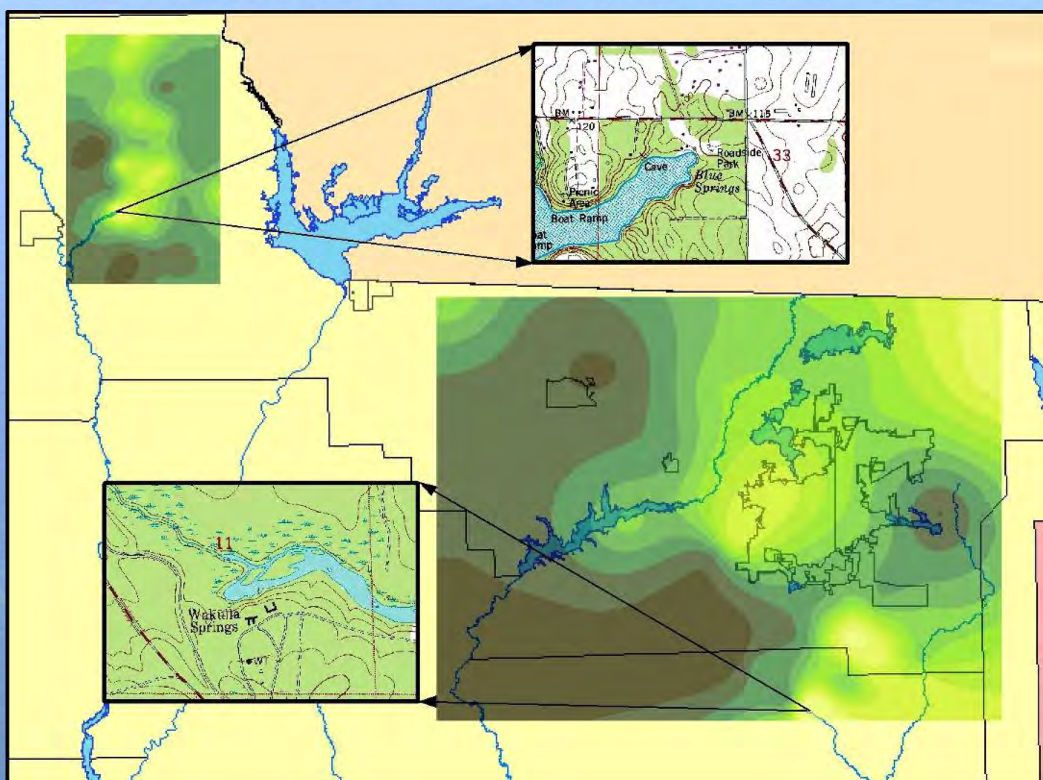
Ground Water Chemical Characterization of Jackson Blue Spring and Wakulla Springs, Florida

Water Resources Special Report 05-01



PREPARED BY:

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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GROUND WATER CHEMICAL CHARACTERIZATION OF JACKSON BLUE SPRING AND WAKULLA SPRINGS, FLORIDA

Water Resources Special Report 05-01

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Acknowledgements

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Introduction

In 2001, the Florida Legislature funded the first phase of the Florida Springs Initiative (FSI) to study and preserve the quality of Florida's springs. The Florida Department of Environmental Protection (FDEP), administrator of FSI funding, contracted with the Northwest Florida Water Management District (NWFWMD) to monitor first magnitude springs within the District, delineate springsheds, and perform other research regarding springs water quality and distribution. The 2004 Florida Legislature continued funding and FDEP requested project proposals for additional work. The NWFWMD proposed completion of a ground water chemical characterization of the Jackson Blue Spring and Wakulla Spring basins in an effort to aid in delineation of the spring basins. This study was performed under FDEP contract GW245 (July 2004) during the period of September 2004 through June 2005.

Two primary goals formed the foundation for this study. The first was to apply statistical methods (principle component analysis and hierarchical cluster analysis) for characterizing spring basin water quality developed in other areas of the state to two of the first magnitude springs within the Northwest Florida Water Management District. Previous works by Dalton and Upchurch (1978) and Jones, et al (1996) demonstrated the effectiveness of the statistical analysis of common ions in identifying intra-basin relationships and geochemical facies for Floridan Aquifer springs. The second objective was to determine whether the same statistical methods could be used to assist in the delineation of the spring basin boundary and/or the identification of the principle contribution area within the spring basin boundary.

Study Area and Hydrogeology

Jackson Blue Spring

Jackson Blue Spring is located within the Dougherty Karst Plain District, which encompasses the northern portions of Bay and Calhoun counties, all of Jackson County and most of Washington and Holmes counties. The Floridan Aquifer is recharged through the leaky confinement of the Intermediate System and discharges to springs and rivers throughout the Dougherty Karst Plain. The semi-confined condition of the Floridan Aquifer across the Dougherty Karst Plain allows for large amounts of local recharge, but also makes the Floridan Aquifer especially vulnerable to contamination from activities occurring on the land surface.

In Jackson County, the Floridan Aquifer is comprised of the Chattahoochee Formation, the undifferentiated Marianna/Suwannee Limestone, and the Ocala Limestone (Scott 1993 and Campbell 1993). The region is characterized by a thin and inconsistent confining Intermediate System. Contained within the Intermediate System may be a thin, minimally water-bearing surficial aquifer or minor, confined water-bearing zones. In this region the Floridan Aquifer itself is relatively thin, with a thickness of approximately 100 feet in north Jackson County, where it is composed of the Ocala Limestone only (Moore 1955). Continuing south, the Floridan plunges to approximately 500 feet in thickness with the addition of the younger Marianna, Suwannee, and Chattahootchee formations. The Floridan Aquifer, though relatively thin and only semi-confined in this area, is the primary source of water for consumptive use (i.e. public supply, domestic supply, irrigation, etc.). The Intermediate System generally thickens from north to south as well (Pratt et al. 1996).

Previous investigations in the study area indicate a ground water contribution area for Jackson Blue Spring of an approximate tear-drop shape extending north to just above the Florida-Alabama state line (Chelette, et al. 2002 and Jones and Torak 2004).

Wakulla Springs

Wakulla Springs is located near the western edge of the Woodville Karst Plain area, which includes southeastern Leon County and eastern Wakulla County. In this area the Floridan Aquifer is recharged through a thin layer of Quaternary sediments (Hendry and Sproul 1966). The unconfined condition of the Woodville Karst Plain allows for high rates of local recharge and also increases the vulnerability of the Floridan Aquifer to human impact.

In Gadsden, Leon and Wakulla counties, the Floridan Aquifer consists of the St. Marks Formation, the Suwannee Limestone, and the Ocala Limestone (Scott 1993 and Campbell 1993). The thickness of the aquifer increases from 1000 to 2000 feet, north to south. North of the Cody Scarp, an east-west trending physiographic feature of modest relief, the Floridan Aquifer becomes semi-confined with the addition of the Torreya and Miccosukee Formations, clastic units of variable thickness that may contain minor water-bearing zones. The limestone units comprising the uppermost Floridan Aquifer in the study area are the primary source of consumptive use and consist of the St. Marks Formation and the Suwannee Limestone (Pratt et al. 1996). Both units are of varying thickness within the study area due to karst and channel erosion features (Hendry and Sproul 1966).

Previous work by the USGS (Davis 1996) indicates a contribution area for Wakulla Spring trending north in a broad swath across Leon County into southern Georgia.

Data Collection and Analysis Methods

Sample sites were selected from the NWFWMD Well Inventory and Construction Permitting databases and conformed to the following requirements: wells must possess an open hole or screened interval entirely within the Floridan Aquifer, wells with in-place plumbing must be functioning with a sample withdrawal site located before any filtration equipment, and site location allows for adequate coverage of the study area. A total of twenty-nine ground water samples were collected from wells in the vicinity of Jackson Blue Spring within a three week period during October 2004. Thirty-one ground water samples were collected from wells in the vicinity of Wakulla Springs during a four week period in October and November 2004. In addition, seven water quality samples collected by Florida Geological Survey staff were added to the analysis of the Wakulla Springs basin. Water quality sampling was conducted in accordance with FDEP standard operating procedures listed under DEP-SOP-002/02 (revised 6/28/2004). Lab samples and equipment blanks were submitted to the FDEP Central Chemistry Lab for analysis. Field parameters and laboratory analyses are listed in following table.

Table 1. Field and Laboratory Parameters Collected for this Study

Analysis	**Reported Unit**
Alkalinity, Total (as CaCO3)	mg/L
Ammonia, Total (as N)	mg/L
Total Kjeldhal Nitrogen (TKN)	mg/L
Nitrate+Nitrite, Total (as N)	mg/L
Phosphorus, Total (as P)	mg/L
Orthophosphate, Dissolved (as P)	mg/L
Calcium, Total	mg/L
Magnesium, Total	mg/L
Sodium, Total	mg/L
Potassium, Total	mg/L
Chloride, Total	mg/L
Sulfate, Total	mg/L
Fluoride, Total	mg/L
Total Dissolved Solids (TDS measured)	mg/L
Temperature (field)	^{o}C
Specific Conductance (field)	S/cm
Dissolved Oxygen (field)	mg/L
pH (field)	su

Once the water chemistry results were received, the samples were separated into their respective basins. Individual parameters (variables) were then checked for normal distribution using Lilliefor's test (Arsham 2005). Parameters not passing the normality test were then transformed to more closely approximate a normal distribution. In order to allow the comparison of parameters with different units and widely ranging scales, the parameter results were converted into units of standard deviation. Parameters with significant results below the laboratory method detection limit were removed from the analysis to eliminate an artificial influence on variance within the population. In both spring studies, the parameters Ammonia and TKN were removed. Results below the method detection limit for the balance of the parameters were assigned the detection limit value.

Principle Component Analysis

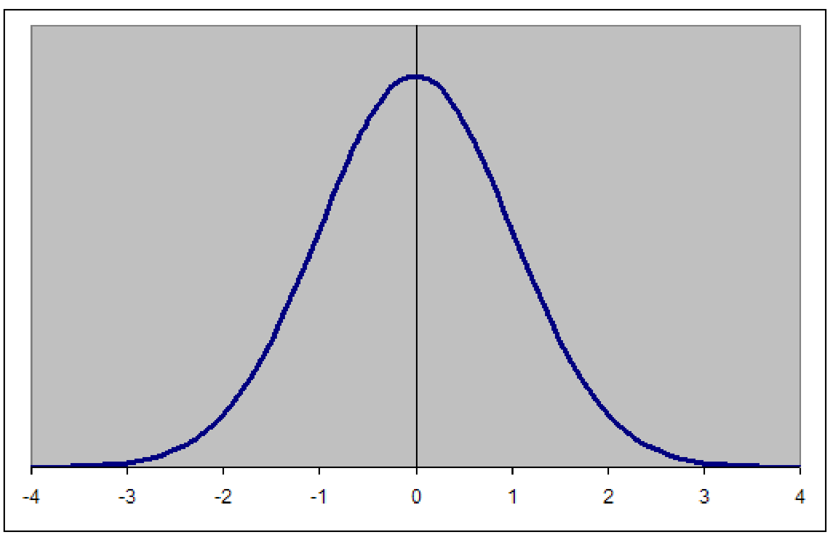
The Principle Component Analysis (PCA) method is used to group the parameters into common components, or root causes of variability, within the sample population. The PCA is also useful in assisting with the clustering of similar samples and determination of the dominant chemical processes in the study area. The PCA used for this study was conducted in Microsoft Excel using methods established by Darlington (2004), Arsham (2005), Tyne, et al (2004) and Dalton and Upchurch (1978). Matrix and linear algebra operations for Excel were completed with the MATRIX.XLA add-in created by the Foxes Team at Calcolo Numerico (Volpi 2004). After normalization and standardization of the water quality variables, a correlation matrix was generated for each data set. The Jacobian eigenvalue and eigenvector matrices were then created. Components with eigenvalues satisfying Kaiser's criterion (eigenvalue >1) were retained and the associated eigenvectors were transformed into component loading coefficients. Varimax rotation was employed in attempt to concentrate variables within a single component. Rotation was successful for the Jackson Blue Spring dataset but did not appreciably aid in the interpretation of the Wakulla Springs dataset. Component scores were then calculated for each sampling location by adding the products of the component loading coefficient and the standardized value for each variable.

Component Score Deviation

Given that a spring discharges ground water from a discrete contribution area, it is logical to expect the spring's water chemistry to represent the aggregate mixing of ground water within its contribution area. Areas within the spring contribution zone with a chemical signature deviating significantly from the spring should therefore contribute less than areas with a chemical signature close to that of the spring. Of course, this assumes that changes in water chemistry during transport to the spring are minimal.

A graph of composite water chemistry within the spring basin can be thought of as a distribution curve with the spring's chemical fingerprint representing the mean value of the distribution. This theoretical frequency distribution is represented in **Figure 1** below, with the x-axis in units of deviation from the spring water quality.

Figure 1. A Normal Distribution



Under this ideal condition, the greater the deviation from the spring, the less mass an area can contribute to the spring without skewing the curve in one direction or another.

In order to quantitatively express each sample location in terms of deviation from the spring's water quality, deviations from the spring's component score were calculated by taking the absolute value of the component score minus the component score for the spring. The composite deviation score was then calculated by adding the products of the absolute component scores and coefficients representing the percent variability attributable to each component.

Gradient maps generated from the composite deviation scores were then created, the results of which will be addressed independently for each basin.

Hierarchical Cluster Analysis

Hierarchical cluster analysis has traditionally been used as an exploratory method to formulate an initial understanding of a dataset by grouping objects to form a structure that reveals the degree of similarity or dissimilarity between samples. In hydrological investigations, hierarchical clustering is used along with component or factor analysis to acquire a spatial understanding of the geochemical and/or anthropogenic processes influencing the chemical character of water throughout a study area.

Hierarchical clustering involves determination of similarity/dissimilarity by algorithms and linkage of groups once the degree of similarity is determined. The clustering was completed with the software SYSTAT 11. The software features eight distance determinations to establish degree of similarity and six linkage methods. It was determined that the Pearson distance determination and the complete linkage method produced a structure that best organized the samples into clusters of common water type.

The approach of the combined application of principal component analysis and hierarchical clustering has differed between various studies. The method of Suk and Lee (1999) appears to be the most applicable to the current study. Particular to hierarchical clustering, Suk and Lee utilized factor scores to complete the cluster analysis.

Jackson Blue Spring Chemical Characterization

A total of twenty-nine ground water samples were collected by NWFWMD staff (**Figure 2**). Well construction data are provided in **Appendix A**. Field and laboratory results are provided in **Appendix B**. Individual parameter concentration contours for the Jackson Blue Spring basin are plotted in **Figures 3-6.** The following table summarizes the basic statistics of the field and lab parameters.

Table 2. Statistical Summary of Jackson Blue Spring Characterization Water Quality Data

Parameter	n	Mean	Median	St. Dev.	Skew.	Kurt.
Water Temperature	29	21.0	20.9	0.4	-0.07	-0.44
Specific Conductance	29	237	231	64	1.40	3.36
Dissolved Oxygen	29	7.41	8.30	2.43	-1.99	3.13
pH	29	7.38	7.39	0.19	-0.09	-0.13
Alkalinity, Total	29	105	104	36	1.29	2.65
Ammonia*	29	0.015	0.010	0.021	4.69	22.9
TKN*	29	0.066	0.060	0.030	5.39	29.0
Nitrate-Nitrite, Total	29	2.55	2.40	1.80	0.21	-0.68
Phosphorus, Total	29	0.021	0.016	0.020	4.56	22.83
Orthophosphate, Dissolved	29	0.016	0.015	0.006	0.81	-0.32
Calcium, Total	29	43.8	41.8	14.0	1.18	2.27
Magnesium, Total	29	2.2	1.0	2.8	2.32	4.67
Sodium, Total	29	1.82	1.76	0.39	1.71	4.19
Potassium, Total	29	0.28	0.24	0.11	1.35	1.25
Chloride, Total	29	3.8	3.5	1.1	0.66	0.19
Sulfate, Total	29	1.11	0.71	1.76	4.88	25.15
Fluoride, Total	29	0.059	0.050	0.016	1.58	0.90
TDS	29	143	138	35	1.49	3.36

*parameter dropped from analysis.

The calculated charge balance for the Jackson Blue Spring dataset ranges from 9.2 to 21.5. Under ideal conditions, all components of the water chemistry can be sampled and identified and the resulting charge balance will be zero. Usually a charge balance less than five is acceptable. This discrepancy indicates that an ion(s) responsible for a portion of the water chemistry was not sampled. Two parameters with importance in carbonate aquifer chemistry not included in this study are silica and iron. Future studies of similar design should include these parameters in the analysis.

Principle Component Analysis

The PCA for the Jackson Blue Basin resulted in four principle components derived from the original data, together accounting for 79 percent of the variability within the sample population. Individual component loading coefficients are listed in **Table 3**. An elevated positive or negative component loading indicates a positive or negative correlation for the variable with that component. The communality represents the percent variance for any single parameter explained by the four components.

Figure 2. Jackson Blue Characterization Study Area and Sampling Locations

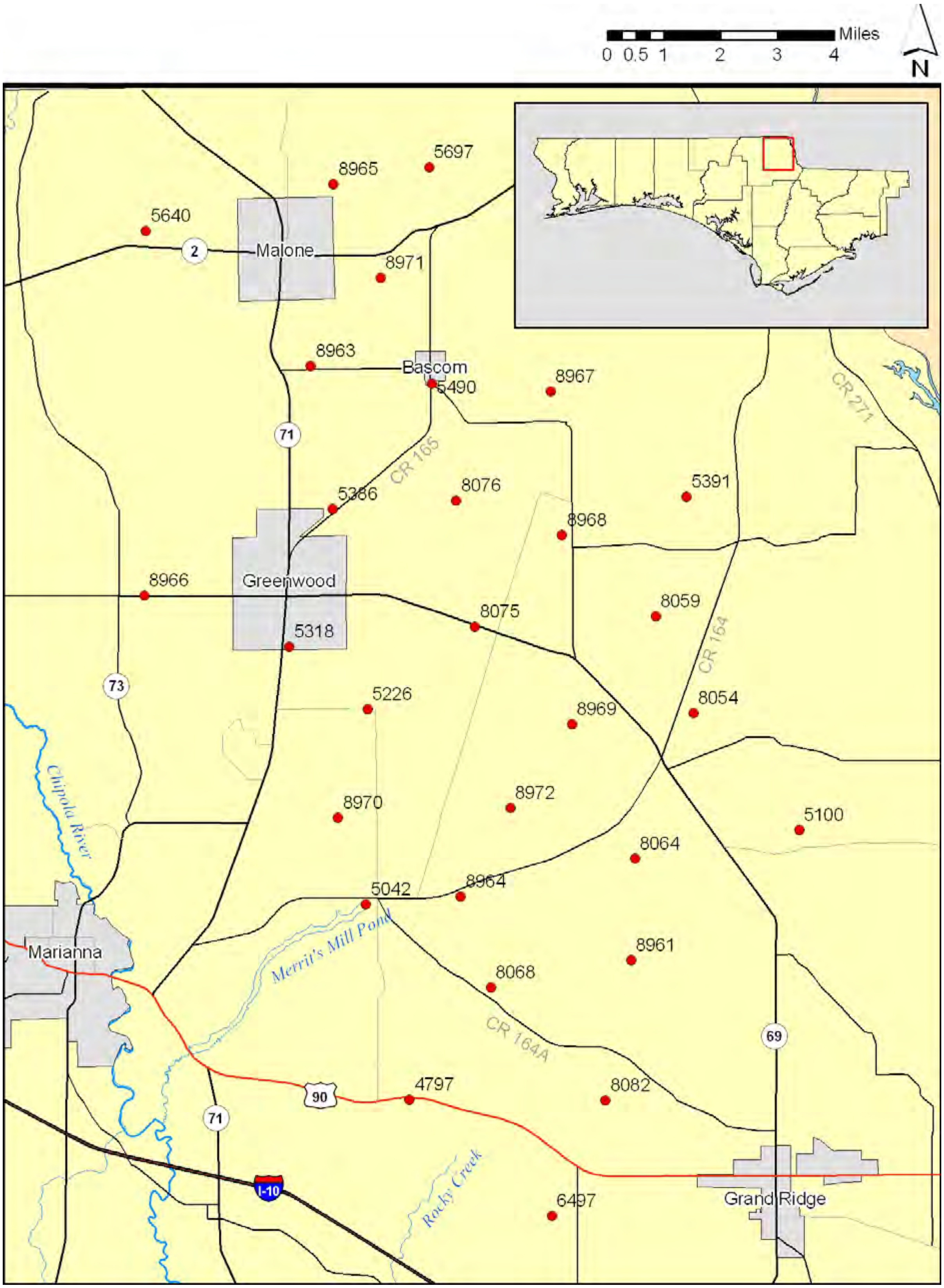


Figure 3. Jackson Blue Characterization Field Analytical Data, Collected 10/06/2004-10/21/2004

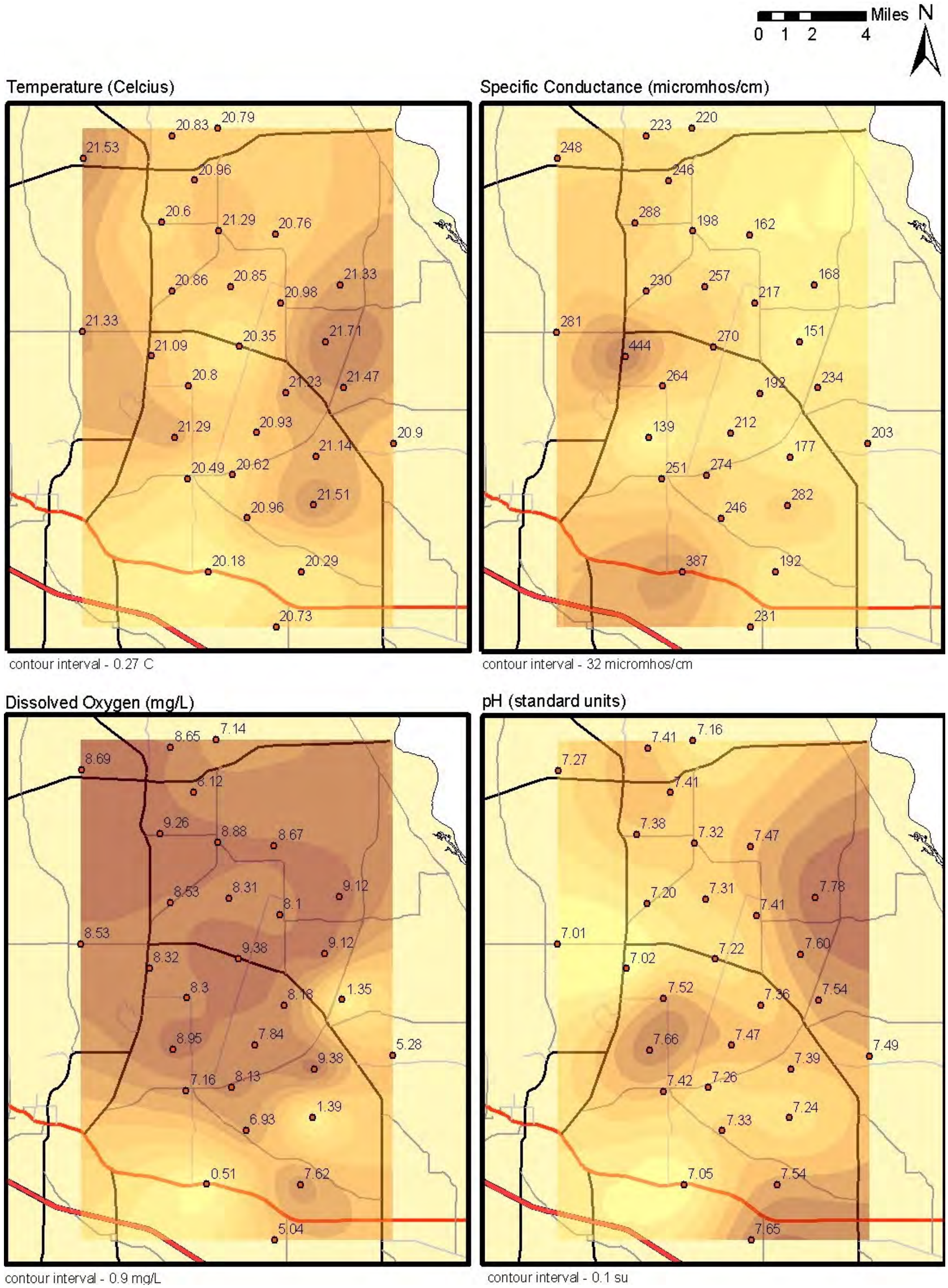


Figure 4. Jackson Blue Characterization Lab Analytical Data, Collected 10/06/2004-10/21/2004

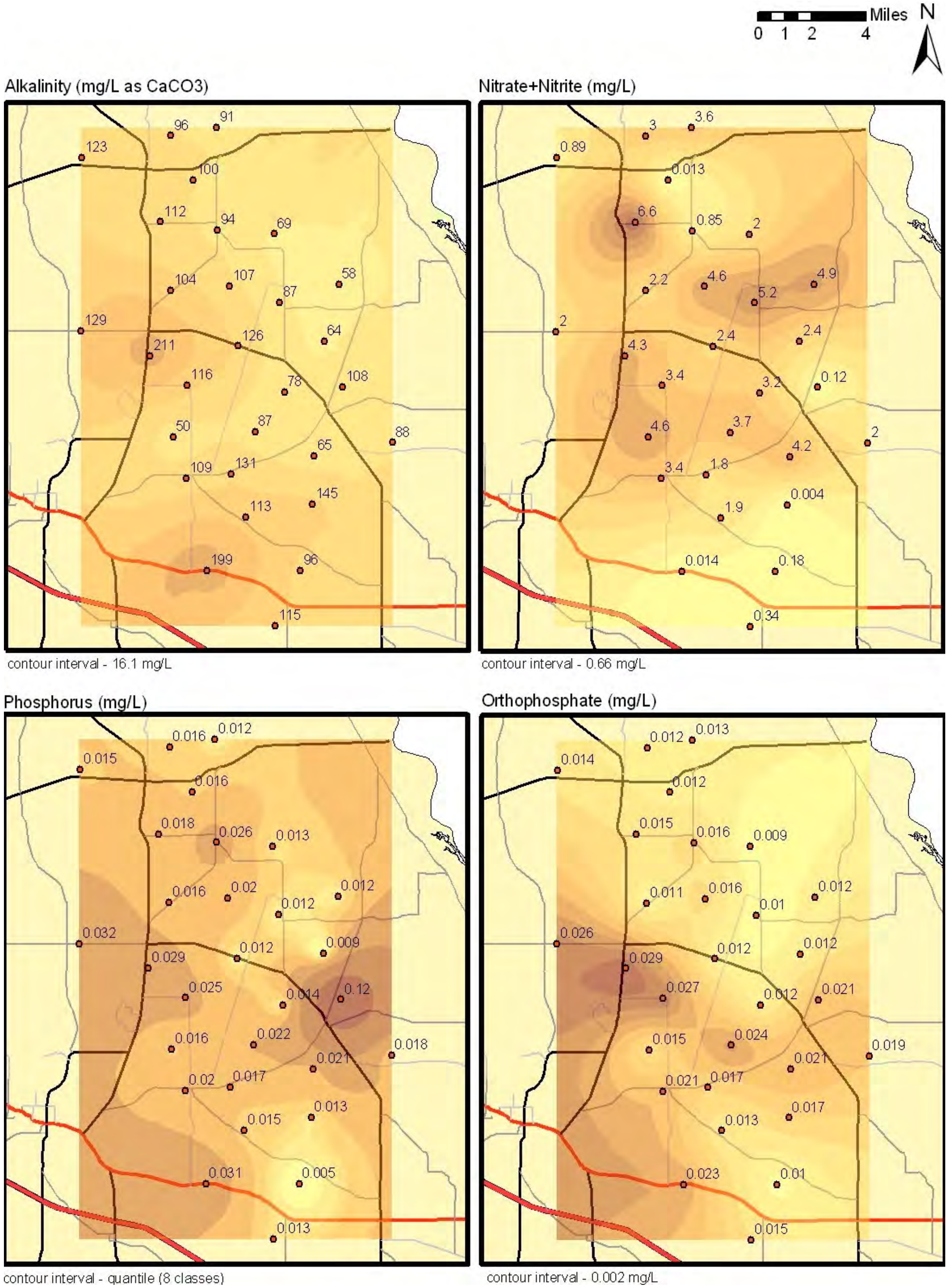


Figure 5. Jackson Blue Characterization Lab Analytical Data, Collected 10/06/2004-10/21/2004

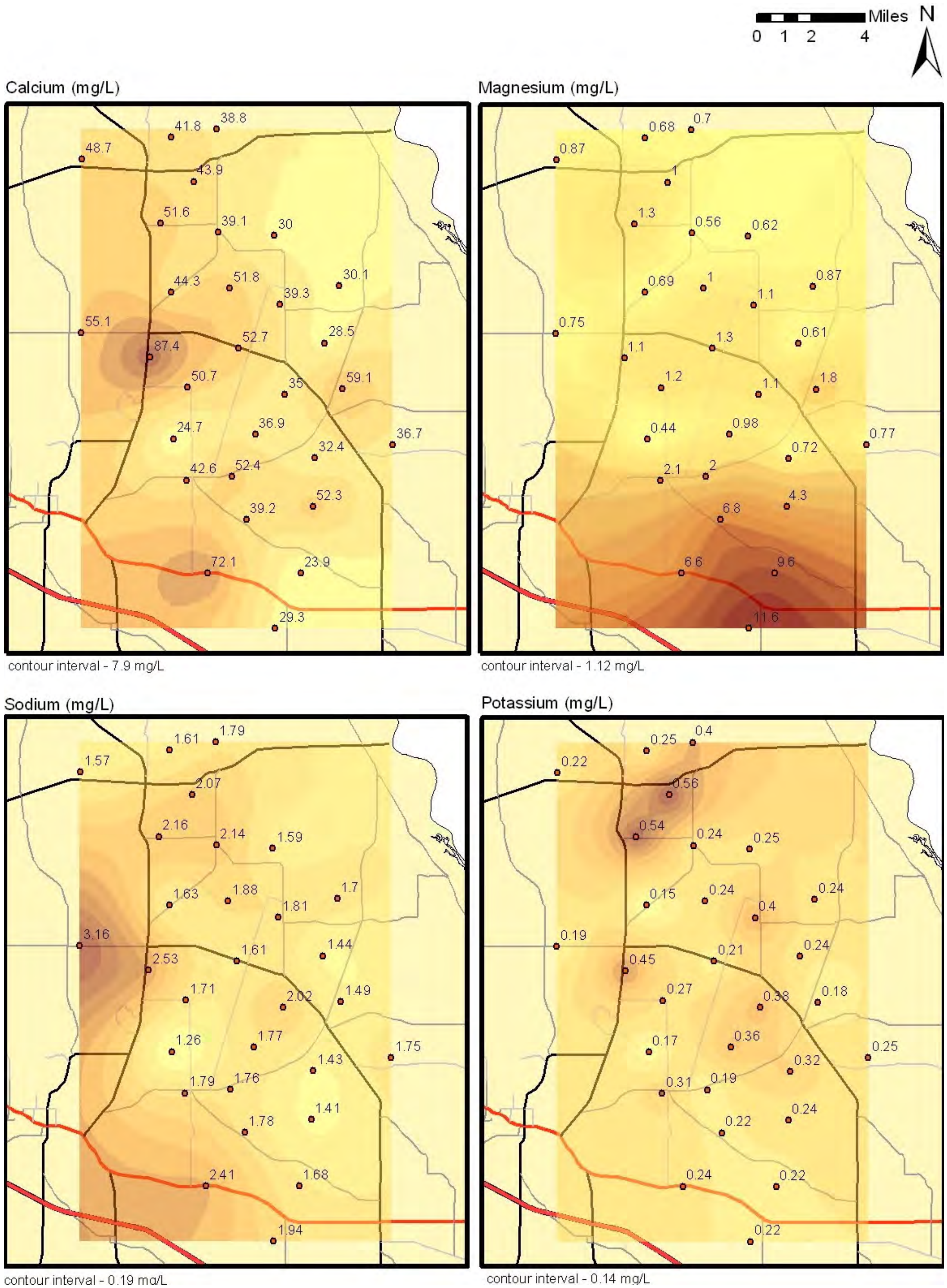


Figure 6. Jackson Blue Characterization Lab Analytical Data, Collected 10/06/2004-10/21/2004

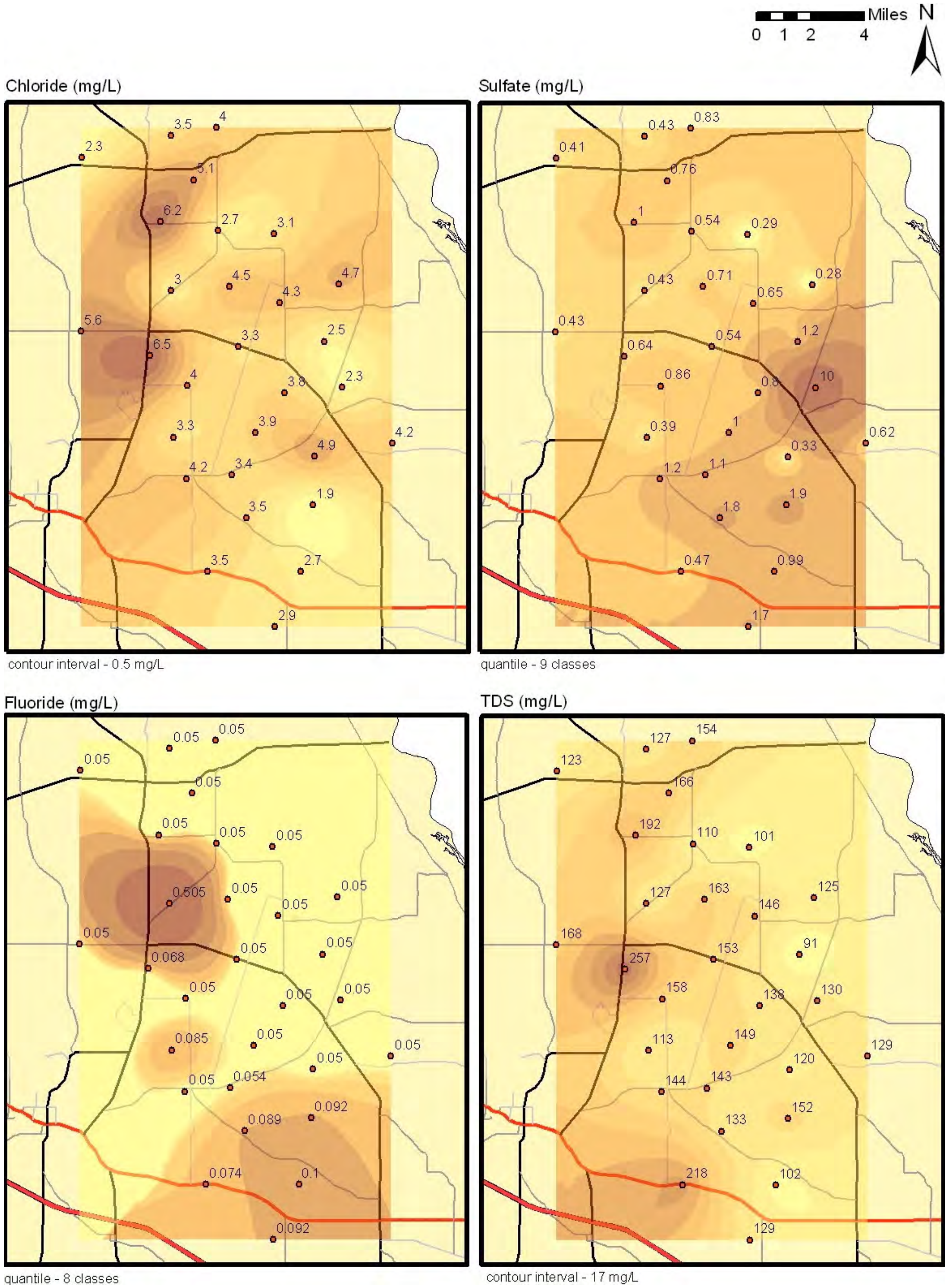


Table 3. Component Loadings for Individual Parameters, Jackson Blue Spring Characterization

Component Loadings	I	II	III	IV	Communality (%)
Water Temperature	0.31	-0.34	**0.52**	-0.21	52.3
Specific Conductance	**-0.93**	0.25	0.11	0.15	95.1
Dissolved Oxygen	0.16	**-0.77**	-0.33	0.21	77.8
pH	**0.88**	0.14	0.05	0.12	81.2
Alkalinity, Total	**-0.91**	0.34	0.08	-0.06	95.0
Nitrate-Nitrite, Total	0.13	-0.45	-0.05	**0.71**	72.1
Phosphorus, Total	-0.35	-0.06	**0.85**	-0.03	85.0
Orthophosphate, Dissolved	-0.49	0.08	**0.62**	0.17	66.4
Calcium, Total	**-0.87**	0.00	0.38	0.03	90.2
Magnesium, Total	-0.16	**0.92**	-0.18	-0.09	91.7
Sodium, Total	**-0.70**	-0.01	-0.01	0.32	59.5
Potassium, Total	-0.11	-0.01	-0.03	**0.83**	69.7
Chloride, Total	-0.38	-0.28	0.01	**0.82**	88.5
Sulfate, Total	0.13	**0.66**	**0.58**	-0.05	78.8
TDS	**-0.83**	0.12	0.13	0.46	94.1
Fluoride, Total	-0.02	**0.75**	-0.28	-0.19	67.1

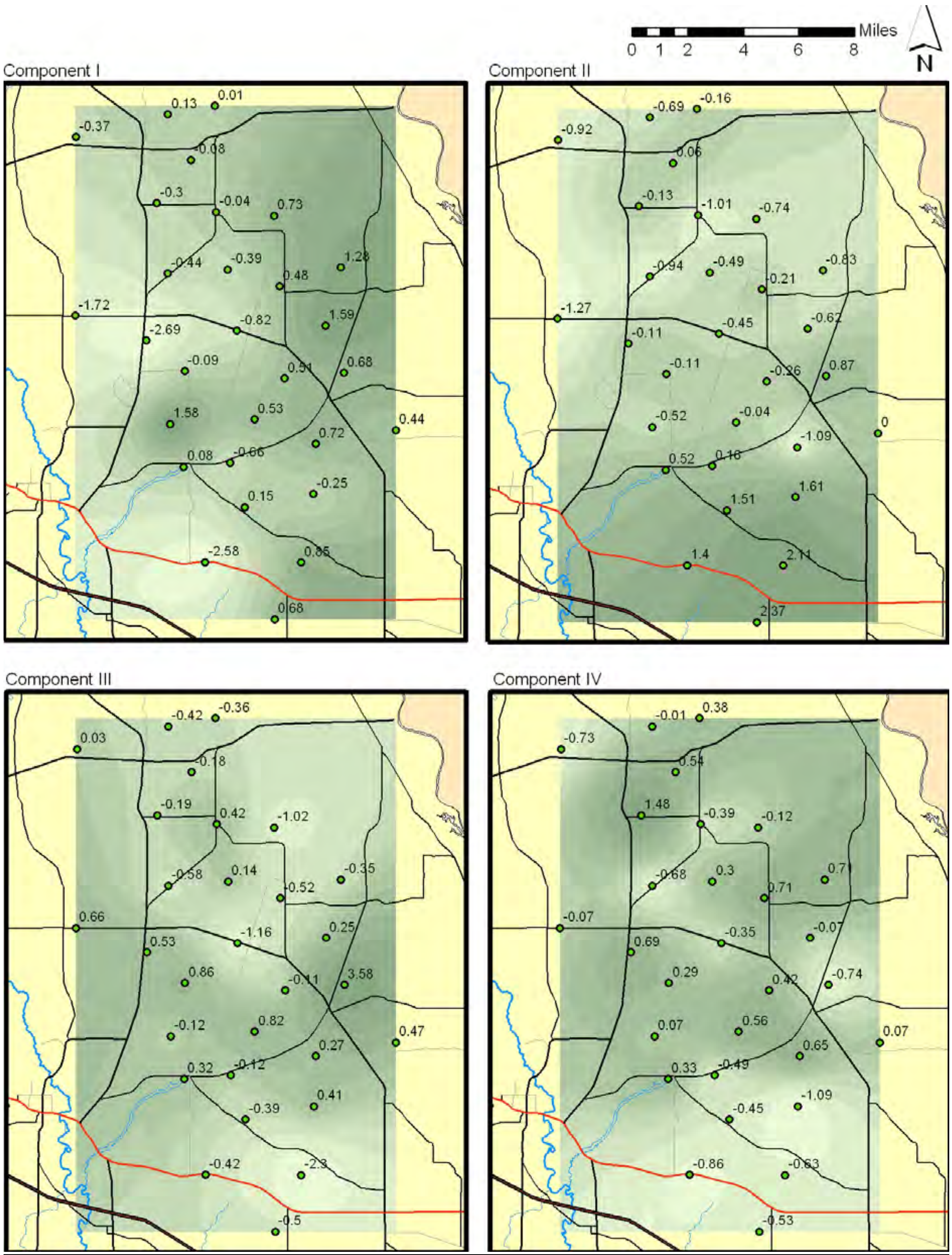
As indicated by the table above, Component I is primarily influenced by the variables Specific Conductance, Alkalinity, pH, Calcium, Sodium, and TDS. The variables dominating this component indicate that the component is a measure of the availability and contact with soluble solids (Hem 1992). As shown in **Figure 7**, locations with elevated scores for Component I are concentrated in the eastern extent of the study area. As an artifact of rotation, the component scores for this component are inversely related to the concentrations of its constituent variables. Therefore, the associated variables with this component are actually elevated in the western extent of the study area. This east-west demarcation is visible with the individual variables as well. The increase in concentration to the west appears to be due to the shift from recharge through Eocene residuum sediments to weathered Ocala Limestone (a geologic map based on the 2001 FGS Geologic Map of Florida is included in **Appendix C** to aid interpretation of the ground water chemistry).

Component II is primarily influenced by the variables Dissolved Oxygen, Magnesium, Sulfate, and Fluoride. Low concentrations of dissolved oxygen are indicative of relatively older water and increased contact with reducing material (Hem 1992). The lower dissolved oxygen concentrations in the south appear to reflect slower recharge to the less permeable Marianna/Suwannee Limestone. Magnesium, in this instance, indicates contact with dolomitized Marianna/Suwannee Limestone. The presence of evaporate deposits associated with the shallow marine depositional environment of the Marianna/Suwannee Limestone accounts for the inclusion of Sulfate and Fluoride in this component (Moore 1955). Component II, then, is clearly associated with the presence of the Marianna/Suwannee Limestone in the southern extent of the study area.

Component III consists primarily of the variables Temperature, Phosphorus, Orthophosphate, and Sulfate. As indicated in **Figure 7**, areas with elevated Component III scores are located in an east-west trending band through the study area. This area happens to coincide with the transition zone between the Eocene Ocala Limestone and the Oligocene Marianna/Suwannee Limestone referred to as the Bumpnose Member of the Ocala Limestone (Moore 1955 and Green 2003). The increase in the concentration of the constituent variables in this location may be related to this transition area.

Component IV consists of the variables Nitrate-Nitrite, Potassium, and Chloride. The presence of nitrate-nitrite in ground water above natural concentrations is associated with anthropogenic sources such as septic tanks, waste water treatment, and fertilizers. Potassium is a common ingredient in fertilizers as well, and chloride is associated with water irrigation and water treatment (Hem 1992). Therefore, the combination of these three variables appears to represent the influence of agricultural activities within the study area.

Figure 7. Jackson Blue Characterization Component Scores



Spring Composite Deviation

The results from the calculation of the composite deviation scores are presented in **Figure 8**. Areas within the figure that have a composite score closer to zero, therefore more similar to the spring in chemical composition, are represented with lighter shades while those with higher scores gradually darken. In order for the spring's water chemistry to reflect the net contribution from within its basin, areas containing the dominant chemical signature influencing the spring's water chemistry must then represent the primary contribution area within the spring basin. This core does not delineate the boundary of the spring contribution area; rather, it enhances the understanding of processes within the spring basin.

The Floridan potentiometric surface map and ground water contribution area for Jackson Blue Spring produced by Chelette, et al (2002) are presented in **Figure 9**. The primary contribution area generated from the composite deviation scores correlates very well with the potentiometric basin boundary and principle flow paths.

Hierarchical Clustering

Clustering of the samples from the Jackson Blue springshed produced seven clusters (**Figure 10**). As stated above, four components as determined by PCA explain 79 percent of the variability in the sample population for the Jackson Blue springshed. The parameters and processes involved in producing the four components are discussed above. As a means of visualizing sample similarity/dissimilarity determined by the clustering, radial diagrams were constructed for each sample using the component scores as determined by the PCA. Examples of the general chemical character of each cluster are shown in **Figure 11**. The spatial relationship of the clusters can be seen in **Figure 12**.

The average component scores for the samples in Cluster 1 reveal Components I, III, and IV most influence the chemical character of the cluster with Component II having minimal influence. This hierarchy of influence is consistent in the individual samples that compose the cluster. This implies that there is a mixing of water from the following sources: native Floridan Aquifer water, possible interaction with materials at the Eocene-Oligocene contact, and anthropogenic sources. Due to the lack of Component II, there is little contribution from the Marianna/Suwannee Limestone further to the south.

The average component scores for the samples in Cluster 2 reveal that native Floridan Aquifer water that produces Component I is most influential in determining the chemical character of the cluster. This is consistent in the individual samples within the cluster. Although not to the extent as Component I, Component IV is significant in determining chemical character. This pattern would describe the mixing of native ground water with water influenced by anthropogenic activities. Components II and III appear to have the least influence on the water type in Cluster 2. Therefore, the presence of Oligocene materials further to the south appears to offer a minimal contribution to the cluster.

The average component scores and individual samples show that Component IV is the primary contributor to the chemical character of Cluster 3. Conversely, Component III appears to be of least significance in determining chemical character. The significance of Components I and II varies throughout the cluster. Given the presence of Component IV, anthropogenic influences appear to dictate the chemical character of the cluster. The remainder of the character is determined by a mixture of waters influenced by geochemical factors.

In contrast to the previously discussed clusters, Component II is of greatest significance in Cluster 4. The spatial distribution of this component reveals that its greatest presence coincides with the Marianna/Suwannee Limestone located at the southern portion of the basin. Due to the prevalence of Component I, it is apparent that the Marianna/Suwannee Limestone water is mixing with native Floridan Aquifer water to produce the chemical character of the cluster. Components III and IV are of minor consequence throughout the cluster. This trend is reflected in the average component scores and individual samples within the cluster.

Cluster 5 is similar in that Component II is the dominant component determining the character of the water samples in the cluster. However, in this cluster, the significance of Component I is reduced in place of Component III. Component III is described to coincide with the geologic units of the Eocene-Oligocene transition. Given the location of this cluster, it is not surprising that the influence of Component III is increased. Of note is the relative absence of Component IV in Clusters 4 and 5. It can be inferred from this that, relative to the rest of the basin, anthropogenic impacts are not as significant in the southern portion of the springshed. The limited presence of Component IV does not apply to one sample in the cluster. The chemical character of Jackson Blue Spring features an increase in the significance of Component IV implying that the spring is receiving water from sources influenced by anthropogenic impacts.

In Cluster 6, Components III and IV play the most significant role in determining the chemical character of the cluster. This would imply that in that area there is mixing primarily of waters derived from both geochemical and anthropogenic sources. These sources along with Component II to a minor agree dilute the native Floridan Aquifer signature represented by Component I.

Consistently among the samples in Cluster 7, Component III is most influential in determining chemical character. The existence of Components I, II, and IV to varying degrees may signify the different degrees of mixing of waters from both geochemical and anthropogenic sources. As confirmation of what has been described earlier, it should be noted that the predominance of Component III in Clusters 6 and 7 does coincide spatially with the geologic units of the Eocene-Oligocene transition.

Figure 8. Jackson Blue Characterization Composite Deviation Scores

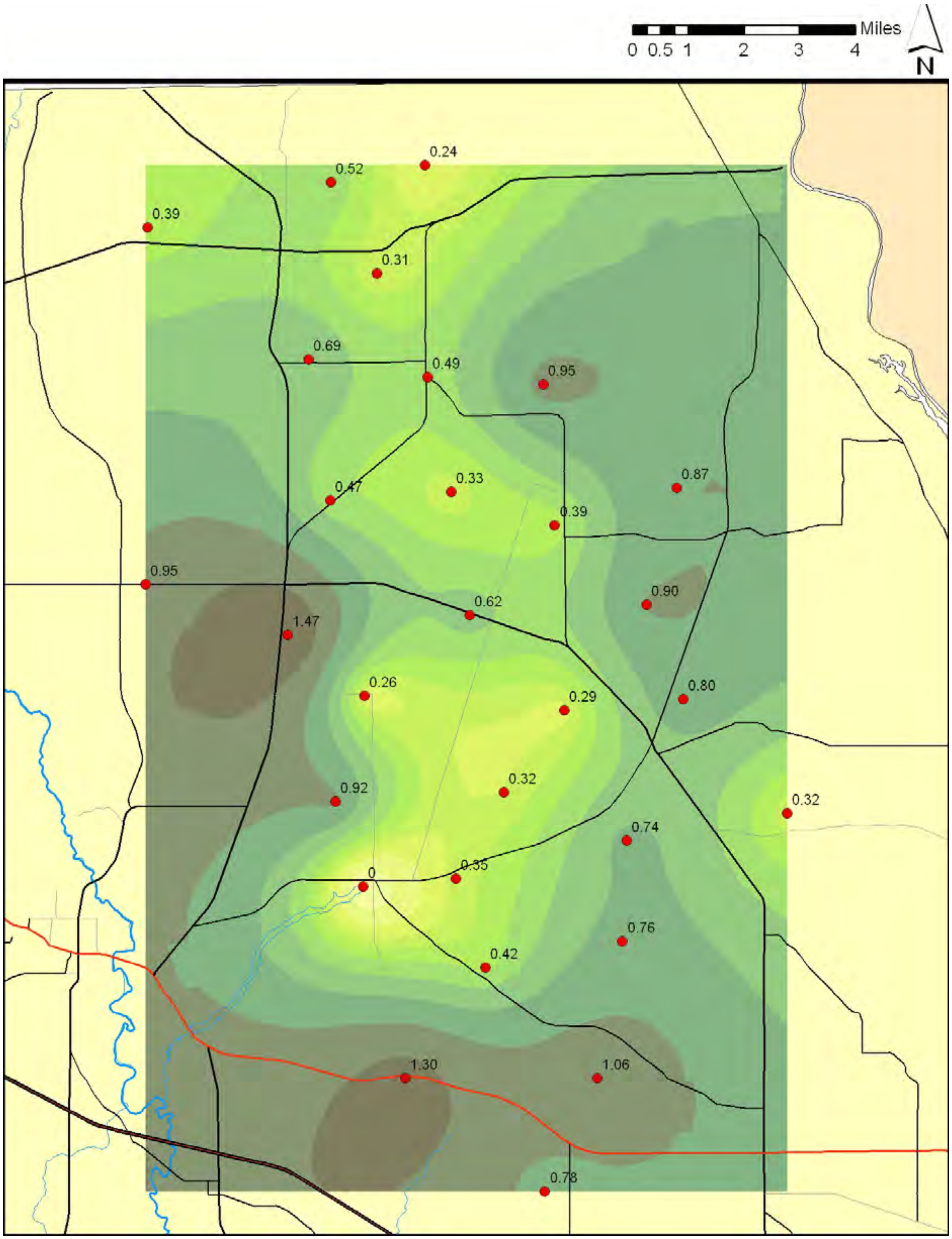
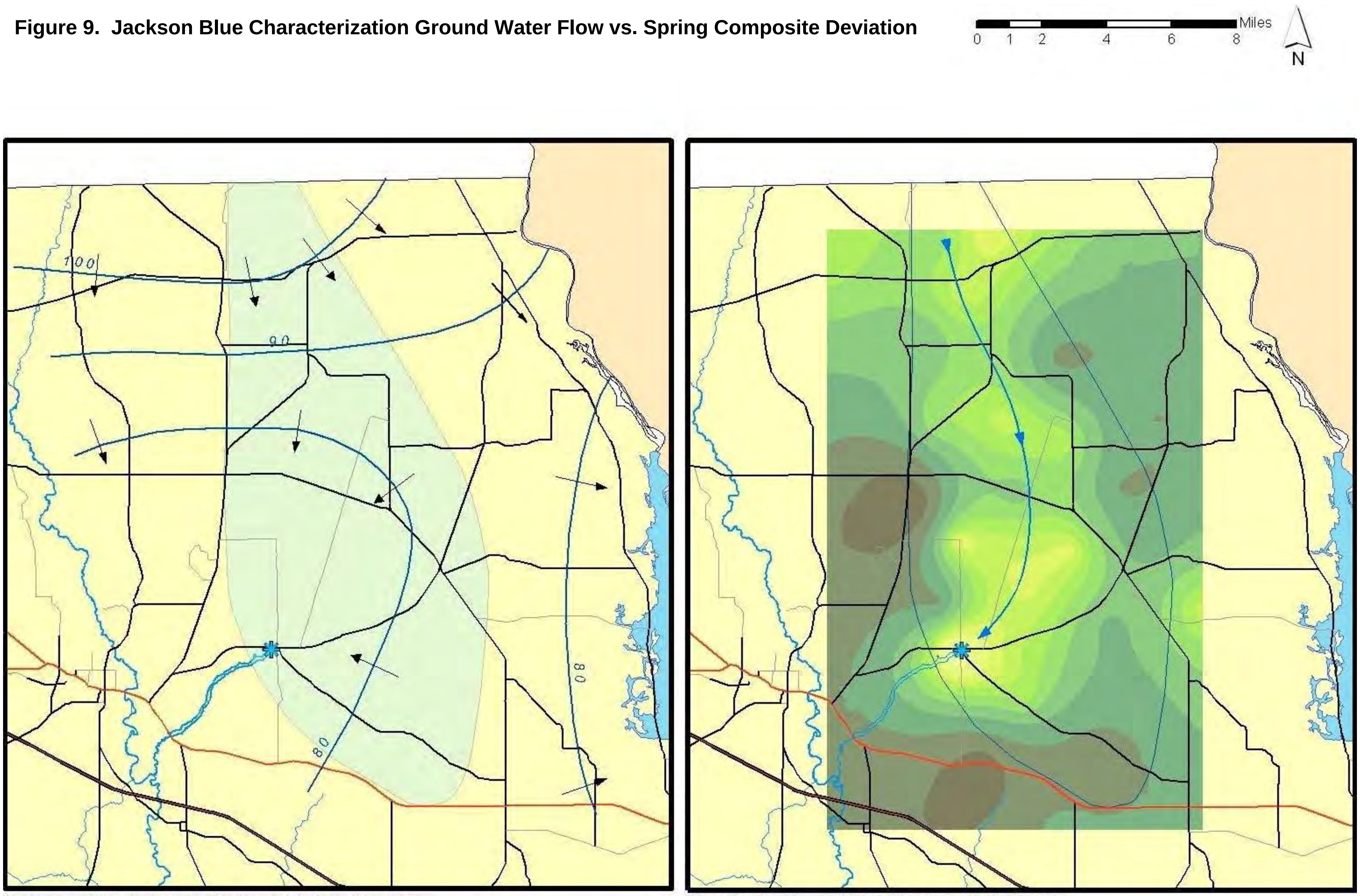


Figure 9. Jackson Blue Characterization Ground Water Flow vs. Spring Composite Deviation



Floridan Aquifer Potentiometric Surface and Jackson Blue Spring Contribution Area from Chelette, et al, 2002.

Conceptualized flow path through primary contribution area.

Figure 10. Results from Clustering Jackson Blue Characterization Sample Data

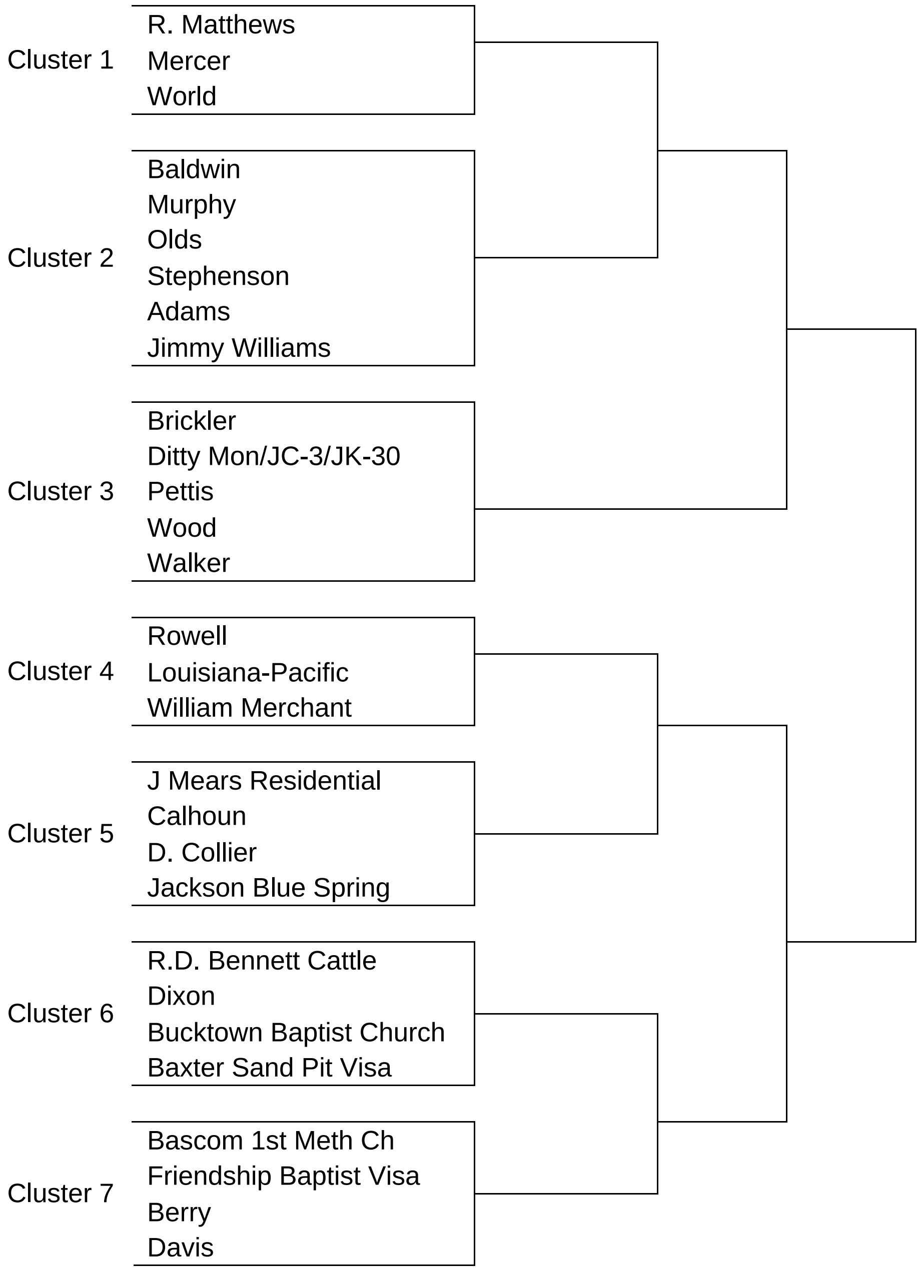


Figure 11. Radial Diagrams for the Average Component Scores of Each Cluster Computed from the Jackson Blue Characterization Sample Data

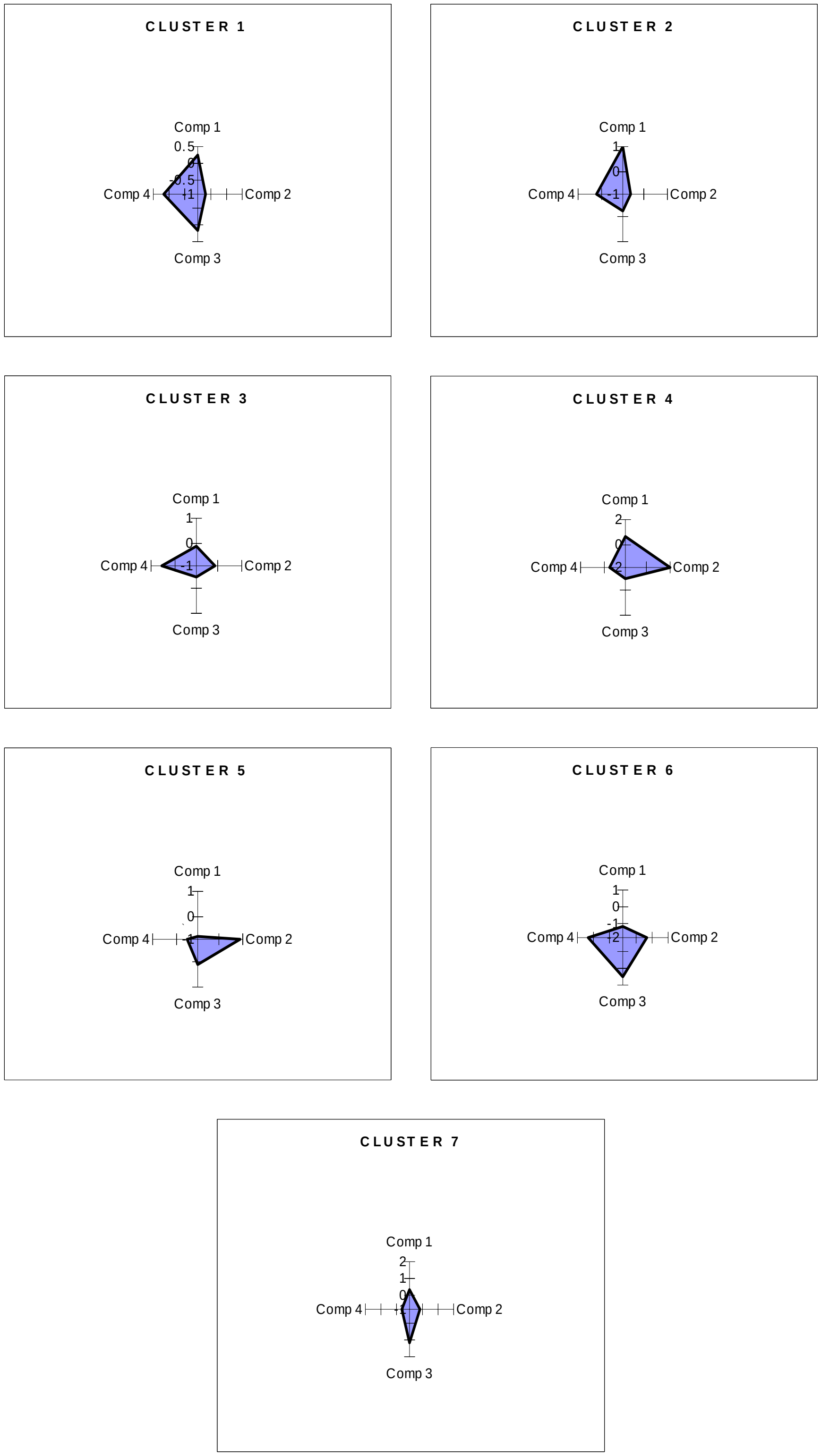
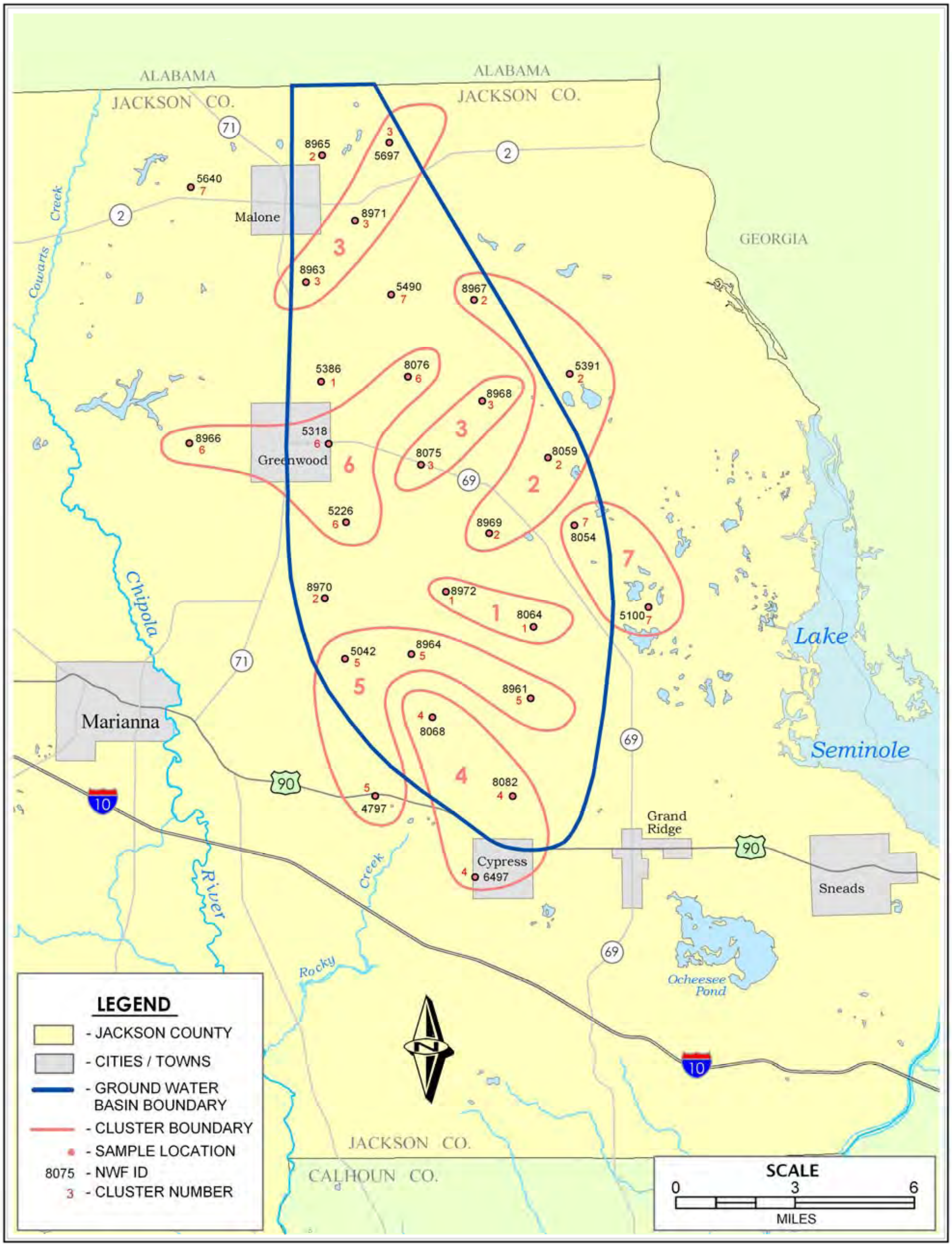


Figure 12. Distribution of Clusters within Jackson Blue Characterization Study Area



Wakulla Springs Chemical Characterization

A total of thirty-one ground water samples were collected by NWFWMD staff (**Figure 13)**. In addition, seven samples collected by Florida Geological Survey staff were added to the analysis. Well construction data are provided in **Appendix A**. Field and laboratory results are provided in **Appendix B**. Individual parameter concentration contours for the Wakulla Springs basin are plotted in **Figures 14-17.** The following table summarizes the basic statistics of the field and lab parameters.

Table 4. Statistical Summary of Wakulla Springs Characterization Water Quality Data

Parameter	n	Mean	Median	St. Dev.	Skew.	Kurt.
Water Temperature	38	21.18	21.13	1.03	0.40	0.21
Specific Conductance	38	304	303	59	0.15	0.35
Dissolved Oxygen	38	3.06	2.61	2.35	0.63	-0.58
pH	38	7.25	7.23	0.24	-0.07	-0.64
Alkalinity, Total	38	142	144	30	-0.17	0.70
Ammonia*	38	0.03	0.01	0.07	5.02	27.76
TKN*	38	0.08	0.06	0.06	5.63	33.05
Nitrate-Nitrite, Total	38	0.546	0.315	0.883	3.20	11.21
Phosphorus, Total	38	0.027	0.025	0.021	2.34	8.90
Orthophosphate, Dissolved	38	0.025	0.025	0.021	2.72	11.40
Calcium, Total	38	45.9	43.6	14.4	1.00	0.90
Magnesium, Total	38	8.6	9.2	4.6	0.11	-0.54
Sodium, Total	38	4.03	3.75	2.53	3.49	16.34
Potassium, Total	38	0.72	0.51	0.54	1.99	3.53
Chloride, Total	38	5.8	4.5	4.4	2.87	9.61
Sulfate, Total	38	6.7	6.6	4.8	0.94	1.97
Fluoride, Total	38	0.179	0.155	0.115	1.89	3.84
TDS	38	166	168	36	0.08	1.47

*parameter dropped from analysis.

The calculated charge balance for the Wakulla Springs dataset ranges from 5.7 to 14.9. Under ideal conditions, all components of the water chemistry can be sampled and identified and the resulting charge balance will be zero. Usually a charge balance less than five is acceptable. This discrepancy indicates that an ion(s) responsible for a portion of the water chemistry was not sampled. Two parameters with importance in carbonate aquifer chemistry not included in this study are silica and iron. Future studies of similar design should include these parameters in the analysis.

Principle Component Analysis

The PCA for the Wakulla Basin resulted in four principle components derived from the original data, together accounting for 78 percent of the variability within the sample population. Individual component loading coefficients are listed in **Table 5**. An elevated positive or negative component loading indicates a positive or negative correlation for the variable with that component. The communality represents the percent variance for any single parameter explained by the four components.

Figure 13 . Wakulla Characterization Study Area and Sampling Locations

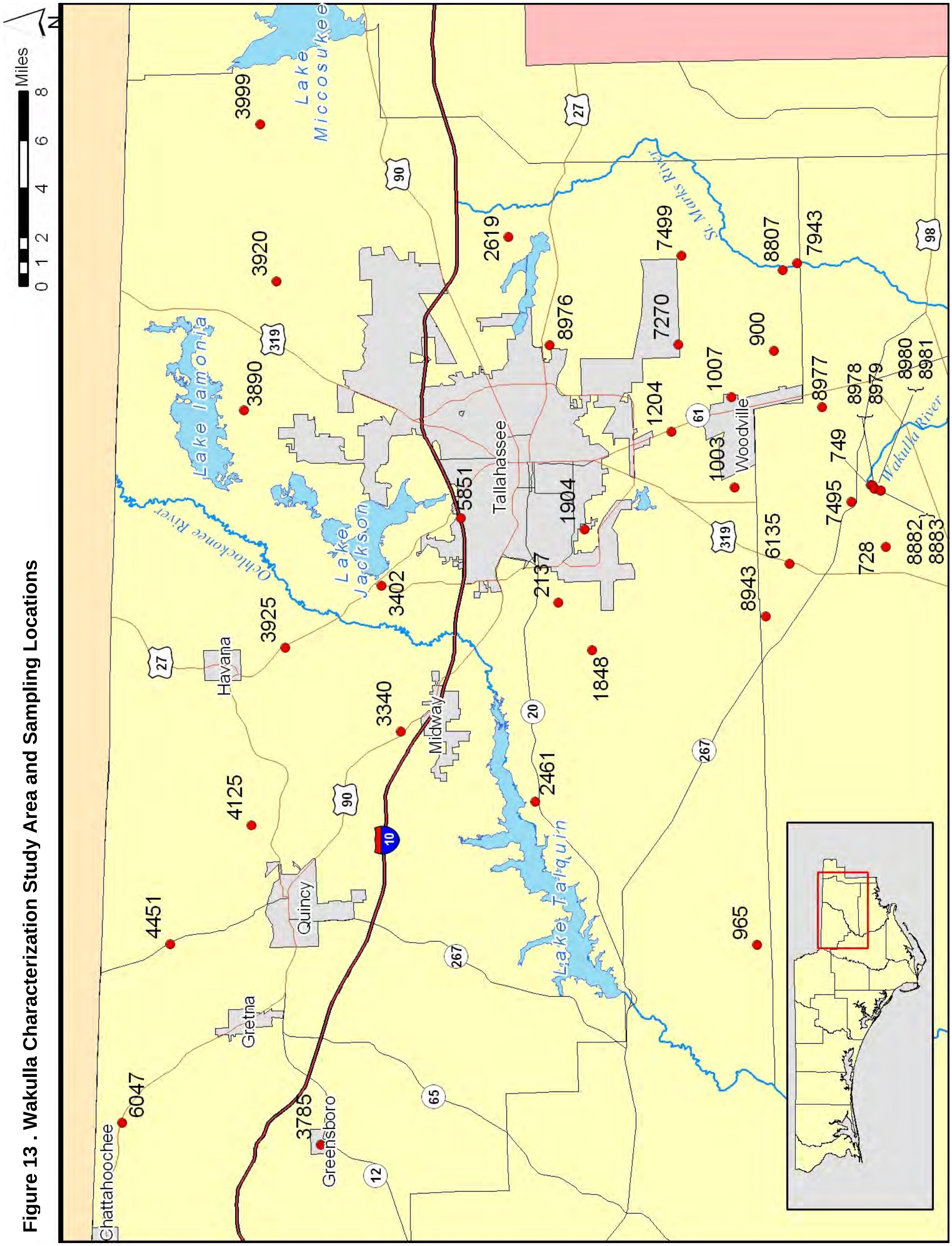


Figure 14. Wakulla Characterization Field Analytical Data, 4/7/2004-12/1/2004

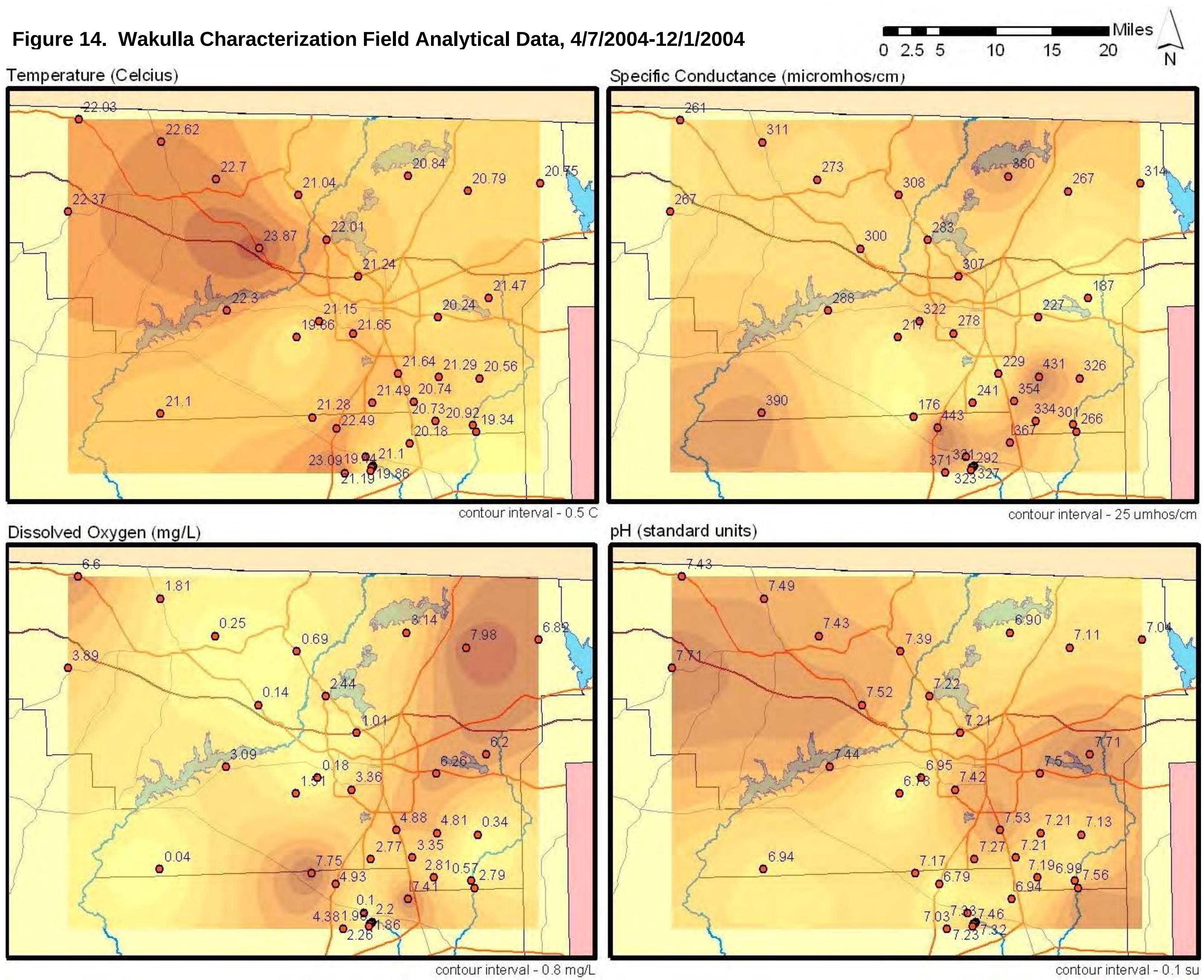


Figure 15. Wakulla Characterization Lab Analytical Data, 4/7/2004-12/1/2004

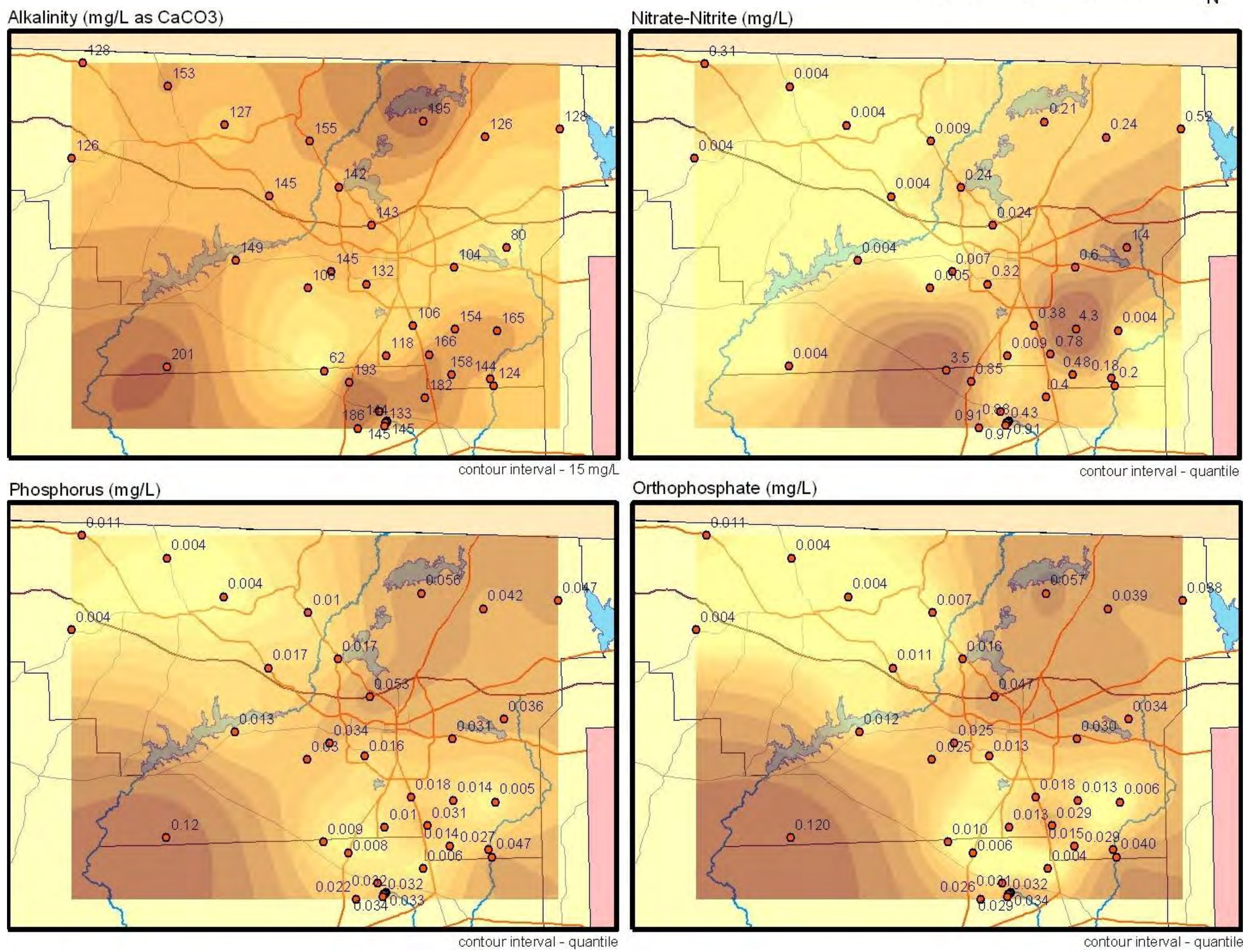


Figure 16. Wakulla Characterization Lab Analytical Data, 4/7/2004-12/1/2004

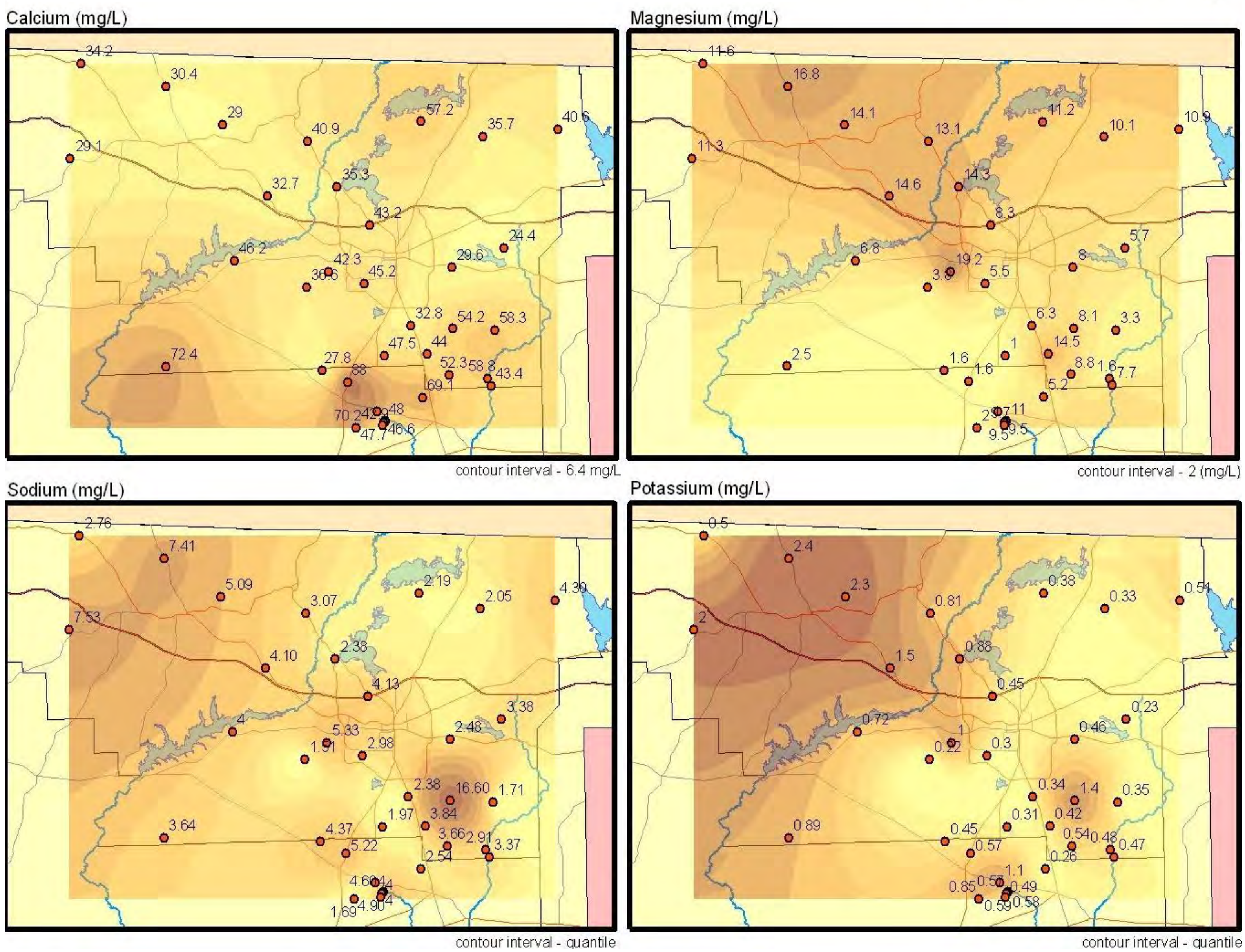


Figure 17. Wakulla Characterization Lab Analytical Data, 4/7/2004-12/1/2004

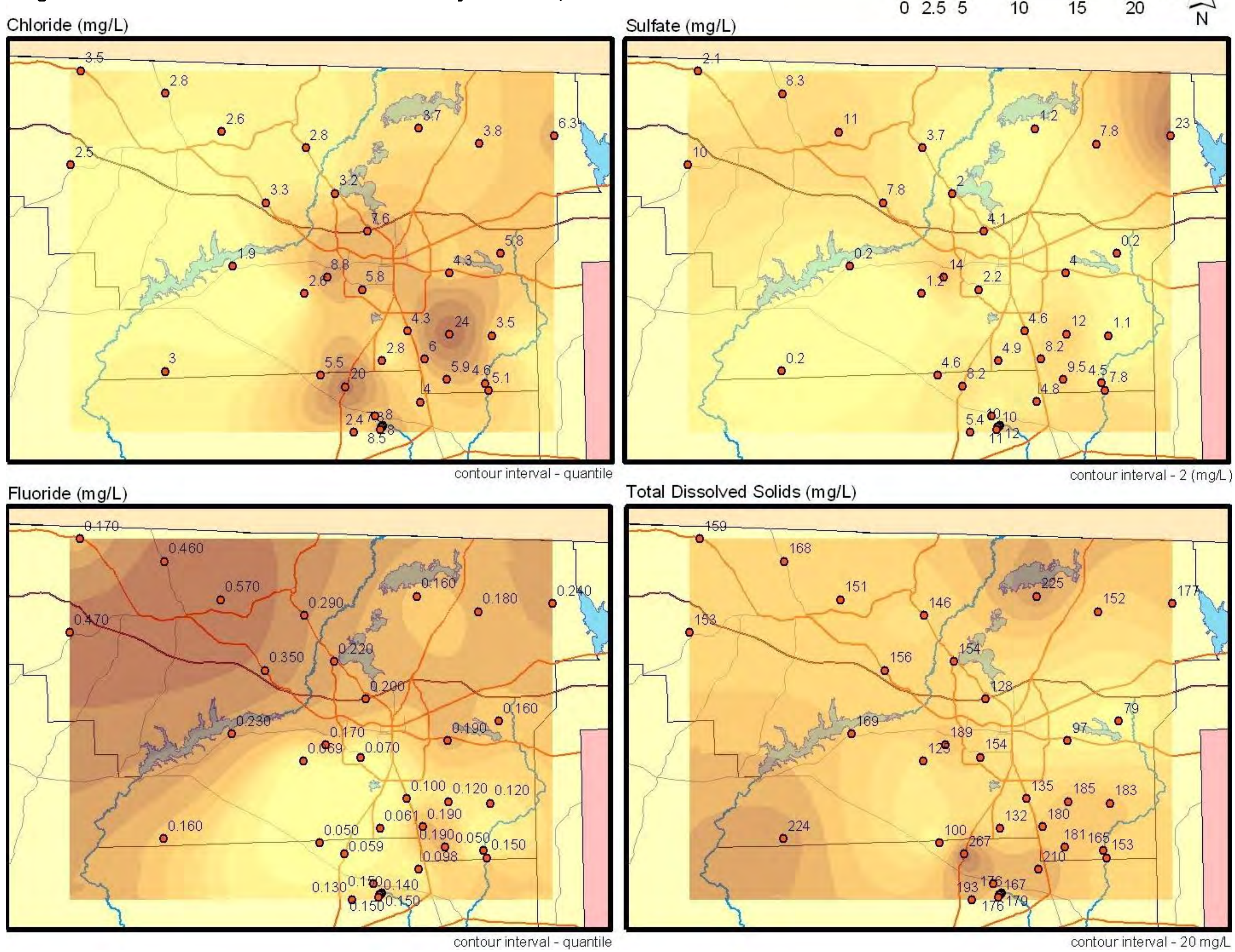


Table 5. Component Loading for Individual Parameters, Wakulla Springs Characterization

Component Loadings	I	II	III	IV	Communality (%)
Water Temperature	-0.203	**0.533**	-0.166	-0.386	50.2
Specific Conductance	**0.880**	0.389	0.123	-0.059	94.4
Dissolved Oxygen	-0.264	-0.384	**0.429**	-0.307	49.5
pH	**-0.755**	0.240	0.062	0.148	65.3
Alkalinity, Total	**0.852**	0.363	-0.259	-0.066	92.9
Nitrate-Nitrite, Total	0.012	-0.278	**0.840**	-0.108	79.4
Phosphorus, Total	0.324	-0.388	-0.049	**0.818**	92.7
Orthophosphate, Dissolved	0.334	-0.420	-0.076	**0.780**	90.3
Calcium, Total	**0.949**	-0.065	-0.063	-0.214	95.5
Magnesium, Total	-0.258	**0.665**	0.101	0.467	73.7
Sodium, Total	-0.014	**0.584**	**0.644**	0.171	78.6
Potassium, Total	-0.030	**0.898**	-0.012	0.036	81.0
Chloride, Total	0.350	-0.051	**0.846**	0.136	86.0
Sulfate, Total	0.025	0.376	**0.603**	0.045	50.8
Fluoride, Total	-0.337	**0.742**	-0.199	0.373	84.3
TDS	**0.852**	0.392	-0.017	-0.072	88.4

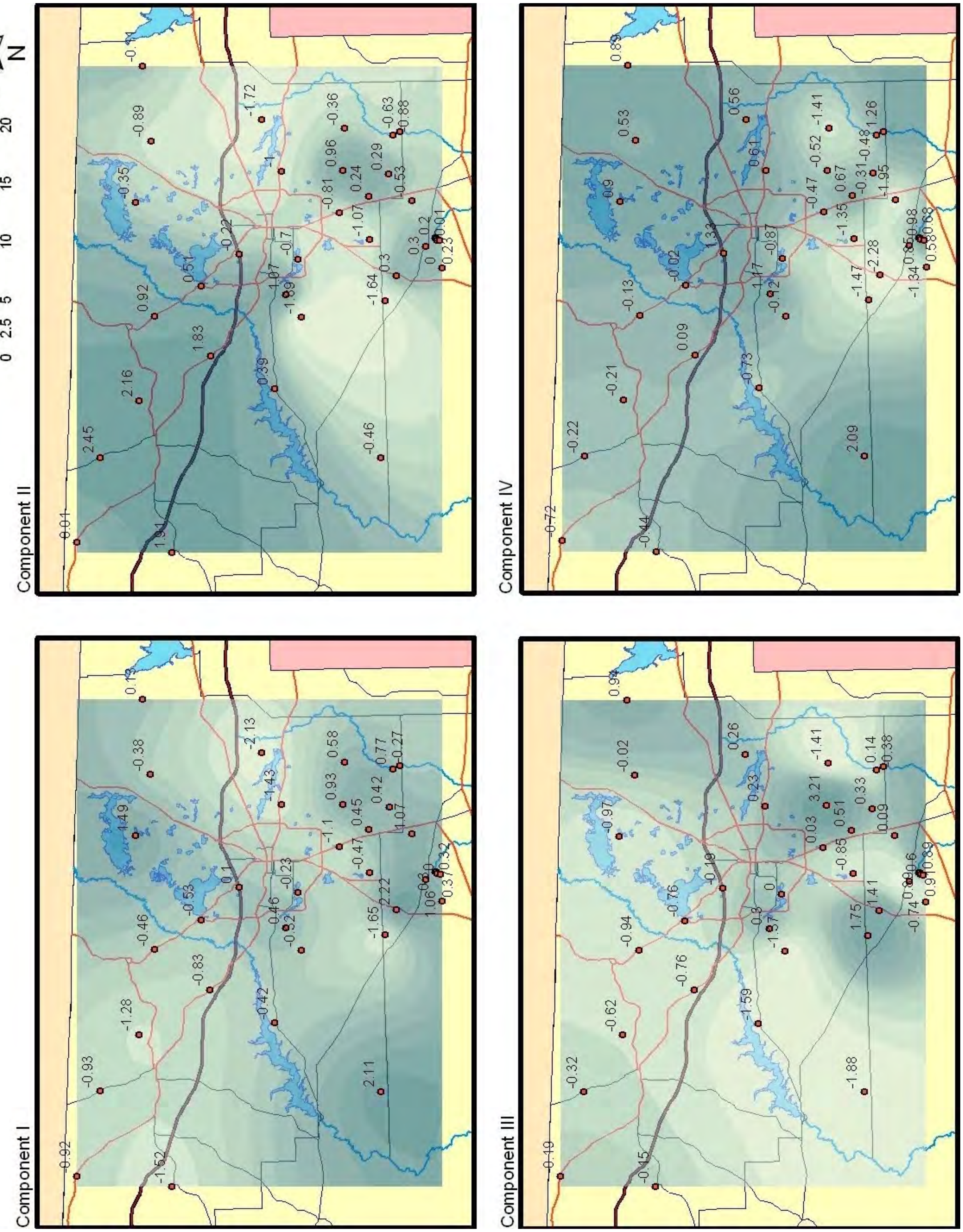
As indicated by the table above Component I is primarily influenced by the variables Specific Conductance, Alkalinity, pH, Calcium, and TDS. The variables dominating this component indicate that the component is a measure of the availability and contact with soluble solids (Hem 1992). As shown in **Figure 18**, locations with elevated scores for Component I are concentrated in the southern extent of the study area, near Wakulla Springs, and possibly represent local recharge through weathered limestone above the Floridan Aquifer (a geologic map based on the 2001 FGS Geologic Map of Florida is included in **Appendix C** to aid interpretation of the ground water chemistry).

Component II is primarily influenced by the variables Sodium, Potassium, Magnesium, Fluoride, and, to a minor extent, Orthophosphate. Sodium and Potassium in ground water are typically associated with the presence of connate (fossil) water trapped within the aquifer matrix during formation and also as a weathering product of clays. Magnesium is also associated with connate water and the weathering of clays, but in addition indicates the dolomitization of limestone (Hem 1992). Fluoride and Phosphate are naturally present in Florida within the sediments of the Torreya Formation (Scott 2001). The presence of elevated Component II scores in the north and northwestern extent of the study area seem to indicate contact with sediments of the Torreya Formation and connate water in Gadsden County.

Component III consists primarily of the variables Dissolved Oxygen, Nitrate-Nitrite, Sodium, Chloride, and Sulfate. Higher concentrations of dissolved oxygen are indicative of younger water and/or contact with reduced oxidizable material. The presence of nitrate-nitrite in ground water is usually associated with anthropogenic sources such as septic tanks, waste water treatment, and fertilizers. Sulfate is also associated with anthropogenic sources as well as surface water contributions to ground water (Hem 1992). The variables Sodium and Chloride can be associated with connate water but, given the concentration of elevated Component III scores in the southern extent of the study area, represent the influence of water treatment and irrigation. Component III, then, represents the impact of human activities to the Floridan Aquifer.

Component IV is dominated by the variables Phosphorus and Orthophosphate. These two parameters are associated with marine margin sediments, such as those present in the Torreya Formation in north Leon County. Organic material and the contribution of surface streams to the Floridan Aquifer can also contribute to these variables. This component may represent areas with recharge through a combination of these factors.

Figure 18. Wakulla Characterization Component Scores



Spring Composite Deviation

The results from the calculation of the composite deviation scores are presented in **Figure 19**. Areas within the figure that have a composite score closer to zero, therefore more similar to the spring in chemical composition, are represented with lighter shades while those with higher scores gradually darken. In order for the spring's water chemistry to reflect the net contribution from within its basin, areas containing the dominant chemical signature influencing the spring's water chemistry must then represent the primary contribution area within the spring basin. This core does not delineate the boundary of the spring contribution area; rather, it enhances the understanding of processes within the spring basin.

Floridan Aquifer potentiometric surface maps produced in the past three decades all show a consistent trend of a wide ground water "trough" extending in an arc north from Wakulla Springs through the Lake Jackson area into Gadsden County. Following the "rule of V's" and the fact that ground water moves down-gradient perpendicular to lines of equal elevation, a reasonable flow path and ground water basin boundary can be identified for the spring. Two potentiometric surfaces created from different data sets are displayed in **Figure 20,** with arrows representing the direction of regional ground water flow. The primary contribution areas generated from the composite deviation scores correlate very well with the potentiometric basin boundaries and principle flow paths.

Hierarchical Clustering

Clustering of the samples from the Wakulla springshed produced seven clusters (**Figure 21**). As stated above, four components as determined by PCA explain 78 percent of the variability in the sample population for the Wakulla springshed. The parameters and processes involved in producing the four components are discussed above. As a means of visualizing sample similarity/dissimilarity determined by the clustering, radial diagrams were constructed for each sample using the component scores as determined by the PCA. Examples of the general chemical character of each cluster are shown in **Figure 22**. The spatial relationship of the clusters can be seen in **Figure 23**.

The average component scores and individual samples indicate that Components I and IV are most influential in determining the chemical character of Cluster 1. This would indicate that this character is the result of mixing of native Floridan aquifer water and potential recharge waters. Components II and III are relatively insignificant in the samples from Cluster 1. Of note, the samples do not form a spatial cluster but rather the sites grouped as Cluster 1 are located randomly throughout the study area.

Based on the average component scores and with the exception of one sample (Natural Bridge Recreation Area), Components I and II are most significant in determining the chemical character of Cluster 2. This pattern would indicate that the character results from the mixing of waters influenced by geochemical processes. Components III and IV are of limited significance. As with Cluster 1, these samples do not form a spatial cluster. However, the individual samples do abide by a physiographic trend in that they are all located south of the Cody Scarp.

In Cluster 3, the average component scores and the individual samples within the cluster reveal that the presence of Components I, II, and III determine the chemical characterization. The cluster therefore likely results from the mixing of resident Floridan Aquifer water, potential recharge waters, and water influenced by anthropogenic activities. Component IV is an insignificant influence on the cluster’s chemical character.

Clusters 4a and 4b are similar in that Components III and IV are the principal components in determining their chemical characterization. Components I and II are of little significance. The mixing of water influenced by anthropogenic activities and water representing possible recharge define these clusters. These two clusters differ in that the anthropogenic signature of Component III is of greatest consequence in Cluster 4a while Component IV is of greatest consequence in Cluster 4b. Samples from the Wakulla conduit wells were clustered with 4a and 4b.

In contrast to previously discussed clusters, Clusters 5 and 6 feature Component II as the dominant component in determining the chemical character of the samples in these clusters. The clusters are located in the northwest corner of the study area where the presence of particular geologic units likely produces this component. Different degrees of mixing of water from sources producing Components I, III, and IV in Cluster 5 determine the character of the individual samples. In Cluster 6, Components III and IV are of near equal significance with Component I being of minimal significance.

Figure 19. Wakulla Characterization Spring Composite Deviation Scores

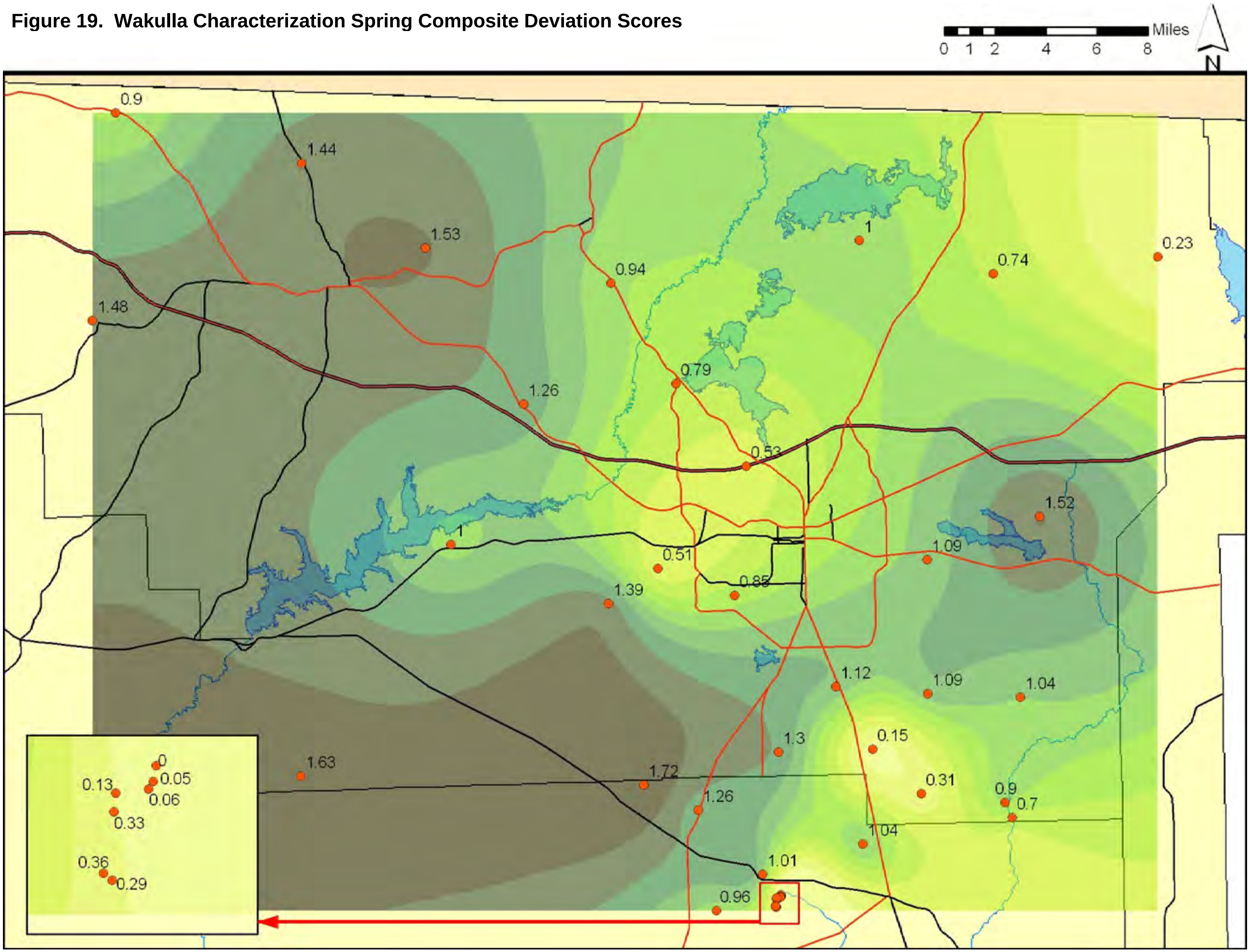
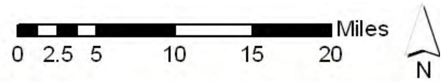
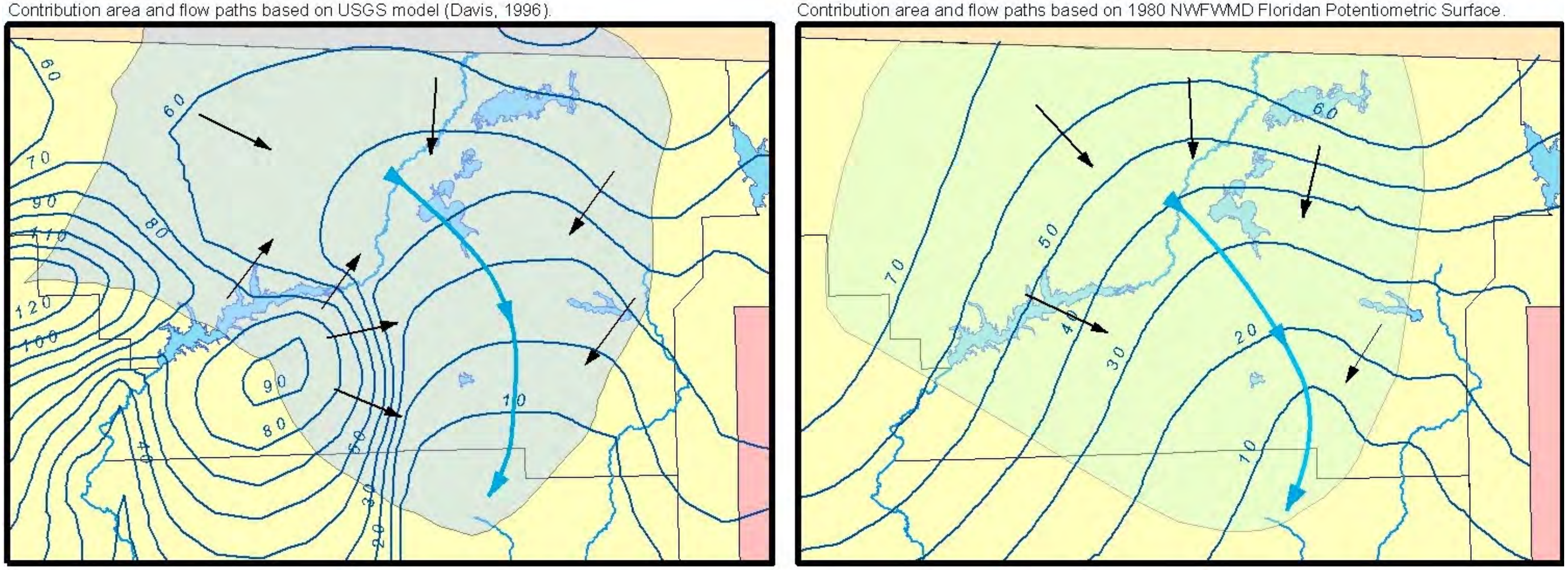


Figure 20. Wakulla Characterization Ground Water Flow vs. Composite Deviation



Contribution area and flow paths based on USGS model (Davis, 1996).

Contribution area and flow paths based on 1980 NWFWMD Floridan Potentiometric Surface.



Corellation between ground water flow path and primary contribution area based on ground water chemistry.

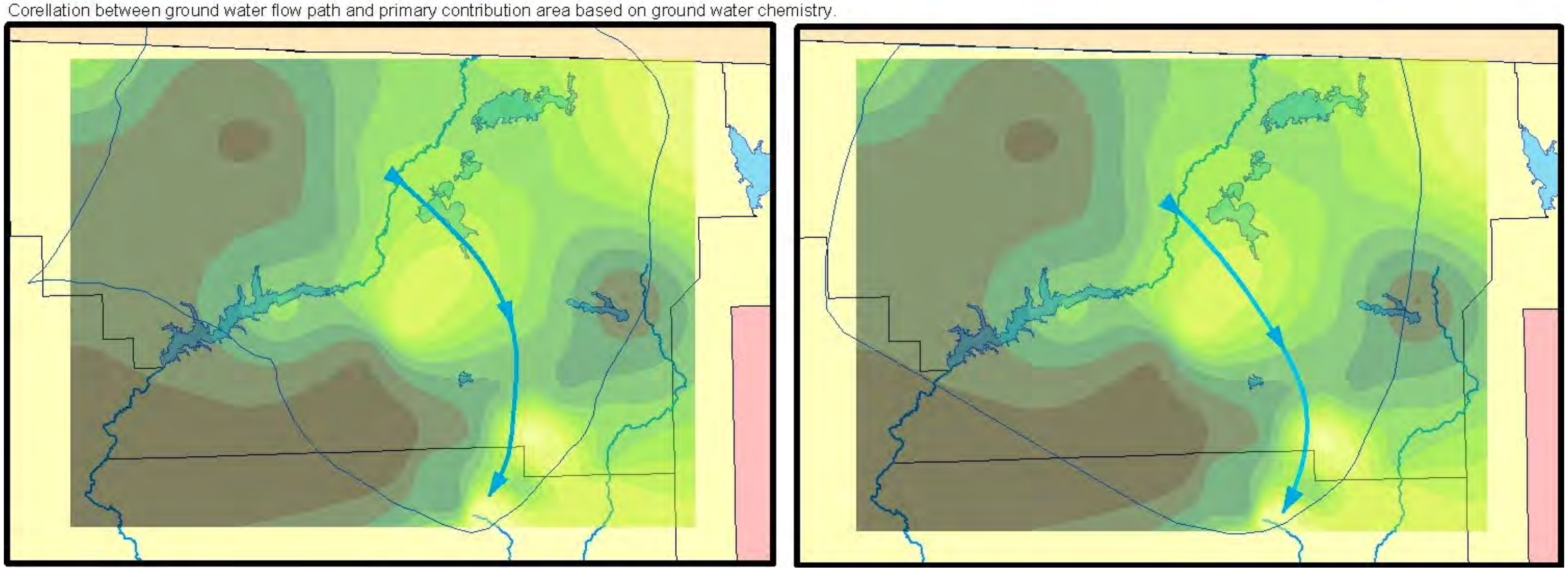


Figure 21. Results from Clustering Wakulla Characterization Sample Data

Figure 22. Radial Diagrams for the Average Component Scores of Each Cluster Computed from the Wakulla Characterization Sample Data

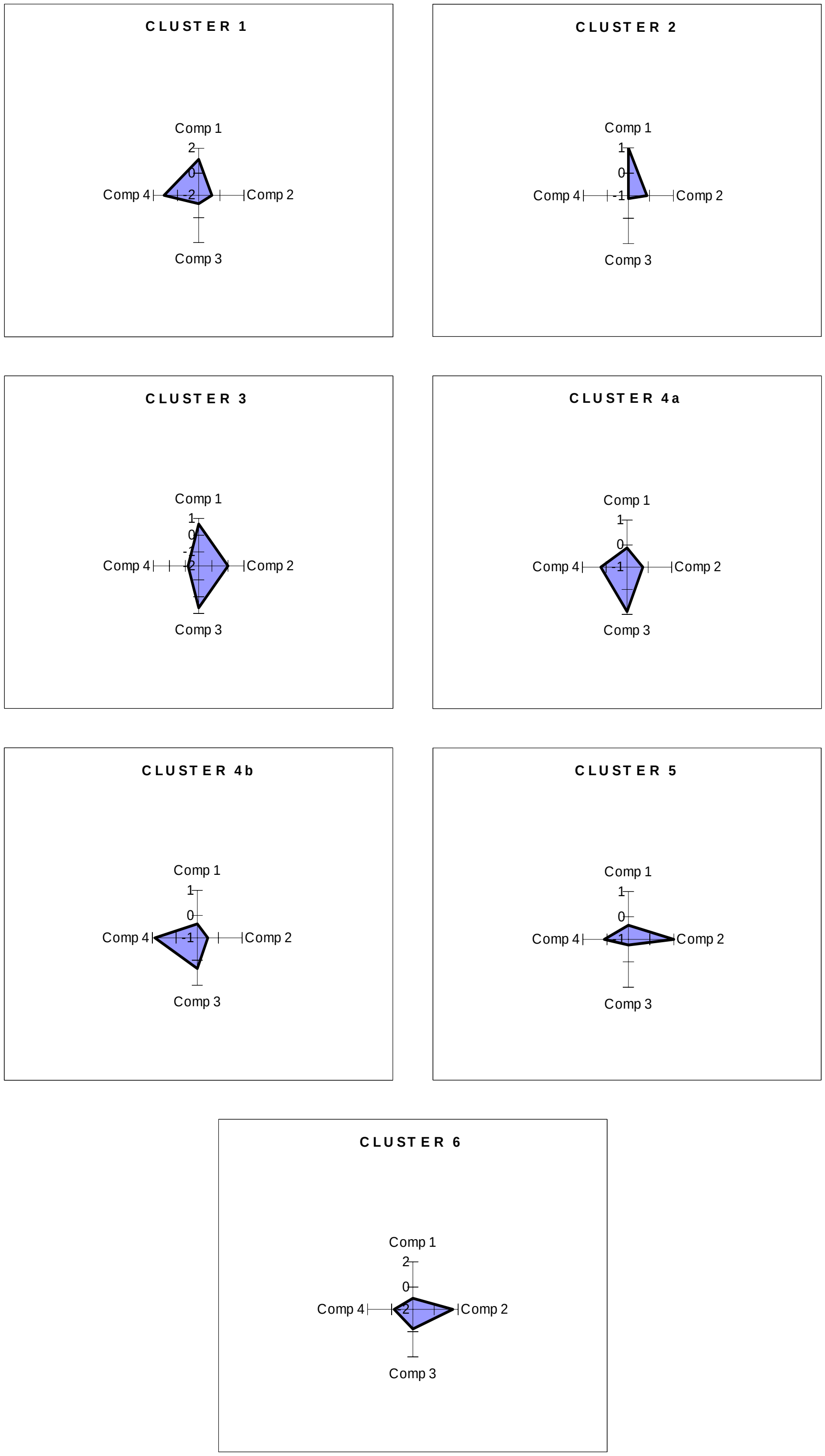
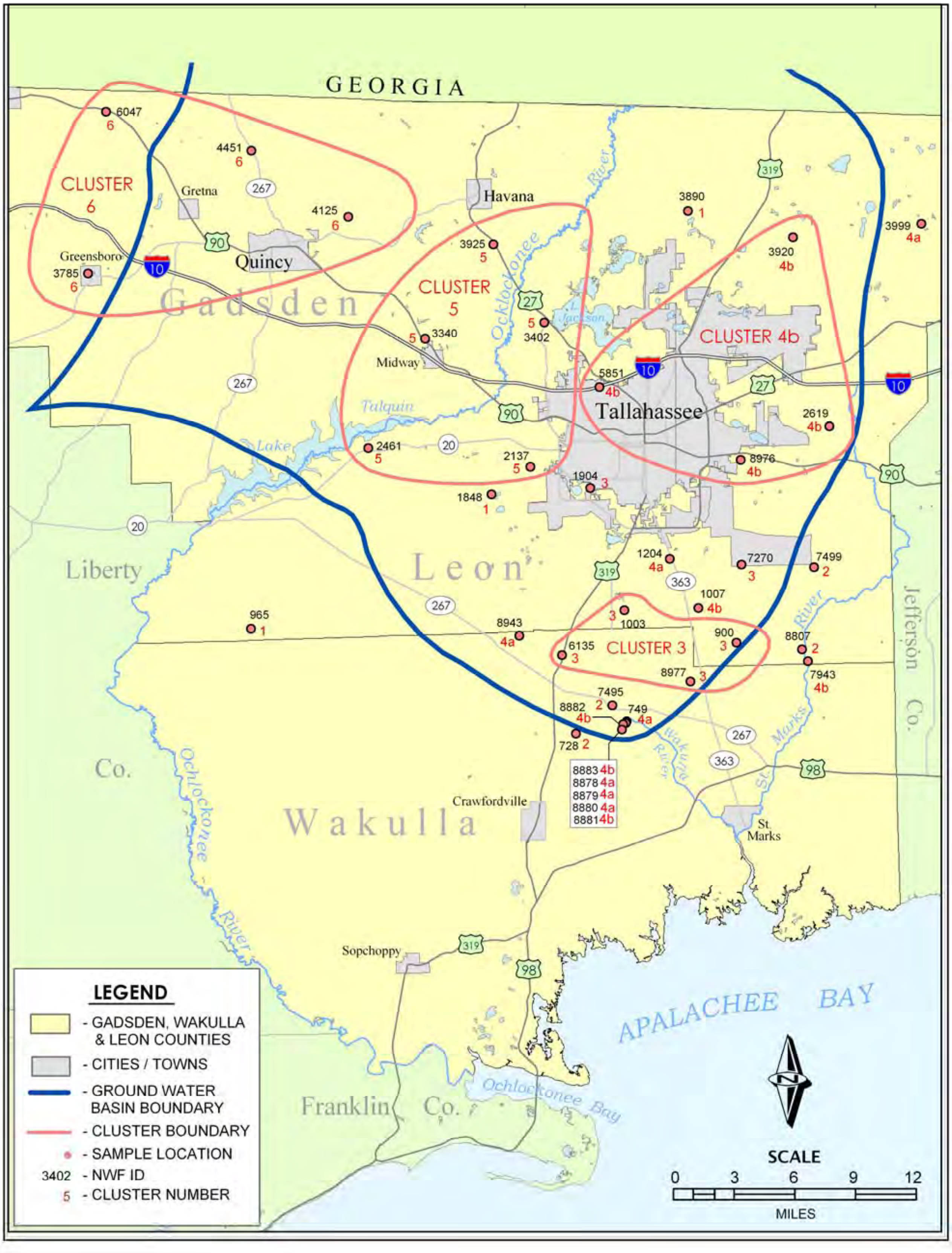


Figure 23. Distribution of Clusters within Wakulla Characterization Study Area



Conclusions

1. The principle component analysis of the Jackson Blue Spring and Wakulla Springs water quality data resulted in the distillation of four components in each basin explaining the majority of the variance within the sample population.

2. The principle components appear to represent understood physiographic, stratigraphic, and anthropogenic influences upon the chemical composition of the Floridan Aquifer within the spring basins.

3. The Pearson distance determination and the complete linkage method produced clusters whose individual samples share common chemical character and, with few exceptions, have a common spatial relationship. The radial diagrams constructed with the component scores from the PCA reveal that the chemical character of the clusters is determined by both single components and by the mixing of components representing multiple water types. The mapped clusters serve as a composite view of the water types as determined by the four components.

4. The primary contribution area for both springs as defined by the composite deviation score coincides with established spring basin boundaries and ground water flow directions.

5. The primary contribution area is useful in understanding the dynamics within the spring basin and complements the development of a spring basin boundary or springshed.

6. The use of principle component analysis and hierarchical cluster analysis in their interpretation of spring basin ground water chemistry assumes that samples from individual wells are representative of the ground water chemistry in the vicinity of the well and that proximate land use impacts are not great enough to cause the chemistry to deviate significantly from surrounding conditions. An effort should be made when conducting studies of this nature to maximize the number of sample sites, with thirty sites falling within the lower end of the acceptable range.

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Appendix A

Well Construction Data

Table 6. Well Location and Construction Data, Jackson Blue Spring Characterization

NWF ID	SITE ID	WELL NAME	LATITUDE	LONGITUDE	LOCATION DATUM	ELEVATION (ft)	ELEVATION DATUM	DEPTH OF WELL (ft)	DEPTH OF CASING (ft)	DIAMETER (in)
4797	304424085074101	D COLLIER	30.74007645	-85.12824570	WGS84	129	NGVD29	110	63	4
5042	304725085082601	JACKSON BLUE SPRING	30.79033333	-85.14017500	WGS84	77	NGVD29	SPRING		
5100	304828085003901	BERRY	30.80753333	-85.01125000	WGS84	100	NGVD29	70	59	4
5226	305025085082101	NWFWMD-BAXTER SAND PIT VISA	30.84034444	-85.13875833	WGS84	129.31	NGVD29	118	85	4
5318	305209085084403	R.D. BENNETT CATTLE	30.85668333	-85.16168333	WGS84	115	NGVD29	126	84	4
5386	305331085085401	WORLD	30.89175532	-85.14808607	WGS84	132	NGVD29	110	63	4
5391	305336085023601	STEPHENSON	30.89342110	-85.04293442	WGS84	119.23	NGVD29	110	84	4
5490	305524085070501	BASCOM 1ST METH CH	30.92358144	-85.11799744	WGS84	140.65	NGVD29	98	76	4
5640	305749085120701	NWFWMD-FRIENDSHIP BAPTIST VISA	30.96398056	-85.20225000	WGS84	141.64	NGVD29	177	82	4
5697	305845085070301	DITTY MON\JC-3\JK-30	30.97906667	-85.11769444	WGS84	154	NGVD29	123	83	4
6497	304235085051101	LOUISIANA-PACIFIC	30.70976287	-85.08659448	WGS84	133	NGVD29	100	84	4
8054	305016085023101	DAVIS	30.83800278	-85.04202500	WGS84	115	NGVD29	150	88	4
8059	305146085030901	BALDWIN	30.86290332	-85.05269845	WGS84	122	NGVD29	130	60	4
8064	304803085033601	MERCER	30.80104524	-85.06007916	WGS84	130	NGVD29	135	84	4
8068	304512085050501	WILLIAM MERCHANT	30.76859101	-85.10352743	WGS84	110	NGVD29	89	60	4
8075	305140085062401	WALKER	30.86101174	-85.10646025	WGS84	125	NGVD29	132	95	4
8076	305336085064001	DIXON	30.89339210	-85.11144505	WGS84	132	NGVD29	95	63	4
8082	304417085042001	ROWELL	30.73915847	-85.07013387	WGS84	150	NGVD29	140	105	4
8961	304605085034601	J. MEARS RESIDENTIAL	30.77490309	-85.06181622	WGS84	120	NGVD29	180	120	4
8963	305543085091301	PETTIS	30.92867711	-85.15395173	WGS84	140	NGVD29	125	93	4
8964	304730085064301	CALHOUN	30.79189255	-85.11202416	WGS84	115	NGVD29	150	50	4
8965	305830085084601	ADAMS	30.97506667	-85.14626667	WGS84	151	NGVD29	122	74	4
8966	305213085121601	BUCKTOWN BAPTIST CHURCH	30.87040000	-85.20448333	WGS84	132	NGVD29	140	80	4
8967	305515085045801	OLDS	30.92115000	-85.08285000	WGS84	135	NGVD29	100	73	4
8968	305302085044801	BRICKLER	30.88410000	-85.08015000	WGS84	132	NGVD29	130	120	4
8969	305008085044101	JIMMY WILLIAMS	30.83568333	-85.07815000	WGS84	130	NGVD29	130	90	2
8970	304846085085301	MURPHY	30.81275000	-85.14806667	WGS84	118	NGVD29	100	63	4
8971	305703085075701	WOOD	30.95100000	-85.13271667	WGS84	155	NGVD29	70	58	2
8972	304852085054801	R. MATTHEWS	30.81445000	-85.09691667	WGS84	118	NGVD29	110	80	4

Table 7. Well Location and Construction Data, Wakulla Springs Characterization

NWF ID	SITE ID	WELL NAME	LATITUDE	LONGITUDE	LOCATION DATUM	ELEVATION (ft)	ELEVATION DATUM	DEPTH OF WELL (ft)	DEPTH OF CASING (ft)	DIAMETER (in)
728	301337084204001	R. MCKEITHON	30.226663611	-84.344185280	WGS84	18.32	NGVD29	75	36	4
900	301725084122601	WALTER GERREL	30.290450000	-84.207519440	WGS84	30.26	NGVD29	70	40	4
965	301831084365601	NWFWMD-OTTER CAMP FLORIDAN	30.308794720	-84.615567780	WGS84	110	NGVD29	255	218	4
1003	301857084180401	SPRIGGS AG	30.316204493	-84.300986352	WGS84	25.04	NGVD29	148	110	4
1007	301900084141801	WOODVILLE #2	30.316585843	-84.238861734	WGS84	35	NGVD29	200	122	14
1204	302109084154701	NWFWMD-BIKE TRAIL	30.352966333	-84.261918373	WGS84	37.33	NGVD29	90	80	4
1848	302411084243801	SILVER LAKE	30.403360348	-84.410615764	WGS84	90	NGVD29	202	63	6
1904	302423084193801	LAKE BRADFORD TRL PK	30.406236944	-84.327288550	WGS84	72	NGVD29	170	137	6
2137	302522084224001	NWFWMD-BRADFORD BROOK DEEP	30.422850761	-84.377428189	WGS84	45.76	NGVD29	140	133	4
2461	302621084305201	FT. BRADEN #2	30.439212002	-84.513553895	WGS84	150	NGVD29	328	187	6
2619	302655084073001	GAY	30.447157786	-84.124740415	WGS84	125	NGVD29	167	74	4
3340	303109084275403	NWFWMD-HQ FLORIDAN OBS	30.518471389	-84.463648333	WGS84	200.06	NGVD29	356	232	4
3402	303142084214601	LAKE JACKSON FLORIDAN	30.528197222	-84.362736111	WGS84	122.2	NGVD29	225	100	6
3785	303418084444701	GREENSBORO #3	30.571397778	-84.746636111	WGS84	275.26	NGVD29	420	264	6
3890	303459084141402	TEC-KILLEARN LAKES #2	30.607410556	-84.239365556	WGS84	210	NGVD29	350	260	12
3920	303510084090401	TEC-BAKER	30.586252500	-84.151379444	WGS84	180	NGVD29	340	232	12
3925	303514084241701	EDWIN HERRING	30.586382364	-84.404124158	WGS84	150	NGVD29	250	169	4
3999	303539084023401	TEC-MICCOSUKEE	30.593704722	-84.042730556	WGS84	214	NGVD29	320	224	6
4125	303632084313401	TEC-#5-ST HEBRON	30.608838380	-84.526014754	WGS84	253	NGVD29	465	210	6
4451	303931084362401	ST JOHNS ELEM SCHOOL	30.658829533	-84.606625527	WGS84	297.57	NGVD29	426	283	6
5851	302847084190502	TALLAHASSEE #26	30.479908484	-84.317640318	WGS84	135	NGVD29	407	309	24
6047	303435084232301	TEC-#11-OAK GROVE	30.689624260	-84.728652934	WGS84	289	NGVD29	469	331	12
6135	301712084211401	A. SCOTT	30.284442703	-84.354393544	WGS84	24.05	NGVD29	28	22	4
7270	302051084120501	SE22A (7270)	30.347563190	-84.201579012	WGS84	31.87	NGVD29	121	96	4
7495	301448084184601	NWFWMD-NITRATE #4	30.246726682	-84.313039393	WGS84	13.46	NGVD29	70	50	4
7499	302039084082601	NWFWMD-NITRATE #6	30.344252808	-84.140608533	WGS84	28.35	NGVD88	90	70	4
8807	301710084090501	NATURAL BRIDGE RECREATION AREA	30.284363559	-84.152518270	WGS84	24	NGVD29	70	42	4
8943	301757084232301	R. SCOTT	30.299357969	-84.389891102	WGS84	52	NGVD29	65	48	4
8976	302527084120001	C.B. HUGGINS	30.424233241	-84.200124011	WGS84	140	NGVD88	275	170	4
8977	301545084144901	D. BURNS	30.262801123	-84.247042336	WGS84	30	NGVD88	90	42	4
7943	301633084085601	ST MARKS RIVER RISE	30.275600000	-84.147800000	WGS84	8	NGVD29	SPRING		
749	301405084181001	WAKULLA COMPOSITE	30.234788889	-84.301469444	WGS84	5	NGVD29	SPRING		
8881	301458084181603	WAKULLA TUBING A/D-TUNNEL	30.232648333	-84.304338056	WGS84	25	NGVD29	273	273	3/8
8883	301344084182003	WAKULLA TUBING A/K-TUNNEL	30.228794722	-84.305448611	WGS84	25	NGVD29	299	299	3/8
8878	301401084180702	WAKULLA TUBING B-TUNNEL	30.233561944	-84.302073333	WGS84	20	NGVD29	302	302	3/8
8879	301401084180703	WAKULLA TUBING C-TUNNEL	30.233561944	-84.302073333	WGS84	20	NGVD29	289	289	3/8
8880	301458084181602	WAKULLA TUBING D-TUNNEL	30.232648333	-84.304338056	WGS84	25	NGVD29	281	281	3/8
8882	301344084182002	WAKULLA TUBING K-TUNNEL	30.228794722	-84.305448611	WGS84	25	NGVD29	269	269	3/8

Appendix B

Tabular Water Quality Results

Table 8. Field and Laboratory Results, Jackson Blue Spring Characterization

NWF ID	Station Name	Date Collected	Temperature	Conductance	DO	pH	Alkalinity	Ammonia	Ammonia+ Organic Nitrogen	Nitrate+ Nitrite	P	PO4	Ca	Mg	Na	K	Cl	SO4	F	TDS
4797	D COLLIER	10/6/2004 10:21	20.18	387	0.51	7.05	199	0.12	0.22	0.014	0.031	0.023	72.1	6.6	2.41	0.24I	3.5	0.47I	0.074I	218
5042	JACKSON BLUE SPRING	10/21/2004 18:46	20.49	251	7.16	7.42	109	0.01U	0.06U	3.4	0.02	0.021	42.6	2.1	1.79	0.31	4.2	1.2	0.05U	144
5100	BERRY	10/21/2004 17:22	20.9	203	5.28	7.49	88	0.01U	0.06U	2	0.018	0.019	36.7	0.77	1.75	0.25	4.2	0.62	0.05U	129
5226	BAXTER SAND PIT VISA	10/14/2004 15:10	20.8	264	8.3	7.52	116	0.01U	0.06U	3.4	0.025	0.027	50.7	1.2	1.71	0.27	4	0.86	0.05U	158
5318	R.D. BENNET CATTLE	10/14/2004 12:27	21.09	444	8.32	7.02	211	0.01U	0.06U	4.3	0.029	0.029	87.4	1.1	2.53	0.45	6.5	0.64	0.068I	257
5386	320067701	10/14/2004 10:54	20.86	230	8.53	7.2	104	0.01U	0.06U	2.2	0.016	0.011	44.3	0.69	1.63	0.15I	3	0.43I	0.05U	127
5391	STEPHENSON	10/7/2004 14:26	21.33	168	9.12	7.78	58	0.01U	0.06U	4.9	0.012	0.012	30.1	0.87	1.7	0.24U	4.7	0.28I	0.05U	125
5491	BASCOM 1ST METH ST	10/7/2004 11:53	21.29	198	8.88	7.32	94	0.01U	0.06U	0.85	0.026	0.016	39.1	0.56	2.14	0.24U	2.7	0.54	0.05U	110
5640	FRNDSHP BAPTIST VISA	10/19/2004 11:41	21.53	248	8.69	7.27	123	0.01U	0.06U	0.89	0.015	0.014	48.7	0.87	1.57	0.22	2.3	0.41I	0.05U	123
5697	DITTY MON\JC-3\JK-30	10/21/2004 12:40	20.79	220	7.14	7.16	91	0.047	0.06U	3.6	0.012	0.013	38.8	0.7	1.79	0.4	4	0.83	0.05U	154
6497	T198000790	10/6/2004 11:34	20.73	231	5.04	7.65	115	0.01U	0.06U	0.34	0.013	0.015	29.3	11.6	1.94	0.22U	2.9	1.7	0.092I	129
8054	T200001901	10/14/2004 16:29	21.47	234	1.35	7.54	108	0.01U	0.06U	0.12	0.12	0.021	59.1	1.8	1.49	0.18I	2.3	10	0.05U	130
8059	T199901192	10/7/2004 15:49	21.71	151	9.12	7.6	64	0.01U	0.06U	2.4	0.009I	0.012	28.5	0.61	1.44	0.24U	2.5	1.2	0.05U	91
8064	T200002003	10/6/2004 14:44	21.14	177	9.38	7.39	65	0.01U	0.06U	4.2	0.021	0.021	32.4	0.72	1.43	0.32I	4.9	0.33I	0.05U	120
8068	WILLIAM MERCHANT	10/6/2004 13:38	20.96	246	6.93	7.33	113	0.01U	0.06U	1.9	0.015	0.013	39.2	6.8	1.78	0.22U	3.5	1.8	0.089I	133
8075	T200100611	10/13/2004 14:14	20.35	270	9.38	7.22	126	0.01U	0.06U	2.4	0.012	0.012	52.7	1.3	1.61	0.21	3.3	0.54	0.05U	153
8076	T200101297	10/7/2004 13:05	20.85	257	8.31	7.31	107	0.01U	0.06U	4.6	0.02	0.016	51.8	1	1.88	0.24U	4.5	0.71	0.05U	163
8082	ROWELL	10/6/2004 12:37	20.29	192	7.62	7.54	96	0.01U	0.06U	0.18	0.005I	0.01I	23.9	9.6	1.68	0.22U	2.7	0.99	0.1	102
8961	J MEARS RESIDENTIAL	10/7/2004 17:03	21.51	282	1.39	7.24	145	0.01U	0.06U	0.004U	0.013	0.017	52.3	4.3	1.41	0.24U	1.9	1.9	0.092I	152
8963	T200200606	10/13/2004 13:07	20.6	288	9.26	7.38	112	0.01U	0.06U	6.6	0.018	0.015	51.6	1.3	2.16	0.54	6.2	1	0.05U	192
8964	CALHOUN	10/13/2004 15:36	20.62	274	8.13	7.26	131	0.01U	0.06U	1.8	0.017	0.017	52.4	2	1.76	0.19I	3.4	1.1	0.054I	143
8965	T199800274	10/19/2004 12:55	20.83	223	8.65	7.41	96	0.01U	0.06U	3	0.016	0.012	41.8	0.68	1.61	0.25	3.5	0.43I	0.05U	127
8966	BUCKTOWN	10/20/2004 10:45	21.33	281	8.53	7.01	129	0.01U	0.06U	2	0.032	0.026	55.1	0.75	3.16	0.19I	5.6	0.43I	0.05U	168
8967	OLDS	10/20/2004 12:26	20.76	162	8.67	7.47	69	0.01U	0.06U	2	0.013	0.009I	30	0.62	1.59	0.25	3.1	0.29I	0.05U	101
8968	BRICKLER	10/20/2004 13:28	20.98	217	8.1	7.41	87	0.01U	0.06U	5.2	0.012	0.01	39.3	1.1	1.81	0.4	4.3	0.65	0.05U	146
8969	T200101474	10/20/2004 14:41	21.23	192	8.18	7.36	78	0.01U	0.06U	3.2	0.014	0.012	35	1.1	2.02	0.38	3.8	0.8	0.05U	138
8970	T200203484	10/20/2004 17:02	21.29	139	8.95	7.66	50	0.01U	0.06U	4.6	0.016	0.015	24.7	0.44	1.26	0.17I	3.3	0.39I	0.085I	113
8971	WOOD	10/21/2004 14:06	20.96	246	8.12	7.41	100	0.01U	0.06U	0.013	0.016	0.012	43.9	1	2.07	0.56	5.1	0.76	0.05U	166
8972	M199301013	10/21/2004 16:01	20.93	212	7.84	7.47	87	0.01U	0.06U	3.7	0.022	0.024	36.9	0.98	1.77	0.36	3.9	1	0.05U	149

U=result at or below method detection limit
I=result between method detection limit and practical quantification limit

Table 9. Field and Laboratory Results, Wakulla Springs Characterization

NWF ID	Station Name	Date Collected	Temperature	Conductance	DO	pH	Alkalinity	Ammonia	Ammonia+ Organic Nitrogen	Nitrate+ Nitrite	P	PO4	Ca	Mg	Na	K	Cl	SO4	F	TDS
728	R. MCKEITHON	10/25/04 10:31	23.09	371	4.38	7.03	186	0.01U	0.072IQ	0.910	0.022	0.026	70.2	2.0	1.69	0.85	2.4	5.4	0.130	193
900	WALTER GERREL	10/28/04 10:46	20.73	334	2.81	7.19	158	0.01U	0.06U	0.480	0.014	0.015	52.3	8.8	3.66	0.54	5.9	9.5	0.190	181
965	OTTER CAMP FLORIDAN	10/25/04 13:23	21.10	390	0.04	6.94	201	0.400	0.450	0.004U	0.120	0.120	72.4	2.5	3.64	0.89	3.0	0.2U	0.160	224
1003	SPRIGGS AG WELL	10/28/04 16:52	21.49	241	2.77	7.27	118	0.062	0.076IJ	0.009I	0.010	0.013	47.5	1.0	1.97	0.31	2.8	4.9	0.061I	132
1007	WOODVILLE #2	12/1/04 14:13	20.74	354	3.35	7.21	166	0.01U	0.06U	0.780	0.031	0.029	44.0	14.5	3.84	0.42	6.0	8.2	0.190	180
1204	BIKE TRAIL WELL	11/17/04 14:33	21.64	229	4.88	7.53	106	0.01U	0.06U	0.380	0.018	0.018	32.8	6.3	2.38	0.34	4.3	4.6	0.100	135
1848	SILVER LAKE	11/18/04 10:25	19.86	217	1.51	6.78	106	0.027	0.06U	0.005I	0.030	0.025	36.6	3.8	1.51	0.22	2.6	1.2	0.069I	125
1904	LAKE BRADFORD TRL PK	11/17/04 12:55	21.65	278	3.36	7.42	132	0.01U	0.06U	0.320	0.016	0.013	45.2	5.5	2.98	0.30	5.8	2.2	0.07I	154
2137	BRADFORD BROOK DEEP	11/9/04 16:19	21.15	322	0.18	6.95	145	0.080	0.1I	0.007I	0.034	0.025	42.3	19.2	5.33	1.00	8.8	14.0	0.170	189
2461	FT. BRADEN #2	11/18/04 12:35	22.30	288	3.09	7.44	149	0.120	0.15I	0.004U	0.013	0.012	46.2	6.8	4.00	0.72	1.9	0.2U	0.230	169
2619	GAY	11/23/04 12:35	21.47	187	6.20	7.71	80	0.01U	0.06U	1.400	0.036	0.034	24.4	5.7	3.38	0.23	5.8	0.2U	0.160	79
3340	NWFWMD FLORIDAN OBS	11/16/04 12:16	23.87	300	0.14	7.52	145	0.01U	0.06U	0.004U	0.017	0.011	32.7	14.6	4.10	1.50	3.3	7.8	0.350	156
3402	LAKE JACKSON DEEP	11/9/04 12:38	22.01	283	2.44	7.22	142	0.01U	0.06U	0.240	0.017	0.016	35.3	14.3	2.38	0.88	3.2	2.0	0.220	154
3785	GREENSBORO #3	11/17/04 15:55	22.37	267	3.89	7.71	126	0.039	0.06U	0.004U	0.004U	0.004U	29.1	11.3	7.53	2.00	2.5	10.0	0.470	153
3890	TEC-KILLEARN LAKES #2	11/16/04 11:00	20.84	380	3.14	6.90	195	0.01U	0.06U	0.210	0.056	0.057	57.2	11.2	2.19	0.38	3.7	1.2	0.160	225
3920	TEC-BAKER	11/16/04 12:18	20.79	267	7.98	7.11	126	0.01U	0.06U	0.240	0.042	0.039	35.7	10.1	2.05	0.33	3.8	7.8	0.180	152
3925	EDWIN HERRING	11/23/04 14:15	21.04	308	0.69	7.39	155	0.049	0.06U	0.009I	0.010	0.007I	40.9	13.1	3.07	0.81	2.8	3.7	0.290	146
3999	TEC-MICCOSUKEE	11/16/04 13:06	20.75	314	6.82	7.04	128	0.01U	0.06U	0.520	0.047	0.038	40.6	10.9	4.30	0.51	6.3	23.0	0.240	177
4125	TEC-#5-ST HEBRON	11/15/04 12:00	22.70	273	0.25	7.43	127	0.022	0.06U	0.004I	0.004U	0.004U	29.0	14.1	5.09	2.30	2.6	11.0	0.570	151
4451	ST JOHNS ELEM SCHOOL	11/17/04 10:55	22.62	311	1.81	7.49	153	0.017I	0.06U	0.004U	0.004U	0.004U	30.4	16.8	7.41	2.40	2.8	8.3	0.460	168
5851	TALLAHASSEE #26	12/1/04 10:35	21.24	307	1.01	7.21	143	0.063	0.067I	0.024	0.053	0.047	43.2	8.3	4.13	0.45	7.6	4.1	0.200	128
6047	TEC-#11-OAK GROVE	11/15/04 10:45	22.03	261	6.60	7.43	128	0.01U	0.06U	0.310	0.011	0.011	34.2	11.6	2.76	0.50	3.5	2.1	0.170	159
6135	A. SCOTT	10/28/04 13:55	22.49	443	4.93	6.79	193	0.01U	0.06U	0.850	0.008I	0.006I	88.0	1.6	5.22	0.57	20.0	8.2	0.059I	267
7270	SE22A (7270)	12/1/04 12:39	21.29	431	4.81	7.21	154	0.01U	0.06U	4.300	0.014	0.013	54.2	8.1	16.60	1.40	24.0	12.0	0.120	185
7495	NITRATE #4	10/28/04 12:31	20.43	379	0.10	7.01	192	0.047	0.068I	0.004U	0.016	0.016	73.6	4.1	2.52	1.10	4.2	2.5	0.110	203
7499	NITRATE #6	11/17/04 12:19	20.56	326	0.34	7.13	165	0.016I	0.06U	0.004U	0.005I	0.006I	58.3	3.3	1.71	0.35	3.5	1.1	0.120	183
8807	NATURAL BRIDGE RECREATION AREA	11/22/04 12:50	20.92	301	0.57	6.99	144	0.01U	0.06U	0.180	0.027	0.029	58.8	1.6	2.91	0.48	4.6	4.5	0.05U	165
8943	R. SCOTT	10/28/04 15:09	21.28	176	7.75	7.17	62	0.01U	0.06U	3.500	0.009I	0.01I	27.8	1.6	4.37	0.45	5.5	4.6	0.05U	100
8976	C.B. HUGGINS	11/23/04 11:20	20.24	227	6.26	7.50	104	0.01U	0.06U	0.600	0.031	0.030	29.6	8.0	2.48	0.46	4.3	4.0	0.190	97
8977	D. BURNS	11/22/04 10:35	20.18	367	7.41	6.94	182	0.01U	0.06U	0.400	0.006I	0.004U	69.1	5.2	2.54	0.26I	4.0	4.8	0.098I	210
7943	ST. MARKS RIVER RISE-9693	4/7/04 11:26	19.34	266	2.79	7.56	124	0.011I	0.082I	0.2	0.047	0.04	43.4	7.7	3.37	0.47	5.1	7.8	0.15	153
749	WAKULLA COMPOSITE	10/25/04 11:30	21.10	305	2.20	7.16	137	0.01U	0.061I	0.780	0.029	0.031	46.8	10.3	5.62	0.63	8.0	10.0	0.160	179
8881	WAKULLA TUBING A/D-TUNNEL	4/12/04 12:14	20.36	294	2.25	7.28	133	0.01U	0.062I	0.45	0.043	0.031	43.1	9.5	4	0.48	7.4	10	0.14	161
8883	WAKULLA TUBING A/K-TUNNEL	4/12/04 16:42	19.45	299	1.16	7.38	133	0.01U	0.06U	0.42	0.033	0.031	43.8	9.5	4	0.48	7.3	11	0.13	179
8878	WAKULLA TUBING B-TUNNEL	4/12/04 13:37	21.17	323	2.28	7.23	145	0.01U	0.06U	0.97	0.034	0.029	47.7	11	4.9	0.59	8.5	11	0.15	176
8879	WAKULLA TUBING C-TUNNEL	4/12/04 13:41	21.19	327	1.98	7.32	145	0.01U	0.06U	0.91	0.033	0.034	48	10.7	4.9	0.58	8.5	12	0.15	179
8880	WAKULLA TUBING D-TUNNEL	4/12/04 12:24	19.86	321	2.26	7.33	144	0.01U	0.06U	0.88	0.032	0.031	46.6	11.1	4.6	0.57	8	10	0.15	176
8882	WAKULLA TUBING K-TUNNEL	4/12/04 16:46	19.44	292	1.86	7.46	133	0.01U	0.06U	0.43	0.032	0.032	42.9	9.7	4	0.49	7.3	10	0.14	167

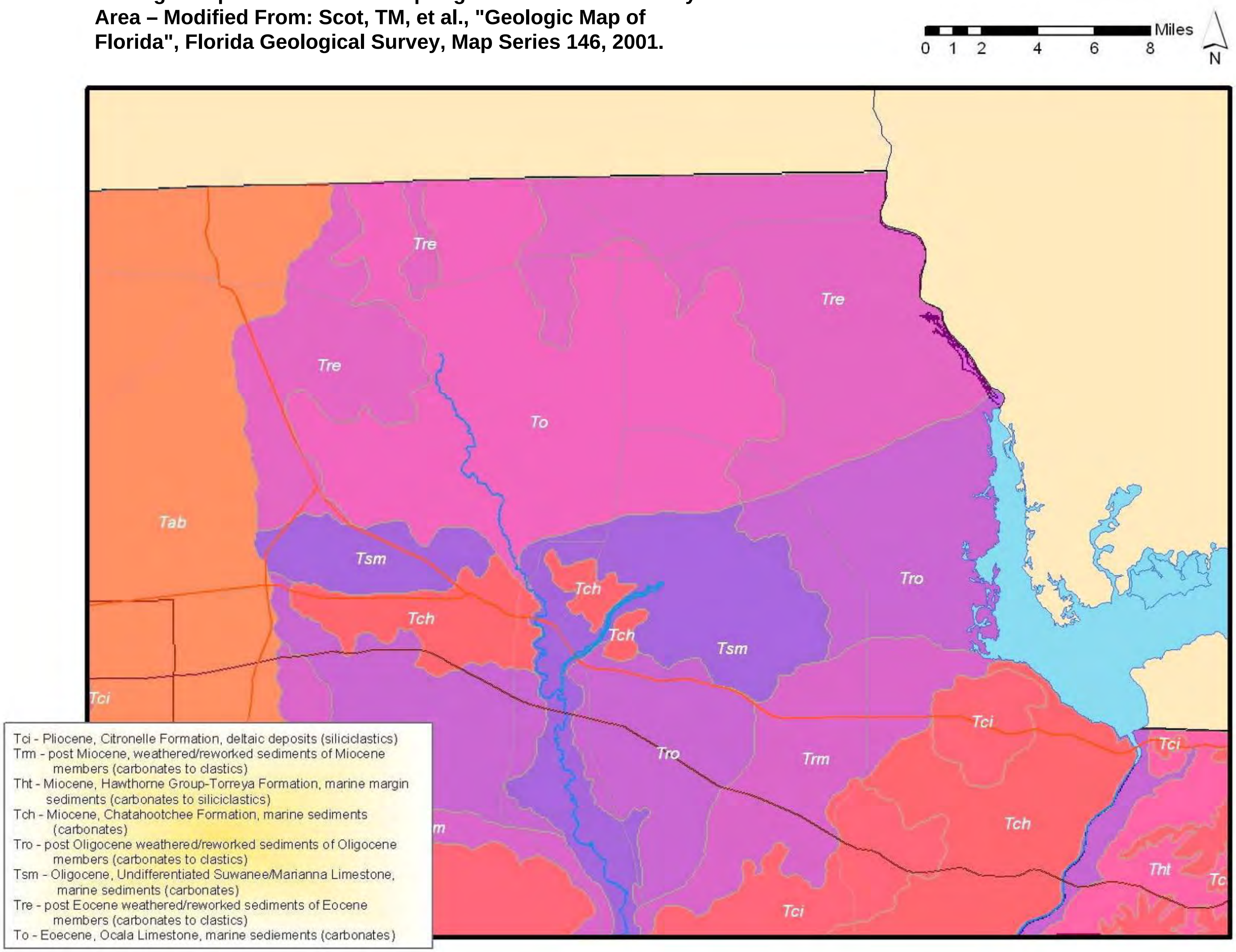
U=result at or below method detection limit
I=result between method detection limit and practical quantification limit

J= Estimated value; value may not be accurate.
Q= Sample held beyond the accepted holding time.

Appendix C

Geologic Maps of Study Areas

Geologic Map of Jackson Blue Spring Characterization Study Area – Modified From: Scot, TM, et al., "Geologic Map of Florida", Florida Geological Survey, Map Series 146, 2001.



Geologic Map of Wakulla Springs Characterization Study Area – Modified From: Scot, TM, et al., "Geologic Map of Florida", Florida Geological Survey, Map Series 146, 2001.