8	27.0
OSF-82L	5	25.8	1.9	0.9	22.6	25.5	26.3	27.2	27.2
OSF-98	4	25.3	0.8	0.4	24.6	24.8	25.3	25.8	26.2
OSF-109U	3	27.0	0.9	0.5	26.4	26.5	26.6	27.4	28.1
OSF-111	1	26.7	-	-	26.7	26.7	26.7	26.7	26.7
OSF-112	1	23.0	-	-	23.0	23.0	23.0	23.0	23.0
PBF-12	18	24.8	2.5	0.6	22.6	23.6	24.2	25.2	33.8
PBF-15L	7	28.4	0.7	0.3	27.0	28.2	28.6	28.8	29.0
PBF-5	17	22.9	0.9	0.2	21.9	22.4	22.8	23.1	25.6
POF-29	3	26.8	0.6	0.4	26.4	26.5	26.5	27.0	27.5
ROMP74X-LF	17	27.5	0.4	0.1	26.9	27.2	27.4	27.8	28.1
SEPOLK-DEW	2	26.9	0.0	0.0	26.9	26.9	26.9	26.9	26.9
SR-LFPW	1	26.7	-	-	26.7	26.7	26.7	26.7	26.7

- not applicable.