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A morphometric analysis of the geomorphology of Florida's springs

Andrew Curtis Walker
University of South Florida

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A Morphometric Analysis of the Geomorphology of Florida's Springs

by

Andrew Curtis Walker

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
Department of Geography
College of Arts and Sciences
University of South Florida

Major Professor: Philip Reeder, Ph.D.
Robert Brinkmann, Ph.D.
Paul Zandbergen, Ph.D.

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ABSTRACT

An exploratory study of the geomorphology of Florida's springs was conducted using morphometric analysis. Spatial datasets for spring locations, elevation data, physiography, geology and hydrography were acquired for incorporation and analysis with GIS technology. ArcGIS 9 was used to measure certain morphometric parameters from the spatial data for Florida's springs. Other Parameters representing physical and dimensional characteristics of the springs were acquired from FGS Bulletin 66, *Springs of Florida*. All measured and collected data was compiled into a usable morphometric database. The data is described statistically and summarized according to the spatial distribution of Florida's springs with respect to geology and landforms. This examination is carried out at two different scales; 1) the entire population of Florida's 754 springs is examined with emphasis placed upon geology, physiography, and elevation, 2) a subset of 102 springs that is deemed to be a representative sample is examined according to all morphometric parameters. It was concluded that the presence of karst terrain at the majority of the spring sites that were examined in this study is the

prevailing factor that has influenced where springs have resurged in Florida. This was observed at both scales in the study. It is also concluded that spring sites in Florida are strongly linked to lower elevations, and therefore that elevation also influences their distribution. Suggestions for future research are posed, including specific ways in which the current methodology can be expanded upon and improved.

Chapter One

Introduction

This research is an exploratory study of several aspects of Florida's springs. Location data for 754 springs within the state has been acquired and this population will be examined relative to their elevation, physiography, and geology. Additionally, a subset of 102 first, second and third magnitude springs will be studied in more detail. By using an abstract application of morphometric analysis, dimensional and spatial attributes of both data sets will be explored. Figure 1 shows the location of all 754 springs for which location data was obtained, and the first, second and third magnitude springs that are part of the 102 spring data subset are differentiated.

This research gives attention to both the spatial distribution and frequency of spring locations with respect to the physiographic and geologic regions of Florida, and it is also concerned with observing any trends that exist with respect to the orientation of all generated spring runs, as well as spring elevation, discharge, run length, pool length, pool width, pool area, depth, and distance to coast. The research objectives are carried out in an effort to provide information about the geographical and geomorphological characteristics of Florida's springs that will readily compliment the Florida Springs Classification System (Copeland, 2003). This research will also help to evaluate the usefulness of GIS as a research tool in a morphometric study.

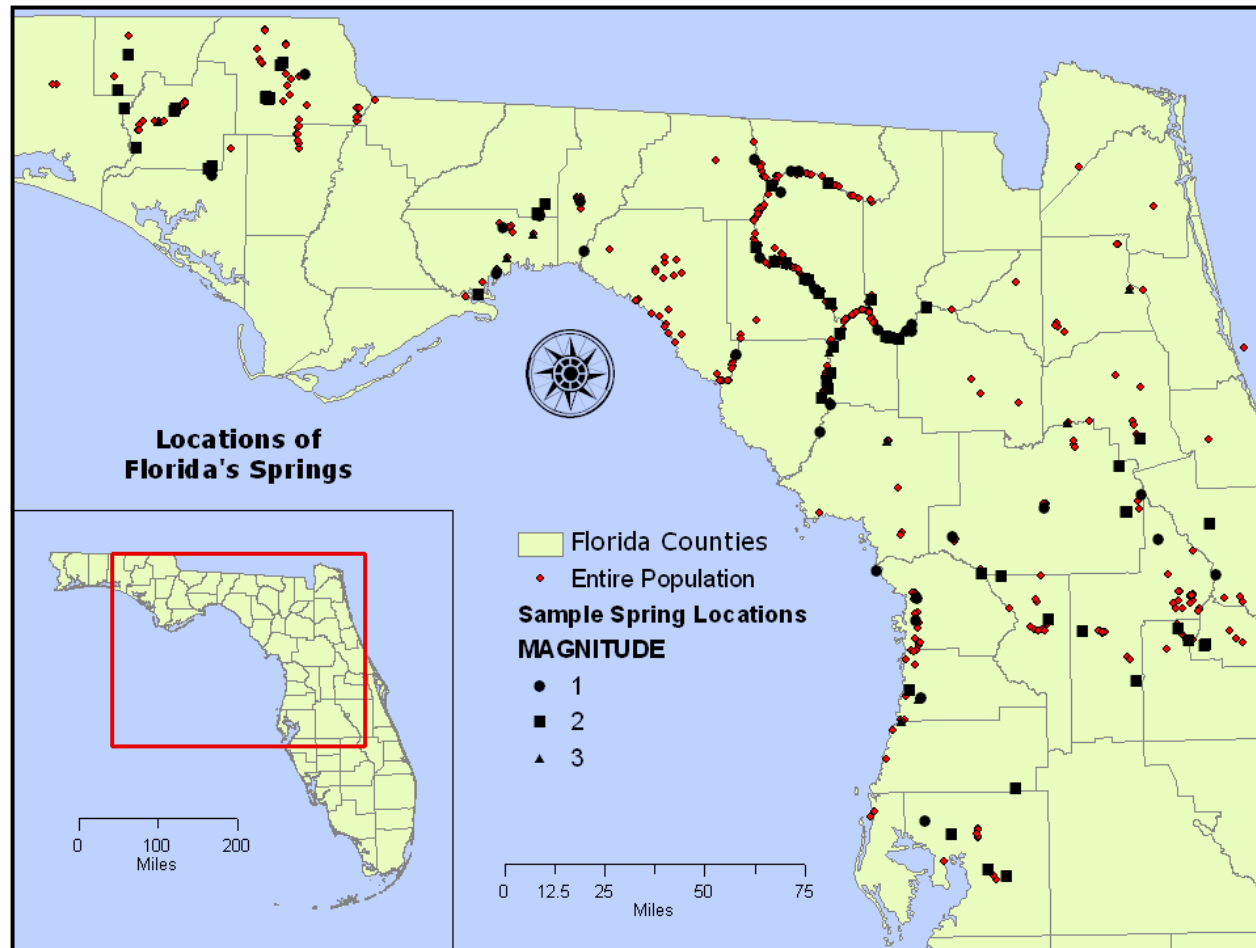


Figure 1: The locations of Florida's known springs with first, second, and third magnitude springs differentiated.

Research Design

Problem Statement

Contemporary research on Florida's springs has yet to compile a comprehensive database of each spring's geographical and geomorphological attributes. An abstract application of morphometric analysis will aid in forming such a compilation of data into a format that is both usable with current studies and applicable to future research of Florida's springs. It will also allow a preliminary analysis of the spatial aspects of the geographical and geomorphological components of the spring database.

Research Questions

- Do springs that exist in different geographic regions of Florida exhibit distinct morphometric patterns relative to these regions?
- Does physiography and geology influence the spatial distribution of Florida's springs?

Sample Design

There are currently over 700 known spring resurgences in Florida. The vast majority of Florida's springs, including all those that are of the first magnitude, are karst springs (Bulletin 66, 2004). There are several seeps and karst windows as well. Figure 2 displays how these features are categorized by the Florida Springs Classification System. Using this system, the vast majority of Florida's springs fall into the onshore vent category. Out of the entire population, 462 have been visited and surveyed by Florida Geologic Survey (FGS) field teams. While the locations of all of the springs in Florida are important in this study, morphometric data is not comprehensive for the entire

population. This research is therefore conducted at two scales. Locations for 754 springs have been acquired. The entire population will be examined relative to elevation, physiography, and geology. A sample consisting of 102 first, second and third magnitude

SPRING		
	ONSHORE	OFFSHORE
	<u>Onshore Vent</u>	<u>Offshore Vent</u>
VENT	Examples: Karst spring Resurgence (River Rise) Estavelle (intermittent resurgence or exsurgence) Subaqueous riverine vent Subaqueous lacustrine vent Sand boil	Examples: Offshore karst spring Unnamed offshore vent Offshore estavelle vent
	<u>Onshore Seep</u>	<u>Offshore Seep</u>
SEEP	Examples: Subaerial riverine seep Subaqueous lacustrine seep	Examples: Unnamed offshore seep Offshore estavelle seep

Figure 2: Florida Springs Classification System (Copeland, 2003)

springs will be examined in greater detail based on the greater amount of morphometric data that exists for these features. These 102 springs represent the most well known springs in Florida for which the most historical data is available (Dewitt, 2006).

Consequently, FGS Bulletin 66 contains considerably more flow data on these 102 springs than the others that have been surveyed and included in the publication. This subset comprises a good representative sample of the entire population (Dewitt, 2006). Several of the first magnitude springs are actually groups of multiple resurgences or vents that have been studied as a single feature for the purposes of measuring their combined flow value. Flow data is not available for the individual springs in each spring group and

therefore the groups will be traditionally represented by single features for analysis purposes.

Significance and Rationale

This study is significant to current research being conducted on Florida's springs in its capacity to consolidate many important physical parameters of the springs into a single database. This morphometry has yet to be pursued for Florida's natural springs and will serve as an informative tool for future studies, as well as the foundation for a more comprehensive morphometric analysis.

Chapter Two

Literature Review

Ritter (1978) in his book entitled *Process Geomorphology* provides a very useful understanding of general geomorphologic processes. The chapter on karst processes and landforms was the most directly related to this research on Florida's springs. Gaining an understanding of this is essential for studying Florida's landforms and springs as part of the natural and physical landscape. Ritter (1978) provides a detailed explanation of terms related to Florida such as 'exsurgence' and 'resurgence', which are distinguished one apart from the other. Resurgences are noted to be more unpredictable due to the variety of discharge and chemistry characteristics than exsurgences. This research will focus on spring resurgences as per their abundance and characteristics. Ritter also discusses some of the specifics of karst drainage systems and he outlines some of the aspects of morphology as well.

White (1988) in his book *Geomorphology and Hydrology of Karst Terrains*, provides a comprehensive text on both subjects, and how they are related in geographic studies. This research of Florida's springs requires, and even assumes, some basic knowledge of geomorphology and specifically karst hydrology due to the carbonate geology of most of Florida. White's book has been an excellent source regarding understanding the fundamental principals of karst hydrology and geomorphology. White begins by distinguishing between the nature of each of the two sciences. He states that while geomorphology has been regarded as qualitative in nature, hydrology is decidedly

quantitative. This difference is further elucidated through specific examples. White makes specific mention of karst springs with respect to their formation, development, and classification. Karst springs are categorized into several groups: gravity springs, alluvial springs, vauclosian springs and offshore springs. Each category is explained with a full description, which was very helpful in facilitating a better basic understanding of the characteristics of Florida's springs in this study.

In an article entitled *Karst Lands*, Mylroie (1995) gives a comprehensive overview of karst features and processes. Carbonate rocks and their importance to karst development are explained. Mylroie describes the fine balance that must exist between mechanically sound rocks and the rapid chemical weathering of them. These processes are further explained and elaborated upon. Karst lands are placed in a geographical perspective with the information on world-wide total land-cover that corresponds to karst features. Mylroie also discusses drainage basins in karst areas, giving information on underground drainage systems and interaction between them and surface hydrology. Springs are mentioned as one of the key features to most conduit systems. Of particular interest to the research on Florida's springs is the explanation of discharge from karst aquifers. The Floridan aquifer underlies the study area, and is characterized as being a conduit system. Mylroie draws attention to springs as being the typical outlet for discharge in conduit systems. He also mentions that these points of discharge are usually found at lower elevations. The research on Florida's springs has yielded the same trend, and will discuss this observation further.

Blackith and Reyment's (1971) book *Multivariate Morphometrics* is one of the earliest textbooks on morphometrics. Morphometrics, a branch of mathematical and

scientific study, is widely applicable to geographic study. Specific topics contained in this book related to this research include the role of significance testing in morphometrics and the use of quadratic discriminants. Blackith and Reyment also discuss geography's influence over the amount of environmental variation observed in occurrences of the study subject, as well as trend-surface analysis. A difference is also stated between the morphometry of biological subjects, compared to geographic features. While it is generally understood that morphometry of animals is a product of adaptation, the reasons for geographic morphometry are causal in nature. Blackith and Reyment establish that morphometrics began as a tool for studying plants and animals. By 1971, the publication date of this book, morphometrics was just beginning to be abstractly applied to studies and analyses in other fields such as geology and/or geography. More recently morphometry has been utilized as an analytical tool, similar to how it is used in this research on Florida's springs.

An article entitled *The Marine Resources of the Parker River - Plum Island Sound Estuary: An Update After 30 Years* (2003) is a biological resource survey conducted by the Massachusetts Audubon Society. This study was a follow up to a previous study of the marine biological resources, and it sought to compare data from both studies in order to discover and understand any changes that occurred in the Parker River – Plum Island Sound ecosystem between the two study periods. As part of this assessment it was necessary to include information about the morphometry of the rivers and estuaries that comprise the study area. Several physical characteristics of the study area are outlined in detail to serve as an informative quantitative description of the region. Specific attributes that comprised the morphometry include both maximum and mean values for length,

width and depth, shoreline length, total surface area and volume. It is clear that within the scope of the Plum Island study, the morphometric portion of the analysis that was conducted to better understand the general nature of the study area prior to the study of its marine biological resources. All of the attributes studied are physical characteristics relating to its size and shape. This is in keeping with the traditional uses of morphometrics. This study contributes to the building of a morphometry of Florida's springs by providing another example of how morphometrics can further the understanding and examination of a geographic region based on its physical characteristics. Furthermore, the methodology for this research has also included several morphometric parameters that represent the physical attributes of the springs being studied. This approach is influenced by the success of the Parker River study.

Chalkias and Karymbalis (2003) in their study entitled *Prototype GIS Application in Delta Morphometry* seek to develop a reliable means of morphometric analysis on deltas using a customized GIS. It is stated in the problem statement that morphometrics can benefit delta research by providing a systematic means of quantifying the physical characteristics and processes that shape the features over time. This relationship is better explained later in the publication where morphometry is described as a quantitative method that can relate processes to morphology. The morphometric analysis is focused on the deltaic protrusion portion of the study area. All of the morphometric parameters that are used are indices or ratios, and are similar to those collected in previously reviewed studies: length and width of delta protrusion, length of shoreline, etc. although this morphometric analysis contains significantly more calculated parameters. The measured parameters were used to derive several other values crucial to the study: sediment volume

of delta segments, ratio of the seaward portion of the deltaic protrusion, protrusion distribution indexes and a vulnerability ratio. This research contributes to the building of a morphometry of Florida's springs by providing an example of how calculated morphometric parameters can be custom-tailored to the specific needs of the study. It also shows how morphometrics can be abstractly applied to studying parameters that are not in the strictest sense shape or size related.

Sauchyn, Cruden and Hu (1997) in their paper entitled *Structural control of the morphometry of open rock basins, Kananaskis region, Canadian Rocky Mountains*, examine variations in morphometry as they relate to geographic changes in dominant structural formation in the Canadian Rocky Mountains. This research seeks to add to previous geomorphologic knowledge of steep rock slope development by using morphometric analysis to relate open rock basins to rock fall mass wasting events. Rock formations that were examined include funnels, cirques and chutes located across 56 basin sites. Morphometric data was acquired from DEMs with custom coordinate system. Measured morphometric parameters for the basins include length, width, relief, area, perimeter compactness, length-width ratio, length-relief ratio, width-relief ratio, and area-relief ratio, although the resolution of the DEMs was unmentioned in the paper. A Wilcoxon rank sum test was performed on the morphometric data to allow for statistical analysis. This paper is helpful to the task of building a morphometry of Florida's springs by providing a good example of a substantial list of parameters that could and indeed should be included when studying a phenomenon based on its morphometry. Many of the same physical characteristics that are measured from rock basins and analyzed in this paper will also be measured for Florida's springs.

Ganas, Pavlides and Karastathis (2004) in their paper entitled *DEM-based morphometry of range-front escarpments in Attica, central Greece, and its relation to fault slip rates* use DEM data as a method to identify active fault locations. This paper builds on previous research, which used shaded relief imagery created from DEM data to display the known location of the Fili fault segment in Parnitha Mountain, Greece. DEM analysis is combined with measured morphometric data to identify and describe four additional faults in Attica. The study area is a region of Greece in the Aegean Sea where normal faulting is constantly occurring. Two DEM mosaics, 20m and 60m, were used to map the fault segments. The DEMs were derived from contour maps produced by the Hellenic Army Geographical Service. Active fault characteristics were identified by searching for sharp tonal changes between pixels on the shaded relief imagery. Slope angles were computed for pixels corresponding to areas of sharp tonal changes. Abrupt slope changes were interpreted as possible locations of active faults. Slope profiles were also generated. One significant way in which this study utilized slope profiles was to compute mean slope angles for several range-fronts in the study area. These values were used to estimate ages and slip-rates for the four potentially active faults. The paper is concluded with confirmed identification of five active faults, and a magnitude prediction for the next major earthquake that occurs along any of them. This research is relevant to the Florida spring research conducted for this thesis because it gives a clear example of how morphometry can be measured and used to identify spatial phenomena

Dong, Wang and Wang (2004) in their article *Geomorphology of the megadunes in the Badain Jaran Desert* give an example of how effective morphometric analysis can be for studying and understanding the physical characteristics of a spatial phenomenon.

The study area is one of the few places on the earth where megadunes form. Several parameters representing the physical attributes of the megadunes are measured and analyzed morphometrically. This analysis contributes new knowledge of how and why megadunes form where they form in the Badain Jaran Desert. The springs research is also attempting to add to the knowledge base on what factors most influence where springs form in Florida, and similarly, will do so through an analysis of their morphometric parameters.

Frumkin and Fischhindler (2005) in their article entitled *Morphometry and distribution of isolated caves as a guide for phreatic and confined paleohydrological conditions*, conduct a study that serves as an excellent example of the utility of morphometric analyses of geomorphological landforms. Isolated caves are defined and explained in terms of their physical and developmental characteristics. Morphometric parameters for several known isolated caves in the region surrounding Jerusalem were measured and analyzed. A set of criteria consisting of acceptable value ranges for these morphometric parameters was established. The study is concluded with a presentation of these criteria as good and effective for determining if any cave should be classified as isolated. This article was the first of several to be referenced in this study of Florida's springs. Although the springs research is not aimed at using morphometrics to classify them, this source was very informative in showing how morphometry can be abstractly applied to a geographic study.

Randazzo and Jones (1997) in their book entitled *The Geology of Florida* provide a very comprehensive overview of Florida's geology, and of particular interest to this thesis, its geomorphology, hydrogeology, fossil record, and coastal and environmental

geology. More specifically it provides a good overview on how Florida's springs are an integral part of Florida's groundwater systems. The chapter on the hydrogeology of Florida differentiates the five aquifers that make up Florida's freshwater resources.

First magnitude springs are quantitatively defined as those discharging at least 100 cubic feet per second, and all of the known springs of this magnitude issue from the Floridan aquifer. A small-scale map from 1970 is included, that shows all of the known first magnitude springs in Florida at that time (six more have been discovered since then, bringing the current total to 33). This book was also among the first to be referenced for the springs research. While it covers a broad topic in a sense, it was particularly helpful in its capacity to explain the previously referenced topics of karst terrain and hydrology in terms of their role in the geography of Florida.

In an article entitled *Use of chemical and isotopic tracers to characterize the interactions between ground water and surface water in mantled karst*, Davis (1997) conducted a study aimed at determining if the interaction between surface and groundwater affects water quality in the Upper Floridan Aquifer. The study area consisted of two areas in Leon County, Lake Bradford and a large sinkhole. Davis identifies the Upper Floridan aquifer as providing northern Florida with most of its water supply. He also states that the knowledge base concerning water quality in this aquifer is currently very small. Lake Bradford and the sinkhole were chosen because they represent sites where the intermingling of surface and groundwater could result in a negative impact upon water quality. Water samples were taken over the course of about one month for each site, and then tested for specific elements and pollutants. He discusses

the relationship between surface water and ground water interaction and the closeness to karst terrain.

Davis concludes that the degree to which the water quality of the Upper Floridan aquifer is influenced by its interaction with surface water is determined by the level of interconnectivity between the two. This influence, as stated in the article, is related to the abundance of karst terrain in the study area. The article specifically mentions the important role that proximity to karst features plays in determining the level of interaction between surface and ground water. Davis's article has been beneficial to the research on Florida's springs by providing an explanation of one of the ways in which groundwater in Florida is influenced by karst lands. The springs research has also made some conclusions regarding the relationship between karst terrain and springs. These conclusions are later discussed in greater detail, and center on how springs locations are tied to the distribution of karst lands.

In an article entitled *Conduit properties and karstification in the unconfined Floridan Aquifer*, Smith (2004) continues with an existing study of the hydraulics of a portion of the Floridan Aquifer. His study is concerned with determining the overall loss or gain of fluids across the portion of the Santa Fe River that flows underground. It is stated in the article that younger aquifers, such as the Floridan, exhibit much higher hydraulic conductivity rates outside of conduits than do older aquifers. This fact suggests an increased risk for contaminants to leech into groundwater from the surrounding matrix. It also suggests a relationship between the rate of flow through conduits and the intensity of karstification in the surrounding matrix. Data was collected at several karst windows in the study area, as well as at the two sites marking the beginning and end of

the underground portion of the Santa Fe River. Data was gathered over twelve months, from August of 2001 to August of 2002. This collection phase was affected by drought conditions.

The information that is presented on fluid transfer between conduits and the surrounding matrix, and the conditions that must be present for the transfer to occur, facilitates a broader knowledge base for this thesis on the topics of karst processes. Smith concludes that fluid only passes from the conduits into the surrounding matrix during peak discharge events. This article contributes specifically to the research on Florida's springs by providing information on another way in which groundwater and karst lands in Florida are related.

In an article entitled *A ground-water sapping landscape in the Florida Panhandle*, Schumm, Boyd, Wolff and Spitz (1994) study spring steepheads in Okaloosa and Walton Counties. The authors begin by explaining the relationship between surface runoff and the capacity for infiltration in the surrounding land. The term "steephead" is defined as a linear-forming valley with a steep semicircular feature at the springhead, somewhat resembling a natural amphitheatre. These features are acknowledged to be the result of spring-sapping. In this study, the authors endeavor to measure and quantify Florida steephead topography.

This article has aided the research on Florida's springs by serving as another source in which the karst terrain in Florida is identified and described in terms of its role in the geomorphology of the state's landforms. The authors describe Florida as a land of plentiful ground-water and home to very permeable soils. Of specific interest to this thesis is the physiographic description of Florida's Panhandle that the authors offer. The

Eglin Air Force Base, a region spanning the southern part of Okaloosa County, is said to be made up of Western Highlands and Gulf Coastal Lowlands. These physiographic designations were surmised to be representative of most of the panhandle. The support that is given in this article is important to the research on Florida's springs, as it encourages an understanding of the parts of the panhandle that are not included in some physiographic datasets.

Reese and Zarikian (2004) in their report entitled *Review of Aquifer Storage and Recovery in the Floridan Aquifer system of southern Florida* give a synopsis of aquifer storage and recovery research as it is being conducted in southern Florida. A brief description of aquifer storage and recovery (ASR) practices is given by way of summarizing the means by which excess freshwater runoff is stored in local groundwater systems for later on-demand use during dry seasons. A survey of 30 ASR wells in southern Florida and the data that was yielded from them is included. This report initially served the research on Florida's springs as a reference for aquifer depths and also as a comparable method of monitoring groundwater conditions to that of the recording of discharge measurements in Florida's springs.

A report by the Southwest Florida Water Management District entitled (2001) *The Hydrology and Water Quality of Springs in West-Central Florida* is a compilation of data and information on several of the larger springs in the district. All of the springs mentioned in the report are included as part of this thesis. Much of the hydrologic data presented in the SWFWMD report is typical of many of Florida's karst springs, and is therefore applicable to this research. Reasons for the lack of springs in the north-central section of the district are given, as well as speculations on the scarcity of rivers and

streams. Major rivers in the springs region are listed and described, as are the overall geologic characteristics of SWFWMD.

Open file report #85 by the FSG, *First Magnitude Springs of Florida* (2002) was equally, if not more informative than the previously mentioned SWFMWD report. This publication contains a wealth of information on the classification of Florida's springs. This information served as an introduction to first magnitude springs of Florida and each of the eight magnitude classes are defined according to their range of quantitative flow values, and several accepted units of flow measurement are listed. The information contained in this report provided a reference for some of the characteristics of Florida's springs that could and indeed should be included in the morphometry. This report was also informative in its description of the geography of Florida's first magnitude springs and how the panhandle's geology differs from peninsular Florida.

Open file report #66 by the FSG, *Springs of Florida* (2004) served as a foundation for the data gathering portion of this thesis. This publication contains detailed quantitative data of the physical attributes of over 450 springs in Florida, and names a total of over 700 that are known in the state. These attributes include pool length, pool width, depth, presence of spring run, spring run length, and discharge. This data collectively represented a small scale version of spring morphometry that was built upon with the addition of other attributes that had to be measured for the study. Having the data that is available in FGS Bulletin 66 in a single concise source greatly expedited the initial data gathering phase of this thesis.

Based on this review of literature it was determined that a wealth of literature exists on the hydrologic aspects of springs, but the breath of the literature is more limited

when assessing springs as part of the physical landscape. Regarding the springs of Florida, various detailed technical reports, produced mostly by government agencies, provide both an overview of Florida's springs, as well as technical details. But none of these sources really considers the geomorphologic aspect of springs and views springs and related morphologic characteristics as part of the physical landscape of Florida. This thesis takes this geographic approach to studying Florida's springs, and will thus add an important new perspective to the existing literature on Florida springs.

Chapter Three

The Study Area

The study area for this research is defined by the portions of the state of Florida within which natural springs occur. More generally this includes all of the panhandle and most of peninsular Florida down to just south of Hillsborough County (see Figure 1). The highest density of spring resurgences is centered on the big bend area where peninsular Florida and the panhandle meet. This distribution is mostly due to the shallow depth of the Floridan aquifer and the pervading carbonate limestone underlying the region (Randazzo, 1997).

Southern Florida has a more tropical climate while central and northern Florida are sub-tropical. Average maximum summer and temperatures range between 88° F and 92°F. Average minimum winter temperatures range between 42° F and 64° F. Average annual rainfall varies across the study area, as shown in Figure 3. The northern portion of peninsular Florida is at the low end of the range, receiving between 54 and just under 50 inches of precipitation annually. The big bend region receives 50-60 inches, and the western panhandle receives as much as 68 inches (SCAS, OSU, 2006).

The geographic center of Florida is about 12 miles north of the town of Brooksville. The state is made up of over 53,000 square miles of land and has over 8,700 miles of coastline. Topography is characterized by very little relief, ranging from sea level to about 345 feet at the highest point. Most elevations are in the range of 50 to 100 feet (SCAS, OSU, 2006). Physiography is varied, but mostly consists of coastal lowlands

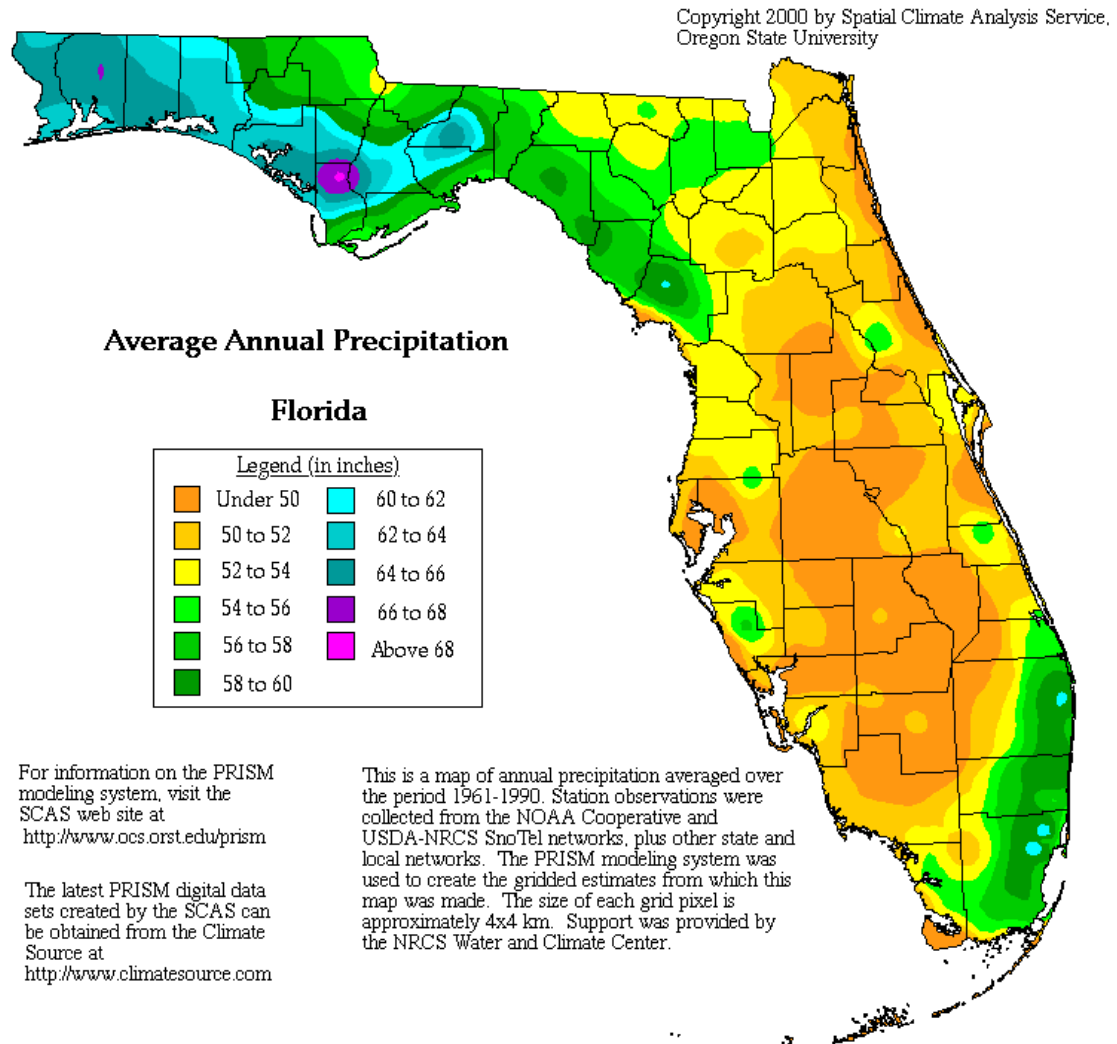


Figure 3 - Precipitation map of Florida
(From: <http://www.ocs.orst.edu/pub/maps/Precipitation/Total/States/FL/fl.gif>)

and interior uplands. There are several ridges constituting regions of slightly greater relief than most of the state, the most prominent of which is the Brooksville Ridge. Of particular interest to this thesis are the lowland regions, as they are the location where the majority of springs resurge. Approximately three quarters of Florida is classified as coastal lowland. These regions range from being only 10 miles wide to penetrating up to 100 miles inland. Figure 4 displays the physiographic regions of Florida as delineated by Randazzo and Jones (1997).

of Lake Okeechobee south to the Everglades. Spodosols, though also present throughout, are more abundant in peninsular Florida than in the panhandle. Ultisols are heavily distributed across the northern panhandle and the big bend area. Figure 5 shows the distribution of Florida's seven soil orders.

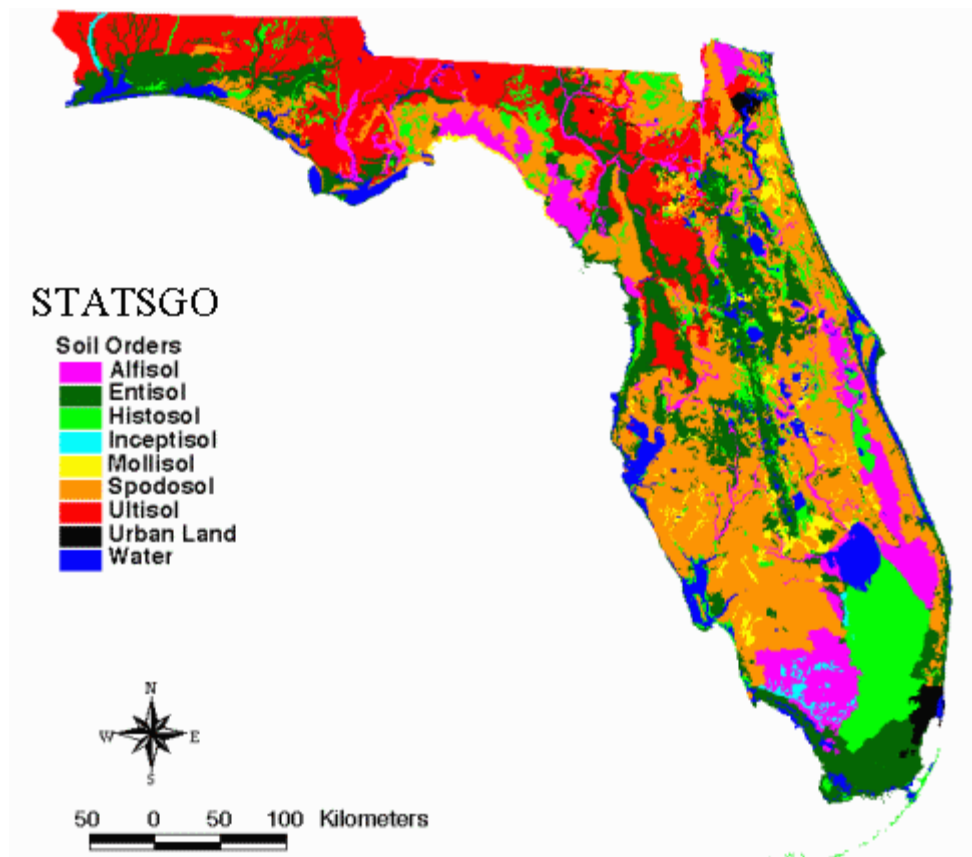


Figure 5: Soil Orders in Florida (UFL, 2005)
(From http://grunwald.ifas.ufl.edu/Projects/NRC_2001/STATSGO.gif)

The general nature of the geology of the state can be summarized by the environmental geology map of Florida shown in Figure 6. Sand and silt are present throughout the state, with the highest concentrations centered on central peninsular Florida. Peat and clay are somewhat confined to the southern peninsula and the far northwestern portion of the panhandle. Of particular interest to this thesis are the regions

predominated by limestone. These areas are centered on the big bend region and underlie the highest density of springs in the state.

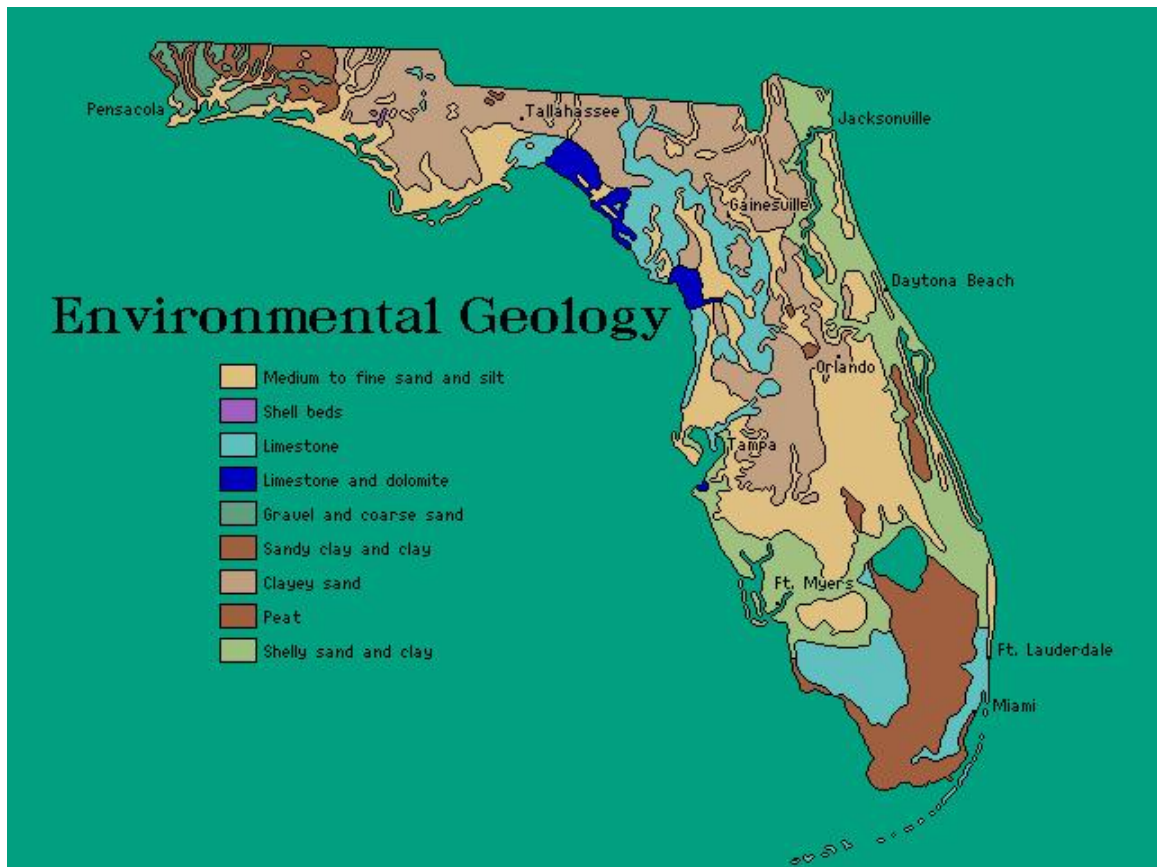


Figure 6: Environmental Geology of Florida (USGS)
(From <http://www.luddist.com/karst2.GIF>)

Florida is dominated by karst terrain as seen in Figure 7. Limestone is present throughout the state, although not always exposed at the surface. The big bend area, in terms of karst, is characterized by well-established karst terrain and limestone that is exposed or just under the surface. This region is of particular interest to this thesis as it corresponds to the previously mentioned high density of springs. Around and amongst this area are other areas characterized by limestone that lies beneath a moderate or thick layer of sediment. Both categories of karst are also present in parts of the western

panhandle. Further elaboration upon the geology of Florida can be summarized by Figure 8 which displays the geologic formations that underlie the state. Florida is an ongoing recipient of deposition, as can be seen by the far-reaching coverage of the Pleistocene and recent formation. The Oligocene formation has the most discrete distribution, and the Eocene can be seen to correspond to the big bend area around which the high density of karst springs is centered.

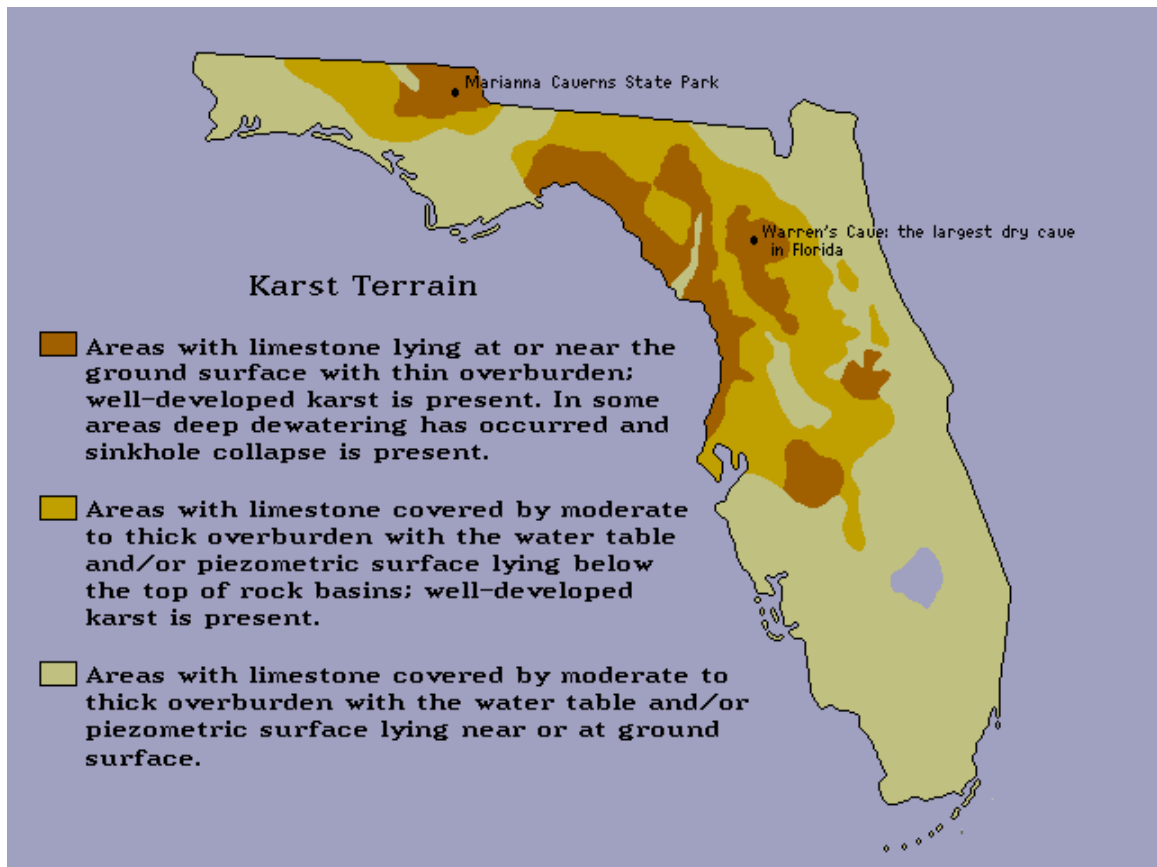


Figure 7: Florida's Karst Terrain
(From http://www.caves.com/fss/pages/misc/images/karst_map.gif)

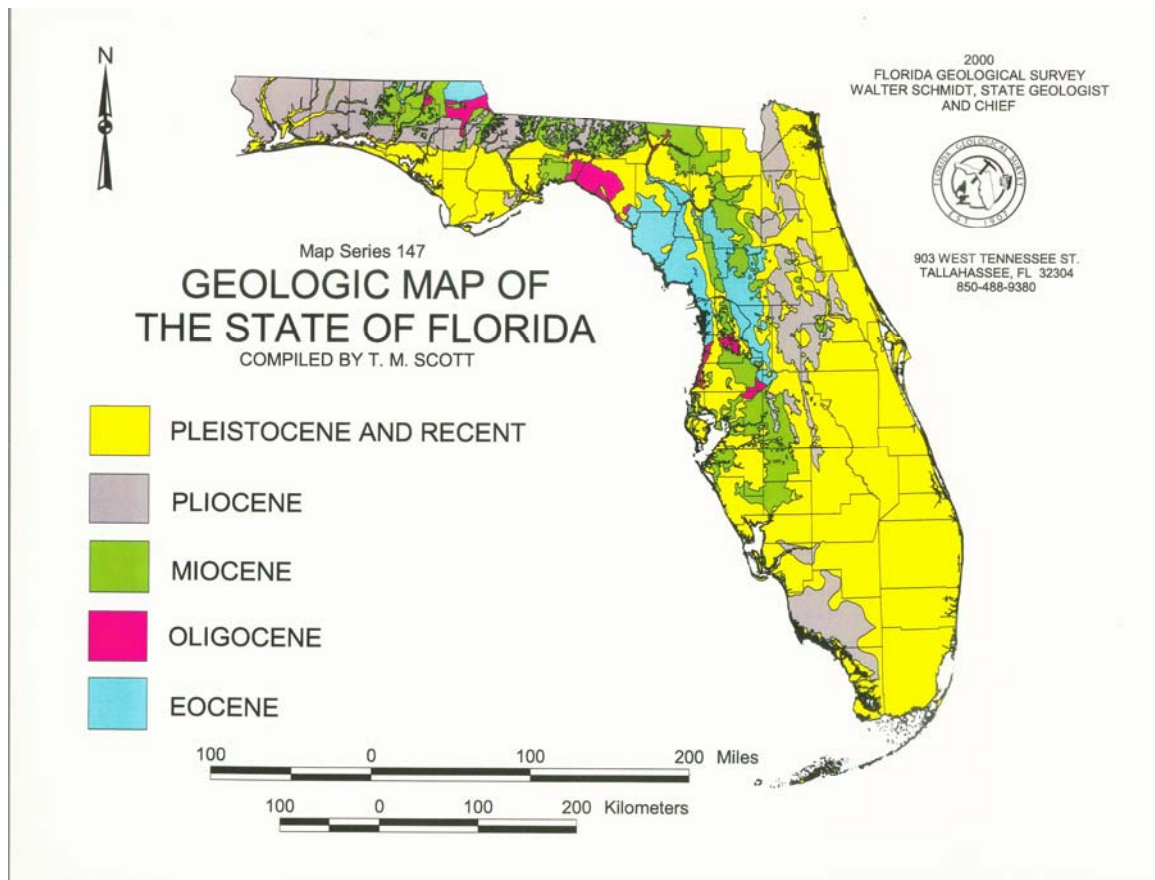


Figure 8: Geologic Formations of Florida (FGS, 2000)
(From http://www.dep.state.fl.us/geology/gisdatamaps/geo_map_florida.jpg)

As previously mentioned, Florida's geology is dominated by sandy units, most of which are associated with the Pleistocene, and carbonate units that form karst landforms, including springs. Considering the carbonate units, the Ocala, Suwannee and St. Marks Formations are most important. The geologic periods corresponding to them, specifically the Eocene, Miocene, and Oligocene, are displayed in Figure 8. The Ocala Limestone is the most widely distributed carbonate unit in Florida, covering nearly 4000 square miles. The Suwannee limestone is second to the Ocala, covering just under 1000 square miles, and the St. Marks formation occupies about 300 square miles.

In terms of Florida's groundwater system, the Principal Artesian Aquifer extends beneath the entire state and covers parts of southern Alabama and Georgia. The Floridan Aquifer also underlies the study area and is the source for most of the springs in this study (FGS Bulletin 66). The Floridan aquifer ranges in depth from about 200 feet to as deep as 2700 feet (ISWD, 2004). Karst topography is present throughout Florida, and accounts for the porous limestone that makes possible the expansive groundwater system of the state (Randazzo, 1997). Figure 9 displays the aquifers of Florida and their extents. All of the springs in this study are part of the Floridan Aquifer system.

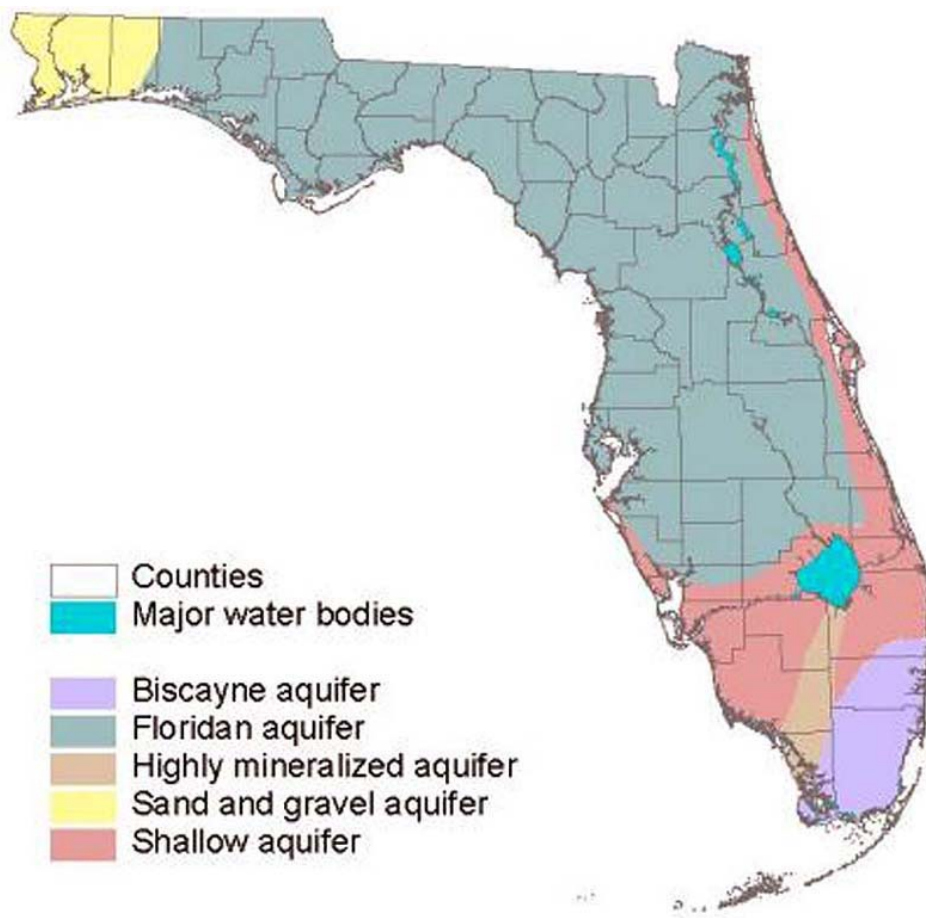


Figure 9: The Aquifers of Florida

Land use in the state of Florida is classified according to eight distinct categories, including several levels for urban, forest, agricultural, wetlands, and transportation. Between 1936 and 1995, the state saw a decline in forested lands by 22% and also in wetlands by 51%. Total agricultural lands grew by 60% and developed lands by over 600% (Kautz, 1998). As seen in Figure 10, much of the land that makes up the study area is occupied by agriculture and preserved lands. Some localized and sparsely distributed commercial and residential lands are also present. Most of the major water bodies that are located within the study area are found in northern peninsular Florida.

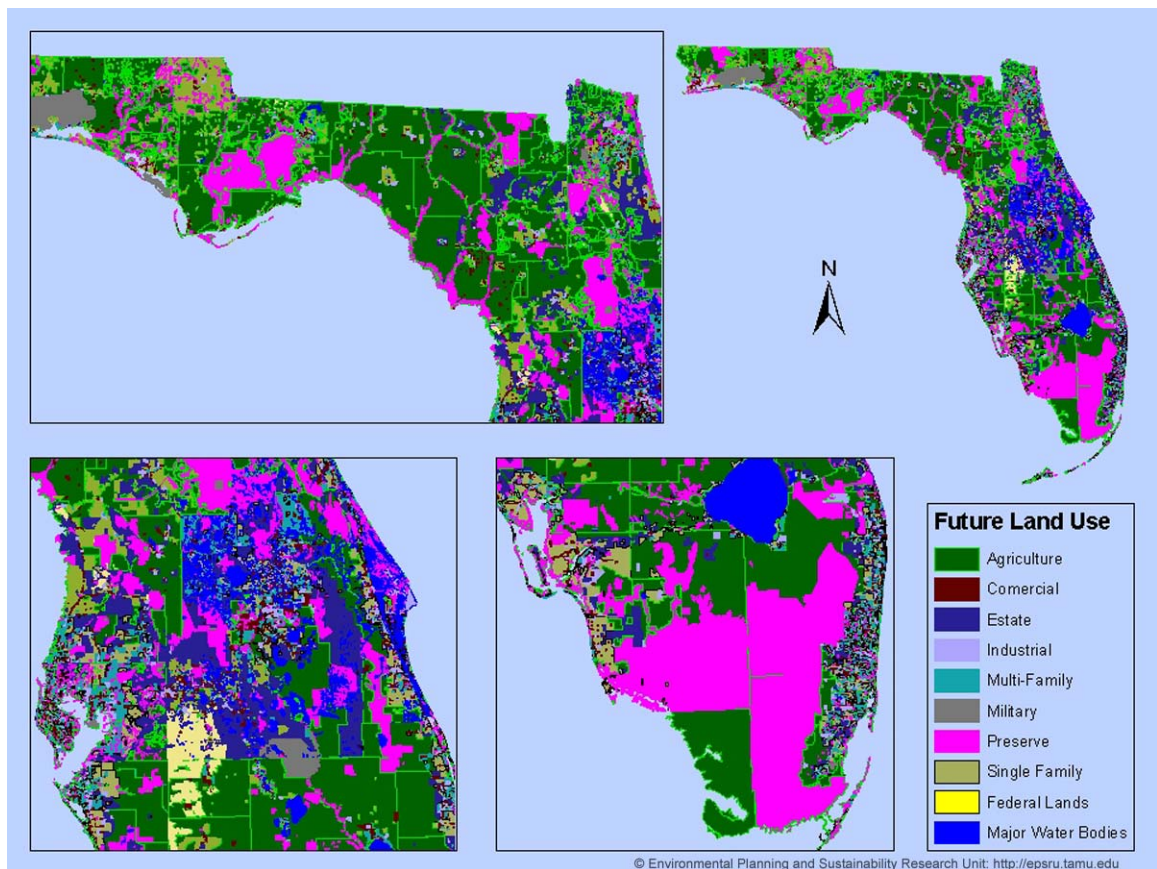


Figure 10 - Land Use in Florida

(From: <http://archone.tamu.edu/epsru/images/Maps/FLU.jpg>)

Chapter Four

Methodology

It should be noted that morphometry in its conceptual sense is infinite to some degree and is defined not only by the quantity of parameters examined, but also by the nature of these parameters. This study considered a mixture of physical and geographical characteristics in its examination of the spatial distribution of Florida's springs. These characteristics are presented as the morphometry of the springs. However, the morphometry of Florida's springs should not be assumed to be restricted to just the parameters that are considered in this study. For the sake of methodological explanation, the data that is used in this study can be separated into two categories: (1) preexisting data and (2) measured data. Many of the parameters for which data was needed had already been measured by the FGS. The remaining parameters for which data did not already exist essentially had to be created for use in this research. Table 1 lists each parameter and its data source.

Compiling Morphometric Data

FGS Bulletin 66 played an integral role in this study because it contains data for many of the parameters that collectively make up the morphometry of Florida's springs. These data were measured in the field by various researchers associated with the FGS. Since the main interest in studying the morphometry of these features is to explore their spatial distributions, it is first necessary to establish the location of each spring. Latitude

and longitude coordinates are given in FGS Bulletin 66 for every known spring in Florida. This information was used to create a table of spring names with their coordinates. This same table served as the foundation upon which all other compiled parameter values were appended. The first set of parameters that were compiled for the database are dimensional in nature. As previously stated, this approach is in keeping with that of *The Marine Resources of the Parker River*(2003).

Parameter	Source
elevation	USGS NED
discharge	FGS Bulletin 66
magnitude	FGS Bulletin 66
generates run	FGS Bulletin 66
run length	FGS Bulletin 69, USGS NHD
run orientation	derived from USGS NED
pool length	FGS Bulletin 66
pool width	FGS Bulletin 66
pool area	derived from Bulletin 66
depth	FGS Bulletin 66
geologic region	USGS
physiographic region	FDEP
distance to coastline	created with ArcGIS 9.1

Table 1: Morphometric Parameters and Data Sources

With the exception of noting which county each spring is located in, and giving a brief set of directions for navigating to the sites, all of the data contained in FGS Bulletin 66 corresponds to the physical characteristics of the springs. The data is given in paragraph form describing each individual spring or spring group. All of this information was parsed out of the publication and put into a database. The parameters spring location, elevation, geologic region and physiographic region were utilized for analysis of the entire 754-spring database. The parameters length of spring run, pool length, pool width, pool depth, and discharge were utilized for analysis of the 102 spring data subset.

Two more dimensional parameters, magnitude and pool area were also applied to the data subset. The resulting table was then joined to a spatial dataset of point data for Florida's springs. Every point in the springs dataset has a unique name attribute that is shared by a single record of parameter entries in the morphometric database. The join was based on this relationship. It should be noted that magnitude values were derived from the median discharge measurement that is available for each spring. This is done according to the convention set forth in the Florida Springs Classification system (Copeland, 2003).

Spatial Data Preparation

ArcGIS 9.1 was used for spatially exploring the morphometry of Florida's springs. Locations for all 754 springs in the study had to be established in a known coordinate system before they could be incorporated using the software. Once prepared for use in a GIS, the parameters listed in the original table would serve as attribute fields for the 754-spring database and/or the 102 spring subset data base. The previously created table containing all parameters found in FGS Bulletin 66 was used to create a new spatial dataset of Florida's springs. The latitude and longitude values contained therein served as x/y inputs for the location of each feature.

All of the remaining parameters could then be added as additional attribute fields. Values for these remaining geographical parameters were collected from several other spatial datasets. Elevation, hydrography, physiography and geology, were acquired from various sources. The spatial datasets were not all digitized in the same coordinate system or projection at the time of their creation. Each one had to be prepared for incorporation with each other in ArcGIS 9.1. It was not only necessary to have all data in the same projection and coordinate system, but also to choose a projection that maximized

accuracy and conformality for the study area. The Albers Equal Area Conic projection is customized specifically for the state of Florida and has been used because it meets both of these needs.

Measuring Morphometric Data

All of the data that was created for this study corresponds to the geographical parameters of Florida's springs. That is, the spatial characteristics that help to define each spring based on the details of where they are located. ArcGIS 9.1 was utilized as the analysis tool for measuring the geographical parameters and then populating the database with values for each one. These parameters are: elevation, physiographic region, geologic region (for the entire data base), distance to coastline and spring run orientation (for the 102 data subset).

Elevation data was provided by several USGS NED 30m DEMs. They were used to create a mosaic covering the entire state of Florida. This mosaic was overlaid with the springs dataset and the 'extract values to points' tool was used to generate elevation values for each spring point. This tool assigns a value to each point that is equal to the value of the raster cell that it falls within. The elevation field is then populated with these values. A hillshade raster layer was generated using the DEM, and serves as a visual aid to interpreting all figures which display elevation data.

A spatial join was used to observe which physiographic and geologic region each spring is located in. The two fields for listing these designations were then populated with the names of the physiographic or geologic region that corresponds to each spring respectively. Both datasets have statewide coverage.

The distance from each spring to the nearest coastline was computed with aid of raster analysis. ArcGIS 9.1 was used to generate a raster layer with the same extents as the DEM mosaic given it statewide coverage. This raster consisted of cells that existed everywhere within the extents, but not over any portion of the state of Florida. A Euclidian distance function was then applied to the raster layer. This resulted in a new raster layer for which every cell had a value equal to its distance to the nearest cell of the first raster layer. That is, each cell in the raster produced with the Euclidian distance function had a value equal to its distance to the nearest coastline (102 spring data subset). The same 'extract values to points' tool that was used to generate elevation values for each spring was used again here in the same fashion. The field for distance to coastline was then populated with values corresponding each individual spring.

Because each of the spatial datasets came from a different source and were not digitized together, the features contained within them are not coincident. Spring points do not coincide with endpoints of river and stream polylines from the National Hydrography Dataset (NHD). These same polylines do not perfectly coincide with county boundaries that are drawn according to major rivers either. This presents a challenge when trying to identify the polylines that represent the runs for springs in the 102 spring data subset that are known to generate one according to the information provided in FGS Bulletin 66. Each polyline representing a spring run needed to be identified in order to determine its orientation. To accomplish this, the characteristics of all polylines believed to be spring runs were meticulously compared with the descriptions given in FGS Bulletin 66. In addition to facilitating the determination of spring run orientation this procedure produced more accurate values for the run length field. The

run lengths given in FGS Bulletin 66 are somewhat generalized. They are reported in either whole feet for the shorter runs and whole miles for the longer ones. The NHD was used to locate the runs mentioned in Bulletin 66 and then more exact values were measured for each run. These values have been reported in feet rather than miles. To be confirmed as spring run using the NHD, a polyline corresponding to the run of a specific spring had to originate in the vicinity of that spring and its length had to match the generalized length given in FGS Bulletin 66.

It should be noted that this procedure brought to attention one of the weaknesses of the NHD. Only the longer spring runs with lengths of at least a mile were included when the data was digitized. Shorter spring runs of less than a mile were not included and therefore an orientation value was not determined for them in this study. It should also be noted that this peculiarity gave rise to a reliable means to verify the total number of spring runs that were recognized using the NHD. The database of morphometric parameters for the 102 springs in the data subset shows that 13 of the springs generate a run exceeding one mile in length. This methodology recognized exactly 13 polylines as representing spring runs using the NHD. A comparison of the NAME attributes between the polylines and the spring points confirmed all 13 matches.

An orientation value was then calculated for each of these polylines using a VB script in ArcMap 9.1. The azimuth of each polyline is measured at its midpoint and then values are reported in degrees. It should be noted that this method is less desirable than having an azimuth value that represents the mean all azimuths taken at multiple points along the polyline, for example. However, no such VB script was found for implementation in this study. Another VB script was used to calculate lengths for all 13

of the spring run polylines so that the reported values could be compared with the more generalized lengths give in FGS Bulletin 66.

Chapter Five

Results & Discussion

Compiling and measuring of morphometric parameters using ArcGIS 9.1 resulted in a spatial dataset for 754 Florida springs, as well as a 102 spring data subset for a sampling of first, second and third magnitude springs. Because this dataset represents a compilation of descriptive and geographic information about Florida's springs, the features can be symbolized according to their parameters in such a way as to display any nonrandom spatial distributions of the spring features with similar parameters. The assumption is that there are geographic factors influencing where springs with certain parameters occur.

As previously mentioned, this research has evaluated Florida's springs on two scales. The data that was available for this study for the 102-spring data subset was more extensive and detailed because these springs tend to be the most well-known, or the most frequently visited. This level of data was not available for the entire 754-spring database, and as a result, data that describes some of the physical attributes of the springs wasn't available for the entire population. Although the data is incomplete for all of the springs, the geographic parameters (location, elevation, physiography and geology) that were derived through this study's methodology are examined for the entire population of 754 springs. Figure 11 displays Florida's springs overlaid with the 30m DEM mosaic and a hillshade raster layer.

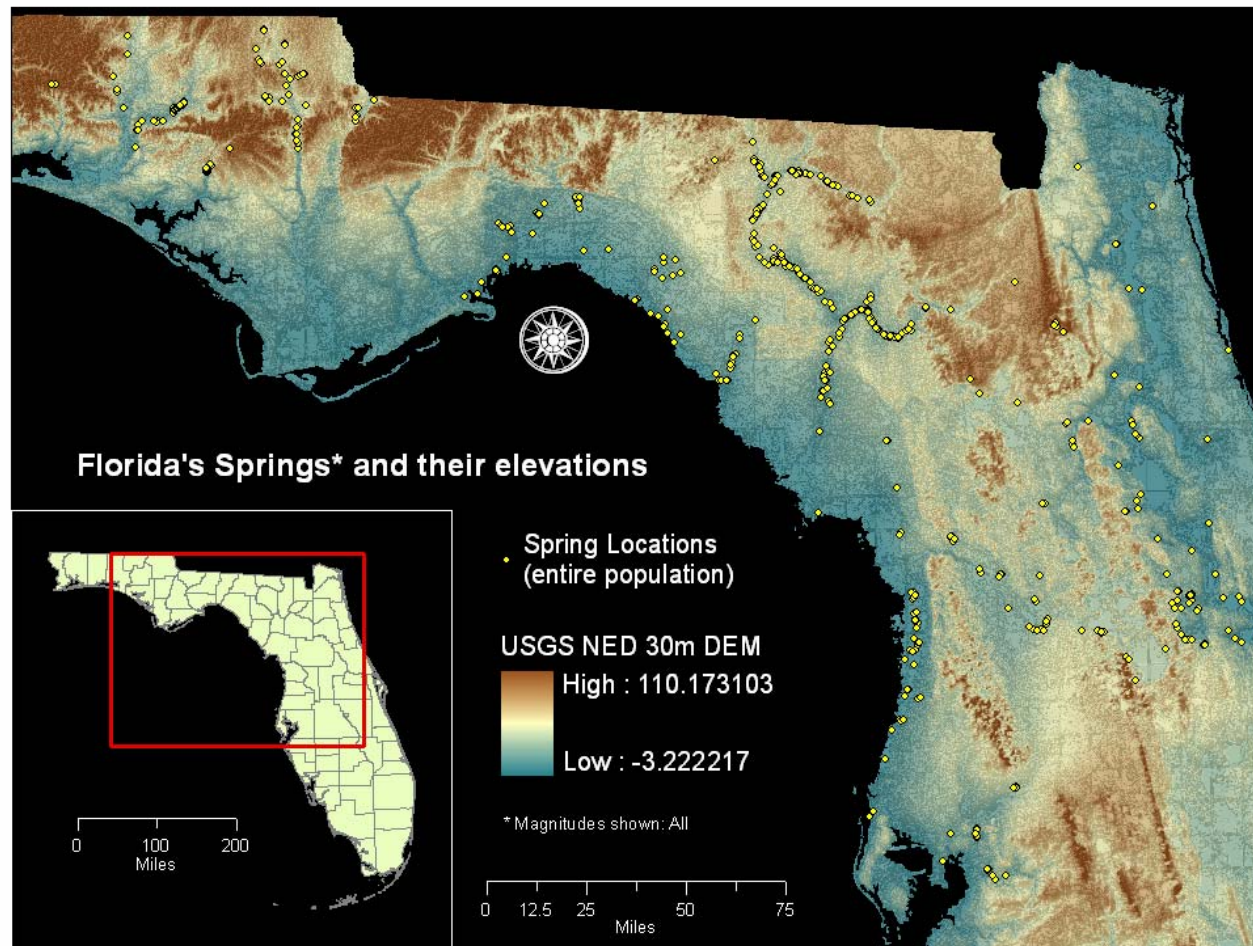


Figure 11: Spring locations overlaid with 30m DEM and hillshade raster

A visual inspection of Figure 11 provides information related to the spatial distribution of Florida's springs. First of all, the areas of higher elevation, as indicated by the brown hillshade grading toward yellow, contain very few spring resurgences. The spatial distribution of the spring resurgences seems to be more aligned with lower elevation areas. Also, the spring resurgences in the north-central part of the state and the panhandle appear to be related to surface hydrologic/geomorphic features. Surface dendritic drainage patterns are easily discernable on the 30 meter DEM, and many of the spring resurgences in these areas correspond to the surface drainage pattern. This observation seems to indicate a link between surface stream hydrology, area geomorphology related to these stream (valley incision, headward erosion), and the spatial location of the spring resurgences. In the coastal sections of the western extension of the Big Bend area of the state, the relationships mentioned above are not as clear, but can still be observed. Moving around the Big Bend and along the west coast toward Tampa Bay, numerous springs are located in the lower elevation areas between the Gulf of Mexico and the Brooksville Ridge section of Florida (see Figure 4). This relationship may result from the groundwater associated with the karst topography of the Brooksville Ridge flowing down gradient toward the Gulf of Mexico. When this water meets the sediments of the Gulf Lowland areas it comes to the surface as the various spring resurgences found in the area. This may also be the case with the springs located essentially at the same latitude, but on the east side of the state. These springs are seaward of upland area, and resurge at lower elevations.

The springs were classified according to their elevation values. Thirteen classes were established, each one representing a 20-foot elevation range. These classes and the

number of springs each one represents are shown in Table 2. A graph illustrating this data is shown in Figure 12.

Class #	Elevation Class (feet)	# of springs	% of Population
1	0-20.00	271	35.94
2	20.01-40.00	241	31.96
3	40.01-60.00	134	17.77
4	60.01-80.00	59	7.82
5	80.01-100.00	28	3.71
6	100.01-120.00	9	1.19
7	120.01-140.00	2	0.27
8	140.01-160.00	4	0.53
9	160.01-180.00	0	0.00
10	180.01-200.00	2	0.27
11	200.01-220.00	2	0.27
12	220.01-240.00	0	0.00
13	240.01-260.00	2	0.27

Table 2: % of spring population corresponding to 20-foot elevation ranges

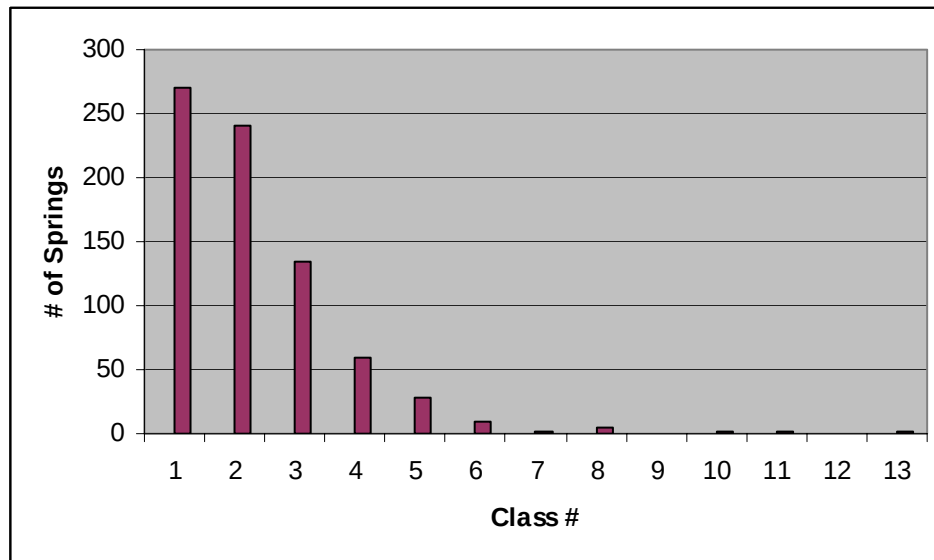


Figure 12: Bar graph of 20-foot elevation ranges & corresponding spring totals

The first class, ranging from zero to 20.00 feet above sea level, contains the largest percentage of springs. About 36% of the population corresponds to this elevation range. About 32% of the population has elevations ranging from 20.01 to 40.00 feet above sea level. Nearly 18% of the population has elevations ranging from 40.01 to 60.00 feet above sea level. Together, these three classes represent 646 of Florida's 754 springs, or about 86%. The fact that 86% of the springs in the data set are found at lower elevations (<60 feet) reconfirms the previously discussed observations from Figure 11.

At the other end of the scale, there are very few springs found in the higher elevation classes. The seven classes that correspond to elevations ranging from 120.01 to 260.00 feet above sea level represent only 12 springs, or about 1.6% of the population, which again reconfirms the observation that Florida springs are more directly associated more with lower elevation areas of the state.

Florida's springs are only found at elevations ranging from sea level to about 260 feet. Regarding this range of values, 86% of the springs correspond to the lower 25% of the range. This fact suggests that elevation has considerable influence over where springs are located in Florida. Not only are there a number of high-discharge first-magnitude springs in Florida, but most of the entire population are located at elevations that range in the lower 25% of all elevations at which springs are found. Mylroie (1995), also observed the tendency for springs to be located at generally low elevations. The examination of spring elevations values in this thesis support Mylroie's observation.

The entire population of Florida's springs was examined with regard to the underlying geologic formations. It should be noted that the geology dataset that was acquired from the USGS, was created to represent surface or near-surface geology. In

digitizing this spatial data, FGS geologists mapped the first recognizable lithostratigraphic unit occurring within 20 feet of the land surface. Table 3 displays the number of springs located within each geologic formation, and Figure 13 displays a graph of this data. Please note that two formations, the Ocala Limestone and the Suwannee Limestone, have been omitted from this graph because they are outliers and skew the display of the rest of the data. The data corresponding to these two formations is subsequently discussed in further detail.

Formation	Name	# of springs	% of pop.
Qal	Alluvium	66	8.75
Qbd	Beach ridge and dune	8	1.06
Qh	Holocene sediments	22	2.92
Qtr	Trail Ridge sands	4	0.53
Qu	Undifferentiated sediments	45	5.97
TQsu	Shelly sediments of Plio-Pleistocene age	1	0.13
TQu	Undifferentiated sediments	1	0.13
Tab	Alum Bluff Group	35	4.64
Tap	Avon Park Formation	2	0.27
Tc	Cypresshead Formation	38	5.04
Tch	Chatahoochee Formation	17	2.25
Tci	Citronelle Formation	13	1.72
Th	Hawthorn Group	2	0.27
Tha	Hawthorn Group, Arcadia Formation	1	0.13
That	Hawthorn Group, Arcadia Formation, Tampa Member	13	1.72
Thc	Hawthorn Group, Coosawhatchie Formation	14	1.86
Thp	Hawthorn Group, Peace River Formation	4	0.53
Ths	Hawthorn Group, Statenville Formation	4	0.53
Tht	Hawthorn Group, Torreya Formation	1	0.13
Tmc	Miccosukee Formation	1	0.13
To	Ocala Limestone	273	36.21
Tre	Residuum on Eocene sediments	5	0.66
Tro	Residuum on Oligocene sediments	11	1.46
Ts	Suwannee Limestone	107	14.19
Tsm	Suwannee Limestone - Marianna Limestone undifferentiated	13	1.72
Tsmk	St. Marks Formation	53	7.03

Table 3: % of spring population corresponding to geologic formations

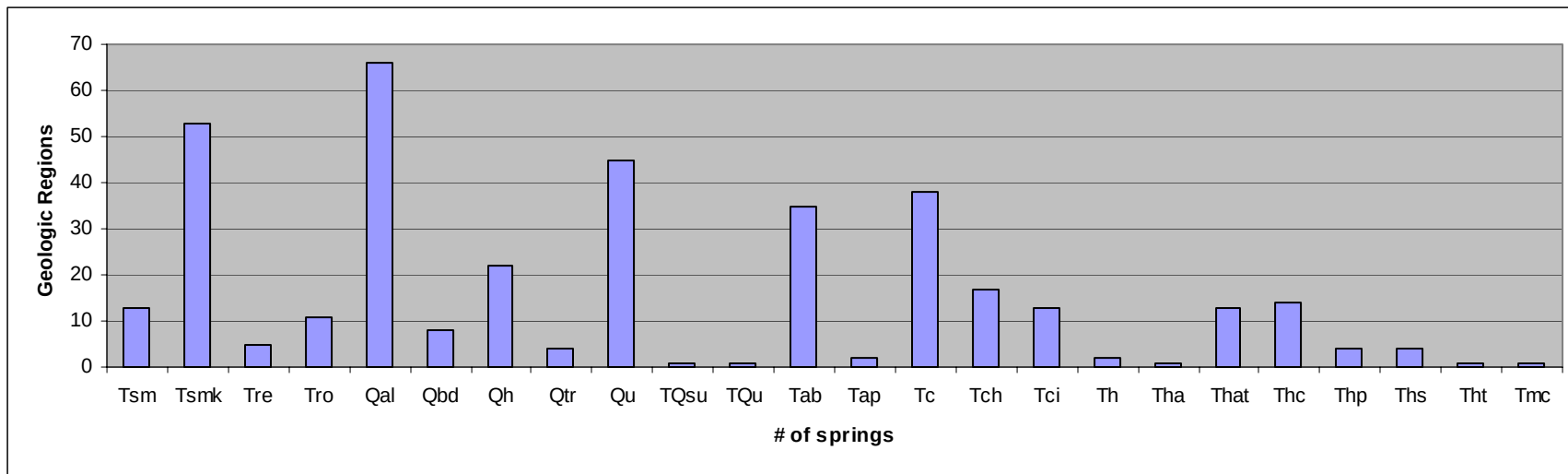


Figure 13: Bar graph of geologic formations and corresponding spring totals

Several formations stand out as representing significantly more springs than others. The Ocala Limestone corresponds to 273 springs, roughly one third of the entire population. The Suwannee Limestone corresponds to 107 springs, or about 14%. Alluvium corresponds to 66 springs (about 9%) and the St. Marks Formation corresponds to 53 springs (about 7%). As previously mentioned, all of this information is displayed in the preceding figure and table with the exception of the Ocala Limestone and the Suwannee Limestone.

This breakdown of Florida's springs into the individual geologic formations from which they issue helps provide a better understanding of the relationship between geology and the distribution of the springs. As depicted in the preceding data, three of the 37 geologic formations found in Florida represent over half of the entire population of springs. All three of these formations are representative of karst terrain, and together correspond to the largest percentage of Florida's springs that are geologically related. In all, approximately 60% of Florida's springs correspond to carbonate geologic units. This fact indicates that karst terrain is a factor that strongly influences the location of the largest percentage of Florida's springs.

Figure 14 displays the entire population of Florida's springs overlaid with geologic data for the entire state. Figure 15 depicts only the three previously mentioned formations (Ocala Limestone, Suwannee Limestone, St. Marks Formation). The observed correspondence between these formations and the bulk of the entire springs population is readily noticeable when Figures 14 and 15 are visually compared and viewed spatially. The importance of these formations to the representative sample of 102 springs will be discussed later in the study.

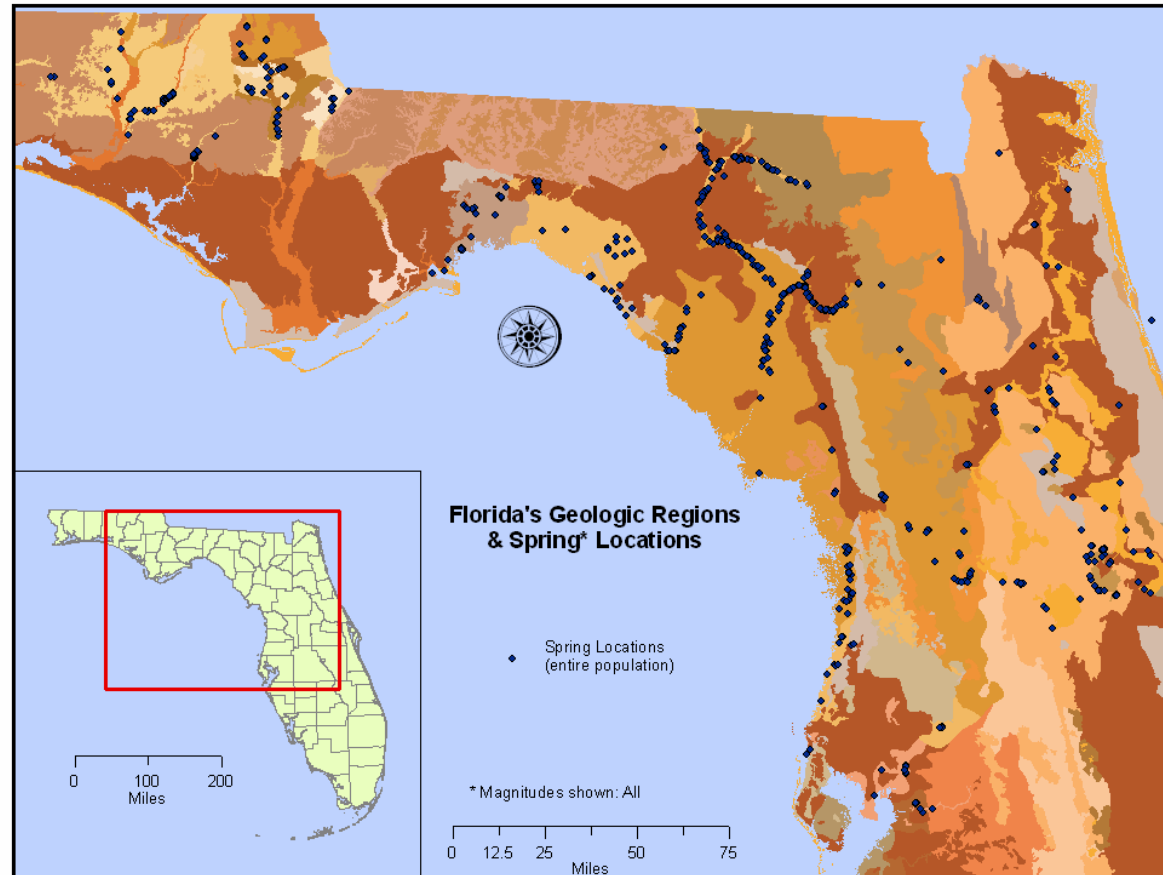


Figure 14: Entire spring population overlaid with geology

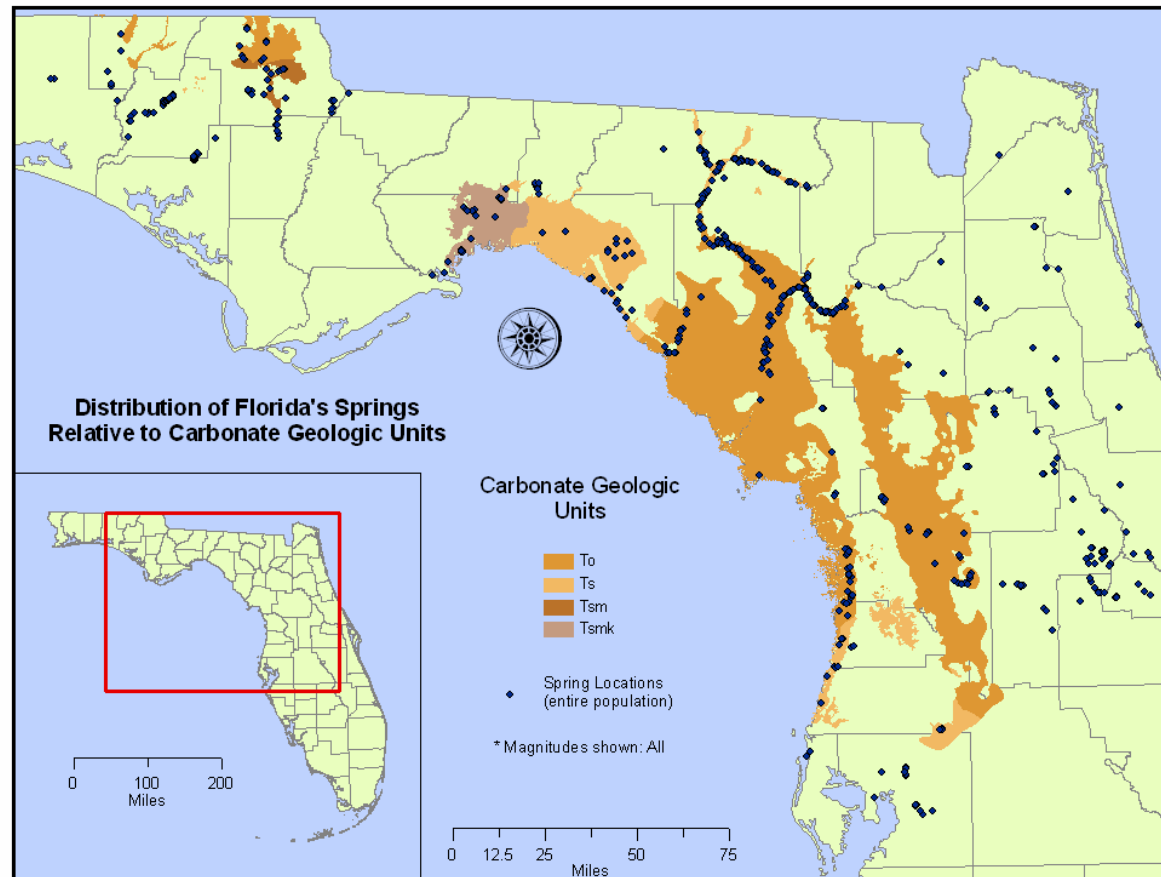


Figure 15: Spring locations overlaid with geology

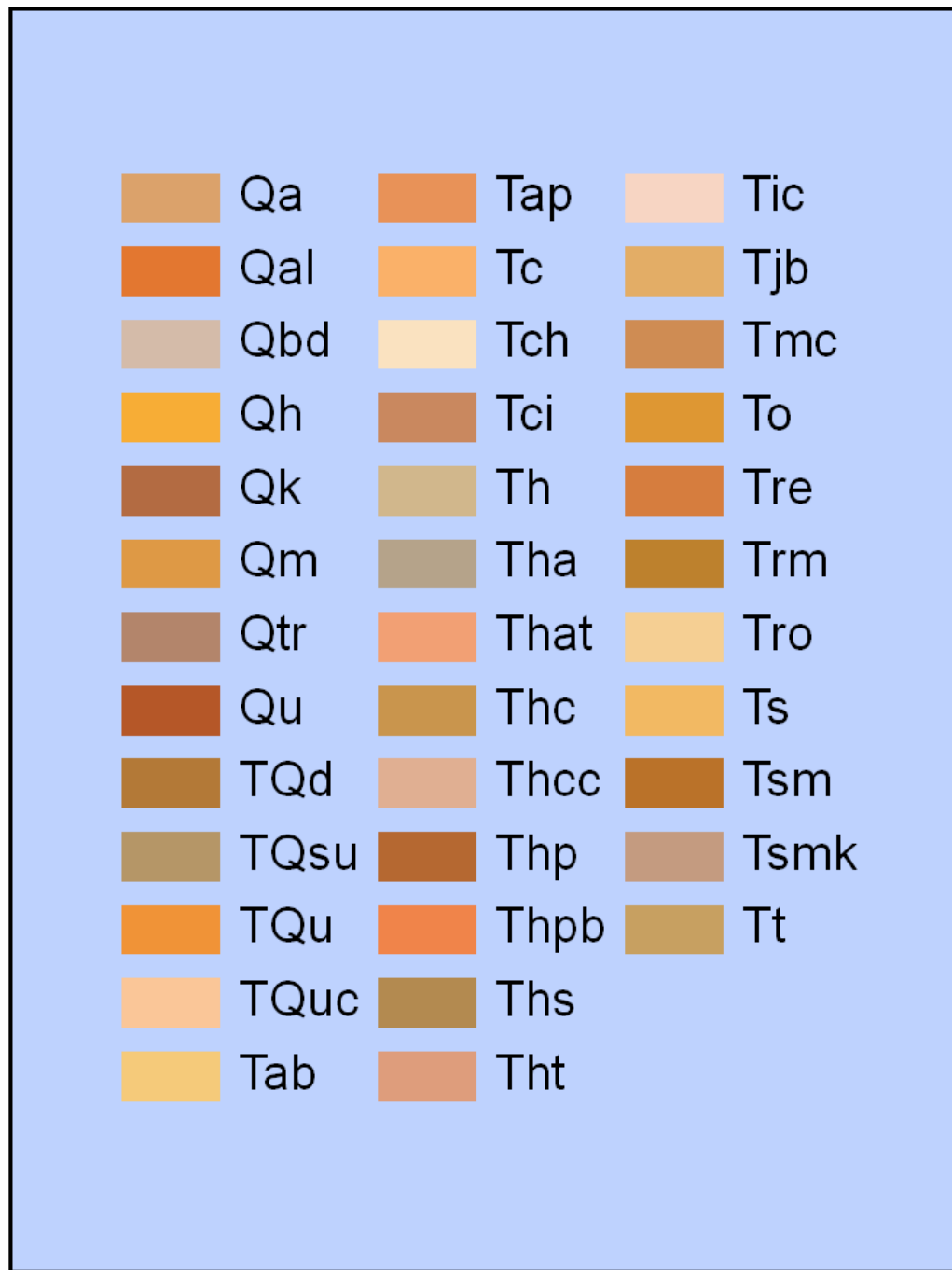


Figure 16: Legend of geologic formations

The geologic dataset includes an attribute identifying each geologic formation.

This terminology is explained in Tables 4 and 5. Each formation is identified here by its common name.

Quaternary	
Holocene	
Qh	Holocene sediments
Pleistocene/Holocene	
Qal	Alluvium
Qbd	Beach ridge and dune
Qu	Undifferentiated sediments
Pleistocene	
Qa	Anastasia Formation
Qk	Key Largo Limestone
Qm	Miami Limestone
Qtr	Trail Ridge sands

Tertiary/Quaternary	
Pliocene/Pleistocene	
TQsu	Shelly sediments of Plio-Pleistocene age
TQu	Undifferentiated sediments
TQd	Dunes
TQuc	Reworked Cypresshead sediments

Table 4: Formation names of the Quaternary and Tertiary/Quaternary Periods

Tertiary	
Pliocene	
Tc	Cypresshead Formation
Tci	Citronelle Formation
Tmc	Miccosukee Formation
Tic	Intracoastal Formation
Tt	Tamiami Formation
Tjb	Jackson Bluff Formation
Miocene/Pliocene	
Thcc	Hawthorn Group, Coosawhatchie Formation, Charlton Member
Thp	Hawthorn Group, Peace River Formation
Thpb	Hawthorn Group, Peace River Formation, Bone Valley Member
Miocene	
Trm	Residuum on Miocene sediments
Tab	Alum Bluff Group
Th	Hawthorn Group
Thc	Hawthorn Group, Coosawhatchie Formation
Ths	Hawthorn Group, Statenville Formation
Tht	Hawthorn Group, Torreya Formation
Tch	Chatahoochee Formation
Tsmk	St. Marks Formation
Oligocene/Miocene	
Tha	Hawthorn Group, Arcadia Formation
That	Hawthorn Group, Arcadia Formation, Tampa Member
Oligocene	
Tro	Residuum on Oligocene sediments
Ts	Suwannee Limestone
Tsm	Suwannee Limestone - Marianna Limestone undifferentiated
Eocene	
Tre	Residuum on Eocene sediments
To	Ocala Limestone
Tap	Avon Park Formation

Table 5: Formation names of the Tertiary period

The entire population of Florida's springs was also examined with regard to physiographic regions. Table 6 shows the number of springs that are located within each physiographic region, and Figure 16 displays a graph of these values. Please note that two regions, the Gulf Coastal Lowland and the Marriana Lowland, have been omitted

from this graph because they are outliers and skew the display of the rest of the data. The data corresponding to these two regions is subsequently discussed in greater detail.

Physiographic Region	# of springs	% of pop.
Central Valley	29	3.85
Coastal Swamps	37	4.91
Crescent City Ridge	1	0.13
Deland Ridge	1	0.13
Duval Upland	1	0.13
Eastern Valley	12	1.59
Fountain Slope	6	0.80
Geneva Hill	1	0.13
Grand Ridge	2	0.27
Greenhead Slope	9	1.19
Gulf Coastal Lowlands	337	44.69
High Springs Gap	28	3.71
Kenwood Gap	1	0.13
Lake Harris Cross Valley	1	0.13
Lake Wales Ridge	1	0.13
Marianna Lowlands	130	17.24
Marion Upland	30	3.98
Mount Dora Ridge	3	0.40
New Hope Ridge	1	0.13
Northern Highlands	22	2.92
Osceola Plain	12	1.59
Palatka Hill	1	0.13
Polk Upland	4	0.53
St. Johns River Offset	8	1.06
Sumter Upland	1	0.13
Tallahassee Hills	1	0.13
Trail Ridge	4	0.53
Tsala Apopka Plain	17	2.25
Wakulla Sand Hills	1	0.13
Western Highlands	5	0.66
Western Valley	32	4.24
Zephyrhills Gap	15	1.99

Table 6: % of spring population corresponding to physiographic regions

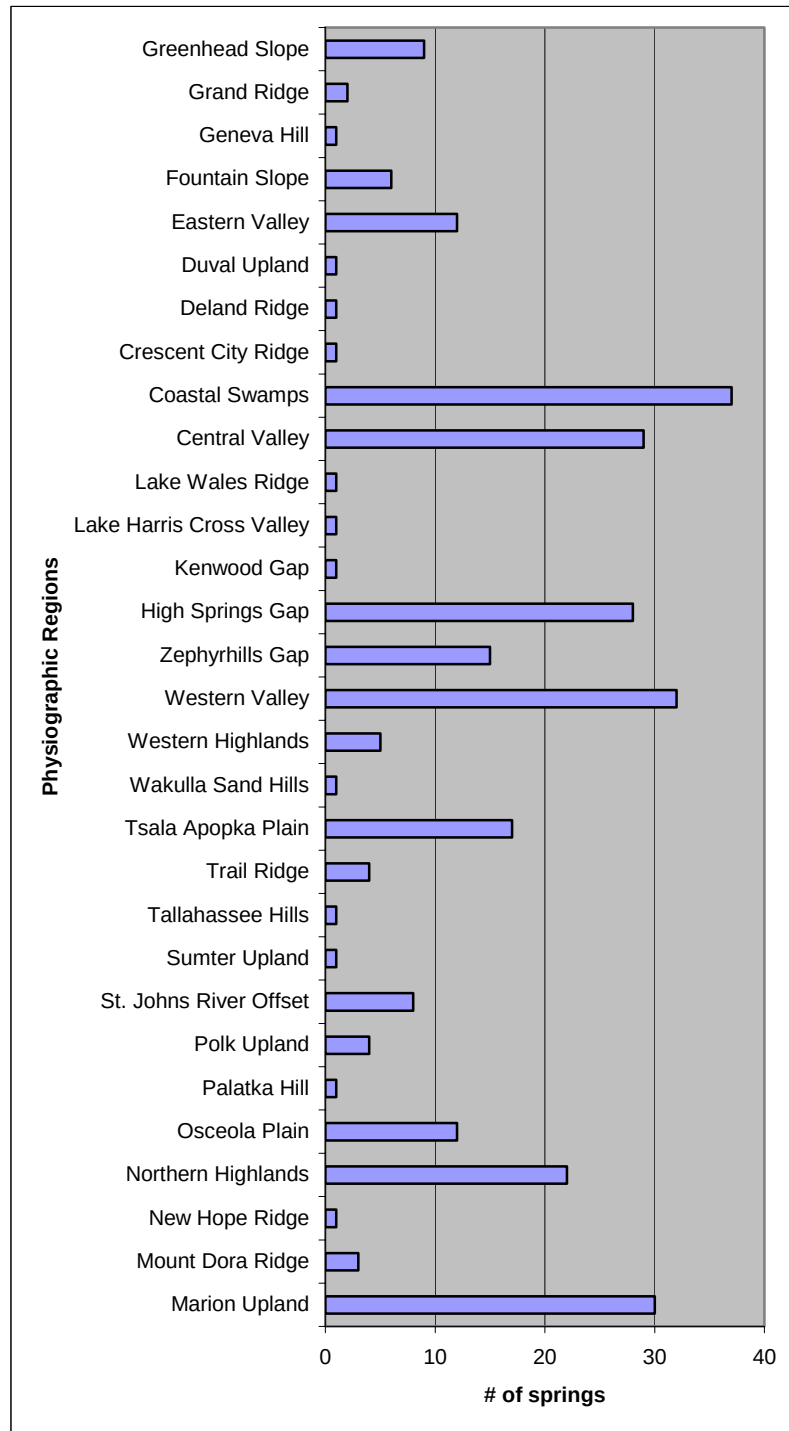


Figure 17: Bar graph of physiographic regions & corresponding spring totals

The largest percentage of springs is located within the Gulf Coastal Lowlands. This region contains 337 springs, or about 45%. Other regions of note are the Marianna Lowlands, which contains 130 springs (about 17%), the Coastal Swamps, containing 37 springs (about 5%), and the Western Valley, containing 32 springs (about 4%). The distribution of springs within these regions is closely related to the distribution of the carbonate geologic units that underlay them. The relationship between spring locations and carbonate geology will be illustrated in greater detail at the second scale of examination, as this fact again implicates karst terrain as being an influencing factor in the locations of Florida's springs. Also, the fact that a majority of the spring resurgences in the data set correspond to lowland and valley physiographic regions further validates the similar observations derived from the visual inspection of the 30-meter DEM (Figure 11).

The high concentration of springs in the Gulf Coastal Lowland can be observed in Figure 17, which displays the entire population of Florida's springs overlaid with physiographic data. The Gulf Coastal Lowland is represented by the light green region that covers much of the big bend area. The large quantity of springs that this region encompasses is clearly notable. Figure 18 serves as a legend of names for each physiographic region.

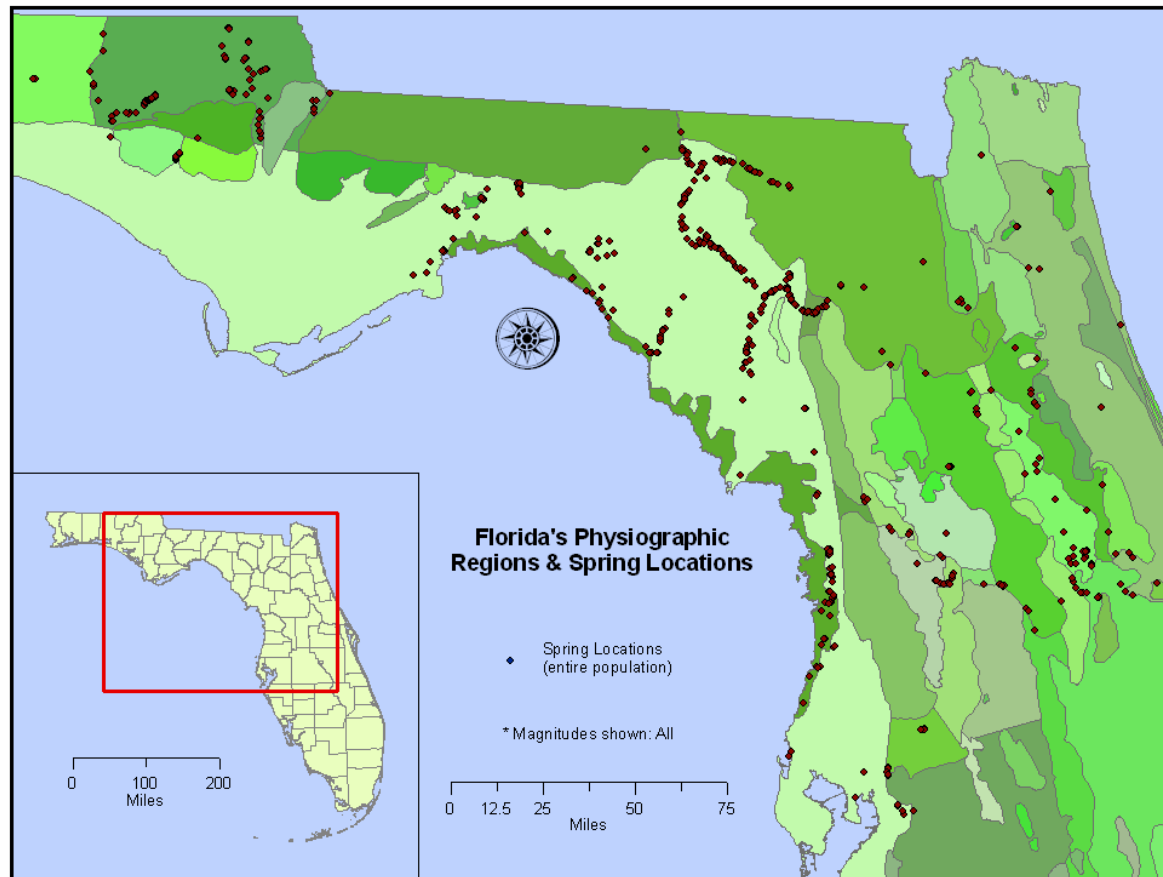


Figure 18: Spring locations overlaid with physiography



Figure 19: Legend of Physiographic Region

Exploration of the springs database

This study's examination of the entire population of Florida's springs has indicated that there is a relationship between elevation and geology, and the location of spring resurgences. A subset of the 754 springs was created to allow a more detailed analysis of the relationship between spring location and various morphometric characteristics to be completed. A representative sample of 102 springs is hereafter discussed, with the analysis focusing on examining the springs with respect to the spatial datasets representing elevation, physiography and geology. These examinations do not differ in method from those that were conducted at the first scale. The difference is the fact that the second data set is smaller and only represents the higher magnitude springs (magnitudes 1, 2, and 3). Visual appraisal of maps created for the 102 spring data base yields three observed clusters of springs, as well as a seemingly high number of springs located within certain physiographic and geologic regions. These supposed trends are hereafter explored and discussed.

A database comprised of values for all of the morphometric parameters in this portion of the study was compiled. Descriptive statistics were calculated for the entirety of the morphometric database, and are shown in Table 7. It has been noted within Table 4 that statistics for run length represent 79 springs, from the sample of 102, due to this being the number of springs that generate a spring run. The other 23 springs do not generate a spring run and therefore have a value of zero for their run length attribute.

PARAMETER	MIN	MAX	MEAN
ELEVATION (ft)	0.330	86.346	32.127
DISCHARGE (cfs)	0.36	1153.5	110.781
RUN LENGTH (79 SPRINGS) (ft)	7	89760	6907.658
POOL LENGTH (ft)	6	396	117.054
POOL WIDTH (ft)	6	372	122.075
POOL AREA (sq. ft)	36	147312	19390.452
DEPTH (ft)	2	185	29.334
DISTANCE TO COAST (mi)	0.028	15.822	6.914

Table 7: Descriptive Statistics of the Springs Database

Existing literature on Florida's springs states that most of them are karst springs (FGS Bulletin 66, Randazzo, 1997). The following discussion will seek to demonstrate how the presence of karst landscapes is related to the regions of Florida where springs are found. Karst springs are points of groundwater resurgence in the landscape. The groundwater travels below the surface as an underground stream in discrete continuous diffuse flow through naturally enlarged micro-openings. Its direction and point of resurgence are controlled partially by local geologic conditions including: 1) strike and dip of area rocks, 2) degree of karstification, 3) presence or absence of geologic structure such as faults, joints and bedding planes, and 4) the physical and chemical nature of area bedrock. In northern peninsular Florida and parts of the panhandle where springs are found, limestone formations are generally shallow or exposed at the surface.

Jackson Blue spring has the highest elevation in the database, at 86.35 feet above sea level. It is located in the panhandle and is therefore outside the coverage of the physiography dataset. However, its distance of 12.22 miles from the coastline would most likely place it outside of the coastal lowlands physiographic region in the panhandle, which contains numerous spring resurgences. The spring issues from Suwannee Limestone – Marianna Limestone Undifferentiated which probably indicates

that this spring is a karst solution spring. The nature of the karst landscape contributes to the ability of the groundwater at the spring site to make its way through the system of voids found in the karst aquifers, to eventually emerge on the land.

The Spring Creek springs group has the highest maximum discharge of 1153.5 cubic feet per second. It is located in the panhandle and very near the coastline. The group lies outside of the extents of the physiography dataset, and it issues from the St. Marks formation. The St. Marks formation is a sandy marine limestone from the Lower Miocene that is often exposed in streambeds and sinkholes in northern Florida (FGS, 2006). It should be noted that there are 14 different springs that make up the Spring Creek springs group, a fact that undoubtedly influences the extremely high amount of discharge. The low elevation and close proximity to the coastline are not necessarily causal factors for high discharge.

Wekiwa spring generates the longest spring run at about 89,760 feet, or about 17 miles. It is located in northern peninsular Florida in the Osceola Plain, and it resurges from the Cypresshead formation. This formation is a shallow marine sandstone indigenous to peninsular Florida and parts of Georgia (USGS, 2004). Other maximums in the data set include the fact that Apopka spring is the furthest from the coastline at 51.91 miles. It is located in northern peninsular Florida in the Central Valley, and issues from the Cypresshead formation. Wakulla spring has the deepest pool at about 185 feet. The spring issues from the St. Marks formation.

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The distribution of the springs in the representative sample relative to Florida's physiographic regions and geologic formations was also examined. Attention has been given to which regions and formations contain the highest concentrations of springs. Because this research has generated a large volume of data related to numerous aspects of Florida's springs, it will not be practical to discuss the entire database. Instead, only the portions of the database deemed as most pertinent after visual inspection of figures and tables will be discussed in detail. In tables 5-11 the gray-shaded rows of data fit this description and are therefore discussed in detail.

Tables 8-14 show descriptive statistics for each of the physiographic regions that contain springs. Since the springs are concentrated within 21 physiographic regions, 64 regions do not contain any first, second, or third magnitude springs that are examined in this study. Please note that some physiographic regions only contain one spring group. Descriptives for these regions were not calculated. Although springs groups are considered to be a single feature, morphometric data is rarely available for each individual vent in the group. Some general observations were made concerning the Gulf Coastal Lowland region. This region is exceptionally notable in Tables 5-18 as follows.

PHYIOGRAPHIC REGION	N	Magnitude			Run	
		1	2	3	Yes	No
Central Valley	2	1	0	1	2	0
Coastal Swamps	5	2	1	2	4	1
Crescent City Ridge	1	0	1	0	1	0
Eastern Valley	1	0	0	1	1	0
Fountain Slope	2	1	1	0	2	0
Greenhead Slope	1	0	1	0	1	0
Gulf Coastal Lowlands	47	19	23	5	39	8
High Springs Gap	7	4	3	0	4	3
Lake Harris Cross Valley	1	0	1	0	1	0
Lake Wales Ridge	1	0	1	0	0	1
Marianna Lowlands	13	1	11	1	12	1
Marion Upland	5	2	3	0	5	0
Mount Dora Ridge	1	0	1	0	1	0
Northern Highlands	2	0	2	0	2	0
Osceola Plain	3	0	3	0	3	0
Polk Upland	1	0	1	0	1	0
St. Johns River Offset	2	1	1	0	2	0
Tsala Apopka Plain	2	0	2	0	2	0
Wakulla Sand Hills	1	0	1	0	1	0
Western Valley	3	2	1	0	2	1
Zephyrhills Gap	1	0	1	0	0	1

Table 8: Magnitude and run generation by physiographic region

The Gulf Coastal Lowlands stands out for its higher percentage of springs that do not generate a spring run. Out of the 47 springs located within this region, eight (or about 17%) do not generate a spring run. The high percentage of springs that do not generate a spring run can also be attributed to the nature of the karst landscape. Higher secondary porosity and permeability values in some areas of the Ocala Limestone probably inhibit surface flow in these areas.

PHYIOGRAPHIC REGION	N	ELEVATION (FT.)		
		MIN	MAX	MEAN
Central Valley	2	24.693	45.061	34.877
Coastal Swamps	5	3.491	27.396	10.693
Crescent City Ridge	1	18.226	18.226	18.226
Eastern Valley	1	16.139	16.139	16.139
Fountain Slope	2	18.790	27.688	23.239
Greenhead Slope	1	30.123	30.123	30.123
Gulf Coastal Lowlands	47	0.330	80.798	27.056
High Springs Gap	7	24.365	49.582	32.651
Lake Harris Cross Valley	1	62.227	62.227	62.227
Lake Wales Ridge	1	68.120	68.120	68.120
Marianna Lowlands	13	26.688	86.346	58.269
Marion Upland	5	4.068	32.052	18.617
Mount Dora Ridge	1	50.892	50.892	50.892
Northern Highlands	2	39.769	48.966	44.367
Osceola Plain	3	27.006	39.014	34.076
Polk Upland	1	6.585	6.585	6.585
St. Johns River Offset	2	0.502	14.423	7.463
Tsala Apopka Plain	2	37.144	44.080	40.612
Wakulla Sand Hills	1	15.759	15.759	15.759
Western Valley	3	33.617	53.710	40.880
Zephyrhills Gap	1	51.643	51.643	51.643

Table 9: Elevation descriptives by physiographic region

The Marianna Lowlands contains Jackson Blue Spring, the highest elevation spring in the sample at 86.346 feet above sea level, and also contains Blue Hole Spring at 84.480 feet of elevation. Springs in the Gulf Coastal Lowland represent the second-highest maximum elevation value, occurring at Owens Spring, 80.879 feet above sea level. It interesting to note the these regions contain springs with some of the highest elevation values in the sample, and yet they are classified as lowlands. This further illustrates the marginal range of elevation values at which Florida's springs are typically found.

PHYIOGRAPHIC REGION	N	DISCHARGE (CFS)		
		MIN	MAX	MEAN
Central Valley	2	5.270	556.000	280.635
Coastal Swamps	5	0.360	360.000	118.084
Crescent City Ridge	1	10.710	10.710	10.710
Eastern Valley	1	3.590	3.590	3.590
Fountain Slope	2	11.530	160.800	86.165
Greenhead Slope	1	26.480	26.480	26.480
Gulf Coastal Lowlands	47	7.650	1153.500	138.591
High Springs Gap	7	39.500	222.930	104.930
Lake Harris Cross Valley	1	10.930	10.930	10.930
Lake Wales Ridge	1	30.090	30.090	30.090
Marianna Lowlands	13	5.700	165.600	48.458
Marion Upland	5	10.630	118.000	67.044
Mount Dora Ridge	1	57.310	57.310	57.310
Northern Highlands	2	27.830	98.950	63.390
Osceola Plain	3	15.300	70.050	34.700
Polk Upland	1	33.540	33.540	33.540
St. Johns River Offset	2	26.350	121.000	73.675
Tsala Apopka Plain	2	15.960	35.170	25.565
Wakulla Sand Hills	1	15.000	15.000	15.000
Western Valley	3	33.920	783.600	310.297
Zephyrhills Gap	1	75.670	75.670	75.670

Table 10: Discharge descriptives by physiographic region

The Gulf Coastal Lowland shows a relatively high mean discharge, and contains three of the highest discharging springs in the sample: the Spring Creek Springs Group at over 1000 cfs, the Kings Bay Springs Group at 975 cfs, and the Alaphia River Rise at 605 cfs (Table 7). This is attributed to the well-developed karst landscape in the region that is characterized by the Ocala Limestone. Hence, this indicates that the springs are karst solution springs.

PHYIOGRAPHIC REGION	N	DEPTH (FT.)		
		MIN	MAX	MEAN
Central Valley	2	12.000	12.000	12.000
Coastal Swamps	5	4.000	53.000	22.100
Crescent City Ridge	1	18.000	18.000	18.000
Eastern Valley	1	28.000	28.000	28.000
Fountain Slope	2	2.000	2.000	2.000
Greenhead Slope	1	10.100	10.100	10.100
Gulf Coastal Lowlands	47	5.900	185.000	29.550
High Springs Gap	7	12.200	49.000	26.971
Lake Harris Cross Valley	1	170.000	170.000	170.000
Lake Wales Ridge	1	45.000	45.000	45.000
Marianna Lowlands	13	14.000	49.100	27.169
Marion Upland	5	5.000	25.000	15.940
Mount Dora Ridge	1	5.000	0.000	0.000
Northern Highlands	2	7.800	83.000	45.400
Osceola Plain	3	7.200	14.800	11.900
Polk Upland	1	8.200	8.200	8.200
St. Johns River Offset	2	20.000	28.000	24.000
Tsala Apopka Plain	2	9.800	22.000	15.900
Wakulla Sand Hills	1	12.000	12.000	12.000
Western Valley	3	21.400	34.500	27.950
Zephyrhills Gap	1	10.000	10.000	10.000

Table 11: Depth descriptives by physiographic region

The Gulf Coastal Lowland contains Wakulla spring, the deepest spring in the sample at 185 feet. Springs in the Marrianna Lowlands also exhibit a relatively high mean depth, considering the higher number of springs contained within the region. It is difficult to speculate upon the significance of regions like the Lake Harris Cross Valley or the Lake Wales Ridge. Although these regions also stand out for their depth values, they only contain a single spring.

PHYIOGRAPHIC REGION	N	POOL AREA (SQ. FT.)		
		MIN	MAX	MEAN
Central Valley	2	10989.000	10989.000	10989.000
Coastal Swamps	5	2430.000	62040.000	18060.000
Crescent City Ridge	1	18963.000	18963.000	18963.000
Eastern Valley	1	225.000	225.000	225.000
Fountain Slope	2	5985.000	5985.000	5985.000
Greenhead Slope	1	3249.000	3249.000	3249.000
Gulf Coastal Lowlands	47	36.000	99225.000	14721.917
High Springs Gap	7	6300.000	28875.000	15460.571
Lake Harris Cross Valley	1	147312.000	147312.000	147312.000
Lake Wales Ridge	1	32400.000	32400.000	32400.000
Marianna Lowlands	13	900.000	90000.000	23060.308
Marion Upland	5	10800.000	77400.000	31856.200
Mount Dora Ridge	1	NA	NA	NA
Northern Highlands	2	425.000	41280.000	20852.500
Osceola Plain	3	900.000	11025.000	5427.000
Polk Upland	1	30240.000	30240.000	30240.000
St. Johns River Offset	2	14175.000	31752.000	22963.500
Tsala Apopka Plain	2	5589.000	14400.000	9994.500
Wakulla Sand Hills	1	1225.000	1225.000	1225.000
Western Valley	3	4536.000	22785.000	9107.000
Zephyrhills Gap	1	37260.000	37260.000	37260.000

Table 12: Pool area descriptives by physiographic region

It is interesting to note that the lowest minimum pool area value as well as one of the highest maximum pool area values both correspond to springs that are located within the Gulf Coastal Lowlands. This could be a result of that region containing the highest number of springs in the dataset, and the fact that any given spring has a higher probability of being located within the Gulf Coastal Lowland than in any other region.

PHYIOGRAPHIC REGION	N	RUN LENGTH (FT.)		
		MIN	MAX	MEAN
Central Valley	2	500.000	26400.000	13450.000
Coastal Swamps	4	75.000	29040.000	6949.000
Crescent City Ridge	1	2500.000	2500.000	2500.000
Eastern Valley	1	450.000	450.000	450.000
Fountain Slope	2	500.000	820.000	660.000
Greenhead Slope	1	443.000	443.000	443.000
Gulf Coastal Lowlands	47	7.000	39600.000	2846.438
High Springs Gap	7	500.000	1100.000	819.000
Lake Harris Cross Valley	1	4224.000	4224.000	4224.000
Lake Wales Ridge	1	0.000	0.000	0.000
Marianna Lowlands	13	150.000	8448.000	1441.846
Marion Upland	5	600.000	52800.000	24144.000
Mount Dora Ridge	1	45408.000	45408.000	45408.000
Northern Highlands	2	90.000	90.000	90.000
Osceola Plain	3	500.000	89760.000	30086.667
Polk Upland	1	950.000	950.000	950.000
St. Johns River Offset	2	1050.000	1320.000	1185.000
Tsala Apopka Plain	2	2112.000	4224.000	3168.000
Wakulla Sand Hills	1	50.000	50.000	50.000
Western Valley	3	21270.000	30096.000	25683.000
Zephyrhills Gap	1	0.000	0.000	0.000

Table 13: Distance to coastline descriptives by physiographic region

The Coastal Swamps region contains the lowest minimum, maximum, and mean values for distance to coastline in the entire sample dataset. This is not surprising, due to the region being a very narrow strip of Florida's land that skirts the gulf coast in the big bend area. No clear trend in the data could be found for this variable.

PHYIOGRAPHIC REGION	N	RUN LENGTH (FT.)		
		MIN	MAX	MEAN
Central Valley	2	500.000	26400.000	13450.000
Coastal Swamps	5	75.000	29040.000	6949.000
Crescent City Ridge	1	2500.000	2500.000	2500.000
Eastern Valley	1	450.000	450.000	450.000
Fountain Slope	2	500.000	820.000	660.000
Greenhead Slope	1	443.000	443.000	443.000
Gulf Coastal Lowlands	47	7.000	39600.000	2846.438
High Springs Gap	7	500.000	1100.000	819.000
Lake Harris Cross Valley	1	4224.000	4224.000	4224.000
Lake Wales Ridge	1	NA	NA	NA
Marianna Lowlands	13	150.000	8448.000	1441.846
Marion Upland	5	600.000	52800.000	24144.000
Mount Dora Ridge	1	45408.000	45408.000	45408.000
Northern Highlands	2	90.000	90.000	90.000
Osceola Plain	3	500.000	89760.000	30086.667
Polk Upland	1	950.000	950.000	950.000
St. Johns River Offset	2	1050.000	1320.000	1185.000
Tsala Apopka Plain	2	2112.000	4224.000	3168.000
Wakulla Sand Hills	1	50.000	50.000	50.000
Western Valley	3	21270.000	30096.000	25683.000
Zephyrhills Gap	1	NA	NA	NA

Table 14: Run length descriptives by physiographic region

Spring runs in the Gulf Coastal Lowland represent the lowest mean length of the entire sample, due to the springs discharging over a short distance into the three major rivers in the region.

Regarding the distribution of springs among the physiographic regions, there is a relatively large difference between the region with the highest number of springs and the region with the second-highest number of springs (Table 5). The Gulf Coastal Lowlands region contains a total of 47 springs (19 first magnitude, 23 second magnitude, and 5 third magnitude), which is nearly four times as many springs as the next-closest

hysiographic region (Marianna Lowlands with 13 springs). Figures 19 displays this concentration of springs within the Gulf Coastal Lowland.

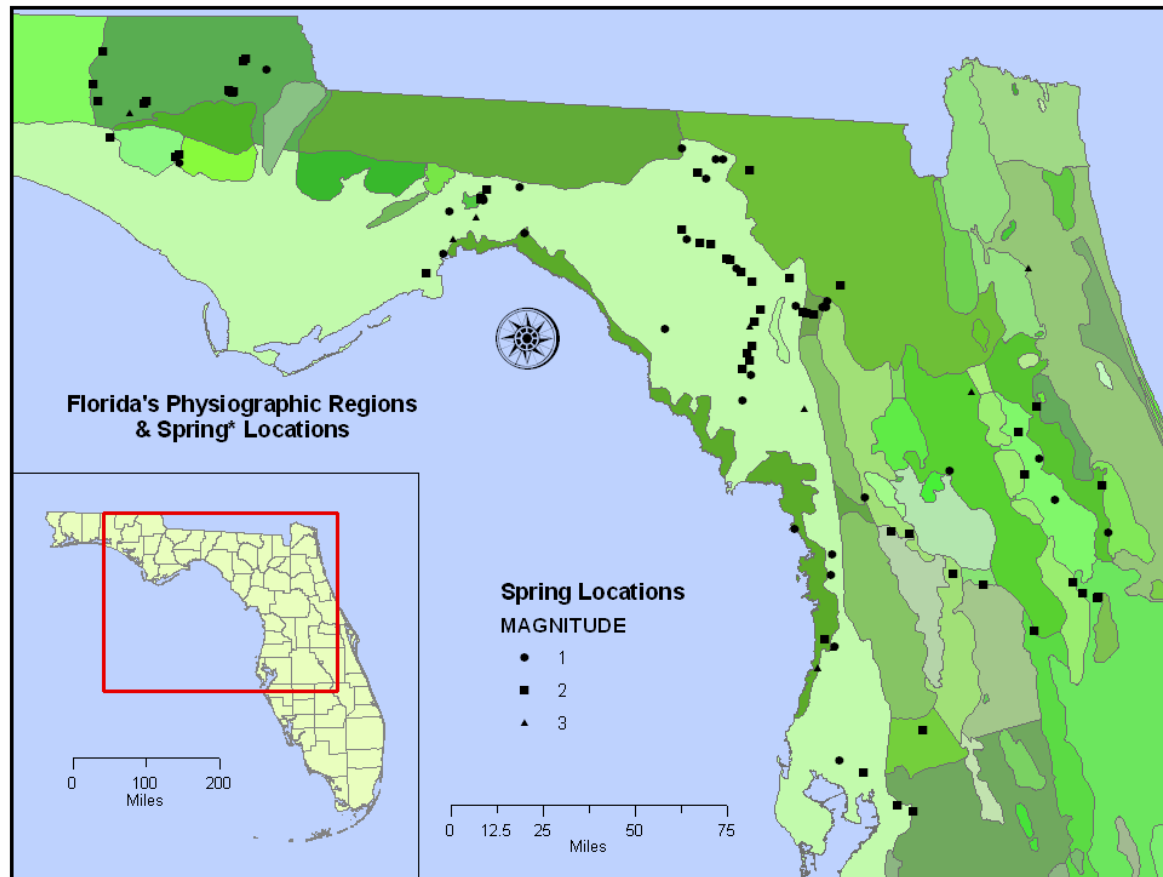


Figure 20: Physiography overlaid with spring locations

There are 37 different geologic formations in Florida. All of the springs in the sample are distributed within 15 of those formations, leaving 22 formations that do not contain any springs. Tables 15-21 show descriptive statistics for each of the 15 geologic formations that contain springs. Table 16 contains a topology which indicates the general nature of the geologic formation contained in the database used in this research. 69 springs issue from carbonate (karst forming) units, 22 from unconsolidated sediments, and 10 from a quartz sandstone unit.

Geologic Formation	N	Magnitude			Run	
		1	2	3	Yes	No
Alluvium	5	0	4	1	5	0
Alum bluff group	5	0	5	0	5	0
Beach ridge and dune	1	1	0	0	1	0
Cypresshead formation	6	2	4	0	5	1
Hawthorn Group, Arcadia Formation, Tampa Member	3	0	2	1	3	0
Hawthorn Group, Coosawhatchie Formation	4	0	4	0	4	0
Hawthorn Group, Peace River Formation	1	0	1	0	1	0
Holocene Sediments	3	1	2	0	3	0
Ocala Limestone	39	16	23	2	30	9
Residuum on Oligocene sediments	4	0	4	0	4	0
St. Marks Formation	9	4	4	2	8	1
Suwannee Limestone	11	4	5	2	7	4
Suwannee Limestone - Marianna Limestone undifferentiated	2	1	0	1	1	1
Undifferentiated sediments	9	4	1	4	9	0

Table 15: Magnitude and run generation descriptives by geologic formation

The vast majority of Florida's first magnitude springs correspond to karst geologic units (all 33 first magnitude springs are included in the representative sample). Of these 33 springs 28, or 84.8% correspond to the carbonate geologic units highlighted in the table above.

GEOLOGIC FORMATION	N	TYP.	ELEVATION (FT.)		
			MIN	MAX	MEAN
ALLUVIUM	5	US	26.688	195.922	59.714
ALUM BLUFF GROUP	5	C	22.252	163.401	49.802
BEACH RIDGE AND DUNE	1	US	17.645	57.894	17.645
CYPRESSHEAD FORMATION	6	S	13.718	223.502	68.120
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	C	6.585	25.168	7.671
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	S	27.006	128.006	39.014
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	M	9.121	29.927	9.121
HOLOCENE SEDIMENTS	3	US	0.502	50.219	15.306
OCALA LIMESTONE	39	C	1.083	277.176	84.479
RESIDUUM ON OLIGOCENE SEDIMENTS	4	US	68.514	260.534	79.407
ST. MARKS FORMATION	9	C	3.461	60.122	18.324
SUWANNEE LIMESTONE	11	C	3.491	194.867	59.393
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	C	86.346	283.301	86.346
UNDIFFERENTIATED SEDIMENTS	9	US	16.139	199.787	60.892

Table 16: Elevation descriptives by geologic formation. Also included is a typology for each of the geologic formations that expresses the general nature of the geology. US=unconsolidated sediment, S=sandstone, C=carbonate rock, and M=mixed geology .

It is interesting to note the range of mean elevation values among the listed physiographic regions. Most regions contain springs with mean elevation less than 60 feet. It was previously observed that about 86% of Florida's springs fall into this range. Even those regions with mean elevation values higher than 60 feet, such as the Ocala Limestone, Residuum on Oligocene Sediments, the Hawthorne Group, Arcadia Formation, Tampa Member, and the Suwannee Limestone-Marianna Limestone Undifferentiated, all have mean elevation values that are, relatively speaking, not much higher than the most populous range.

GEOLOGIC FORMATION	N	DEPTH (FT.)		
		MIN	MAX	MEAN
ALLUVIUM	5	15	46	29.05
ALUM BLUFF GROUP	5	2	36	17.22
BEACH RIDGE AND DUNE	1	45	45	45
CYPRESSHEAD FORMATION	6	13.7	170	54.74
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	8.2	30	19.1
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	5	14.8	9.675
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	8.3	8.3	8.3
HOLOCENE SEDIMENTS	3	18	28	22
OCALA LIMESTONE	39	5.9	84	24.8
RESIDUUM ON OLIGOCENE SEDIMENTS	4	18	49.1	32.125
ST. MARKS FORMATION	9	6	185	41.867
SUWANNEE LIMESTONE	11	4	150	43.936
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	16.5	16.5	16.5
UNDIFFERENTIATED SEDIMENTS	9	9	39	19.833

Table 17: Depth descriptives by geologic formation

The three formations with highest mean depth values, the Cypresshead Formation, the St Marks Formation, and the Suwannee Limestone, all contain a very deep spring that skews this statistic. Wakulla spring, the deepest in the entire dataset, corresponds to the St Marks Formation. There is no clear trend in the data for this variable.

GEOLOGIC FORMATION	N	DISCHARGE (CFS)		
		MIN	MAX	MEAN
ALLUVIUM	5	5.7	89.47	46.708
ALUM BLUFF GROUP	5	11.53	40.52	25.048
BEACH RIDGE AND DUNE	1	176	176	176
CYPRESSHEAD FORMATION	6	10.93	121	70.014
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	33.54	62.43	47.985
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	10.63	18.75	14.64
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	13.23	13.23	13.23
HOLOCENE SEDIMENTS	3	26.35	112	73.02
OCALA LIMESTONE	39	9.98	350	74.377
RESIDUUM ON OLIGOCENE SEDIMENTS	4	15.4	62.4	35.245
ST. MARKS FORMATION	9	7.65	452	113.93
SUWANNEE LIMESTONE	11	0.36	605.4	134.753
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	165.6	165.6	165.6
UNDIFFERENTIATED SEDIMENTS	9	3.59	184	37.013

Table 18: Discharge descriptives by geologic formation

The highest mean discharge values are all associated with karst geologic formations. The Suwannee Limestone corresponds to the Alaphia River Rise, the highest discharging spring in the sample at 605.4 cfs, and also corresponds to the Nutall River Rise which discharges 360 cfs. The second highest maximum discharge is found among the spring of the St. Marks Formation, due to the St. Marks River Rise at 452 cfs. This formation also corresponds to Wakulla Spring, another very high discharging spring at 390 cfs.

GEOLOGIC FORMATION	N	POOL AREA (SQ. FT.)		
		MIN	MAX	MEAN
ALLUVIUM	5	900	90000	26712
ALUM BLUFF GROUP	5	3249	28620	12366
BEACH RIDGE AND DUNE	1	34650	34650	34650
CYPRESSHEAD FORMATION	6	11025	147312	56462.4
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	8100	30240	19170
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	900	11700	6939
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	2025	2025	2025
HOLOCENE SEDIMENTS	3	24381	35000	30377.667
OCALA LIMESTONE	39	1190	53865	14740.111
RESIDUUM ON OLIGOCENE SEDIMENTS	4	4680	22500	12917.25
ST. MARKS FORMATION	9	1225	99225	22102.778
SUWANNEE LIMESTONE	11	36	62040	16552.273
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	55920	55920	55920
UNDIFFERENTIATED SEDIMENTS	9	225	24336	10710

Table 19: Pool area descriptives by geologic formation

The Suwannee Limestone-Marianna Limestone Undifferentiated formation corresponds to the lowest minimum pool area. The highest maximum pool area is found issuing from the Cypresshead Formation, and many of the highest maximum and mean pool area values correspond to carbonate geologic units. However, there is no clear trend in the data for this variable.

GEOLOGIC FORMATION	N	DISTANCE TO COASTLINE (MI.)		
		MIN	MAX	MEAN
ALLUVIUM	5	9.563	23.079	17.598
ALUM BLUFF GROUP	5	7.994	22.785	14.459
BEACH RIDGE AND DUNE	1	4.6	4.6	4.6
CYPRESSHEAD FORMATION	6	23.949	51.914	38.324
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	5.219	9.423	7.321
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	33.033	38.873	35.987
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	5.663	5.663	5.663
HOLOCENE SEDIMENTS	3	21.134	36.096	30.272
OCALA LIMESTONE	39	2.768	43.735	30.307
RESIDUUM ON OLIGOCENE SEDIMENTS	4	19.948	20.544	20.227
ST. MARKS FORMATION	9	1.582	14.213	9.8
SUWANNEE LIMESTONE	11	0.876	20.895	10.116
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	12.219	12.219	12.219
UNDIFFERENTIATED SEDIMENTS	9	4.216	43.145	22.034

Table 20: Distance to coastline descriptives by geologic formation

The lowest minimum distance to the coastline corresponds to the St. Marks formation, which also represents one of the lowest mean values. The highest maximum distance from the coastline for any spring is found issuing from the Cypresshead formation. The Gulf Coastal Lowland also corresponds to a high maximum and mean value for this variable, probably due to its widespread coverage. No clear trend in the data could be found for this variable.

GEOLOGIC FORMATION	N	RUN LENGTH (FT.)		
		MIN	MAX	MEAN
ALLUVIUM	5	1800	29040	15420
ALUM BLUFF GROUP	5	150	3696	1399
BEACH RIDGE AND DUNE	1	350	4752	1389
CYPRESSHEAD FORMATION	6	26400	26400	26400
HAWTHORN GROUP, ARCADIA FORMATION, TAMPA MEMBER	3	1050	89760	36536.4
HAWTHORN GROUP, COOSAWHATCHIE FORMATION	4	650	950	800
HAWTHORNE GROUP, PEACE RIVER FORMATION	1	500	52800	17966.667
HOLOCENE SEDIMENTS	3	15	15	15
OCALA LIMESTONE	39	1320	21120	8800
RESIDUUM ON OLIGOCENE SEDIMENTS	4	25	31680	4019.379
ST. MARKS FORMATION	9	275	1025	662.5
SUWANNEE LIMESTONE	11	50	39600	6095
SUWANNEE LIMESTONE-MARIANNA LIMESTONE UNDIFF.	2	75	5280	2377
UNDIFFERENTIATED SEDIMENTS	9	350	26400	5108.333

Table 21: Run length descriptives by geologic formation

While the Holocene Sediments formation corresponds to the lowest minimum run length value, it interesting to notice that some of the lowest mean values for this variable (relatively speaking) correspond to carbonate units such as the Suwannee Limestone and the St. Marks formation. With this said, other carbonate units, such as the Ocala Limestone, correspond to a much higher mean run length value. No clear trend in the data could be found for this variable.

Several geologic formations stand out as having substantially more springs located within them than the others. These include the Ocala Limestone, the Suwannee Limestone, the St. Marks Formation (a marine limestone), and the designation undifferentiated sediments. Because 70 of the 102 first, second, and third magnitude springs used in this study resurge from carbonate units, it appears that many of Florida's springs can be specifically classified as karst solution springs. Areas where the limestone

is exposed at or near to the surface will therefore be the most likely locations where springs will form. The Ocala Limestone contains nearly four times as many spring resurgences as the Suwannee Limestone, which contains the second highest number of resurgences. 37.2% of the springs in the study issue from the Ocala Limestone, while 10.9% resurge from the Suwannee Limestone. In total 59 springs (or 57.8%) issue from geologic units that contain limestone or are formed in some type of carbonate material, and are thus directly associated with Florida's karst landscape.

Figure 20 displays the representative sample of Florida's springs overlaid with geologic data. The four previously mentioned formations (Ocala Limestone, Suwannee Limestone, St. Marks Formation, and Undifferentiated sediments) are shown. These formations are singled out because they exhibit high concentrations of springs. As was the case with the previous examination of the entire population of springs relative to area geology, the observed correspondence between these formations and the bulk of the entire springs population is hereby observed.

Figure 21 displays spring locations overlaid with the Gulf Coastal Lowland and carbonate geologic formations. The Ocala Limestone, the Suwannee Limestone, the St. Marks formation, and Undifferentiated Sediments are shown.

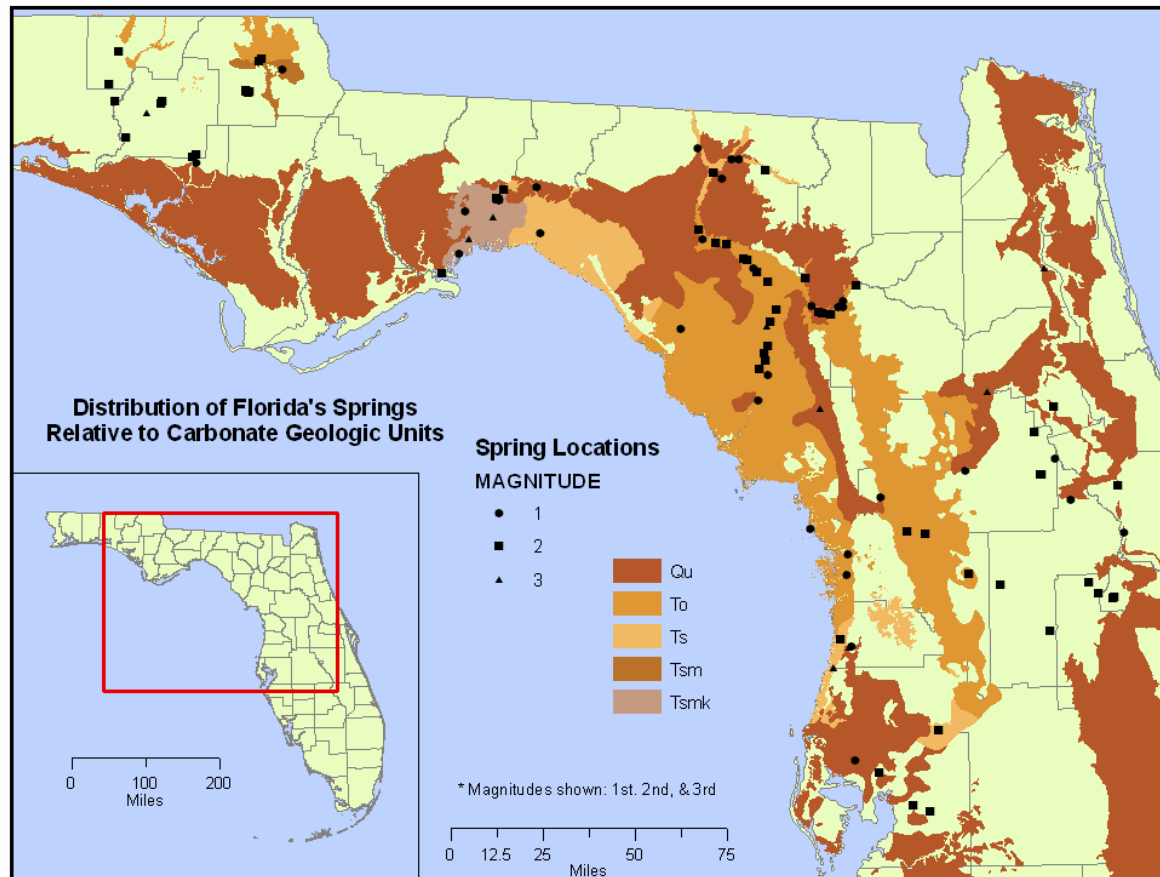


Figure 21: Geologic formations overlaid with spring locations

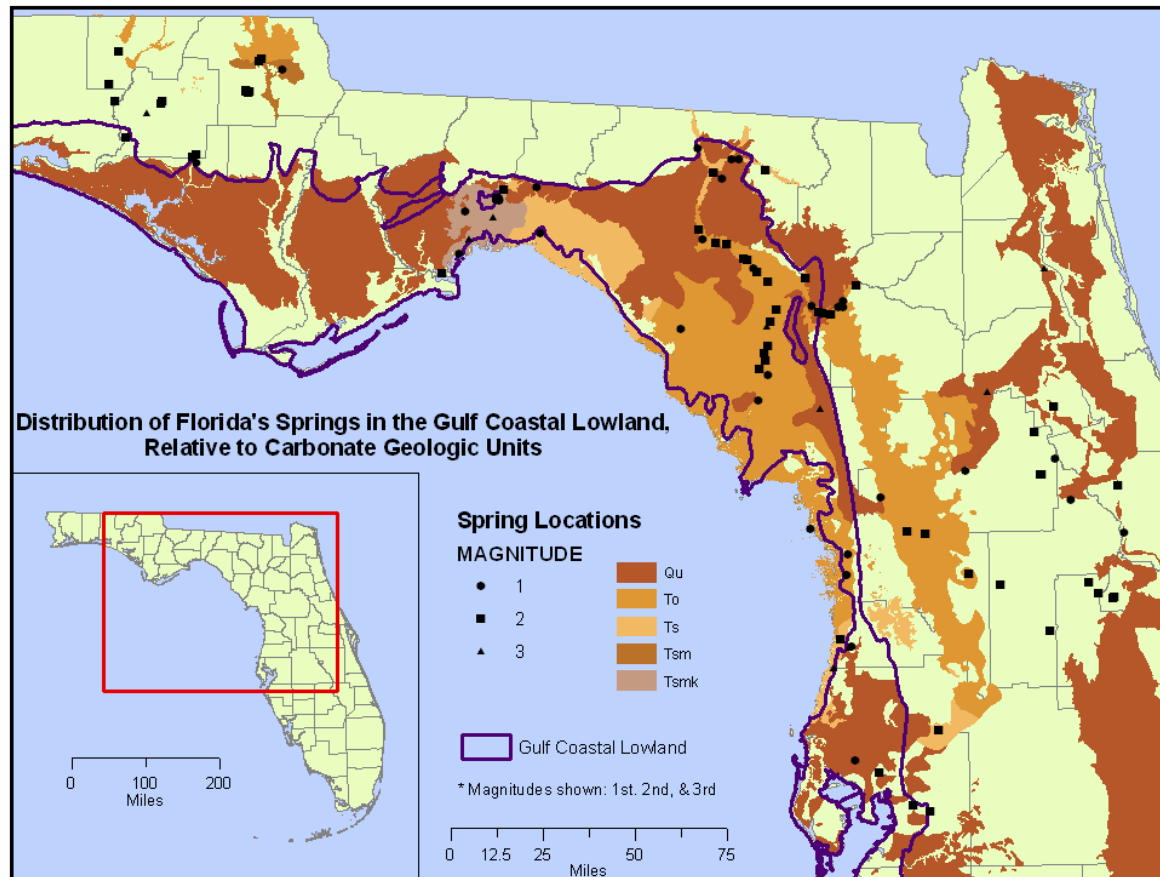


Figure 22: Locations of springs corresponding to the Gulf Coastal Lowlands and the Ocala Limestone

Figure 21 displays data that serve to aid in the examination of how the distribution of the sample of Florida's springs compares with the distribution of karst lands. Out of the total of 47 springs in the Gulf Coastal Lowland, 25 (or about 53%) correspond to the Ocala Limestone, 8 (or about 17%) correspond to the St. Marks Formation, and 5 (or 10.7%) correspond to the Suwannee Limestone. The overlap that is seen between springs in this region and those that correspond to the Ocala Limestone and the other carbonate units is also recognizable. As previously noted, 72.2% of the springs in the Gulf Coastal Lowland region resurge from the Ocala Limestone and about 28% issue directly from other carbonate units. The influence that karst terrain has on spring locations can be observed through visual appraisal of the spatial distribution of springs relative to the Gulf Coastal Lowland and the three geologic formations mentioned. This again is an indication of the importance of the karst landscape influence on spring development.

Several additional observations were also made with respect to the relationship between the geologic formations and the springs that resurge from these formations. The most noteworthy of these observations all correspond to limestone formations, thus further illuminating the relationship between area geology and the influence it exerts upon spring formation in Florida. As previously noted, the Ocala Limestone is associated with 39 springs, more than any other geologic formation, the Suwannee Limestone contains 11 spring resurgences (the second highest number in the database), and the St. Marks Formation and Undifferentiated Sediments each possess nine spring resurgences (Table 15). The Ocala Limestone contains the highest number of springs that do not generate a spring run (Table 15). The Ocala and Suwannee/Marianna Limestone

formations correspond to the two springs with the highest mean discharge values (Table 18). The undifferentiated sediments geologic formation also has one of the highest mean discharge values, as well as the second highest number of springs. The high mean discharge value, as well as the high number of springs, can be attributed to the fact that the sediment buries adjacent to carbonate geologic units. Groundwater resurging from the associated limestone units is possibly seeping through the undifferentiated sediments to eventually resurge on the land surface.

The data accumulated and discussed thus far seems to indicate that the springs studied as part of this research are for the most part associated with the limestone formations and karst terrain of the study area. This point is further illuminated by the point that the geologic formations that are characterized by carbonate units or are somehow associated with the carbonates, like the undifferentiated sediments, are most commonly associated with physiographic regions that contain the highest number of springs. Hence, this examination of Florida's springs in terms of geology and physiography supports the conclusion that majority of Florida's springs are located in regions characterized by karst terrain. More specifically, this phenomenon in fact imparts the prevailing influence on the spatial distribution of Florida's springs.

This is further illustrated by the fact that 69 of the 102 (about 68%) springs utilized in this study issue from carbonate geologic units (see table 16). Twenty-two springs (21%) resurge from unconsolidated sediments, which as previously noted, are probably related to the carbonate units in that groundwater discharges from the carbonates, and seeps through the sediments to eventually resurge on the land surface. Of the 102 springs utilized in this study, only eleven (10.7%) resurge from sandstone, or

geologically mixed units, and these springs may also have some relation to area carbonate units. The connection that has been observed between spring distribution and karst lands is related to observations made by Smith (2004) and Davis (1997). Smith (2004) discusses the influence of karst lands upon the degree to which the water quality of the Upper Floridan aquifer is influenced by its interaction with surface water, and states its dependency proximity to karst features. Davis (1997) discusses the role that karst plays in the effectiveness of fluid transfer between conduits and the surrounding matrix. Both discussions point to karst terrain as a strong influencing factor upon specific attributes and processes of the Floridan Aquifer. The research on Florida's springs also names karst terrain as the prevailing influence upon the distribution of Florida's springs, a collection of karst features that are part of the Floridan Aquifer.

Elevation & Distance to Coastline

Figure 22 shows the DEM mosaic and hillshade raster overlaid with springs data points. The hillshade/DEM combination offers a perspective that makes the elevation data easier to interpret visually. It has been noted in this figure that most of the springs points correspond to areas with low elevations. As was to be expected, the pattern of springs in the representative sample being distributed mostly across areas with low elevations reflects that of the entire population. This observation is also in keeping with those of Mylroie (1995), who, as previously stated, observed the trend of springs being located and generally low elevations.

Figure 23 displays the Euclidian distance raster layer overlaid with locations of Florida's springs. Initial visual appraisal of the spatial distribution of springs across the Euclidian distance raster does not indicate a relationship between the two.

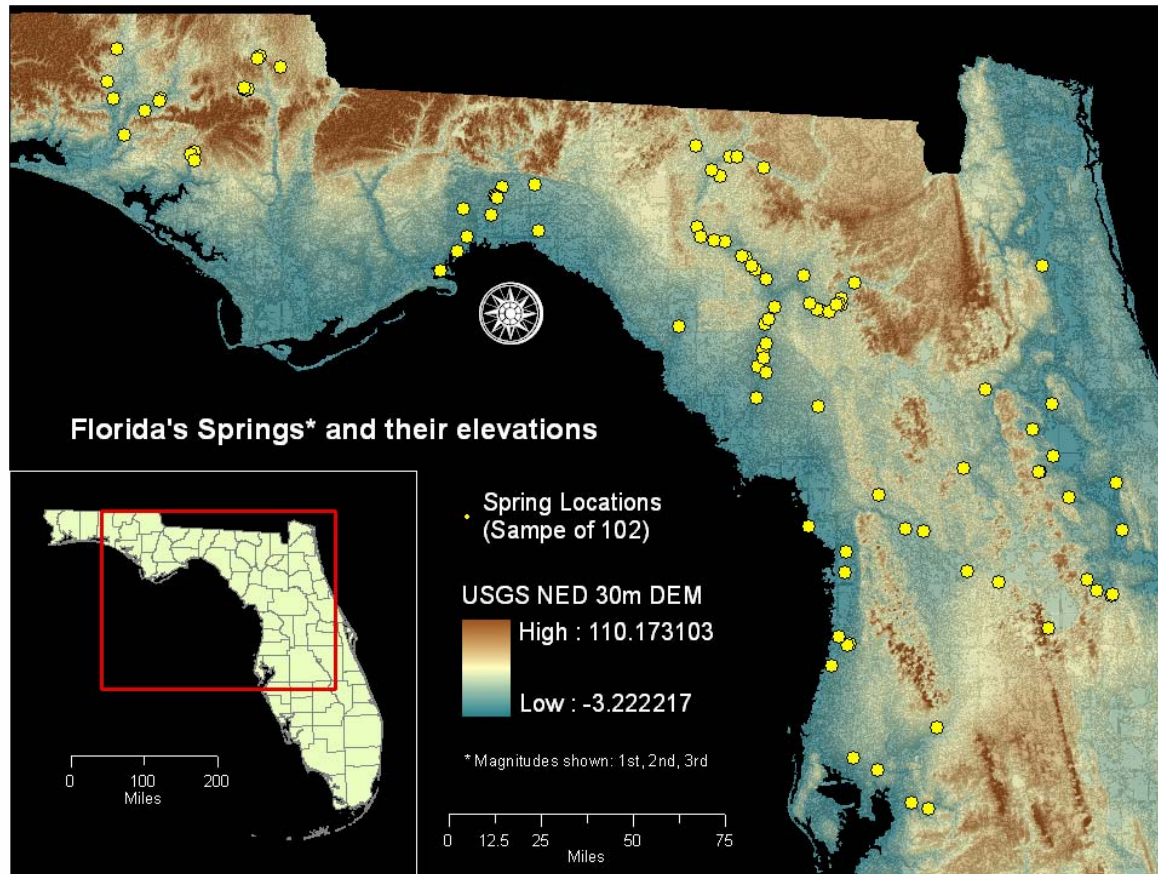


Figure 23: USGS 30m DEM overlaid with spring locations

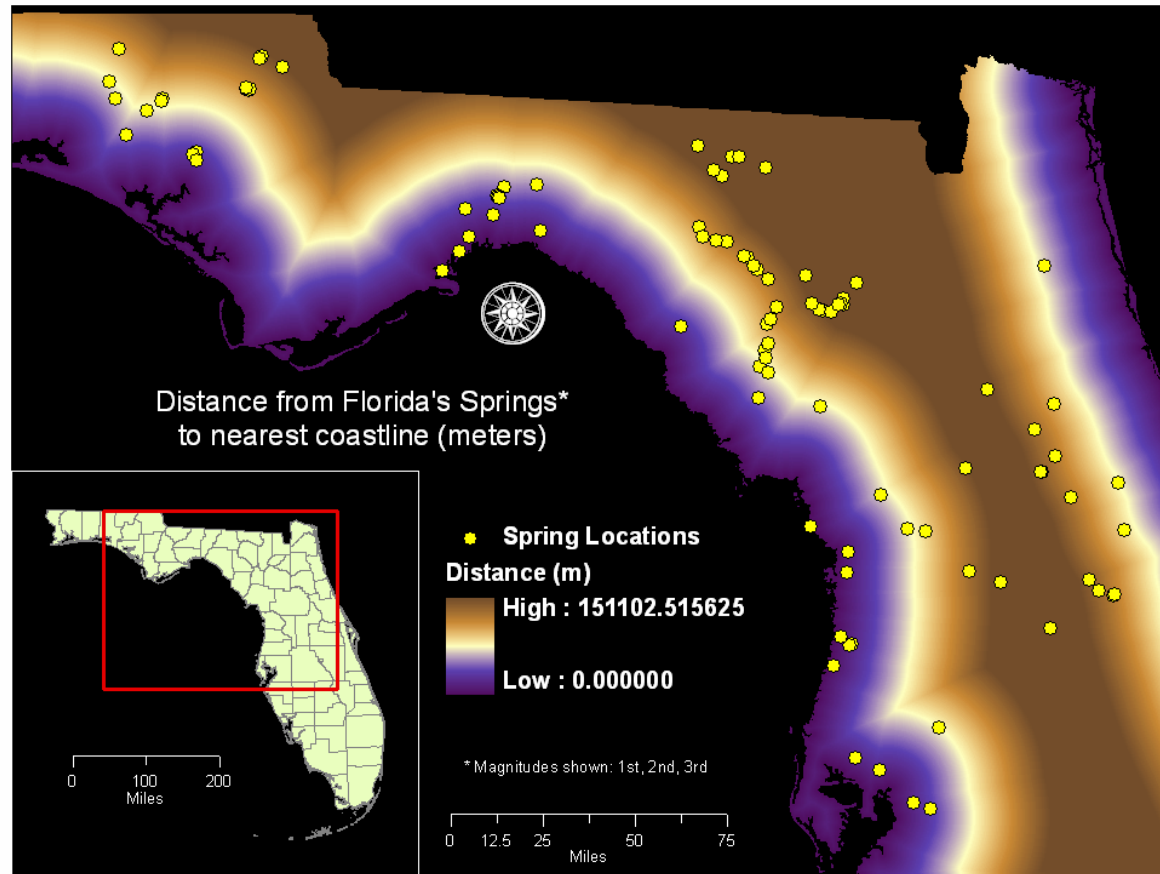


Figure 24: Euclidian distance to coastline overlaid with spring locations

Comparison of Noticeable Spring Clusters

There are several noticeable clusters of springs. Springs within each cluster are in such close proximity to each other and in such distant proximity to those in other clusters that these clusters can be observed and recognized visually. Attention has been given to noting how springs in each cluster are similar to each other but differ from those in other clusters. Attention has also been given to noting the similarities and differences as expressed through notable morphometric trends or patterns between the clusters themselves. For the sake of discussion, the clusters have been assigned numbers 1, 2 and 3. Figure 24 shows these clusters as they have been visually noted.

Cluster 1 is made up of 17 springs (16.6% of the springs used in this study) and is located near the western end of the panhandle. All of the springs in this cluster drain to either the Apalachicola or the Choctawhatchee Rivers. Of the 16 springs in this cluster that generate a run, 12 of them, or 75% are less than 1000 feet long. The close proximity of spring in this cluster to major rivers may be influencing the shorter spring run lengths as is the case with cluster 3 as well. Table 22 shows descriptive statistics for cluster 1.

PARAMETER	MIN	MAX	MEAN
DEPTH (FT.)	2.000	49.100	22.782
DISCHARGE (CFM)	5.700	165.600	51.134
ELEVATION (M)	5.727	26.317	15.353
POOL AREA (SQ. FT.)	900.000	90000.000	18902.294
DISTANCE TO COAST (MI.)	7.071	23.079	15.679
RUN LENGTH (FT.)	150.000	8448.000	1485.824

Table 22: Cluster 1 descriptives

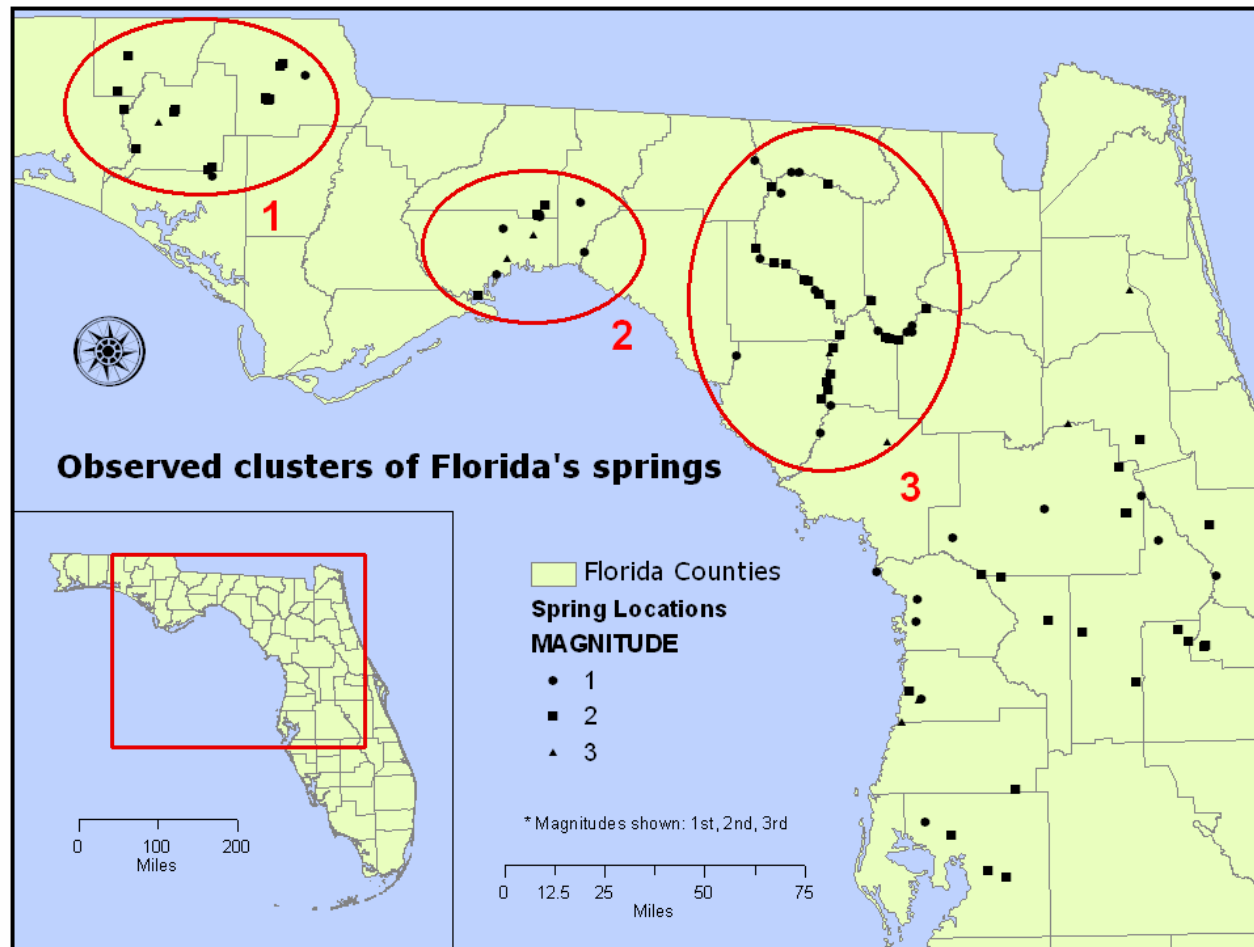


Figure 25: Locations of spring clusters

Cluster 2 is made up of 13 springs (12.7% of the springs used in this study) and is located in the panhandle just west of the big bend area. This cluster is characterized by most of its springs being very close to the gulf coast. They range from being less than a tenth of a mile to the coastline to 15.257 miles distant. Furthermore, springs in cluster 2 establish a shorter range of distances to the coastline than clusters 1 and 3. This constitutes the lowest mean distance to coastline out of the three clusters. Springs in cluster 2 also establish the lowest mean elevation, with values ranging from about three quarters of a meter up to 9.263 meters high. This is also a manifestation of the fact that they are close to the Gulf's coastline. It is also noted that cluster 2 has the longest mean run length of 39,600 feet, or about 7.5 miles. Table 23 shows descriptive statistics for cluster 2.

PARAMETER	MIN	MAX	MEAN
DEPTH (FT.)	6.000	185.000	36.062
DISCHARGE (CFM)	7.650	1153.500	221.796
ELEVATION (M)	0.725	9.263	3.394
POOL AREA (SQ. FT.)	1225.000	99225.000	25837.692
DISTANCE TO COAST (MI.)	0.093	15.257	8.235
RUN LENGTH (FT.)	50.000	39600.000	3889.231

Table 23: Cluster 2 descriptives

Examining cluster 2 based on its morphometry helps to explain some preliminary observations made on the springs it contains. All of the springs in cluster 2 either drain directly to the gulf via a small stream or drain to a lesser river such as the Wakulla or the Saint Marks Rivers, which ultimately flow into the gulf. This trend is very different from the other two clusters, especially cluster 3 in which all of the springs flow directly into a major river. As a result, it could be expected that run lengths of springs that drain

directly to the gulf will be longer than those which can drain to a nearby major river.

Springs in cluster 2 are also located in a coastal lowland region, accounting for their low elevation values. The morphometry of cluster 2 supports these expectations, and furthermore may be typical of springs that are in such close proximity to the coastline.

Cluster 3 is made up of 38 springs (37% of the springs used in this study) and is located at the big bend area. All of the 29 springs in this cluster which generate a run drain into one of three major rivers: the Suwannee, the Withlacoochee, or the Santa Fe River. Consequently, the longest spring run found in cluster 3 is only a mile long. Of the 29 spring runs corresponding to this cluster, 23 of them, or 79.3% are less than 1000 feet long. This trend is unique to cluster 3, as is the large percentage of springs within the cluster that all correspond to the same physiographic region. The Gulf Coastal Lowland underlies 36 of the 38 springs in cluster 3, or 94.7%. Table 24 shows descriptive statistics for cluster 3.

PARAMETER	MIN	MAX	MEAN
DEPTH (FT.)	5.900	150.000	30.090
DISCHARGE (CFM)	9.270	605.400	94.678
ELEVATION (M)	1.081	24.626	11.592
POOL AREA (SQ. FT.)	36.000	42750.000	12975.790
DISTANCE TO COAST (MI.)	8.388	43.735	29.093
RUN LENGTH (FT.)	25.000	5280.000	646.368

Table 24: Cluster 3 descriptives

These results are supported by the initial observations of the springs in cluster 3. They are all in very close proximity (one mile distant or less) to either the Suwannee, the Withlacoochee, or the Santa Fe River. Spring runs in this cluster discharge into these hydrographic features rather than draining all the way to the gulf coast. As a result,

springs in this area generate the shortest distance runs overall of any region in Florida. This trend places cluster 3 in very sharp contrast to cluster 2. These two clusters also differ significantly with regard to the range of elevations at which springs are located. Cluster 3 represents a wider range of elevation values because the springs contained within it are spread out across an area that also represents a wider range of distances to the coastline. This cluster reaches further inland and therefore also reaches areas of higher elevations than those found in the lower coastal lowlands that underlie cluster 2. Figures 25 and 26 display spring locations symbolized according to their run length attribute values, overlaid with geology and Euclidian distance to coastline. The trends in run length can be viewed here, particularly with regard to those discussed in cluster 3.

The remaining 33 springs spread across northern peninsular Florida are not grouped into any visually recognizable clusters. Examination of the morphometry of these springs does not yield any noticeable trends or patterns. Descriptive statistics for these springs are displayed in Table 25.

PARAMETER	MIN	MAX	MEAN
DEPTH (FT.)	4.000	170.000	21.230
DISCHARGE (CFM)	0.360	975.000	119.566
ELEVATION (M)	0.153	20.762	7.523
POOL AREA (SQ. FT.)	900.000	147312.000	19781.152
DISTANCE TO COAST (MI.)	0.876	51.914	22.471
RUN LENGTH (FT.)	15.000	89760.000	13481.030

Table 25: Descriptives for non-clustered springs in northern peninsular Florida

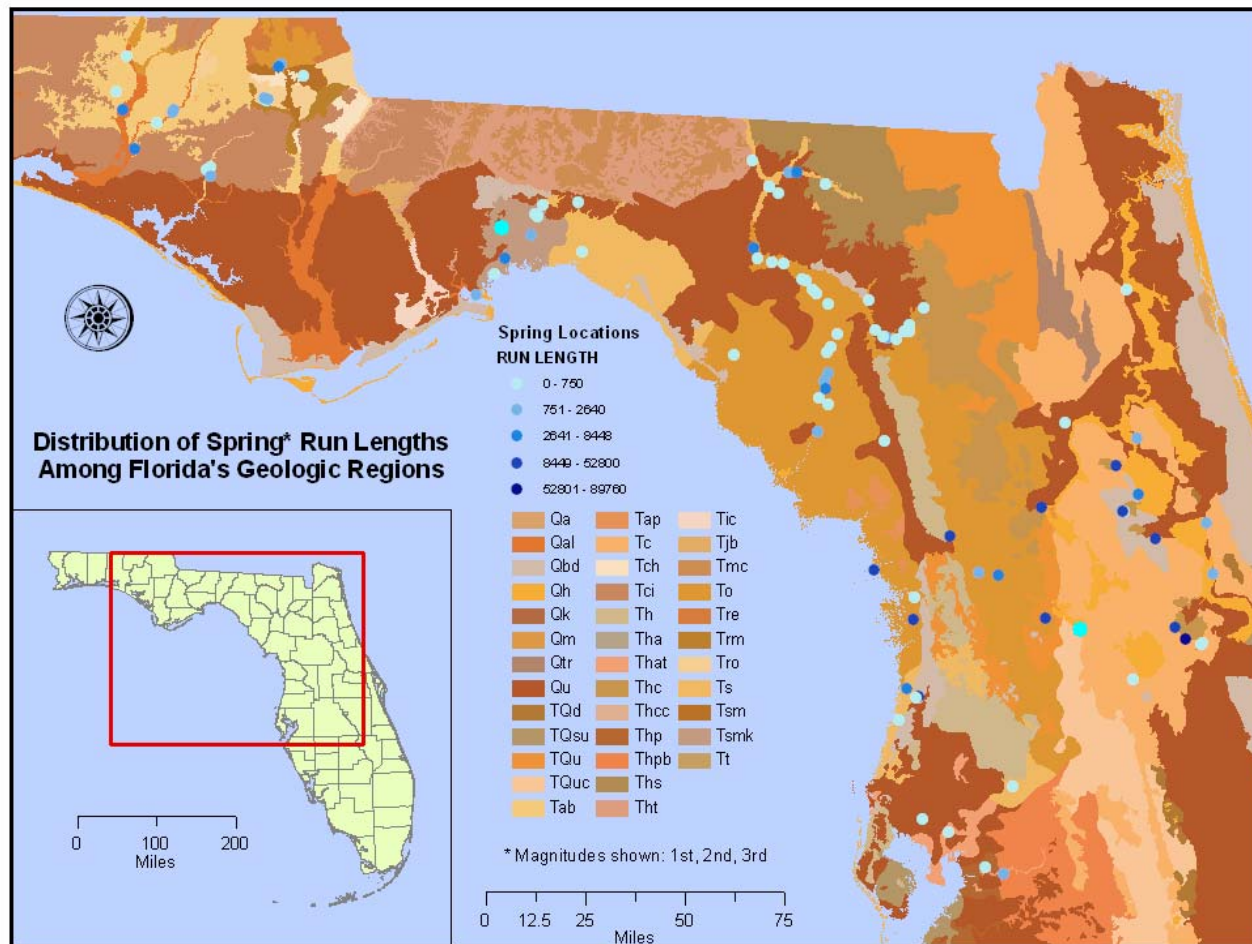


Figure 26: Spring locations symbolized by run length and overlaid with geologic formations

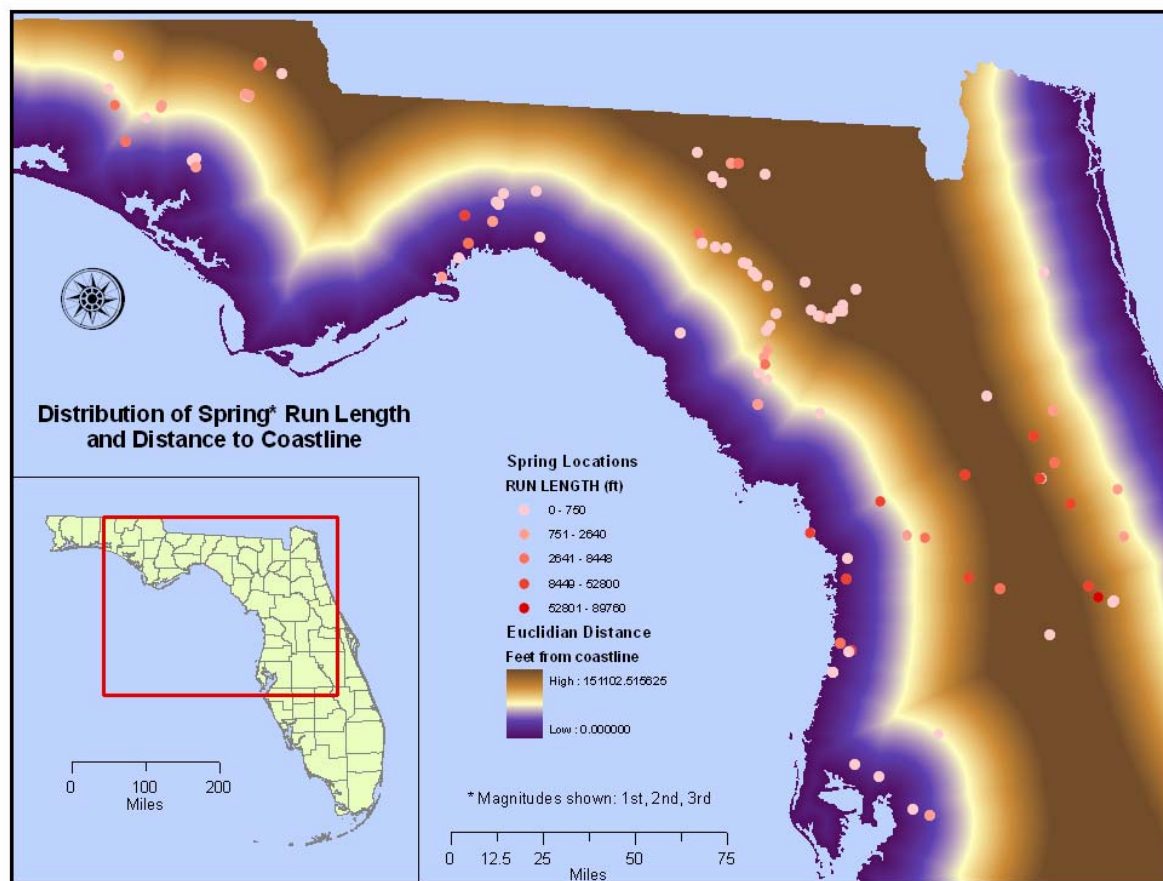


Figure 27: Spring locations symbolized by run length and overlaid with Euclidian distance to coastline

Evaluation of GIS as an asset to morphometric analysis

The overall usefulness of GIS as a research tool in this study has been evaluated. This evaluation considers how well ArcGIS 9.1 aided the user in exploring the descriptive elements of Florida's springs and how they relate to their locations. In order for any tool to be considered a valuable asset to a study whose main purpose is to conduct research on the morphometry of a spatial phenomenon, that tool must give the user some perspective of how the description of that phenomenon varies according to the location of each occurrence. The spatial dataset of Florida's springs that was created in this study represents a union of these two things. Implementing GIS in this study increased the overall efficiency of the tasks associated with compiling, creating and consolidating the final morphometric database. Acquiring values for the geographical parameters was expedited due to the automated functions of ArcMap 9.1. More generally speaking, this study finds that the fundamental capability of processing location and attribute information about a single dataset that is found with almost all GIS technologies is naturally suited to a morphometric study.

Chapter 6

Summary & Conclusions

This study has sought to examine a subset of Florida's springs based on their geographic locations and morphometric attributes. Research was conducted on two different scales to better facilitate this objective. Regarding the question of whether springs that exist in different geographic regions of Florida exhibit distinct morphometric patterns, those that have been examined in this study can be distinguished by observed trends among the attributes that have been used to classify them. On the broadest scale, the distribution of springs in Florida can be separated into two large areas: 1) those found across the panhandle or centered on the big bend area and 2) those found in the northern peninsula. The distribution of springs in both broad regions is most clearly seen when viewing the entire population of 754 springs, and is less apparent when only considering the representative sample of 102 springs. The latter region does not seem to contain any noticeable patterns or clusters. The distribution of springs in northern peninsular Florida was thereby excluded from the closer examination of spring clusters, and the three visual clusters noted in the Panhandle were discussed in detail.

Regarding the question of whether physiography and geology influence the locations of Florida's springs, it is concluded that the presence of karst terrain at the majority of the spring sites that were examined in this study is the prevailing factor that has influenced where springs have resurged in Florida. Even in physiographic regions that do not contain a great deal of limestone geologic formations, such as is the case with

the Western Valley, the springs that are located in the region are all associated with the limestone. The springs that are located within the Gulf Coastal Lowland have been demonstrated to be closely linked to the presence of carbonate geologic units within the region. The high percentage of springs that issue from karst terrain further testifies to the influence that such geology has upon the locations of Florida's springs. These trends have been observed at both scales in the study, with the observations of the representative sample of 102 springs essentially echoing those that were made regarding the entire population of 754 springs. The geography of Florida's springs is therefore heavily influenced by where karst geology is located.

Elevation also influences the distribution of springs in Florida. Spring sites are strongly linked to lower elevations, a fact that is supported by the vast majority of Florida's springs being located in the lowest quarter of the full range of elevations at which they occur. This trend is striking enough that it can be identified visually by viewing an appropriately symbolized terrain map of Florida that contains spring locations (see figures 11 and 23).

To further facilitate this examination and answer the question of whether physiography and geology influence the locations of Florida's springs, the springs were separated into spatially occurring clusters. There are factors influencing the existence of two smaller clusters of springs in the panhandle, and one larger cluster located at the big bend. All three clusters that were examined share a common geographic characteristic. Each cluster is comprised of springs that are either mostly or in part located in a coastal lowland region. In the case of cluster 2, the close proximity of these springs to the gulf coast accounts for the lower elevation values corresponding to them, and furthermore has

influenced the direction and distance over which their generated runs drain. This conclusion is in keeping with the observed trend of longer spring runs that flow directly to the gulf rather than into major rivers. This trend stands in sharp contrast to that which has been noted of cluster 3. Higher elevation values correspond to these springs, and the Ocala Limestone is very common in this region. A relationship exists between the Ocala Limestone and spring locations in the big bend area. This area is also characterized by the Gulf Coastal Lowland. The Ocala Limestone has influenced the higher number of springs found in the Gulf Coastal Lowlands, most of which discharge directly into the Suwannee, Santa Fe, and Withlacoochee Rivers. The close proximity of these rivers to the springs in the big bend area has influenced the high percentage of relatively short runs. Being a representative sample of Florida springs in general, the subset of 102 springs that was examined in this study was presumed to include mostly karst solution springs. The presumption is supported by the high number (about 66%) of the springs in the subset issuing from limestone formations.

Future research should seek to improve upon this study in several ways. First and foremost the sample size should be increased. The FGS currently has published data on all of the morphometric parameters tested in this study for an additional 450 springs in Florida. This data can be appended to the morphometric database that has resulted from this study using its methodology. Perhaps increasing the sample size will unearth and define the noticed patterns of the morphometric parameters of Florida's springs even further. Future research should also attempt to increase the utility of the NHD by appending as many of the missing spring runs as possible. It is recommended that arials consisting of 2004 or newer DOQQ's be used as a base layer for the digitizing of these

spring runs. The addition of this data would allow for additional methodology for determining and examination spring run orientation on a statewide scale. This study would also have benefited from a complete physiography dataset with coverage for the entire state of Florida. Conclusions regarding the influence that geology and physiography have had upon the location of spring clusters being in such close proximity to the gulf coast, could be further substantiated by having an official confirmation of the coastal lowland areas actually extending around the big bend and along the panhandle coastline as this study has conjectured.

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