EXAMINING THE RELATIONSHIPS BETWEEN FBCS AND ACTIVE BUILT ENVIRONMENT

By

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To Moonkyoung

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APA	American Planning Association
BMI	Body Mass Index
CDC	Center for Disease Control and Prevention
FBCI	Form-Based Codes Institute
FBCs	Form-based Codes
FDOT	Florida Department of Transportation
FGDL	Florida Geographic Data Library
FLC	Florida League of Cities
FTIS	Florida Transit Information System
GIS	Geographic Information System
HHS	U.S. Department of Health and Human Service
LUCIS	Land-Use Conflict Identification Strategy
NHTSA	National Highway Traffic Safety Administration
NPS	National Park Service
PAGAC	Physical Activity Guidelines Advisory Committee
RCI	Road Characteristics Inventory
SZZEA	The Standard State Zoning Enabling Act
T-zones	Transect zones
ULI	Urban Land Institute
WHO	World Health Organization

Abstract of Dissertation Presented to the Graduate School
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Recently, Form-based codes (FBCs) have emerged as a strategy to resolve contemporary urban issues that have been caused by urban sprawl in the U.S., especially issues involving physical inactivity. This paper examines whether FBCs are conducive to creating active built environments, urban form that encourages more opportunities for physical activity.

In order to answer the research question, I operationalized environmental variables in terms of how they affect physical activity in a Geographic Information System (GIS). Second, I developed GIS suitability modeling with the operationalized variables. Eventually, I used GIS modeling to compute an active built environment index and applied this index to compare the urban form that have resulted from FBCs, conventional zoning, and historic places in Florida.

This study finds that there is a statistically significant difference among the above groups as determined by a Welch ANOVA test. The scores were statistically different for the comparison groups, with Welch's $F(2, 12.857) = 6.370$ and $p < .012$. Because the assumption of the homogeneity of the variances is violated, I utilized a Welch ANOVA test instead of the standard one-way ANOVA. Additionally, the Games-Howell post hoc

analysis revealed that there is a difference between the scores of 3.6 ± 1.6 in the FBCs group and 2.1 ± 0.4 in the conventional zoning group, a difference of 1.5 (95% CI, 0.1 to 3.0), which is statistically significant (p = .038). These results suggest that FBCs create more urban form that are conducive to physical activity than conventional zoning does.

Using cases in Florida, this study investigates the active living potential of FBCs and confirms that FBCs can create opportunities to support active built environments. Moreover, the GIS-based visualization method provides an expanded set of tools to help urban planners and public health professionals understand the relationships between urban form and active built environments. These map-based visualized results are useful not only in identifying inactive built environment areas, but also in providing valuable information that can help health and urban policymakers and professionals work together to address mutual challenges.

CHAPTER 1
INTRODUCTION

Background

Since the beginning of the Industrial Revolution, addressing public health issues has been an essential element of urban planners' work (Benevolo, 1980). However, the early stages of urban planning focused on public hygiene and its urban infrastructure because of the necessity of infectious disease control. In order to address this need, urban planners and leaders started to establish plans to construct urban infrastructures. After the basic functions were set up, including roads, drainage systems, sewer collection systems, drinking water supplies, and electric power lines, cities started to grow according to regulated master plans such as zoning and comprehensive plan.

However, the desire for better living led to an undesirable phenomenon: urban sprawl. Urban sprawl is a pattern of urban growth that reflects low-density, automobile-dependent, and exclusionary new developments on the fringe of existing urban fabric (Squires, 2002, p. 2). This pattern has caused a number of urban problems, including suburban residents' dependence on automobiles and profusion of health problems, the invasion of preservation areas, and, finally, climate change (Duany, Plater-Zyberk, & Speck, 2010; Resnik, 2010; Sloane, 2006).

Moreover, a decrease in physical activity is the most pressing problem of suburban residents in North America (Lopez & Hynes, 2012). According to the definition of the Physical Activity Guidelines Advisory Committee (PAGAC), physical activity is "any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level," and everyone should attain a certain level of physical activity based on his or her age and body condition (PAGAC, 2008, p. c-1).

A lack of physical activity can lead to serious health problems, such as obesity and type 2 diabetes. A statistic of the Center for Disease Control and Prevention (CDC) reveals that one consequence of physical inactivity—obesity—has increased dramatically in the United States over the last two decades (Figure 1-1). Needless to say, physical activity is an essential factor in weight maintenance and the reduction of obesity. The CDC's statistic partially implies that the average level of physical activity has continued to decrease at an alarming pace since 1990.

With regard to physical activity and built environments, the findings from previous studies suggest that built environments and physical activity have positive associations (Aytur, Rodriguez, Evenson, Catellier, & Rosamond, 2007; Frank, Kerr, Chapman, & Sallis, 2007; Cohen et al., 2007; Handy, Xinyu, & Mokhtarian, 2008; Kaczynski, Potwarka, & Saelens, 2008). In particular, Frank and Engelke (2001) assert that creating active built environments is the most effective way to help people achieve their recommended physical activity as a byproduct of urban form, which is the output of planning regulations (Talen, 2012). Unfortunately, current planning regulations that operate based on functional zoning have resulted in non-active built environment.

In order to address this and other issues that have resulted from functional zoning, urban planners have developed new approaches in the urban planning and urban design fields, such as smart growth, new urbanism, and sustainable developments. These approaches involve efforts to address public health problems, including physical inactivity.

In particular, Form-based Codes (FBCs) have emerged in recent years as an alternative to conventional planning approaches. The Form-Based Codes Institute

(FBCI) states that, “FBCs are regulations adopted into city or county and foster predictable built results and a high-quality public realm by using physical form.” After the city of Seaside, Florida was developed in 1981, many municipalities started to adopt FBCs instead of using conventional zoning regulations (Dancy, 2007, p. 2). This is because many municipalities now believe that FBCs offer numerous advantages and can create better places to live, work, and play (Cable, 2009; Coyle, 2010; Hendon & Adams, 2010). These advantages also enable FBCs to be a possible solution to the problems resulting from urban sprawl (Ross, 2009; Spilowski, 2010; Tombari, 2009).

Research Question

Based on these conditions, this research strives to answer the question of whether FBCs can create active built environments. My ultimate research goal is to determine if the products of FBCs can improve public health, especially through increased physical activity. Therefore, I aim to answer the more specific question of whether FBCs lead to urban forms that provide more opportunities for physical activity than the urban forms created by conventional zoning and historic cities.

As Rodriguez, Khattak, and Everson (2006) assert, people who live in urban forms that support physical activity are more likely to be involved in physical activity in their neighborhoods (p. 52). They argue that there are positive associations between built environments and physical activity. Although positive correlations between built environments and physical activity may not imply causation, research suggests that physical urban forms or patterns are essential to building and maintaining a healthy society (City of New York, 2010, p. 13). Consequently, by assessing urban form suitability to support physical activity, we can compare the planning approaches that have produced different types of built environments in the absence of physical activity measurements.

Research Objectives

In order to answer the research query, several objectives have been established. First, I identify elements of urban forms that have been seen to be related to active built environments in previous studies. This part of the study provides the variables that are utilized in the research method. Second, I create a comparative analysis of chosen urban form sites that were developed from three planning approaches: form-based codes, conventional zoning, and historic cities. Florida was selected as the study area because Florida played a precursory role in using FBCs in the United States and has gone through the evolution of various phases of planning approaches. Third, I build a Geographic Information System (GIS) suitability model to assess the three urban form groups in terms of their abilities to support physical activity. The output of the suitability modeling for each site is a suitability map that is ranked by an active built environment index. Fourth, I perform a statistical comparative analysis of the three urban form groups. The comparative analysis uses the means of the active built environment index in each comparison group as response variables and uses each comparison group as explanatory variables. The analysis of variance (ANOVA) statistical test analyzes whether the differences observed among the groups could have reasonably occurred by chance (H_0: the three groups have identical means). The P-value shows whether H_0 can be rejected or not. The results of this analysis can help to determine which group, FBCs, conventional zoning, or historic cities, has a more significant ability to create urban forms that are conducive to physical activity.

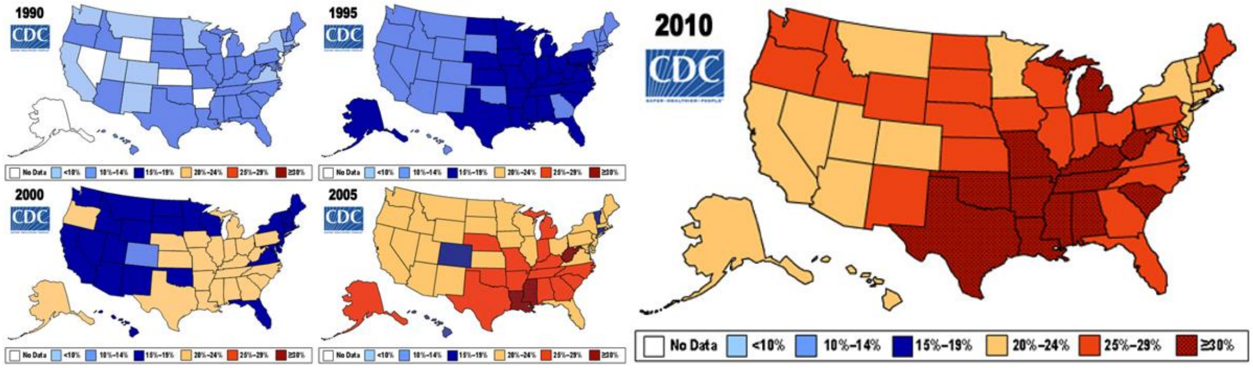

Figure 1-1. Percent of Obese (BMI >30) in U.S. Adults between 1990 and 2010 (CDC, 2013)

CHAPTER 2
LITERATURE REVIEW

This chapter is organized in two sections. The first section examines previous efforts to determine the link between the built environment and health, particularly exploring the relationship as it relates to physical activity. Because the variables which show the correlation between built environment and physical activity are vast and complex, the first section is divided into four categories: Land Use, Recreational Space, Transportation, and Street. The second section examines the historical context and trends of FBCs, the components of FBCs, and the relevant research efforts related to FBCs.

Active Built Environment

Since the active built environment is an urban form that encourages physical activity, this section looks at physical activity and the relationship between physical activity and built environments.

Physical Activity

As aforementioned, physical activity is bodily movements that use skeletal muscles. Physical activity can be categorized by mode, intensity, and purpose (PAGAC, 2008, p. C-1). Mode is the type of activity or exercise that is being performed (biking, walking, rowing, and weight lifting are all examples of different modes of activity). Intensity refers to how much work is performed or the magnitude of the effort required to perform an activity or exercise. Purpose can be identified as occupational, leisure-time or recreational, household, self-care, and transportation or commuting activities (PAGAC, 2008, pp. C-1, C-3, C-4).

However, the recommended physical activity levels vary by age and health condition. The World Health Organization (WHO) established three age categories: 5-17 years old, 18-64 years old, and 65 years old and above (WHO, 2010), whereas the CDC uses four categories: children (6-17 years of age), adults (18-64 years of age), old adults (65 years of age or older), and Healthy Pregnant or Postpartum Women (CDC, 2015b). The U.S. Department of Health and Human Service (HHS) uses the same categories as the CDC but also includes adults with disabilities and people with chronic medical conditions (HHS, 2008).

Table 2-1 summarizes physical activity types by modes and intensity. According to the table, children need more physical activity because they are in a growth period. Although older adults have the same guidelines for physical activity as adults, they should understand their functional limitations can make some activities risky and should select types of physical activities accordingly.

Despite all kinds of theoretical categorization regarding physical activity recommendation, the CDC (2015c) encourages adults to partake in a “10-minute brisk walk, 3 times a day, 5 days a week.” Essentially, if adults walk a total of 30 minutes per day, then walking activity meets the CDC’s minimum recommendation.

Built Environment and Physical Activity

The relationships between built environment and human behavior, especially physical activity, vary by contexts and have several aspects. However, Brownson, Hoehner, Day, Forsyth, and Sallis (2009) tried to identify urban form variables to affect physical activity from about 50 archival research, which are used GIS in their analysis. They found 5 common variables such as density, land use mixed level, accessibility to destinations, and street pattern for assessing urban form. In addition to physical urban forms, Schulz, Williams, Israel, and Lempert (2002) identified that race-based residential segregation is a critical factor of racial disparities in health. Their findings indicates that health outcomes are caused by both socio economic factors and physical built environment. Figure 2-1 demonstrates that physical activity is influenced by a variety of factors. Although this “Social Determinants of Health and Environmental Health Promotion” model includes possible relationships between urban forms and physical activity, many studies have tried to find factors or variables of active built environment within this complex model.

Despite the challenges, in order to determine relevant variables of active built environment, this section explores previous efforts and finds appropriate variables from existing studies. Thus, in this study, to clearly summarize relevant studies, which show the relationships between physical activity and built environment, I have divided them into four parts: Land Use, Recreational Space, Transportation, and Street.

Land Use

Since land use directly defines urban forms, numerous studies have tried to identify the relationships between physical activity and land use.

Mixed-Use. Several studies show how mixed-use development has a strong and positive relationship with physical activity (Table 2-2). Some researchers reported that people are more likely to walk if they live in mixed-used neighborhoods with parks, schools, and commercial destinations nearby (Aytur et al., 2007; Frank et al., 2007; Mumford, Contant, Weissman, Wolf, & Glanz, 2011).

Grocery Stores. Some studies show that the full-size grocery stores in neighborhoods positively correlate with healthier diet and weight among residents. (Morland, Wing, and Diez Roux, 2002; Sallis & Galnz, 2009). Conversely, a high concentration of fast food increases the risk of obesity among neighborhood residents. (Larson, Story, & Nelson, 2009; McCormack, Giles-Corti, & Bulsara, 2008; Moudon et al. 2006).

Children's Play Area. Regarding children's physical activity, these studies have suggested that environments with well-maintained school facilities and well-made streets environment have a positive correlation with children's physical activity (Boarnet, Anderson, Day, McMillan, & Alfonzo, 2005; Dunton, Intille, Wolch, & Pentz, 2012). Also, travel distance to school is a significant variable to the enhancement of children's activity. McDonald (2008) supported this argument by reporting that youth who live within a half mile of a school had a greater likelihood of walking or biking to school (Table 2-3).

Recreational Space

In addition to land use, recreational spaces have been analyzed and researchers have argued for the significance of recreational spaces with regard to active living. Studies found that users of open space have a heightened chance of achieving recommended physical activity levels. Most of these studies have utilized explanatory variables which are related with urban form elements (e.g. travel distance to open space, open space size, and installed facilities in open space) and response variable (number of users).

Distance to Space. The travel distance to an open space is a critical variable that has a strong correlation with the number of park users (Table 2-4). The optimal distance varies, but people who live closer to an open space are more likely to visit parks and exercise more often (Babey, Hastert, Yu, & Brown, 2008; Cohen et al., 2007;

Coutts, 2008; Giles-Corti et al. 2005; Moore, Diez Roux, Evenson, McGinn, & Brines, 2008; Pierce, Denison, Arif, & Rohrer, 2006).

Size of Space. Some studies showed that large open spaces are not only more attractive to people, but also have more park users (Cohen et al., 2009; Farley, Meriwether, Baker, Rice, & Webber, 2008). Table 2-5 explains detailed data and findings regarding the relationships between size of open spaces and physical activity.

Facilities for Activity. Even though open spaces are available, if the open spaces do not have proper facilities, the open space may not encourage physical activity (Table 2-6). Some studies reported appropriate elements of open space—such as trails, paths, playgrounds, drinking fountains, picnic areas, restrooms, and aesthetic features—lead park users to exercise more (Brink et al. 2010; Floyd, Spengler, Maddock, Gobster, & Suau, 2008; Kaczynski et al., 2008; Mobley et al., 2006; Roemmich et al., 2010; Shores & West, 2008).

Transportation

In addition to land use and recreational spaces, transportation has played a significant role in providing more physical activity opportunities. Three transportation modes have been commonly analyzed: public transit (Table 2-7), walking, and biking.

Public Transit. Public transit is an important variable that encourages physical activity (Besser & Dannenberg, 2005; Saelens & Handy, 2008). Rundle et al. (2007) found a reverse relationship between the density of bus and subway stops and obesity among residents. Also, transit stops with well-connected streets are used more heavily than less-connected streets (Lund, Wilson, & Cervero, 2006).

Pedestrian Pathway. This variable is discussed under the “street” category.

Bikeways. Pucher and Buehler (2008) showed that obesity rates of frequent bicycle users are lower in countries that have good bicycle infrastructure. Also, well-connected bikeways with public transit can provide more opportunities for physical activity.

Street

Street walkability, defined as the extent to which the built environment, is walker-friendly (Abley, 2005, p.3) is a key variable to physical activity. As Jacobs (1961) asserted, the street is the main frame which serves many purposes besides accommodating pedestrians (Ehrenfeucht & Loukaitou-Sideris, 2010), and a number of urban designers and architects have stressed the significance of the street connectivity and consistency.

Sidewalk Connectivity. Table 2-8 presents that areas with well-maintained and well-connected sidewalks that offer resident an opportunity to walk in their neighborhoods are more likely to meet physical activity guidelines (Boarnet, Forsyth, Day, & Oakes, 2011; Chin, Van, Giles-Corti, & Knuiman, 2008; Coogan et al., 2011; Dill, 2009; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Gordon-Larsen, Nelson, Page, & Popkin, 2006; Handy, Xinyu, & Mokhtarian, 2008; King, 2008; Lopez-Zetina, Lee, & Friis, 2006; Reed, Wilson, Ainsworth, Bowles, & Mixon, 2006).

Sidewalk Consistency. It is essential to make sidewalks appropriate width for walking (Cevero & Kockelman, 1997; Eyler, Brownson, Bacak, & Houseman, 2003).

Walkability

Despite among numerous theoretical discussions how to achieve daily physical activity recommendation, walking is the most affordable way. The CDC's recommendation that adults take a “10-minute brisk walk, 3 times a day, 5 days a week” is widely accepted. That is, if walking trips are collectively 30 minutes, the walking activity meets the minimum per day suggested aerobic activity for adults.

Urban Morphology and Walkability

As previously mentioned, the street is an essential feature to affect walkability. Thus many studies have investigated the relationships between walkability and urban form, including the street, with morphological dimension, which includes land use, building structures, street patterns, enclosure, and movement pattern.

Land Use. Since everyone depended upon ready access by foot to jobs and the marketplace, walkability was essential in cities before the automobile era. Recent studies also support the fact that people are more likely to walk if they live in mixed-used neighborhoods with parks, schools, and commercial destinations nearby (Aytur et al., 2007; Frank et al., 2007; Mumford et al., 2011).

Building Structure. Since buildings had long, narrow plot patterns and faced their front side into street, these structures support social interaction on the public spaces and streets (Carmona, Heath, Oc, & Tiesdell, 2010, p. 78).

Street Patterns. In urban design, the street is the most important urban features since it provides the opportunity for movement as well as social interaction. To provide various movement options, fine urban grain, which has integrated and connected small delicately meshed streets, is encouraged (Jacobs, 1961). Additionally, recent research argued the significance of well-connected sidewalks because they provide more chances for pedestrian movement in modern cities. Several studies showed that areas with well-maintained and well-connected sidewalks offer residents an opportunity to walk in their neighborhood (Dill, 2009; Frank et al., 2005; Gordon-Larsen et al., 2006; Handy et al., 2008; King, 2008; Lopez-Zetina et al., 2006; Reed et al, 2006).

Movement Patterns. Since pedestrian movement can create trip which means movement from point A to point B as well as social interaction, this moving pattern is an essential factor for walking. Compared to automobile movement, because of walking speed, it is possible to make interaction during the movement.

Other Physical Features. Cervero and Kockelman (1997) coined the “three Ds: Density, Diversity, and Design” and argued that sidewalk width consistency is critical for pedestrian safety. Frank et al. (2010) developed walkability index to measure walkability using net residential density, retail floor area ratio, intersection density measured the connectivity of the street network, and land use mix index. Additionally, trees and other landscape elements contribute to more appealing sidewalks and can be used to help separate pedestrians from vehicular traffic (Larsen et al., 2009).

The Other Factors to Affect Walkability

Even though physical urban form such as destination proximity, density and connectivity make an impact on walkability (Moudon et al. 2006), walkability is a multi-faceted concept that includes qualitative factors (Adkins, Dill, Luhr, & Neal, 2012; Giles-Corti, Kelty, Zubrick, & Villanueva, 2009). Southworth (2005) organized six attributes to affect walkability: connectivity, linkages to other modes, fine-grained and varied land use patterns, safety, quality of path, and path context (e.g. visual interest, landscaping, spatial definition, etc.). This indicates walkability studies have tried to find qualitative variables such as safety, quality, and perceptual context. Alfonzo's (2005) work suggested the basic needs of feasibility (an individual's ability) and accessibility (somewhere to go) to measure walkability as well as qualitative characteristics (safety, comfort, and pleasurability) of walkability. Similarly, Agrawal, Schlossberg, and Irvin (2008) reported that commuters walking to transit stations chose routes based on safety and aesthetic characteristics. Alfonzo, Boarnet, Day, McMillan, and Anderson (2008) reported urban design features related to both accessibility and safety are associated with the amount of walking done in a specific environment. The enclosure, as one of the important visual aesthetic characteristics of urban spaces, is also one of the factors that can encourage walkability. Alexander, Ishikawa, and Silverstein (1977) stated that “An outdoor space is positive when it has a distinct and definite shape, as definite as the shape of a room, and when its shape is as important as the shapes of the buildings which surround it (p. 518).” Jacobs (1993) also has presented the idea that a positive space is defined by proper horizontal and vertical elements. Ewing and Handy (2009) proposed a conceptual framework to explain how built environment elements which cause user reactions (e.g. sense of safety, comfort and level of interest) contribute to an overall perception of walkability and, ultimately, walking behavior. As they discussed, though these five qualities (imageability, enclosure, human scale, transparency, and complexity) cannot fully explain the walkability, the study is valuable because this effort tried to explain qualitative features as quantitative variables regarding urban design.

Although Cervera and Kockelman (1997) asserted these qualitative design elements are too micro to change travel behavior patterns (p. 220), the micro-scale elements still have an influence on travel behavior (Saelens & Handy, 2008).

Built Environment and Health

As seen Figure 2-1, the relationships between built environment and health outcomes are complex. However, several researchers have argued that there is a positive correlation between certain built environment elements and health outcomes. In this section, I examine the evidence that shows the relationships between walkability and health outcomes as well as urban form and health outcomes.

Walkability and Health Outcomes

Several studies showed people were more likely to be overweight or obese if they lived in less walkable environments (Table 2-9). Giles-Corti, Macintyre, Clarkson, Pikora, and Donovan (2003) studied associations between environmental and lifestyle factors and being overweight or obese. They suggested factors that influence excess weight and obesity appear to differ, but aspects of the physical environment may be important. Ewing, Schmid, Killingsworth, Zlot, and Raubenbush (2003) tried to determine the relationship between urban sprawl, health, and health-related behaviors. Saelens, Sallis, Black, and Chen (2003) evaluated a neighborhood environment survey and compared the physical activity and weight status of the residents in 2 neighborhoods. They concluded neighborhood environment was associated with physical activity and overweight prevalence. Frank, Andresen, and Schmid (2004) assessed the relationship between the built environment around each participant's place of residence and self-reported travel patterns (walking and time in a car), BMI, and obesity for specific gender and ethnicity classifications. Frank et al., (2006) examined single-use, low density land development and disconnected street networks and concluded that they were positively associated with auto dependence and negatively associated with walking and transit use. Rosenberg, Sallis, Conway, Cain, and Mckenzie (2006) found active commuting (walking, biking, or skateboarding) to school may contribute to preventing excessive weight gain and leaner children may walk or cycle to school.

Furthermore, several studies reported the relationships between urban sprawl and health outcomes. This is because this type of study regards urban sprawl as increased reliance on automobile transportation and decreased ability to walk to destinations, decreased neighborhood cohesion, and environmental degradation (Lopez, 2004, p. 1594). Lopez (2004) showed a positive association between urban sprawl and the risk of being overweight or obese among U. S. adults. Doyle, Kelly-Schwartz, Schlossberg, and Stockard (2006) argued that living in more walkable counties is associated with more walking and lower body mass indices. Kelly-Schwartz, Stockard, Doyle, and Schlossberg (2004) found that residents who have more walkable environments tend to walk. Additionally they found that subjects reported better health, and were rated by physicians as having better health, when they lived in Metropolitan Statistical Areas that were more walkable. Sturm and Cohen (2004) showed sprawl in metropolitan areas is directly related to the prevalence of chronic diseases.

Finally, Table 2-10 reveals that walking has also been linked to various health benefits and improved cardiovascular health in adults (Manson et al., 2002). Among older adults, research shows links between walking and improved longevity (Hakim et al., 1998), cognitive function (Weuve et al., 2004) and quality of life (Strawbridge, Cohen, Shema, & Kaplan, 1996; Leveille, Guralink, Ferrucci, & Langlois, 1999).

Urban Forms and Health Outcomes

Based on previous studies, one can better recognize the relationships between the elements of the built environments such as mixed land use, proximity to recreational spaces and physical activity. However, some elements of built environment have more solid evidence regarding health outcomes. Recent research reported that several features of the built environment, such as grocery stores, recreational facilities, and sidewalks, have positive associations with desirable health outputs.

First, table 2-11 shows that full-size grocery stores in neighborhoods positively correlate with healthier diet among residents. (Morland et al., 2002; Sallis & Glanz, 2009). Conversely, a high concentration of fast food increases risks of obesity among neighborhood residents. (Larson et al., 2009). Second, access to recreational facilities is key in preventing residents from becoming overweight (Gordon-Larsen et al., 2006; Mobley et al., 2006). Third, areas with well-connected sidewalks that offer residents an opportunity to walk in their neighborhoods are more likely to meet physical activity guidelines (Lopez-Zetina et al., 2006).

Limitations of Existing Research

Even though the relationships between several elements of built environments and health have been documented, it is almost impossible to explain all aspects (social context, stressors, health behaviors, built environment, and etc.) that affect health outcome or well-being in one single model. The following reveals the limitations of previous research regarding active built environment.

Study Variables. Cities are complex communities of heterogeneous individuals, and multiple variables may be important determinants of health outcome. In addition to this complexity, previous studies have had limitations when explaining the relationships among various variables that affect health outcomes. Urban study scholars or public health professionals have used correlations and association ecological analyses to consider the association between factors at the group or aggregate level (Galea & Schulz, 2006, p. 282). These methods are useful to test hypotheses regarding the urban features that may affect active living. But it is not possible to answer how these elements may be associated with health. In the public health discipline, the variables such as stress factors, healthy behaviors, and social context have been shown to be empirically related to individual health (Israel, Farquhar, Schulz, James, & Parker, 2002;

Lantz et al., 1998; Yen & Syme, 1999). However, the above efforts may have limitations because those studies have been conducted in isolation.

Thus, to overcome the limitations, Schulz and Northridge (2004) developed the model of "Social Determinants of Health and Environmental Health Promotion," which addresses "the implications of social and economic inequalities (fundamental factors) for the built environment and social context (intermediate factors) that influence stressors, health behaviors, and social relationships (proximate factors) that ultimately result in individual and population health and wellbeing" (p. 458). However, despite their efforts, Schulz and Northridge (2004) recognized the limitations of presenting social processes and environmental effects as a series of boxes and arrows as they are far more complex (p. 458).

In conclusion, it is difficult to evaluate health outcomes with only one discipline such as medical or urban planning perspectives. Although previous efforts indicate that the relationship between several elements of built environments and health can be demonstrated, it is impossible to explain all aspects that affect health outcome and their relationships. In order to overcome this limitation, Galea and Schulz (2006) suggested quantitative methods to study urban health. Though the approach of Galea and Schulz is useful in utilizing multiple variables simultaneously, it has other issues, including: variable specification issues complex casual pathways and nonlinear association.

Study Durations. In previous studies to identify correlation between physical activity and elements of built environments, these studies have utilized cross-sectional methods (Galea & Schulz, 2006). However, because this type of study relies on cross-sectional data, these results should be interpreted as associations, not causative factors.

Thus longitudinal studies are needed to advance thoughts about how urban characteristics may cause different health behaviors and outcomes (Galea & Schulz, 2006, p.284). Recently, researchers have included longitudinal components to address the issue of causality. Krizek (2003) found that when households moved to neighborhoods with different urban form, the likelihood of using active transportation remained unaltered. Also, Rodriguez et al. (2006) investigated if neighborhood design can support or undermine active lifestyles using suburban neighborhoods and new urbanist neighborhoods. They found residents of the new urbanist neighborhood were more likely to be physically active than were residents of suburbs.

In addition to duration issues, sample size (in public health studies, this refers to the number of people) gives another limitation for research. Because lots of cross-sectional studies have used self-reported data or observational data, there are limited sample numbers.

Both time and people are critical variables for measuring health output and current study methodology cannot fully cover the all variables. Therefore, in order to fill the gaps, further research conducted in the public health discipline and by urban study is necessary to build a solid health model.

Location Choice and Life Style. Since people choose to live in an area for many reasons that do not necessarily relate to healthy lifestyle opportunities, it is also necessary to review how people to select their living location.

Generally, the residential location choice model is able to quantify the trade-offs between transport, amenities and other factors (Kim, Pagliara; & Preston, 2005), but in reality, the choice of where to live is determined by market imperfections combined with preferences. Kleit and Galvez (2011) reported that “personal preferences and information available through close social relationships may play an important role in determining location outcomes” (p. 375). For example, a previous experience of living in a city increases the probability of returning to that city (Feijten, Hooimeijer, & Mulder, 2008) and having lived in a rural area increases the probability of choosing a rural home location (Van Dam, Heins, & Elbersen, 2002).

However, individuals or households with preferences towards certain health behaviors (like physically activity) may choose built environments that support those behaviors (Rodriguez et al., 2006, p. 47). As mentioned previously, this type of research needs further longitudinal research methods. It is important to note that the criteria to select locations for housing are as vast as the complex relationship between built environment and health outcome.

Summary of Previous Studies

Despite complexities inherent in urban forms and physical activity, several studies show positive relationships between physical activities and some urban design elements, such as open space, schools, and transportation facilities. The key response variable of previous research is walking or biking, which is considered everyday physical activity. Thus to encourage everyday physical activity, well-made and maintained built environments are critical.

However, there are still some limitations of the previous studies. First, because most studies utilized self-reported or observational data, there is a data reliability issue.

This is because participants who self-reported data may have remembered incorrectly, or deliberately misreported. Second, case studies might not show unique regional context of each study. Though most studies showed common results, the results are limited to people in the case study areas. This is because every study has different regional context, though using same criteria, the result may vary (Rodriguez et al., 2006). Third, even though this type of research, which analyzes relationships between the built environment and public health, should be conducted across interdisciplinary boundaries, most studies were conducted in individual fields. However, the cooperation informed by science between public health and urban planning is helpful to make substantive progress through intellectual collaboration (Northridge & Freeman, 2011; Northridge, Sclar, & Biswas, 2003). This coordinated approach among academic disciplines is fundamental to answer not only how urban living affects public health but also to research methodological development (Galea & Schulz, 2006).

Form-based Codes

This section examines two topics: FBCs' historical context and what make FBCs a good solution to conventional zoning regulation issues. Furthermore, this section establishes foundational information about FBCs by exploring the following topics: the definition, the basic components and previous studies on the topic.

Historical Context

As Talen (2009) states, many urban places are the result of explicit rules (p. 144), and the present urban spaces result from specific rules such as zoning regulations. In this section, I analyze how these specific rules influence the history of urban planning.

Early Land Use Controls

The initial measures of regulation in the late nineteenth century and early twentieth century were based on the authority of cities to exercise their political power (Parolek, Parolek, & Crawford, 2008, p. 6). It was natural that there were a number of conflicts between individuals and administrative bodies before zoning regulations. In the beginning stage of urban planning, the Supreme Court was focused on civil rights (Yick Wo v. Hopkins, 118 US 356[1] - Supreme Court 1886). But, as city populations increased, cities' authority began to grow. In order to sustain the quality of urban areas, cities developed regulations regarding land use control. Several Supreme Court decisions reflect the time of early 20th century, the Court upheld the regulations of cities (Welch v. Swasey, 214 US 91[2] - Supreme Court 1909 and Hadacheck v. Sebastian, 239 US 394[3] - Supreme Court 1915). However, most of those regulations were passive tactics because they only regulated noxious land use or building height.

New York City in 1916. After the mid-nineteenth century, there was a population boom in New York City because an influx of immigrants. Around the same time, the height of buildings increases because of developing technology. As a result of these drastic changes, the city faced two problems: fire hazards and decreasing light because of the shadows cast by tall buildings. Because of these new situations, the first American zoning ordinance was enacted in New York City in 1916, with the aim of imposing minimum standards of light and air for streets (Barnett, 1982, p. 61). Barnett (1982) also noted that "the ordinance sought to separate activities that were viewed as

[1] Supreme Court invalidated San Francisco Ordinance.
[2] Supreme Court upheld height restrictions in Boston.
[3] Supreme Court upheld ban on brickyards in Los Angeles.

incompatible, such as the factors of the garment center and the fashionable shops and homes along the Fifth avenue" (p. 61). The ordinance had three districts: Residential, Business, and Unrestricted (City of New York, 1916, ARTICLE 2). Though this ordinance had some disadvantages like land use segregation and monotonous building heights in same the zone, it has been expanded out to other municipalities.

The Heyday of Euclidean Zoning

The legal rationale for zoning is the so-called police power of the state to make regulations to protect public health, safety, and general welfare (Barnett, 1982, p. 61). This kind of power was affirmed by following two events in the U.S. urban planning history: "The Standard State Zoning Enabling Act" and "Village of Euclid v. Ambler Realty Co., 272 US 365".

The Standard State Zoning Enabling Act (SSZEA). Herbert Hoover, who was the Commerce Secretary, created an advisory committee to draft model state zoning enabling acts in 1921. The act delegated power to zone; established procedures for amendments, special exceptions, variances; and created the board of zoning appeals. After the SSZEA was issued, By the 1930s, 35 states adopted legislation based on the SSZEA (Meck, 1996, p. 2).

Village of Euclid v. Ambler Realty Co., 272 US 365 - Supreme Court 1926. The Supreme Court upheld the zoning law of Euclid as constitutional because it contributes to the general welfare of the public. After this decision, a number of municipalities adopted zoning legislation. By 1977, 97% of local governments had utilized zoning as the primary regulation tool (Haar & Kayden 1989, p. 185).

New Attempts

The adverse impacts of early zoning regulations were not fully realized until the 1950s (Parolek et al., 2008, p. 8). However, as the problems of conventional zoning (e.g. land use segregation, travel cost increase, air pollution) became more apparent over time, there have been various attempts to fix those issues.

Growth Management. This approach basically regarded land as a limited resource. Its main objectives clearly show that perspective: first, reduce consumption of land; second, make development more compact; third, establish minimum standards of competence for local planning and land use control; fourth, vertical and horizontal integration. In order to achieve original purposes of growth management, there have been several techniques developed: urban growth areas; priority funding areas; permit allocation systems; adequate public facilities ordinances; impact fees; state review of plans, and regulations. Growth management efficiently protects natural recourses, improves sustainability in the development process, and creates opportunities for providing appropriate public facilities (Nelson & Duncan, 1995).

New Urbanism. Though Growth Management is conducive to relieving the problems from urbanization, it was just a temporary tool in terms of urban design. The consequences from modified-conventional zoning have been almost the same since zoning regulations were adopted. While public agency planners were beginning to streamline conventional zoning codes in the 1980s, a group of urban professionals dedicated to promoting walkable and mixed-use places as described in the principal of Smart Growth and the Chapter of the New Urbanism worked collaboratively to formulate and refine an alternative to conventional zoning (Parolek et al., 2008, p. 9).

Form-Based Codes. The first example of this new approach was seen in Seaside, Florida. The Development Code for Seaside of Florida, drafted by Duany Plater-Zyberk in 1981, was one of the first modern day applications of Form-Based Coding (Parolek et al., 2008, p. 9). This alternative approach includes “traditional neighborhood development” ordinances, mixed-use and live/work codes, transit-oriented development ordinances, transit area codes, transect-based codes, smart growth codes, sustainable codes, transit-supportive codes, urbanist codes, and green building codes of various stripes (Talen, 2013, p 178). But in 2001, Chicago consultant Carol Wyant coined the term Form-Based Codes, which has been the common name (Parolek et al., 2008, p. 10).

The distinct difference between FBCs and conventional zoning is that FBCs allow common understanding by relating development characteristics to places within the urban fabric (Local Government Commission, p3). Figure 2-2 shows six Transect zones (T-zones), which have a prototypical rural-to-urban transect as well as provide unique characteristics of each zone. Also, FBCs’ proponents assert that the understanding of context is conducive to creating walkable, mixed-use, and compact development, which lead active living.

Current Status

According to “The Codes Study” by Borys and Talen (2015a), as of January 2015, researchers have tracked 584 codes that meet criteria established by the FBCI (FBCI, 2015), as well as an additional 16 form-based guidelines.

Table 2-12 shows that currently 550 municipalities in all 50 states except Alaska, South Dakota, and North Dakota have adopted FBCs. Florida has the highest amount at 66 codes followed by California (57 codes). The top 10 states, which are Florida, California, Texas, Virginia, Georgia, North Carolina, Michigan, South Carolina, Illinois, Louisiana, and New Jersey have 330 codes (60% of total). That means these states have exerted a lot of effort to establish FBCs as their regulation tools.

Figure 2-4 shows the total number of FBCs by state level. However, based on table 2-12, about 57% (314 codes) of the total number of codes are neighborhood scale, and 181 codes are applied to a citywide scale. This implies that small areas can more easily apply FBCs rather than large (regional or statewide) areas.

In addition to the number of municipals, figure 2-4 shows the number of adopted FBCs by year. As shown, after 2003, the number of municipalities that have adopted FBCs has increased significantly, indicating that many municipalities have recognized FBCs as an alternative to conventional zoning regulations.

Components of FBCs

In order to create urban form, FBCI developed a structure to include a set of minimum components (Table 2-13) that may also accommodate a variety of optional ones (Parolek et al., 2008, p. 15). The required components of FBCs are: a regulating plan, public space standards, building form standards, an administration, and a glossary. Additional components consist of the following standards (these components may be included depending on the needs of the community): Block Standards, Building Type Standards, Architectural Standards, Green Building Standards, Landscape Standards (Parolek et al., 2008, p. 16). In addition to regulating physical urban form, as Parolek et al. (2008) asserted, FBCs emphasize harmony with local contexts. Although supporters of FBCs argue that components are helpful to create active built environment, some architects are concerned about losing their design freedom (Berg, 2010) because of specific standards to define building forms.

Previous Studies

While many municipalities have adopted FBC as a method of settling their unsolved urban issues, few studies have been conducted regarding FBCs. As a part of legal aspect, Barry (2008) claims that FBCs are superior to conventional zoning regulations regardless FBCs are mandatory or optional. Sitkowski and Ohm (2006) summarized legal perspective of FBCs. Rangwala (2012) argued FBCs have certain advantages in terms of civic participation due to the visualized process of FBCs.

Several studies reached that FBCs are helpful to create mixed land use and walkable places. Hansen de Chapman (2008) showed the value of FBCs in the view of walkability and asserted that communities developed from FBCs are superior to other communities. Laakso (2011) urged that FBCs are conducive to create dense and mixed land use. Polikov (2008) added this dense and mixed land use eventually has economic benefits. Talen (2013) asserted FBCs are helpful to mitigate urban sprawl issue. Senbel, van der Laan, Kellett, Girling, and Stuart (2013) concluded FBCs are helpful to reduce greenhouse gas due to compact development characteristics of FBCs.

Another study by Talen (2009) presented the differences between FBCs and conventional zoning regulations in the view of history and defined FBCs as physical planning.

Other non-peer reviewed articles mainly mentioned the regulatory aspects (Broberg, 2010; Katz, 2004; Purdy, 2006; Ross, 2009; Spilowski, 2010; Tombari, 2009) or design perspectives (Berg, 2010; Cable, 2009; Coyle, 2010; Hendon & Adams, 2010; Rangwala, 2010) of FBC. Some articles defined FBCs as a physical planning compared to conventional zoning (Madden & Spikowski, 2006; Mammoser, 2011; Rangwala, 2005). Because of FBCs' physical planning aspect, they concluded FBCs make a direct impact on urban forms. However, most of non-peer reviewed papers lauded FBC without academic verification. This is a critical point since zoning also spread without questions. In order to avoid the same mistake, scholars should pay attention to see if FBCs follow the same trajectory.

Most FBCs efforts started in order to demonstrate that FBCs are a possible solution to solve existing zoning problems. The comparison between conventional zoning codes and FBCs shows why many municipalities have moved from convention zoning to FBCs (see Table 2-14).

Even though FBCs have more opportunities to create mixed-use, compact, and walkable spaces than traditional zoning, there are possible pitfalls of FBC implementation. If FBCs work well, it is good for both urban space and people. However, if FBCs do not work properly, then urban space will be irrevocable. We already have experienced undesirable results from zoning regulation: urban sprawl, climate change, and name a few (Duany et al., 2010). Before reaching a quick decision to adopt FBCs as an alternative of conventional zoning regulations, we need to verify the various effects of FBCs. In fact, urban planners and designers have created new methods—such as new urbanism, smart growth, and sustainable development—that could possibly cure contemporary urban issues. But there have always been gaps between the theory and its implementation in practice (Grant, 2009).

Summary of Literature Review

The literature shows that certain urban form elements—such as open space, schools, and transportation facilities—can affect the creation of active built environment. As one possible solution, FBCs have become a leading method of solving contemporary urban issues created by conventional zoning and can lead to development of more active built environments.

Table 2-1. Physical Activity Guideline by Age (HHS, 2008)

Age group	Type of activity		
	Aerobic activity	Muscle-strengthening activity	Bone-strengthening activity
Children	Moderate-or vigorous-intensity: the 60 or more minutes a day (should include vigorous-intensity at least 3 days a week)	At least 3 days of the week.	At least 3 days of the week.
Adults	Moderate-intensity: at least 150 minutes a week (or) 75 minutes a week of vigorous-intensity	Involve all major muscle groups on 2 or more days a week	
Older Adults	Moderate-intensity: at least 150 minutes a week (or) 75 minutes a week of vigorous-intensity	Involve all major muscle groups on 2 or more days a week	

Table 2-2. The Relationships between Mixed-use Development and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Aytur et al. (2007)	Active Community Environment	Mode (Walking, Biking)	6,694 residents in 67 North Carolina counties	People living in counties with the highest "Active Community Environment" (ACE) scores were more than twice as likely to walk and bike for transportation as residents in counties with the lowest ACE scores
Frank et al. (2007)	Land use type	Children with Walking	2001-2002 from 3,161 Atlanta children	5 to 18 year olds were more likely to walk for transportation if they lived in mixed-used neighborhoods with parks, schools, and commercial destinations nearby
Mumford et al. (2011)	Before and after moving to a mixed use development	Self-reported physical activity and travel behaviors	101 adult residents of Atalantic station	There were significant increases in walking for recreation or fıtness (46%–54%; $p<0.05$) and walking for transportation (44%–84%; $p<0.001$) after moving

Table 2-3. The Relationships between Children's Play Area and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Boarnet et al. (2005)	improvements in sidewalks and street crossings, as well as traffic calming	increase the number of students who walk to school	Recent evaluations of Safe Routes to Schools projects in California	Improvements in sidewalks and street crossings, as well as traffic calming, increase the number of students who walk to school
Mcdonald (2008)	Distance from school	Mode (Walking, Biking)	low-income and minority youth (N=14,553) using data from the 2001 National Household Travel Survey	Youth who live within a half mile of school had a greater likelihood of walking of biking to school, even after controlling for socioeconomic status and neighborhood covariates

Table 2-4. The Relationships between Distance to Recreational Spaces and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Babey et al. (2008)	Urban areas, Neighborhood perceived as unsafe, Income, Ethnic	Regular Physical Activity Regular Physical Inactivity	2003 California Health Interview Survey (N=4010)	Adolescents are more likely to engage in regular physical activity and/or less likely to be inactive when they have access to safe parks
Cohen et al. (2007)	Distance lived from park	% visiting park or exercising weekly	1318 residents of predominantly low-income Los Angeles	People who live closer to a park are more likely to visit parks and exercise more often Adults living within a half mile of a park visit parks and exercise more often
Coutts (2008)	Population density, land-use mixture	physical activity along greenways		Greenways have higher levels of physical activity when: A park or wooded area is nearby, The trail intersects areas with greater land-use mixture, Trail segments connect both green settings and areas with greater land-use mixture
Giles-Corti et al. (2005)	Accessibility, Size	Walking time (Physical Activity Level)	1773 adults (Perth, Australia)	People with very good access to attractive and large Public Open Space (POS) were 50% more likely to achieve high levels of walking, totaling 180 minutes or more per week People who use any POS, regardless of attractiveness or size, were nearly 3 times more likely to achieve recommended physical activity levels of 150 minutes or more per week

Table 2-4. Continued.

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Moore et al. (2008)	Distance to recreational resource	Physical Activity	2,723 adults living in New York, Baltimore, and North Carolina	Adults were 28% more likely to participate in recreational activities if there were more recreational resources within five miles of their homes. The relationship between physical activity and proximity to recreational resources was significantly greater among African Americans and Hispanics.
Pierce et al. (2006)	Destinations within walking distance	% meeting physical activity guidelines by walking		People were more likely to walk 30 minutes 5 times/week if they lived near walkable destinations

Table 2-5. The Relationships between Size of Open Spaces and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Cohen et al. (2009)	Park improvement	Physical Activity	10 urban parks located in predominantly Latino, African-American, and low-income communities in southern California and self-reports from 2867 residents	Although perceptions of safety increased significantly after park improvements were implemented, this was not associated with park use or exercise More parks users observed in larger parks Park use is weakly related to the number of scheduled programs and organized activities Most used parks had many activities or unique features
Farely et al. (2008)	Play Area Features (Field, Basketball, Equipped Concrete, Installed Play Structure)	Number of Active Children	the 2nd through 8th grades over two years	Observations of children in the 2nd through 8th grades over two years in an inner-city New Orleans schoolyard* show that children are more likely to be very active in play areas with installed play structures than those with an open field

Table 2-6. The Relationships between Facilities of Recreational Spaces and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Brink et al. (2010)	Renovated (or not)	Physical Activity	9 public elementary schools in Denver, Colorado	Children had significantly higher rates of physical activity in schoolyards renovated by Learning Landscapes than in schoolyards that were not renovated
Floyd et al. (2008)	Activity Type	Park Users	White, African-American, and Hispanic park users in 10 Tampa parks (N=7043) and 18 Chicago parks (N=2413)	Significantly more users engaged in sedentary behavior than in vigorous or walking activity. Based on direct observation. People using tennis, racquetball, and basketball courts burned more energy than people using other park areas
Kaczynski et al. (2008)	Facilities included trails, paths, playgrounds, and courts. Amenities included drinking fountains, picnic areas, restrooms, and aesthetic features.	Physical Activity	380 adults and 33 neighborhood parks in Ontario, Canada	Parks with more facilities and amenities were more likely to be used for some physical activity
Mobley et al. (2006)	fitness facility per 1000 residents	BMI	2692 low-income women from the CDC's WISEWOMAN study	Women who lived in areas containing a ratio of one fitness facility per 1000 residents had on average a BMI that was 1.39 kg/m2 lower than the BMI of women living in areas with fewer fitness facilities

Table 2-6. Continued.

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Roemmich et al. (2010)	Park elements, Age, Gender	Physical Activity	children aged 8 to 16 (N=106) in Buffalo, NY	Younger children use play equipment more than older children, while older children are more likely to use open natural areas. Findings suggest play areas should incorporate diverse features to encourage physical activity among different age groups of youth.
Shores & West (2008)	Park elements (Shelter, Green space, Courts, Path, Playground)	Physical Activity		SOPARC (System for Observing Play and Recreation in Communities) observations of four suburban parks in the southeastern US found that park visitors are more likely to engage in vigorous physical activity when using courts, paths, and playgrounds

Table 2-7. The Relationships between Public Transit and Physical Activity

Citation	Data	Key findings
Besser & Dannenberg (2005)	3312 transit users among 105,942 respondents (2001 National Household Travel survey)	29% achieve ≥30 minutes of physical activity a day solely by walking to and from transit rail users, minorities, people in households earning <$15,000 a year, and people in high-density urban areas were more likely to spend ≥30 minutes walking
Saelens & Handy (2008)	original studies published in 2005 to 2006	Walking for transportation is most strongly related to living in neighborhoods with high residential density, mixed land use, and short distances to destinations.

Table 2-8. The Relationships between Street Connectivity and Physical Activity

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Besser & Dannernberg (2005)	Public Transit Users	Percent walked 30+minutes/day	2001 National Household Travel Survey (N=3,312)	29% of public transit users achieve the Surgeon General's recommendation of 30 minutes or more of physical activity a day while walking to and from transit. Racial/ethnic minorities reported even greater percentages of achieving the recommended level of activity.
Dill (2009)	Importance of factors in bicycle route choice	Mean Score	adult cyclists in Portland, OR (N=166)	Well-connected network of low-traffic neighborhood streets Bike lanes should be networked with paths and bike boulevards Zoning standards that support mixed land use
Frank et al. (2005)	Urban Form	Physical Activity	357 Atlanta adults	People who live in walkable neighborhoods are more likely to meet recommended daily levels of physical activity
Gorden-Larsen et al. (2006)	Physical Activity Facility	Physical Activity, Weight	US adolescents (N=20,745)	A greater number of physical activity facilities is directly related to increased physical activity and inversely related to risk of overweight

Table 2-8. Continued.

Citation	Explanatory variable(s)	Response variable(s)	Data	Key findings
Handy et al. (2008)	Neighborhood Characteristic	Physical Activity	residents (N=1,497) in northern California	After controlling for sociodemographic and attitudinal variables, certain neighborhood characteristics are significantly associated with physical activity frequency within the neighborhood
King (2008)	Walkability, Safety, Social cohesion	Physical Activity	seniors in Denver, CO (N=190)	Total physical activity and community-based activity were highest in neighborhoods with fewer walkability variables but higher respondent perceptions of safety and social cohesion ($p<.01$)
Lopez-Zetina et al. (2006)	Vehicle Miles traveled	Obesity	33 California cities	Adults who drove the most had obesity rates (27%) that were three times higher than those who drove the least (9.5%).
Reed et al. (2006)	Sidewalk	Physical Activity	1,148 adults living in the southeastern US	The number of adults who met physical activity guidelines was 15% higher in neighborhoods with sidewalks.

Table 2-9. The Relationships between Walkability and Obesity

Citation	Data and methods	Key findings
Ewing et al. (2003)	Measures: Sprawl indices, derived with principal components analysis from census and other data (independent variables). Self-reported behavior and health status from BRFSS (dependent variables). Subjects: Adults (n=206,992) from pooled 1998, 1999, and 2000 BRFSS.	After controlling for demographic and behavioral covariates, significant associations with minutes walked, obesity, BMI, and hypertension. Residents of sprawling counties were likely to walk less during leisure time, weigh more, and have greater prevalence of hypertension than residents of compact counties.
Frank et al. (2004)	10,878 participants (Atlanta, Georgia region): BMI, minutes spent in a car, kilometers walked, age, income, educational attainment, and gender. Objective measures of land use mix, net residential density, and street connectivity (within a 1-kilometer network distance of each participant's place).	Each additional hour spent in a car per day was associated with a 6% increase in the likelihood of obesity. Each additional kilometer walked per day was associated with a 4.8% reduction in the likelihood of obesity.
Frank et al. (2006)	The association between a single index of walkability that incorporated land use mix, street connectivity, net residential density, and retail floor area ratios, with health-related outcomes (King County, Washington).	5% increase in walkability to be associated with a per capita 32.1% increase in time spent in physically active travel, a 0.23-point reduction in BMI.
Giles-Corti et al. (2003)	Measures: Four lifestyle factors, one social environmental factor, and five physical environment factors (three objectively measured). Data: Healthy sedentary workers and homemakers aged 18 to 59 years (n = 1803) living in areas within the top and bottom quintiles of social disadvantage.	Overweight was associated with living on a highway or streets with no sidewalks or sidewalks on one side only and perceiving no paths within walking distance. Also, poor access to four or more recreational facilities and sidewalks and perceiving no shop within walking distance were associated with obesity. Conversely, access to a motor vehicle all the time was negatively associated with obesity.

Table 2-9. Continued.

Citation	Data and methods	Key findings
Rosenberg et al. (2006)	Elementary schools' students: 4th grade (N=1083) and 5th grade (N =924). Participants were classified as active (walking, biking, or skateboarding) or non-active commuters to school. Accelerometers were used to measure physical activity. Height, weight, and skinfolds were objectively assessed.	Boys who actively commuted to school had lower BMI ($p<0.01$) and skinfolds ($p< 0.05$) than non-active commuters to school in the fourth grade.
Saelens et al. (2003)	On 2 occasions, 107 adults from neighborhoods with different walkability. Physical activity was assessed by self-report and by accelerometer, height and weight were assessed by self-report.	Residents of high walkability had more than 70 more minutes of physical activity and had lower obesity prevalence than did residents of low-walkability neighborhoods.

Table 2-10. The Relationships between Walkability and Health Outcomes

Citation	Methods and data	Key findings
Hakim et al. (1998)	707 nonsmoking retired men (61 – 81) The distance walked (miles per day) was recorded at a base-line examination (1980 - 1982) Data on overall mortality (from any cause) were collected over a 12-year period of follow-up.	After adjustment for age, the mortality rate among the men who walked less than 1 mile per day was nearly twice that among those who walked more than 2 miles per day. The cumulative incidence of death after 12 years for the most active walkers was reached in less than 7 years among the men who were least active.
Leveille et al. (1999)	Estimate the prevalence of having no disability in the year prior to death in very old age and to examine factors associated with this outcome. Participants were men and women aged 65 years and older who were followed prospectively between 1981 and 1991 from three communities.	Physical activity was a key factor predicting nondisability before death. There was nearly a twofold increased likelihood of dying without disability among the most physically active group compared with sedentary.
Manson et al. (2002)	73,743 postmenopausal women (50 – 79 & they were free of diagnosed cardiovascular disease and cancer) Completed detailed questionnaires about physical activity.	An increasing physical-activity score had a strong, graded, inverse association with the risk of both coronary events and total cardiovascular events. Walking and vigorous exercise were associated with similar risk reductions, and the results did not vary substantially according to race, age, or body-mass index.

Table 2-10. Continued.

Citation	Methods and data	Key findings
Strawbridge et al. (1996)	356 Alameda County men & women (65-95) measured prospectively in 1984 and followed to 1990. Successful aging: needing no assistance nor having difficulty on any of 13 activity/mobility measures.	Cross-sectional comparisons at follow-up revealed significantly higher community involvement, physical activity, and mental health for those aging successfully.
Weuve et al. (2004)	Women reported participation in leisure-time physical activities beginning in 1986. Assessed long-term activity in 1986 through participants' baseline cognitive assessments (1995 to 2001). Linear regression to estimate adjusted mean differences in cognitive performance.	Higher levels of activity were associated with better cognitive performance. Compared with women in the lowest physical activity quintile, we found a 20% lower risk of cognitive impairment for women in the highest quintile of activity.

Table 2-11. The Relationships between Grocery Stores and Health Outcomes

Citation	Methods and data	Key findings
Larson et al. (2009)	A snowball strategy was used to identify relevant research studies (n=54) completed in the U.S. and published between 1985 and April 2008.	Neighborhood residents who have better access to supermarkets and limited access to convenience stores tend to have healthier diets and lower levels of obesity. Residents with limited access to fast-food restaurants have healthier diets and lower levels of obesity.
Morland et al. (2002)	Recommended intakes of foods and nutrients for 10,623 Atherosclerosis Risk in Communities participants were estimated from food frequency questionnaires. Supermarkets, grocery stores, and full-service and fast-food restaurants were geocoded to census tracts.	Black Americans' fruit and vegetable intake increased by 32% for each additional supermarket in the census tract White Americans' fruit and vegetable intake increased by 11% with the presence of 1 or more supermarket.
Sallis & Glanz (2009)	Summarizes and synthesizes recent reviews and provides examples of representative studies.	Residents of communities with ready access to healthy foods also tend to have more healthful diets.

Table 2-12. FBCs by State and Scale in U.S. as of January 2015 (Borys & Talen, 2015a)

State	Largest Scale				Total numbers
	Neighborhood	City	Region	State	
Alabama	9	4	1		14
Arkansas		2	1		3
Arizona	3	5			8
California	33	21	2	1	57
Colorado	5	6			11
Connecticut	7				7
Delaware			1		1
Florida	31	25	8	2	66
Georgia	13	5	3	1	22
Hawaii	1	1	2		4
Iowa	2	1			3
Idaho	1	1	1		3
Illinois	11	6	1		18
Indiana	3	1			4
Kansas	1	3			4
Kentucky	7	1			8
Louisiana	6	11	1		18
Massachusetts	4	3	1		8
Maryland	4	2	2		8
Maine	8	1			9
Michigan	14	5	1	1	21
Minnesota	3	1			4
Missouri	4	4			8
Mississippi	4	10	2	1	17
Montana		1			1
North Carolina	12	10			22
Nebraska	2	1			3
New Hampshire	7	2			9
New Jersey	16	1	1		18
New Mexico	3	2	1		6

Table 2-12. Continued.

State	Largest Scale				Total numbers
	Neighborhood	City	Region	State	
Nevada		1	1		2
New York	5	5	1		11
Ohio	3	2			5
Oklahoma	1				1
Oregon	4	1			5
Pennsylvania	5	4	1		10
Rhode Island	2				2
South Carolina	12	5	3		20
Tennessee	7	4	1		12
Texas	25	16	2		43
Utah	6	1			7
Virginia	17	1	7		25
Vermont	5	2	1		8
Washington	6		2		8
Wisconsin	1	1		1	3
West Virginia		1			1
Wyoming	1	1			2
Grand Total	314	181	48	7	550

Table 2-13. The Required Components of FBCs (Parolek et al., 2008, pp. 15-18, 28-38, 41-54)

Components	Sub-Components
A regulating Plan	Administrative Direct Regulation Planning
Public Space Standards	Thoroughfares: Movement Type, Design Speed, Pedestrian Crossing Time, Transect Zone, Right-of-Way Width, Curb Face to Curb Face Width, Traffic Lanes, Bicycle Lanes, Parking Lanes, Curb Type, Planter Type, Landscape Type, Walkway Type, Lighting, Curb Radius, Distance between Intersections Civic Space: Acreage, Location, Size, Allowable Transect Zones, Activity Type, General Character
Building Form standards	Overview of the zone Building Placement regulations: Build-to-Line (BTL), Setback, Maximum Lot Width, Minimum Lot Width Building Form regulations: Minimum Building Height, Maximum Building Height, Ground-Floor Finished Level Height, Minimum Ground-Floor Ceiling Height, Minimum Upper-Floor(s) Ceiling Height, Maximum Building Width, Maximum Building Depth, Maximum Ancillary Building Size Parking regulations: Required Spaces, Location Allowed use types and detailed use table Allowed Frontage types Allowed Encroachments Allowed Building Types
Administration	
Glossary	

Table 2-14. Conventional zoning code vs. FBCs (Parolek et al., 2008, p. 13)

Conventional zoning code	FBCs
Auto oriented, segregated land use planning principles	Mixed use, walkable, compact development-oriented principles
Organized around single-use zones	Based on spatial organizing principles that identify and reinforce an urban hierarchy, such as the rural-to-urban transect
Use is primary	Physical form and character are primary, with secondary attention to use
Reactive to individual development proposals	Proactive community visioning
Proscriptive regulations, regulating what is not permitted, as well as unpredictable numeric parameters, like density and FAR	Prescriptive regulations, describing what is required, such as build-to lines and combined min/max building heights
Regulates to create buildings	Regulate to create places

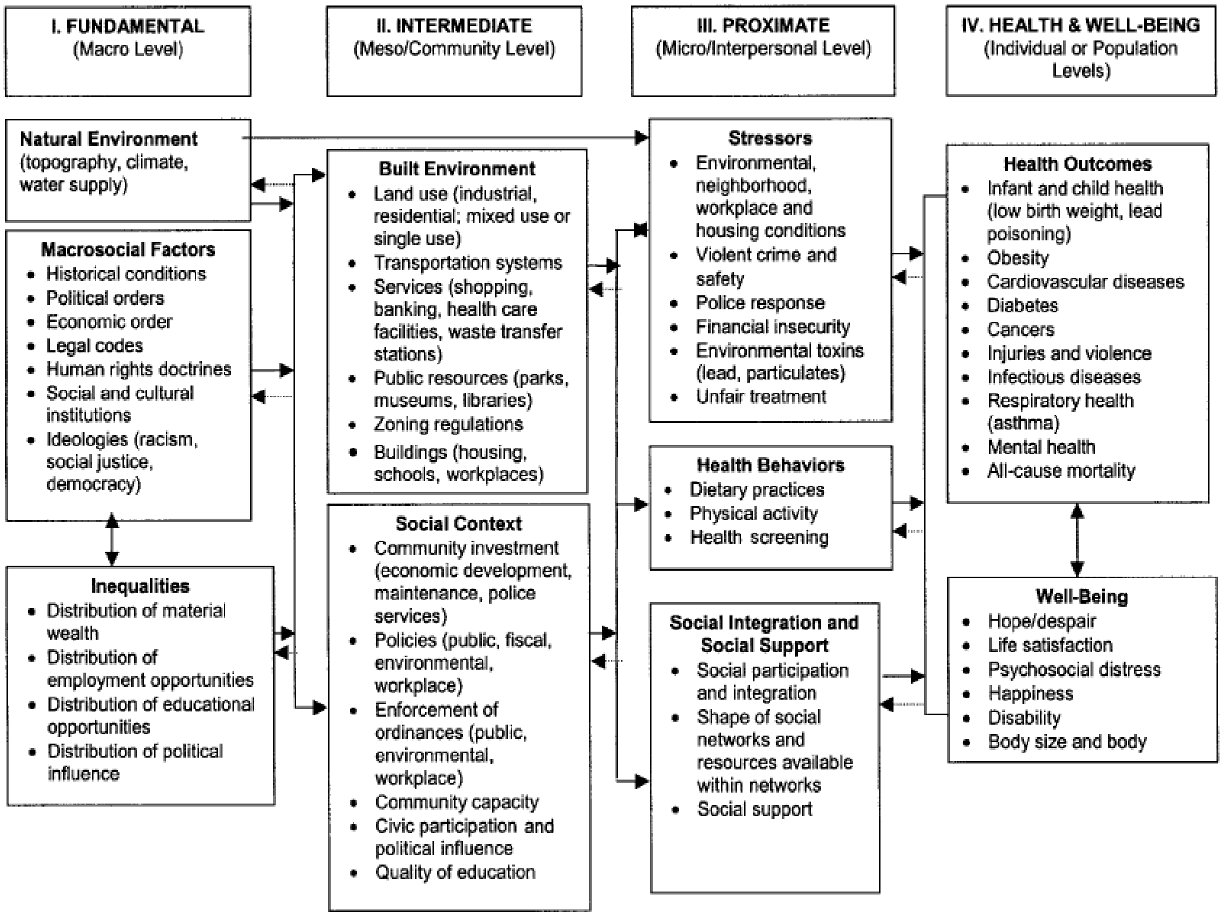

Figure 2-1. Social Determinants of Health and Environmental Health Promotion (Northridge et al., 2003, p. 559)

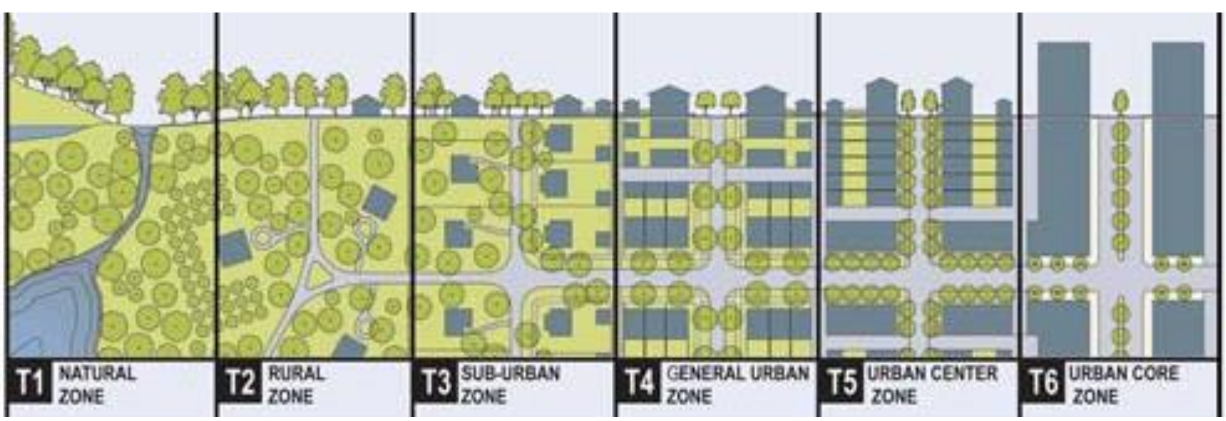

Figure 2-2. Transect Zone (Retrieved from http://www.transect.org/transect.html)

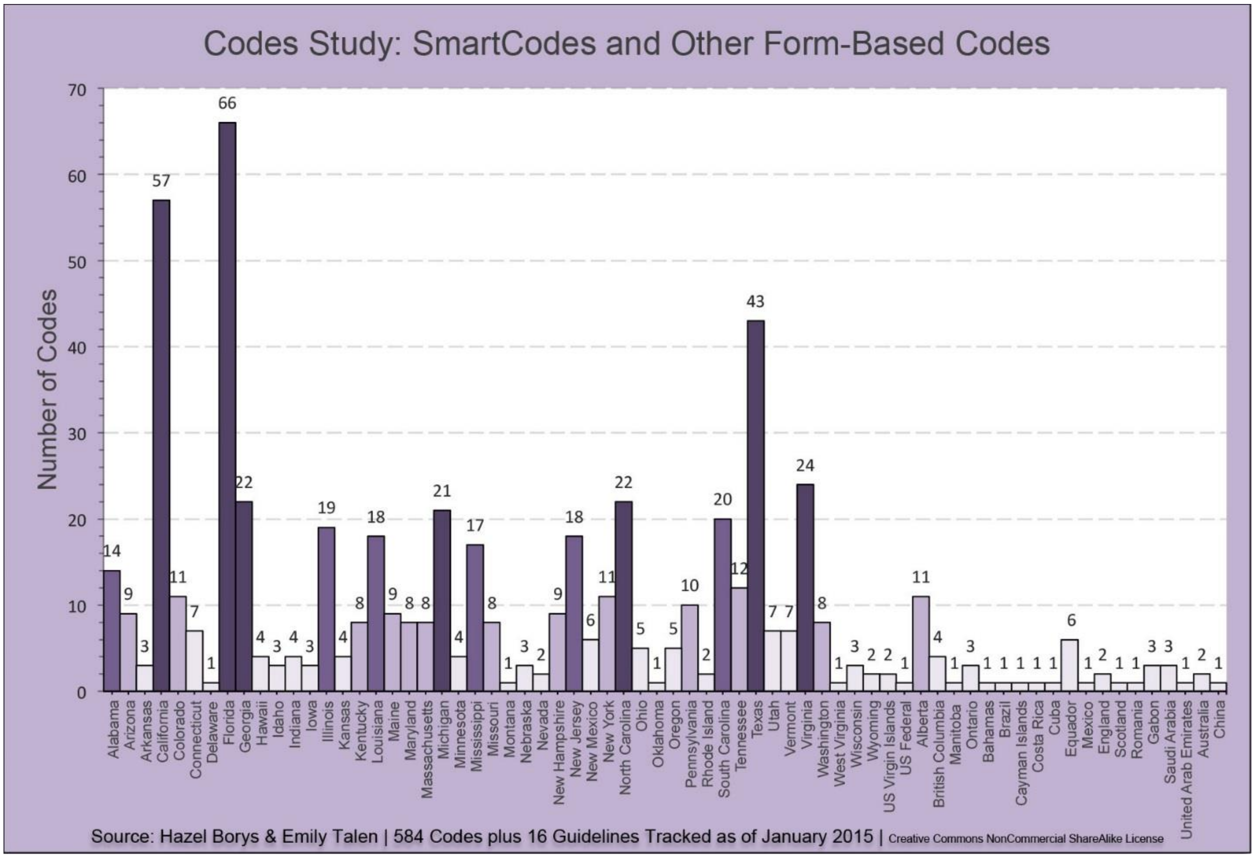

Figure 2-3. Number of FBCs by State (Borys & Talen, 2015b)

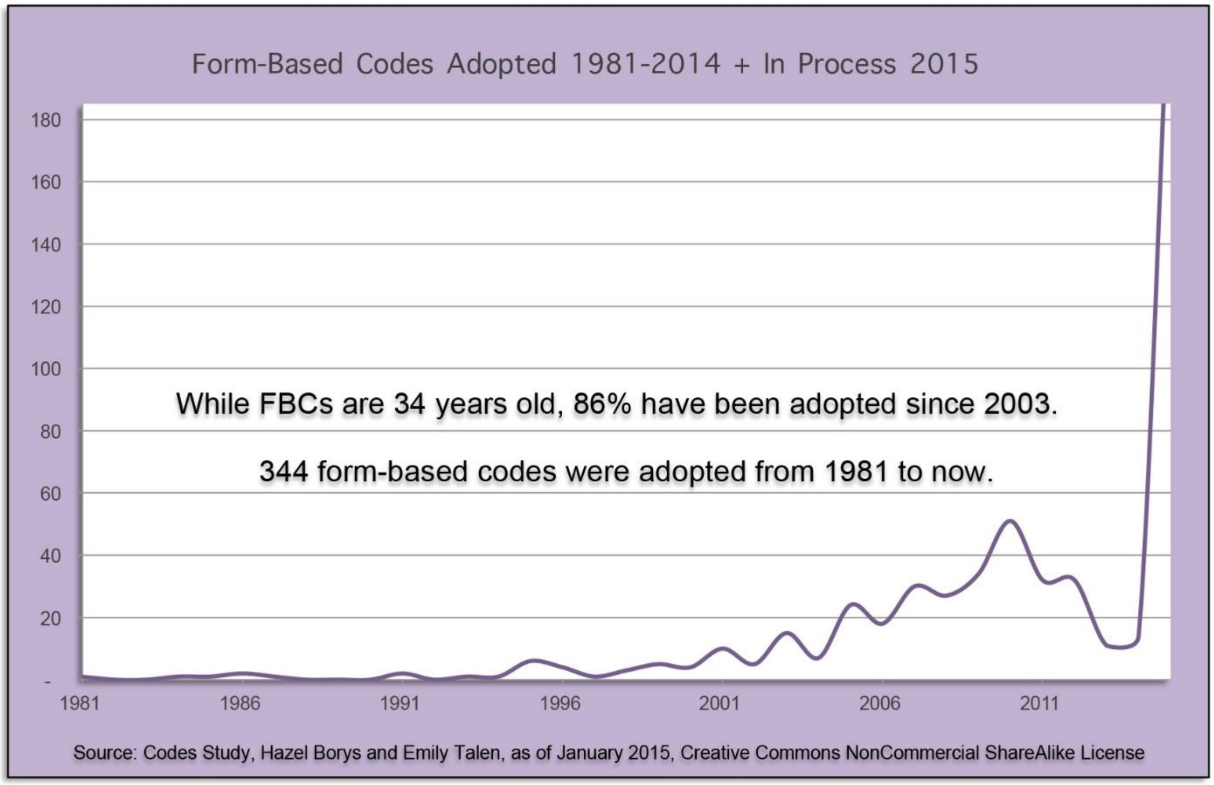

Figure 2-4. Number of Adopted FBCs by Year (Borys & Talen, 2015c)

CHAPTER 3
METHODOLOGY

This chapter is organized into three parts: the selection of the study area and urban form groups, the suitability modeling for assessing urban forms, and a comparative analysis of the urban form types. In order to conduct the comparative study, the first part of this chapter explains the differences between FBCs, conventional zoning, and historic cities and establishes the specific sites to be studied. The second part examines the selected urban form groups based on variables related to physical activity using GIS suitability modeling. Finally, the last part compares the urban form groups using a one-way ANOVA F-test.

Study Areas

Criteria for Selecting the Study Areas

In order to analyze built environments in terms of their ability to support physical activity, this study required FBCs sites and other urban form sites to be compared. It is appropriate to compare conventional zoning areas to FBCs because many FBC supporters argue that FBCs are superior to conventional zoning in terms of prompting active living. In addition, historic cities are another suitable comparison group because some researchers have pointed out that FBCs are about “returning to traditional urban form” because they embrace the compact urban forms of historic cities (Talen, 2009).

Accordingly, in order to conduct the comparative analysis, this study utilizes three groups: form-based codes sites, conventional zoning sites, and historic cities. The following sections describe the selection criteria for each group.

FBCs Cases

This research selected Florida as the study area. According to Borys and Talen (2015b), Florida has 66 cases of form-based codes being used, which is the highest amount of any state in the U.S. In addition, Florida has played a precursory role in terms of FBCs in the U.S. Finally, Florida has an abundant availability of GIS data, which is needed in order to perform this analysis.

Although Florida has many cases of FBCs, it is hard to verify the effectiveness of FBCs that were adopted too recently. That is, time is a very critical element in creating urban space based on certain land regulations. In the U.S., 83% of FBCs were adopted after 2003. This shows that, although FBCs have gained popularity, most are still in their incipient stages. Therefore, this study utilizes only areas that adopted FBCs between 1981 and 2003. Ten cases were selected (Table 3-1 and Figure 3-1): University Heights (Gainesville), Jacksonville Traditional Neighborhood Development District, Fort Myers Beach, Downtown Kendall, Naranja Urban Center, Baldwin Park (Orlando), Parramore Heritage District (Orlando), Winter Springs Town Center District, Seaside, and Rosemary Beach.

Conventional Zoning Areas

After Florida was incorporated into the U.S., transportation improvements, including enhancements to automobiles and trains, enabled people who were interested in vacation homes during the winter to move to Florida; this occurred primarily in the 1920s. This was the starting point for Florida’s so-called second great land boom (Mormino, 2005, p. 45). During this period, urban planning was ignored and did not play a major role in controlling land development. However, this development boom did not last long. In the late 1920s, hurricanes added to the woe of those who had moved to

Florida, and the national depression solidified the land boom's collapse (RuBino & Starnes, p. 91).

Though zoning had prevailing power after 1930, World War II changed urban planning perspectives. During this war, a lot of developments were made for military purposes, and urban planning was neglected (RuBino & Starnes, 2008, p. 125).

However, the Federal Aid Highway Act of 1956 led to an unforeseen spread of population and economic activity in U.S. cities (RuBino & Starnes, 2008, p. 104). In addition, technological developments, the rising numbers of senior citizens, and political and leisure revolutions shaped the development of modern Florida (Mormino, 2005, p. 45). These complex circumstances led to Florida's third boom. One of the negative developmental results of this process was suburbanization, which led to sprawl; this urban development pattern was ruled by conventional zoning regulations.

Thus, in selecting its conventional zoning sites, this study focused on areas that were developed between 1950 and 1980. Drawing from both RuBino and Starnes (2008) and Mormino (2005), the following cases are selected (Table 3-2 and Figure 3-1): Malabar, Palm Bay, Miramar, Port Charlotte, Citrus Springs, Pine Ridge, Cape Coral, Lehigh Acres, Key Biscayne, Palm Beach Gardens, St. Augustine Shores, Port St. Lucie, and Deltona.

Historic Cities

This study also adds traditional urban forms to the comparative analysis between FBCs and conventional zoning cases. As Talen (2009) asserts, "The constraints which include transportation, construction methods, and the need for defense, identity and proximity to agricultural land created urban form that today's FBCs emulate in many ways" (p. 158). FBCs embody certain elements from traditional cities: a pedestrian-oriented scale, public space locations, small block sizes, and mixed land use. Although it is hard for places to maintain their historic urban forms without changing at all, older cities tend to sustain relatively traditional urban forms.

Before selecting historic cases in Florida for this study, it was necessary to understand the regulatory systems of early colonial settlements and how those rules have affected urban forms. At the beginning of U.S. history, part of North America was a battlefield in which England, France, and Spain fought to gain control of the continent. Their governments took different approaches to ruling colonized lands, and these differences deeply affected the settlement of the U.S.

Florida was mainly controlled by Spain before it became a U.S. territory; therefore, Spanish regulations made the largest impact on its newly developed towns. In particular, the Laws of the Indies that the Spanish Empire enacted in its colonies delineated street or plaza configurations and the locations of important buildings. Since these laws provided generic rules for new colonial towns, it is most likely that early Floridian towns were developed with them in mind. The details of the laws regarding urban planning techniques were as follows: First, they provided criteria for the selection of appropriate settlement locations; second, they allocated populations by geographic scale such as neighborhoods and towns; finally, they offered a draft of a new town's patterns, including the placement of plazas, plots, and streets. These laws especially emphasized the significance and functionality of the plaza. Also, they proposed the shapes of street networks (Mundigo & Crouch, 1977).

In summary, many Floridian cities were built according to Spanish colonial laws that detailed the placement of specific urban features such as streets, plazas, and plots.

These main controlling features have several commonalities with the central characteristics of FBCs in terms of how they regulate physical urban forms and harmonize with local contexts. Thus, along with conventional zoning, I have added historic cases as one of the comparison groups in this study.

In order to select the historic cities to be examined, this study used Floridian municipalities' years of incorporation. As Figure 3-2 presents, before Florida became the 27th state in 1845, several human settlements were established. Additionally, most cities that were established before 1845 have historic districts (Florida Division of Historical Resources), meaning that they have maintained some traditional urban forms. Thus, the following 10 cities were selected for this group: Pensacola, St. Augustine, Fernandina, Marianna, Tallahassee, Key West, Quincy, Apalachicola, Micanopy, and Milton (Figure 3-1).

Suitability Modeling to Assess Urban Form

Suitability Modeling

Introduction to Suitability Modeling

A suitability model is a method for finding the most suitable locations based on a given set of criteria. Since Charles Eliot and Warren Manning used the sunprints technique, which overlays multiple site characteristics in order to analyze a current project site, the methods of synthesizing multiple layers have been well-developed in GIS application (Carr & Zwick, 2007, p. 46). Figure 3-3 presents the theoretical suitability modeling process. Basically, a suitability model works with multipart hierarchical structures, which consist of goals and objectives. As Carr and Zwick (2007) summarize, "Goals and objectives are a hierarchical set of statements that first define what is to be accomplished, and second, define how each accomplishment is to be achieved" (p. 82). In a suitability model, the sequence of hierarchical combinations is repeated until a rating is achieved that includes all relevant factors (Hopkins, 1977, p. 396).

However, this modeling process has been challenged by its complexity, which is one reason to utilize GIS for suitability modeling. In the early stages of GIS development, GIS had certain limitations. As Malczewski (1999) explains, although GIS was useful for data storage, management, manipulation, and analysis, it still lacked the capacity to solve complex spatial issues. However, the improvement of computer technology has overcome those issues. For instance, the Land-Use Conflict Identification Strategy (LUCIS) model uses a suitability model to aid land use decision-making processes.

Based on a given definition of land use suitability and its defined criteria and factors, GIS can allow researchers to answer the following questions: Which of a group of locations is the best one? Which is the most typical in the suitability model? In this type of analysis, a researcher defines what constitutes "best" and specifies the factors that influence flow. The results of this type of analysis can be used to answer questions like: Where should new factories be built? Which areas are safe from floods? Where should we build a new public facility? GIS also allows researchers to explore alternate scenarios by changing the criteria and parameters that they specify.

The Connection between Suitability Modeling and this Study

Given suitability modeling's ability to account for multiple parameters, my initial research question could be modified to include: Where are the most and least suitable locations for physical activity among the chosen sites? This question does not simply entail naming the best or the worst locations, but will also allow them to be evaluated.

This study will look at various characteristics of a set of locations in order to determine how suitable they are for physical activity. The various characteristics will be represented by layers of information. These include not only the characteristics of the locations themselves (e.g., levels of mixed use), but also of the surrounding or nearby contexts, such as the sites' distances from open space (Mitchell, 2012, p. 3). By using suitability modeling, I can not only identify areas in which residents will most likely become involved in physical activity, but also pinpoint other areas that need to be developed in order to increase a region's conduciveness to physical activity.

When applying built environment variables that are related to physical activity, suitability modeling can provide several advantages. First, it may overcome one of the limitations of previous research. For example, many of the previous studies that examined the relationship between built environments and physical activity failed to investigate the regional contexts. Using GIS suitability modeling, it is possible to determine geographical patterns of urban form that offer more opportunities for physical activity. Second, a suitability model can handle a large data size and high level of complexity better. The built environment variables that are related to people's physical activity are complex. However, these variables can be converted to GIS layers, which can be controlled in the modeling process. Third, the model has the ability to derive new information from the data and also to identify spatial relationships among the combined layers.

Conceptual Suitability Modeling Process for this Study

This research follows the LUCIS modeling process that was established by Carr and Zwick (2007): Define the question, define the criteria, collect the source layers, create the suitability layers, and combine the layers.

Define the Question. Based on my research question, I established this question for the suitability model: Where in this study area are the locations that are the most and the least conducive to physical activity?

Define the Criteria. I looked at the literature to determine the specific criteria that make a location more or less suitable for physical activity. The literature claims that built environments that support physical activity include areas with mixed use, sidewalks, and certain land uses such as grocery stores, public facilities, schools, recreational spaces, public transit, and bike paths. Each criterion has a corresponding source data layer. In order to create a model to rate the suitable locations, I assigned a relative suitability value to each value on a source layer.

Collect the Source Layers. In order to build a suitability model, the first task is to determine the relevant variables. According to the findings from the literature review, the following are the built environment variables most associated with the potential for physical activity: access to grocery stores, schools, public facilities, parks, public spaces, streets, bikeways, and public transit. In order to get the most detailed scale, this study mostly used property parcel-level data. This is because parcel data could provide the necessary variables in a fine-grain resolution in GIS format. In addition to parcel data, street network data was utilized to examine the sidewalk network.

Create the Suitability Layers. Before combining the source layers, it is necessary to assign relative suitability values to each one, thus creating corresponding suitability layers (Mitchell, 2012, p. 102). In order to convert the source layers to suitability layers, I evaluated each source layer and grouped its values into classes.

In terms of physical activity for adults between 18 and 64, the minimum adult aerobic activity guidelines are met if an individual's walking trips take 30 minutes per day. Thus, I chose pedestrian proximity as the level of measurement for each source layer, except for mixed use and bikeways. The walking distance is measured along the actual street network rather than in straight lines or Euclidian distance. In order to gauge the mixed-use levels, I utilized the entropy index, which is commonly used as a measure of land use diversity.

After reclassifying the source layers, the next step was to decide on a suitability scale. In this study, suitability values are assigned on an interval scale, which measures relative values. For example, on a scale of 1 to 5, a location with a value of 5 is more suitable than a location with a value of 1; however, this does not mean that the location with the value of 5 it is five times as suitable as the location with a value of 1.

Combine the Layers. After creating the suitability layers, I combined them into a single layer to assign an overall suitability value to each cell. In suitability modeling, some criteria might be more important than others. In that case, performing a weighted overlay allows the researcher to assign weights to the suitability layers in order to specify the degree to which suitability is dependent on each criterion (Mitchell, 2012, p. 115). The final suitability maps for physical activity show location maps and include tabular data. The final suitability layer can be used to derive statistics and other summary information.

Suitability Modeling for Measuring Active Built environment

Study Variables

In building a suitability model, the first task is to determine the relevant variables. According to the findings from the literature review, the following are built environment variables that are associated with the potential for physical activity (Table 3-3).

Land Use. The most significant and frequently appearing variables are mixed use, grocery store locations, school locations, and public facility locations. That is, in terms of land use, attractive or magnet points are required in order for the residents to achieve a certain level of average physical activity.

Recreational Space. Open space is essential for promoting physical activity. This category includes parks, public spaces, and recreational facilities.

Transportation. An active transportation system, which includes street walking and bicycling, is one of the agenda items for healthy cities. In addition, the availability of public transit encourages more physical activity and less dependency on cars.

Data and Analysis Unit

Since this study uses GIS suitability modeling, it was critical to obtain appropriate GIS data for measuring active built environments. Table 3-4 gives detailed descriptions of each dataset.

Analysis Boundary. In order to identify each case, obtaining a proper analysis boundary is required. As listed in the section on the areas being studied, some sites matched city or census place boundaries. In these cases, I used city or census place boundaries from the Florida Geographic Digital Library (FGDL). In addition to defined municipality boundaries, since the National Park Service (NPS) provides historic place boundaries in Filegeodatabase format, I obtained data on historic places from the NPS website. However, GIS data was not available for some FBCs sites and historic places. In this case, I digitized boundaries for the sites using the available non-digital information.

Entropy Index. Two data layers are required to calculate the entropy index: land use and census boundaries. I used land use data from the Florida Department of Transportation (FDOT), since this department maintains generalized land use derived from parcels. For census boundaries, I used 2010 census block boundaries from the U.S. Census Bureau.

Land Use and Recreational Spaces. I used parcel data for parks, schools, and public facilities. FGDL maintains county-level data, which includes tax information and specific land uses.

Transportation. This category includes three datasets: public transit, bikeways, and sidewalks. To find public transit locations, I used public transit information from the Florida Transit Information System (FTIS). For bikeways, I utilized bike land features from the Road Characteristics Inventory (RCI) of FDOT. Regarding sidewalks, I used NAVTEQ street data, since this contains detailed street networks and a functional classification of roads.

Analysis Unit. Suitability modeling uses raster-based data, wherein each cell provides geolocation as well as quantified information. Determining the proper analysis cell size is critical because cell size affects the resolution of the results, the model performance, and the disk storage requirements. This study uses a 5-meter cell size in order to capture the details of parcel-level data.

Creating Suitability Layers by Types of Measurement

In order to convert the source data to suitability layers, it was necessary to process the raw GIS data by suitability values. Table 3-5 shows the values assigned to each data layer. As discussed in the previous chapter, walking is the most effective way to achieve a high physical activity level in everyday life. Thus, pedestrian proximity determines the level of measurement for most of the variables above, except for bikeways and mixed use. Based on the nature of the variables, the types of measurements can be categorized into three groups: the entropy index, walking catchment areas, and buffer areas from transportation modes.

Entropy Index. Although there are many methods to measure mixed land use, I chose the entropy index since this measurement is one of the most common methods in geography and urban planning (Manaugh & Kreider, 2013). Figure 3-4 shows the entropy index equation. As the expression shows, the entropy index is set at 1 when land use is maximally diverse and set at 0 when land use is maximally homogeneous. This measurement has been used in a study that found a positive correlation between the entropy index and increased levels of physical activity (Frank et al., 2010; Kockelman, 1997).

Land use and census data is required in order to calculate the entropy index. Although many researchers have used census tract data, I used census block data because it provides finer geographic units. In addition, I used land use data that contained 15 generalized classes of land use. However, since there are no tools to calculate this index in ArcGIS, I developed a geoprocessing tool and programmed a Python script (see Appendix). The general algorithm of the script is as follows: First, it intersected land use with census block groups; next, it selected all of the land uses associated with each census block group; it then found the amount of unique land use in each census block group and found the total area in acres for all of the land uses in each census block group; next, for each unique land use, it found the total area and calculated the portion of current land use area over the total land use area; finally, it calculated the entropy index using a portion of the land use and the unique land use count. Figure 3-7 presents the input data, the process, and an output example for the whole modeling procedure, applied to the Jacksonville site as example.

Network Walking Catchment Areas. This measurement is used to determine pedestrian proximity to variables such as grocery stores, public facilities, schools, parks, public spaces, and recreational facilities. The mechanism of this measurement is almost identical for all of these variables. This is the process for developing measurements for the grocery store variable: Obtain grocery dataset (A02), convert it into points (A02_p), and create a network dataset, generating network distance buffers by 5 minutes walking distance from grocery store points (A02_srv).

However, there are two potential methods to create walking catchment areas: one possibility involves residents walking the smallest distance possible, and the other involves residents walking the necessary distance as an opportunity to exercise. The following paragraphs show how to develop suitability values for each method, assuming that people will walk a maximum of 1/2 mile to a bus stop.

First, there are walking catchment areas based on distance. In order to create a suitability layer using walking distance, I reclassified the distance from the bus stop point layer into two classes: areas within 1/2 mile of bus stops and areas over 1/2 mile from bus stops. After reclassifying the source layers, I set up the suitability scale, with areas within 1/2 mile receiving a value of 3 and the remaining areas receiving a value of 1. In Figure 3-5, the blue area has a suitability value of 3 and the white area has a suitability value of 1 within the study's boundaries. Also, the left graph shows the relationship between distance and suitability values, with walking proximity generated by Euclidean distance. However, as previously discussed, this distance suitability simply indicates if the value is either "within1/2 mile" or "over 1/2 mile" from a bus stop. It may be difficult to define this specific range as most suitable because some pedestrians who live within 0.7 miles of the bus stop may still walk to it. That is, this distance-based analysis might miss the "walking for exercise" perspective in determining distance suitability.

Second, there are walking catchment areas based on exercise. "Fuzzy Membership" (ArcGIS Spatial Analyst Tools-Overlay-Fuzzy Membership) is a possible option for overcoming the limitations of the previous method. This is because the fuzzy membership tool allows researchers to specify the likelihood that a given value is a member of a set rather than merely specifying whether the value is either inside or outside of the set (Mitchell, 2012, p. 129). That is, fuzzy membership can display the possibilities for the "exercise" option. In essence,

> The Fuzzy Membership tool reclassifies or transforms the input data to a 0 to 1 scale based on the possibility of being a member of a specified set. 0 is assigned to those locations that are definitely not a member of the specified set and 1 is assigned to those values that are definitely a member of the specified set (ESRI, 2014).

However, each specific membership function varies in its equation and application. In order to identify the exercise possibility, I chose the "fuzzy small transformation function" because the smaller input values are more likely to be members of the set. In other words, as the distance from a bus stop decreases, it is more likely that someone would walk to it, so it is more likely that the locations will be members of the favorable and suitable set. Using this function, source layer values are assigned corresponding values on this continuous scale according to the possibility that they may be members of the set. Thus, a new layer is created with corresponding fuzzy membership values rating from 1 to 0, accordingly. The left diagram of Figure 3-6 shows the locations from which people are most likely (dark blue) and least likely (light blue) to walk to bus stops. The graph in Figure 3-6 allows us to visualize the relationship between observed values (distance, in this example) and fuzzy membership values. Another benefit to using fuzzy membership is that the output value is in the same scale as the entropy index, which ranges from 0 to 1. This common scale simplifies the overlay process and helps avoid the need to reclassify the data.

Thus, this study utilizes fuzzy membership to create suitable layers for walking catchment areas. Figures 3-8, 3-9, 3-10, 3-11, 3-12, and 3-13 present the input data, the process, and output examples of each suitability layer in this analysis category, using Jacksonville as an example.

Buffer from Transportation Options. The last measurement is used to determine proximity based on whatever transportation options available, such as bus routes, pedestrian pathways, and bikeways. Both public transportation routes and pedestrian pathways are used for assessing potential walkability, and bikeways are used for finding potential physical activities via bike usage. Though the data on bus routes is different from the data on pedestrian pathways, the measurement method is identical for both variables.

This is the process for the bus routes variable: Obtain bus routes dataset (C01) and create 5-minute walking distance buffers from routes (C01_bfr). Figures 3-14 and 3-15 present the input data, process, and output examples (using the Jacksonville case) regarding public transportation and pedestrian paths. In assessing bikeways, the process is as follows: Obtain bikeways dataset (C03) and create 0.5-mile and 1-mile distance buffers from routes (C03_bfr). At the end of each process, a suitability layer is created using fuzzy membership. Figure 3-16 presents the input data, the process, and some output examples (using Jacksonville) of the bikeways variable.

Comprehensive Active Built Environment Scores

The last step in this model is to combine the outputs from the previous individual scoring process. The cells with combined high scores represent locations with a higher suitability for physical activity. First, Figure 3-17 shows the procedure of creating the composite layer by category and outputs. The final step of this modeling process is to combine three layers into three categories (Figure 3-18). There are four typical rules for combining the spatial data: 1) enumeration, 2) dominance, 3) contributory, and 4) interaction (Carr & Zwick, 2007, p. 47). This study uses the LUCIS model rule, which is interaction. Generally, during the composite scoring process, it is possible to weight the datasets differently based on their importance. In this study, all of the variables are considered to have equal weights. Since this model uses 10 variables and the maximum score of each variable is 1, 10 would be a perfect score. Figure 3-19 presents the entire model structure for generating the physical activity suitability map.

Spatial Statistics for Analyzing Patterns

In addition to the active built environment index, it is possible to use the output of previous modeling for another type of spatial analysis: Hot Spot Analysis. Although Hot

Spot Analysis in GIS uses vector data to create output, since the cell size of the active built environment index map is 5 meters, it is not hard to apply this cell to each parcel. I assigned each parcel the mean of the active built environment index values of all of the cells that belong to that parcel using the Zonal Statistics function of GIS. After that, I ran a Hot Spot Analysis in GIS. This parcel-level Hot Spot Analysis provides additional valuable information because it statistically identifies which parcels have higher or lower active built environment indexes as well as clustering patterns. This is valuable because the Hot Spot Analysis results can indicate if a spatial pattern is random, implying that there is no evidence of underlying causes.

Comparative Statistical Analysis

The outcomes of the suitability modeling assign a measure of opportunities for physical activity to locations. The output cells have two types of information: spatial and quantitative. While the spatial information indicates locations that provide a higher level of opportunities for physical activity, the quantitative information enabled me to utilize statistical analysis tools to compare the three different groups of urban form. Below is a descriptive statistical analysis of composite scoring results and a discussion of the one-way ANOVA that compared the three groups.

Statistical Analysis

To conduct a comparative statistical analysis, each case must be represented by a single numeric value. Table 3-6 shows the results from the previous section (the suitability model) in terms of both the quantitative response variable and the categorical explanatory variable. These two types of variables are essential for comparing the means of several groups related to the association between quantitative response variables and categorical explanatory variables (Agresti & Finlay, 2009, p. 369).

Based on the results from the suitability model, each case was given both a suitability map for physical activity and a distribution of scores. In order to generalize the score results, this study used a mean value for each case: the physical activity opportunity scores in Table 3-6. In this table, the quantitative response variable is the active built environment index, and the categorical explanatory variable represents each group.

One Way ANOVA

Table 3-6 summarizes the statistical results of each group's sites. The explanatory variable is each group, and the response variable is measured as the active built environment index mean for each case. Accordingly, in order to compare the three groups, it is reasonable to use the analysis of variance (ANOVA) test because ANOVA is an assessment of the independence between the quantitative response variable and the categorical explanatory variable (Agresti & Finlay, 2009, p. 370).

Hypotheses. The initial research question of this study was: Do FBCs contain elements of urban form that provide more opportunities for residents to engage in physical activities? Based on this question, it was hypothesized that the FBCs cases in this study would obtain higher average scores than the other cases. In order to verify this hypothesis, the statistical test examined whether the three populations had equal means. Accordingly, the null hypothesis was that each group had an identical mean.

Therefore, ANOVA is an F test for:

- H_0: $\mu_F=\mu_Z=\mu_H$ (where μ_F is the population mean for the FBCs areas, μ_Z is the population mean for conventional zoning areas, and μ_H is the population mean for historic cities)
- H_a: At least two of the population means are unequal.

The test analyzed whether, if H_0 were true, the differences observed among the sample means could have reasonably occurred by chance (Agresti & Finlay, 2009, p. 370).

Test statistic. For testing H_0: $\mu_F = \mu_Z = \mu_H$, the statistic uses the analysis of variance F statistics (ANOVA F statistics). Using SPSS software, the test results can be presented as in Table 3-7. In this table, if H_0 is true, we can expect the values of F to be near 1.0. Additionally, the significance (P-value) uses F distribution (Agresti & Finlay, 2009, p. 373). The P-value shows whether we can reject H_0 or not. If we reject H_0, it means that there are differences among the three groups that are being compared.

Table 3-1. Form-based Codes Study Areas

Title	Adoption year
Seaside Form Based Code	1981
Jacksonville Traditional Neighborhood Development District Ordinance	1987
Orlando: Parramore Heritage District	1994
Rosemary Beach	1995
Winter Springs Town Center District	1996
Kendall: Downtown Kendall Master Plan and Code	1998
Fort Myers Beach	1999
Naranja Urban Center, Miami-Dade County	1999
Gainesville: University Heights	2000
Orlando: Baldwin Park Form Based Code	2001

Table 3-2. Conventional Zoning Study Areas (RuBino & Starnes, 2008, pp. 101-178; Mormino, 2005, pp. 44-60)

County	Name	Census unit
Brevard	Malabar	Town
Brevard	Palm Bay	City
Broward	Miramar	City
Charlotte	Port Charlotte	Census Designated Place
Citrus	Citrus Springs	Census Designated Place
Citrus	Pine Ridge	Census Designated Place
Lee	Cape Coral	City
Lee	Lehigh Acres	Census Designated Place
Miami-Dade	Key Biscayne	village
Palm Beach	Palm Beach Gardens	City
St. Johns	St. Augustine Shores	Census Designated Place
St. Lucie	Port St. Lucie	City
Volusia	Deltona	City

Table 3-3. Study Variables by Category

Category	Variables	Description
Land Use	Mixed-use	Mixed-use level by entropy index
	Grocery Store	Community shopping for fresh produce
	Public facility	Library, theater, or auditorium
	School	Public and private school
Recreational Space	Park	Recreational park
	Public space	Outdoor recreational space
	Recreational facility	Any space for physical activity
Transportation	Public Transit	Bus routes
	Pedestrian pathways	Sidewalks
	Bikeways	Bike routes

Table 3-4. GIS Data and Sources

Layer Name	Year	Originator	Description
City Limits	2011	University of Florida GeoPlan Center	City limits from Florida's parcel data
Census Places	2010	U.S. Census Bureau	The U.S. Census Bureau's 2010 Census Places for the State of Florida
Historic Places	2014	National Park Service	A comprehensive inventory of all cultural resources that are listed in the National Register of Historic Places
Census Blocks	2011	U.S. Census Bureau	The U.S. Census Bureau's 2010 Census Blocks for the State of Florida
Land Use	2014	University of Florida GeoPlan Center	Generalized land use derived from parcel-specific land use for FDOT
Parcels	2010	Florida Department of Revenue	Parcel boundaries for each county in Florida, with each parcel's associated tax information from the Florida Department of Revenue's tax database
Streets (Sidewalks)	2010	NAVTEQ	The functional classifications of roads (sidewalks, highways, etc.) detailed street network
Bike Lanes	2015	Florida Department of Transportation	Bike lane features from FDOT Roads Characteristics inventory (RCI) dataset
Public Transit Routes	2008	Florida Transit Information System	Florida's public transit routes

Table 3-5. Operationalization of Variables

Variables	Data and Process	Coding
Mixed-use	Entropy Index by Python Script	Most diversity: 1 Poor diversity: 0
Grocery Store	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	Less than 5 min: 12 Between 5-10 min: 11 Between 10-15 min: 10 Between 15-20 min: 9
Public Facility	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	Between 20-25 min: 8 Between 25-30 min: 7 Between 30-35 min: 6 Between 35-40 min: 5
School	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	Between 40-45 min: 4 Between 45-50 min: 3 Between 50-55 min: 2 Between 55-60 min: 1
Park	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	More than 60 min: 0
Public Space	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	
Recreational facility	Select parcel center point (converted from parcel) → Network analysis (using sidewalk network) → Create walking catchment areas by walking time	
Public Transit	Transit routes → Buffer → Create buffer areas	Less than 400 meters: 2 More than 400 meters: 1
Pedestrian pathways	Sidewalk network → Buffer → Create buffer areas	Less than 400 meters: 2 More than 400 meters: 1
Bikeways	Bike routes → Buffer → Create buffer areas	Less than 800 meters: 3 From 600-800 meters: 2 More than 1600 meters: 1

Table 3-6. Comprehensive Active Built environment Scores Table by Group

Group	$CABS_M$*					Sample Size**	Mean	Standard Deviation
FBCs	F_1	F_2	F_3	F_4	…	S_F	M_F	SD_F
Zoning	Z_1	Z_2	Z_3	Z_4	…	S_Z	M_Z	SD_z
Historic	H_1	H_2	H_3	H_4	…	S_H	M_H	SD_H

Note: * $CABS_M$ is a mean of each case's active built environment index ** Sample size is the number of cases

Table 3-7. Standard ANOVA table

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Between Group	SST*	t-1	MST=SST/(t-1)	F=MST/MSE	P-value
Within Group	SSE**	N-t	MSE=SSE/(N-t)		
Total	TSS	N-1			

Note: *SST: Between Group (Sample) Variation **SSE: Within Group (Sample) Variation

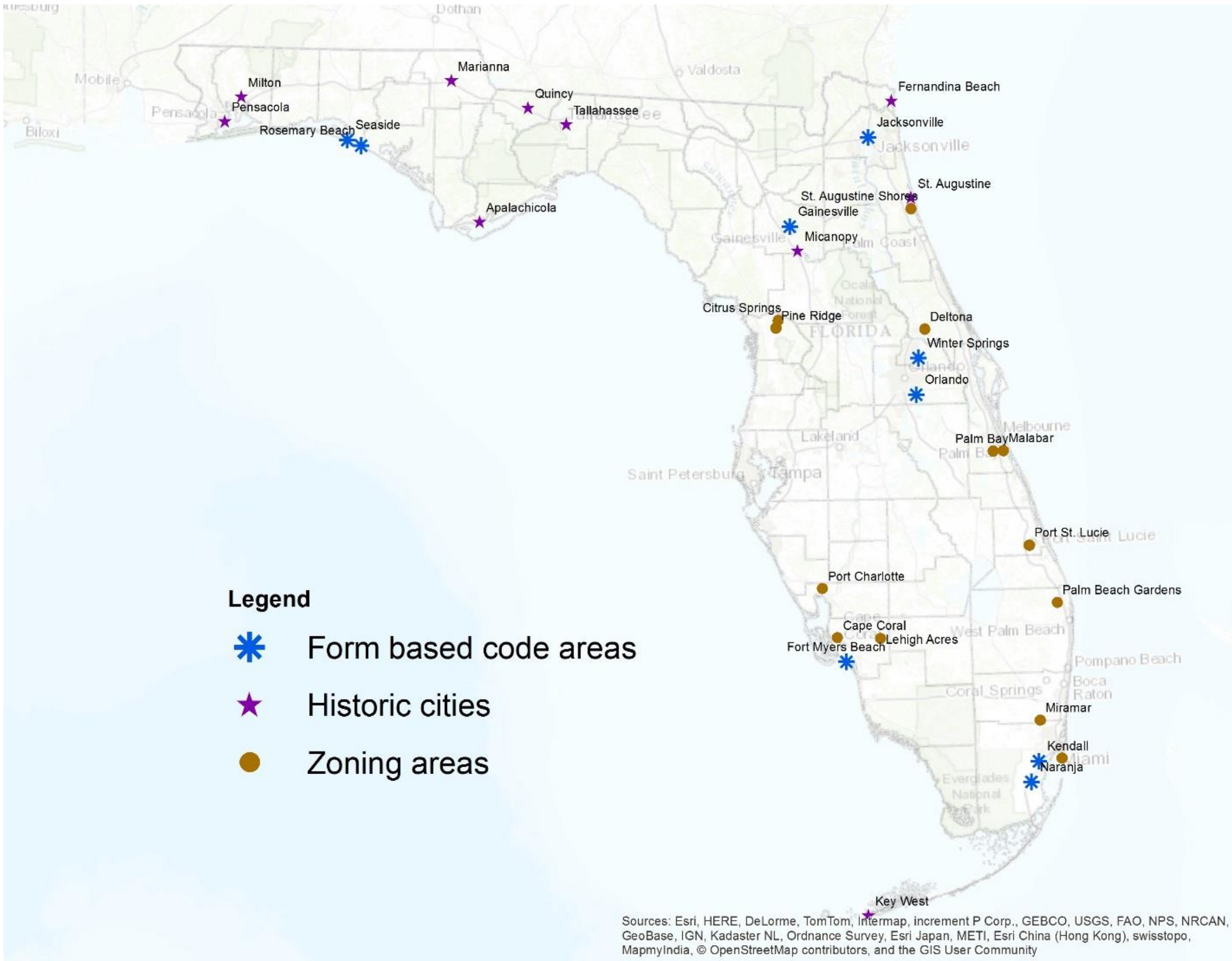

Figure 3-1. Case Study Areas

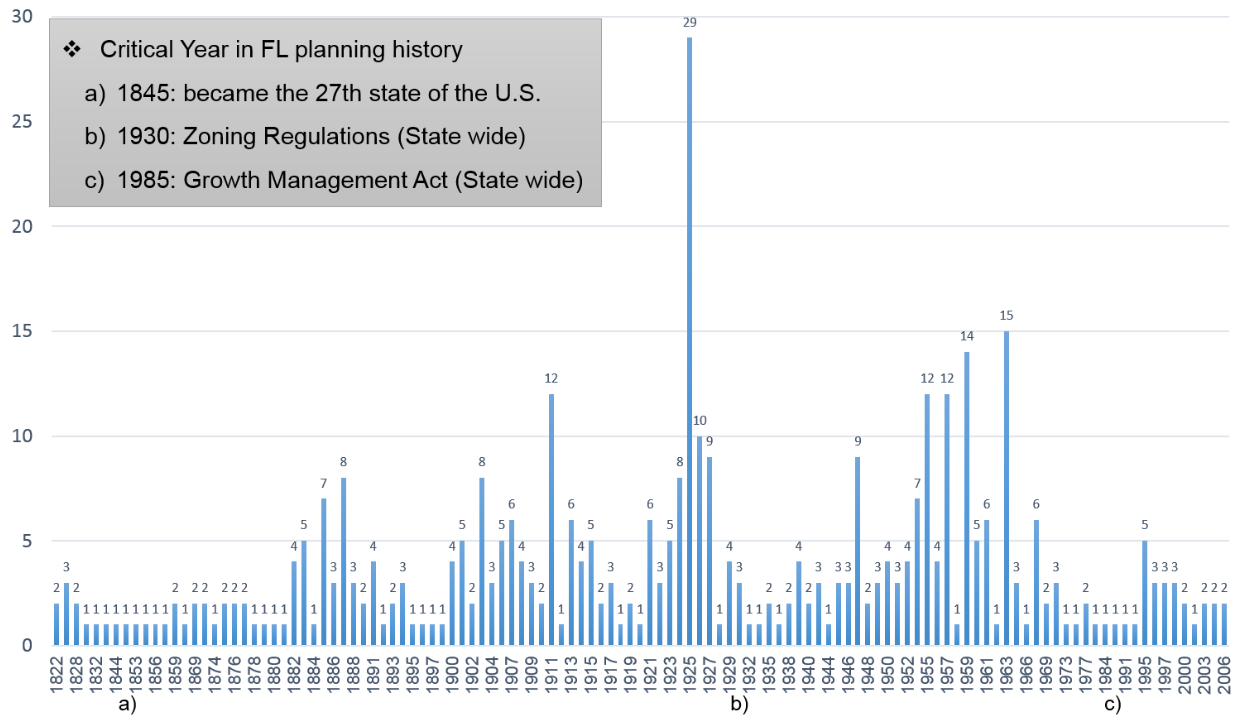

Figure 3-2. The Number of Municipalities by Year of Incorporation (FLC, 2015)

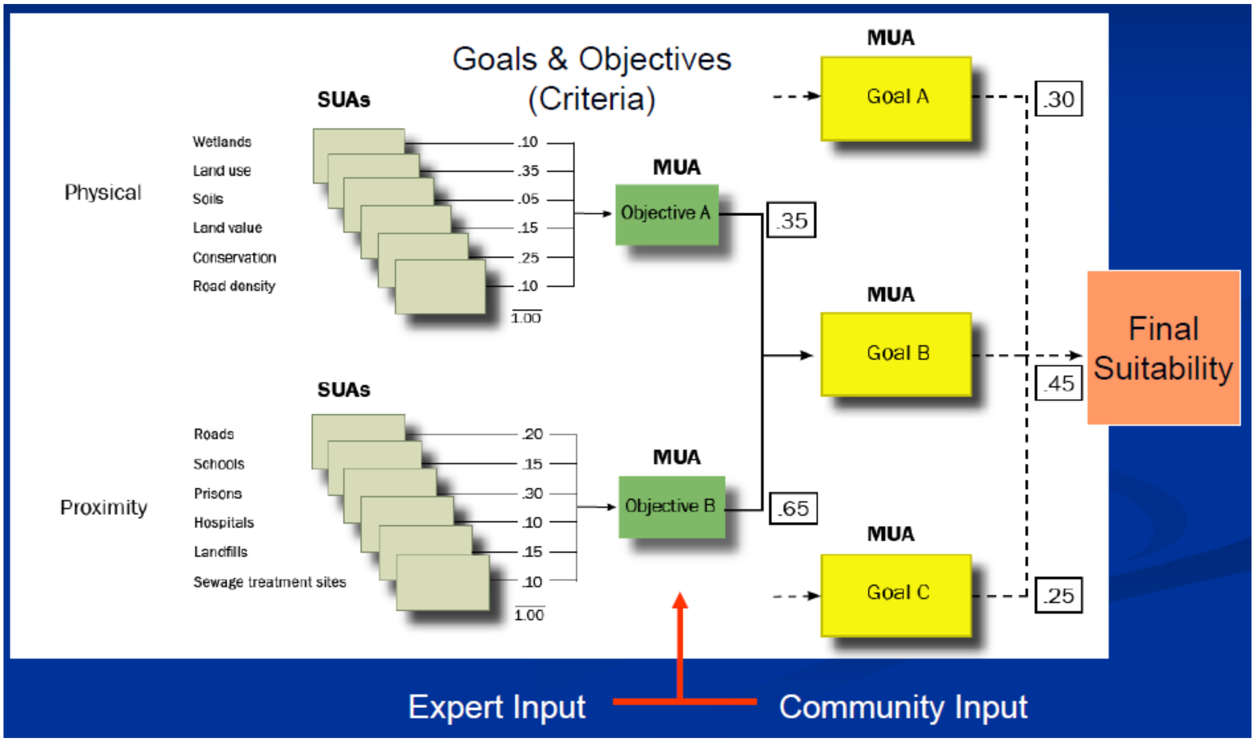

Figure 3-3. Conceptual GIS Suitability Modeling (Zwick, 2009)

$$\frac{-\Sigma(A_{ij} \ln A_{ij})}{\ln N_j}$$

Where:

- A_{ij} = Percent of land use i in census tract j
- N_j = Number of represented land uses in census tract j

Figure 3-4. Formula to Calculate Entropy Index (Manaugh & Kreider, 2013, p. 64)

.

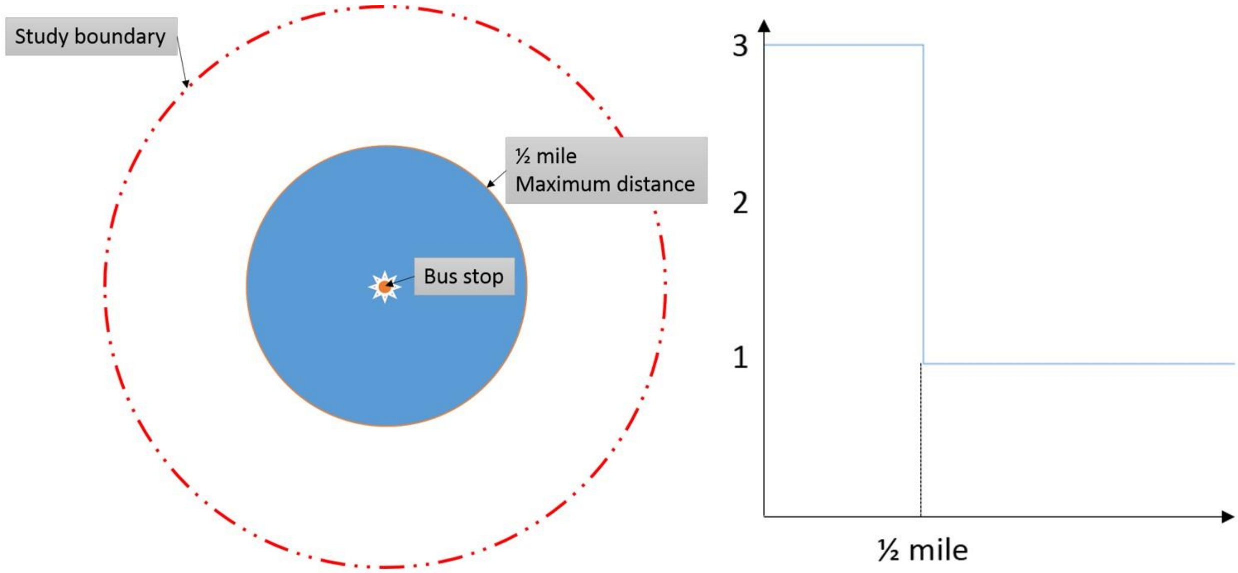

Figure 3-5. Conceptual Diagram for Creating Walking Catchment Area by Distance

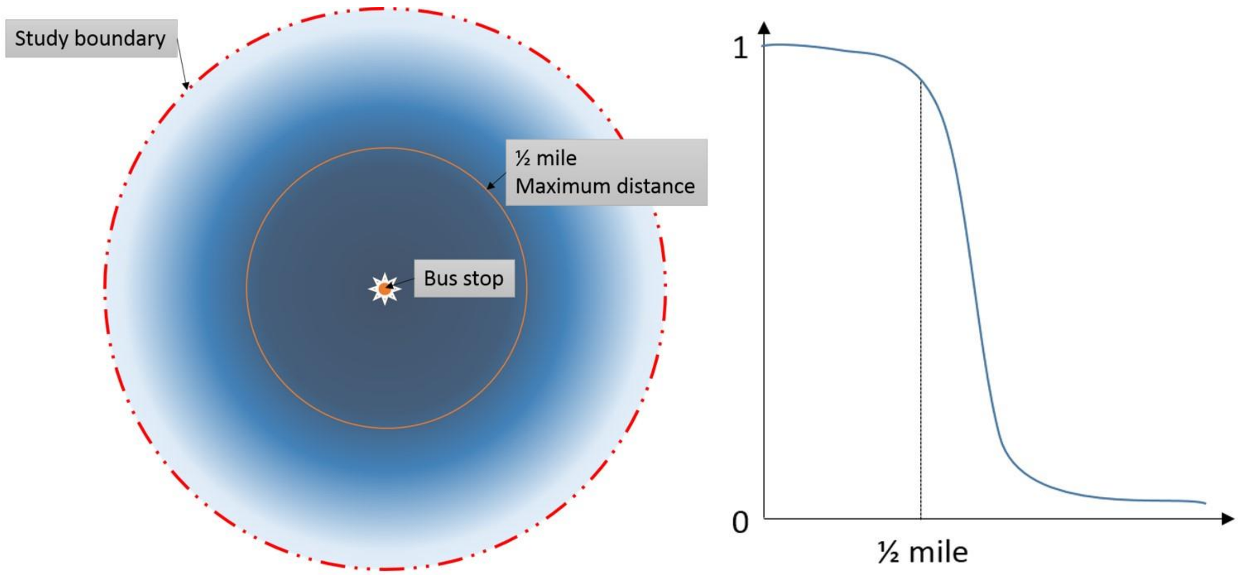

Figure 3-6. Conceptual Diagram for Creating Walking Catchment Area by Exercise

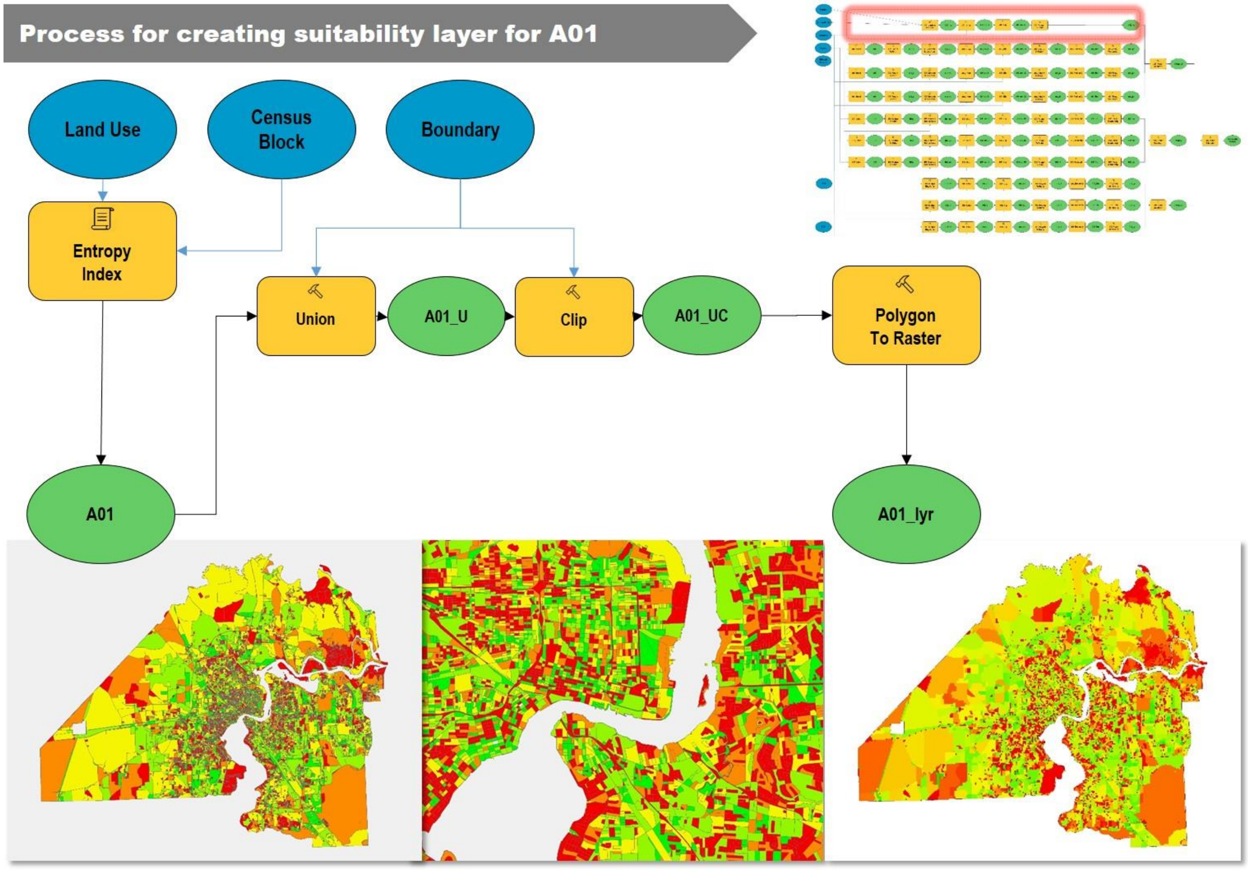

Figure 3-7. Creating Suitability Layer for Entropy Index (A01)

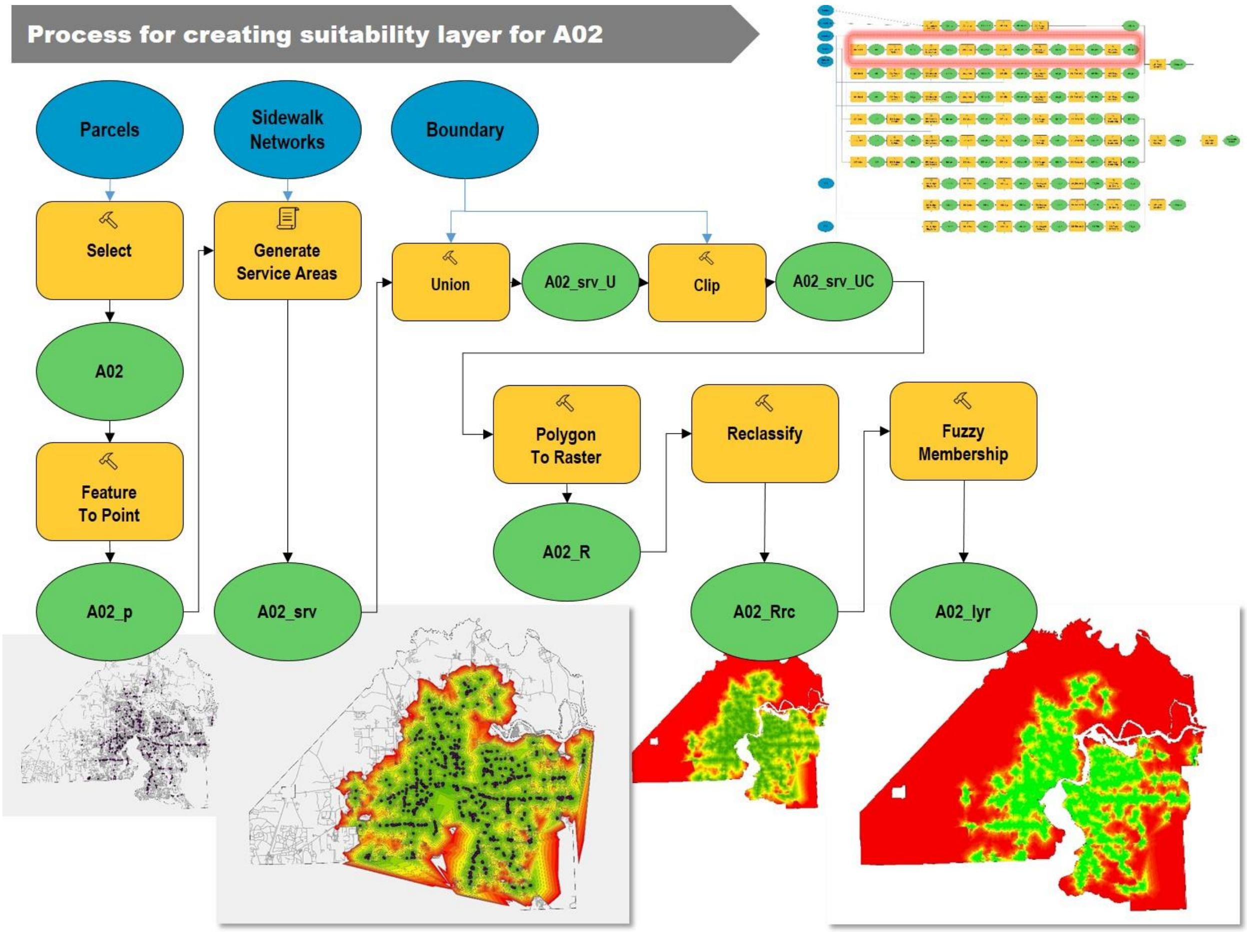

Figure 3-8. Creating Suitability Layer for Grocery Store (A02)

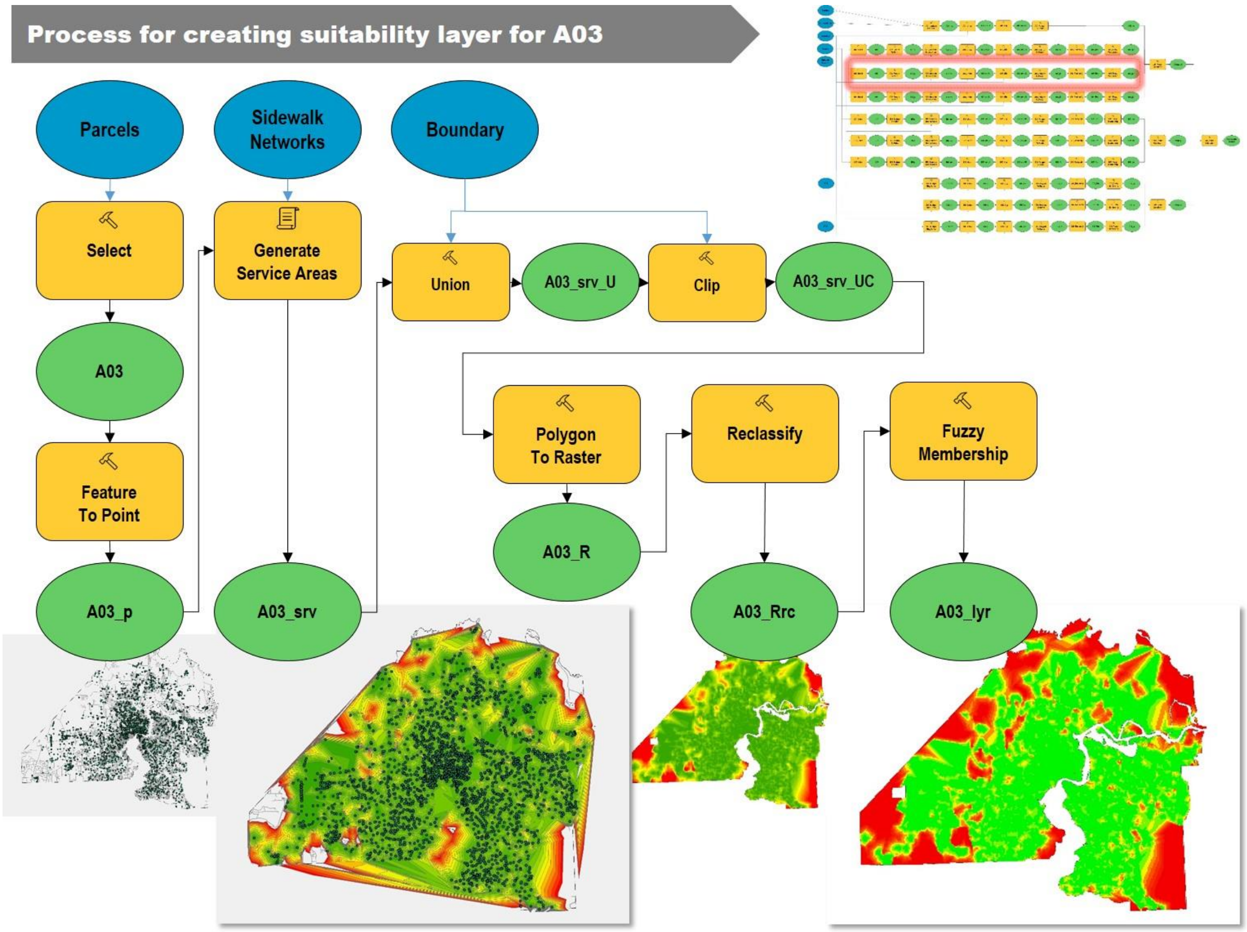

Figure 3-9. Creating Suitability Layer for Public Facility (A03)

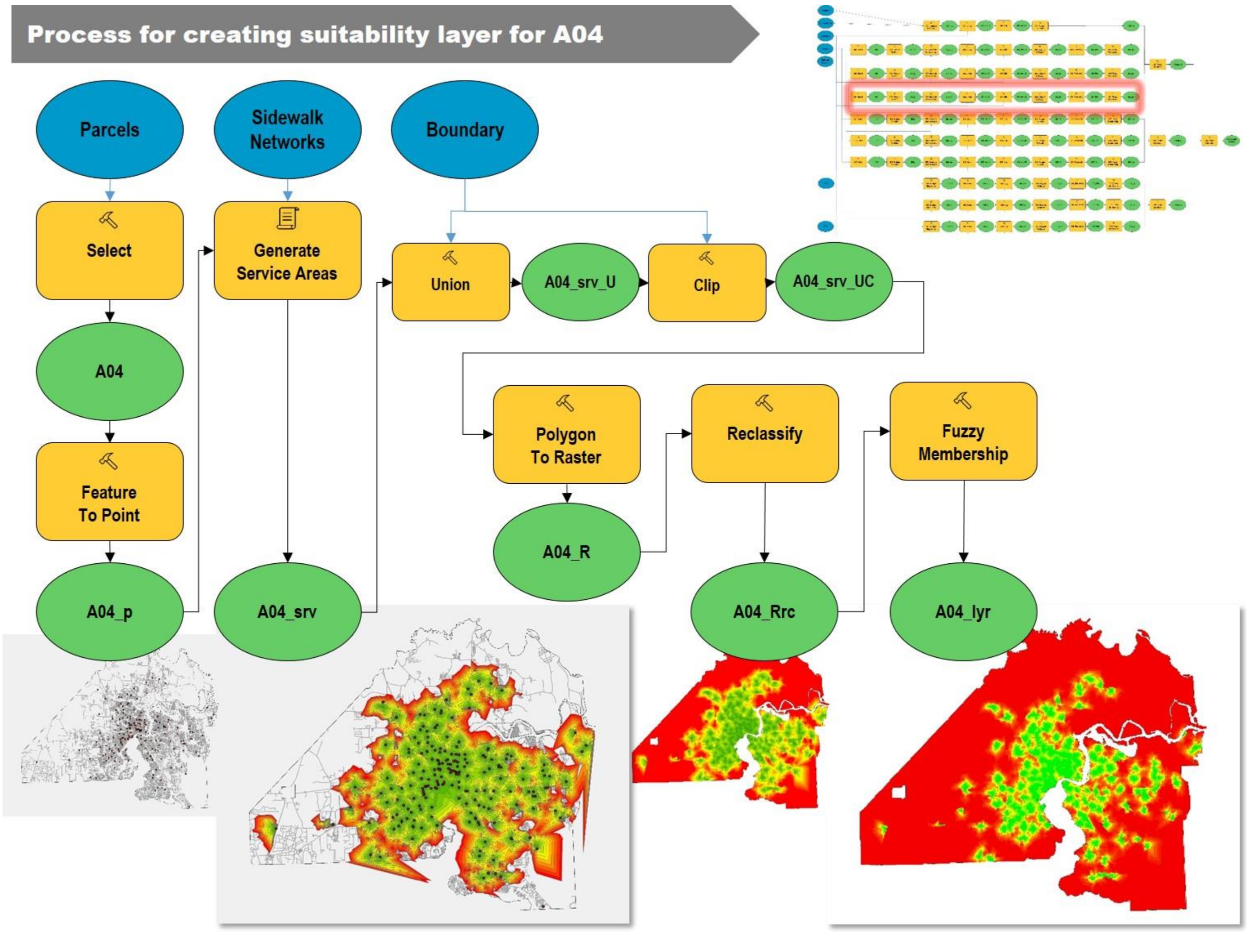

Figure 3-10. Creating Suitability Layer for School (A04)

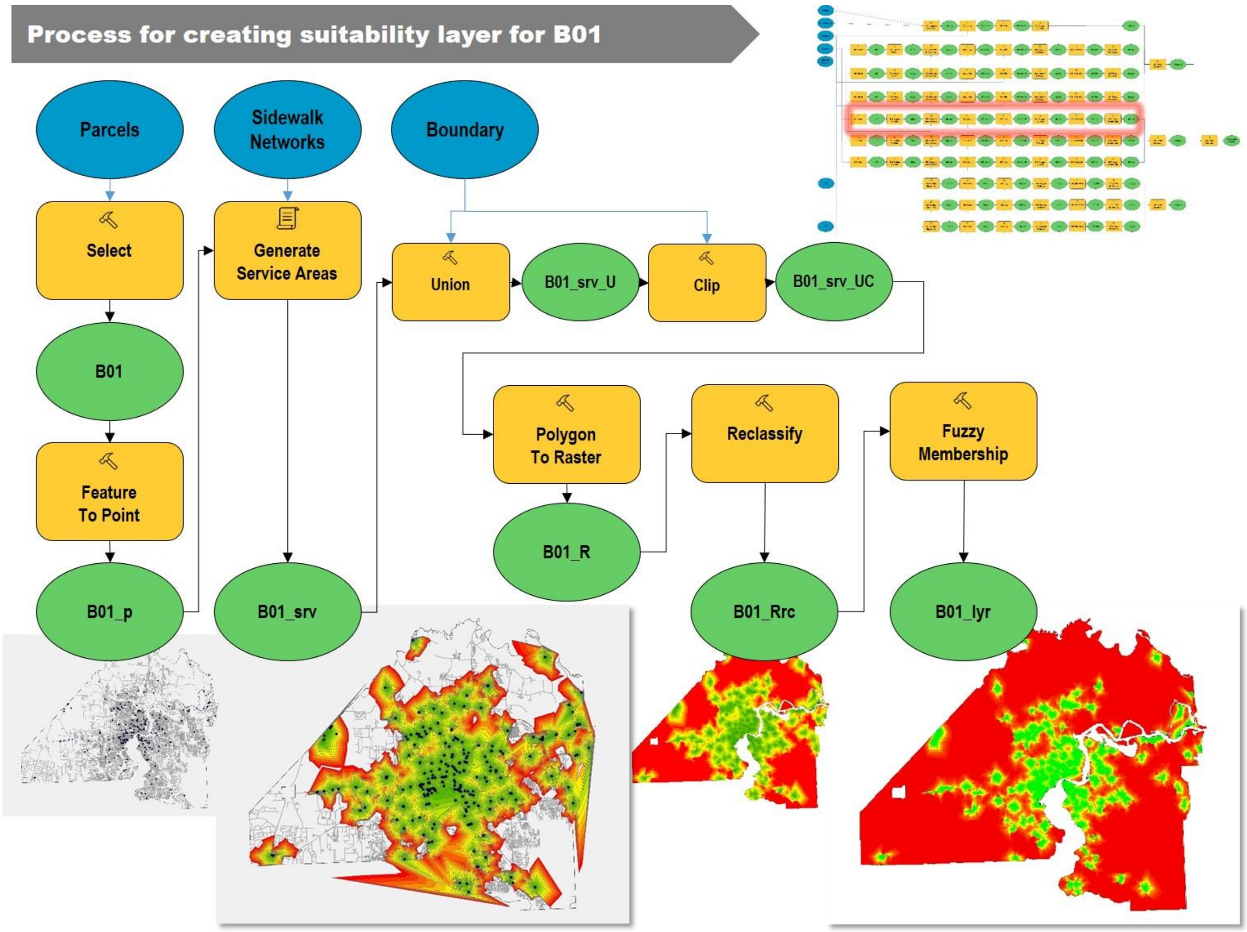

Figure 3-11. Creating Suitability Layer for Park (B01)

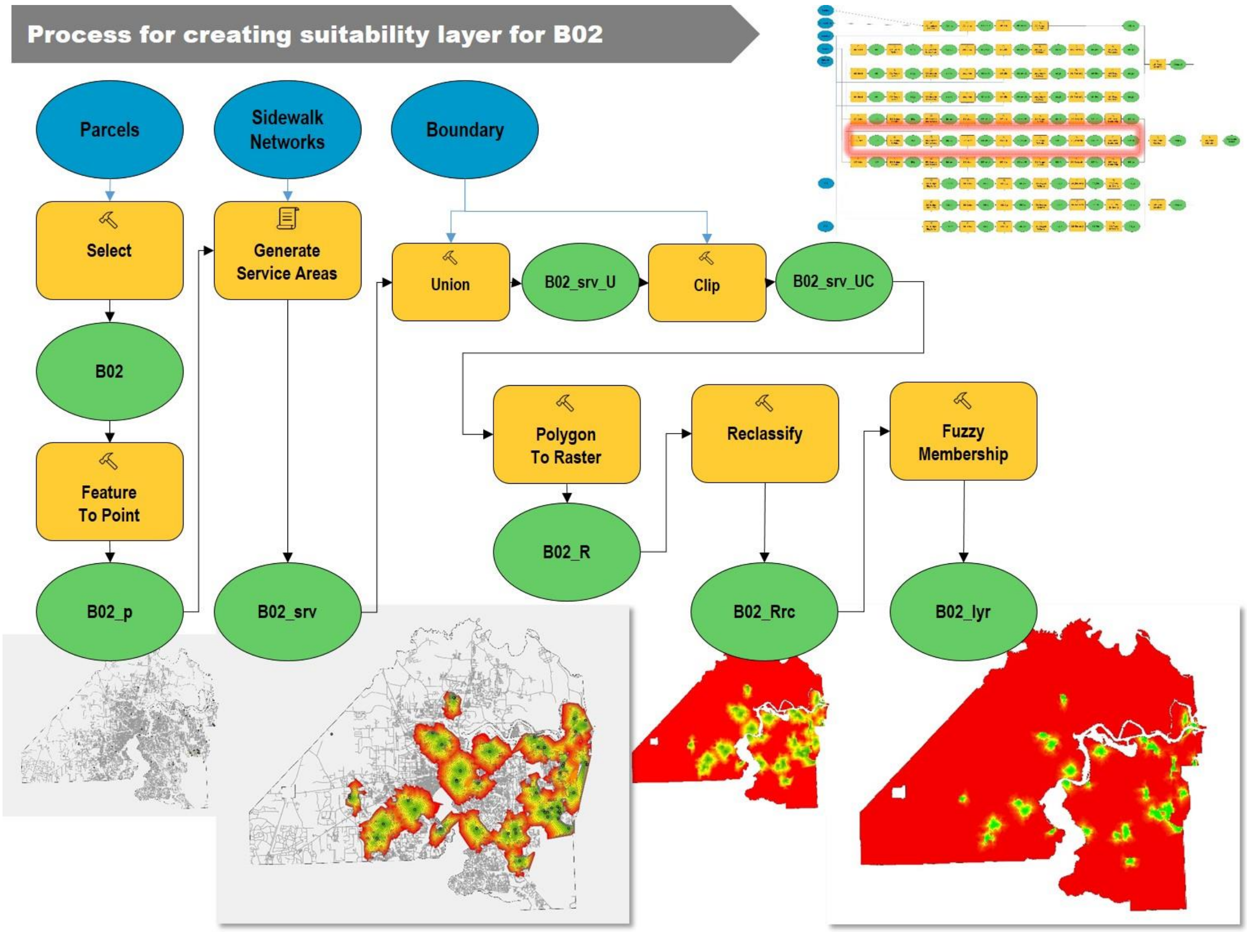

Figure 3-12. Creating Suitability Layer for Public Space (B02)

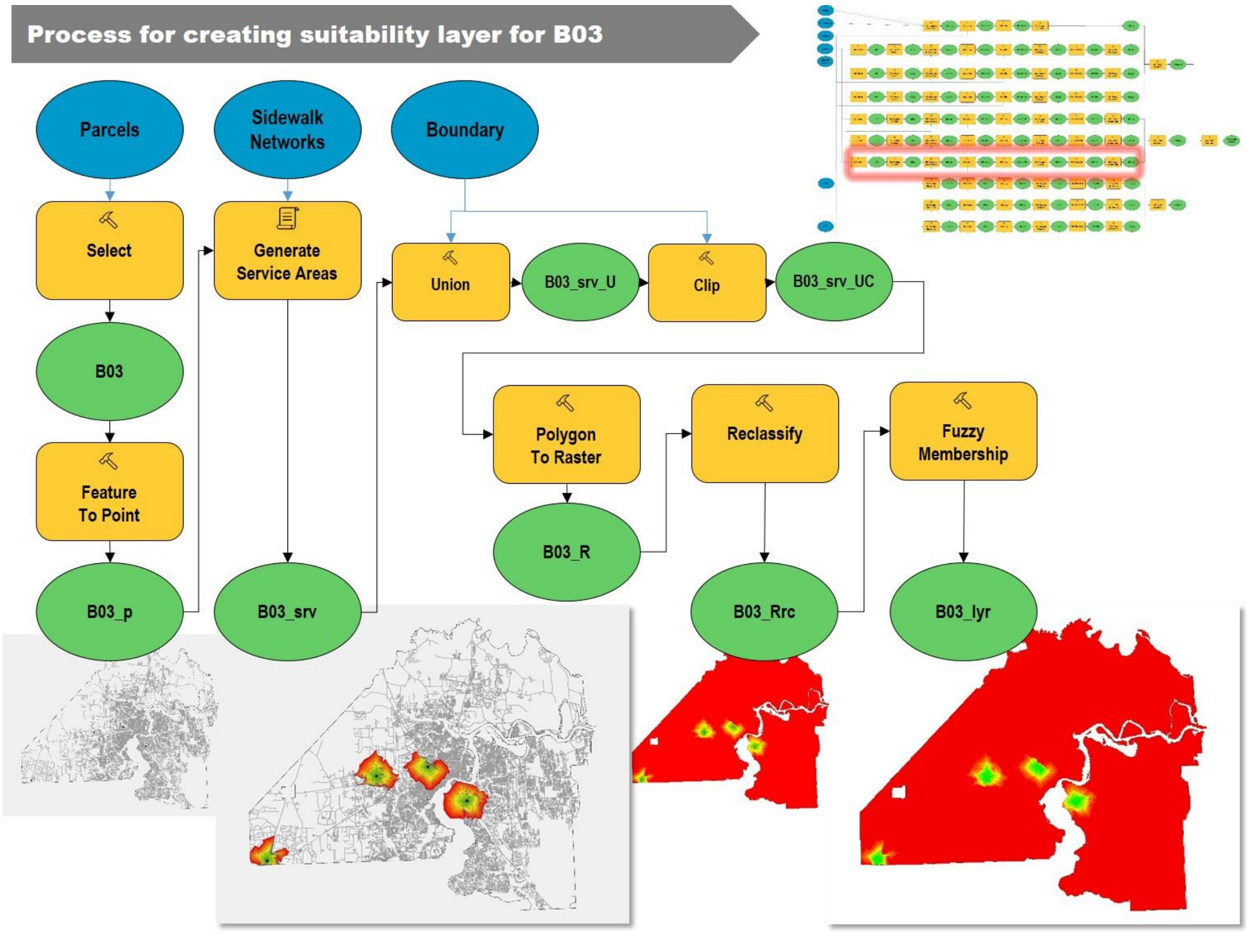

Figure 3-13. Creating Suitability Layer for Recreational Facility (B03)

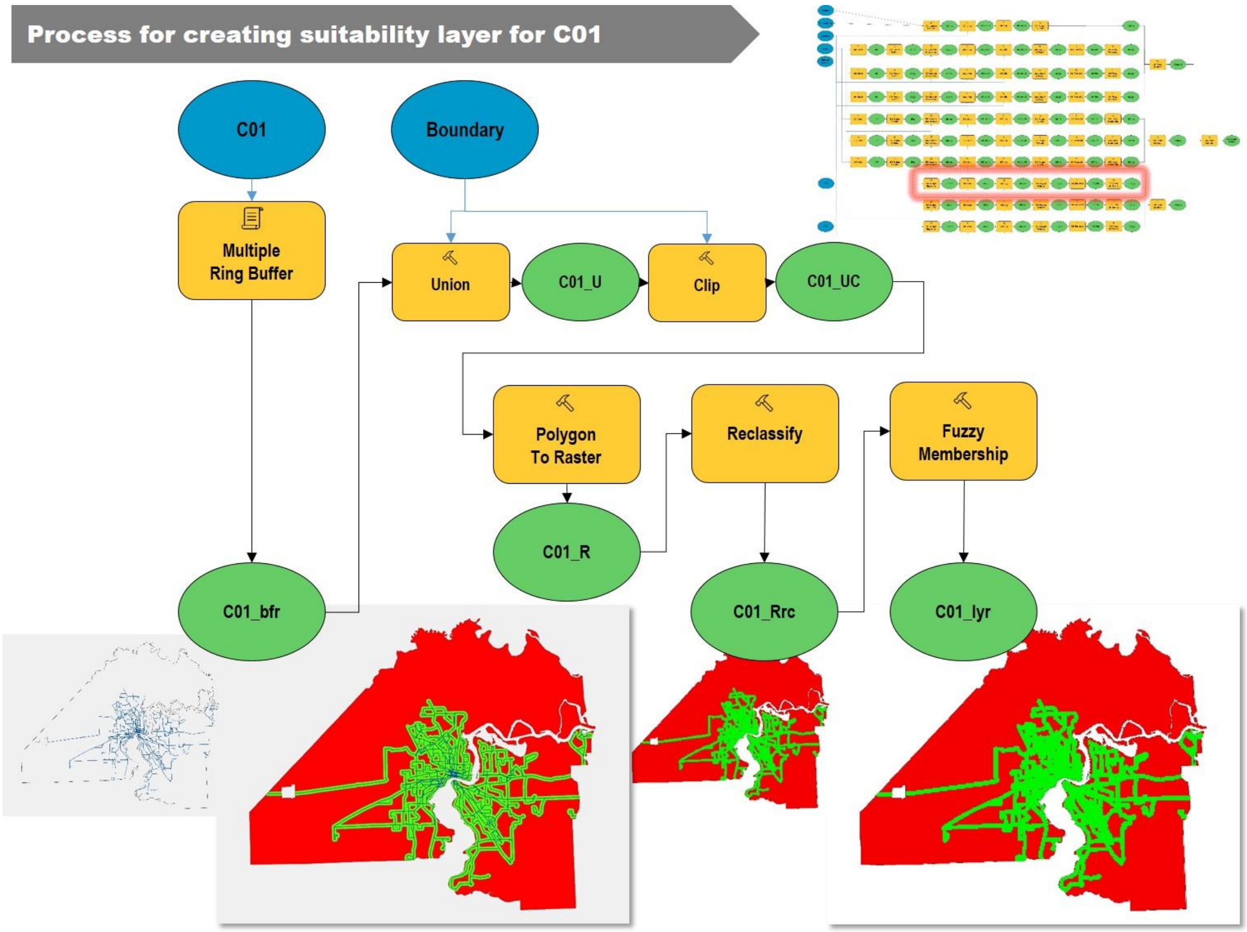

Figure 3-14. Creating Suitability Layer for Public Transit (C01)

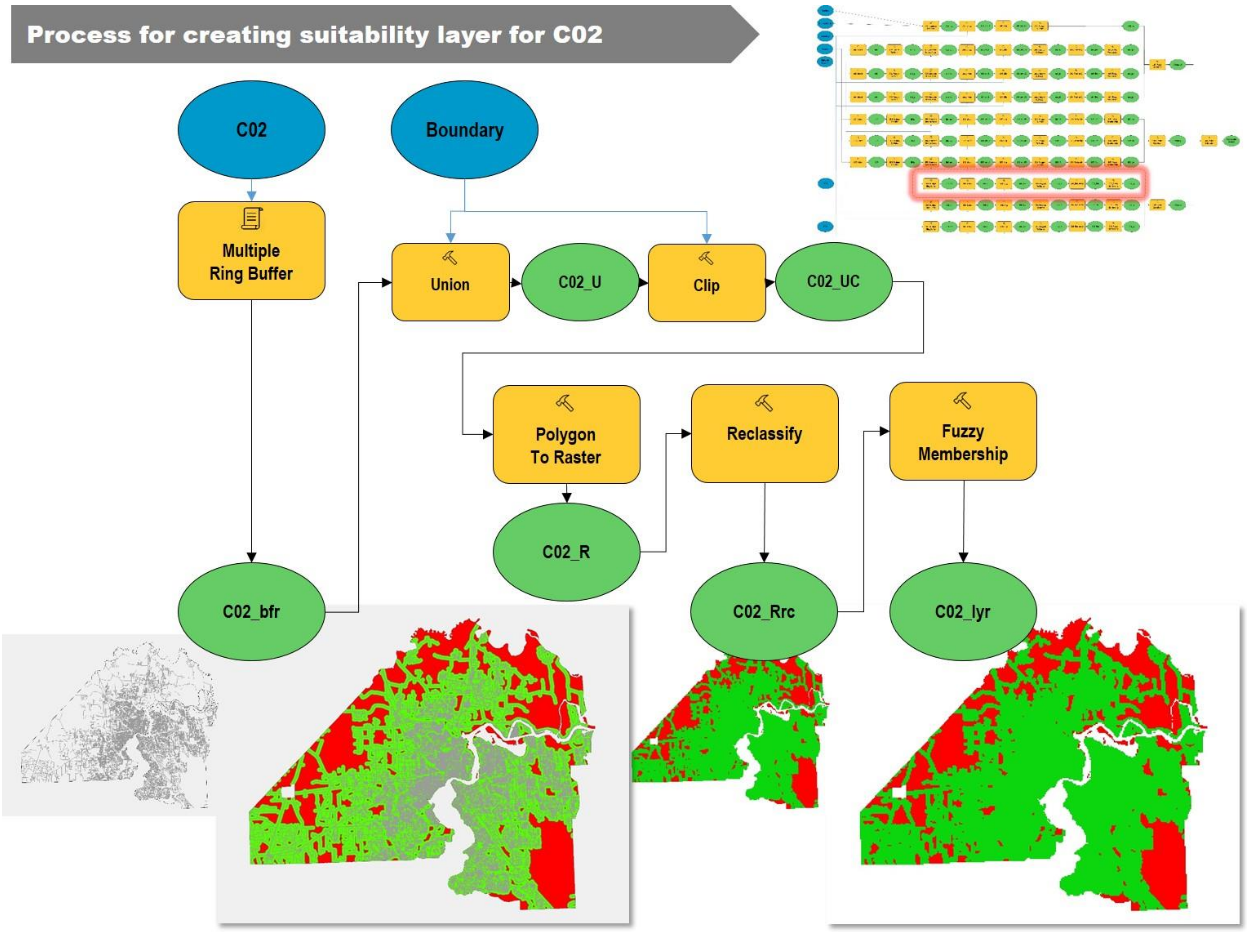

Figure 3-15. Creating Suitability Layer for Pedestrian Path (C02)

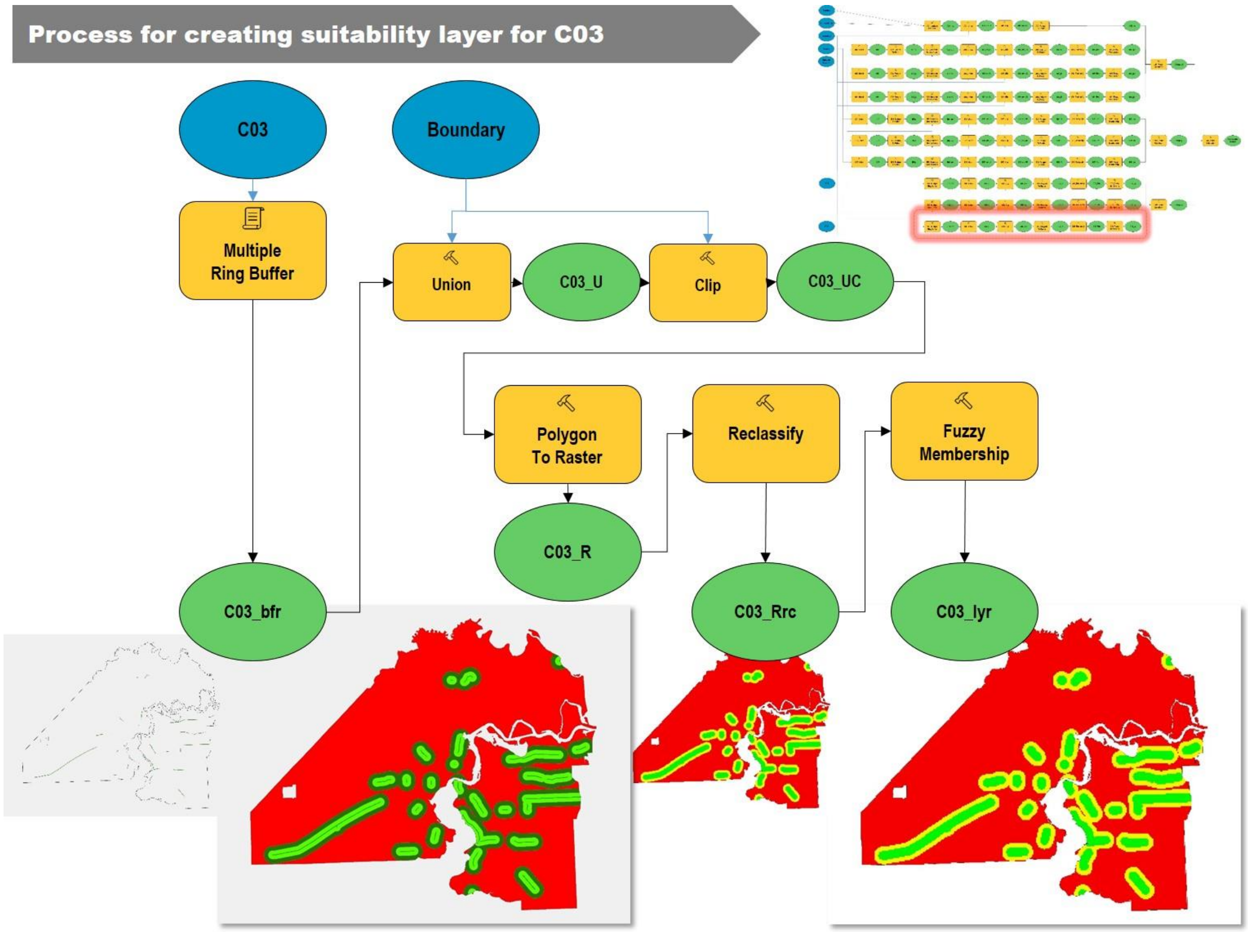

Figure 3-16. Creating Suitability Layer for Bikeways (C03)

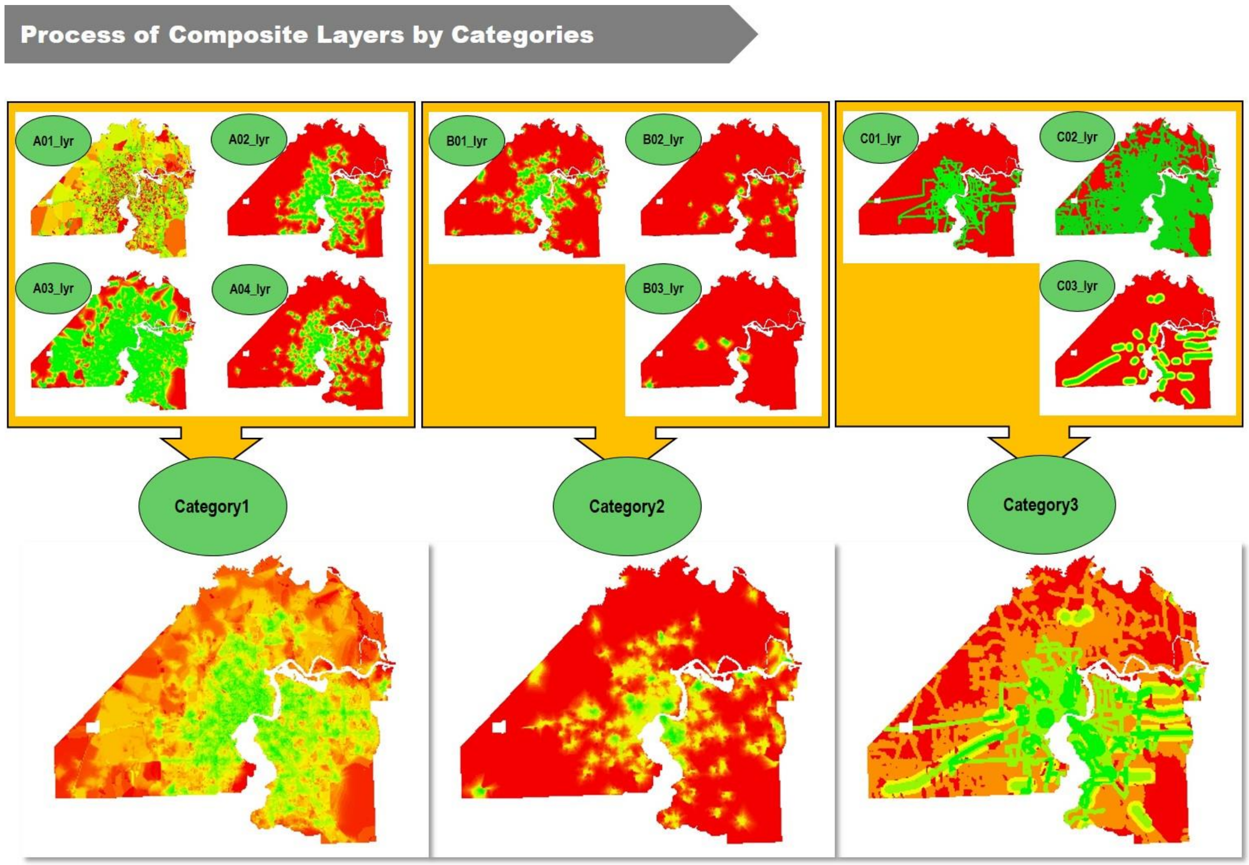

Figure 3-17. Creating Suitability Layer for each Category

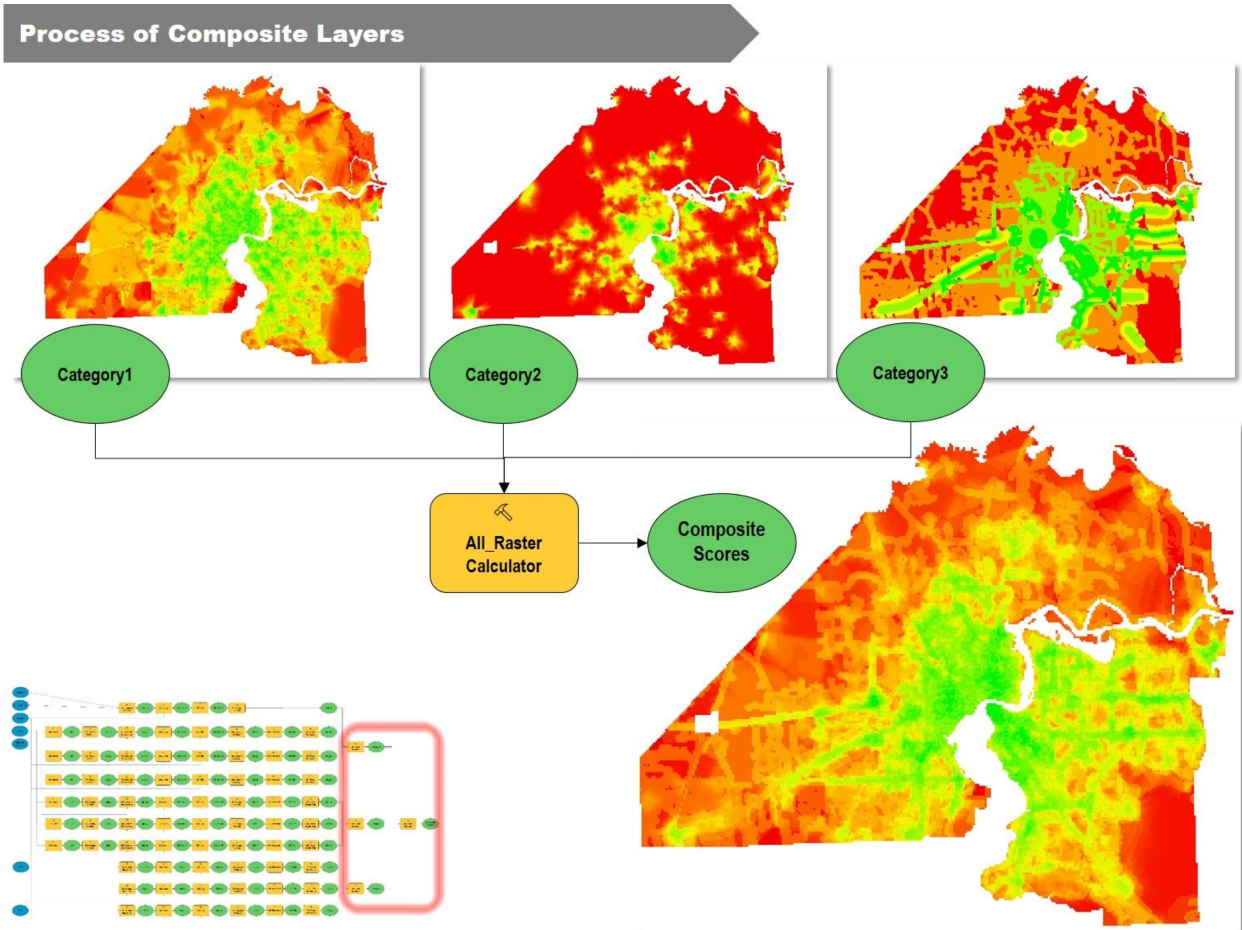

Figure 3-18. Creating Comprehensive Active Built environment Score Map

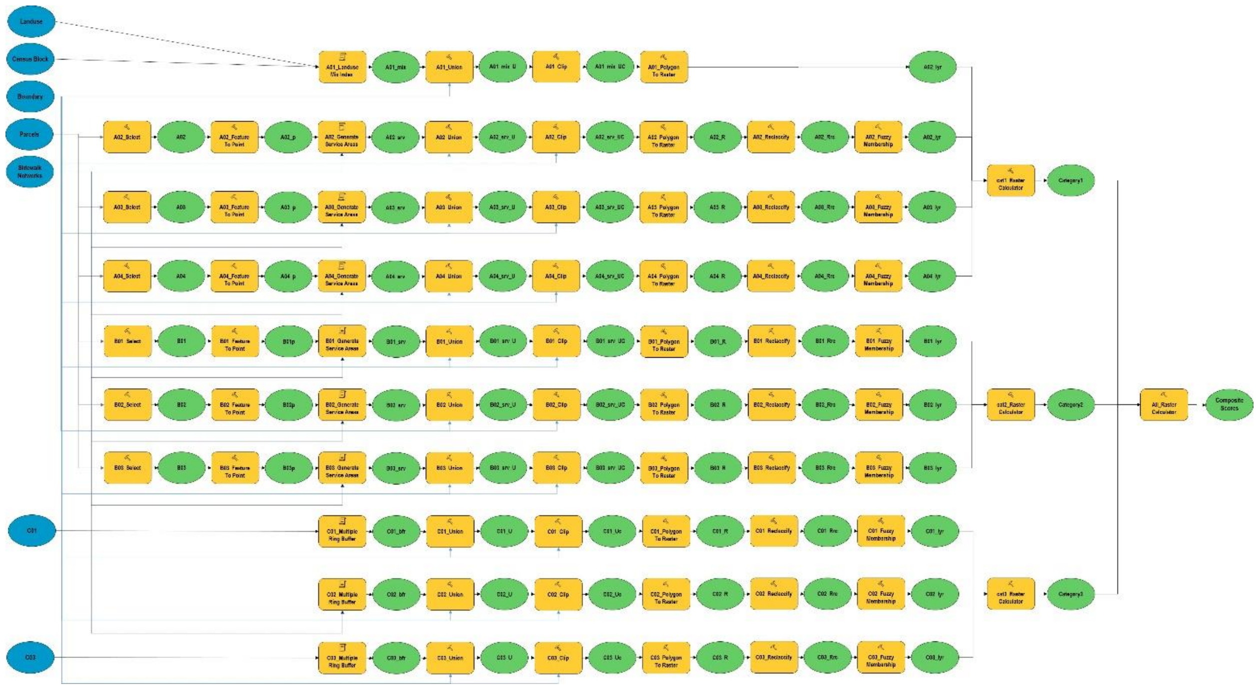

Figure 3-19. Suitability Modeling Process

CHAPTER 4
RESULTS

Suitability Modeling Results

The following sections presents the active built environment index along with the maps for each case. In order to identify each case difference through the maps, I used a legend with the same color range and scale (e.g. active built environment index with 1-10 scale). Along with the active built environment index results, Hot Spot Analysis results are shown to analyze the scoring pattern.

FBCs Cases

University Heights (Gainesville). Figure 4-1 presents the GIS suitability modeling results. The map shows the scores, which are mainly between 3 and 6, as well as their spatial distributions. In descriptive statistics, this case ranges from 4.74 to 6.26 (M = 5.61, SD = 0.38). Scores of 5.35, 5.64, and 5.83 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to the left since the median is greater than mean.

Figure 4-2A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-2B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 2,393 of 2,435 total residential units are located in hot spots. This indicates that 98.3% of residential units have relatively good potential to be involved in physical activity.

Traditional Neighborhood Development District (Jacksonville). Figure 4-3 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 5 and 7, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.04 to 8.99 (M = 6.02, SD = 1.16). Scores of 5.41, 6.15, and 6.81 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-4A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-4B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 742 of 61,455 total residential units are located in cold spots. This indicates that 1.21% of residential units have less potential to be involved in physical activity.

Fort Myers Beach. Figure 4-5 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.01 to 5.81 (M = 2.82, SD = 0.67). Scores of 2.40, 2.84, and 3.34 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-6A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-6B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 1,122 of

3,192 total residential units are located in cold spots. This indicates that 35.15% of residential units have less potential to be involved in physical activity.

Downtown Kendall. Figure 4-7 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 2.01 to 3.87 (M = 2.84, SD = 0.47). Scores of 2.51, 2.52, and 3.42 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-8A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-8B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, there is no residential units since this area is located in downtown.

Naranja Urban Center. Figure 4-9 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.01 to 7.71 (M = 2.36, SD = 0.42). Scores of 2.01, 2.35, and 2.73 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-10A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-10B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 750 of 818 total residential units are located in cold spots. This indicates that 91.69% of residential units have less potential to be involved in physical activity.

Orlando Baldwin Park. Figure 4-11 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 3 and 5, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.17 to 5.92 (M = 3.88, SD = 0.99). Scores of 3.30, 3.95, and 4.67 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-12A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-12B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 922 of 1,565 total residential units are located in cold spots. This indicates that 58.91% of residential units have less potential to be involved in physical activity.

Orlando Parramore Heritage District. Figure 4-13 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 5 and 6, as well as their spatial distributions. In descriptive statistics, this case ranges from 3.86 to 7.44 (M = 5.94, SD = 0.60). Scores of 5.49, 6.02, and 6.30 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-14A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-14B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 1,733 of 1,909 total residential units are located in hot spots. This indicates that 90.78% of residential units have relatively good potential to be involved in physical activity.

Winter Springs Town Center. Figure 4-15 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.18 to 3.97 (M = 2.56, SD = 0.83). Scores of 1.98, 2.61, and 3.22 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-16A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-16B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 12 of 268 total residential units are located in cold spots. This indicates that 4.48% of residential units have less potential to be involved in physical activity.

Seaside. Figure 4-17 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.01 to 4.51 (M = 2.11, SD =

0.76). Scores of 1.44, 1.64, and 3.51 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-18A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-18B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 232 of 354 total residential units are located in cold spots. This indicates that 65.54% of residential units have less potential to be involved in physical activity.

Rosemary Beach. Figure 4-19 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.01 to 3.52 (M = 1.39, SD = 0.36). Scores of 1.01, 1.47, and 1.56 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-20A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-20B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 144 of 290 total residential units are located in cold spots. This indicates that 49.66% of residential units have less potential to be involved in physical activity.

Historic Cities

Micanopy Historic District. Figure 4-21 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.50 to 2.92 (M = 2.38, SD = 0.37). Scores of 2.00, 2.43, and 2.75 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-22A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-22B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 37 of 173 total residential units are located in cold spots. This indicates that 21.39% of residential units have less potential to be involved in physical activity.

Pensacola Historic District. Figure 4-23 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 4 and 6, as well as their spatial distributions. In descriptive statistics, this case ranges from 2.95 to 6.47 (M = 5.13, SD = 0.64). Scores of 4.90, 5.26 and 5.62 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-24A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-24B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in

hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 168 of 168 total residential units are located in hot spots. This indicates that all residential units have relatively good potential to be involved in physical activity.

Apalachicola Historic District. Figure 4-25 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.40 to 4.94 (M = 1.97, SD = 0.21). Scores of 1.86, 2.00, and 2.41 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-3A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-3B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 135 of 556 total residential units are located in cold spots. This indicates that 24.28% of residential units have less potential to be involved in physical activity.

Quincy Historic District. Figure 4-27 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.04 to 2.05 (M = 1.56, SD = 0.39). Scores of 1.05, 1.65, and 1.87 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-28A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-28B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 75 of 170 total residential units are located in cold spots. This indicates that 44.12% of residential units have less potential to be involved in physical activity.

Marianna Historic District. Figure 4-29 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 3 and 4, as well as their spatial distributions. In descriptive statistics, this case ranges from 2.33 to 4.06 (M = 3.31, SD = 0.33). Scores of 3.03, 3.35 and 3.48 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-30A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-30B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 4 of 309 total residential units are located in cold spots. This indicates that 1.29% of residential units have less potential to be involved in physical activity.

Tallahassee Park Avenue Historic District. Figure 4-31 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 6 and 7, as well as their spatial distributions. In descriptive statistics, this case ranges from 5.50 to 7.03 (M = 6.48, SD = 0.33). Scores of 6.03, 6.55, and 6.78 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-32A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-32B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 137 of 138 total residential units are located in hot spots. This indicates, except one residential units, all residential units have relatively good potential to be involved in physical activity.

Key West Historic District. Figure 4-33 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 4 and 5, as well as their spatial distributions. In descriptive statistics, this case ranges from 2.02 to 5.00 (M = 4.36, SD = 0.38). Scores of 4.07, 4.46, and 4.68 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-34A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-34B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 93 of 3,722 total residential units are located in cold spots. This indicates that 2.50% of residential units have less potential to be involved in physical activity.

Fernandina Beach Historic District. Figure 4-35 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 3 and 4, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.86 to 4.15 (M = 3.24, SD = 0.41). Scores of 1.86, 3.26, and 3.58 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-36A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-36B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 84 of 236 total residential units are located in cold spots. This indicates that 35.59% of residential units have less potential to be involved in physical activity.

Milton Historic District. Figure 4-37 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.51 to 6.72 (M = 2.67, SD = 0.32). Scores of 2.46, 2.74, and 2.92 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-38A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-38B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 94 of 110 total residential units are located in hot spots. This indicates that 85.45% of residential units have relatively good potential to be involved in physical activity.

St. Augustine Historic District. Figure 4-39 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.04 to 2.53 (M = 1.92, SD = 0.28). Scores of 1.71, 1.90, and 2.17 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-40A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-40B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 128 of 143 total residential units are located in cold spots. This indicates that 89.51% of residential units have less potential to be involved in physical activity.

Conventional Zoning Areas

Malaba. Figure 4-41 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.01 to 3.85 (M = 1.79, SD = 0.56). Scores of 1.60, 1.70, and 1.99 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-42A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-42B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 529 of 1045 total residential units are located in cold spots. This indicates that 50.62% of residential units have less potential to be involved in physical activity.

Palm Bay. Figure 4-43 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.01 to 6.77 (M = 2.05, SD = 1.38). Scores of 0.94, 2.03, and 2.97 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-44A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-44B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 16,824 of 50,260 total residential units are located in cold spots. This indicates that 33.47% of residential units have less potential to be involved in physical activity.

Miramar. Figure 4-45 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.03 to 4.98 (M = 2.40, SD = 0.96). Scores of 1.71, 2.33, and 3.00 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-46A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-46B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 9,218 of 32,414 total residential units are located in cold spots. This indicates that 28.44% of residential units have less potential to be involved in physical activity.

Port Charlotte. Figure 4-47 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.01 to 4.96 (M = 1.84, SD = 0.80). Scores of 1.17, 1.68, and 2.37 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-48A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-48B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in

hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 10,397 of 26,032 total residential units are located in cold spots. This indicates that 39.94% of residential units have less potential to be involved in physical activity.

Citrus Springs. Figure 4-49 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.60 to 3.80 (M = 1.98, SD = 0.50). Scores of 1.63, 1.99, and 2.33 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-50A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-50B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 926 of 3,874 total residential units are located in cold spots. This indicates that 23.90% of residential units have less potential to be involved in physical activity.

Pine Ridge. Figure 4-51 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.06 to 4.84 (M = 2.12, SD = 0.84). Scores of 1.47, 2.02, and 2.64 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-52A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-52B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 1,670 of 4,114 total residential units are located in cold spots. This indicates that 40.59% of residential units have less potential to be involved in physical activity.

Cape Coral. Figure 4-53 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case range from 0.01 to 6.59 (M = 2.32, SD = 1.10). Scores of 1.57, 2.31, and 2.98 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-54A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-54B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 26,296 of 69,329 total residential units are located in cold spots. This indicates that 37.93% of residential units have less potential to be involved in physical activity.

Lehigh Acres. Figure 4-55 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics this case ranges from 0.02 to 5.67 (M = 1.90, SD =

0.84). Scores of 1.16, 1.85, and 2.21 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-56A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-56B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 10,282 of 34,476 total residential units are located in cold spots. This indicates that 29.82% of residential units have less potential to be involved in physical activity.

Key Biscayne. Figure 4-57 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 2 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 1.01 to 6.96 (M = 2.45, SD = 0.59). Scores of 2.02, 2.26, and 2.86 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-58A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-58B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 835 of 1,320 total residential units are located in cold spots. This indicates that 63.26% of residential units have less potential to be involved in physical activity.

Palm Beach Gardens. Figure 4-59 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 0 and 2, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.01 to 5.90 (M = 1.27, SD = 1.42). Scores of 0.03, 0.66, and 2.02 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-60A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-60B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 7,433 of 24,367 total residential units are located in cold spots. This indicates that 30.50% of residential units have less potential to be involved in physical activity.

St. Augustine Shores. Figure 4-61 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case ranges from 0.66 to 3.99 (M = 2.55, SD = 0.70). Scores of 1.96, 2.46, and 3.01 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-62A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-62B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in

hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 819 of 2,386 total residential units are located in cold spots. This indicates that 34.33% of residential units have less potential to be involved in physical activity.

Port St. Lucie. Figure 4-63 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics this case ranges from 0.01 to 7.89 (M = 2.31, SD = 1.54). Scores of 1.06, 2.38, and 3.35 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to left since median is greater than mean.

Figure 4-64A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-64B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 23,787 of 63,949 total residential units are located in cold spots. This indicates that 37.20% of residential units have less potential to be involved in physical activity.

Deltona. Figure 4-65 presents GIS suitability modeling results. The map shows the scores, which are mainly consist of between 1 and 3, as well as their spatial distributions. In descriptive statistics, this case range from 0.01 to 5.77 (M = 2.43, SD = 1.00). Scores of 1.71, 2.22, and 3.13 represent the 25th, 50th, and 75th percentiles respectively. The distributions of active built environment index are skewed to right since mean is greater than median.

Figure 4-66A shows the mean active built environment index values for each parcel calculated using Zonal Statistics. Figure 4-66B shows the hot and cold spots of spatial clustering of parcels calculated using Hot Spot Analysis based on the mean active built environment index values. The number of residential units were calculated in hot and cold spots with 90%, 95%, and 99% confidence level. For this site, 13,754 of 31,602 total residential units are located in cold spots. This indicates that 43.52% of residential units have less potential to be involved in physical activity.

Statistical Comparative Analysis Results

Descriptive Statistics

Figure 4-67 presents descriptive statistics for the three comparison groups. First, the average scores of the FBCs group ranged from 1.81 to 6.02 (M = 3.63, SD = 1.62). The scores had an asymmetrical distribution, with a skewness of 0.70 (SE = 0.69) and kurtosis of -1.39 (SE = 1.33). As seen in Figure 4-68, the mass of the distribution is concentrated on the left side of the histogram. Second, the average scores of the historic group ranged from 1.47 to 6.43 (M = 3.30, SD = 1.61). The scores had an asymmetrical distribution, with a skewness of 0.89 (SE = 0.69) and kurtosis of -0.07 (SE = 1.33). As seen in Figure 4-69, the mass of the distribution is concentrated on the left side of the histogram. Finally, the average scores of the zoning group ranged from 1.27 to 2.55 (M = 2.11, SD = 0.36). The scores had an asymmetrical distribution, with a skewness of -0.99 (SE = 0.61) and kurtosis of 1.13 (SE = 1.19). As seen in Figure 4-70, the mass of the distribution is concentrated on the right side of the histogram.

One Way ANOVA Test Results

In order to perform a one-way ANOVA test, several assumptions were considered. First, it was necessary to determine if each group had outliers. There were no outliers in the data, as assessed by an inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box (Figure 4-71). Second, I needed to determine if each group's data was normally distributed. The scores were normally distributed for the historic and zoning groups, as assessed by Shapiro-Wilk's test ($p > .05$). However, the scores of the FBCs group were not normally distributed (Figure 4-72). Since the FBCs group did not have a normal distribution, I transformed all of the groups' data using the square root. After the transformation, all of the groups' scores were normally distributed (Figure 4-73), as assessed by Shapiro-Wilk's test ($p > .05$). Third, it was necessary to determine if the population variances of the dependent variable were equal for the three groups of the independent variable. However, the assumption of the homogeneity of the variances was violated, as assessed by Levene's test (Figure 4-74) for equality of variances ($p = .001$).

Since the assumption of the homogeneity of the variances was violated, the standard one-way ANOVA test (Figure 4-75) was not applicable to the data. Thus, I used a Welch ANOVA test instead. The scores were statistically different for the comparison groups, with Welch's $F(2, 12.857) = 6.370$ and $p < .012$ (Figure 4-76). Because the test was statistically significant, I could use the results of the Games-Howell post hoc test to identify where the differences were located (Figure 4-77). A Games-Howell post hoc analysis revealed a difference between the scores of 3.6 ± 1.6 in the FBCs group and 2.1 ± 0.4 in the conventional zoning group, a difference of 1.5 (95% CI, 0.1 to 3.0), which is statistically significant ($p = .038$).

Test Hypotheses. The group means were discovered to be statistically significantly different ($p < .05$). Therefore, the null hypothesis could be rejected, and the alternative hypothesis could be accepted.

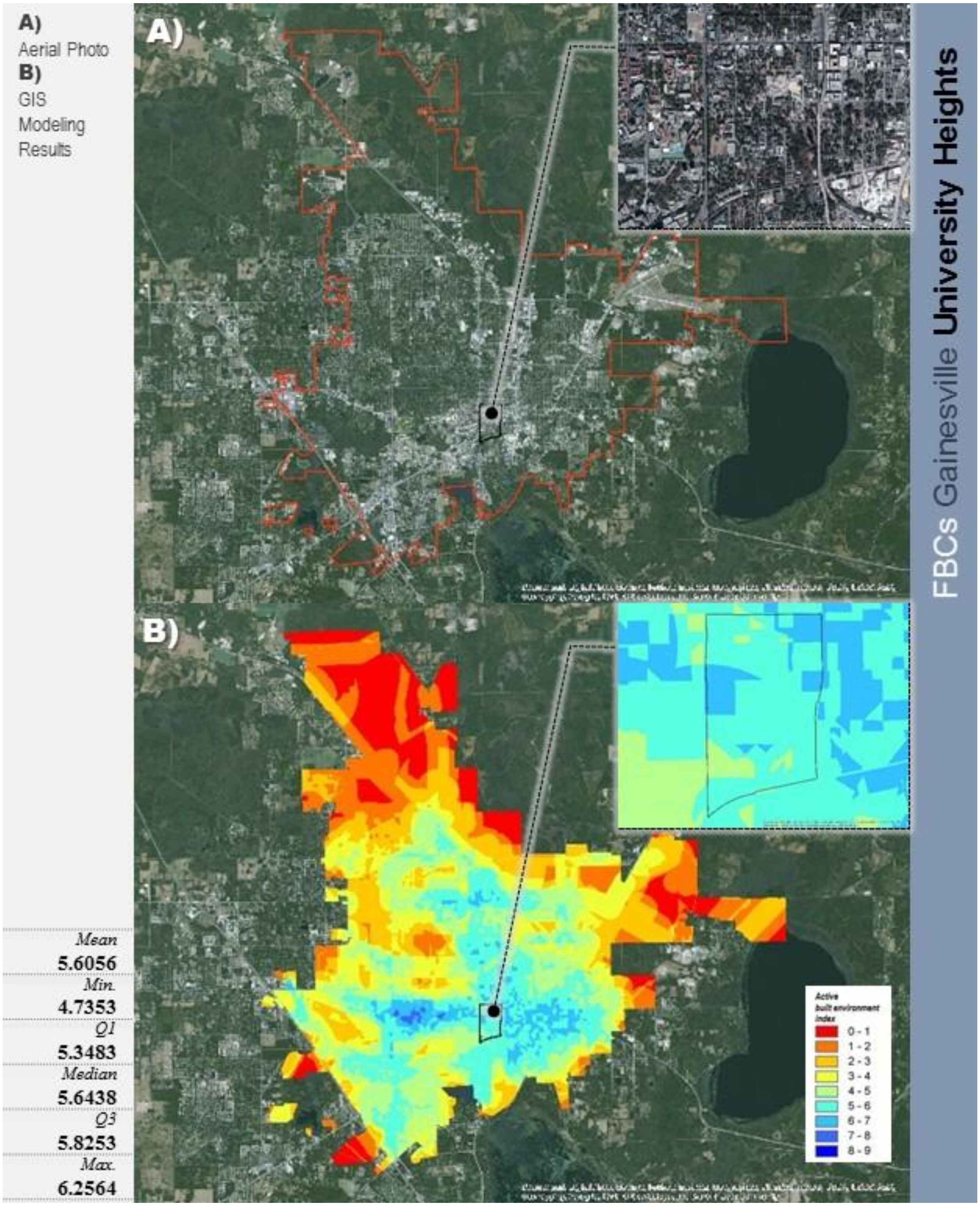

Figure 4-1. GIS Modeling Results of University Heights (Gainesville). A) Aerial Photo. B) GIS Suitability Modeling Results.

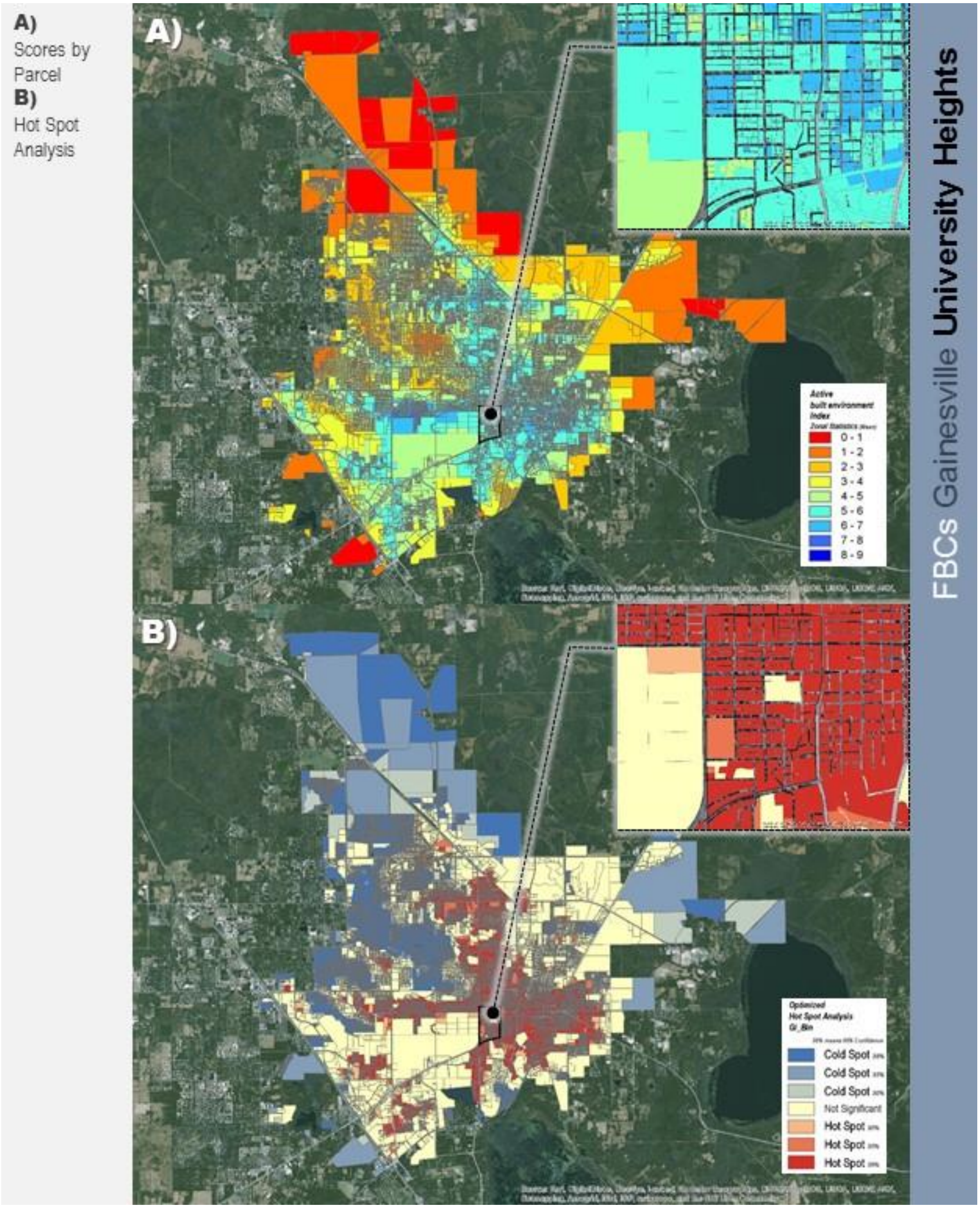

Figure 4-2. Scores by Parcel and Hot Spot Analysis of University Heights (Gainesville). A) Zonal Statistics. B) Hot Spot Analysis.

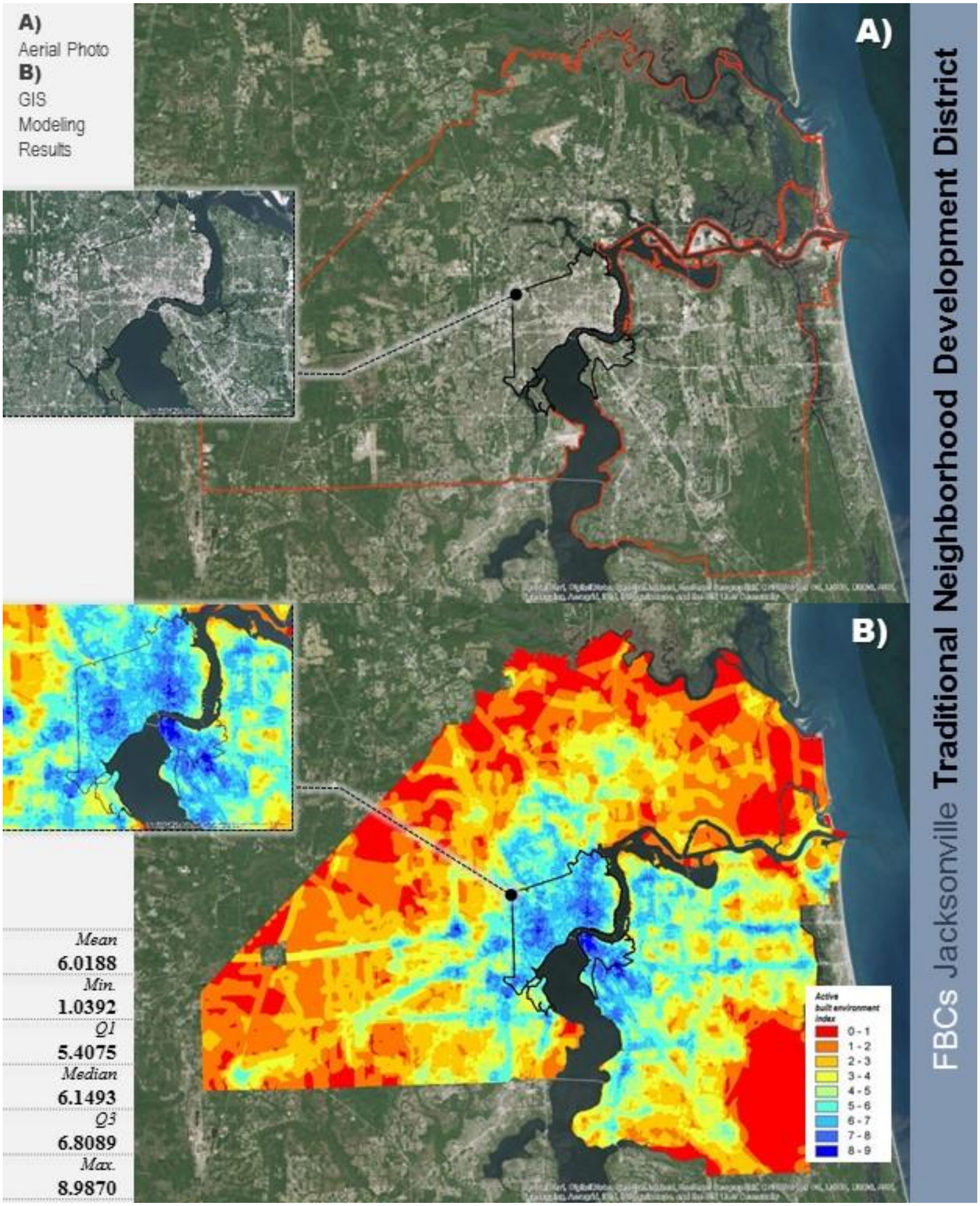

Figure 4-3. GIS Modeling Results of Traditional Neighborhood Development District (Jacksonville). A) Aerial Photo. B) GIS Suitability Modeling Results.

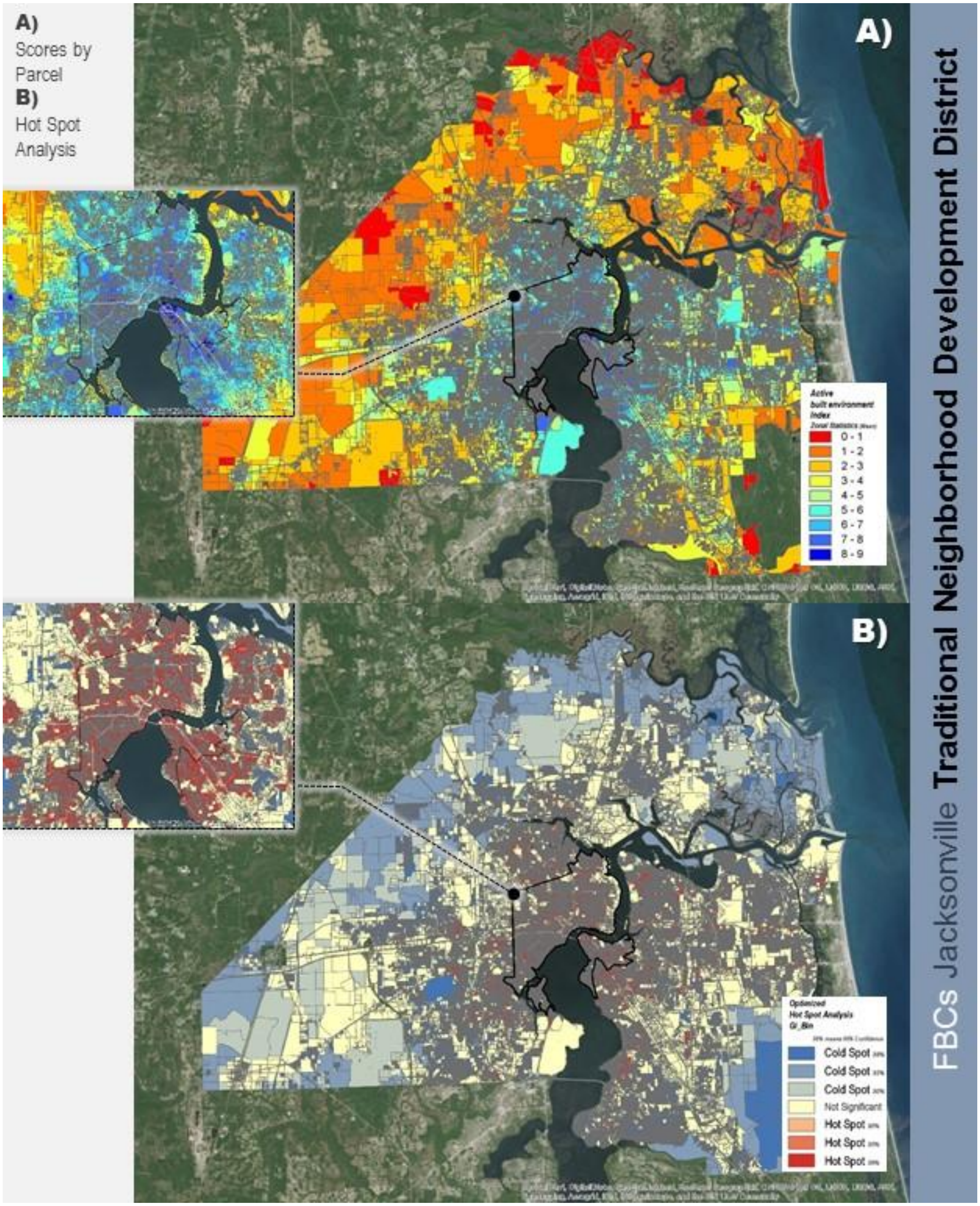

Figure 4-4. Scores by Parcel and Hot Spot Analysis of Traditional Neighborhood Development District (Jacksonville). A) Zonal Statistics. B) Hot Spot Analysis.

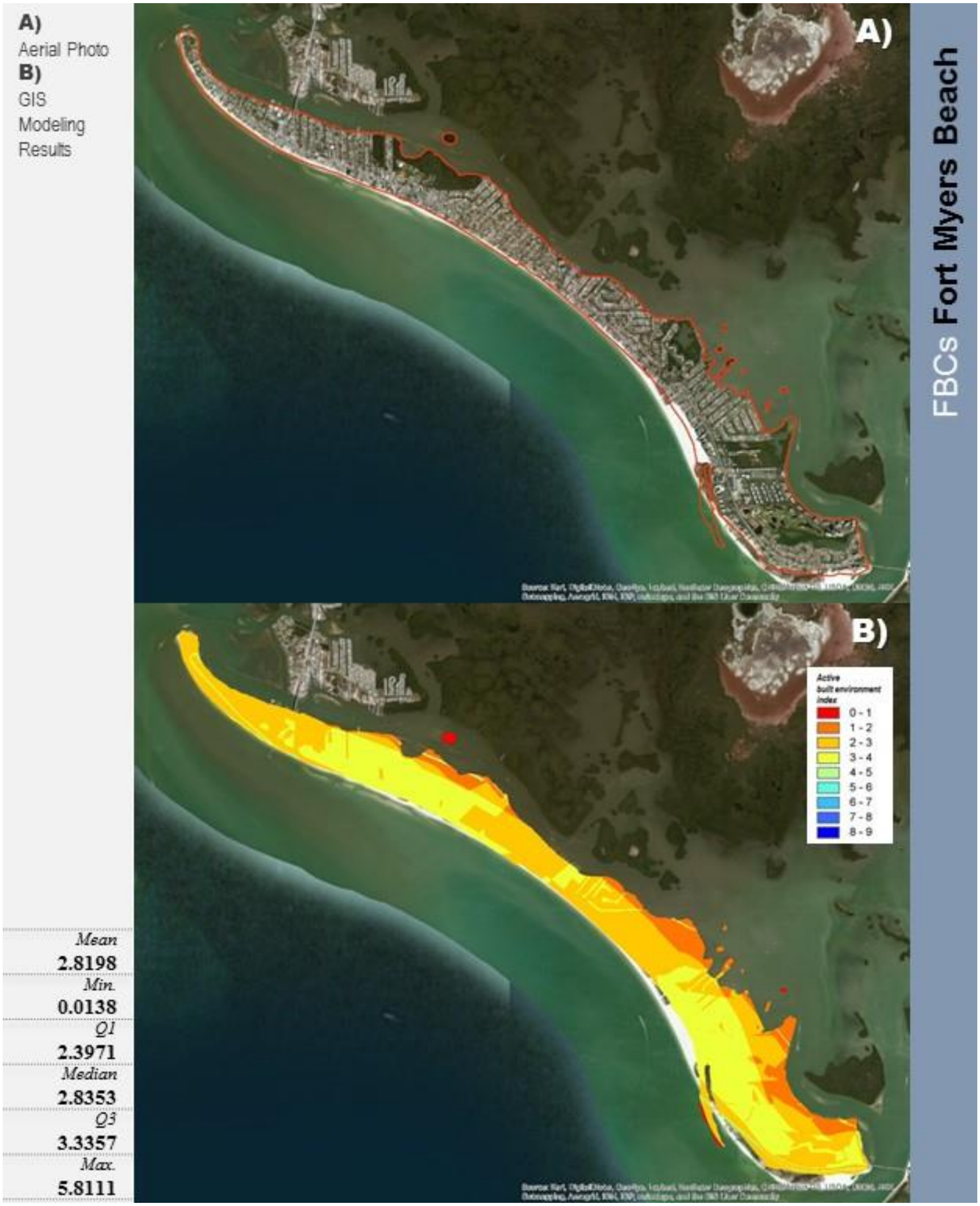

Figure 4-5. GIS Modeling Results of Fort Myers Beach. A) Aerial Photo. B) GIS Suitability Modeling Results.

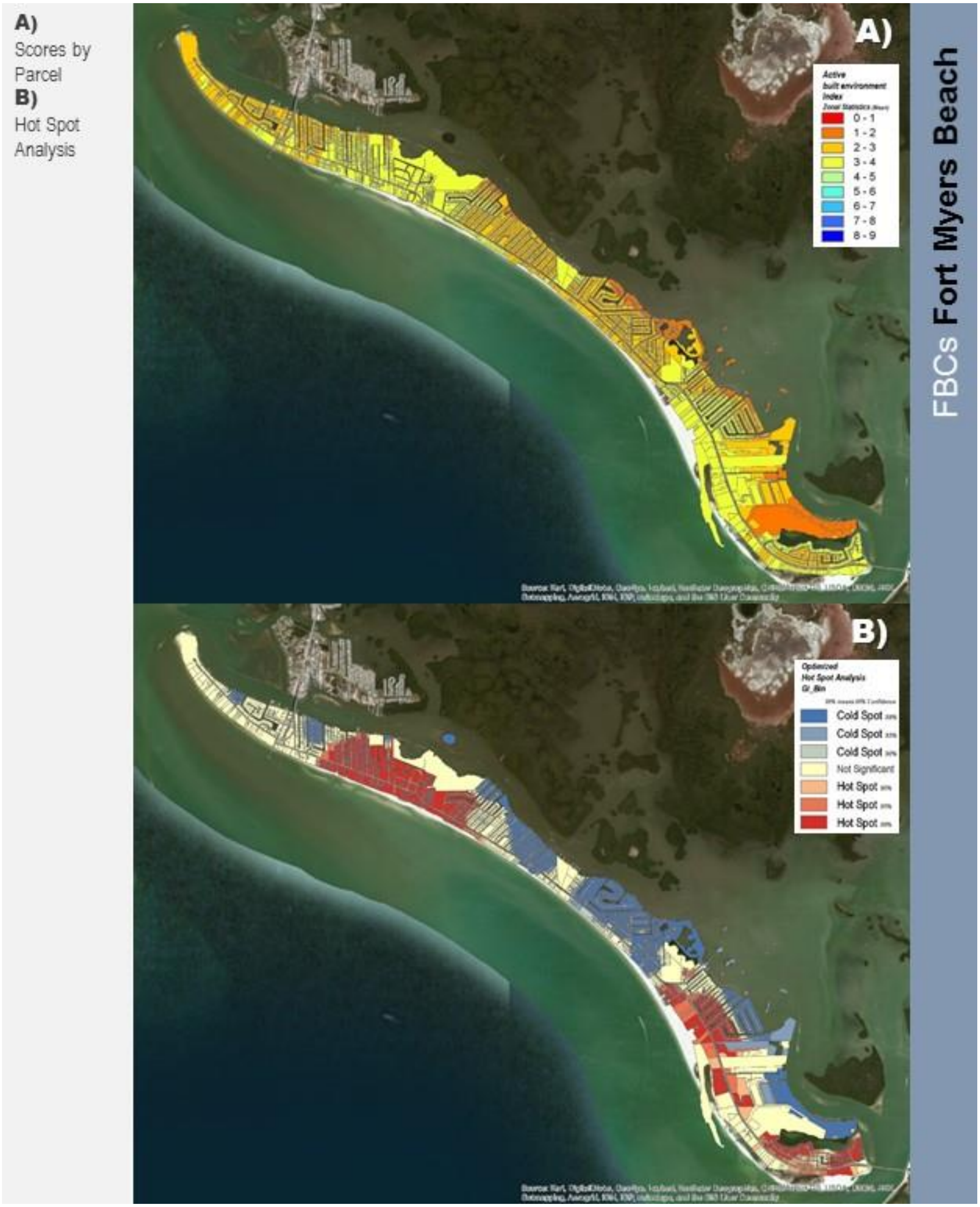

Figure 4-6. Scores by Parcel and Hot Spot Analysis of Fort Myers Beach. A) Zonal Statistics. B) Hot Spot Analysis.

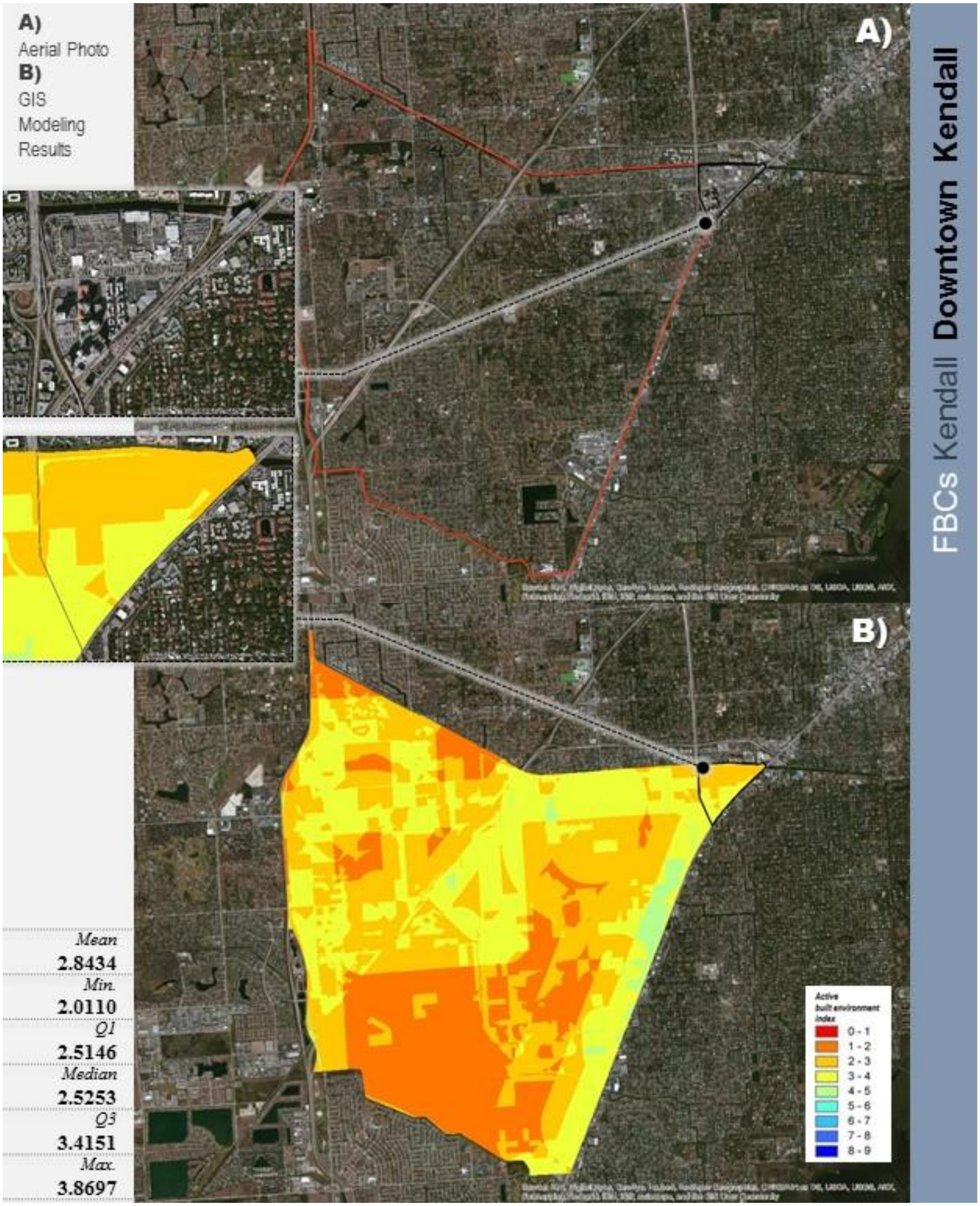

Figure 4-7. GIS Modeling Results of Downtown Kendall. A) Aerial Photo. B) GIS Suitability Modeling Results.

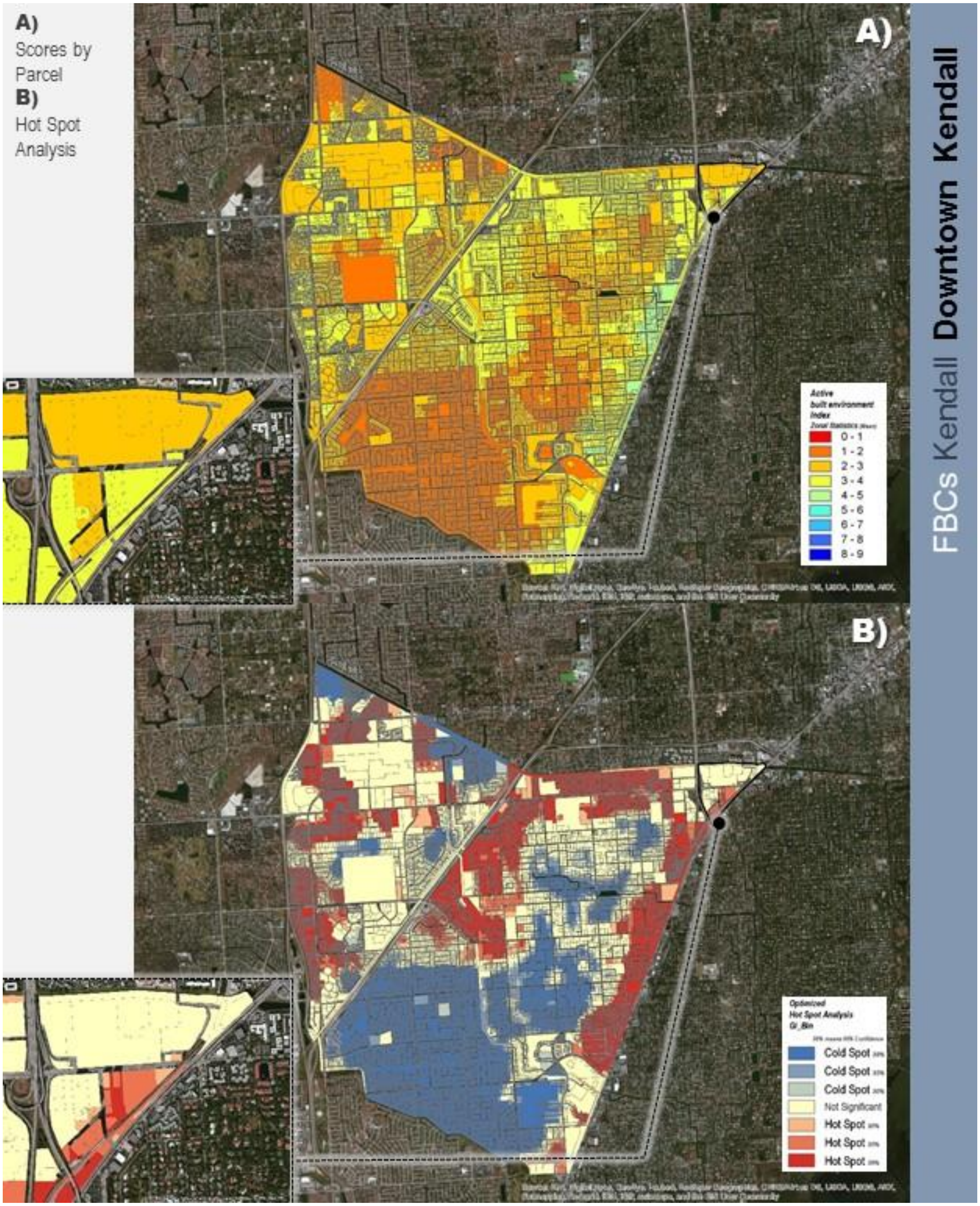

Figure 4-8. Scores by Parcel and Hot Spot Analysis of Downtown Kendall. A) Zonal Statistics. B) Hot Spot Analysis.

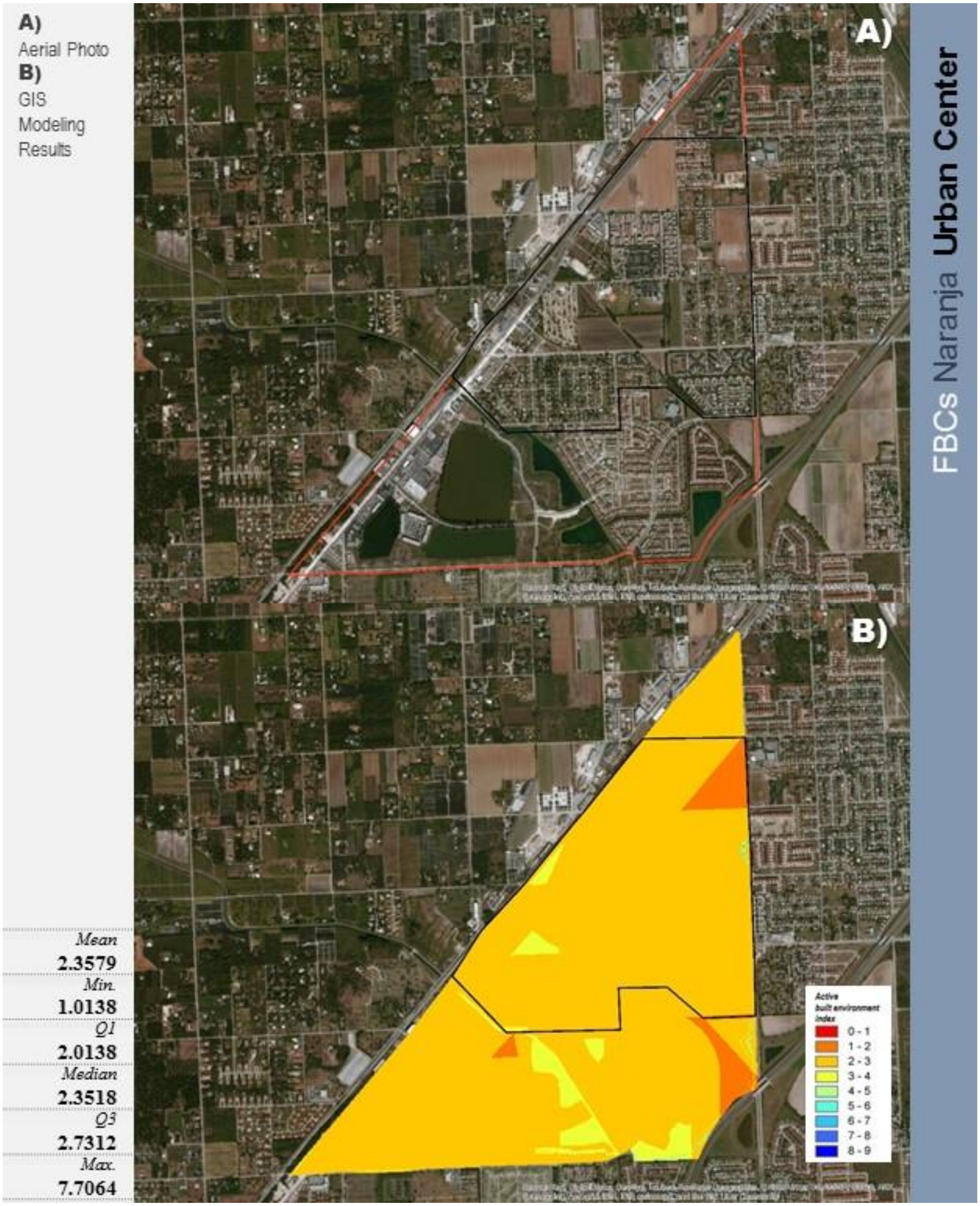

Figure 4-9. GIS Modeling Results of Naranja Urban Center. A) Aerial Photo. B) GIS Suitability Modeling Results.

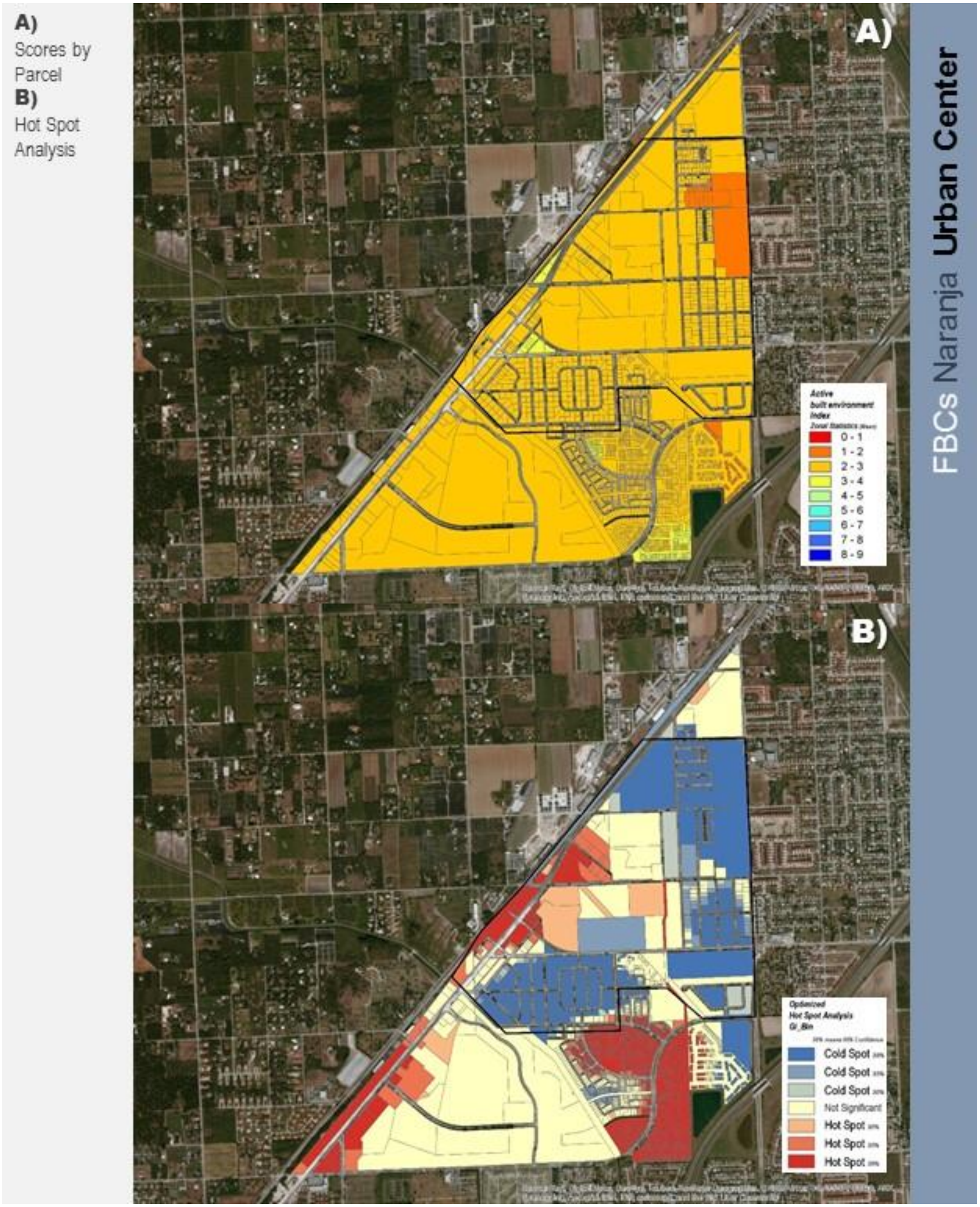

Figure 4-10. Scores by Parcel and Hot Spot Analysis of Naranja Urban Center. A) Zonal Statistics. B) Hot Spot Analysis.

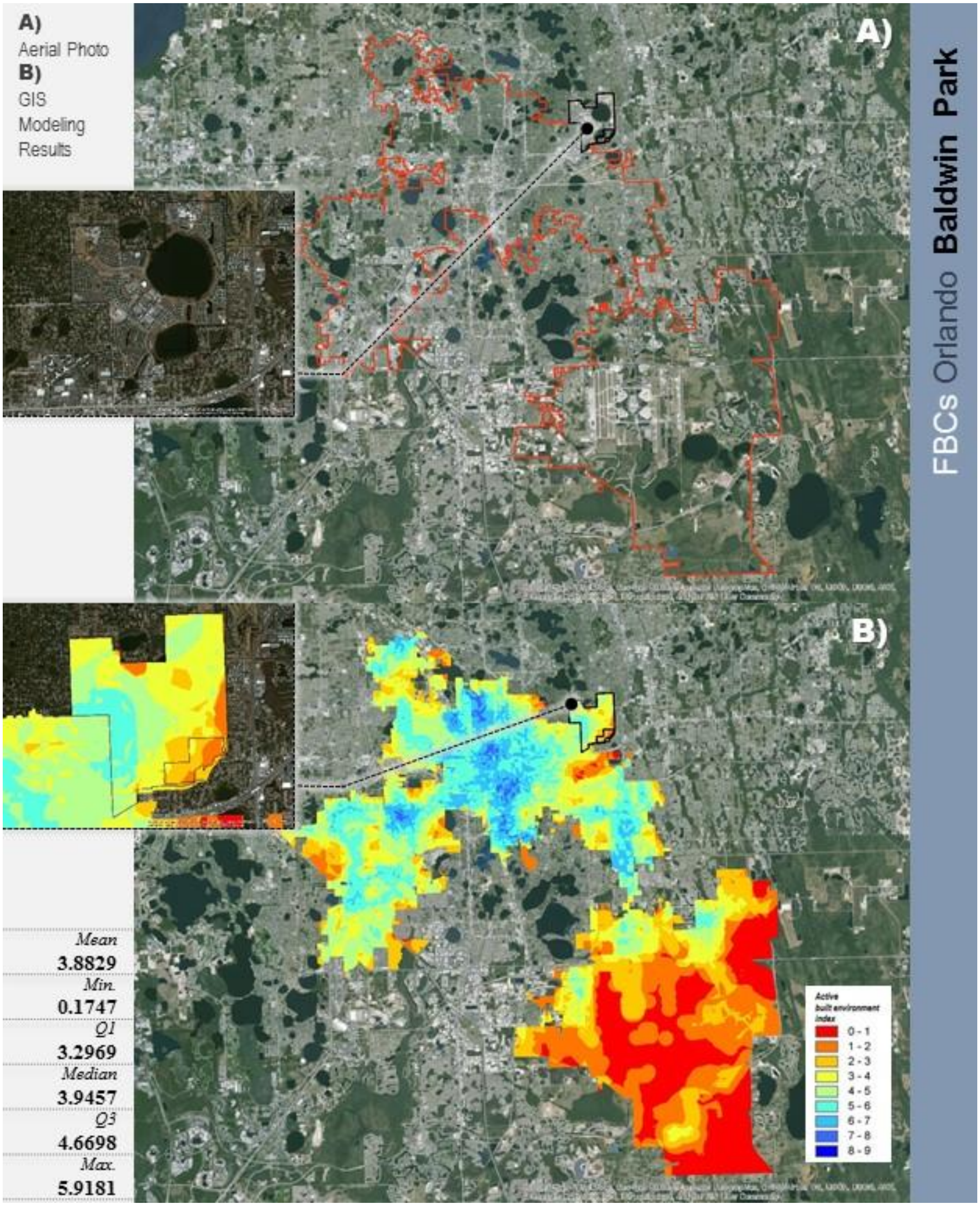

Figure 4-11. GIS Modeling Results of Baldwin Park (Orlando). A) Aerial Photo. B) GIS Suitability Modeling Results.

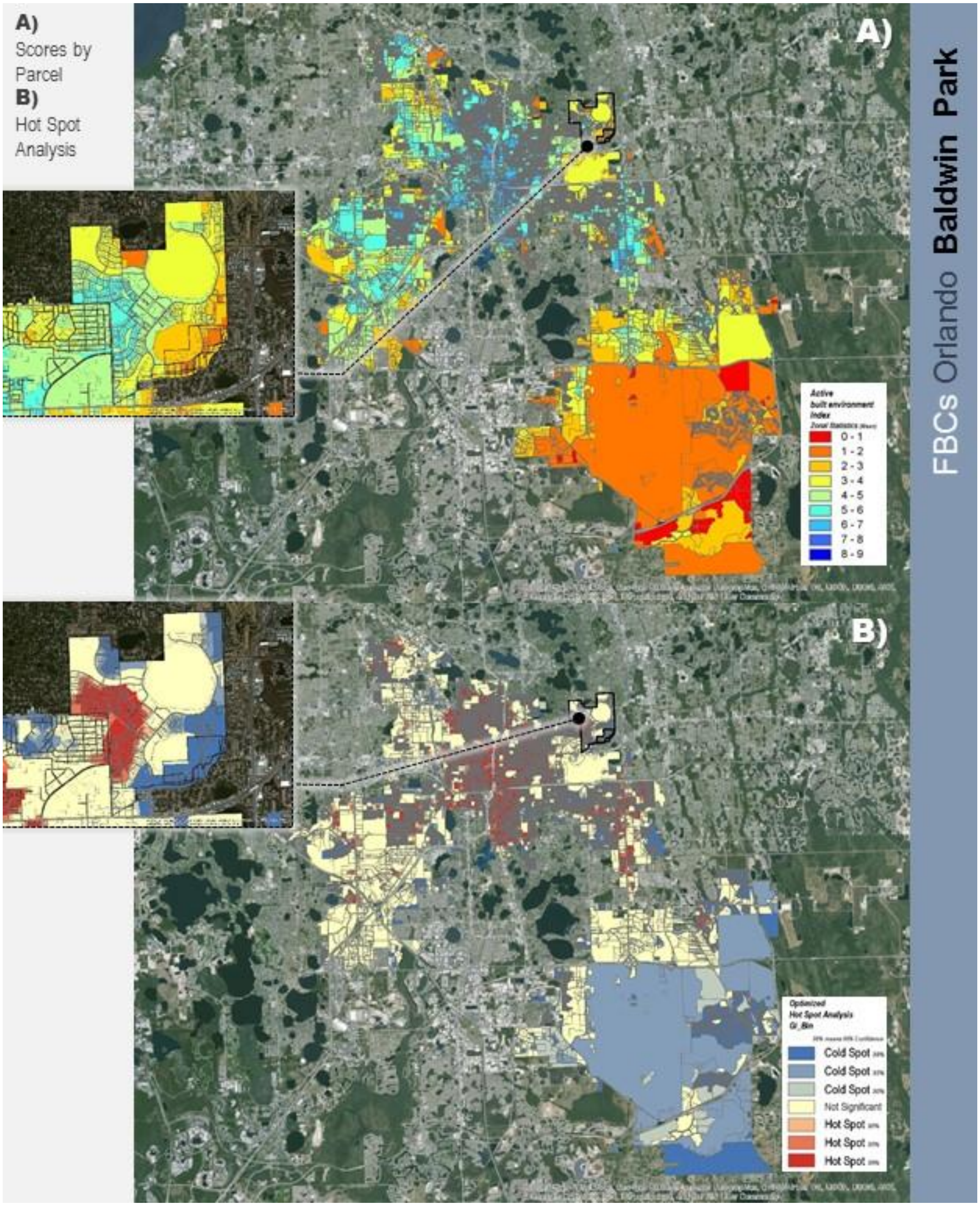

Figure 4-12. Scores by Parcel and Hot Spot Analysis of Baldwin Park (Orlando). A) Zonal Statistics. B) Hot Spot Analysis.

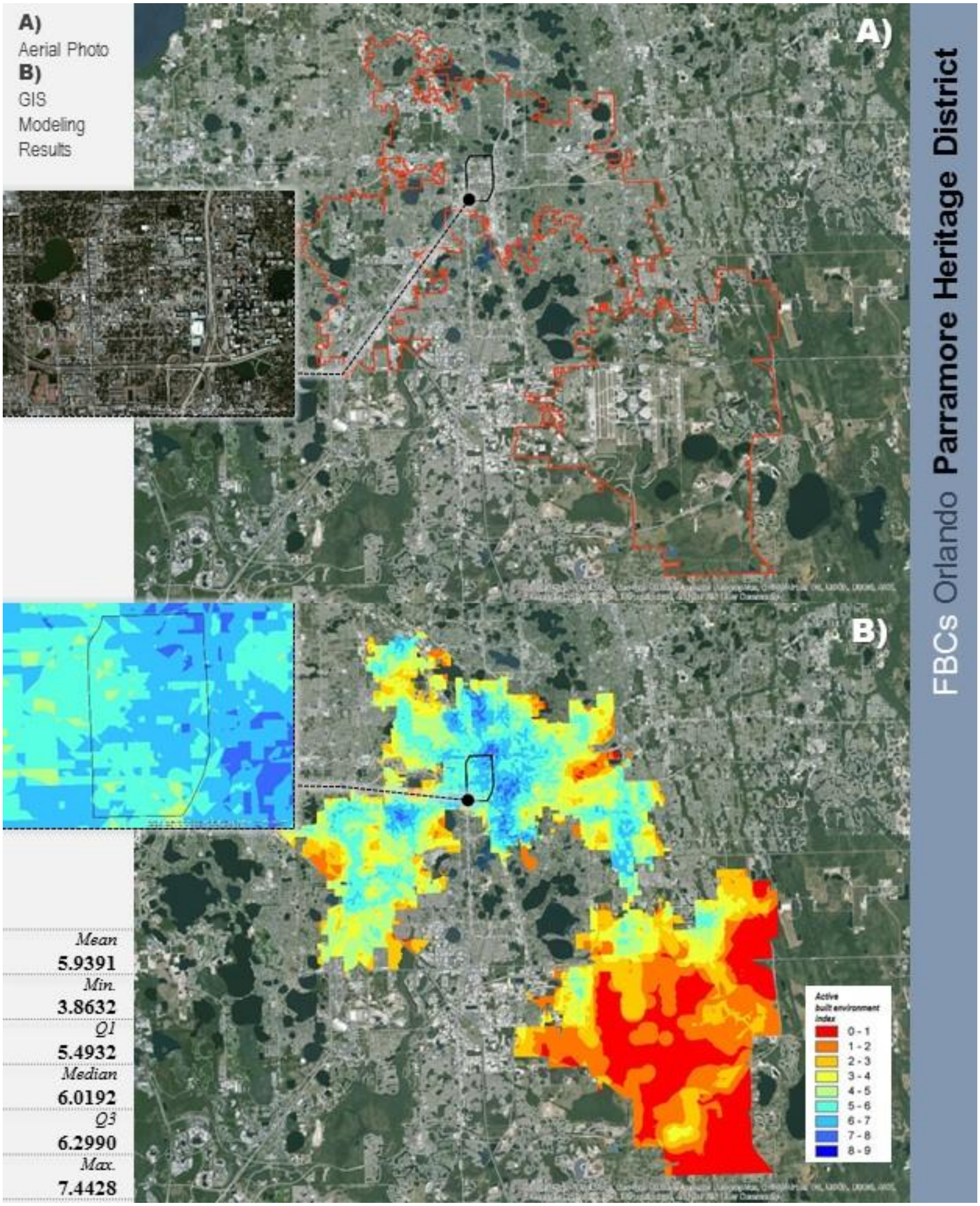

Figure 4-13. GIS Modeling Results of Parramore Heritage District (Orlando). A) Aerial Photo. B) GIS Suitability Modeling Results.

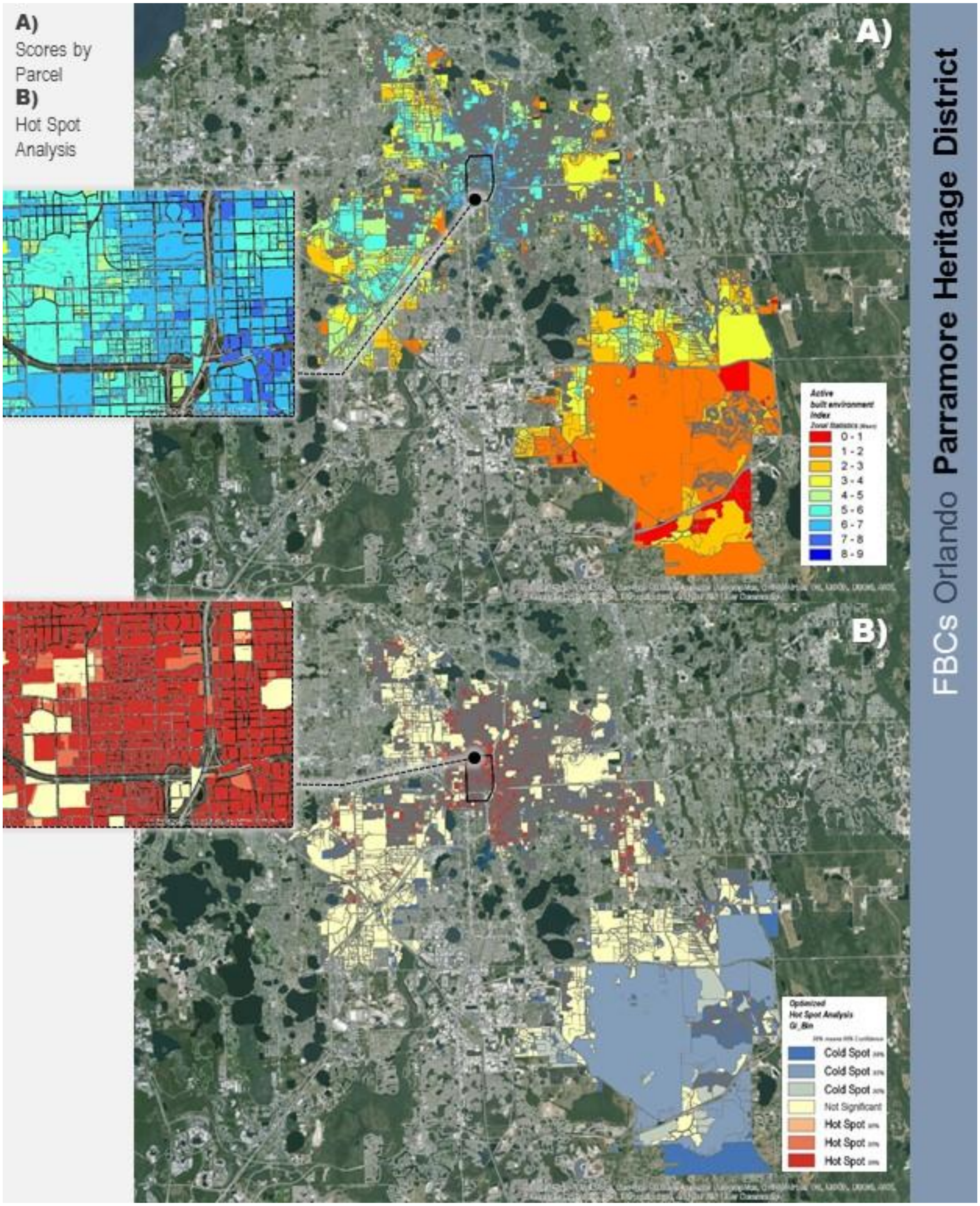

Figure 4-14. Scores by Parcel and Hot Spot Analysis of Parramore Heritage District (Orlando). A) Zonal Statistics. B) Hot Spot Analysis.

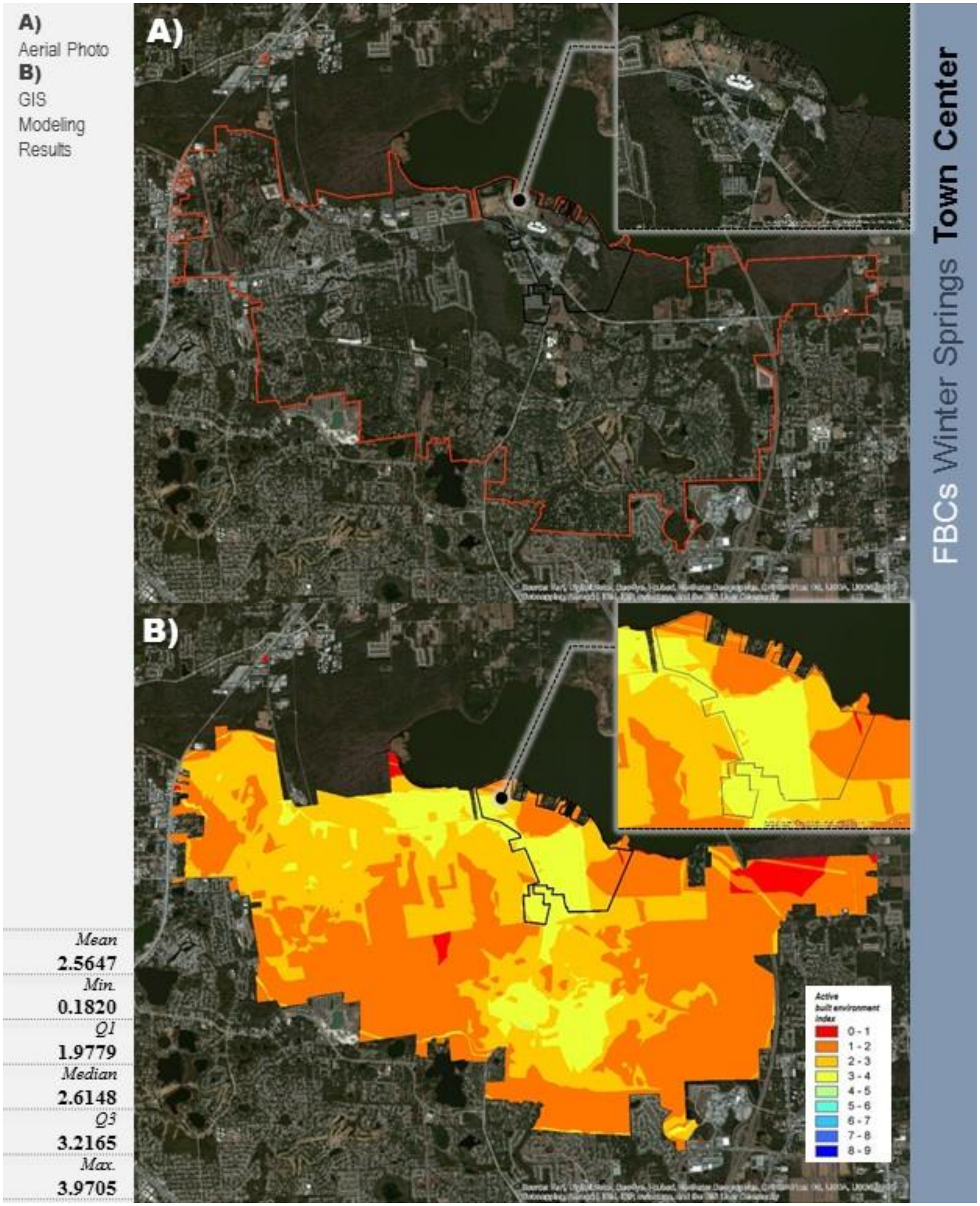

Figure 4-15. GIS Modeling Results of Winter Springs Town Center. A) Aerial Photo. B) GIS Suitability Modeling Results.

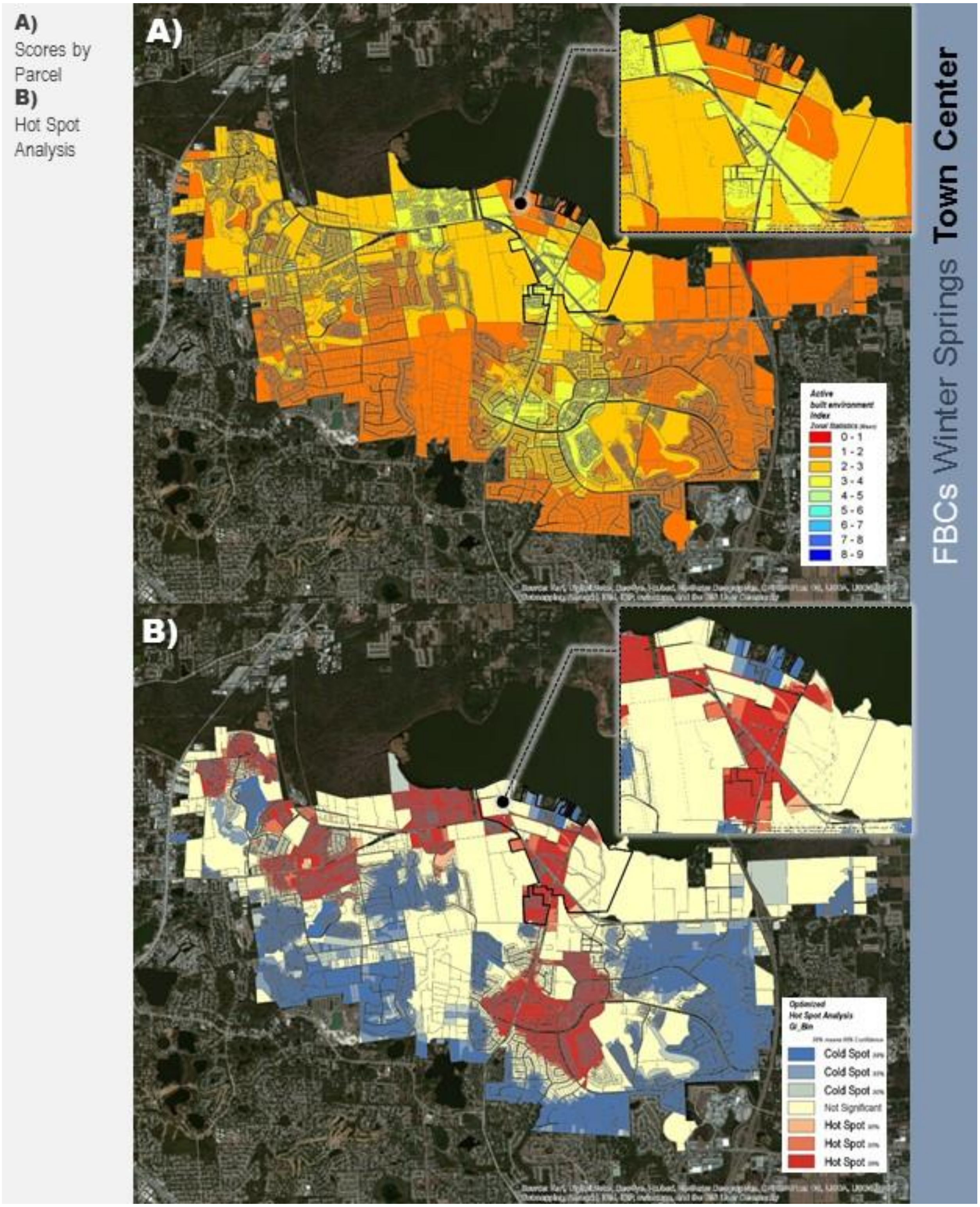

Figure 4-16. Scores by Parcel and Hot Spot Analysis of Winter Springs Town Center. A) Zonal Statistics. B) Hot Spot Analysis.

Figure 4-17. GIS Modeling Results of Seaside. A) Aerial Photo. B) GIS Suitability Modeling Results.

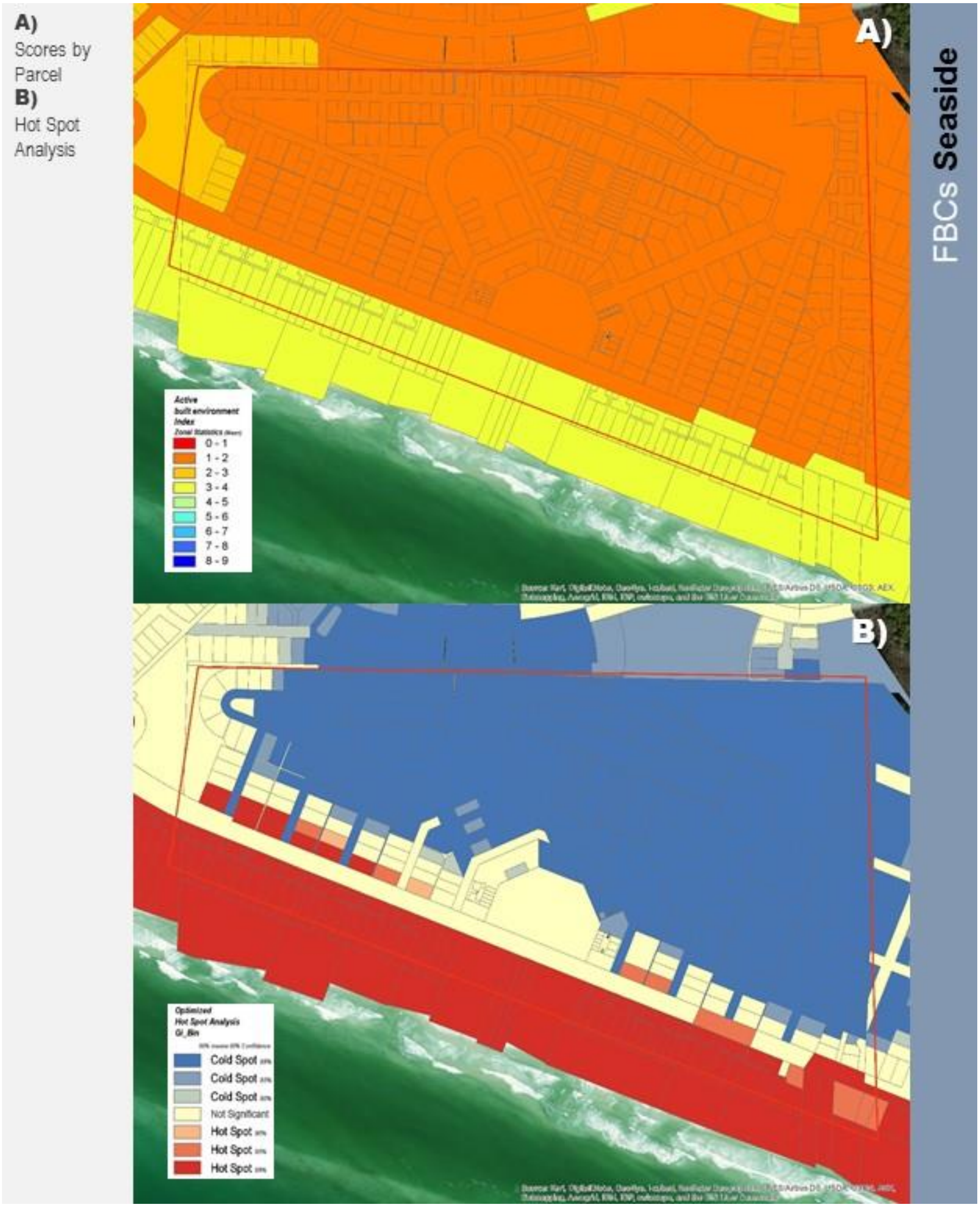

Figure 4-18. Scores by Parcel and Hot Spot Analysis of Seaside. A) Zonal Statistics. B) Hot Spot Analysis.

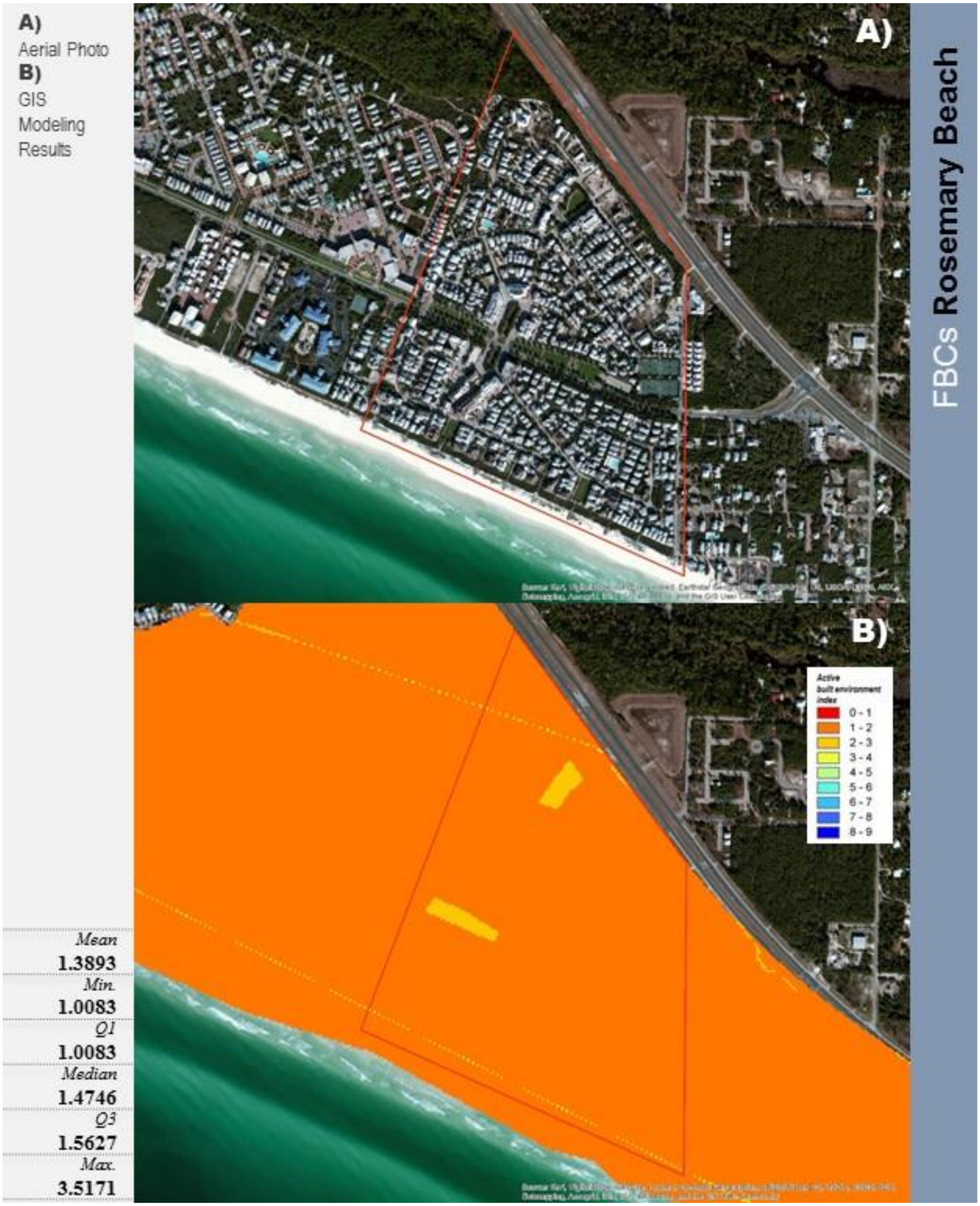

Figure 4-19. GIS Modeling Results of Rosemary Beach. A) Aerial Photo. B) GIS Suitability Modeling Results.

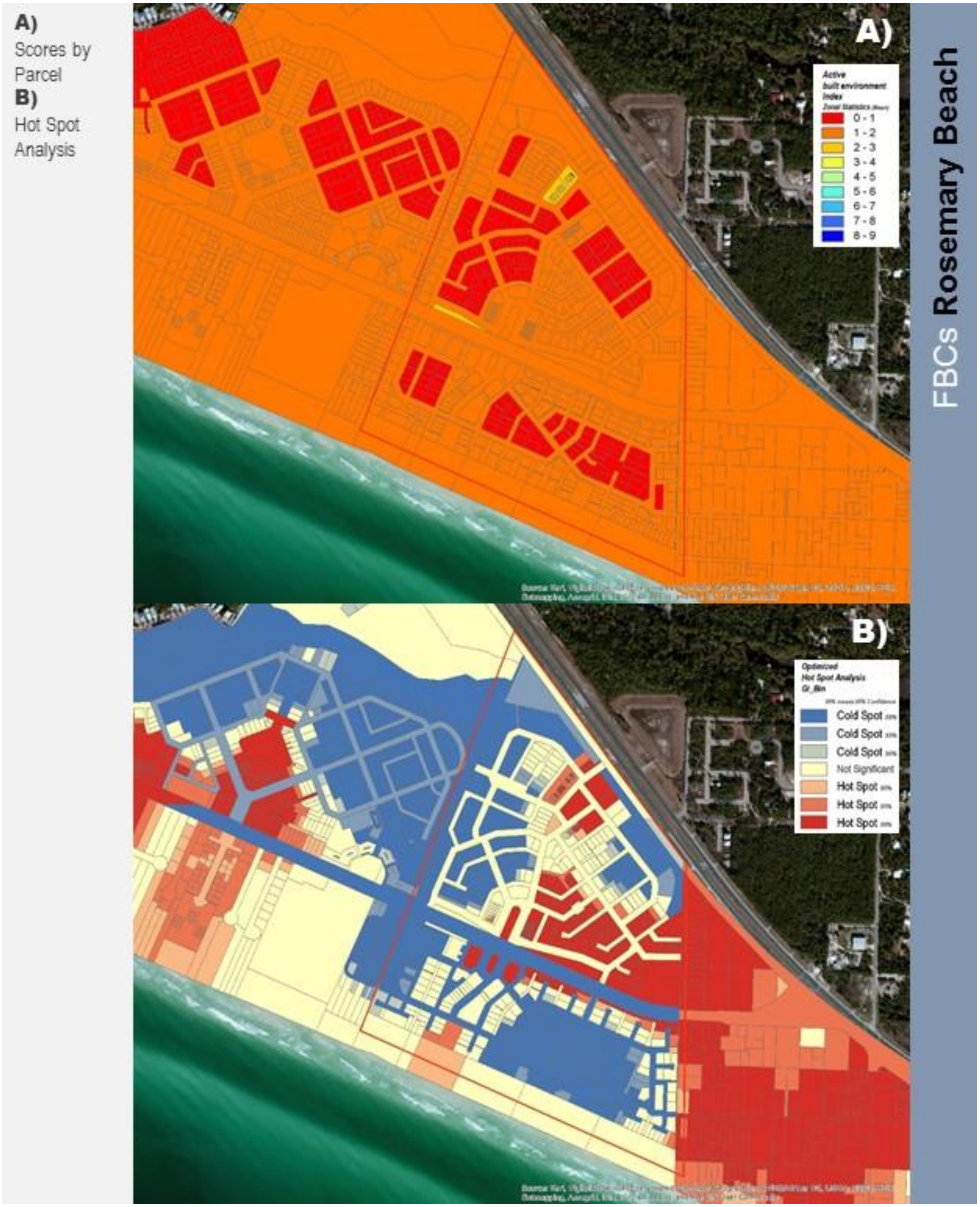

Figure 4-20. Scores by Parcel and Hot Spot Analysis of Rosemary Beach. A) Zonal Statistics. B) Hot Spot Analysis.

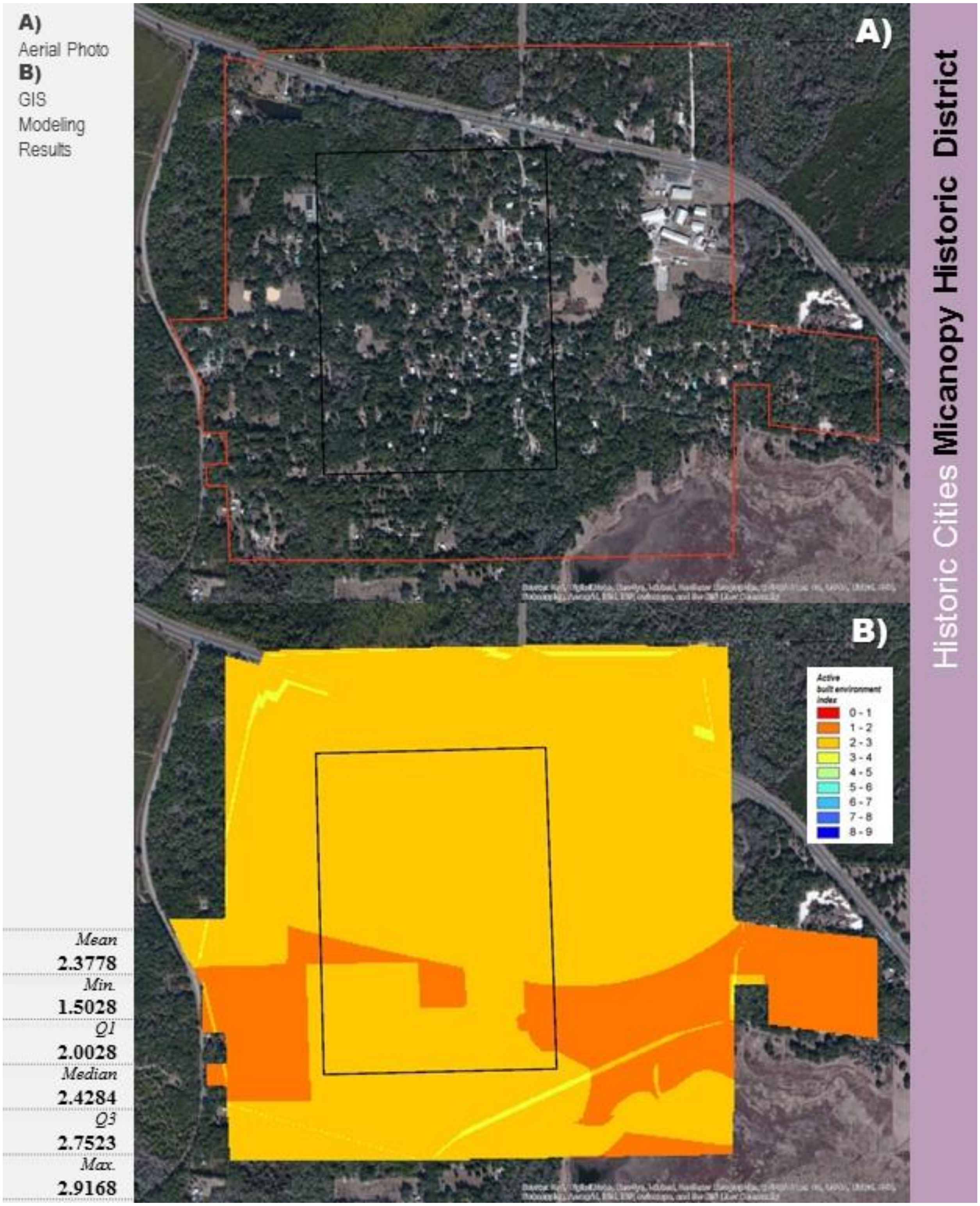

Figure 4-21. GIS Modeling Results of Micanopy Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

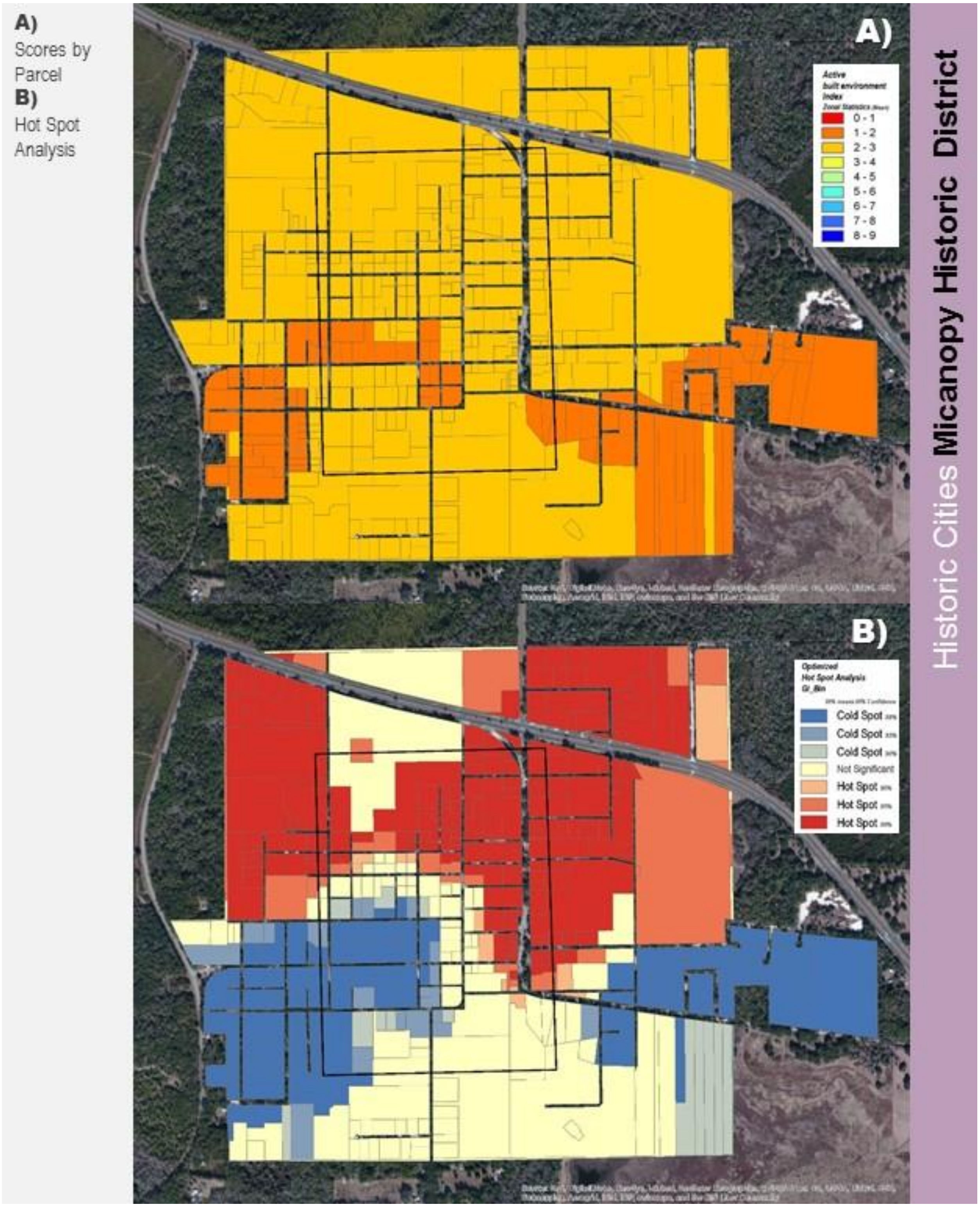

Figure 4-22. Scores by Parcel and Hot Spot Analysis of Micanopy Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

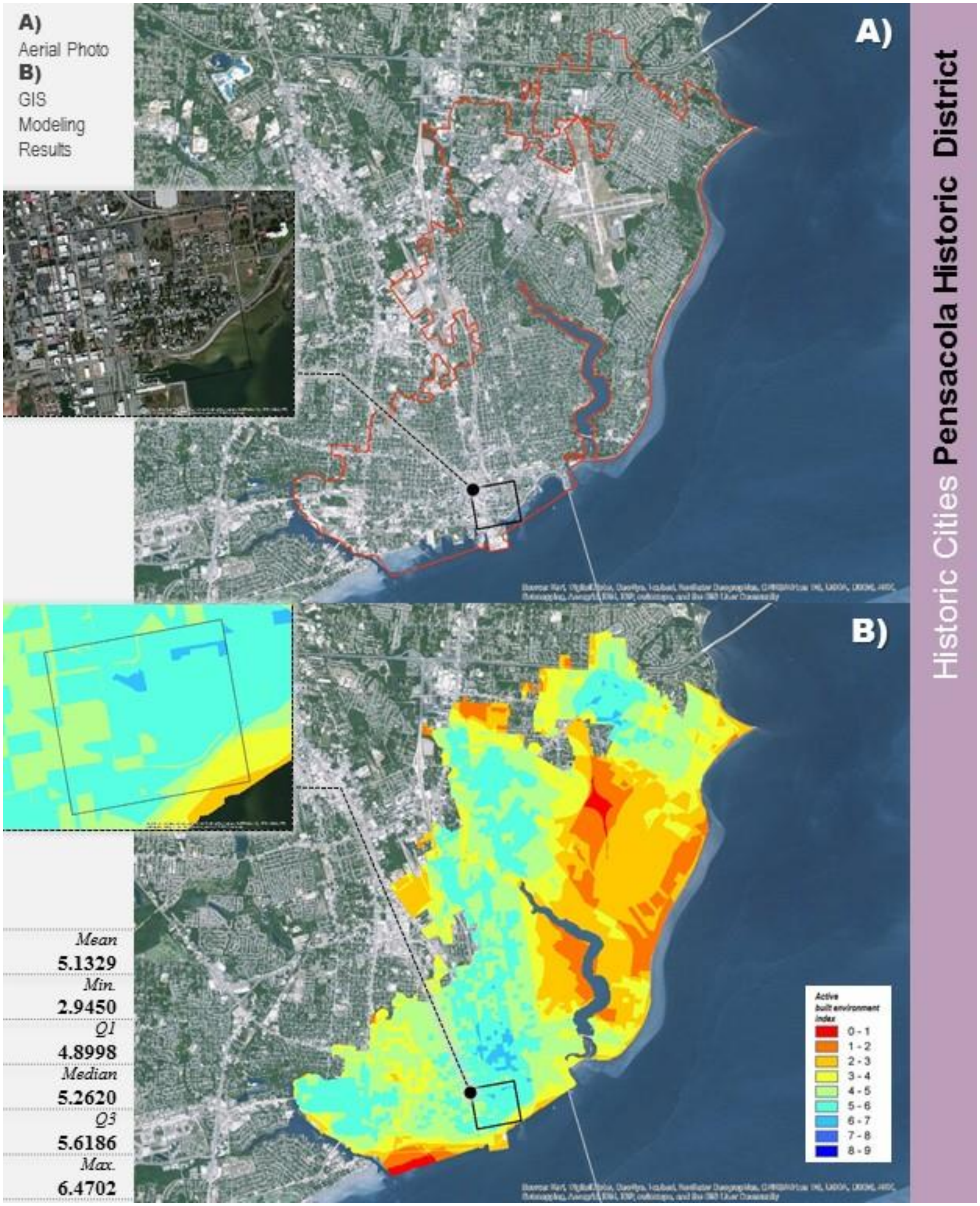

Figure 4-23. GIS Modeling Results of Pensacola Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

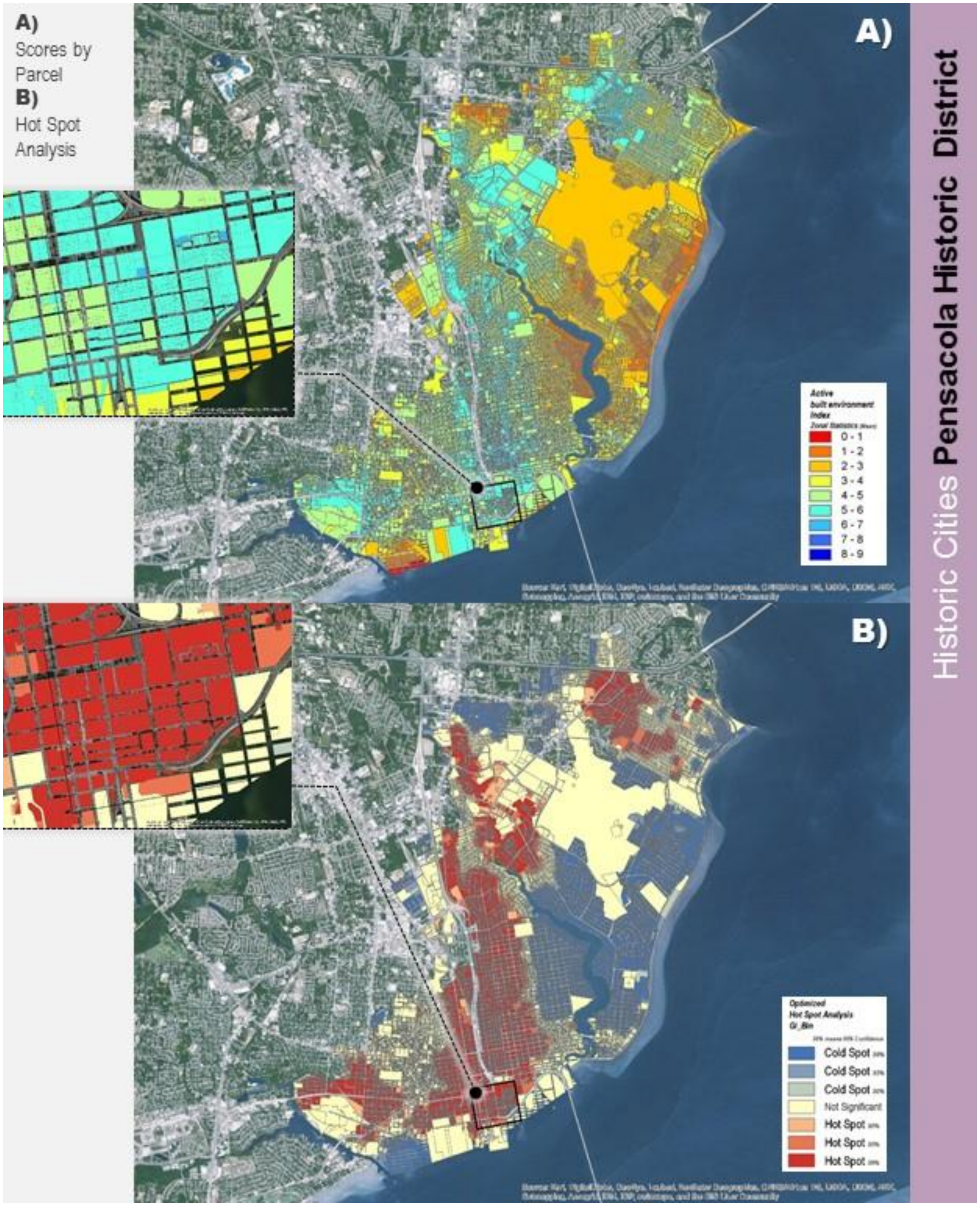

Figure 4-24. Scores by Parcel and Hot Spot Analysis of Pensacola Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

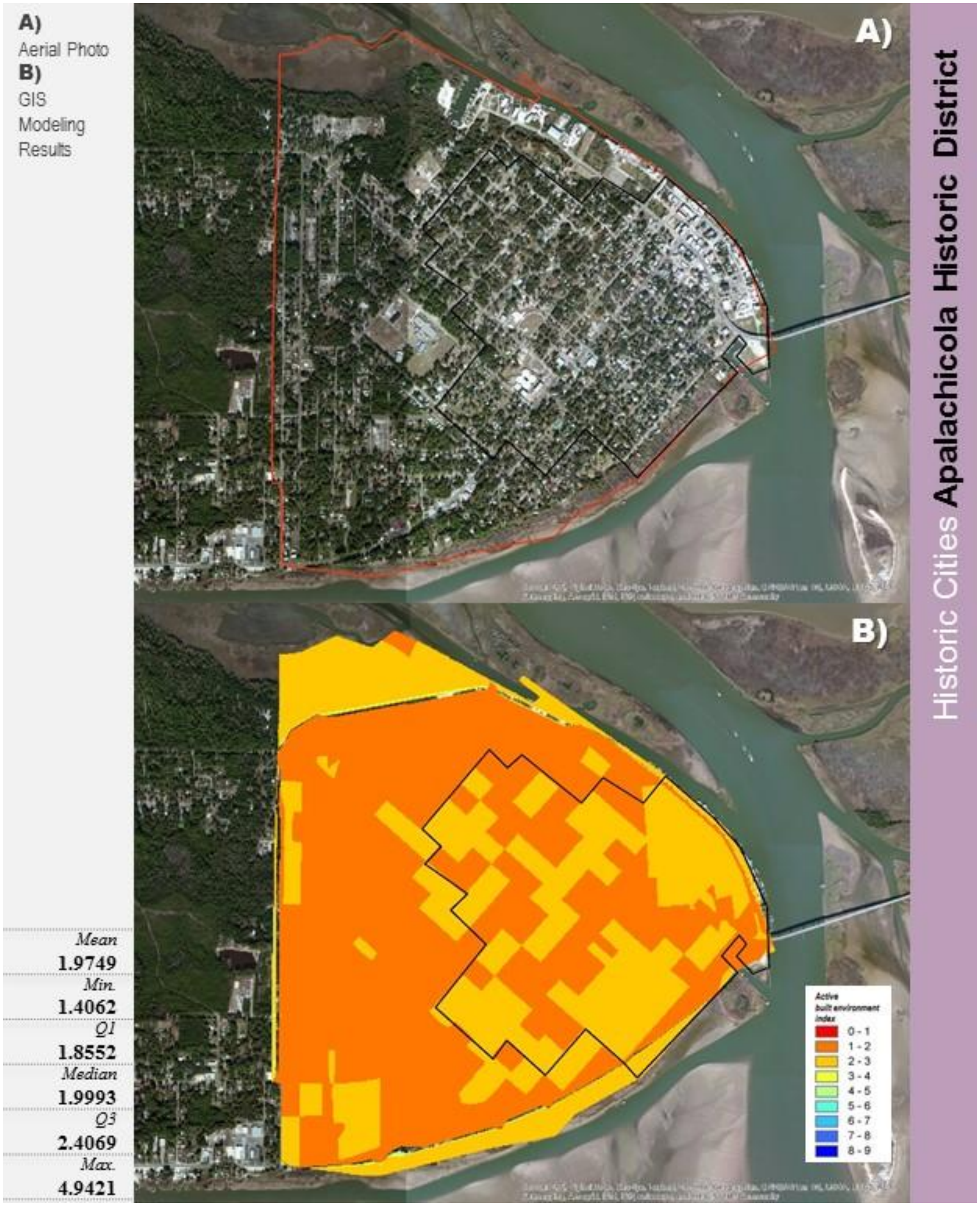

Figure 4-25. GIS Modeling Results of Apalachicola Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

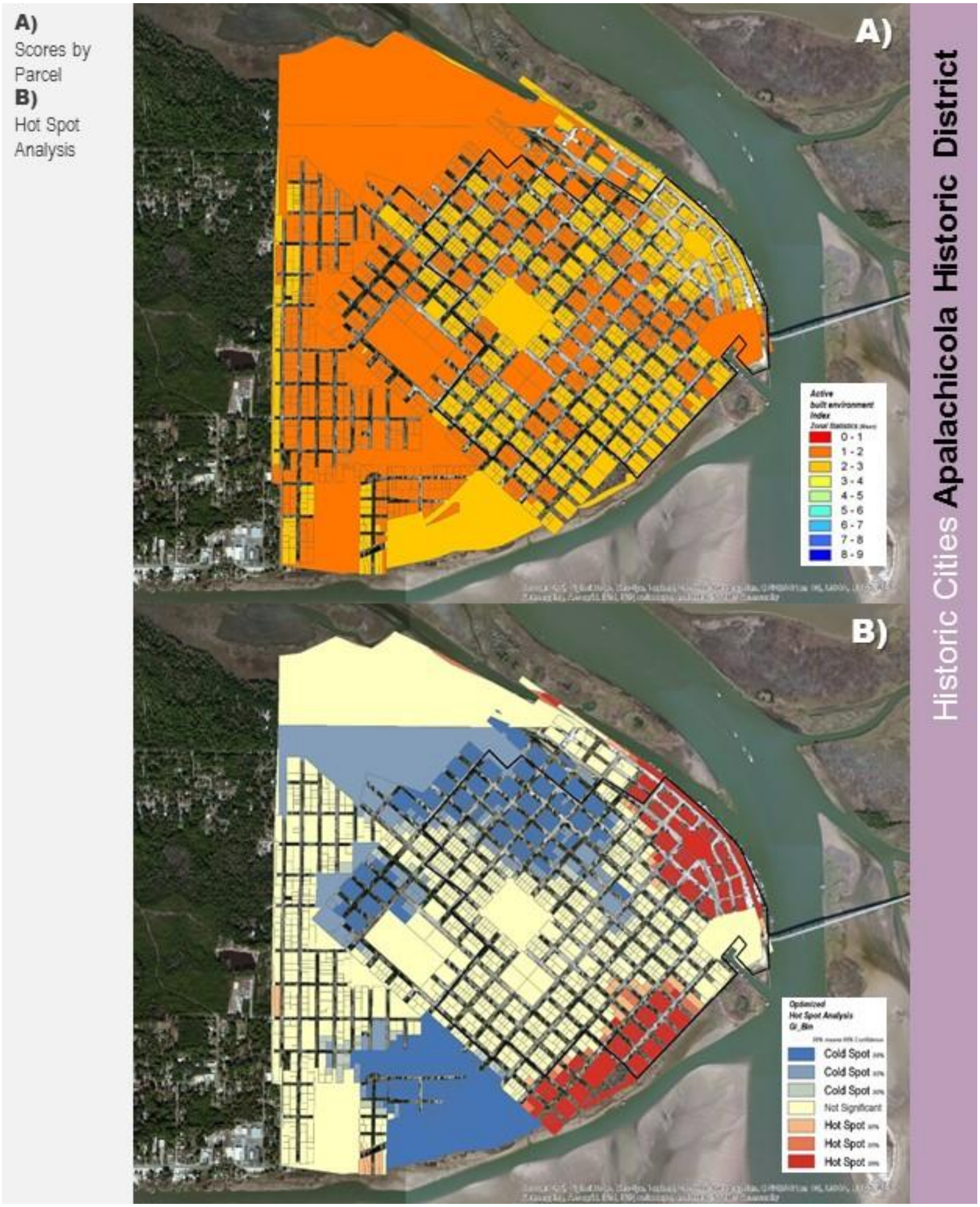

Figure 4-26. Scores by Parcel and Hot Spot Analysis of Apalachicola Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

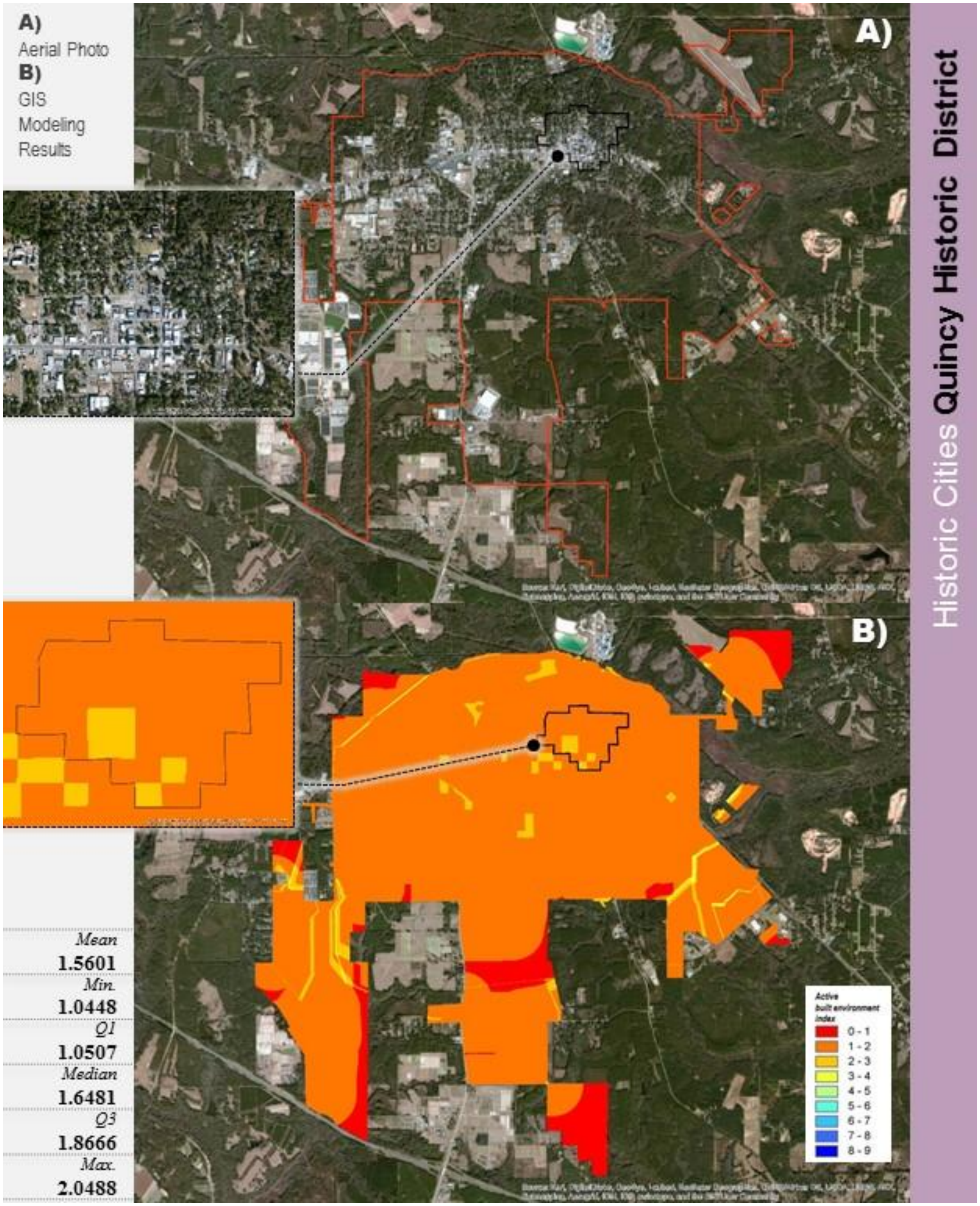

Figure 4-27. GIS Modeling Results of Quincy Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

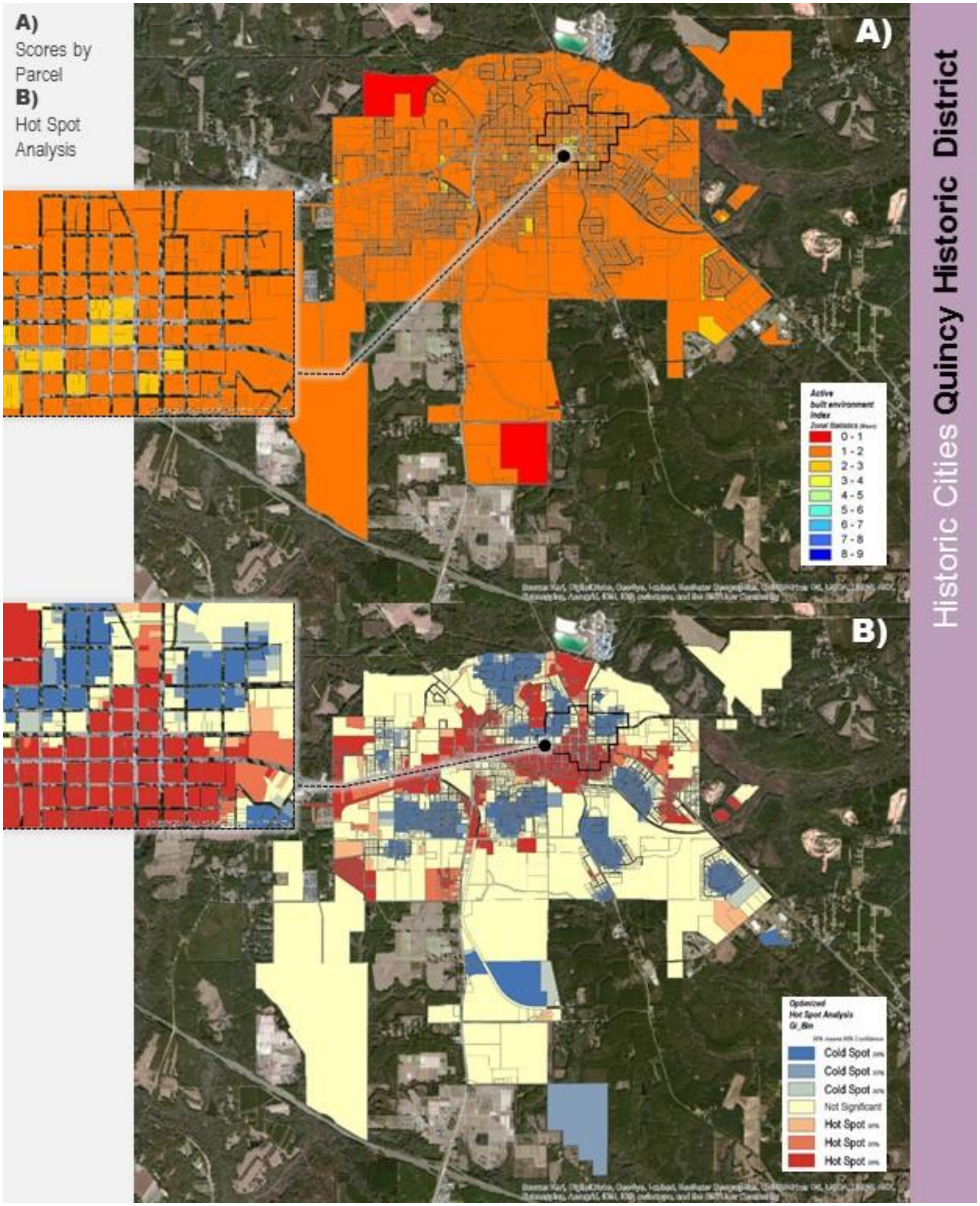

Figure 4-28. Scores by Parcel and Hot Spot Analysis of Quincy Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

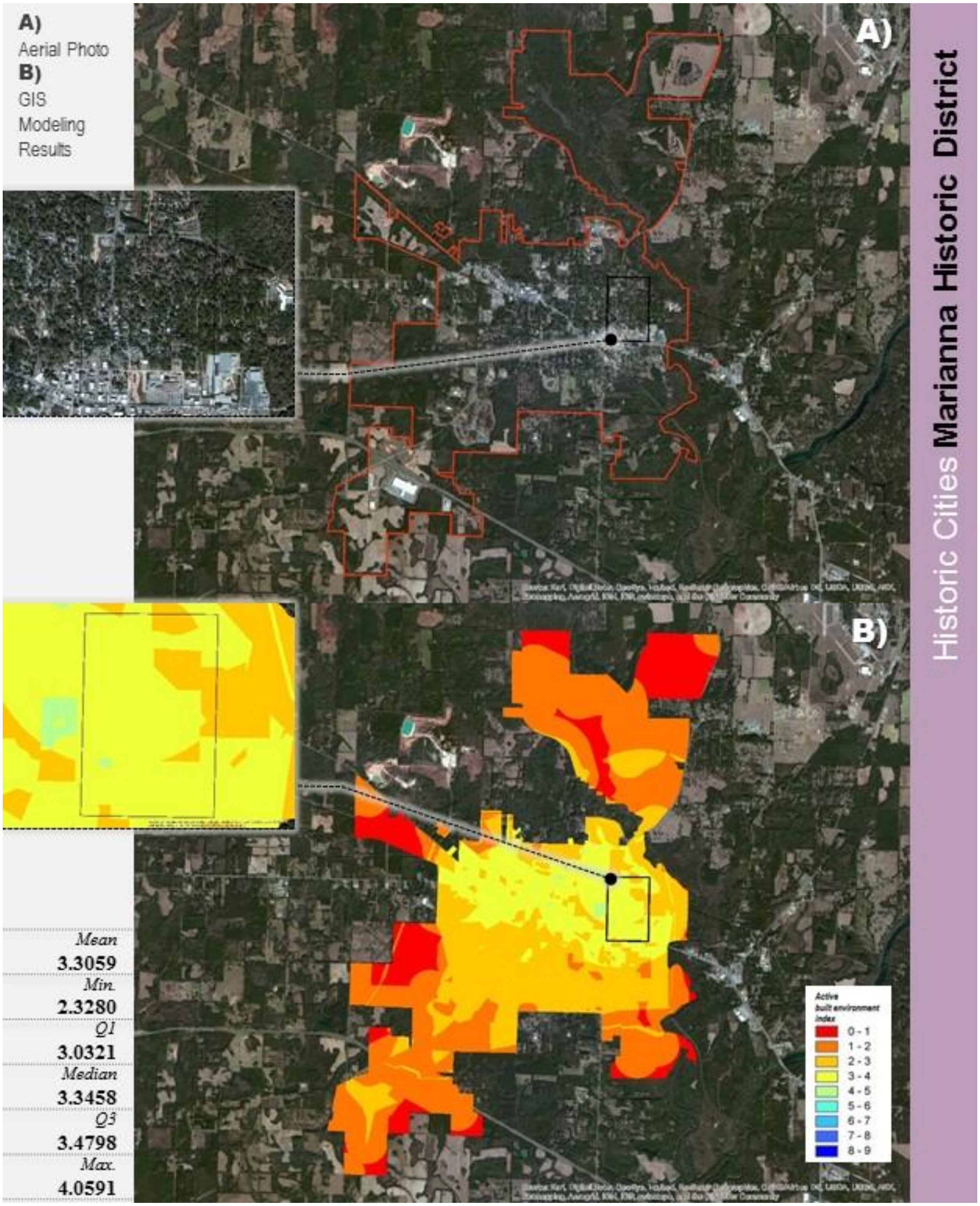

Figure 4-29. GIS Modeling Results of Marianna Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

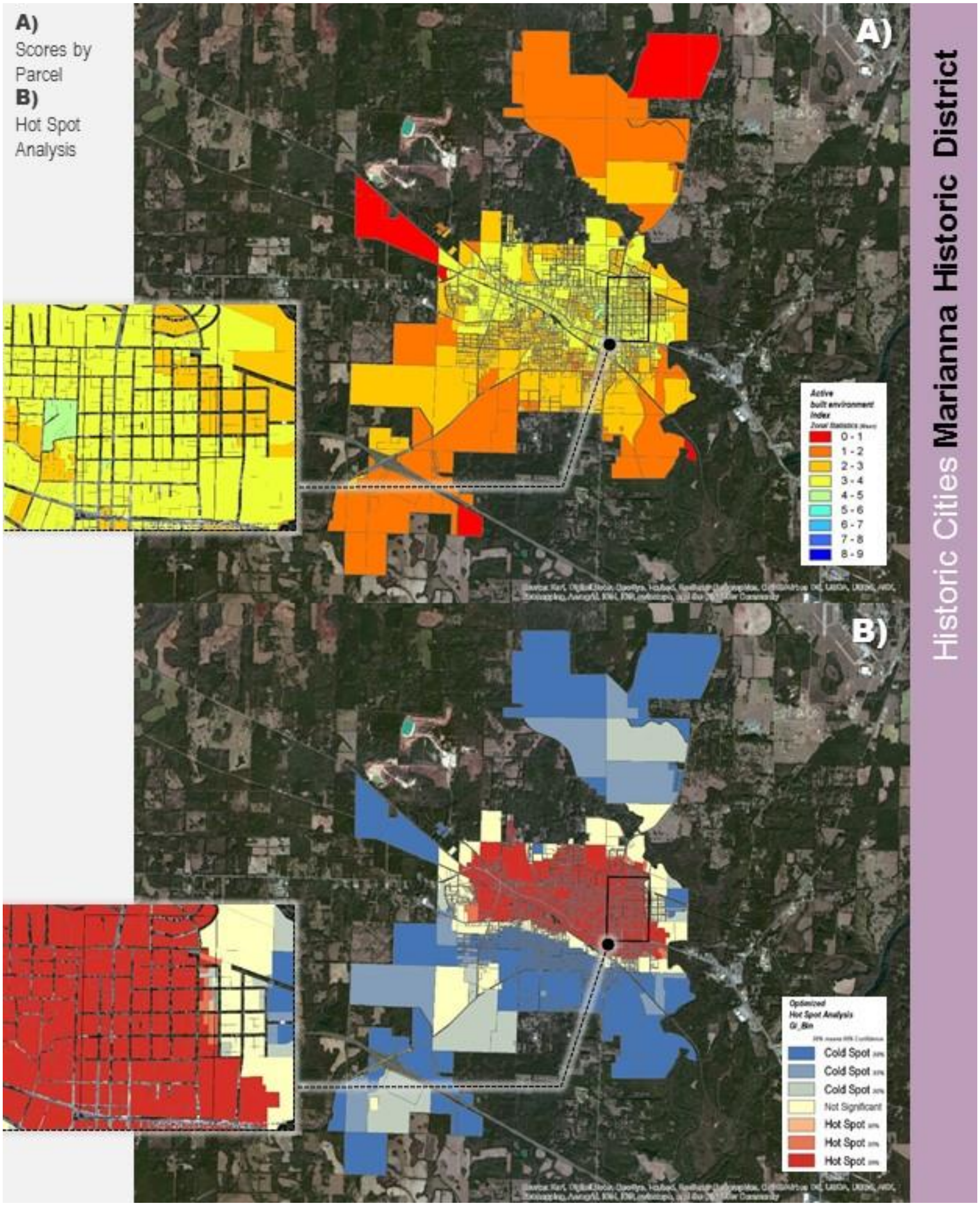

Figure 4-30. Scores by Parcel and Hot Spot Analysis of Marianna Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

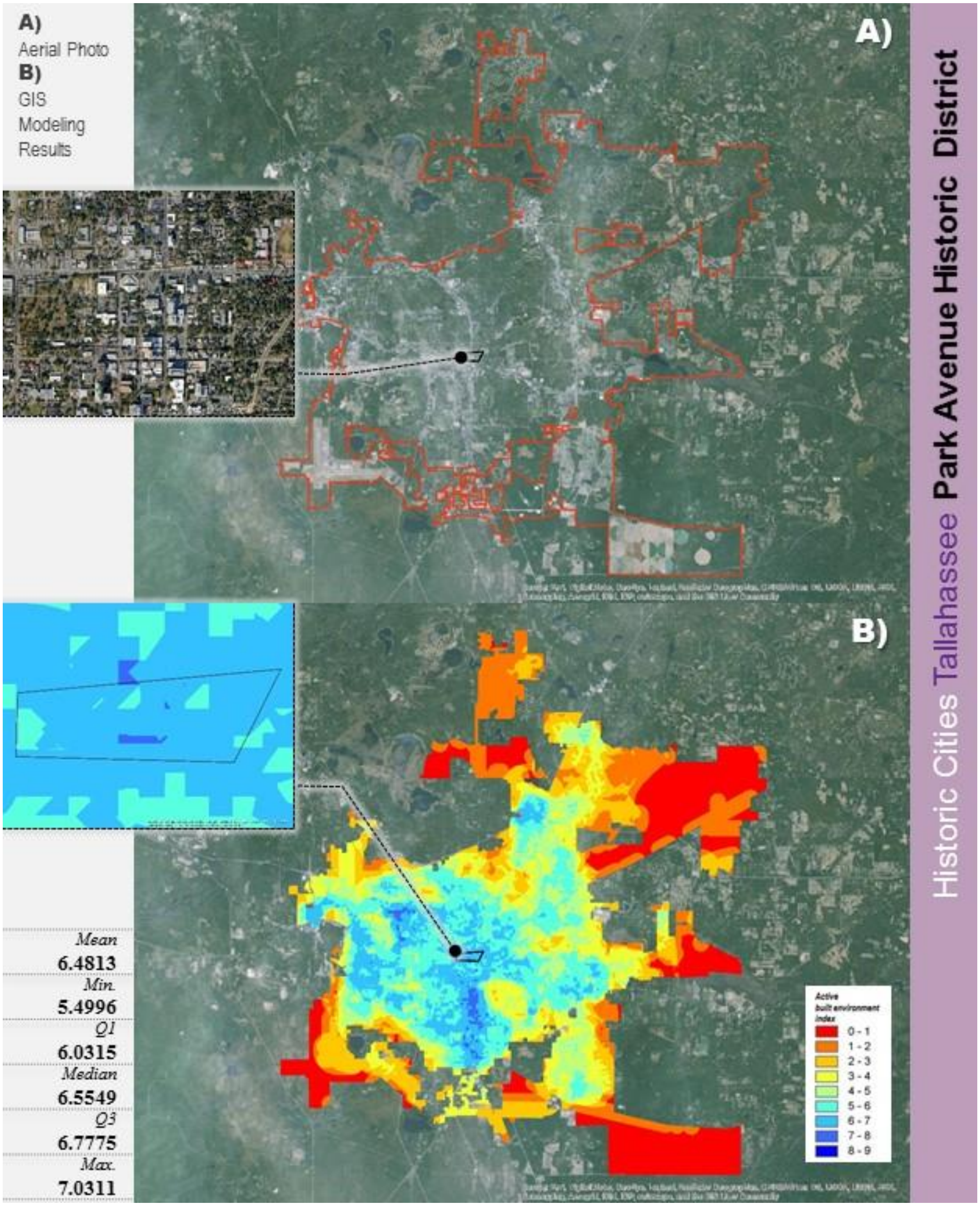

Figure 4-31. GIS Modeling Results of Tallahassee Park Avenue Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

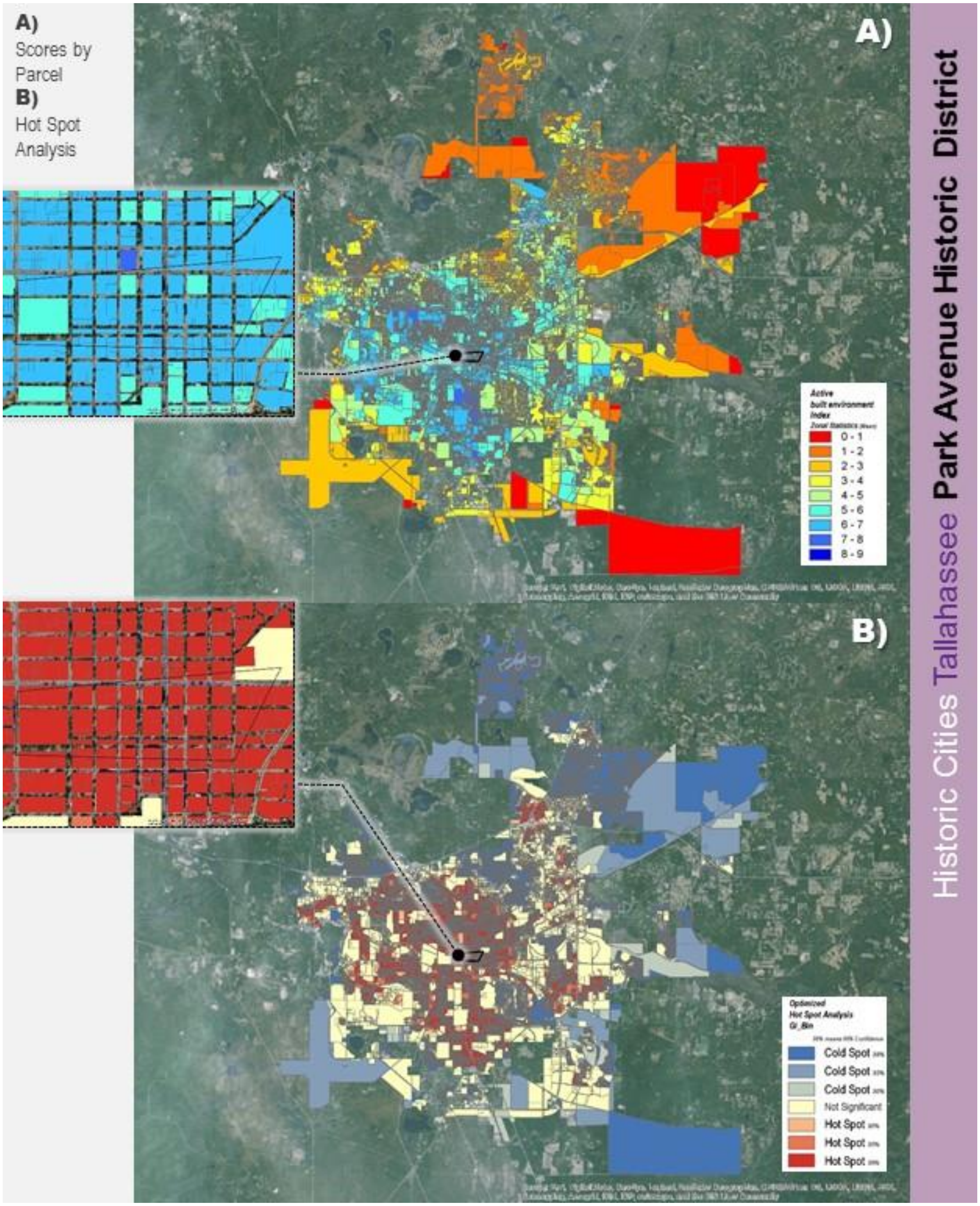

Figure 4-32. Scores by Parcel and Hot Spot Analysis of Tallahassee Park Avenue Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

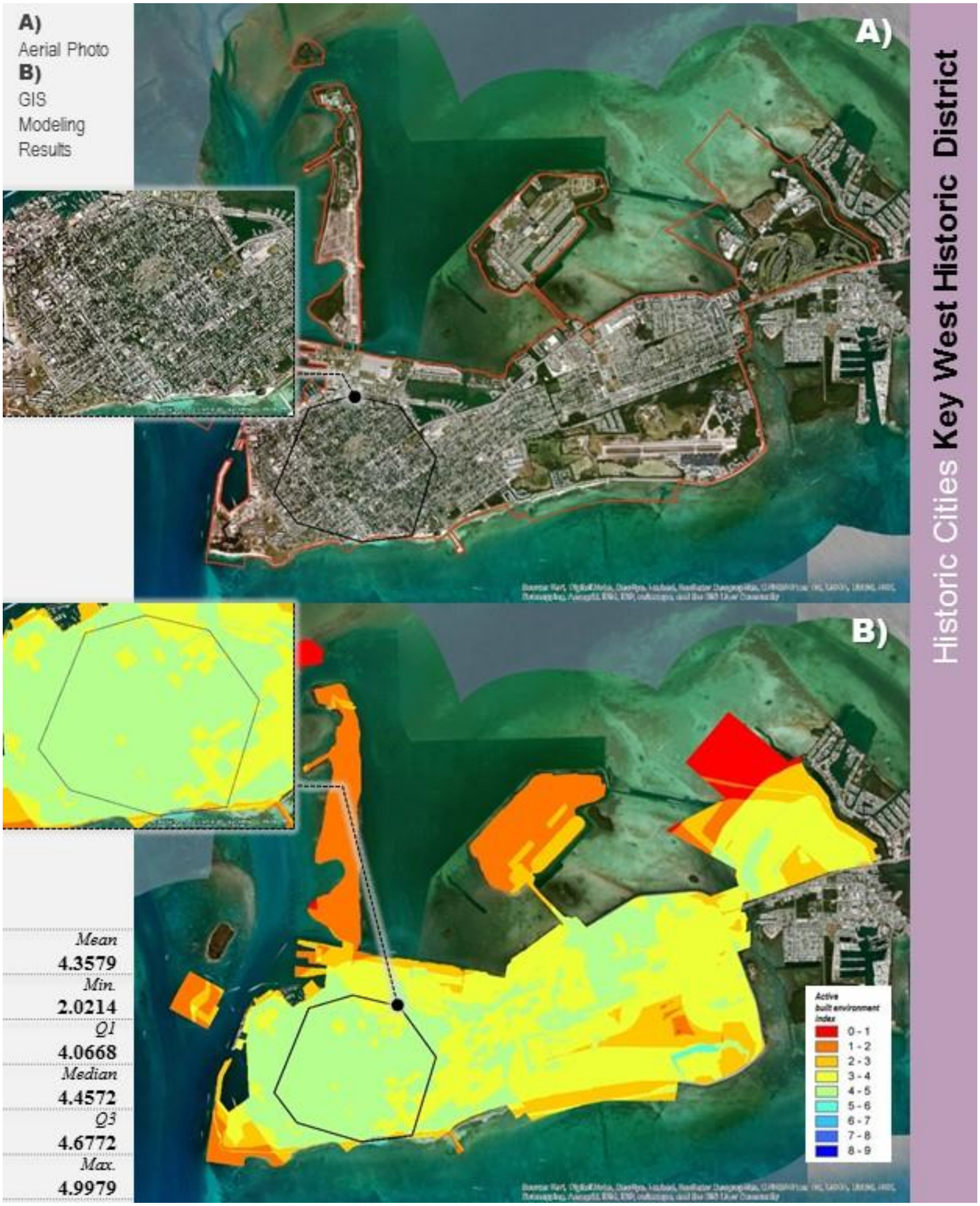

Figure 4-33. GIS Modeling Results of Key West Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

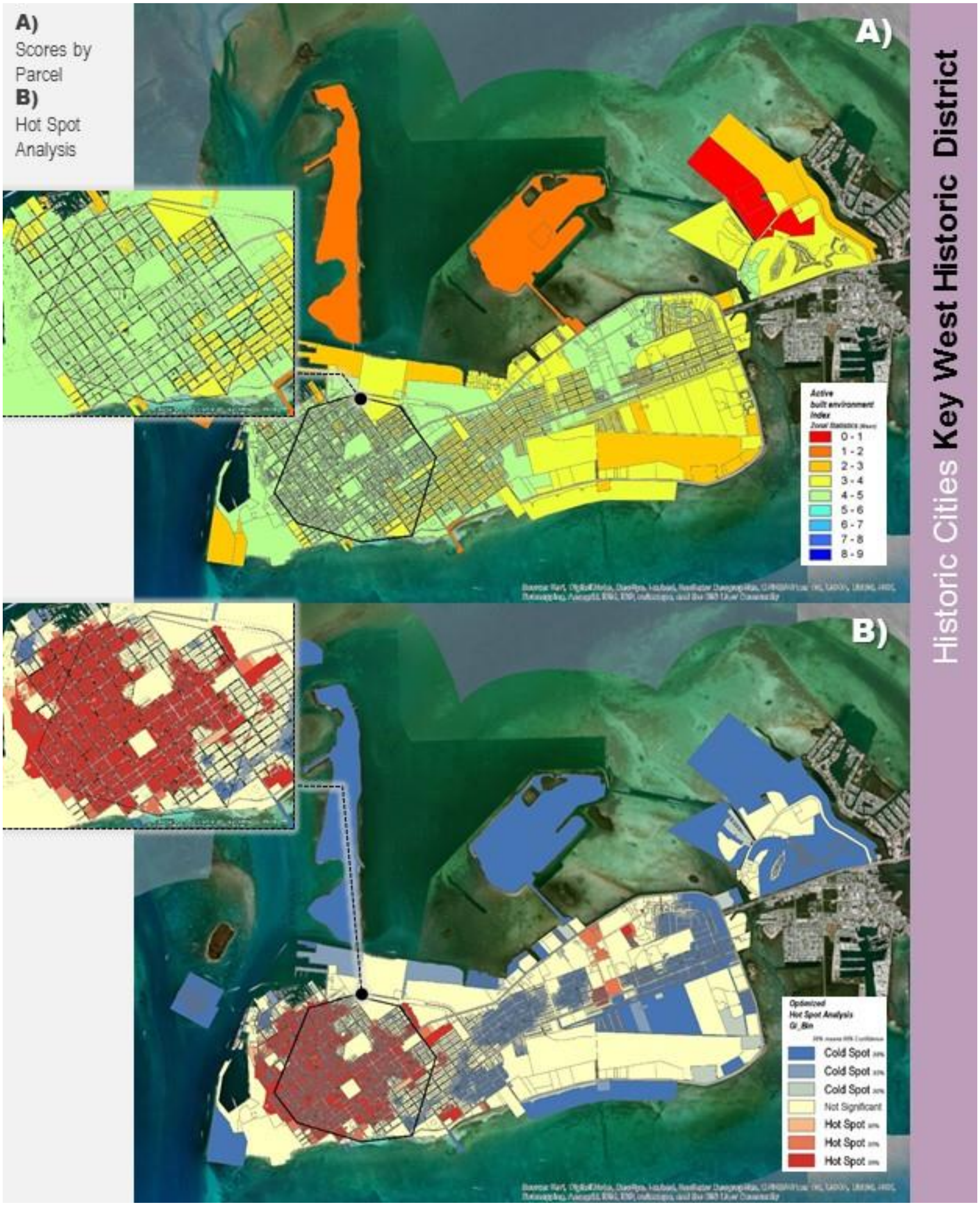

Figure 4-34. Scores by Parcel and Hot Spot Analysis of Key West Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

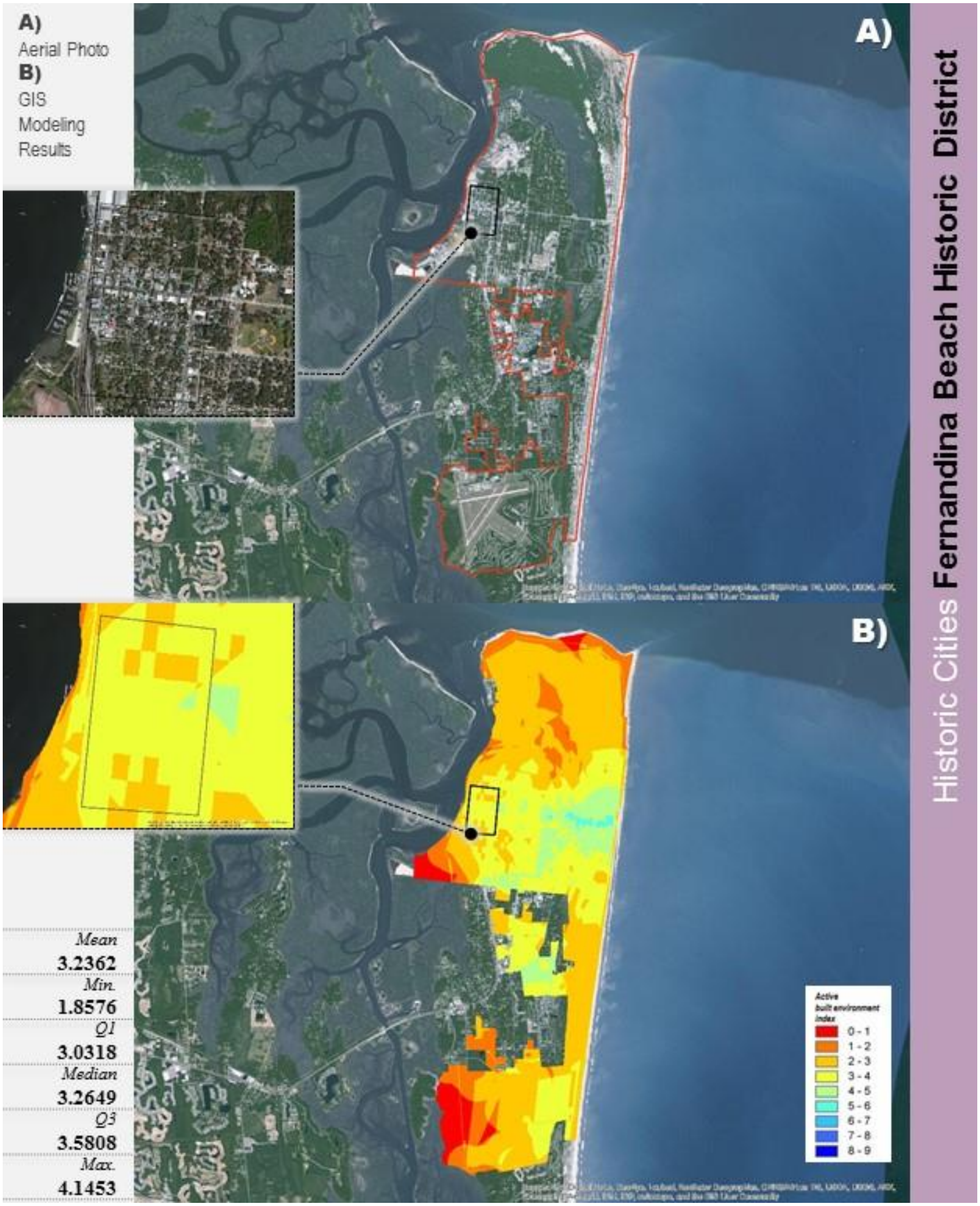

Figure 4-35. GIS Modeling Results of Fernandina Beach Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

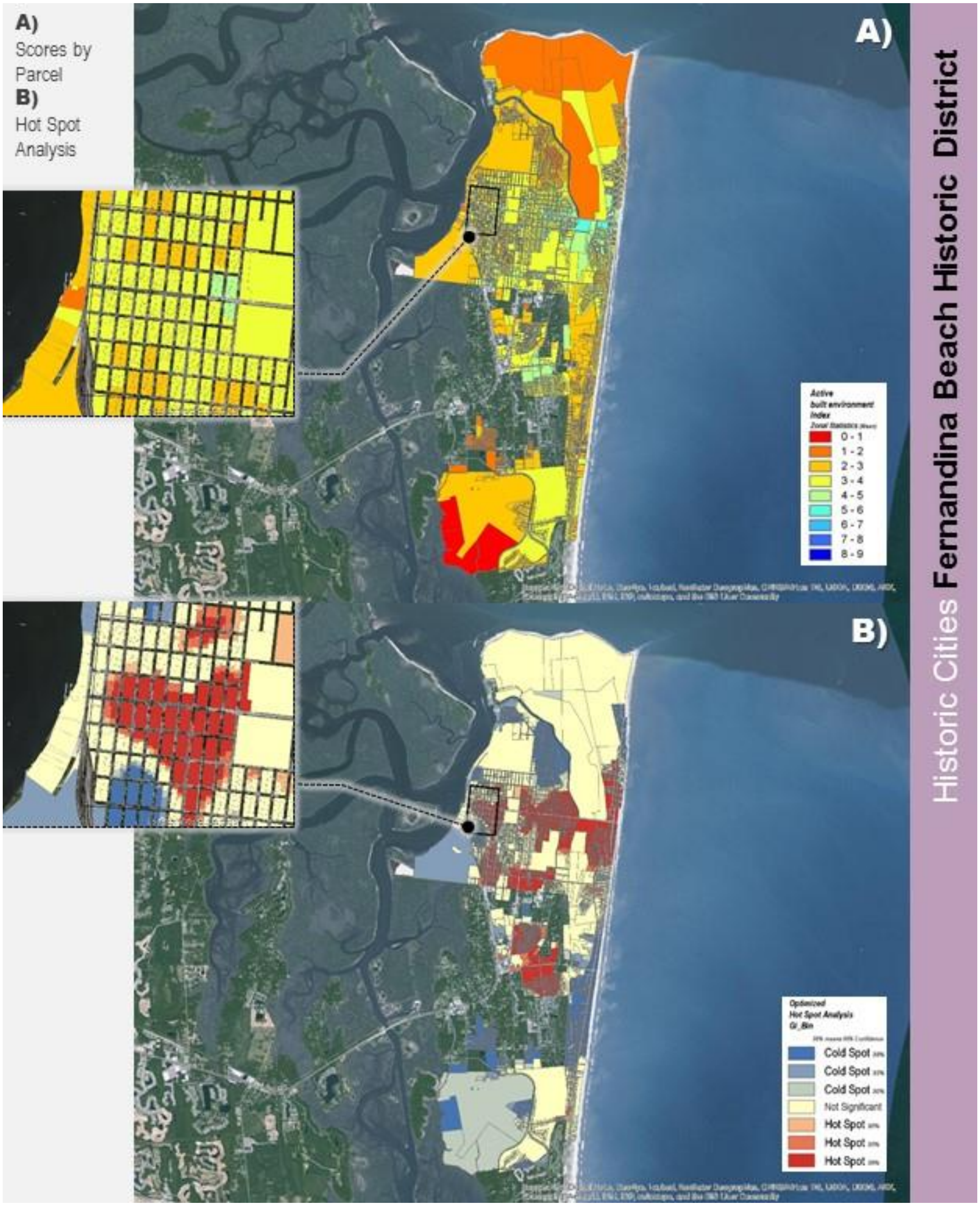

Figure 4-36. Scores by Parcel and Hot Spot Analysis of Fernandina Beach Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

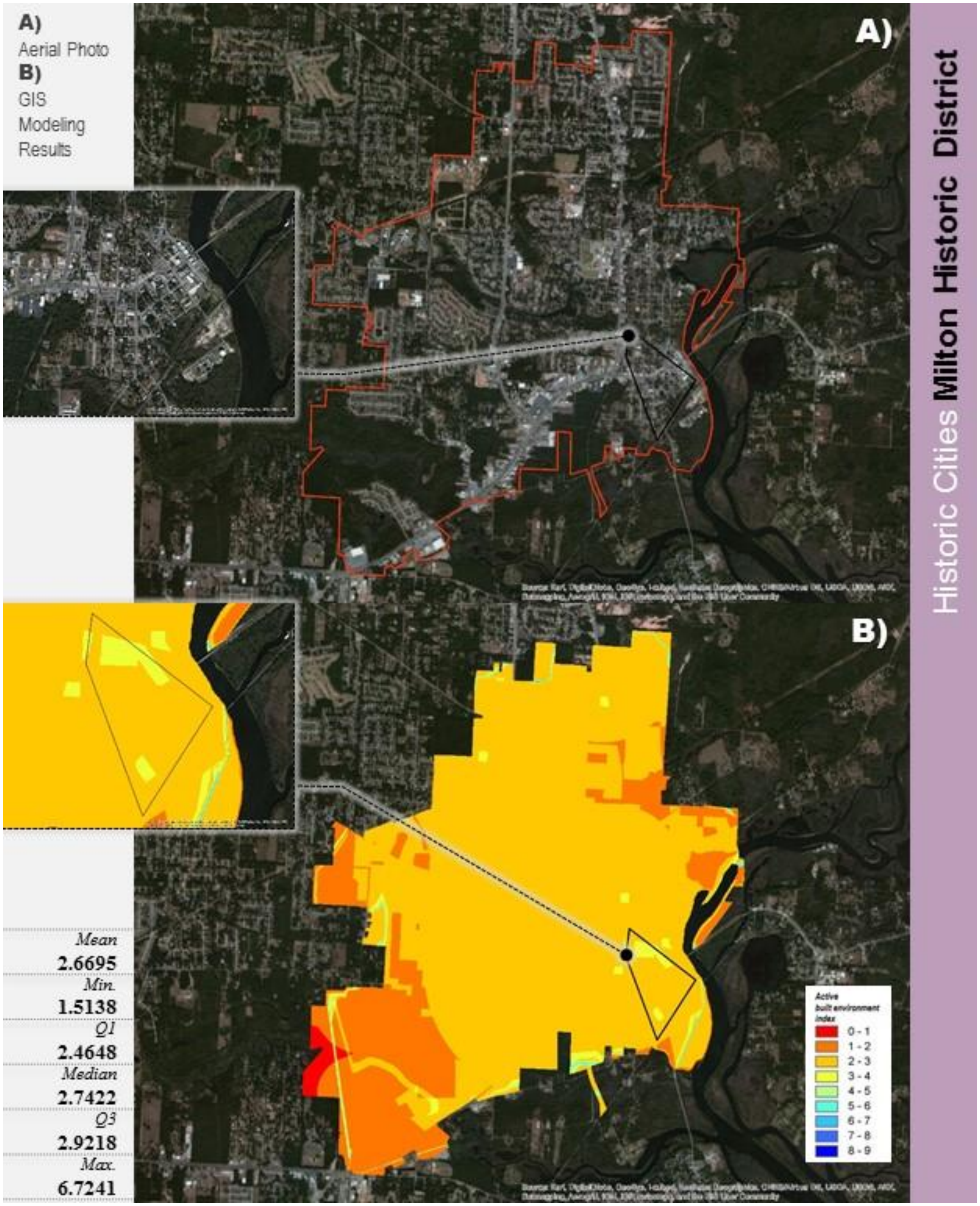

Figure 4-37. GIS Modeling Results of Milton Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

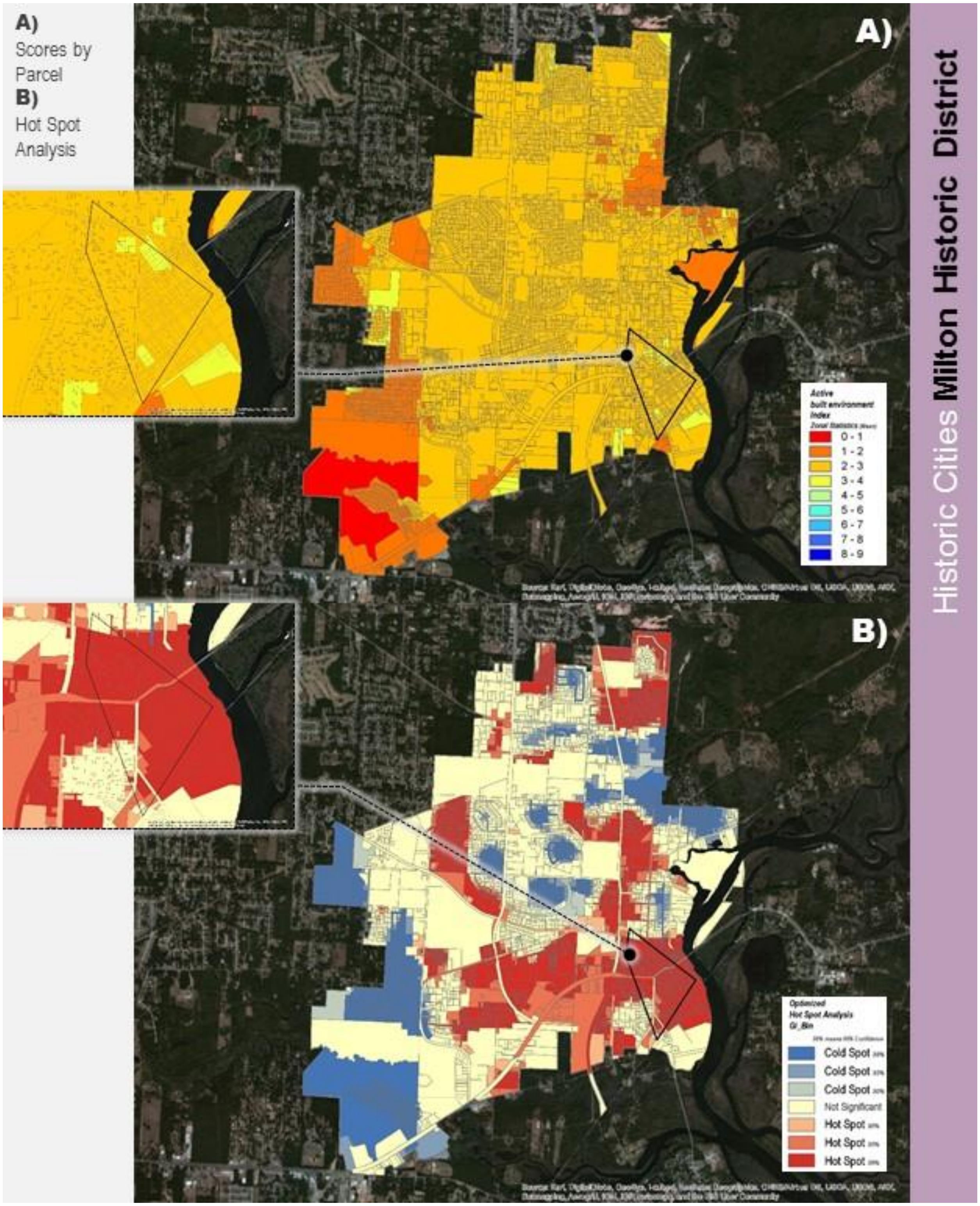

Figure 4-38. Scores by Parcel and Hot Spot Analysis of Milton Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

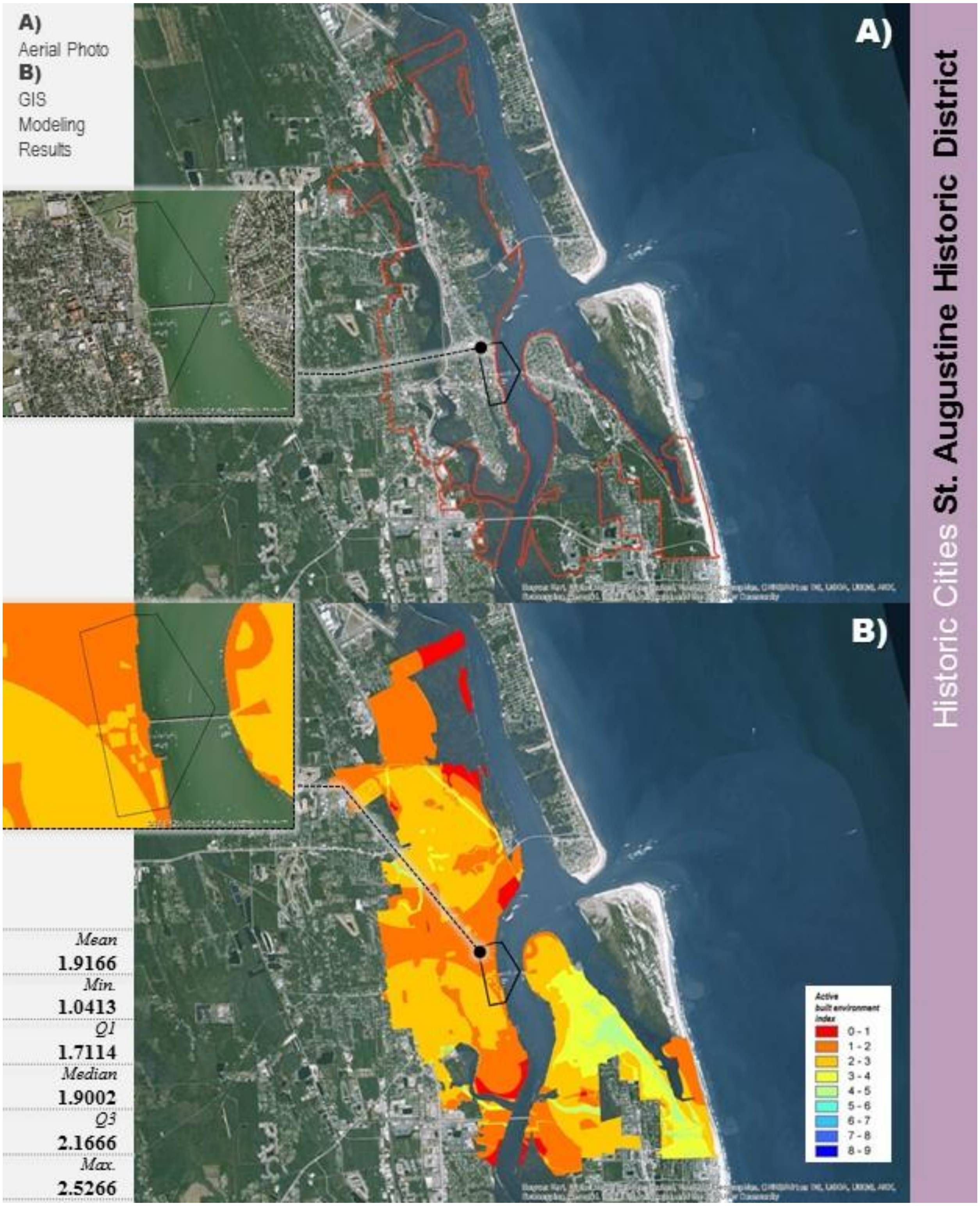

Figure 4-39. GIS Modeling Results of St. Augustine Historic District. A) Aerial Photo. B) GIS Suitability Modeling Results.

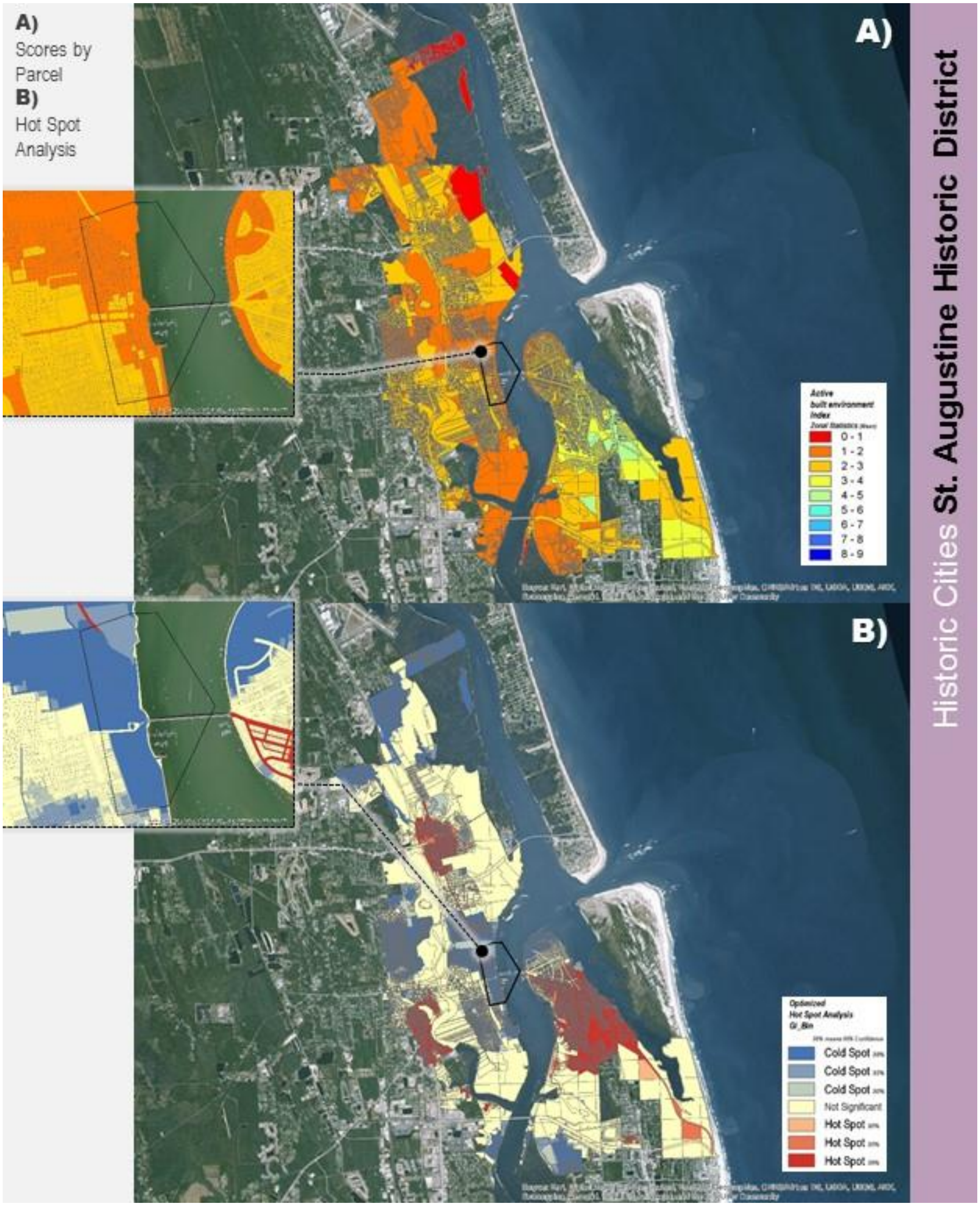

Figure 4-40. Scores by Parcel and Hot Spot Analysis of St. Augustine Historic District. A) Zonal Statistics. B) Hot Spot Analysis.

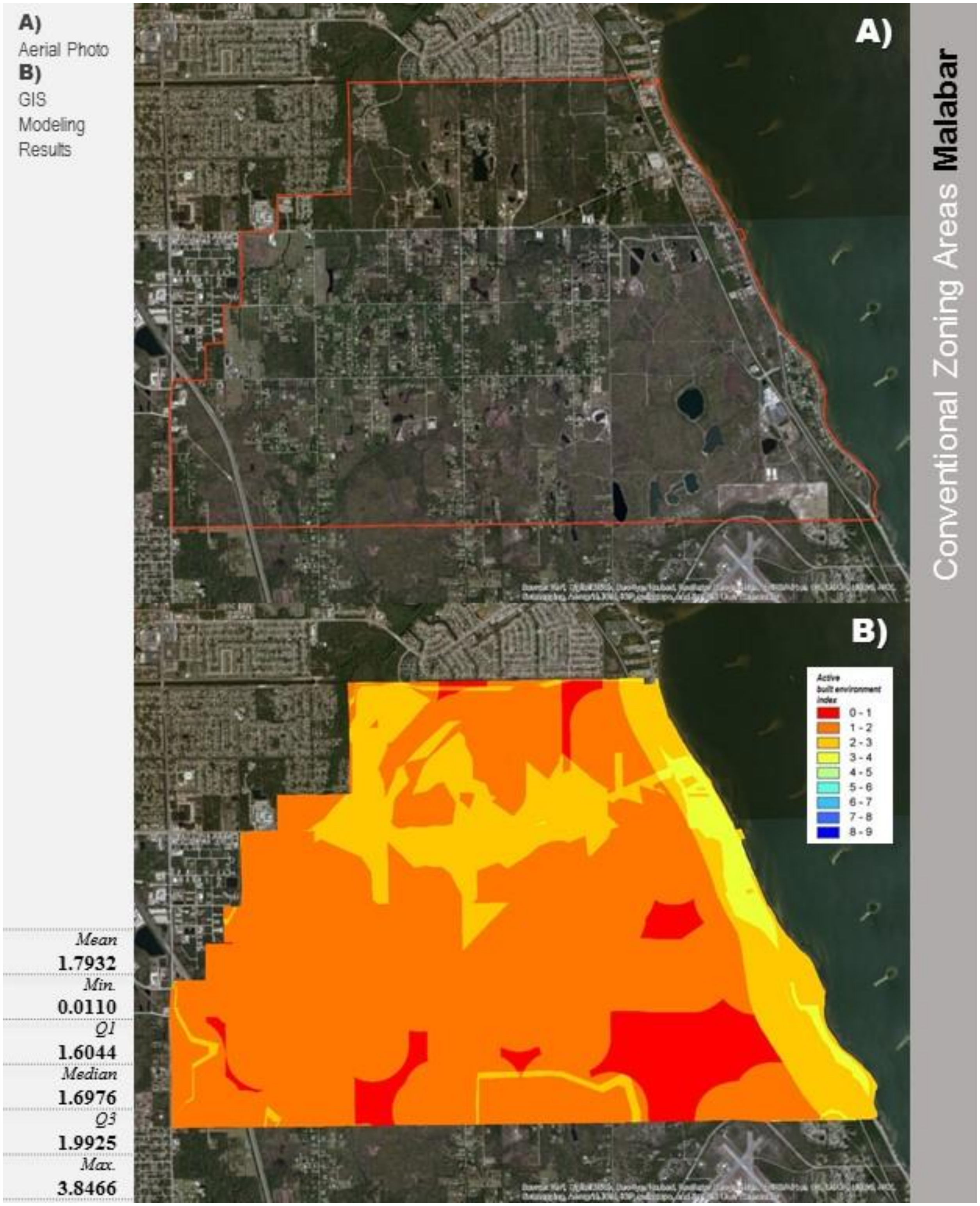

Figure 4-41. GIS Modeling Results of Malabar. A) Aerial Photo. B) GIS Suitability Modeling Results.

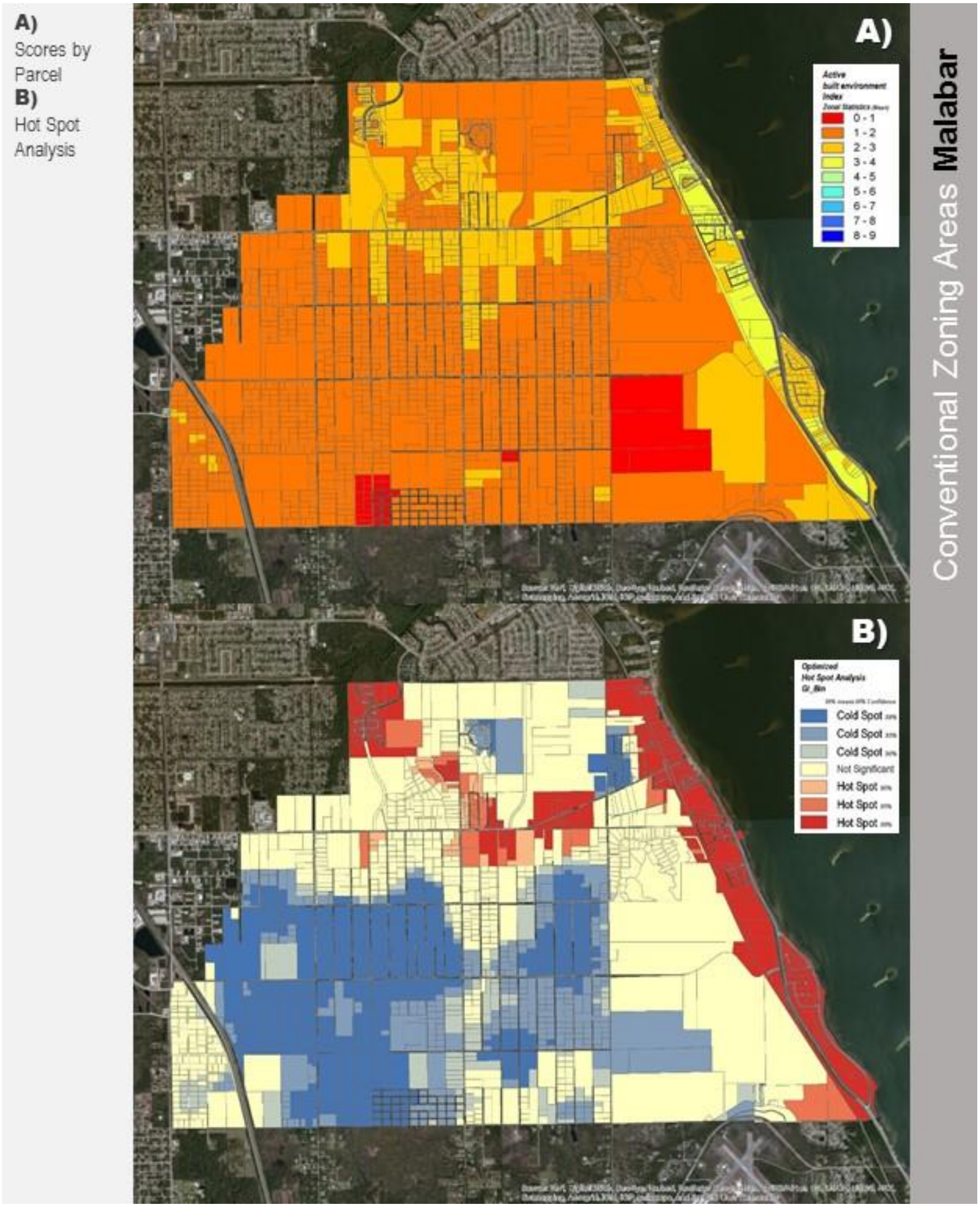

Figure 4-42. Scores by Parcel and Hot Spot Analysis of Malabar. A) Zonal Statistics. B) Hot Spot Analysis.

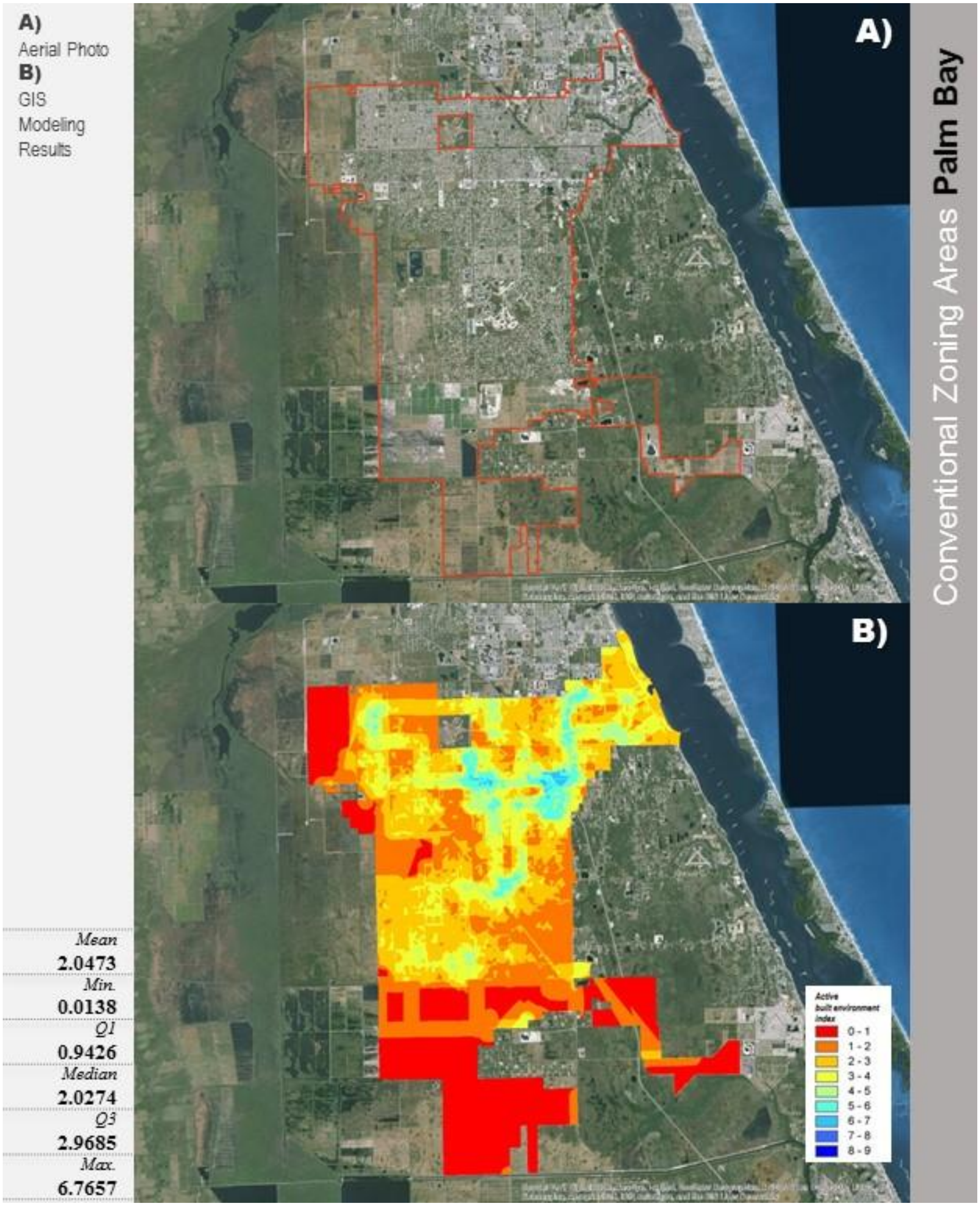

Figure 4-43. GIS Modeling Results of Palm Bay. A) Aerial Photo. B) GIS Suitability Modeling Results.

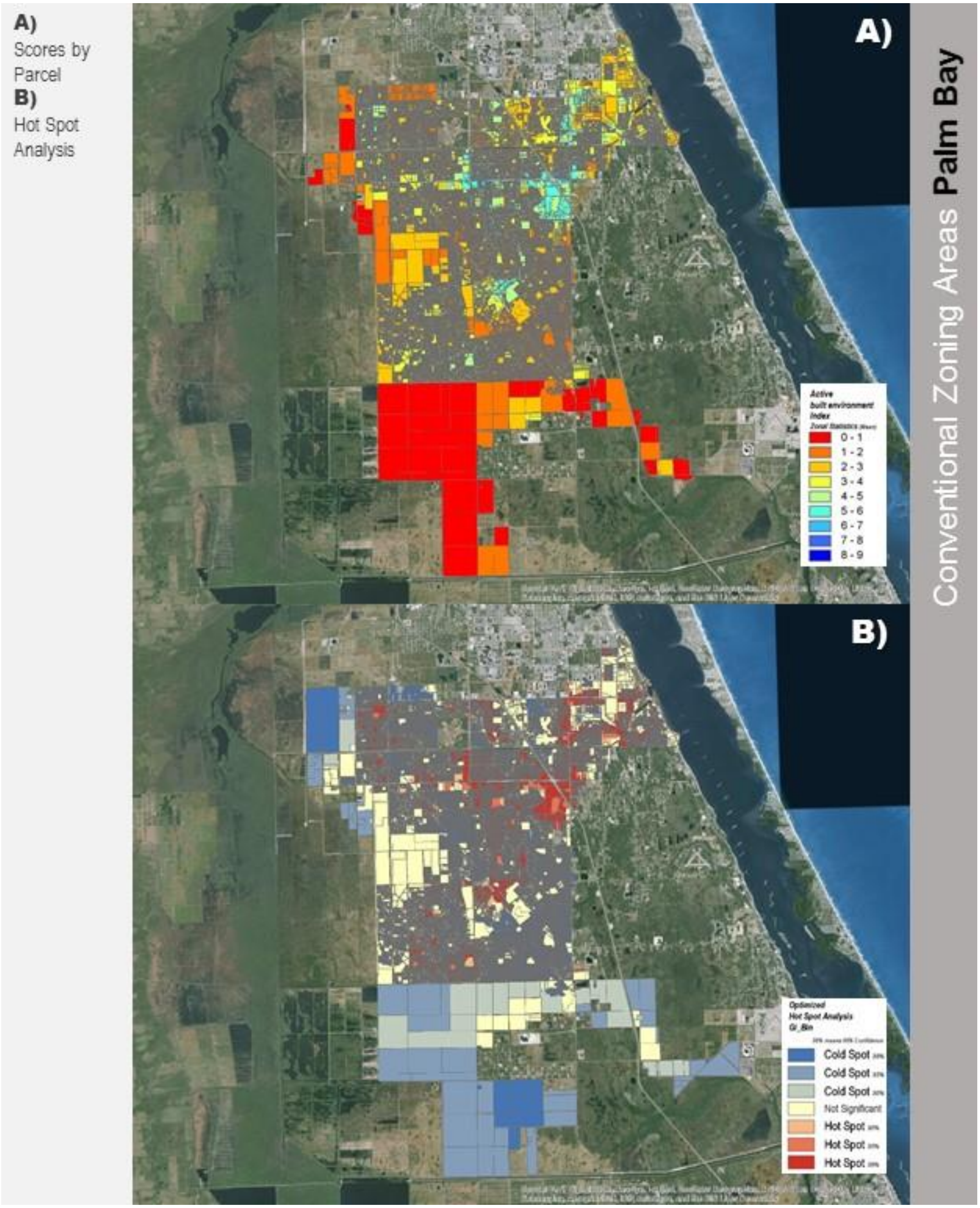

Figure 4-44. Scores by Parcel and Hot Spot Analysis of Palm Bay. A) Zonal Statistics.
B) Hot Spot Analysis.

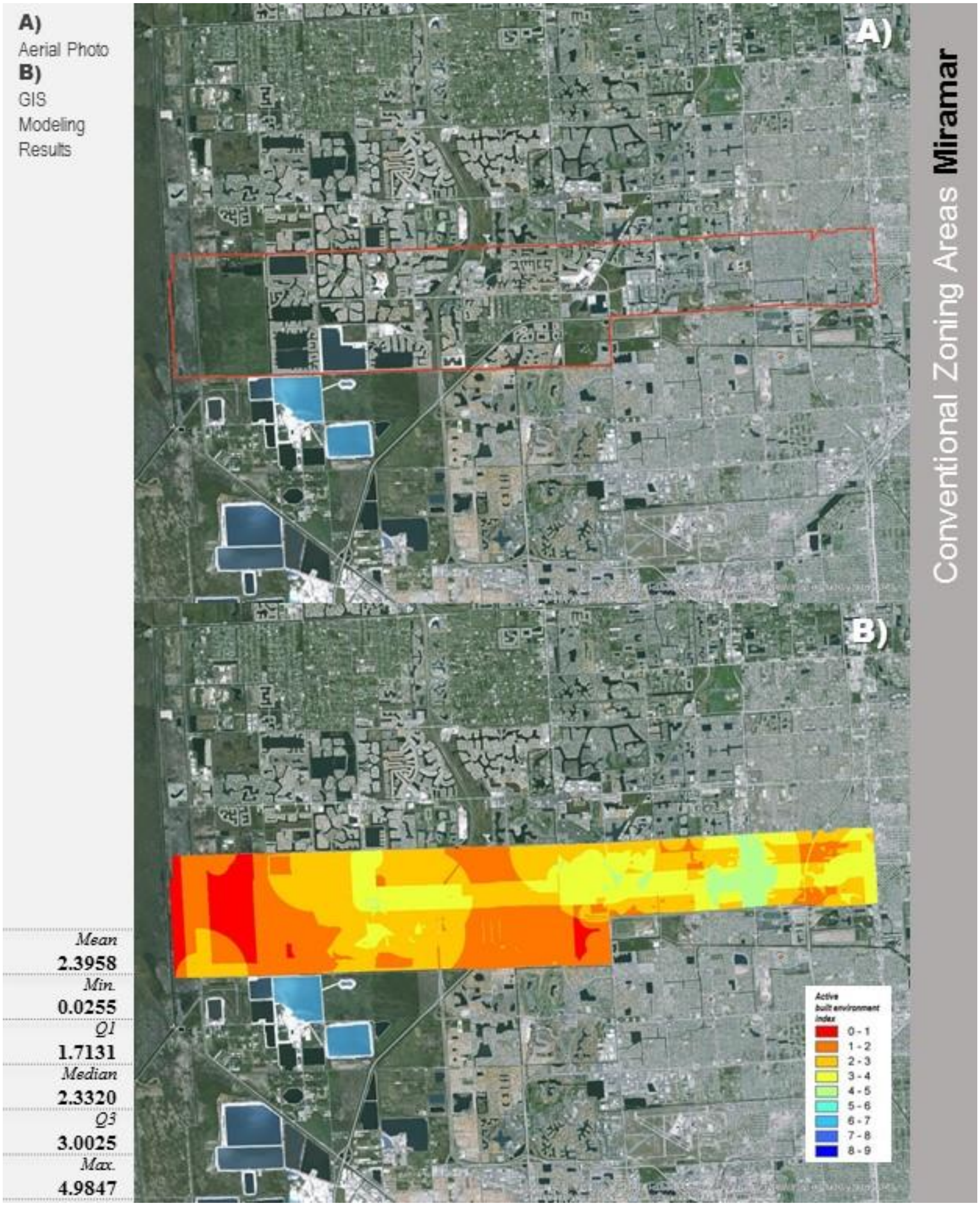

Figure 4-45. GIS Modeling Results of Miramar. A) Aerial Photo. B) GIS Suitability Modeling Results.

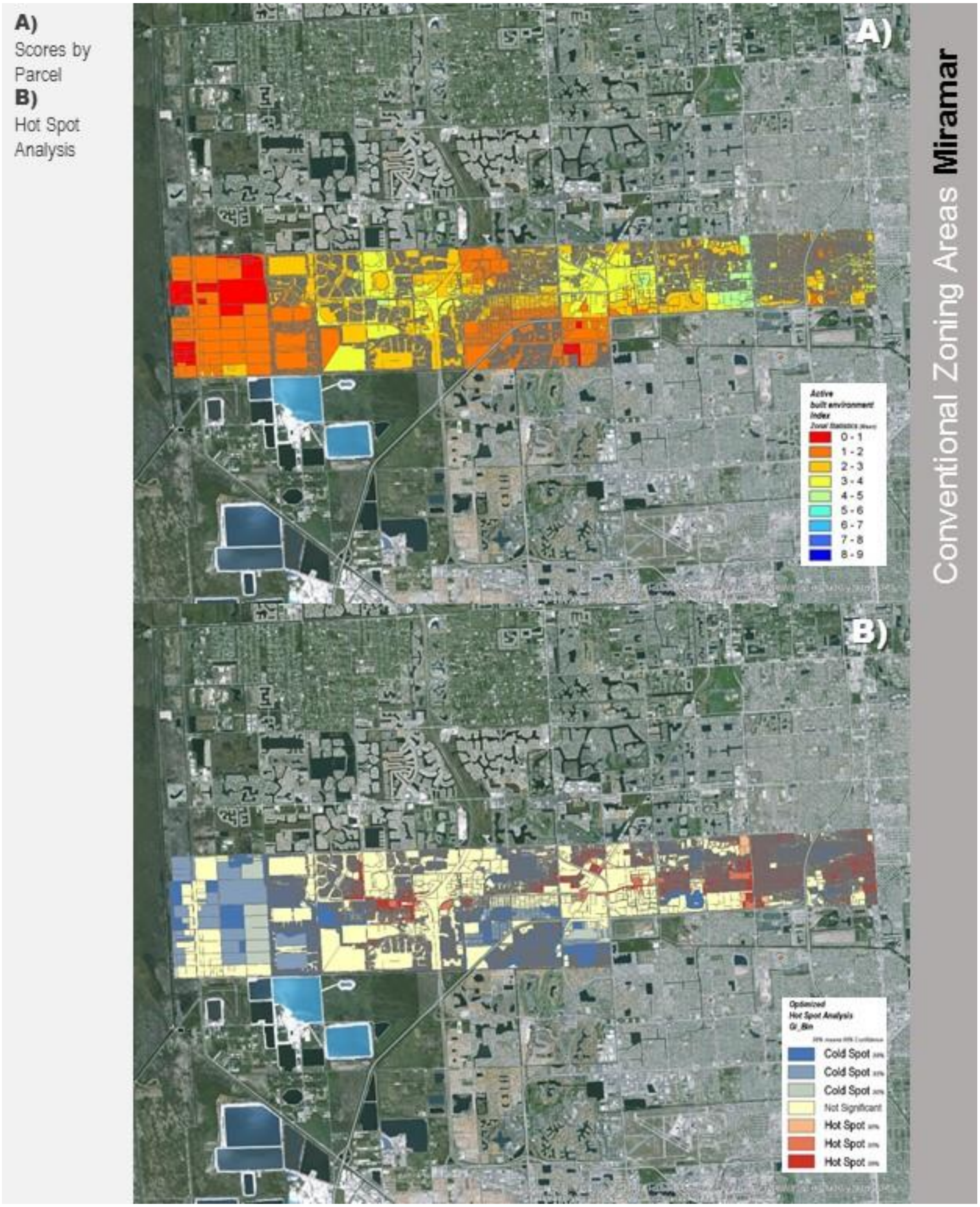

Figure 4-46. Scores by Parcel and Hot Spot Analysis of Miramar. A) Zonal Statistics. B) Hot Spot Analysis.

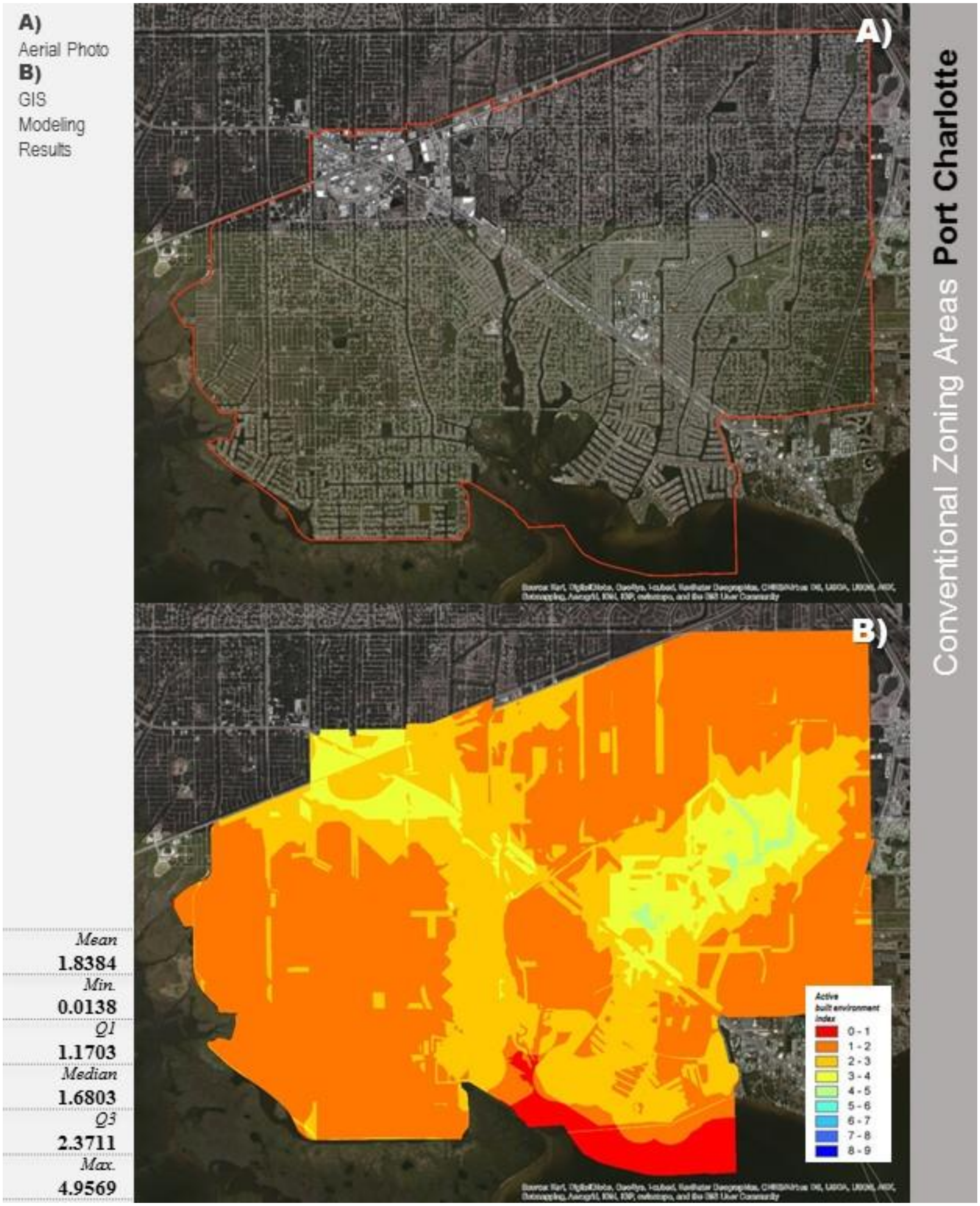

Figure 4-47. GIS Modeling Results of Port Charlotte. A) Aerial Photo. B) GIS Suitability Modeling Results.

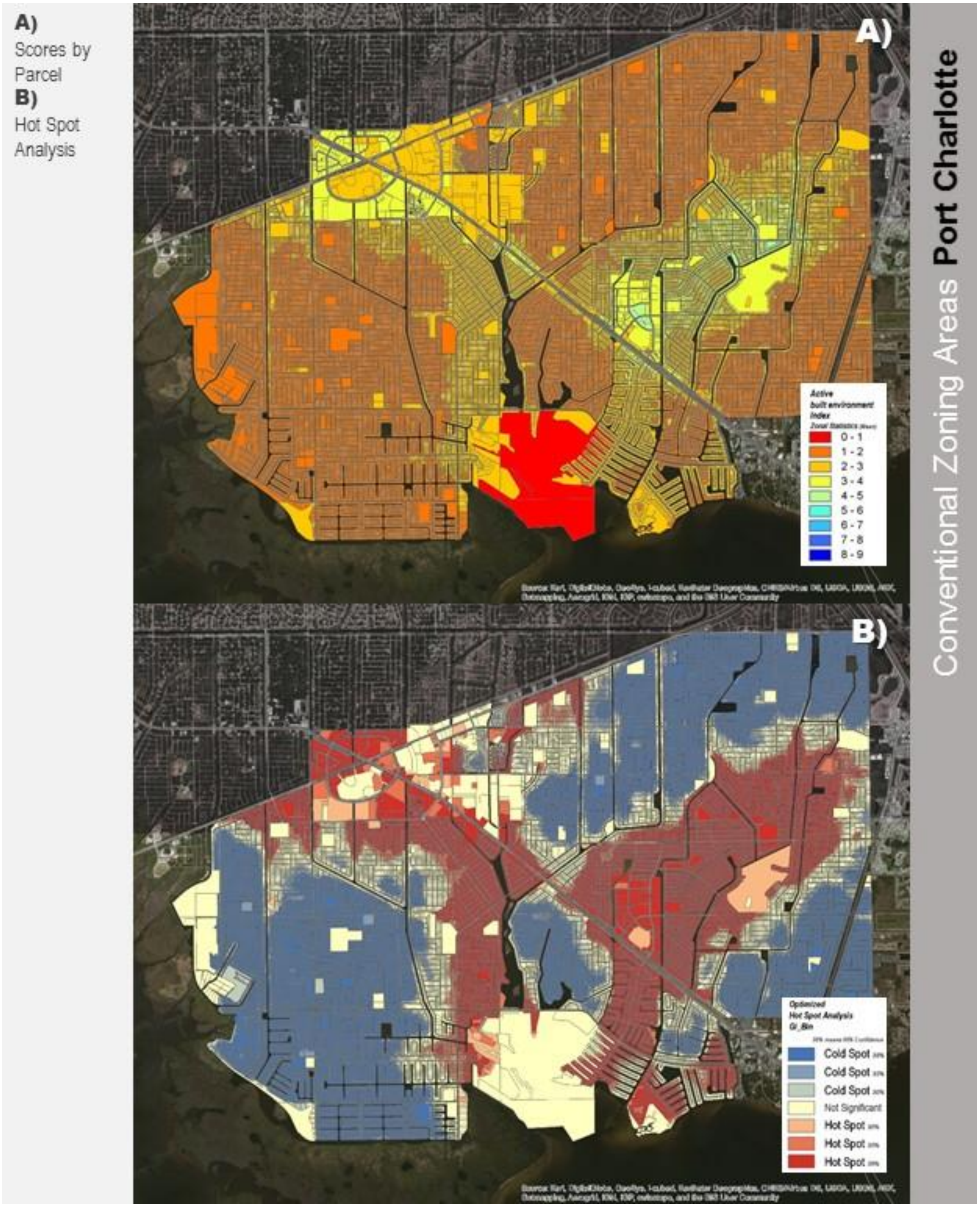

Figure 4-48. Scores by Parcel and Hot Spot Analysis of Port Charlotte. A) Zonal Statistics. B) Hot Spot Analysis.

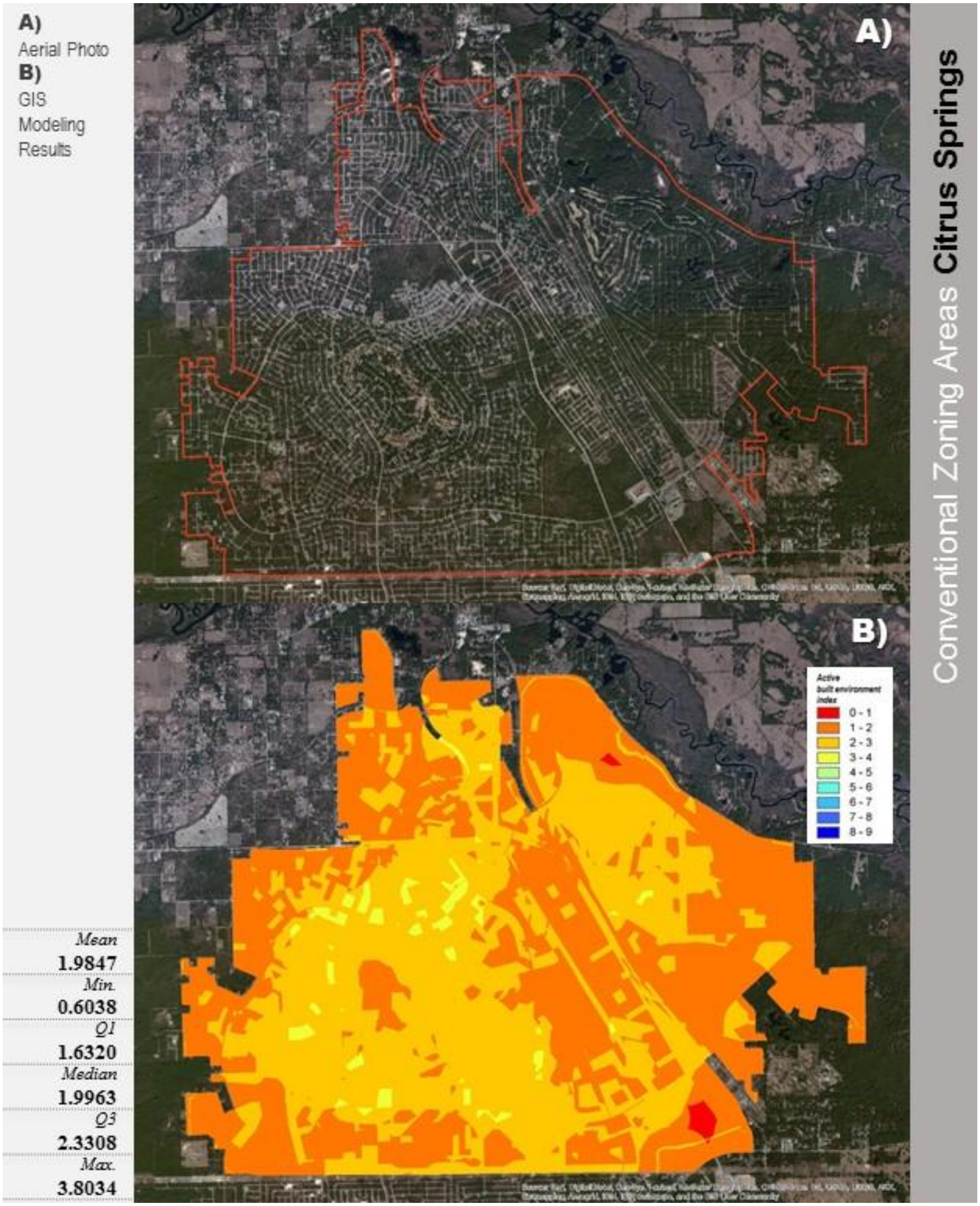

Figure 4-49. GIS Modeling Results of Citrus Springs. A) Aerial Photo. B) GIS Suitability Modeling Results.

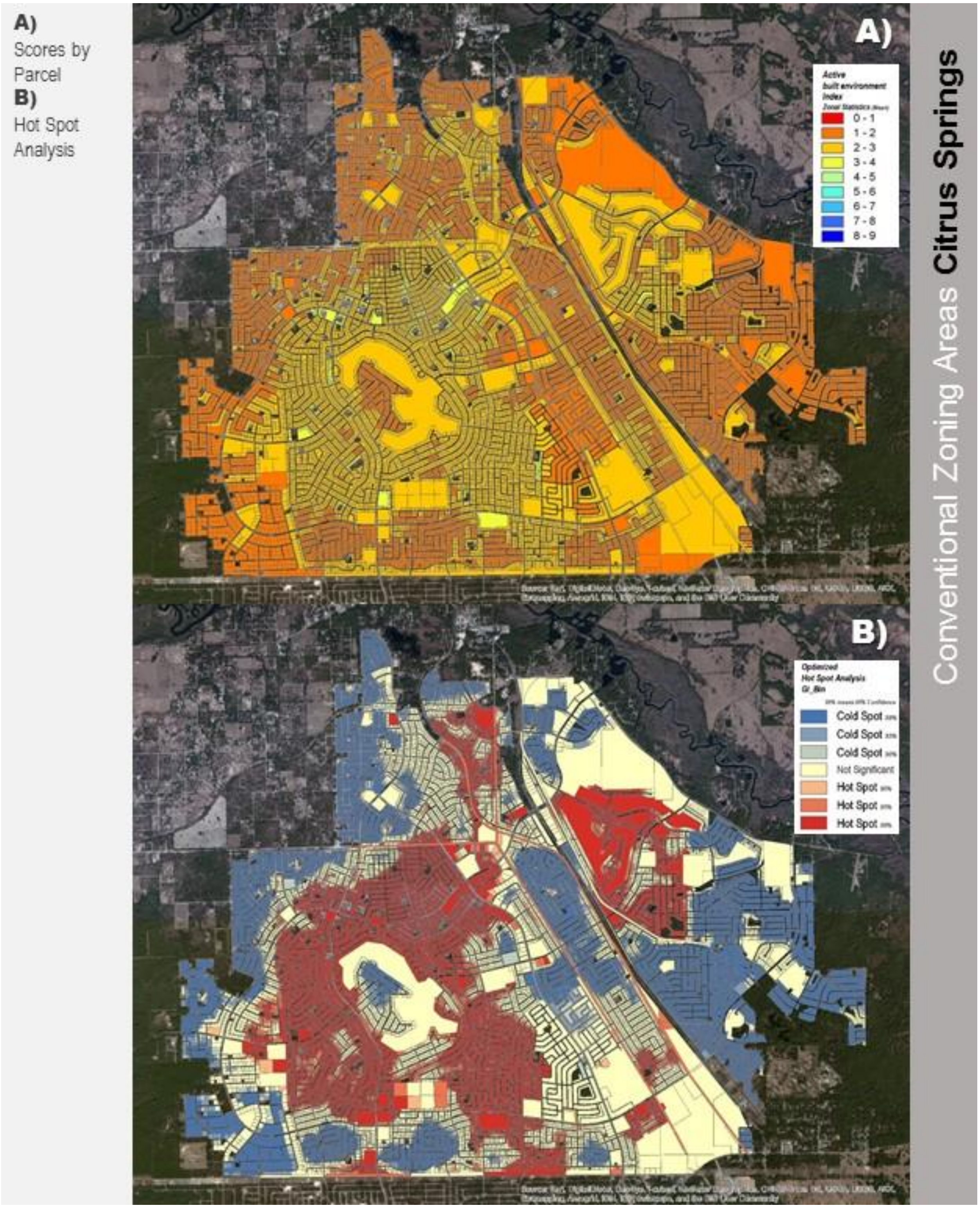

Figure 4-50. Scores by Parcel and Hot Spot Analysis of Citrus Springs. A) Zonal Statistics. B) Hot Spot Analysis.

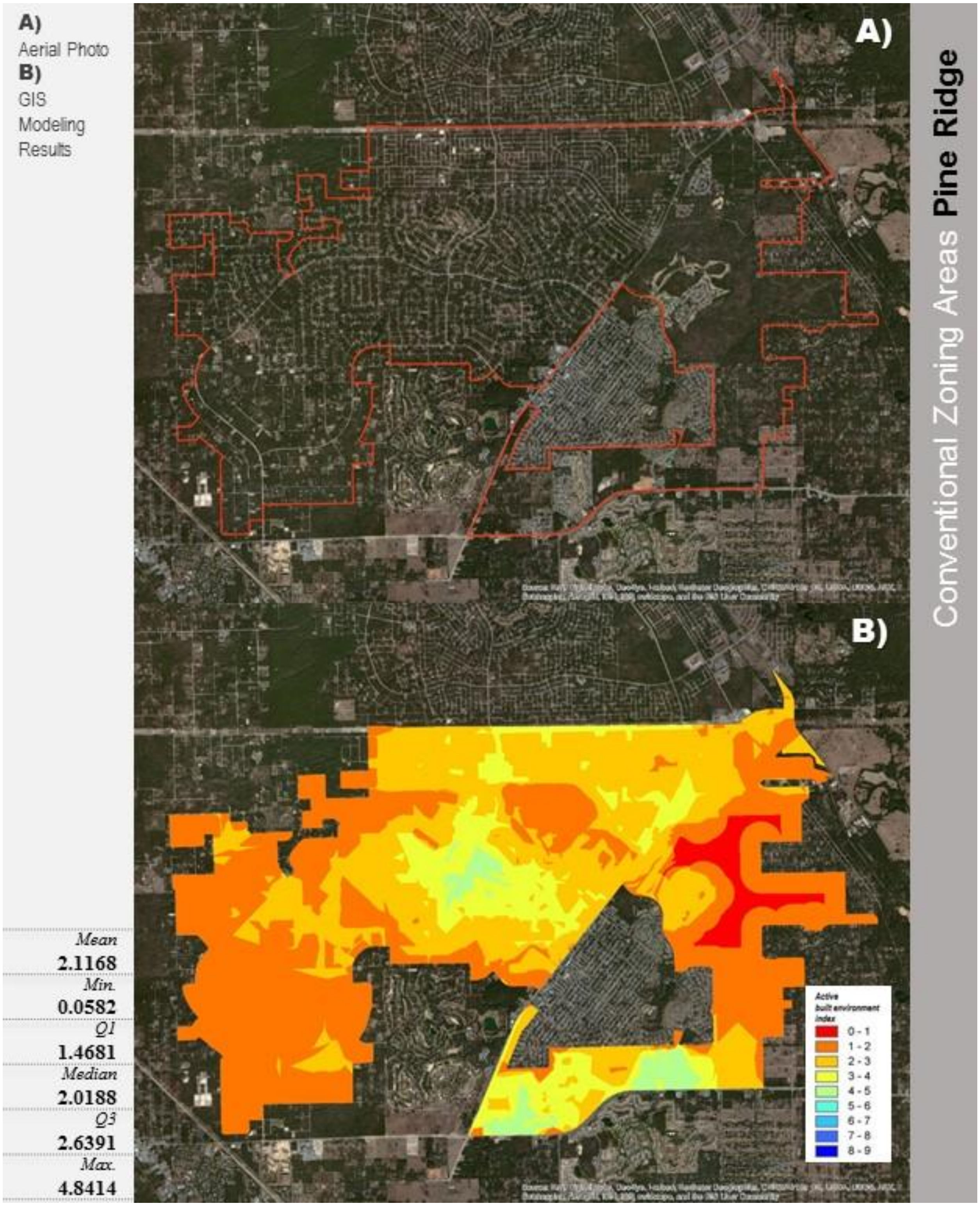

Figure 4-51. GIS Modeling Results of Pine Ridge. A) Aerial Photo. B) GIS Suitability Modeling Results.

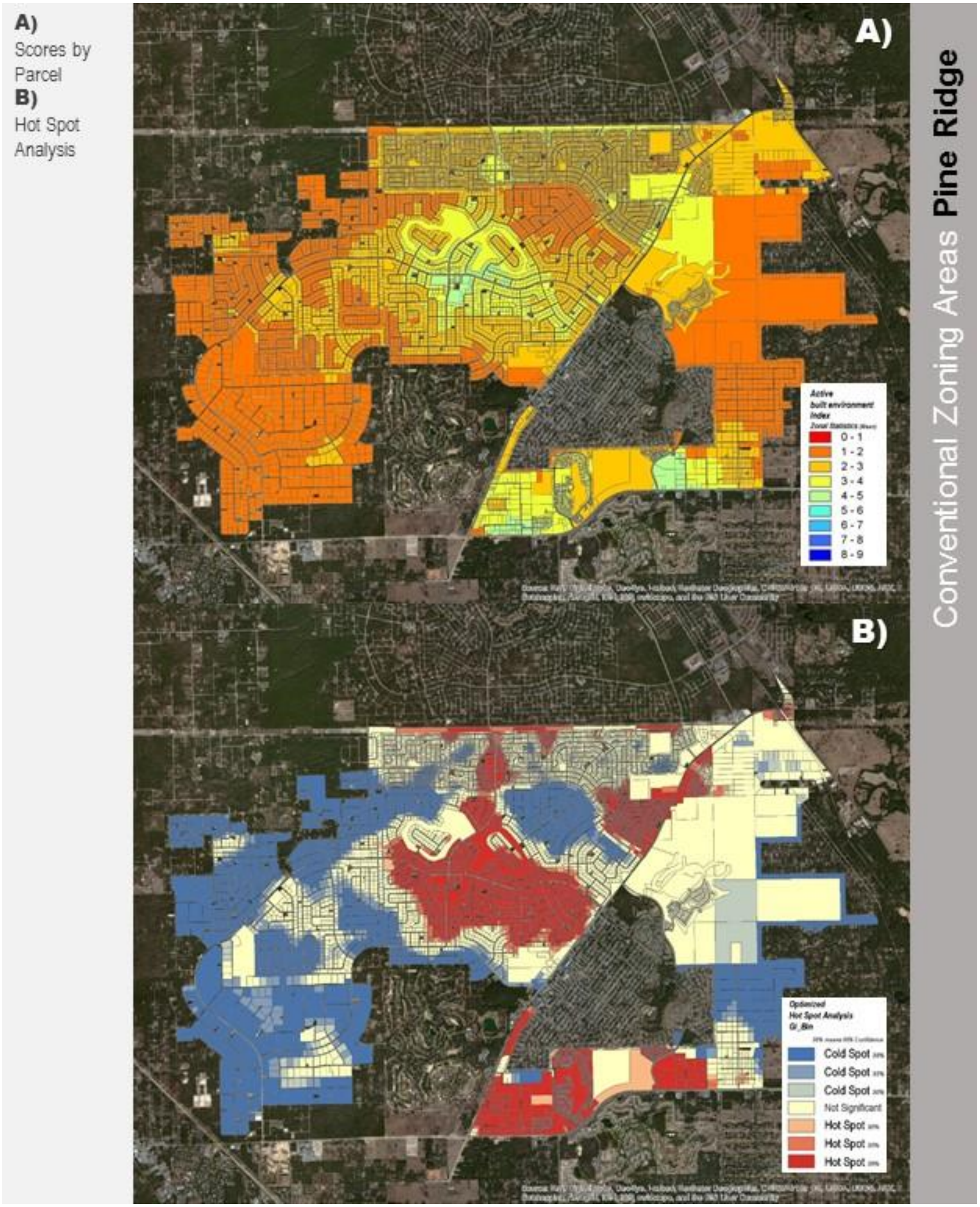

Figure 4-52. Scores by Parcel and Hot Spot Analysis of Pine Ridge. A) Zonal Statistics. B) Hot Spot Analysis.

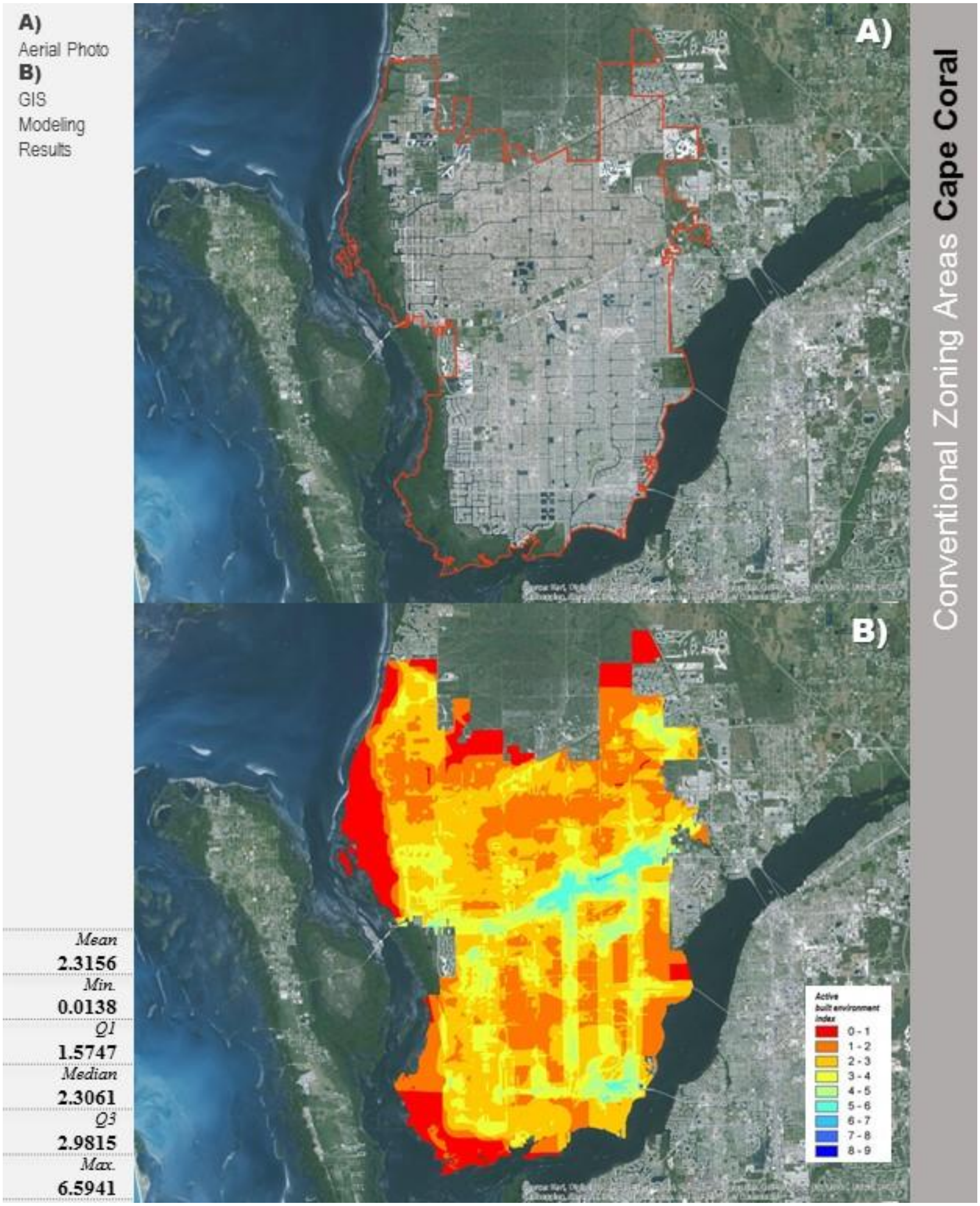

Figure 4-53. GIS Modeling Results of Cape Coral. A) Aerial Photo. B) GIS Suitability Modeling Results.

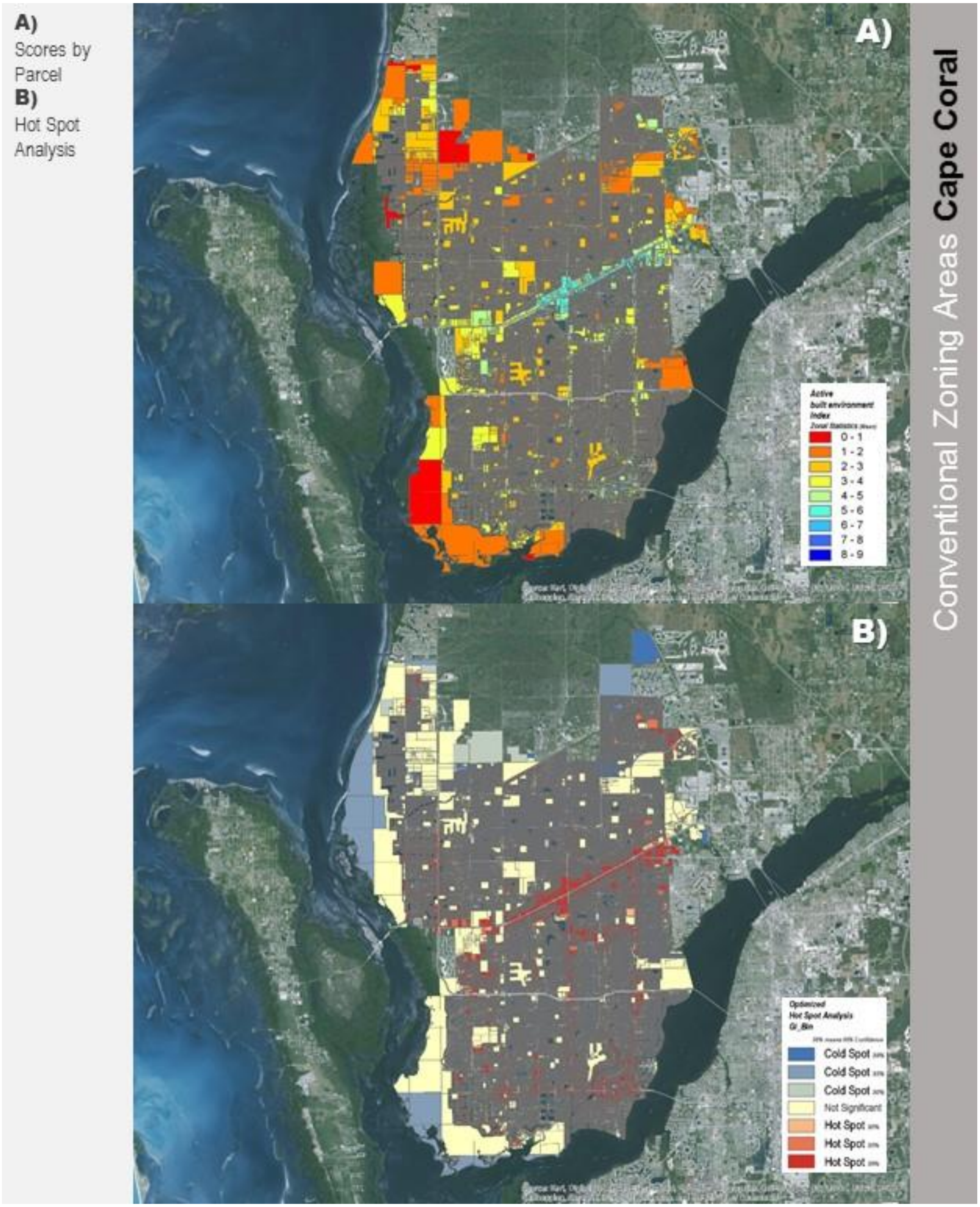

Figure 4-54. Scores by Parcel and Hot Spot Analysis of Cape Coral. A) Zonal Statistics. B) Hot Spot Analysis.

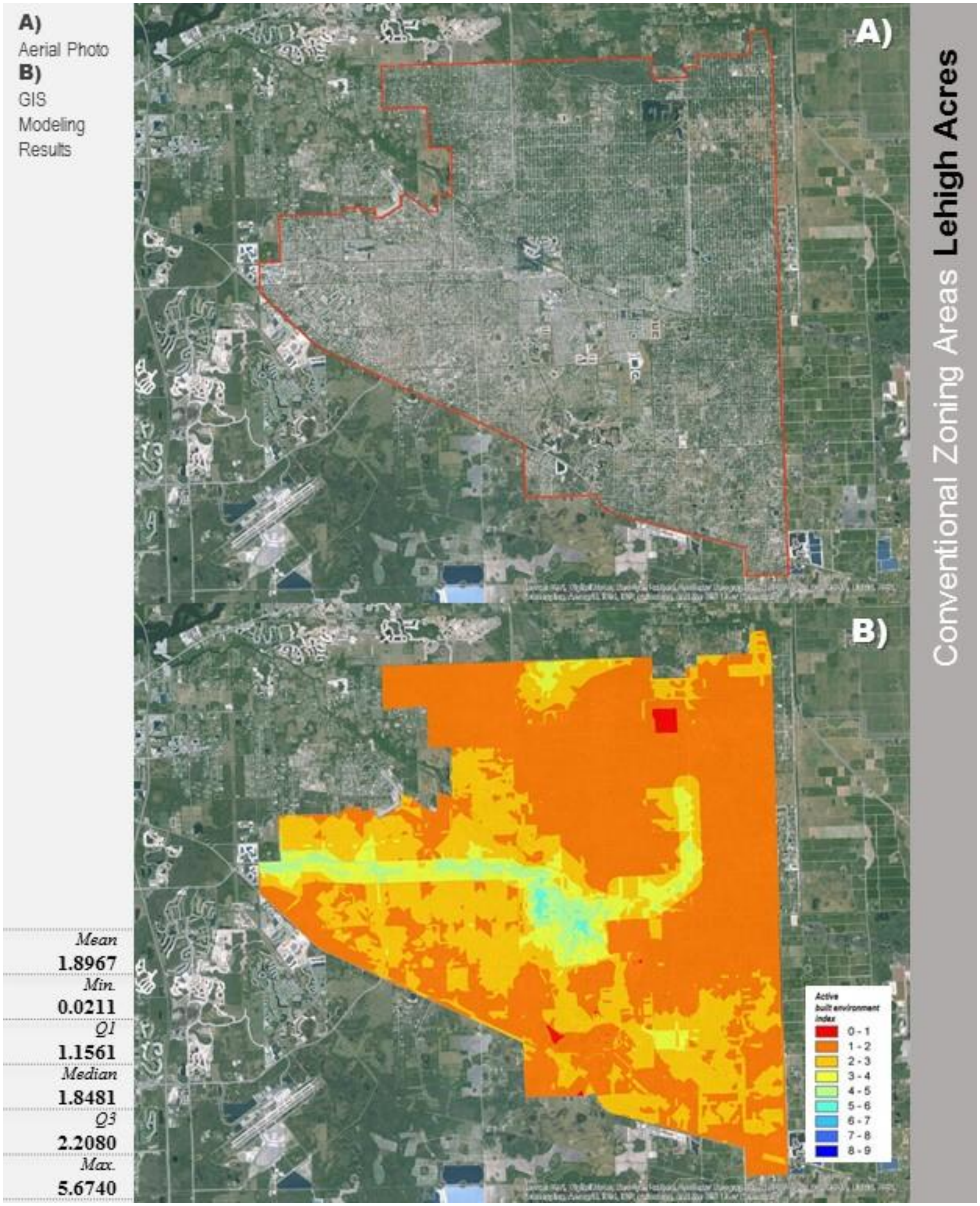

Figure 4-55. GIS Modeling Results of Lehigh Acres. A) Aerial Photo. B) GIS Suitability Modeling Results.

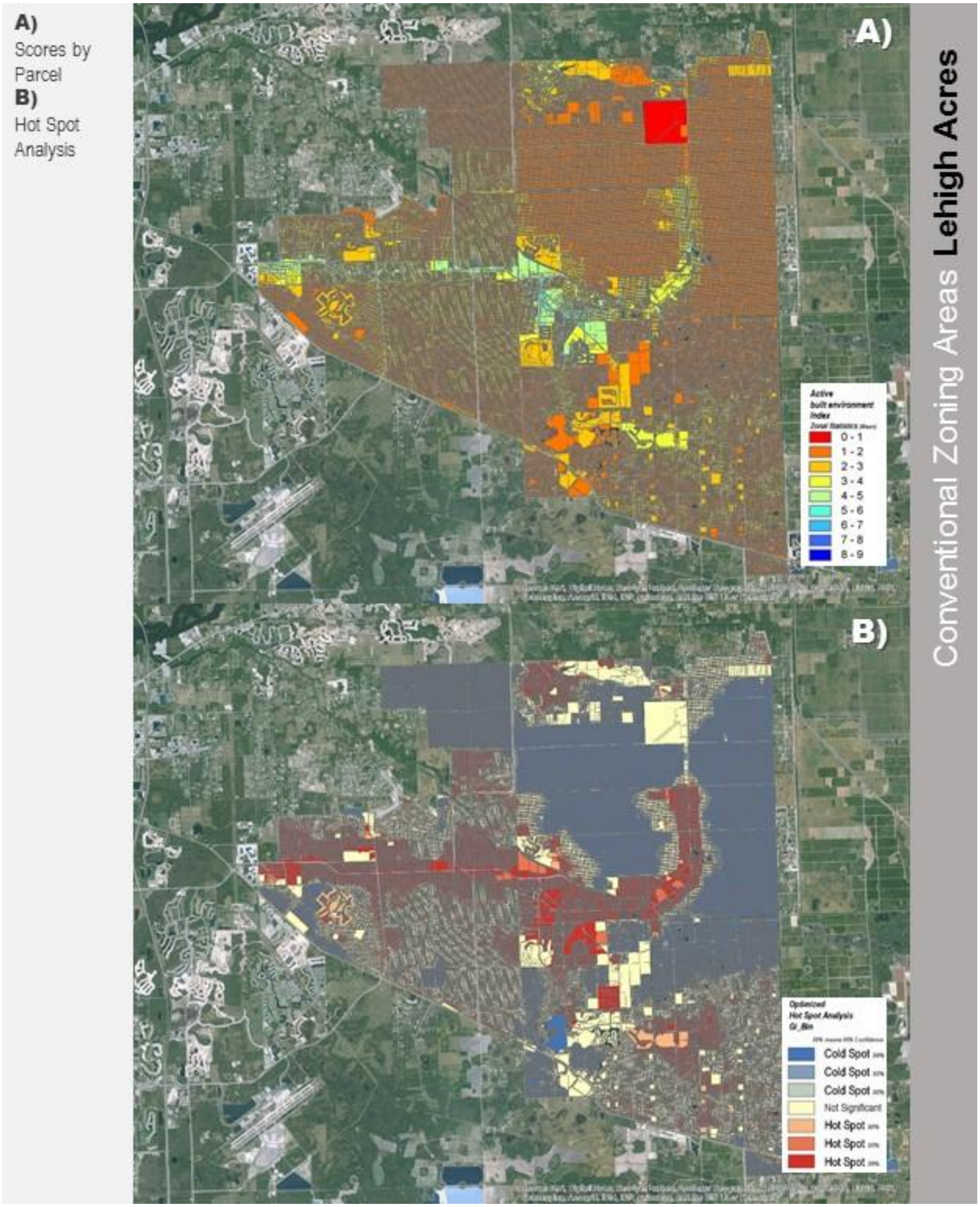

Figure 4-56. Scores by Parcel and Hot Spot Analysis of Lehigh Acres. A) Zonal Statistics. B) Hot Spot Analysis.

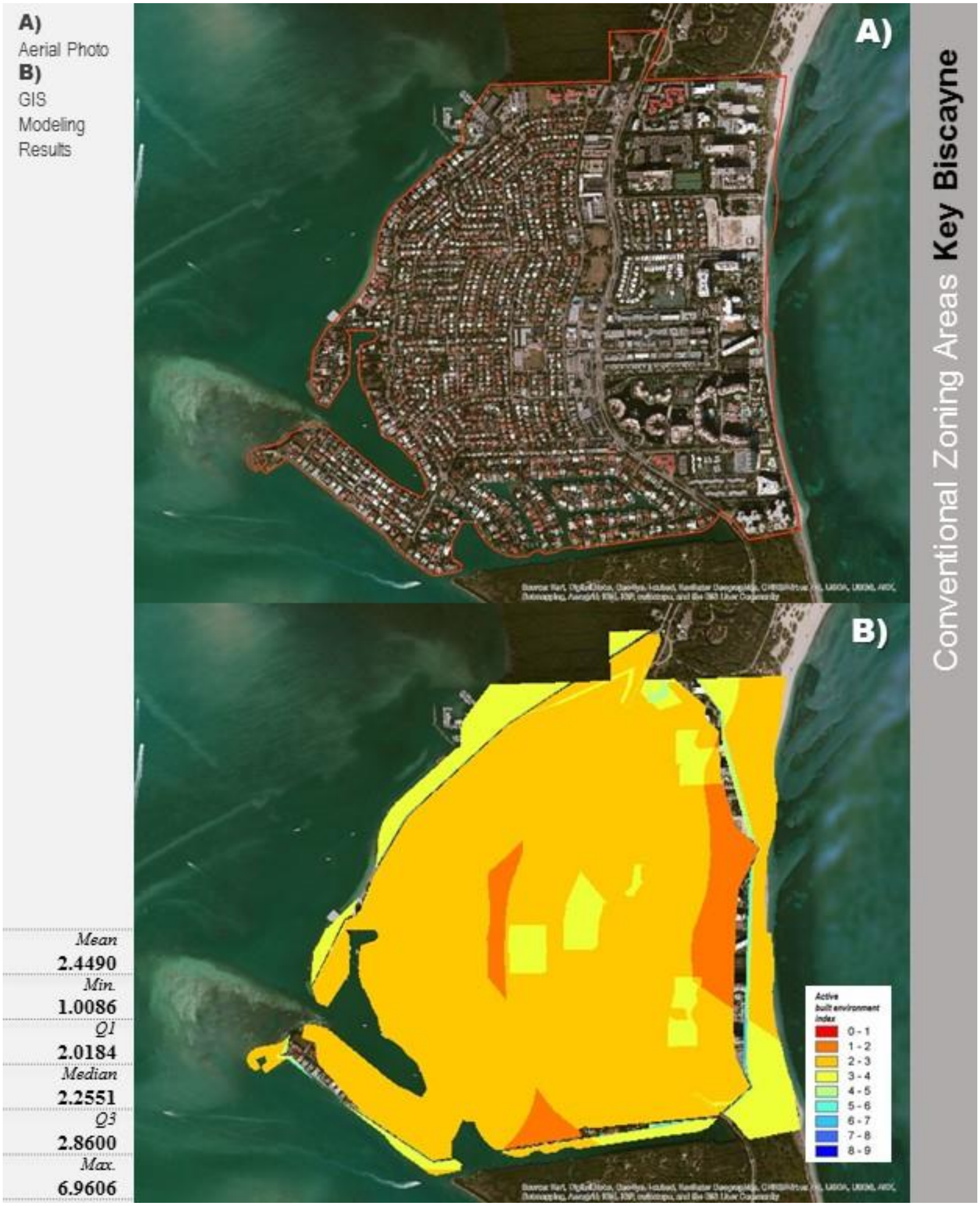

Figure 4-57. GIS Modeling Results of Key Biscayne. A) Aerial Photo. B) GIS Suitability Modeling Results.

Figure 4-58. Scores by Parcel and Hot Spot Analysis of Key Biscayne. A) Zonal Statistics. B) Hot Spot Analysis.

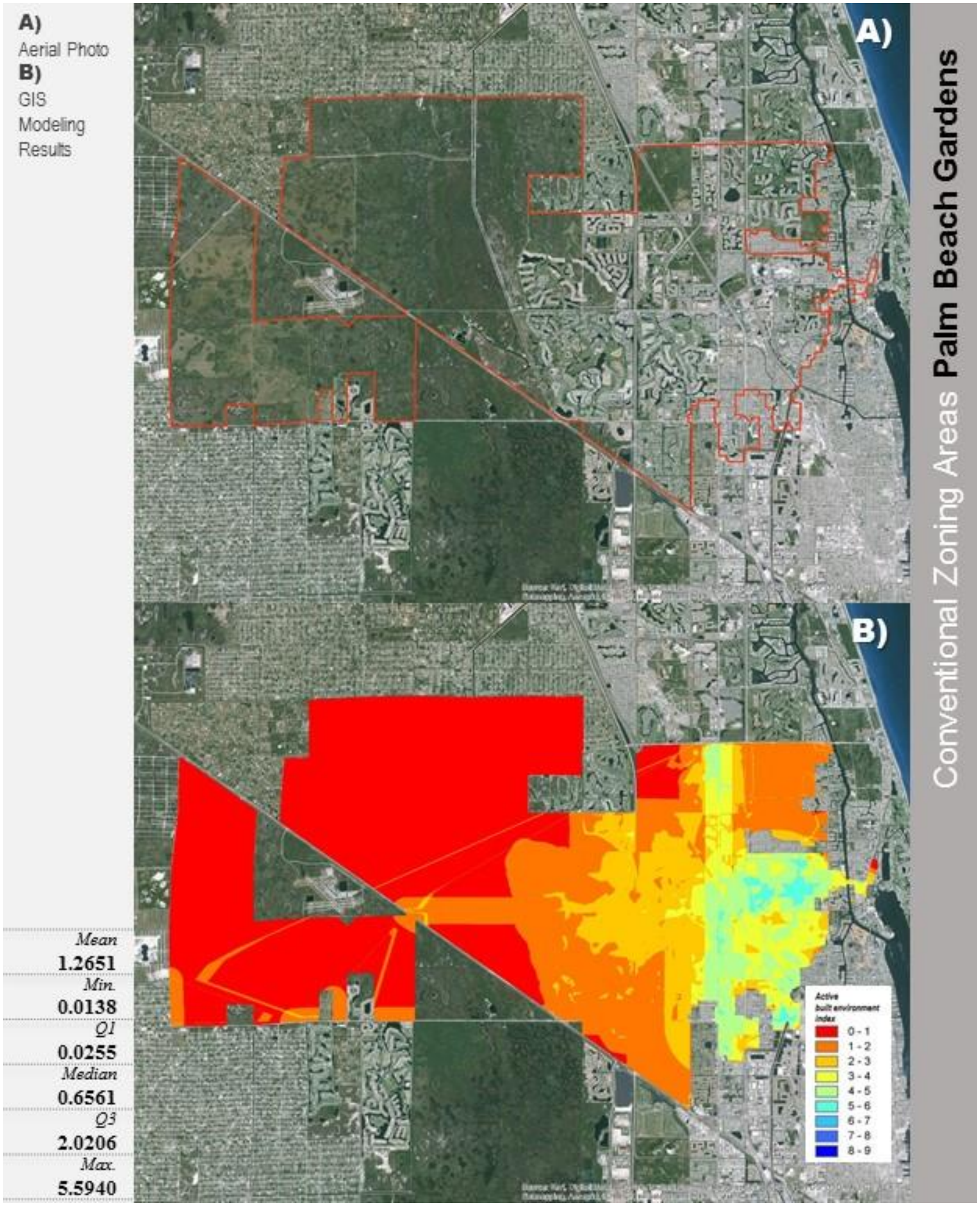

Figure 4-59. GIS Modeling Results of Palm Beach Gardens. A) Aerial Photo. B) GIS Suitability Modeling Results.

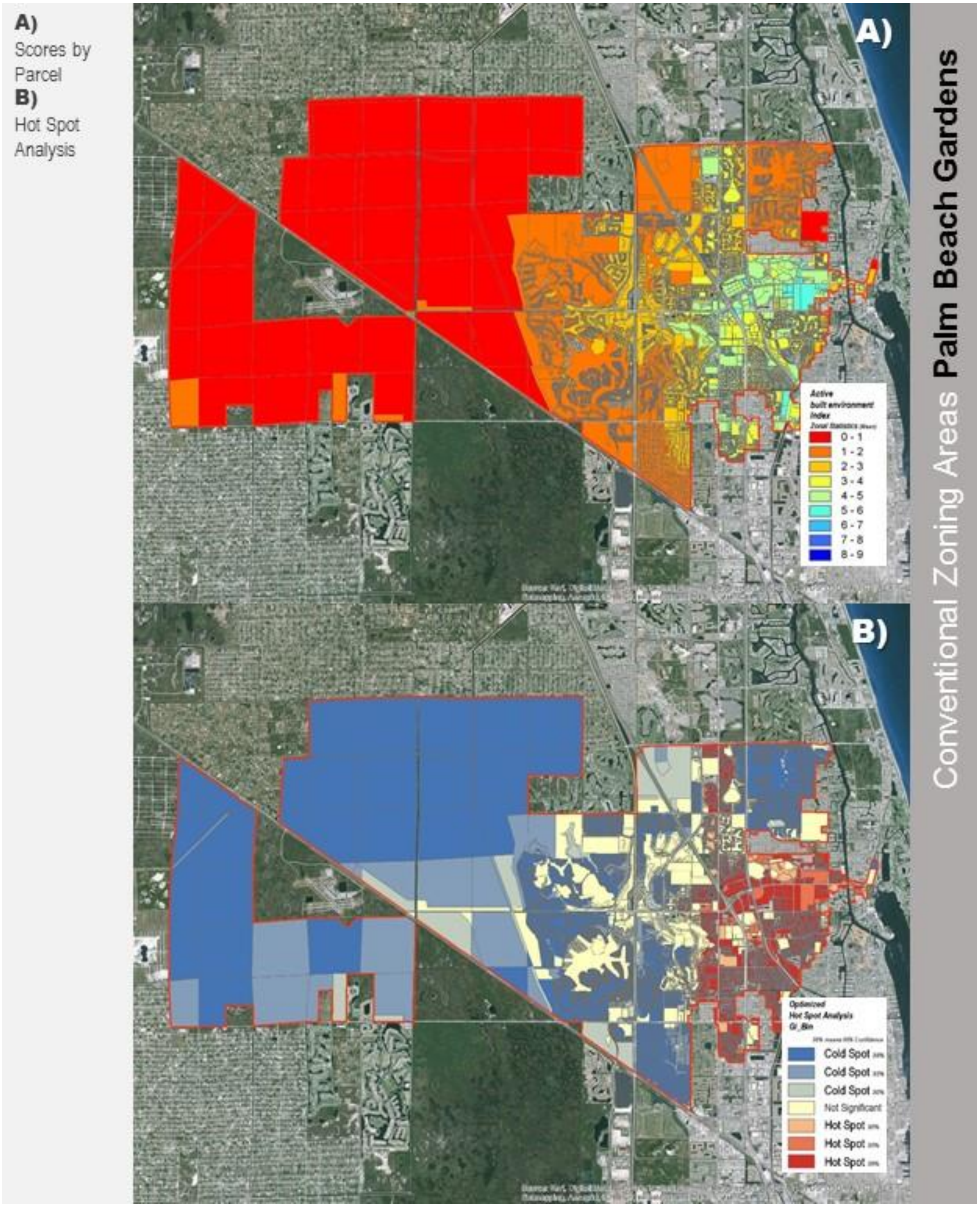

Figure 4-60. Scores by Parcel and Hot Spot Analysis of Palm Beach Gardens. A) Zonal Statistics. B) Hot Spot Analysis.

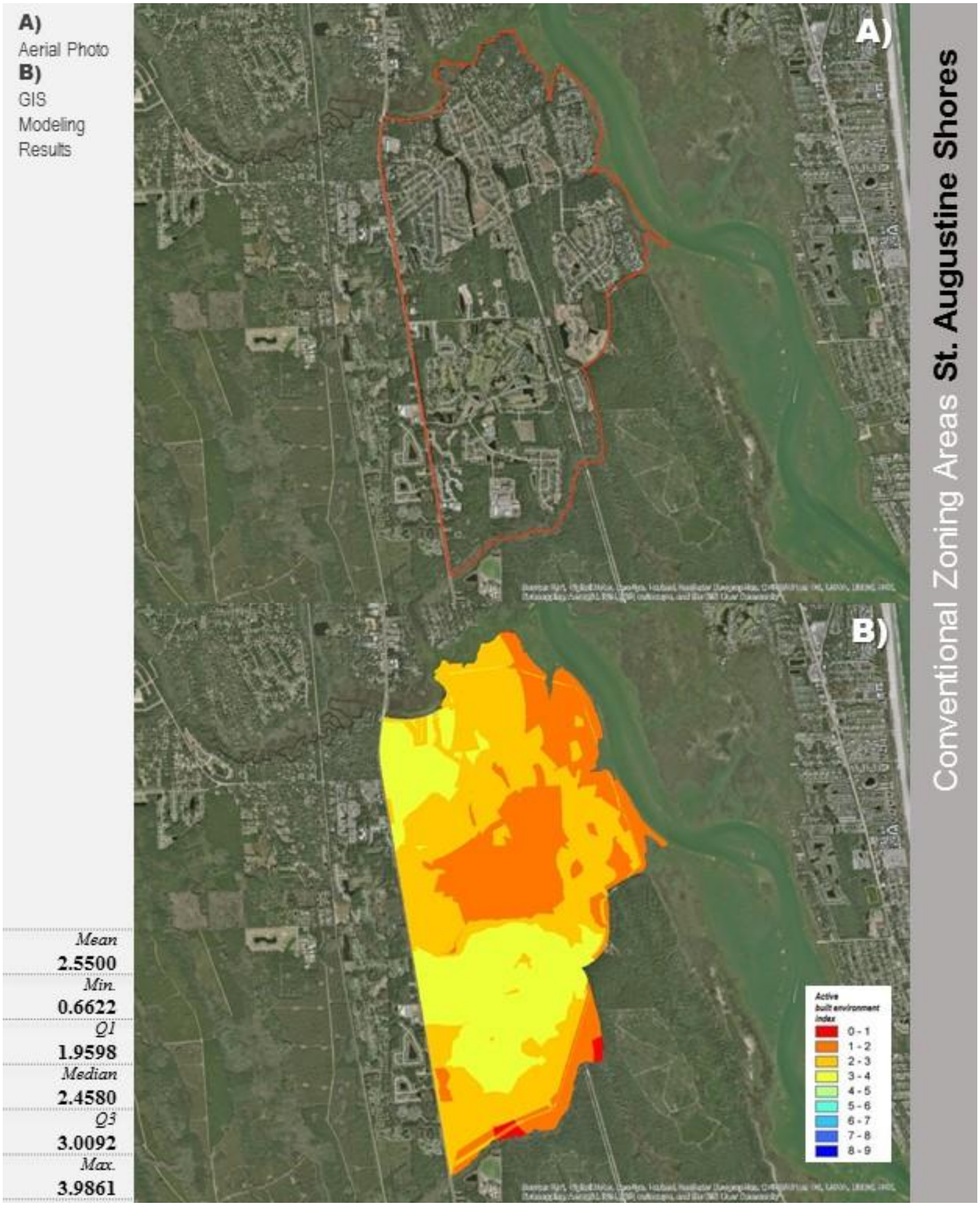

Figure 4-61. GIS Modeling Results of St. Augustine Shores. A) Aerial Photo. B) GIS Suitability Modeling Results.

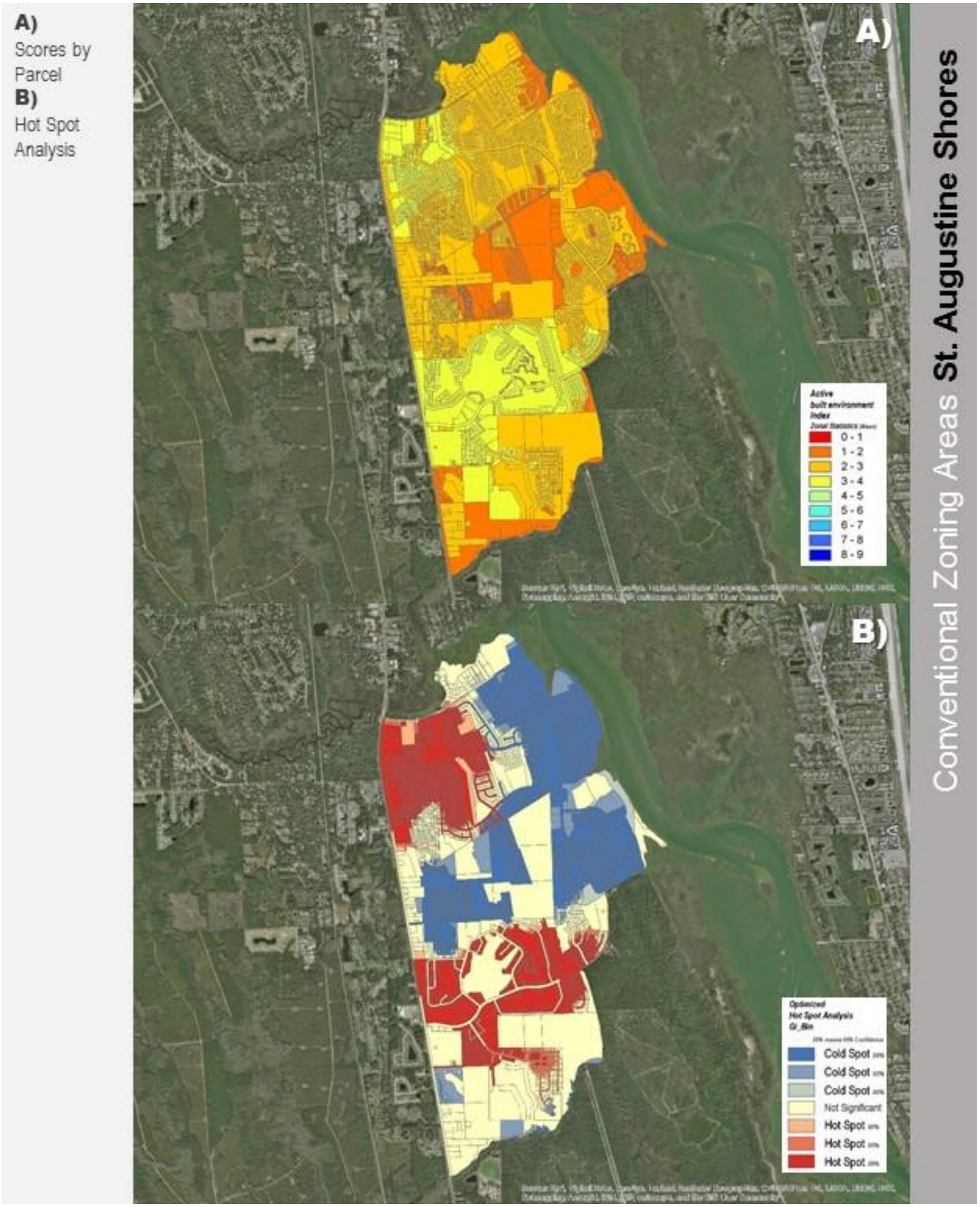

Figure 4-62. Scores by Parcel and Hot Spot Analysis of St. Augustine Shores. A) Zonal Statistics. B) Hot Spot Analysis.

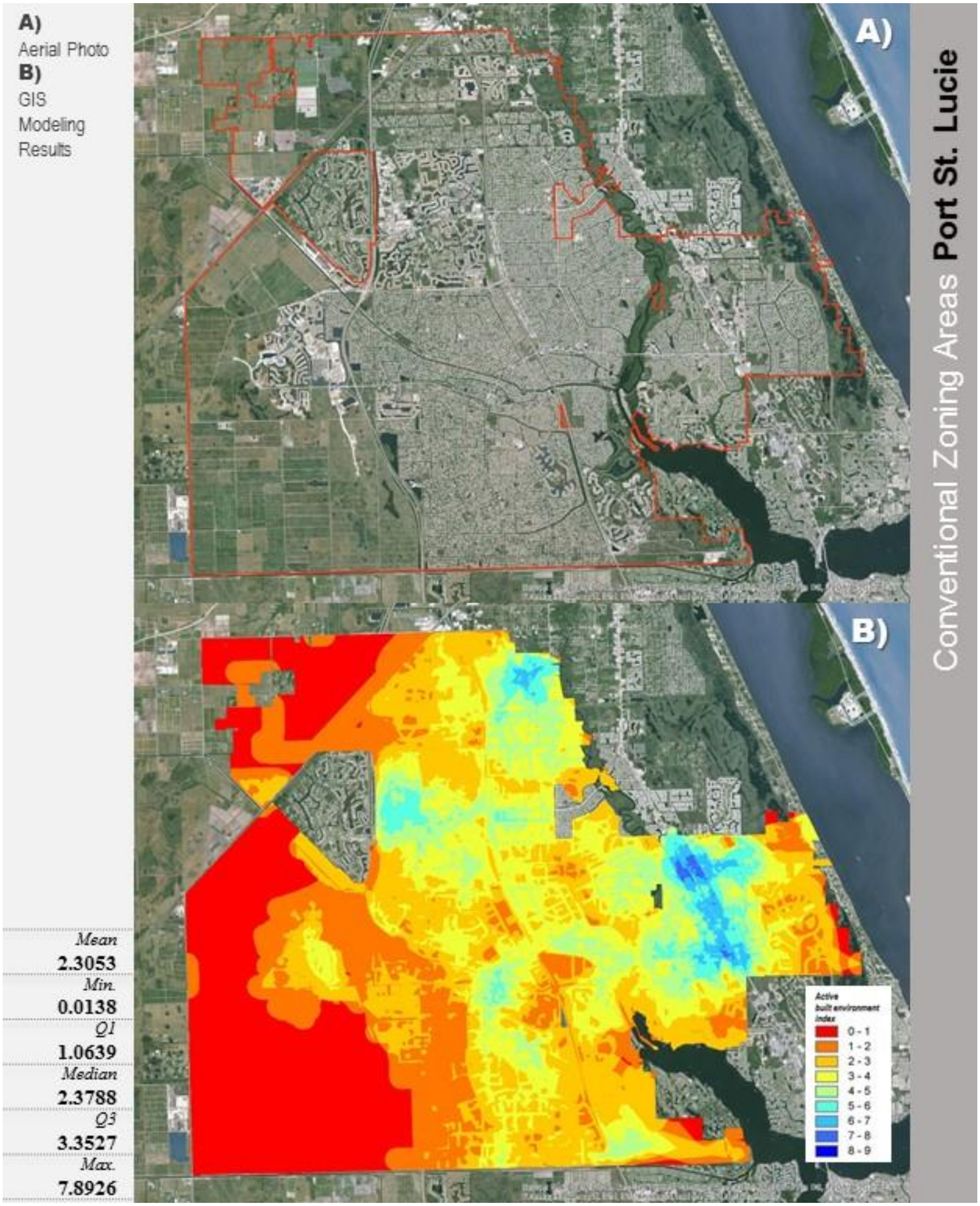

Figure 4-63. GIS Modeling Results of Port St. Lucie. A) Aerial Photo. B) GIS Suitability Modeling Results.

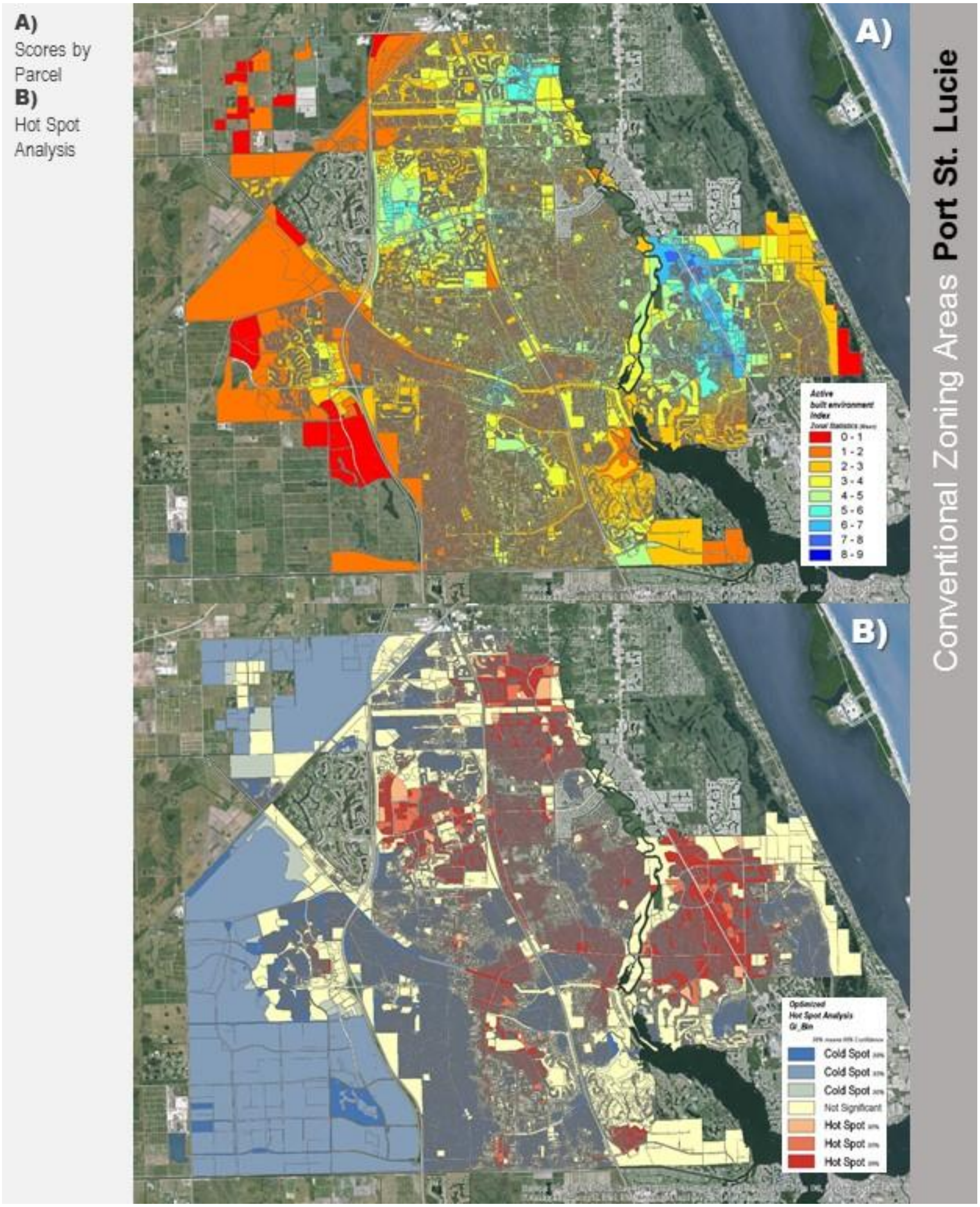

Figure 4-64. Scores by Parcel and Hot Spot Analysis of Port St. Lucie. A) Zonal Statistics. B) Hot Spot Analysis.

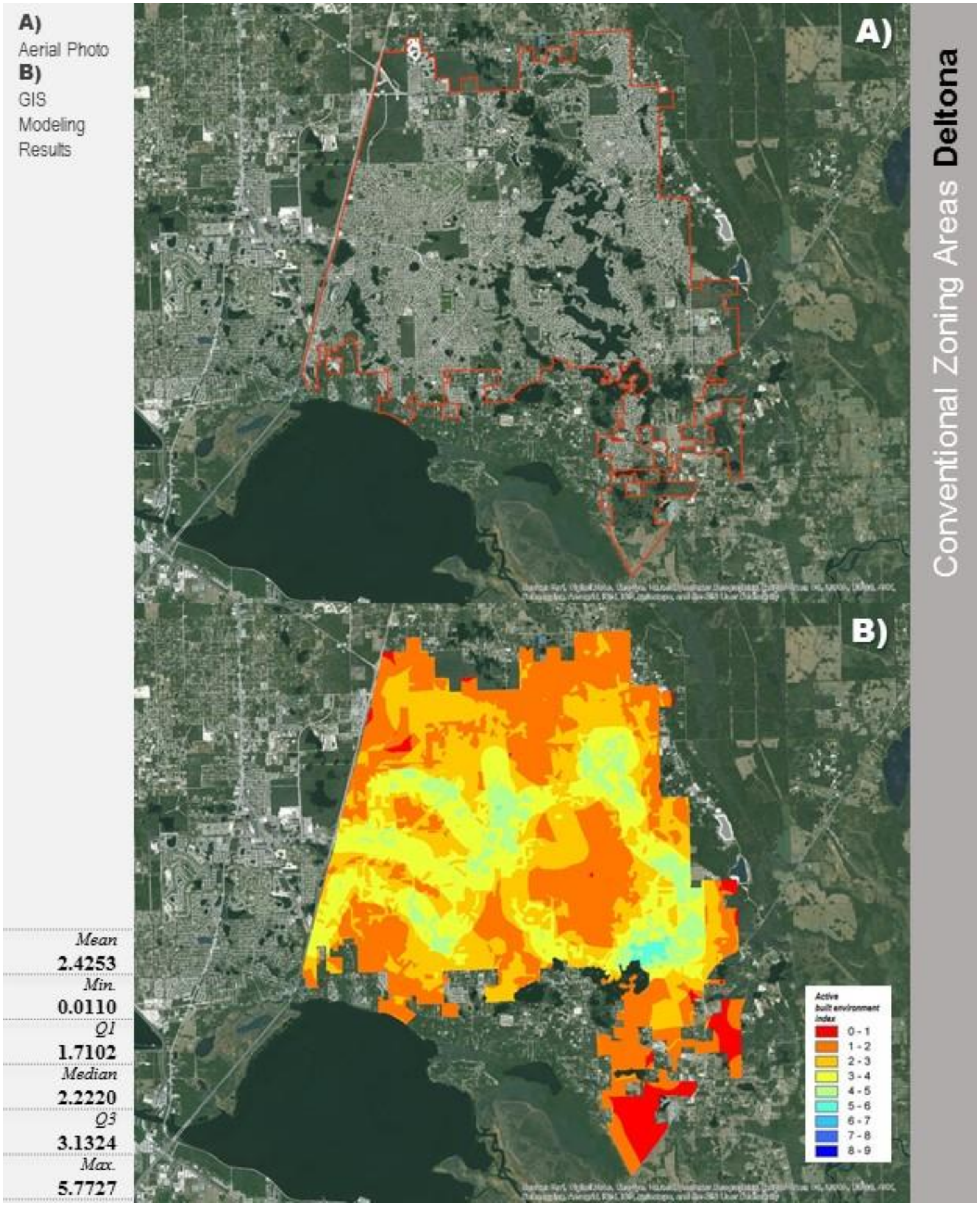

Figure 4-65. GIS Modeling Results of Deltona. A) Aerial Photo. B) GIS Suitability Modeling Results.

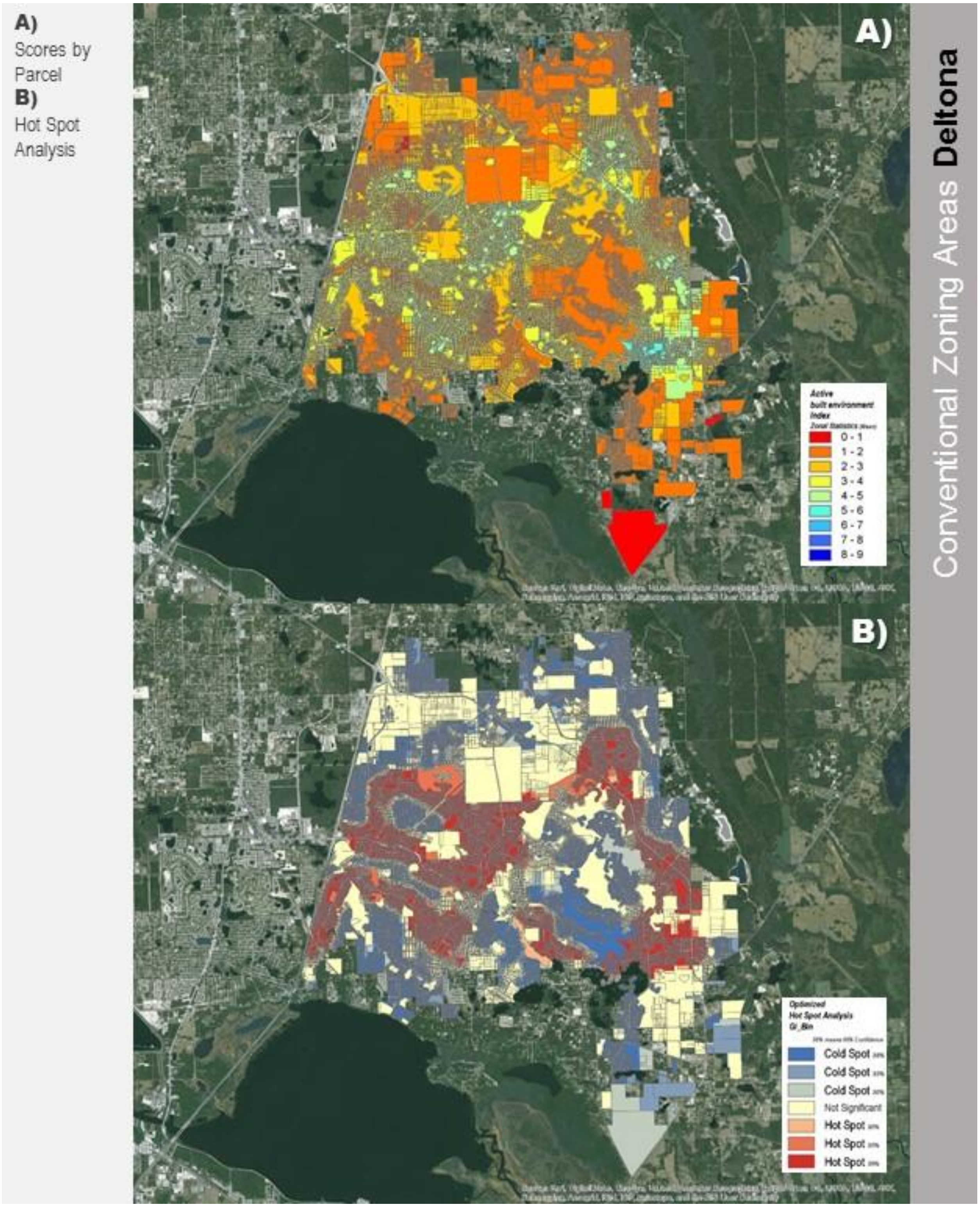

Figure 4-66. Scores by Parcel and Hot Spot Analysis of Deltona. A) Zonal Statistics. B) Hot Spot Analysis.

Descriptives

Scores

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
FBCs	10	3.6337800	1.61864457	.51186036	2.4758714	4.7916886	1.81010	6.01880
Historic	10	3.2993300	1.61097978	.50943654	2.1469045	4.4517555	1.46710	6.42790
Zoning	13	2.1064000	.35625611	.09880767	1.8911166	2.3216834	1.26510	2.55000
Total	33	2.9307364	1.40973876	.24540402	2.4308647	3.4306080	1.26510	6.42790

Figure 4-67. Descriptive Statistics of FBCs, Historic, and Zoning Group (SPSS)

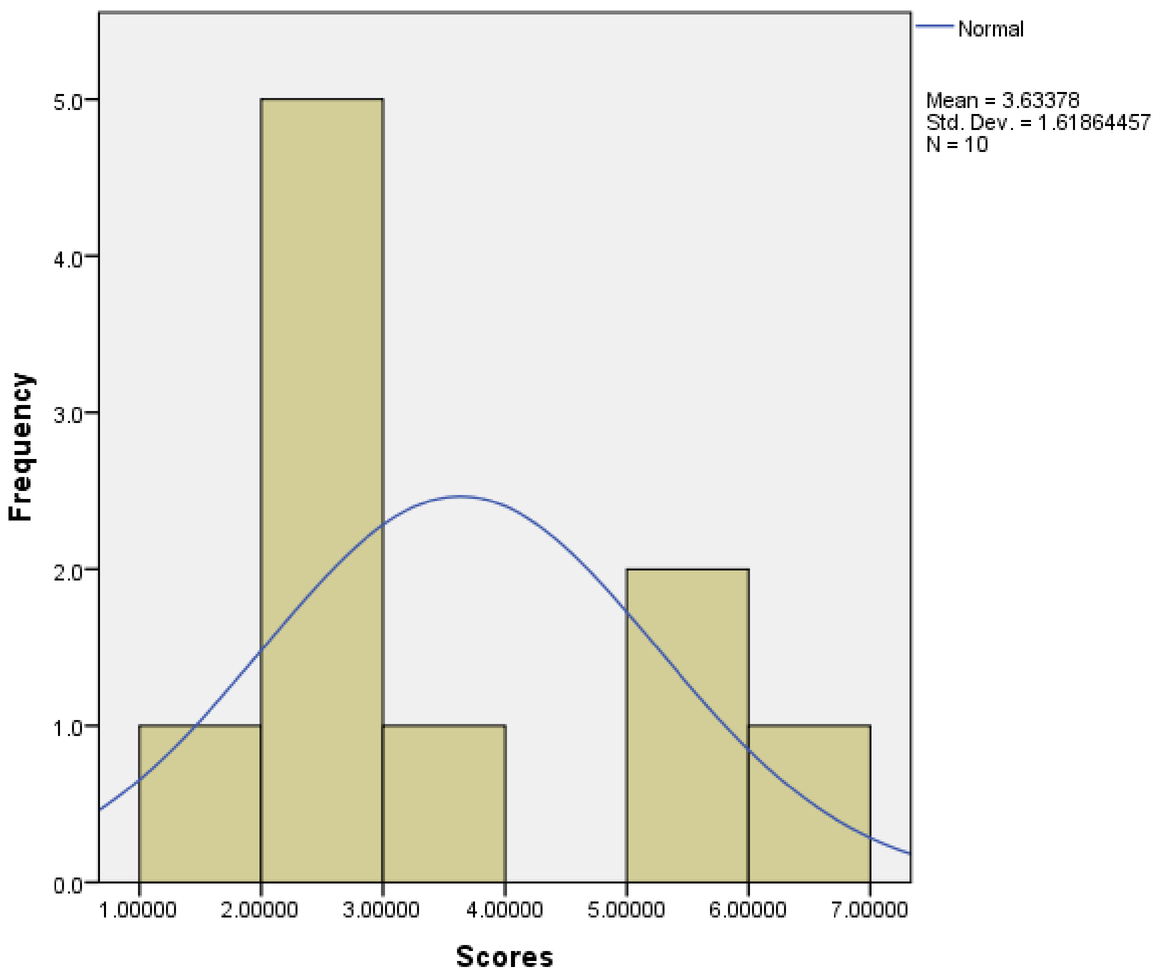

Figure 4-68. Histogram of FBCs Group Scores (SPSS)

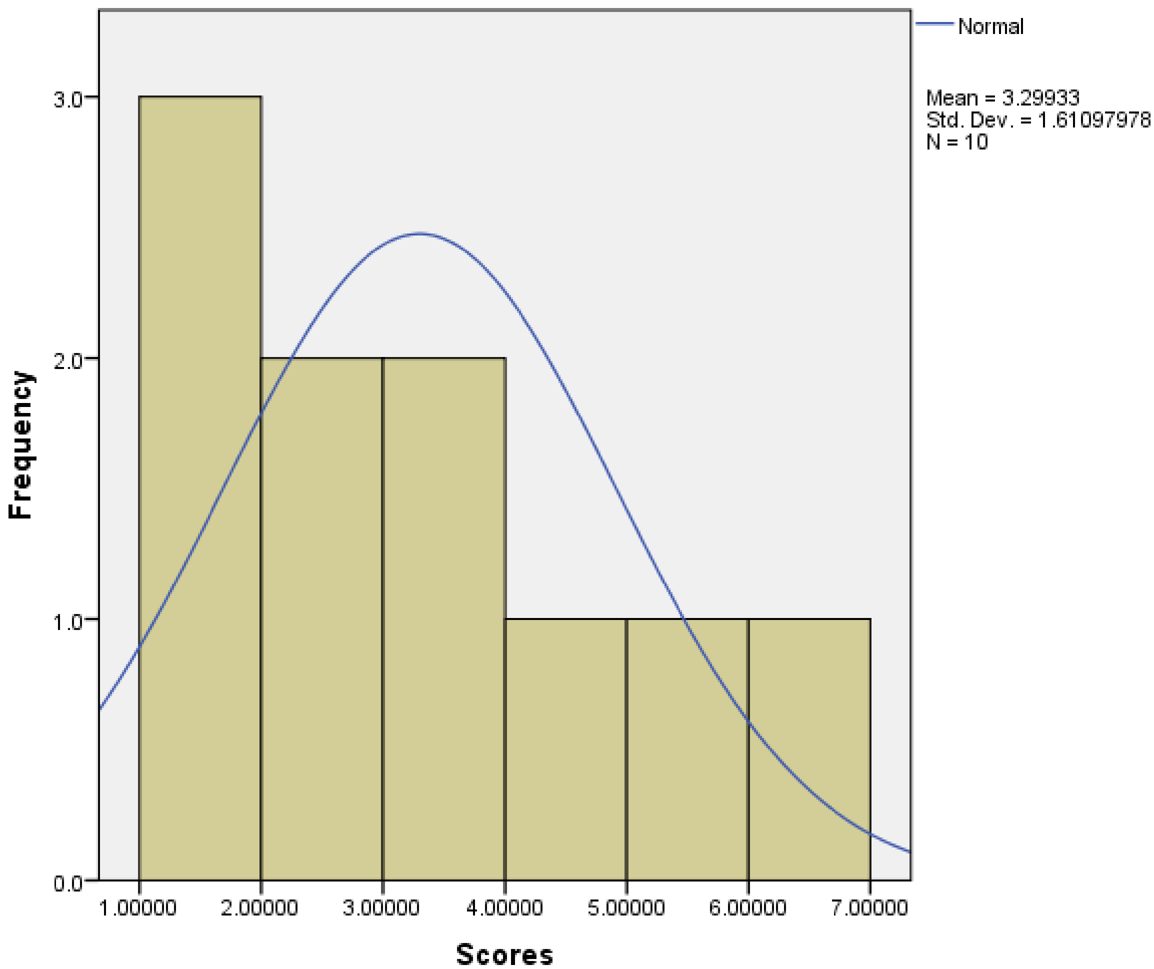

Figure 4-69. Histogram of Historic Group Scores (SPSS)

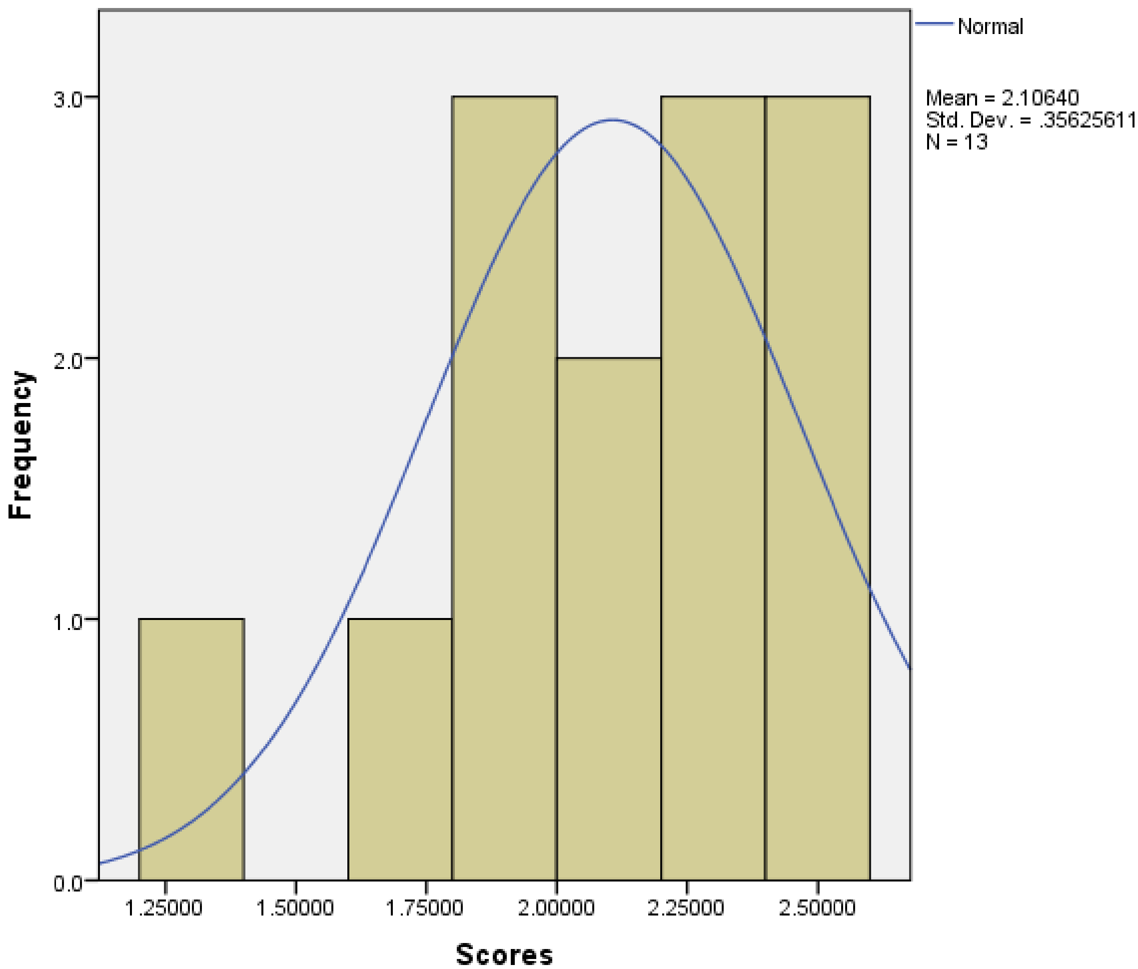

Figure 4-70. Histogram of Zoning Group Scores (SPSS)

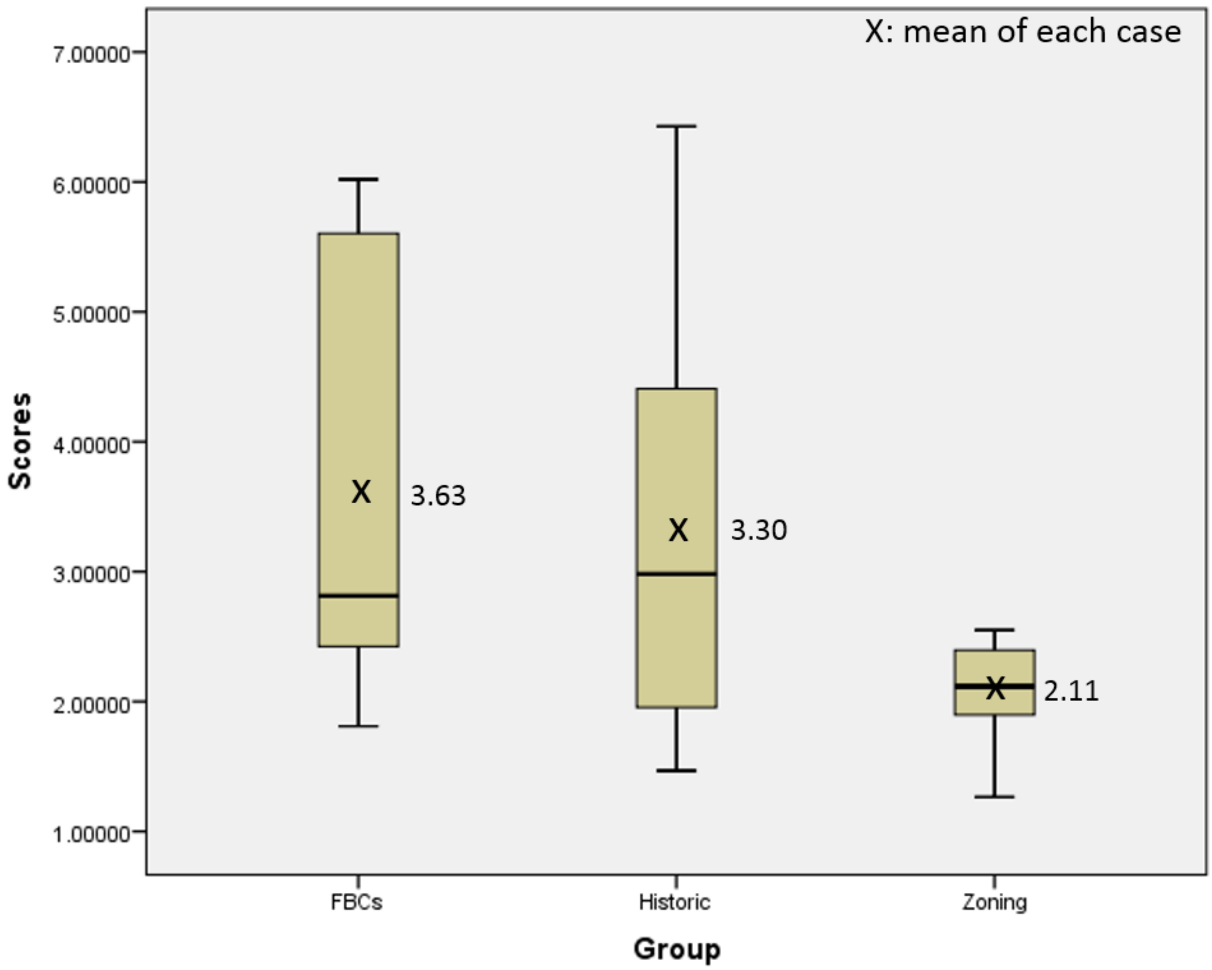

Figure 4-71. Box Plots of three Groups (SPSS)

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Scores	FBCs	.293	10	.015	.829	10	.032
	Historic	.197	10	.200*	.919	10	.348
	Zoning	.173	13	.200*	.920	13	.250

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 4-72. Test of Normality with Raw Scores (SPSS)

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Scores_aqrt	FBCs	.275	10	.031	.859	10	.074
	Historic	.154	10	.200*	.953	10	.710
	Zoning	.174	13	.200*	.895	13	.115

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 4-73. Test of Normality with Transformed Scores (SPSS)

Test of Homogeneity of Variances

Scores

Levene Statistic	df1	df2	Sig.
9.779	2	30	.001

Figure 4-74. Test of Homogeneity of Variances (SPSS)

ANOVA

Scores

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.135	2	7.568	4.685	.017
Within Groups	48.460	30	1.615		
Total	63.596	32			

Figure 4-75. Standard ANOVA table (SPSS)

Robust Tests of Equality of Means

Scores

	Statistic[a]	df1	df2	Sig.
Welch	6.370	2	12.857	.012

a. Asymptotically F distributed.

Figure 4-76. Robust Tests of Equality of Means (SPSS)

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Scores

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	FBCs	Historic	.33445000	.56839198	.827	-1.0667904	1.7356904
		Zoning	1.52738000*	.53459536	.020	.2094574	2.8453026
	Historic	FBCs	-.33445000	.56839198	.827	-1.7356904	1.0667904
		Zoning	1.19293000	.53459536	.082	-.1249926	2.5108526
	Zoning	FBCs	-1.52738000*	.53459536	.020	-2.8453026	-.2094574
		Historic	-1.19293000	.53459536	.082	-2.5108526	.1249926
Games-Howell	FBCs	Historic	.33445000	.72216799	.889	-1.5086442	2.1775442
		Zoning	1.52738000*	.52130987	.038	.0903556	2.9644044
	Historic	FBCs	-.33445000	.72216799	.889	-2.1775442	1.5086442
		Zoning	1.19293000	.51893019	.104	-.2373727	2.6232327
	Zoning	FBCs	-1.52738000*	.52130987	.038	-2.9644044	-.0903556
		Historic	-1.19293000	.51893019	.104	-2.6232327	.2373727

*. The mean difference is significant at the 0.05 level.

Figure 4-77. Post Hoc Tests (SPSS)

CHAPTER 5
CONCLUSIONS

Summary of Study

Most FBCs were introduced as a method of addressing problems that were created by conventional zoning, such as a lack of support for physical activity. However, evidence is required to support this capability of FBCs. As such, this paper examines whether FBCs are conducive to creating active built environments.

In order to answer the research question, the following objectives were established: first, to determine and operationalize the built environment variables that affect physical activity in a GIS, and second, to employ GIS-suitability modeling to develop an index of active built environments that could be used to compare the urban forms of FBCs, conventional zoning, and historic cities.

The literature reveals that several urban form elements—such as open spaces, grocery stores, schools, and transportation facilities—can affect the physical activity levels of an area’s residents. Previous studies on this topic also disclose the fact that FBCs have become a leading alternative for creating active built environments and mitigating contemporary urban issues that have been caused by conventional zoning.

The methodology of this study consists of four parts. For the first part, developing a comparative analysis, this study selected different sites within each of the three groups: form-based codes, conventional zoning, and historic cities. Florida was chosen as the area to be studied because Florida has played a precursory role in the development of FBCs in the U.S. and has experienced the evolution of various phases of planning approaches. Second, based on prior studies, this study categorized and aggregated any GIS data that was relevant to active built environments in Florida. Third, this study built a GIS suitability model to assess the three urban form groups. Suitability modeling was chosen for its ability to overcome the limitations of previous efforts regarding the assessment of active built environments as well as the analysis of complex urban form data. Since each GIS-modeling process yields a suitability map ranked by the active built environment index, the GIS modeling results not only reveal the spatial distribution of the scores, but also provide cell-based quantified output. Fourth, the study performed a statistical comparative analysis among the three groups. An ANOVA test was used to determine if the differences observed among the groups could have reasonably occurred by chance. The results of this analysis could reveal whether or not FBCs have a significant ability to create urban forms that are more conducive to physical activity than those developed by conventional zoning or historic cities.

Because the assumption of the homogeneity of the variances was violated, a standard one-way ANOVA test was not be applicable to this study; therefore, the study used a Welch ANOVA test instead. In terms of the results, a statistically significant difference was found between the scores of the comparison groups, with Welch's $F(2, 12.857) = 6.370$ and $p < .012$. However, this result does not reveal which groups were different. In order to identify specific group differences, I performed a Games-Howell post hoc analysis. The Games-Howell post hoc analysis revealed a difference between the scores of 3.6 ± 1.6 in the FBCs group and 2.1 ± 0.4 in the conventional zoning group, a difference of 1.5 (95% CI, 0.1 to 3.0); this is statistically significant ($p = .038$). These results indicate that, in Florida, urban forms created based on FBCs are more likely to lead to active living than urban forms created as a result of conventional zoning regulations.

Discussion

As mentioned in the literature review, previous research efforts have described how built environments are related to physical activity. However, since each study has been conducted separately, it is difficult to find urban planners and policymakers with comprehensive perspectives on the full impacts that urban form can have on health. This study begins to overcome this kind of limitation. In order to do this, I used GIS-based methods to assess three different urban forms by active built environment criteria (characterized by mixed use, proximity to open space, public facilities, and active transportation options). Additionally, the use of the same GIS-based index in 33 cases allowed me to compare the outcomes of three different regulations.

As a result, I found that urban forms created based on FBCs are more likely to lead to active living than urban forms created by conventional zoning regulations. Also, I initially expected that historic cities would score higher than traditional zoning cases, since the urban forms of traditional cities are typically more compact and designed for walkability. Although the scores of the historic cases were higher than those of the conventional zoning cases and were close to the scores of the FBCs cases, the ANOVA test did not show a statistical difference between the historic cities and conventional zoning cases. More research may be needed to explore this result further.

During the case selection process, I assumed that cases consisted of mutually exclusive sub-groups and used judgement to select them. This process, however, revealed some case selection issues in the study design. Because FBCs, conventional zoning, and historic cases have developed during different timelines, I chose cases based on fundamental events that occurred in Florida's urban planning history. For cases involving FBCs, I found 10 sites that adopted FBCs between 1981, the first year that FBCs were utilized in Florida, and 2003; this latter date was chosen because the FBCs adopted after 2003 are still in their incipient stages. Next, for historic cases, I found 10 sites that have historic districts and were established before 1845, since these cities tend to maintain relatively traditional urban forms. The urban forms of historic cities that adopted conventional zoning or FBCs after 1845 might have been affected by those rules, however. For zoning cases, I tried to find conventional cities that were built between 1950 and 1980 because many Florida cities were developed by zoning regulation after World War II. Based on data from the Florida League of Cities (2015), 107 cities were applicable. In this study, I selected the 13 cases that were presented by RuBino and Starnes (2008). This non-random selection was based on the assumption that RuBino and Starnes had chosen these cases to represent the most typical examples of conventional zoning in Florida for that period.

This study used physical distance as the measurement of walkability. However, as mentioned in the literature review, there are additional factors that affect walkability, such as the socioeconomic status of the residents (their races and incomes) or qualitative variables (the sense of enclosure and pleasurability). I did not include these variables due to data unavailability. However, if data on these variables become available, future research will be able to identify a more detailed relationship between walkability and various factors, including urban form, socioeconomic status, and qualitative variables.

An entropy index was used to measure the land use mix. Although the entropy index is a useful tool to assess land use diversity, it also has one limitation. As Brown et al. (2009) note, the entropy formula (Figure 3-1) sometimes does not present land use diversity. In Figure 5-2, both indexes are the same (with a value of 1 for both); however, while the right diagram only has two land uses (multifamily and single family), the left diagram shows six different land uses (multifamily, single family, office, retail, education, and entertainment). However, in all of my 33 cases, the entropy index results did not reveal this theoretical issue.

Although there are several potential problems with this modeling process, the GIS-based visualization method provides an expanded set of tools that can help urban planners and public health professionals to understand the relationship between urban form and active built environments. In addition to visualizing the results, the modeling process has the potential to present changes over time (e.g., before and after); this is because the GIS modeling process can not only show existing active built environment conditions, but can also show what future active built environment conditions could be. The capability of GIS to visualize future settings can be used for alternative future land use scenarios, and it is relatively easy to add or change variables in the modeling sequence (Carr & Zwick, 2007, p. 200). Also, although this study employed a static model, increasing the GIS capacity could support a more dynamic model that would be more responsive to variable changes over time.

Health Promoting Urban Design

Recently, a number of urban planners and institutions have recognized that the most successful and innovative solutions of contemporary urban issues, such as physical inactivity, are created when multiple professionals collaborate. For example, the Planning and Community Health Center of the American Planning Association (APA) has provided practical tools and policies to prompt public health through active living, healthy eating, and health living in all planning policies. Additionally, the Urban Land Institute (ULI) has initiated collaboration with health care, architecture, planning, and development professionals to improve public health and increase active living (The Building Healthy Places Initiative).

In addition to these interdisciplinary efforts to resolve current urban problems, though the GIS modeling yielded meaningful results, I recognized the necessity of a more comprehensive framework for analysis. This is because, as Northridge et al. (2003) argued, the relationships between study variables and physical activity is complex.

Thus, before discussing future research, I summarize the findings of collaboration efforts for active living and to see if there is a comprehensive analysis framework that will embrace complex variables and methods of active built environment analysis.

As Badland and Schofield (2005) argued, the limitations of built environments influence on physical activity, suitable built environments is essential to sustaining physical activity behaviors (p. 177). The most common suggestions for healthy communities are active living and heathy eating. Within this context, ULI introduced ten principles for building healthy places (ULI, 2013, pp. 10-29):

- Put People First: Individuals are more likely to be active in a community designed around their needs.
- Recognize the Economic Value: Healthy places can create enhanced economic value for both the private and public sectors.
- Empower Champions for Health: Every movement needs its champions.

- Energize Shared Spaces: Public gathering places have a direct, positive impact on human health.
- Make Healthy Choices Easy: Communities should make the healthy choice the one that is SAFE—safe, accessible, fun, and easy.
- Ensure Equitable Access: Many segments of the population would benefit from better access to services, amenities, and opportunities.
- Mix It Up: A variety of land uses, building types, and public spaces can be used to improve physical and social activity.
- Embrace Unique Character: Places that are different, unusual, or unique can be helpful in promoting physical activity.
- Promote Access to Healthy Food: Because diet affects human health, access to healthy food should be a considered as part of any development proposal.
- Make It Active: Urban design can be employed to create an active community.

Despite the great potential to create healthy places, the above recommendations cannot be accomplished by one discipline. Even so, as an urban designer, I would like to explore several urban design strategies to achieve above principles. In urban design, one common and strong method to prompt physical activity is walking, since walking is the most effective ways to achieve the daily physical activity recommendation of adults and can be incorporated into everyday life (Gehl, 2010, p. 111). Below I describe the known approaches to enhance walkability.

Destinations

First of all, walkability requires destinations. For this study, destinations such as grocery stores, parks, and public facilities were used as variables. By walking to destinations, people include physical activity in their daily lives without noticing. However, during the analysis process, I recognized each destination has a different hierarchy. Figure 5-1 describes possible amenities by distance and implies the difference of walking intensity by amenity. Thus, when designing for those amenities, urban designers should consider their locations as well as their suggested walking distance to maximize walking.

Street Design for Walking

As mentioned previously, streets not only provide space for the movement of people but also offer a place for social interaction. Well known street design concepts for walking include: provide well-designed transit stops for encouraging transit use and walking on the streets; place public plazas along with streets since pedestrian networks that alternate street and squares can make the psychological impact on making walking distance shorter (Gehl, 1987); and since traffic calming also affects walkability, incorporate street additions such as curb extensions, medians, and raised speed reducers. Including aforementioned concepts, the City of New York (2010) listed the following design strategies:

- Provide seating, drinking fountains, restrooms, and other infrastructure that support increased frequency and duration of walking.
- Provide lights on sidewalks and active play areas to extend opportunities for physical activity into the evening.
- Make sidewalks wide enough to comfortably accommodate pedestrians, including those with disabilities.
- Incorporate traffic calming street additions such as curb extensions, medians, and raised speed reducers.
- Create a buffer to separate pedestrians from moving vehicles using street furniture, trees, and other sidewalk infrastructure.
- Create paths with auditory crossing signals, adequate crossing times, clear signage, visible access ramps, and connections to walking.

Different Design by Users

Furthermore, it is also crucial for design strategies to accommodate the variations of healthy physical activity by age or health conditions. Here I discuss the literature findings specific to designing for vulnerable populations such as school children and senior citizens.

For children's walking activity, the literature shows the significance of amenities on the street. In order to support their physical activity, as Boarnet et al. (2005)

reported, well-made sidewalks and street environments allow children to walk safely. Regarding “well-made,” Larsen et al. (2009) observed the presence of trees has been associated with higher rates of walking to school among children. Also, Lockett, Willis, and Edwards (2005) showed that benches and restrooms would support children in walking more, while traffic hazards were a deterrent.

Compared to children’s activity, senior citizens’ safety and comfortability were identified as key components to encouraging their activity. Traffic calming measures are important for the elderly, who are more vulnerable to pedestrian accidents due to slower reaction time and limited mobility. Statistics from the National Highway Traffic Safety Administration (NHTSA) indicated that for older people, 63 percent of pedestrian fatalities in 2010 occurred at non-intersection locations. That means sidewalks for seniors need more proper street calming additions such as medians and raised speed reducers. In addition to traffic calming, frequent seating places make streets more accessible for elders as well as handicapped people who have difficulty standing for extended periods.

Design Regulation

Although design regulations do not *ipso facto* create high quality places, regulations are the primary method to create urban spaces (Carmona et al., 2010, p. 319). Thus, well-established urban design regulations are helpful to create healthy places. From the regulations perspective, FBCs have several advantages that can help build the places that both designers and citizens desire.

First, FBCs can embrace the aforementioned active urban design strategies since FBCs have the capacity to include detailed urban design elements using public space standards and building form standards.

Second, FBCs can fill the gaps between initial design and the outputs. Despite all good features in urban design, if the reality is different from what people expected, they become skeptical. However, FBCs might alleviate such concerns since FBCs have administrative power as well as visualization process. Parolek et al. (2008) argued that:

> The codes work best when they are developed in draft form during the multiday charrette. Presenting the proposed ordinance alongside the team's rendering brings increased confidence that what is drawn might actually be built. Furthermore, by riding the wave of enthusiasm that often accompanies the charrette process, the FBCs can be written into law much more quickly, thus minimizing the inevitable watering-down process that can severely comprise a worthy development plan. (Parolek et al., 2008, p. 14)

That is, FBCs are a possible answer for questions regarding gaps between initial renderings and final results, and they are easily translated into written regulations based on the envisioned process.

Study Limitations and Directions of Future Research

This study opens up several opportunities for future research. First, since I successfully converted an active built environment index into parcel level scores and analyzed which areas showed statistically significant spatial clustering, researchers can recognize the areas that have potential issues in terms of active living. That is, the visual outputs of this analysis provide information on sites for future study by researchers, urban designers, community planners, and public health professionals. Second, although I used composite GIS layers and their scores for a comparison study, since the suitability model of this study consists of multiple layers, researchers can use the analysis to determine the elements of built environments that are statistically different.

Nevertheless, there are several limitations to this study. First, I utilized only quantified data for the analysis. Although several studies suggest that well-established urban forms are positively correlated with physical activity, there are a number of factors that cannot be easily quantified. As several researchers have argued, qualitative values such as safety, comfort, and pleasurability might make an impact on physical activity. In future research, these qualitative variables should be considered in the modeling process.

Second, although “vertical” variables such as enclosures and streetscapes are also critical factors in encouraging physical activity (Heath et al., 2006), this study only showed “horizontal” active living suitability. Although some of the FBCs cases actually involved walkable urban forms that included both 3-D (vertical) and 2-D (horizontal) factors, this limitation might explain why some FBCs areas showed a lower suitability than others. Future research needs to include these 3-D variables in the modeling process.

Third, some data was unavailable or only available for different time periods. The transportation data particularly varied in terms of its date of issue, since it was aggregated from different sources. Bus stop data were not available at the time of the analysis, so I utilized bus routes to create walking catchment areas instead; this expanded the data on access to transit more than is normally possible through bus stop data alone.

Fourth, I used the same weights for the combined layers. Typically, suitability modeling uses weighted layers to allow each variable to impact the model differently.

Thus, future research may consider establishing an appropriate weight for each variable.

Finally, I only assessed how active living potential was affected by physical urban forms. There have been efforts to identify the connection between built environment and behavioral patterns using accelerometer data (Kang, Moudon, Hurbitz, Reichley, & Saelens, 2013; Saelens et al., 2003). However, as Badland and Schofield (2005) note, these devices may not detect certain types of body movements (such as cycling), and the cost of the devices is an issue (p. 192). Due to recent smartphone and smart watch technology developments, though, this data has become more reliable and easy to use. Therefore, in future research, tracking the movement patterns of residents via smart wearable devices will enable actual measures of physical activity and health outcomes. This data would tremendously enhance the methodology adopted in this study.

	Possible facility – Catchment population		
4–10km radius	City facilities	Stadium	City
		Cathedral	City
		City hall	City
		Theatre	City
2–6km	District or Town	Sports centre	25000–40000
		District centre	25000–40000
		Library	12000–30000
		Health centre	9000–12000
400–600m	Neighbour hood	Community offices	7500
		Community centre	7000–15000
		Pub	5000– 7000
		Post office	5000–10000
150–250m	Local hubs	Primary school	2500– 4000
		Doctor	2500– 3000
		Corner shop	2000– 5000

This chart is indicative and is based upon city-scale urban areas. Catchments will vary in specific areas.

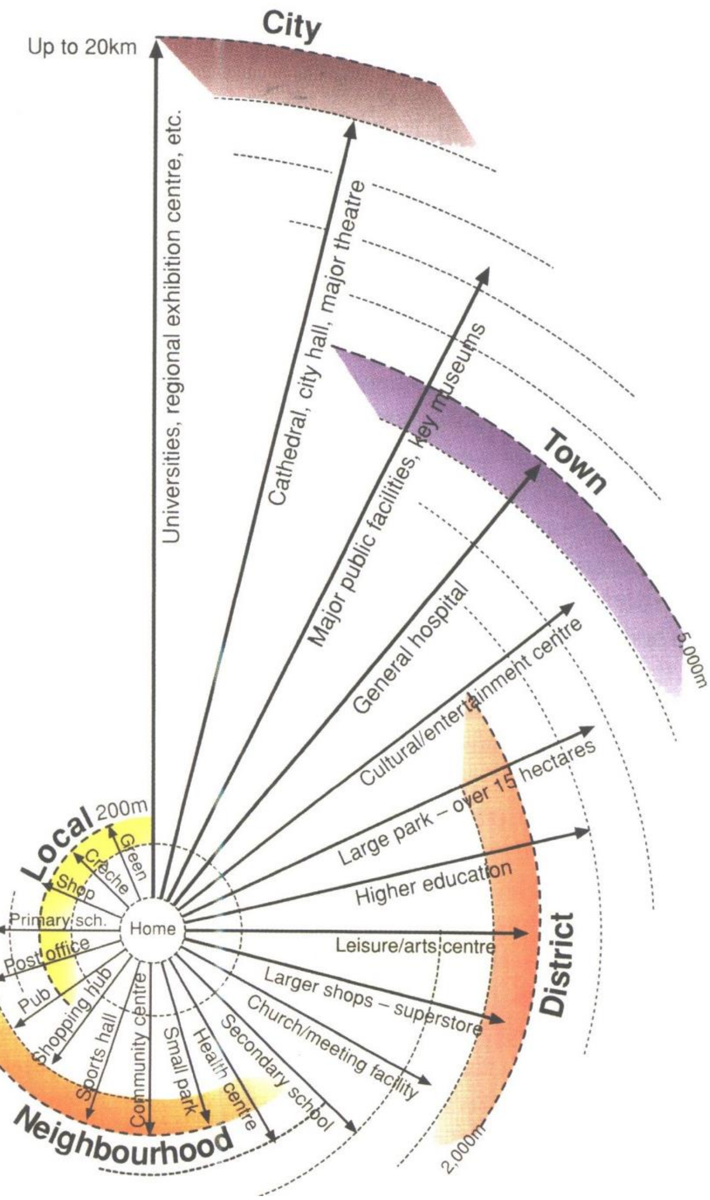

Figure 5-1. Facilities Types by Walking Distance (Carmona et al,. 2010, p. 237)

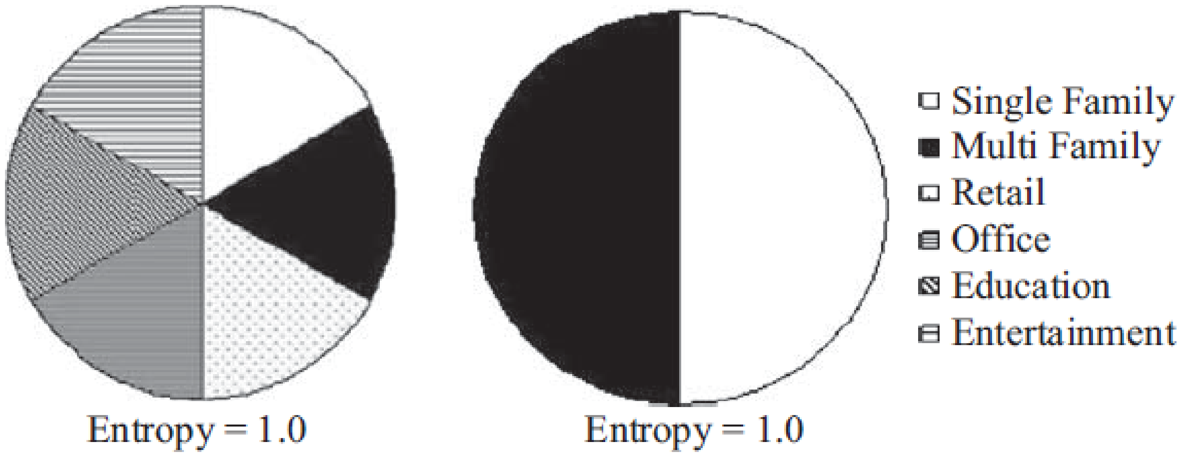

Figure 5-2. Conceptual Diagram for Comparing Entropy Index (Brown et al., 2009, p. 1132)

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