Focused Implementation of Best Management Practices in the Santa Fe River Basin:

Three-Year Progress Report for the Santa Fe Restoration Focus Area (January 2013–December 2015)

A Joint Document Prepared by the

Division of Environmental Assessment and Restoration
Florida Department of Environmental Protection
Tallahassee, Florida

and

Office of Agricultural Water Policy
Florida Department of Agriculture and Consumer Services
Tallahassee, Florida

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Executive Summary

As part of the basin management action plan (BMAP) to restore water quality in the Santa Fe River and its impaired spring-fed tributaries by reducing nitrogen loads to the system, the Florida Department of Environmental Protection (DEP) and the Florida Department of Agriculture and Consumer Services (FDACS) Office of Agricultural Water Policy (OAWP) are collaborating on a restoration focus area (RFA) in the Santa Fe River Basin. The two agencies are concentrating staff and funding to expedite the implementation of nutrient management best management practices (BMPs) and to evaluate their impact on water quality. The 185-square-mile RFA includes the combined springsheds of Ginnie and Gilchrist Blue Springs, a significant source of nitrate-nitrogen to the lower Santa Fe River. Major land uses/land cover (2010) in the RFA include forest land (44 %), agriculture (29 %), and urban/residential (12 %; mostly low-density residential).

Within the RFA, agency resources are focused on a high-intensity effort to work with agricultural producers to implement nutrient management BMPs and to monitor water quality changes in groundwater, springs, and the Santa Fe River. The RFA activities began in January 2013 and include ongoing efforts to maximize enrollment in agricultural BMPs for vegetable and agronomic crops and cow-calf operations, and to monitor (quarterly) water quality at 20 monitoring wells, 4 springs, and 3 Santa Fe River stations. In addition, continuous water quality monitoring equipment (nitrate as nitrogen [nitrate-N], pH, temperature, dissolved oxygen [DO], and specific conductance), a rain gauge, and a velocity meter were installed at Ginnie Springs to better understand how nitrate-N in water from the spring responds to rainfall, fluctuations in groundwater levels, land use practices, and other factors. The continuous water quality sensor, rainfall, and spring velocity data are sent via telemetry to a website where they can be viewed in real time.

Progress and findings from the initial three years of RFA activities (January 2013 through December 2015) include the following:

- The OAWP has enrolled most of the agricultural acreage in BMPs. During 2015 in the RFA, an additional 13,968 acres of commercial agricultural acres were enrolled in BMPs. This brings the total amount of agricultural area enrolled or signed notices of intent (NOIs) to 41,573 acres. The number of NOIs in the RFA by the end of December 2015 increased to 135 from 89 at the end of 2014.

- The main source of elevated nitrate-N concentrations in groundwater and spring water is inorganic fertilizer, based on data for nitrate isotopes, potassium, chloride, and bromide.

- Twelve monitoring wells are located adjacent to and/or downgradient from parcels that have signed NOIs or are currently enrolled in agricultural BMPs. Nitrate-N concentrations in quarterly samples were assessed for trends over the 3 years of the study. The trend analyses are preliminary and likely are not definitive due to the relatively small number of samples (11) from each well. Of the 12 wells monitored, 7 had statistically significant increasing trends, 3 had decreasing trends, and 2 did not show any trend. Nitrate-N concentrations decreased substantially (25 to 10 milligrams per liter [mg/L] and 10 to 4.6 mg/L) from January 2013 to September 2015 in 2 wells. These 2 wells are located near irrigated field crops and pasture that support a dairy and are adjacent to parcels that have been enrolled in BMPs. Both dairies were enrolled in BMPs after monitoring had started. Considerable changes in agricultural practices have occurred that involved moving from traditional crop production to sod-based rotation practices. Additional information is not available on the timing and specific types of BMPs being used at agricultural sites near these wells.

- No trends in nitrate-N concentrations were observed for wells located near or downgradient from residential areas or the Newberry wastewater treatment facility (WWTF).

- During the period from January 2013 to September 2015, there was a statistically significant relation between nitrate-N concentrations and groundwater levels. This likely indicates that as the amount of rainfall and hence recharge to the aquifer increase, nitrate-N concentrations increase in groundwater as a result of the leaching of fertilizer nitrogen and/or organic sources of nitrogen (e.g., livestock manure).

- No significant decreases in nitrate concentration were observed over the three-year period in the sampled springs or Santa Fe River sites. This lack of response may be related to (1) insufficient time for changes in agricultural practices to affect ground water quality (a lag effect from when BMPs are implemented to when improvements in water quality are seen); (2) legacy nitrogen in soil and shallow groundwater from past practices; (3) compliance issues in the implementation of BMPs; and/or (4) the limitations of BMP effectiveness because of soil conditions, cropping rates, fertilization rates, and irrigation needs that may warrant additional measures.

Introduction

As part of the basin management action plan (BMAP) to address nutrient total maximum daily loads (TMDLs) in the Suwannee River Basin, the Florida Department of Environmental Protection (DEP) and the Florida Department of Agriculture and Consumer Services (FDACS) Office of Agricultural Water Policy (OAWP) selected a restoration focus area (RFA) in the Santa Fe Springs Basin. The purpose of an RFA is to concentrate staff and funding on expediting the implementation of best management practices (BMPs) and evaluating their impact on water quality. The Ginnie and Gilchrist Blue springsheds were selected to evaluate how BMPs affect nitrogen loading to ground water and nitrate as nitrogen (nitrate-N) concentrations in springs.

The Santa Fe Basin RFA shown in **Figure 1** was delineated using springshed maps from a groundwater flow model developed by Geohydros (Kinkaid et al. 2009). The RFA is bounded to the north by the Santa Fe River, to the east by the Poe and Lily Springs springsheds, to the west by the edge of the Waccasassa Flats, and to the south by the southern boundary of the Santa Fe River groundwater contributing area. It is based primarily on a composite of modeled low-flow (worst-case) groundwater capture areas (springsheds) for Ginnie and Gilchrist Blue Springs, but the RFA also includes the smaller Twin Spring springshed to the west, a small area between the Ginnie–Gilchrist Blue and Poe–Lily springsheds, and the major springs that discharge into the Santa Fe River west of Poe Spring from south of the river. The criteria for selecting this area are listed in the 2013 joint DEP-FDACS document, *Focused Implementation of Best Management Practices in the Santa Fe River Basin*.

The RFA includes approximately 185 square miles in Gilchrist and Alachua Counties. According to the most recent land use/land cover map of the Suwannee River Water Management District (SRWMD), based on 2010 and 2011 aerial photographs, the major land uses/land cover in the area include forestland (44 %), agriculture (29 %), and urban/residential (12 %; mostly low-density residential). A recently updated land use map for 2012 (**Figure 2)** highlights land uses that may contribute nitrate-N to groundwater. This joint DEP-FDACS effort is monitoring land use changes in the RFA that may influence nitrogen loading.

The city of Newberry, the only incorporated area in the RFA, covers 54.6 square miles. Newberry has its own wastewater treatment facility (WWTF), which serves the more densely developed portion of the city and has a design flow of approximately 0.415 million gallons per day (mgd). This WWTF discharges treated effluent to a sprayfield in the RFA. The remaining homes and businesses in the RFA are served by septic systems, also referred to as onsite sewage treatment and disposal systems (OSTDS). Overall, there are 3,500 OSTDS in the Santa Fe Basin RFA, most of them in the Newberry area. Also, the High Springs WWTF in Alachua County lies just outside (east and upstream of) the RFA boundary and has a design capacity of 0.24 mgd.

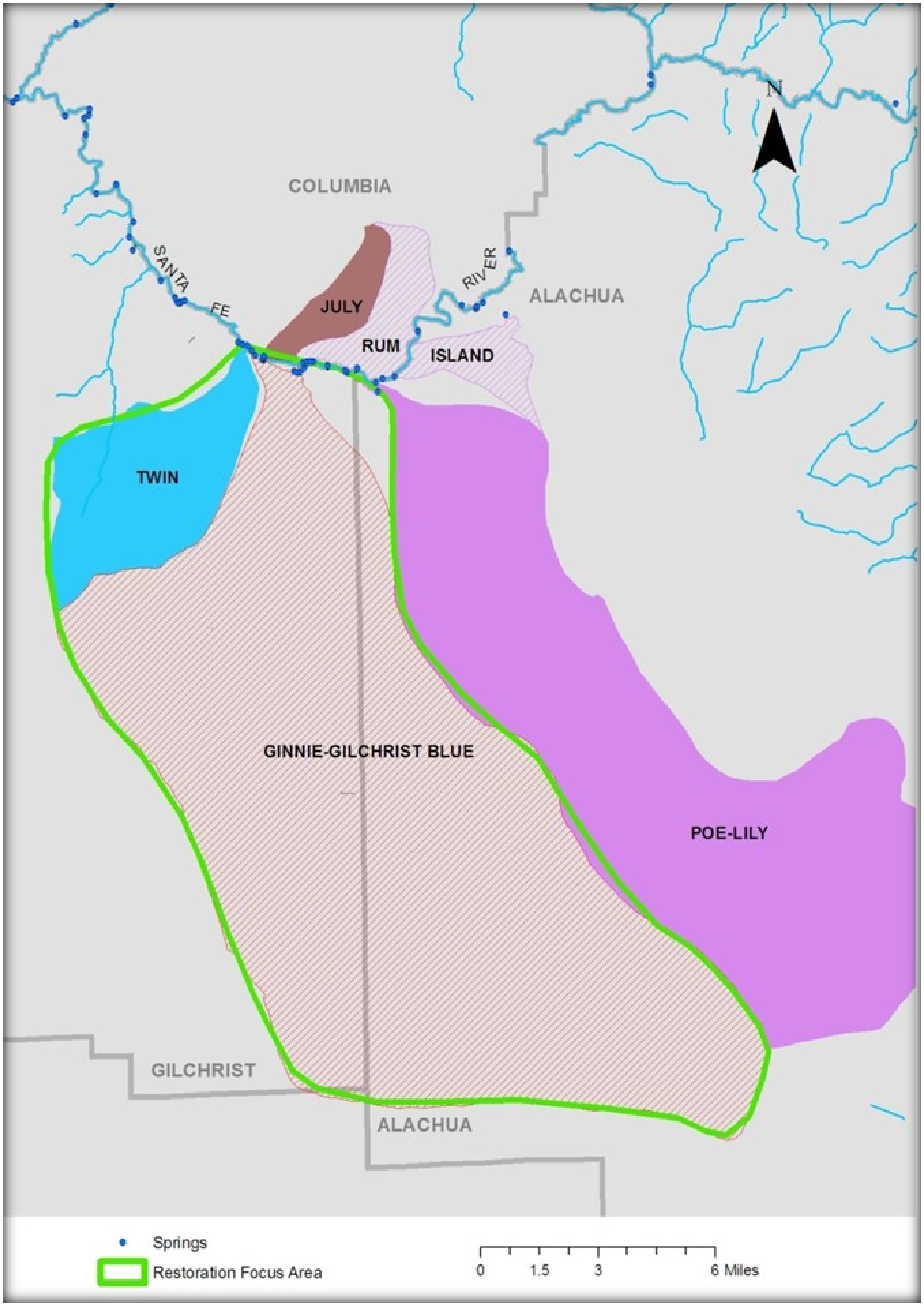

Figure 1. Santa Fe Springs Basin, RFA boundary, and adjacent springsheds

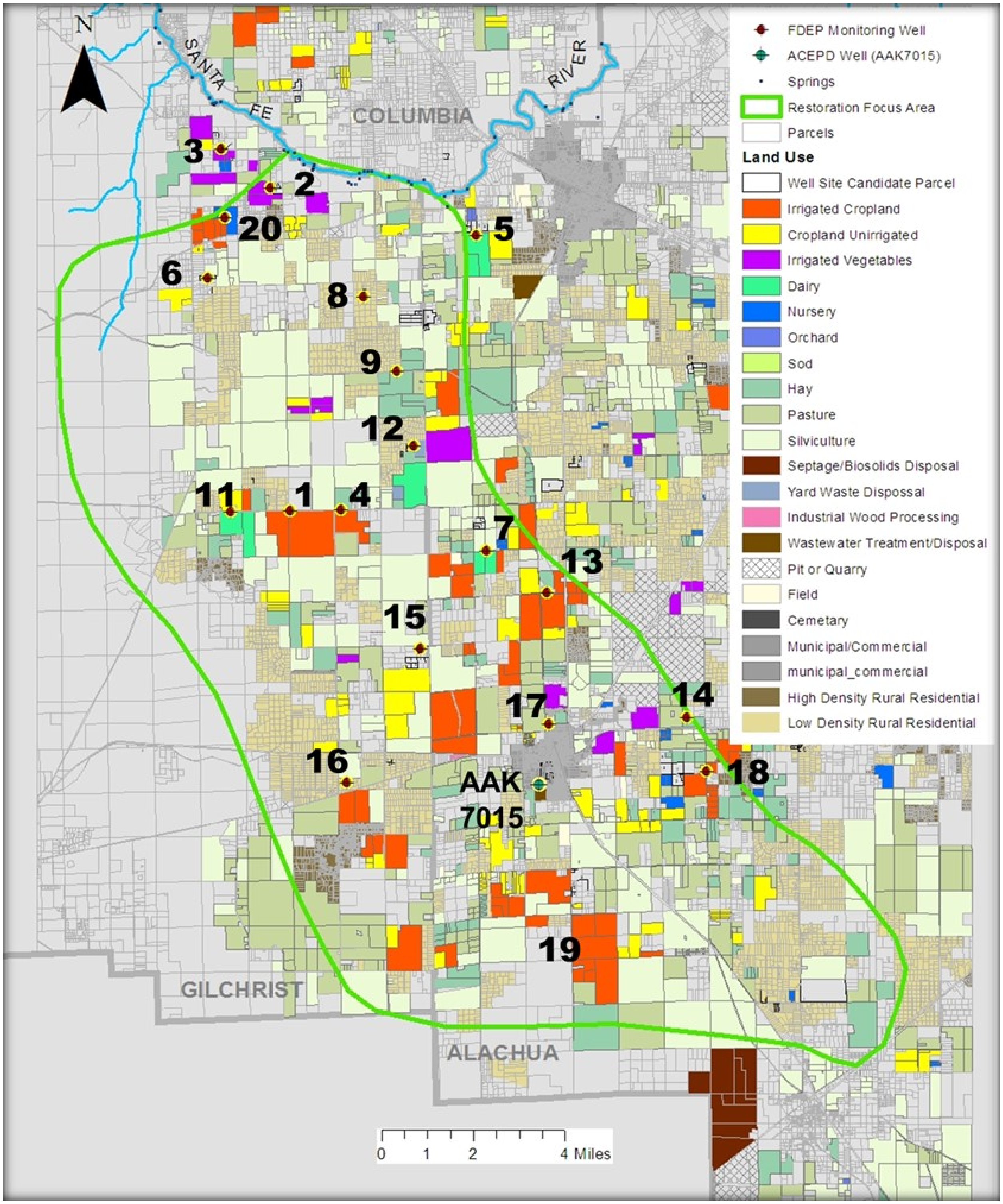

Figure 2. Land use and monitoring well locations in the Santa Fe Basin RFA in 2012

The strategy for evaluating the water quality effects of BMPs and other actions in the RFA includes two main components of measurement: (1) quarterly water quality monitoring of groundwater, springs, and river water; and (2) enrollment in and the implementation of BMPs for vegetable and agronomic crops, container nurseries, and cow-calf operations (FDACS 2008, 2014, and 2015). This second component includes gaining agricultural landowner participation in the BMP Program, identifying priority practices to focus cost-share and implementation assurance efforts (nutrient and irrigation BMPs), and determining compliance with applicable fertilizer ordinances in urban areas. Also, FDACS Forest Hydrology Section provides information to Florida's private and public forest landowners regarding BMPs associated with silviculture activities in the 2008 *Silviculture Best Management Practices Manual*.

The DEP–FDACS document (DEP 2014) describes the RFA process, criteria for selecting the RFA, actions completed to attain stakeholder involvement in the RFA effort, steps for assessing progress in the RFA, and the water quality monitoring plan. DEP and FDACS also prepared a 2014 progress report (published in 2015) that includes water quality and BMP enrollment information collected from 2013 through 2014.

This three-year Progress Report includes comprehensive information from January 2013 through December 2015. The water quality information presented here focuses on nitrate-N concentrations in groundwater, springs, and river water samples. However, other chemical data are included that help to determine the sources of nitrate and processes that affect the movement of nitrate in the RFA.

Water Quality Monitoring Network

Groundwater Sites

Table 1 lists the 20 monitoring wells that were installed, developed, and surveyed for the groundwater monitoring network in the RFA. In addition, a monitoring well near the Newberry WWTF sprayfield was added to the sampling network in August 2013. **Figure 2** shows the locations of the ground water monitoring wells with respect to land use and land cover designations in the RFA. Water samples were collected quarterly from monitoring wells during 2013 and 2014. In 2015, DEP sampled monitoring wells during March, June, and September.

Selected groundwater quality data (nitrate-N, potassium, sulfate, dissolved solids) and groundwater levels for the period from January 2013 to July 2015 were evaluated using statistical tests for trends and seasonality (R. Copeland, 2015, DEP, written communication). Seasonality tests were conducted for quarterly and semiannual sampling. Based on the groundwater level data, a dry season exists from November through April, and a wet season exists from May through October. A statistically significant six-month seasonality was found for groundwater levels. However, nitrate-N, potassium, sulfate, and dissolved solids did not show statistically significant seasonality.

Based on the results from these seasonality tests for nitrate-N, potassium, sulfate, and dissolved solids, the sampling schedule was modified after September 2015. The new sampling frequency of the monitoring wells was reduced from quarterly to semiannually, with the exception of Monitoring Well #12. Water samples from this well have had high nitrate-N concentrations (greater than 40 mg/L) and increased during the study period. This site is also located near a pump and treat system that is passing groundwater with elevated nitrate-N concentrations through a bioreactor to reduce nitrate concentrations in the treated effluent recharged to the aquifer.

Springs and Surface Waters

DEP collected quarterly spring water quality samples from Ginnie Spring, Gilchrist Blue Spring, Devil's Eye Spring, and Twin Spring (**Figure 3**) from 2013 to 2015.These springs represent the major contributions of spring water discharge to the Santa Fe River in the RFA. DEP also collected river water samples quarterly at three stations on the Santa Fe River from 2013 to 2015 (**Figure 3**). **Figure 4a** shows the mean daily discharge values for the Santa Fe River at Fort White for the period from January 2013 to December 2015. **Figure 4b** shows the mean daily discharge for the Santa Fe River near Ft. White from January through December 2015. **Figure 4c** shows the daily rainfall amounts during January through December 2015 measured at the SRWMD Forest Grove site.

Continuous Monitoring at Ginnie Spring

Specialized continuous monitoring equipment was installed in March and April 2014 at Ginnie Spring to obtain continuous measurements of nitrate-N and other water quality parameters. Continuous water quality sensors include probes to measure pH, temperature, dissolved oxygen (DO), and specific conductance. A submersible ultraviolet nitrate analyzer (SUNA) provides measurements of nitrate (as nitrogen). Also, a rain gauge was installed near Ginnie Spring that provides continuous measurements of rainfall. In addition, equipment was installed in the spring to continuously measure spring stage, velocity, and flow direction. Spring flow (discharge) is estimated by multiplying the water velocity times the cross-sectional area of the spring vent opening.

Water from the spring is pumped about 80 feet to a flow-through cell housed in a nearby shelter, where the various sensors take measurements every 15 minutes. The continuous data for water quality, rainfall, and velocity data are sent via telemetry to a website where they can be viewed in real time. The nitrate-N and other water quality data are being analyzed relative to information on rainfall, groundwater levels, spring flow, river flow, and other factors.

[Table 1. Summary information on monitoring wells used in the RFA pilot study

[1] Used in Alachua County Environmental Protection Division quarterly monitoring program.
N/A = Not available; - = Empty cell/no data
Information in comments is from December 2012 field observations and other data. These are updated as new information is received.

Monitoring Well Number	Well Screen Interval Depth (feet)	Adjacent Land Use	Well Distance from Land Use (feet)	Comments
1	38–48	Irrigated cropland	40	In production since 2012; previously scrub
2	38–48	Irrigated vegetables	30	In production since 2012; previously pasture
3	21–31	Irrigated vegetables	430	Vegetables since 2004 aerial; pasture before that
4	58–68	Irrigated cropland	40	Partially irrigated cropland since before 1994
5	48–58	Pasture/crop; supporting dairy	75	Dairy since before 1994 (current status unknown)
6	25–35	Low-density residential		Potential septic tank influence
7	48–58	Irrigated field crop supporting dairy	20	Dairy since before 1994 (current status unknown)
8	58–68	Low-density residential	N/A	Background
9	44–54	Pasture	90	Pasture or nonirrigated crops approximately 20+ years
10	61–71	Irrigated cropland	100	Irrigated cropland since before 1994
11	38–48	Irrigated field crop and pasture supporting dairy	40	Dairy since before 1994
12	68–78	Residential; irrigated field crop supporting dairy	35	Dairy since early 2000s; residential developed in early 2000s
13	51–61	Irrigated cropland	90	Was pasture until approximately 2010
14	48–58	Hay	20	Hayfield or pasture since before 1994
15	61–71	Irrigated cropland	2,300	Multiple agricultural land uses in vicinity
16	58–68	Pasture	60	No change in land use since before 1994
17	35–45	Urban	N/A	In Newberry urban area
18	55–65	Irrigated cropland	80	Cropland since before 1994; not irrigated until possibly 2010
20	58–68	Irrigated cropland	360	Approximately 20+ years; irrigated in early 2000s
21 (AAK7015)[1]		Domestic wastewater cemetery		Adjacent to city of Newberry wastewater treatment plant (WWTP) sprayfield

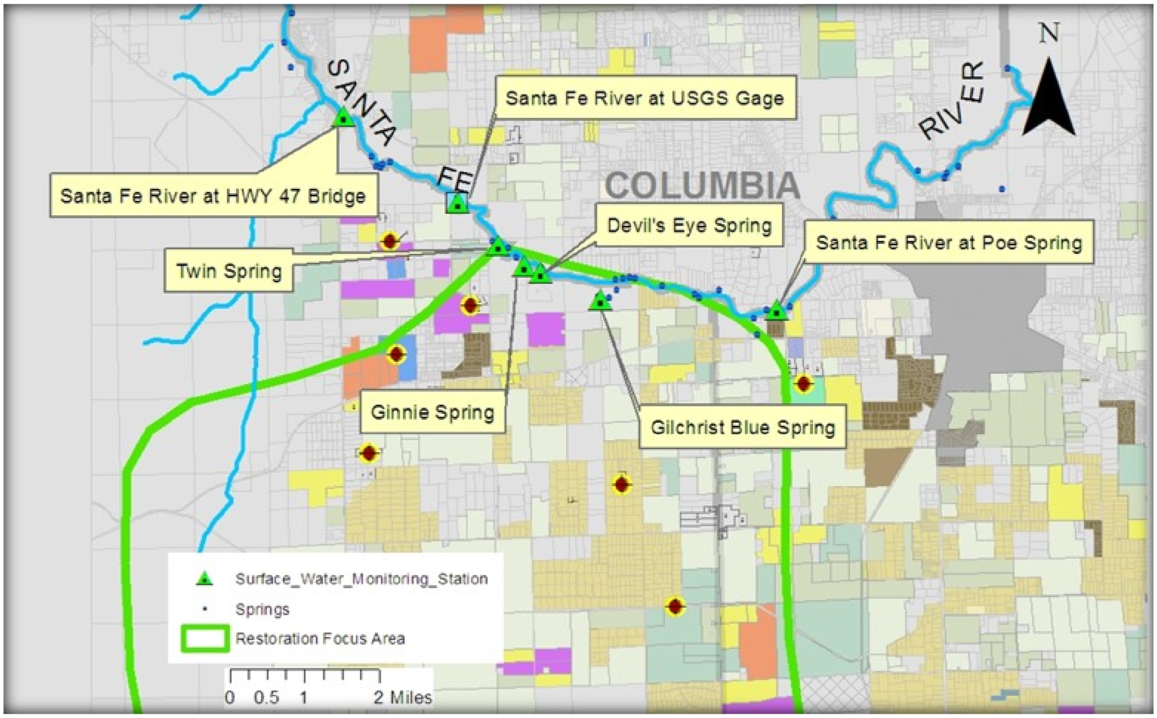

Figure 3. Santa Fe River Basin RFA spring and river monitoring stations

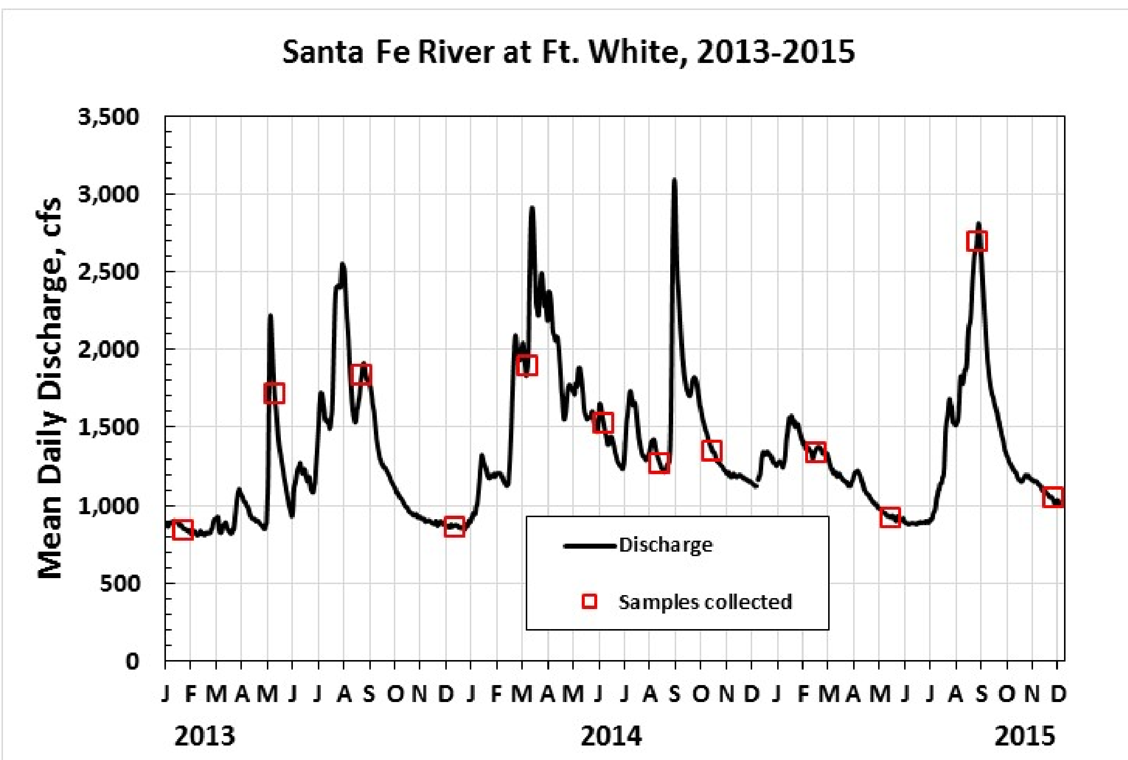

Figure 4a. Mean daily discharge for the Santa Fe River near Fort White, January 2013–December 2015 (U.S. Geological Survey [USGS] data) and collection dates for river samples

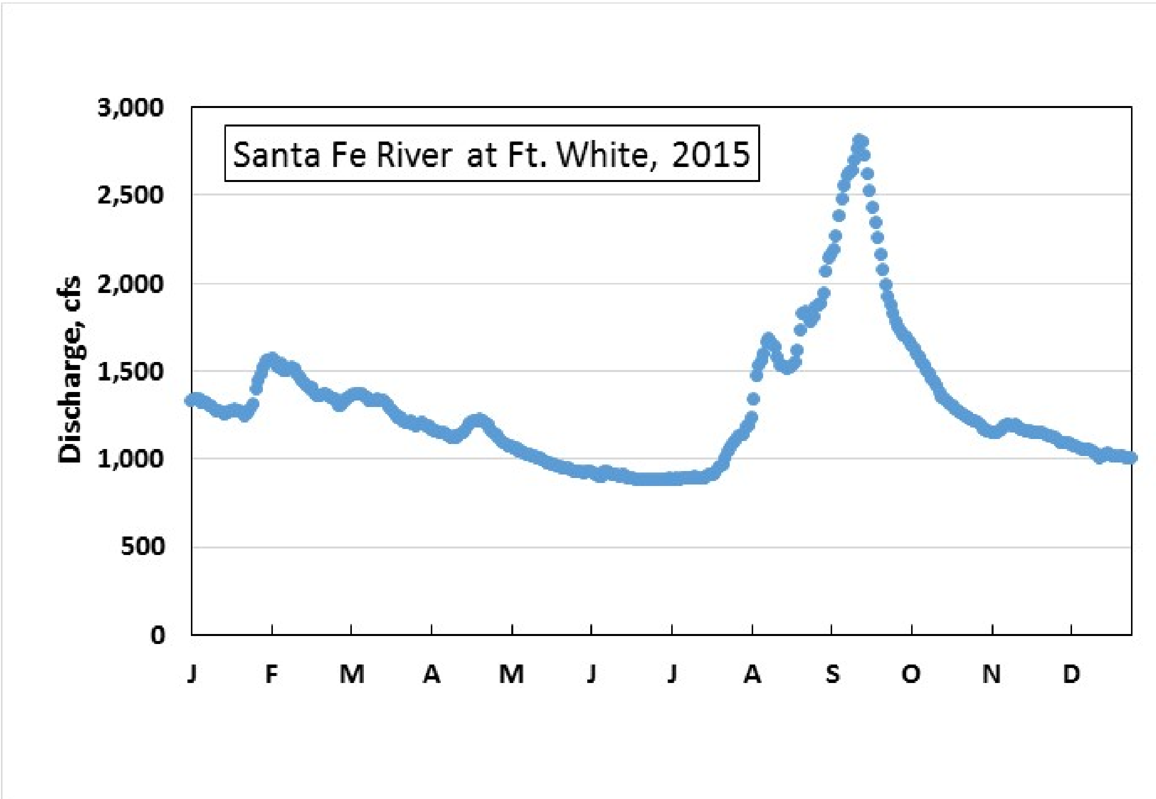

Figure 4b. Mean daily discharge for the Santa Fe River near Fort White, January–December 2015 (from USGS data)

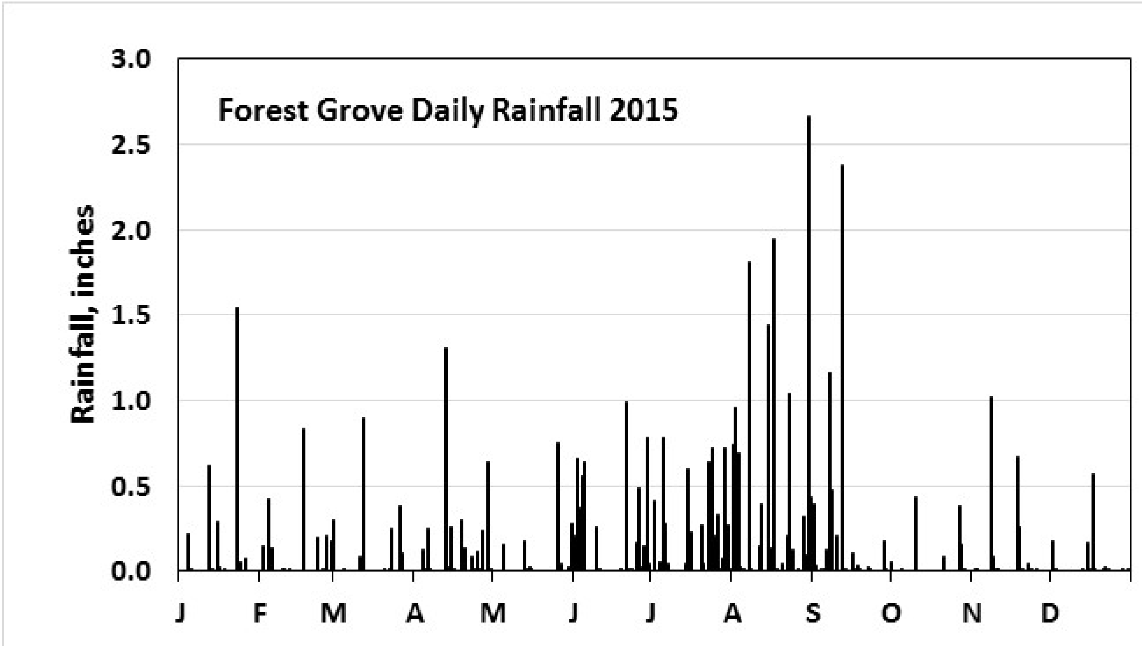

Figure 4c. Daily rainfall amounts during January through December 2015 measured at the SRWMD Forest Grove site

Results

Groundwater Levels

Groundwater elevations at most wells decreased during 2015 compared with increased groundwater levels in 2014 (**Figure 5a, Figure 5b**, and **Figure 5c**). The decrease in water level elevations in 2015 likely resulted from the low amounts of rainfall during January through May (**Figure 6a** and **Figure 6b**).

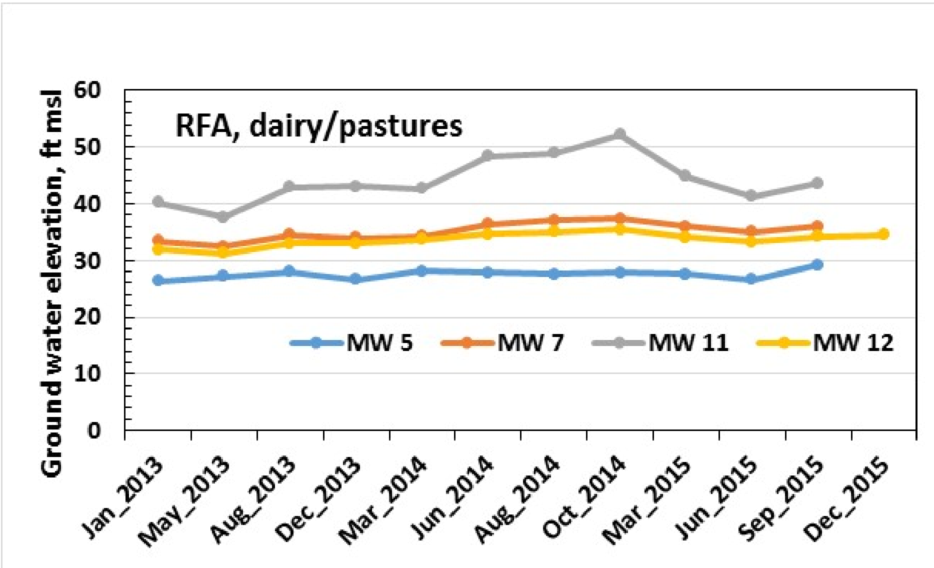

Figure 5a. Santa Fe RFA ground water elevations measured during sampling periods, 2013–15, for wells in dairy/pasture areas

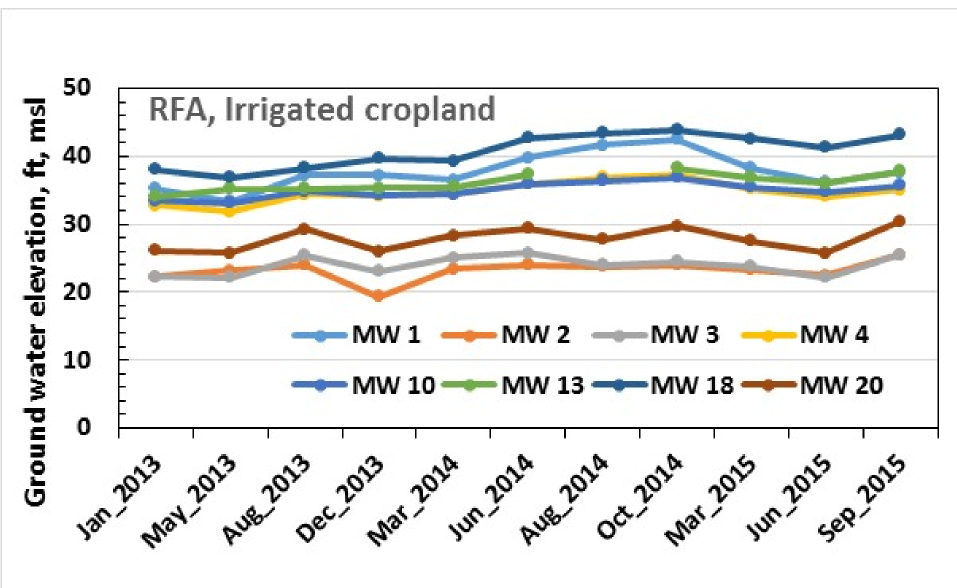

Figure 5b. Santa Fe RFA ground water elevations measured during sampling periods, 2013–15, for wells in irrigated cropland areas

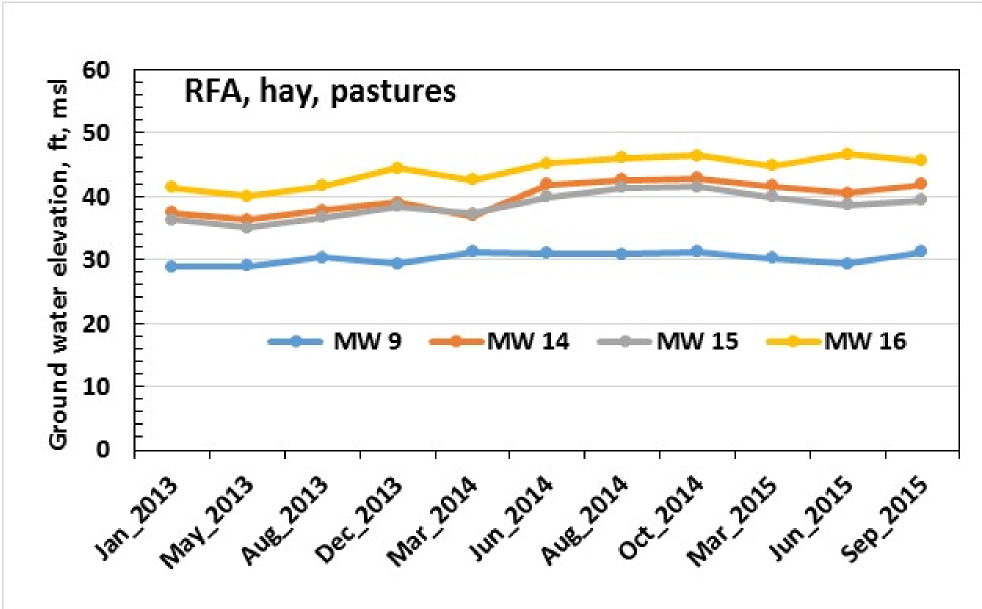

Figure 5c. Santa Fe RFA ground water elevations measured during sampling periods, 2013–15, for wells in hay and pasture areas

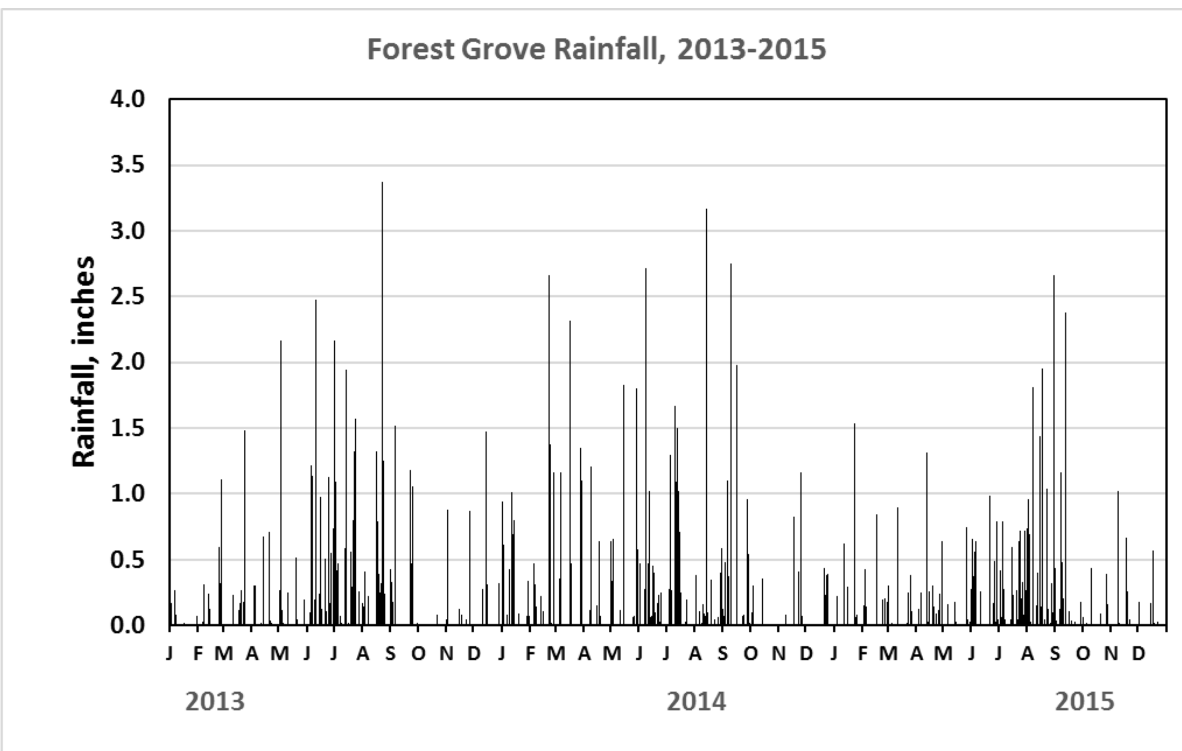

Figure 6a. Daily rainfall totals at the Forest Grove station, near Newberry, Florida, January 2013–December 2015

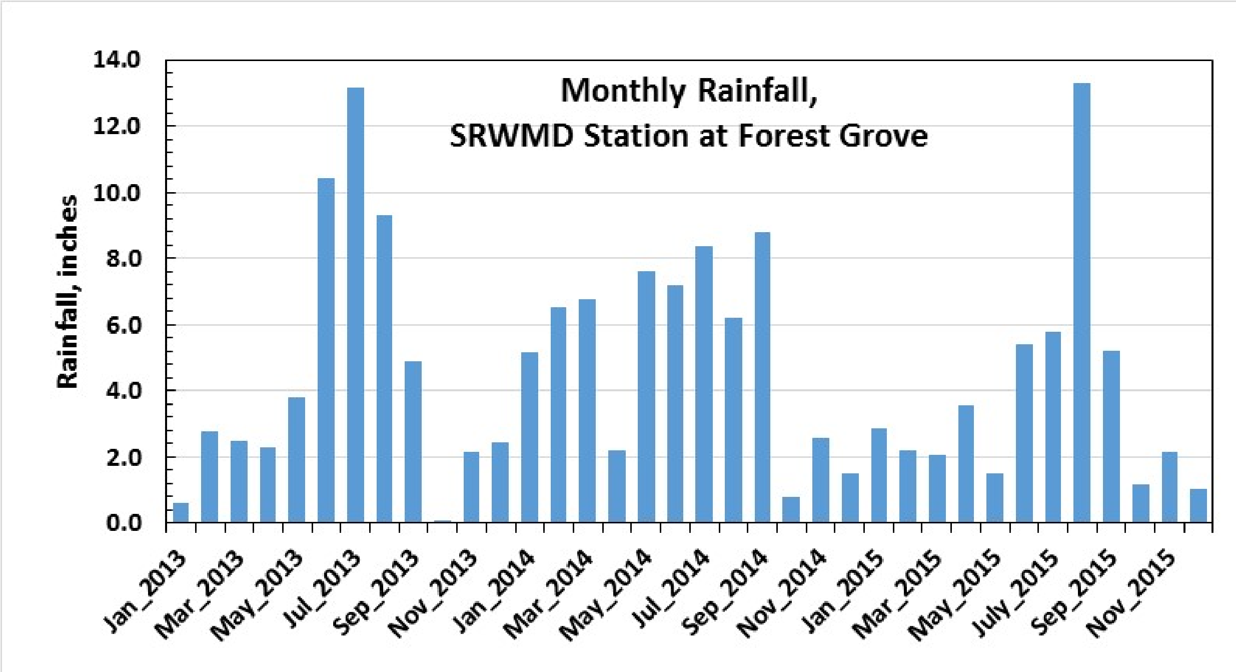

Figure 6b. Monthly rainfall totals at the SRWMD Forest Grove station, near Newberry, Florida, January 2013–December 2015

Nitrate-N Concentrations in Groundwater, Springs, and River Water

One of the main objectives of the RFA study is to investigate the transport and fate of nitrate-N in groundwater, springs, and surface water. Another main objective is to evaluate the potential relationships between changes in nitrate-N concentrations in wells, springs, and river sites with the increased use of BMPs in the RFA. Therefore, this section focuses primarily on nitrate-N in ground water, springs, and river water samples collected from 2013 to 2015. **Appendix 3** contains the complete set of water quality results from groundwater, springs, and river water samples collected during this period, along with analytical data qualifiers and quality assurance/quality control (QA/QC) information. The Appendix 3 spreadsheet is available on request.

Wells were subdivided into four groups based on similar land use classification for the sake of comparing nitrate-N concentrations (pastures supporting dairies, irrigated cropland, hay and nonirrigated pastures, and residential and spray field). For the pasture/dairy sites, nitrate-N concentrations decreased in water samples from Wells 7 and 11 (**Figure 7a**). In contrast, nitrate-N concentrations in water samples from Well 12 increased in March 2015, decreased slightly in June 2015, increased to 67 mg/L in September 2015, and decreased to 59 mg/L in December 2015. Another possible source has been noted for the high nitrate-N concentrations in water samples from Well #12. There may have been a permitted yard debris disposal site near or upgradient from the field where Monitoring Well #12 is located (D. Bottcher, personal communication, SWET, Inc., 2015).

For wells near irrigated cropland, nitrate-N concentrations in Wells 2, 4, and 10 increased during 2015, while nitrate-N concentrations decreased in Well 3 (**Figure 7b**). Nitrate-N concentrations in other wells (1, 13, 18, and 20) in irrigated cropland areas remained relatively constant during 2015.

For wells near nonirrigated pastures/hayfields, nitrate-N concentrations in Well 14 continued to decrease until June 2015, followed by an increase from 8.3 to 11 mg/L in September 2015. Slight increases in nitrate-N concentrations were found in Wells 5 and 9 (**Figure 7c**). Nitrate-N concentrations in Wells 15 and 16 remained consistently low.

For wells near residential areas (Wells 6, 8, and 17), nitrate-N concentrations remained relatively constant throughout the three-year period (**Figure 7d**). Nitrate-N concentrations in Well AAK7015 increased during 2015 after a slight decrease from August 2013 to March 2015. The relation between changes in nitrate-N concentrations over time and parcels enrolled in agricultural BMPs is discussed in the later section on *Implementation of Management Actions*.

During the 3-year period, there was a statistically significant increase in nitrate-N concentrations in wells with an increase in groundwater levels (feet above mean sea level) (Spearman's rho = 0.22, p = 0.001. This indicates that more nitrate is being transported during periods of higher recharge to groundwater, resulting in an increase in nitrate concentrations and an increase in groundwater levels.

During the initial 3 years of the study, nitrate-N concentrations in samples of spring water remained relatively constant and elevated. The following narrow ranges of nitrate-N concentrations were observed from January 2013 through December 2015 for the 4 monitored springs in the RFA: 2.0 to 2.4 mg/L in Gilchrist Blue Spring, 1.4 to 1.6 mg/L in Ginnie Spring, 1.4 to 2.0 mg/L in Devil's Eye Spring, and 0.9 to 1.3 mg/L in Twin Spring. Nitrate-N concentrations in all sampled springs continued to exceed 0.35 mg/L, which is the TMDL for springs in the Santa Fe River BMAP area.

From 2013 to 2015, nitrate-N concentrations in river water samples were consistently lower than in springs but showed considerably more fluctuation from one quarterly sample to another (**Figure 8**). The river water samples were collected over a wide range of discharge values (846 to 2,690 cubic feet per second [cfs]), as measured at the USGS Santa Fe River station near Fort White (**Figure 4a**). There was a significant inverse relation between nitrate-N concentrations and discharge in samples collected at the Fort White site (Spearman's rho = -0.63, p=0.039) and at the State Road 47 Bridge site (Spearman's rho = -0.63, p=0.037). Nitrate-N concentrations were consistently lower in samples from the river site upstream from Poe Spring.

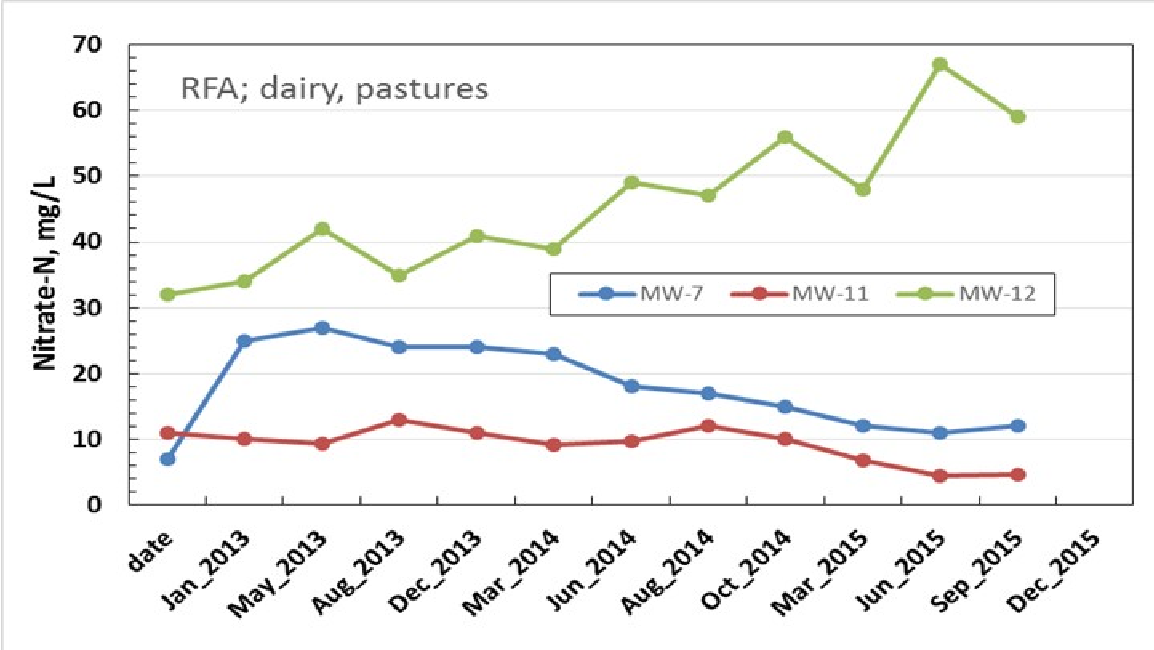

Figure 7a. Nitrate-N concentrations in RFA ground water samples collected in 2013–15, from wells near dairy and pastureland uses

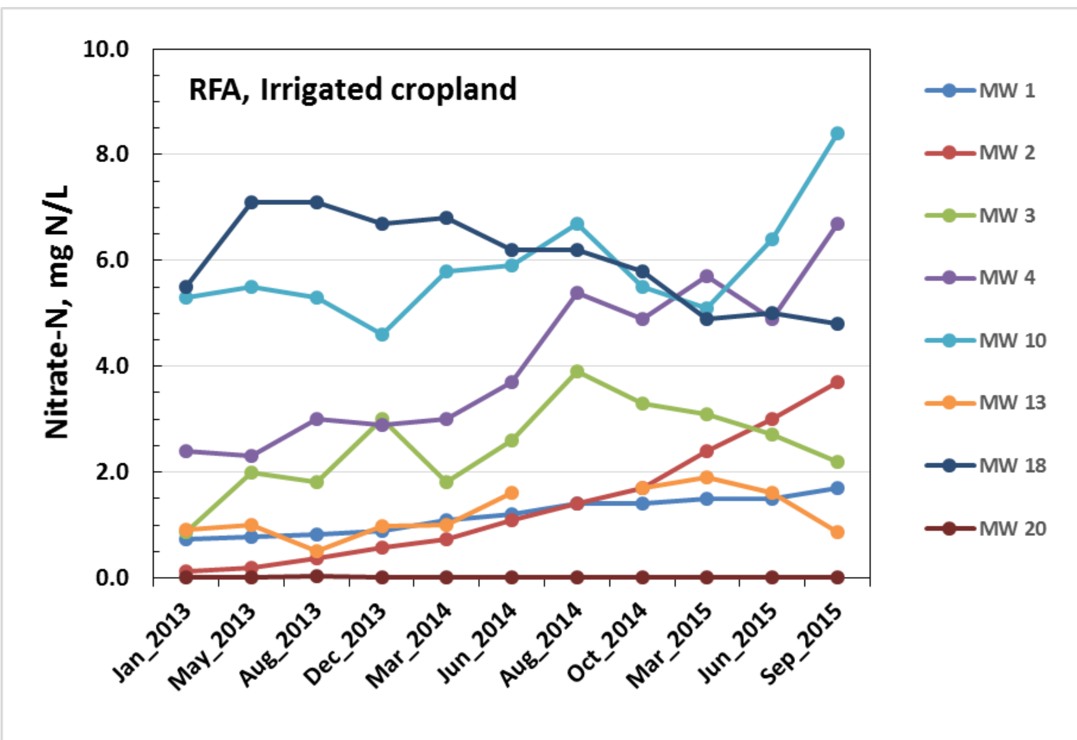

Figure 7b. Nitrate-N concentrations in RFA ground water samples collected in 2013–15, from wells near irrigated cropland land uses

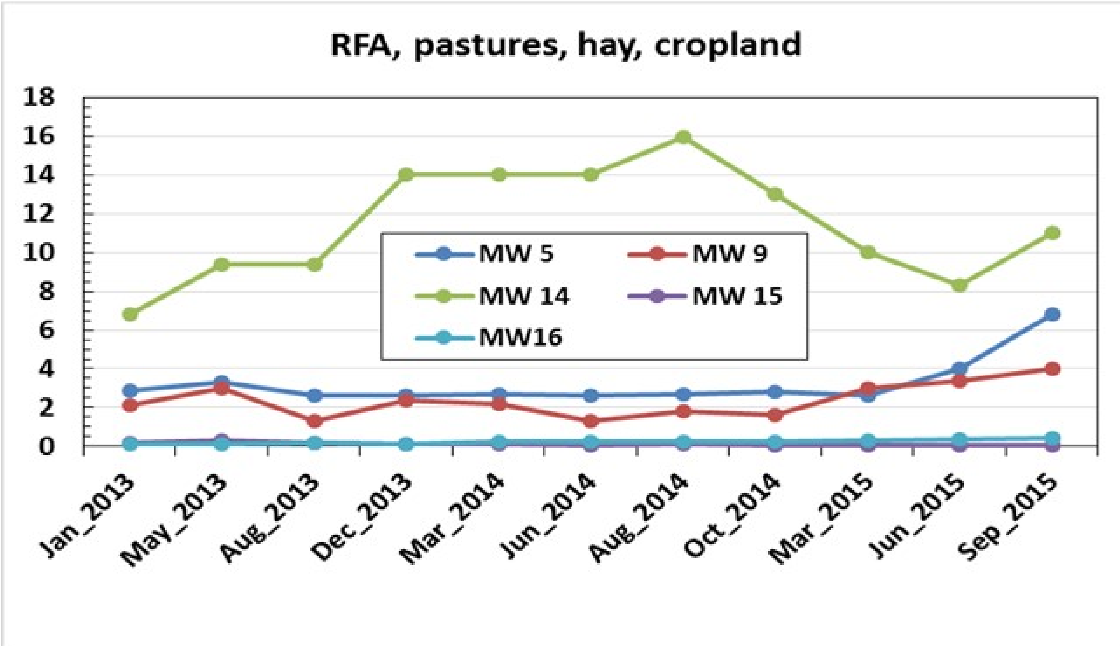

Figure 7c. Nitrate-N concentrations in RFA ground water samples collected in 2013–15, from wells near pastures, hayfields, and cropland land uses

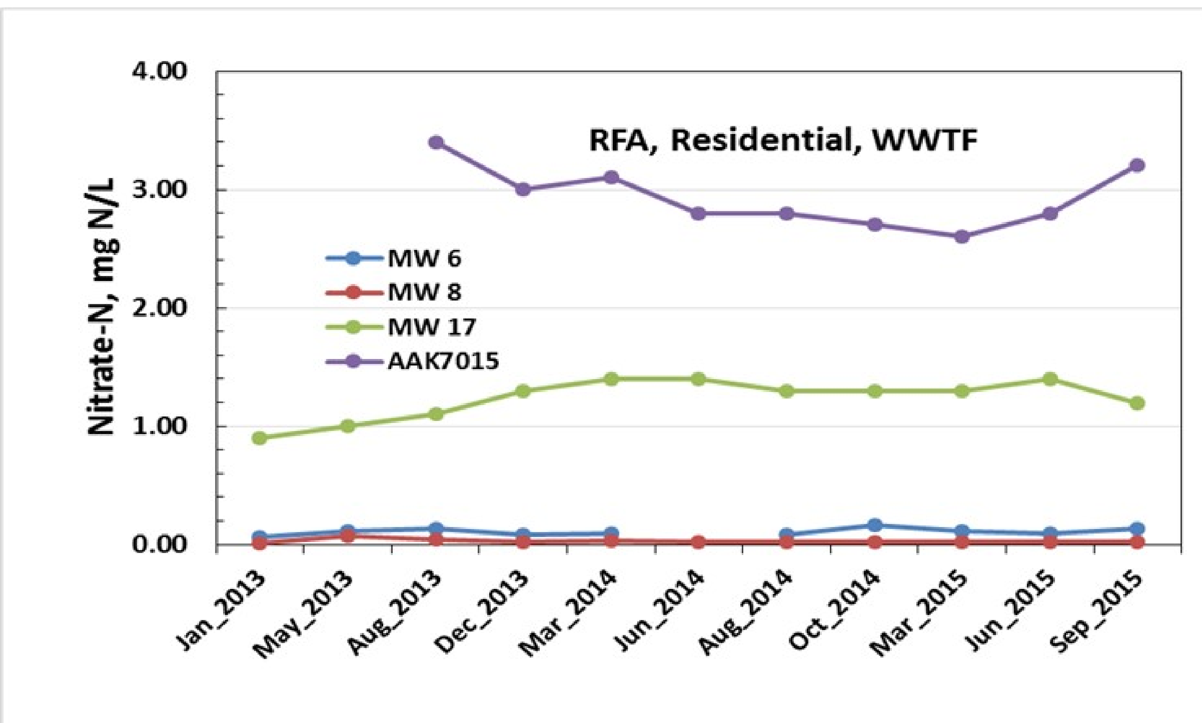

Figure 7d. Nitrate-N concentrations in RFA ground water samples collected in 2013–15, subdivided by wells near residential and WWTF land uses

The inverse relation between nitrate-N and discharge likely indicates that higher nitrate-N concentrations are originating from groundwater inflow to the river during low-flow conditions, and nitrate-N concentrations are being diluted with upstream waters with low nitrate-N concentrations during high-flow conditions. There appears to be an inverse relation between nitrate-N concentrations and discharge at the river site upstream from Poe Spring. However, there was no statistically significant trend (Spearman's rho = -0.46, p=0.16). The lower nitrate-N concentrations in samples from this site may reflect a greater amount of denitrification in groundwater due to more reducing conditions near the river in this area.

Continuous Monitoring Data at Ginnie Spring

The continuous water quality data—along with information on rainfall, spring flow velocity, and Santa Fe River discharge—provide a more complete understanding of short-term interactions between river water and the groundwater that discharges from Ginnie Spring, and how these interactions affect nitrate concentrations in the spring. This section summarizes the continuous water quality data measured using various sensors (conductivity [specific conductance], DO, pH, temperature, and nitrate-N). **Figure 9a** shows the continuous measurements of DO, nitrate-N, temperature, conductivity and pH from June 1, 2014, through December 31, 2014. **Figure 9b** shows continuous water quality monitoring data for January through December 2015.

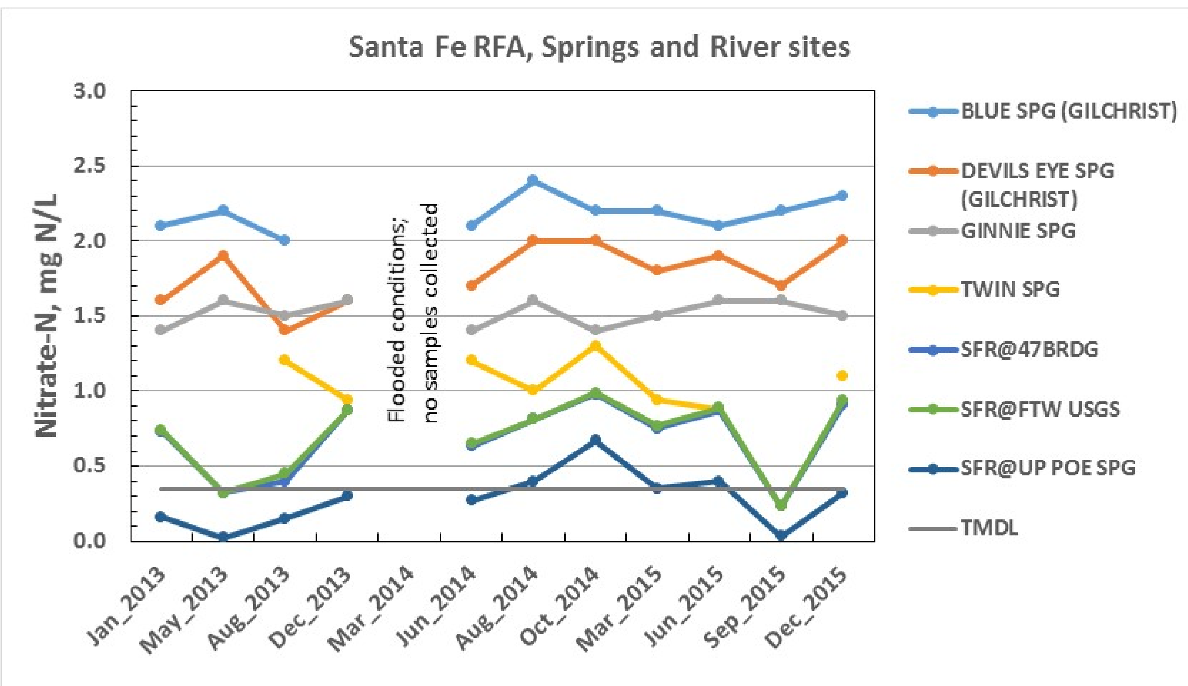

Figure 8. Nitrate-N concentrations in springs and river water samples collected from 2013 to 2015. No water samples were collected from springs or river sites in March 2014 or from Twin Spring in September 2015 due to extreme high-water conditions.

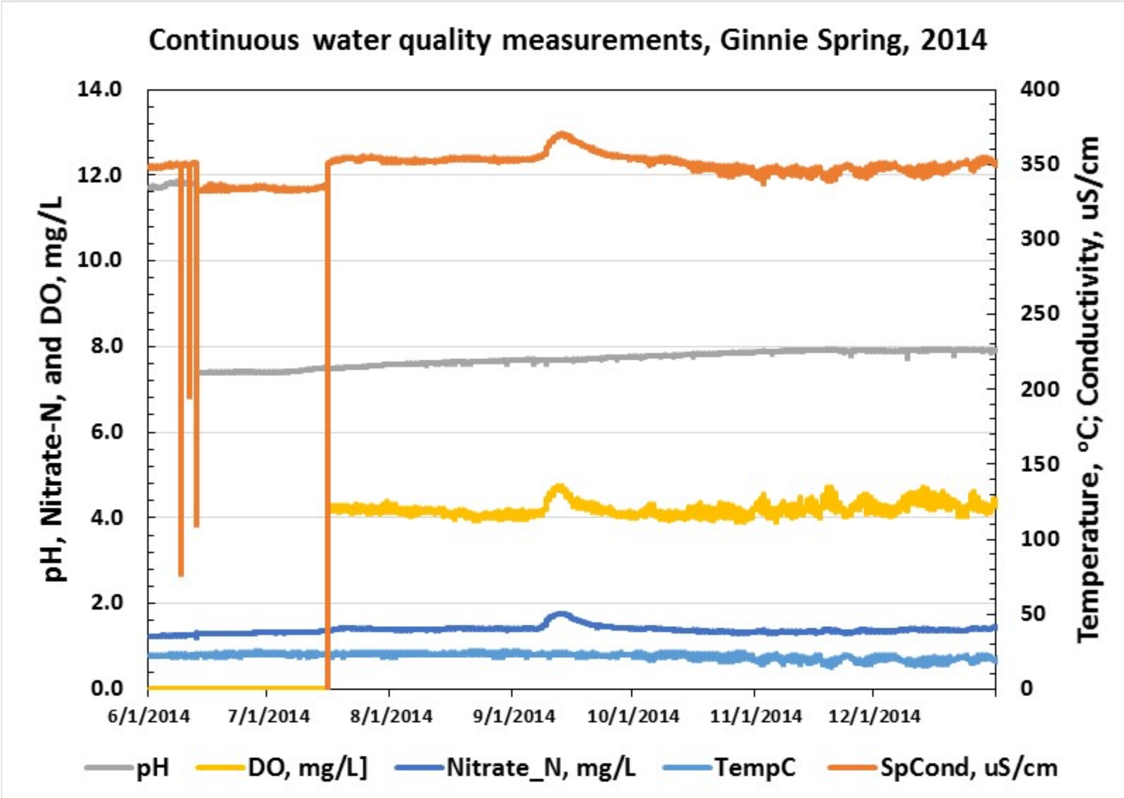

Figure 9a. Continuous measurements of water quality, Ginnie Spring, 2014

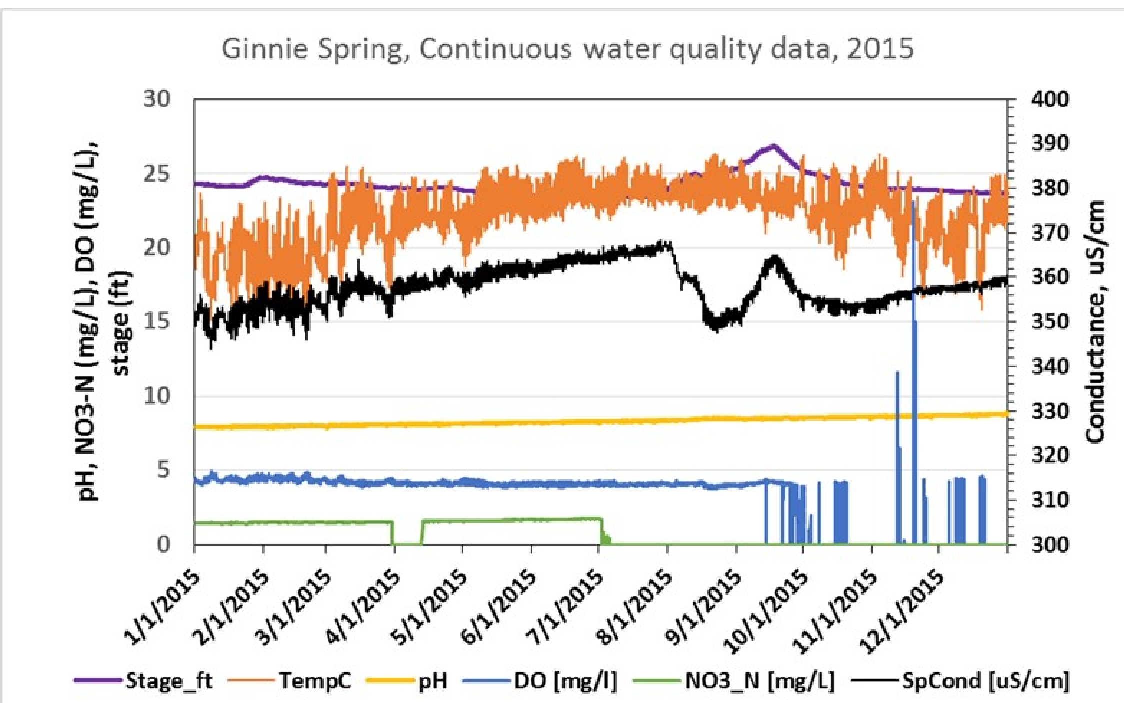

Figure 9b. Continuous measurements of water quality, Ginnie Spring, 2015

There were several issues with the continuous monitoring sensors during 2014 and 2015. Conductivity and DO measurements stabilized in mid-July 2014 after an erratic start in June 2014. The nitrate sensor (SUNA) was not operative for two weeks in April 2015 and from July through December (**Figure 9b**). The DO sensor malfunctioned in September 2015, and no DO data were measured for the remainder of the year. During both years, problems persisted with the continuous temperature sensor measurements that could affect other water quality parameters. Because the water is pumped from the spring to a flow-through cell for the sensor measurements, the water temperature of the spring water sample is affected by the air temperature in the shelter and in the flow-through cell. The fluctuations in spring water temperatures measured in the flow-through cell are affected by changes in air temperature in the shelter throughout the 24-hour period (**Figure 10**).

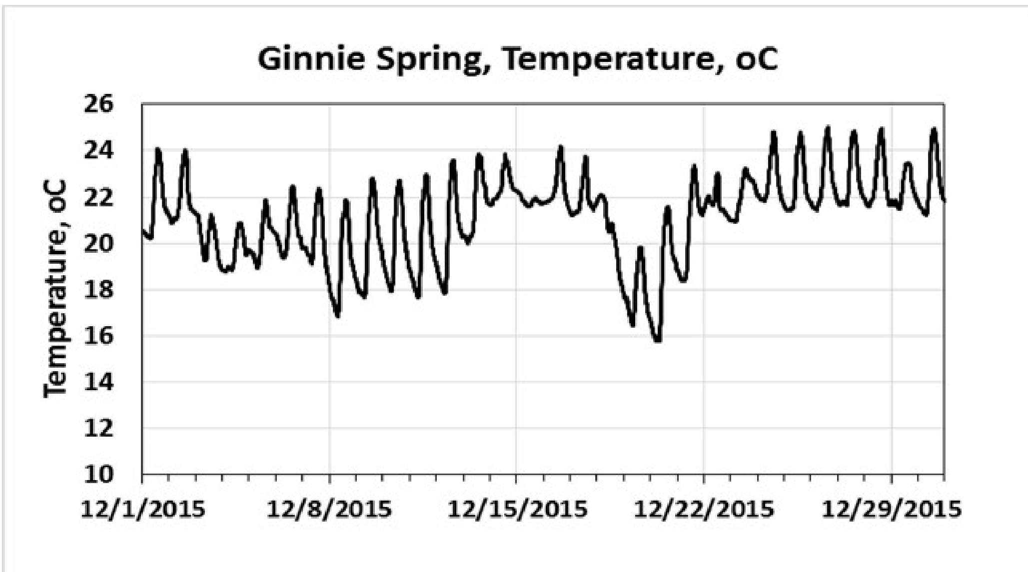

Figure 10. Continuous measurements of water temperature from Ginnie Spring during December 2015 (expanded view)

These fluctuations in temperature also appear to be causing subtle changes in some water quality parameters that likely are not representative of conditions in groundwater discharging from the spring. An increase in water temperature can cause an increase in the mobility of ions in solution due to the dissociation of molecules, and this would lead to an increase in conductivity. The fluctuations in nitrate-N concentrations that are similar to changes in conductivity throughout the day also appear to be related to changes in air temperature in the shelter and not actual changes in the aquifer.

Conversely, as water temperatures increase, the solubility of oxygen and other gases decreases, and DO values decrease. Consequently, pH also increases with higher temperatures, as less carbon dioxide (CO_2) gas is present. To alleviate these fluctuations, a higher volume pump will be installed, and flow cell purge and sampling rates will be modified.

An important quality control check on the accuracy of the readings from the continuous water quality sensors is to compare these data with field-calibrated measurements. In **Table 2,** SUNA-measured nitrate-N concentrations closely matched (±0.1 mg/L) the nitrate-N concentrations in water samples collected on March 2, 2015, and June 2, 2015, and analyzed at the DEP Laboratory (**Figure 2**). Unfortunately, due to a malfunctioning SUNA, there were no measurements to compare with field values in September and December 2015. Continuous sensor conductivity measurements are about 10 % higher than those measured in the field during sample collection. In addition, continuous pH sensor measurements were 0.5 to 0.7 units higher than field measurements in March and June 2015, but more than 1.2 units higher in September and December, indicating that the pH sensor was not providing accurate pH measurements. The continuous DO measurements are about 0.3 to 0.5 mg/L lower than the field measurements, and likely are affected by the changes in temperature when water is pumped from the spring to the flow-through chamber and the incomplete purging of water from previous samples from the chamber. Continuous temperature measurements are about 0.5 to more than 3.5 degrees higher than field measurements in March, September, and December 2015 (**Table 2**).

Figure 9a shows the continuous nitrate-N measurements measured by the SUNA in Ginnie Spring during 2014. Nitrate-N concentrations steadily increased from 1.45 mg/L on January 1, 2015, to 1.73 mg/L on June 30, 2015. The increase in nitrate-N appears to be related to the lower stage and increased spring flow velocity from January through June 2015 (**Figure 11)** compared with higher values during 2014. The lower spring stage and flow velocity likely result from the lower Santa Fe River discharge during this same period compared with 2014 conditions (**Figure 11**). An increase of recharge to ground water with higher nitrate concentrations in 2014 (after above normal rainfall during May through September 2014, **Figure 6b**) may account for the slightly higher nitrate-N concentrations discharging from the spring during May-June 2015. Another possible explanation for the slight increase in nitrate-N measurements during January to June 2015 is sensor drift that occurred prior to malfunction of the sensor in July 2015.

Table 2. Comparison of data from continuous monitoring equipment at Ginnie Spring with field and laboratory measurements

NM = Not measured due to sensor malfunction.
µS/cm = microSiemens per centimeter

Ginnie Spring	Date	Time	Conductivity (µS/cm)	pH	DO (mg/L)	Temp (°C.)	NO_3_N	mg/L
Field YSI	3/2/15	1645	338	7.51	4.56	22.85	Lab	1.5
Continuous	3/2/15	1645	359	8.04	4.14	23.80	Continuous	1.45
Field YSI	6/2/15	1621	337	7.50	4.30	23.0	Lab	1.6
Continuous	6/2/15	1615	362	8.22	3.99	23.57	Continuous	1.66
Field YSI	9/15/15	1520	339	7.30	4.60	22.80	Lab	1.6
Continuous	9/15/15	1515	360	8.51	4.08	26.65	Continuous	NM
Field YSI	12/15/15	1413	340	7.40	4.00	22.20	Lab	1.5
Continuous	12/15/15	1415	358	8.72	NM	23.70	Continuous	NM

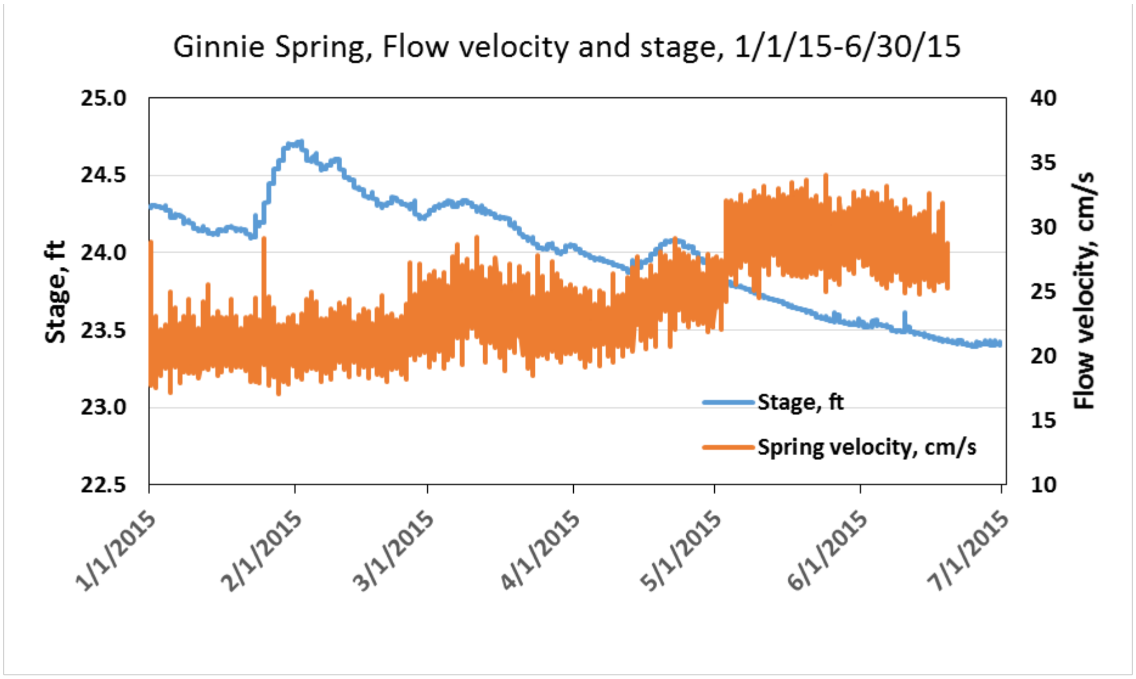

Figure 11. Continuous measurements of flow velocity (centimeters per second [cm/s]) and stage (feet) at Ginnie Spring, January–June 2015

Nitrate Isotopes

The stable isotope signatures of nitrate, including delta N-15 of nitrogen, $\delta^{15}N\text{-}NO_3$, and delta O-18 of oxygen, $\delta^{18}O\text{-}NO_3$, have been used effectively to attribute nitrate in groundwater and surface waters to specific sources. As of this writing (December 2015), water samples collected in March and June 2015 have not yet been analyzed for nitrate isotopes by the DEP contract laboratory. Therefore, nitrate isotope results from water samples collected in 2013–14 are presented below. There typically is some overlap between the ranges of isotopic values for different sources. However, values of $\delta^{15}N\text{-}NO_3$ less than 5 parts per thousand (ppt) generally indicate an inorganic nitrogen source (synthetic fertilizer), while values of $\delta^{15}N\text{-}NO_3$ greater than 8 ppt generally are consistent with an organic nitrogen source (animal or human wastes). Also, the two isotopes of nitrate are useful in assessing denitrification, which generally leads to a 2:1 increase in the ratio for $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ values.

Water samples from most wells (14 of 21) had average N isotope values less than 6 ppt, consistent with an inorganic fertilizer source of nitrogen (**Figure 12**). Values of $\delta^{15}N\text{-}NO_3$ in groundwater samples (January 2013–October 2014) fluctuated from about 2 to 3 ppt but remained below 5 ppt in slightly more than half of the RFA monitoring wells (**Figure 13**). Groundwater samples from Wells 5, 7, 11, 12, 15, 16, and 20 had $\delta^{15}N\text{-}NO_3$values that fluctuated between 5 and 9.5 ppt, which may indicate a mixed inorganic and organic source of nitrogen (**Figure 13**). The $\delta^{15}N\text{-}NO_3$ values in water samples from Well 11 decreased from 9.6 ppt in

January 2013 to 7.9 ppt in October 2014, while the nitrate-N concentration increased from 10 to 12 mg/L.

This well is located about 40 feet from an irrigated crop field and pasture that support a dairy, which has been in operation since before 1994. The top of the well screen is 38 feet below the land surface. Denitrification may account for the higher $\delta^{15}N$-NO_3 values. However, it is unlikely that it is occurring in the aquifer as DO levels are generally greater than 4 mg/L. Water samples from Well AAK7015, which is next to the Newberry sprayfield where treated wastewater is applied to a grassed area, had an isotopic composition consistent with a domestic wastewater source. There does not appear to be any consistent trend in $\delta^{15}N$-NO_3 values with time or nitrate concentrations in any of the monitoring wells.

Samples of spring water have a nitrate isotopic composition consistent with an inorganic nitrogen source. Santa Fe River water samples downstream from Ginnie Spring had a nitrate isotopic signature consistent with a mixed source of nitrogen, while the nitrate isotopic composition of Santa Fe River water samples upstream from Poe Spring indicated that denitrification likely has occurred (**Figure 13**).

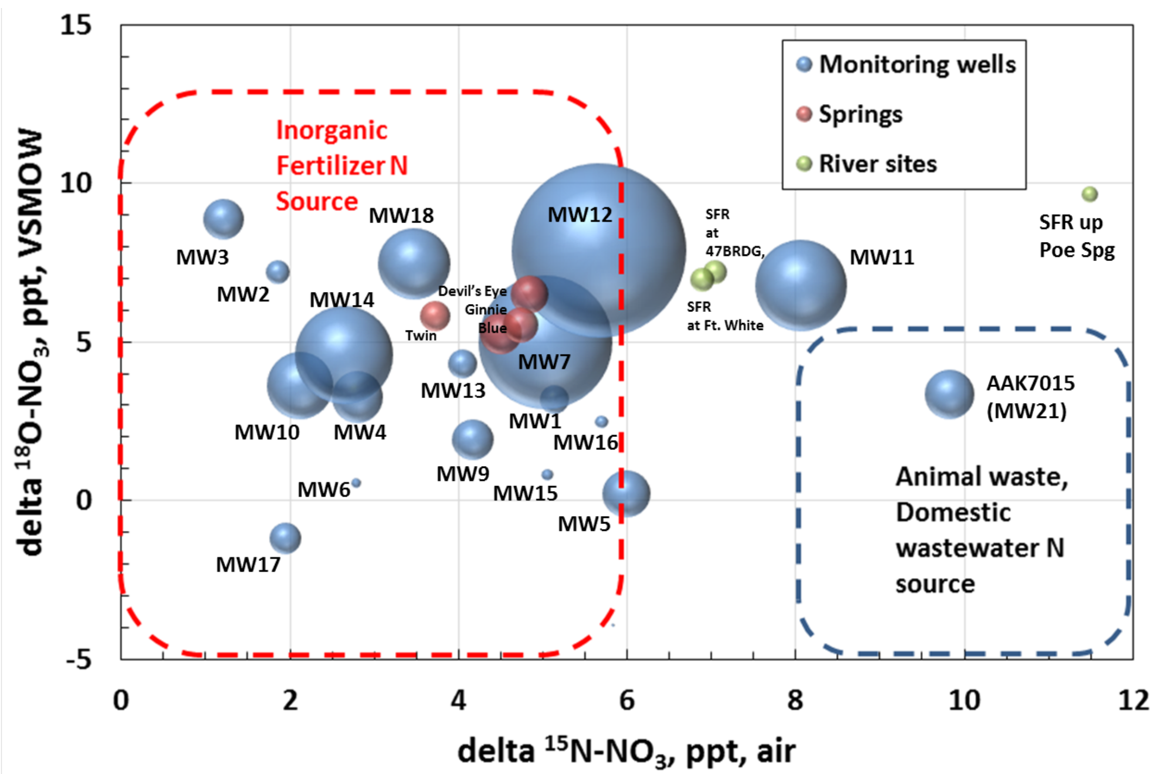

Figure 12. Average nitrate isotopic composition in water samples from wells, springs, and river sites, January 2013–October 2014. Symbol size is proportional to average nitrate-N concentration.

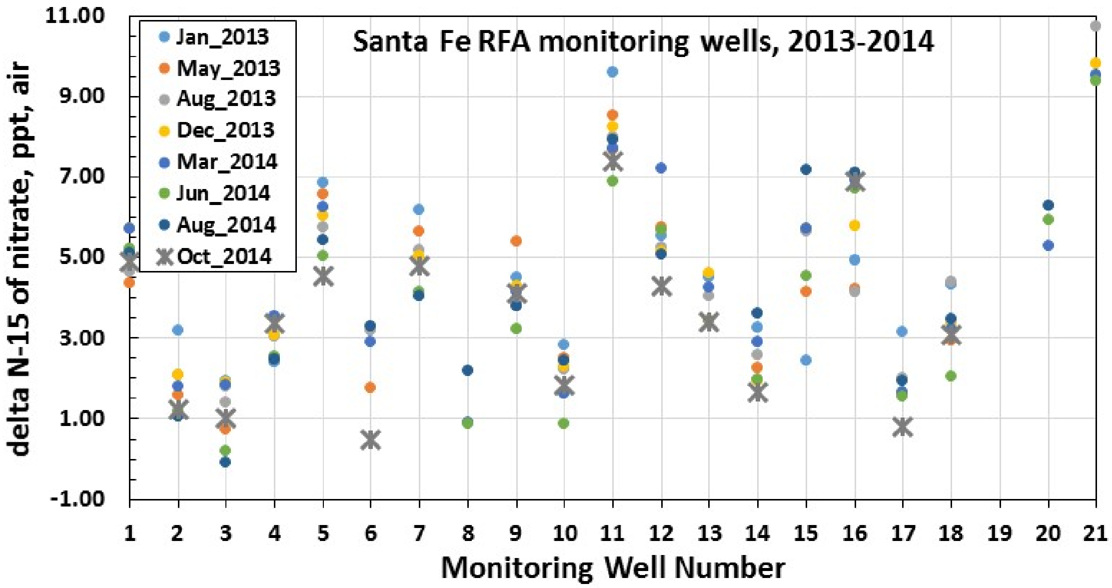

Figure 13. Plot showing the variations in delta N-15 of nitrate in water samples collected from monitoring wells, January 2013–October 2014

Other Water Quality Data

Potassium

Along with nitrogen and phosphorus, potassium is a major component of synthetic fertilizers. Although potassium is not a constituent of concern under the BMAP, it can be a useful indicator of a fertilizer source. However, the relationship between nitrate-N and potassium is not as straightforward as one might expect given that the nitrate isotope data indicate that fertilizers are the dominant source of nitrate-N in the RFA. Sites with the highest nitrate-N concentrations tend to be associated with low potassium values, and sites with the highest potassium concentrations tend to have low nitrate-N concentrations (**Figure 14**). For example, water from wells with the highest nitrate-N concentrations (12, 7, 11, and 14, listed in order of decreasing concentrations) generally had potassium concentrations less than 2 mg/L. The one exception was Well 7 (pasture supporting dairy), where potassium concentrations steadily increased from 1.2 mg/L in January 2013 to 8.0 mg/L in June 2015. The potassium concentrations in Well 14, located near a hayfield, increased from 0.98 mg/L in March 2014 to 1.70 mg/L in June 2015. Nitrate-N concentrations in Well 14 also remained high but continued to decrease from 10 mg/L in March 2015 to 8.3 mg/L in June 2015.

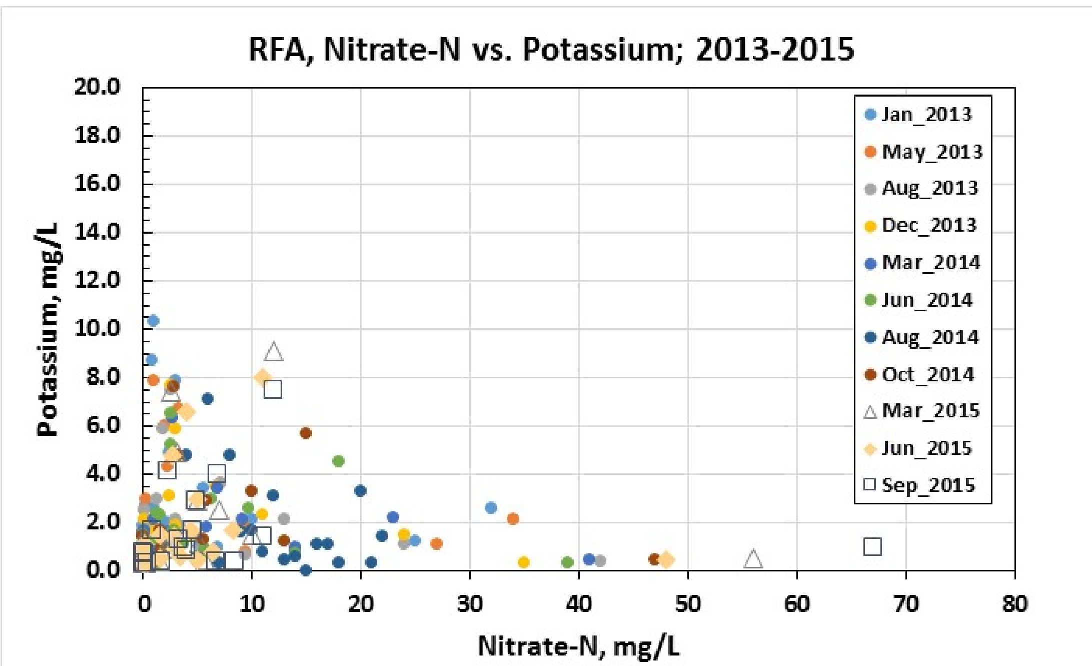

Figure 14. Relation between nitrate-N and potassium in water samples from RFA monitoring wells, 2013–15

For wells near pastures supporting dairies, potassium concentrations increased substantially in Well 7 until March 2015, followed by lower concentrations in June and September 2015. A similar decrease in potassium concentrations in 2015 was observed in Well 11. Potassium concentrations remained low in Well 12 even though nitrate-N concentrations increased substantially over the three-year period (**Figure 15a**).

For wells near irrigated cropland areas, potassium concentrations remained relatively constant in samples collected throughout the 3-year period. However, potassium concentrations decreased in Wells 3 and 4 (**Figure 15b**). It is worth noting that there was a statistically significant correlation (Spearman's rho = 0.43, $p<0.001$) between potassium and nitrate-N in wells near irrigated cropland.

For wells near nonirrigated pastures and hayfields, potassium concentrations remained below 2 mg/L, with the exception of Wells 5 and 9. Well 5 had elevated concentrations (> 6 mg/L) until June 2015, followed by a decrease to 4 mg/L in September 2015 (**Figure 15c**). There was no correlation ($p=0.09$) between potassium and nitrate in wells near nonirrigated cropland and hayfields.

In wells near residential areas, potassium concentrations remained above 20 mg/L in Well 17, but have decreased substantially from the peak concentration of 120 mg/L in August 2013) (**Figure 15d**). The high potassium concentrations at this location are surprising given that Well 17 is located in Newberry, where land use is classified as urban. However, the elevated concentrations may result from past agricultural practices. Potassium concentrations in the 3 other wells near residential areas remained low and unchanged.

The potassium concentration in groundwater is also affected by the thickness and type of clays and other materials that overlie the Upper Floridan aquifer (UFA) at each site. Potassium and other positively charged ions (cations, calcium [Ca], magnesium [Mg], and sodium [Na]) are sorbed by negatively charged sites on clay minerals and soils. Water samples from wells with the highest potassium concentrations (particularly Well 17, but also Wells 3, 5, 7, 9, and 18) tend to occur at sites where the depth to limestone is generally less than 20 feet below the land surface. Conversely, lower potassium concentrations were found in water samples from wells at sites where the thickness of sands and clays overlying the UFA was greater.

Potassium concentrations in spring waters ranged from 0.33 to 0.52 mg/L in December 2015 and were considerably lower than most potassium concentrations in samples of groundwater from wells. Potassium concentrations in river water samples in December 2015 were slightly higher than in spring waters (generally 0.75 to 1.0 mg/L).

Sulfate and Dissolved Solids

Sulfate concentrations in most monitoring wells ranged from 1 to 10 mg/L. Two wells, 17 and 18, consistently had sulfate concentrations greater than 10 mg/L, although sulfate concentrations in Well 17 decreased from a high concentration of 81 mg/L in August 2013 to 9.1 mg/L in September 2015 (**Figure 16**). Likewise, potassium concentrations in Well 17 also decreased substantially from the highest concentration of 120 mg/L in water samples collected in August 2013 to 30 mg/L in September 2015. Also, dissolved solids concentrations in Well 17 decreased from a high of 550 mg/L in August 2013, to 287 mg/L and 286 mg/L in March and June 2015, respectively (**Figure 17**). The dissolved solids concentration represents the total amount of all inorganic and organic material that dissolves in water as it moves beneath the land surface and into the aquifer, including naturally occurring minerals and anthropogenic sources (e.g., fertilizers, wastewater). These solids have to be small enough to pass through a 0.45-micron filter to be considered dissolved.

A prior application of fertilizer containing potassium sulfate (K_2SO_4), could have accounted for the spike in potassium and sulfate concentrations in water samples from Well 17. The nitrate-N concentration only increased slightly from 1.0 mg/L (May 2013) to 1.4 mg/L (September 2015). However, nitrate isotope values were consistent with an inorganic nitrogen fertilizer source in samples collected during May and August 2013. Additional information on past land use practices near Well #17 would likely help to explain the anomalously high potassium and sulfate concentrations in groundwater at this site.

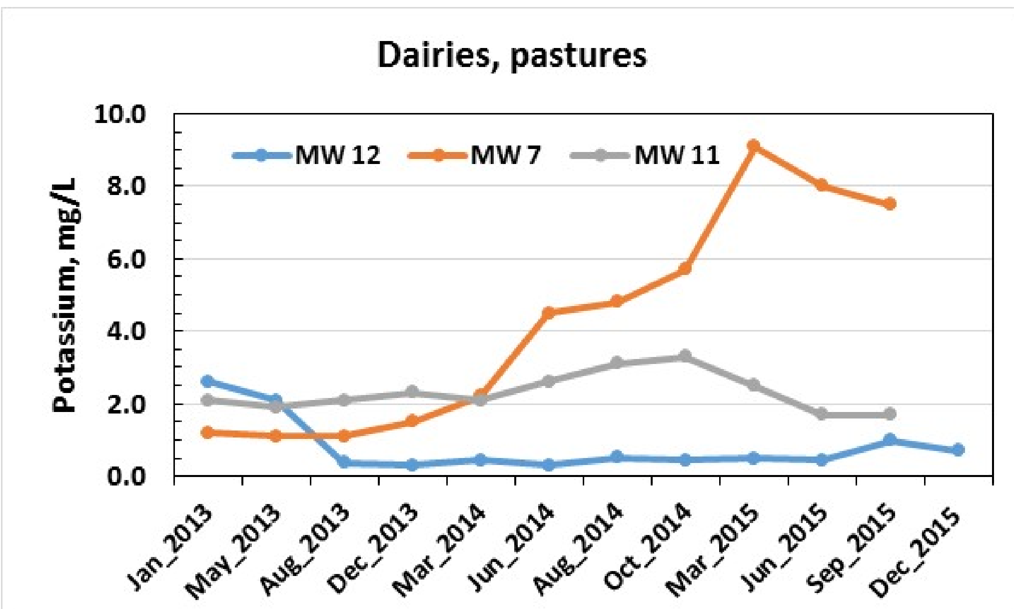

Figure 15a. Potassium concentrations in water samples from wells near dairy, pastures in the RFA, 2013–15

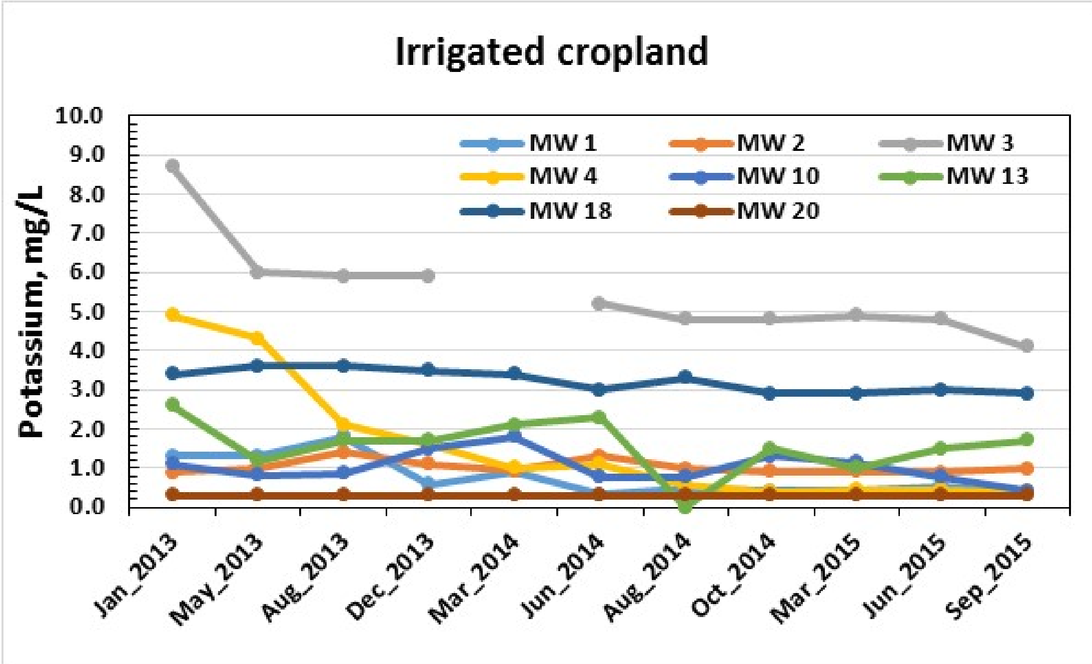

Figure 15b. Potassium concentrations in water samples from wells near irrigated cropland in the RFA, 2013–15

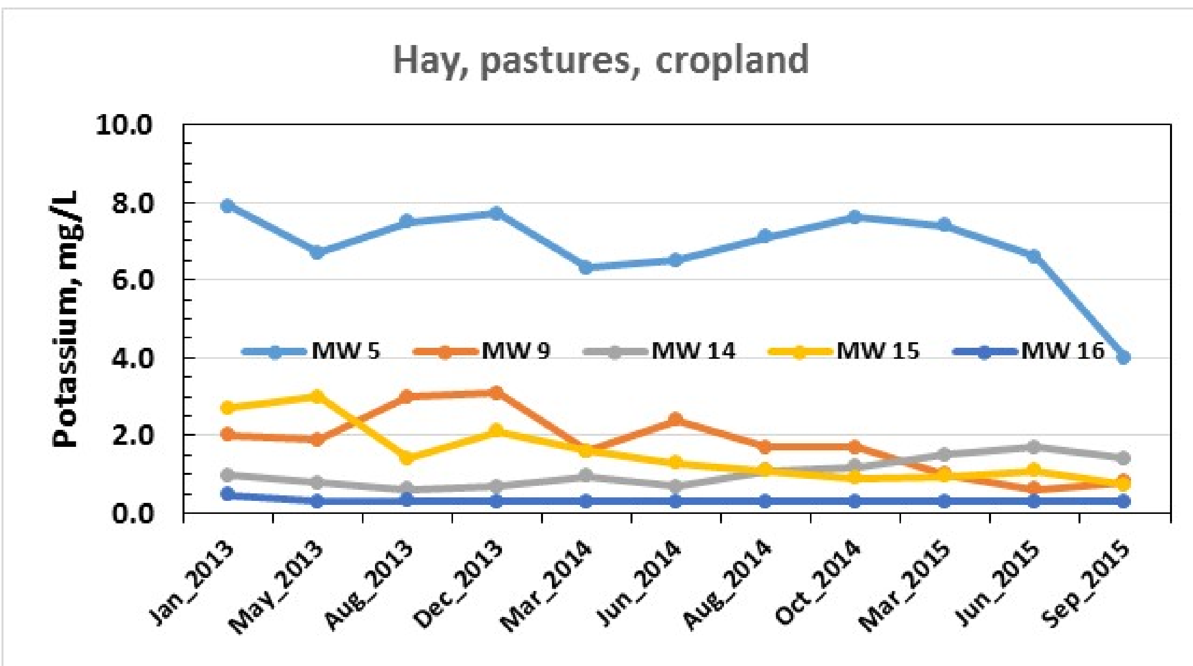

Figure 15c. Potassium concentrations in water samples from wells near hayfields, pastures, and cropland in the RFA, 2013–15

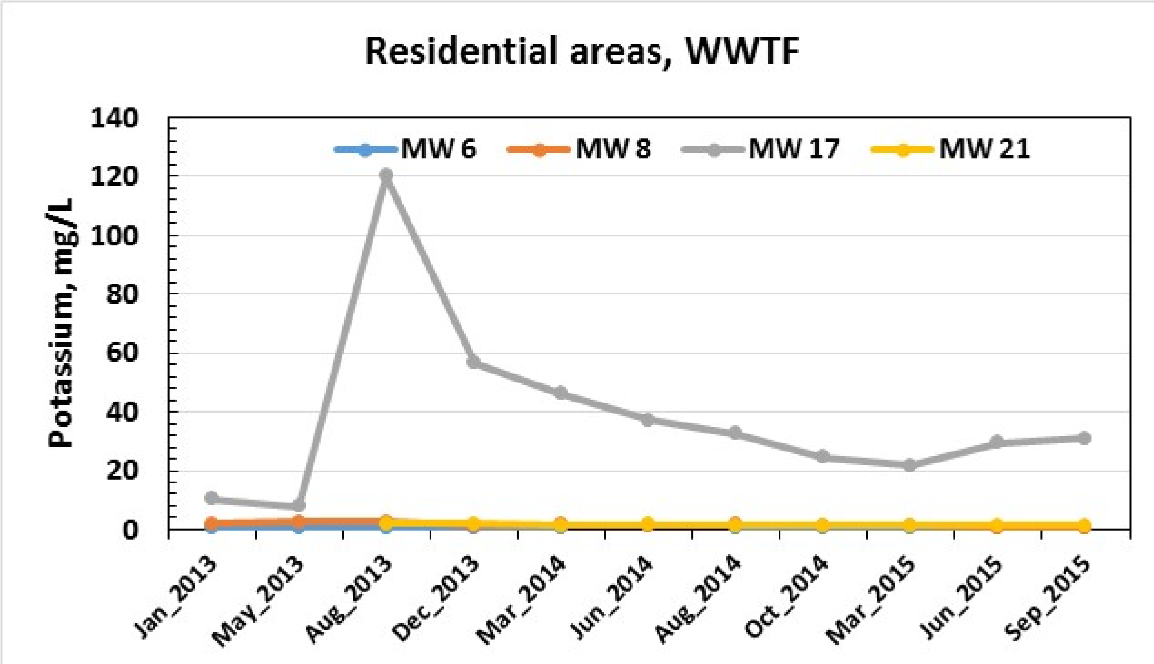

Figure 15d. Potassium concentrations in water samples from wells near residential areas and a WWTF in the RFA, 2013–15

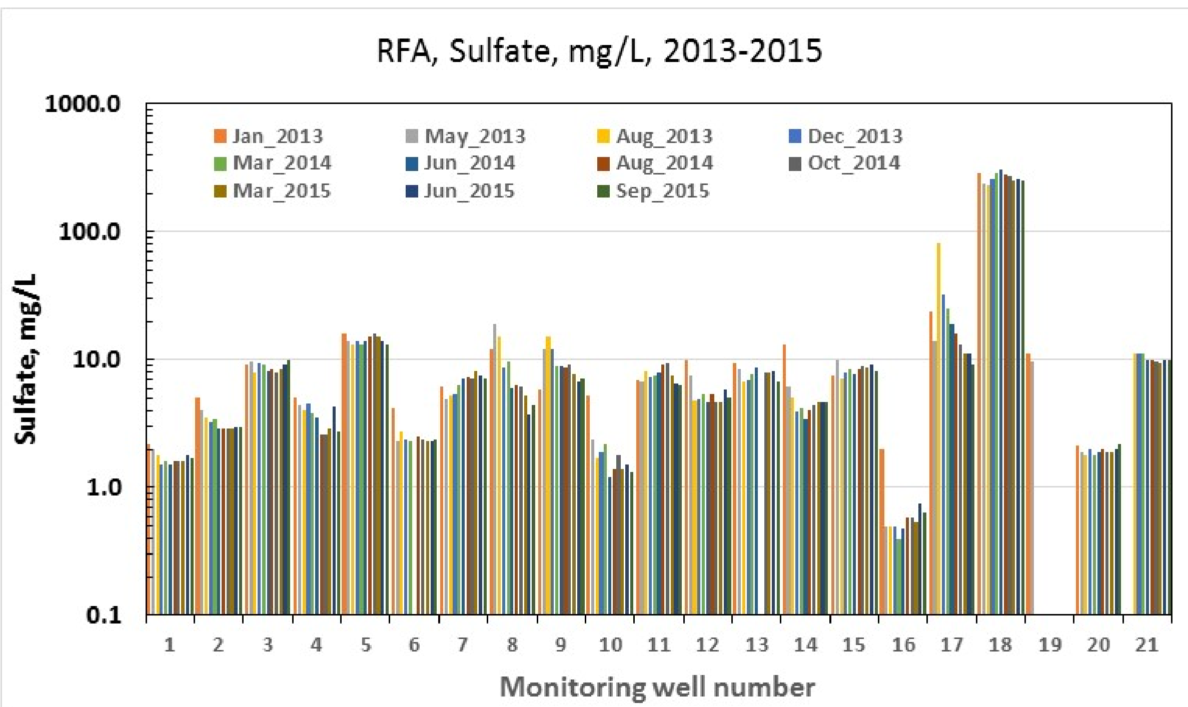

Figure 16. Sulfate concentrations in water samples from RFA monitoring wells, 2013–14

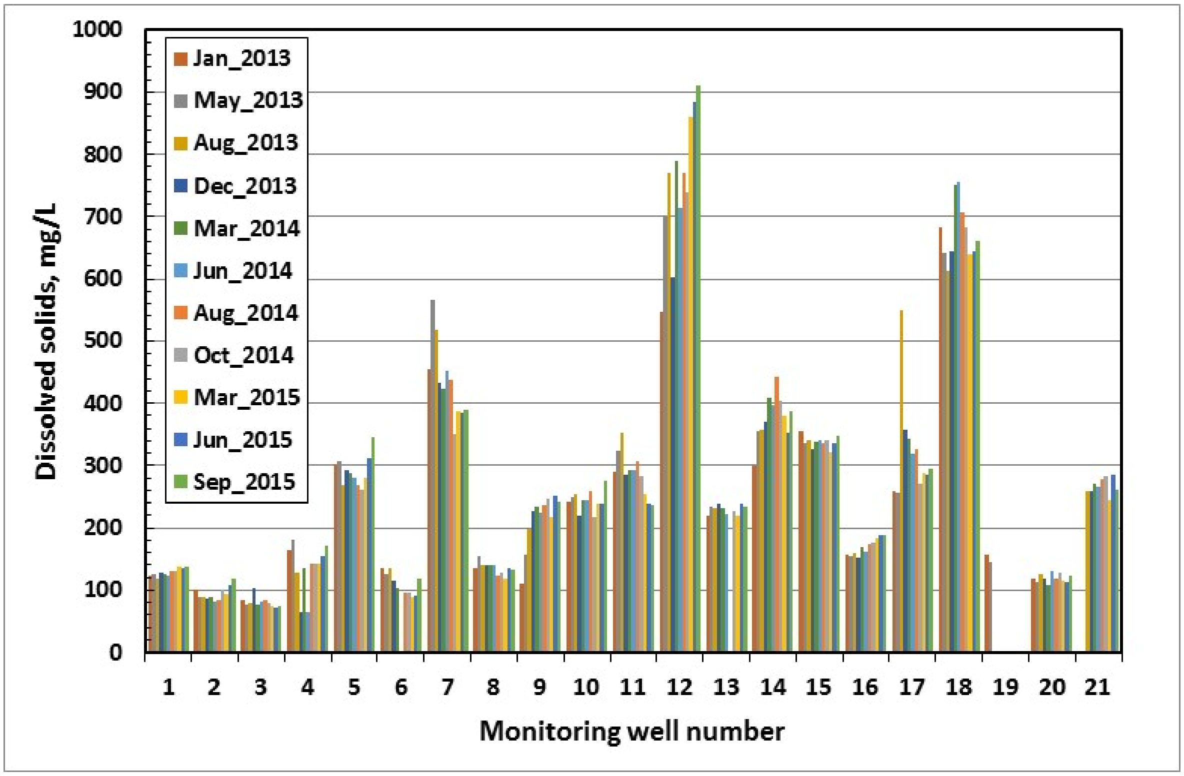

Figure 17. Dissolved solids concentration in water samples from RFA monitoring wells, 2013–15

Water samples from Well 18 continued to have high sulfate and calcium concentrations (250 and 195 mg/L in September 2015, respectively) and dissolved solids concentrations (643 and 661 mg/L in June and September 2015, respectively) compared with other groundwater samples, with the exception of water from Well 12. The elevated (excess) sulfate and calcium concentrations in water from Well 18 (compared with other wells in the RFA) were consistent with the 1:1 molar ratio of calcium to sulfate as found in gypsum ($CaSO_4$), which is frequently applied to peanut fields as a soil conditioner (**Figure 18**).

Sulfate concentrations in spring water during the study period (January 2013–December 2015) ranged from 9.6 to 14 mg/L (median, 12 mg/L), and were slightly higher compared with most groundwater samples, with the exception of the high sulfate concentrations found in water samples from Wells 17 and 18. Two water samples were collected from Poe Spring in January and May 2013, and sulfate concentrations ranged from 27 to 35 mg/L.

Sulfate concentrations in river water samples were considerably higher than spring water samples, ranging from 4.5 to 72 mg/L. During high-flow conditions, sulfate concentrations typically were less than 12 mg/L in samples from the 3 sites. At the Santa Fe River site upstream from Poe Spring, sulfate concentrations were considerably higher (4.5 to 72 mg/L), with a median concentration of 43 mg/L.

Cl/Br Mass Ratio

The mass ratio of chloride to bromide (Cl/Br) also has been used to assess sources of solutes in groundwater and surface water (Panno et al. 2006; Alcalá and Custodio 2008). Relatively distinct ranges of the Cl/Br ratio have been reported for sewage and septic tank effluent, road salt, animal waste, atmospheric deposition, seawater, and landfill leachate (Katz et al. 2011). Although there is a considerable range in the Cl/Br mass ratio in water samples from each well, spring, or river site (**Figure 19** and **Figure 20**), sites with an inorganic nitrogen source (based on nitrate isotope data) generally have Cl/Br ratios below 400. The range in Cl/Br mass ratios mainly results from dividing the relatively uniform chloride concentrations by fluctuations in the low bromide concentrations (generally less than 0.1 mg/L). The spike in the Cl/Br ratio for Ginnie Spring and Gilchrist Blue Spring in September 2015 was due to the exceptionally low bromide concentrations in those water samples (**Figure 20**).

Sites influenced by an organic nitrogen source or mixed source tend to have Cl/Br ratios greater than 500. Wells 12, 15, and 16 showed considerable variability of Cl/Br ratios from one sample to another and tended to plot in both the inorganic and organic nitrogen source areas. This may indicate that both sources are contributing nitrate to groundwater in these areas. There is a statistically significant correlation between the Cl/Br mass ratio and $\delta^{15}N\text{-}NO_3$ concentrations in water samples from monitoring wells (Spearman's rho = 0.51; $p<0.0001$). Therefore, the Cl/Br mass ratio may be useful as a surrogate for nitrogen isotopes as a nitrate-N source indicator (**Figure 21**).

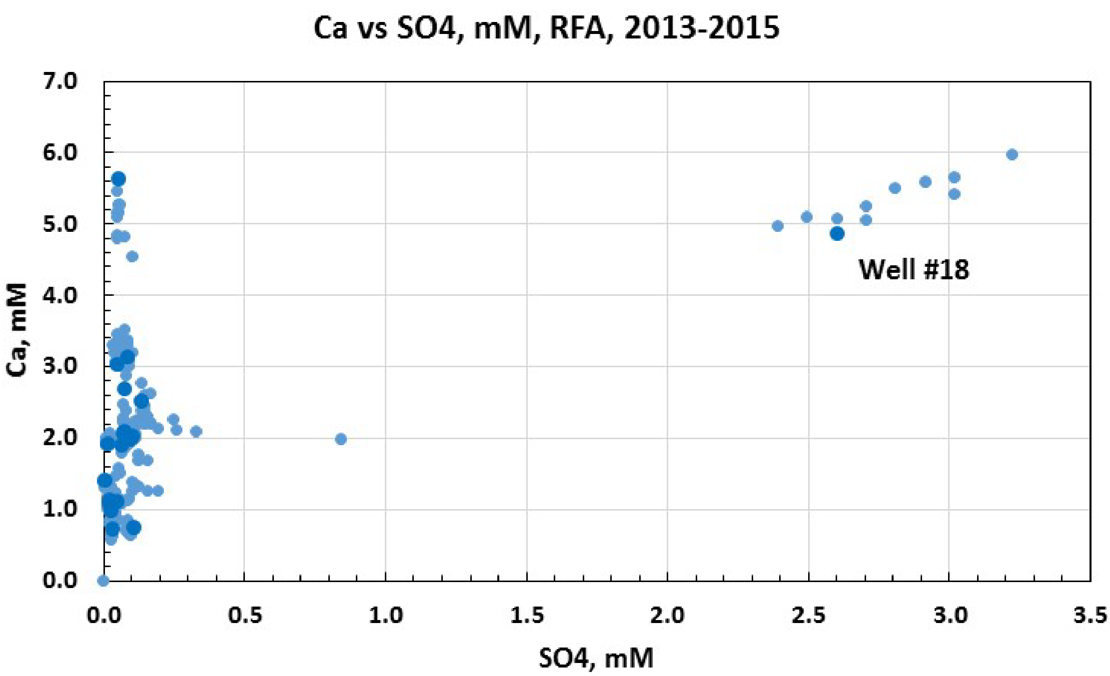

Figure 18. Excess sulfate (SO_4) and calcium (Ca) in RFA Well 18 likely resulting from the application of gypsum ($CaSO_4$) at the land surface as a soil conditioner, 2013–15

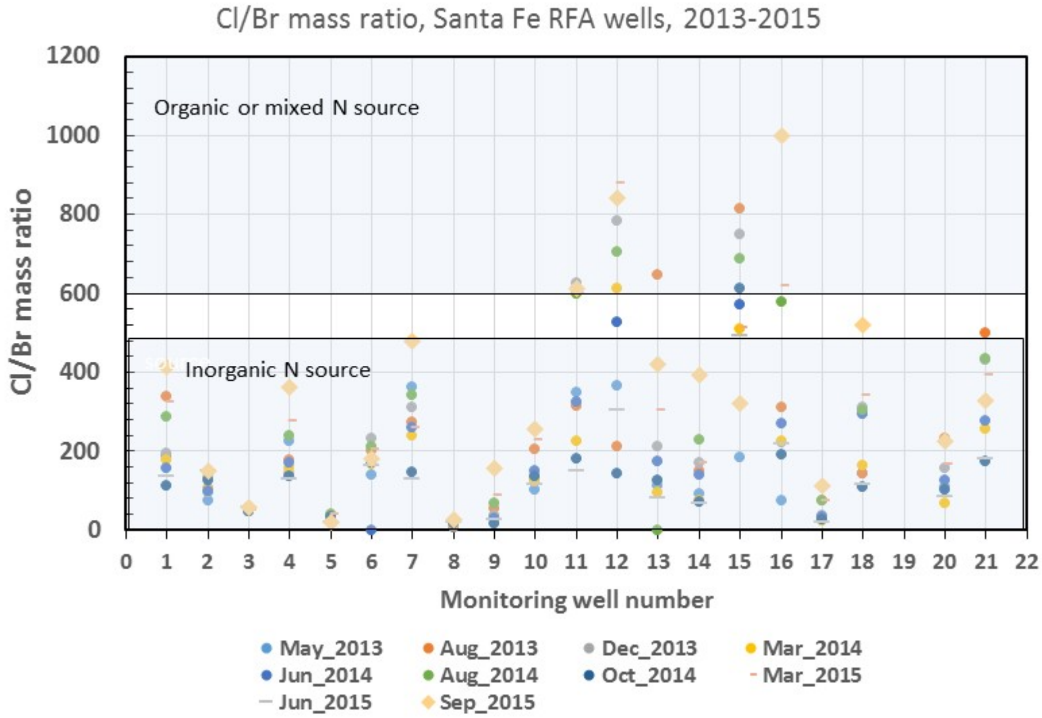

Figure 19. Variations in the Cl/Br mass ratio for water samples from monitoring wells, 2013–14

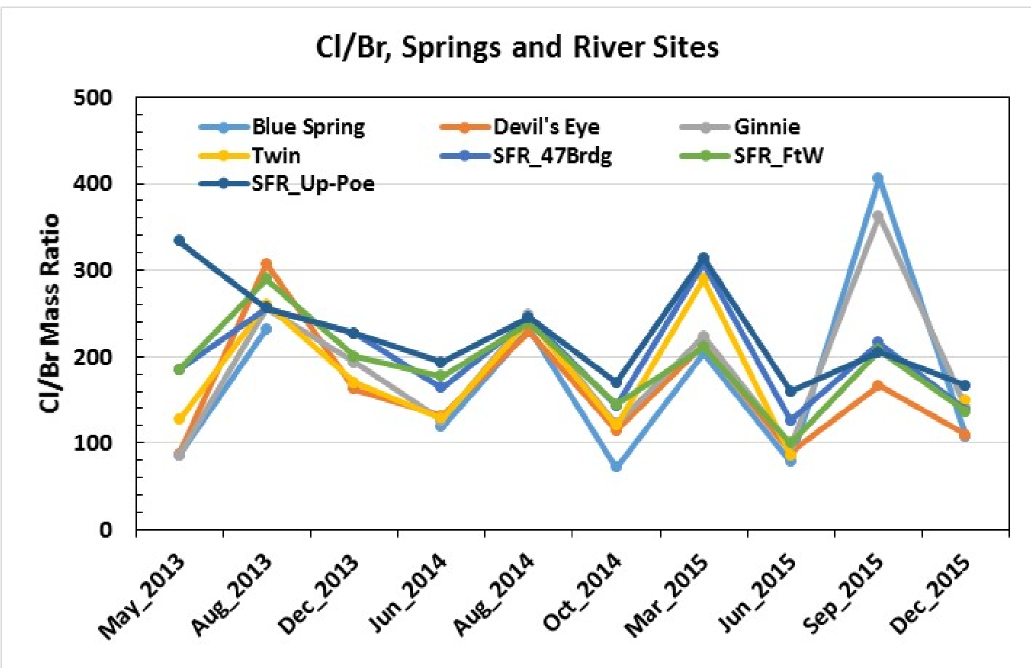

Figure 20. Variations in the Cl/Br mass ratio for water samples from springs and river sites, 2013–15

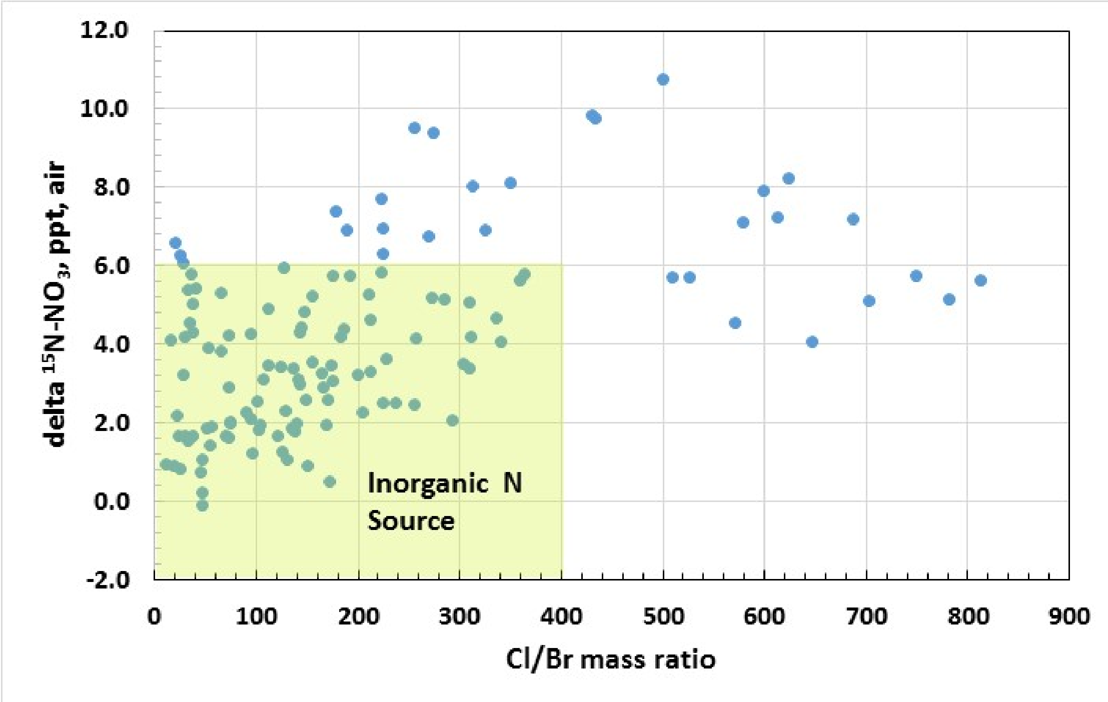

Figure 21. Plot showing the relation between the Cl/Br mass ratio and the $\delta^{15}N$ of nitrate for water samples from RFA monitoring wells, 2013–14

Pesticide Compounds

DEP collected water samples from monitoring wells in August 2014, October 2014, and June 2015 that were analyzed for numerous pesticide compounds (see **Appendix 4** for a complete list). Samples for pesticide analyses were collected from springs and river sites in August 2014, October 2014, and June 2015. Additional samples for pesticides were collected from Ginnie and Gilchrist Blue Spring in November 2014, and from Devil's Eye Spring in September and December 2015. Devil's Eye Spring was sampled as part of another DEP springs sampling network for water quality. **Table 3** lists data for samples collected in August and October 2014 and June 2015; and **Table 4** lists data for samples collected from Devil's Eye Spring in September and December 2015.

Herbicides were the only pesticide compounds detected (reported) in water samples from wells, springs, and river sites. Chlorpyrophos ethyl (an insecticide) was detected in water samples from Ginnie Spring, Twin Spring, and the Santa Fe River site upstream from Poe Spring. Atrazine, desethyl atrazine (an atrazine degradate), and hexazinone were the most frequently detected herbicides. Atrazine is a selective triazine herbicide used to control weeds in various crops and in conifer reforestation plantings. It does not adsorb strongly to soil particles and has a half-life of 60 to greater than 100 days. Hexazinone, also a triazine herbicide used to control weeds, is mostly used on noncrop areas. It has a half-life of less than 30 to 180 days. Almost all reported values of herbicide compounds and chlorpyrophos ethyl were qualified by the DEP Laboratory as being between the laboratory method detection limit and the laboratory practical quantitation limit, or less than the criterion of detection (**Table 3**). Reported herbicide concentrations (nanograms per liter [ng/L]) in spring water samples were extremely low; a nanogram is one-thousandth of a microgram (µg).

Reported atrazine concentrations were higher in samples of river water than in spring water in June 2015, and in August 2014; DEP did not collect any spring water samples for pesticide analyses in October 2014 (**Table 3**). Reported desethyl atrazine concentrations were higher than atrazine concentrations in water samples from Blue Spring and Ginnie Spring, but desethyl atrazine was not detected in Twin Spring in June 2015. Reported atrazine and desethyl atrazine concentrations were lower in river water samples collected in June 2015 than in river water samples collected in August and October 2014. The higher reported concentrations of desethyl atrazine compared with atrazine in the August 2014 spring water samples may indicate that the spring is discharging a small (nonquantifiable) component of groundwater that was recharged and has moved through the system anywhere from three months to possibly as much as a year. Atrazine was detected in June 2015 samples from Wells 5, 12, 13, and AAK7015, but was not detected in any monitoring wells in the October 2014 samples. Desethyl atrazine was detected in samples from Wells 5, 12, and 13 in the June 2015 samples. Concentrations in MW-13 were slightly lower in samples collected in June 2015 than in October 2014.

Hexazinone also was reported in samples collected in June 2015 from Well 20 and AAK7015, but not in MW-4, where it was detected in October 2014. In June 2015, hexazinone was only detected in Gilchrist Blue Spring compared with detections in samples from Gilchrist Blue, Ginnie, and Twin Springs in August 2014. Bentazon was the only other reported herbicide in the June 2015 samples in MW-4, which had a detection in an October 2014 sample. No detections for 2,4-D were reported in the June 2015 samples compared with detections in October 2014 samples from Wells 5 and 6. Norflurazon was detected in samples from Wells 8, 9, and 19 in October 2014 samples but not in any samples from June 2015 (**Table 3**). Norflurazon is a pyridazinone herbicide used to control grass and broadleaf weeds. Its half-life in soils is 90 days. Norflurazon was not detected in any samples of spring water or river water.

Samples collected from Devil's Eye Spring in September and December 2015 showed a similar pattern of pesticide detections. All compounds listed in **Table 4** were detected at very low concentrations (ng/L), and all were qualified by the DEP Laboratory as being (1) at the laboratory method detection limit, (2) between the laboratory method detection limit and the laboratory practical quantitation limit, (3) estimated value, or (4) less than the criterion of detection.

The presence of these herbicide compounds in groundwater, springs, and river water, albeit in extremely low concentrations at or near laboratory detection limits, indicates their mobility and persistence in trace amounts in the subsurface from applications on cropland and other areas.

With the limited number of water samples and the range in half-lives for atrazine, desethyl atrazine, and hexazinone, it is not possible to determine if the presence of these compounds originated from herbicide applications in 2014 or several years prior. It is worth noting that the reported atrazine concentrations are more than an order of magnitude lower than atrazine concentrations reported in water samples from monitoring wells located throughout the UFA in Florida, Georgia, and South Carolina (Berndt et al. 2014).

Table 3. Water samples from wells, springs, and river sites that had detects for pesticides, August 2014, October 2014, and June 2015

ND = Not detected; Q = Qualifier code; NA = Not analyzed

		DEP SOP: LC-001-2(USGS O-2060-01)		EPA 8270D(method)									
FIELD ID	DATE	*analyte* (ug/L)	Q	ATRAZINE (ng/L)	Q	HEXAZINONE (ng/L)	Q	ATRAZINE DESETHYL (ng/L)	Q	NORFLURAZON (ng/L)	Q	CHLORPYRIFOS ETHYL(ng/L)	Q
MW-4	10/29/2014	0.0021(Bentazon)	I	ND	U	0.42	T	0.29	I	ND	U	NA	
MW-5	10/27/2014	0.0058(2,4-D)	IQ	ND	U	ND	U	ND	U	ND	U	NA	
MW-6	10/27/2014	0.0048(2,4-D)	IQ	ND	U	ND	U	ND	U	ND	U	NA	
MW-8	10/21/2014	ND	U	ND	U	ND	U	ND	U	0.50	TQ	NA	
MW-8_dup	10/21/2014	ND	U	ND	U	ND	U	ND	U	0.62	TQ	NA	
MW-9	10/29/2014	ND	U	ND	U	ND	U	ND	U	0.90	T	NA	
MW-13	10/28/2014	NA		ND	U	ND	U	0.67	IQ	ND	U	NA	
MW-18	10/22/2014	ND	U	ND	U	ND	U	0.79	IQ	0.53	TQ	NA	
AAK7015	10/22/2014	ND	U	ND	U	45.00	QJ	0.20	TQ	ND	U	NA	
MW-20	10/21/2014	ND	U	ND	U	12.00	QJ	ND	U	ND	U	NA	
MW-4	6/3/2015	0.0052(BENTAZON)	I	ND	U	ND	U	ND	U	ND	U	NA	
MW-5	6/2/2015	ALL	U	4.00		ND	U	1.40	J	ND	U	NA	
MW-12	6/3/2015	ALL	U	1.80		ND	U	0.49	IJ	ND	U	NA	
MW-13	6/3/2015	ALL	U	0.14	T	ND	U	0.47	IJ	ND	U	NA	
MW-20	6/2/2015	ALL	U	ND	U	9.20		ND	U	ND	U	NA	
AAK7015	6/3/2015	ALL	U	0.13	T	72.00		ND	U	ND	U	NA	
BLUE SPRING (GILCHRIST)	8/26/2014	NA		0.14	T	1.00	U	0.72	IJ	ND	U	NA	
BLUE SPRING (GILCHRIST)_dup	8/26/2014	NA		0.16	T	1.00	U	0.78	IJ	ND	U	NA	
GINNIE SPRING	8/27/2014	NA		0.11	T	0.69	T	0.49	IJ	ND	U	NA	
TWIN SPRING	8/27/2014	NA		0.25	U	0.94	T	0.22	TJ	ND	U	NA	
BLUE SPRING (GILCHRIST)	6/3/2015	ALL	U	0.130	T	0.580	T	0.860	IJ	ND	U	ALL	U
DEVILS EYE SPRING	6/2/2015	ALL	U	0.230	T	ND	U	ND	U	ND	U	ALL	U
GINNIE SPRING	6/2/2015	ALL	U	ND	U	ND	U	0.370	IJ	ND	U	0.055	T
TWIN SPRING	6/2/2015	ALL	U	ND	U	ND	U	ND	U	ND	U	0.059	T
TWIN SPRING_dup	6/2/2015	ALL	U	ND	U	ND	U	ND	U	ND	U	0.100	I
SFR@47BRDG	8/25/2014	NA		0.73	I	0.84	T	0.66	IJ	ND	U	NA	
SFR@47BRDG_dup	8/25/2014	NA		0.74	I	0.87	T	0.53	IJ	ND	U	NA	
SFR@FTW USGS	8/25/2014	NA		0.69	I	0.81	T	0.47	IJ	ND	U	NA	
SFR@UP POE SPG	8/25/2014	NA		0.72	IJ	0.89	TJ	0.28	IJ	ND	U	NA	
SFR@47BRDG	10/28/2014	NA		0.66	I	0.73	T	0.62	T	ND	U	NA	
SFR@FTW USGS	10/28/2014	NA		0.53	I	0.77	T	0.62	I	ND	U	NA	
SFR@UP POE SPG	10/28/2014	NA		0.73	I	0.65	T	ND	U	ND	U	NA	
SFR@UP POE SPG_dup	10/28/2014	NA		0.62	I	0.65	T	ND	U	ND	U	NA	
SFR@47BRDG	6/2/2015	ALL	U	0.33	I	ND	U	0.52	IJ	ND	U	ND	U
SFR@FTW USGS	6/2/2015	ALL	U	0.35	I	ND	U	0.45	IJ	ND	U	ND	U
SFR@UP POE SPG	6/2/2015	ALL	U	0.38	I	ND	U	ND	U	ND	U	0.066	T
SFR@UP POE SPG_dup	6/2/2015	ALL	U	0.38	I	ND	U	ND	U	ND	U	0.045	T

Table 3 Legend

A - Value reported is the mean of two or more determinations
B - Results based on colony counts outside the acceptable range.
I - The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.
J - Estimated value
K - Actual value is known to be less than value given
L - Actual value is known to be greater than value given
N - Presumptive evidence of presence of material.
O - Sampled, but analysis lost or not performed.
Q - Sample held beyond normal holding time.
T - Value reported is less than the criterion of detection.
U - Material was analyzed for but not detected. The reported value is the method detection limit for the sample analyzed.
V - Analyte was detected in both sample and method blank.
X - Too few individuals to calculate SCI value.
Y - The laboratory analysis was from an unpreserved or improperly preserved sample. The data may not be accurate
Z - Colonies were too numerous to count (TNTC).

Table 4. Water samples from Devil's Eye Spring that had detects for pesticides, September and December 2015

ND = No data

9/30/15

Compound	ng/L	Q
Atrazine	0.22	T
Desethyl atrazine	0.98	T
Dicofol	0.02	UJ
Hexazinone	0.47	T
Norflurazon	ND	U
Azinphos methyl	2.20	UJ
Methoxychlor	ND	U

12/15/15

Compound	ng/L	Q
Atrazine	0.190	T
Desethyl atrazine	1.1	T
Dicofol	0.023	UJ
Hexazinone	0.500	U
Norflurazon	0.500	U
Azinphos methyl	ND	U
Methoxychlor	0.010	UJ

Implementation of Management Actions

The implementation of agricultural management actions in the RFA currently includes securing landowner participation in the BMP Program. Assessing progress to that end in the RFA involves tracking the number of growers and the agricultural acreage enrolled in the BMP Program over time. As illustrated in **Figure 2**, the predominant agricultural land uses in the RFA include irrigated and nonirrigated row and field crops, hay and silage, pasture, irrigated vegetables (also inventoried as row crops), and dairies, which are partially subdivided into pasture and field cropland categories.

As of December 31, 2015, 41,573 acres were enrolled under 135 NOIs, an increase of 13,968 acres and 46 NOIs since December 31, 2014 (**Table 5**).

The OAWP has a statewide implementation assurance (IA) program for agricultural BMPs. For BMPs that are listed as "planned practices," the OAWP expects that they will be in place within 18 months. This schedule will be modified for BMPs that require engineering, structure, and/or cost-share support to complete.

Figure 22 shows the locations of monitoring wells and agricultural areas that were addressed by BMPs or NOIs as of the end of 2015 and new areas enrolled in BMPs or with signed NOIs for BMP implementation compared with December 2014. The agricultural areas enrolled (or in NOIs) is about 7,200 acres higher than the total acres of agricultural land use in the RFA. Some possible reasons for this discrepancy include the following: (1) production acreage has increased since the last update in land use information; (2) enrollment figures include areas that may not be classified as agriculture in the most recent land use information but for which BMPs still apply (wetlands protection, buffers, etc.); and (3) there have been increases in agricultural acreage since the last land use assessment in 2012.

Twelve monitoring wells (1, 2, 3, 4, 7, 9, 11, 12, 13, 15, 16, and 20) are located adjacent to and/or downgradient from parcels that have signed NOIs or are currently enrolled in BMPs (**Figure 22**). Nitrate-N concentrations in quarterly samples were assessed for trends over the 3 years of the study using a seasonal Kendall nonparametric test. **Table 6** lists the results. These trend analyses are preliminary and likely are not definitive. More than 11 samples are needed to determine trends with a higher level of confidence. Most analyses for trends require a minimum of 24 samples (6 years of quarterly sampling) before a trend can definitively be assessed. With this in mind, for these 12 monitoring wells, 7 had statistically significant increasing trends, 3 had decreasing trends, and 2 did not show any trend (**Table 6**).

Nitrate-N concentrations decreased in Well 7 from 25 mg/L in January 2013 to 12 mg/L in September 2015, and decreased in Well 11 from 10 mg/L to 4.6 mg/L over the same period. Both wells are located near irrigated field crops and pasture that support a dairy and are adjacent to parcels that have been enrolled in BMPs. Both dairies were enrolled in BMPs after monitoring had started. Considerable changes in agricultural practices have taken place that involved moving from traditional crop production to sod-based rotation practices. Additional information is not available about the timing and specific types of BMPs being used at agricultural sites near these wells.

No statistically significant changes in nitrate concentrations were observed in quarterly water samples from the four springs or three river sites. This delay or lack of response in reducing nitrogen in the groundwater near sites where BMPs are being implemented may be due to one or more of the following factors:

1. Insufficient time for changes in agricultural practices to affect groundwater quality (a lag effect from when BMPs are implemented to when improvements in water quality are seen).

2. Legacy nitrogen in soil and shallow groundwater from past practices.

3. Compliance issues in the implementation of BMPs (most of the enrollment in the RFA has been in the past two years).

4. Limitations of BMP effectiveness because of soil conditions, cropping rates, fertilization rates, and irrigation needs that may warrant additional measures.

As discussed previously, the OAWP has an implementation assurance program designed to determine compliance with BMPs. Also, BMPs may not be the most appropriate tool to deal with legacy nitrogen loading from past land use activities. Additional measures, such as regional projects, would likely be needed to address nutrient loads.

Table 5. Agricultural BMP enrollment in the Santa Fe RFA area as of December 31, 2015

Agricultural BMP Enrollment within the Santa Fe BMAP RFA, as of December 2015

LU/LC Code	Code Description	Total Acres	Related FDACS BMP Programs	Acreage Enrolled, Dec 2012	# of NOIs	Acreage Enrolled, Dec 2015	# of NOIs
2120	Unimproved Pasture	1,479.6	Cow/Calf	894.8	3	17,005.9	48
2130	Woodland Pasture	2,326.8					
2110	Improved Pasture	17,445.3					
			Sod	-	-	60.3	1
2153	Hay	9,140.5	Vegetable/Agronomic Crops	5,231.4	26	24,459.7	84
2140	Row Crop	351.9					
2150	Field Crops	2,921.7					
2240	Abandoned Tree Crops (citrus)		N/A	N/A	N/A	N/A	N/A
2310	Cattle Feeding Operation	3.8	Conservation Plan Rule	-	-	-	-
2330	Poultry Feeding Operation	74.2					
2410	Tree Nurseries	106.7	Nursery	-	-	-	-
2430	Ornamentals	43.2					
2400	Nurseries and Vineyards	22.1					
			Specialty Fruit & Nut	-	-	46.8	2
2230	Other Groves	52.7					
2510	Horse Farm	26.7	Equine	-	-	-	-
2520	Dairies	40.3	Dairy	-	N/A	-	N/A
2610	Fallow Cropland	318.5	N/A	N/A	N/A	N/A	N/A
	Totals	34,354.0		6,126.2	29	41,572.8	135

		% of Watershed Acreage
RFA Acreage:	118,541.1	100.0%
Approximate Ag Acreage in RFA:	34,354.0	29.0%
		% Ag Acreage Enrolled
Acreage Enrolled in BMPs as of December 2015:	41,572.8	121.0%

Disclaimer:
This map/information represents anestimate of the amount and/or location of agricultural acreage enrolled in FDACS/OAWP BMP programs for specific commodities and/or regions of the state. It is not binding, and does not otherwise affect the interest of any persons, including any vested rights or existing uses of real property. The accuracy and reliability of this map/information are not guaranteed, and are affected by continual changes in land use, crop production, and other socioeconomic factors. Due to parcel number format changes some enrolled acreage may not be displayed.

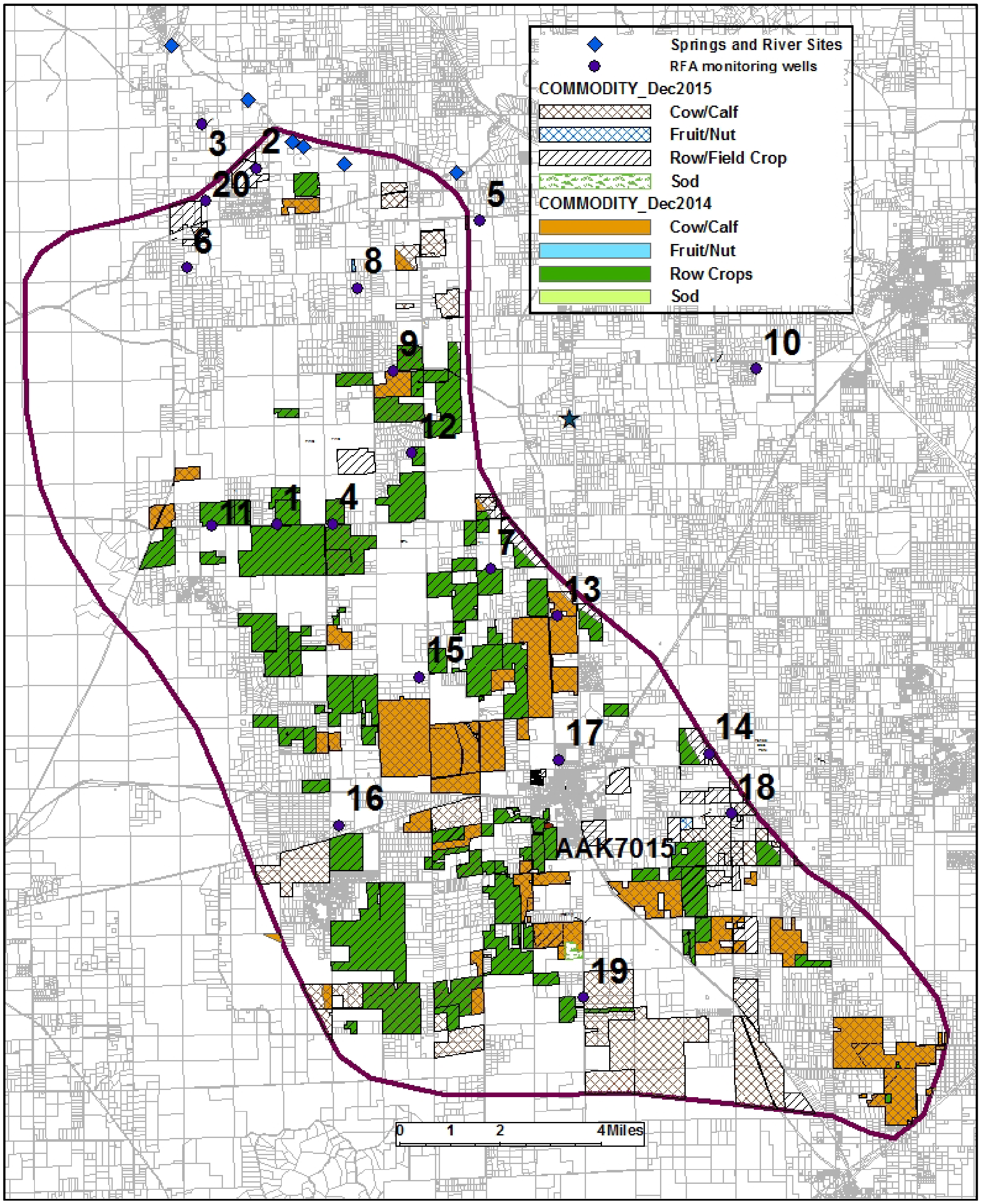

Figure 22. Map showing location of monitoring wells in relation to land parcels enrolled in agricultural BMPs by commodity in the Santa Fe RFA as of December 31, 2014, and new parcels enrolled as of December 31, 2015 (BMP enrollment information provided by FDACS OAWP)

Table 6. Results of Seasonal Kendall statistical test for trends in nitrate-N concentrations in water samples from monitoring wells near land parcels with NOIs to implement agricultural BMPs

Monitoring Well Number	Nearby Land Use	BMP Status of Nearby Lands	Nitrate-N Trend	Seasonal Kendall Test p Value
1	Irrigated cropland	Row crop	**Increase**	0.009
2	Irrigated vegetables	Row crop	**Increase**	0.009
3	Irrigated vegetables	Row crop	**Increase**	0.009
4	Irrigated cropland	Row crop	**Increase**	0.009
5	Irrigated cropland/dairy	None	**No change**	0.772
6	Low-density residential	None	**No change**	0.488
7	Irrigated field crops/pasture/dairy	Row crop	**Decrease**	0.009
8	Low-density residential	None	**No change**	0.149
9	Pasture/nonirrigated crops	Row crop/cow-calf	**No change**	0.149
10	Irrigated cropland	None	**No change**	0.149
11	Irrigated field crops/pasture/dairy	Row crop	**Decrease**	0.043
12	Irrigated field crops/pasture/dairy	Row crop	**Increase**	0.004
13	Irrigated cropland	Cow-calf	**Increase**	0.038
14	Hay	None	**No change**	1.0
15	Irrigated cropland	Cow-calf/row crop	**Decrease**	0.009
16	Pasture	Row crop	**Increase**	0.009
17	Urban	None	**No change**	0.343
18	Irrigated cropland	None	**Decrease**	0.043
20	Irrigated cropland	Row crop	**No change**	1.0
21	AAK-7015; WWTP	None	**No change**	0.4

Future Sampling Schedule and Next Steps

Based on the previously mentioned seasonality tests for selected groundwater quality data (nitrate-N, potassium, sulfate, and dissolved solids), the sampling schedule was modified in mid-2015 to reduce the sampling frequency of the RFA monitoring wells from quarterly to semiannually, with the exception of Monitoring Well #12. This well with high nitrate-N concentrations (consistently exceeding 40 mg/L) is located near an experimental groundwater remediation site, which includes several scavenger wells that pump water into a bioreactor designed to reduce nitrate-N concentrations in groundwater. The total number of monitoring wells (20) will not be reduced in the semiannual sampling.

Quarterly sampling will continue for the four RFA springs (Ginnie, Gilchrist Blue, Twin, and Devil's Eye) and the three Santa Fe River sites. Water quality trend analyses will continue as additional data are collected from future sampling events. Nitrate and other water quality data will continue to be evaluated on a regular basis, and sampling frequency will be adjusted as needed in future events based on the results. For example, if there are substantial changes in land use, rainfall, nitrate-N concentrations, or BMPs, the sampling frequency of all impacted monitoring wells would go back to quarterly.

In addition to the implementation of agricultural BMPs, FDACS, the SRWMD, and DEP will continue to review results from the ongoing bioremediation study, which consists of a network of scavenger wells and a bioreactor designed to remove nitrogen from recovered groundwater beneath an agricultural property with elevated groundwater nitrate-N concentrations. This "pump and treat" technology will be evaluated as a potential cost-effective way of reducing nitrogen loads from properties where historical agricultural practices have contributed to nutrient enrichment in the aquifer.

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Appendices

Appendix 1. List of analytes in water samples from wells, springs, and river sites in the Santa Fe RFA monitoring network

mg/L = Milligrams per liter; TDS = Total dissolved solids; TSS = Total suspended solids;
mg N/L = Milligrams per liter of nitrogen; mg P/L = Milligrams per liter of phosphorus; µg/L = Micrograms per liter; Ortho-P = Orthophosphate; Total-P = Total phosphorus; ppt = parts per thousand (‰)

Chemical Indicators	Unit	Laboratory (L) or Field (F) Analysis Method	Justification
Alkalinity	mg $CaCO_3$/L	SM 2320 B (L)	Aquifer properties
Chloride	mg/L	Method 300 (L)	Source indicator
Fluoride	mg/L	SM 4500 F-C (L)	Confinement indicator
Sulfate	mg/L	Method 300 (L)	Source indicator
TDS	mg/L	SM 2540 C (L)	Source indicator
TSS	mg/L	SM 2540 D (L)	Source indicator
Bromide	mg/L		Source indicator
Boron	mg/L		Source indicator
Calcium	mg/L	Method 200.7 (L)	Aquifer properties
Magnesium	mg/L	Method 200.7 (L)	Aquifer properties
Potassium	mg/L	Method 200.7 (L)	Source indicator
Sodium	mg/L	Method 200.7 (L)	Source indicator
Ammonia-N	mg N/L	Method 350.1 (L)	Source indicator/ aquifer properties
Nitrate-Nitrite-N	mg N/L	Method 353.2	Management action influence; source indicator/nitrogen species transformation
Total-P	mg P/L	In-house based on Method 365.4 (L)	Aquifer properties; Hawthorne influence
Total Kjeldahl Nitrogen	mg N/L	In-house based on Method 351.2 (L)	Source indicator/ nitrogen species transformation
Organic Carbon	mg C/L	In-house based on	Aquifer properties

Chemical Indicators	Unit	Laboratory (L) or Field (F) Analysis Method	Justification
		Method 415.1 (L)	
Ortho-P	mg P/L	Method 365.1 (L)	Aquifer properties; Hawthorne influence
Sucralose	µg/L	In-house	Source indicator
Nitrogen and Oxygen Isotopes in nitrate (δ15N and δ18O in NO_3)	ppt	Colorado Plateau Stable Isotope Laboratory	Nitrate-N source indicator; denitrification indictor

Appendix 2. List of field-measured physical and chemical indicators for groundwater, springs, and river water sites in the Santa Fe RFA monitoring network

DO = Dissolved oxygen; mg/L = Milligrams per liter; SU = Standard units; µS/cm = Micromhos per centimeter;
NTU = Nephelometric turbidity units; PCU = Platinum cobalt units; °C = Degrees Celsius; ft = feet

Physical Indicators	Unit	Analysis Method	Justification
DO	mg/L	DEP-SOP-001/01 FT 1500 (F)	Aquifer properties/ redox conditions
pH	SU	DEP-SOP-001/01 FT 1100 (F)	Aquifer properties
Specific Conductance	µS/cm	DEP-SOP-001/01 FT 1200 (F)	Aquifer properties
Turbidity	NTU	Method 180.1 (L)	Aquifer properties
Color	PCU	SM 2120 B (L)	Aquifer properties
Temperature	°C	DEP-SOP-001/01 FT 1400 (F)	Aquifer properties
Depth to Water (wells)	ft	Field Measurement	Recharge to aquifer

Appendix 3. 2013–15 RFA Water Quality Data

Spreadsheet containing water quality data is available on request.

Appendix 4. List of pesticide compounds analyzed by the DEP Laboratory along with their detection limits

DEP SOP: GC-011-5 (based on EPA 608 and 617)

µg/L = Micrograms per liter

Pesticide	Detection Limit	Unit of Measurement
Aldrin	0.0019	µg/L
Alpha-BHC	0.0019	µg/L
Beta-BHC	0.0019	µg/L
Delta-BHC	0.0019	µg/L
Gamma-BHC	0.0019	µg/L
Carbophenothion	0.0057	µg/L
Chlorothalonil	0.0076	µg/L
Cypermethrin	0.011	µg/L
DDD-p,p*	0.0038	µg/L
DDE-p,p*	0.0038	µg/L
DDT-p,p*	0.0038	µg/L
Dicofol	0.023	µg/L
Endosulfan I	0.0019	µg/L
Endosulfan II	0.0019	µg/L
Endosulfan Sulfate	0.0038	µg/L
Endrin	0.0038	µg/L
Endrin Aldehyde	0.0038	µg/L
Heptachlor	0.0019	µg/L
Heptachlor Epoxide	0.0019	µg/L
Methoxychlor	0.0095	µg/L
Mirex	0.0038	µg/L
Permethrin	0.0095	µg/L
Trifluralin	0.0076	µg/L

DEP SOP: LC-001-2 (based on USGS O-2060-01)

µg/L = Micrograms per liter

Pesticide	Detection Limit	Unit of Measurement
2,4-D	0.0020	µg/L
Diuron	0.0020	µg/L
Fenuron	0.0080	µg/L
2,4,5-T	0.0020	µg/L
Acifluorfen	0.0020	µg/L
Imidacloprid	0.0020	µg/L
Bentazon	0.0020	µg/L
Linuron	0.0040	µg/L
Silvex	0.0020	µg/L

EPA 8321B

µg/L = Micrograms per liter

Compound	Detection Limit	Unit of Measurement
Sucralose	0.010	µg/L
2,4-D	0.0020	µg/L
Diuron	0.0020	µg/L
2,4-DB	0.0020	µg/L
Fenuron	0.0040	µg/L
2,4,5-T	0.0020	µg/L
Acifluorfen	0.0020	µg/L
Imidacloprid	0.0020	µg/L
Bentazon	0.0020	µg/L
Linuron	0.0040	µg/L
Dichlorprop	0.0020	µg/L
Dinoseb	0.020	µg/L
MCPA	0.0040	µg/L
MCPP	0.0040	µg/L
Silvex	0.0020	µg/L

EPA 8270D

ng/L = Nanograms per liter

Compound	Detection Limit	Unit of Measurement
Dieldrin	0.38	ng/L
Ametryn	0.19	ng/L
Atrazine	0.24	ng/L
Chlorpyrifos Ethyl	0.097	ng/L
Chlorpyrifos Methyl	0.12	ng/L
Disulfoton	0.49	ng/L
Ethion	0.097	ng/L
Ethoprop	0.097	ng/L
Hexazinone	0.97	ng/L
Malathion	0.12	ng/L
Metribuzin	0.24	ng/L
Mevinphos	0.24	ng/L
Norflurazon	0.97	ng/L
Phorate	0.24	ng/L
Prometryn	0.24	ng/L
Simazine**	0.24	ng/L
Atrazine Desethyl	0.24	ng/L
Fipronil	0.49	ng/L
Molinate	0.29	ng/L
Pendimethalin	0.49	ng/L
Terbufos	0.097	ng/L
EPTC	0.29	ng/L
Terbuthylazine	0.19	ng/L
Bromacil	0.49	ng/L
Fipronil Sulfide	0.19	ng/L
Fipronil Sulfone	0.19	ng/L

EPA 8270D

ng/L = Nanograms per liter

Compound	Detection Limit	Unit of Measurement
Ametryn	0.19	ng/L
Atrazine	0.24	ng/L
Chlorpyrifos Ethyl	0.097	ng/L
Chlorpyrifos Methyl	0.12	ng/L
Disulfoton	0.49	ng/L
Ethion	0.097	ng/L
Ethoprop	0.097	ng/L
Hexazinone	0.97	ng/L
Malathion	0.12	ng/L
Metribuzin	0.24	ng/L
Mevinphos	0.24	ng/L
Norflurazon	0.97	ng/L
Phorate	0.24	ng/L
Prometryn	0.24	ng/L
Simazine	0.24	ng/L
Atrazine Desethyl	0.24	ng/L
Fipronil	0.49	ng/L
Molinate	0.29	ng/L
Pendimethalin	0.49	ng/L
Terbufos	0.097	ng/L
EPTC	0.29	ng/L
Terbuthylazine	0.19	ng/L
Bromacil	0.49	ng/L
Fipronil Sulfide	0.19	ng/L
Fipronil Sulfone	0.19	ng/L

Appendix 5: Important Links

Other Water Quality Data: Pesticide Compounds:

Atrazine: http://extoxnet.orst.edu/pips/atrazine.htm

Hexazinone: http://extoxnet.orst.edu/pips/hexazin.htm

Norflurazon: http://www.wsdot.wa.gov/NR/rdonlyres/5CCF6051-0429-49BB-99B8-E023E0A8A2A7/0/Norflurazon.pdf

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