GROUNDWATER QUALITY SOURCE EVALUATION FOR THE RAINBOW SPRINGS GROUP MARION COUNTY, FLORIDA

JULY 2017

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LIMITATIONS AND CERTIFICATIONS

The contents of ***GROUNDWATER QUALITY SOURCE EVALUATION FOR THE RAINBOW SPRINGS GROUP, MARION COUNTY, FLORIDA*** were prepared on behalf of our clients, the Southwest Florida Water Management District (SWFWMD) and Interflow Engineering, LLC (IE), and are intended for their use. Water Resource Associates, LLC (WRA) assumes no liability for the misuse of this information by others. The professional opinions and/or recommendations included within this report are based on the interpretations of the testing and/or data collection activities performed in Marion, Levy, and Alachua counties. Based on current methodologies and the current state of the professional practice of geology, the geologic information provided is true and correct based on the data collected. WRA reserves the right to update this report should additional information become available.

The signatories have signed and sealed this document in accordance with applicable Florida state statutes. If not signed and sealed by the professionals named and shown as its authors, the findings, conclusions, and opinions cannot be relied upon by anyone for any reason; as such, the document has been provided for informational purposes only.

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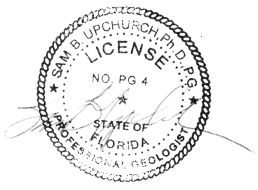

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EXECUTIVE SUMMARY

There are more than one hundred-fifty springs within the Southwest Florida Water Management District (District), all of which have become threatened in varying degrees by anthropogenic activities and other factors. The District has recently established a “Springs Team” comprised of in-house experts charged with evaluating and applying a variety of techniques, such as regulation, monitoring, research and development, restoration, and education, to minimize stresses which have diminished water quantity and quality observed at the springs. Of these stresses, increased nitrate concentrations in spring discharge over the last 50 years is paramount. This report presents a new approach to identification of nitrate sources and related recharge within a springshed.

Traditional approaches to springs protection and restoration have focused on areas proximal to the spring or spring group. While many projects have evaluated the quantity and quality of water discharging from specific springs or spring groups, these efforts have been focused on delineation of the springsheds and identification of spring protection areas based on proximity to the spring or pre-existing knowledge from dye traces or other site-specific evidence. Use of proximity to a spring is reasonable in many situations, but it assumes that the sources(s) of nutrients and associated recharge are spatially and uniformly widespread and, because of dilution and dispersion of water distal to the spring, only those sources nearest the spring are of concern. The assumption that dilution and dispersion may negate the effects of nutrient discharge at locations distal to springs may be problematic, especially where there is fracture or conduit flow.

Rather than large scale, “catch-all” approaches of the past, such as delineation of a spring protection zone near the spring, the intent of this report is to evaluate a “surgical” approach to hydrogeologic evaluation and establishment of site-specific, nutrient-reduction target areas. This approach hopes to enhance solution of water-quality problems by streamlining a spatially focused, cost-effective means for spring protection and source identification. As presented in this report, WRA utilized District data, such as existing monitoring well and spring water-quality data, to identify the most probable primary source areas of nutrients and related recharge water from within the Rainbow Springs Group springshed.

The pilot program evaluation method described herein increases in complexity with each step of the evaluation; however, the end result links aqueous geochemical statistics to potential karst features and land uses during the three 10-year time frames evaluated. Like any hydrogeological investigation, the foundation is a sound conceptual site model. This included a regional and site-specific review from a stratigraphic, geomorphic, and karst science perspective. Once potenitally relatable karst features were identified, statistical analyses of District water-quality data were completed to cluster the water-quality data into process-related factors. Site-specific loadings of water-quality data to process-related factors can be mapped to identify potential sites of interest within a springshed. The statistical approach included: geochemical fingerprinting by pattern recognition and analysis; principal component analyses (PCA); and factor analyses (FA). These geostatistical/geochemical analyses along with the karst hydrogeological evaluation allowed for the identification of potential “hot spots”.

Areas impacted by direct, rapid, artificial recharge through drainage wells and sinkholes, as well as by slow, natural recharge into the Upper Floridan aquifer (UFA), were delineated within these “hot spots”. Three factors which represent different chemical processes were identified and their relative areal impact determined. These processes are: (1) regional dissolution of the aquifer limestone and/or dolostone matrices and recharge of meteoric water; (2) recharge from local, urban, and agricultural fertilizer runoff; and (3) recharge from local, urban, and agricultural soil amendment runoff.

This results of this pilot program report can be used develop strategies for cost-effective improvement of the quantity and quality of District spring systems.

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1.0 INTRODUCTION

There are more than one hundred-fifty springs within the Southwest Florida Water Management District (District), all of which have become threatened in varying degrees by anthropogenic activities and other factors. The District has recently established a "Springs Team" comprised of in-house experts charged with evaluating and applying a variety of techniques such as regulation, monitoring, research and development, restoration, and education to relieve stresses which have diminished water quantity and quality observed at the springs.

Traditional approaches to springs protection and restoration have focused on areas proximal to the spring or spring group (Figure 1-1; Scott et al., 2004; Florida Department of Environmental Protection, 2000; Water Resource Associates and SDII Global Corporation, 2005). While many projects have evaluated the quantity and quality of water discharging from specific springs or spring groups, these efforts have been focused on delineation of the springsheds and identification of spring protection areas based on proximity to the spring, dye traces, or other site-specific evidence. Use of proximity to a spring as a criterion for springs protection is reasonable in many situations, but it assumes that the sources(s) of nutrients and associated recharge are spatially and uniformly widespread. Because of dilution and dispersion of water distal to the spring, only those sources nearest the spring are typically of concern. The fundamental assumption upon which this process is based is that the groundwater flow is Darcian and through a homogeneous and isotropic medium with basin-wide recharge. While arguments have been successfully made that karstic aquifers with conduit flow can be treated as "equivalent porous media" on a regional scale (Hickey, 1984; Vacher and Mylroie, 2002; Scanlon et al., 2003), this approach tends to reduce our ability to target specific nutrient sources associated with conduit flow to the spring, especially along conduits originating some distance from the spring.

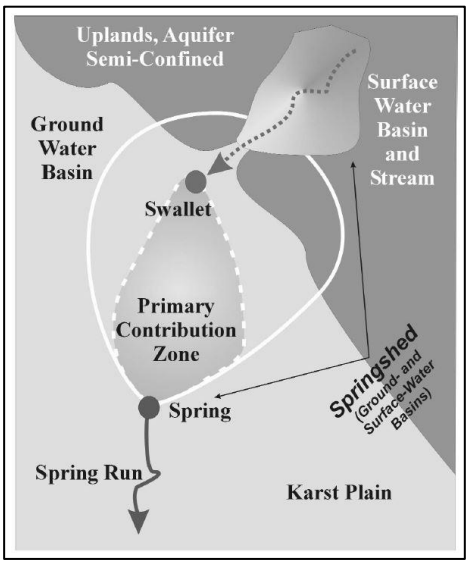

Figure 1-1. Hypothetical spring protection zone ("Primary Contribution Zone") based on proximity to a spring. Figure from Scott et al. (2004).

Spring protection strategies based on regional hydrogeologic assumptions with proximity to a spring as a focus are complicated by two important and related issues to overcome: economics and political pressures. The costs to implement such approaches are enormous and state and water management districts, local governments, and the private sector could probably never allocate those types of funds for this effort. A springshed-wide or proximal area-scale approach to springshed management would require state and local governments to enact and land owners to support such activities as

1. Implementation of best-management practices (BMPs),
2. Implementation of total maximum daily load (TMDL) restrictions,
3. Adoption of regional land-use restrictions,
4. Establishment of point and, more importantly, non-point source discharge regulations, and
5. Possible removal or replacement of existing infrastructure, such as septic tanks and industrial facilities.

With our current springshed-wide approach, this would be required for a very large area that would encompass many square miles of existing land-use activities.

Second, it has been shown that the local governments are hesitant to undertake this type of effort, which would affect numerous landowners and business. These issues were evident in the

preparation of a spring protection plan developed for Marion County in 2007 by Water Resource Associates (WRA) to address the water impacts to Silver Spring. The study delineated the 10 and 100-year travel time springsheds and recommended several pollution-prevention ordinances. The report and recommendations were presented to the Marion County Commission, which immediately rejected the recommendations for the following reasons:

1. Too widespread an application of pollution reduction requirements;
2. Too many homeowners affected by septic tank requirements;
3. Too many businesses affected; and
4. May be impediment to growth.

Districts and the Florida Department of Environmental Protection (FDEP) are encouraging landowners to use BMPs and the FDEP is developing and implementing TMDLs for nitrate control at the springshed or larger scale. The effectiveness of these approaches remains to be determined.

Currently, there are District efforts to evaluate the potential for the removal of septic tanks and the conversion to sewers and to evaluate treated effluent discharge options (i.e., spray fields, rapid infiltration basins, etc.) to improve groundwater quality within the springsheds located within the northern reaches of the District. While these preventative/correction measures should be taken, the results of this study demonstrate that it could be done in a more efficient and focused manner.

Rather than large-scale, "catch-all" approaches currently being implemented, such as delineation of a spring protection zone near the spring itself or use of springshed-wide implementation of BMPs, TMDLs, and other measures, the WRA Team proposed a pilot program to evaluate a "surgical" approach to hydrogeologic characterization and nutrient-reduction implementation to streamline and provide a spatially focused, more cost-effective means for spring protection in order to assist the District's Springs Team in their mission. While geographically larger recharge areas related to contaminants and larger features, such as large fracture traces, may be identified, the identification of relatively small recharge areas, such as individual sinkholes, may not be readily identified through available data and existing monitoring well networks. This would greatly reduce the spatial reach of the area(s) that would require pollution control instead of large springsheds.

As we learned from the District's 1996 investigations of nutrient sources at Rainbow Springs, karst systems with well-defined conduits may discharge water primarily derived from locations some distance from the spring vent (Jones et al., 1996). Faulkner opined that Rainbow Springs was capturing water from directions to the north and east (1973). He suggested that a fault with elevated hydraulic conductivity was capturing westward flowing groundwater and causing it to discharge at the springs. Jones et al. (1996) used chemical fingerprinting techniques to identify source areas for the various vents of the Rainbow springshed and determined that the water discharging from the various vents in the spring group had different and discrete origins to the north and east of the spring, but not to the west or south.

WRA and SDII Global Corporation (SDII) delineated the capture area of Rainbow Springs group (Figure 1-2***)*** based on two groundwater flow models and particle tracking, They determined that the 100-year capture area extends to the north and east of the springs and that it has a very limited extent to the west (Water Resource Associates and SDII Global Corporation, 2005). As a result, focusing on protection and remediation in areas near the spring may not adequately address the primary sources of water and nutrients discharging from that spring.

Prior investigations by Lawrence and Upchurch (1976, 1982) and Upchurch and Champion (2003a, b, and c)' have identified several methods for identification of nutrient source areas and potential spring protection areas within a springshed, including identification of localized areas

within the larger springshed. The opportunity to combine these methods in a systematic search for spatially restricted source areas has not arisen.

We believe the targeted approach completed during this pilot program and presented in this report minimizes the non-scientific issues and makes spring protection implementation more palatable for the public and local officials. Understanding that there will be limited funds to address the multitude of springs in Florida, this cost-effective approach makes great sense.

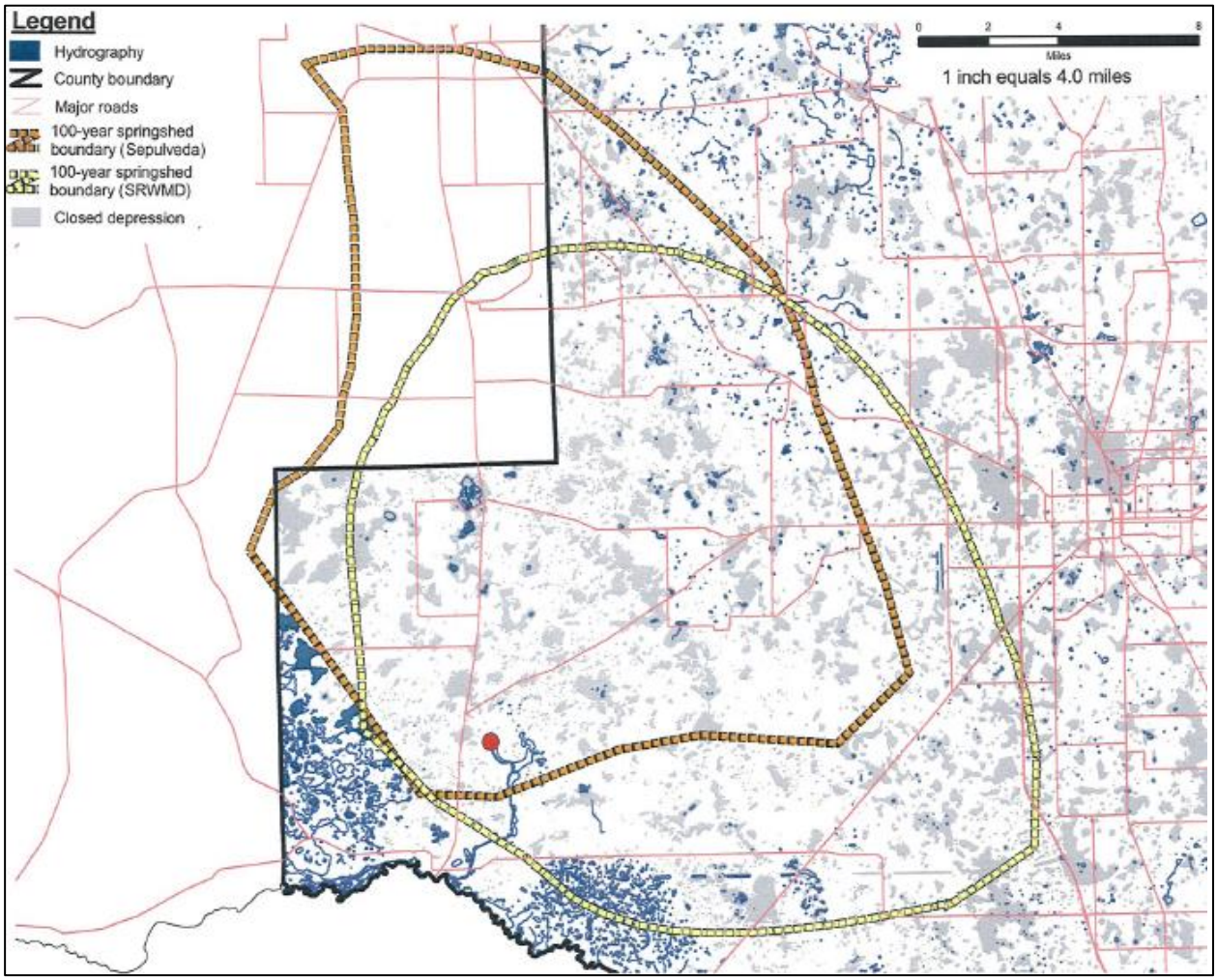

Figure 1-2. Computer simulated, 100-year travel times of Upper Floridan aquifer groundwater flow to Rainbow Springs. Modified from WRA and SDII (2005).

2.0 REGIONAL GEOLOGY

2.1 Definition of Study Area

There have been several attempts to delineate the springshed of the Rainbow Springs Group (Figure 2-1). These attempts and our critiques of them can be found below. For the purposes of this and following sections, the springshed delineation depicting 2005 conditions represents the "study area" (Holzwart et al., 2017).

2.2 Geomorphology

The largest springshed defined by flow-net analysis suggests that the study area is located, from southwest to northeast, within the Chiefland Karst Plain, the Brooksville Ridge, the Williston Karst Plain, the Ocala Karst Hills, and the Fairfield Karst Hills provinces of the Ocala Karst District, and the Hawthorne Lakes Region Province of the Central Lakes District (Scott, 2005; Williams et al., in preparation; Figure 2-2).[1] Groundwater flow modeling and the work of Jones et al. (1996) indicate a much smaller springshed. For the sake of completeness and in order to define an area somewhat larger than the study area, these provinces are briefly described below.

2.2.1 Chiefland Karst Plain Province, Ocala Karst District

The Chiefland Karst Plain is topographically diverse and several large areas of the province show little evidence of karst development, while others are true karst landscapes. Fluctuating sea levels sculpted the region through alternating depositional and erosional cycles. Varying thicknesses of unconsolidated to indurated sand, silt and clay overlie limestone throughout this region. Elevations range from sea level to approximately 70 feet North American Vertical Datum (ft. NAVD) near Dunnellon.

2.2.2 Brooksville Ridge Province, Ocala Karst District

The Brooksville Ridge is located along the western edge of Marion County and is bound by the Chiefland Karst Plain Province to the west and the Williston Karst Plain Province to the east. The Brooksville Ridge is separated into two sections at the southwestern-most corner of Marion County near Dunnellon by the Withlacoochee River. Fluctuating sea levels and karstification created the ridge through erosion and dissolution of an older, broader highland. Although limestone occurs near the surface in limited areas of the Brooksville Ridge, much of the ridge has a thick sequence of sand, silt, and clay overlying limestone. The terrain is highly irregular with some of the greatest topographic relief found in peninsular Florida. Karst features, including large bowl-shaped depressions that are the result of dissolution of the limestone surface at depth, are common. Aeolian sand dunes are also common topographic features on the Brooksville Ridge. The Brooksville Ridge is generally well drained. Poorly drained conditions typically occur only in the low-lying areas. Owing to the large, ancient sinkholes within portions of the ridge, much of the surface-water drainage is internal, into low areas within these large, relict sinkhole complexes. Elevations range from approximately 70 ft. NAVD to more than 300 ft. NAVD.

[1] NOTE: This Technical Memorandum uses the more recent revision of the geomorphic provinces of Florida, which are a modification of White (1970) by Scott (2005) and Williams et al. (in preparation). Based on White (1970), the study area is located from southwest to northeast within the Gulf Costal Lowlands, Brooksville Ridge, Western Valley, Tsala Apopka Plain, Cotton Plant Ridge, Sumter Upland, Martel Hill, Fairfield Hills, Ocala Hills, Alachua Cross Valley, Central Valley, and Northern Highlands provinces.

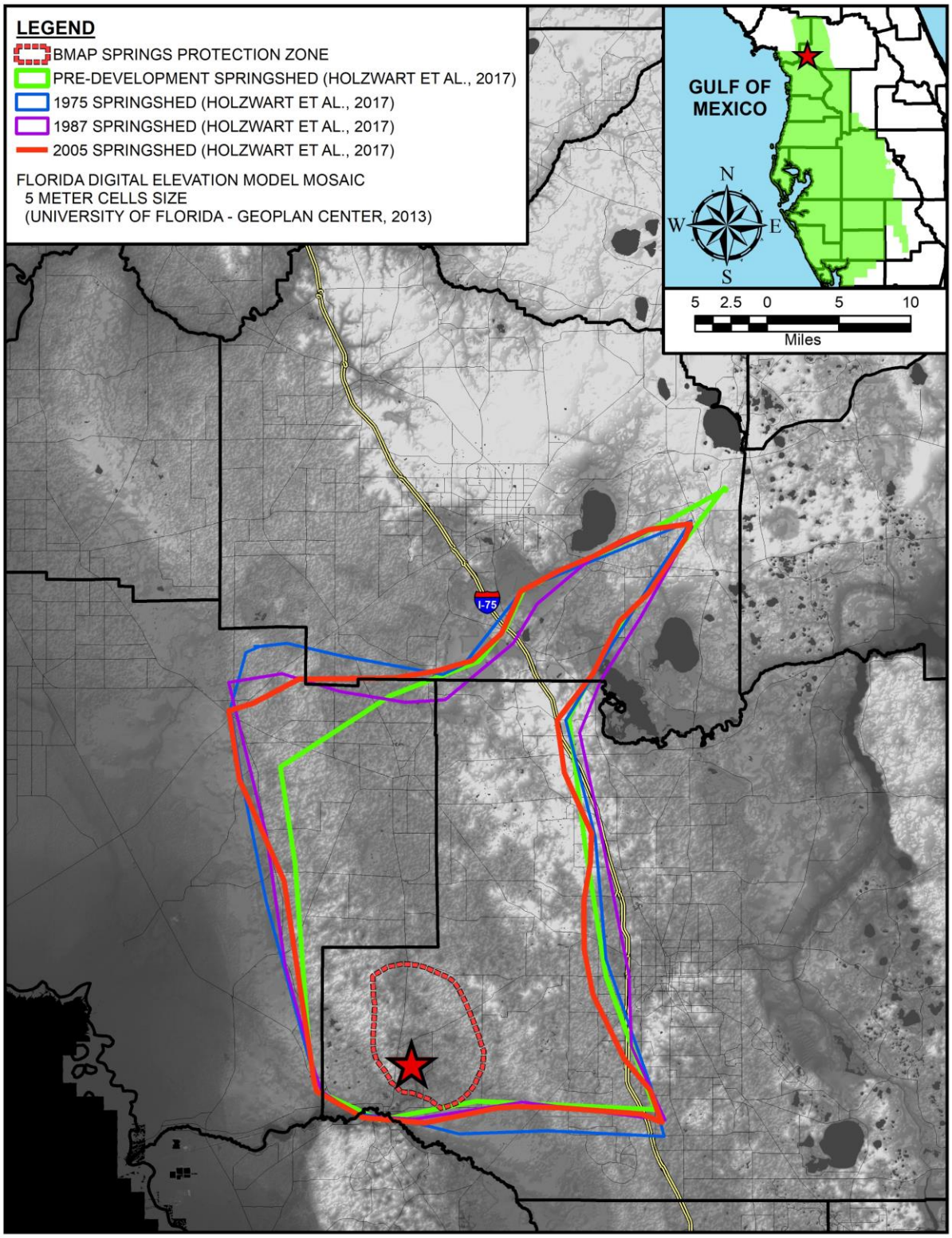

Figure 2-1. Springshed delineations map (Holzwart et al., 2017). Red Star: Rainbow Springs Group location.

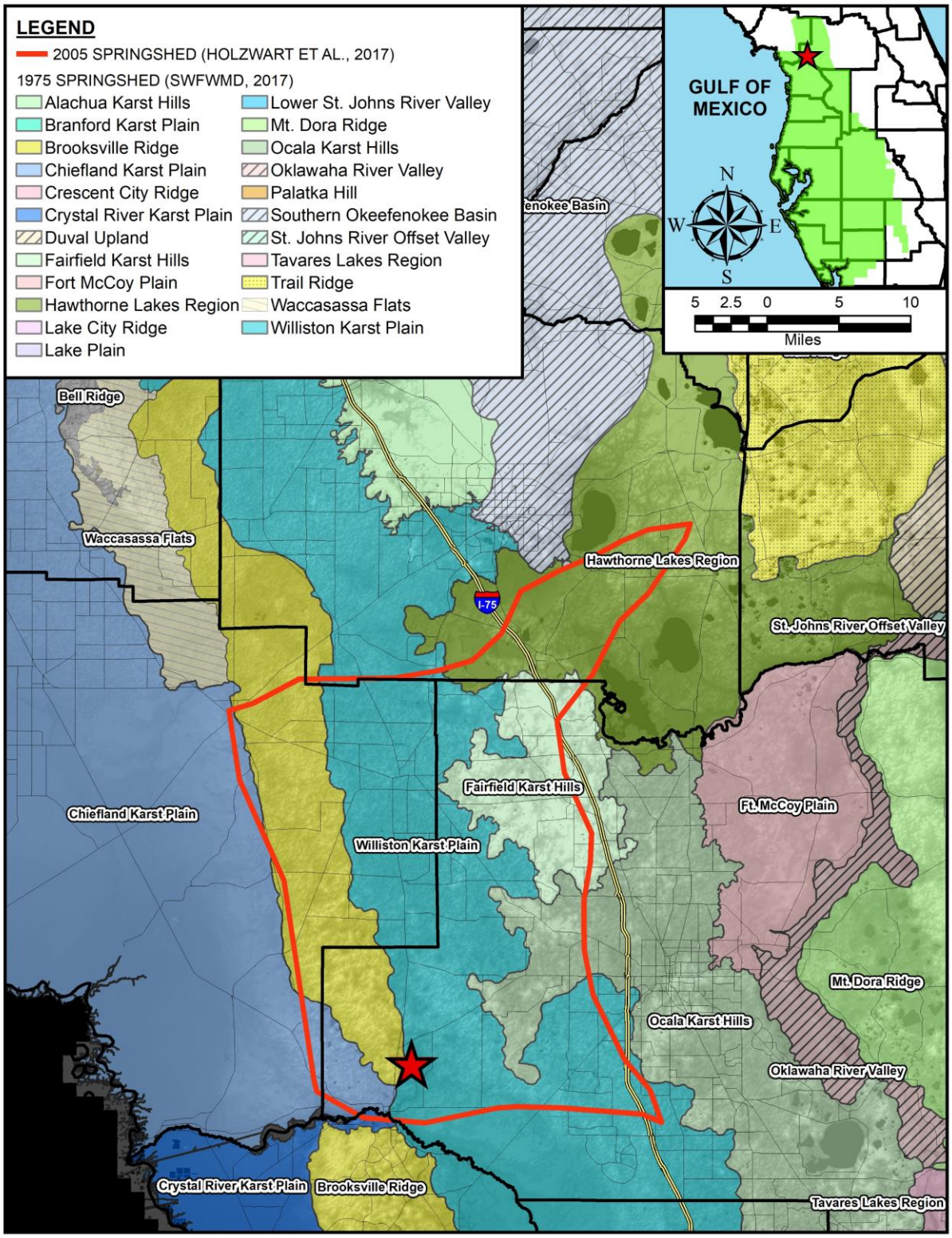

Figure 2-2. Regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

2.2.3 Williston Karst Plain Province, Ocala Karst District

The Williston Karst Plain Province occurs east of the Brooksville Ridge and west of the Fairfield Karst Hills and the Ocala Karst Hills in Marion County. The Withlacoochee River flows through portions of the province. In part, the region owes its origin to karstification. Limited surface drainage features across this karstified area would suggests relatively permeable sediments overlie limestone, with well-developed internal drainage to the subsurface. The terrain is flat to very gently rolling. Fluvial erosion and marine erosion due to sea level fluctuations played a role in the development of the area. Varying thicknesses of poorly drained sand, silt, and clay overlie limestone throughout this region. Wind-blown sand dunes and small beach ridges are scattered across the land surface of the Province. Elevations range from approximately 50 feet NAVD to more than 100 feet NAVD.

2.2.4 Ocala Karst Hills Province, Ocala Karst District

The Ocala Karst Hills Province consists of a small ridge that has been perforated by numerous sinkholes on the northeastern side of the Ocala Karst District. The Ocala Karst Hills are typically underlain by Hawthorn Group clay-rich strata, so small, intermittent streams are common. These streams discharge to swallets in the bottoms of the closed depressions within the hilly landscape. The Ocala Karst Hills Province does not include any mapped springs. Elevations in the province range from 50 ft. NAVD at the eastern toe of the ridge on the Ocklawaha River floodplain to greater than 180 ft. NAVD on the crests of several of the highest hills near Ocala.

2.2.5 Fairfield Karst Hills Province, Ocala Karst District

The Fairfield Karst Hills, in northwestern Marion County, are surrounded by the Hawthorne Lakes Region Province of the Central Lakes Geomorphic District to the northeast, the Williston Karst Plain Province to the west, and the Ocala Karst Hills Province to the east and southeast Resulting in a hummocky/hilly terrain, karst in this area is also dependent on the sediment cover overlying limestone. The Fairfield Karst Hills are dotted by numerous closed depressions. Small streams are developed on the clay-rich Miocene Coosawhatchee Formation (Hawthorn Group), but they have no spatial extent as they drain to nearby swallets. The province is important because the elevations in the hills have made it possible to mine the palygorskite- and smectite-rich clays of the Coosawhatchee for “Fuller’s earth” and the underlying Ocala Limestone for aggregate and cement. The Fairfield Karst Hills appear to consist of an outlier of Hawthorn Group sediments related to development of the Ocala Karst Hills. Elevations in the Province range from about 75 ft. NAVD on the surrounding karst plain to over 70 ft. NAVD on the crests of the hills.

2.2.6 Hawthorne Lakes Region Province, Central Lakes District

The Hawthorne Lakes Region is characterized by numerous large, relatively shallow and irregularly shaped lakes and wetlands and closed depressions. Many of the largest lakes are shallow and may or may not be karstic. Many of the deeper features have steep sides and imbedded circular depressions, which suggest that they are sediment-filled poljes. Uplands between the wetlands and lakes often exceed 200 ft. NAVD. Elevations of the wetlands and lakes are typically 80 to 100 ft. NAVD in elevation.

2.3 Stratigraphy

As depicted on Figure 2-3 and presented on Table 2-1, the near-surface geologic units within the springshed range in age from Middle Eocene to Holocene (approximately 40 million years ago to the present). These include, from oldest to youngest, the Middle Eocene Avon Park Formation; the Upper Eocene Ocala Limestone; the Miocene Hawthorn Group (undifferentiated); the Pliocene Cypresshead Formation; and undifferentiated Plio-Pleistocene to Holocene sediments (Scott, 2001; Arthur et al., 2008).

The Middle Eocene Avon Park Formation occurs beneath all of study area. The formation generally dips to the east-northeast (Scott, 2001). The Avon Park Formation lithology varies

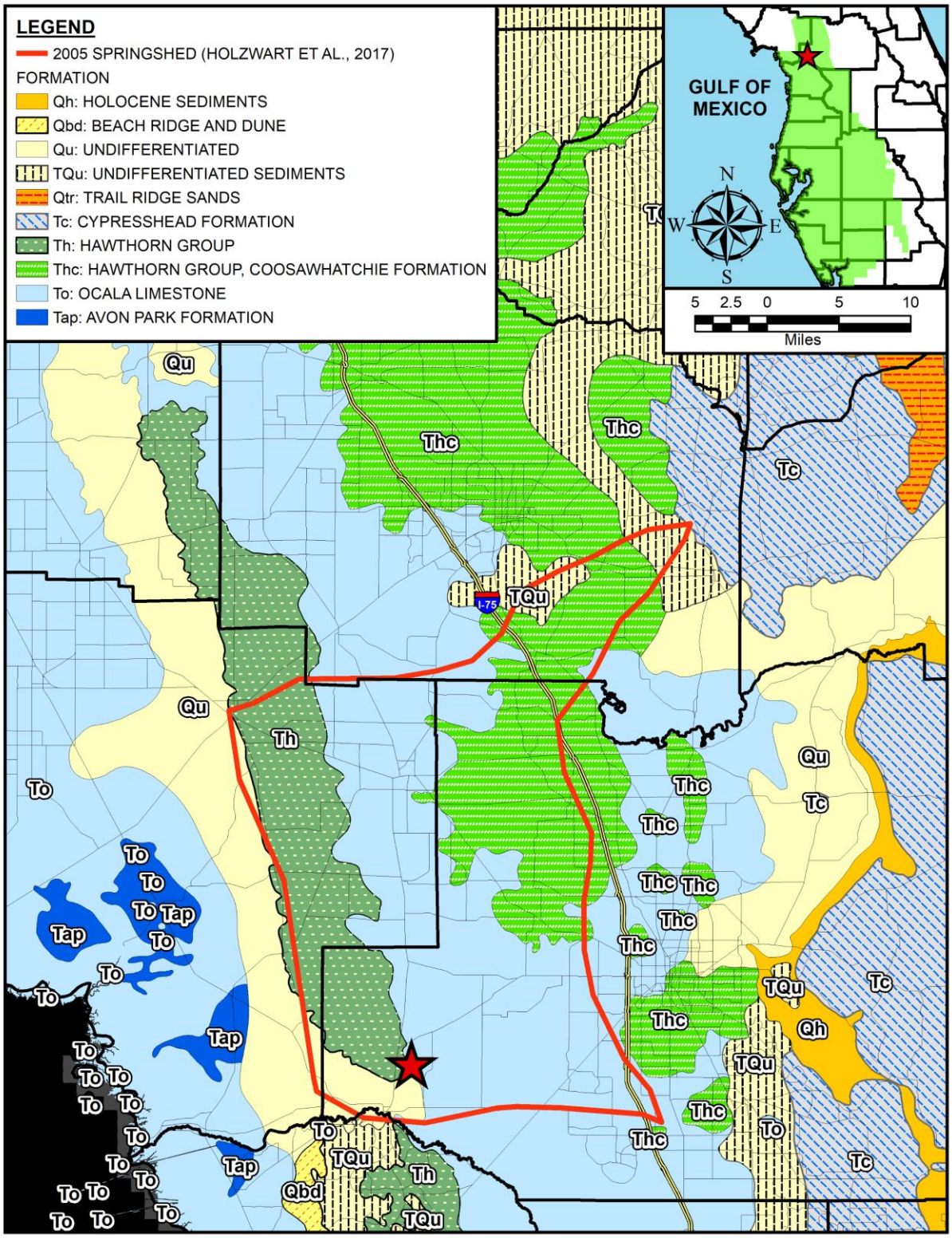

Figure 2-3. Regional geology (modified from Scott et al., 2001; FGS, 2016). Red Star: Rainbow Springs Group location.

Table 2-1. Hydrostratigraphic nomenclature chart (modified from Sepulveda, 2002 and USGS Mineral Resources On-Line Spatial Data [http://mrdata.usgs.gov/geology/state], 2014).

SYSTEM	SERIES	STRATIGRAPHIC UNIT	GENERAL LTHOLOGY	HYDROGEOLOGIC UNIT
QUATERNARY	Holocene	Surficial deposits	Undifferentiated well sorted sand, trace to with interbedded clay, shell, organics, and limestone	surficial aquifer (SA)
	Plio-Pleistocene		Undifferentiated well sorted sand with interbedded clay, shell, and limestone, terrace and shallow marine deposits	
TERTIARY	Miocene	Hawthorn Group	Gray-green to brown, calcareous clay with variable percentages of dolomitic silt and sand, with interbedded, occasionally fossiliferous, limestone and dolostone, trace to with phosphorite, and trace to with chert	intermediate confining unit (ICU)
	Eocene	Ocala Limestone	Upper Facies - white, poorly to well indurated, poorly sorted, very fossiliferous (large and smaller foraminifers, echinoids, bryozoans and mollusks - Lepidocyclina sp. is abundant in the upper facies and extremely limited in the lower facies) occasional chert, limestone (grainstone, packstone and wackestone)	Upper Floridan aquifer (UFA) Ocala Permeable Zone
			Lower Facies - white to cream-colored, fine to medium grained, poorly to moderately indurated, very fossiliferous (large and smaller foraminifers, echinoids, bryozoans and mollusks) limestone (grainstone and packstone), may be partially to completely dolomitized in some regions (Miller, 1986). -Nearly pure limestone and occasional dolostone-	Upper Floridan aquifer (UFA) Ocala Low-Permeable Zone
		Avon Park Formation	Cream to light-brown or tan, poorly indurated to well indurated, variably fossiliferous (mollusks, foraminifers, echinoids, algae and carbonized plant remains), molds and casts of gypsum crystals occur locally, limestone (grainstone, packstone and wackestone, with rare mudstone) interbedded with tan to brown, very poorly indurated to well indurated, very fine to medium crystalline, fossiliferous (molds and casts), vuggy dolostone	Upper Floridan aquifer (UFA) Avon Park Permeable Zone
				middle confining/semi-confining unit (MCU/MSCU)
		Oldsmar Formation	Pale, off-white to light gray, micritic pelletal limestone with interbedded gray to tan to light brown fine to medium crystalline, vuggy, dolostone	Lower Floridan aquifer (LFA)
	Paleocene	Cedar Keys Formation	Upper Facies - gray to cream, tan to gray to cream, coarsely crystalline dolostone	
			Lower Facies - tan to gray, finely to microcrystalline dolostone with interbedded interlithic or “chicken wire” texture anhydrite at depth	sub-Floridan confining unit (SFCU)

between dolostone and limestone. The limestone portions are typically cream to light gray, poorly to well indurated, fossiliferous wackestone to grainstone with mudstone. The limestone can have dark brown to tan, very fine to coarse grained, vuggy interbedded dolostones. It is unconformably overlain by the Ocala Limestone.

The Late Eocene Ocala Limestone occurs throughout the study area (Scott, 2001). In the study area, it is unconformably overlain by Plio-Pleistocene to Holocene sediments throughout the Williston Karst Plain and by undifferentiated Miocene Hawthorn Group sediments in the vicinity of the Brooksville Ridge and Coosawhatchee Formation in the vicinity of the Fairfield Karst Hills and Ocala Karst Hills provinces. The Ocala Limestone is a soft to hard, fossiliferous limestone with minor dolostone (Arthur et al., 2008; Scott, 2001). The upper surface has been highly weathered over millions of years and exhibits numerous karst features (e.g., dissolution-enlarged fractures, cavities and pinnacled limestone). The Ocala Limestone in Marion County is well-known for its caves and caverns and highly transmissive solution channels. The surface of the Ocala Limestone often has significant relief due to the long, ancient history of erosion and dissolution. Epikarst is often well developed, because of the long-term weathering of the limestone. Chert is a common component of the Ocala Limestone, especially near the epikarst.

The undifferentiated Miocene Hawthorn Group covers much of the Brooksville Ridge. In the Fairfield Karst Hills and a portion of the Ocala Karst Hills provinces, the Hawthorn Group is represented by the Coosawhatchee Formation. These unconformably overlie the Late Eocene Ocala Limestone and underlie any Plio-Pleistocene to Holocene sediments. The Hawthorn Group is generally composed of sand, clay, and carbonate (limestone and dolostone) with generally

minor percentages of phosphate. Portions of the Hawthorn Group sediments have been weathered over millions of years. Sinkholes have breached this unit in some areas. In many cases, sand, clay, and phosphate deposits have subsequently filled the karst features creating buried paleo-sinkholes. Notable occurrences of this secondary phosphatic sinkhole fill, known as "hard-rock phosphate" deposits, occur in close proximity to the Rainbow Springs Group and within the state park.

At the northeastern-most extent of the springshed delineation, the Pliocene Cypresshead Formation occurs in eastern Alachua County. It is a shallow marine, near shore deposit equivalent to the Citronelle Formation deltaic sediments found in the Florida panhandle. The Cypresshead Formation overlies the Miocene Hawthorn Group strata and consists of reddish brown to reddish orange, unconsolidated to poorly consolidated, often cross-bedded, fine to very coarse grained, clean to clayey sands with gravel. Original fossil material is typically not present; however, poorly preserved molds and casts of mollusks and burrow structures are occasionally present.

The undifferentiated Plio-Pleistocene to Holocene sediments that overlie the Late Eocene Ocala Limestone and the Miocene Hawthorn Group strata include sand, silt, clay, and organic-rich sediments in southwestern Marion County and eastern Alachua County, the southwestern and northeastern extent of the springshed delineation, respectively. These sediments were deposited in marine, fluvial, and aeolian environments. They mantle the study area with variable thicknesses of sediment. These sediments often fill paleo-sinkholes.

2.4 Hydrogeology

The main aquifer in the study area, which directly affects the Rainbow Springs Group is the Upper Floridan aquifer (UFA; Table 2-1***;*** Miller, 1986; Sepulveda, 2002). Hydrogeologic parameters estimated from aquifer performance testing (APT) completed within the water management districts have been applied in their groundwater flow modeling efforts for evaluating this system.

2.4.1 Floridan Aquifer System

The Floridan aquifer system (FAS) is composed of Paleogene to early Neogene carbonates with highly variable permeability. In central Florida, the base of the FAS occurs within lower Paleogene rocks where evaporites (gypsum/anhydrite and fine-grained limestone/dolostone) restrict permeability (Miller, 1986; Sepulveda, 2002). The FAS consists of the Lower Floridan aquifer (LFA), which is of no concern to the identification of UFA geochemical processes in this study, the middle confining/semi-confining unit (MCU), and the UFA. In the vicinity of the springs group, the UFA is predominantly unconfined.

The MCU is comprised solely of less permeable limestone and dolostone of the Eocene Avon Park Formation. The top of the MCU in the study area forms the base of the UFA (Miller, 1986), which is the aquifer that supplies water to the Rainbow Springs Group.

The top of the UFA occurs where the carbonates are overlain by substantially more permeable sediments of the ICU or by the land surface. The top of the UFA in the study area occurs at base of the ICU (Miocene Hawthorn Group sediments), where present, (Miller, 1986) and at the top of the Ocala Limestone elsewhere in southwestern Marion County. By definition, if the UFA is unconfined or poorly confined, the aquifer extends into any saturated sands that overlie the carbonates of the aquifer. Because of this definition, water-saturated surficial sands that overlie unconfined UFA carbonate rocks in the Williston Karst Plain portion of the springshed are considered to belong to the UFA and not the surficial aquifer. From oldest to youngest, the UFA in the study area is comprised of the Middle Eocene Avon Park Formation and Late Eocene Ocala Limestone (Table 2-1).

The May and September 2014 potentiometric surface of the UFA is presented on Figure 2-4. Potentials in the UFA are the result of water level measurements in wells completed in one or more of the strata discussed above.

2.4.2 Intermediate Confining Unit

Within the study area, the ICU is composed relatively impermeable sediments deposited during the Miocene Epoch. The siliciclastics flooding onto the Florida Platform during the Miocene contained an abundance of clay. Deposition of the clayey sediments on top of the Paleogene carbonates in the study area created a low permeability sequence of confining beds (Miller, 1986, 1997; Scott, 1988). Permeable carbonate and siliciclastic sediments are, in some areas, interbedded with the less permeable units creating regional, water-producing zones (Miller, 1986, 1997; Scott, 1988).

The base of the ICU occurs at the top of the regionally extensive, permeable carbonate rocks of the UFA. Where present, the top of the ICU is placed at the top of the laterally extensive and vertically persistent lower permeability beds. The unit is essentially absent along the Rainbow Springs Group spring run and within the springshed (study area), but is present in the Brooksville Ridge and Fairfield Hills, where it is perforated by sinkholes.

2.4.3 Surficial Aquifer

In much of Florida, the first aquifer to be recharged by rainfall and stream runoff is the surficial aquifer. Where present, the surficial aquifer is composed of Pliocene through Pleistocene–Holocene permeable siliciclastic and carbonate sediments with some zones of more clayey, less-permeable sediments (Berndt et al., 1998). The base of the surficial aquifer occurs at the top of the laterally extensive and vertically persistent lower-permeability beds of the ICU.

The surficial aquifer is generally absent in the study area near the springs group. However, it may be locally and intermittently present in the Brooksville Ridge, Fairfield Hills, and scattered locations where remnants of the Hawthorn Group sediments remain.

2.5 Karst Features of Interest

The development of karst features (depressions, caves, sinkholes, swallets, springs, etc.) within the study area is largely influenced by the thickness of the cover material overlying the carbonate rock (Figure 2-5). Limestone varies from being at the land surface to more than 150 feet below the land surface (ft. BLS) in the study area (Sinclair and Stewart, 1985). The area is located within a FDEP “Sensitive Karst Area” (FDEP, 2016). Per the FDEP: “*In areas where the overburden is thin to absent, the potential for karst terrain development such as sinkholes and collapse features is increased. Karst terrain provides preferential flow paths for surface water to enter the underlying aquifer system, and therefore places them at a greater risk of contamination from the surface*” (FDEP, 2016). The following describes the karst features identified by the WRA team within the study area.

2.5.1 Depressions

The study area is dotted with closed depressions. These depressions are both karstic and the result of eolian dune development, which creates closed depressions in inter-dune areas and deflation zones. Large uvalas are relatively common. The UFA potentiometric surface is below the land surface in the springshed away from the springs and Rainbow River so poljes are uncommon and typically relatively small. In general, mappable closed depressions related to sinkhole development are found where thickness of the surficial sand is more than 15 ft. The nature of the material overlying the limestone, thickness of the cover, and

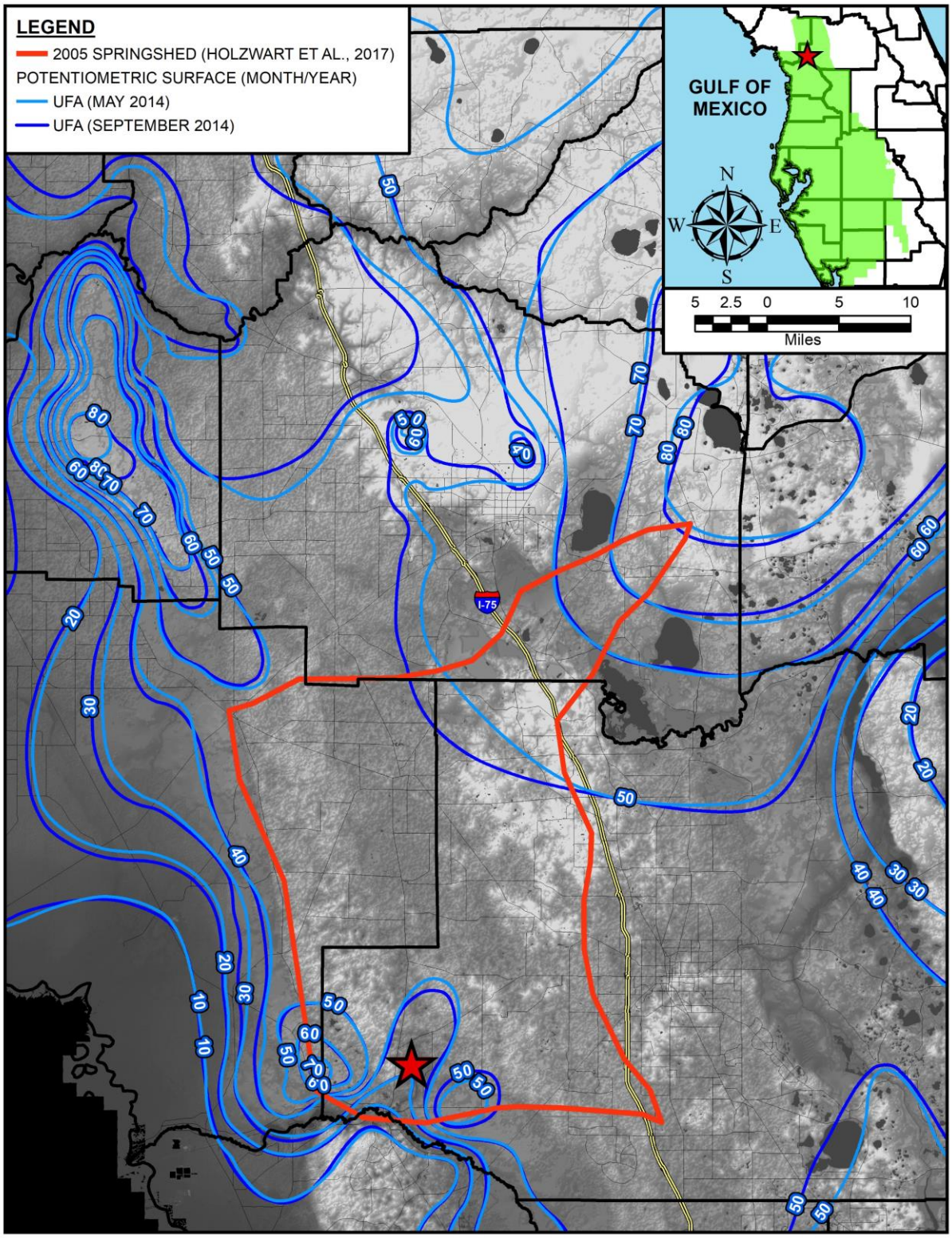

Figure 2-4. UFA potentiometric surfaces for May and September 2014.

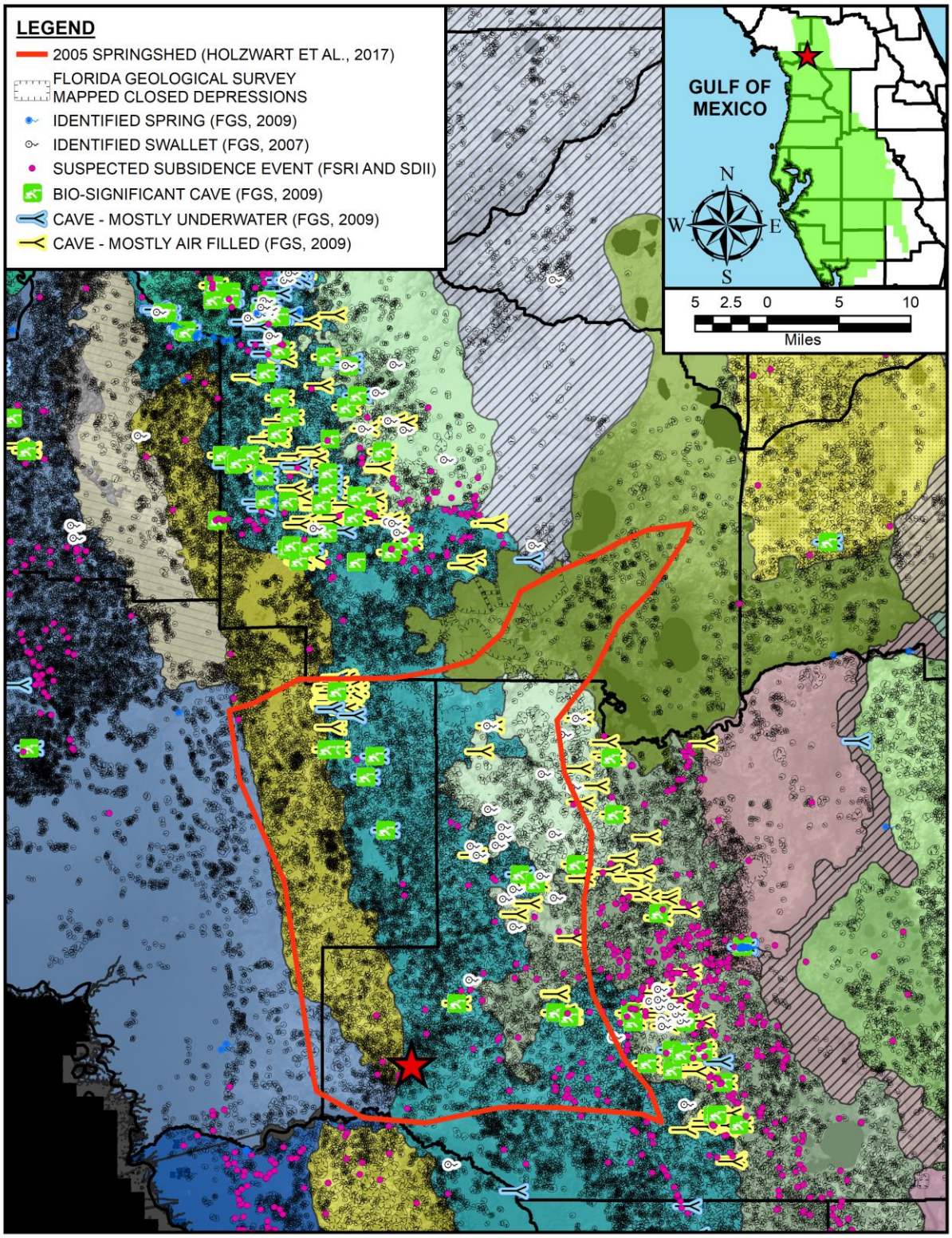

Figure 2-5. Regional karst geomorpologic features overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

distribution of strength with depth within the cover sediments are critical to determining whether a sinkhole will develop. Figure 2-6 presents closed depressions near the springs[2] based on USGS 1:24,000 topographic maps and Florida Geological Survey (FGS) geospatial coverage derived from the USGS maps.

2.5.2 Caves

A cave is natural underground opening or series of openings and passages large enough to be entered by an adult person. As depicted on Figure 2-7, the caves within the delineated springshed are predominantly within Marion County.[3] Six of these caves are identified by the FGS (2009) as being mostly underwater and include: Blue Grotto, Devils Den, Forty Fathom Grotto, Jug Sink Cave, Peanut Cave, and Williston Stadium. Located primarily within the Ocala Karst Hills Province and along the edges of the Fairfield Karst Hills Province, sixty-eight of the caves within the springshed delineation are identified by the FGS (2009) as being air-filled. These caves include: Ann's Cave, Any Name Pit (Two Oak Pit), Anthropod Cave, Baptismal Cave, Bately Signature Cave, Beals Cave, Brain Fungus Cave (Sheild Cave), Catfish Cave, Cathedral Cave, Cave 1733, Cave 582, Collapsed Cave, Cute Cave, Davis Cave, Day of the Fish Cave, Dessert Cave, Dolphin Cave, Domino Catacombs, Domino Crevice, Dozers Surprise, Edison Arch Pit/GSF 1, Elkam Cave, Enonchs Cave, Finley Cave, Flat Cave, Four Cave, Frog Crawl Cave, Goat Cave, Gods Cave , Golden Orb Cave, Half Moon Cave, Hell Hole, Hickory Cave, Hallowed Ground, Horn Bone Cave, Indian Cave (Marion), Indian Railroad Cave E1, Indian Railroad Cave E2, Jennings Cave, Jerico Cave, Jo Mama Cave, Libby's Cave, Lost Bandana Cave, mathews Fossil Cave, Mattox (Alligator Lair) Cave, Mays Sink Cave, McDill Hole (Davidson Swallet), Michaulas Cave, Mud Dome Cave, Octopus Cave, Point Cave E1, Possum Chimney (Alachua), Running Buffalo Cave, Ruthann's Pit, Sandy Ledges Cave, Shirls Lost Calf Cave, Short Cave, Sistrunk Cave, Straight & Narrow Cave, Sugarberry Cave, Trinity Cave, Turnaroun Cave, and Vanguard Cave. Of those caves identified above, twelve are identified by the FGS as biologically significant caves and include: Blue Grotto, Devils Den, Forty Fathom Grotto, Four Cave, Frog Crawl Cave, Half Moon Cave, Hell Hole Cave, Hollowed Ground Cave, Indian Cave, Jennings Cave, Octopus Cave, and Peanut Cave.

2.5.3 Modern Sinkhole Formation

For sinkholes to form through migration of sediments downward into voids in the limestone (described in detail below), there must be a downward hydraulic gradient. This occurs in much of study area. The only locations where the hydraulic gradient is not downward are near the springs and streams along the western margin of the Williston Karst Plain. Near Rainbow Springs, the Rainbow River, and along the Withlacoochee River north of Lake Tsala Apopka, hydraulic gradients are upward and UFA groundwater discharges to the land surface. These areas of upward hydraulic gradient are not expected to develop sinkholes today. Therefore, the sinkholes present in the areas of upward gradient likely formed before the present-day UFA flow system had developed.

The use of the term "modern" is in reference to subsidence events that have occurred from the early 1980s to present. The databases from which these events were identified include (1) the FGS "Subsidence Incidence Report" database, which may contain unverified sinkhole occurrences, and (2) a set of verified subsidence and "sinkhole activity"[4] occurrences from a proprietary database developed by SDII Global Corporation. Figure 2-8 presents the locations of known/suspected incidences of subsidence near the springshed.

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[2] NOTE: Closed depressions on their own should never to be misconstrued with confirmed karst features, such as sinkholes, and may be the result of other geologic processes.
[3] The caves are not individually identified on Figure 2-5 due to the data density.
[4] "Sinkhole activity" is defined in Chapter 627.706 F.S. as evidence of subsidence or systematic weakening in the subsurface. No ground-surface depression has developed and the weakened sediments in the subsurface are considered reflective of the early stages of sinkhole development. The presence of sinkhole activity does not suggest that development of a closed depression is imminent, only that there is a potential for development of a depression.

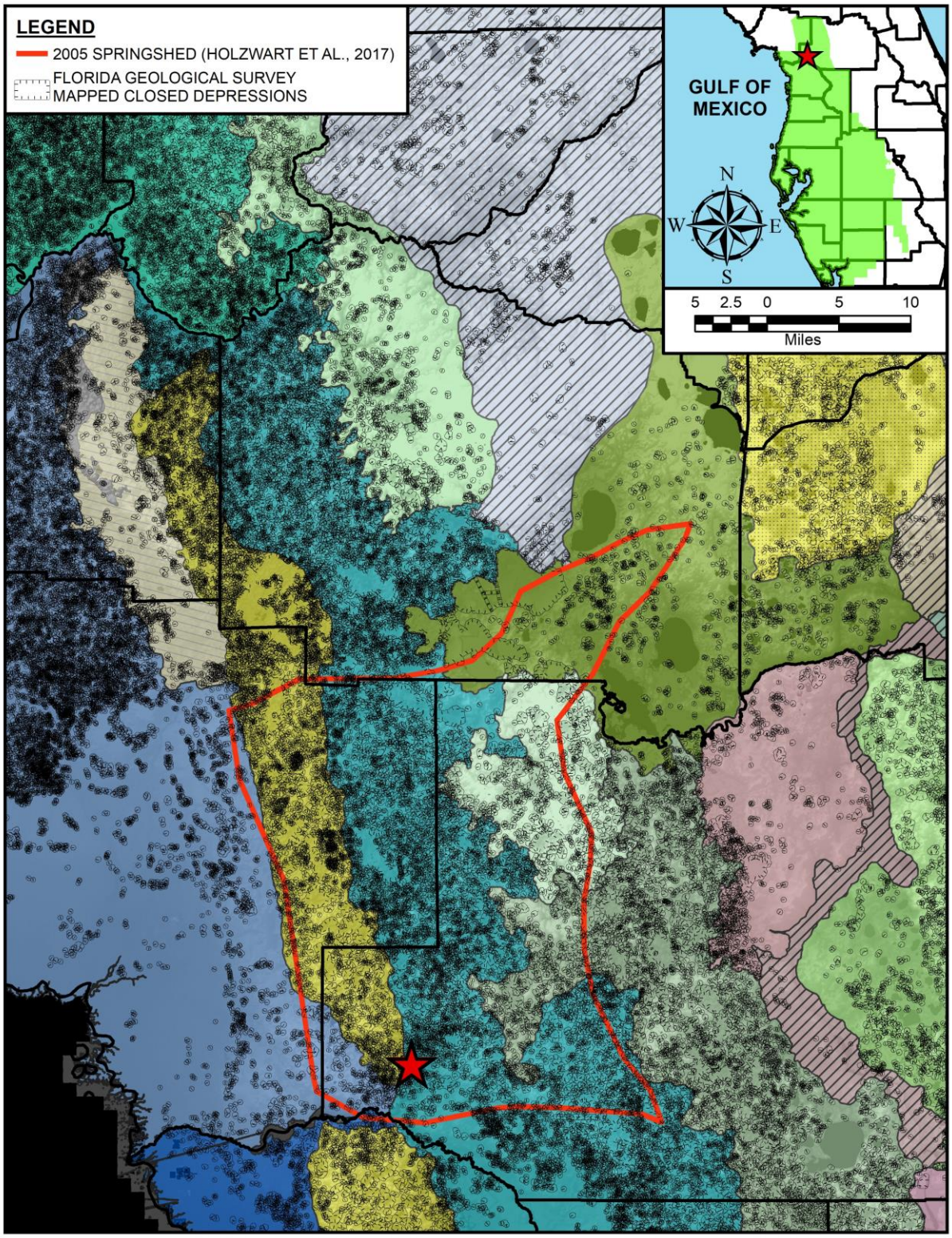


Figure 2-6. FGS closed depressions overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

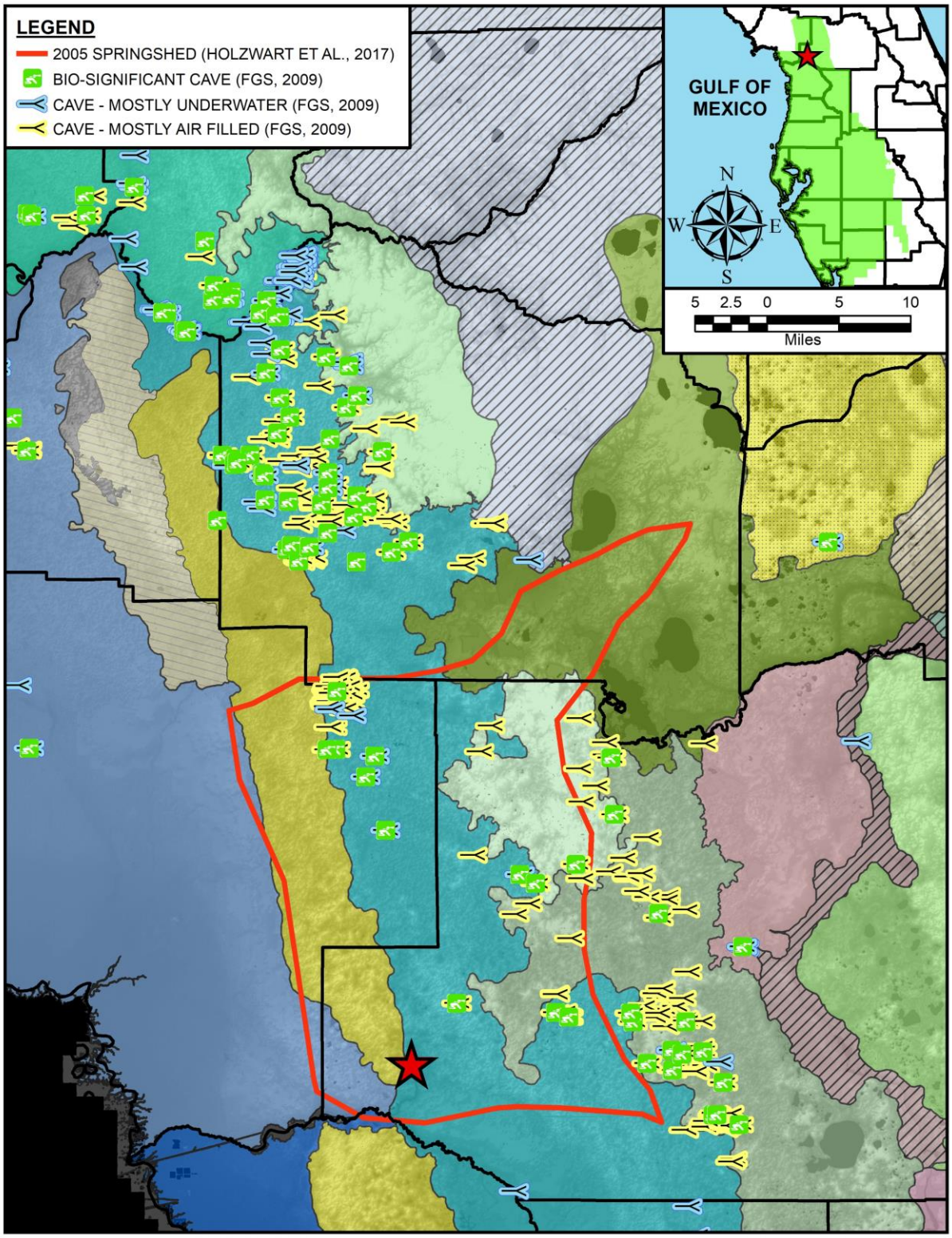


Figure 2-7. FGS cave locations overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

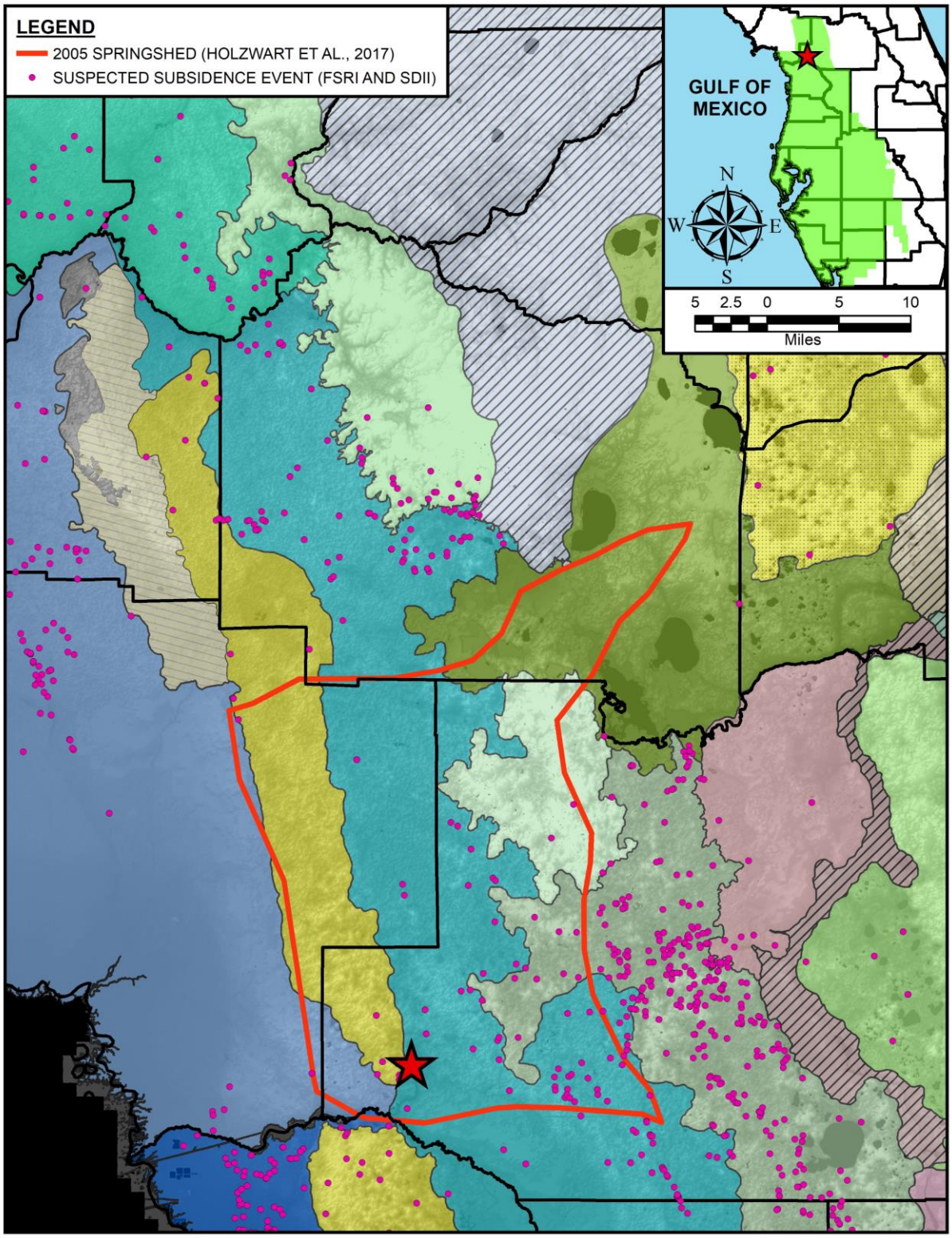


Figure 2-8. Locations of suspected subsidence events (FSRI and SDII) overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

2.5.4 Swallets

A swallet is sinkhole that normally captures all, or most, of a sinking stream. During high runoff events, the swallet may not be able to take all of the runoff, in which case the excess runoff flows overland along a normally dry streambed. Swallets allow for a direct connection to the underlying aquifer.

As depicted on Figure 2-9, the identified swallet locations are oriented in a similar northwest-southeast trend as the cave locations. Within the springshed delineation, the majority of the swallets are located within topographic lows in the Fairfield Karst Hills Province. Swallets have also been identified on the west side of the Brooksville Ridge, where runoff from the ridge goes underground.

2.5.5 Springs

A spring occurs in a place where the potentiometric surface or water table of an aquifer intersects the land surface. Groundwater discharges at the point of intersection to form the spring. FGS identified spring locations are presented on Figure 2-10. Comparison of spring locations in, and near, the study area with relative land-surface elevations suggests that springs within the study area are located along drainage systems where elevations are lowest, namely at Rainbow Springs and the Rainbow River, near lakes Panasoffkee and Tsala Apopka, Magnesia Springs, and Silver Springs. Except for Rainbow Springs and Silver Springs, these springs are second, third, or fourth magnitude. Citrus Blue Spring and the Gum Slough group of springs are in the swampy areas associated with Tsala Apopka.

2.5.5.1 Rainbow Springs Group

Rainbow Springs is a spring group consisting of at least eighteen springs (Jones et al., 1996). Collectively, they constitute a large first-magnitude spring system. Based on the data provided by the District, the average discharge of the spring group between 1931 and 2015 was 690 cubic feet per second (cfs). The springs discharge to an approximately 5.7 mile (mi.) long spring run, the Rainbow River (also known as Blue Run), which discharges to the south into the Withlacoochee River near Dunnellon in Marion County. The springs are largely within the Rainbow Springs State Park, and the head spring and Rainbow River are popular swimming, tubing, and boating amenities. The state park was once a private attraction with boats that allowed spectators an underwater view. Remnants of the attraction remain, including beautiful, but somewhat overgrown, gardens and created waterfalls.

There is a localized potentiometric-surface high in the UFA under the Brooksville Ridge north and west of the Withlacoochee River that is sharply terminated on its south end, near the city of Dunnellon and the Withlacoochee River (Figure 2-4). There is also a reentrant in the potentiometric surface around Rainbow Springs caused by spring discharge. Faulkner (1973) studied the area within which the saddle in the potentiometric surface occurs in order to evaluate the hydrogeologic consequences of construction of the proposed Cross Florida Barge Canal. The canal followed the potentiometric-surface saddle from the Gulf of Mexico to the vicinity of Ocala, where it turned north along the Ocklawaha River corridor to the St. Johns River near Palatka. While Faulkner's report indicated that the effects of completion of the canal might be minimal in some areas, he was critical of its effects in other areas. Ultimately, the canal was deauthorized by the government and abandoned (Noll and Tegeder, 2009). Faulkner (1973) discussed the causes for the location of the Rainbow Springs Group. These included upward flow along a fault or fracture and/or potential damming of flow in the Ocala Limestone by onlap on to the Avon Park Formation to the west.

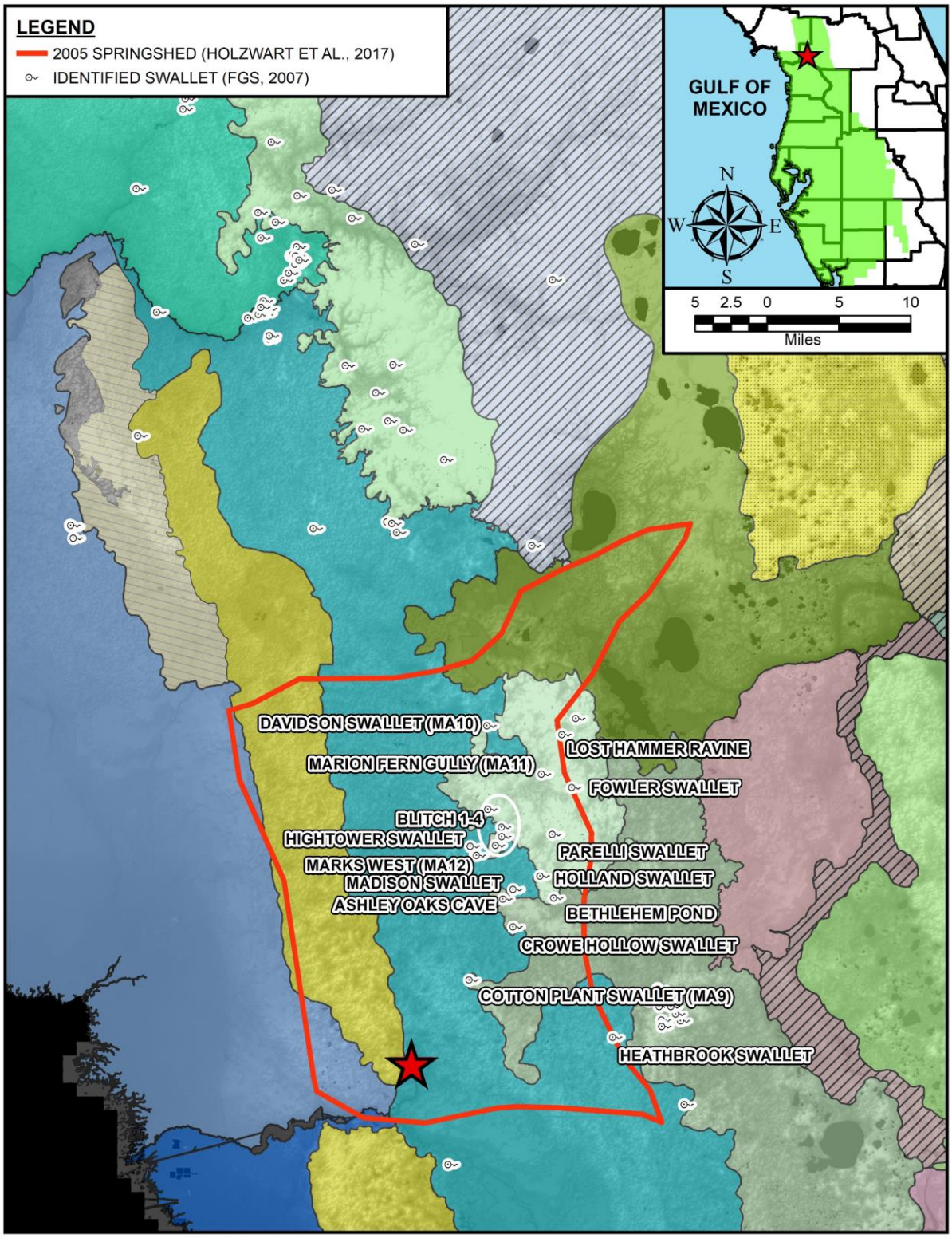


Figure 2-9. FGS swallet locations overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

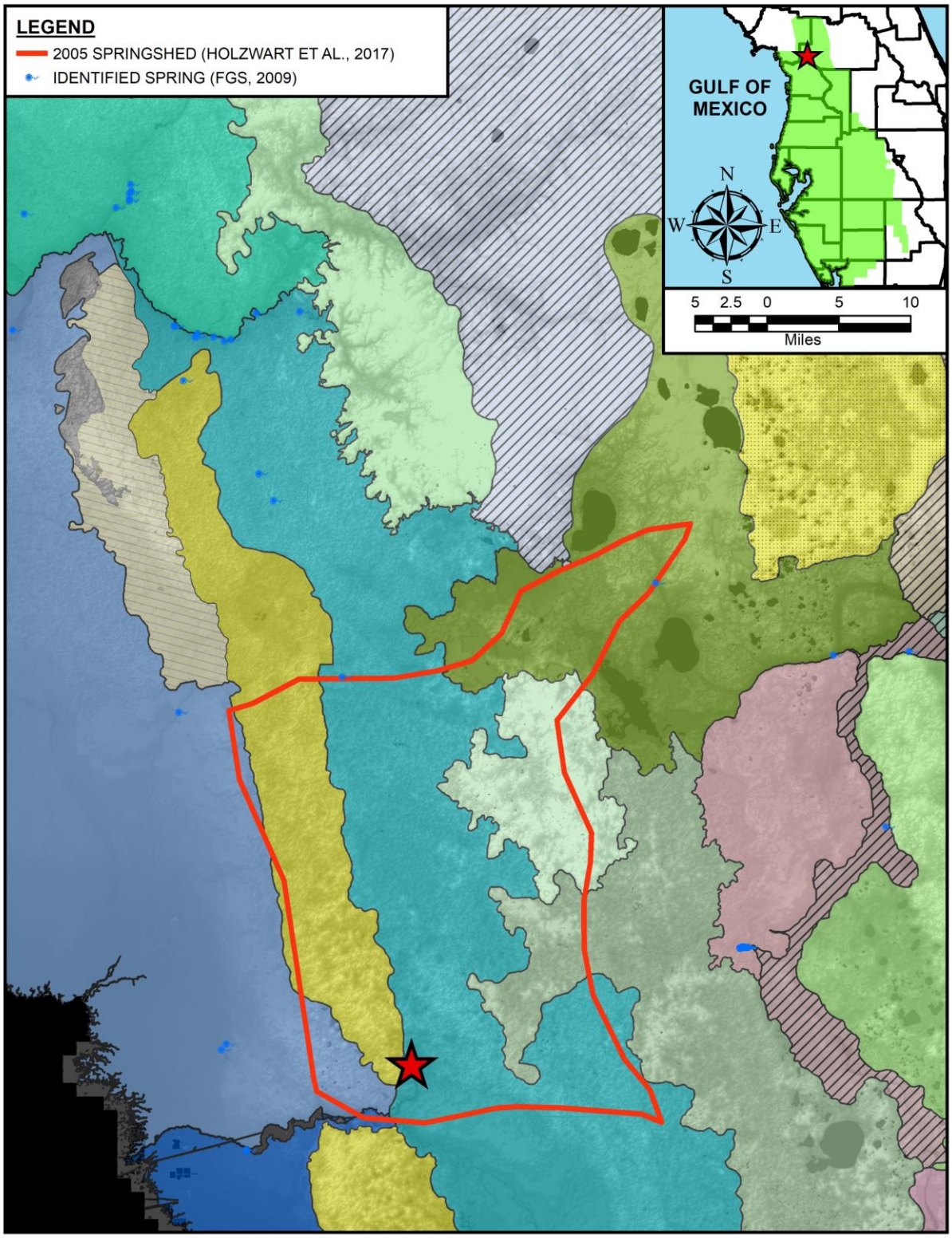


Figure 2-10. FGS spring locations overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation). Red Star: Rainbow Springs Group location.

2.5.5.2 Springshed Boundary

Over the years, there have been several attempts to delineate the springshed of the Rainbow Springs Group (Figure 2-11). Figure 2-11 was produced after an exhaustive exploration of flow paths defined by groundwater flow models and USGS/SWFWMD UFA potentiometric surface maps. This section discussed some of the results of this evaluation.

Based on the potentiometric surface of the UFA, the springshed of Rainbow Springs appears elongated and predominantly oriented northeast-southwest. The Rainbow Springs springshed abuts the Silver Springs springshed at its eastern boundary. Where these two springsheds meet, the UFA potentiometric surface is relatively flat, so the boundary between the two springsheds is indistinct. It appears, however, that the boundary is relatively stable over time.

Although the UFA potentiometric surface maps were utilized as the study area for this project, with respect to fate and transport, it is our professional opinion that those areas at significant distances away from the spring vents have a lower probability of impacting the water quality of the Rainbow Spring Group for three reasons.

1. Springsheds along the Santa Fe River River clearly capture water from the UFA that, according to flow-net analysis of the UFA potentiometric surface, should flow southwest to the vicinity of Rainbow Springs. These springsheds have been delineated by Upchurch et al. (2008).
2. There is a lack of karst features with higher probabilities for direct connections between surface activities and the UFA, such as sinkholes or swallets (Figures 2-8 and 2-9) in the northeastern extent of the springshed delineated by flow-net analysis within the Hawthorn Lakes Region and the Trail Ridge geomorphic providences. The lack of closed depressions limits the probability of water quality impacts at the Rainbow Springs Group.
3. The water quality at the furthest extent of potentiometric surface delineation may be altered over the course of the southwesterly flow path within the Ocala Karst Hills and the Fairfield Karst Hills geomorphic provinces where a higher density of identified karst features, such as sinkholes or swallets, exists.

With this in mind, several hydrogeological groundwater flow models were evaluated to provide further insight as to where the majority of the direct interconnections with surface activities may occur within the potentiometric surface-delineated springshed. Jones et al. (1996; Figure 2-12) identified capture areas and determined that the springshed extends to the north and east of the springs. Per their analysis, very limited spring water is captured to the west. Water-quality fingerprinting of the springs and samples from wells in the springshed supported this conclusion as none of the springs investigated by Jones et al. (1996) derived groundwater from under the Brooksville Ridge.

In 2005, WRA and SDII utilized the Suwannee River Water Management District (SRWMD) North Florida Model (NFM; SDII Global Corporation, 2008) and the USGS Peninsular Groundwater Flow Model (USGS, 2002) to define 5-, 10-, and 100-year capture zones, around the springs. Their capture zones corresponded well with the near-field springshed identified by Jones et al. (1996).

The capture zone of the springs group was re-evaluated utilizing the District-Wide Regulation Model version 3 (DWRMv3) and the MODPATH (Pollack, 1994) particle-tracking module. Reverse particle tracking was used to approximate the areas within which water might be expected to reach the spring system over a 100-year interval. One hundred particles were placed in the cells within which each spring vent/seep (18 vents/seeps in total) is located. The model is then run in “reverse” so that the particles are tracked backwards to illustrate groundwater flow patterns. As presented on Figure 2-12, the extent of the particle tracking was relatively similar in extent when compared to the NFM model result; however, the zone was relatively narrower. Furthermore, when particle tracking was used in model runs to steady state, the predicted groundwater flow paths within the springshed, but distant from the springs veered

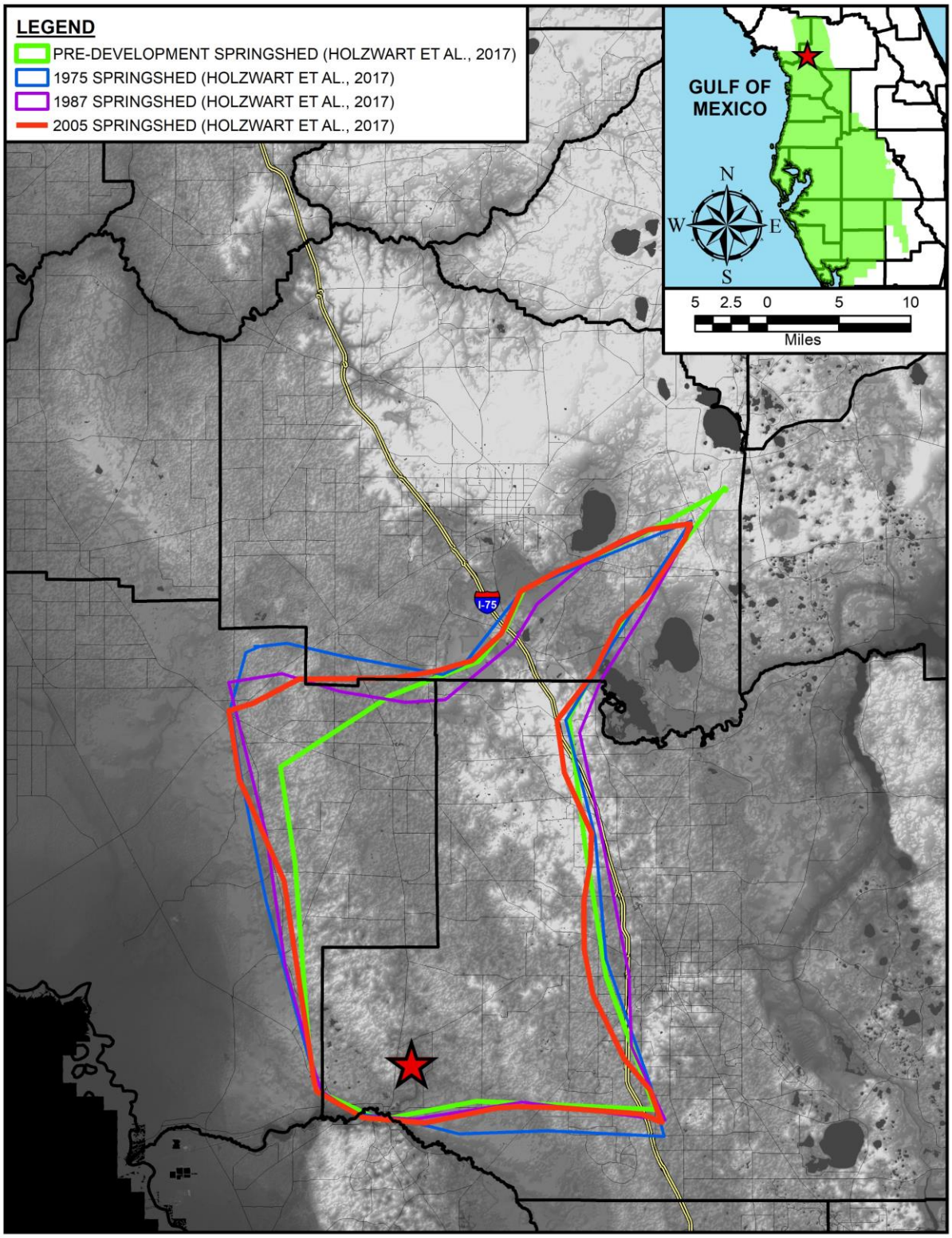


Figure 2-11. Rainbow Springs Group springshed delineation extent (Holzwart et al., 2017).

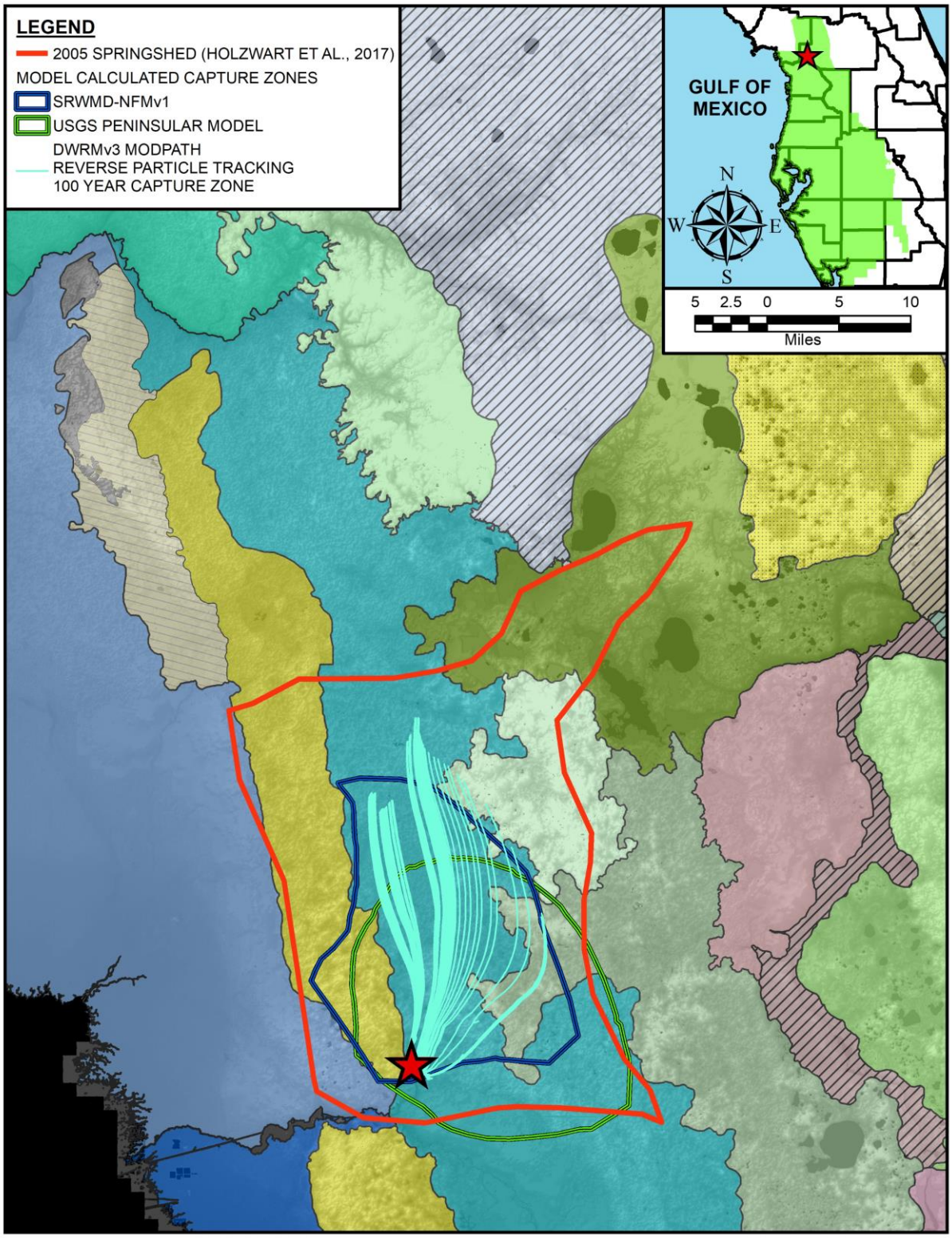


Figure 2-12. Simulated Rainbow Springs Group capture zone extent (modified from Jones et al., 1996) overlaid on regional geomorpologic provinces (modified from Scott, 2005 and Williams et al., in preparation).

to the north and north northwest in directions that were inconsistent with the previous springshed-delineation attempts. It should be noted that there is variability in the capture zones estimated by the groundwater flow models when compared to the springshed boundary derived from flow-net analysis. This difference in springshed delineations is probably an artifact of the construction of the finite-difference flow models, as well as the lack of a well-defined and simulated conduit network.

Even with the model construction and the resultant variability, the simulated capture zones generally fall within the springshed identified by Jones et al. (1996). Interestingly, the upgradient terminus of these capture zones within the UFA potentiometric surface delineation is predominantly located at the edge of the Williston Karst Plain Province abutting the Ocala Karst Hills and the Fairfield Karst Hills geomorphic provinces, where subsidence events and/or swallets have been identified (Figures 2-8 and 2-9). For this reason, the simulated capture zones were the focus area within the study area for the geochemical modeling evaluation.

2.6 Regional Photolineament Evaluation

Photolineaments are more-or-less linear features observed on the land surface through the use of aerial photographs, satellite images, or other remote sensing methods. While they are not true photolineaments, alignments of closed depressions as depicted on topographic maps are considered to be photolineaments, as well. These linear features may represent fractures in the underlying rock, cultural features (pipelines, cattle paths, etc.), artifacts of the imagery (raster lines, etc.), or other origins. Photolineaments should be field verified prior to concluding that they represent fracture traces.

Identification of fractures in bedrock is important because of (1) the information their orientations may provide as to the tectonic history of an area and (2) the economic importance of the fractures to mineral deposits, groundwater flow, and karst development. In Florida, we are most concerned with groundwater flow. Identification of fractures on a regional scale is important, because the flow of groundwater tends to preferentially occupy the fractures owing to higher permeabilities/transmissivities within the fractures as compared to the bulk host rock. Lattman and Parizek (1964) showed that exploration for groundwater in fractured rock could be greatly enhanced by identification of fractures, especially intersections of fractures. Identification of fracture trace intersections has since become a standard investigation procedure for locating water-supply wells. Similarly, Littlefield et al. (1984) showed that sinkholes tend to preferentially occur on fracture traces and at fracture trace intersections. To our knowledge, none of the photolineaments identified in this report have been field verified, so they should not be taken as literal locations of bedrock fractures. Rather, their orientations and spatial abundance should be considered as being indicative of probable, general groundwater flow paths and directions.

The authors normally rank their confidence in individual photolineaments on the basis of the number of indicators identified along their lengths. When the indicators (closed depressions, stream segments, soil tonal alignments, etc.) are abundant and varied, high confidence is assigned. If there are few indicators, low confidence is assigned. On the regional photolineament map discussed below, the confidence was high on the lineations depicted, so they were not ranked. Small, poorly defined lineaments were ignored owing to the scale of the map. The second map depicts lineaments near the springs identified using multiple data sources. This map has better resolution because of the map scale and use of aerial photographs.

To better understand the potential orientations of pathways of geochemical constituents of interest, two lineament studies were completed at the regional (springshed) and local scales. For the regional scale map, closed depressions represented on 7.5-minute USGS topographic maps were utilized. At this scale, smaller aerial features are lost due to mapping constraints. The minimum closed depression resolution on the 1:24,000 topographic maps from which the data were taken is approximately 50 ft. in diameter. As depicted on Figure 2-13, the lineaments identified are predominantly aligned in northeast-southwest and northwest-southeast

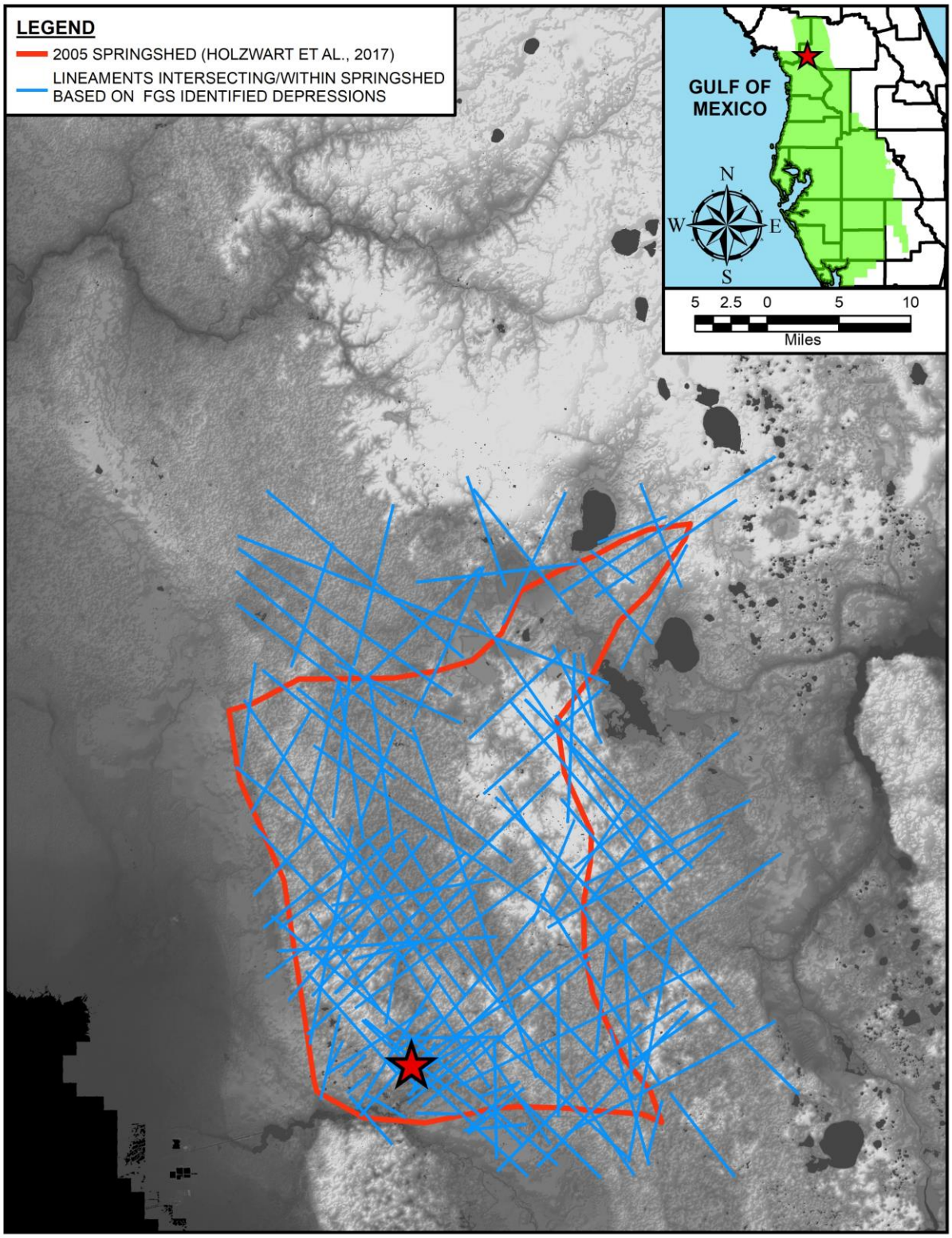


Figure 2-13. Regional lineaments intersecting/within the springshed delineation. Red Star: Rainbow Springs Group location.

orientations. Note that there are photolineaments which appear to converge on the springs from the northeast.

For the photolineament evaluation near the springs, USDA aerial photography from the 1930s and 1940s and the 1991 7.5 minute USGS Dunnellon Quadrangle were utilized. The 2003 SWFWMD lineament interpretations (SWFWMD, 2003) were reviewed and utilized and added, as appropriate. Figure 2-14 presents the local scale lineament interpretation, along with possible faults as identified by Vernon (1951). Like the regional evaluation, the lineaments identified are also predominantly aligned in northeast-southwest and northwest-southeast orientations.

The northeast-southwest and northwest-southeast alignments are consistent with fractures caused by tidal stresses (Hills, 1972 and Merritt, 2004). Therefore, while individual photolineaments were not confirmed by field testing, the general pattern of photolinears appears to represent the regional fracturing system.

When overlain on the regional lineament map (Figure 2-13), a direct correlation with karst features can be observed (Figures 2-15 through 2-20). Therefore, if the lineaments identified in this investigation are validated as fractures through additional geological testing (geophysical or subsurface tests), the locations of modern sinkhole formation, as well as other karst features, along these lineaments could potentially allow for a direct connection between activities occurring at land surface and the water quality and aqueous geochemistry observed at the spring vents.

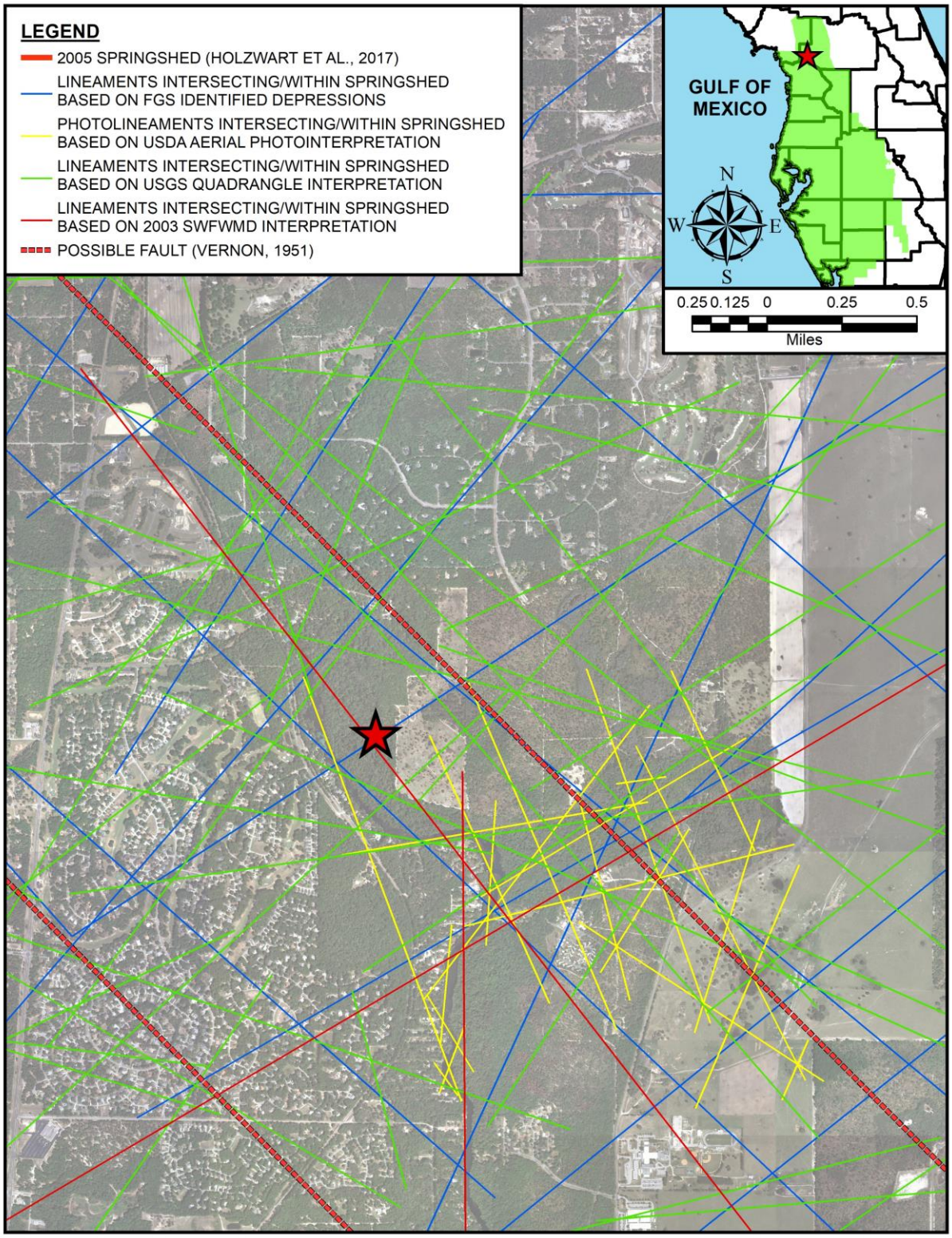


Figure 2-14. Local lineaments and photolineaments. Aerial photography provided by FDEP Land Boundary Information System (LABINS). Red Star: Rainbow Springs Group location.

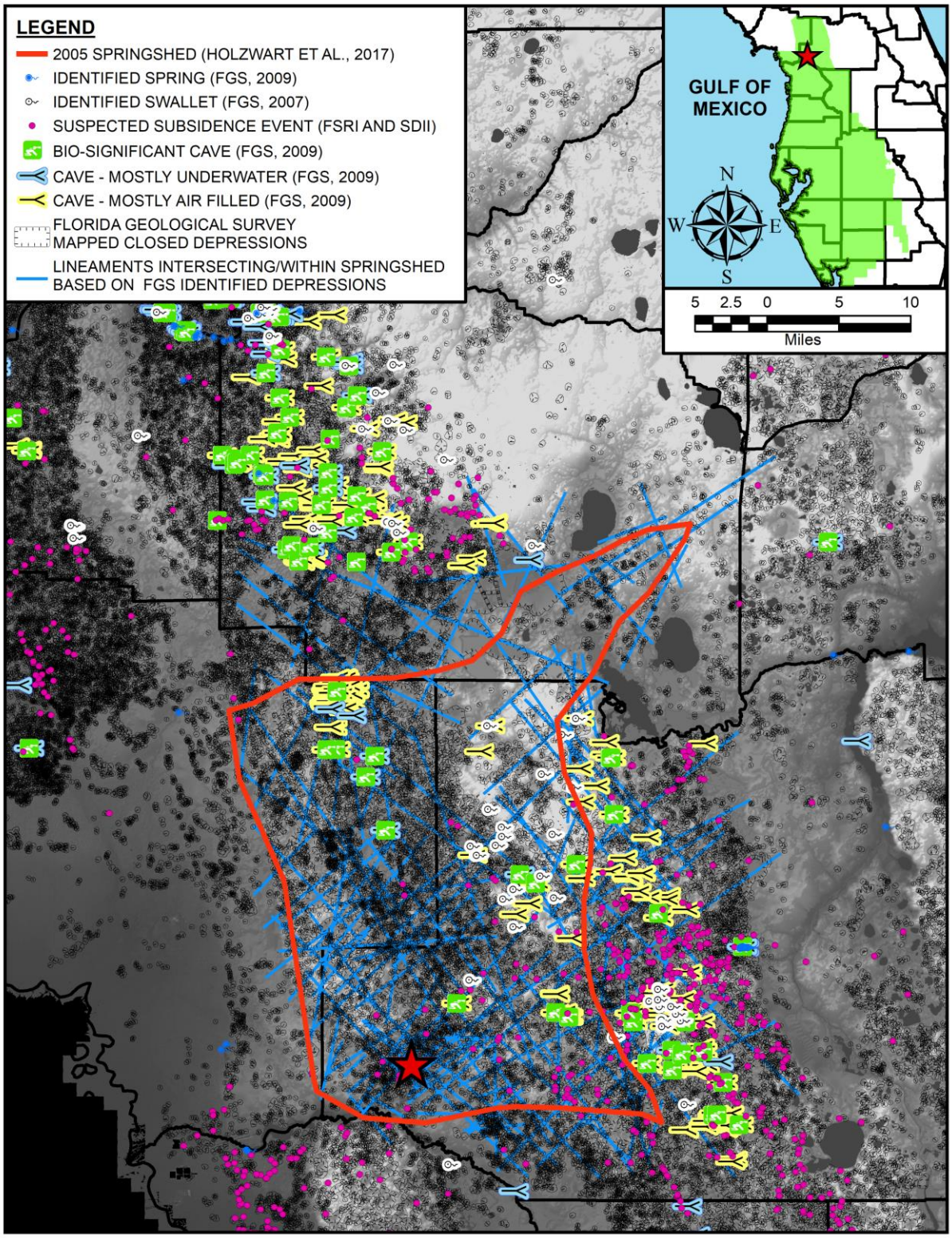


Figure 2-15. Locations of suspected subsidence events and other identified karst features with regional lineaments. Red Star: Rainbow Springs Group location.

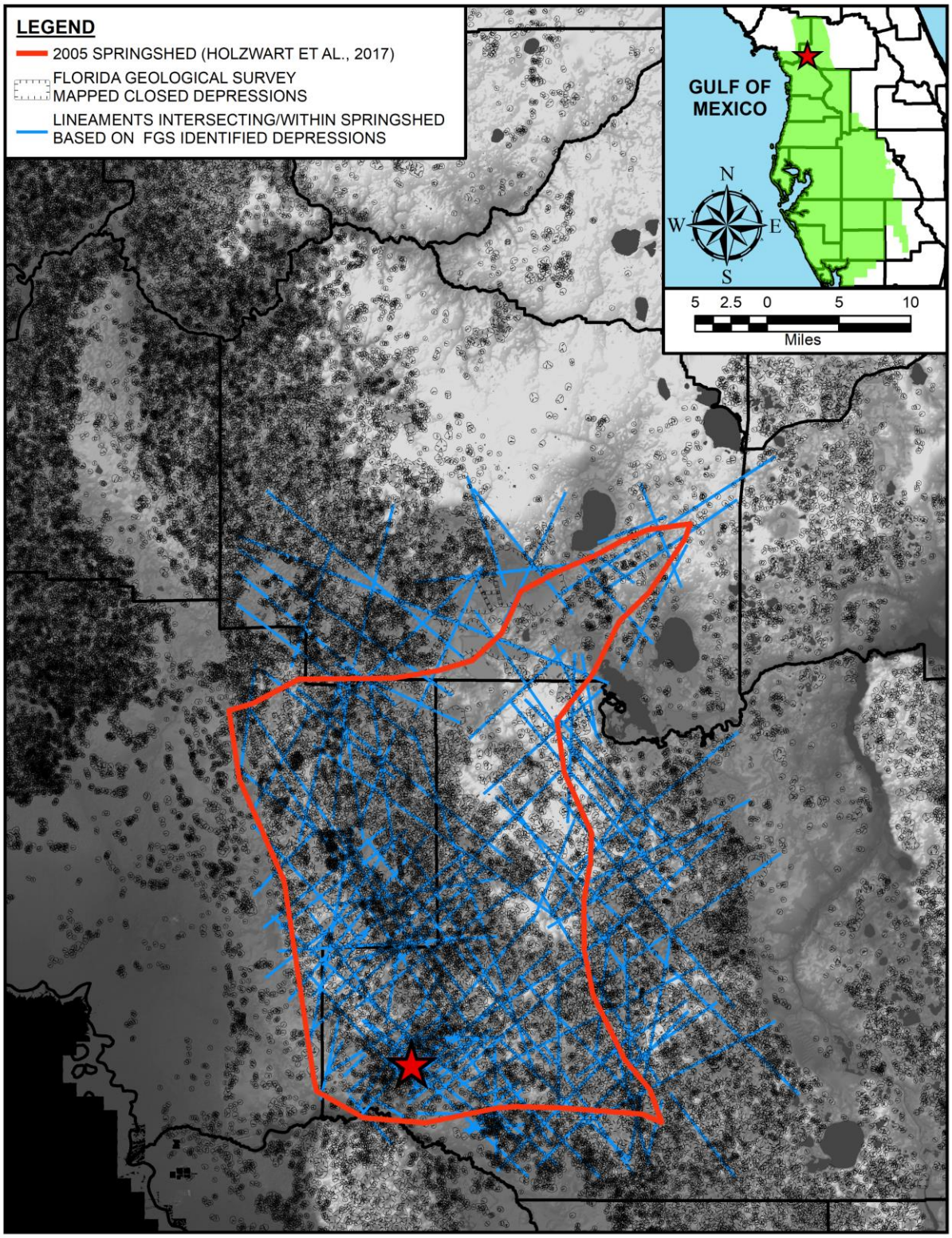


Figure 2-16. FGS closed depressions with regional lineaments. Red Star: Rainbow Springs Group location.

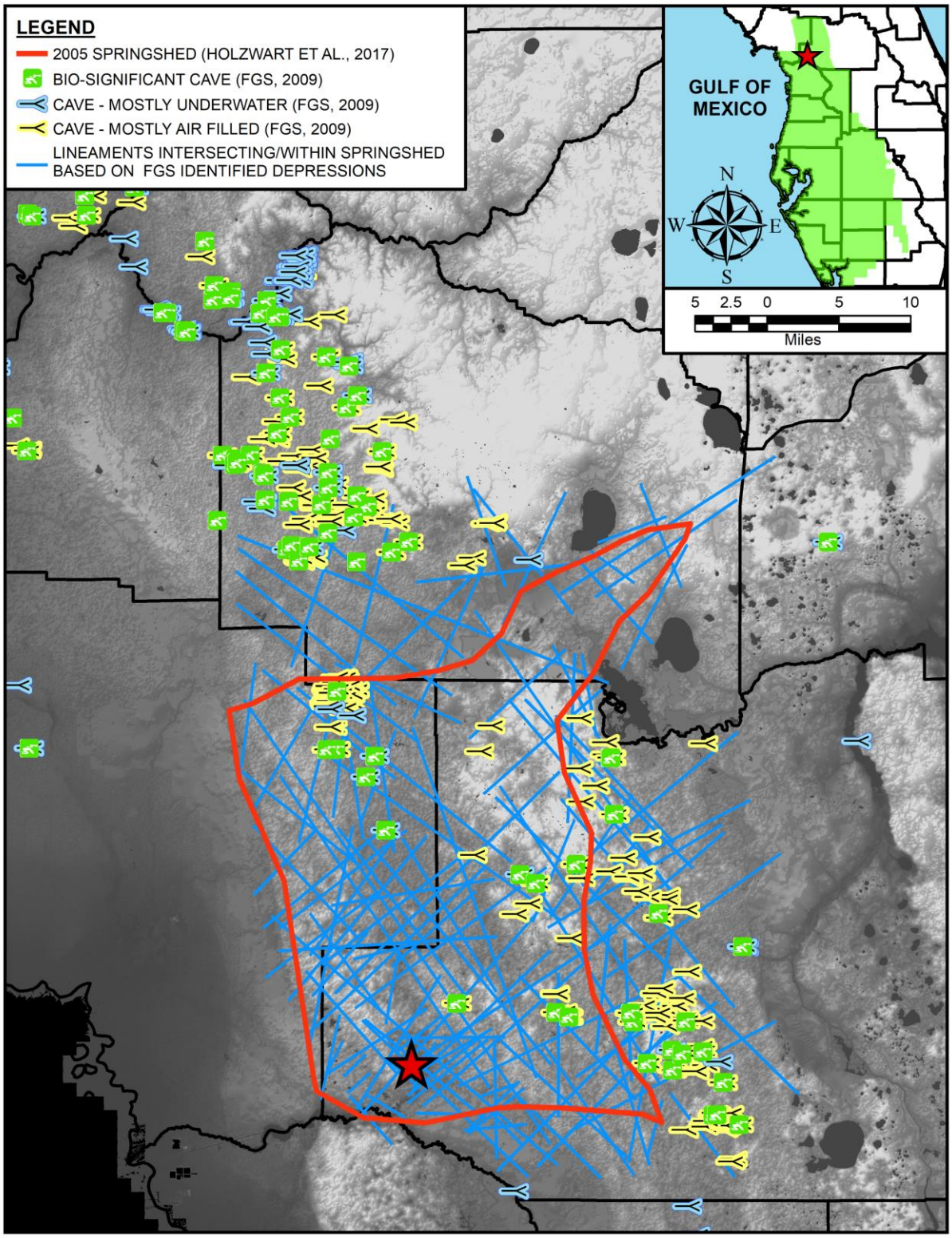


Figure 2-17. FGS cave locations with regional lineaments. Red Star: Rainbow Springs Group location.

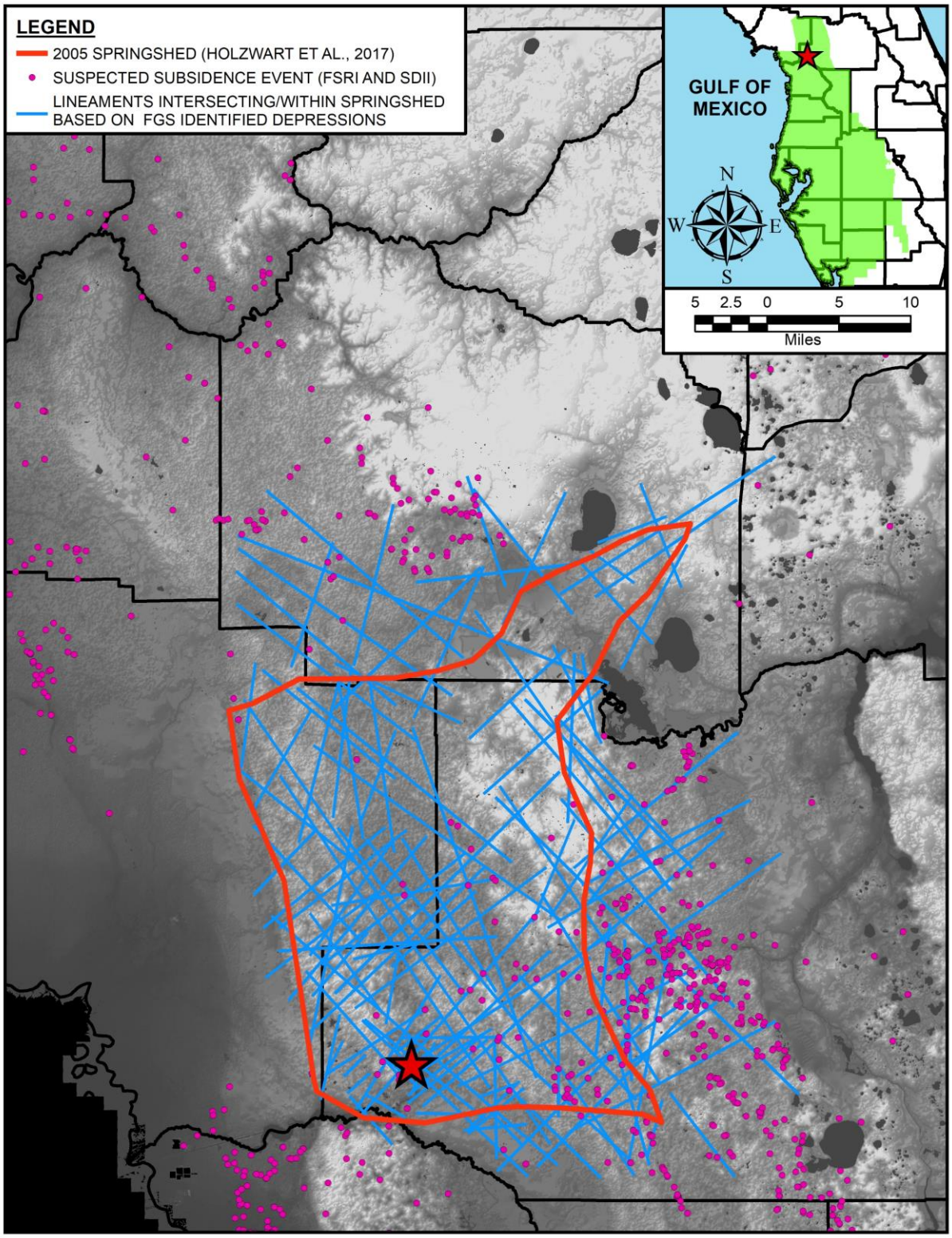


Figure 2-18. Locations of suspected subsidence events (FSRI and SDII) with regional lineaments. Red Star: Rainbow Springs Group location.

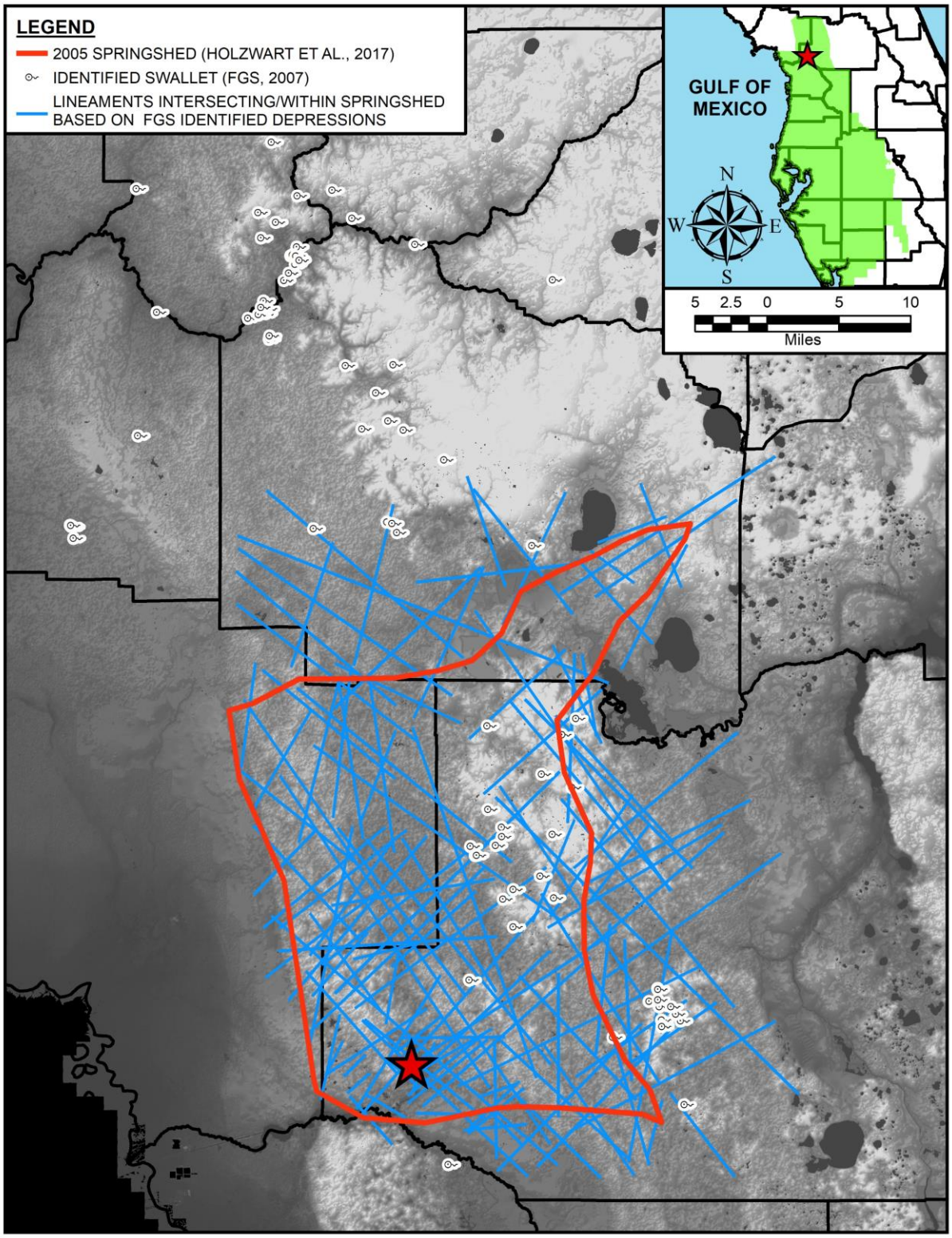


Figure 2-19. FGS swallet locations with regional lineaments. Red Star: Rainbow Springs Group location.

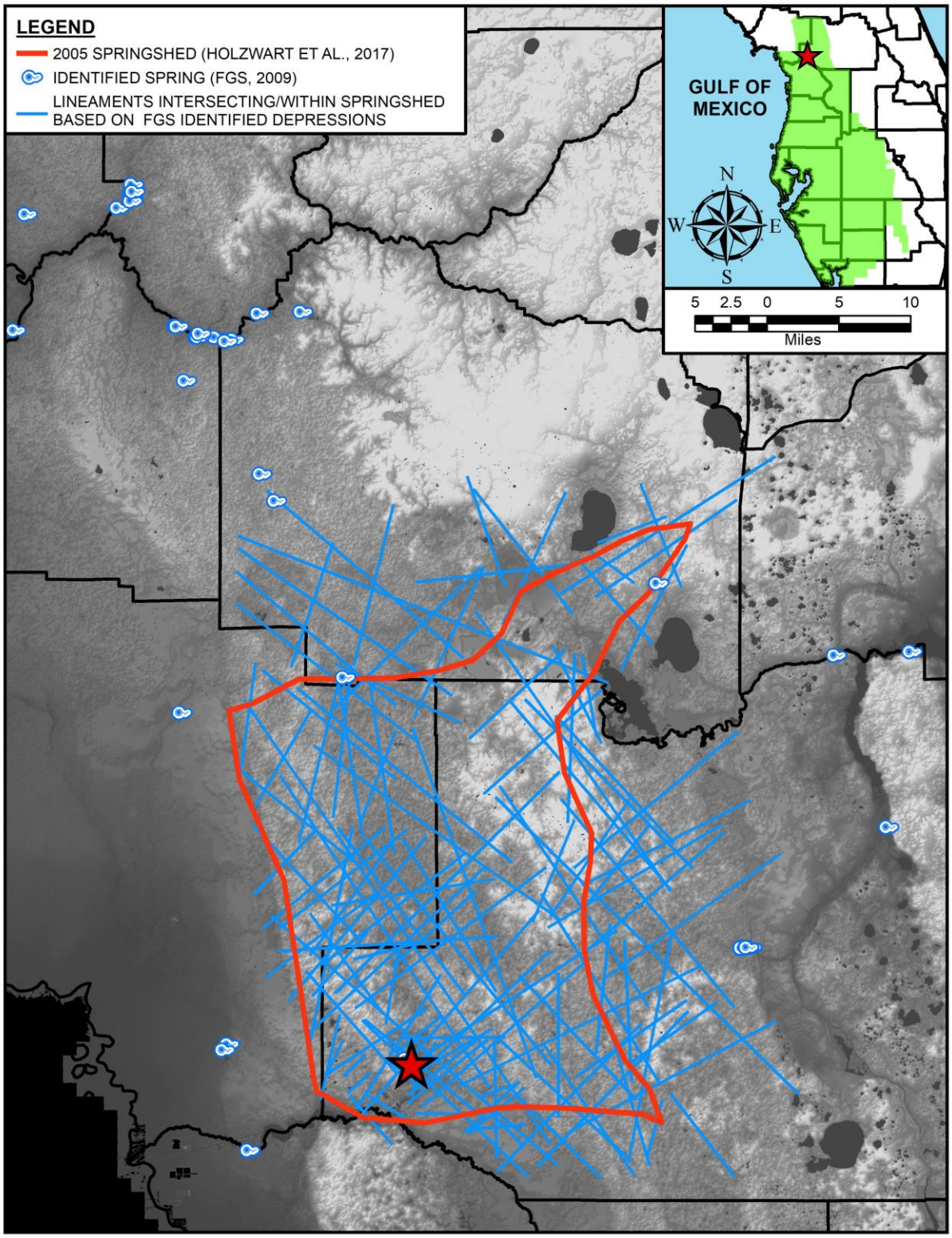


Figure 2-20. FGS spring locations with regional lineaments. Red Star: Rainbow Springs Group location.

3.0. REGIONAL LAND USE

Within the Rainbow Springs Group springshed, Levy and Marion counties are predominantly picturesque agricultural areas (i.e., cropland/pastureland, tree plantations, specialty farms, etc.) on a flat to rolling topography. Figures 3-1 through 3-3 present the land use in 1995, 2005, and 2010 (SWFWMD, 2017) and specifically depict land uses that are known to influence groundwater quality within and in proximity to the 100-year capture zones (Figure 2-12; Jones et al., 1996). As depicted on Figures 3-1 through 3-3, over the last 30 years, areas within both counties have seen population growth with the conversion from these mixed agricultural uses to low and medium density residential land uses. Low density residential use are areas with less than two dwelling units per acre, while medium density residential use are areas with two to five dwelling units per acre. Along with this conversion of land use, there has been an increase of low to medium density residential uses in close proximity to the springheads and the Rainbow Spring run.

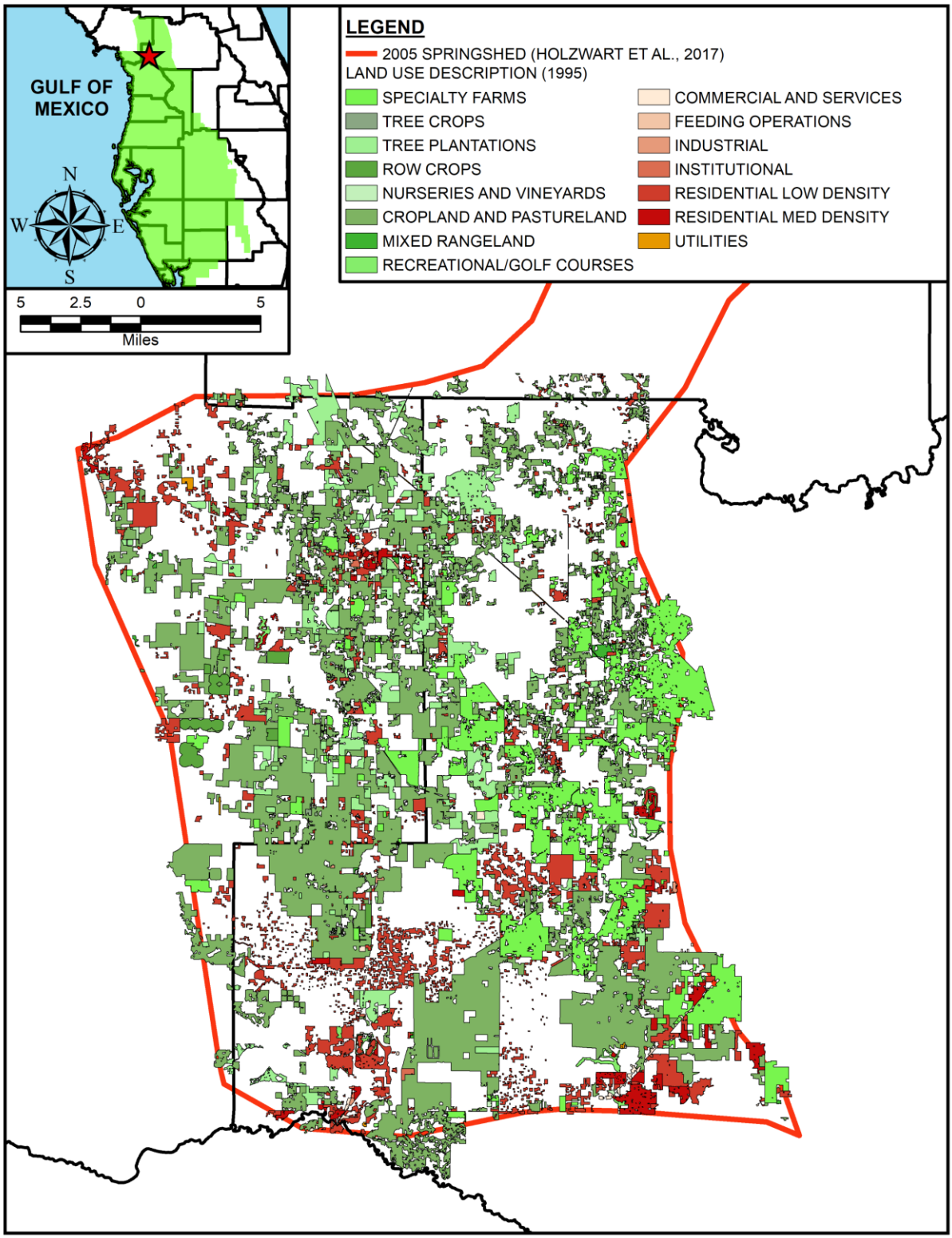


Figure 3-1. 1995 land uses of interest within the defined Rainbow Springs Group springshed and the 100-year capture zones identified on Figure 2-12 (Holzwart et al., 2017; SWFWMD, 2017). Green shading: predominantly agricultural based. Red shading: predominantly anthropogenic based.

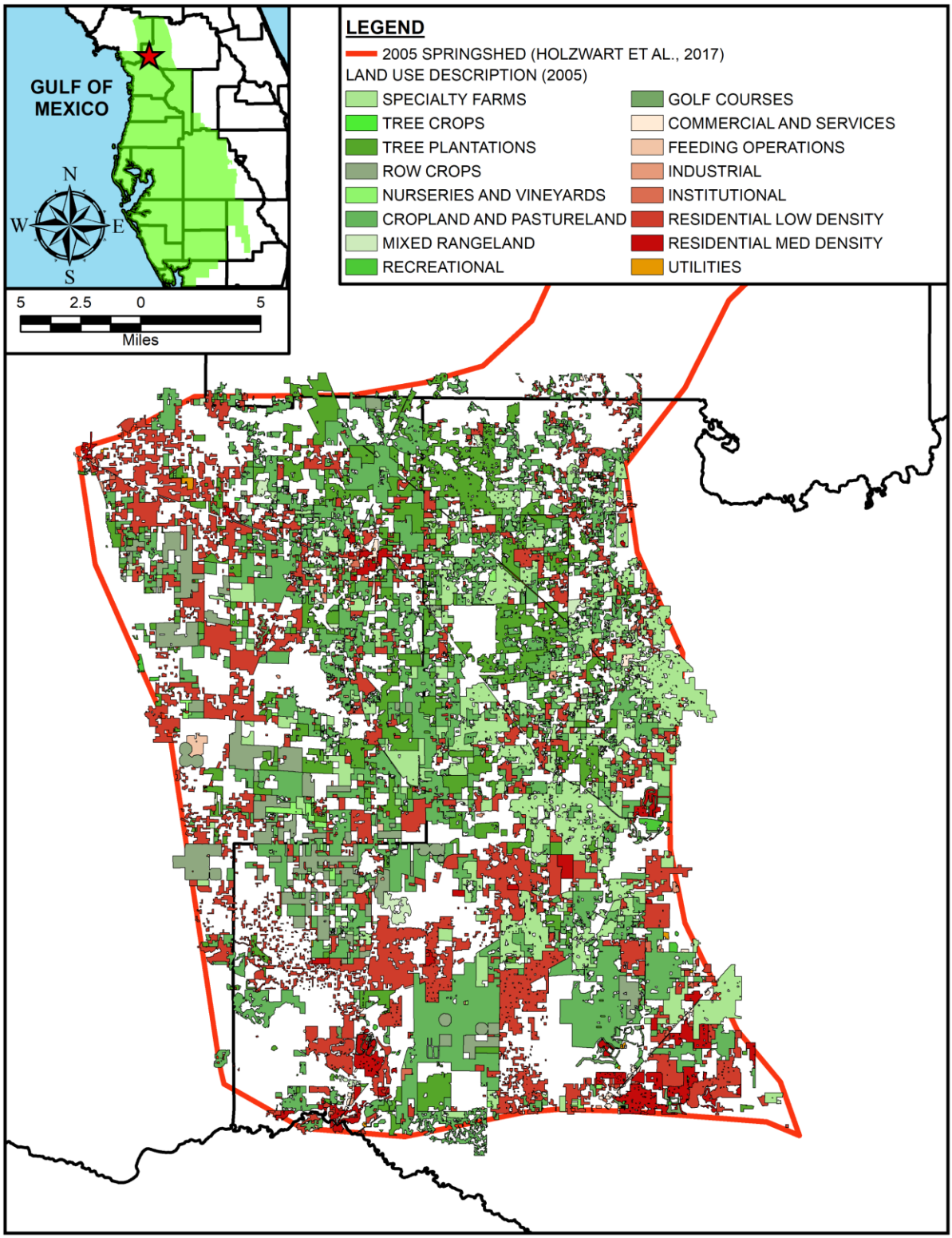


Figure 3-2. 2005 land uses of interest within the defined Rainbow Springs Group springshed and the 100-year capture zones identified on Figure 2-12 (Holzwart et al., 2017; SWFWMD, 2017). Green shading: predominantly agricultural based. Red shading: predominantly anthropogenic based.

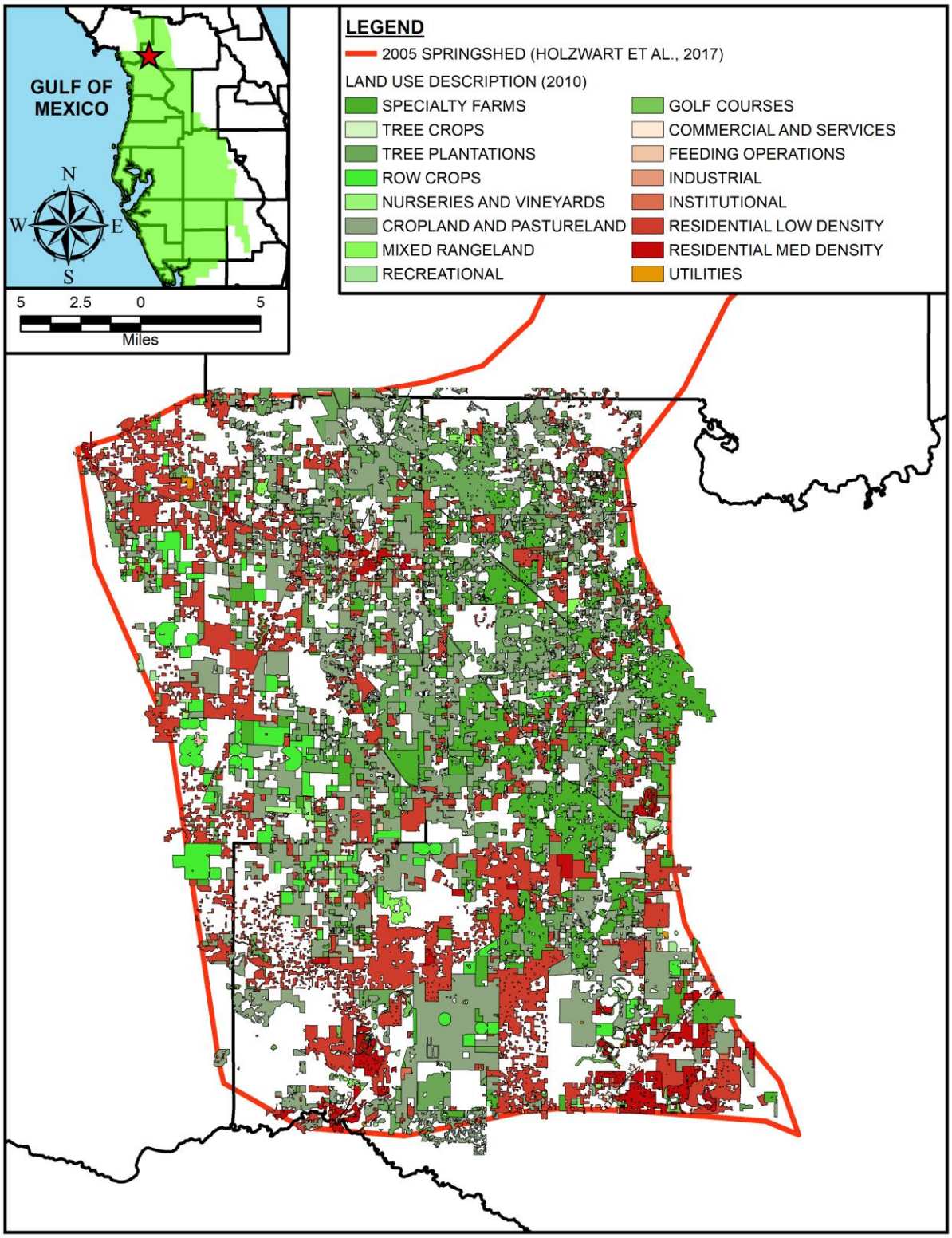


Figure 3-3. 2010 land uses of interest within the defined Rainbow Springs Group springshed and the 100-year capture zones identified on Figure 2-12 (Holzwart et al., 2017; SWFWMD, 2017). Green shading: predominantly agricultural based. Red shading: predominantly anthropogenic based.

4.0 AQUEOUS GEOCHEMISTRY

The chemistry of groundwater within the Rainbow Springs Group springshed is affected by numerous geologic, hydrologic, and anthropogenic factors. These include: the dissolution of limestone; recharge contributions by rainfall, and leaching of anthropogenic chemicals. High recharge rates and the presence of agricultural and other land uses in areas near karst features, such as sinkholes, swallets, caves, are known to exist upgradient of the Rainbow Springs Group.

4.1 Data Evaluation and Conditioning

WRA provided the District with spatial coordinates that encompassed the study area as identified on the basis of springshed delineation and groundwater flow modeling to assist in water-quality data retrieval. District staff retrieved well construction, location, and geochemical data from wells and springs within the study area for use in this analysis. The following software packages were utilized in the principal component analyses and the geochemical fingerprint mapping presented in report:

1. ArcMap, v.10.3, by ESRI for spatial analysis and preparation of figures for this report;
2. EnviroInsite, v.10.0.0.45, by HydroAnalysis, Inc. for water-quality analysis and preparation of figures for this report;
3. Excel 2010 by Microsoft Corporation for data analysis and conditioning; and
4. Minitab 17, v. 17.3.1., by MiniTab, Inc. for data analysis, including principal components and factor analyses.

All totaled, 130 wells and springs had been sampled for 17 chemical analytes. Samples ranged in time from 1985 through 2015. In order to optimize the data sets, the sample sets were stratified into three, 10-year time frames. These were:

1. 1985-1995, which included the sampling interval for Jones et al. (1996);
2. 1996-2005; and
3. 2005-2015, which included the most recent sampling campaign by the District.

Figure 4-1 shows the distribution of available data within the study area for the period 1985-1995. Data from 92 sampling locations were available for this time period. Figure 4-2 depicts the locations of the 36 sample locations for the period 1995 to 2005, and Figure 4-3 provides the 55 sample locations for 2005 to 2015.

4.2 Water-Quality Evaluation

Groundwater-quality data provided by the District included the analytes shown in Table 4-1.

After examining the data for outliers and problematic results using the statistical characterizations available in MiniTab, three variables (bicarbonate, hardness, and dissolved silica) were removed from the dataset, because there were too many missing observations in

Table 4-1. Geochemical analytes in the dataset provided by the District. All units except pH were in mg/L; pH was reported in standard units.

Ammonium (NH_4),
Bicarbonate (HCO_3^-),
Dissolved calcium (Ca^{2+}),
Chloride (Cl^-),
Fluoride (F^-),
Hardness (Ca^{2+} + Mg^{2+}),
Dissolved iron (mostly Fe^{2+}),
Dissolved magnesium (Mg^{2+}),
Nitrate (NO_3^-) plus nitrite (NO_2^-),
Dissolved orthophosphate (PO_4^{3-}),
pH,
Dissolved potassium (K^+),
Dissolved silica (mostly H_2SiO_4),
Dissolved sodium (Na^+),
Specific conductance, and
Dissolved sulfate (SO_4^{2-}).

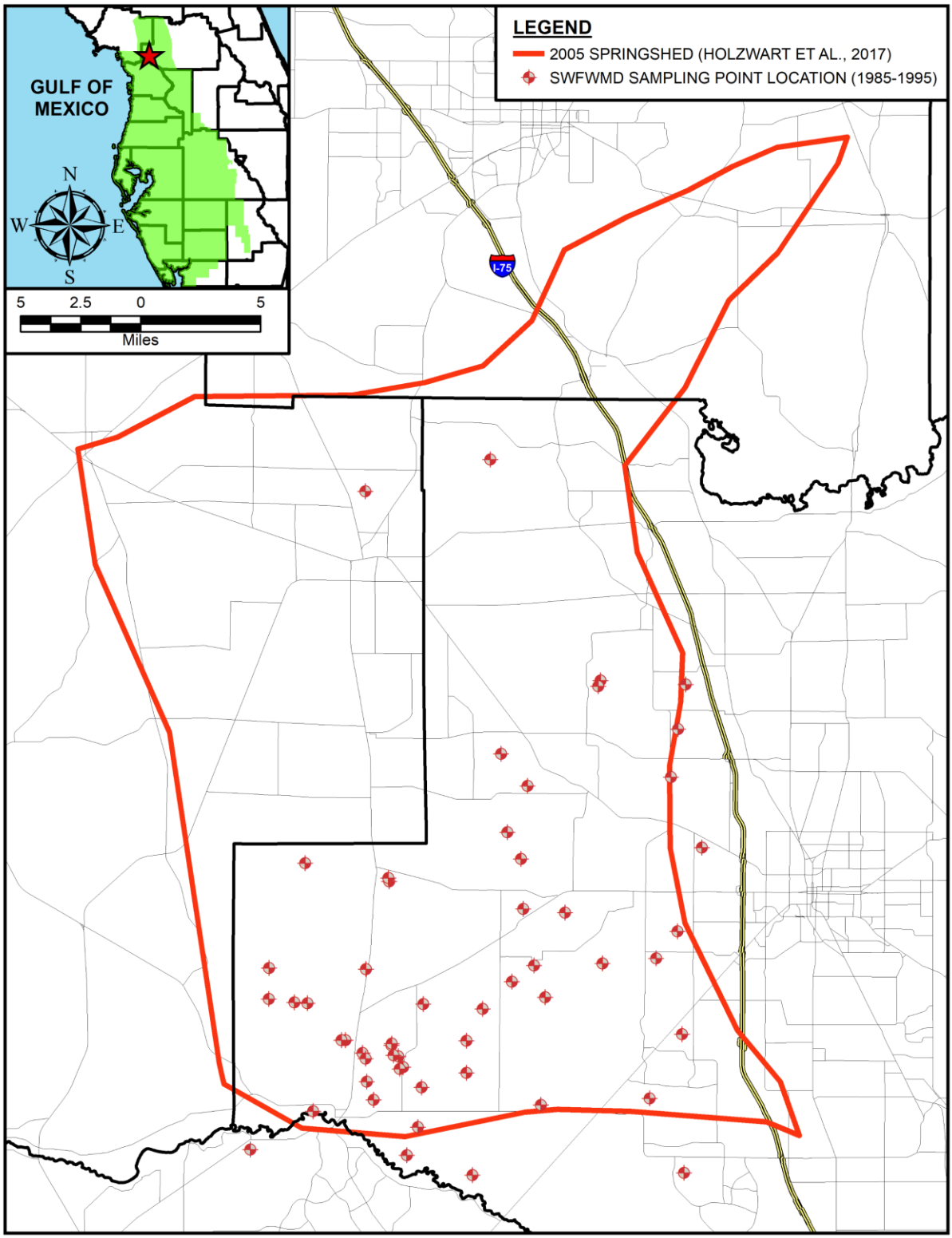


Figure 4-1. Sampling point locations for the period 1985 to 1995.

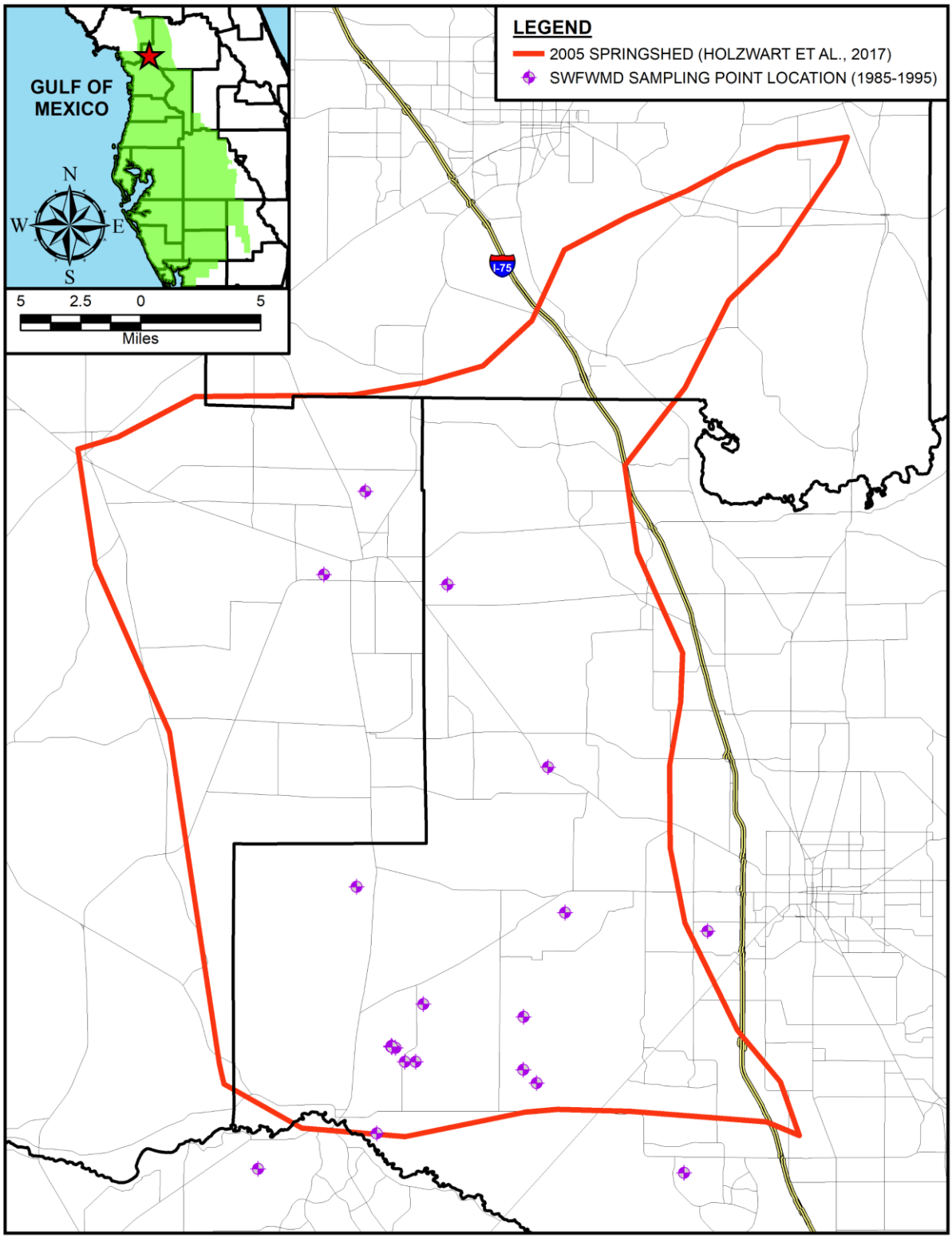


Figure 4-2. Sampling point locations for the period 1995 to 2005.

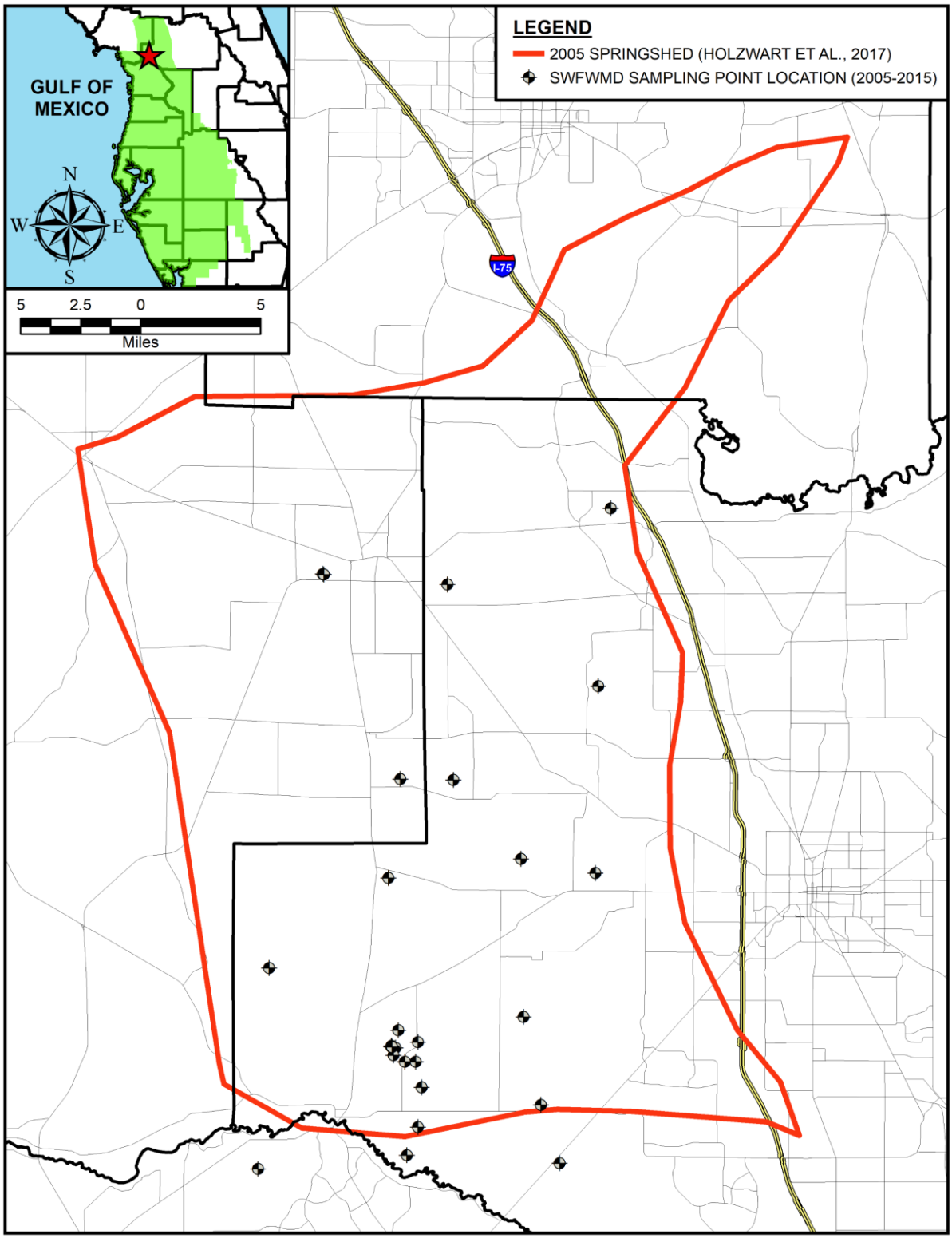


Figure 4-3. Sampling point locations for the period 2005 to 2015.

each dataset for use in the cluster analyses.

Early exploration of the data indicated that the District's sampling program was somewhat inconsistent in dates for sampling and analytes included in the data gathering process. As a result, there were many samples with missing analytical data and insufficient samples for synoptic analysis over short time intervals. To provide a complete data set for each sample location, the geometric means for each analyte at each sample location over the 10-year timeframes were used in this evaluation. This averaging process resulted in more samples for analysis and fewer missing analytes.

4.3 Cluster Analysis

The ultimate purpose of this study is to determine if multivariate cluster analysis can be used to identify nutrient-related "hot spots" where land-use activities are affecting groundwater quality within the springshed. If these hot spots can be identified, it is possible that site-specific techniques can be used to mediate the sources and reduce the burden of remedial approaches to the remainder of the springshed.

To accomplish the search for hot spots, principal components and factor analyses (PCA and FA, respectively) were used to cluster the water-quality data into process-related factors that can be mapped. The advantage to working with derived variables (factor scores) obtained with principal components and/or factor analyses are (Gorsuch, 1983):

1. Each principal component or factor represents a set of chemical processes that can be detected by correlations between analytes and samples.
2. The method creates a new, derived set of variables, one for each factor or cluster of variables in the data set. Thus, the array of complex measured data can be reduced to a smaller set of calculated variables, each representing one or more of the original, measured variables. For example, calcium, pH, and specific conductance all represent dissolution of the calcite in limestone. These three variables are combined into a single factor, or cluster, representing the process of limestone dissolution.
3. Once the factors, or data clusters, are identified, factor scores are calculated to represent the strength of each factor at each sample station. The calculated factor scores are, therefore, robust in that they represent multiple analytes that reinforce the reliability of the factor scores.
4. Calculation of factors, or clusters, in a multivariate data set has the additional advantage of creating parsimony for the purpose of analysis. For example, a dataset containing 20 different variables can be reduced to a smaller dataset consisting of a few (rarely over five) new variables (factors) thus simplifying data interpretation.
5. The factor scores are dimensionless and are equivalent to Z scores. That is the factor scores range from approximately +3 to -3. The range of factor scores represents the intensity of each process characterized by a factor. The highest, positive factor scores represent water that has been most intensely affected by the process (i.e., dissolution of limestone) and the lowest, negative scores reflect the least intensity of the process (i.e., newly recharged water that has not reacted with the limestone).
6. Statistically, the factor scores are independent. That is, any correlations between different factors (processes) have been removed. Maintaining statistical independence between factors simplifies data interpretation. Statistical independence of the factor scores is achieved by equimax rotation of the variable in N space such that pairs of factors are mathematically orthogonal.
7. Mapping of factor scores, by factor, provides a robust, highly constrained display of the spatial intensity of geochemical processes. The correlations between associated analytes strengthen confidence and allow for many of the uncertainties associated with mapping of single analyte distributions.

Cluster analysis of the average compositions of groundwater, by station, was a three-step process. First, the averaged data for each analyte over the 10-year time frame were subjected to a basic statistical evaluation in MiniTab. This evaluation returns such data as the means, averages, quartiles, skewness, and other parametric properties of each analyte. No outliers or other data issues were identified.

The second step was to perform classical principal components analysis (PCA) on the data. This analysis identifies relationships between groups of data with minimal data manipulation. Based on this analysis, it was clear that there were clusters of data within the dataset that represent geochemical and anthropogenic processes. Based on the PCA, it was determined that the factor analysis should be constrained to three factors.

The last step was to perform factor analysis (FA), which is mathematically similar to simple PCA, but allows for data adjustment to create statistically independent clusters of analytes (Lawrence and Upchurch, 1976, 1982). Prior to factor analysis, the data were “normalized” according to criteria presented by Howarth and Earle (1979). This is necessary since the first step in the factor analysis is computation of a correlation coefficient matrix, which requires normal distributions in all variables. Entry with a correlation matrix causes the factor analysis to compare and cluster variables according to linear correlation coefficients. This type of analysis is termed “R-mode” factor analysis. The equimax rotation was utilized to adjust the clusters, so that the axis of each cluster is orthogonal to all others in N space, thus insuring statistical independence.

Groundwater from sample sites with high positive scores are interpreted as having been strongly affected by the factor being mapped. For example, if a sample has a high (>2) factor score representing calcium, specific conductance, and other limestone-dissolution indicators, it can be concluded that limestone dissolution is advanced and the groundwater has been in contact with the rock for a long period of time. Low (<1 or <2) factor scores represent samples where the process has not progressed to the point where the chemistry of the water has been significantly affected by, for example, limestone dissolution. In this example, low factor scores often represent areas of higher recharge, where the groundwater has not equilibrated with the host aquifer.

It is important to understand relationships between analytes. By examining the factor loadings, communalities, and eigenvalues, those variables belonging to a specific chemical process can be identified and the importance of the chemical can be evaluated in terms of the total data set and in terms of each factor. Many factors include positive and negative loadings on a factor. These represent negatively correlated analytes where the pairs of analytes are inversely related. In the Rainbow Springs dataset, there are two relationships that reflect this pattern. pH is negatively correlated with calcium, magnesium, and specific conductance, because of the loss of acidity (pH increases) when water reacts with the host carbonate rock. Also, the ion ammonium (commonly and incorrectly referred to as ammonia) is inversely correlated to nitrate plus nitrite by the oxidation reaction. Ammonium is consumed during this reaction and nitrate plus nitrite forms.

4.4 Hydrogeochemical Fingerprinting

Analyzing the “fingerprint” or pattern of water quality at each sample station, the relative concentrations or values (for pH) were plotted on circular, or star, diagrams with the axes representing the analytes. These star diagrams were plotted for each sample location on maps of the study area. Jones et al. (1996) utilized similar star diagrams to identify groundwater domains and the springs to which they discharge in the Rainbow Springs Group springshed.

The star diagrams allow for visual recognition of hydrogeochemical patterns in UFA groundwater within the springshed. No effort was made to revisit the hydrogeochemical domains defined by Jones et al. (1996) because of the short time frame of the project and the need to move on to the cluster analyses – the goal of the project. However, visual inspection of the maps showing the star diagrams for each sample location during each 10-year sampling interval clearly suggests the presence of geochemical patterns within the samples and of domains similar to those identified by Jones et al. (1996).

4.5 Geochemical Evaluation Results

The following sections present the findings of the aqueous geochemical evaluation completed with the methods discussed above.

4.4.1 Cluster Analysis

4.4.2.1 1985-1995 Results

Analysis of the 1985-1995 data included 80 to 89 valid analyte detections for the 92 sample stations. Missing data ranged from 12 fluoride results to 3 chloride results.

Table 4-2 presents the eigenvalues for the PCA for the 72 cases without missing values. Eigenvalues represent the contribution to the total variability of the data by the unrotated cluster analysis. This preliminary analysis indicates that 76.2 percent of the total data variability can be accounted for by three factors, thus providing parsimony for the analysis. These three factors have eigenvalues greater than 1 indicating that they account for more than 1/13 of the total variability in the 13-analyte data set. Eigenvalues less than 1 indicated that the factors they represent account for less than 1/13 of the total variability within the data set and that a proportion of their varaibility has been accounted for by the factors with eigenvalues greater than 1. Thus, three factors account for at least some of the variability within the entire 13-variable data set.

Table 4-3 presents the factor loading results from the FA using the equimax rotation technique on the 1985-1995 dataset and constraining the analysis to three factors. Highlighted factor loadings represent analytes that are significant contributors to each factor. Loadings in **bold** are considered minor contributors to the factor. Other loadings represent minimal influence on the factor.

Factor 1 represents the analytes that constituted the general background water quality in the springshed in 1985-1995. The presence of calcium, chloride, magnesium, potassium, sodium, specific conductance (a surrogate variable that reflects dissolution of calcite (limestone) and dolomite (dolostone)) coupled with sodium and chloride from rainfall, and calcium and sulfate from (1) oxidation of pyrite, (2) use of gypsum ($CaSO_4.nH_2O$) soil amendments, or (3) the presence of dilute Ca-SO_4 water from deeper in the aquifer.

Factor 2 represents negative ammonium, fluoride, and iron loadings and positive nitrate plus nitrite. The negative ammonia and positive nitrate + nitrite relationship indicates that loading by ammonia as a fertilizer is followed by

Table 4-2. Eigenvalues and proportions of data accounted for by each of the 13 potential factors for the 1985-1995 dataset.

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13
EIGENVALUE	7.03	1.61	1.27	0.97	0.78	0.60	0.27	0.15	0.13	0.10	0.05	0.02	0.01
PROPORTION	0.54	0.12	0.10	0.07	0.06	0.05	0.02	0.01	0.01	0.01	0.00	0.00	0.00
CUM. % VARIANCE	54.10	66.50	76.20	83.70	89.70	94.30	96.40	97.60	98.60	99.40	99.80	99.90	100.00

Table 4-3. Factor Loadings After Equimax Rotation for Data Collected from 1985 to 1995. Yellow cells reflect high, or low, loadings.

ANALYTES	FACTOR 1	FACTOR 2	FACTOR 3
AMMONIUM	0.4585	-0.7798	-0.073
CALCIUM	0.857	-0.3079	-0.2394
CHLORIDE	0.8387	-0.0329	-0.1149
FLUORIDE	**0.5757**	-0.6996	-0.1642
IRON	-0.2601	-0.7297	-0.3592
MAGNESIUM	0.8129	**-0.4484**	0.1587
NITRATE + NITRITE	-0.0629	0.6238	-0.1772
ORTHOPHOSPHATE	-0.0997	-0.05	-0.6841
pH	-0.4768	-0.0662	0.7138
POTASSIUM	0.8333	-0.339	0.081
SODIUM	0.8175	-0.0216	-0.1907
SP. CONDUCTANCE	0.907	-0.2958	-0.1929
SULFATE	0.8426	**-0.4263**	0.1072
INTERPRETATION	***ROCK-WATER INTERACTION + RAINFALL***	***NITRATE, NEG. CORR. W/ AMMONIUM, FLUORIDE, IRON***	***pH COMPONENT, NEG. CORR. W/ ORTHOPHOSPHATE***

oxidation to nitrate and/or nitrite. The relationship of ammonia, iron, and fluoride is problematic. These relationships may reflect a specific source or a relationship with ammonium. Factor 2 clearly represents the process of application of ammonium and/or nitrate + nitrite as fertilizer followed by oxidation of the ammonium to nitrate. When mapping the factor scores, both "tails" of the Factor 2 score distribution are, therefore, of importance. The negative tail of the factor-score distribution represents areas where ammonium and related analytes are greatest and the positive-score tail reflects areas where nitrate plus nitrite is maximal, either as a result of ammonium oxidation or direct application as a fertilizer or waste product.

Factor 3 (Table 4-3) represents the chemical relationship between orthophosphate and acidity (Upchurch, 1992). Orthophosphate is soluble in acidic water and precipitates as the calcium-phosphate mineral apatite in basic waters. Therefore, an inverse correlation results between orthophosphate and pH. This factor may reflect dissolution and reprecipitation of phosphate related to the many hard-rock phosphate mines near the spring or use of phosphatic fertilizers.

Examination of the factor-score distribution maps for the three factors suggests that there are localized occurrences where the three sets of geochemical processes are unusual. The Factor 1 map (Figure 4-4) shows a broad distribution with only one, small area that exhibited a high factor score as a result of elevated specific conductance and sulfate. It appears that the wells within this area are somewhat deeper that others in the study area and that they are tapping a more sulfate rich hydrochemical facies in the aquifer.

The distribution of Factor 2 scores (Figure 4-4), which represent nitrogen-based fertilizer applications also reflects a widespread occurrence of nitrogen-based ions in the groundwater. The extremely low factor score area in the southwest corner of the study area is west of the Brooksville Ridge and unrelated to the Rainbow Springs springshed. The high factor score areas are along the western edge of the Williston Karst Plain adjacent to the Ocala Karst Hills.

Similarly, the Factor 3 scores reflect a broad expanse of water with relatively low orthophosphate content and high pH (Figure 4-4). The high factor scores near the spring (scores from +1 to +2) are located in the Brooksville Ridge and represent a volume of low pH water. The areas with negative scores reflect varying concentrations of orthophosphate. One would not expect high orthophosphate concentrations in the relatively alkaline water of the UFA. Where high concentrations (low Factor 3 scores) exist, a source is very nearby.

Finally, note the low factor scores for factors 2 and 3 in the southwestern corner of the study area. The location of these negative scores is west of the Brooksville Ridge, in an area of swallets. These scores indicate recharge of water that is relatively rich in ammonia and orthophosphate, which is expected in a localized recharge area.

4.4.2.2 1995-2005 Results

Table 4-4 presents the eigenvalues for PCA of the four cases without missing values in the 1995-2005 dataset. Thirty-two samples had missing data. All totaled, there were 36 wells sampled in this time period. The missing data ranged from 3 to 28 analytes per sample. Eigenvalue analysis indicates that 100 percent of the variability can be accounted for by three factors, thus providing parsimony for the analysis. The eigenvalues indicate a weak and

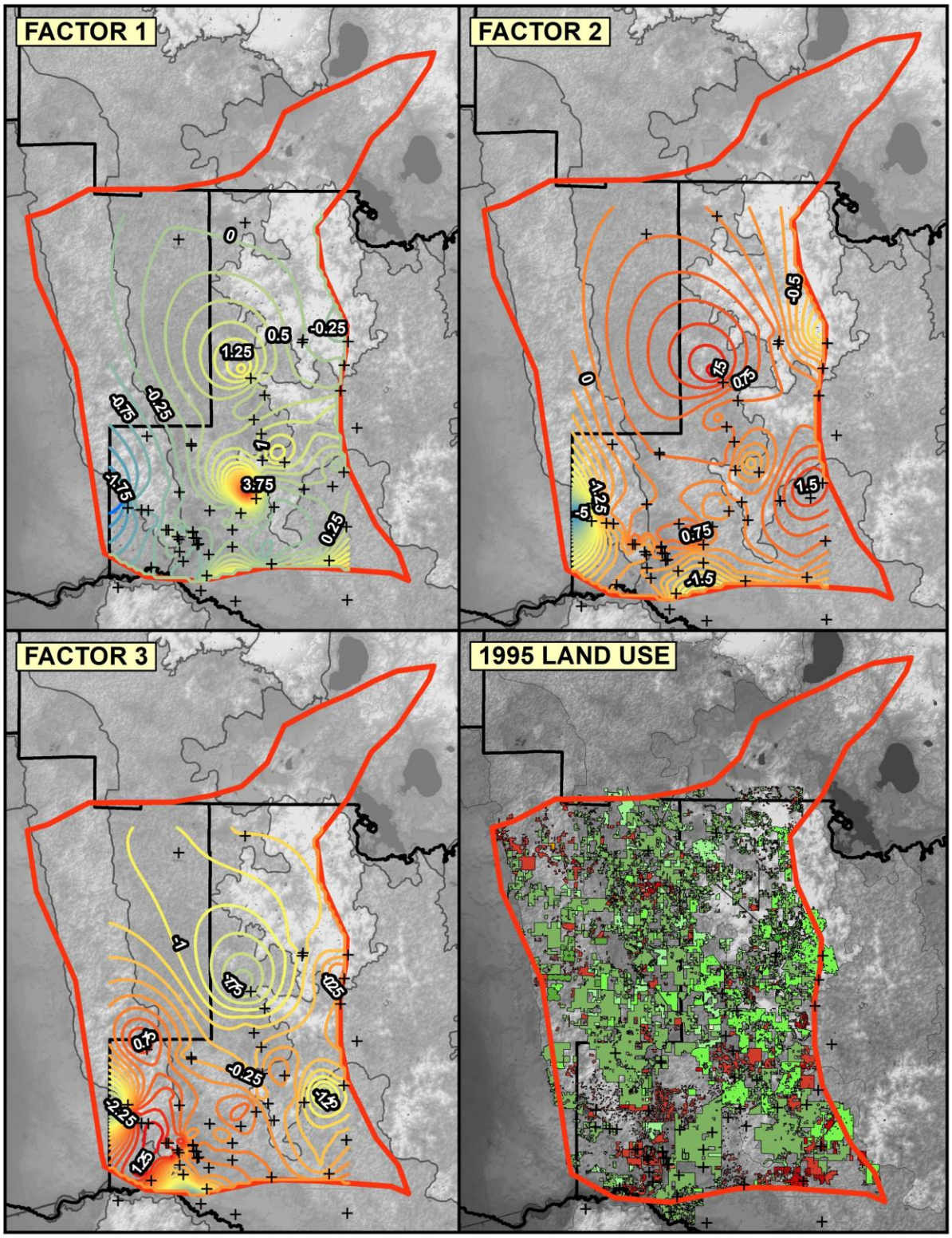


Figure 4-4. Distribution of factor scores for the period 1985 to 1995 and 1995 land use of interest (SWFWMD, 2017). 0.25 factor score contour coloration is from "hot" (red) to "cold" (blue) representing positive to negative factor scores, respectively. These correlate to the water quality parameters presented on Table 3-3. Factor Loadings After Equimax Rotation for Data Collected from 1985 to 1995.

Table 4-4. Eigenvalues and proportions of data accounted for by each of the 13 potential factors for the 1995-2005 dataset.

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13
EIGENVALUE	11.40	5.04	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PROPORTION	0.67	0.30	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CUM. % VARIANCE	66.80	96.40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

unreliable dataset and analysis. For completeness, an analysis of the 1995-2005 data is presented below, but the reader is cautioned to be wary of the results because of the high amount of missing data. Table 4-5 presents the results of the FA using the equimax rotation technique and constraining the analysis to three factors.

Table 4-5. Factor Loadings After Equimax Rotation for Data Collected from 1995 to 2005. Yellow cells reflect high, or low, loadings.

ANALYTES	FACTOR 1	FACTOR 2	FACTOR 3
AMMONIUM	0.896	0.1556	-0.1038
CALCIUM	0.7357	0.6253	-0.1021
CHLORIDE	0.9022	0.2894	0.1924
FLUORIDE	0.8297	0.2738	0.1009
IRON	-0.2561	-0.1985	-0.783
MAGNESIUM	0.9601	0.1091	-0.1453
NITRATE + NITRITE	-0.3817	0.0735	0.6159
ORTHOPHOSPHATE	-0.0663	0.5632	-0.7106
pH	0.0072	-0.9366	-0.157
POTASSIUM	0.9105	0.2763	0.0296
SODIUM	0.9093	0.2789	0.1121
SP. CONDUCTANCE	0.8121	0.5567	-0.0808
SULFATE	0.904	0.1544	-0.1521
INTERPRETATION	***ROCK-WATER INTERACTION + RAINFALL***	***ROCK-WATER INTERACTION + RAINFALL***	***FERTILIZER COMPONENTS***

Factor 1 represents the analytes that constitute the general background water quality in the springshed in 1995-2005. As noted above, the poor quality of the data limits interpretation of the processes that control the factors. It is important to note that ammonium, a typical fertilizer component, is grouped with the Factor 1 analytes (Table 4-5).

Factor 2 (Table 4-5) represents positive calcium and specific conductance and negative pH. In a limestone terrain, this relationship represents dissolution of limestone as a process.

Factor 3 (Table 4-5) includes positive loading of nitrate + nitrite and negative relationships for iron, and orthophosphate. This set of correlations is problematic, but it appears to reflect a relationship of iron and orthophosphate and an inverse relationship of this pair to nitrate + nitrite. The relationship of iron and orthophosphate may reflect an issue related to sampling since orthophosphate strongly sorbs to ferric hydroxide (Rea and Upchurch, 1980).

Maps showing the distributions of the factor scores within the study area are similar to the maps for the 1985-1995 period. Factor 1 scores (Figure 4-5) reveal little variability within the study area. Relatively high factor scores representing the samples outside and south of the study area have resulted in contouring a factor-score high in the southeastern corner of the study area. Factor 3 scores (Figure 4-5) reflect a gentle geochemical gradient to the southwest with the high scores (calcium and specific conductance) to the northwest and declining concentrations toward the springs. In spite of the poor data quality, this pattern may be indicating that the water nearest to the springs is younger than the water in distal parts of the springshed. Finally, the Factor 3 map (Figure 4-5) also reveals little variability. There is a low-score region in the southern part of the springshed that appears to have relatively high iron and orthophosphate.

4.4.2.3 2005-2015 Results

PCA of unrotated data resulted in eigenvalues greater than one for five factors (Table 4-6). These factors each reflect more than 1/13 of the total variability in the data set. Normally, onewould extract five factors using factor analysis, but the goal of this study is to explore the

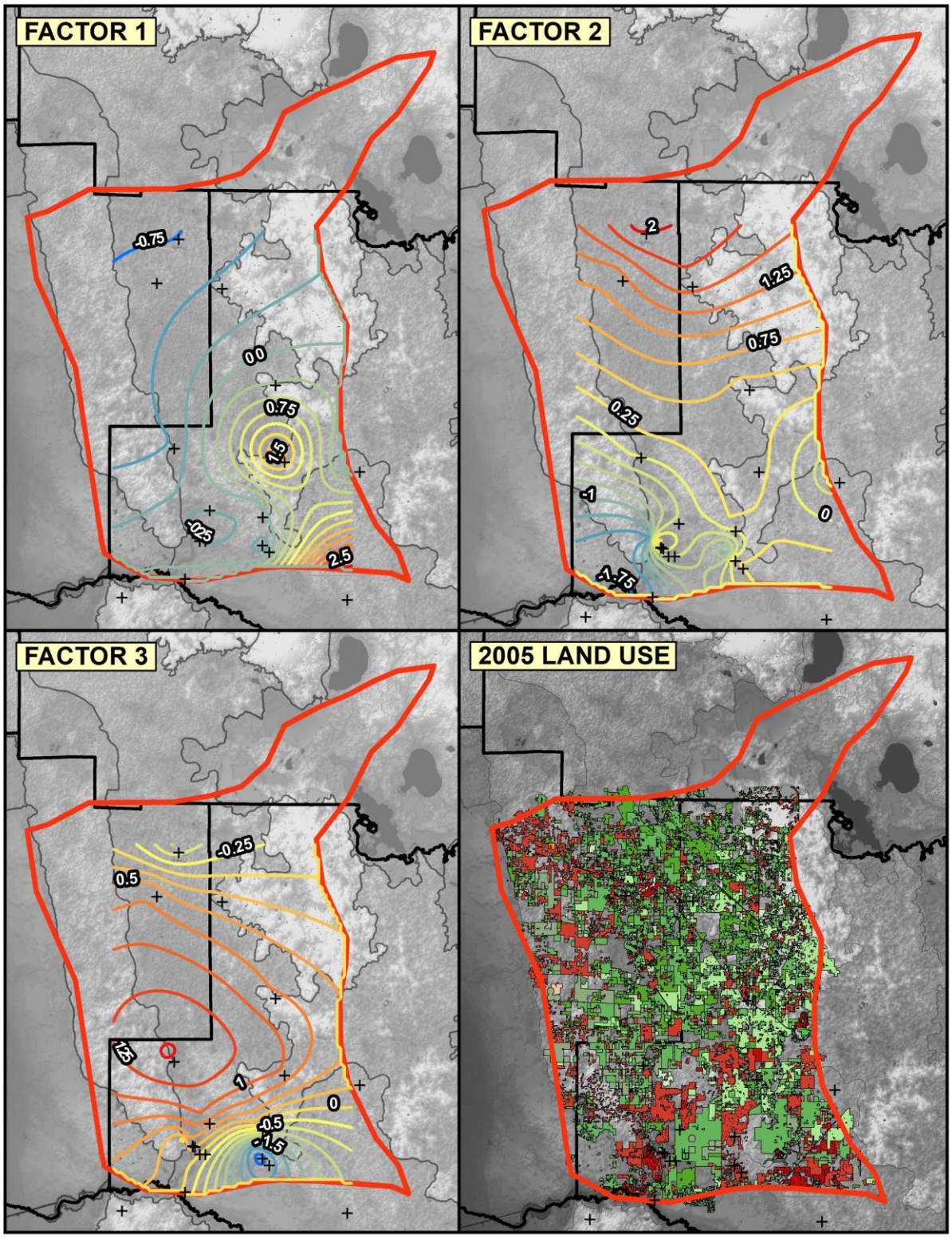


Figure 4-5. Distribution of factor scores for the period 1995 to 2005 and 2005 land uses of interest (SWFWMD, 2017). 0.25 factor score contour coloration is from "hot" (red) to "cold" (blue) representing positive to negative factor scores, respectively. These correlate to the water quality parameters presented on Table 3-5. Factor Loadings After Equimax Rotation for Data Collected from 1995 to 2005.

Table 4-6. Eigenvalues and proportions of data accounted for by each of the 13 potential factors for the 2005-2015 dataset.

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13
EIGENVALUE	4.80	2.18	1.63	1.35	1.07	0.80	0.70	0.33	0.05	0.04	0.03	0.01	0.00
PROPORTION	36.90	16.80	12.60	10.40	8.30	6.20	5.40	2.50	0.40	0.30	0.20	0.10	0.00
CUM. % VARIANCE	36.90	53.70	66.30	76.70	84.90	91.10	96.50	99.00	99.40	99.70	99.90	100.00	100.00

distributions of nutrients in groundwater. In order to force nutrient factors and develop a cluster analysis that is comparable to the other two, the factor analysis was limited to three factors. As such, these three factors account for 66 percent of the total variability of the dataset (Table 4-6).

Table 4-7. Factor Loadings After Equimax Rotation for Data Collected from 2005 to 2015. Yellow cells reflect high, or low, loadings.

ANALYTES	FACTOR 1	FACTOR 2	FACTOR 3
AMMONIUM	-0.0332	0.971	0.0566
CALCIUM	0.8682	-0.198	0.1954
CHLORIDE	0.748	-0.0451	0.1995
FLUORIDE	0.0933	-0.1689	-0.0206
IRON	-0.0452	0.9735	0.0302
MAGNESIUM	-0.045	0.0272	-0.8221
NITRATE + NITRITE	0.7331	-0.1215	**-0.4285**
ORTHOPHOSPHATE	0.0636	0.3967	0.3844
pH	-0.8428	0.1287	-0.117
POTASSIUM	0.6737	0.0033	**-0.4436**
SODIUM	0.8209	-0.0447	-0.0983
SP. CONDUCTANCE	0.9546	-0.166	0.0547
SULFATE	-0.0397	-0.1296	-0.6985
INTERPRETATION	***ROCK-WATER INTERACTION, NITRATE***	***FERTILIZERS (AMMONIUM)***	***IRON, SULFATE***

Table 4-7 presents the factor loadings for the rotated factor scores. Factor 1 continues to reflect the rock-water interactions, including dissolution of limestone. Of note in the Factor 1 analyte list is nitrate + nitrite and the absence of sulfate. Factor 2 includes ammonia and iron, and Factor 3 represents negative magnesium and sulfate. Nitrate + nitrite is also a contributing analyte to this factor, so Factor 3 appears to represent fertilizer and soil amendment applications.

Maps showing the spatial distribution of the factor scores are presented in Figure 4-6. Similar to the map showing the Factor 1 results of the 1995-2005 analysis, the scores for Factor 1 in 2005-2015 show a high near the center of the springshed and a pattern of declining score values toward the springs and southwestern corner of the study area. Again, this pattern suggests that water with longer contact times with the limestone occur near the center of the study area and water that has experienced less contact with the host limestone occurs near the springs. The 2005-2015 data are more reliable than the 1995-2005 data and more confidence can be placed in interpreting the maps. There are at least two explanations for this pattern. One is that the groundwater is, in fact older in the central part of the study area, because of lower recharge and slower flow-through in that area. The other possibility is that the amount of water recharging the two areas is similar, but the karst conduiting in the area near the springs is better developed and, therefore more efficient. The latter explanation is preferred since the development of cavernous porosity is generally greatest near limestone springs relative to distal portions of a springshed.

Factor 2 water is uniformly distributed across most of the study area (Figure 4-6). There is an area on the extreme western side of the study area where iron and ammonium plot as high concentrations. This area is within and down gradient from the Brooksville Ridge and the springs. Similarly, the Factor 3 map (Figure 4-6) a relatively uniform distribution of the factor. There is one data point east of the springs that has high negative scores, representing relatively high magnesium and sulfate concentrations.

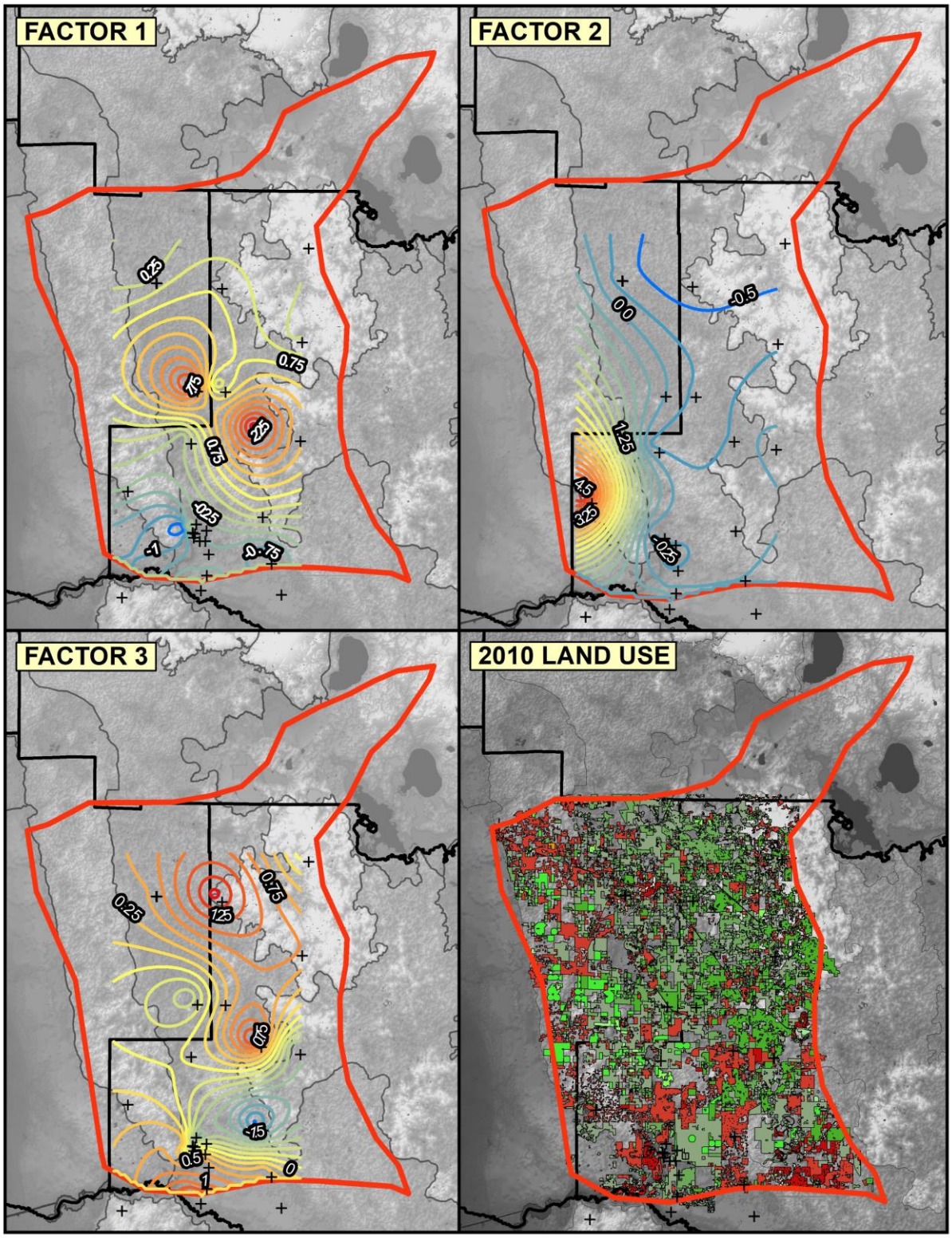


Figure 4-6. Distribution of factor scores for the period 2005 to 2015 and 2010 land uses of interest (SWFWMD, 2017). 0.25 factor score contour coloration is from "hot" (red) to "cold" (blue) representing positive to negative factor scores, respectively. These correlate to the water quality parameters presented on Table 3-7. Factor Loadings After Equimax Rotation for Data Collected from 2005 to 2015.

RAINBOW SPRING RUN
0 0.25 0.5 1
SCALE IN MILES

LEGEND:

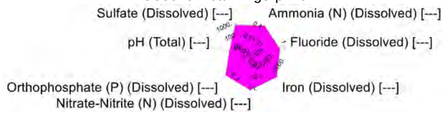
2005 Springshed (Holzwart et al., 2017)

Geomorphic Provinces
(Scott, 2005; Williams et al., In Progress)

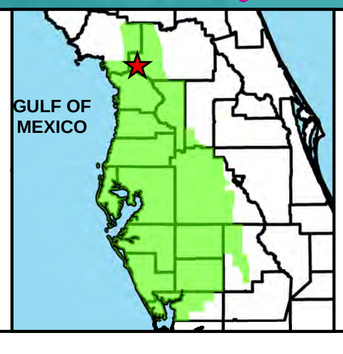
- Alachua Karst Hills
- Branford Karst Plain
- Brooksville Ridge
- Chiefland Karst Plain
- Crescent City Ridge
- Crystal River Karst Plain
- Duval Upland
- Fairfield Karst Hills
- Fort McCoy Plain
- Hawthorne Lakes Region
- Lake City Ridge
- Lake Plain
- Lower St. Johns River Valley
- Mt. Dora Ridge
- Ocala Karst Hills
- Oklawaha River Valley
- Palatka Hill
- Southern Okeefenokee Basin
- St. Johns River Offset Valley
- Tavares Lakes Region
- Trail Ridge
- Waccasassa Flats
- Williston Karst Plain

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone
Suspected Subsidence Event (FSRI AND SDII)
Identified Swallet (FGS, 2007)
Bio-significant Cave (FGS, 2009)
Cave - Mostly Underwater (FGS, 2009)
Cave - Mostly Air Filled (FGS, 2009)

Geochemical Fingerprint



N
W E
S
0 0.5 1 2
SCALE IN MILES



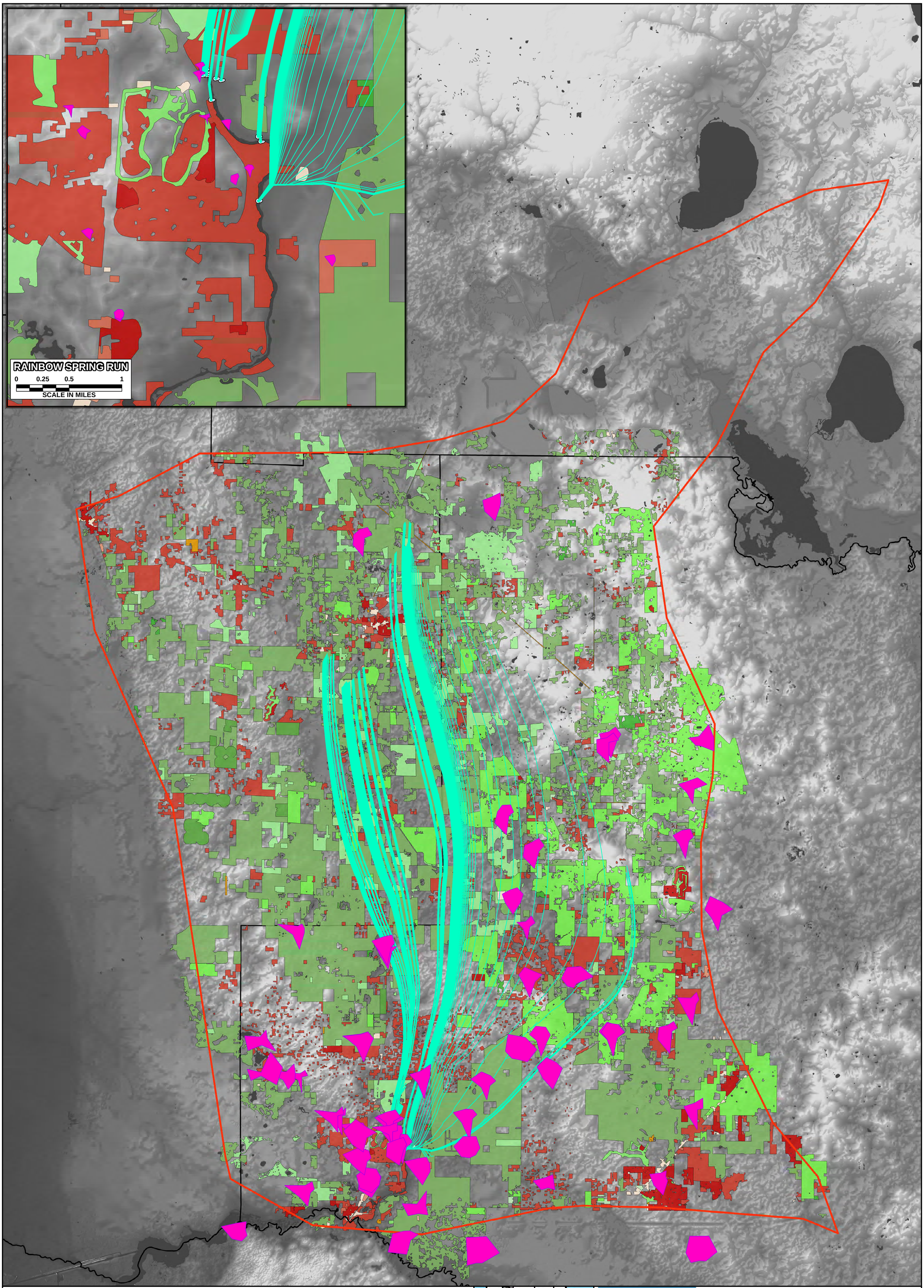
GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 1985-1995 DATASET AND IDENTIFIED REGIONAL KARST FEATURES

Water Resource Associates

SCALE AS SHOWN

FIGURE 4-7



LEGEND:

2005 Springshed (Holzwart et al., 2017)

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone

Land Use Description (1995)

- SPECIALTY FARMS
- TREE CROPS
- TREE PLANTATIONS
- ROW CROPS
- NURSERIES AND VINEYARDS
- CROPLAND AND PASTURELAND
- MIXED RANGELAND
- RECREATIONAL/GOLF COURSES
- COMMERCIAL AND SERVICES
- FEEDING OPERATIONS
- INDUSTRIAL
- INSTITUTIONAL
- RESIDENTIAL LOW DENSITY
- RESIDENTIAL MED DENSITY
- UTILITIES

Geochemical Fingerprint

Sulfate (Dissolved) [---] · Ammonia (N) (Dissolved) [---] · pH (Total) [---] · Fluoride (Dissolved) [---] · Orthophosphate (P) (Dissolved) [---] · Iron (Dissolved) [---] · Nitrate-Nitrite (N) (Dissolved) [---]

N W E S

0 0.5 1 2

SCALE IN MILES

GULF OF MEXICO

GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 1985-1995 DATASET AND IDENTIFIED REGIONAL 1995 LAND USE

Water Resource Associates

SCALE AS SHOWN

FIGURE 4-8

RAINBOW SPRING RUN
0 0.25 0.5 1
SCALE IN MILES

LEGEND:

2005 Springshed (Holzwart et al., 2017)

Geomorphic Provinces
(Scott, 2005; Williams et al., In Progress)

- Alachua Karst Hills
- Branford Karst Plain
- Brooksville Ridge
- Chiefland Karst Plain
- Crescent City Ridge
- Crystal River Karst Plain
- Duval Upland
- Fairfield Karst Hills
- Fort McCoy Plain
- Hawthorne Lakes Region
- Lake City Ridge
- Lake Plain
- Lower St. Johns River Valley
- Mt. Dora Ridge
- Ocala Karst Hills
- Oklawaha River Valley
- Palatka Hill
- Southern Okeefenokee Basin
- St. Johns River Offset Valley
- Tavares Lakes Region
- Trail Ridge
- Waccasassa Flats
- Williston Karst Plain

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone

Suspected Subsidence Event (FSRI AND SDII)

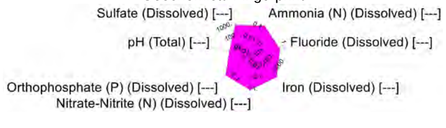
Identified Swallet (FGS, 2007)

Bio-significant Cave (FGS, 2009)

Cave - Mostly Underwater (FGS, 2009)

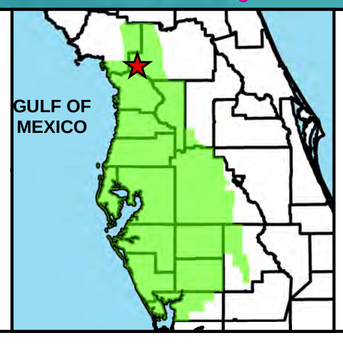
Cave - Mostly Air Filled (FGS, 2009)

Geochemical Fingerprint



N W E S

0 0.5 1 2
SCALE IN MILES



GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 1995-2005 DATASET AND IDENTIFIED REGIONAL KARST FEATURES

Water Resource Associates

SCALE AS SHOWN

FIGURE 4-9

RAINBOW SPRING RUN

0 0.25 0.5 1

SCALE IN MILES

LEGEND:

2005 Springshed (Holzwart et al., 2017)

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone

Land Use Description (2005)

- SPECIALTY FARMS
- TREE CROPS
- TREE PLANTATIONS
- ROW CROPS
- NURSERIES AND VINEYARDS
- CROPLAND AND PASTURELAND
- MIXED RANGELAND
- RECREATIONAL
- GOLF COURSES
- COMMERCIAL AND SERVICES
- FEEDING OPERATIONS
- INDUSTRIAL
- INSTITUTIONAL
- RESIDENTIAL LOW DENSITY
- RESIDENTIAL MED DENSITY
- UTILITIES

Geochemical Fingerprint

Sulfate (Dissolved) [---]
Ammonia (N) (Dissolved) [---]
pH (Total) [---]
Fluoride (Dissolved) [---]
Orthophosphate (P) (Dissolved) [---]
Iron (Dissolved) [---]
Nitrate-Nitrite (N) (Dissolved) [---]

N W E S

0 0.5 1 2

SCALE IN MILES

GULF OF MEXICO

Water Resource ASSOCIATES

GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 1995-2005 DATASET AND IDENTIFIED REGIONAL 2005 LAND USE

SCALE AS SHOWN

FIGURE 4-10

RAINBOW SPRING RUN
0 0.25 0.5 1
SCALE IN MILES

LEGEND:

2005 Springshed (Holzwart et al., 2017)

Geomorphic Provinces
(Scott, 2005; Williams et al., In Progress)

- Alachua Karst Hills
- Branford Karst Plain
- Brooksville Ridge
- Chiefland Karst Plain
- Crescent City Ridge
- Crystal River Karst Plain
- Duval Upland
- Fairfield Karst Hills
- Fort McCoy Plain
- Hawthorne Lakes Region
- Lake City Ridge
- Lake Plain
- Lower St. Johns River Valley
- Mt. Dora Ridge
- Ocala Karst Hills
- Oklawaha River Valley
- Palatka Hill
- Southern Okeefenokee Basin
- St. Johns River Offset Valley
- Tavares Lakes Region
- Trail Ridge
- Waccasassa Flats
- Williston Karst Plain

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone

Suspected Subsidence Event (FSRI AND SDII)

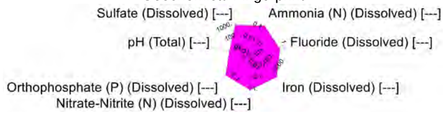
Identified Swallet (FGS, 2007)

Bio-significant Cave (FGS, 2009)

Cave - Mostly Underwater (FGS, 2009)

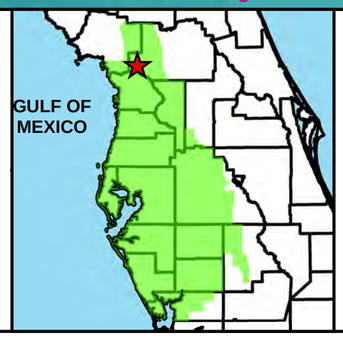
Cave - Mostly Air Filled (FGS, 2009)

Geochemical Fingerprint



N W E S

0 0.5 1 2
SCALE IN MILES



GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 2005-2015 DATASET AND IDENTIFIED REGIONAL KARST FEATURES

Water Resource Associates

SCALE AS SHOWN

FIGURE 4-11

RAINBOW SPRING RUN

0 0.25 0.5 1

SCALE IN MILES

LEGEND:

2005 Springshed (Holzwart et al., 2017)

DWRMv3 MODPATH Reverse Particle Tracking 100-Year Capture Zone

LAND USE DESCRIPTION (2010)

- SPECIALTY FARMS
- TREE CROPS
- TREE PLANTATIONS
- ROW CROPS
- NURSERIES AND VINEYARDS
- CROPLAND AND PASTURELAND
- MIXED RANGELAND
- RECREATIONAL
- GOLF COURSES
- COMMERCIAL AND SERVICES
- FEEDING OPERATIONS
- INDUSTRIAL
- INSTITUTIONAL
- RESIDENTIAL LOW DENSITY
- RESIDENTIAL MED DENSITY
- UTILITIES

Geochemical Fingerprint

Sulfate (Dissolved) [---]
Ammonia (N) (Dissolved) [---]
pH (Total) [---]
Fluoride (Dissolved) [---]
Orthophosphate (P) (Dissolved) [---]
Iron (Dissolved) [---]
Nitrate-Nitrite (N) (Dissolved) [---]

N W E S

0 0.5 1 2

SCALE IN MILES

GULF OF MEXICO

Water Resource ASSOCIATES

GROUNDWATER QUALITY SOURCE EVALUATION FOR
THE RAINBOW SPRINGS GROUP
MARION COUNTY, FLORIDA

GEOCHEMICAL FINGERPRINTING 2005-2015 DATASET AND IDENTIFIED REGIONAL 2010 LAND USE

SCALE AS SHOWN

FIGURE 4-12

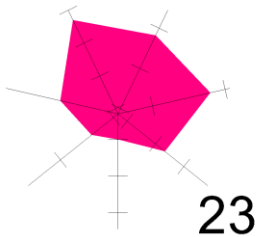
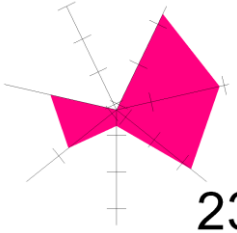
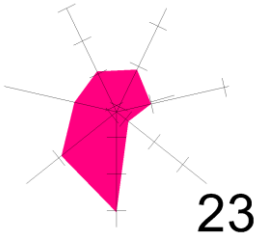
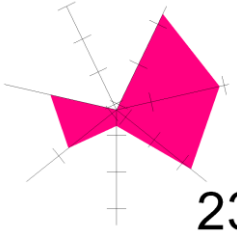
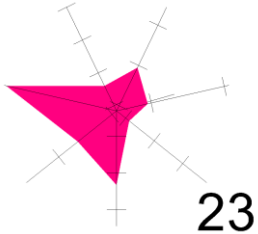
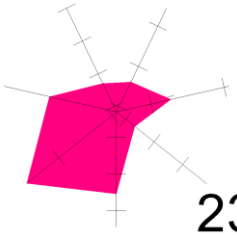
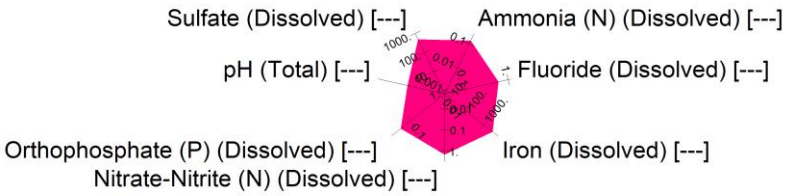
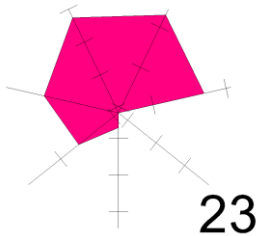
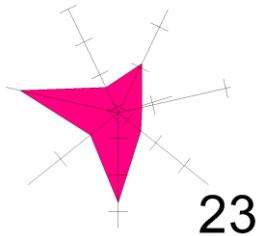
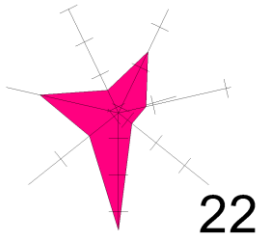
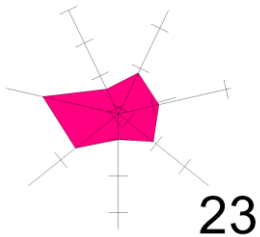
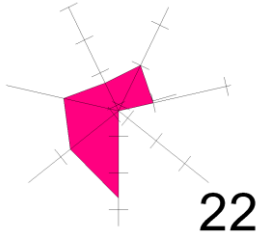
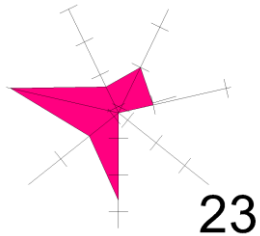
FACTOR SCORE RANGE	HIGHEST FACTOR SCORE	LOWEST FACTOR SCORE
SAMPLING INTERVAL 1985-1995		
FACTOR 1	 23352	 23376
FACTOR 2	 23364	 23376
FACTOR 3	 23310	 23248
LEGEND:		

Figure 4-13. 1985-1995 radial patterns in respect to those sample point locations with the highest and lowest factor scores.

FACTOR SCORE RANGE	HIGHEST FACTOR SCORE	LOWEST FACTOR SCORE
	SAMPLING INTERVAL 1995-2005	
FACTOR 1	 23229	 23321
FACTOR 2	 22919	 23259
FACTOR 3	 22930	 23327

LEGEND:

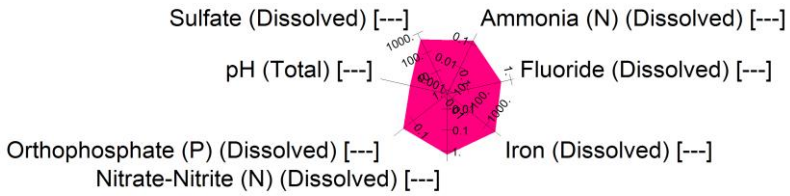
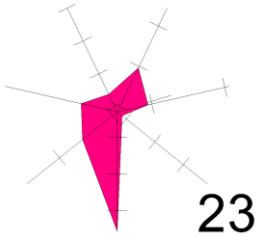
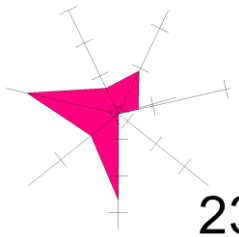
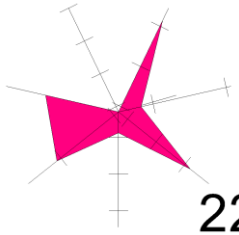
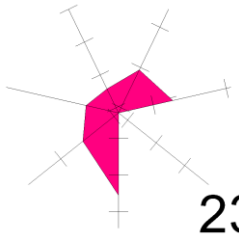
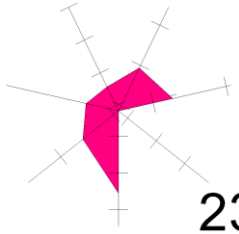
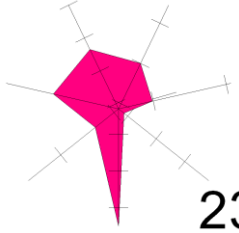


Figure 4-14. 1995-2005 radial patterns in respect to those sample point locations with the highest and lowest factor scores.

FACTOR SCORE RANGE	HIGHEST FACTOR SCORE	LOWEST FACTOR SCORE
	SAMPLING INTERVAL 2005-2015	
FACTOR 1	 23351	 23315
FACTOR 2	 22916	 23216
FACTOR 3	 23216	 23260

LEGEND:

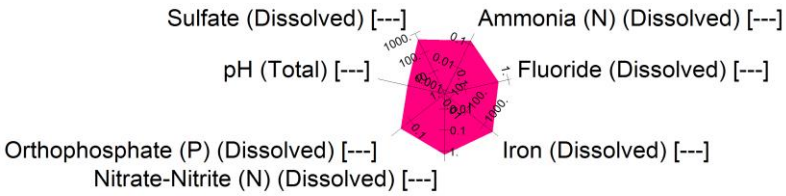


Figure 4-15. 2005-2015 radial patterns in respect to those sample point locations with the highest and lowest factor scores.

4.4.2 Geochemical Patterns

Plotting of star diagrams for each sample presents water-quality patterns that compare favorably with those identified for a smaller set of analytes by Jones et al. (1996). Figures 4-7 through 4-12 show the distributions of star diagrams representing overall water quality within the study area in 1985 to1995. There are clearly spatially different water-quality patterns represented in the data.

The distributions of these different water-quality patterns are represented in the factor-score maps presented in the following section Figures 4-13 through Figure 4-15 present the radial diagrams for the samples that have the highest and lowest factor scores for each factor and sampling date. If one compares the changes in the patterns from highest to lowest factor scores, it becomes clear that, for the most part, the facor scores reflect shifts in one or two analytes, For example, the Factor 3 scores for the 2005-2015 sampling interval (Figure 4-15) indicate that ammonium, fluoride, nitrate, and orthophosphate concentrations are similar for the highest and lowest factor-score samples. The factor scores are sensitive to the changes in sulfate and pH, which decrease in concentration from the lowest to highest scoring samples.

Since several “hot spots” (areas with unusually high or low factor scores and the tails of the distributions of the scores) were identified, it is appropriate to examine each hot spot and determine if an identifiable cause (source) of the hot spot can be identified. Since the purpose of this project was to determine if the methods presented in this report can assist in identification of specific sources of nutrients, only the factors that reflect variations in nutrients (ammonium, nitrate, and orthophosphate) were examined.

5.0 SOURCE WATER DELINEATION

Based on the geochemical fingerprinting, PCA, and FA, there is evidence of domains influencing the water quality at the Rainbow Springs Group. It is expected that the springs systems will be influenced by water-carbonate interaction; however, other distinct fingerprints were identified in this study and are of interest in respect to spring water quality and could be related to land use. The water quality parameters of interest are nitrate + nitrite, ammonia, iron, fluoride, and orthophosphate. Distinct patterns were identified in respect to the geomorphic provinces and land uses. Utilizing the PCA, FA, and geochemical fingerprinting, specific areas of interest have been identified. The following describes the findings from each time period evaluated.

5.1 1985-1995 Source Water Delineation

5.1.1 Factor 2

Figure 5-1 depicts the frequency distribution of factor 2 scores for the 1985-1995 sampling period. The star diagram patterns showing the variation of water quality from the lowest to the highest scores are also decipted. Note that the greatest change in water quality is the low nitrate + nitrite and sulfate concentrations and high ammonia, fluoride, and iron concentrations as compared to the highest scoring sample. The highest scoring sample is within the positive tail of the frequency distribution and does not appear to be an outlier from the distribution. This relationship indicated that elevated nitrate + nitrite and, to a lesser degree, orthophosphate were common in the springshed in 1985-1995. The two samples with the lowest scores in the distribution are apparently outliers. They are characterized by elevated pH and relatively high concentrations of phosphate and ammonia.

As depicted on Figure 5-1, the three highest factor scores were at sample points 23364, 23345, and 23346 (A, B, and C, respectively on Figures 5-2 and 5-4), while the three lowest factor scores were at sample points 23376, 23246, and 22916 (Z, Y, and X, respectively on Figures 5-3 and 5-4).

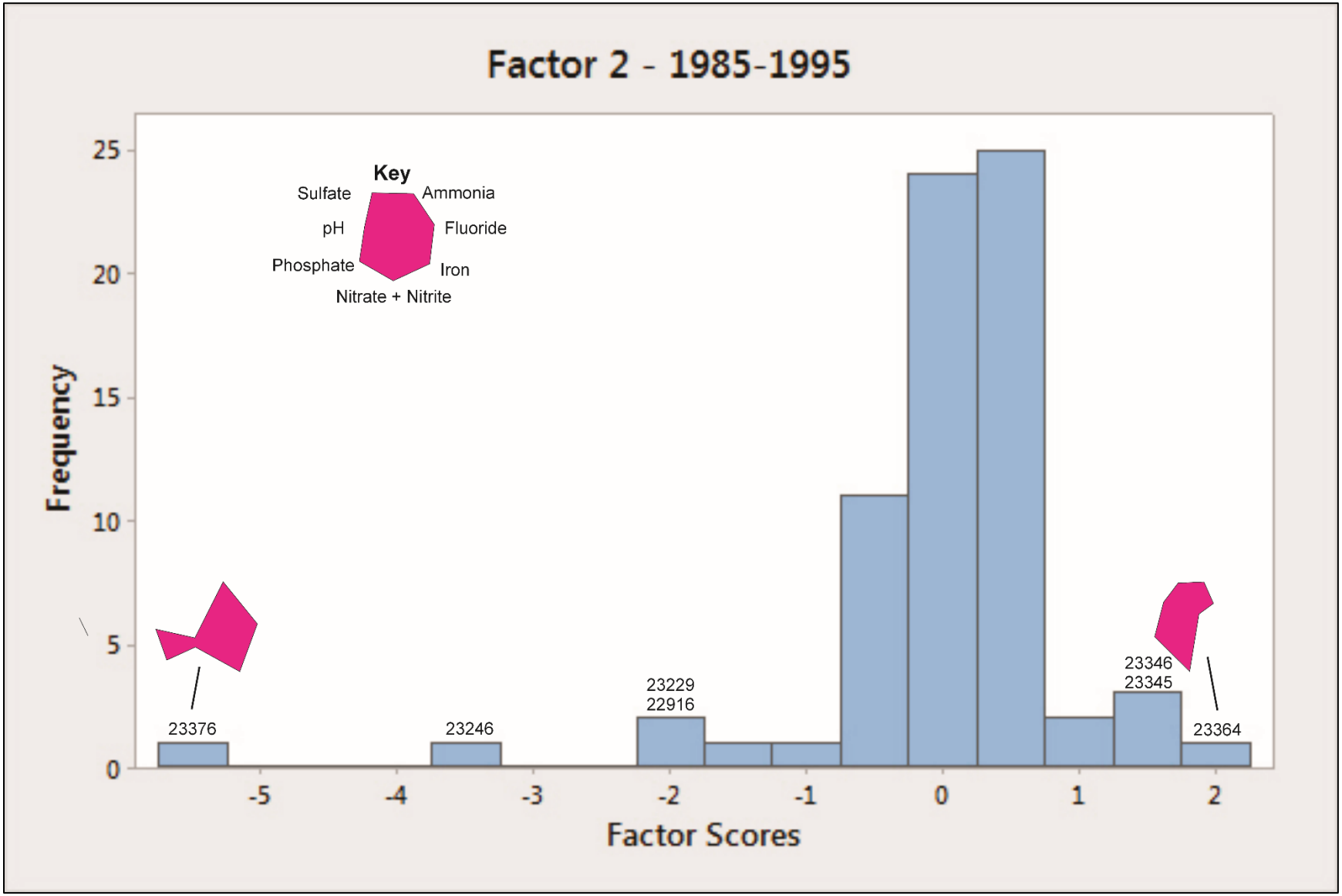


Figure 5-1. 1985-1995 Factor 2 histogram. Positive: Nitrate+Nitrite signal. Negative: Aluminum/Iron/Flouride signal.

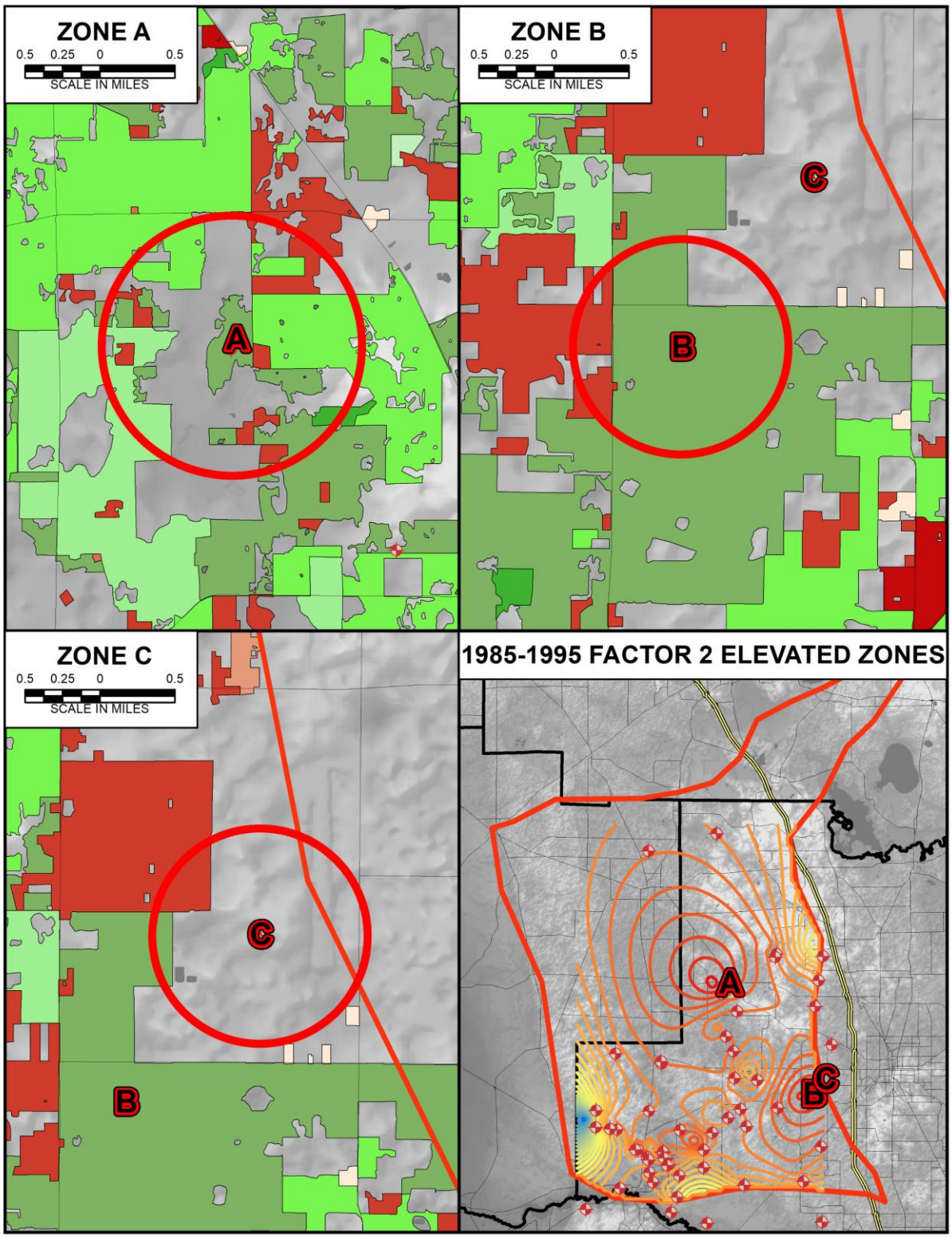


Figure 5-2. 1985-1995 Factor 2 elevated factor score zones (nitrite+nitrate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. A: highest factor score. B: second highest factor score. C: third highest factor score. See Figure 3-1 for the land use color key.

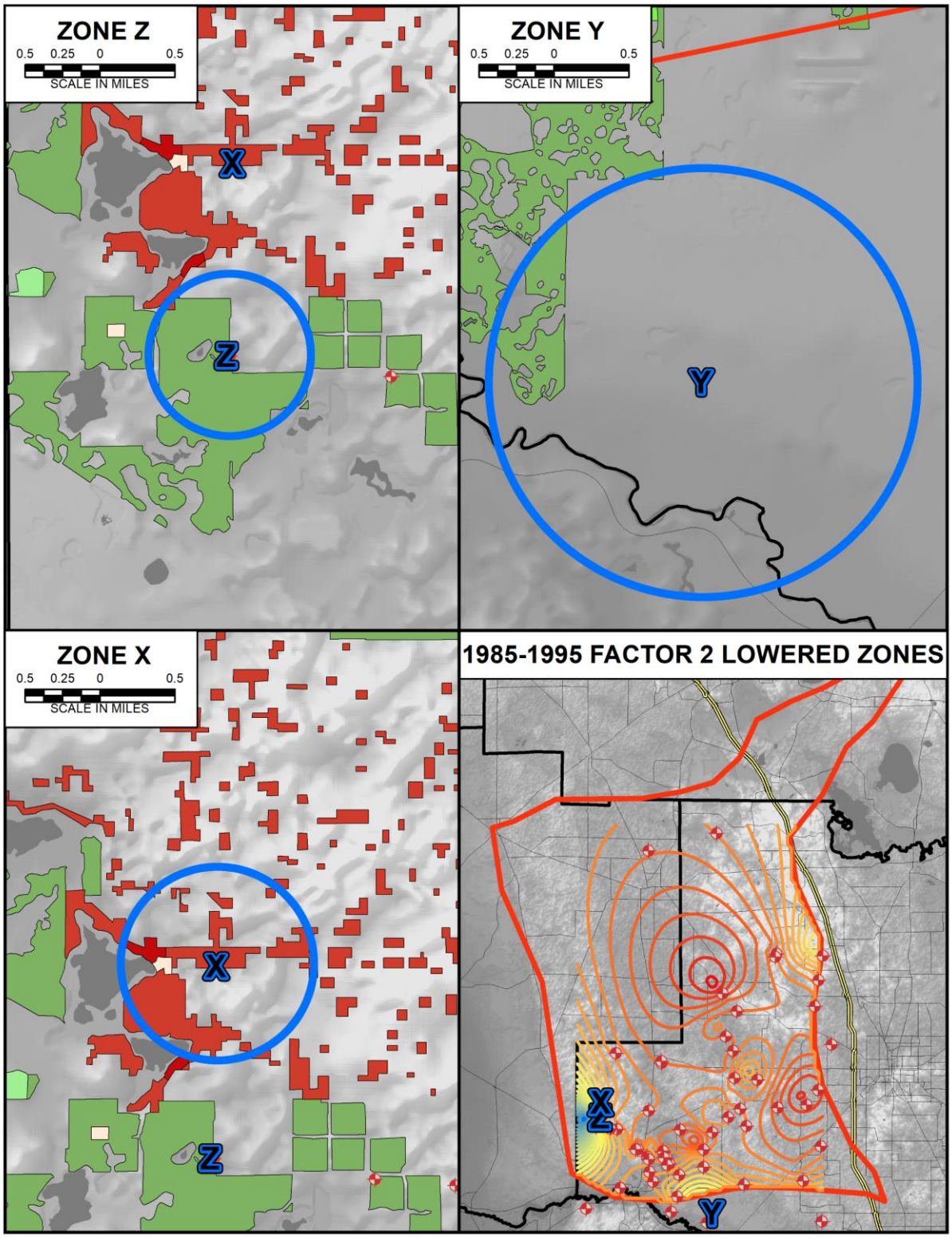


Figure 5-3. 1985-1995 Factor 2 lowered factor score zones (ammonium/iron/flouride signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. See Figure 3-1 for the land use color key.

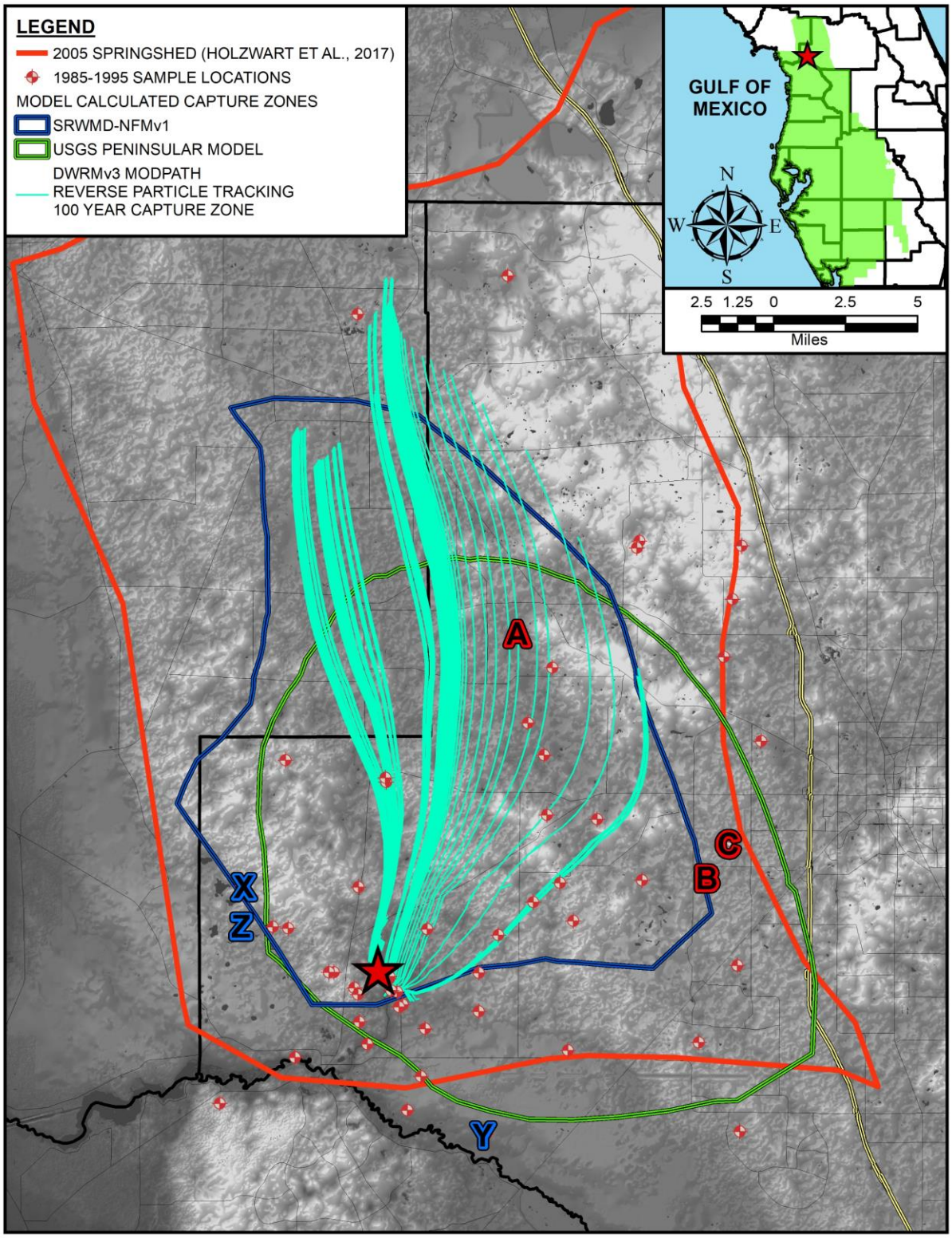


Figure 5-4. 1985-1995 Factor 2 elevated and lowered factor score zone (nitrate+nitrite signal and ammonium/iron/flouride signal) locations and simulated capture zones identified on Figure 2-12. A: highest factor score. B: second highest factor score. C: third highest factor score. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. Red Star: Rainbow Springs Group location.

The samples with the highest factors scores were from wells within the Williston Karst Plain adjacent to the Fairfield Karst Hills and the Ocala Karst Hills, respectively. As depicted on Figures 2-7 through 2-9, both of these areas have prominent nearby cave systems and, swallets and suspected subsidence events. These areas were dominated by agricultural land uses based on the 1995 land use maps (Figure 5-2). As depcited on Figure 5-4, only sample point 23364 (A) is located within the 100-year capture zones identified by Jones et al. (1996) and the DWRMv3 MODPATH analysis presented in this report, while sample points 23345 and 23346 (B and C, respectively) are located only within the 100-year capture zones identified by Jones et al. (1996).

The samples with the lowest factors scores were from wells within the Chiefland Karst Plain, west of the Brooksvile Ridge and the Williston Karst Plain, respectively. As depicted on Figures 2-7 through 2-9, unlike the areas of the high factors scores, both of these areas lack prominant cave systems, swallets, and suspected subsidence events. These areas were predominantly agricultural land and low density residential uses based on the 1995 land use maps (Figure 5-3). The lowest factor score sample point 23376 (Z) is located within the springshed (Holzwart et al., 2017; Figure 5-4). The second lowest factor score sample point 23246 (Y) is not located within any of the modeled 100-year capture zones nor within the District's adopted springshed (Holzwart et al., 2017). The third lowest factor score sample point 22916 (X) is located within the 100-year capture zone based on the SRWMD model (Jones et al., 1996) and within the springshed (Holzwart et al., 2017).

The eastern Brooksville Ridge has been extensively mined for hard-rock phosphate (deposits of carbonate hydroxyapatite in relict sinkholes; Upchurch, 1992) in the early 20th Century. Waste phosphatic silt and clay were deposited in some of the sinkholes after washing the ore. These wastes were nearly pure carbonate hydroxyapatite and were recovered for commercial uses into the 1970s. High pH, orthophosphate, and possibly ammonia are expected artifacts of these mining and recovery operations. Therefore, samples with elevated pH, phosphate, or nitrogen compounds from, or near, the Brooksville Ridge may reflect these operations.

5.1.2 Factor 3

The frequency histogram for Factor 3 scores (Figure 5-5) reveals that the samples with the highest scores are within the expected distribution of scores and that the samples with the lowest factor scores are outliers. Factor 3 reflects the transition from samples with elevated phosphate, pH, and iron concentrations (low scores) to elevated sulfate and nitrate + nitrite concentrations (high scores).

Orthophosphate is soluble in acidic water and precipitates as the calcium-phosphate mineral carbonate hydroxyapatite in basic waters. Therefore, an inverse correlation should result between orthophosphate and pH. This factor may reflect dissolution and reprecipitation of phosphate related to the many hard-rock phosphate mines near the springs or use of phosphatic fertilizers. As depicted on Figure 5-5, the three highest factor scores were at sample points 23310, 23333, and 23332 (A, B, and C, respectively on Figures 5-6 and 5-8), while the three lowest factor scores were at sample points 23248, 23376, and 23364 (Z, Y, and X, respectively on Figures 5-7 and 5-8).

The wells with water that scored highest factors scores were within the Brooksville Ridge north of the Dunnellon Gap (White, 1970) and within the Cheifland Karst Plain within the Dunnellon Gap (White, 1970). The Brooksville Ridge has significantly greater cover thickness as compared to the Chiefland, Crystal River and Williston karst plains, which surround it. These areas were predominantly low to medium density residential use based on the 1995 land use maps (Figure 5-6). As depcited on Figure 5-8, only sample points 23333 and 23332 (B and C, respectively) are located within the 100-year capture zones identified by Jones et al. (1996), while sample point 23310 (A) is located only within the springshed (Holzwart et al., 2017).

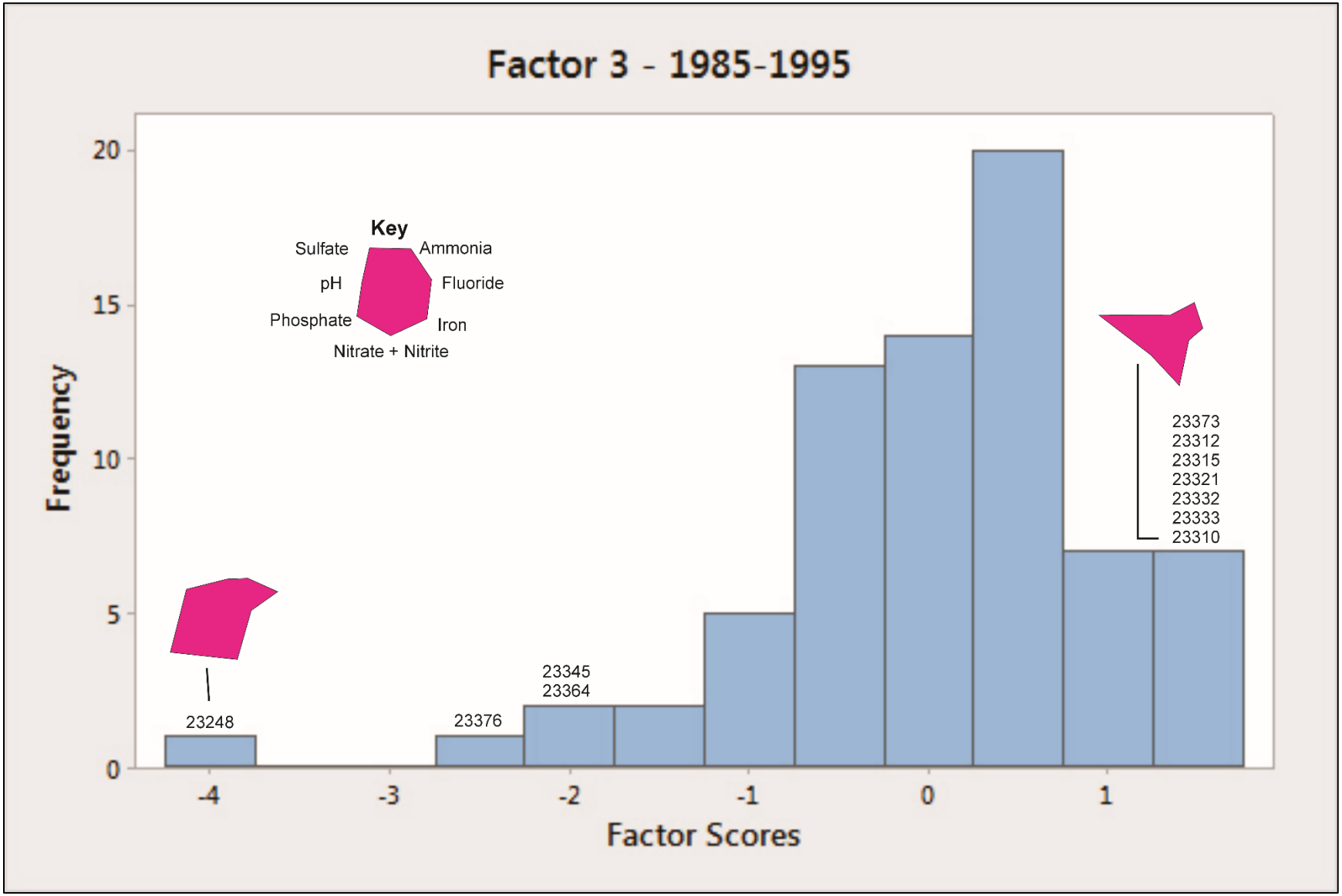


Figure 5-5. 1985-1995 Factor 3 histogram. Positive: pH signal. Negative: Orthophosphate signal.

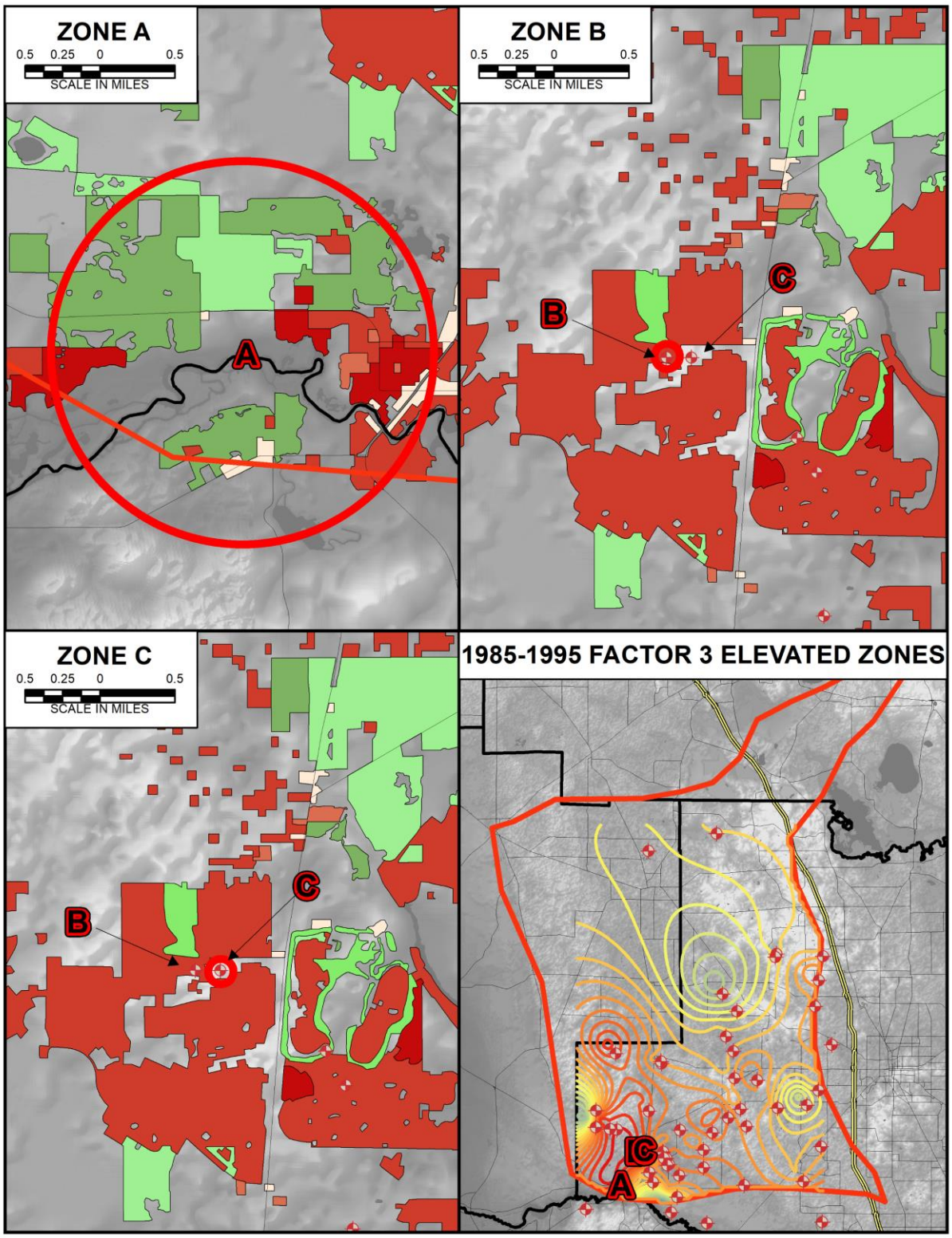


Figure 5-6. 1985-1995 Factor 3 elevated factor score zones (pH signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. A: highest factor score. B: second highest factor score. C: third highest factor score. See Figure 3-1 for the land use color key.

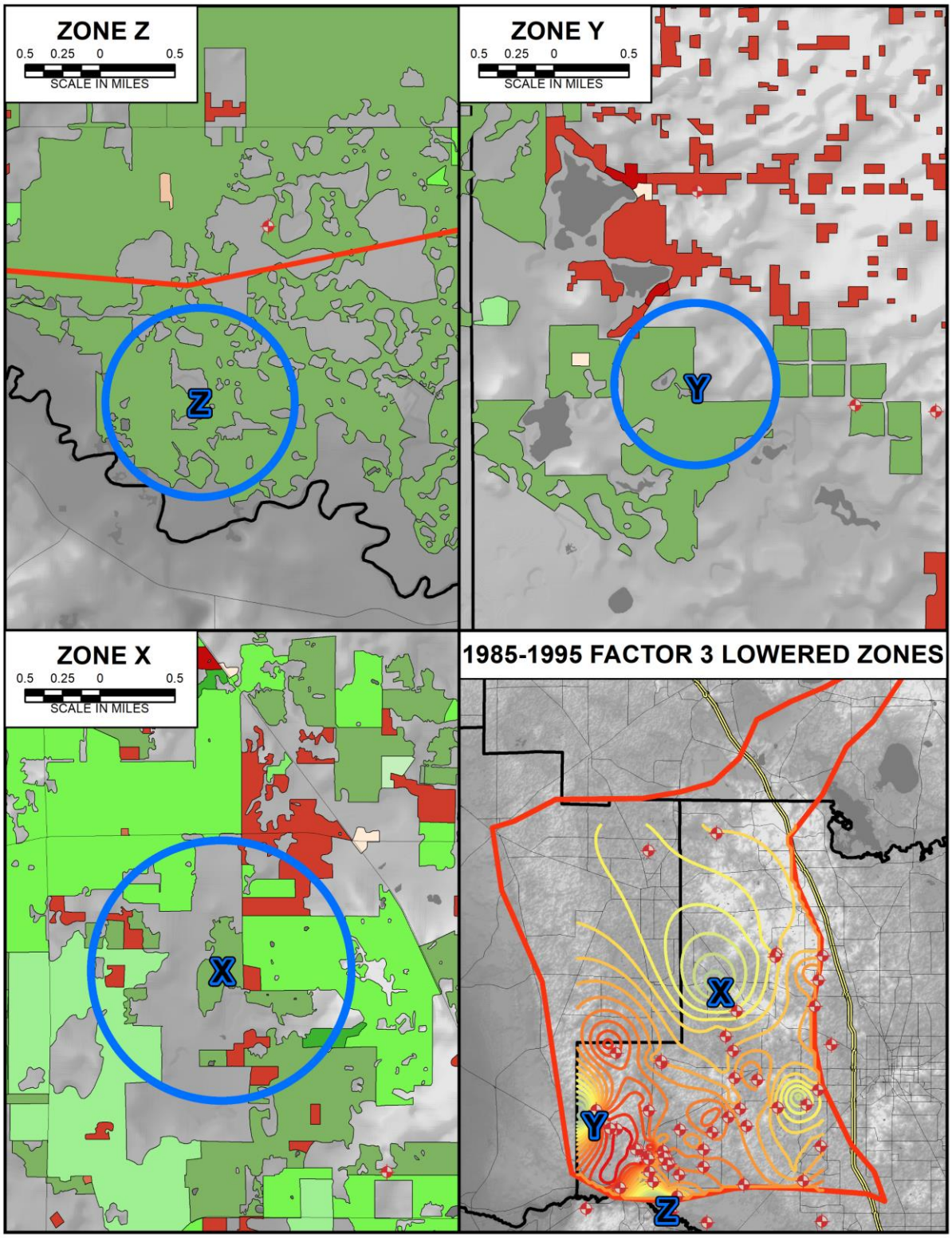


Figure 5-7. 1985-1995 Factor 3 lowered factor score zones (orthophosphate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. See Figure 3-1 for the land use color key.

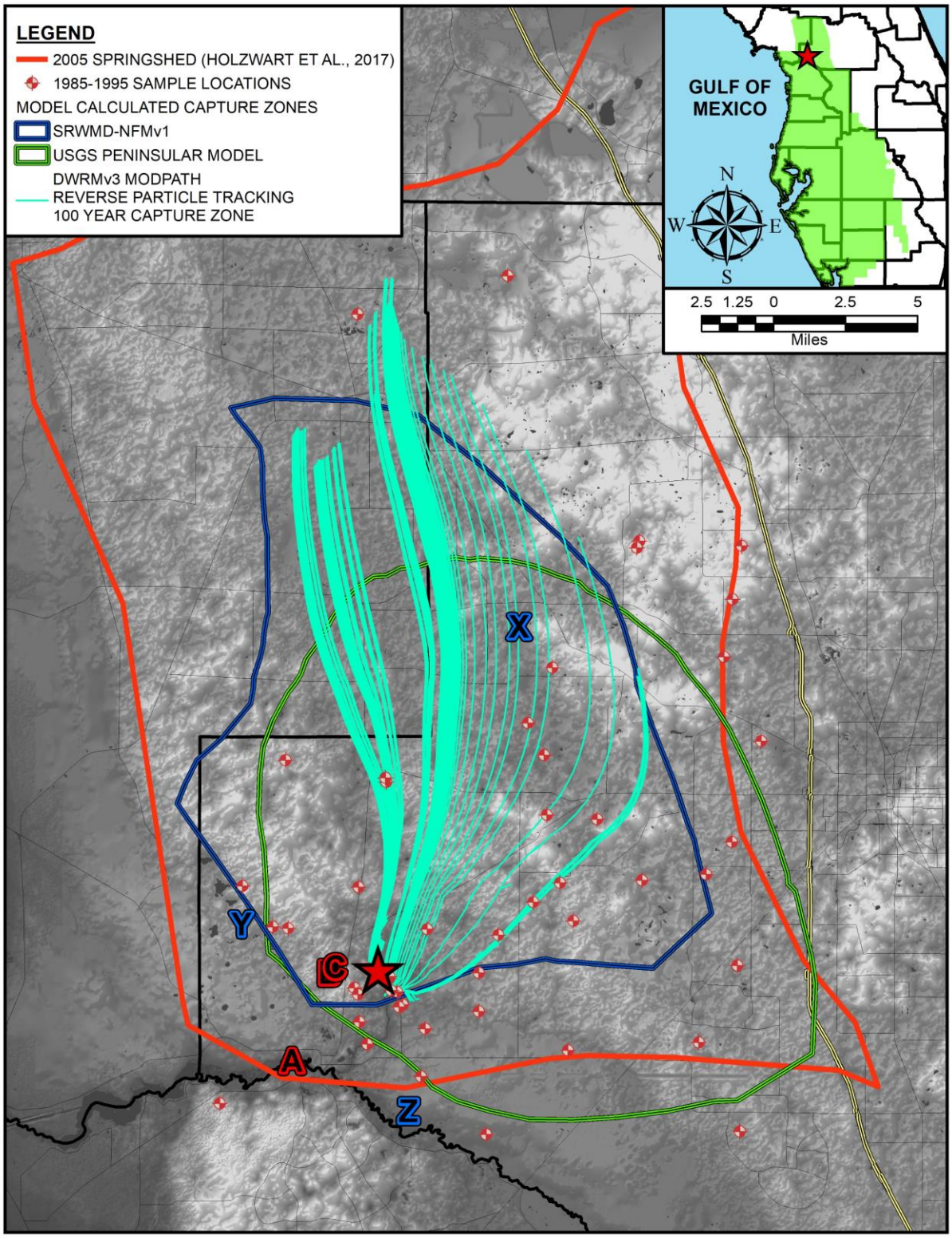


Figure 5-8. 1985-1995 Factor 3 elevated and lowered factor score zone (pH signal and orthophosphate signal) locations and simulated capture zones identified on Figure 2-12. A: highest factor score. B: second highest factor score. C: third highest factor score. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. Red Star: Rainbow Springs Group location.

Like the low Factor 2 scores, the samples with the lowest Factor 3 scores were within the Chiefland Karst Plain adjacent to the Brooksvile Ridge and within the Williston Karst Plain near the Ocala Karst Hills, respectively. As depicted on Figures 2-7 through 2-9, the third lowest factor score (sample point 23364/X) is in an area with more prominant cave systems and swallets, and suspected subsidence events, while sample points 23248 and 23376 (Z and Y, respectively) are not. These areas were predominantly agricultural land based on the 1995 land use maps (Figure 5-7). The lowest factor score sample point 23248 (Z) is located outisde of the springshed (Holzwart et al., 2017; Figure 5-8). The second lowest factor score sample point 23376 (Y) is not located within any of the modeled 100-year capture zones, but is within the springshed (Holzwart et al., 2017). The third lowest factor score sample point 23364 (X) is located within the 100-year capture zones based on the SRWMD model (Jones et al., 1996) and DWRMv3 MODPATH analysis presented in this report, as well as the springshed (Holzwart et al., 2017).

5.2 1995-2005 Source Water Delineation

5.2.1 Factor 3

The samples with the highest and lowest factor scores all appear to be outliers in the Factor 3 score population. All samples had elevated nitrate + nitrite and ammonia concentrations. The greates difference between the lowest and highest factor scores in the change from elevated orthophosphate and moderate pH (highest score; Figure 5-9) to low phosphate and elevated pH (lowest score). As indicated eariler, this set of correlations is problematic, but it appears to reflect a relationship of pH and orthophosphate. The relationship of iron and orthophosphate may reflect an issue related to sampling since orthophosphate strongly sorbs to ferric hydroxide (Rea and Upchurch, 1980).

As depicted on Figure 5-9, the three highest factor scores were at sample points 22919, 23349, and 23353 (A, B, and C, respectively on Figures 5-10 and 5-12), while the three lowest factor scores were at sample points 23259, 23258, and 22930 (Z, Y, and X, respectively on Figures 5-11 and 5-12).

The wells with water that had the highest factors scores are within the Williston Karst Plain and the Ocala Karst Hills. As depicted on Figures 2-7 through 2-9, both of these areas have prominent nearby caves and, swallets and suspected subsidence events. These areas had agricultural and low to medium density residential land usee based on the 2005 land use maps (Figure 5-10). The three highest factor score locations (Figure 5-12) are within the 100-year capture zones identified by Jones et al. (1996), while sample points 23349 and 23353 (B and C, respectively) align along flowpaths based on the DWRMv3 MODPATH analysis presented in this report.

The samples with the lowest Factor 3 scores were from wells within the Williston Karst Plain. As depicted on Figures 2-7 and 2-8, the lowest factor scores are in areas with a higher density of caves and suspected subsidence events. While sample locations 23259 and 23258 (Z and Y, respectively) were predominantly characterized by low residential land use areas based on the 2005 land use maps (Figure 5-11), sample location 22930 (X) was located within an agricultural land use area. The lowest factor score sample location 23248 (Z) and the second lowest factor score location 23258 (Y) are located within USGS model capture zone per Jones et al. (1996), neither location is within the SRWMD model capture zone (Jones et al., 1996) or within the 100-year capture zone based on the DWRMv3 MODPATH analysis presented in this report. Sample location 22930 (X) is just upgradient of the 100-year capture zone based on the DWRMv3 MODPATH, but is outside of the two capture zones identifed by Jones et al. (1996).

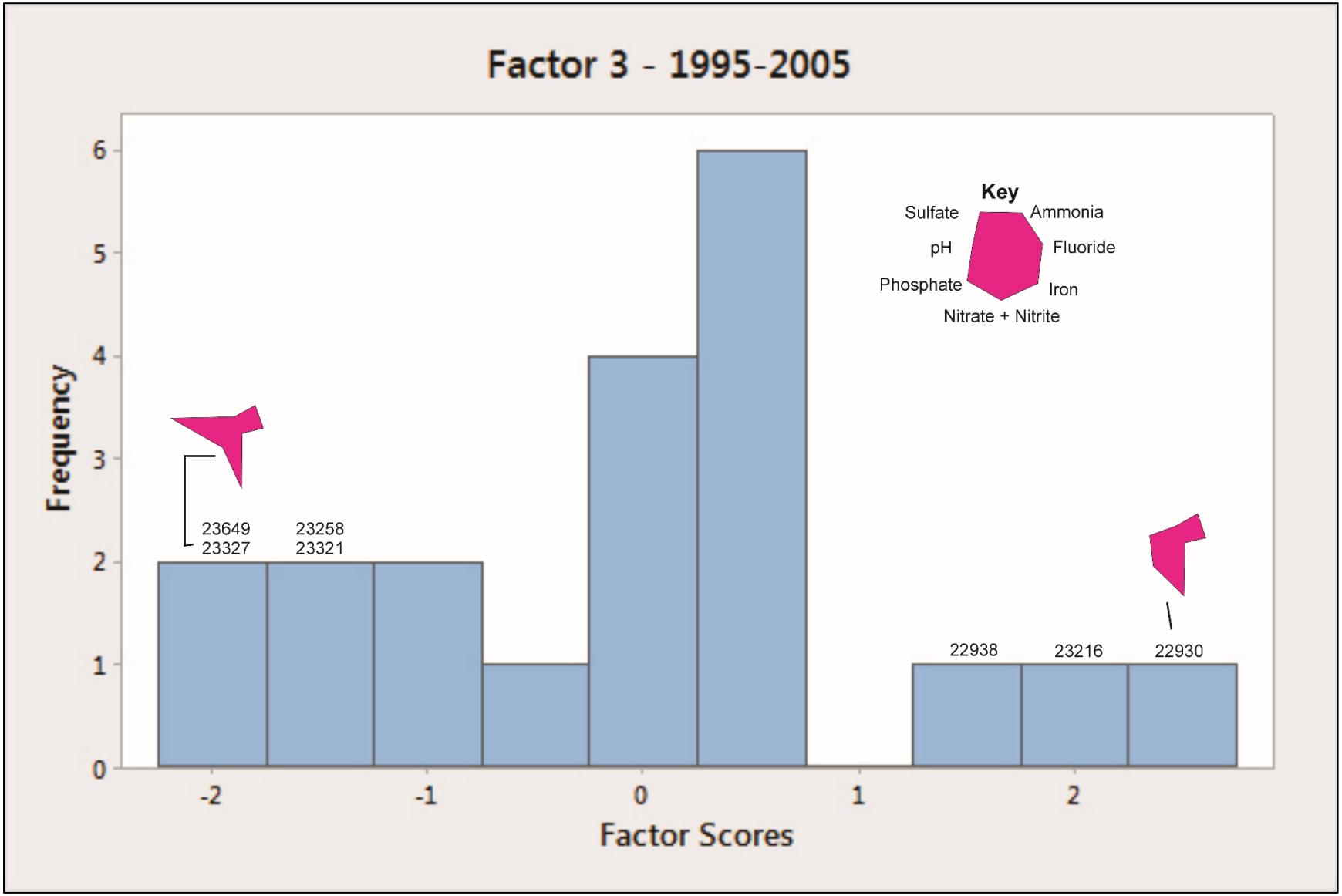


Figure 5-9. 1995-2005 Factor 3 histogram. Positive: Nitrate+Nitrite signal. Negative: Iron/Orthophosphate signal.

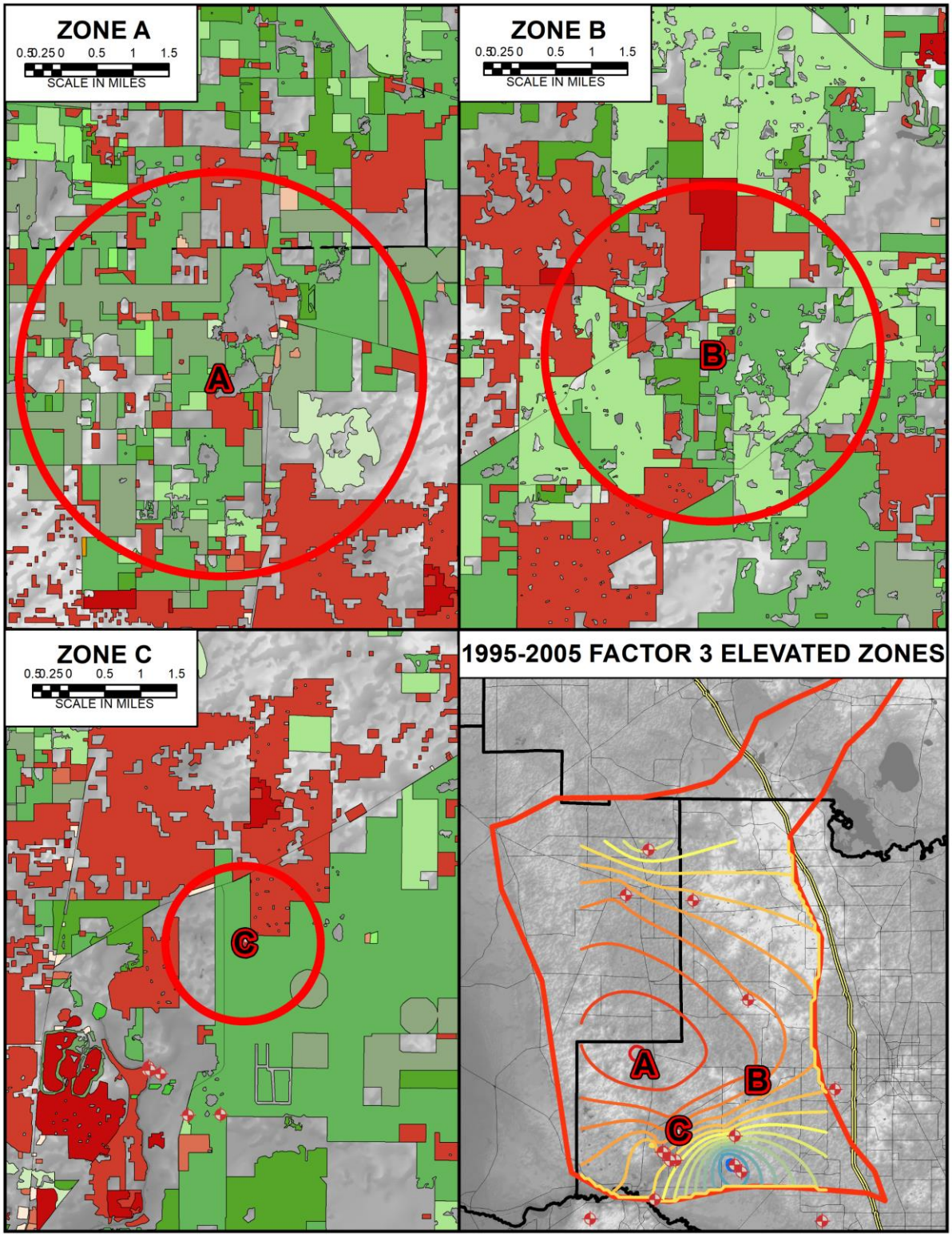


Figure 5-10. 1995-2005 Factor 3 elevated factor score zones (nitrite+nitrate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. A: highest factor score. B: second highest factor score. C: third highest factor score. See Figure 3-2 for the land use color key.

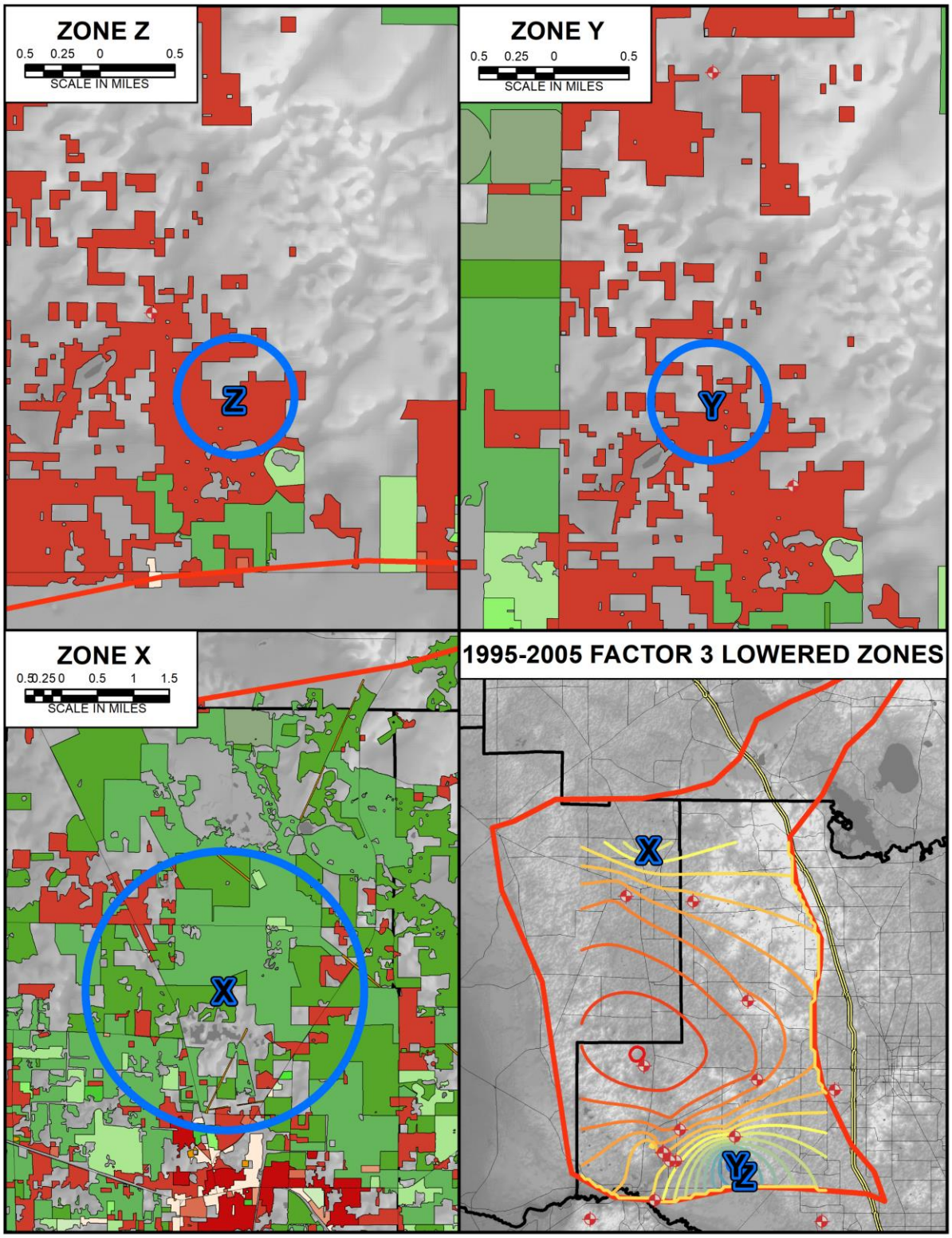


Figure 5-11. 1995-2005 Factor 3 lowered factor score zones (iron/orthophosphate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. See Figure 3-2 for the land use color key.

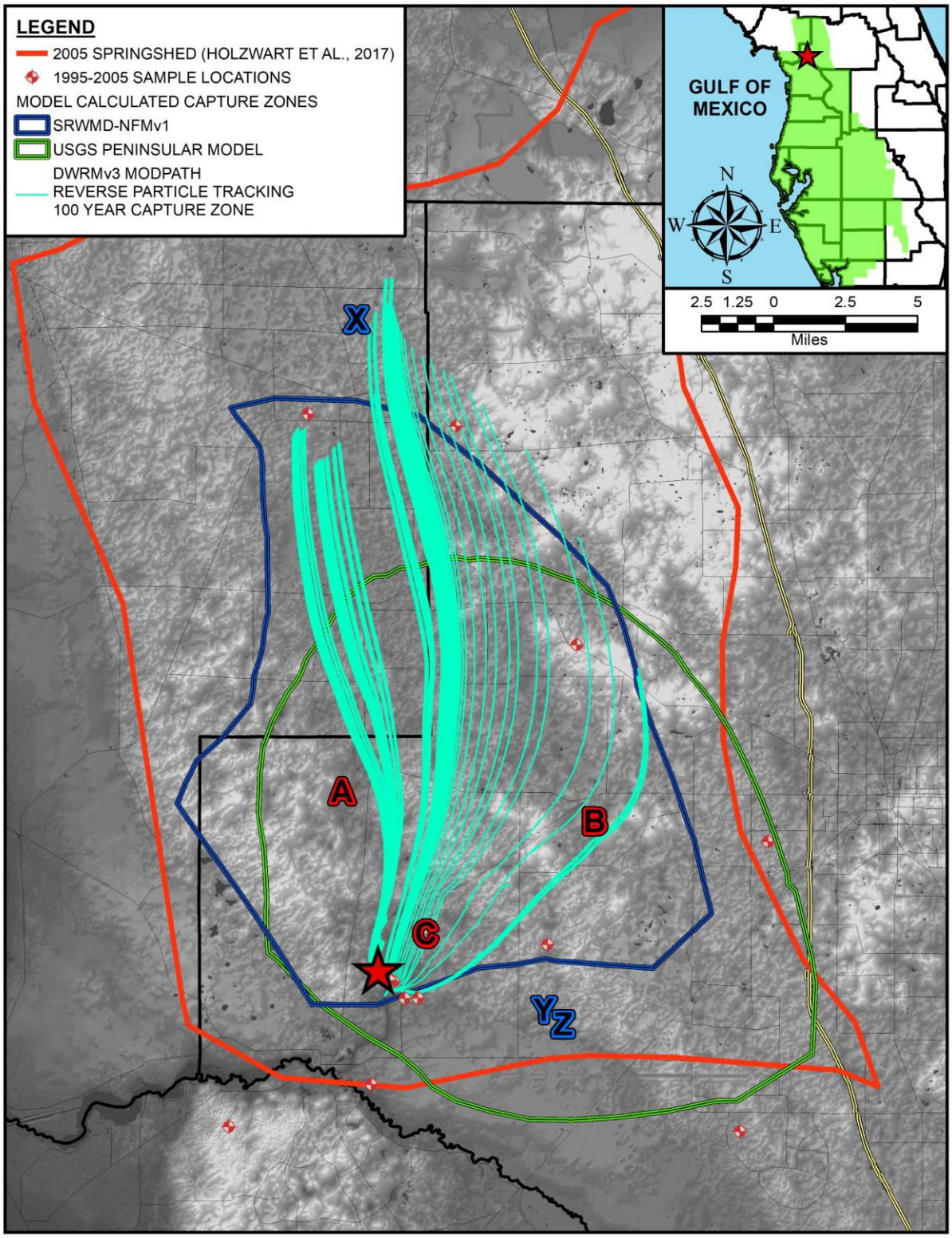


Figure 5-12. 1995-2005 Factor 3 elevated and lowered factor score zone (nitrate+nitrite signal and iron/orthophosphate signal) locations and simulated capture zones identified on Figure 2-12. A: highest factor score. B: second highest factor score. C: third highest factor score. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. Red Star: Rainbow Springs Group location.

5.3 2005-2015 Source Water Delineation

5.3.1 Factor 2

The distribution of Factor 2 scores (Figure 5-13) suggests a more-or-less normal distribution of scores with one outlier. This outlier (sample 22916) has a high factor score. The majority of samples are characterized by low iron concentrations and relatively elevated concentration for the other analytes. The positive outlier has a distinctive fingerprint with elevated ammonium, iron, phosphate, and pH.

There is an area on the extreme western side of the study area where iron and ammonium plot as high concentrations. This area is within and down gradient from the Brooksville Ridge and the springs. As depicted on Figure 5-13, the three highest factor scores were at sample points 22916, 23248, and 726932 (A, B, and C, respectively on Figures 5-14 and 5-16), while the three lowest factor scores were at sample points 23216, 23218, and 22938 (Z, Y, and X, respectively on Figures 5-15 and 5-16).

While the highest factor score location (sample location 22916 [A]) was located within the Brooksville Ridge, the wells with water that resulted in the second and third highest factor scores (23248 and 726932 [B and C, respectively]) are within the Williston Karst Plain. Sample location 23351 was located in predominantly low to medium density residential use based on the 2010 land use maps[5] (Figure 5-14), while sample locations 23248 and 726932 (B and C, respectively) were located outside of the springshed as defined by Holtwart et al. (2017). As depcited on Figure 5-26, the highest and third highest factor score locations (A and C, respectively) are within or in close proximity to one or the other 100-year capture zones identified by Jones et al. (1996), but not both and none of the three highest factor score locations were along flowpaths based on the DWRMv3 MODPATH analysis presented in this report.

The wells with water that had the lowest Factor 3 scores are within the Williston Karst Plain and the Fairfield Karst Hills. As depicted on Figures 2-7 and 2-8, the lowest factor scores are in areas with prominant cave systems and swallets, as well as suspected subsidence events. All sample locations were predominantly agricultural areas with nearby low residential land use areas based on the 2010 land use maps (Figure 5-15). The lowest factor score sample location 23216 (Z) and the third lowest factor score location 22938 (X) are located within the capture zone delineated by Jones et al. (1996) and within the 100-year capture zone based on the DWRMv3 MODPATH analysis presented in this report. Sample location 23218 (Y) is outside of the simulated 100-year capture zones, but within the District's springshed (Holtwart et al., 2017).

5.3.2 Factor 3

The frequency distribution for Factor 3 scores (Figure 5-17) shows a simple, "bell-shaped" histogram with no outliers. The highest factor-scare sample (23246) has an unusual "C" shaped pattern with low relative iron concentration and relatively high fluoride conentrations. In contrast, the sample with the lowest score (23260) has a characteristic "dagger-shaped" pattern with high nitrate + nitrite and low phosphate concentrations.

Factor 3 represents negative magnesium and sulfate. Nitrate + nitrite is also a contributing analyte to this factor, so Factor 3 appears to represent fertilizer and soil amendment applications. As depicted on Figure 5-17, the three highest factor scores were at sample points 23351, 23248, and 23216 (A, B, and C, respectively on Figures 5-18 and 5-20), while the three lowest factor scores were at sample points 23260, 23290, and 23298 (Z, Y, and X, respectively on Figures 5-19 and 5-20).

[5] Note the 2015 land use map has not been released or uploaded to the District website. As such, the 2010 land use map was used in this investigation.

The samples with the highest factors scores are from within the Williston Karst Plain and the Fairfield Karst Hills. As depicted on Figures 2-8 through 2-9, both of these areas have prominent nearby swallets and suspected subsidence events. Sample location 23351 was located in predominantly low to medium density residential land use based on the 2010 land use maps (Figure 5-18), while sample location 23216 was located within an agricultural use area. As depcited on Figure 5-20, the highest and third highest factor score locations (A and C, respectively) are within or in close proximity to the 100-year capture zones identified by Jones et al. (1996) and are along flowpaths based on the DWRMv3 MODPATH analysis presented in this report. Sample location 23216 (B) was outside of springshed delineation (Holtzwart et al., 2017).

The samples with the lowest Factor 3 scores were from within the Williston Karst Plain. As depicted on Figures 2-7 and 2-8, the lowest factor scores are in areas with suspected subsidence events. While sample location 23260 (Z) was located in predominantly low residential land use areas based on the 2010 land use maps (Figure 5-19), sample locations 23290 and 23298 (Y and X, respectively) were located within an agricultural land use area. The three lowest factor scores all were located within the two 100-year capture zones as presented by Jones et al. (1996); however only sample locations 23290 and 23298 (Y and X, respectively) fell along flowpaths based on the DWRMv3 MODPATH analysis presented in this report.

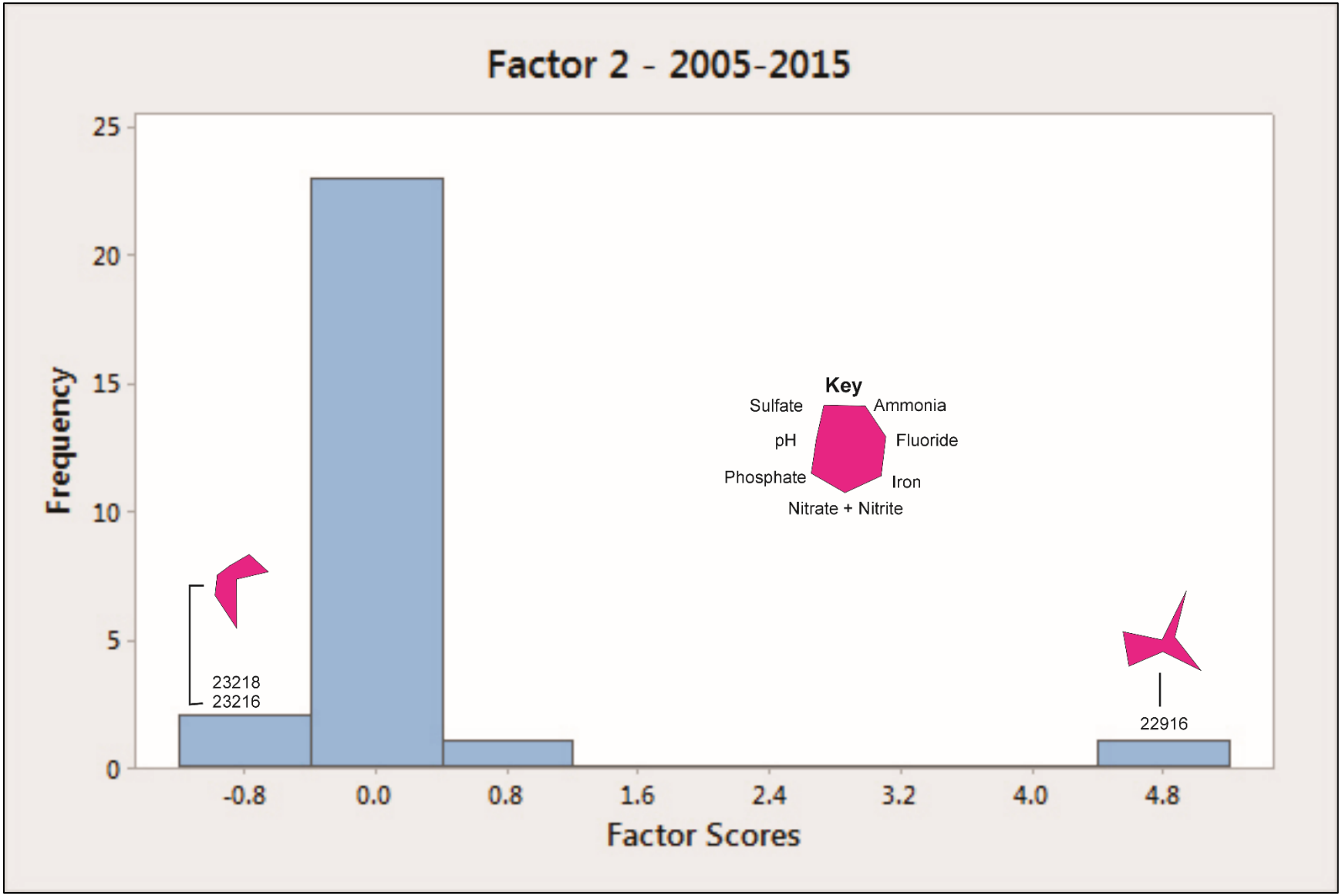


Figure 5-13. 2005-2015 Factor 2 histogram. Positive: Ammonium/Iron signal. Negative: Nitrate+Nitrite/Sulfate/ signal.

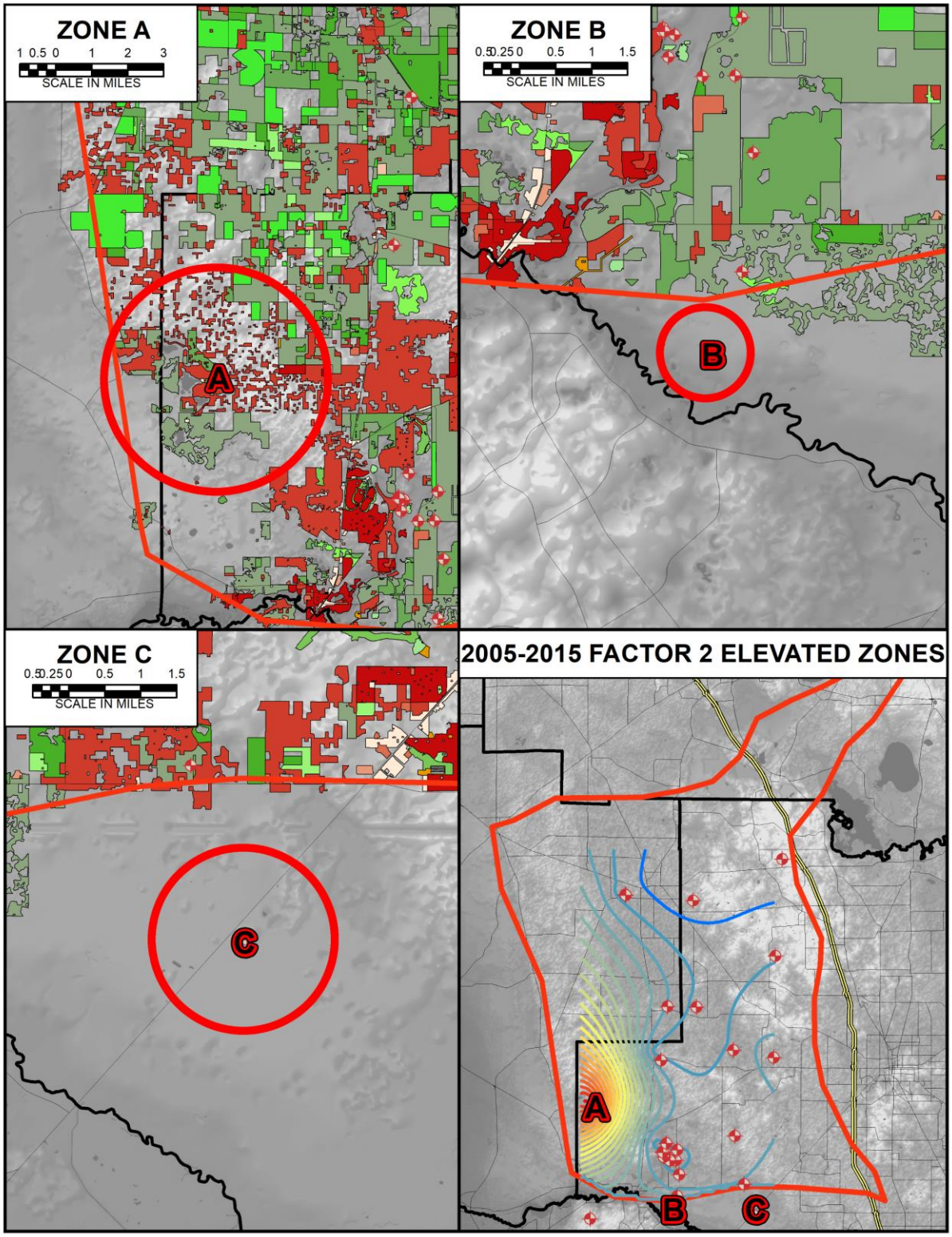


Figure 5-14. 2005-2015 Factor 2 elevated factor score zones (ammonium/iron signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. A: highest factor score. B: second highest factor score. C: third highest factor score. See Figure 3-3 for the land use color key.

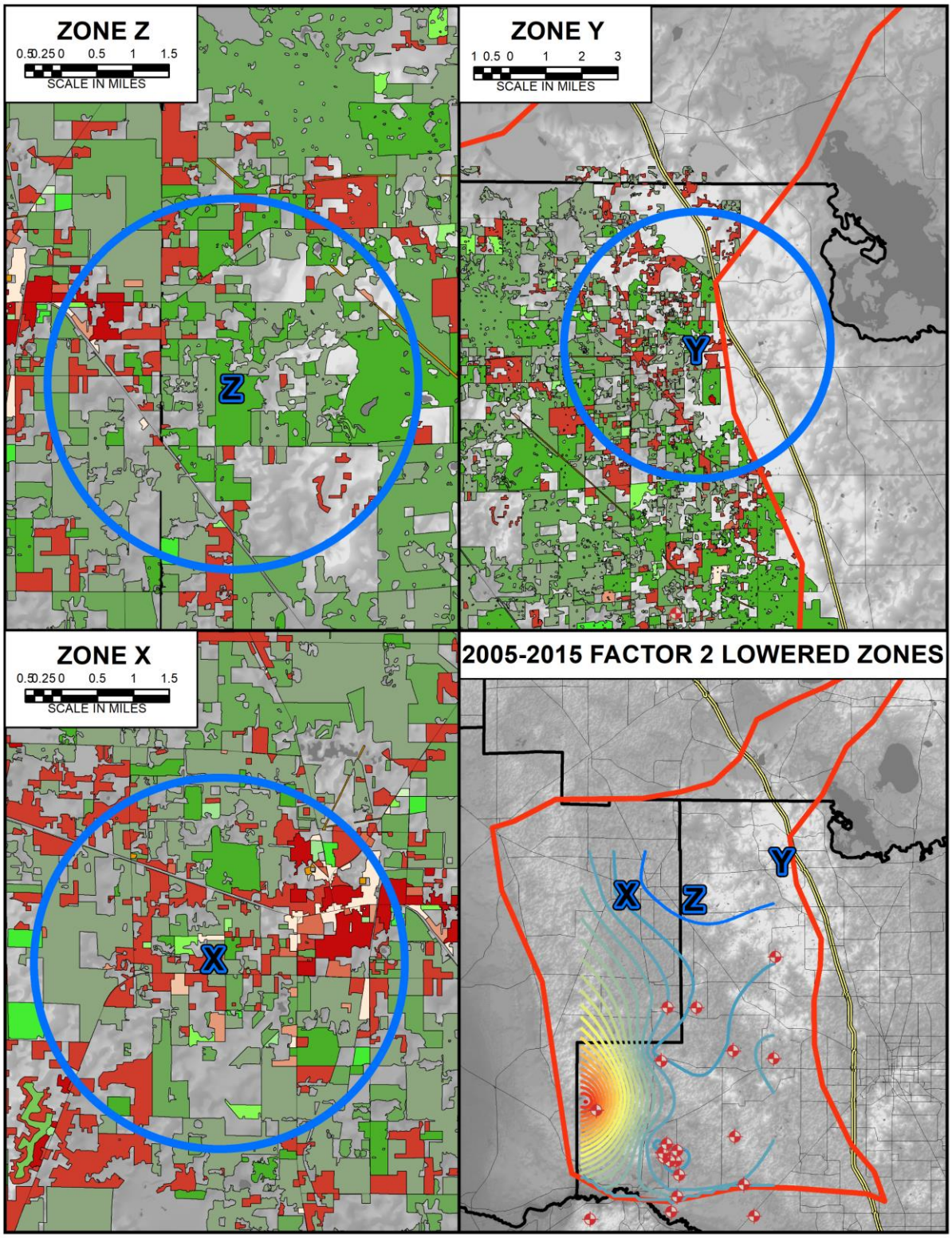


Figure 5-15. 2005-2015 Factor 2 lowered factor score zones (nitrate+nitrite/sulfate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. See Figure 3-3 for the land use color key.

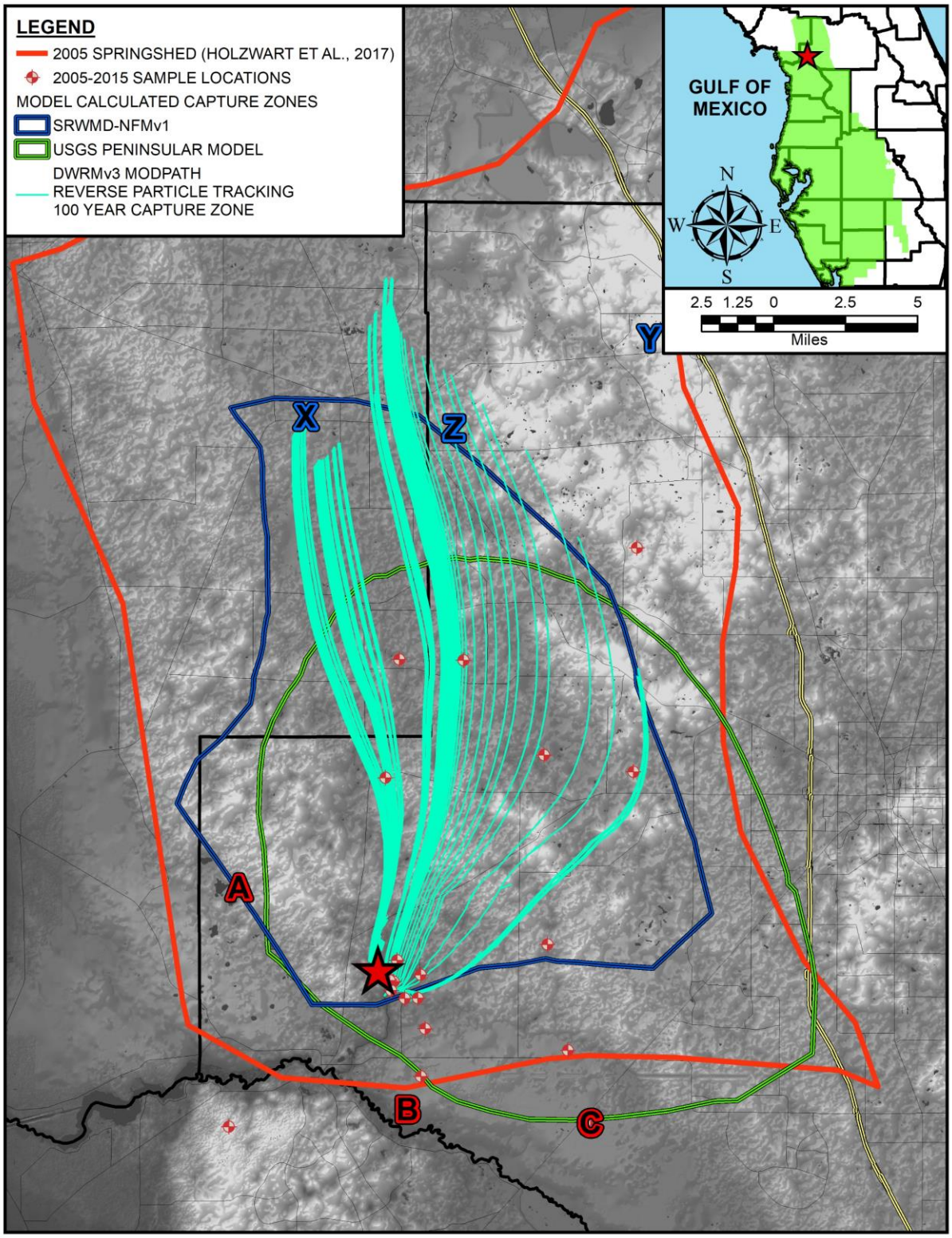


Figure 5-16. 2005-2015 Factor 2 elevated and lowered factor score zone (ammonium/iron signal and nitrate+nitrite/sulfate signal) locations and simulated capture zones identified on Figure 2-12. A: highest factor score. B: second highest factor score. C: third highest factor score. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. Red Star: Rainbow Springs Group location.

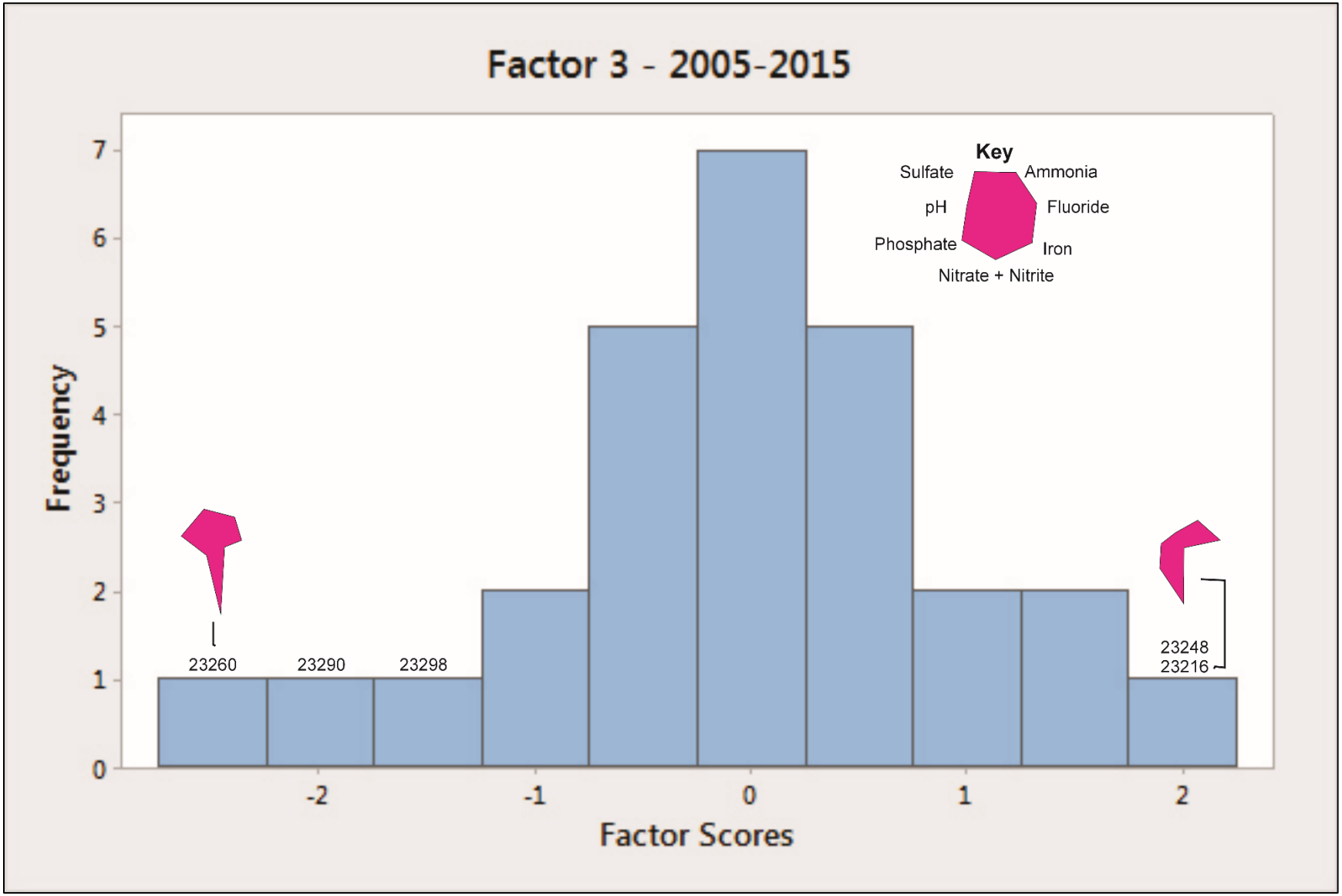


Figure 5-17. 2005-2015 Factor 3 histogram. Positive: Orthophosphate signal. Negative: Sulfate/Magnesium signal.

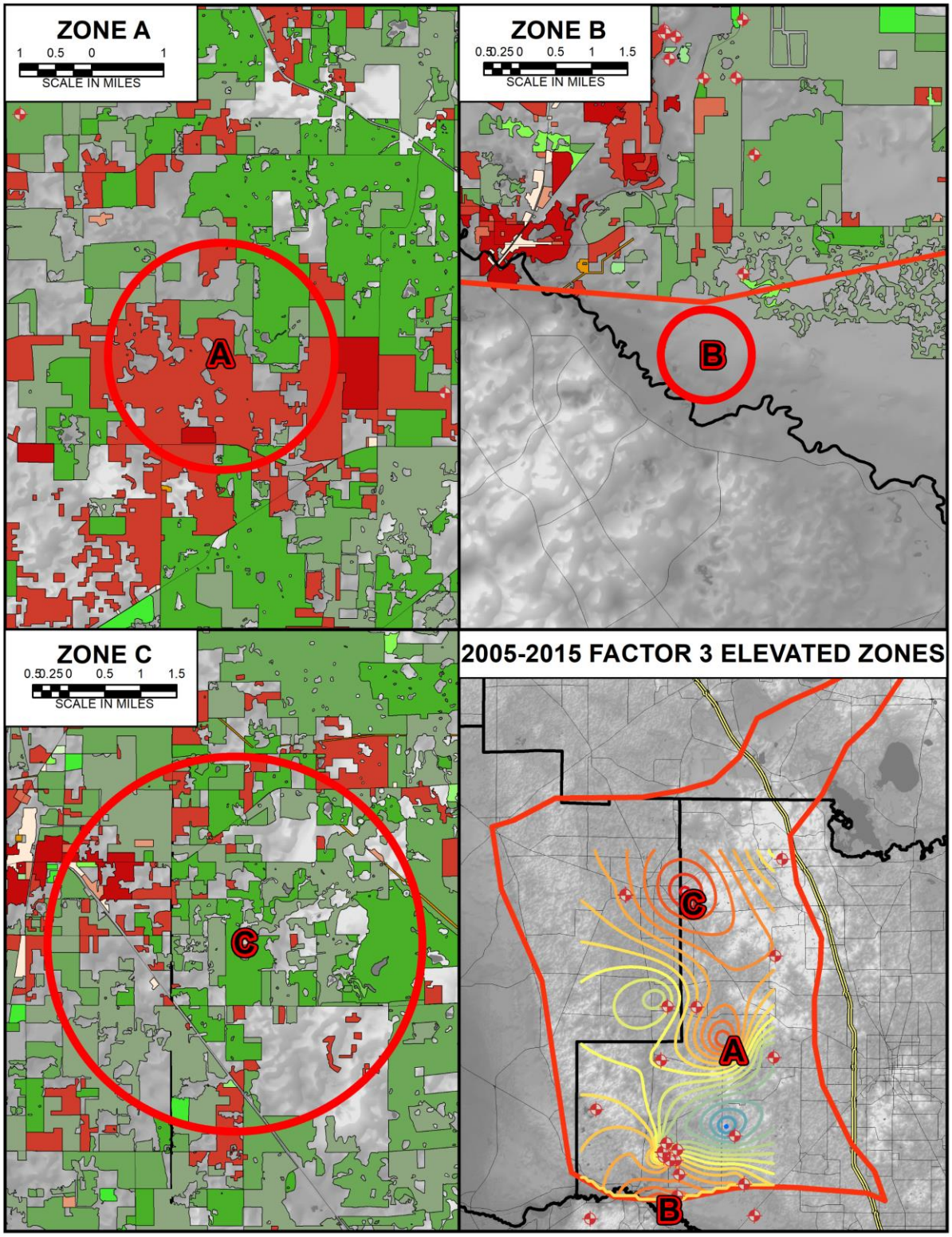


Figure 5-18. 2005-2015 Factor 3 elevated factor score zones (orthophosphate signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. A: highest factor score. B: second highest factor score. C: third highest factor score. See Figure 3-3 for the land use color key.

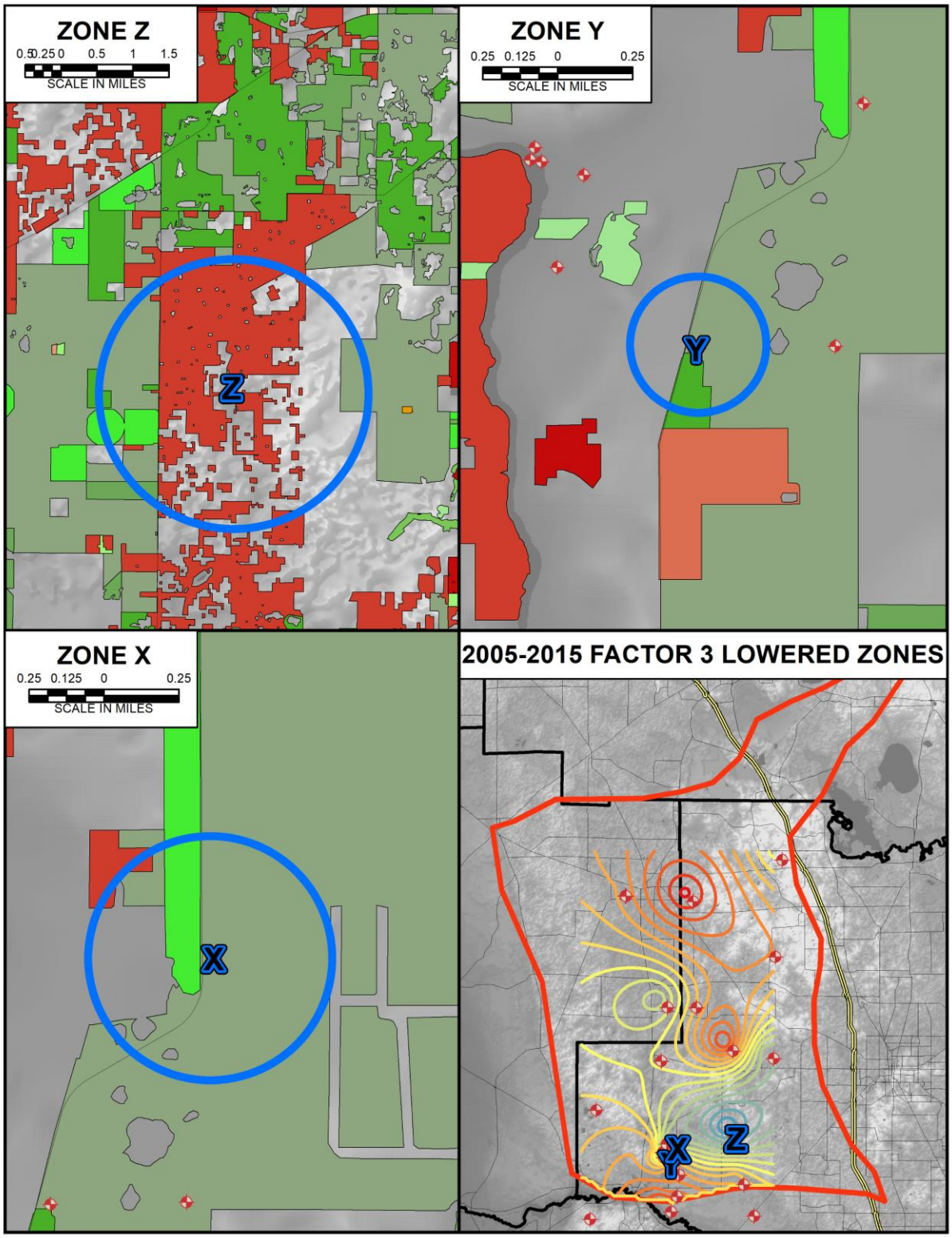


Figure 5-19. 2005-2015 Factor 3 lowered factor score zones (sulfate/magnesium signal). Note buffer surrounding the sample point with the elevated factor score is set to one-half the distance between the sample point of interest and the nearest sample point. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. See Figure 3-3 for the land use color key.

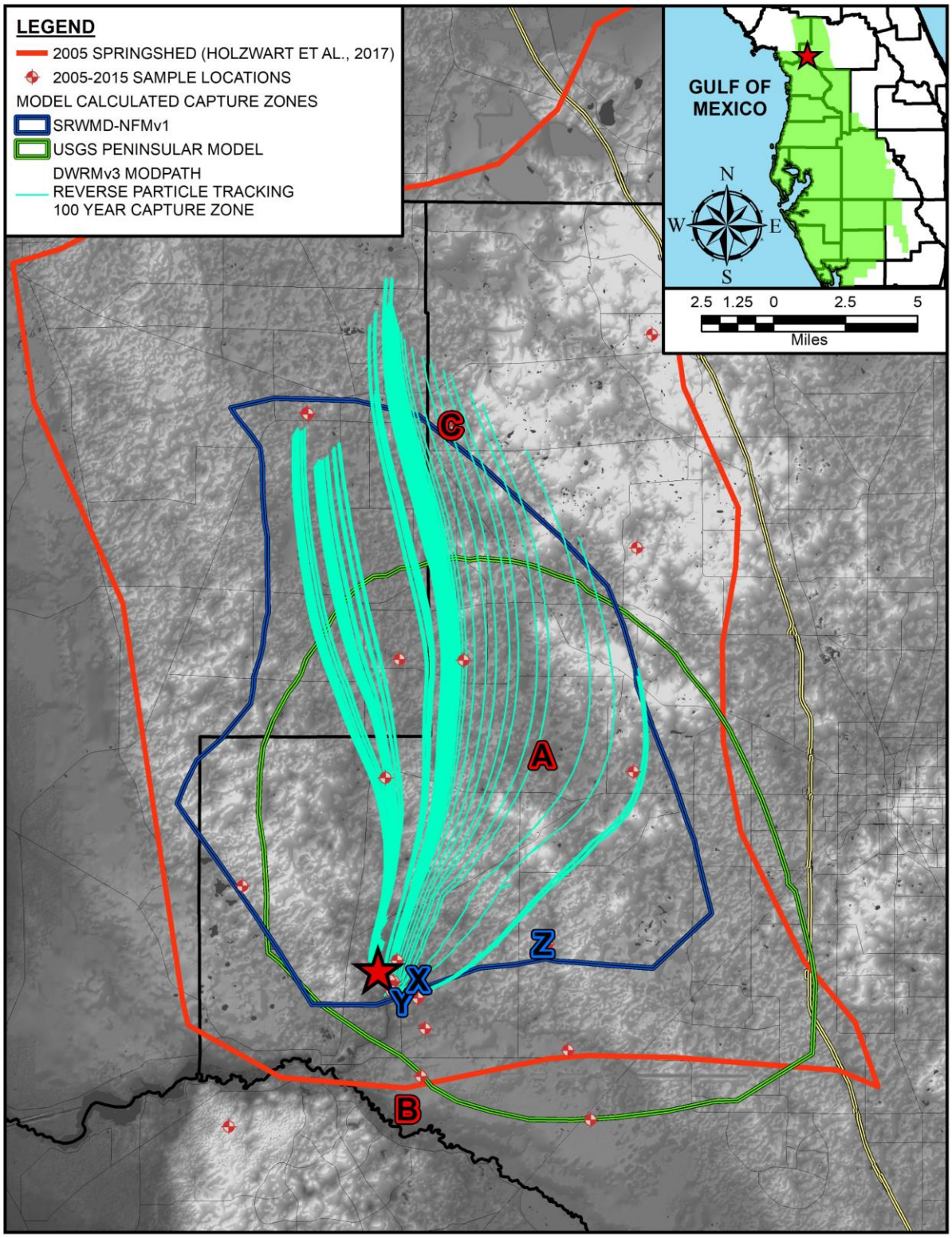


Figure 5-20. 2005-2015 Factor 3 elevated and lowered factor score zone (orthophosphate signal and sulfate/magnesium signal) locations and simulated capture zones identified on Figure 2-12. A: highest factor score. B: second highest factor score. C: third highest factor score. Z: lowest factor score. Y: second lowest factor score. X: third lowest factor score. Red Star: Rainbow Springs Group location.

6.0 SUMMARY AND CONCLUSIONS

6.1 Results

Based on the PCA and FA, for averaged water-quality data representing three time intervals (1985-1995, 1995-2005, and 2005-2015) the data can be clustered into three factors that represent geochemical and land use patterns. The first and stongest factor is related to rock-water interactions and rainfall contributions. The second and third factors are related to nutrient use and dispersion through the springshed.

There is evidence of hydrogeochemical groundwater domains that influence water quality in the springshed of the Rainbow Springs Group. While it was not within the scope of this project, these domains can be mapped to show locations with common groundwater-quality characteristics. As expected, the springs are influenced by rock-water interactions. Other nutrient-related fingerprints were identified in the study area that are of interest relative to water quality. Comparison of the geochemical patterns and land use suggest a relationship. The next step in a project like this is to field verify land uses at the hot spots where unusual nutrient loading may be present and attempt to identify areas where site-specific remedial actions are approprite. These patterns are important, because they demonstrate the utility of factor analysis and water-quality fingerprinting as data filtering and pattern recognition techniques for identification of nutrient sources and recharge areas.

The aqueous geochemical analyses aid in sorting out chemical variables related to hydrogeologic processes beyond strict lithologic controls. In this study, the technique improved the conceptual model for recharge to the UFA and included: (1) confirming that recharge rates and pathways are related to topographic regions; (2) identifying possible fracture traces that influence recharge and groundwater movement; and (3) delineating areas in the vicinity of the Rainbow Springs Group, where groundwater is impacted by artificial recharge from urban and agriculture sources.

There are, however, disadvantages to using the methodology described in this report. The method should not be treated as a “black box” and is only useful in correlation with sound aqueous geochemical, hydrogeological, and karst science principles and procedures. The system studies must be relatively simple and relatively free of gross pollution or other strong geochemical processes. In addition, some *a priori* knowledge of the hydrogeologic processes operating on the system and familiarity with relevant land uses in the area are required to interpret the factor solution.

The following summarizes the findings and conclusions of the study:

- Use of PCA and FA is a viable means for identifying sources and processes of groundwater quality in a springshed.
- In this study, the analysis was constrained in such a way as to force inclusion of analytes related to rock-water interactions into a single factor.
- The remaining two factors reflected analytes related to phosphate mining, fertilization and, possibly, soil amendment application.
- There are issues with the data provided for this study. These included:
    - Omission of different analytes in the suite measured at each sampling event resulted in missing factor score data.
    - The number of different sample locations within a given time interval is critical. There were not enough samples without missing data in the 1995-2005 sampling interval, for example.
    - Relatively small sample sizes and uneven spatial dispersion of sample sites.
- Averaging analyte values to build a more comprehensive data set that incorporated analytes that were infrequently sampled appears to be a viable approach for improvement of the data set.

- "Hot spot" delineations, based on the cluster analyses, identified areas of elevated nutrient concentrations, primarily fertilizer use most-likely related to agricultural activities in the Brooksville Ridge and Williston Karst Plain geomorphic provinces. This was also reflected in the geochemical fingerprinting over the three 10-year time frames evaluated.
    - These geochemical signatures predominantly fall within the 100-year capture zones identified in this report.
    - The 100-year capture zone aligned fairly well with photolineaments and Williston Karst Plain karst-related features, such as sinkholes, swallets, and cave systems, identified in this report.

6.2 Post-Pilot Program Recommendations

Based on the results of this investigation, WRA recommends a two-step approach as a follow-up from this pilot program. First, WRA suggests a new round of water-quality sampling of all wells and springs within the springshed should be completed. This sampling program should include all pertinent analytes and should be completed over a relatively brief timeframe. The analytical data should then be evaluated with the geochemical/geostatistical methodologies completed for this evaluation. This dataset would be representative of current existing conditions.

Second, based on the finding of the proposed current existing conditions and the finding of the three 10-year time periods evaluated in this report, all identified "hot spots" or probable spring-protection areas should be ranked based on factor score, proximity to the springs group, and potential contribution percentage to specific spring vents. This ranking would be used for improving protection areas and optimizing the effectiveness of the protection areas through recommended engineered design solutions and/or best management practices. The recommendation matrices should include, but are not limited to the following: overall estimated cost; environmental implications; permitability; funding potential; sustainability; public acceptance; and water-quality reliance.

Some possible remedial design measures may include water-quality treatment, isolation of karst features, stormwater management alternatives, land-use and nutrient application measures, and other techniques with the goal of preserving the water resource as a groundwater recharge or surface water supply after treatment. Additionally, there may be opportunities for natural water-quality enhancement and habitat generation through wetland treatment systems. Note that these recommendations may be specific to a single facility (or type of facility) or they may represent a limited area where karst conditions have localized and enhanced nutrient-rich recharge. As a result, the recommended mitigation measures may vary in scope and scale of implementation.

In addition to the recommended remedial-design solutions, source-area specific best management practices, if they exist, should be evaluated to assure that the implemented design will function as prescribed. This may include, but is not limited to, recommending land-use restrictions following remedial implementation; springs protection through local involvement or maintenance of the proposed remedial system; and/or District land procurement.

7.0 ACKNOWLEDGMENTS

The following Southwest Florida Water Management personnel made significant contributions to this study. We would like to thank: Mr. E. DeHaven, P.G. for bringing the proposal for this pilot project to fruition; the SWFWMD Springs Team, specifically Mr. R. Basso, P.G. and Mr. D. DeWitt, P.G., for assistance in data interpretation and manuscript review; and Ms. B. Nordheim-Shelt for management of the project. Special thanks Mr. J. Loper, P.E. at Interflow Engineering, LLC for text and figure draft review and input, as well as non-SWFWMD project management.

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APPENDIX A:
GEOCHEMICAL DATA

Analytes													
Location	Ammonia (N) (Dissolved)	Calcium (Dissolved)	Chloride (Dissolved)	Fluoride (Dissolved)	Iron (Dissolved)	Magnesium (Dissolved)	Nitrate-Nitrite (N) (Dissolved)	Orthophosphate (P) (Dissolved)	pH (Total)	Potassium (Dissolved)	Sodium (Dissolved)	Specific Conductance (Total)	Sulfate (Dissolved)
22916	0.01	40.00	4.10	0.08	1213.92	4.90	0.01	0.14	7.84	0.10	3.30	216.00	1.79
22917	0.00	59.00	5.30	0.12	20.00	4.80	1.01	0.05	7.43	0.05	2.90	337.00	7.50
22918	0.01	50.00	5.60	0.10	20.00	3.90	1.17	0.05	7.69	0.20	3.20	289.00	9.80
22920								0.04	7.24			448.00	
22922	0.06	68.00	5.90	0.23	702.99	6.70	0.01	0.03	7.32	0.50	3.90	407.39	2.74
22923	0.01	77.00	4.40	0.15	44.00	2.90	1.34	0.05	7.29	0.20	4.30	374.00	3.30
22925	0.01	66.00	4.60	0.08	30.00	1.40	0.39	0.07	7.36	0.05	3.40	404.11	6.00
22930	0.01	84.70	4.08	0.13	8.59	2.18	0.73	0.07	7.04	0.29	2.09	396.47	7.94
23020	0.07	42.95	4.92	0.10	178.88	2.45	0.01	0.07	7.79	0.20	3.82	176.59	2.12
23216	0.01	100.00	5.20	0.20	7.00	1.30	0.55		7.10	0.10	3.40	437.63	3.10
23217	0.04	2.60	8.20	0.10	6900.00	1.40	1.60		6.28	0.10	8.40	133.00	8.30
23221	0.01	74.00	4.90	0.15	0.45	2.50	0.95	0.10	7.34	0.30	3.60	373.42	3.19
23229	0.17	203.96	13.64	0.49	57.53	36.95	0.01	0.05	7.47	2.10	10.84	1159.01	540.00
23246	0.28	329.00	12.00	1.16	49.60	32.00	0.01	0.05	6.98	1.10	8.00	1456.00	715.00
23248	0.00	52.00	7.10	0.19	21.45	2.80	0.36	0.40	7.53	0.20	4.80	267.33	5.20
23252	0.02	60.00	10.00	0.08	0.45	0.90	0.84	0.05	7.46	0.05	5.00	320.50	6.00
23254	0.00	66.00	4.60		26.00		0.13	0.04					5.80
23257	0.00	108.00	5.30	0.05	27.39	1.70	0.42	0.06	7.46	0.20	3.50	410.66	3.00
23261	0.01	56.00	6.00	0.14	58.99	5.00	0.58	0.06	7.71	0.20	4.00	337.47	55.00
23267	0.01	37.00	3.10	0.08	67.97	3.90	0.01	0.03	7.63	0.05	2.40	195.00	6.20
23271	0.01	70.00	4.20	0.14	90.99	11.00	0.56	0.13	7.31	0.20	3.40	430.00	25.00
23272	0.00	25.00	7.00	0.08	10.00	4.10	1.99	0.03	8.20	0.10	4.40	165.92	6.05
23273	0.01	55.00	4.40	0.13	90.00	10.00	0.13	0.09	7.66	0.20	3.40	357.00	29.00
23278	0.01	34.58	4.03	0.09	18.69	5.10	0.43	0.03	7.83	0.10	2.56	208.14	11.79
23281	0.02	45.50	4.14	0.07	30.00	3.90	0.67	0.04	7.79	0.05	2.28	245.50	10.44
23282	0.01	38.33	4.07	0.08	20.60	4.23	0.71	0.04	7.84	0.08	2.49	219.22	10.67
23283	0.01	58.00	4.50	0.14	20.00	6.70	0.75	0.03	7.54	0.20	3.80	457.68	24.00
23286	0.01	40.26	4.08	0.11	22.12	3.57	0.96	0.04	7.82	0.08	2.46	220.70	8.51
23287	0.01	32.13	4.45	0.07	24.26	3.41	1.43	0.04	7.83	0.07	2.47	221.56	10.81
23290	0.02	51.65	5.29	0.13	12.47	6.08	0.86	0.02	7.72	0.20	3.47	308.50	36.20
23291	0.01	50.48	5.14	0.12	17.68	5.94	0.89	0.02	7.77	0.20	3.43	301.59	31.04
23292	0.01	48.00	4.00	0.10	91.98	2.10	0.69	0.06	7.96	0.05	2.40	268.00	8.05
23293	0.00	37.00	4.90	0.10	14.14	2.70	2.68	0.04	7.79	0.30	2.90	227.47	8.00
23295	0.01	44.00	5.00	0.13	16.12	4.70	0.34	0.03	7.75	0.30	3.30	290.00	29.00
23296	0.03	67.00	5.50	0.16	49.60	6.20	0.02	0.05	7.72	0.20	3.50	407.00	70.00
23299	0.01	63.00	4.10	0.26	20.98	6.70	0.90	0.03	7.75	0.10	3.40	333.00	11.00
23300	0.02	55.89	4.46	0.12	20.75	5.67	1.09	0.03	7.58	0.09	2.91	316.83	7.93
23301	0.01	63.00	3.98	0.14	12.65	6.40	0.83	0.02	7.54	0.10	3.30	331.00	8.80
23302	0.01						0.98	0.03	7.50			325.45	
23303	0.01	27.00	4.20	0.07	12.65	5.20	0.48	0.06	8.02	0.05	2.60	185.00	10.00
23310	0.01	26.00	3.50	0.09	13.42	4.60	0.22	0.04	8.56	0.10	2.90	150.00	4.05
23312	0.01	44.00	4.00	0.09	13.42	13.00	0.22	0.06	8.39	0.20	3.60	250.35	36.00
23313		4.90	3.30		48.00	0.60		0.01	7.07	0.07	1.90	38.00	3.40
23314	0.01	55.00	5.20	0.23	16.73	19.00	0.32	0.09	8.17	0.30	3.70	439.00	146.00
23315	0.01	24.00	2.70	0.07	0.14	4.10	0.24	0.02	8.24	0.10	2.30	148.88	5.74
23317	0.01	35.33	3.87	0.07	18.09	4.05	0.87	0.03	7.95	0.08	2.78	195.02	6.69
23319	0.03	25.37	3.36	0.09	26.35	3.42	0.90	0.03	8.09	0.08	2.28	149.95	5.61
23321	0.03	20.07	3.12	0.06	27.80	3.11	0.46	0.02	8.39	0.08	2.06	124.46	4.81

Analytes													
Location	Ammonia (N) (Dissolved)	Calcium (Dissolved)	Chloride (Dissolved)	Fluoride (Dissolved)	Iron (Dissolved)	Magnesium (Dissolved)	Nitrate-Nitrite (N) (Dissolved)	Orthophosphate (P) (Dissolved)	pH (Total)	Potassium (Dissolved)	Sodium (Dissolved)	Specific Conductance (Total)	Sulfate (Dissolved)
23322	0.01	34.46	3.69	0.09	12.82	4.41	0.32	0.03	7.63	0.10	2.41	201.45	6.41
23325	0.01	41.43	4.06	0.07	24.88	4.52	0.98	0.02	7.79	0.08	2.53	235.31	5.61
23326	0.03												
23327		34.27	4.15		6.32	3.70							
23328		20.00	3.00	0.05	30.00	2.50							
23329	0.02	30.71	3.55	0.09	30.00	3.80	1.03	0.03	7.95	0.14	2.37	182.42	5.30
23330	0.01	37.85	3.89	0.04	14.55	4.39	0.85	0.02	7.84	0.08	2.43	218.35	5.03
23332	0.01	22.02	6.41	0.05	3.04	2.65	0.70	0.03	8.59	0.07	3.85	120.49	1.58
23333	0.01	19.05	3.00	0.08	1.59	1.12	0.29	0.04	8.60	0.05	1.96	103.65	2.10
23337	0.01	43.00	2.80	0.10	3.00	2.10	0.69		7.53	0.20	2.00	236.41	5.80
23339	0.01	111.36	16.88	0.31	20.00	12.00	0.53	0.03	7.45	0.50	7.40	428.99	160.62
23342	0.01	82.00	6.80	0.14	49.50	4.10	0.70	0.02	7.28	0.10	4.80	382.00	27.00
23343	0.01	65.00	5.60	0.16	15.49	6.50	1.24	0.03	7.55	0.30	4.00	383.00	51.00
23344	0.01	80.00	6.50	0.19	21.45	5.70	1.36	0.03	7.33	0.20	4.10	413.18	38.00
23345	0.01	81.05	4.81	0.10	10.86	1.00	2.70	0.10	7.18	0.20	3.20	447.39	3.01
23346	0.01	36.00	3.50	0.09	19.49	0.70	2.82	0.05	7.61	0.05	3.30	194.96	1.95
23347	0.00	85.00	7.80	0.22	37.42	6.20	0.79	0.03	7.21	0.30	5.60	470.00	22.00
23349	0.04	101.20	11.32	0.65	14.23	18.44	0.01	0.03	7.35	1.25	9.06	566.81	71.33
23351	0.01	92.00	16.00	0.11	12.65	1.10	0.21	0.02	7.15	0.05	5.90	442.71	1.95
23352	0.07	195.00	35.00	0.63	217.72	40.00	0.01	0.03	7.33	1.70	21.00	1240.00	510.00
23353	0.03	51.06	3.83	0.08	23.70	2.15	1.06	0.03	7.59	0.45	2.30	231.33	6.80
23354	0.00	21.00	3.80	0.07	30.98	2.40	0.84	0.03	8.40	0.05	2.30	140.00	2.00
23356	0.01	53.00	5.00	0.29	8.94	7.10	0.27	0.03	7.57	0.30	3.90	319.00	7.15
23357	0.01	105.00	5.10	0.15	28.46	2.80	1.07	0.08	7.06	0.10	3.60	493.28	4.15
23358	0.01	77.00	4.40	0.11	17.32	6.10	0.89	0.03	7.37	0.10	3.70	392.50	10.00
23359	0.01	79.00	8.50	0.20	3.00	5.50	0.39		7.20	0.10	5.20	400.70	2.10
23361	0.01	60.00	5.10	0.30	0.45	8.60	0.15		7.39				
23362	0.01	85.00	5.00	0.16	90.00	4.60	0.43	0.04	7.18	0.10	3.30	440.00	6.05
23364	0.01	112.00	15.00	0.10	12.65	2.00	1.14	0.09	7.00	0.10	19.00	601.64	12.00
23366	0.01	34.00	3.30	0.14	51.96	3.90	1.10	0.03	8.33	0.05	2.50	207.00	6.80
23368	0.01	35.00	3.30	0.15	58.48	4.00	1.09	0.04	8.16	0.05	2.40	207.96	6.15
23371	0.00	24.00	2.80	0.08	0.14	3.70	0.22	0.02	7.97	0.10	2.60	143.00	2.10
23371			12.20									455.00	0.94
23373	0.02	26.00	2.90	0.10	60.00	3.40	0.11	0.02	8.28	0.05	2.10	157.00	2.74
23374		3.00	5.34		74.00	0.90		0.05	7.16	0.40	3.70	50.00	6.24
23375		2.79	5.48		38.00	0.80		0.01	6.40	0.30	3.50	49.00	5.83
23376	0.18	57.00	4.30	0.87	1977.37	7.20	0.01	0.07	7.51	0.10	3.50	311.00	0.95
23377		3.69	4.98		75.00	0.90		0.02	7.14	1.20	3.50	55.00	4.96
23378	0.01	23.00	3.00	0.07		2.30	0.10	0.02	8.18	0.05	2.20	138.00	1.58
23381	0.01	12.00	2.20		17.00		0.18	0.06					1.60
23382	0.02	19.00	2.70	0.12	11.83	2.30	0.17	0.09	8.35	0.10	2.10	95.40	
23415	0.01	27.00	3.50	0.06	40.00	2.60	0.04	0.06	8.23	0.20	2.30	200.00	11.00
23651		2.19	18.22		37.00	0.70		0.01	6.84	0.07	4.01	41.00	3.46
26379	0.01	45.00	6.40	0.10	27.39	4.50	0.67	0.12	7.33	0.10	4.00	244.00	5.95

Loadings After Equimax Rotation			
Analytes	**F!**	**F!**	**F!**
Ammonia	0.4585	-0.7798	-0.0730
Calcium	0.8570	-0.3079	-0.2394
Chloride	0.8387	-0.0329	-0.1149
Fluoride	**0.5757**	-0.6996	-0.1642
Iron	-0.2601	-0.7297	-0.3592
Magnesium	0.8129	**-0.4484**	0.1587
Nitrate+Nitrite	-0.0629	0.6238	-0.1772
Orthophosphate	-0.0997	-0.0500	-0.6841
pH	-0.4768	-0.0662	0.7138
Potassium	0.8333	-0.3390	0.0810
Sodium	0.8175	-0.0216	-0.1907
Sp. Conductance	0.9070	-0.2958	-0.1929
Sulfate	0.8426	**-0.4263**	0.1072
Interpretation	***Rock-water interactions + rainfall***	***Nitrate, neg corr w/ Ammonia, F, Fe***	***Phosphate component, neg w/ pH***

Factor Score Coefficients		
C1	C2	C3
-0.0395	-0.3194	-0.0008
0.1373	0.0084	-0.1134
0.1944	0.1456	-0.0255
-0.0018	-0.2525	-0.0651
-0.2308	-0.4220	-0.2789
0.1295	-0.0846	0.1971
0.0897	0.3199	-0.1599
-0.0858	-0.0262	-0.5385
-0.0780	-0.1452	0.5216
0.1495	-0.0213	0.1351
0.1856	0.1496	-0.0864
0.1556	0.0230	-0.0737
0.1372	-0.0660	0.1586

Factor Scores					
Location	Northing	Easting	FS1	FS2	FS3
22916	489513.7825	1750932.01	-1.5823	-2.0335	-1.6699
22917	515935.0908	1769970.297	-0.0566	0.5446	-0.4205
22918	515760.8733	1770779.025	-0.0686	0.5158	-0.0551
22920	575082.5221	1826764.475			
22922	581161.1018	1813318.492	-0.3866	-1.5197	-0.6574
22923	562397.0612	1814170.049	0.1368	0.6841	-0.8236
22925	538207.2028	1862823.22	-0.1854	0.2398	-0.7183
22930	510659.8783	1855807.891	0.0214	0.4131	-1.0794
23020	522264.9607	1715956.924	-0.6112	-0.8077	-0.0460
23216	528710.2057	1835301.545			
23217	557164.0563	1860752.57			
23221	561951.4115	1812959.06	0.0259	0.4835	-1.1119
23229	580820.9942	1705842.916	3.4671	-1.8789	1.2249
23246	534249.129	1705365.549	3.4675	-3.5268	-0.3141
23248	519794.4532	1709758.301	-0.6444	0.0088	-4.0107
23252	580386.7543	1736354.335	0.1541	0.6985	-0.4997
23254	546446.5826	1717448.818			
23257	573259.5077	1722228.559	0.0548	0.3503	-0.5147
23261	550250.1462	1744506.68	-0.0334	0.1148	-0.0609
23267	549280.8552	1720780.946	-0.5707	-0.2363	0.3098
23271	512471.3711	1721906.366	-0.0315	0.0230	-1.2243
23272	510027.6187	1732217.565	-0.0782	0.9445	0.5968
23273	512472.2526	1721905.353	-0.2043	-0.3077	-0.2468
23278	519324.8098	1727335.246	-0.4041	-0.0044	0.5671
23281	522529.9809	1730453.953	-0.3940	0.0812	0.2697
23282	522618.6998	1730454.649	-0.3778	0.1590	0.4408
23283	518977.4224	1729153.635	0.1239	0.2703	0.0755
23286	522530.3421	1730555.97	-0.3528	0.2908	0.2704
23287	521738.2095	1730339.606	-0.2984	0.5949	0.1658
23290	519337.3619	1730299.775	0.0187	0.2402	0.4602
23291	519848.4222	1730067.622	-0.0098	0.3111	0.4983
23292	523080.0634	1724691.553	-0.4985	0.0123	0.1867
23293	532925.567	1734964.808	0.0440	1.2910	-0.2057
23295	536495.967	1741921.776	-0.1174	0.0233	0.5632
23296	532902.404	1727893.374	-0.0330	-0.4218	0.3151
23299	516453.2227	1733907.258	-0.0673	0.1044	0.2072
23300	517307.2206	1733351.583	-0.0824	0.3514	0.0173
23301	516512.3915	1734313.093	-0.0368	0.2952	0.0931
23302	505866.5965	1734354.119			
23303	517920.4356	1731480.681	-0.5129	0.0154	0.5818
23310	499151.1831	1719433.318	-0.6761	-0.3702	1.4680
23312	510979.3022	1725951.387	-0.2582	-0.3716	1.2703
23313	486072.0154	1724752.652			
23314	510732.637	1731002.735	0.2495	-0.5095	0.9039
23315	516839.0211	1731727.089	-0.6390	-0.2397	1.3621
23317	516496.9975	1733750.535	-0.3780	0.2573	0.6589
23319	516443.2102	1733838.612	-0.5580	-0.0094	0.8145
23321	516364.3206	1733616.687	-0.7364	-0.3576	1.3893

Eigenvalues		
Eigenvalues	**Percent**	**Cumulative Percent**
7.0315	70.9561	70.9561
1.6103	16.2501	87.2062
1.2678	12.7938	100.0000
Total	9.909582171	

Factor Scores					
Location	Northing	Easting	FS1	FS2	FS3
23322	516785.5045	1732367.676	-0.4066	0.0447	0.4103
23325	516560.2694	1733589.698	-0.2870	0.3621	0.4187
23326	516863.3534	1733506.756			
23327	513153.2857	1714530.231			
23328	516686.6796	1733708.418			
23329	516774.6417	1733506.075	-0.4232	0.1724	0.6000
23330	516527.7809	1733679.715	-0.3511	0.2848	0.5471
23332	506312.9559	1735060.409	-0.4837	0.1240	1.4231
23333	505425.8947	1735063.954	-0.8780	-0.3432	1.4558
23337	585999.6249	1759051.678			
23339	584722.7298	1777453.554	1.3530	0.3526	0.0607
23342	547787.1534	1751485.232	0.2448	0.4456	-0.3848
23343	562861.6308	1751947.757	0.2939	0.5270	0.0002
23344	562862.5163	1751947.755	0.3841	0.6583	-0.4477
23345	574657.333	1753032.376	0.2826	1.5506	-1.8953
23346	579368.6149	1758982.852	-0.1352	1.4207	-0.7401
23347	545429.837	1763914.048	0.5417	0.5134	-0.5799
23349	554611.439	1763130.496	1.5319	-0.7322	0.2832
23351	544919.1585	1774916.377	0.6518	0.7531	-0.6363
23352	542899.842	1747962.371	4.8762	-0.3003	0.5456
23353	523440.1286	1742993.873	-0.1548	0.2818	0.1128
23354	497428.6032	1773984.551	-0.6501	0.0764	1.1513
23356	579459.9776	1803523.074	-0.0004	-0.1883	0.2569
23357	546395.6113	1790981.514	0.2003	0.6441	-1.5541
23358	577931.6581	1792921.358	0.1024	0.4583	-0.3190
23359	550881.0984	1795114.024			
23361	568828.8007	1801325.249			
23362	541935.8207	1780793.969	0.0262	0.1417	-0.6953
23364	540570.7948	1798068.73	1.6465	1.8713	-2.2282
23366	510807.9357	1750699.09	-0.5071	0.0499	0.9928
23368	510808.817	1750698.077	-0.4929	0.0836	0.6746
23371	497919.8923	1743175.5	-0.5780	-0.1020	0.9902
23373	495082.7651	1743388.563	-0.7641	-0.5145	1.2677
23374	487925.6882	1747567.383			
23375	490142.8097	1744390.866			
23376	489409.0612	1744120.378	-2.0209	-5.3929	-2.4054
23377	485626.3352	1752468.658			
23378	491827.4258	1749362.224			
23381	492514.2368	1764714.76			
23382	492253.6202	1765926.001			
23415	485357.5447	1711007.589	-0.6723	-0.3692	0.8878
23651	503830.8349	1710465.839			
26379	518266.1859	1728752.205	-0.2092	0.4021	-1.2443

Eigenvalues		
Eigenvalues	Percent	Cumulative Percent

Analytes													
Location	Ammonia (N) (Dissolved)	Calcium (Dissolved)	Chloride (Dissolved)	Fluoride (Dissolved)	Iron (Dissolved)	Magnesium (Dissolved)	Nitrate-Nitrite (N) (Dissolved)	Orthophosphate (P) (Dissolved)	pH (Total)	Potassium (Dissolved)	Sodium (Dissolved)	Specific Conductance (Total)	Sulfate (Dissolved)
20183		59.73	4.86			5.21		0.03	7.79	0.19	2.71	246.37	13.60
22919	0.02	42.00	4.40	0.08	14.14	4.00	3.27	0.03	7.78	0.05	2.50	238.50	3.40
22923	0.01						1.20	0.06	7.25			377.50	
22930	0.01	88.50	3.60	0.10	3.00	1.74	0.49	0.07	7.26	0.62	2.16	447.00	4.90
22938	0.01	68.91	4.73	0.09	24.04	3.23	1.78	0.03	7.22	0.29	2.72	355.53	3.92
23216	0.01	111.00	4.70	0.18	4.00	1.31	0.56	0.04	7.15	0.10	3.42	520.00	3.20
23229	0.20	211.00	15.00	0.50	4.00	36.80	0.01	0.05	7.69	2.19	9.84	1200.00	550.00
23245		50.90	5.84		420.00	9.59				0.79	6.60		0.18
23255		29.36	2.35		53.55	0.85		0.01	7.52	0.15	1.08	156.91	0.26
23258	0.01	37.00	2.70	0.10	87.98	9.90	0.01	0.04	8.07	0.20	2.40	227.00	20.00
23259	0.01	53.00	3.40	0.12	80.00	4.20	0.01	0.05	7.72	0.05	2.50	290.00	3.95
23259	0.01	53.00	3.40	0.12	80.00	4.20	0.01	0.05	7.72	0.05	2.50	290.00	3.95
23260	0.01	44.00	4.70	0.15	7.75	4.30	1.17	0.04	7.77	0.20	3.50	289.06	35.00
23287	0.01	43.36	4.80	0.08	27.60	3.76	1.31	0.03	7.68	0.15	2.77	251.36	11.82
23290	0.01	53.39	6.09	0.12	24.69	6.39	0.95	0.03	7.63	0.22	3.69	325.09	35.22
23300	0.01	56.15	5.19	0.12	24.16	5.92	1.22	0.03	7.50	0.13	3.02	322.14	7.43
23313		4.94	4.96		98.06	0.67		0.01	5.85	0.24	2.46	42.00	2.82
23319	0.01	22.86	3.84	0.10	23.07	3.59	1.14	0.03	8.09	0.09	2.37	152.88	4.60
23321	0.01	17.81	3.08	0.07	30.10	3.09	0.57	0.03	8.25	0.09	2.05	125.91	4.14
23325	0.01	40.58	4.47	0.12	23.11	4.83	1.40	0.04	7.71	0.10	2.62	239.36	4.66
23327	0.01	17.30	3.40	0.10	5.00	3.04	0.50	0.03	8.49	0.10	2.03	120.00	4.30
23332	0.02						0.95	0.01					
23337	0.01	43.10	2.50	0.10	4.00	2.07	0.64	0.03	7.90	0.20	1.89	230.00	4.60
23349	0.03	92.80	13.00	0.67	3.00	17.20	0.01	0.02	7.37	1.68	9.09	590.00	70.00
23353	0.01	37.60	4.10	0.10	8.00	2.00	0.83	0.02	7.64	0.50	2.30	252.00	5.60
23359	0.01	79.10	8.10	0.21	11.00	5.48	0.42	0.02	7.39	0.20	5.14	437.00	1.90
23371			12.20									455.00	0.94
23374		3.16	6.80		165.23	1.02		0.01	5.71	0.23	3.35	52.34	5.20
23375		3.16	6.36		68.14	0.96		0.01	5.74	0.30	3.30	54.06	6.04
23377		3.59	5.35		63.46	1.13		0.01	6.24	0.85	2.61	56.11	7.14
23380		14.00	5.00			4.95		3.35		25.50	1.68		1.70
23414		44.67	7.72			4.23		0.04	7.23	0.64	4.66	261.72	14.90
23421		23.31	3.38		24.28	6.56			8.09	0.16	2.52	176.49	6.34
23435	0.01						0.18		8.18			130.00	
23649	0.01	23.00	4.20	0.05	20.00	3.80	0.54	0.02	8.32	0.10	2.60	130.00	4.00
23651		2.03	7.66		81.13	0.83		0.01	5.77	0.28	4.22	47.29	2.25

Rotated Factor Loadings			
Analyte	F1	F2	F3
Ammonia	0.8960	0.1556	-0.1038
Calcium	0.7357	0.6253	-0.1021
Chloride	0.9022	0.2894	0.1924
Fluoride	0.8297	0.2738	0.1009
Iron	-0.2561	-0.1985	-0.7830
Magnesium	0.9601	0.1091	-0.1453
Nitrate+Nitrite	-0.3817	0.0735	0.6159
Orthophosphate	-0.0663	0.5632	-0.7106
pH	0.0072	-0.9366	-0.1570
Potassium	0.9105	0.2763	0.0296
Sodium	0.9093	0.2789	0.1121
Sp. Conductance	0.8121	0.5567	-0.0808
Sulfate	0.9040	0.1544	-0.1521
Interpretation	***Rock-water interactions***	***Rock-water interaction***	***Fertilizer components***

Factor Score Coefficients		
FS1	**FS2**	**FS3**
0.1517	-0.0838	-0.0571
0.0248	0.2441	-0.0461
0.1269	0.0057	0.1253
0.1150	0.0084	0.0693
-0.0146	-0.0910	-0.4794
0.1740	-0.1269	-0.0831
-0.0911	0.1363	0.3737
-0.1282	0.3522	-0.4182
0.1887	-0.5947	-0.1158
0.1308	-0.0077	0.0264
0.1303	-0.0040	0.0764
0.0543	0.1861	-0.0346
0.1535	-0.0872	-0.0864

Factor Scores					
Location	**Northing**	**Easting**	**FS1**	**FS2**	**FS3**
20183	512919.3941	1714641.217			
22919	508751.8349	1768786.767	-0.5287	0.1022	1.5307
22923	562397.0612	1814170.049			
22930	510659.8783	1855807.891	-0.7875	2.0780	-0.7767
22938	501564.0238	1837480.952	-0.6349	1.1467	0.6650
23216	528710.2057	1835301.545	-0.4909	1.6877	0.2788
23229	580820.9942	1705842.916	3.7365	0.6439	-0.7716
23245	574083.9033	1709697.134			
23255	546758.8606	1722911.336			
23258	545414.295	1728561.528	-0.0600	-1.0586	-1.9170
23259	548333.6779	1725624.878	-0.5140	0.2356	-2.0955
23260	545512.4175	1740200.258	-0.2471	0.2260	0.2205
23287	521738.2095	1730339.606	-0.3960	0.0730	0.2169
23290	519337.3619	1730299.775	-0.0365	-0.0384	0.3856
23300	517307.2206	1733351.583	-0.3251	0.3881	0.3858
23313	486072.0154	1724752.652			
23319	516443.2102	1733838.612	-0.1993	-1.0010	0.3294
23321	516364.3206	1733616.687	-0.1384	-1.4357	-0.1735
23325	516560.2694	1733589.698	-0.4193	0.1081	0.2286
23327	513153.2857	1714530.231	0.0171	-1.7079	0.1504
23332	506312.9559	1735060.409			
23337	585999.6249	1759051.678	-0.3087	-0.4613	0.3564
23349	554611.439	1763130.496	1.8025	0.4035	1.0677
23353	523440.1286	1742993.873	-0.1734	-0.3824	0.9655
23359	550881.0984	1795114.024	0.1570	0.4663	0.7751
23371	497919.8923	1743175.5			
23374	487925.6882	1747567.383			
23375	490142.8097	1744390.866			
23377	485626.3352	1752468.658			
23380	505644.6846	1765951.655			
23414	507668.212	1713183.795			
23421	499993.8507	1710524.923			
23435	487045.8671	1711406.037			
23649	487026.7756	1706751.661	0.0607	-1.7094	0.2734
23651	503830.8349	1710465.839			

Eigenvalues		
Eigenvalue	Percent	Cumulative Percent
8.0213	72.3662	72.3662
1.6600	14.9759	87.3421
1.4030	12.6579	100.0000

Total 11.08428702

Analytes													
Location	Ammonia (N) (Dissolved)	Calcium (Dissolved)	Chloride (Dissolved)	Fluoride (Dissolved)	Iron (Dissolved)	Magnesium (Dissolved)	Nitrate-Nitrite (N) (Dissolved)	Orthophosphate (P) (Dissolved)	pH (Total)	Potassium (Dissolved)	Sodium (Dissolved)	Specific Conductance (Total)	Sulfate (Dissolved)
22916	0.14	34.86	5.93	0.07	1575.43	4.83	0.01	0.12	7.66	0.19	3.08	226.42	0.24
22918	0.01	54.30	7.56	0.11	12.50	4.71	2.21	0.03	7.29	0.28	3.67	315.73	10.11
22922	0.06		7.00	0.21			0.01	0.00	7.04			396.98	2.20
22937	0.01	72.24	5.41	0.09	26.34	3.37	1.69	0.04	7.32	0.28	2.68	366.26	4.70
22938	0.01	75.74	6.03	0.08	5.97	3.23	1.59	0.03	7.10	0.33	2.99	398.21	6.26
23020	0.02	41.53	5.41	0.09	23.41	2.34	0.03	0.05	7.50	0.25	3.08	240.06	5.61
23216	0.01	122.70	4.71	0.19	5.60	1.42	0.36	0.04	6.80	0.15	3.26	559.71	3.74
23218	0.01	69.28	11.21	0.82	4.76	6.62	1.64	0.01	7.14	0.21	6.84	400.62	3.72
23221	0.01	71.79	6.30	0.13	5.59	2.96	1.27	0.06	7.15	0.34	3.78	375.45	1.72
23242		142.81	11.49		196.08	16.34			7.81	1.27	8.72	762.53	80.11
23244		51.00	3.10		333.00	0.68			7.33	0.13	2.02	252.60	1.60
23248	0.01	44.44	9.54	0.17	32.11	2.11	0.01	0.32	7.36	0.37	4.03	256.19	5.68
23255		27.83	1.72		34.72	0.89		0.01	7.81	0.26	0.97	155.85	0.28
23260	0.01	51.93	9.66	0.10	7.42	5.08	3.22	0.02	7.48	0.59	18.47	374.61	44.72
23262		46.93			3.58	5.72		0.03	7.71	0.27	3.60	284.06	
23263		46.79			3.58	5.72		0.03	7.74	0.27	3.62	284.04	
23267	0.01	31.18	3.91	0.08	113.61	3.62	0.00	0.05	7.97	0.15	2.18	194.59	5.72
23268		46.86			3.58	5.70		0.03	7.49	0.27	3.58	285.34	
23269		46.20			3.51	5.69		0.01	7.97	0.27	3.64	280.80	
23277		46.93			3.51	5.67		0.03	7.86	0.29	3.71	282.62	
23285		45.90			3.59	5.62		0.03	7.67	0.23	3.33	274.47	
23287	0.01	45.87	6.24	0.08	5.04	4.17	1.75	0.03	7.56	0.30	3.23	271.54	13.16
23289		44.62			3.51	5.47		0.03	7.57	0.21	3.21	271.08	
23290	0.01	57.21	7.74	0.12	5.04	7.05	1.19	0.03	7.47	0.36	4.30	353.59	36.04
23292	0.01	50.44	4.77	0.07	4.76	3.04	0.21	0.05	7.62	0.17	2.44	277.01	7.83
23294		29.41			3.51	4.29		0.03	7.68	0.17	2.90	186.52	
23298	0.01	44.56	6.86	0.10	4.76	6.66	1.41	0.03	7.57	0.28	3.52	318.13	26.86
23300	0.01	60.87	6.60	0.13	5.04	6.65	1.43	0.03	7.26	0.24	3.42	354.70	9.27
23304			19.77									787.31	216.54
23305		57.15	13.42		22.83	7.53				0.36	4.28	572.37	118.16
23313		4.84	6.01		63.52	0.70		0.01	5.79	0.26	2.55	58.76	3.87
23315	0.01	21.23	3.97	0.06	4.76	3.86	0.46	0.03	8.09	0.18	2.22	149.51	4.20
23319	0.01	23.70	5.14	0.08	5.04	3.85	1.67	0.03	7.98	0.18	2.73	164.71	5.22
23321	0.01	20.35	4.62	0.06	5.04	3.49	1.26	0.03	8.10	0.18	2.50	145.12	4.65
23325	0.01	44.45	5.82	0.11	5.04	5.42	1.70	0.03	7.53	0.20	2.99	270.37	5.74
23351	0.01	117.38	93.38	0.09	7.08	2.22	3.69	0.04	6.87	0.27	29.96	767.14	2.39
23363	0.01	82.86	6.29	0.12	8.98	5.14	1.18	0.04	7.12	0.39	3.12	435.34	6.32
23374		2.66	7.40		43.47	0.99		0.01	5.58	0.23	3.50	48.76	5.41
23375		2.58	7.17		31.96	0.99		0.01	5.52	0.24	3.51	47.69	5.61
23377		3.03	5.34		29.83	1.06		0.01	5.86	0.59	2.50	41.78	3.76
23414		50.37	7.83			5.44		0.03	7.51	0.39	4.42	310.52	21.40
23421		23.76	3.46		8.14	6.47			7.95	0.22	2.62	181.21	7.15
23649	0.01	23.11	5.12	0.05	5.60	3.85	0.61	0.03	8.05	0.17	2.79	158.45	4.94
23651		2.40	9.50		27.28	0.77		0.01	5.67	0.12	4.48	49.77	1.97
665203		389.89	44.47		762.23	82.80			7.63	4.29	30.41	2143.15	1118.03

Analytes													
Location	Ammonia (N) (Dissolved)	Calcium (Dissolved)	Chloride (Dissolved)	Fluoride (Dissolved)	Iron (Dissolved)	Magnesium (Dissolved)	Nitrate-Nitrite (N) (Dissolved)	Orthophosphate (P) (Dissolved)	pH (Total)	Potassium (Dissolved)	Sodium (Dissolved)	Specific Conductance (Total)	Sulfate (Dissolved)
665234		121.45	9.78	1.60	4.95	14.01		0.00	7.49	1.26	6.52	725.44	209.19
670340	0.01	116.87	26.20	0.08	4.79	4.83	7.69	0.08	6.76	1.02	16.58	670.59	4.89
670341	0.01	69.57	18.49	0.09	4.76	4.71	7.77	0.04	7.12	0.81	9.29	458.83	6.32
709163		76.51	8.39		18.78	12.81			7.80	0.63	5.68	482.80	10.48
725438		194.25	31.29		62.08	45.19			8.01	1.92	15.55	1179.66	440.53
726932	0.04	51.78	4.67	0.08	111.72	1.56	0.06	0.05	7.56	0.26	3.17	268.41	16.54
737521		367.00	32.20		128.00	94.00			7.22	5.31	21.40	2050.20	1070.00
738458	0.01	49.02	6.14	0.11	4.67	5.66	2.00	0.03	7.47	0.21	3.06	299.50	5.83
750173		48.93	6.07	0.22	41.63	13.96		0.01	7.61	0.40	3.85	361.25	34.65
750867		67.73	7.28	0.25	4.11	12.92		0.07	7.25	0.57	4.35	445.85	3.49

Factor Loadings			
Analytes	**F1**	**F2**	**F3**
Ammonia	-0.0332	0.9710	0.0566
Calcium	0.8682	-0.1980	0.1954
Chloride	0.7480	-0.0451	0.1995
Fluoride	0.0933	-0.1689	-0.0206
Iron	-0.0452	0.9735	0.0302
Magnesium	-0.0450	0.0272	-0.8221
Nitrate+Nitrite	0.7331	-0.1215	**-0.4285**
Orthophosphate	0.0636	0.3967	0.3844
pH	-0.8428	0.1287	-0.1170
Potassium	0.6737	0.0033	**-0.4436**
Sodium	0.8209	-0.0447	-0.0983
Sp. Conductance	0.9546	-0.1660	0.0547
Sulfate	-0.0397	-0.1296	-0.6985
Interpretation	***Rock-water interactions, nitrate***	***Fertilizers (ammonia)***	***Iron, sulfate***

Factor Score Coefficients		
FS1	FS2	FS3
0.0579	0.4648	-0.0394
0.1845	-0.0523	0.1313
0.1675	0.0136	0.1216
0.0097	-0.0742	0.0014
0.0552	0.4671	-0.0546
-0.0139	0.0705	-0.4690
0.1548	0.0216	-0.2294
0.0436	0.1685	0.1896
-0.1828	0.0146	-0.0816
0.1496	0.0793	-0.2476
0.1821	0.0405	-0.0470
0.2052	-0.0206	0.0497
-0.0224	-0.0143	-0.3873

2005-2015 Factor Scores					
Location	**Easting**	**Northing**	**FS1**	**FS2**	**FS3**
22916	489513.7825	1750932.01	-0.1229	4.8386	0.0365
22918	515760.8733	1770779.025	-0.0938	-0.2777	-0.2464
22922	581161.1018	1813318.492			
22937	501289.0342	1837633.97	0.0348	-0.2253	0.5080
22938	501564.0238	1837480.952	0.2251	-0.3927	0.5252
23020	522264.9607	1715956.924	-0.5371	-0.0523	0.7963
23216	528710.2057	1835301.545	0.7082	-0.6730	1.8492
23218	564702.2876	1852042.199	0.2516	-0.6624	-0.3573
23221	561951.4115	1812959.06	0.1936	-0.2811	0.8463
23242	553271.8948	1707933.013			
23244	555531.303	1708352.152			
23248	519794.4532	1709758.301	-0.0795	0.5877	1.7013
23255	546758.8606	1722911.336			
23260	545512.4175	1740200.258	0.5526	-0.0529	-2.3009
23262	513097.2848	1714741.549			
23263	511404.7593	1713131.893			
23267	549280.8552	1720780.946	-1.0431	-0.0806	0.3799
23268	513816.0856	1717061.995			
23269	512746.1123	1715752.957			
23277	519779.3997	1721788.29			
23285	519100.3913	1730274.374			
23287	521738.2095	1730339.606	-0.3900	-0.2893	-0.2897
23289	517241.8103	1731493.282			
23290	519337.3619	1730299.775	-0.1930	-0.2303	-1.9154
23292	523080.0634	1724691.553	-0.5958	-0.3060	0.6589
23294	516628.303	1733515.708			
23298	522230.7206	1734611.482	-0.4102	-0.1519	-1.4802
23300	517307.2206	1733351.583	-0.1049	-0.2709	-0.6057
23304	524785.019	1740312.44			
23305	524763.7667	1741083.205			
23313	486072.0154	1724752.652			
23315	516839.0211	1731727.089	-1.1967	-0.2356	0.1365
23319	516443.2102	1733838.612	-0.9906	-0.2888	-0.0009
23321	516364.3206	1733616.687	-1.1407	-0.2877	0.1265
23325	516560.2694	1733589.698	-0.4719	-0.2814	-0.2591
23351	544919.1585	1774916.377	2.8906	-0.2718	1.5854
23363	530076.8244	1792309.766	0.3309	-0.2400	-0.0174
23374	487925.6882	1747567.383			
23375	490142.8097	1744390.866			
23377	485626.3352	1752468.658			
23414	507668.212	1713183.795			
23421	499993.8507	1710524.923			
23649	487026.7756	1706751.661	-1.1200	-0.2184	0.1459
23651	503830.8349	1710465.839			
665203	553295.9383	1707961.229			

Factor Loadings			
Analytes	F1	F2	F3

Factor Score Coefficients		
FS1	FS2	FS3

2005-2015 Factor Scores					
Location	Easting	Northing	FS1	FS2	FS3
665234	553410.5763	1708007.379			
670340	518344.4597	1792491.595	2.6434	0.1622	-0.9396
670341	561285.8512	1771840.08	1.4078	0.0835	-1.1798
709163	557481.9553	1815286.774			
725438	517973.6589	1737274.297			
726932	553411.4089	1707987.176	-0.4174	0.3064	0.6346
737521	553295.9381	1707961.229			
738458	517934.6243	1737271.429	-0.3308	-0.2084	-0.3380
750173	517959.4705	1737275.36			
750867	557483.739	1815291.82			

Eigenvalues		
Eigenvalue	Percent	Cumulative Percent
4.8017	55.7263	55.7263
2.1830	25.3354	81.0617
1.6318	18.9383	100.0000

Total 8.616569467