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Application and Refinement of the Karst Disturbance Index in West Central, Florida

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Application and Refinement of the Karst Disturbance Index in West Central, Florida

by

Leslie A. North

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

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anthropogenic change, pollution, sinkholes, caves

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Dedication

This thesis could not have been completed without the loving and unwavering support of my friends and family. I would first like to dedicate this work to Jason Polk for lovingly supporting me without waver through the good times and the bad, the crying and laughter. You always listened patiently and provided words of encouragement regardless of how busy you were. Thanks Jas, I love you. I would also like to thank my loving parents, Ernest North and Patti Dorris, for supporting every imaginable facet of my education from preschool to a Master's. Finally, I would like to acknowledge "Maverick," starring Mel Gibson, without which I would not have been able to spend countless hours in front of the computer working on this document.

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Application and Refinement of the Karst Disturbance Index in West-central, Florida

Leslie A. North

ABSTRACT

A hierarchical and standardized environmental disturbance index, specifically designed for karst landscapes, was created by van Beynen and Townsend (2005). To assess the applicability of the index and provide recommendations for its refinement, the index was applied in four west-central Florida counties and interviews were conducted with local and state officials, community planners, and land resource managers. The karst disturbance index consists of 30 indicators contained within five broad categories: geomorphology, hydrology, atmosphere, biota, and culture. Data was readily available for most environmental indicators used to construct the index. Overall, levels of disturbance vary between the counties due to the level of urbanization, with the highly populated Hillsborough and Pinellas Counties having higher degrees of disturbance than less developed Pasco and Hernando Counties. While this result may seem obvious, the measure of disturbance using many indicators provides benchmarks of levels of disturbance that can be reassessed with time and highlights those aspects of the environment most in need of attention. Several minor issues arose during the testing: the need for broader indicator descriptions that encompass a variety of scenarios, a new water quality indicator, obsolete sinkhole data, and a lack of data for biota indicators. The lack of data for certain indicators suggests where future research efforts can be directed.

Chapter One

Introduction

The study of karst environments is a growing topic in the disciplines of environmental science, geology, and geography. While prior scientific research investigated disturbance of karst environments, it largely concentrated on isolated factors impacting the environment, such as the biotic, geomorphic, or economic value of a cave or sinkhole. However, to effectively assess threats to karst environments, a more holistic approach is needed, one which accounts for economic, scientific, and cultural factors. Until a recent publication by van Beynen and Townsend (2005), no such method of comparing, measuring, and contrasting karst disturbance existed. In their publication, a standardized and hierarchical environmental disturbance index was proposed, “to measure risk and serve as a standard tool for karst scientists to measure, compare, and contrast the degree of disturbance in their particular region” and “help organizations that have investigated protection of a karst region by evaluating the region’s disturbance level and identifying areas of the karst system that require more protection or more study,” (van Beynen and Townsend 2005, p. 101). Through use of their karst disturbance index (KDI), an accurate depiction of the disturbance caused by humans can be evaluated and measures can be taken to address the problem of karst disturbance.

Karst environments are significantly unique, fragile, and non-renewable resources that have substantial scientific, cultural, hydrological, recreational, mineralogical,

biological, and economic importance. Karst can possess deposits of water, minerals, fossil fuels, and also serve as tourist attractions. The diverse nature of karst often leads to a series of environmental problems, including drought, flooding, and surface collapse (Daoxian and Zaihua 1998). Furthermore, karst terrains are increasingly disturbed by physical, economic, and social processes, including, but not limited to, groundwater pollution, urban development, agricultural practices, quarrying, cave modification, and deforestation (Gunn et al. 2000).

The combination of karst sensitivity with high population density and expansion of urban centers in the Tampa Bay Metropolitan Area (TBMA) (*Figure 1*) creates an area prone to karst degradation and high frequencies of karst-related environmental problems (Tihansky and Knochenmus 2002). This area is defined by the United States Census Bureau to include Hernando, Pasco, Pinellas, and Hillsborough Counties (United States Census Bureau, undated) and serves as the study area for this research. To date, in the TBMA groundwater is contaminated by agricultural and urban waste (Trommer 1992; Jones and Upchurch 1993; 1996), springs have stopped flowing (Trommer 1992), lakes have dried-up (Stewart 1982), natural surface-drainage patterns are altered (Tihansky 1999), freshwater aquifers are saline (Tihansky 1999), and sinkholes are infilled (Wilson 2004). These occurrences take their toll on the area's karst terrain, but few studies have examined the amount or rate of disturbance that is occurring in the TBMA. Protecting the karst terrain and developing an index to assess the problem of karst disturbance is important due to the area's ever-growing population and its demands on the environment.

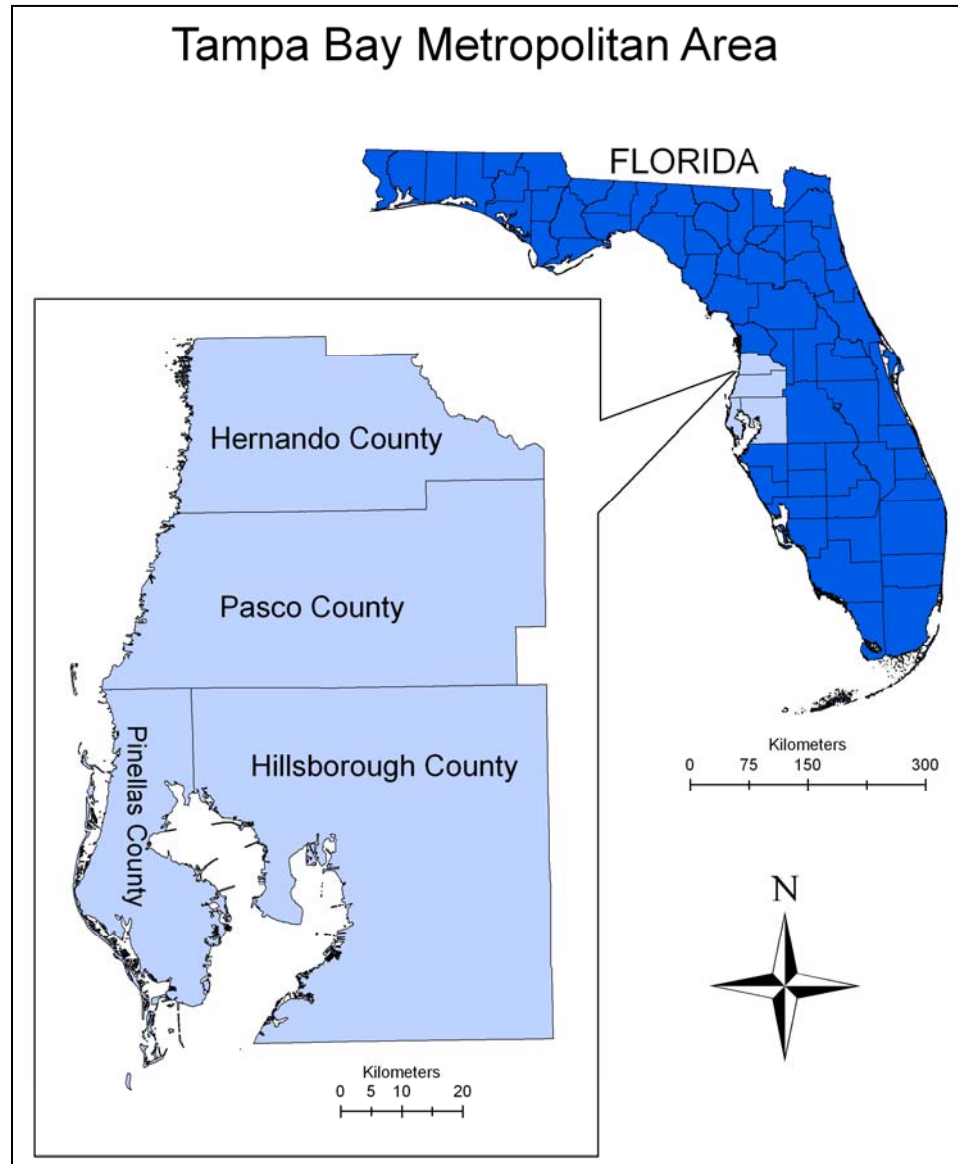


Figure 1. Map of TBMA. Includes Hernando, Pasco, Hillsborough, and Pinellas Counties.

Research Strategy

Problem Statement

While prior scientific research focused on isolated factors impacting karst environments, such as the biotic, geomorphic, or economic value of a cave or sinkhole, no method existed to holistically assess threats to karst environments. In other words, no

tool for evaluating human-induced disturbance analyzed each component of a karst system, including the destruction of karst biota, aquifers, bedrock, vegetation, and caves. Through the application of the KDI recently created by van Beynen and Townsend (2005), an accurate depiction of the anthropogenic disturbance to karst environments can be holistically evaluated and measures can be taken to address the human-induced impacts on karst. However, the applicability of the index and its ability to aid in karst management were, as of yet, untested.

Research Purpose

The purpose of this study was to evaluate the applicability of the KDI and make recommendations for its future refinement, by applying it to the TBMA, a study area with a mix of rural and urban land uses, state parks, and quarries. The detection of any indicators not addressed by the KDI, and also how indicators change between study areas, was also determined. To evaluate and improve the practical application of the KDI outside of academic communities, interviews were undertaken of local and state officials, community planners, and land resource managers, who may come to utilize the KDI. These individuals from varying background and professions each view disturbance to karst environments from a differing perspective. These differing viewpoints were obtained so recommendations could be made to improve the KDI in order to satisfy the needs of not only the scientific, but also the public and professional communities.

Research Questions

The research questions involved in this study included:

- 1) What is the level of karst disturbance in the counties comprising the TBMA?

- 2) Does the KDI comprehensively assess the amount of karst disturbance in these areas, and if not, what changes are needed to address areas of concern?
- 3) How useful is the KDI to resource managers?

Research Objectives

To address these questions, several objectives were needed:

- 1) To use the KDI to determine the amount of karst disturbance in the TMBA.
- 2) To determine if areas of concern exist where the KDI either does not accurately address or completely ignores certain areas of karst disturbance.
- 3) To address the areas of concern by making recommendations to refine the KDI's indicators and structure to increase its overall effectiveness.
- 4) To use personal interviews with county and state officials to determine the usefulness and applicability of the KDI in policy making.

Karst Environments

Karst, characterized by unique hydrologic and morphologic conditions, is considered the surficial expression of solution phenomena resultant from the interaction of water and carbonate rock masses (Bahtijarevic 1996). Literally meaning a bleak, waterless place (Sinclair et al. 1985), karst terrains were originally named for the Kras plateau region of western Slovenia and eastern Italy near the eastern shore of the Adriatic Sea (Veni et al. 2001; Rosenburg 2006). Modern geology glossaries define karst as an aggregate of characteristic landforms and subsurface features resultant from the solutional removal of rock or sediment (Quinlan 1970).

The geographic distribution of karst features reflects the geographic distribution of carbonate rocks and the diverse nature of karst landforms. Commonly found in humid, temperate environments that have abundant circulating water and warm, tropical environments possessing verdant vegetation and copious rainfall (Kochel et al. 1995), these terrains are formed by the dissolution of soluble rock, such as limestone, dolomite, and gypsum (Ford and Williams 1989). High rock solubility and secondary porosity are dominant in karst terrains, forming depressions, caves, springs, sinkholes, and enlarged openings that create subsurface drainage systems (van Beynen and Townsend 2005).

Karst covers approximately 12 percent of the world's land surface, providing habitable conditions for over 25 percent of the world's population (Ford and Williams 1989). Moreover, karst aquifers supply over 20 percent of the world's population with drinking water in regions including, but not limited to, the Caribbean Islands, southern China, Southeast Asia, Mediterranean Basin, United States, and Europe (Ford and Williams 1989). In the United States alone, 16 percent of the land surface is karst and 40 percent of drinking water supplies are obtained from karst aquifers (Veni et al. 2001; Karst Waters Institute, undated). In fact, 35 percent of all counties in the United States, 1144 out of 3211, have at least one cave within their boundaries (Culver et al. 1999). Some of the major karst features of the United States include the Appalachian Mountains, the Black Hills, the Guadalupe Mountains, the Edwards Plateau, and the Florida Lime Sinks (Culver et al. 1999). The most widespread karst region of the United States occurs in the Mississippian Age limestones of the Interior Low Plateau in Indiana, Tennessee, and Kentucky.

Evolution of Karst Terrains

During the late nineteenth and early twentieth centuries, Yugoslavian scientist Jovan Cvijic pioneered the first systematic study of the hydrology and geomorphology of karst (Bahtijarevic 1996). In 1893, Cvijic developed a model of karst evolution, which was later expanded by numerous karst scientists including, but not limited to, White (1970), Sweeting (1973), Lane (1986), Ford and Williams (1989), and Scott (2002). From these works, the complex nature and sensitivity of karst, in addition to the morphographic and morphometric aspects of karst analysis, are understood (Bahtijarevic 1996).

The evolution of any landscape is influenced by a balance of two key processes: vertical tectonic movements and erosion and deposition (Kaufmann 2002). In addition to these two processes, the development of karst landscapes, specifically, is dependent upon soluble carbonate rocks and slightly acidic water (Lane 1986; Ralston and Oweis 1999; White 1970). This predominant erosive process forming karst terrains is chemical weathering (White 1970). Porosity, the amount of water a rock can hold, and permeability, the ease in which water can flow through a rock, all impact this process (Kochel et al. 1995). Moreover, the structural orientation of the rock, vegetation of the environment, suspended objects within the waters flowing over karst landscapes, thickness of overburden materials, and the temperature of the water and atmosphere surrounding karst landscapes have a large effect on the development and evolution of karst landscapes (White 1970; Bahtijarevic 1996).

Karstification is an epigenic process driven by the hydrologic cycle (White 1970). The formation of a karst terrain begins as small, closed openings within rocks having a solubility component greater than 70 percent (Onac 2000). While karst landscapes may

form in evaporites such as gypsum, halite, and anhydrite, the most common rock varieties meeting this requirement are calcium carbonate (CaCO_3) rocks such as limestone or dolomite. As water descends through the atmosphere or through overburden material atop soluble rocks, it becomes slightly acidic as water molecules bind to carbon dioxide molecules (Bahtijarevic 1996; Ford and Williams 1989). These carbon dioxide molecules are derived from biologically generated carbon dioxide in decaying humus or atmospheric carbon dioxide absorbed in precipitation as it approaches the land surface (Bahtijarevic 1996; Ford and Williams 1989; White 1988). As the slightly acidic water passes over the soluble rocks a $\text{CaCO}_3\text{-CO}_2\text{-H}_2\text{O}$ reaction is stimulated, breaking CaCO_3 into HCO_3^- and Ca^{2+} (White 1988). During this dissolution process, the Ca^{2+} ion, the most important ion comprising carbonate rocks and subsequently the principal ion in the karstification process, is removed from the rock mass leaving behind small bedrock openings that typify karst landscapes (Onac 2000).

In time, the dissolution of the calcium carbonate slowly enlarges the small openings to create cavities within the rock. As carbonate dissolution continues, larger amounts of water enter the karst system, eventually producing sizeable interconnected underground flow systems that can change surficial drainage patterns and related landforms. Mechanical erosion by suspended materials in the water can accelerate this process (Bahtijarevic 1996; Ford and Williams 1989; White 1988). In short, “active karstification results in an increase in size and complexity of closed depressions with time” (Bahtijarevic 1996, p.2).

Assessment of Karst Disturbances

Karst features are highly susceptible to human influence. Removing tree cover, disposing of wastes improperly, excessive pumping of ground water, opening or closing cave entrances, quarrying, infilling sinkholes, and modifying surficial drainage patterns, just to name a few items, each negatively impact karst terrains. As regions grow in population, the building of roads, houses, and office buildings limits the amount of water reaching karst aquifers, and places unnecessary stress on groundcover (Zhou et al. 2005). Meanwhile, increasing quantities of water extracted from karst aquifers for industrial and municipal purposes, results in an imbalance in the hydrologic cycle, sinkhole generation (Tihansky 1999; van Beynen and Townsend 2005), and salt water intrusion (Arfib et al. 2000). Deforestation for the expansion of urban growth can increase flooding, sedimentation rates in caves, and turbidity in water (Harding and Ford 1993; Sauro 1993; Wood et al. 2002; van Beynen and Townsend 2005; Gunn et al. 2000).

In 2005, van Beynen and Townsend created a standardized and hierarchal karst disturbance index. Their index provides researchers with a tool to measure risk and to compare and contrast the degree of karst disturbance in a region. Prior to this publication, no method for holistically comparing, measuring, and contrasting karst disturbance existed. The elements of karst systems discussed in their article include geomorphologic aspects of surface and subsurface karst, soils, atmospheric conditions within air-filled caves, hydrologic components such as water quality and quantity, biota both above and below the ground surface, and cultural aspects of karst such as the stewardship of a karst region. The KDI provides justification for the need to evaluate each indicator, a method for assessing these indicators, and a rational for scoring each indicator. The essential

components of karst terrains which are addressed by the KDI are illustrated in *Figure 2*. Articles which narrowly discuss a single impact to karst environments and highlight the need for a holistic karst disturbance evaluation technique are discussed below.

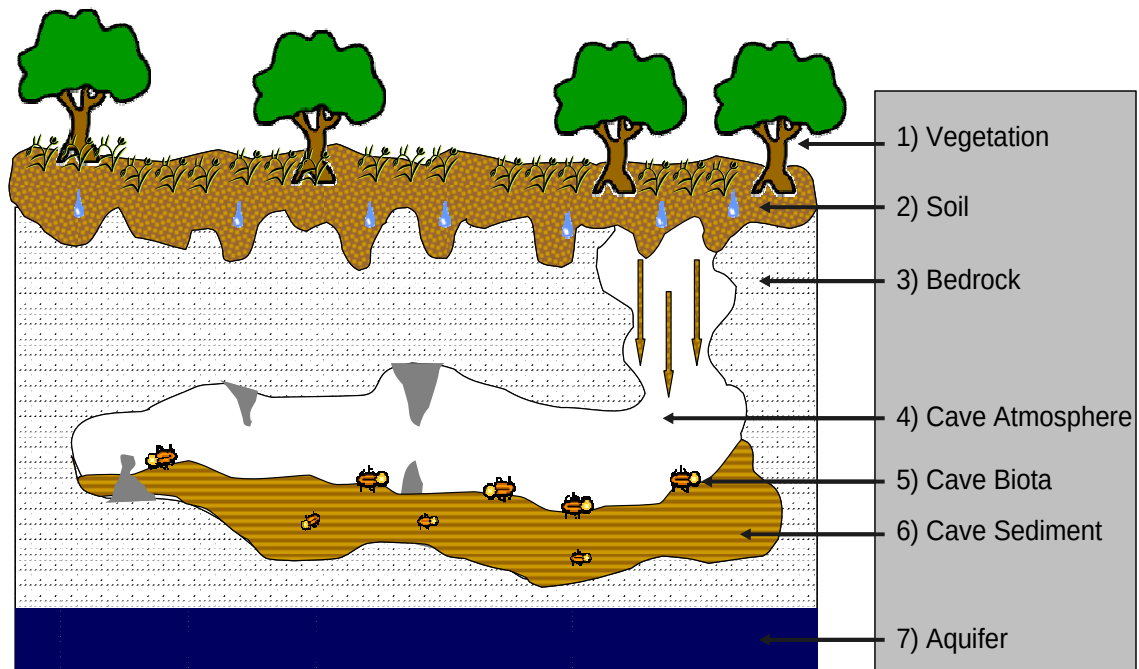


Figure 2. Karst features evaluated by the karst disturbance index. (Modified from Polk 2005).

Vegetation above cave systems prevents soil erosion and promotes karstification by providing CO_2 necessary for the creation of carbonic acid. Therefore, vegetation is an important component of karst systems (van Beynen and Townsend 2005). The removal of trees in karst landscapes disputes the natural evolution of karst (James 1993; Harding and Ford 1993), promotes surface erosion, increases flooding within caves, sedimentation rates in caves, and turbidity in water (Sauro 1993; Wood et al. 2002; van Beynen and Townsend 2005). A study performed by Harding and Ford (1993) on Vancouver Island, Canada, estimated the effects of deforestation, the susceptibility of karst to those effects, and vegetal regeneration success on karst after deforestation. The results of this study

showed that deforestation causes soil erosion, burning significantly increases soil erosion, and vegetal regeneration is unlikely without the presence of a highly developed epikarst. Similar effects of deforestation and agriculture were noted in the Italian Venetian Fore Alps by Sauro (1993) and Gams et al. (1993) in France and Italy, a karst region affected by both prehistoric and modern deforestation. Liu et al. (2003) illustrated how deforestation accelerates the decomposition rate of the soil organic matter necessary for the production of carbonic acid and buildup of soil in southwest China. Urich et al. (2001) revealed how protecting karst areas from deforestation while trying to respect the property rights of landowners and farmers can lead to ineffective karst policies and civil unrest. Jakal (2000) described how deforestation for farming purposes resulted in the rocky desertification of a lush Slovakian karst plateau. While each of these studies demonstrate how human actions can lead to deforestation, soil erosion, desertification, and accelerated decomposition of soil organic matter, each study only narrowly evaluates how a region's natural karst evolution can be disrupted by man.

Research focusing specifically on the percent decline of cave biota species richness or population density in the TBMA is nonexistent. Globally, however, Roth (1993) revealed that factors such as cave lights, clothes lint, skin flakes, and artificial entrances all negatively impact cave species. Gunn et al. (2000) documented the decline of cave biota from quarrying, agriculture, waste disposal, groundwater extraction, and tourism in England, while additional research shows the decline of cave biota from agricultural pollutants in groundwater (Wood et al. 2002). Boulton et al. (2003) demonstrated that Australian groundwater biota is negatively impacted by excessive groundwater pumping, while Schilthuizen et al. (2005) revealed a decline in unique

limestone-dwelling land snail communities in Sabah Malaysian Borneo, as a result of forest degradation.

Bats are the most commonly researched cave species. Richter et al. (1993), Petit (1996), Mann et al. (2002), and Parson et al. (2003), each illustrated that changing ambient conditions within caves, the destruction of bat feeding grounds, and bats being perceived as pests results in a decline of bat populations. Spanjar and Fenton (2005) and Martin et al. (2006) quantitatively measured the impact of cave gates and cave passage manipulation on bat colonies. Despite each of these studies comprehensively addressing local problems for their respective study areas, each still only narrowly focuses on specific aspects of cave biota disturbance in a localized geographic area.

The destruction of karst bedrock by quarrying and mining activities was first shown by Aw (1978). This work illustrated the destruction of archaeological artifacts and rare flora and fauna habitats in Malaysian Limestone Hills. Gunn and Bailey (1993) discussed the removal of rock from limestone quarries in Great Britain, while Goldie (1993) revealed that the same country removed karst pavements for gardens. A unique group of speleothems, groundwater, soil, and surface water in Sorbas, Spain is continually being impacted by gypsum quarries (Pulido-Bosch et al. 2004). Dewatering karst aquifers occurs throughout China in an attempt to protect coal miners from water intrushes (Li and Zhou 2006). Dunn and Gagen (1987) revealed how land surface development and quarrying is often responsible for both the destruction of sinkholes and production of large closed depressions known as quarry rock basins in the English Peak District. Wilson (2004) illustrated the impact vast urbanization in Pinellas County, Florida has on sinkhole formations, showing that more than 92 percent of sinkholes in the

county are infilled, while Sinclair et al. (1985) demonstrated a similar trend in the remainder of west-central Florida. Few other studies have addressed sinkhole problems related to the anthropogenic-induced change, with even less attempting to quantify sinkhole disturbance.

The degradation of the atmosphere above and within caves (Huppert et al. 1993; Pulido- Bosch et al. 1997; van Beynen and Townsend 2005), and also the compaction of cave sediment by foot traffic (Gillieson 1996), has a detrimental affect on karst environments and the biota whose survival depends upon preservation of these environments. Donahue (1990), Baker and Genty (1998), Craven (1999), Silverwood (2000), and Jeong et al. (2003) each illustrated the negative impact of cave visitors on speleothems caused by changing drip water chemistry and the atmospheric composition within caves. Villar et al. (1986) discussed the effects of increased evaporation, condensation corrosion, and desiccation resultant from cave tourist body heat, CO₂ respiration, and artificial lighting on cave environments, while artificial cave entrances have impacted glowworms in Glowworm Cave in Waitomo, New Zealand (Pugsley 1984). While these works illustrate some of the problems with anthropogenic cave disturbance, they do not provide a holistic approach at evaluating and managing the worldwide distribution of numerous caves and their associated problems.

Groundwater within karst landscapes faces several detrimental human practices. Crawford (1984), White et al. (1984), and Keith et al. (1997) revealed that sinkholes are often drainage points for stormwater, which thereby pollutes the aquifer. On the Kentucky Sinkhole Plain, Quilan and Ewers (1985) discussed the use of sinkholes as small landfills. This activity may pollute groundwater and disrupt natural drainage

through sinkholes by clogging of sinkhole bottoms. Urich (1993) observed the negative impact of rice cultivation practices and heavy pesticide and herbicide use has on karst waters in Bohol, Philippines. Drew (1996) documented how eutrophication resultant from effluent spraying and leaking septic tanks contaminate karst aquifers in Ireland, while Schindler (1978) and Memon et al. (2002) revealed that algal blooms in surface waters results from excessive phosphorus concentrations. Volatile organic compounds and non-aqueous phase liquids often pollute karst groundwater despite being deposited, either purposefully or accidentally, on the surface (Quilan and Ewers 1985; Loop and White 2001; Xie et al. 2002). Ford and Williams (1989) discussed the contamination of drinking water supplies in Olkusz, Poland after tailings pond collapsed. In west-central Florida alone, natural surface-drainage patterns are altered (Tihansky 1999), groundwater is contaminated by agricultural and urban waste (Trommer 1992; Jones and Upchurch 1993; 1996), select springs are no longer flowing (Trommer 1992), lakes have dried-up (Stewart 1982), and freshwater aquifers are saline (Tihansky 1999; Arfib et. al. 2000).

While all of the aforementioned studies touched briefly on the multitude of different karst disturbance issues found throughout the world, none holistically address karst issues. This is important because many karst areas suffer from disturbance to multiple karst features, requiring an assessment of disturbance using an approach that can evaluate each of the diverse features found in a well-developed karst landscape. As illustrated in many of the above studies, the fragmented approach of analyzing only select disturbances complicates the proper management of an interconnected karst system. Failure of the current literature to consistently acknowledge the widespread existence of karst landscapes and the commonality of problems associated with them creates a gap in

policymaking and management due to a lack of cohesiveness in strategies for both recognizing and addressing disturbance issues.

Chapter Two

Study Area

This study was conducted in west-central Florida's TBMA, which includes Hernando, Hillsborough, Pasco, and Pinellas counties (United States Census Bureau, undated) (*Figure 1*). The TBMA is a karstified landscape and is conducive for researching the applicability of the KDI for several reasons. First, the TBMA is comprised of four distinct counties of differing levels of urbanization within culturally defined geographic boundaries. Secondly, the TBMA provides a diverse mix of features, such as state parks and mining areas, thereby providing a more extensive testing of the KDI's indicators in a karst landscape. Lastly, the continuing growth and urbanization in the TBMA warrants an examination of both the level of karst disturbance and a method for assessing this problem to provide a foundation for future policy making and community development. The following section describes Florida's geology and karst, the karst of west-central Florida, and the features of each county comprising the TBMA.

Florida Geography and Climate

Florida is 719 kilometers long and 580 kilometers wide at its most distant points for a total area of approximately 170,270 square kilometers. More than 17,702 kilometers of rivers, streams, and waterways in Florida ranks it third in the country for land area covered by water. The St. Johns River is the longest river in Florida while Lake Okeechobee is the largest lake at 1,813 square kilometers. There are 1,717 kilometers of

beaches in the state. The highest natural point in Florida is Britton Hill in Walton County, with an elevation of 105 meters (Netstate 2006). The geographic center of Florida is located twelve miles northwest of Brooksville in Hernando County. Despite being Florida's second smallest county, Pinellas County is the most densely populated county in the state, containing more than 1,250 people per square kilometer (Pinellas County Government, undated (a)).

The climate of Florida is characterized by long, warm, humid summers and cool, mild, dry winters. In west-central Florida, average rainfall ranges from 102-153 centimeters per year. Approximately 60 percent falls during the months of June through September, while the driest months are November through February (Stankey 1982). Tropical storms can affect the area any time between early June and mid-November. The heavy rain associated with these storms causes increased dissolution of the area's limestone (Hyde et al. 1977). Extended periods of dry weather are most common in the spring, decreasing plant growth and karstification. Summer temperatures vary little from day to day and average 34° C. Winter temperatures vary greatly across the state, ranging from 21° C in Key West to 10° C in Tallahassee. Freezing temperatures occur an average of five to ten days a year as far south as Tampa (Vanatta et al. 1972). Relative humidity in the state is high, with a mid-afternoon average of 50-65 percent and a dawn average of 85-95 percent (Hyde et al. 1977).

The vegetation of west-central Florida consists largely of pine and saw palmetto flatlands, with patchy areas of salt-tolerant grassy marsh along the coastal portions of the state. Stands of turkey oaks occur on the area's sandy hills. Low hammock land with

heavy shrub growth is found near the region's lakes. These regions are distinctly different from the hardwood hammocks located in the eastern Florida (Abbott 1979).

Florida has five natural topographic divisions: the Central Highlands, the Tallahassee Hills, the Marianna Lowlands, the Western Highlands, and the Gulf Coastal Lowlands (*Figure 3*). The Central Highlands follow the crest of the Floridian Plateau. The division is highly diversified consisting of extensive plains, the highest hills in the state, large lakes with broad, low prairies surrounding them, and sandy soils derived from Pleistocene marine terraces. This area extends from the Georgia state line southward to Glades County, Florida. The Tallahassee Hills are a 40-kilometer-wide strip of plains surrounded by rolling hills along the Georgia state line. This division is underlain by the red sand of the Citronelle formation. The Marianna Lowlands lies between the Tallahassee Hills and the Western Highlands in the Florida panhandle and is completely underlain by Ocala limestone. This limestone crops out in many areas resulting in several springs, which contribute to the Chipola River. This area is largely occupied by the Flint River formation. The Western Highlands, located in the western-most portion of the panhandle, consists of a southward sloping plateau underlain by the Citronelle formation and high-level Pleistocene terrace deposits. This region also contains several large streams flowing through float-bottomed valleys and patches of rolling hills. Although the Gulf Coastal Lowlands border the entire coast of Florida, they are widest in southern Florida. This division largely contains level plains covered by light-gray sand, except in the southern portions of Florida where surficial deposits of Pliocene sandy limestone are prevalent. Past sea level stands left successive shorelines at 31, 21, 13, and 8 meters above the present sea level in the region (Cooke 1939; Cooke 1945).

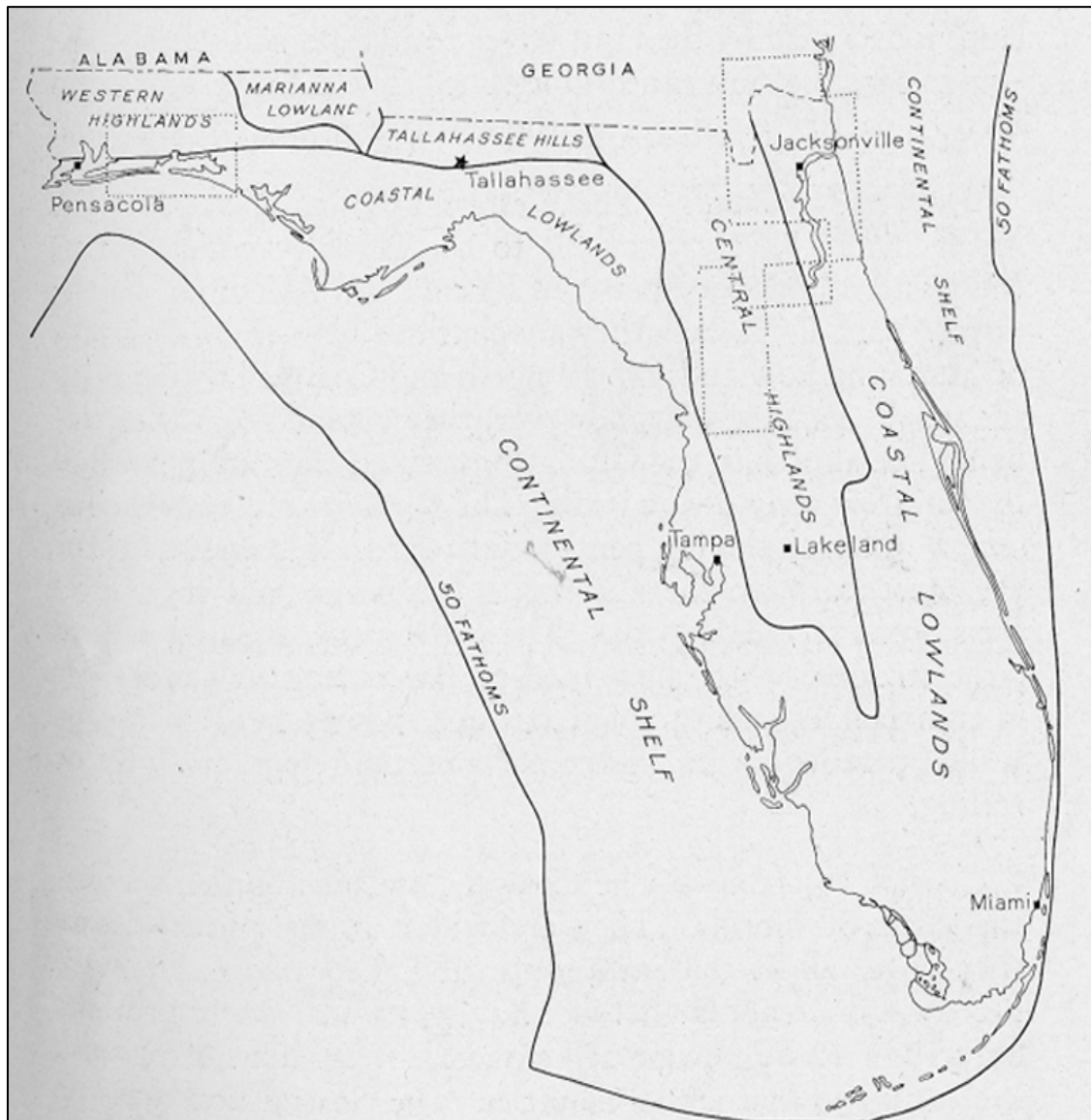


Figure 3. Topographic divisions of Florida. (Taken from Cooke 1945, p. 9).

Florida Geology and Geomorphology

During the Late Precambrian, approximately 700 million years ago, the Florida platform was a part of the West African continental margin near Senegal. During the Triassic period, tectonic forces rifted the platform from the margin (Wilson 2004). Over the next 200 million years, the Florida platform wandered to its present-day location.

This theory is supported by geochemical and geochronologic data correlating Florida basement rocks to the basement rocks of West Africa (Lane 1994; Randazzo and Jones 1997; Wilson 2004).

Several thousand feet of rocks of Precambrian, Paleozoic, and Mesozoic age comprise the basement rocks of Florida. Basalts, which formed during the Late Triassic and Early Jurassic periods, are the primary basement rocks of south Florida, while central Florida's basement rocks are 550 million-year-old granites. Middle Paleozoic sandstones, siltstones, and shales underlie northern peninsular Florida (Lane 1994).

Florida's state boundaries are considered to be the raised portion of a much larger carbonate rock platform capped by a mantling sequence of relatively insoluble sand and clay deposits (Scott 1988; Scott 1997; Tihansky and Knochenmus 2002). As shallow-water dwelling marine organisms die, they may be preserved as a calcium carbonate rock mass. Consequently, extremely gradual subsidence of proto-Florida's basaltic lava crust during the Cretaceous Period, approximately 144 to 65 million years ago, resulted in the early deposition of the state's carbonate platform. This platform is primarily composed of dolomite with varying amounts of interbedded evaporates in the northern two-thirds of peninsula Florida and limestone in southern peninsular Florida and the easternmost portions of the panhandle (Scott 1992). The platform extends 160 kilometers west of Tampa on the western edge and 4 to 6 kilometers southeast of Miami on the eastern edge (Lane 1994). During the Neogene Period, the Florida peninsula surfaced from the submarine environment (Smith and Lord 1997).

Florida has existed for millions of years as an alternately dry and submerged land mass (Cooke 1939). The dominant factors shaping the Florida peninsula and its

underlying platform are marine and coastal processes (Scott 1988). Fluctuations in sea-level and groundwater movement during the Cenozoic Era roughly 65 million years ago continuously altered the peninsula thereby creating the present-day configuration of Florida through sediment deposition and erosion (Cooke 1939; Scott 1997). Sea-level was significantly higher and lower than the present level during this time period; geologists believe that the Cenozoic sea-level in Florida fluctuated from several hundred feet above to several hundred feet below the present sea-level stands (Lane 1994). As a result, Florida was nearly entirely covered by carbonate sediments by the beginning of the Miocene Epoch even though deposition continued intermittently through the Pleistocene Epoch (Lane 1994; Miller 1997; Scott 1997). These Cenozoic sediments are represented by the Paleogene and Neogene-Quaternary sediment groups; the Paleogene sediment group is dominated by carbonate sediments, while the Neogene-Quaternary group is dominated by quartz sand, silt, and clay (Lane 1994). The oldest sediments exposed in the state are on the Ocala Platform in west-central Florida (Lane 1994).

Figure 4 illustrates the age and location of the state's geologic units.

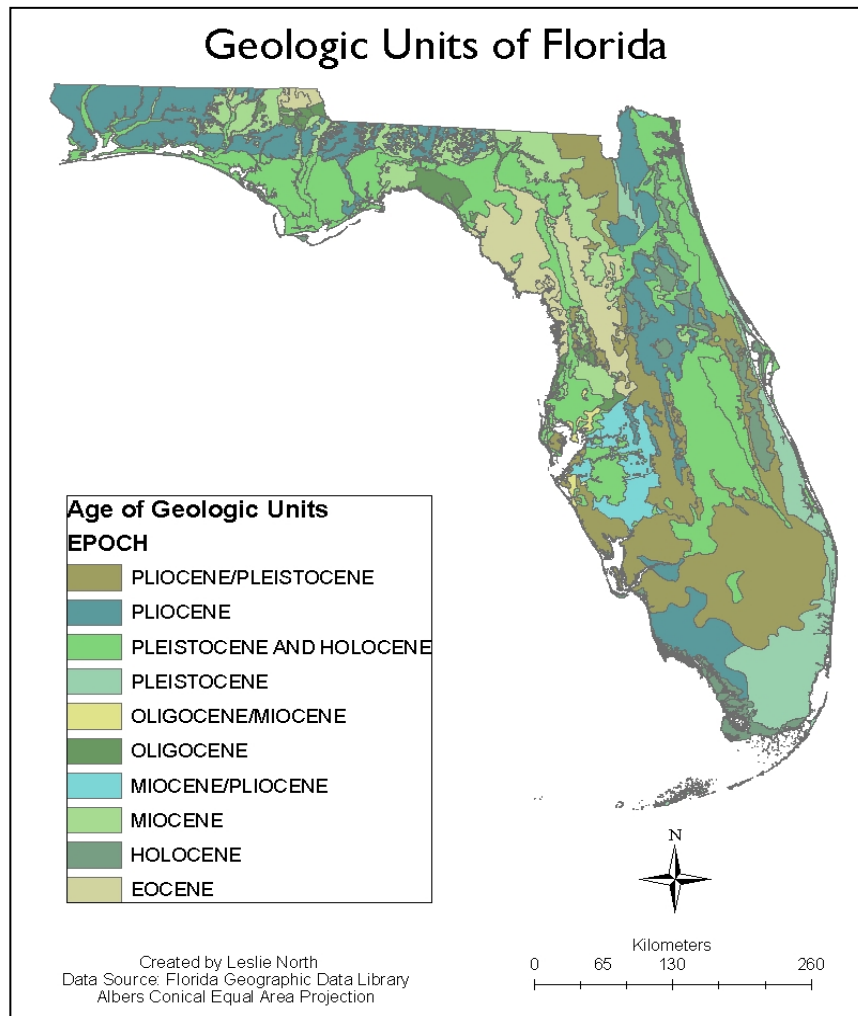


Figure 4. Geologic Units in Florida.

Siliciclastic deposition dominated in the Middle Miocene Epoch and continued until the Late Miocene Epoch not only from fluctuations in sea-level, but also from the Appalachian Mountains (Lane 1994; Randazzo and Jones 1997). During the mid-Cenozoic erosion of southern portions of the mountain chain greatly increased as the chain was uplifted. The eroded siliciclastic sediments filled in the Gulf Trough and eventually covered the Florida carbonate platform, producing an area overlain by siliciclastic sediments of various thicknesses and permeabilities (Lane 1994) and a spine

of clayey sands on the peninsula (Wilson 2004). The siliciclastic sediments appear in the early Miocene in northern Florida and the mid-Miocene in southern Florida; however, rivers and longshore currents continued to transport sediment from the coastal plain surrounding the mountain chain into Florida through the Pleistocene Epoch (Lane 1994). Due to this siliciclastic cover, the Florida platform only has a handful of bare karst exposures, these limited to coastal zones and areas of cover perforation. Moreover, Florida's relief "has the general characteristics of covered karst with closed depressions developed partially or entirely in siliciclastic cover" (Bahtijarevic 1996, p. 2).

Glaciation during the Pleistocene Epoch of the Quaternary Period approximately 1.8 million to 10,000 years ago dramatically increased the state's land area, while low sea-level stands resulted in a fresh-water table lower than present day (Cooke 1939; Cooke 1945; Lane 1994). Surface water features such as springs and lakes were less copious while only hardwood trees and dry-tolerant grasses flourished giving Florida the appearance of an African savanna during this time. During Pleistocene interglacial periods, when Florida consisted of islands, most of the state's modern topographic features were developed under the shallow seas. After surficial sediments were deposited, waves and currents eroded the previous epochs' formations, redistributing the eroded sediments over the underlying limestones. As the seas retreated once again, shore waves and near-shore currents eroded relict scarps and created sand ridges including, but not limited to the Cody Scarp, Brooksville Ridge, and Lake Wales Ridge (Lane 1994).

The development of Florida's Pleistocene landforms was influenced by karst processes in the Eocene, Oligocene, and Miocene Epochs. Prior to the Pleistocene, groundwater flowed through Florida's limestones dissolving conduits and caverns.

Karst activity in the Pleistocene Epoch resulted in the collapse of these caverns and the formation of sinkholes; these sinkholes remain today as lakes. Moreover, karst processes lowered the state's limestone bedrock, forming dissolution valleys, such as the Western and Central Valleys of the central peninsula (Lane 1994).

Table 1 summarizes Florida's Tertiary geologic formations, the most significant formations in the evolution of the state's present-day karst. The Avon Park limestone, of Eocene age, is the oldest formation exposed at the surface; it crops out in west-central Florida's Citrus County. The Pliocene deposits, which lie close to the surface in nearly all parts of Florida, are divided into seven contemporaneous formations. Six are marine or partly estuarine (Cooke 1939; Cooke 1945).

GEOLOGIC FORMATIONS IN FLORIDA (CONT.)

TERTIARY SYSTEM					
PLIOCENE SERIES	Deformation, tilting, and emergence.				
	Alachua formation (terrestrial, of Hemphill age).	Bone Valley formation (estuarine, of Hemphill age).	Buckingham marl (marine).	Caloosahatchee formation (marine).	Charlton formation (estuarine).
MIOCENE SERIES	Erosion interval.				
	Duplin marl (marine, of late Yorktown age).				
OLIGOCENE SERIES	Erosion interval during early Yorktown time.				
	Alum Bluff group: Shoal River formation (marine).				
Eocene SERIES	Chipola formation (marine).				
	Hawthorn formation (marine).				
PALEO- CENE SERIES	Tampa limestone (marine, of Anguilla age).				
	Erosion interval.				
Pleistocene SERIES	Suwannee limestone (marine).				
	Flint River formation (littoral, of Antigua age).				
Pleistocene SERIES	Erosion interval.				
	Byram limestone (marine, of late Vicksburg age).				
Pleistocene SERIES	Marianna limestone (marine, of early Vicksburg age).				
	Erosion interval during Red Bluff time.				
Pleistocene SERIES	Ocala limestone (marine, of Jackson age).				
	Erosion interval.				
Pleistocene SERIES	Avon Park limestone (marine, of Claiborne age).				
	Tallahassee limestone (marine, of Claiborne age).				
Pleistocene SERIES	Lake City limestone (marine, of Claiborne age).				
	Erosion interval.				
Pleistocene SERIES	Oldsmar limestone (marine).				
	Salt Mountain limestone (marine, of Wilcox age).				
Pleistocene SERIES	Cedar Key limestone (marine).				
	Porters Creek formation (marine, of Midway age).				

Table 1. Tertiary System Geologic Formations in Florida. (Taken from Cooke 1945, p. 18).

Florida Karst

Limestone and dolomite almost entirely underlie Florida. The state's depositional history and infilling processes resulted in a region composed of varying thicknesses of sand and clay deposits. Florida's warm climate, plentiful precipitation, low relief, and multiple Pleistocene sea-level changes of 100 meters or more allows for widespread limestone dissolution. Recrystallization, replacement, extensive dissolution, and cementation of the platform's carbonate-evaporite sequences, produced a karst-dominated topography containing extensive dolines, springs, disappearing streams, caves, and internal drainage networks (Lane 1986; Randazzo and Jones 1997; Wilson 2004). Most of the state's karst-dominated regions correlate with areas of unconfined and semiconfined conditions of the Floridan Aquifer. Karst landforms are commonly well developed and pronounced in these regions. Geographically, this area covers most of central Florida and portions of north-central Florida (Bahtijarevic 1996).

Sinkholes are the most common and easily recognized karst landform in Florida, with west-central Florida having the highest frequency of these features. Chemical weathering is the primary cause of this land subsidence, with dissolution preferentially occurring near recharge areas and saltwater/freshwater coastal mixing zones. Of these two areas, recharge zones are most influential for sinkhole development (Upchurch and Randazzo 1997). However, because of increased groundwater use and urban development in Florida, sinkholes occur more frequently in these areas. The most common sinkhole varieties in Florida are collapse and solution sinkholes, although multiple stages of karstification in the state have resulted in many sinkhole types with varying ages and degrees of development (Tihansky 1999). Many alluvial sinkholes, the oldest of Florida's

sinkholes, are partially filled with marine and wetland sediments (Wilson 2004). Modern sinkholes operate as direct pathways of groundwater contamination; for this reason, sinkholes are often viewed as cheap and convenient disposal sites.

The limestone of Florida is honeycombed with caverns. However, the water table is generally so high that most cave passages are submerged. The Florida Caverns State Park north of Marianna is an exception, which includes twelve connected rooms highly decorated with small stalactites. Significantly smaller and less decorated dry caves are found in northern west-central Florida's Withlacoochee State Park (Cooke 1939). These caves are formed by chemical and structural processes (Brinkmann and Reeder 1994).

Karstification plays a significant role in the hydrogeology of Florida. The state's karst drainage is characterized by sinkholes, springs, caves, disappearing streams, and underground drainage channels (Wilson 2004). Soils and rocks with high permeabilities exist at or near the land surface across most of the state. Fractures, fissures, and bedding planes in Florida's carbonates are potential zones of weakness, which concentrate groundwater flow creating sinkholes and springs as dissolution of the rock mass intensifies (Scott 1992; Lane 1994; Wilson 2004). Approximately 95 percent of central and western Florida's lakes are solution-based lakes occupying the basins formed by this dissolution and subsequent lowering of the land surface as overburden materials settled into the underlying limestone cavities (Wilson 2004). These lakes generally have the physical characteristics of sinkholes including steep sloping sides, no surface stream input, and circular outlines (Lane 1986). Aquifer water levels, which change in response to precipitation, control the water level of these lakes and many of the state's streams (Lane 1994; Wilson 2004).

Five principal aquifer systems are present in Florida: the Floridan aquifer system, the Intermediate aquifer system, the Surficial aquifer system, Biscayne aquifer system, and the Sand and Gravel aquifer (Florida Department of Environmental Protection, 2006a). *Figure 5* illustrates the locations of these systems. The Surficial aquifer system is a predominantly sand aquifer composed primarily of Pliocene-Holocene unconsolidated siliciclastics. This system encompasses any undefined aquifer appearing at the land surface (Tihansky and Knochenmus 2002; Wilson 2004). The shallow Sand-and-Gravel Aquifer and Biscayne Aquifer supply drinking water in the west and south, respectively. The Intermediate aquifer system of southwest Florida consists of interbedded siliciclastics and carbonates. This system is completely buried by shallower aquifers or confining units. Miocene sediments form the confining unit of the aquifer system, which separates the Surficial and Floridan aquifers when siliciclastic units of the Hawthorn Group are present (Tihansky and Knochenmus 2002). The Floridan aquifer system, the most productive system in the region, occurs throughout the subsurface of Florida. This system is divided into the Upper and Lower Floridan aquifers, which are separated by a confining unit, and includes portions of the Cedar Keys Formation, Oldsmar and Avon Park formations, Ocala Limestone, and Suwannee Limestone (Miller 1986; Bahtijarevic 1996; Scott 1997). Groundwater recharge occurs at varying rates over approximately 55 percent of Florida as precipitation infiltrates the sediment lying atop of these aquifers (Scott 1992; Wilson 2004).

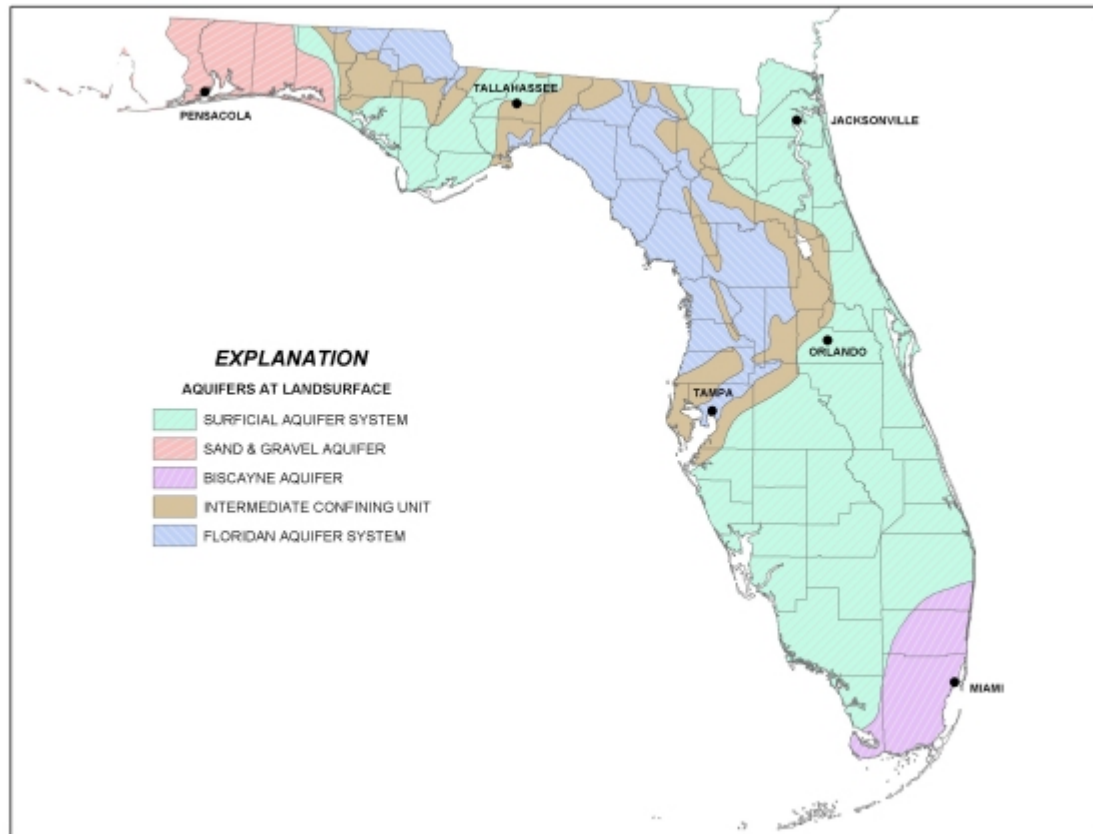


Figure 5. Florida's Aquifer Systems. (Florida Department of Environmental Protection (FDEP) website, taken on 10/20/06).

Karst features evolve in response to changing hydrologic conditions over geologic time. Moreover, the geology and geomorphology of Florida controls the distribution of the state's springs (Scott et al. 2002). Although many of Florida's coastal springs formed in areas unsuitable for present-day formation (Tihansky and Knochenmus 2002), karst springs generally occur where soluble rock and low surface elevations are present to allow for the flow of groundwater at the surface. The springs of Florida fall into two categories, seepage springs, forming where the ground stands lower than the water table, and the more common artesian springs, in which flow comes from a distant source through underground channels that lie at a lower level than the outlet (Cooke 1939).

Florida had over 700 known springs, 33 of which were first-magnitude springs with a flow of more than 100 cubic feet per second, as of 2004. Each major spring in Florida discharges from the Floridan Aquifer (Scott et al. 2002).

West-Central Florida Karst

West-central Florida is comprised of Citrus, Sumter, Hernando, Pasco, Pinellas, Hillsborough, Sarasota, and Manatee Counties (*Figure 6*) (US Geological Survey, 2004). The karst terrains of the region are typified by closed depressions overlain on relict late Pliocene and Pleistocene marine terraces (Bahtijarevic 1996). The development of karst in west-central Florida is controlled by lithology, the movement of groundwater, degree of dissolution of carbonate bedrock by chemically aggressive water, thickness and composition of overburden material, and sea-level. The area, which lies within the Gulf Coastal Lowlands physiographic unit (*Figure 3*), is largely characterized by discontinuous ridges separated by broad valleys. This physiographic unit, which is at the 100-foot contour line, extends inland at variable distances within west-central Florida and consists of plains representing four marine terraces: Wicomico terrace, Penholoway terrace, Talbot terrace, and Pamlico terrace. These terraces remain in nearly their original condition over large portions of the region, but are modified by underground solution and surface erosion in select areas. Within the Gulf Coastal Lowlands are well drained relict sand dunes and hectares of wet pastureland, resulting in an area covered by pine forests and an undergrowth of saw palmettos. These areas are interspersed with cypress swamps in the low, poorly drained sands of the region (Cooke 1939).

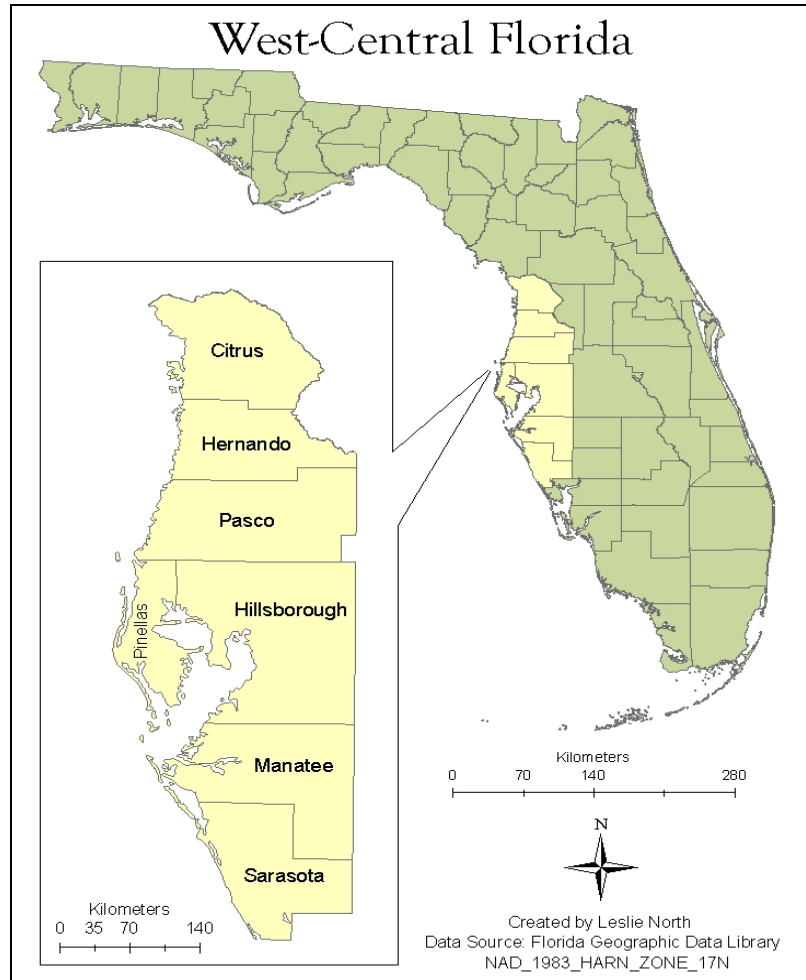


Figure 6. Counties Comprising West-Central Florida.

The carbonate sequence of west-central Florida is comprised of the Oldsmar and Cedar Keys Limestones, the Avon Park Formation, the Ocala Group, Tampa Limestone, and the Suwannee Limestone (Trommer 1987). The Cedar Keys formation is a 550 feet thick hard cream-colored limestone deposited in the open ocean. Oldsmar limestone of Wilcox age is predominantly limestone, but contains some gypsum and chert; it has a thickness ranging from 137-366 meters and was deposited in the open ocean, far away from land. The Avon Park formation is a cream-colored chalky limestone with a thickness ranging from 15-91 meters that was deposited onto a completely submerged

Floridan Plateau receiving little sand and clay (Stewart 1968). The Ocala limestone is a pure white to cream colored Jackson age limestone with an approximate thickness of 122 meters. The texture of this limestone is commonly granular, but parts are converted into hard, compact rock by the deposition of travertine or calcite. As little as four-tenths of one percent of impurities is found in this limestone facilitating the solution of the rock. The Miocene-aged Tampa Limestone is a hard and dense, sandy white to light-tan fossiliferous limestone (Stewart 1968). This limestone is approximately 80 feet below the land surface in Pinellas County and contains numerous large solution channels with large storage capacities (Heath and Smith 1954). The Late Oligocene-aged Suwannee Limestone immediately underlies the Tampa Limestone. It is a 15-30 meter thick, yellow-colored, hard and resonant limestone containing approximately ten percent silica impurity (Cooke 1945; Bahtijarevic 1996). Hernando County contains the second largest outcropping of this limestone. The Tampa and Suwannee Limestones are the largest contributors of water in Pinellas, Pasco, and Hillsborough Counties (Stewart 1968).

The Miocene Hawthorn Group, characterized by low relief, sandy clay interspersed with calcareous rock, overlies the area's carbonate sequence (Cooke 1945). This group contains beds of discontinuous, low permeability sand, making it a poor producer of water. An unconsolidated and undifferentiated unit of quartz sand, clay, phosphate, peat, and shell deposits of Pleistocene age lies above the Hawthorn Group in thicknesses ranging from 9-60 meters (Heath and Smith 1954). This unit retards groundwater flow into and from the underlying limestone (Heath and Smith 1954) and established distinct geomorphic regions with varying karst features throughout west-central Florida (Tihansky and Knochenmus 2002).

Karst features in west-central Florida include sinkholes, springs, caves, subsurface drainage networks, and heterogeneous aquifers. Florida's underlying rocks are confined by varying amounts of clay positioned at the base of undifferentiated surficial deposits. However, in west-central Florida, sinkholes breach these clay deposits revealing the underlying carbonate rocks (Trommer, 1987). Accordingly, in comparison to the remainder of the state, this region has the highest frequency of sinkhole activity. Moreover, the majority of karst features in west-central Florida are limited to the upper 91.44 meters of the land surface (Tihansky and Knochenmus 2002). As such, this region's karst is generally classified into four zones based on the prevalence of three sinkhole types: dissolution sinkholes caused by chemical erosion of the carbonate bedrock, cover-subsidence sinkholes formed as overburden material infill subsurface cavities, and abruptly formed cover-collapse sinkholes (Sinclair et al. 1985).

In the northern portions of west-central Florida, dissolution sinkholes result from the rapid movement of precipitation into the subsurface and dissolution of a carbonate mass overlain by highly permeable sediments 0-9 meters thick. The central portions of the region have thicker and less permeable clayey overburden material approximately 9-61 meters thick, resulting in the formation of cover-subsidence and cover-collapse sinkholes (Sinclair et al. 1985). Overburden material is typically greater than 61 meters thick and consists of cohesive sediments interlayered with carbonate rock in the southernmost sections of west-central Florida so sinkhole formation is uncommon.

More than one aquifer system, correlating with undifferentiated clay and sand deposits, occurs in west-central Florida. The Upper Floridan aquifer ranges from 183-427 meters and is found in the region's Ocala and Suwannee Limestone. The bottom of this

aquifer system forms where vertically and horizontally persistent evaporites, such as gypsum and anhydrite, are present within the lower Avon Park Formation (Wolansky and Garbade 1981; Ryder 1985). These evaporites underlie the Upper Floridan aquifer throughout west-central Florida, forming the middle confining unit of the system. The intermediate aquifer system coincides with the Hawthorn Group and is 0-213 meters thick within west-central Florida. The group is eroded away in the northern portions of west-central Florida so the Intermediate aquifer system is not extensive (Scott 1988; Tihansky and Knochenmus 2002).

The largest springs in west-central Florida are artesian. The water flowing from these springs rises through deep, vertical limestone conduits. Underground rivers flow through nearly horizontal caverns at the bottom of these conduits. The greatest majority of these springs flow through the Ocala limestone formation, although some penetrate the Suwannee limestone (Cooke 1939). Springs deriving from the Tampa Limestone and Hawthorn formation generally yield sulphur water. Notable west-central Florida springs with this characteristic include Sulphur Spring in Hillsborough County, Lithia Spring in Hernando County, and Kissengen Spring in Polk County (Cooke 1939).

Tampa Bay Metropolitan Area

Pinellas County

Pinellas County is one of the least known and most developed karst regions of the world. The county has 684 square kilometers of land surface. It is bound by Hillsborough County on the east, Pasco County to the north, Tampa Bay on the west, and the Gulf of Mexico to the south. Despite being the second smallest county in Florida, Pinellas

County is the most densely populated county in the state, with a population density of more than 1,271 people per square kilometer. In 2004, a total of 928,537 people were permanent residents, while an additional 40,921 people were seasonal residents (Pinellas County Government, undated (a)). Pinellas County has an annual population growth rate of two percent, which may be explained by an already existing high urban density and land base that is fairly built-out. In 1992, only 1,300 hectares of the county were cropland (Institute of Food and Agricultural Services 2000a).

The county is comprised of a mainland peninsula with various barrier islands (White 1970). Apart of the Gulf Coastal Lowlands physiographic unit, Pinellas County consists of low-angle scarps and terraces which formed during the Pleistocene. Two major geologic formations are present in the county, the Hawthorn Formation of the lower Miocene and the Caloosahatchee Marl of the lower Pliocene (Vanatta et. al 1972). A “white to light yellow, soft, moderately sandy and clayey, finely granular, and locally fossiliferous, with high porosity” Tampa Limestone is the uppermost consolidated rock in the county (Wilson 2004, p.15). Overburden material roughly 9-60 meters thick overlies the limestone, influencing groundwater flow and establishing distinct geomorphic regions with varying karst features throughout the county (Tihansky and Knochenmus 2002). “Surficial evidence of the karst landscape in Pinellas County is limited to sinkholes, sinkhole associated features, and springs,” which are increasingly disturbed by the county’s excessive urbanization (Wilson 2004, p.15).

The climate of the county is characterized by long, humid summers and mild winters. Annual rainfall is 140 centimeters; 60 percent falls from June to September.

Freezing temperatures occur approximately ten days a year. The County's average summer temperature is 28 °C; winter temperatures average 16° C (Vanatta et. al 1972).

Hillsborough County

Hillsborough County is bound by Pinellas County on the west, Polk County on the east, Manatee County to the south, and Pasco County to the north. In 2003, approximately 45 percent of the County's 2,729 square kilometers of land was urban, while 55 percent was rural. In 2005, a total of 1.1 million people were permanent residents. The county has an annual population growth rate of 20 percent (US Census 2005a). In fact, approximately 9,100 new homes were built between 2000 and 2004, mostly within the eastern portion of the county, which is currently undergoing rapid development and urban sprawl. The county has a population density of 367 people per square kilometer (US Census 2005b). Total cropland in the county totals 43,541 hectares (Institute of Food and Agricultural Services 2000b).

Hillsborough County lies within the Gulf Coastal Lowlands physiographic unit (Randazzo and Jones 1997). The unit consists of the Ocala-Suwannee Limestone Groups, overlain by Hawthorn Group sediments. The Hillsborough River meanders from the northeast to the southwest as it flows from the Green Swamp to the Tampa Bay, bisecting the county. Subsurface flooded caverns help generate small sinkholes in the northwest portion of the county. No known vadose caves exist in the county.

The climate of Hillsborough County is characterized by long, humid summers and mild winters. Annual rainfall is 117 centimeters per year. Freezing temperatures occur 11 days a year with an average winter temperature of 11°C. The average summer

temperature is 30 °C. The vegetation of the county consists largely of pine and saw palmetto flatlands (Leighty et. al 1982).

Pasco County

Pasco County is bound by Hillsborough County to the south, the Gulf of Mexico on the west, Polk and Sumter counties on the east, and Hernando County to the north. The county's total land surface is 1,929 square kilometers. State and federal governments own 28 square kilometers of Pasco County, most of which is contained within the Withlacoochee State Forest. Pasco County's main enterprise is agriculture, containing more than 26,000 hectares of cropland in 1992 (Institute of Food and Agricultural Services 2000c). In 2005, 429,000 people were permanent residents, a 25 percent increase from 2000. The population density of the county is approximately 179 persons per square kilometer (US Census 2005c). New Port Richey, with a population of 16,334, is the County's largest municipality.

Pasco County is characterized by discontinuous ridges separated by broad valleys, and is divided into five physiographic areas: the Coastal Swamps, the Gulf Coastal Lowlands, the Brooksville Ridge, the Tsala Apopka Plain, and the Western Valley. Several meters of limestone rock underlie the county. Gently sloping, flat limestone terrain of poorly drained soils characterizes the Coastal Swamps. Within the Gulf Coastal Lowlands are well drained relict sand dunes and hectares of wet pastureland. Along the Brooksville Ridge, local relief results from extensive sinkhole development. A few meters of poorly drained sandy to clayey soils cover most of the area (Stankey 1982).

The climate of the county is characterized by long, warm, humid summers and cool, mild, dry winters. Average rainfall in the area is 139 centimeters per year. Approximately 60 percent of this rain falls from June to September, while the driest months are November through February. Freezing temperatures are expected every eight out of ten years. The average winter temperature in the county is 15 °C, while summer temperatures average 31 °C. The vegetation of the county consists largely of pine and saw palmetto flatlands, with patchy areas of salt-tolerant grassy marsh along the coastal portions of the county (Stankey 1982).

Hernando County

Hernando County is a 29 kilometer long and 62 kilometer wide county bordered by Citrus County to the north, Pasco County to the south, Sumter County on the east, and the Gulf of Mexico on the west. The county consists of approximately 1,295 square kilometers of land area (Hernando County Government 2006). Of that, the Florida state and federal governments owns 182 square kilometers in the Withlacoochee State Forest and the Chassahowitzka and Chinsegut National Wildlife Refuges. Hernando County lies in the Gulf Coastal Lowlands physiographic unit (Hyde et. al. 1977). Limestone mining is the largest non-agricultural industry in Hernando County. The county has 9,923 hectares of cropland (Institute of Food and Agricultural Services 2000d).

In 2005, the county had 156,000 permanent residents and a population density of 106 people per square kilometer. Hernando County is not undergoing the rapid growth and urban sprawl seen in the remainder of the counties comprising the TBMA. In fact, the County's estimated annual growth rate over the past few years is only 5 percent

(Hernando County Government 2006). The climate of Hernando County is characterized by long, warm, humid summers and mild, dry winters. Annual rainfall is 140 centimeters per year with the majority falling from June to September. Freezing temperatures occur four days a year for periods of ten days or more. The County's average summer temperature is 32 °C. The average winter temperature in Hernando County is 12 °C. There is no well defined surface drainage system in the county. The vegetation of Hernando County consists largely of pine and saw palmetto flatlands (Hyde et. al. 1977). Table 2 illustrates population growth trends in the TBMA from 1960 to 2000.

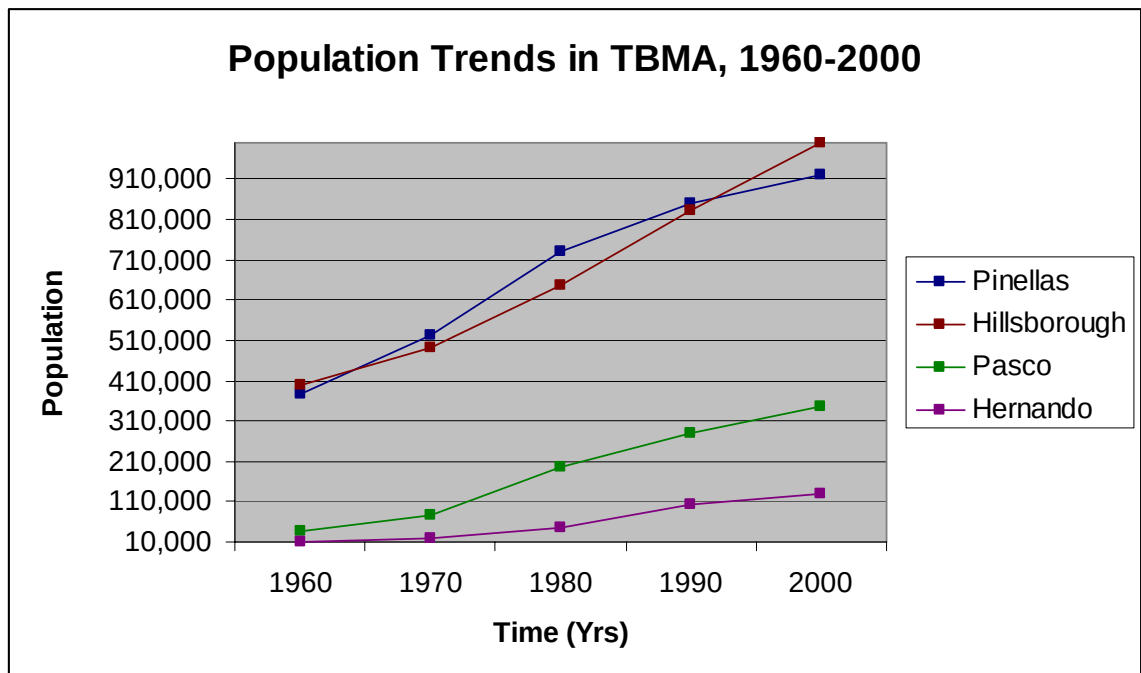


Table 2. Population Growth in the TBMA, 1960-2000.
(Data taken from CensusScope 2000).

Chapter Three

Methodology

This study required the application of the KDI to the four counties comprising the TBMA, and interviews with select local and state officials, community planners, and land resource managers, to help with the evaluation of the applicability of the KDI.

Summary of Methodology

The figure shown below (*Figure 7*) is a flow chart summarizing the methodology used in this study.

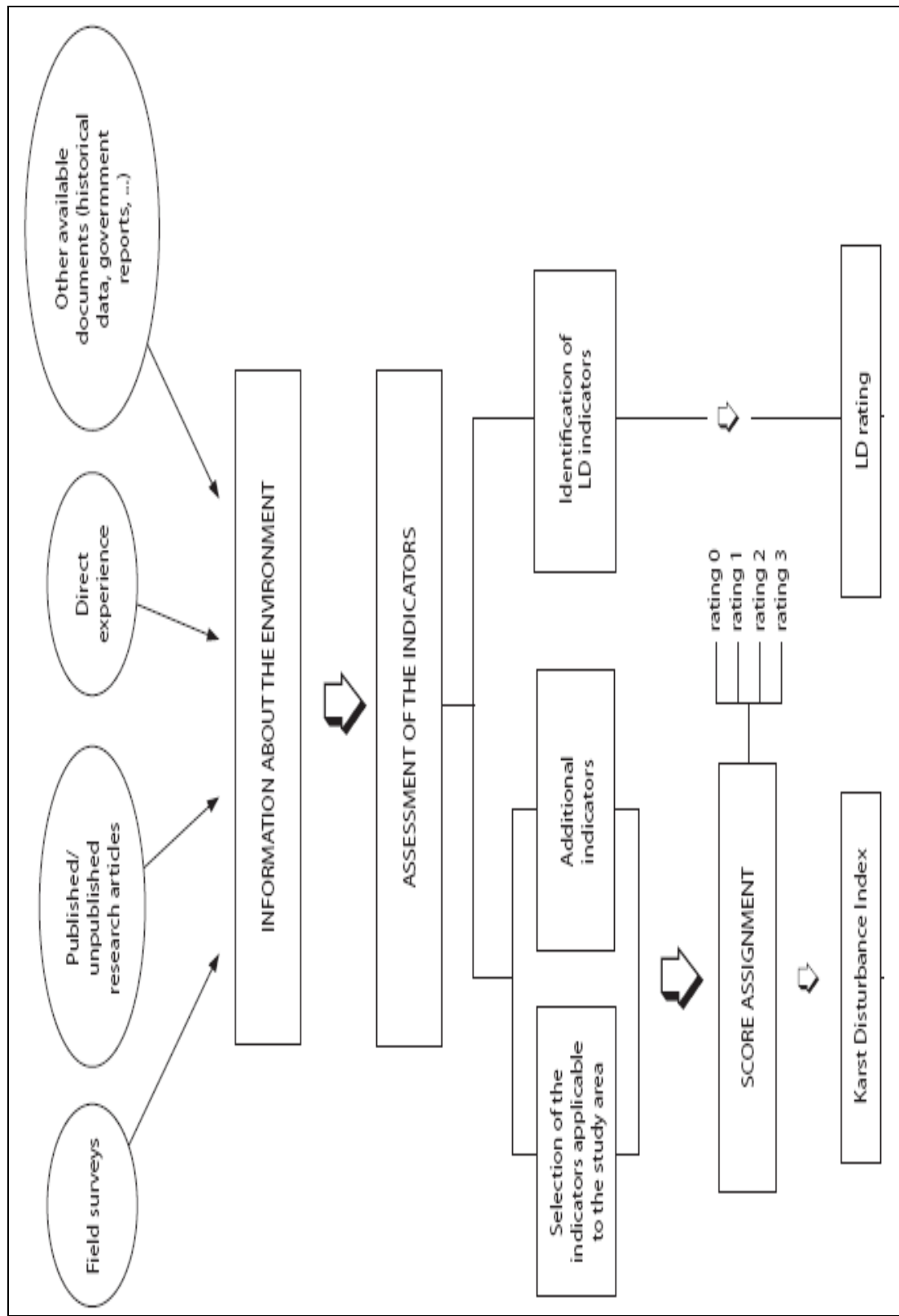


Figure 7. Methodology Flow Chart (Adapted from (Calo and Parise 2006, p. 49).

Assessment of Indicators

Table 3 depicts the KDI indicators evaluated in this study. Several data sources were employed to assess the degree of disturbance to each of these karst environment indicators. How these indicators were evaluated in this study is discussed in further detail below and summarized at the conclusion of this section in *Table 4*. Cave indicators were evaluated through personal interviews with local caving experts, state park officials, and miscellaneous publications discussing the caves within the TBMA. GIS Databases utilized in this study include the Florida Geographic Data Library, SWFWMD GIS Database, FDEP Geographic Information Database, and also the Hillsborough County, Pinellas County, Pasco County, and Hernando County Governments GIS Data Libraries.

Table 3. Karst Disturbance Index Indicators. (Taken from van Beynen and Townsend 2005, p. 106).

Category	Attribute	Scale	Indicator	3	2	1	0
Geomorphology	Surface Landforms	Macro	Quarrying/ Mining	Large open cast mines	Small working mines	Small scale removal of pavement	None
		Macro /Meso	Flooding (human built surface structure)	Total flooding of valley for hydroelectric dams	Flooding of fields for irrigation	Small scale reservoirs built for farming	Natural precipitation induced flooding
		Meso	Stormwater drainage (% of total stormwater funneled into sinks)	>66%	34-66%	1-34%	None
		Meso	Infilling (% of infilled caves/sinks)	>66%	34-66%	1-34%	None
	Soils	Micro	Dumping (% of sinkholes affected)	>66%	34-66%	1-34%	None
		Macro	Erosion	Severe	High	Moderate	Natural rate
Subsurface Karst	Soils	Micro	Compaction due to livestock or humans	Widespread and high levels	Widespread but low levels	Few isolated concentrated areas	None
		Macro	Flooding (human-induced flooding due to surface alteration)	Permanent cave inundation	Increased intermittent flooding & >50% filling	Increased intermittent flooding & <50% filling	Only natural flooding due to high rainfall
	Subsurface Karst	Micro	Decoration removal – vandalism	Widespread destruction	~50% of speleothems removed	Isolated spots of removal	Pristine

Table 3. (Continued)

Geomorphology (continued)	Subsurface Karst (continued)	Micro	Mineral – sediment removal	Most of Material removed	~50% of cave affected	Some isolated spots
		Micro	Floor sediment compaction – destruction	Most of floor sediments – decorations affected	~ 50% of floor sediments – decorations affected	Small trail through cave
Atmosphere	Air Quality	Macro	Desiccation	Widespread and high levels	Widespread but low levels	Isolated and very low levels
		Micro	Human- induced condensation corrosion	Widespread and high levels	Widespread but low levels	Isolated and very low level
Hydrology	Water Quality – Surface Practices	Meso	Pesticides and herbicides	Leakage of concentrated chemicals into aquifer	Heavy spraying of crops/weeds on surface	Little use of chemicals
		Micro	Industrial/ petroleum spills or dumping	>20 Brownfields	10-19 Brownfields	1-9 Brownfields
	Water Quality – Springs	At all Scales	Concentrations of harmful chemical constituents in springs	Harmful year round	Harmful for short periods	Just above natural levels
	Water Quantity	Macro	Changes in water table (decline in meters)	>35	15	<5

Table 3. (Continued)

Hydrology (continued)	Water Quantity (continued)	Micro	Changes in cave drip waters	Total cessation	Long dry spells (not seasonal)	Slight reduction
Biota	Vegetation Disturbance	At all scales	Vegetation removal (% of total)	>66%	34-66%	1-34%
	Subsurface Biota – Cave	Micro	Species richness (% decline)	50-75%	20-49%	1-19%
		Micro	Population density	50-75%	20-49%	1-19%
		Micro	Species richness (% decline)	50-75%	20-49%	1-19%
		Micro	Population density	50-75%	20-49%	1-19%
		At all scales	Destruction/removal of historical artifact (% taken)	>50%	20-49%	1-19%
Cultural	Human Artifacts	At all scales	Regulatory protection	No regulation	A few weak regulations	Statutes in place but with loopholes
	Stewardship of Karst Region	At all scales	Enforcement of regulations	Widespread destruction/no enforcement	No policing but little damage done	Some infrequent enforcement
		At all scales	Public Education	None, public hostility	None, public indifference	Attempts through NGOs
		Macro	Building of roads	Major highways	Some two lane roads	Some country lanes
	Building infrastructure	Meso	Building over karst features	Large cities	Some two lane roads	Some country lanes
		Micro	Construction in caves	Major modification	Major tourist cave	Cave trail marked

Geomorphology – Surface Landforms

USGS topographic maps and aerial photographs from the 1990's-2000 allowed for the exact determination of the type and prevalence of quarrying and mining in each county. In addition, personal interviews with county officials provided confirmation of data extrapolated from the topographic maps. Any additional information not contained in the maps or photos was also obtained from these officials and GIS files.

Sinkholes present on 1940-1950's topographic maps were compared to sinkholes present on 1990's-2000 topographic maps to determine the percent loss of sinkholes before and during periods of urbanization. Satellite images were utilized when recent topographic maps were unavailable. Any published research discussing the percentage loss of sinkholes was also utilized. Field surveys were conducted to verify "lost" sinkhole locations, using a randomized sample of sinkholes from the FDEP Sinkhole Database.

The percentage of sinkholes utilized as stormwater drains was determined through personal interviews with county stormwater managers. These managers provided data on the number of sinkholes still used as stormwater drains. This number was divided by the total number of sinkholes estimated for each county to determine the percentage of stormwater funneled into sinkholes.

Geomorphology - Soils

United States Department of Agriculture soil surveys and deforestation maps were used to determine the estimated degree of soil erosion for each county. Agricultural Marketing Service reports and county planning reports, which provide accurate and complete data on land use, were used to determine the percentage of land area utilized for

activities potentially resulting in the compaction of soil. GIS files from the Florida Geographic Data Library provided supplemental data when needed. Agricultural Marketing Service and the FDEP reports were analyzed to determine the percentage of land area affected by the human manipulation of water flow.

Geomorphology – Subsurface Karst and Atmosphere – Air Quality

A lack of vadose caves in Pinellas, Hillsborough, and Pasco Counties made the indicators under these attributes only applicable in Hernando County. Interviews with local cavers was used to evaluate the degree of decoration removal/vandalism within caves, percentage of area within the caves affected by sediment removal, level of construction within caves, desiccation, human-induced condensation corrosion, and the percentage of cave floor affected by soil compaction. No flooding of caves has occurred in the TBMA due to the absence of large dams so the flooding in caves indicator received a score of zero. Disturbance scores for these indicators were ascertained by dividing the number of caves impacting by each disturbance by the total number of caves in Hernando County. A score for vandalism was determined by dividing the number of formations remaining in each cave by the number of formations that should be present in the cave. Personal interviews with caving experts also provided information on the changes of cave drip waters within caves in the study area.

Hydrology – Water Quality

Rather than determining pesticide and herbicide concentration levels in the aquifer, determining a score for this indicator involved the analysis of the frequency and quantity of herbicide and pesticide application within the TBMA. To do this, policies

regulating the application of pesticides and herbicides were evaluated. In addition, personal interviews with officials from the FDEP provided supplemental information of the level of pesticide and herbicide application in each county. The number of golf courses and residential establishments potentially applying these chemicals was also determined from interviews with county officials. The United States Environmental Protection Agency website was used to determine the number of brownfields present in each county to evaluate the industrial and petroleum spills or dumping indicator. Moreover, any information found through grey literature searches was used to determine any additional sources of groundwater contamination.

Hydrology – Water Quantity

Reports from the Southwest Florida Water Management District (SWFWMD), who closely monitor the level of salt water intrusion and decline of the Floridan aquifer, were used to evaluate the changes in water table indicator. A lack of data concerning algal blooms discovered during the application of the KDI in Hillsborough County, Florida revealed the need to evaluate the concentration of harmful chemical constituents in springs to evaluate water quality. As such, SWFWMD spring water quality reports, which clearly state the level of chemical concentrations above normal, were utilized.

Biota – Vegetation Disturbance and Subsurface Biota

Deforestation maps created with GIS Arcview data obtained from the Florida Geographic Data Library allowed for the calculation of the total percentage of deforestation in each county to evaluate the vegetation removal indicator. Any scientific report discussing the percentage of species richness and population density within caves

and groundwater were utilized to evaluate the species richness and population density indicators. Personal collection of this data was beyond the scope of this research project, however, the Withlacoochee State Forest is starting this project in the near future.

Cultural – Stewardship of Karst

Local, county, and government websites and personal interviews with officials from each county was the largest source of information regarding the public education indicator, due to the nature of public education being largely internet-based. The determination of administrative codes, government statutes, and programs related to the protection of karst through internet searches and personal interviews were used to evaluate the regulatory protection indicator and the accessibility of these regulations and programs to the public. To evaluate the enforcement of regulations indicator, a FDEP report on the agency's statistics of civil and criminal enforcement of environmental laws was utilized. Information on each individual county's enforcement of regulations was gleaned using consent order data obtained from the FDEP. Fluctuations in the enforcement of regulations were determined from this information.

Cultural – Building Infrastructure

United States Census Bureau reports provided information on the degree of building on karst landscapes. In addition, reports prepared by county planning departments provided information on housing densities, and estimated number and size of malls, industrial parks, and apartment complexes built within each county. The Florida Metropolitan Planning Organization report on Florida highways and major roads was used to evaluate the building of roads indicator.

Table 4. Data sources used to score disturbance indicators in the TBMA.

Quarrying/Mining	USGS Topographic Maps, County Officials, Aerial Photographs, Hernando County Business Office
Flooding	Florida Department of Agriculture and Consumer Services, FDEP, McGovern (2004)
Stormwater Drainage	Florida Administrative code: Chapter 62-522.300(3), County Officials
Infilling of Sinkholes	USGS topographic maps, Aerial Photographs, <i>Google Earth</i> , Wilson (2004)
Dumping of Refuse into Sinks	FDEP Sinkhole Database, Fieldwork
Soil Erosion	US Department of Agriculture Soil Surveys, GIS Data
Soil Compaction	Agricultural Marketing Service Agriculture Census Data, GIS Directories, County Planning Departments
Decoration Removal and Vandalism	Communications with Local Cavers
Mineral Sediment Removal	Communications with Local Cavers
Floor Sediment Compaction	Communications with Local Cavers
Desiccation	Communications with Local Cavers
Condensation Corrosion	Communications with Local Cavers
Pesticide and Herbicide Use	Lantigua (2005), Florida Department of Agriculture and Consumer Services, FDEP, County Officials, Grey Literature Sources
Industrial Spills or Dumping	United States EPA, Florida EPA, Scorecard
Chemical Constituents in Springs	SWFWMD, Grey Literature Sources
Changes in the Water Table	SWFWMD
Changes in Cave Drip Waters	Communications with Local Cavers
Vegetation Removal	Florida Geographic Data Library (USGS Landuse)
Cave Biota Species Richness	No Data Found
Cave Biota Population Density	No Data Found
Groundwater Species Richness	No Data Found
Groundwater Population Density	No Data Found
Destruction of Artifacts	Florida Division of Historical Resources, Local archaeologists
Regulatory Protection	Florida Statutes; Florida Administrative Code; Florida Forever Program, FDEP, County Gov't Websites
Enforcement of Regulations	Office of the General Council Enforcement, FDEP
Public Education	SWFWMD Website, FDEP Website, County Websites
Building of Roads	Metropolitan Planning Organizations, GIS Directories
Building Over Karst Features	GIS Directories, USGS
Construction within Caves	Local Cavers, Grey Literature Sources

Participant Interviews

Qualitative interviews were conducted through a semi-structured face to face meeting with a purposeful selection of eight key informants who had professional knowledge and interest in the karst of the TBMA. These informants were county and state officials, community planners, and land resource managers, holding a position which allows for the KDI to be a tool used to conduct his or her job. County positions must have been held within the TBMA to maintain a consistent study area. Selecting interviewees based upon these criteria ensured that participants had expertise in their field. Only eight informants were selected because these eight agreed to be interviewed and comments, ideas, and perspectives, started to be iterated by several informants. Two interviews were conducted through telephone communication.

Interviewees were provided a copy of the KDI and the results of the KDI's application to Hillsborough County, Florida prior to meeting, to ensure informed participants and eliminate the risk of persuasion by the interviewer. Questions related to whether or not the KDI would or would not be a useful tool for the interviewees to employ in their job. Other questions involved whether or not interviewees had any suggestions for improving the KDI to make it a more practical tool to employ, whether or not karst knowledge is incorporated into their jobs, and also their opinions on the use of qualitative and quantitative data. All answers were tape-recorded for accurate reporting of results. An example set of questions is provided below.

Interviews with key informants were also conducted to attain data for individual indicators. However, these interviews did not have the same depth as the interviews

concerning the usefulness of the KDI. These interviews did not occur through a face-to-face meeting, but rather through telephone and email communication.

Sample Interview Question Set

- 1) *In your work, do you incorporate knowledge of karst?*
- 2) *Do you have any training or education in karst science?*
- 3) *Is the Karst Disturbance Index useful to your work? Why or why not?*
- 4) *What do you think could be incorporated into the KDI to make it more useful?*
- 5) *How do you define and/or describe qualitative and quantitative data?*
- 6) *What sort of information is valuable to you? (Qualitative, Quantitative, both)?*
- 7) *How do you use qualitative data, do you use it with quantitative data?*

Disturbance Scoring System

Using the compilation of the KDI indicators (*Table 2*) from van Beynen and Townsend (2005) as a guideline, each applicable indicator was assigned a score from 0 to 3: 0- no human impacts, 1- localized and not severe, 2- highly disturbed and widespread, 3- severe disturbance. Indicators were assigned a disturbance scale: macro- large scale disturbance, meso- localized small scale disturbance, and micro- highly concentrated small scale disturbance. Indicator scores were then tallied and divided by the highest possible score, obtaining a number between 0 and 1. This value corresponds to the five karst disturbance level categories given in van Beynen and Townsend (2005): 0.0-0.19 (pristine), 0.2-0.39 (little disturbance), 0.4-0.59 (disturbed), 0.6-0.79 (highly disturbed), and 0.8-1.0 (severely disturbed). The closer the value is to one, the greater the degree of disturbance. This scoring system is summarized in *Table 5*.

Table 5. Disturbance Classifications.

Score (sum/total possible sum)	Degree of Disturbance
0.8-1.0	Highly Disturbed
0.6-0.79	Moderately Disturbed
0.4-0.59	Disturbed
0.2-0.39	Little Disturbance
0-0.19	Pristine

Level of Confidence

In accordance with the KDI guidelines, when an indicator has inadequate data, yet is applicable to the study area, a Lack of Data (LD) score was given. The total number of LDs assigned to indicators was divided by the total number of indicators, resulting in a score from 0.0-1.0. This value represents the degree of confidence in the calculated disturbance level of each county. A total LD score less than 0.1 suggests a high confidence in the index results, whereas rating values greater than 0.4 suggests that more research is required. Thus, the higher the LD scores, the lower the degree of certainty in the determined degree of disturbance. Inapplicable indicators were completely discarded from this study (van Beynen and Townsend 2005).

Chapter Four

Results

This study required the application of the KDI to the four counties comprising the TBMA, which entailed the assessment of each applicable indicator listed in the KDI. Indicators were evaluated from 2006 to 2007. What follows is a table summarizing the TBMA results and justifications for these results (*Table 6*). After which, indicators are individual discussed to provide detailed justifications for each indicator score assigned in the TBMA. Following, the total degree of disturbance and the level of confidence in the disturbance calculations for each TBMA county is discussed. This section concludes with a summary of the information obtained from participant interviews.

Table 6. Summary of TBMA Results and Justifications.

Category	Attribute	Indicator	County	Scale	Score	Justification
Geomorphology	Surface Landforms	Quarrying and Mining	Pinellas	Macro	0	No quarries, stripmines, or recalimed mines (Ryburn, personal communication, 2006)
			Hillsborough	Macro	2	Contains active and inactive mines, including 1 limestone quarry, 7 phosphate mines, 9 fill quarries, and 13 pit mines; covers 64 km ²
			Pasco	Macro	1	10 very small working mines covering 14 km ² ; peat, clay, limestone, and sand extracted (Stanley, personal communication, 2006)
			Hernando	Macro	2	5 active mines totaling 76.35 km ²
			Pinellas	Meso	1	6.43 km ² of 683 total km ² irrigated cropland
		Flooding of surface karst	Hillsborough	Meso	1	174 km ² of 2,729 total km ² irrigated cropland
			Pasco	Meso	1	48 km ² of 1,929 total km ² irrigated cropland
			Hernando	Meso	1	5.64 km ² of 1,295 total km ² irrigated cropland
			Pinellas	Meso	1	7 of 261 (3%) of sinks piped for drainage
			Hillsborough	Meso	1	5 of 321 (1.6%) of sinks piped for drainage
		Stormwater flow into sinkholes	Pasco	Meso	1	8 of 619 (1.3%) of sinks piped for drainage
			Hernando	Meso	1	4 of 604 (.66%) of sinks piped for drainage
			Pinellas	Meso	3	83% of sinks present in 1920s filled by 2000s
			Hillsborough	Meso	2	63% of sinks present in 1940s filled by 2000s
			Pasco	Meso	2	61% of sinks present in 1950s filled by 2000s
			Hernando	Meso	2	40% of sinks present in 1960s filled by 2000s

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Geomorphology (continued)	Surface Landforms (continued)	Dumping refuse into sinkholes	Pinellas	Meso	2	Refuse in 19 or 34 (55.8%) visited sinkholes
			Hillsborough	Meso	2	Refuse in 24 of 37 (64.8%) visited sinkholes
			Pasco	Meso	2	Refuse in 23 of 38 (60.5%) visited sinkholes
			Hernando	Meso	2	Refuse in 10 of 22 (45.4%) visited sinkholes
			Pinellas	Macro	1	Slope less than 5% in 21 of 25 soil series
	Soils	Soil erosion	Hillsborough	Macro	1	Slope between 0 and 2 % in 63 of 74 soil series
			Pasco	Macro	1	Slope less than 5% in 49 of 58 soil series
			Hernando	Macro	1	Slope between 0 and 2% in 15 of 39 soil series, slope less than 12% in 12 more soil series
			Pinellas	Macro	3	Urban areas cover 94% of total land area; County ranks 30 th in nation for population density
			Hillsborough	Meso	3	Urban areas cover 45% of total land area; County ranked 7 th in state for population density
	Subsurface Karst	Flooding of subsurface karst	Pasco	Meso	2	Urban areas cover 50% of total land area; population density 179 persons per km ²
			Hernando	Meso	2	Urban areas cover 41.5% of total land area; population density only 106 persons per km ²
			Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
			Hernando	-	-	Not Applicable

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Geomorphology (continued)	Subsurface Karst (continued)	Decoration removal or vandalism	Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
		Mineral or sediment removal	Hernando	Micro	2	4 of 7 (57%) caves with decorations impacted
			Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
Atmosphere	Air Quality	Floor sediment compaction or destruction	Hernando	Micro	1	No minerals extracted, cave breakdown and sediment removed to increase human capacity
			Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
		Desiccation	Pasco	-	-	Not Applicable
			Hernando	Micro	1	No tourist caves, 7 of 15 caves have very small noticeable paths of compacted sediment
			Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
			Hernando	Micro	1	No tourist caves; caves are visited by local cavers causing low levels of desiccation
			Hernando	Micro	1	No tourist caves; caves are visited by local cavers causing low levels of desiccation

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Atmosphere (continued)	Air Quality (continued)	Human-induced condensation corrosion	Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
			Hernando	Micro	1	No tourist caves; caves visited by locals resulting in very minor condensation corrosion
Hydrology	Water Quality from Surface Practices	Pesticide and herbicide use	Pinellas	Meso	2	6.43 km ² cropland; 73 golf courses; 126 home lawn maintenance companies; programs ran to minimize effects of chemicals
			Hillsborough	Meso	2	Agriculture in county is horticultural using large amounts of pesticides and herbicides; over 300 farms in county; steps taken to ban illegal dumping of pesticides
			Pasco	Meso	2	48 km ² of 1,929 total km ² cropland; 30 golf courses; programs ran to minimize effects of chemicals
			Hernando	Meso	2	510 km ² of 1,295 total km ² is cropland; 23 golf courses; 57 lawn maintenance companies; programs ran to minimize effects of chemicals
		Industrial and petroleum spills or dumping	Pinellas	Meso	1	1 superfund site in county
			Hillsborough	Meso	1	4 designated superfund sites in county
			Pasco	Meso	1	2 designated superfund sites in county
			Hernando	Meso	0	No known brownfields in county

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Hydrology (continued)	Spring Water Quality	Concentration of harmful chemical constituents in springs	Pinellas	At all scales	2	Fungi found in Crystal Beach Spring; Wall Spring holding pond for 1.1 billion gallons of effluent; Nitrate concentrations in springs throughout the SWFWMD continually increasing
			Hillsborough	At all scales	2	All springs in county had elevated concentrations of nitrate in 2001
			Pasco	At all scales	2	Most county springs are not closely monitored; Crystal Spring has nitrate level 1.29 mg/l above normal
			Hernando	At all scales	2	5 well researched springs – all had nitrate concentrations higher than normal level of 0.01 mg/l; algae growth in 1 spring
			Pinellas	Macro	3	26 to 50% increase in chloride concentrations in most Pinellas County wells in 2005; 32% of monitored wells saltwater intruded; water levels in 82% of TBMA wells lower by average of 1.54 meters from 2004 to 2005
	Water Quantity	Changes in water table	Hillsborough	Meso	2	3 to 6 meter decline in aquifer underneath the county since 1930s; 13 meter decline in areas
			Pasco	Meso	2	28% of wells saltwater intruded in 2004
			Hernando	Meso	2	25% of wells saltwater intruded in 2004

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Hydrology (continued)	Water Quantity (continued)	Changes in cave drip waters	Pinellas	-	-	Not Applicable
			Hillsborough	-	-	Not Applicable
			Pasco	-	-	Not Applicable
			Hernando	Micro	1	No significant changes in cave drip waters
Biota	Vegetation Disturbance	Vegetation removal	Pinellas	Macro	3	95% of forested lands destroyed
			Hillsborough	Macro	3	95% of forested lands destroyed
			Pasco	Macro	1	33.4% of forested lands destroyed
			Hernando	Macro	2	34.2% of forested lands destroyed
	Subsurface Cave Biota	Species richness <i>and</i> population density of cave biota	Pinellas	-	-	Not applicable
			Hillsborough	-	-	Not applicable
			Pasco	-	-	Not applicable
			Hernando	-	LD	Lack of data available
	Subsurface Groundwater Biota	Species richness <i>and</i> population density of groundwater biota	Pinellas	-	LD	Lack of data available
			Hillsborough	-	LD	Lack of data available
			Pasco	-	LD	Lack of data available
			Hernando	-	LD	Lack of data available

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Cultural	Human Artifacts	Destruction or removal of historical artifacts	Pinellas	Micro	3	420 archaeological sites; unknown how many are destroyed; protection is lacking so high urbanization has destroyed most TBMA sites
			Hillsborough	Micro	3	355 archaeological sites; 40% reportedly destroyed, but this number is deemed low because no sites in county are protected
			Pasco	Micro	2	975 sites; unknown how many are destroyed; increasing urbanization likely destructive
			Hernando	Micro	2	357 sites; unknown how many are destroyed; protection is lacking, but destructive urbanization not as high in this county
	Stewardship of Karst Region	Regulatory protection	Pinellas	At all scales	1	Florida Administrative code Chapter 62-522.300(3) prohibiting water discharge into sinks; Chapter 62-610.523(9) regulating reclaimed water discharged into aquifers; Florida Statute 810.13 protection caves and sinkholes; karst risk assessments; Florida Forever Program (land acquisition program); NPDES regulating the discharge of pollutants; each county also maintains local regulations
			Hillsborough	At all scales	1	
			Pasco	At all scales	1	
			Hernando	At all scales	1	
		Enforcement of regulations	Pinellas	At all scales	0	45% increase in consent orders issued between 1986-1996 and 1997-2005; 62 issued in 1 year
			Hillsborough	At all scales	1	14% increase in orders issued between 1986-1996 and 1997-2005; only 30 issued in 1 year
			Pasco	At all scales	1	Decrease in orders issued between 1986-1996 and 1997-2005
			Hernando	At all scales	1	45% increase in orders issued between 1986-1999 and 2000-2005; only 12 issued in 1 year

Table 6. (Continued)

Category	Attribute	Indicator	County	Scale	Score	Justification
Cultural (continued)	Stewardship of Karst Region (continued)	Public education	Pinellas	At all scales	1	Governmental and non-governmental agencies educating public, however, programs are largely internet based and reach citizens seeking information; programs include Neighborhood Environmental Action Team; FL Solid and Hazardous Waste Handbook; entertainment-based programs such as <i>Water's Journey</i> and water conservation plays; each county also maintains local programs
			Hillsborough	At all scales	1	
			Pasco	At all scales	1	
			Hernando	At all scales	1	
	Building Infrastructure	Building of roads	Pinellas	Macro	3	2 interstates and 31 roads with at least 6 lanes
			Hillsborough	Macro	3	3 interstates and 34 roads with at least 8 lanes
			Pasco	Macro	3	1 interstate and 7 roads with at least 6 lanes
			Hernando	Macro	3	2 interstates and 4 roads with at least 6 lanes
		Building over karst features	Pinellas	Meso	3	First county in Florida to achieve buildout; population density ranks 30 th in nation; urban areas cover 94% of total land area
			Hillsborough	Meso	3	45% of total land area is urban; 5.9% increase in home construction from 2000-2002 alone
			Pasco	Meso	3	50% of land area is urban; population density 179 people per km ² – 25% increase from 2000
			Hernando	Meso	2	106 people per km ² ; not undergoing rapid urbanization – 5% annual growth rate; 42% of total land area is urban
		Construction within caves	Pinellas	-	-	Not applicable
			Hillsborough	-	-	Not applicable
			Pasco	-	-	Not applicable
			Hernando	Micro	1	Caves are gated

Assessment of Indicators

The following section will individually discuss each indicator to provide detailed justifications for each indicator score assigned in the TBMA.

Geomorphology – Surface Landforms

This attribute focuses on the human-induced disturbance of surficial karst features, that is, land features formed by karst processes at or near the land surface. Quarrying is a localized practice, yet it causes the most destruction to karst terrains (van Beynen and Townsend 2005). These disturbances include destroying caves and sinkholes, changing spring discharge and groundwater levels, and also removing carbonate rock masses essential for the development of karst terrains. Natural flooding of surface karst can result in small-scale damage of karst terrains. Human manipulation of water flow can heighten the effects of this destruction, irregardless of whether the flooding is the total inundation of a valley or localized flooding of a farm. Sinkholes serve as possible drainage sites for urban stormwater and raise pollution levels within aquifers (van Beynen and Townsend 2005). Moreover, sinkholes are frequently infilled for urban construction projects, altering natural karst drainage patterns.

Quarrying/Mining – The disturbance score for this indicator is based on the coverage of quarrying and mining areas versus total land area in each county. USGS topographic maps from the 1990s-2000 were utilized to indicate the type and prevalence of quarrying and mining that occurs in Hillsborough County. Information from the Hillsborough County Planning and Growth Management Development Service was used to account for any new mines not covered by the topographic maps. Phosphate mine data was collected

from the Florida Institute of Phosphate Research. In total, Hillsborough County has 1 limestone quarry, 7 active or recently inactive phosphate mines, 9 fill quarries, 13 small sand pit mines and numerous reclaimed mines, covering 64 km², or 2.4 percent of the County's total land area. These mines produce little toxic tailings. Acidic tailings ponds are found only in southern Hillsborough County, where the phosphate mines are located.

Information from the Hernando County Office of Business Management revealed that the county contains five active mining operations. Rinker Materials, Vulcan Materials, and Cemex collectively extract limestone for construction aggregate and cement production on 5,746 hectares of land, while Florida Rock-Limestone mines 1,618 hectares of land. Lastly, ER Jahna-Limestone mines 271 hectares for products utilized in roadway construction (McHugh, personal communication, 2007). One insignificant clay mine is also located in the county. Overall, six percent of Hernando County's land is covered by mines. *Figure 8* shows the location of these mining operations.

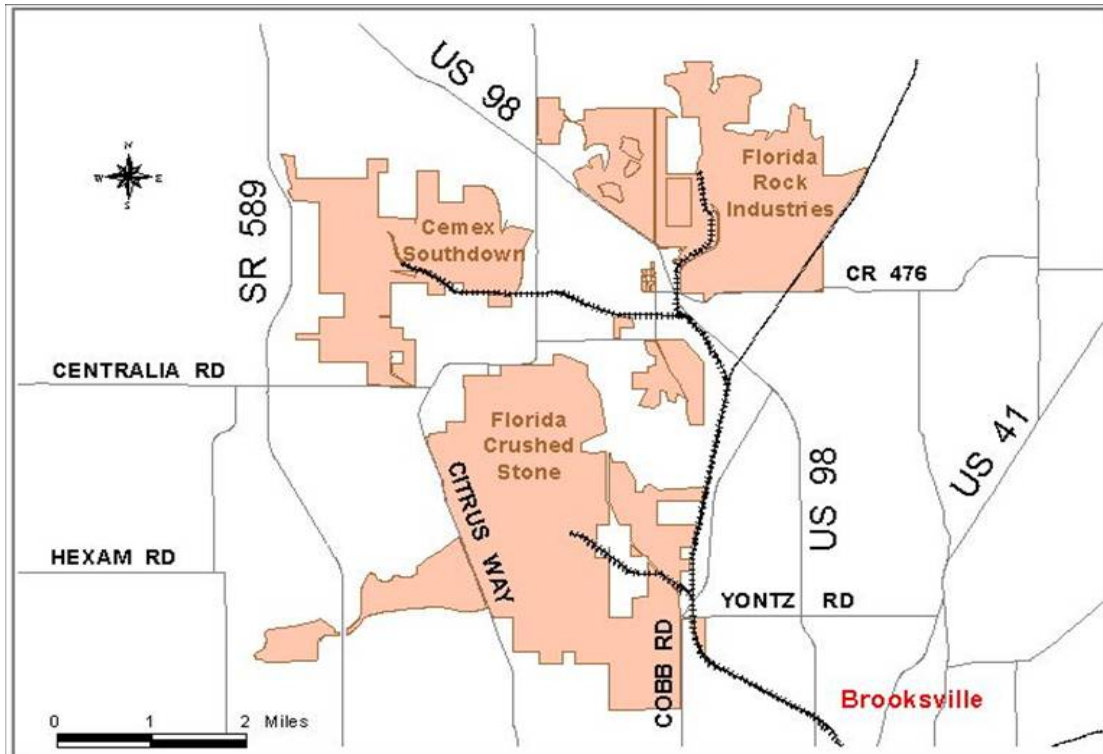


Figure 8. Mining Operations in Hernando County, Florida

Flooding of Surface Karst – During Florida’s dry season, crops require the addition of water via irrigation. As shown in Figure 9, 48 km² of Pasco County’s 1,929 km² of land were irrigated cropland in 2002 (Agricultural Marketing Service 2002a). Irrigation systems are also used to grow blueberries, watermelons, corn, soybeans, and citrus fruits in Hernando county on 5.64 km² of land (Figure 10) (Agricultural Marketing Service 2002b). Only 6.43 km², out of 683 total km² of land in Pinellas County, were irrigated citrus crops the same year (Figure 11) (Agricultural Marketing Service 2002c). In Hillsborough County, agricultural irrigation systems are used to grow watermelons, strawberries, squash, and citrus on 174 km² of cropland (Figure 12) (McGovern 2004), while Flood control mechanisms are instituted on each County’s croplands to prevent crop damage and agricultural flooding of the karst terrain (Florida DEP 2004a).

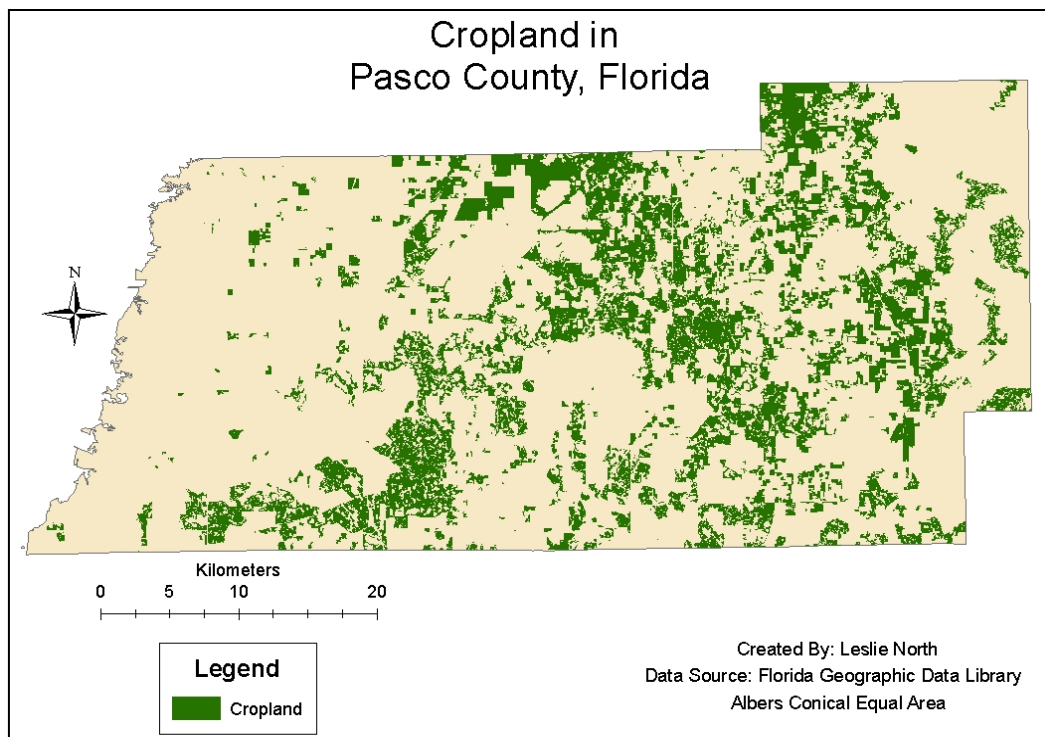


Figure 9. Pasco County, Florida Cropland in 2002.

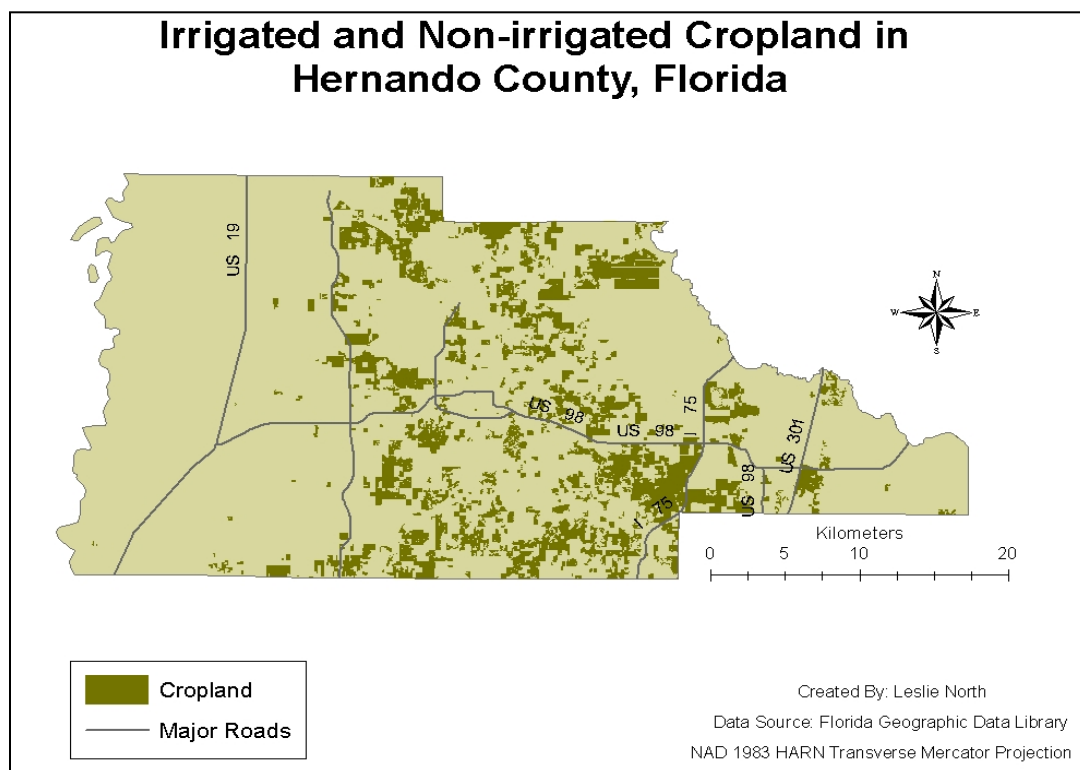


Figure 10. Irrigated and Non-irrigated Cropland in Hernando County, Florida.

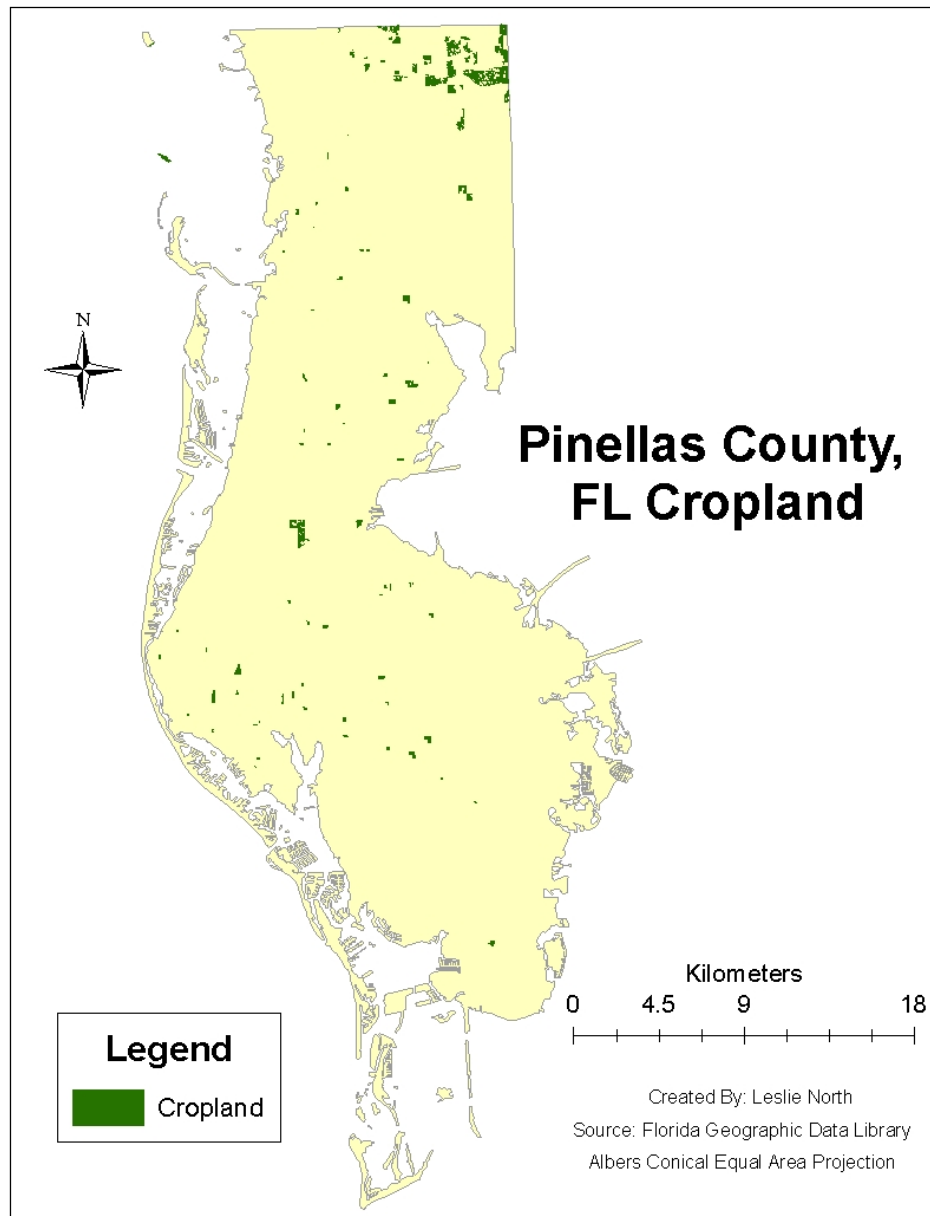


Figure 11. Pinellas County, Florida Cropland in 2002.

Hillsborough County, Florida Cropland

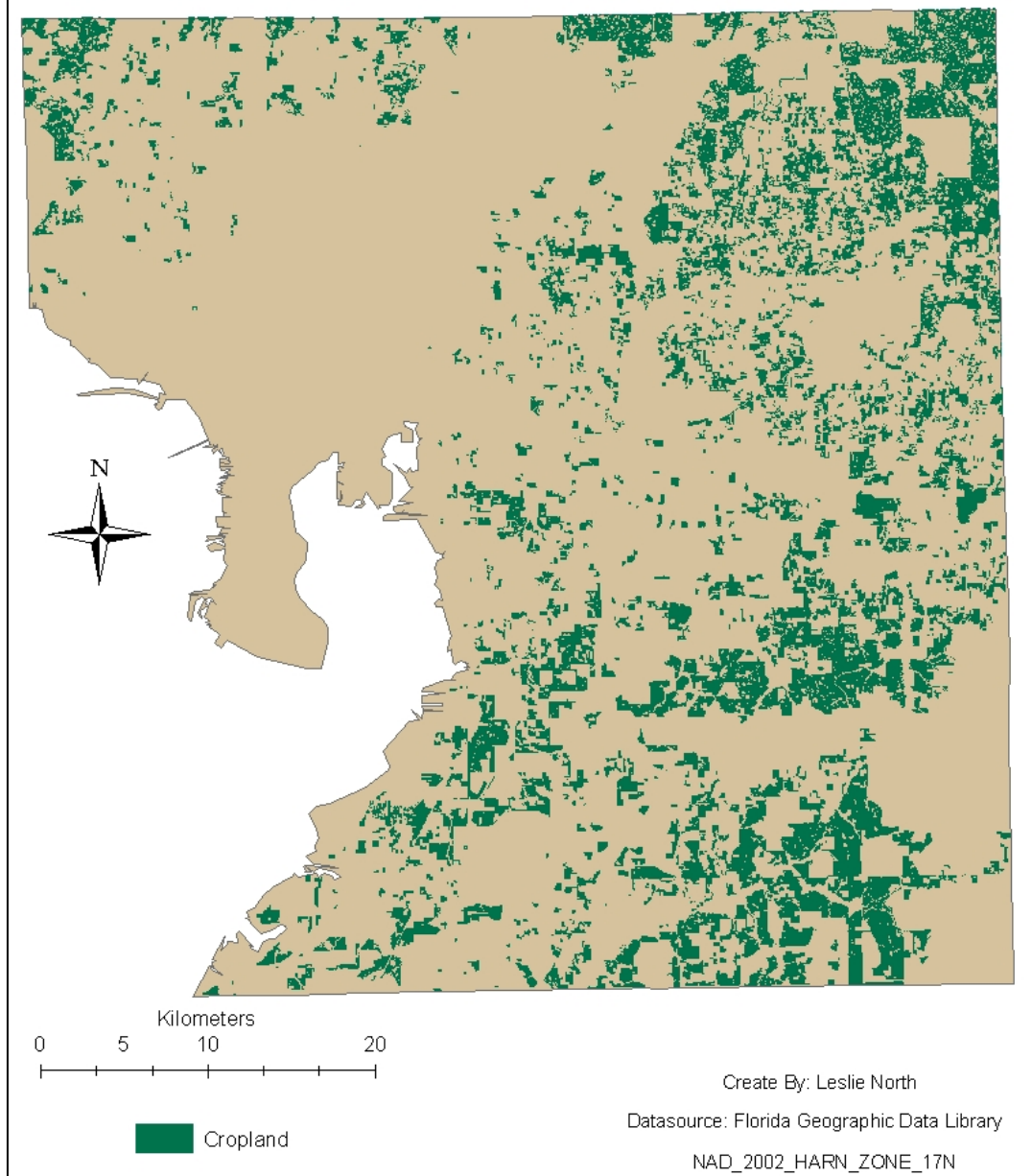


Figure 12. Hillsborough County, Florida Cropland in 2002.

Stormwater Flow into Sinkholes – To evaluate this indicator, the percentage of sinkholes utilized as stormwater drains in each TBMA county was determined. Florida Administrative code, Chapter 62-522.300(3), states “discharges through wells or sinkholes that allow direct contact with Class G-I, Class F-I, or Class G-II groundwater shall not be allowed a zone of discharge” (Florida Administrative code, Chapter 62-522.300(3)). However, some sinkholes previously used for stormwater drainage are not re-piped. In 2000, Pinellas County contained 261 sinkholes (Wilson 2004). Of these 261 sinkholes, only seven, or 3%, are reportedly used for stormwater drainage (Holt, personal communication, 2006). Five Hillsborough County sinkholes are piped for stormwater drainage (Awad, personal communication, 2005), while eight Pasco County sinkholes (Tietz, personal communication, 2006) and four Hernando County sinkholes are piped for stormwater drainage (Velsor, personal communication, 2007). Nonetheless, although the determination of an exact figure is beyond the scope of this project, many of Florida’s old stormwater retention ponds were built in depressions, which were likely sinkholes (Holt, personal communication, 2006). Documentation supporting this suspicion is unavailable, hence its exclusion when determining indicator scores.

Infilling of Sinkholes – Evaluating this disturbance requires the determination of the percentage of infilled sinkholes within each county. Construction projects require sinkholes to be covered or infilled for development. If the sinkhole is not properly infilled, buildings on the surface are vulnerable to subsidence (Sinclair et al. 1985). Using aerial photographs from 1926 and 2000, Wilson (2004) calculated the percentage of sinkholes lost to infilling from rapid urbanization. While 1926 aerial photographs

revealed 1,570 sinkholes, only 261 sinkholes were present in the 2000 aerial photographs. Consequently, 83 percent of the sinkholes present in 1926 were infilled by 2000.

USGS 1:24:00 topographic maps of Hillsborough County were utilized to assess the number of filled sinkholes by comparing 1940s maps to updated maps from 1990-2000. The 1940s quadrangles contained 871 sinkholes, compared to only 321 sinkholes on the 1990-2000 topographic maps. Consequently, 63 percent of the sinkholes present in 1940 were filled by 1990. The sinkholes were assumed infilled if the area containing the sinkhole was shown as non-residential on the 1940s maps, but residential on the 1990-2000 maps. For example, a mall that appeared on the 1990 map was in the same location of a sinkhole on the 1940 map, so it is safe to assume the sinkhole was infilled. Ground-truthing was undertaken to check the validity of this assumption. A sample of 30 of the proposed infilled sinkhole sites, were visited throughout Hillsborough County. All sinkholes were no longer present.

The loss of sinkholes in Pasco and Hernando Counties was determined using USGS 1:24:00 topographic maps from the 1950s-1960s and satellite images from the 2000s. The 1950s and 1960s topographic maps were last updated in the 1970s. Therefore, in order to attain the most accurate and up-to-date estimate for sinkholes infilled during development, more recently updated satellite images on *Google Earth* were utilized. In Pasco County approximately 1,558 sinkholes were counted on the 1950s topographic maps. By 2002, there were 619 sinkholes detected on the satellite images of the county. Thus, 61 percent of sinkholes present in the 1950s in Pasco County were infilled by 2004. Similarly, 1,017 sinkholes were counted on 1960s quadrangle maps of Hernando County,

while only 604 sinkholes were present on the 2000s satellite images of the county. Consequently, 40% of the sinkholes present in 1960s were filled by 2002.

Dumping Refuse into Sinkholes – While this indicator encompasses both intentional and incidental dumping of refuse into sinkholes, only sinkholes “with materials dumped into it of a quantity or quality to impact karst through clogging, pollution, and aesthetics” were considered when assigning an indicator score (van Beynen and Townsend 2005, p.105). Approximately 50 percent of the existing sinkholes listed in the FDEP Sinkhole Database (2005) for each county were visited to visually check for the presence of garbage in order to assign scores to this disturbance. In Pinellas County 34 sinkholes listed in the database were visited. Refuse was present in 19 of 34 visited sinkholes and consisted of soda cans, paper, a tire, and a five gallon bucket. In Hillsborough County, 37 randomly sampled sinkholes were visited. Dumping within these visited sinkholes included, but was not limited to, soda cans, hangers, and boxes. Moreover, Blue Sink, one of the largest sinkholes in Hillsborough County became clogged when a dumpster from a neighboring car dealership fell into it.

In Pasco County 38 randomly selected sinkholes were inspected. Although the contents of four sinkholes were not visible and three sinkholes were infilled, refuse was present in 23 sinkholes and consisted of soda cans, a household garbage bag, and cardboard boxes. In Hernando County, 31 sinkholes listed in the FDEP Sinkhole Database (2005) were inspected. Nine sinkholes were infilled. Refuse was present in 10 of the 22 remaining sinkholes and consisted of cardboard boxes, a cinder block, sheets of plywood, and large quantities golf balls.

Geomorphology – Soils

The development of karst landscapes is dependent upon soluble carbonate rocks and slightly acidic water (Lane 1986; Ralston and Oweis 1999). Soils are a major contributing source of the carbonic acid necessary to acidify percolation water, making soil conservation of great importance to the continued natural formation of karst terrains (van Beynen and Townsend 2005). Nonetheless, soils are continually eroded by poor agricultural and forestry practices and compacted by humans and livestock reducing water percolation, accumulating water on the surface, increasing flooding of the area, and lowering aquifer recharge rates (van Beynen and Townsend 2005). The indicators under this attribute attempt to analyze each of these human-induced disturbances.

Soil Erosion – The TBMA is apart of the Gulf Coastal Lowlands. Increased development and continuing urban sprawl in Pinellas, Hillsborough, and Pasco Counties led to an increase of deforestation practices and an increase in soil erosion rates. For example, of the 272,900 hectares of land in Hillsborough County, only 17,634 hectares are still forested, indicating a 94 percent decline in the forested lands in the county. *Figure 13* shows the current location of these forested and urban areas.

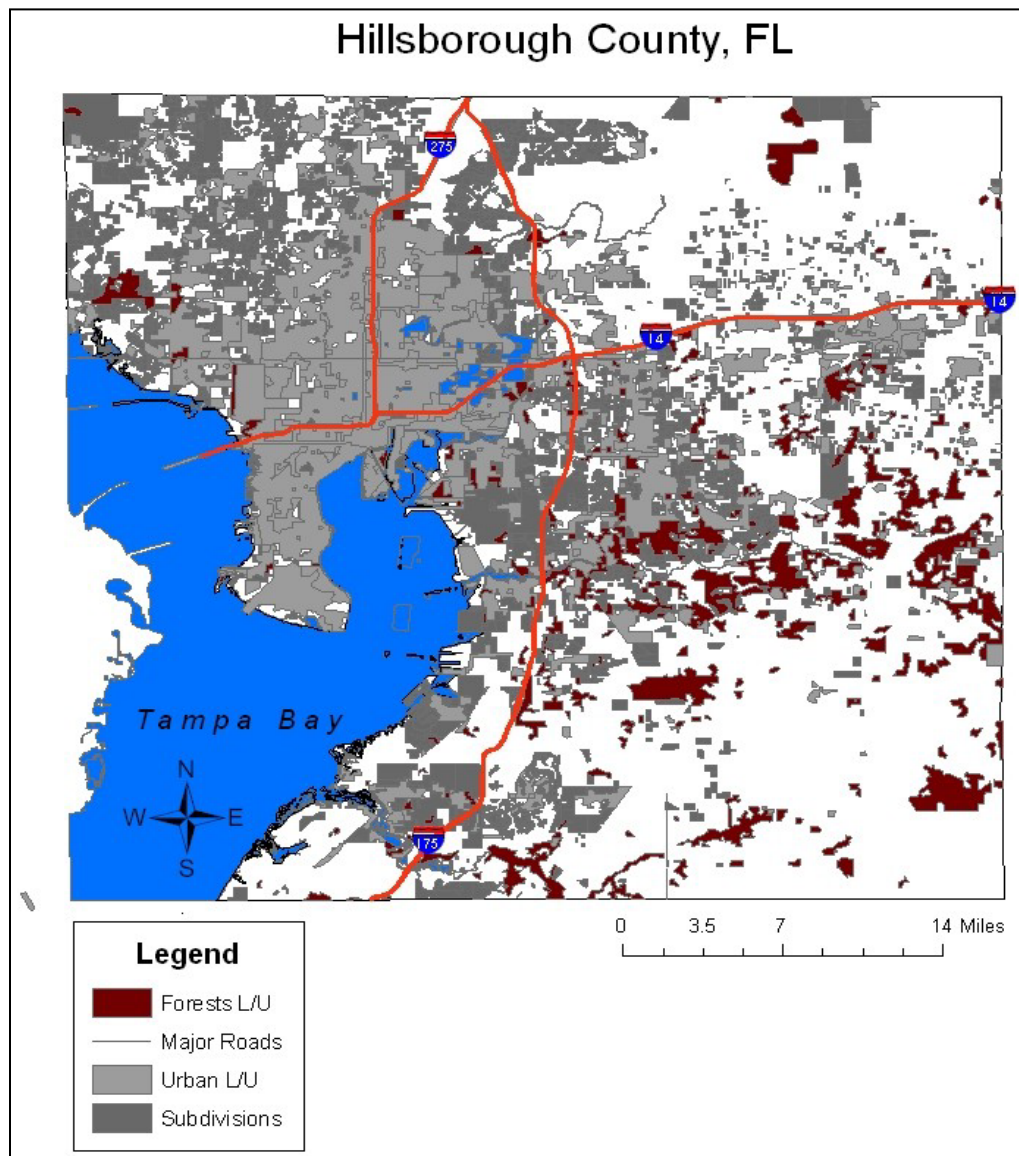


Figure 13. Forest and Urban Areas in Hillsborough County, Florida.

While karst terrains generally have a thin layer of soil cover, overburden material is approximately 9-60 meters thick in Pinellas County (Tihansky and Knochenmus 2002) and 0-244 cm thick in Hernando and Pasco Counties. Subsequently, the limestone underlying these counties is not as susceptible to the effects of soil erosion as typical karst terrains (Randazzo and Jones 1997). Hillsborough County's limestone is also

covered with a mantel of approximately five meters of sandy clay (Randazzo and Jones 1997). Unlike the other counties comprising the TBMA, Hernando County is not experiencing rapid urbanization or deforestation so soil erosion is minimized.

Although urban development can lead to deforestation and soil erosion, steep gradients are necessary to accelerate the erosion process. Pinellas County lacks steep gradients. Only 4 out of the 25 soil series in Pinellas County have a slope greater than five percent (Agricultural Marketing Services 2002a). In Hernando County, 15 out of 39 soil series have slopes between 0 and 2 percent. Twelve more series have slopes less than 5 percent (Hyde et. al. 1977). Only 9 of the 58 soil series in Pasco County have a slope greater than 5 percent (Stankey 1982). Lastly, 63 of the 74 soil classifications in Hillsborough County have slopes between 0 and 2 percent (Leighty 1958). Weed mats prevent soil from washing away from construction sites in each of these counties, while shelter belts are used to decrease aeolian erosion in rural areas (van Beynen et al. 2007).

Soil Compaction – The scoring of this indicator was established by comparing the amount of urban land to total land area in each county. Agricultural activities, livestock, and urbanization can affect soil compaction. Only 6.43 km² of Pinellas County are considered cropland (Agricultural Marketing Service 2002a). Thus, agriculture does not significantly compact the County's soil. Instead, soil compaction results from the building of roads, houses, and commercial and industrial infrastructure. *Figure 14* shows current urban areas in Pinellas County. In 2003, only six percent of the County's 683 km² was vacant developable land (Pinellas County Planning Department 2003). In fact, the

population density of Pinellas County, 1,217 people per square kilometer, ranks 30th amongst all counties in the United States (KnowledgePlex 2007).

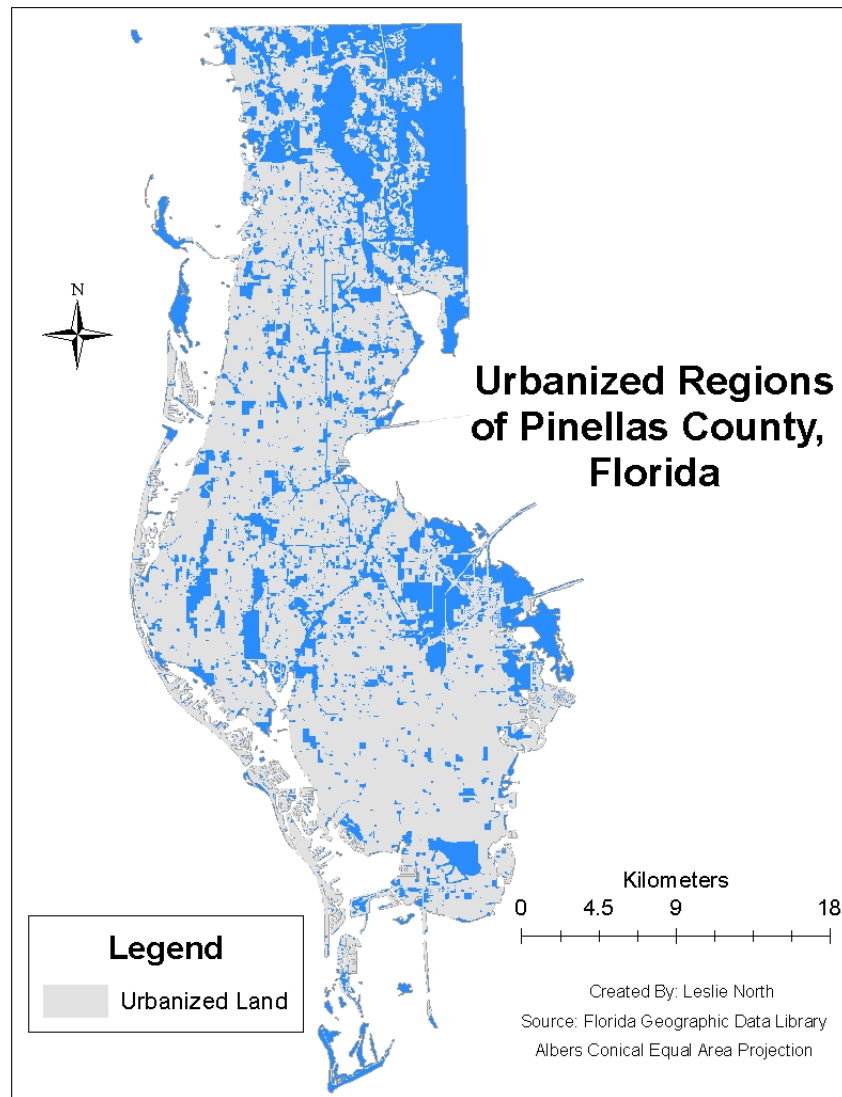


Figure 14. Urban development in Pinellas County, Florida.

Soil compaction also results from urbanization in Hillsborough County. The sandy soils in the county are not greatly compacted by agriculture. Urban lands account for 38 percent of the County's total land area (Figure 13). Moreover, in 2002, the county was ranked 7th in the state for population density (Floyd 2003).

Only 4,800 hectares of Pasco County's 192,900 hectares of land were irrigated cropland in 2002 (Agricultural Marketing Service 2002b), so agricultural activities do not extensively impact the County's soil. As such, soil compaction in Pasco County largely results from vast urbanization in this county as well. In 2005, only 40 percent of the 1,929 km² of total land area in the county was unurbanized (Pasco County Planning Department 2000). *Figure 15* shows Pasco County's urbanized areas as of 2000.

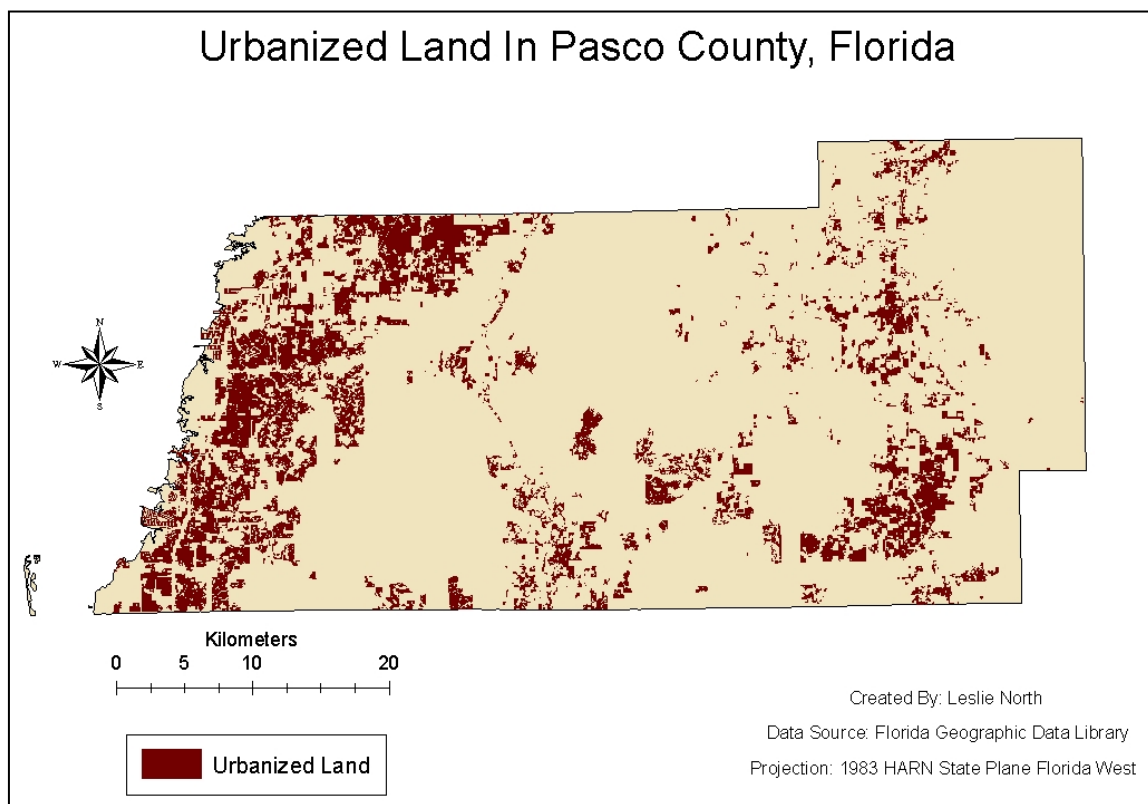


Figure 15. Urbanized Regions in Pasco County, Florida in 2000.

Agricultural activities, nor vast urbanization, have a significant impact on Hernando County's soil. Only 564 hectares of the County's 129,500 hectares of land were irrigated cropland in 2002 (*Figure 16*) (Agricultural Marketing Service 2002c). In 2003, an estimated 1,127 km², of the 1,929 km² of total land area in the county, was

unurbanized (Hernando County Planning Department 2003). Moreover, the population density in the county is only 106 people per km² (Hernando County Government 2006).

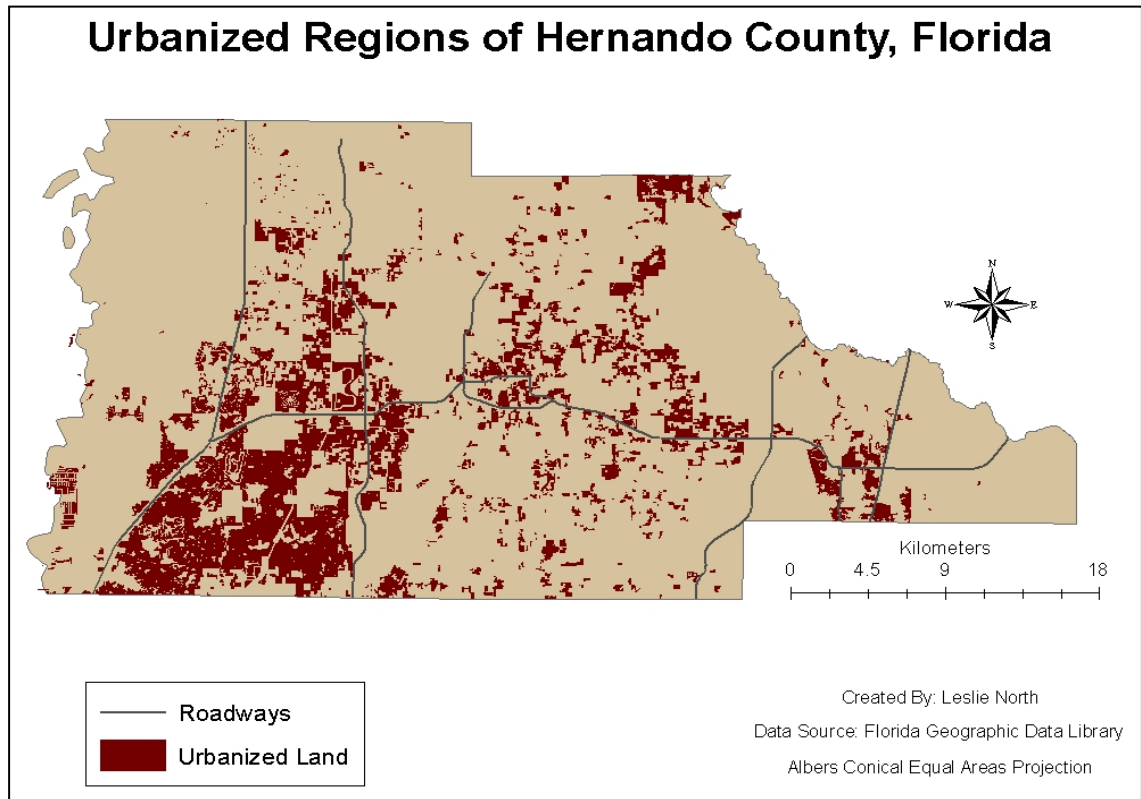


Figure 16. Urbanized Land in Hernando County, Florida.

Geomorphology – Subsurface Karst

The following indicators evaluate the conditions of both vadose and semi-phreatic caves. The disturbance to phreatic caves is assessed under the “Hydrology” category. Disturbance to this attribute’s indicators can change the aesthetic nature of the cave, alter cave climate by changing air flow patterns, and destroy the habitat of delicate cave biota. The degree of human-induced flooding in a cave determines the degree of disturbance caused to cave systems. Decoration removal destroys the aesthesis of cave systems, alters air flow patterns, and changes dripwater patterns. The removal of cave minerals and

sediment alters cave passages, change air flow patterns within the cave systems, and results in the removal of cave organisms food and habitat (Villar et al. 1986; van Beynen and Townsend 2005). The compaction of floor sediment via foot traffic, which can result in a concrete-like surface, also destroys cave organisms' habitat (Gillieson 1996). For these reasons an understanding of the degree of human-induced disturbance to cave floors, minerals, and decorations is important in understanding the overall human-induced impact to karst.

Pinellas, Hillsborough, and Pasco Counties only contain submerged caves. Therefore, disturbance caused by cave flooding, decoration removal, sediment removal, and floor sediment compaction in these three counties was discarded from this study. There are fifteen known vadose caves in Hernando County that were each evaluated for these aforementioned disturbances.

Flooding – Hernando County contains no large dams which alter the land surface. Therefore, this indicator was discarded from this study.

Decoration Removal/Vandalism – Many of Hernando County's caves do not have decorations. In fact, of the fifteen known vadose caves in the Hernando County, six have decorations (Turner, personal communication, 2007). Only small portions of each of these caves are decorated. For instance, Bloodblister Cave has one section in a larger room, which is decorated with a pristine column/flowstone formation. BRC Cave arguably contains the most amazing array of speleothems in Florida; only the speleothems at the caves' entrance are destroyed (Turner, personal communication, 2007). A high level of vandalism is reported in caves just north of the Hernando County

line, but not in any Hernando County caves. Overall, a score for this indicator was based upon the percentage of decoration removal or vandalism in Hernando County's caves as a whole. Of the seven vadose caves in Hernando County that contain formations, four, or 57 percent, are impacted by decoration removal.

Mineral Sediment Removal – No minerals are extracted from any of Hernando County's caves. However, due to the small nature of the County's caves, debris and sediment is often removed from cave entrance to widen openings and cave rooms to increase human capacity (Turner, personal communication, 2007). Two Hernando County caves are located at abandoned quarries, but no minerals or sediments were extracted from the caves themselves. Quarter Cave and Dan's Tomb contain no sediments (Turner, personal communication, 2007).

Floor Sediment Compaction or Destruction – Hernando County does not contain any tourist caves, minimizing foot traffic within the County's caves. Moreover, the caves with the county are not frequently visited due to their relative inaccessibility and small size (Turner, personal communication, 2007). However, six of the County's fifteen caves do have small noticeable paths of compacted sediment. One of Hernando County's caves has a highly compacted crawlway.

Atmosphere – Air Quality

The deterioration of cave air quality destroys karst rocks and secondary deposits (van Beynen and Townsend 2005). Thus, the indicators within this category evaluate the level of desiccation and condensation corrosion of cave passages and decorations.

Desiccation and condensation corrosion within caves can result from artificial cave lighting, body heat, and respired CO₂ (Villar et al. 1986).

The exact determination of the level of desiccation through the measurement of relative humidity changes was not used during this study. Instead, indicator scores were determined by evaluating individual cave decorations for both the desiccation and condensation corrosion indicators. Cave decorations and passages affected by desiccation generally loss moisture and dry out. Due to a lack of vadose caves, the desiccation and human-induced condensation corrosion indicators under the “Air Quality” attribute were discarded in Pinellas, Pasco, and Hillsborough Counties.

Desiccation – Hernando County contains no tourist caves, diminishing the possibility of desiccation by intense artificial cave lightening and tourist body heat. Moreover, as previously mentioned, the county contains few caves with decorations that could experience desiccation. Nonetheless, Hernando County’s caves are occasionally visited by local residents and cavers, resulting in very low levels of desiccation (Turner, personal communication, 2007).

Human-induced Condensation Corrosion – For the same reasons listed in the desiccation indicator discussion, condensation corrosion is not a significant disturbance to Hernando County’s caves (Turner, personal communication, 2007). However, persons have visited each cave within the county, resulting in very minor occurrences of human-induced condensation corrosion.

Hydrology – Water Quality from Surface Practices

This section deals with surface practices, which may impact groundwater quality. Water is an essential component of karst environments. Therefore, maintaining the quality of both surface water and groundwater in these environments is vital. However, nutrient concentrations vary greatly between regions. Thus, exact nutrient levels were not evaluated when assessing the indicators of this attribute.

Pesticide and Herbicide Use – Both agricultural and residential properties utilize pesticides and herbicides. Swancar (1996) revealed the presence of high concentrations of chemical constituents in groundwater under golf courses compared to undeveloped land. Therefore, rather than determining pesticide and herbicide concentration levels in the aquifer, determining a score for this indicator involved the analysis of the frequency and quantity of herbicide and pesticide application on each of these properties. Overall, due to the widespread nature of agricultural fields, pesticide and herbicide use is considered a macro-scale disturbance in Hillsborough, Pasco, and Hernando Counties. However, in lieu of the rapid conversion of rural to urban areas within Hillsborough and Pasco Counties, this indicator will probably become a meso-scale disturbance within a decade.

In 2002, 6.43 km² in Pinellas County were citrus, nursery stock, or floriculture farms (United States Department of Agriculture 2002), while 48 km² in Pasco County were cropland. In the same year, 51,054 hectares of Hernando County's 129,500 hectares of land was cropland (Agricultural Marketing Service 2002b). None of these croplands were associated with heavy pesticide or herbicide use. In fact, the largest portion of these croplands is agriculture, not horticulture. Horticulture generally uses large amounts of

pesticides and herbicides. Florida is the largest users of these products in the nation (Lantigua 2005). Hillsborough County contains over 300 farms (Troutt, personal communication, 2006). Small cattle farms are also scattered throughout the county, but there is no record of pesticide or herbicide use on these farms.

Pinellas County also contains 73 golf courses, which extensively apply pesticides and herbicides (Ryburn, personal communication, 2006). A tabulation of homeowners employing the use of lawn pesticides and herbicides is difficult. Nonetheless, it should be noted that there are 126 home lawn maintenance companies servicing Pinellas County, which employ the use of pesticides and herbicides (Business Broker, undated). Similarly, Hernando County contains 23 golf courses, which extensively apply pesticides and herbicides (McHugh, personal communication, 2007). There are also 57 home lawn maintenance companies servicing the county (McHugh, personal communication, 2007). Lastly, Pasco County has 30 golf courses (Pasco County Office of Tourism 2004).

Despite the high frequency of pesticide and herbicide application within each of these counties, steps have been taken to minimize the effects of pesticide and herbicide use. The FDEP published “*Best Management Practices for Golf Course Maintenance Departments*,” in 1995. The principal of this work is “to minimize irrigation, fertilizer, and pesticide use requirements through the use of integrated pest management and native or naturalized vegetation” (Florida DEP 1995, p.2). The FDEP’s Operation Cleansweep has collected over 60,600 pounds of cancelled, suspended, and unusable pesticides for safe disposal (Florida DEP 2006b). Each county supports the Florida Yards and Neighborhoods Program, a program developed to help residents decrease pollution by improving landscape management (Florida Yards and Neighborhoods Program, undated).

The University of Florida's Institute of Food and Agricultural Sciences (IFAS) directs the Management of Water Program in each county. This program is directly responsible for three container grown nurseries and two golf courses establishing plant filtration barriers to reduce pesticide runoff (IFAS 2002).

The Florida Department of Agriculture Bureau of Pesticides regulates pesticides, maintains a chemical laboratory for the monitoring of ground and surface water for excessive pesticide or herbicide concentrations, registers pesticide products, and conducts scientific reviews on the environmental and health risks of pesticide use in any particular region. However, the benefit of this monitoring program is minimized due to a lack of personnel. For example, Hillsborough County only has one inspector who is responsible for monitoring 300 farms (Lantigua 2005). As such, farms are only inspected once every two years; farmers are usually told a week in advance of an impending inspection.

The Pollution Prevention and Resource Recovery Department of the Pinellas County Government, in partnership with the FDEP, Autobahn Society, and golf course owners, are currently formulating a program to "get the issue of golf course runoff under control," (Ryburn, personal communication, 2006). Participating golf courses managers will receive information on "how the nutrients in reclaimed water can replace the use of pesticides and herbicides" (Ryburn, personal communication, 2006). Moreover, partakers will attend certification courses demonstrating the most environmentally conscious methods of pesticide and herbicide application. However, participation in the program is voluntary, so the potential benefits may be minimized.

The Hernando County Government Cooperative Extension Service Office provides Hernando County citizens with planned agricultural programs, designed to

“provide practical and useful information via meetings, tours, demonstrations, and individual consultations” (Hernando County Extension Office 2006). These programs focus on environmental friendly insect management, integrated pest management, fertilizers and soil fertility, and pesticide use. This office also provides pesticide applicator training and certification. Other miscellaneous information contained on their website includes tips for reducing stormwater runoff pollution, the herbicides-pesticides-fertilizers information packet, and tips for reducing water pollution at home and at work. The county also strongly promotes the concept that reducing stormwater pollution depends on each individual becoming part of the solution through their “Do your part to prevent stormwater runoff” brochure (Hernando County Extension Office 2006). The Hernando County NPDES Stormwater Program, in corporation with the EPA, implements regulations and policies to meet six minimum measures. These include public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff control, post-construction runoff control, and pollution prevention and good housekeeping (Hernando County Department of Public Works 2003). The status of the program is continually updated on the Hernando County Government website.

Industrial and Petroleum Spills or Dumping – Brownfields and industrial spills are a source of harmful groundwater leachate. Scoring for this indicator is based upon the number of brownfields in each county. A brownfield is defined as “real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant,” (USEPA 2003).

Volatile organic compounds and dense non-aqueous phase liquids generally occur in high concentrations at these sites (van Beynen and Townsend 2005).

Pinellas County only contains one superfund site, resulting in a score on one. Nonetheless, several other Pinellas County sites are a source of groundwater contamination. The Progress Energy Plant in St. Petersburg, Florida released 1,438 pounds of toxic chemicals onto county land in 2002 (Scorecard 2005a). The Building 100 Area in Largo, Florida is a former 4.5-acre Department of Energy facility. The improper disposal of organic solvents and metals used during the production of neutron generators contaminated groundwater at this site. In 1997, remediation activities at the site removed 83 drums and 303 tons of contaminated soil (United States Department of Energy 1998). Molex TBO Incorporated accidentally released 1,887 pounds of copper onto Pinellas County land in 2004. The same year, 205 pounds of copper and 43 pounds of lead were released by Elreha Printed Circuits. Also in 2004, West Pharmaceutical Services released 29,710 pounds of zinc compounds (USEPA 2004). This site is still waiting to be cleaned.

Hillsborough County also has a history of contaminated sites. Honeywell International had a major spill in 1982 and has not taken measures to clean the site. The company is resisting DEP orders to undertake remediation measures (Salinero 2005). Although Honeywell has not disclosed what chemicals were spilled, circuit boards, which are produced with compounds such as polybrominated diphenyl ethers (possible endocrine disrupter), ferric chloride (corrosive, irritant and mutagen), and numerous acids, were produced at the site. Another example of industrial pollution is the Helena Chemical Company's contamination of soil and groundwater with wettable dusting sulfur and formulated pesticides, herbicides, fungicides, and fertilizers. This site is adjacent to

another spill, the Alaric Area Groundwater Plume Site, which is commingling with the Helena pollution plume (USEPA 2005). To date, the EPA has classified four brownfields in the county.

Pasco County has two superfund sites which released 2,643 pounds of nickel compounds onto the ground (Scorecard 2005b). In addition, in 2004, the county had 13,869 pounds of contaminated soil removed after a toxic release at an aircraft part manufacturer in New Port Richey (USEPA 2004). Similarly, two Hernando County sites are a source of groundwater contamination: Sparton Electronics Florida Incorporated and Sun Fiberglass Products Incorporated. Sparton Electronics Florida, Inc. released 5,808 pounds of lead compounds and sulfuric acid onto county land in 2004, while Sun Fiberglass Products, Inc. released 1,297 pounds of styrene the same year (USEPA 2004). To date, the EPA has recognized zero brownfields in Hernando County.

Hydrology – Spring Water Quality

The improper disposal of effluent onto pastures, excessive use of nitrogen and phosphate fertilizers, and leaking septic tanks each impact spring water quality by elevating concentrations of harmful chemicals. These chemicals may then generate the occurrence of algal blooms in surface waters. However, measuring the occurrence of algal blooms is imprecise and misses aspects of water pollution. Therefore, this indicator was substituted for the following indicator, evaluated through the determination of the severity and longevity of harmful chemical constituents in surface waters fed by karst aquifers (van Beynen et al. 2007).

Harmful Chemical Constituents in Springs – Elevated levels of harmful chemicals in the outflows of karst areas, namely springs, is a measure of the human impact on karst water quality. Nonetheless, many of Florida's springs are not well monitored or documented. Consequently, there is no way to know the affect of drought, pollution, or development on these springs (Greene 2001). However, meso-scale events have impacted large portions of the TBMA. For instance, nitrates and phosphates are problematic in inducing environmental eutrophication in the TBMA. An example of this is that the seagrass population dropped dramatically in Tampa Bay due in part to increased nitrogen loading (Lewis et al. 1985). Evidence for these increased nitrate loads are also shown in spring data obtained from *The Hydrology and Water Quality of Select Springs in the Southwest Florida Water Management District* (SWFWMD 2001). While nitrate levels should be less than 0.01 mg/l, 64 percent of the District's springs have nitrate concentrations greater than 1.00 mg/l, leading to more frequent occurrences of *Lyngbya*. Spring water data for each TBMA county follows.

Several springs are located within northern Pinellas County, yet very little is known about these springs. Moreover, the health of several of the County's springs is not monitored and therefore could be included in this study. For example, while Crystal Beach Spring is well known amongst the County's diving community, the spring is located offshore and has no associated run. The health of the spring is not monitored. Divers, however, have unofficially reported the presence of fungi along the spring's passages (Florida Geological Survey 2004).

Despite the lack of scientific data concerning most Pinellas County springs, the county is home to two well-researched springs: Wall Spring and Phillippi Spring.

These are the only springs listed in the Florida Springs Database for this county. A cabana-style bathhouse at Wall Spring once attracted tourists. However, the spring is now a holding pond for 1.1 billion gallons of effluent. Consequently, nitrogen pollution resulted in the closing of the spring to the public (Call and Stephenson 2003). Phillippi Spring no longer flows as a result of vandals closing the spring opening with rocks.

In 2001, all springs in Hillsborough County had more than 3.0 mg/l of nitrate, with Bell Creek Spring having more than 10 mg/l. Total phosphorous levels ranged from 0.01-0.05 mg/l throughout the county (SWFWMD 2001). The report stated that Sulphur Springs had a nitrate level of 0.89 mg/l and a phosphorus level of 0.11 mg/l. In addition, Lettuce Lake Spring, mostly covered by algae blooms, had a nitrate level of 3.05 mg/l and a phosphorus level of 0.06 mg/l.

Crystal Springs, which is a complex of six springs and three swamp springs, is the only major spring found in Pasco County, although several unnamed, lower magnitude springs do exist (Johnson 2006). Horseshoe and Salt Springs are also located in the county. Horseshoe Spring and Salt Springs are at the edge of a tidal marsh. These springs have no utilization, so water quality data is not kept up-to-date. Crystal Spring run was once a private recreation area having a nitrate level of 1.3 mg/l, 1.29mg/l over the natural limit (SWFWMD 2001). The spring is being restored (Florida Geological Survey 2004).

Several springs are located within Hernando County, including Aripeka Springs, Beauford Spring, Betty Jay Spring, Boat Spring, Bobhill Spring, Mud Spring, Rita Marie Springs, Ryles Spring, Blue Run Spring, and Jenkins Creek Spring (Johnson 2006).

While little scientific data concerning most of these Hernando County's springs exists, the county is home to five well-researched springs: Gator Spring, Little Spring, Magnolia

Spring, Salt Spring, and Weeki Wachee Spring (Florida Geological Survey 2004). Gator Spring is a 4th order magnitude spring located one mile west of Aripeka Spring. The spring is located on private property. While nitrate levels should be less than 0.01 mg/l, in 2003, the spring had a nitrate concentration of 0.49 mg/l. Similarly, although Little Spring is an undeveloped spring surrounded by SWFWMD property, it had a nitrate concentration of 0.71 mg/l in 2003 (Florida Geological Survey 2004). Magnolia Spring had a nitrate concentration of 0.54 mg/l. Hernando Salt Spring had 0.38 mg/l of nitrates, while Weeki Wachee Spring, a highly developed tourist attraction, had a nitrate concentration of 0.66 mg/l in 2001. Lastly, Blind Spring reportedly has large concentrations of algae growth along the base of the spring, although specific water quality data for this spring is unavailable. Insignificant amounts of phosphate were found at each spring (Florida Geological Survey 2004).

Hydrology – Water Quantity

Over-pumping an aquifer is a macro-scale disturbance, which can lead to a lower water table, reduced spring and stream flow, and saltwater intrusion (SWFWMD 1993). Although, natural variation in the water table due to seasonal precipitation changes or drought (Heath and Smith 1954; Stewart 1968), these natural variations were disregarded when assessing this indicator to better reflect human-induced disturbance.

Changes in Water Table – Although the pumpage of groundwater began in the 1920s in St. Petersburg, potentiometric levels of the Upper Floridan aquifer underlying Pinellas County didn't start to significantly decline until the 1930s (Stewart 1968). As the population of Pinellas County grew, municipalities required the extraction of larger

quantities of drinking water to sustain the populace. By 1966, an estimated 44.2 million gallons of groundwater were extracted each day in northwest Hillsborough, northeast Pinellas, and southwest Pasco Counties. Ninety-seven percent of this water was extracted for municipal use (Stewart 1968). From 1960 to 1989, the Upper Floridan aquifer potentiometric surface dropped 6.1 to 9.1 meters due to groundwater withdrawals (SWFWMD, 1993); however, Pinellas County's groundwater was already experiencing saltwater intrusion as early as the 1950s (Stewart 1968).

The first significant withdrawal of groundwater in Hillsborough County started in September of 1930. As of November 16, 2005, water levels had decreased an average of 0.25 meters in Hillsborough County in the month of October alone, despite the county having record amounts of rainfall during the same month (SWFWMD 2005). The Floridan Aquifer underneath Hillsborough County has declined three to six meters since the 1930s and in some areas as much as thirteen meters (SWFWMD 2005, 2001, 1993).

On top of the domestic use of groundwater supplies, the agricultural farms that cover Pasco County use groundwater for irrigation purposes. Potentiometric levels of the Upper Floridan aquifer in Pasco County began declining in the 1940s (Stewart 1968). From 1960 to 1989, the Upper Floridan aquifer potentiometric surface dropped 10 to 20 feet due to groundwater withdrawals in the west-central portions of Pasco County alone (SWFWMD 1993). In April 2004, 28 percent of the freshwater wells monitored by SWFWMD in Pasco County experienced saltwater intrusion (SWFWMD 2005). Additionally, SWFWMD reported that 62 percent of the wells monitored in the county had up to a 25 percent increase in chloride concentrations.

Potentiometric levels of the Upper Floridan aquifer in southern portions of Hernando County began declining in the 1940s. From the 1960 to 1989, Upper Floridan aquifer potentiometric surface dropped 10 feet due to groundwater withdrawals in the southwest portions of Hernando County (SWFWMD 1993). A 1987 SWFWMD report demonstrated that water extraction in Hernando County for public use increased from one million gallons per day in 1977, to more than seven million gallons a day by 1985 (SWFWMD 1987). Chloride concentrations began increasing along Hernando County's coast during this same time period (Fretwell 1985). In April 2004, 25 percent of the freshwater wells monitored by SWFWMD in Hernando County had saltwater intrusion (SWFWMD 2005). Of these, chloride concentrations increased 0 to 25 percent in eight percent of the wells, 26 to 50 percent in 13 percent of the wells, and 51 to 100 percent in four percent of the wells (SWFWMD 2005). In October 2005, 82 percent of the wells monitored by SWFWMD in the TBMA had lower water levels than in October 2004 by an average of 1.54 meters (SWFWMD 2005).

Changes in Cave Drip Waters – Pinellas, Hillsborough, and Pasco Counties contain no vadose caves. Thus, a disturbance score for these counties was discarded from this study. However, a score for this disturbance was determined for Hernando County through communication with experienced Hernando County cavers. The score was based upon the degree of change in the amount of water reaching the County's caves from the overlying bedrock. Reportedly, Hernando County's cave systems have not experienced significant changes in the amount of cave drip waters (Turner, personal communication, 2007).

In fact, the greatest majority of the County's caves do not even contain formations, which could reflect these changes.

Biota – Vegetation Disturbance

For the purposes of this study, deforestation refers to the removal of substantive forest growth that would lead to karst impacts. Vegetation disturbance, resulting from urban growth, clear cutting for agriculture, logging, or fire, can adversely affect karst terrains through the increase in soil erosion and the degradation of groundwater supplies (Harding and Ford 1993; van Beynen and Townsend 2005). Moreover, vegetation is important for the karstification process. The decay of vegetal litter helps build soil, which provides carbonic acid for the dissolution of limestone (van Beynen and Townsend 2005). For these reasons, an understanding of the degree to which deforestation has occurred in each of the counties comprising the TBMA is essential in understanding the overall health of the region's karst environment.

Vegetation Removal – This indicator was based on the total percentage of deforestation, or the total percentage of substantive vegetation removal that could adversely impact a karst system. The percentage of deforestation in each county was calculated using data collected from the SWFWMD GIS Database. Dividing the total hectares of forested land remaining in Pinellas County (*Figure 17*), 3,411, by the County's total hectares of land, 68,375, indicates that 95 percent of Pinellas County's forested lands are destroyed. This analysis suggests that vegetation removal is a severe karst disturbance in Pinellas County. Of the 192,900 hectares of total land area in Pasco County, 128,437 hectares are still in their natural vegetative state. Dividing the total hectares of forested land remaining in

Pasco County, by the County's total hectares of land, indicates that 33.4 percent of Pasco County's forested lands are destroyed. *Figure 18* shows the remaining forests.

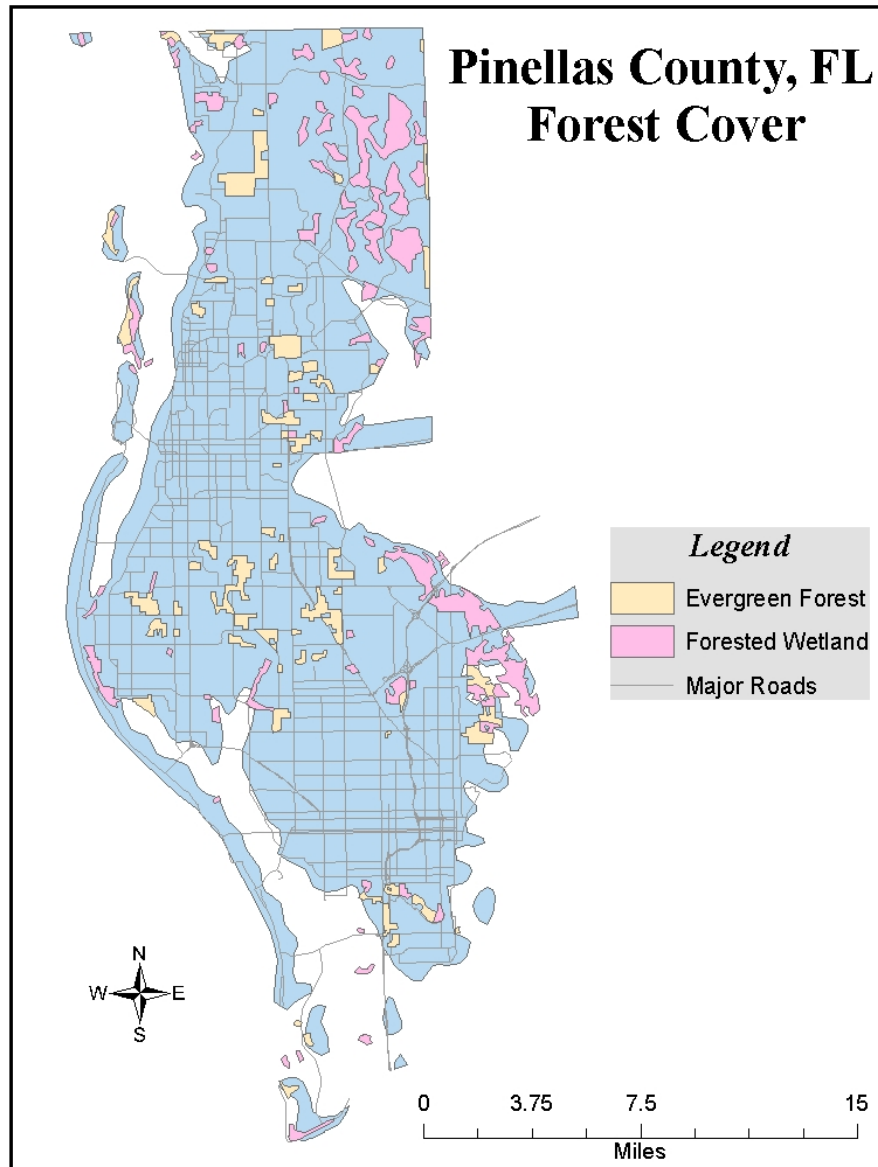


Figure 17. Forest Cover in Pinellas County, Florida.

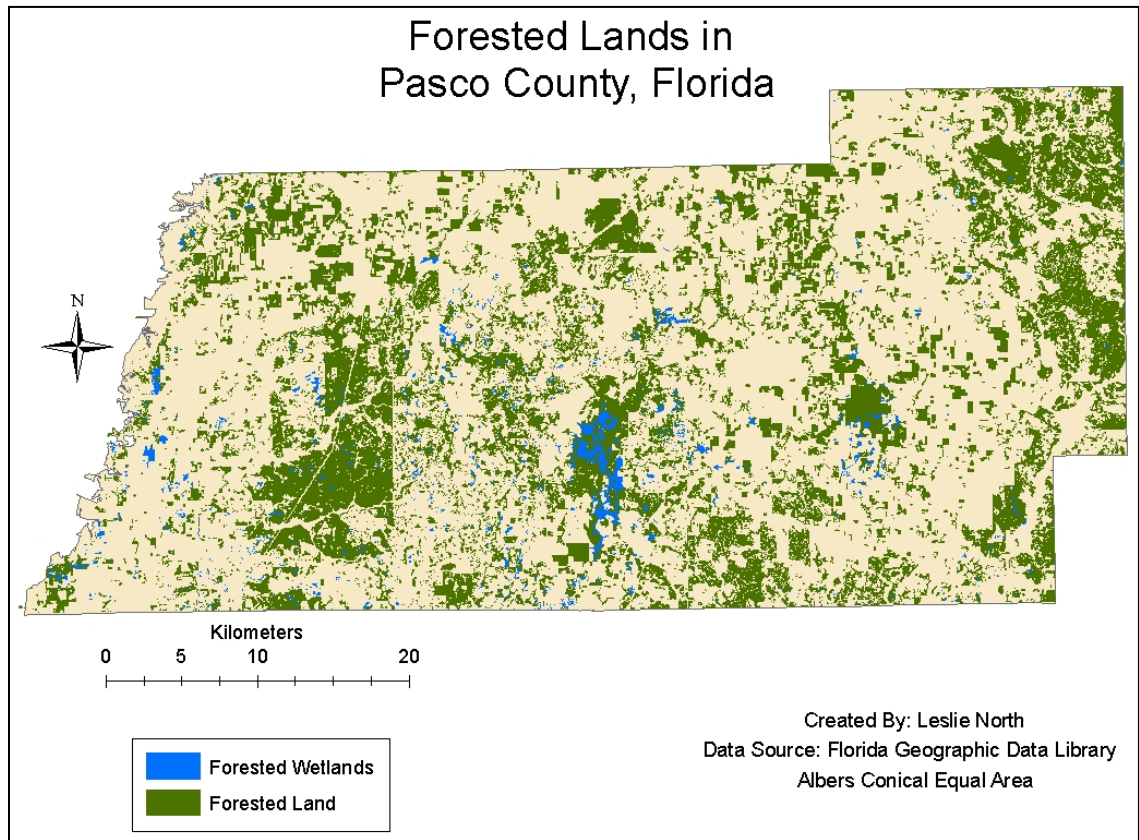


Figure 18. Forested Land in Pasco County, Florida.

Dividing the total number of forested lands in Hillsborough County, 17 km², by the total land area in the county, 339 km², indicates that 95% of the County's forested lands are destroyed. These numbers were also determined from GIS data collected from the Hillsborough County Government. *Figure 13* illustrates the remaining forest cover in the county. Lastly, dividing the total number of forested lands, 828 km², by the total land area in Hernando County, 1,259 km², indicates that 34.2 percent of the County's forested lands are destroyed. This lower percentage is due in part to the presence of the Withlacoochee State Forest (159 km²) and the County's distance from Tampa. *Figure 19* illustrates all of the remaining forest cover in the county.

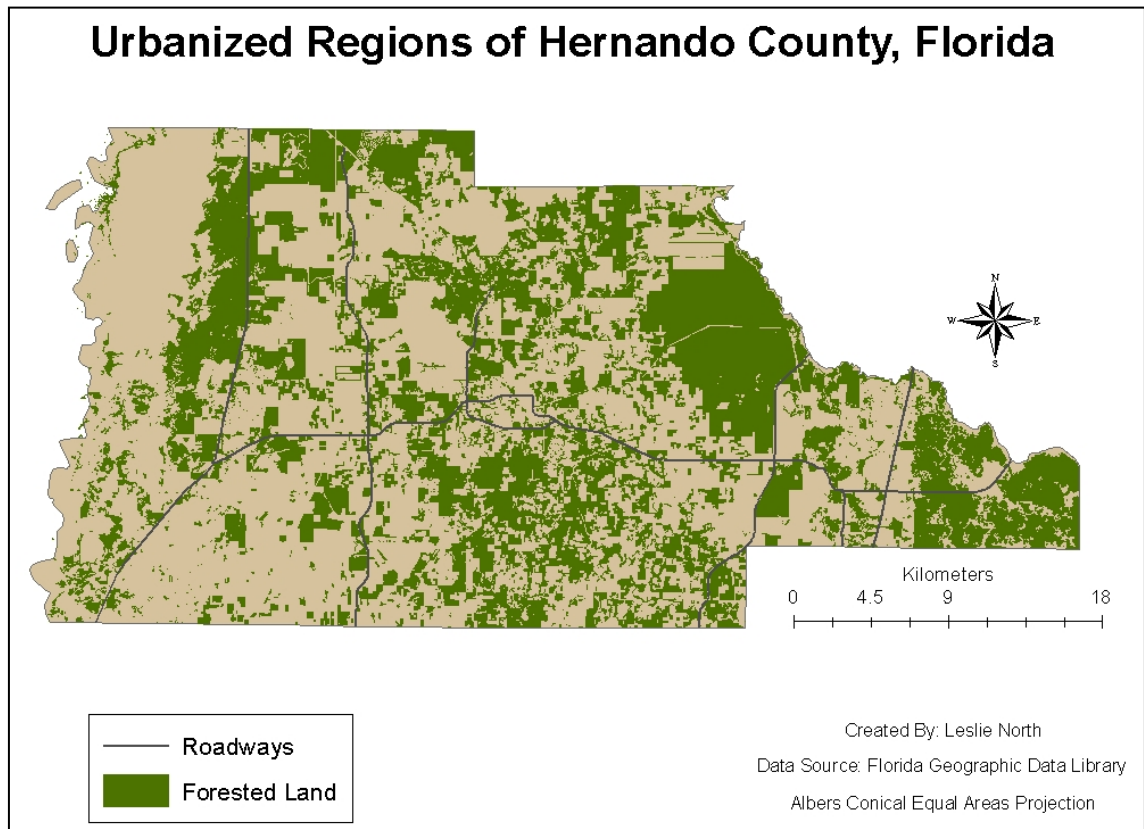


Figure 19. Forested Land in Hernando County, Florida.

Biota – Subsurface Cave Biota

Unlike Pinellas, Hillsborough, and Pasco Counties, the *Species Richness* and *Species Population Density* of subsurface cave biota indicators are applicable in Hernando County. However, even though all Hernando County caves are not submerged, data concerning subsurface cave species is significantly lacking. Therefore the *Species Richness* and *Species Population Density* indicators under the “Subsurface Cave Biota” attribute were each assigned a Lack of Data (LD). These two LD ratings are reflected in this study’s confidence level.

Biota – Subsurface Groundwater Biota

Subsurface biota can indicator the overall health of karst system due to their heightened sensitivity to change. Species richness is the number of species within a given community, while population density is the measure of the number of individuals within each species (Wikipedia 2006). Data concerning species richness and species population density of groundwater dwelling species is lacking in all four TBMA counties.

Unfortunately, the collection of this data requires the monitoring of species for several consecutive years, an undertaking that is beyond the scope of this study. Nonetheless, Pinellas, Hillsborough, Pasco, and Hernando Counties have subsurface groundwater biota that may be disturbed due to human activities, making the *Species Richness* and *Species Population Density* indicators applicable to this study. Therefore, both of these indicators were assigned a Lack of Data (LD) in all four TBMA counties.

Cultural – Human Artifacts

Human artifacts found in karst environments are typically produced with or on the limestone that typifies karst terrains, highlighting the importance of understanding the degree of human-induced disturbance to these artifacts. The scoring for this indicator, which occurs at all scales, is based upon the percentage of historic artifacts removed from the karst terrain.

Destruction or Removal of Historic Artifacts – The removal and destruction of the artifacts from karst terrains determined the scoring for this indicator. The database for historical artifacts, on The Florida Division of Historical Resources Florida Master Site File (Florida Department of State 2005), was utilized to determine areas throughout each

county where artifacts were discovered. Although unflooded caves are not found in Pinellas, Hillsborough, and Pasco Counties, surface sites are still common archaeological sites. Artifacts found in both surface sites and caves were analyzed in Hernando County.

Thus far 420 archaeological sites are uncovered in Pinellas County: 15 middens, 74 mounds, 54 settlements, 16 burial sites, 30 camping sites, and several other miscellaneous archaeological remains. The site file did not indicate if any of the sites were protected, nor did it describe what happened to the artifacts after their discovery (Florida Department of State 2005). However, several of these Pinellas County sites can be visited by the public. These include Arrowhead Middens, Tierra Verde Burial Mound, Canton Street Midden, John's Pass Burial Mound, Weedon Island Mounds, Safety Harbor Mounds, Philippe Park Temple Mound and Middens, and Four Mile Bayou Village, amongst others.

In Hillsborough County, 355 archaeological sites (de Montmollin 1983) are uncovered: 38 middens, 58 mounds, 38 settlements, 2 burial sites, and 1 fishing site. As aforementioned, the Florida Master Site File did not indicate if any of the sites were protected (Florida Department of State 2005). However, Deming (1980) stated 40 percent of these sites are destroyed, a number deemed very low by Dr. Weisman, an University of South Florida anthropologist who conducts research in the county (Weisman, personal communication, 2006).

In Pasco County, 975 archaeological sites are uncovered including 26 middens, 11 mounds, 115 low-density scattered artifact settlements, 230 miscellaneous terrestrial land artifact sties, 7 prehistoric habitats, 239 camping sites, and 109 quarries or lithic scatter. Lastly, 357 archaeological sites are uncovered in Hernando County: 15 middens,

5 mounds, 22 low-density scattered artifact settlements, 4 burial mounds, 67 miscellaneous terrestrial land artifact sites, 27 prehistoric habitats and buildings, 65 camping sites, and 49 quarries or lithic scatter. Again, no information concerning the protection of these sites was available (Florida Department of State 2005).

Dr. Brent Weisman of the University of South Florida Anthropology Department suggests that sites situated on developments described as having regional significance, more than twenty hectares, are not be protected. Large burial mounds are an exception. For an archaeological site to be protected from development it must meet the eligibility requirements for listing in the National Registry of Historic Places or be located within a state or county park (Weisman, personal communication, 2006). Dr. Weisman admits that most of the artifact sites in the TBMA would meet the requirements of the National Registry of Historic Places, but urban development and major roadways destroyed them. For example, no archaeological sites in Hillsborough County have been thorough this long, rigorous process. The most significant site in the county was a large settlement-burial mound complex in downtown Tampa, though very little remains of the site due to commercial development. This situation exists at most Pinellas County sites as well. Overall, little remains of many archaeological sites in the TBMA (Weisman, personal communication, 2006), although Hernando County is not experiencing the rapid urbanization seen in the other TBMA counties.

Cultural – Stewardship of Karst Region

As stated in the van Beynen and Townsend (2005), “the degree of recognition and protection of human and environmental value of karst regions is a measure of human

stewardship” (van Beynen and Townsend 2005, p. 112). Therefore, the following indicators are not only concentrated on the existing regulations and their enforcement, but also the initiatives taken by the counties comprising the TBMA to educate the public on the importance of karst terrains, the sensitivity of karst to human actions, and the steps a person can take to minimize their impact on karst. This stewardship occurs at all scales.

Regulatory Protection – This indicator incorporates laws which prohibit or limit the amount of disturbance to a karst area and laws which regulate aspects of karst features (van Beynen and Townsend 2005). Several Florida Administrative codes directly or indirectly protect karst systems. For instance, Florida administrative code, Chapter 62-522.300(3), “prohibits any discharge through sinkholes that will have direct contact with class G-I groundwater (dissolved solids of < 3,000 mg/L), F-I groundwater (dissolved solids of < 3,000 mg/l that was specifically reclassified as F-I), or G-II groundwater (dissolved solids of < 10,000 mg/l).” Chapter 62-610.523(9) prohibits the direct movement of reclaimed water to underlying aquifers unless total nitrogen is less than 10 mg/l, suspended solids is less than 5mg/l, and the water received no less than secondary treatment and high-level disinfection (Florida Administrative Code, 62-610.523(9)). Under Florida Statute 810.13 vandalizing, defacing, or removing, any cave, cave life, sinkhole, speleogen, or speleothem on public or private property without the written permission of the owner is a misdemeanor crime (Florida Statute 810.13). This law also prohibits the sale of speleothems or storage of any material hazardous to the “waters of the state” within a cave. Under the Federal Cave Resources Protection Act of 1988, caves and cave resources on federal lands are protected as an “invaluable and irreplaceable part

of the Nation's natural heritage" (United States 1988), however Pinellas, Pasco, and Hillsborough Counties do not have any caves on federal lands that receive this statutory protection. Additional national policies that indirectly protect karst areas include the Clean Water Act, Endangered Species Act, Cave Resources Protection Act, and the Federal Insecticide, and Fungicide, and Rodenticide Act (LaMoreaux et al. 1997).

The DEP requires the completion of a karst risk analysis when planning the collection or channelization of storm water, reclaimed water, or effluent that may be introduced to karst systems (van Beynen et al. 2007). If the reports, which are similar to an environmental impact statement, conclude that the karst system may incur damage, the planned construction is ceased. The Florida Legislature established the Florida Forever Program in 1999 to restore environmental systems, including Florida's springs, and increase the amount of protection through the acquisition of conservation areas (FDEP, undated). Ideally, by setting aside more areas for recreational parks, karst environments would benefit. However, in Florida the selection of land for conservation is based upon nomination and population demands, not on any environmental criteria. Nevertheless, the mission of the Hillsborough County Department of Parks is to provide recreation and preservation of resources (Hillsborough County Parks Department).

In 1995, the FDEP implemented the National Pollutant Discharge Elimination System, which requires a permit for the discharge of pollutants into United States waters mainly from industrial and domestic wastewater facilities (USEPA 2003). The same policy regulates hazardous landfill leachate that degrades groundwater quality. Although Florida has reduced the discharges to surface waters since receiving the authorization by 32 percent (USEPA 2003), allowable discharges are still disturbing karst systems.

Although landfill regulations can be considered indirect protection for karst areas since the landfill material can pollute groundwater, the intense monitoring of abandoned landfills is lacking. For instance, there are 162 abandoned landfills that are not monitored by the state in Hillsborough County alone, because Chapter 403.0885 of the Florida Statute (2001), which promotes the establishment and authorization of the NPDES program, was passed after the abandonment of these sites. However, Hillsborough County does monitor groundwater for sixteen landfills, while the City of Tampa is responsible for monitoring 49 landfills. Ninety seven landfills are not considered the responsibility of the City of Tampa or Hillsborough County (Cope, personal communication, 2005).

In addition to the aforementioned regulations at the federal and state level protecting the karst terrain of the TBMA, each county maintains county level regulations. For instance, the Pinellas County Wellhead Protection Ordinance “protects and safeguards the health, safety, and welfare of the residents and visitors of the county by providing criteria for regulating and prohibiting the use, handling, production, disposal, and storage of certain regulated substances which may impair present and future public potable water supply wells and wellfields” (Pinellas County Wellhead Protection Ordinance 1990, p. 4). Pasco County instituted the Groundwater Protection Ordinance to protect the County’s groundwater supplies. The ordinance regulates the handling, production, disposal, and storage of materials hazardous to groundwater supplies (Metcalf and Eddy 2001).

Hernando County exemplifies more karst stewardship than any of the remaining counties comprising the TBMA. The County’s government closely monitors all activities

undertaken within the county, provides the public with karst related data on their website, and continually creates karst related regulations. The GIS department is the leading source of data in the county, providing information on sensitive karst areas within the county by incorporating recharge locations with the locations of golf courses, roads, agricultural fields, and other miscellaneous business using products which could deteriorate groundwater quality. The department also maintains multiple GIS shapefiles pertaining to land use and geologic information on the County's underlying karst, incorporating data from multiple sources including the SWFWMD, FDEP, insurance companies, and the EPA (Sutherland, personal communication, 2007).

Hernando County implemented a Landscaping Ordinance in 2001. This ordinance states that it shall be unlawful for any person, firm, or corporation to clear, redevelop, or begin to develop any land unless in compliance with the terms of the ordinance. These terms describe the required number of trees per acre (15), the number of trees that shall be shade trees, required percentage of preserved natural vegetation (3), required vegetative buffers in feet (5), prohibition of non-native Florida plants, and ground cover requirements (Landscaping Ordinance 2001). The county also maintains ordinances which regulate watering operations and solid waste disposal (Hernando County Utilities Department, undated). Hernando County strongly regulates stormwater runoff, litter, chemical, and organic pollution, through partnership with the EPA and the Hernando County Stormwater Program (Hernando County Department of Public Works Department 2003). Finally, the Hernando County Groundwater Protection and Siting Ordinance protects "the quality of groundwater in Hernando County by providing criteria for land uses and the siting of facilities which use, handle, produce, store or dispose of

regulated substances; and by providing protection to features which discharge directly to the Floridan aquifer” (Groundwater Protection and Siting Ordinance 1994, p.2).

On the whole, the regulations protecting Pinellas, Hillsborough, Pasco, and Hernando Counties, whether they are maintained at the federal, state, or county level, only indirectly regulate karst environments. Moreover, these regulations are not ironclad, with loopholes that allow their circumvention. Thus, despite the presence of policies, the lack of direct karst protection resulted in a disturbance score of one for this indicator.

Enforcement of Regulations – This indicator evaluates the occurrence of regulatory enforcement to determine whether each County’s karst is being protected through the enforcement of the previously mentioned regulations. A 2004 FDEP report on the statistics of statewide civil and criminal enforcement of environmental laws, revealed a 35 percent increase in regulatory enforcement throughout Florida and a ten million dollar increase in fines from 2000 to 2004 (FDEP 2004b). Moreover, in comparison to the previous years, over a thousand more consent orders, an agreement between the violator and the FDEP, were issued statewide during this time period. To determine if an increase in regulation enforcement has occurred in each TBMA county specifically, consent order issued from 1986 to 2005 in each county was collected from the FDEP.

In Pinellas County, a clear increase in the number of issued consent orders can be noted, eleven consent orders were issued in 1986 compared to 62 consent orders in 2005 (*Figure 20*). Comparing the number of consent orders issued from 1986 to 1996 to the number of consent order issued from 1997 to 2005, reveals that the earlier period had an annual average of 21.9 consent orders while the later period had a 39.9 annual average, a

45 percent increase in enforcement. Similarly, an average of 23.21 consent orders were issued from 1986 to 1999, while 45.83 consent orders were issued from 2000 to 2005, the time period discussed in the FDEP publication. This is a 50 percent increase in enforcement. Thus, since enforcement of regulations has increased in Pinellas County since 2000 and as many as sixty consent orders were issued in a single year.

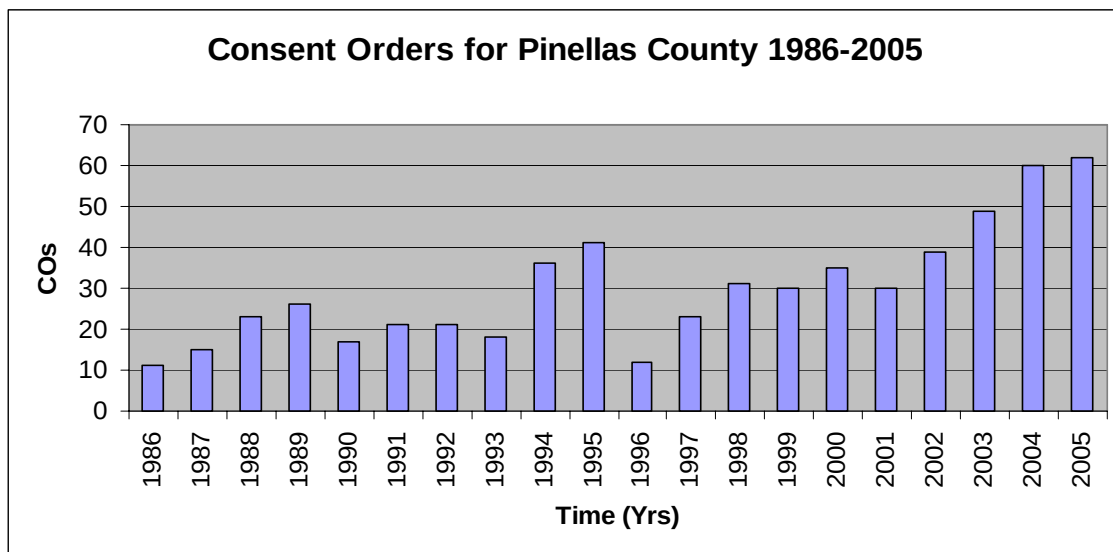


Figure 20. Consent Orders Issued in Pinellas County, FL (1986-2005).

In Hillsborough County, the collected consent order data indicates an increase in the number of consent orders issued from 2000 to 2004 (*Figure 21*); however, the low number of consent orders issued from 1986 to 1999 could simply indicate that either fewer violations occurred in the county or that enforcement was not as strict. Comparing the increase in enforcement from 1986 to 1996 with the period from 1997 to 2005, the earlier period had an annual average of 21.9 consent orders, whereas the period from 1997 to 2005 had an annual average of 22.2 consent orders, a 2 percent increase in enforcement. An annual average of 20.9 consent orders were issued from 1996 to 1999,

while an average 24.4 consent orders were issued annually from 2000 to 2004; this is only a 14 percent increase in enforcement. Overall, there was not an increase in enforcement as claimed in previously mentioned FDEP report on the agency's statistics and no year had higher than thirty issued consent orders.

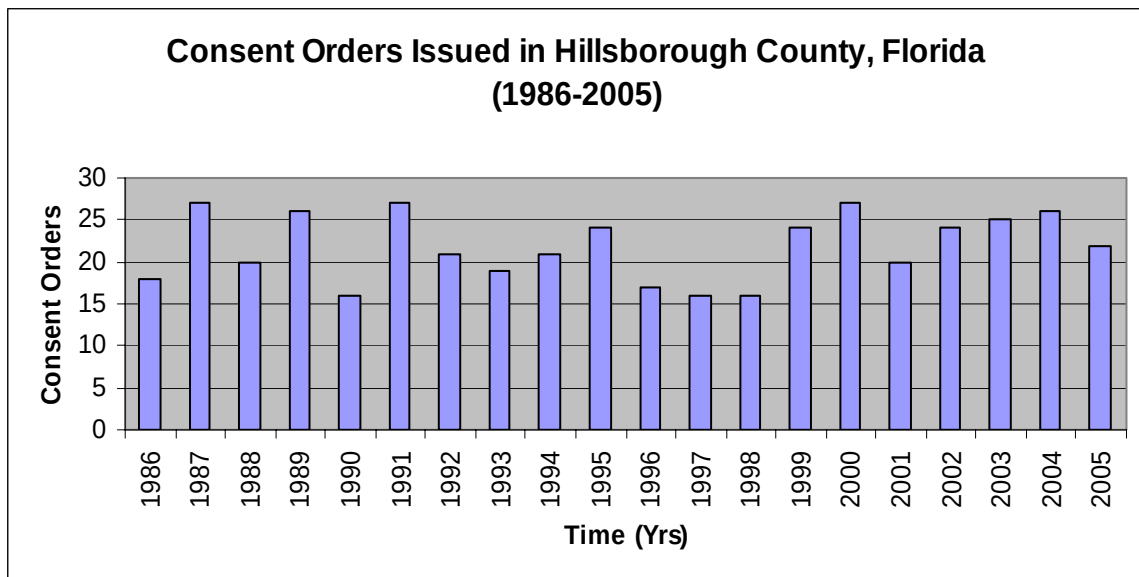


Figure 21. Consent Orders Issued in Hillsborough County, FL (1986-2005).

No clear increase in issued consent orders occurred in Pasco County from 1986 to 2005; in fact, there was a decrease in issued consent order during this time (*Figure 22*). From 1986 to 1996 the average number of issued consent orders was 12.36, while 1997 to 2005 had an average of 10.54 consent orders. Similarly, when comparing consent order data from 1986 to 2000 to data from 2000 to 2005, a decline in enforcement was deduced. From 1986 to 2000 the annual average of issued consent orders was 12.7, while 2000 to 2005 had an annual average of 12.1 consent orders. Moreover, the number of consent orders issued in a single year only fluctuates from six to eighteen over the nineteen year span.

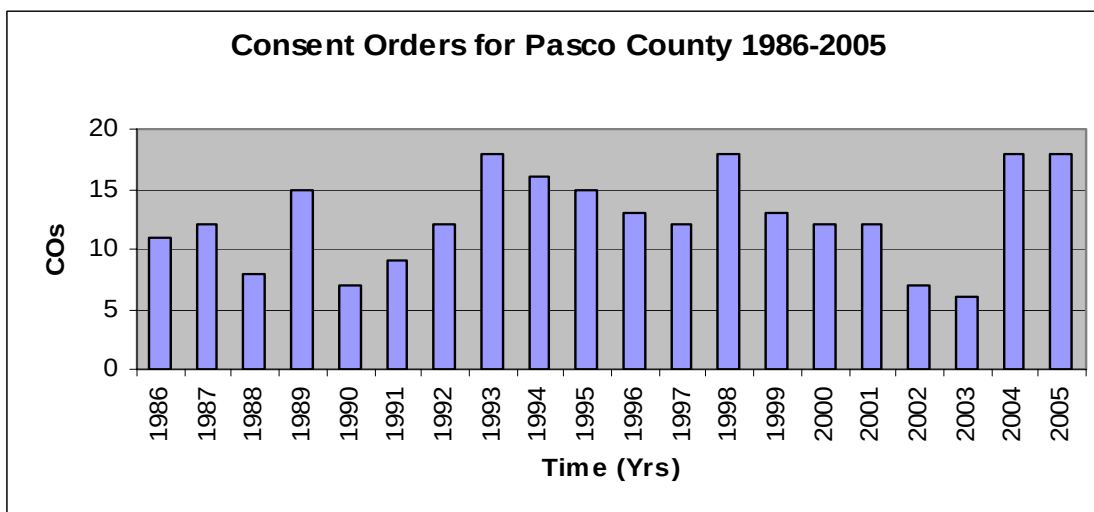


Figure 22. Consent Orders Issued in Pasco County, FL (1986-2005).

In comparison to the years prior to 2000, a 45 percent increase in issued consent orders occurred in Hernando County from 2000-2005 (Figure 23). From 1986-1999 the average number of issued consent orders was 4.2, while 2000-2005 had an average of 7.2 consent orders. However, the number of consent orders issued in the county only fluctuates from zero to twelve over the nineteen year span, indicating that either few violations occur in Hernando County or that enforcement of regulations is not strong.

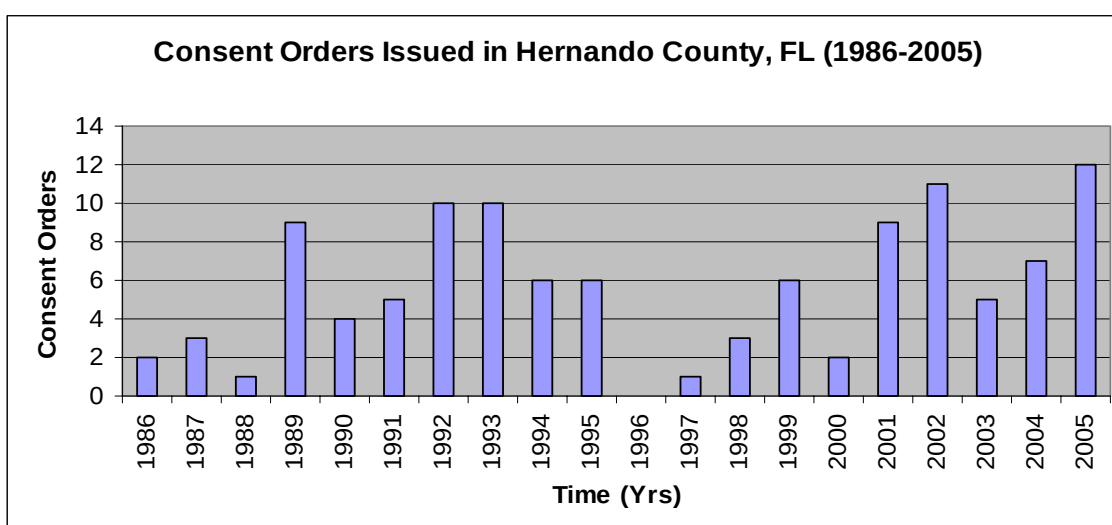


Figure 23. Consent Orders Issued in Hernando County, FL (1986-2005).

Public Education – Public awareness of karst sensitivity and protection practices are necessary to minimize karst disturbance. Therefore, this indicator analyzes the roles of governmental and non-governmental programs that directly or indirectly protect karst environments (van Beynen and Townsend 2005). Collaboration between the University of South Florida and SWFWMD produced *The Linked Resources for Community Education in Hydrogeology*. This project teaches residents about sinkholes, the hydrologic system, stormwater runoff, and Florida-friendly vegetation (SWFWMD, undated). SWFWMD also created The Neighborhood Environmental Action Team to report environmental violations and collect non-hazardous materials for proper disposal. The University of Florida's IFAS produced the *Florida Solid and Hazardous Waste Regulation Handbook*. This handbook outlines the proper storage and disposal methods for oil, tires, batteries, and pesticides (Olexa et al. 2003). The Karst Research Group at the University of South Florida is also active in the TBMA (Karst Research Group 2005).

Entertainment-based programs are also responsible for educating the public on the importance of protecting karst environments. WUSF-TV and PBS repeatedly airs *Water's Journey: the Hidden Rivers of Florida*, a SWFWMD documentary focusing on the local aquifer (Karst Productions Inc. 2004). The City of Tampa Water Department runs water conservation programs for K-12 grade TBMA students. The city also funds CTTV Water Conservation Plays, which educates children on the importance of water conservation (City of Tampa 2005). The FDEP website promotes an educational program for third to fifth graders to develop a model of how pollutants can alter water quality (FDEP 2005). Lastly, the Hydrogeology section of the FDEP produced an interactive video on human-induced threats to Florida's springs and aquifer (FDEP 2005).

Each county also operate several programs designed to protect various aspects of the local karst environment. The Environmental Management section of the Pinellas County Government runs the Pollution Prevention and Resource Recovery program to assist citizens with the reduction of their use of hazardous and toxic materials (Pinellas County Government, undated (b)). The City of St. Petersburg produces *Mr. Sparkle and the Recyclables*, a handbook listing recyclable items and the proper steps to creating a home recycling center (St. Petersburg Government, undated). On the Pinellas County Government website, parents can download the *Hydroblast Coloring Book*, *Recycling Activity Book*, *Lewey the Lizard Presents the Wet Gazette*, and *M. Phibian Frog's Stormwater Pollution Coloring Book and Puzzles*. These activity books are designed to teach children about reclaimed water, recycling, water conservation, and stormwater pollution (Pinellas County Government, undated (c)).

In Hillsborough County, the City of Tampa Solid Waste Department is very active in its public education efforts, producing brochures listing hazardous waste materials and disposal methods (City of Tampa 2005). The Special Projects Department of the Pasco County Government maintains several environmental and hazardous waste programs such as the Anti-Freeze Recycling, Paint Recycling, and Used Motor Oil Recycling programs. These programs are all aimed at protecting human health and the environment (Pasco County Government, undated (a)). The government also leads the Purple Rain Education Program designed to educate the public on the benefits, use, and availability of reclaimed water (Pasco County Cooperative Extension Service, undated). Lastly, educational games, such as the *Water Busters Conservation Game*, are available on the Pasco County Government website (Pasco County Government, undated (b)).

The Hernando County Government also promotes several public education programs. The Hernando County Department of Public Works website contains numerous brochures concerned with educating the public on the importance of preventing stormwater pollution, watersheds, the dangers of herbicides and pesticides, and how to become a part of the “pollution solution” (Hernando County Public Works Department, undated). Similarly, the County’s Solid Waste and Recycling Division website contains public guidebooks on recycling, household hazardous wastes, and pollution prevention. This department also holds Household Hazardous Waste Collection Days, which allow Hernando County citizens to dispose of household hazardous waste for free (Hernando County Utilities Department, undated). The Citizens for Water Committee, a branch of the Hernando County Utilities Department, consists of three working committees designated to inform the public on the need to conserve and protect precious water resources. The committee continually hands out brochures, sends questionnaires in customer bills, attends public venues, holds public meetings, and broadcasts information on local cable channels. Their website also contains a “calculate your water usage game” (Citizens for Water, undated). Sadly, other than the karst documentary *Water’s Journey: The Hidden River’s of Florida* (Karst Productions Inc. 2004) and the Florida DEP’s interactive video on human threats to Florida’s springs (Florida DEP 2005), entertainment-based educational programs are unavailable in Hernando County.

Although varying agencies attempt to educate the public on environmental hazards, these educational programs are not strongly promoted. Moreover, the information within educational publications largely reaches citizens who actively seek it

or who are already aware of the importance of environmental protection. Consequently, this indicator was assigned a disturbance score of one in each TBMA county.

Cultural – Building Infrastructure

Urbanization results in the building of houses, malls, industrial parks, and apartment complexes. During this process, sinkholes are infilled, negatively impacting karst features. The building of roads over karst areas can also compact soil, increase surface flooding, and lower aquifer recharge rates (van Beynen and Townsend 2005). Large highways, which cover the largest area and contribute the largest quantity of contaminated stormwater runoff to groundwater, induce the highest level of disturbance to karst terrains. The indicators that follow evaluate these human-induced disturbances by estimating the current degree of urbanization in each TBMA county.

Building of Roads – In Pinellas County there are two interstate highways and 31 major roads with at least six lanes divided by a median (Pinellas County Metropolitan Planning Organization 2005). *Figure 24* shows Pinellas County’s interstate highways and major roads. *Figure 25* shows the major roads and highways in Hillsborough County. There are three interstate highways and 34 major roads with eight lanes divided by a median in the county (Hillsborough County Transportation Division 2005).

Pasco and Hernando Counties do not have as many major roads as the remaining counties comprising the TBMA. In fact, Pasco County only has one interstate highway and seven major roads with at least six lanes divided by a median (Pasco County Metropolitan Planning Organization 2004). *Figure 26* shows the location of these roads. There are two interstate highways, I-75 and the Suncoast Parkway, and four major roads

with at least six lanes divided by a median in Hernando County (Diez, personal communication, 2007). *Figure 27* shows the locations of Hernando County's major roads and highways. Overall, although these counties do not contain as many major roads and highways as the remainder of the counties comprising the TBMA, major highways are in existence within the each county, leading to a disturbance score of three.

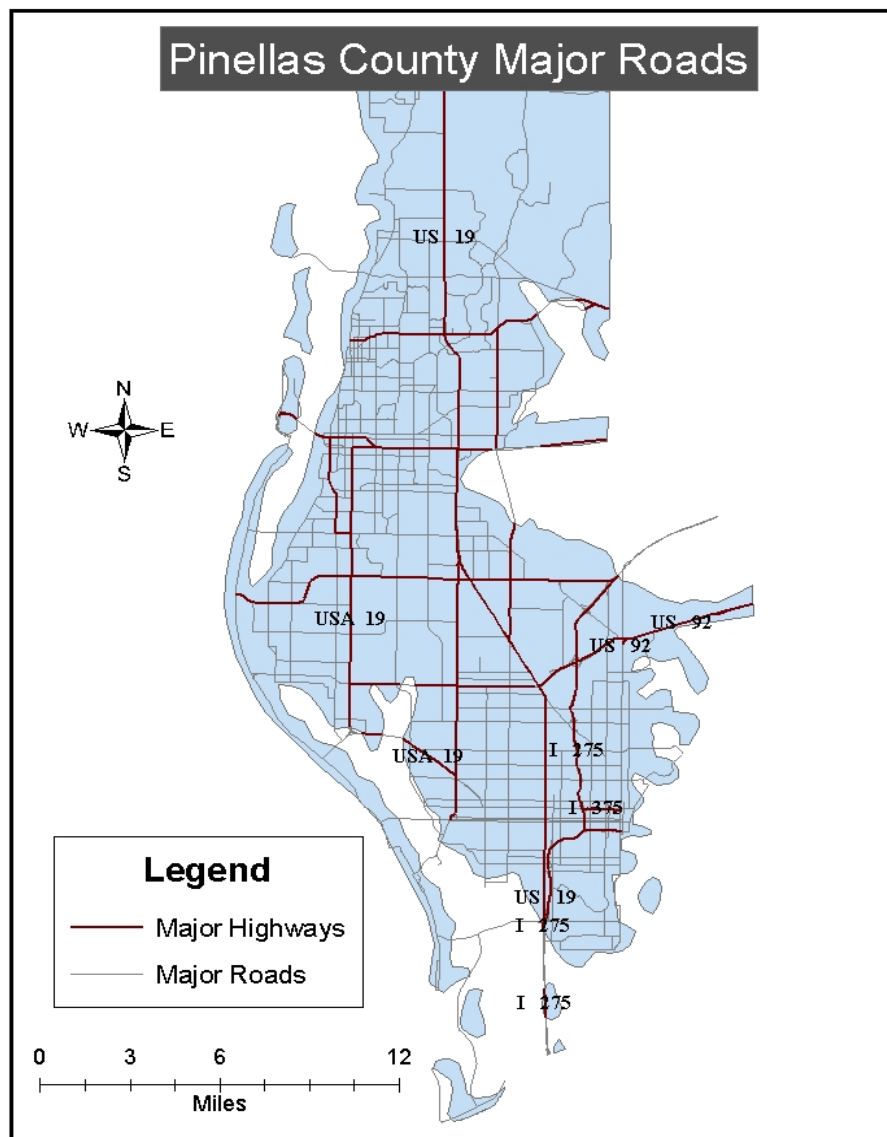


Figure 24. Major highways in Pinellas County, Florida.

Major Roads in Hillsborough County, Florida

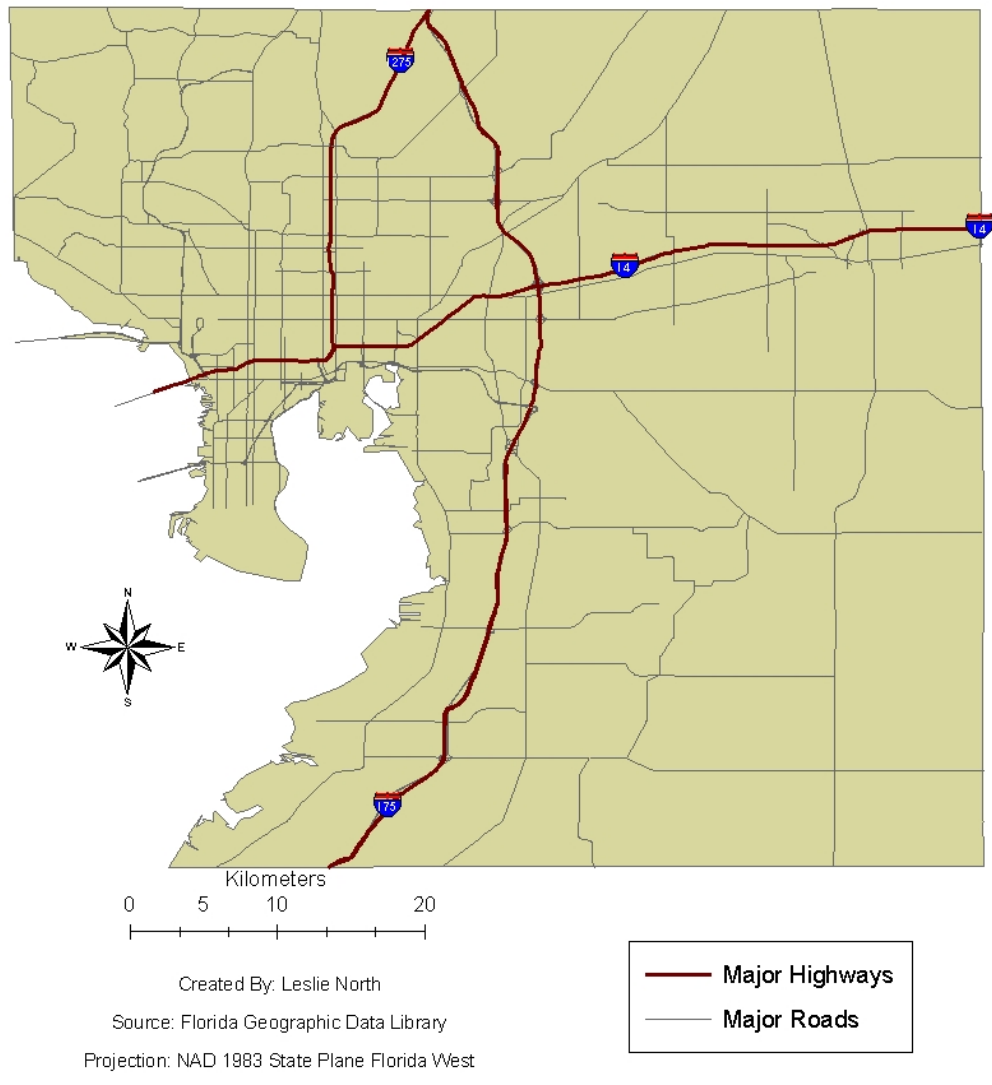


Figure 25. Major Roads in Hillsborough County, Florida.

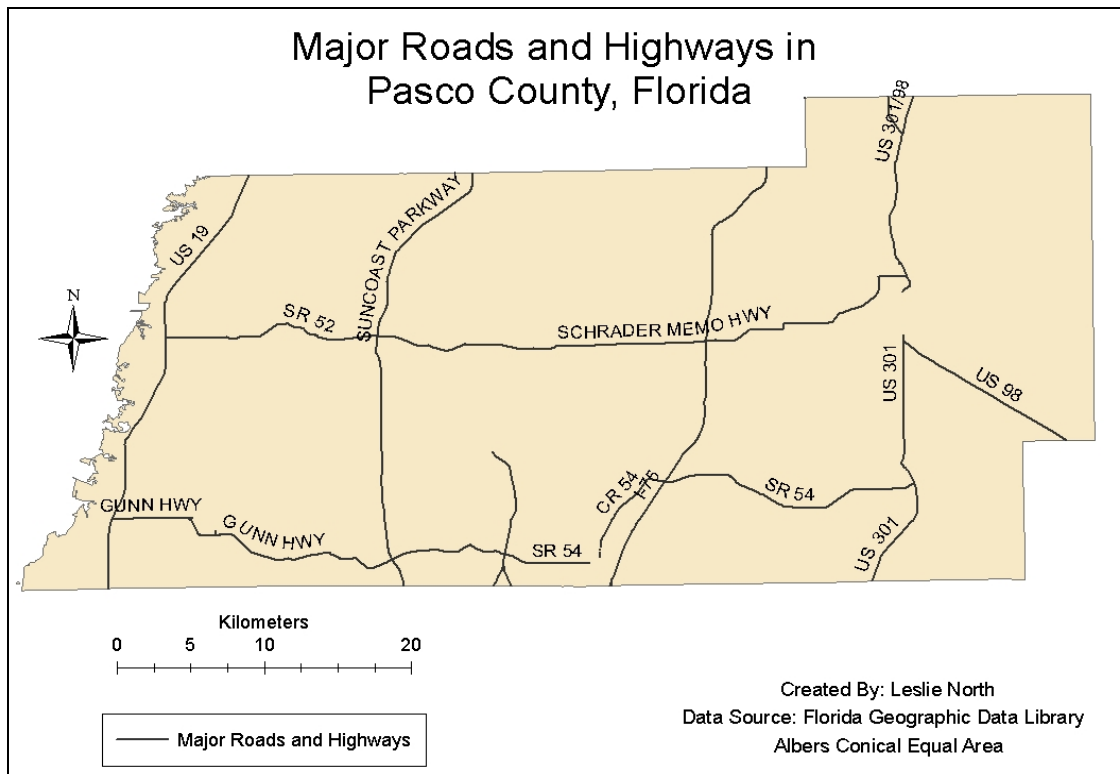


Figure 26. Major Roads and Highways in Pasco County, Florida

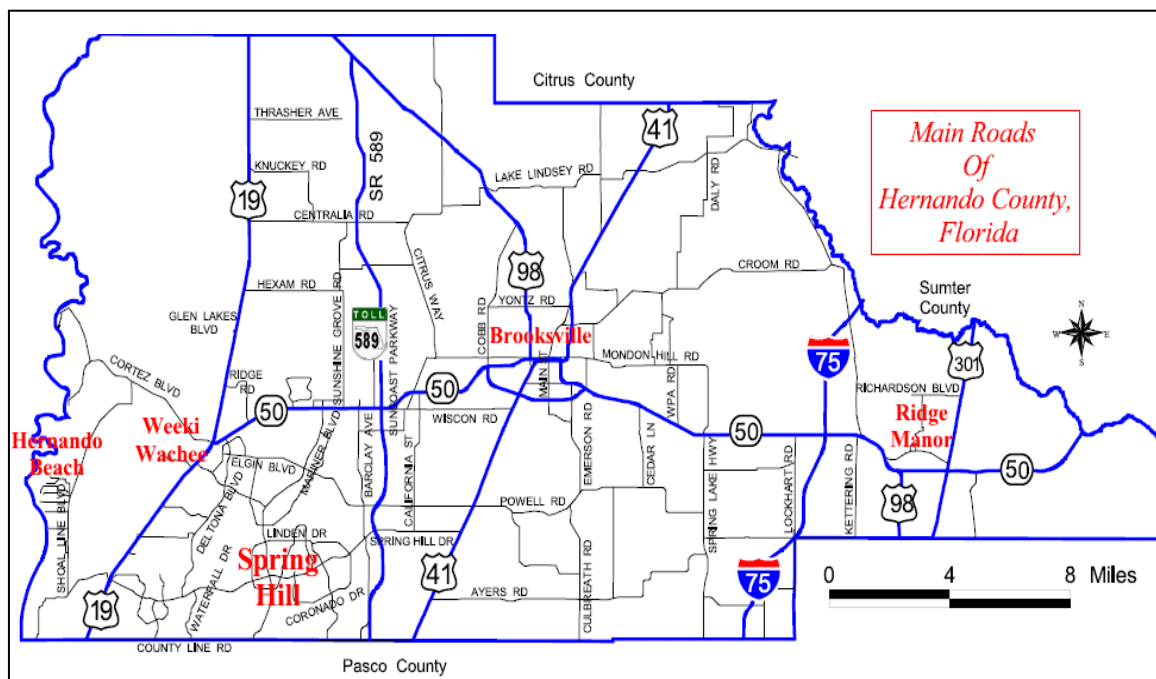


Figure 27. Major Roads and Highways in Hernando County, Florida. (Hernando County Government Planning Department Website, taken on 3/07/2007).

Construction within Caves – All known caves in Pinellas, Hillsborough, and Pasco Counties are submerged, making construction impossible. Thus, despite some caves containing a few non-obstructive underwater markers that are utilized by cave divers, this indicator was removed for this study when analyzing these three counties. Even though all known caves in Hernando County are not submerged, construction within the County's caves has not occurred. However, Hernando County's caves are gated. Therefore, a disturbance score of one was assigned to this indicator.

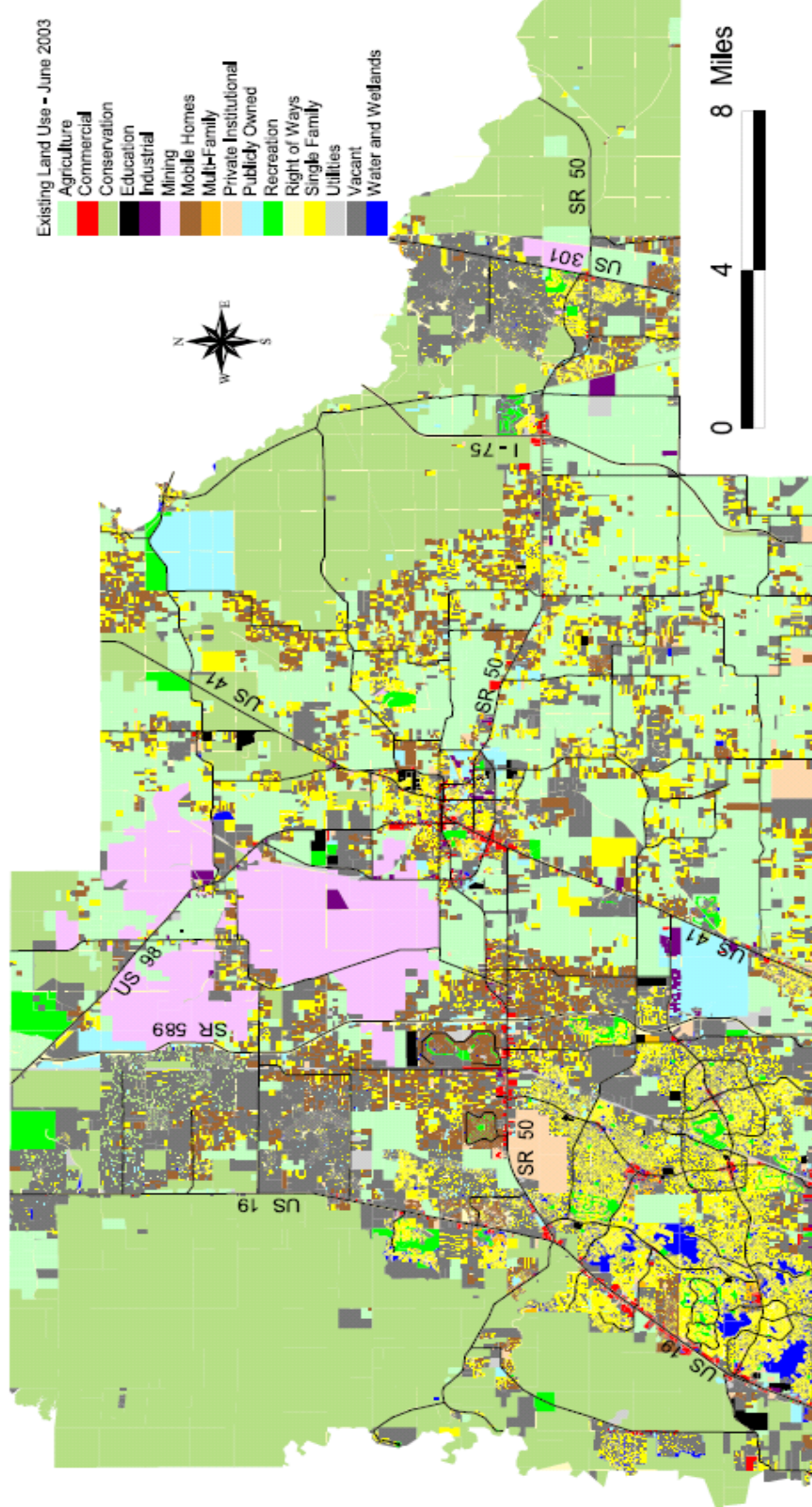
Building over Karst Features – At the beginning of the twenty-first century, approximately 921,482 permanent residents lived in Pinellas County. The population rose to 928,032 by 2005 (United States Census Bureau 2006). Moreover, the population density of Pinellas County ranks 30th amongst all counties in the United States (KnowledgePlex 2007). The largest percentage of the County's land is devoted to low density housing, while low buildings dominate urbanized centers. According to the Pinellas County Planning Department (2003), Pinellas County will be the first county in Florida to achieve buildout.

In 2002, Hillsborough County had a population density of over 405 people per square kilometer (US Census 2005a). In 2003, approximately 45 percent of the County's 2,729 km² of land was urban. Moreover, the county experienced a 5.9 percent increase in home construction between 2000 and 2002 alone (Floyd 2003). In fact, about 9,100 new homes were built between 2000 and 2004 (US Census 2005b). In 2005, a total of 1.1 million people were permanent residents in the county. *Figure 13* shows the County's current urban areas.

In 2005, there were 429,000 permanent residents in Pasco County; this is a 25 percent increase from 2000 (US Census Bureau 2005c). The largest percentage of the County's land is devoted to agriculture, leaving approximately fifty percent of area's land unurbanized. The population density of Pasco County is 500 people per square kilometer (West Pasco Chamber of Commerce 2006).

Hernando County is not currently undergoing the rapid growth and urban sprawl seen in the remainder of the counties comprising the TBMA; in fact, the County's estimated annual growth rate in recent years is only five percent (Hernando County Government 2006). During the 1980s the county was the third fastest growing county in the United States. By the 1990s the population growth rate decreased by approximately 40 percent; however, the number of new homes built in Hernando County during this time period ranked eighth amongst the remainder of Florida's counties (Tampa Bay Demographics 1995). In 2005, there were 156,000 permanent residents in the county, for a population density of 106 people per square kilometer (Hernando County Government 2006). *Figure 28* summarizes Hernando County's land use in 2003.

Existing Land Use* - Hernando County, FL



* Source: Hernando County Property Appraiser - FL Department of Revenue (DOR) Codes

Figure 28. 2003 Land Use in Hernando County, Florida. (Hernando County Planning Department 2003, taken on 03/15/2007)

Degrees of Disturbance and Levels of Confidence

Table 7 summarizes the disturbance scores assigned to each indicator and the total degree of disturbance in each county. This is followed by an explanation of the total degree of disturbance calculated for each county.

Table 7. TBMA Indicator Scores.

Indicator	Pinellas	Hillsborough	Pasco	Hernando
Quarrying/Mining	0	2	1	2
Surface Flooding	1	1	1	1
Stormwater drainage	1	1	1	1
Infilling	3	2	2	2
Dumping	2	2	2	2
Erosion	1	1	1	1
Soil Compaction	3	3	2	2
Decoration Removal	-	-	-	2
Mineral Removal	-	-	-	1
Floor Compaction	-	-	-	1
Desiccation	-	-	-	1
Condensation corrosion	-	-	-	1
Pesticides and herbicides	2	2	2	2
Industrial/petroleum Spills	1	1	1	0
Chemical constituents in springs	2	2	2	2
Changes in water table	3	2	2	2
Changes in cave drip waters	-	-	-	1
Vegetation removal	3	3	1	2
Species richness	-	-	-	LD
Population density	-	-	-	LD
Species richness	LD	LD	LD	LD
Population density	LD	LD	LD	LD
Destruction of historical artifact	3	3	2	2
Regulatory protection	1	1	1	1
Enforcement of regulations	0	1	1	1
Public Education	1	1	1	1
Building of roads	3	3	3	3
Building over karst features	3	3	3	2
Construction in caves	-	-	-	1
Total Indicator Score (A)	33	34	29	37
Total Possible Score (B)	54	54	54	75
Level of Disturbance (A/B)	0.61	0.63	0.54	0.49

Degree of Disturbance: Pinellas County, Florida

A total indicator score of 33 out of a possible 54 was calculated for Pinellas County, resulting in a total karst disturbance score of 0.61. This value equates to a *highly disturbed* karst area (van Beynen and Townsend 2005). Two indicators received a “Lack of Data” designation: *Species richness* and *Population density* under the biota category. As outlined in van Beynen and Townsend (2005), the number of “Lack of Data” indicators divided by the total number of assessed indicators reflects the confidence level of the total karst disturbance score. Confidence scores less than 0.1 signify a high degree of confidence in the total disturbance score, where as scores greater than 0.4 suggest more research is needed before the application of the index is plausible. Only 2 out of 20 indicators evaluated in this study received a “Lack of Data” score. Thus, the confidence level for this study’s results is 0.1, signifying a high degree of confidence in the estimation of Pinellas County’s level of karst disturbance.

Degree of Disturbance: Hillsborough County, Florida

A total score of 34 out of a possible 54 was calculated for applicable indicators in Hillsborough County, indicating that the County’s karst is *highly disturbed* with a total disturbance score of 0.63. It is worth noting that this score is only slightly higher than the score calculated for Pinellas County. Two indicators received a “Lack of Data” designation: *Species richness* and *Population density* under the biota category leading to a confidence score of 0.1, signifying a high degree of confidence in the estimation of Hillsborough County’s level of karst disturbance as well.

Degree of Disturbance: Pasco County, Florida

A total indicator score of 29 out of a possible 54 was calculated for Pasco County, resulting in a total karst disturbance score of 0.54. This value equates to a *disturbed* karst region (van Beynen and Townsend 2005). Five indicators received a lower score in Pasco County than in Pinellas County: *Vegetation removal*, *Building over karst features*, *Changes in the water table*, *Soil compaction*, the *Infilling of sinkholes*. This led to a score 0.09 points lower than the Pinellas County disturbance score. As with the previous counties, the *Species richness* and *Population density* indicators under the biota category were assigned a “Lack of Data,” resulting in a confidence level of 0.1 for this County’s disturbance score. This signifies a high degree of confidence in the estimation of Pasco County’s level of karst disturbance.

Degree of Disturbance: Hernando County, Florida

A total indicator score of 37 out of a possible 75 was calculated for Hernando County, resulting in a total karst disturbance score of 0.49. Similar to Pasco County, this score equates to a *disturbed* karst area (van Beynen and Townsend 2005). As opposed to the previous counties, four indicators received a “Lack of Data” designation: *Species richness* and *Population density* under the subsurface cave and subsurface groundwater attributes. By dividing the total evaluated indicators, 29, by the number of indicators receiving a “Lack of Data” designation, four, resulted in a confidence level of 0.14. Thus, the degree of confidence in the estimation of Hernando County’s level of karst disturbance is high.

Participant Interviews

As previously described, qualitative interviews were conducted with eight key informants. Four informants worked at a district level, holding positions in resource conservation (*informant A*), development (*informant B*), planning (*informant C*) and resource conservation data development departments (*informant D*). Three informants worked at the county-level in Hillsborough and Hernando Counties Government Offices as an urban forester (*informant E*) and community planners (*informants F and G*).

Informant H, held a state-level position at the Florida Geological Survey. Recall that the informants were questioned on the utility of the KDI in their jobs, suggestions for making the KDI a more practical tool to employ outside of the academic community, whether or not karst knowledge is incorporated into their jobs, and their opinions on the use of qualitative and quantitative data. What follows is an abbreviated description of the information obtained from these informants as a collective whole.

Each informant reported that they incorporate knowledge of karst into their work. For instance, *informant A* is often involved in collecting, designing, constructing, and testing monitor wells in west-central Florida. Nearly all of these wells are drilled into “karstic carbonates.” Similarly, *informant F* continually collects information on groundwater recharge from sinkholes when evaluating proposed developments. Other informants incorporated knowledge of karst when analyzing spring water quality, establishing nutrient remediation plans designed to address the issue of increasing nitrogen levels in springs, and monitoring groundwater resources.

Despite the incorporation of karst knowledge into every informant’s work, all participants did not have formal training or education in karst science. *Informant C* stated

their “broad, yet shallow” knowledge of karst concepts and issues was gained while working towards a degree in Natural Resource Economics. Likewise, *informant F* revealed that, despite being a professional geologist, they never received any specialized training in karst. *Informant G* received training in karst through courses offered by the county government. The remaining informants each reportedly have extensive training in karst obtained through completed courses on Karst Hydrogeology in Florida at local scholastic institutions, hydrogeology field camps, or courses completed with “premier karst scientists working in the Western Hemisphere,” including William White.

Informants responded differently when asked whether or not the KDI could be useful in their work. *Informant A*’s work largely deals with land parcels usually too small to evaluate using the KDI. Instead, this informant believes the KDI would be useful to workers in regulation departments who make decisions about granting permits for large scale land use or workers who study land parcels for purchase or protection in land resources department. *Informants C, F, and G* stated that the KDI would not be useful in their day-to-day work, but on an occasional basis when needing to identify areas where a rule or activity would cause potential improvements or harm. Lastly, *informants B, D, E, and H* all agreed that the KDI could be useful in their jobs, but only after some slight modifications. These included incorporating more information on the vulnerability of the area to specific disturbances, adding indicators concentrated on water quality and petroleum spills, and narrowing total disturbance categories to better reflect small regional differences.

When asked what information should be incorporated into the KDI to increase its usefulness, *informants F, A, and C* stated that they weren’t sure what should be

incorporated into KDI. *Informant C* did state that the most useful aspects of an index to their work would include information on spring flow, water quality, and sinkhole formation. *Informant E* stated that a short explanation of the KDI explaining who should use it and why, would be invaluable when attempting to expand its use outside of the academic community. As an example, this informant stated that the KDI could be very useful to agencies such as the Department of Environmental Protection, but only if there is a short explanation of the use of the KDI, so agency employees would not have to read the entire van Beynen and Townsend (2005) publication. *Informants B* and *G* believed that the KDI was sufficient “as is” as an educational tool. *Informant B* also stated that in work at the district level, the KDI would be more useful if it was adaptable in order to address any additional concerns a region may be facing. For instance, in west-central Florida, spring flow reduction for coastal springs used by manatees, the freshwater component of discharging brackish water, and stormwater drainage into spring pools are major issues that could be addressed by the KDI. *Informant D* believes that private property rights, the number of petroleum tanks underground, paleontological remains that are an invaluable scientific resource often found in caves, changing groundwater hydrology through the recontouring of land, and the liming of soil to improve crop production by altering pH should all be considered. *Informants D* and *H* thought the simplicity of the total disturbance scores is nice, but may be more useful if more disturbance levels were incorporated to better reflect subtle differences between regions. *Informants A* and *H* reported that the terminology of the total disturbance classifications is misleading and should be changed. This suggested change includes switching the “disturbed” and “moderately disturbed” classifications. Lastly, five informants

commented positively on the inclusion of Lack of Data ratings, stating that although enough data to quantify an indicator may not be available, it is still necessary to document its potential impact on karst.

The remainder of the information obtained from the informants focused on the use of quantitative and qualitative data when applying the KDI. Every participant overwhelming agreed that qualitative data is invaluable when assessing human-induced disturbances, but quantitative data should be emphasized. All informants also reported very similar definitions of qualitative and quantitative data. Qualitative data was described as non-numerical data deduced from simple observations. As stated by *informant D*, “qualitative data is the first step to getting an impression that will lead to causality.” In contrast, quantitative data was described as numerical data without subjectivity. Each informant uses both qualitative and quantitative data in their work.

Chapter Five

Discussion

Human Disturbance of Karst in the TBMA

The application of the KDI allowed for the identification of the most threatened components of the karst terrain in the TBMA. Overall, levels of disturbance vary between the counties due to the level of urbanization, with the highly populated Hillsborough and Pinellas Counties having higher degrees of disturbance than less developed Pasco and Hernando Counties. This is reflected in the differing degrees of disturbance determined for each county. The karst in Hernando County is *disturbed* with a disturbance score of 0.49, while Pasco County is also *disturbed* with a score of 0.54. Hillsborough County is *highly disturbed* with a total disturbance score of 0.63. Pinellas County is also *highly disturbed* with a total disturbance score of 0.61. While this result may seem obvious, the measure of disturbance using many indicators provides benchmarks of levels of disturbance that can be reassessed with time and highlights those aspects of the environment under the greatest stress and in the most need of attention. For instance, although Pinellas County is slightly more urbanized than Hillsborough County, Hillsborough County surprisingly had a higher total disturbance score. After analyzing individual indicator scores, it was deduced that this difference in disturbance scores is due in large part to the destructive nature of mines and quarries present in Hillsborough County and not Pinellas County. Thus, the KDI is a useful and user-friendly tool that

provides organizations with an opportunity to holistically analyze a karst terrain in a systematic and standardized manner.

The Infilling of Sinkholes, Soil Compaction, Changes in the Water Table, Vegetation Removal, Destruction of Archaeological Sites, Building of Roads, and Building over Karst Features indicators are the main factors influencing the scoring difference between the four counties. Each of these indicators scored a severe disturbance score of three only in the more urbanized regions. Pinellas County consistently scored the highest with respect to each of these indicators, demonstrating that urbanization is one of the most influential factors in karst disturbance.

The *Building of Roads* indicator received a severe disturbance score of three in each county, further illustrating the impact of urbanization on karst terrains. However, the number of major roads and highways in the less urbanized counties was significantly lower than those present in the two more urbanized counties. Multiple major roads and highways are necessary to accommodate the large driving populations seen in Hillsborough and Pinellas Counties. As precipitation travels over these roads, it becomes contaminated with oil, heavy metals, and other pollutants. Some of this contaminated water eventually reaches the underground aquifer. Thus, the karst aquifer underlying these two counties is polluted from high quantities of contaminated stormwater runoff (SWFWMD 2005), the source of which is directly linked to each County's sizeable driving population. Moreover, the urban sprawl seen in each of these counties has spurred the building of continually larger roads to accommodate large quantities of commuters.

The *Changes in the Water Table* indicator received a score of three only in Pinellas County. The other TBMA counties received a score of two. However, the reason

for the decline in the water table differs between the less urbanized and more urbanized counties. In Pinellas and Hillsborough Counties the decline in the water table occurred largely as a result of over-pumping for municipal drinking water supply. As the population of Pinellas and Hillsborough Counties grew, municipalities required the extraction of larger quantities of drinking water to sustain the population. Due to the excessive use of the karst aquifer underlying Pinellas County, the aquifer is no longer capable of supplying freshwater to the County's citizens. In Pasco and Hernando Counties the pumping for municipal supply lead to a small decline in the water table. The other causal factor is the extraction of groundwater for agriculture. Thus, this indicator helps to demonstrate the impact of not only urbanization, but also agricultural practices.

Massive deforestation in Pinellas and Hillsborough Counties, originally the result of agriculture practices, is now a consequence of urban construction. Vegetation is important for the karstification process. Moreover, vegetation decreases soil erosion rates by reducing rain-splash (Sauro 1993). Despite the importance of vegetation on karst terrains, 95 percent of both Pinellas and Hillsborough County's forested lands are destroyed. These lands are now replaced by buildings, houses, and roads (Pinellas County Metropolitan Planning Organization 2005). In Pasco and Hernando Counties, only 34 percent of the forested lands are destroyed, due in large part to the presence of the Withalcoochee State Forest.

Overall, through use of the KDI, each of the above indicators was able to highlight the areas of concern in the TBMA and the factors to closely monitor as Pasco and Hernando Counties continue to grow. This concern is generated by large increases in population. The human footprint and subsequent increasing environmental impact on the

TBMA's karst terrain is spurred by the growth of new suburban development.

Agriculture preceded the urban sprawl in each TBMA county. However, it had a lesser impact on the karst terrain (van Beynen et al. 2007).

The *Public Education* and *Regulatory Protection* indicators received a score of one, as opposed to zero. Regulations and programs in each TBMA county do not apply directly to karst environments, making it difficult to determine which laws and public awareness plans pertain to karst stewardship problematic. This study revealed that county officials should focus on karst education and protection, specifically, to increase stewardship in the area.

Lastly, the KDI revealed that the characteristics of differing karst environments determine the karst features more prone to disturbance. For example, the TBMA is a region riddled with sinkholes. As such, indicators concentrated on sinkholes, such as the *Infilling of Sinkholes* and *Dumping of Refuse into Sinkholes* received significantly higher disturbance scores than indicators concentrated on caves. Only one county in the TBMA, Hernando County, contains vadose cave systems. These systems are generally small and, therefore, are not utilized as tourist attractions or frequently visited by local cavers. Thus, these TBMA karst features are not particularly impacted. Other regions have fewer occurrences of sinkholes and larger cave systems. In these regions, the KDI may reveal that cave-related indicators, such as *Condensation Corrosion*, *Destruction of Decorations*, and *Floor Sediment Compaction*, are more readily impacted than sinkholes or may be as disturbed as the sinkhole-related indicators.

Utility of KDI and Recommendations for its Refinement

The application of the KDI in the TBMA not only provided an opportunity to identify the most threatened aspects of the karst terrain of the TBMA, but also allowed for the index's refinement. Although data was readily available for most environmental indicators of the index, several minor issues arose during its application to the TBMA. For example there is a need for broader indicator descriptions that encompass a variety of scenarios, a new water quality indicator, obsolete data on sinkholes, and a lack of data for biota indicators. Each of these issues will be individually discussed below.

Eighty-nine percent of the indicators applicable to this study had sufficient data to determine levels of disturbance. This led to a high degree of confidence in the accuracy of the total disturbance scores calculated in each TBMA county. However, the use of the KDI revealed a lack of current data for certain indicators. This lack of data suggests where future research efforts can be directed; for the TBMA region this includes species richness and population density of subsurface cave and groundwater biota. As previously discussed, the counties of the TBMA have a degraded aquifer. However, issues arising from the degradation of this aquifer may affect more than drinking water supplies; the ecosystems of each County's fragile subsurface biotic life may be in decline.

Unfortunately, little is known about the biota of karst systems, representing a problem with karst research in general, not a short-coming of the index. However, the OECD's and IDRC's indicator guidelines state that indicators should be consistent and reproducible. Thus, the insufficient data for these indicators presents a problem for the comparable application of the index (van Beynen et al. 2007). Nonetheless, these indicators should remain in the index, even though they are likely to continually receive a

LD rating because only developed areas such as North America and Europe will have the necessary data available to evaluate these indicators. Otherwise, the destruction of subsurface biota may continue to be indirectly endangered in many regions.

The quality of and inconsistency in data related to sinkhole locations and status held by state and local agencies increased the difficulty of determining a disturbance score for the *Infilling of Sinkholes* and *Dumping of Refuse into Sinkholes* indicators. The Florida Sinkhole Research Institute at the University of Central Florida once maintained a database which provided valuable data on sinkhole occurrence in the state. However, due to insufficient funding, the program dissipated. The Florida Geological Survey currently maintains the database. However, some of the sinkholes reported in the database are from insurance claims, leading to a debate as to whether many of the “sinkholes” are in fact sinkholes or subsidence of sediment beneath homes. For this reason, a newly verified database accessible to the public is recommended for the documentation of sinkhole locations and their status (van Beynen et al. 2007).

Topographic maps were utilized to determine the degree of sinkhole infilling, occurring in Hillsborough, Pasco, and Hernando Counties. In Hillsborough County, topographic maps from the 1940s and 1990-2000 were analyzed to evaluate this karst disturbance. Unfortunately, when the later maps were updated, they were not completely modified and contour lines showing depressions were not removed after the sinkholes were infilled. Except for a few select quadrangles, the topographic maps of Pasco and Hernando Counties were last updated in the 1950s and 1960s. Therefore, in order to evaluate this disturbance, the number of sinkholes counted on early topographic maps was compared to the number of sinkholes present on satellite images from the 2000s.

By analyzing the *Infilling of Sinkholes* indicator in this manner, the ability of the researcher to maintain a consistent scale becomes an issue. For instance, while the topographic maps had a defined scale of 1:24,000, the satellite images scale had to be estimated which made counting the exact number of sinkholes infilled difficult. The reason for this was that it was easier to count sinkholes on the satellite images that may have not been shown on the topographic maps. Examining aerial photographs when determining the number of infilled sinkholes in Pinellas County, as performed by Wilson (2004), is a better way to determine if sinkholes present in previous years were filled. Recent aerial photographs would also help locate open sinkholes to be inspected for the presence of refuse. However, developing countries may not have topographic maps, satellite images, or aerial photographs readily available. Nonetheless, the KDI is designed in such a way that indicators with insufficient data may be assigned a LD rating to be reflected in the confidence level for the study. Therefore, regions with differing available data sources may still be analyzed using the KDI, even if the infilling of sinkholes indicator is assigned an LD rating. Moreover, if an investigator is familiar with the study area, rough estimates of the degree of infilling may be possible.

Application of the *Use of Pesticides and Herbicides* KDI indicator was problematic. Although the amount of concentrated chemicals dispersed onto croplands and golf courses is relatively easy to determine, the quantification of the use of pesticides and herbicides by home owners is significantly more difficult. Home use of these chemicals is particularly dangerous to karst environments because home owners are not trained in the safe and environmentally-friendly application of pesticides and herbicides. Home lawns also generally cover significantly more area than golf courses or cropland.

Moreover, home owners are more likely to use overly concentrated levels of these chemicals. Although knowing how many home lawn maintenance companies are in a study area is useful when trying to quantify the degree of home pesticide and herbicide use, not all home owners utilize these businesses. Future users of the KDI should be aware of these issues when analyzing this indicator.

This study also revealed that the *Flooding of Surface Karst* indicator is missing a potentially important element of karst disturbance. This indicator analyzes the degree to which a karst terrain is flooded by human-built structures, such as large dams. However, in the TBMA, flood suppression, not increased flooding, has altered the natural distribution of surficial water. Although the index provides no method for evaluating flood suppression, it does encourage the addition of any indicators necessary to holistically evaluate the region being studied. However, researchers must be very familiar with the karst terrain of the study area in order to do this. Thus, this researcher believes changing the *Flooding of Surface Karst* indicator to a more comprehensive hydrologic change indicator that is able to evaluate any form of alteration to the natural distribution of surficial water may be more effective in evaluating the human-induced change to a karst terrain's natural hydrology.

Problems associated with the *Petroleum and Industrial Spills* indicator were also discovered while applying the KDI to the TBMA. Currently, the indicator is scored based upon the number of brownfields in a given region. However, this researcher believes this is not an accurate depiction of the disturbance caused by industrial and petroleum products. For instance, Pinellas, Hillsborough, and Pasco Counties each received a disturbance score of one for this indicator solely based upon the number of brownfields in

each locale. However, Pinellas County had over five other industrial spills that occurred in the county from 1997 to 2004, releasing over 33,000 pounds of contaminants onto the karst terrain. In contrast, since 1994, Pasco County has had only one industrial spill, releasing just over 13,000 pounds of contaminants. Hernando County has had two spills releasing 3,000 pounds of contaminants. Hillsborough County has four brownfields, while the other TBMA counties each have no more than two. Despite these apparent differences, each county received a disturbance score of one. Thus, scoring this indicator strictly based upon the number of brownfields in an area may overlook the true disturbance caused by petroleum and industrial spills. Therefore, to holistically evaluate the disturbance caused by industrial and petroleum spills, the descriptors for this indicator should encompass more than the number of brownfields in the study area. This researcher discovered that Hillsborough County already has a GIS coverage of leaks and spills from trunks and tanks.

Other indicators were also constrained by indicator score descriptions listed in van Beynen and Townsend (2005). To resolve this problem, indicator descriptions should be broadened to encompass more scenarios. For example, the descriptor for assigning a score of one to the *Public Education* indicator states that only non-governmental organizations are involved in providing information to the public; however, the governmental agencies of each TBMA county are large educators of the public on the sensitivity of karst environments. Similarly, the *Quarrying and Mining* indicator only suggests the examination of large-scale strip mines. Reclaimed mines are not taken into account. However, karst regions will have varying quarrying and mining characteristics that should be included in the assessment of this indicator's disturbance level.

Consequently, when determining a score for any KDI indicator, researchers should not only rely on the indicator descriptor provided in the index, but also the characterization of each indicator score; that is, a score of three is for severe disturbance, while a score of zero is for a pristine environment (van Beynen et al. 2007).

The *Occurrence of Algal Blooms* was the only KDI indicator entirely replaced in this study (van Beynen et al. 2007). To evaluate the *Occurrence of Algal Blooms* indicator researchers were advised to determine “the severity and longevity of eutrophication of surface water fed by karst aquifers,” (van Beynen and Townsend 2005, p. 110). However, karst regions will probably have different sets of harmful water constituents that may not spur the arbitrary degrees of eutrophication listed in the original KDI indicator table. Therefore, an indicator adaptable to individual karst regions, the *Concentration of Harmful Chemical Constituents in Springs* indicator, was created to holistically evaluate water quality and highlight elevated levels of harmful chemicals in karst waters. The new indicator allows the researcher to determine the problematic constituents and the degree of impact the presence of these constituents has on the water quality of the locale being studied.

Lastly, the wording of the total disturbance rating system should be changed from what is shown in van Beynen and Townsend (2005). Clearer descriptions of the total degree of disturbance and more consistency between individual indicator scores and the final index score are needed (van Beynen et al. 2007). For instance, in van Beynen and Townsend (2005), an indicator score of three meant “catastrophic” disturbance, which may imply completely destroyed with no chance of repair to many people. Therefore, this terminology was changed to mean “severe” disturbance in van Beynen et al. (2007).

This change was also spurred because the label of “severe” disturbance can be correlated more easily with the total disturbance categories which are named “highly disturbed, moderately disturbed, disturbed, little disturbance, and pristine.”

Similar to organizational strategy planning in which an outcome may be evident, the process of applying the KDI provides organizations and communities with an opportunity to holistically analyze their karst terrain in a systematic and standardized manner, forcing organizations to consider karst threats that they may have not previously considered. Overall, the results from the index help resource managers establish a baseline for the degree of human disturbance in a region. With repeated application of the index in the region, these managers can determine if the level of disturbance has improved or worsened over time. Resource managers can also use the KDI to establish indicators receiving a score of three, highlighting where resources necessary to improve the quality of the karst environment should be allocated. Using the KDI also allows managers to highlight hot spots within entire regions that require remediation, if, for example, the KDI were applied to the remainder of west-central Florida.

Participant Interviews

Insightful suggestions for the refinement of the KDI were also obtained from the participant interviews. Each participant agreed that the KDI is a useful tool for evaluating karst terrains. Each interviewee also agreed that the holistic approach of the index increases its utility within varying study areas. From the interviewees it was also ascertained that in the TBMA, the county, not district-level is where the KDI needs to be utilized. As stated by *Informant D*, “the county is starving for tools such as the

KDI...otherwise, they come to us (the district-level) for information.” From the interviews, it also became clear that the KDI is a great tool for the academic community, but cannot be used in the professional community on a daily basis. Therefore, the KDI is useful to many, not all, of the professionals at the county, district, or state levels.

This researcher agrees that an evaluation of the number of petroleum tanks in an area is necessary to holistically assess the disturbance caused by industrial and petroleum spills. The greater the number of underground petroleum tanks, the greater the likelihood that petroleum products are leaking from these tanks into the underground karst aquifer. Although quantifying the exact quantity of products seeping into the aquifers is difficult, the presence of petroleum tanks should still be considered when determining a score for the *Petroleum and Industrial Spills* indicator or a separate indicator should be included to evaluate the potential disturbance from leaking underground storage tanks.

This researcher also agrees with *informant B*, that stormwater flow into spring pools should also be considered when analyzing stormwater flow into sinkholes. Both springs and sinkholes serve as direct links to underground karst aquifers. If contaminated stormwater is funneled into either of these karst features, groundwater supplies and the health of groundwater biota will be jeopardized. Although, this is a problem in Weeki Wachee springs in Hernando County, this researcher had not considered the stormwater flow into spring pools prior to meeting with this informant. The estimation of the disturbance caused by the stormwater flow into spring pools could be completed by contacting local stormwater management officials or analyzing spring water quality for the presence of nutrients and metals often found in stormwater runoff. Although this may be difficult in less developed nations, an LD score can be assigned if necessary.

Although building over karst is undoubtedly a severe karst disturbance, *informant D* explained how recontouring the land in housing developments changes groundwater hydrology by channeling water flow to portions of the landscape it had previously not flowed to or by eliminating the flow of water to areas used for natural drainage. Hydrologic gradients are also altered by this practice. In continually growing regions such as the TBMA, this disturbance could be considered to further evaluate the impact of urbanization on the area's karst terrain. However, the quantification of the degree of land recontouring would be difficult without detailed records. In developing nations it is unlikely that this information will be available. Therefore, more generalized descriptors could be assigned to this indicator to minimize the occurrence of an LD rating for this indicator. The same informant suggested that not only the destruction to archaeological, but also paleontological remains should be evaluated by the KDI. Although paleontological remains are valuable pieces of scientific knowledge, the inclusion of an indicator developed solely for the destruction of these remains would often result in a LD rating due to a lack of documentation of these remains in most regions. To avoid this, paleontological remains could be considered when analyzing the floor sediment compaction indicator. Lastly, this informant suggested that the liming of soil to improve crop production by altering pH should be measured in the KDI. This researcher agrees. Altering soil pH changes the natural development of the karst terrain. Comparing data on the total land coverage of croplands employing these techniques to the total land area in a region could easily lead to an accurate disturbance score. Regions not employing the use of lime could drop the indicator all together.

Several other indicators that could be added to the index were suggested by the informants. However, some of these indicators are too specific to the TBMA region or diverge from true karst disturbance issues. For instance, *informant A* believes that indicators should be included on the decline of manatees using spring pools off the Tampa Bay coast. However, most other regions where the index may be applied will not be concerned with manatees. Moreover, the health of manatees off the coast is not a true karst issue even though these animals are using the karst springs as their habitat. The reduction in spring flow could potentially be evaluated, but not the migration of the manatees alone.

The total disturbance scores included in the index was an issue raised by many of the informants. One concern is the reordering of the total disturbance classifications “disturbed” and “moderately disturbed.” This terminology can be a little misleading because “moderately disturbed” sounds as if it should come after “disturbed,” not before. Another issue raised by the participants is the breakdown of the total disturbance classifications. In van Beynen and Townsend (2005) these classification were as follows: 0.0-0.19 (pristine), 0.2-0.39 (little disturbance), 0.4-0.59 (disturbed), 0.6-0.79 (highly disturbed), and 0.8-1.0 (severely disturbed). Each informant agreed that the simplicity of these disturbance scores are nice, but may be more useful to the professional community if more disturbance levels were incorporated to better reflect subtle interregional differences. Informants making this suggestion each agreed that one or two more classifications would be sufficient.

Future Application of the KDI

Continued research on anthropogenic disturbance is necessary in order to create policy regarding the protection of karst environments. Future work involving this research includes the potential creation of a model for planners managing karst areas to use in determining the amount of disturbance in their respective areas. Additionally, application of the karst disturbance index to other sensitive and unique karst areas, including Jamaica, Belize, and Italy, will continue to evaluate the utility of the index in different karst regions. These proposed studies will continue to detect any indicators not addressed by the KDI, and also determine how indicators change from place to place. Secondly, the indicators should be reviewed to tighten their quantitativeness to reduce any likelihood of evaluator subjectivity (van Beynen et al. 2007).

Chapter Six

Conclusions

A holistic environmental index, combining both quantitative and qualitative indicators, was applied to the TBMA to assess the degree of human disturbance to the area's karst terrain. Through the successful application of the index, the results of this study were able to conclude that urbanization does have an adverse affect on karst terrains: Pinellas County is *highly disturbed* (0.61), Hillsborough County is *highly disturbed* (0.63), Pasco County is *disturbed* (0.54), and Hernando County is *disturbed* (0.49). The application of the index also allowed for the identification of the most threatening effects of urbanization on the karst terrain of the TBMA, these include *Infilling of Sinkholes*, *Soil Compaction*, *Water Table Changes*, *Vegetation Removal*, *Destruction of Archaeological Sites*, and *Building over Karst Features* indicators. Each of these indicators received a score of three exclusively in the more urbanized Pinellas and Hillsborough Counties. Of the applicable indicators, 89 percent had sufficient data to assign a disturbance score, leading to a high confidence level in the total disturbance score calculated for each county in the TBMA.

The application of the KDI in the TBMA also provided an opportunity to identify problems with the KDI and make suggestions for the index's refinement. Overall, the KDI is a user-friendly tool, which clearly outlines guidelines for assessing each indicator, determining total indicator scores, and establishing the degree of confidence in the results

of the KDI's application. Although some indicators, such as the concentrations of harmful chemical constituents indicator, are broad and generalized so they may be evaluated in any karst region, the index as a whole is a systematic and standardized tool that allows for the holistic evaluation of the anthropogenic disturbance to a karst terrain. Nonetheless problems with the KDI were discovered through its application to the TBMA. These problems are summarized in *Table 8*. *Table 9* summarizes the recommendations for addressing these problems and improving the utility of the KDI.

Table 8: Table summarizing problems associated with the KDI.

1) The difficulty of evaluating sinkhole indicators due to the poor quality of and inconsistency in data related to sinkhole locations and status.
2) The difficulty of maintaining a consistent scale when utilizing multiple medias to evaluate the <i>Infilling of Sinkholes</i> indicator.
3) A lack of current data regarding biotic indicators.
4) The overlooking of potential karst disturbances such as leaking petroleum tanks and flood suppression by the index.
5) The need to reword the KDI's disturbance classifications.
6) The constraining nature of indicator score descriptions.
7) <i>Occurrence of Algal Blooms</i> indicator incapable of holistically assessing water quality.

Table 9: Table summarizing recommendations for refining the KDI.

1) Encourage use of aerial photographs, not topographic maps, when analyzing the <i>Infilling of Sinkholes</i> indicator.
2) Broaden indicator score descriptions, such as those found in the <i>Quarrying and Mining</i> , <i>Industrial and Petroleum Spills</i> , and <i>Public Education</i> indicators, to encompass a greater diversity of potential karst disturbance scenarios.
3) Include indicators related to underground petroleum storage tanks, stormwater flow into spring pools, and liming of cropland.
4) Retool the <i>Species Richness</i> and <i>Population Density</i> of cave and groundwater biota indicators to decrease the occurrence of "Lack of Data" designations.
5) Incorporate more total disturbance classifications to better reflect subtle interregional differences.
6) Reword the total disturbance scores presented in van Beynen and Townsend (2005).
7) Change the <i>Occurrence of Algal Blooms</i> indicator to <i>Concentrations of Harmful Chemical Constituents</i> to more holistically evaluate water quality.
8) Change <i>Flooding</i> indicator to more generalized <i>Anthropogenic Hydrologic Change</i> indicator to encompass a wider variety of human-induced changes to karst hydrology.

The results from the repeated application of the KDI can be used by resource managers to assess how the overall state of disturbed regions has improved or worsened over time. These results can also be used to indicate the areas in most need of attention and remediation. In Pinellas and Hillsborough Counties, urban sprawl is responsible for the high degree of disturbance in the area. In Pasco and Hernando Counties, agricultural practices are equally as important as urban growth in disturbing the area's karst. By understanding causality, measures such as urban renewal projects in Pinellas and Hillsborough Counties and better regulation of agricultural practices in Pasco and Hernando Counties can help to minimize the human footprint in these counties. Regional managers can also use the KDI to highlight hot spots within the entire region that require attention by applying the KDI to the remainder of west-central Florida's counties.

In conclusion, no prior research has holistically analyzed the human disturbance of karst. However, through the application of the KDI to the TBMA, a region with a mix of urban and rural land uses, and interviewing of key informants, the level of karst disturbance was holistically evaluated, the impact of urbanization on karst is better understood, and recommendations for the refinement of the KDI were made. This data adds to the existing body of scientific knowledge in that it indicates which types of karst disturbance affect both urban and non-urban karst areas. By evaluating these impacts, measures can continually be taken to address the human-induced disturbance on karst. Similar to organizational strategy planning in which an outcome may be evident, the process of applying the KDI provides organizations and communities with an opportunity to holistically analyze their karst terrain in a systematic and standardized manner, forcing organizations to consider karst threats that they may have not been previously considered.

References Cited

- Abbott, E.M. 1973. *Karst topography as an influence on lands use in west central Florida*. University of Florida, Doctoral Dissertation. 199 pp.
- Agricultural Marketing Service. 2002a. Pasco County Marketing Profile. <http://www.ams.usda.gov/statesummaries/FL/County/County.pdf/Pasco.pdf>.
- Agricultural Marketing Service. 2002b. Hernando County Marketing Profile. <http://www.ams.usda.gov/statesummaries/FL/County/County.pdf/Hernando.pdf>.
- Agricultural Marketing Service. 2002c. Pinellas County Marketing Profile. <http://www.ams.usda.gov/statesummaries/FL/County/County.pdf/Pinellas.pdf>.
- Arfib, B., de Marsily, G., and Ganoulis, J. 2000. Pollution by seawater intrusion into a karst system; new research in the case of the Almyros Source. *Acta Carsologica* **29**, 15-31.
- Aw, P.C. 1978. Conservation of limestone hills: a geologist's view, Malay. *National Journal* **30**(3/4), 449-459.
- Awad, A. 2000. Personal Communication. Hillsborough County Development and Consumer Affairs.
- Bahtijarevic, A. 1996. *Karst Landforms in Florida: Geomorphological Analysis*. University of South Florida, Thesis. 159 pp.
- Baker, A. and Genty, D. 1998. Environmental pressures on conserving cave speleothems: effects of changing surface land use and increased cave tourism. *Journal of Environmental Management* **58**, 165-176.
- Boulton, A.J., Humphreys, W.F., Eberhard, S.M. 2003. Imperiled subsurface waters in Australia: biodiversity, threatening processes and conservation. *Aquatic Ecosystem Health and Management* **6**, 41-54.
- Brinkmann, R. and Reeder, P. 1994. The influence of sea-level change and geologic structure on cave development in west-central Florida. *Physical Geography* **16**(1), 52-61.
- Business Broker, undated website, <http://www.businessbroker.net/listings/blistings.ihtml>.

Call, S. and Stephenson, F. 2003. Spring Time in Florida. Florida State University Office of Research. <http://www.research.fsu.edu/researchr/fall2003/springtime.html>.

Calo, F. and Parise, M. 2006. Evaluating the Human Disturbance to Karst Environments in Southern Italy. *Acta Carsologica* **35/2**, 47-56.

CensusScope. 2000. Florida Population Growth. Social Science Data Analysis Network. http://www.censusscope.org/us/s12/c53/chart_popl.html.

Citizens for Water, undated. Hernando County Office of Extension Services: Brooksville, Florida. <http://www.co.hernando.fl.us/utills/cfw/>.

City of Tampa. 2005. Conservation education. Water Department: Tampa, Florida. http://www.tampagov.net/dept_water/conservation_education/Educators/education_home.asp.

Cooke, C.W. 1939. Scenery of Florida Interpreted by a Geologist. *Florida Geological Survey*, Bulletin No. 17, 118 pp.

Cooke, C.W. 1945. Geology of Florida. *Florida Geological Survey*, Bulletin No. 29, 339pp.

Cope, R. 2005. Personal Communication. Hillsborough County Government Water Management Division.

Craven, S.A. 1999. Speleothem deterioration at Cango Cave, South Africa. *Cave and Karst Science* **26**(1), 29-34.

Crawford, N. C. 1984. Sinkhole flooding associated with urban development upon karst terrain Bowling Green, Kentucky. **In:** Beck, B.F. eds., *Sinkholes: their geology, engineering and environmental impact*. Multidisciplinary Conference on Sinkholes. Orlando, Florida, pp 283-292.

Culver, D.C., Horton, H.H., Christman, M.C., Master, L.L. 1999. Distribution Map of Caves and Cave Animals in the United States. *Journal of Caves and Karst Studies* **61**(3), 139-140.

Daoxian, Y. and Zaihua, L. 1998. *Global Karst Correlation*. International Geological Correlation Program. Philadelphia, PA: Coronet Books Inc. 308 p.

Deming, J. 1980. The cultural resources of Hillsborough County: An assessment of prehistoric resources. Historical Tampa/ Hillsborough County Preservation Board: Tampa, Florida.

de Montmollin, W. 1983. *Environmental factors and prehistoric site location in the Tampa Bay area*. Unpublished M.A. thesis, University of South Florida.

Diez, S. 2007. Personal Communication. Hernando County Government Planning Department.

Donahue, B. 1990. In beauty it is finished, Buzzworm. *The Environmental Journal* 2, 34-39.

Drew, D. 1996. Agriculturally induced environmental changes in the burren karst, Western Ireland. *Environmental Geology* 28, 137-144.

Dunn, J. and Gagen, P. 1987. Limestone quarrying and sinkhole development in the English Peak District. Karst hydrogeology, 2nd conference, Orlando, Florida 1987, 121-125.

Florida Administration Code. 1992. 62-522.300 (3).

Florida Administration Code. 1989. 62-610.523 (9).

Florida Department of Environmental Protection. 1995. Best Management Practices for Golf Course Maintenance Departments.
<http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/golfbmp.pdf>.

Florida Department of Environmental Protection. 2004a. Plant management in Florida waters. Florida agriculture and water use. The Center for Aquatic and Invasive Plants, University of Florida, and the Bureau of Invasive Plant Management, Florida Department of Environmental Protection: Tallahassee, FL.

Florida Department of Environmental Protection. 2004b. Florida DEP Releases 5-year Enforcement Record. Florida Department of Environmental Protection: Tallahassee, Florida <http://www.dep.state.fl.us/secretary/news/2004/dec/files/enforcement.pdf>.

Florida Department of Environmental Protection. 2005. Hydrogeology section. Florida Department of Environmental Protection: Tallahassee, Florida.
http://www.dep.state.fl.us/geology/programs/hydrogeology/hydro_index.htm.

Florida Department of Environmental Protection. 2006a. Aquifers. Florida Department of Environmental Protection: Tallahassee, Florida.
<http://www.dep.state.fl.us/swapp/Aquifer.asp>.

Florida Department of Environmental Protection. 2006b. Operation Cleansweep for Pesticides. Florida Department of Environmental Protection: Tallahassee, Florida.
<http://www.dep.state.fl.us/waste/categories/cleansweep-pesticides/default.htm>.

Florida Department of Environmental Protection Sinkhole Database. 2005.
http://www.dep.state.fl.us/geology/gisdatamaps/sinkhole_database.htm.

Florida Department of Environmental Protection. 2007. DEP Geographic Information Systems. <http://www.dep.state.fl.us/gis/datadir.asp>

Florida Department of Environmental Protection. Florida Forever, undated website, <http://www.dep.state.fl.us/lands/acquisition/FloridaForever/>.

Florida Department of State. 2005. Florida Master Site File. Office of Cultural and Historical Programs: Tallahassee, Florida.
<http://www.flheritage.com/preservation/sitefile/>.

Florida Geographic Data Library. University of Florida GeoPlan Center.
<http://www.fgdl.org/>.

Florida Geological Survey. 2004. Pinellas County Crystal Beach Spring. *Florida Geological Survey*, Bulletin No 66. p. 590-591.

Florida Sinkhole Research Institute. Sinkholes in Florida. Report No. 85-86-4, FSRI/UCF, Orlando Florida.

Florida Statute. 1998. Chapter 810.13.

Florida Statute. 2001. Chapter 403.0885.

Florida Yards and Neighborhoods, undated website, <http://hort.ufl.edu/fyn/>.

Floyd S. (ed). 2003. *Florida statistical abstract 2003*. University of Florida Press, Gainesville, Florida.

Ford, D.C. and Williams, P.W. 1989. *Karst geomorphology and hydrology*. Unwin Hyman: Winchester, Massachusetts. 320 p.

Fretwell, J.D. 1985. Water Resources and Effect of Development in Hernando County, Florida. *United States Geological Survey*, Water-Resources Investigations Report 84-4320.

Gams, I., Nicod, J., Sauro, M. 1993. Environmental Change and Human Impacts on the Mediterranean Karsts of France, Italy, and Dinaric Region. *Catena Supplement* **25**, 59-98.

Gillieson, D.G. 1996. *Caves: processes, development and management*. Oxford: Blackwell Publishers Ltd. 324 p.

- Goldie, H.S. 1993. The legal protection of limestone pavements in Great Britain. *Environmental Geology* **28**, 160-166.
- Greene, L. 2001. Eternal Springs. *St. Petersburg Times*. July 8, 2001.
- Groundwater Protection and Siting Ordinance. 1994. Ordinance No. 94-8.
http://www.epa.gov/nps/ordinance/documents/hernando_fa.pdf.
- Gunn, J. and Bailey, D. 1993. Limestone quarrying and quarry reclamation in Britain. *Environmental Geology* **21**, 167-172.
- Gunn, J., Hardwick, P., and Wood, P.J. 2001. Aquatic Conservation. *Marine and Freshwater Ecosystems* **10**, 353-369.
- Harding, K.A. and Ford, D. 1993. Impact of primary deforestation upon limestone slopes in northern Vancouver Island, British Columbia. *Environmental Geology* **3**, 137-143.
- Heath, R.C. and Smith, P.C. 1954. Groundwater Resources of Pinellas County, Florida. *Florida Geological Survey*, Report of Investigations No. 12, 139 pp.
- Hernando County Department of Public Works. 2003. Hernando County National Pollutant Discharge Elimination System Stormwater Program. Public Works Department: Brooksville, Florida. <http://www.hernandocounty.us/npdes/background.htm>.
- Hernando County Department of Public Works, undated website,
<http://www.hernandocounty.us/dpw/>.
- Hernando County Extension Office. 2006. Extension-helping you put knowledge to work. Office of Extension Services: Brooksville Florida.
http://www.co.hernando.fl.us/County_Extension/.
- Hernando County Government. 2006. Welcome to Hernando County, Florida. Hernando County Government: Brooksville, Florida <http://www.co.hernando.fl.us/hcstat.htm>.
- Hernando County Planning Department. 2003. Existing Land Use – Hernando County, Florida. Hernando County Property Appraiser: Brooksville, Florida.
<http://www.co.hernando.fl.us/plan/library/elu2003.pdf>.
- Hernando County Utilities Department. Solid Waste and Recycling Division: Brooksville, Florida, undated website.
http://www.hernandocounty.us/utis/SolidWaste_Recycling/index.asp.
- Hillsborough County Parks Department. 2005. Parks, Recreation and Conservation Department: Tampa, Florida. <http://www.hillsboroughcounty.org/parks/>.

- Hillsborough County Transportation Division. 2005. Roadway level service report. Transportation Division: Tampa, Florida.
<http://www.hillsboroughcounty.org/pgm/transportation/resources/publications/los/roadwayreport05january.pdf>.
- Holt, J. 2006. Personal Communication. Pinellas County Highway Department.
- Huppert, G., Burri, E., Forti, P., Cigna, A. 1993. Effects of tourist development on caves and karst. *Catena Supplement* **25**, 251-268.
- Hyde, A.G., Law, L., Weatherspoon, R.L., Cheyney, M.D., and Eckenrode, J.J. 1977. *Soil Survey of Hernando County, Florida*. US Soil Conservation Service. US Government Print Office.
- Institute of Food and Agricultural Services. 2000a. Pinellas County, Florida.
<http://www.ifas.ufl.edu/extension/info/pinellas-info.htm>.
- Institute of Food and Agricultural Services. 2000b. Hillsborough County, Florida.
<http://www.ifas.ufl.edu/extension/info/hillsborough-info.htm>.
- Institute of Food and Agricultural Services 2000c. Pasco County, Florida.
<http://www.ifas.ufl.edu/extension/info/pasco-info.htm>.
- Institute of Food and Agricultural Services 2000d. Hernando County, Florida.
<http://www.ifas.ufl.edu/extension/info/hernando-info.htm>.
- Institute of Food and Agricultural Sciences. 2002. Pinellas County Annual Impact 2001.
<http://analysis2001.ifas.ufl.edu/pinellas2001.htm>.
- Jakal, J. 2000. Environmental Changes of karst landscape of Slovenia. *Karstforscher* **46**(1), 42-46.
- James, J.M. 1993. Burial and infilling of a karst in Papua New Guinea by road erosion sediment. *Environmental Geology* **21**, 114-151.
- Jeong, G.Y., Kim, S.J., Chang, S.J. 2003. Black carbon pollution of speleothems by fine urban aerosols in tourist caves. *American Mineralogist* **88**(11/12), 1872-1878.
- Johnson, G. 2006. Florida Springs Database.
<http://www.thiswaytothe.net/springs/floridasprings.shtml#Hernando>.
- Jones, G.W. and Upchurch, S.B. 1996. Origin of Nutrients in Ground Water Discharging from King's Bay Springs. *Southwest Florida Water Management District Ambient Ground-Water Quality Monitoring Program Report*, 133 p.

Jones, G.W. and Upchurch, S.B. 1993. Origin of Nutrients in Ground Water Discharging from Lithia and Buckhorn Springs. *Southwest Florida Water Management District Ambient Ground-Water Quality Monitoring Program Report*, 209 p.

Karst Productions Inc. 2004. Water's journey: the hidden rivers of Florida. High Springs, Florida.

Karst Research Group. 2005. Karst research group. University of South Florida: Tampa, Florida. <http://uweb.cas.usf.edu/~vacher/karsthome.htm>.

Karst Waters Institute, undated website,
<http://www.karstwaters.org/kwitour/whatiskarst.htm>.

Kaufmann, G. 2002. Karst Landscape Evolution. **In:** Gabrovsek, F., ed. Evolution of Karst: From Prekarst to Cessation. Postojna, 243-258.

Keith, J.H., Bassestt, J.L., Duwelius, J.A. 1997. Findings from MOU-related karst studies for Indiana State Road 37, Lawrence County, Indiana. **In:** Beck Stephenson, B.F., Beck Stephenson, and B.F. eds. *The engineering geology and hydrogeology of karst terrains*. 6th Annual Multidisciplinary Conference on Sinkholes, Engineering, and Environmental Impacts, Springfield, Missouri, p. 157-171.

KnowledgePlex. 2007. Pinellas County, Florida Area Overview.
http://www.dataplace.org/area_overview/Pinellas%20County,%20FL.

Kochel, C.R., Miller, J.R., Ritter, D.F. 1995. Chapter 12: Karst-Processes and Landforms. **In:** Kochel, C.R., Miller, J.R., Ritter, D.F. *Process Geomorphology*. Wm C. Brown Publishers: Dubuque, IA, p. 400-427.

LaMoreaux, P.E., Powell, W.J., and LeGrand, H.E. 1997. Environmental and legal aspects of karst areas. *Environmental Geology* **29**(1-2): 23-36.

Landscaping Ordinance. 2001. Hernando County Development Department: Brooksville, Florida. <http://www.hernandocounty.us/bldg/landscape.htm>.

Lane, E. 1986. Karst in Florida. *Florida Geological Survey*, Special Publication No. 29, 100pp.

Lane, E. 1994. Florida's Geological History and Geological Resources. *Florida Geological Survey*, Special Publication No. 35, 64 pp.

Lantigua, J. 2005. Florida's pesticide inspectors spread thin. *Palm Beach Post* 17 July 2005.

Leighty, R.G., Carlisle, V.W., Cruz, O.E., Walker, J.H. Caldwell, R.E., Cremartie, J.L. Huber, E. D., Millsap, Z.T. 1958. *Soil Survey of Hillsborough County, Florida*. United States Soil Conservation Service. US Government Print Office.

Lewis R.R., Durako, M.J., Moffler, M.D., Phillips, R.C. 1985. Seagrass meadows of Tampa Bay—a review. **In:** S. F. Treat., J. L. Simon R. R. Lewis III, R. L. Whitman Jr. (eds.) *Proceedings of the Tampa Bay Area Scientific Information Symposium*, May 1982, University of South Florida, Tampa, p. 210–246.

Li, G. and Zhou, W. 2006. Impact of Karst Water on Coal Mining in North China. *Environmental Geology* **49**, 449-457.

Liu, Q.M., Wang, S.J., Wang, H.C., Ouyang, A.Y. 2003. The changes in soil organic matter in a forest-cultivation sequence traced by stable carbon isotopes. *Australian Journal of Soil Research* **41**(7), 1317-1327.

Loop, C.M., White, W.B. 2001. A conceptual model for DNAPL transport in karst ground water basins. *Groundwater* **39**, 119-127.

Mann, S.L., Steidl, R.J., Dalton, V.M. 2002. Effects of cave tours on breeding *Myotis velifer*. *Journal of Wildlife Management* **66**(3), 618-624.

Martin, K.L., Hensley, S.L., Leslie, Jr. D.M., Payton, M.E., Puckette, W.L. 2006. Impacts of passage manipulation on cave climate: Conservation implications for cave-dwelling bats. *Wildlife Society Bulletin* **34**(1), 137-143.

McGovern B. (ed) 2004. Florida almanac. Dukane Press: Hollywood, Florida.

McHugh, M. 2007. Personal Communication. Hernando County Office of Business Development.

Memon, B.A., Azhem, M.M., Pitts, M.W. 2002. The environmental hazards of locating wastewater impoundments in karst terrain. *Engineering Geology* **65**(2/3), 169-177.

Metcalf and Eddy. 2001. Pasco County Groundwater Protection Study. <http://www.pascocountyfl.net/devser/gm/study/groundwater/gw1.pdf>.

Miller, J.A. 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina. *U.S. Geological Survey*, Professional Paper 1403-B, 91 pp.

Miller, J.A. 1997. Hydrogeology of Florida. **In:** Jones, D.S. and Randazzo, A.F., eds., *The Geology of Florida*. University Press of Florida: Gainesville, p. 69-88.

- Netstate. 2006. The Geography of Florida.
http://www.netstate.com/states/geography/fl_geography.htm.
- Olexa, M.T., Leviten, M., Samek, K. 2003. Florida Solid and Hazardous Waste Regulation Handbook: Miscellaneous Waste Disposal. <http://edis.ifas.ufl.edu/FE458>.
- Onac, B.P. 2000. *Geology of Karst Terrains*. Editura Didactica si Pedagogica: Bucuresti.
- Parsons, K.N., Jones, G., Davidson-Watts, I., Greenaway, F. 2003. Swarming of bats at underground sites in Britain: implications for conservation. *Biological Conservation* **111**, 63-71.
- Pasco County Cooperative Extension Service, undated. Purple Rain Education Program. Pasco County Extension Service Office: New Port Richey, Florida.
http://pasco.ifas.ufl.edu/water_conservationoutdoor/purple_rain/purple_rain_education_prgm.htm.
- Pasco County Government, undated (a),
<http://www.pascocountyfl.net/utilities/hazardous/hazardous.html>.
- Pasco County Government, undated (b),
<http://www.pascocountyfl.net/utilities/water/conservation/main/wtrmain.htm>.
- Pasco County Metropolitan Planning Organization. 2004. Transportation Improvement Program Final Report. Pasco County Metropolitan Planning Organization: New Port Richey, Florida. <http://www.pascocountyfl.net/devser/dept/mpo/prog/tip0405.pdf>.
- Pasco County Office of Tourism. 2004. Visit Pasco County. Pasco County Office of Tourism: New Port Richey, Florida. <http://www.visitpasco.net/contactus.html>.
- Pasco County Planning Department. 2000. Comprehensive Plan October 2000. Pasco County Government Planning Department: New Port Richey, Florida.
<http://www.pascocountyfl.net/devser/gm/complan/cpindex.htm>.
- Petit, S. 1996. The status of bats on Curacao. *Biological Conservation* **77**, 27-31.
- Pinellas County Government, undated website (a),
<http://www.pinellascounty.org/facts.htm>.
- Pinellas County Government, undated website (b),
<http://www.pinellascounty.org/Environment/pagesHTML/pollutionPrevent/pp500.html>.
- Pinellas County Government, undated website (c),
<http://www.pinellascounty.org/kids/default.htm>.

Pinellas County Metropolitan Planning Organization. 2005. Level of Service inventory Report. Pinellas County Metropolitan Planning Organization: St. Petersburg, Florida. http://www.pinellascounty.org/mpo/PDFs/LOS_05Report.pdf.

Pinellas County Planning Department. 2003. Planning to Stay: An Element of the Pinellas County Comprehensive Plan. Board of County Commissioners of St. Petersburg, Florida, http://www.pinellascounty.org/Plan/pdf_files/plan_to_stay.pdf.

Pinellas County Wellhead Protection Ordinance. 1990. <http://www.pinellascounty.org/wpo/ordinance.htm>.

Polk, J.S., van Beynen, P., and Reeder, P. 2005. Paleoclimate Inferences in Belize: $\delta^{13}\text{C}$ Variations in Cave Sediments. Geological Society of America Abstracts with Programs, 37(7): 226.

Pugsley, C. 1984. Ecology of the New Zealand glowworm, *Arachnocampa luminosa* (diptera: Keroplatidae), in the Glowworm Cave, Waitomo. *Journal of the Royal Society of New Zealand* **14**, 387-407.

Pulido-Bosch, A., Calaforra, J.M., Pulido-Leboeuf, P., Torres-García, S. 2004. Impact of quarrying gypsum in a semidesert karstic area (Sorbas, SE Spain). *Environmental Geology* **46**, 583-590.

Quinlan, J.F. 1970. Central Kentucky Karst. Reunion Internationale Karstologie en Langudoc-Provence, 1968, Actes: Mediterrane Etudes et Travaux. No. 7, 235-253.

Quinlan, J. F., and R. O. Ewers. 1985. Groundwater flow in limestone terranes: strategy, rationale and procedure for reliable, efficient monitoring of groundwater quality in karst areas. **In:** *National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, Proceedings*. National Water Well Association, Worthington, Ohio, p. 197-234.

Ralston, M. R. and Oweis, I.S. 1999. *Geotechnical Engineering Considerations for Stormwater Management in Karst Terrains*. October 1999 Southeastern Pennsylvania Stormwater Management Symposium. Villanova University: Villanova, PA.

Randazzo, A.F. and D.S., Jones. 1997. *The Geology of Florida*. Gainesville: The University of Florida Press, 325pp.

Richter, A.R., Humphrey, S.R., Cope, J.B., Brack, V. 1993. Modified cave entrances: thermal effect on body mass and resulting decline of endangered Indiana Bats (*Myotis Sodalis*). *Conservation Biology* **7**, 407-415.

Rosenberg, M. 2006. *Karst Topography and Sinkholes*. About Incorporated Website, <http://geography.about.com/od/physicalgeography/a/karst.htm>.

- Roth, J. 1993. Preserving biodiversity in caves. *Wild Earth* **3**(3), 32-33.
- Ryburn, C. 2006. Personal Communication. Pinellas County Department of Environmental Management.
- Ryder, P.D., 1985. Hydrology of the Floridan Aquifer System in West-Central Florida. *United States Geological Survey*, Professional Paper 1403-F, 63 pp.
- Salinero, M. 2005. Hillsborough to take on Honeywell. *Tampa Tribune*. November 18, 2005.
- Sauro, U. 1993. Human impact on the karst of the Venetian Fore-Alps, Italy. *Environmental Geology* **21**, 115-121.
- Schilthuizen, M., Liew, T., Elahan, B., Lackman-Ancrenaz, I. 2005. Effects of Karst Forest Degradation on Pulmonate and Prosobranch Land Snail Communities in Sabah, Malaysian Borneo. *Conservation Biology* **19**, 949-953.
- Scorecard. 2005a. Land Contamination Report: Pinellas County, FL. http://www.scorecard.org/env-releases/land/county.tcl?fips_county_code=12103#rankings.
- Scorecard. 2005b. Land Contamination Report: Pasco County, FL. http://www.scorecard.org/env-releases/land/county.tcl?fips_county_code=12101#trends.
- Scott, T.M. 1988. The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida. *Florida Geological Survey*, Bulletin No. 59, 138 pp.
- Scott, T.M. 1992. A Geological Overview of Florida. *Florida Geological Survey*, Open File Report No. 50, 78pp.
- Scott, T.M. 1997. Miocene to Holocene History of Florida. **In**: Jones, D.S. and Randazzo, A.F., eds. *The Geology of Florida*. University Press of Florida: Gainesville, p. 1-12.
- Scott, T.M. 2002. Florida's Springs in Jeopardy. *Geotimes* **47**(5), 16-20.
- Scott, T.M., Means, G.H., Means, R.C., Meegan, R.P. 2002. First Magnitude Springs of Florida. *Florida Geological Survey*, Open File Report No. 85, 138 pp.
- Schindler, D.W. 1978. Factors regulating phytoplankton production and standing crop in the world's freshwaters. *Limnological Oceanography* **23**, 478-486.
- Silverwood, N. 2000. The complex of Mega Mania. *Forest and Bird* **297**, 14-18.

Sinclair, W.C., Stewart, J.W., Knutilla, R.L., Gilboy, A.E., Miller, R.L. 1985. Types, Features, and Occurrence of Sinkholes in the Karst of West-Central Florida. *United States Geological Survey, Water-Resources Investigations Report 85-4126*, 81pp.

Smith, D.L. and Lord, K.M. 1997. Tectonic Evolution and Geophysics of the Florida Basement. **In:** Jones, D.S. and Randazzo, A.F., eds. *The Geology of Florida*. University Press of Florida: Gainesville, p. 13-26.

Southwest Florida Water Management District. ArcView Shapfiles Database.
http://www.swfwmd.state.fl.us/data/gis/shape_search.htm.

Southwest Florida Water Management District. 1987. Groundwater Resource Availability Inventory: Hernando County, Florida. Southwest Florida Water Management District, Brooksville, Florida.

Southwest Florida Water Management District. 1993. Eastern Tampa Bay Water Resource Assessment Project. Southwest Florida Water Management District: Brooksville, Florida.

Southwest Florida Water Management District. 2001. The hydrology and water quality of select springs in the southwest Florida water management district. Water Quality Monitoring Program, Southwest Florida Water Management District: Brooksville, Florida. <http://www.swfwmd.state.fl.us/documents/reports/springs.pdf>.

Southwest Florida Water Management District. 2005. Hydrologic conditions. Hydrologic Data Operations Dept., Southwest Florida Water Management District: Brooksville, Florida. <http://www.swfwmd.state.fl.us/waterres/hydro/files/oct05hydro.pdf>.

Southwest Florida Water Management District, undated website,
<http://www.swfwmd.state.fl.us/busfin/grants/hillsborough.html>.

Spanjer, G.R. and Fenton, M.B. 2005. Behavioral responses of bats to gates at caves and mines. *Wildlife Society Bulletin* **33**(3), 1101-1112.

Species Richness. 2006. Wikipedia Encyclopedia,
http://en.wikipedia.org/wiki/Species_diversity.

Stankey, D.L. 1982. *Soil survey of Pasco County, Florida*. United States Soil Conservation Service. US Government Print Office.

Stanley, M.J. 2006. Personal Communication. Executive Director of Pasco Economic Development Council.

Stewart, J.W. 1986. Hydrologic effects of pumping from the Floridan Aquifer in Northwest Hillsborough, Northeast Pinellas, and Southwest Pasco Counties, Florida. *US Geological Survey*, Open-file Report, 241 pp.

Stewart, J.W., 1982. Ground-water Degradation Incidents, West-Central Florida. **In:** *Environmentally Sound Water and Soil Management*. Irrigation and Drainage Division, American Society of Civil Engineers, 445-452.

St. Petersburg Government, undated, <http://www.stpete.org/recycle.htm>.

Sutherland, K. 2007. Personal Communication. Hernando County Planning Department.

Swancar, A. 1996. Water Quality, Pesticide Occurrence, and Effects of Irrigation with Reclaimed Water at Golf Courses in Florida. *US Geological Survey*, Water-Resources Investigations Report 95-4250, 85 pp.

Sweeting, M.M. 1973. *Karst Landforms*. Columbia University Press: New York, 362 pp.

Tampa Bay Demographics. 1995. Hernando County Demographics.
<http://www.webcoast.com/dhernand.htm>.

Tietz, R. 2006. Personal Communication. Pasco County Government Biologist.

Tihansky, A.B. 1999. Sinkholes: West-Central Florida. **In:** Galloway, D., Jones, D.R., Ingebritsen, S.E., eds. *Land Subsidence in the United States*. United States Geological Survey Circular 1182, 177 pp.

Tihansky A.B. and Knochenmus L.A. 2002. Karst Features and Hydrology in West-Central Florida: A Field Perspective. **In:** Kuniansky, E.L., ed. *United States Geological Survey Karst Interest Group Proceedings*, Water-Resources Investigation Report 01-4011, 198-211.

Trommer, J.T. 1992. Effects of Effluent Spray Irrigation and Sludge Disposal on Ground Water in a Karst Region, Northwest Pinellas County, Florida. *United States Geological Survey*, Water-Resources Investigations Report 97-4181, 32 pp.

Troutt, J. 2006. Personal Communication. Hillsborough County Government.

Turner, T. 2007. Personal Communication. Tampa Bay Area Caving Grotto.

United States. 1988. Federal Cave Resources Protection Act, 100 Public Law 691.

United States Census Bureau, undated website, United States Department of Commerce: Washington D.C. <http://www.co.hernando.fl.us/plan/abstr2001/stat102a.htm>.

United States Census. 2005a. Hillsborough County, Florida quick facts. United States Department of Commerce: Washington D.C.
<http://quickfacts.census.gov/qfd/states/12/12057.html>.

United States Census. 2005b. New privately-owned residential building permits Hillsborough County, Florida (057). United States Department of Commerce: Washington D.C. <http://censtats.census.gov/cgi-bin/bldgprmt/bldgdisp.pl>.

United States Census. 2005c. Pasco County, Florida quick facts. United States Department of Commerce: Washington D.C.
<http://quickfacts.census.gov/qfd/states/12/12101.html>.

United States Census Bureau. 2006. Annual Estimates of the Population for Counties in Florida: April 1, 2000 to July 1, 2005. Population Division.
<http://www.census.gov/popest/counties/tables/CO-EST2005-01-12.xls>.

United States Department of Agriculture. 2002. Soil Survey of Pinellas County, FL. United States Department of Agriculture: Washington, D.C.
<http://www.mo15.nrcs.usda.gov/technical/surveys/florida/pinellas/Pinellas.pdf>.

United States Department of Energy. 1998. Pinellas Plant: Largo, Pinellas County, Florida. United States Department of Energy: Washington, D.C.
<http://web.em.doe.gov/cercla97/pinellas.html>.

United States Environmental Protection Agency. 2003. National pollutant discharge elimination system. United States Environmental Protection Agency: Washington D.C.
<http://cfpub.epa.gov/npdes/>.

United State Environmental Protection Agency. 2004. Toxic Release Inventory Database. *TRI Explorer*. United States Environment Protection Agency: Washington D.C.
<http://www.epa.gov/tri/>.

United States Environmental Protection Agency. 2005. Florida NPL/NPL caliber cleanup site summaries. United States Environmental Protection Agency: Washington, D.C.
<http://www.epa.gov/region4/waste/npl/nplfls/helenafl.htm>.

United States Geological Survey. 2004. Hillsborough County. United States Geological Survey: Reston, Virginia.

Upchurch, S.B. and Randazzo, A.F. 1997. Environmental Geology of Florida. **In:** Jones, D.S. and Randazzo, A.F., eds. *The Geology of Florida*. University Press of Florida: Gainesville, 217-249.

Urich, P.B. 1993. Stress on tropical karst cultivated with wet rice: Bohol, Philippines. *Environmental Geology* **21**, 129-136.

- Urich, P.B., Day, M., Lynagh, F. 2001. Policy and practice in karst landscape protection: Bohol, the Philippines. *The Geographical Journal* **67**, 305-323.
- van Beynen, P.E., Feliciano, N., North, L., Townsend, K. 2006. Application of the Karst Disturbance Index in Hillsborough County, Florida. *Environmental Management* **39**, 261-277.
- van Beynen, P.E. and Townsend, K.M. 2005. A Disturbance Index for Karst Environments. *Environmental Management* **36**, 101-116.
- Vanatta, E.S., Stem, L.T., Wittstruck, W.H., Pettry, D.E., Spieth, J.W. 1972. *Soil Survey of Pinellas County, Florida*. United States Soil Conservation Service. US Government Print Office.
- Velsor, D. 2007. Personal Communication. Hernando County Planning Department.
- Veni, G., DuChene, H., Crawford, N.C., Groves, C.G., Huppert, G.N., Kastning E.H., Olson, R., Wheeler, B.J. 2001. *Living with karst: a fragile foundation*. American Geological Institute, Alexandria, VA, 64p.
- Villar, E., Fernandez, P.L., Gutierrez, I., Quindos, L.S., Soto, J. 1986. Influence of visitors on carbon concentrations in Altamira Cave. *Cave Science* **13**(1), 21-23.
- Weisman, B. 2006. Personal Communication. University of South Florida Department of Anthropology.
- West Pasco Chamber of Commerce. 2006. *Florida's perfect location*. <http://www.westpasco.com/>.
- White, W.A. 1970. The Geomorphology of the Florida Peninsula. *Florida Bureau of Geology*, Bulletin No. 51, 164 pp.
- White, E.L., Aaron, G., White, W.B. 1984. The influence of urbanization on sinkhole development in central Pennsylvania. **In:** Beck, B.F. eds., *Sinkholes: their geology, engineering, and environmental impact*. 1st Annual Multidisciplinary Conference on Sinkholes. Orlando, Florida, p. 275-281.
- White, W.B. 1988. *Geomorphology and Hydrology of karst Terrains*. Oxford University Press, New York, 229pp.
- Wilson, K.V. 2004. *Modification of Karst Depressions by Urbanization in Pinellas County, Florida*. University of South Florida, Thesis. 60pp.
- Wolansky, R.M. and Garbade, J.M. 1981. Generalized thickness of the Floridan aquifer. *U.S. Geological Survey*, Open-File Report 80-1288.

Wood, P.J., Gunn, J., Perkins, J. 2002. The impact of pollution on aquatic invertebrates with a subterranean ecosystem – out of site out of mind. *Archives of Hydrobiology* **155**, 223-22.

Xie, Q., Qin, Y., Chen, Y., Zhang, X., Wang, D., Li, J. 2002. Research on the effect of sludge fertilizer on farmland and the safety of heavy metals in a karst area. *Environmental Geology* **41**(3/4), 352-357.

Zhou W.F., Beck B.F., Green T.S. 2005. Evaluation of a peat filtration system for treating highway runoff in a karst setting. *Environmental Geology* **44**, 187–202.