# MAPPING UNIFORMITY OF PARK ACCESS USING CADASTRAL DATA WITHIN NETWORK ANALYST IN WAKE COUNTY, NC

by

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## DEDICATION

I dedicate this document to my wife, Carrie, and my children, Silas and Matilda, for their patience, understanding, and support throughout this entire process.

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I will be forever grateful to my committee chair Professor Robert Vos who has kept me challenged and pushed me to expand my research. Thank you also to my friends Yvonne, Outhong, and Adrianna who have kept me motivated through the long nights to finish what I started.

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## ABSTRACT

Park planners make long-term land acquisition and capital improvement plans based in part on population growth and gap analysis of existing facilities. This study demonstrates a new cadastral-based technique to measure park access for residents in Wake County, NC. Based on road network and cadastral data, the technique uses the Origin-to-Destination Matrix Tool within Esri's Network Analyst extension in conjunction with dasymetric mapping of US Census Data to the cadastral data. The demonstrated workflow provides for a highly detailed assessment of walking distance between parcels and parks, that when linked with the population data, provides a gap analysis based on the amount of parkland and number of parks available at each parcel. Successful completion of an analysis at this level of detail illustrates a very different view of park coverage for Wake County, NC compared to traditional methods, revealing how hard edges created by major thoroughfares and soft edges created by property ownership impact pedestrian accessibility. Using the cadastral-based method, 19.85% fewer parcels have 1/4-mile park access than compared to a buffer based method (6.72% versus 26.27%). The use of this type of technique will allow for a more comprehensive assessment of the peoples served by the park system and when coupled with demographic information, may prove more effective in assessing grants and monitoring the impact of public initiatives promoting equality and uniformity of access to public parks.

# CHAPTER 1: INTRODUCTION

The complexities of the urban environment often impede the ability of planners to predict needs for and appropriately locate public facilities. In the case of public parks and open space, understanding how pedestrians can access a park is necessary to evaluate the effectiveness of the park system in serving the community (Nicholls 2001; Boone et al. 2009). In past studies, planners have evaluated the level of service by measuring the gaps revealed between the parks based on buffers drawn around each park defined by a fixed distance from a set point, what could be termed a coverage method (Nicholls 2001; Hass 2009). The distance often correlates to an assumed walking or travel distance. These maps may not accurately identify the populations served, accurately depict existing service gaps, or provide insightful planning strategies to improve park access.

The primary goal of this study is to develop a cadastral-based method for measuring park access uniformity based on the actual travel routes. This technique requires developing a workflow that solves three primary research objectives: 1) Develop service areas based on walking networks; 2) Assess populations served based on physical location; and 3) Calculate the acreage of parkland available to the population based on the travel distance between the park and the parcel within the ¼ mile walking distance. Developing an analysis tool that incorporates these objectives will provide planners and community leadership a means to conduct repeatable analysis of park service in residential areas.

Evaluating how this tool functions at a county-based scale will help determine its ability to process larger study areas including potentially state wide and regional assessments.  Rather than measure the accessibility of any given park, the proposed approach measures the access from the residential areas to all parks within a specified distance, identifying residential areas that have gaps in service or have more parks than the average. Grounding this process to accurate cadastral data will reduce the level of generalization often involved in system wide analysis (Wolch et al. 2005; Maantay 2007). The availability of a vetted Geographic Information System (GIS) to organize, manage, and analyze complex data facilitates this type of detailed analysis. The study demonstrates a GIS workflow that if widely implemented in local planning agencies could lead to more effective uniformity and gap analysis of park access, identifying where new facilities will be most effective.

### 1.1 Defining Service Areas

Service areas are determined by the distance a person is willing to travel to access a facility (Hass 2009; Duncan 2012). How a service area is defined for a park will greatly influence the calculations regarding populations served. Within the literature, three distinct methods for measuring service area include container, coverage, and gravity model techniques. The container method uses a social or political boundary to determine the number of facilities within a given boundary, such as the municipal limits, and compares the number of facilities to the number of people. The container method is often used within larger scale geographic studies, such as multiple county or statewide assessments, utilizing heavily aggregated data in order to identify spatial patterns and trends at the risk of losing detail.

The coverage method utilizes buffering at a specific distance from a facility to generate a polygon which is used in selecting which populations are potentially influenced by the park based on how much of the underlying population data is covered by the area of the park buffer.  The gravity model, or similar nearest distance model, assigns facilities to end users based on nearest distance. This approach is not typically used because of the complexities in setting it up (Nicholls 2001); this study does not explore the gravity model method as it is rarely utilized due to complexities in establishing the criteria and calculations.

As described above, in the case of parks and open space, service areas are typically measured using the coverage model and based on 1/4 mile buffers from the park periphery (Nicholls 2001).  The ¼ mile distance is an important variable for consideration as it represents a round trip walking distance of ½ mile (Loukaitou-Sideris and Stieglitz 2002; Sister et al. 2010; Hass 2009; Nicholls 2001; Talen 2010). The use of ¼ mile is an accepted standard based on the distance a family with small children is most likely to walk to reach a park or service (Talen and Anselin 1998; Loukaitou-Sideris and Stieglitz 2002). In areas of suburban development and a more car-centric development pattern, the travel distance may increase due to the likelihood of parents driving to facilities. In these cases, basing service areas on vehicular access may likely preclude the use of the facility by families experiencing economic hardship (Loukaitou-Sideris and Stieglitz 2002; Boone et al 2009).

Using buffers as a means to identify service areas can also mask social and physical impediments that prevent accessing the park site. Physical impediments, such as major transportation corridors or natural features such as streams and excessive changes in topography may also be overlooked during a service area analysis using the buffering process.

Both the container and coverage methods are susceptible to the influence of the modifiable areal unit problem (MUAP). In the container method, it is the arbitrary nature of the chosen boundary whether using objects like corporate boundaries or neighborhood boundaries. Within the coverage method, generating buffers based on access points or edge boundaries can create large discrepancies regarding final access statistics as not all boundaries are permeable by the public. Similarly, using a buffer from the center of a feature compared to the outer perimeter will generate differing coverage polygons and skew the results in access assessment. Also, how the buffer intersects existing census boundaries may change measurements. How the buffer is adjusted in terms of travel distance also will lead to variations in results. In general, buffers generate an indiscriminate boundary that does not reflect the actual condition of the user group. A person just outside of the ¼ mile buffer may be just as likely to use the park if there is a safe pedestrian path as someone just inside the ¼ mile is unlikely to use the park if there is no such path.

Parcels that are intersected by the buffer may not be able to access the park based on road networks. Using service areas generated from network analysis will create service areas that reflect the physical access paths. This approach will allow repeatable results that can be modified based on the mode of travel, size of the park and, in the future incorporate a form of costing. This study will utilize such network-based service areas to assign and validate populations to the respective parks, assign park area to the respective parcels, and allow for charting of both work and market development.

One advantage of a gravity based model is that it considers how a park service area may increase based on the park type. Park facilities vary in the level of services provided, whether they are a large regional park or a small neighborhood style park. An example of a large regional park would be Pullen Park in Raleigh, NC. This large regional park provides community residents access to an aquatic center, carousel, playgrounds, and even paddle boats. Compare this to a small neighborhood park, such as Jaycee Park in Raleigh, NC, where the amenities are less diverse and focus on more traditional offerings such as a playground, basketball court, and picnic shelter. The critical contrast in these two park types is the distance that people are willing to travel to access the amenities. People may travel from as far as Cary, NC at 12 miles, or Wake Forest, NC at 14 miles to use at Pullen Park, while they would remain in their own communities when using playground or picnic shelter. This variability in amenities influences the draw power of specific parks when determining what distance people are willing to travel and influences how to measure service areas (Loukaitou-Sideris and Stieglitz 2002). Although this study focuses on basic pedestrian access for any type of park, the overall method of measurement presented here is not inconsistent with a gravity-based model.

**1.2 Measuring Service Areas**

The generally accepted approach for assessing park service areas is generating buffers representing service areas from park features, what is termed the coverage method in this study (Sister et al. 2010; Boone et al. 2009; Hass 2009). As mentioned in the previous section, the buffer approach, or coverage method, uses a fixed distance buffer from the edge of the park property to generate a polygon that represents the service area. The size of the polygon will depend on the variables used during the buffering to represent the assumed travel distance, whether walking or driving. This polygon, representing the service area, aids in a number of assessments including calculating populations served, assessing the system for gaps in coverage, and identifying sites for future parks. Based on findings from the previous studies, this study hypothesizes three main sources of error to the traditional service area measurement approaches: 1) Generalization of physical access to the park, 2) Spatial inconsistencies in assessing populations served, and 3) Gap analysis in coverage that does not represent real use patterns.

### *1.2.1 Physical Access*

Physical access is a primary concern when determining the service area of a park. The common utilization of container and coverage-type approaches often overlooks the nuances of physical access due to either the scale of assessment or lack of detailed information. Coverages generated from buffers are generalizations, overlooking elements such as major roadways, railroad crossings, and property boundaries (e.g., fences) when they are generated using a fixed radius from the park edge.

How a person perceives these varying objects in terms of boundaries, or barriers, involves understanding the differences between the hard and soft barriers that compose a complex urban environment (Lynch 1960). Hard edges, defined by the physical obstructions as noted above can be readily identified and can be measured in how it influences how people may travel through an area; consider something as limiting as a river or a set of high speed railroad tracks. Hard edges are often already recorded in geospatial datasets and thus easy to account in GIS network analysis (Makse et al. 1995).

Soft edges are harder to grasp within GIS. The concept of a soft edge is grounded in how people move in and construct a mental image of a city or urban area (Lynch

1960). The urban fabric in its pure form is one of permeability, allowing people to move freely through the grid, with no hard physical barriers separating them. The reality is that how people perceive the built environment, in terms of built character, social makeup, and physical location in relationship to the overall context serve to create soft edges within a person's mind. It is often related to perception on how people feel about the environment they are within and whether they can traverse across a property or communal path to get to a different portion of the environment.

An example of this soft edge phenomena occurs when you observe the emotional reactions as people cross from one area of the environment to another of differing cultural values, such as crossing from a residential area to an industrial area, or from a poor residential area to an affluent residential area. Due to the variance in reactions on a person-by-person level, it would be difficult to map the varying levels of permeability within an environment and how it can restrict or allow people to travel through the community without extensive human subjects research (Lynch 1960). However, certain assumptions for this study, for example, include people being unwilling to traverse private property boundaries like their neighbors backyards to enter a park.

An improved method for measuring service areas will need to account for physical access routes that connect the parks to the populations served. As these pathways are often well-defined and perceived as public in ownership and access, they are the most easily mapped within a GIS. Understanding where park access points are in relationship to the potential users will be key in developing accurate service area measurements.

How the access points interact with the adjacent vehicular and pedestrian routes may also have a significant influence over how users can access the park. Developing a model that has the ability to adjust the travel distance to match the mode of travel will provide analysts flexibility in determining the service areas. The use of actual access routes will also aid the analysis by excluding properties that are not within the travel distance along the accessible routes, and even potentially offering opportunities for including barriers in the analysis. Details regarding of how these nuances integrate into the approach are described within Chapter 3 of this paper below.

### *1.2.2 Measuring Populations*

A primary goal of developing a service area measurement is to assess what populations are served by a particular park facility. The primary source for population data in park access studies is U.S. Census data. Census data contains population data in one of several different scales depending on the target application. Using the smallest scale of measure, the census block group, analyses are often conducted where the population is calculated by the percentage of the block group within the service area. This poses an interesting challenge when service areas are general buffers. Populations that are within the ¼ mile buffer radius may not necessarily be within ¼ mile travel distance. Using physically grounded service areas in conjunction with accurately located housing unit information may offer significant improvements in estimating park accessibility.

Dasymetric mapping is a form of thematic mapping that assigns data based on one areal unit to another (Maantay 2007). In the case of population analysis, the ability to map the census population data by a shared attribute to the parcel data will allow the population to be mapped to the actual residential areas. This may prove a more accurate means when evaluating the accessibility of parks as only those units within the service area will be selected. Furthermore, this reassignment of population information will allow a ranking analysis to be completed based on the amount of parkland available per person at a parcel level.

#### *1.2.3. Gap Analysis*

A gap analysis represents the culmination of measuring the individual factors and assessing the effectiveness of the park system. A gap analysis looks at the spatial arrangement of the parks within a given system in relationship to the people they serve based on the park service areas. The output of the gap analysis will identify where there is no coverage by parks. For this study, the intended direction of the gap analysis is to reverse the direction of measurement from traditional approaches by starting at the parcel and searching outward for connected parks rather than vice versa.

This concept of a cadastral-based gap analysis is focused on understanding the uniformity of coverage within the park system. By measuring the quantity and area of park available at each parcel within the specified travel distance, the resulting gap analysis maps will help park planners understand how the existing park system serves the community and show where the concentrations of park accessible residential parcels are and where shortfalls in coverage exist. To be clear, this type of measurement will quickly identify those parcels that have more or less park available compared across the study area based on the physical access available to that parcel.

## 1.3 Motivation

The motivation for this project is rooted in the need for an analysis tool that allows park planners, landscape architects, and municipal leaders to quickly understand the level of service of the park system based on the real world urban fabric. Development pressures often outpace the acquisition and development of new park sites. Creating an approach that is tied to cadastral data would allow the planning professionals to have an up-to-date view of where pressures in the system will occur, harnessing the information collected including changes in land use and projected new housing areas based on housing unit counts. It opens up the opportunity for predictive modeling as a means vetting park sites. Current practices of finding the cheapest land available without checking the physical access creates parks that are underutilized and is a misallocation of scarce community resources.

If combined with other datasets, the method demonstrated here could also be used to quantify and map the population of children under the age of 18 as a means of more accurately assessing park locations against the population most likely to utilize the park facilities (Maroko et al. 2009). This is in contrast to comparable studies that have focused on the entire population base as a metric. Healthy lifestyles begin during the early childhood years, understanding the access children have to public parkland can be useful as an evaluation criteria. This method may also reveal where families are concentrated compared to other household types, which may allow for assessing where funds are needed for additional play equipment or for adult activity types such as tennis or fitness trails, providing insight on locations of need (Dalton et al. 2013).

### 1.4 Case Study Wake County, NC

The focus of this study is to assess the accessibility of public parkland within the distributed development patterns and resultant population centers in Wake County, North Carolina. Wake County is located in central North Carolina and covers 835 square miles.

The county encompasses Raleigh, the state capital, as well as eleven other incorporated municipalities. As of the 2010 census, the county population was estimated at 900,993 people. Figure 1 shows the contextual relationship of Wake County, NC within the southeastern region of the United States.

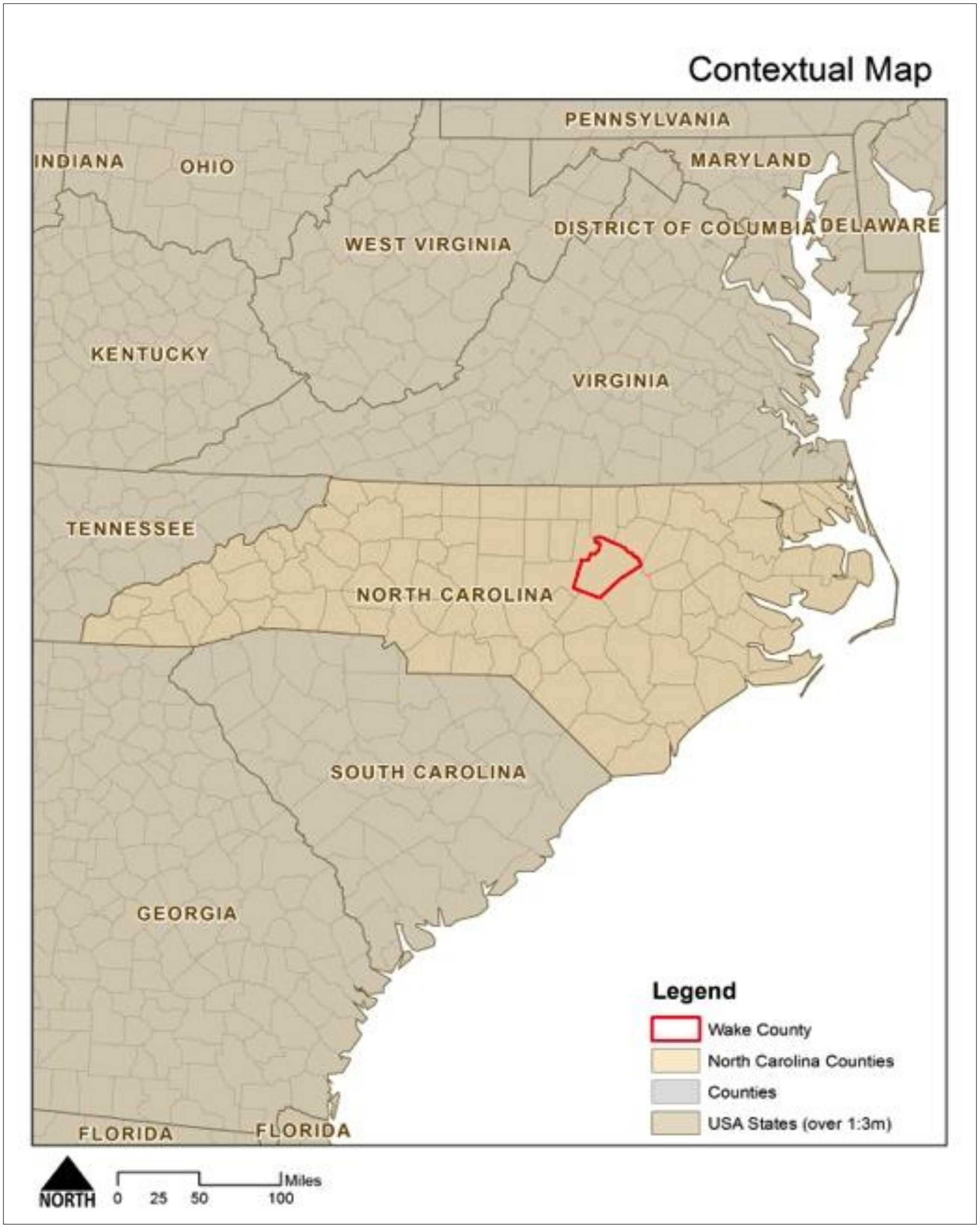



**Figure 1 Contextual Map of Wake County, NC**

Wake County is fast growing in both population and housing. The total population of Wake County grew over 44% between 2000 and 2010 (Wake County

2013). This growth establishes Wake County as the second most populous county in the state. A 2012 estimate calculates the population of Wake County at 952,151 people with over 181,255 under the age of 15 (OSBM 2014). The North Carolina State Demographer projects that the population will exceed one million residents by the year 2015.

The fast growing population has increased demand for new housing, amenities, and recreation areas. The City of Raleigh estimated an addition of 55,425 housing units for an increase of 46% in units between the 2000 and 2010 census (Raleigh 2014). The expansion of housing places strong demand on the remaining undeveloped land within Wake County and may push populations away from Raleigh. As this development advances from the urban core, the pressure on existing parks and the need for new parks may be pronounced.

Early subdivisions in Wake County were not required to provide public open space and parks at the time of development. In planning, the concepts of open space and parkland are often interchangeable. However, to be more specific, open space is a broad term that can include natural areas, state parks, forests, wildlife preserves, and even preserved agricultural lands. In contrast, for this study, parks are areas that have facilities for rest and recreation owned and managed by the city or county for the enjoyment of the public. The intent of both parks and open space is to provide balance between built land and undeveloped lands. While Wake County and the individual municipalities have strived to provide open space and parkland for their respective populations, disconnections exist in the quality of the individual facilities in terms of physical size and amenities. These disconnections can lead to user groups utilizing facilities in adjacent areas, overburdening those facilities, or avoiding using parks due to lack of convenience (Dalton et al. 2013).

Parks are a significant amenity as they provide an environment that encourages increased physical activity through active recreation and play (Dalton et al. 2013). As development increases, parks also aid in preserving and improving the environmental quality in dense urban developments (Carleyolsen et al. 2005). Ensuring that park facilities are equitably distributed in terms of geography and accessibility is a requirement for the success of an existing parks system. Accurately mapping the relationship between facilities and population is key to identifying gaps in facility coverage (Duncan et al. 2012).

It is also important to ensure that these facilities are equitably distributed in terms of need. Historically, park need assessments focus on dense urban areas that have a higher demand for parkland to meet recreational opportunities when compared to traditional suburban development (Wolch et al. 2005; Sister et al. 2010). In Wake County, development has spread from the central core of Raleigh through multiple independent subdivisions, often referred to as urban sprawl. This sprawl has resulted in a decentralization of development in Raleigh, NC. The only dense urban development in Wake County aligns to core area of Raleigh, while the remainder of Wake County is relatively low-density, single-family housing. The average density has the zoning classification of R20 or one residential unit per 20,000 square feet of yard area (Wake 2014). A low-density development pattern is difficult to adequately serve with public facilities.

Another challenge facing park planners is the notion that single family homes provide large yards for children to play in. This is based on the traditional suburban style of detached houses on large green lots (Marusic 2011). As the demand for housing and the cost of land increases, lot sizes are being reduced to increase density. This limits the amount of private green space available to the individual subdivisions. The challenge to this model is the need for children to have varied experiences for play and socialization for healthy development (Loukaitou-Sideris et al. 2002; Sister et al. 2010).

With the increasing rate of residential development on the remaining vacant land within Wake County, the location of the existing parks and their respective service areas is important in evaluating the effectiveness of the park system and its ability to continue to serve the increasing population. Risk exists in the population spreading beyond the reach of existing facilities. Without proper planning, there will not be adequate land for park construction within these newly developed areas due to higher land costs (Carleyolsen et al. 2005). As areas increase in density, existing green areas will continue to be reduced placing a higher burden on existing parklands.

In the denser residential areas of Raleigh, parks are integrated into the neighborhoods. Residential areas close to the center of Raleigh maintain high land values that preclude young and lower income families from living within these more established neighborhoods. As the cost of living continues to drive the population further out from the core, the risk of isolation from public parks will increase due to travel costs, access, and geographic location. Figure 2 shows the number of parks within Wake County, NC. At the time of this study there are 268 distinct parks defined within the attribute data of the Wake County Open Space inventory data file (WakeC 2014).

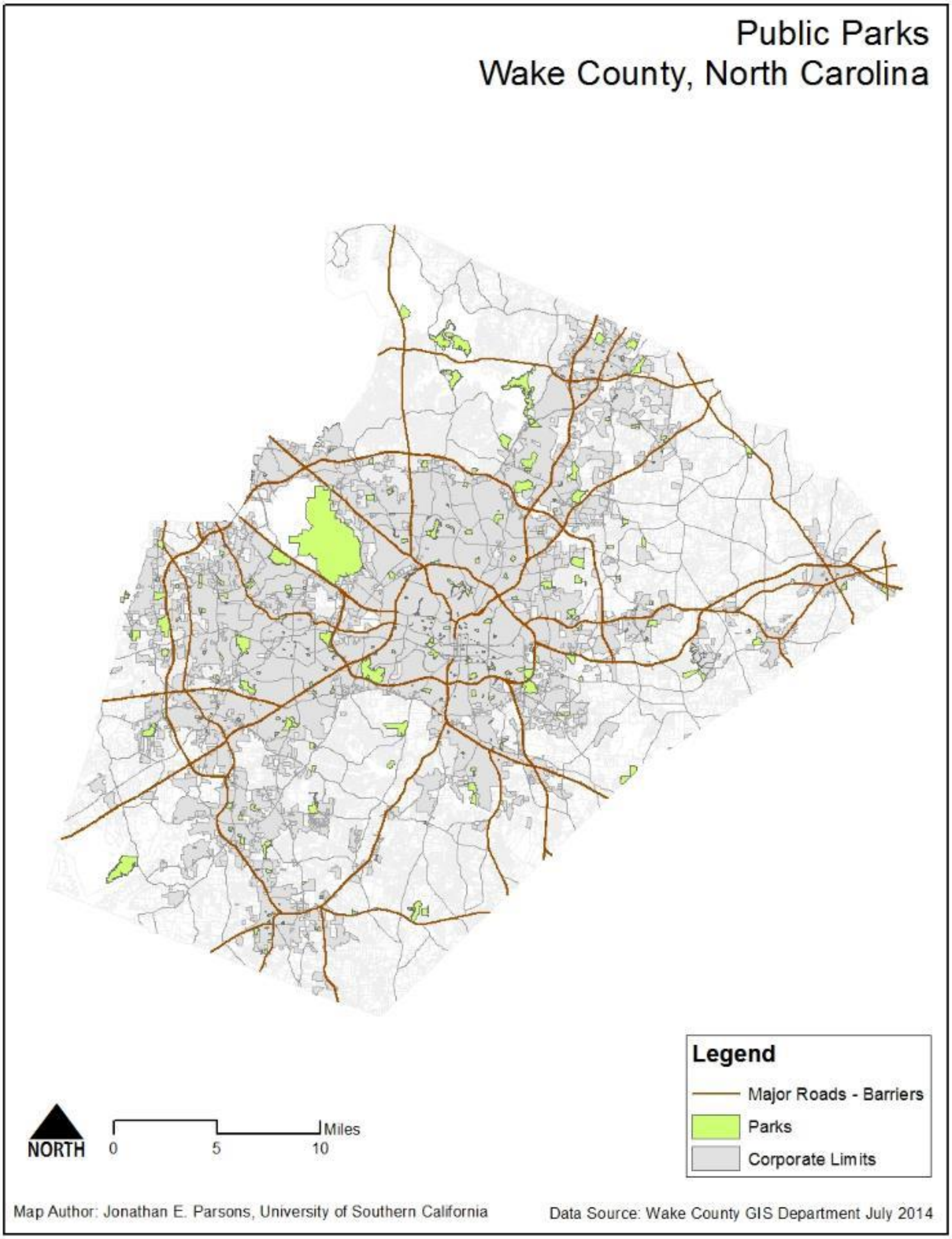



**Figure 2 Map of Parks within Wake County, NC**

### 1.5 Organizational Framework

This thesis is organized into four additional chapters. Chapter 2 focuses on reviewing the literature available and utilizing these examples to identify and discuss the types of service assessments and population measurement techniques presently in use to analyze park accessibility. A discussion of benefits and constraints observed from these studies will also serve as a foundation for the proposed methodology. Chapter 3 focuses on presenting a framework for the proposed cadastral-based measurement technique. This chapter will describe the framework necessary to develop a tool that integrates service area generation through network analysis with dasymetric mapping of populations. The process for developing the application and operational concerns is discussed within this section. Chapter 4 will review the results of the proposed modeling technique. This chapter will present the model outcomes, discuss the benefits, outline the shortfalls, and identify improvements necessary. Chapter 5 will discuss the implications of using this revised approach to generate gap analysis and identify opportunities for future research and exploration. Future research and explorations will also be described within this concluding section.

# CHAPTER 2: RELATED WORK

The realities of human nature lead us to deduce that people will only use parks that they can conveniently access whether by car or by foot. This simple premise defines this study. In order to effectively assess a park system for uniformity of access by the community's residential areas, a measurement technique needs to be developed that is parcel centric. A parcel centric approach focuses on utilizing the cadastral data and travel routes to determine which parcels have access to parks. This approach will provide analysts a means for comparing the quantity of parks and area of parkland available to each parcel and its residents. A common benchmark is to compare the capacity of a park system on the notion of acres per 1000 people available (Moeller 2014). Thus, an effective gap analysis needs to be based on an underlying acres per capita measurement (Hess 2001; Cary 2012). This will provide analysts a clear view of where gaps exist in terms of level of service and inequality in terms of the populations served.

The purpose of this chapter is to explore the existing literature and identify the issues surrounding park accessibility in terms of determining service coverage to the resident population. How have previous studies evaluated physical access and measured uniformity in terms of park space and amenities? Attention is paid to refining the definition of accessibility in regards to the literature and how it will function within this study. Defining accessibility will also require reviewing common measurement techniques. The literature review will also discuss the issue of utilizing a park-centric approach in the current methodology and provide practical examples. This assessment will establish the groundwork for presenting a new measurement approach that focuses on the parcel as a means to evaluate overall park accessibility.

To facilitate this discussion, the chapter is organized into four main subsections: accessibility, dasymetric mapping of residential populations, equity analysis, and a review of practical examples. Through understanding of these variables and how they are influenced by the existing techniques, a foundation for developing a new approach for measuring park accessibility can be laid. This foundation will support the need for a parcel centric approach in lieu of the park centric model currently employed. After the main points are discussed in terms of process and execution. At the conclusion of this chapter, a summary will be provided that outlines how these findings inform the method proposed and demonstrated in this study.

### 2.1 Accessibility

Accessibility can have broad meanings. For this study, accessibility will relate to a person's ability to physically reach a specific park based on known travel routes. This is a more focused view than what is common in the literature, where accessibility is often a combined measurement of equitable distribution determined by both physical and social dimensions (Lindsey et al 2001). Physical dimensions are defined as those tied to coverage-based analysis and travel distances and social dimensions are defined as relating to the perception of a user to traverse a perceived soft edge to reach the park. Within these two vectors, there is often a third measure, which ties back to the area of park available to the people served (Higgs et al. 2012). Focusing on either attribute without respect to the other will result in only a partial assessment of a park system's ability to serve a given community. In the simplest of forms, accessibility of a park system may better be represented as a measure of total opportunities per person to a given origin within a given distance (Hass 2009). Following from this definition, there are typically three primary steps necessary for collecting the information necessary to evaluate accessibility and they are as follows: determine the study area, establish the areal selection unit and analysis method, and conduct the calculations based on the areal unit.

Through the review of existing literature, there are two primary categories of technique deployed: the coverage method and the container method (Tarrant and Cordell 1999). Both methods can determine the potential populations served and aid to complete the final analysis regarding demographics and equality assessments. The following subsections contain a detailed comparison of how these two processes work within an analysis workflow. The focus of this study is to demonstrate whether a cadastral-based approach can replace the traditional methods.

Several studies have focused on the aspect of the total measure of recreational opportunities as a means to determine the equality of park distribution (Talen & Anselin 1998; Lindsey 2001; Sister 2012). Access to parks has been found to relate directly to the health of a community (Carleyolsen et al. 2005). Developing a measurement technique that can respond to the variety of facilities within a given distance of a residence remains the issue when trying to evaluate the availability of specialized park facilities within the greater community. Locating facilities such as aquatics centers and fitness centers in areas that are accessible by the greatest number of residents is key to maintaining a uniform park system. It is also an important aspect to account for the number of people served when setting aside space for parks or open space and for park planners when considering resource management and capital improvements for park amenities (e.g., pools, tennis courts, and playing fields).

### *2.1.1 Comparing Container and Coverage Approaches*

The general process for a container analysis is to identify the region of interest, determine what boundary or area the calculations will use as the unit of analysis. In most studies, the container approach is based on a political boundary such as county or city jurisdiction and serves as a selection tool to select the population data and parks within the given area in order to complete calculations revealing the amount of parkland available per person (Talen & Anselin 1998; Tarrant 1999; Wolch et al 2009). Using the container approach, input data is selected based on how it intersects with the overlaying study boundary. Regarding parks, the total area of all parks within this unit of analysis is calculated. Once complete, this area is divided by the total population of the unit-of-analysis. In studies focused on quantity of parks, the area-person-calculation is replaced by a count of parks available within the unit of analysis. One issue revealed in this approach is how one handles the calculation when only part of the population feature or park feature is located within the container. Determining whether to use the percentage of intersection, or to exclude these intersecting data, can greatly influence the output results.

A key limitation of the coverage approach is that it uses arbitrary boundaries, such as political jurisdictions or census tracts, which contribute to the Modifiable Areal Unit Problem (MAUP). MAUP is an issue in spatial analysis that is created by generalizations that may be introduced into GIS data. The generalizations, whether based on establishing arbitrary boundaries such as political jurisdictions, or by an aggregation of the spatial phenomena being mapped such that the boundaries may not match with the desired scale of the analysis. Census data is susceptible to the MAUP as the boundaries change each census depending on the rate of growth within a specific area and the intent of maintaining each census unit at a specified range of population and households. In most instances, this is a maximum of about 3500 people. Figure 3 provides an example of buffers generated from the park edge at a ¼ mile fixed distance and the access roads that either front the parks or directly access the parks. This exhibit shows the nuances associated between physical access and the arbitrary service areas drawn by buffering of the park. These roads serve as the potential points of access when examining the boundaries of the surrounding properties. Looking at Davis Drive Park, the eastern edge borders a railroad, the south and north by private property, all three of which limit the access to the west side. Fred G. Bond Metro Park is an extreme example showing the amount of park bordered by private land in comparison to road frontage.

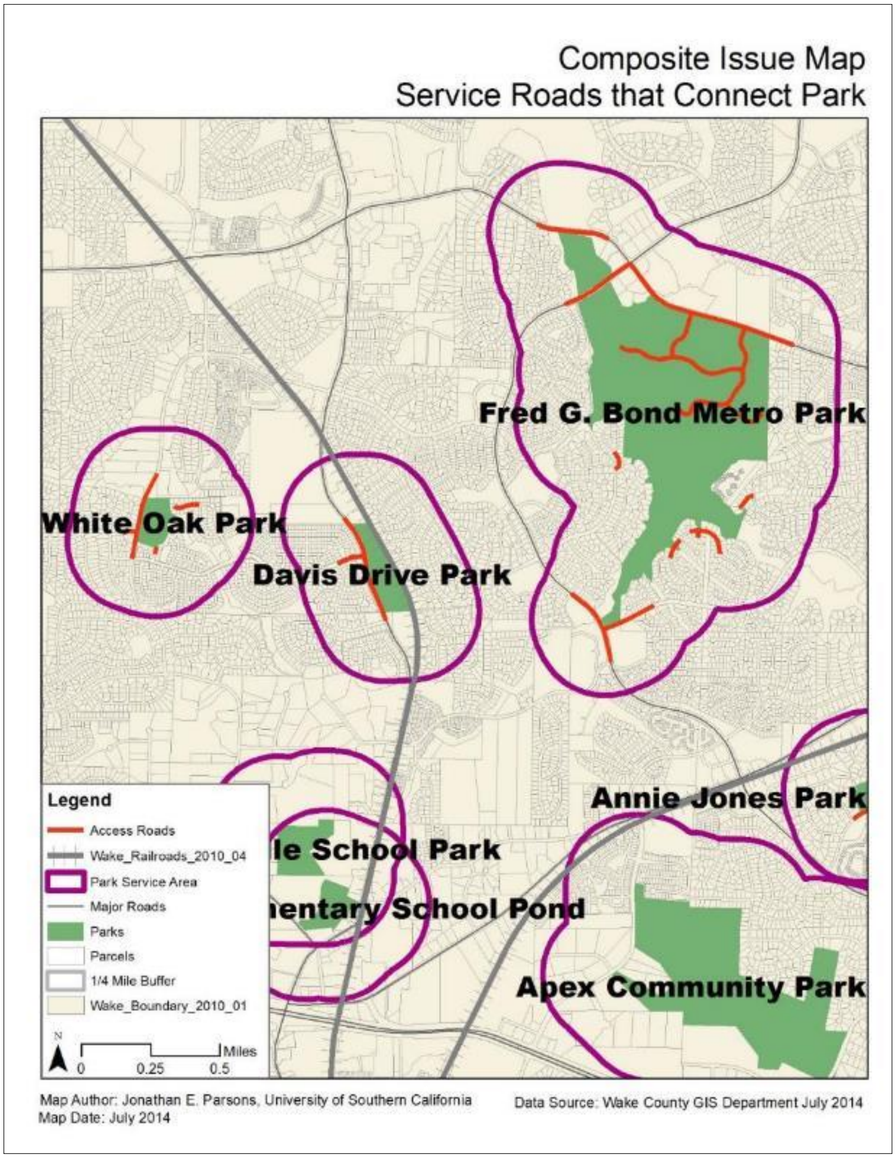



**Figure 3 Example of Buffers Generated from Park Boundaries**

The coverage approach is seen in studies like the LA Green project (Sister et. al 2011). In the LA Green project, the park distribution of Los Angeles County was assessed utilizing the census tract data as the boundaries to evaluate the parks available to those populations of each census tract. Using this approach creates a focused view of parkland by census tract that may or may not reflect how the population circulates within the urban fabric. However, such an approach allows analysts to compare the population data to park data with relatively minor interaction within the GIS environment. This is an important consideration when working with large-scale study areas where detailed analysis may either be computationally prohibitive or the differences in results may be statistically insignificant given the study inputs.

In comparison, the container approach starts from the parks themselves and generates a buffer that serves as an overlay for use in selecting the populations or locations influenced by a given park. In most cases GIS is utilized to generate a fixed distance from either a center point or edge of the park feature to generate a polygon shape. This creates a polygon that is then used to select or exclude data as necessary from the analysis. Nicholls credits the initial coverage workflow to R.L. Hodgart (Nicholls 2001). This is clearly a park centric approach.

The container method often claims to generate service areas for parks. A service area, as a simplified definition, is as a means to generalize the travel distance from the park out into the community into an area that will likely draw users. This is useful in potentially identifying how many of a specific population may use the park (Nicholls 2001; Talen 1999). The typical approach utilized to generate a service area is to create a buffer around the feature of interest, in the case of this study a park. The buffer is generated either from the centroid or from the perimeter of the subject property. The buffer distance is based on the mode of travel being tested, such as walking or driving. (Talen and Anselin 1998; Nicholls 2001; Hass; 2009; Joseph 2011)

To measure the population within the resulting service area, the analyst can then select features based on location, selecting those underlying objects that are within the cover of the service area. For those objects that either are at the periphery or partially cut off, the analyst can calculate the percentage of the population within the service area based on the area of overlap (Boone et al 2009; Nicholls 2001; Tarrant 1999). The coverage approach, when using shapes generated by buffers, is often selected because of the approximation that can be completed for reflecting travel patterns of those populations that may use the park. This approach also follows the park planning guidelines as it allows planners to easily create coverage circles based on park type and size (Talen 2010).

The challenges facing a coverage based on buffers are rooted in the risks of generalization of the ground condition. Whenever a buffer is used there is a risk of generalization whether from spatial estimation or oversimplification of the ground features. The precise dimensions of the buffer is also a factor of whether the analyst uses a centroid or boundary object (Nicholls 2001; Hass 2011). This falls within the realm of the modifiable areal unit problem (MAUP) which is a fundamental source of error when conducting GIS Analysis (Talen & Anselin 1998). This will be covered in further detail within Chapter 4 through a comparison of parcels served as selected through a coverage analysis based on buffers and a selection set based on the Origin to Destination Matrix Tool.

### *2.1.2 Accounting for Physical Accessibility*

Planning doctrine tells us that parks need to be located where they will serve the most people. This typically translates to those sites that can be easily reached by walking or driving (Talen 1997). The influence of physical access on a populations' ability to use a park is a key variable to accurately measure in park accessibility assessments. People will only travel to a destination that provides tangible benefits that exceed the effort in reaching the destination (Tarrant 1999 & Cordell 1999; Nicholls 2001; Hass 2009). This potential is akin to the idea of gravitational pull: the amount of distance users are willing to travel relates to the size and type of park. Larger parks with a larger number of specialized amenities will pull populations from further away. This is noted in planning doctrine regarding appropriate planning metrics for park quantities based on park type and population rates. For example, the Town of Cary located within Wake County, North Carolina reflects this phenomenon in their use-ability assessment by assigning differing travel distances between community level parks and their metro or regional class park (Cary 2012).

It is possible to analyze the actual transportation routes that the target population may utilize to access a given park using a GIS. This physical accessibility is determined using digitized road and park data. The benefit of utilizing GIS to conduct a physical accessibility analysis depends on the availability of the data. While a more detailed overview of the process will be covered in the methods section, the use of network analysis provides a means to calculate service areas maps based on potential travel paths. While no one case represented a complete accessibility assessment in which population data and park statistics are integrated, there are several key points worth discussing in regards to success and potential for error.

In the work done by Nicholls (2001), network analysis served as a means to generate the service area to conduct a traditional coverage based analysis. This approach utilizes road networks to develop the service area for each park based on the access points as mapped by the field team (Nicholls 2001). The roadways approximated the sidewalks and normal paths of travel used by park patrons. Greenways and other footpaths were not included in the study, nor were large regional parks or community centers where vehicles are the primary mode of travel. Parks with multiple access points and derived service areas combined into single service areas using the union tool within ArcGIS. This creates one simplified service area per park for analyzing coverage. This approach is similar to work done by Hass (2009) in testing of the use of Service Area Calculations within ArcGIS Network Analyst to determine regional park access.

Within the Nicholls (2001) study, Network Analyst derived service areas were compared to buffer-generated service areas. In both applications, the respective service areas were generated using a ¼ mile as the distance. The buffer was generated from the boundaries of the parks. The resulting differences between the parks were compared by subtracting the difference in areas between the two coverages as well as sampling the differences in populations. This analysis was conducted using simple, two variable statistical comparisons. This work was done completely within ArcGIS as sampled using the “select by location” feature within arc GIS.

Comparing the two methods of coverage generation revealed appreciable differences between the network analysis and the buffer based coverages (Nicholls 2001). Nicholls (2001) concluded that the largest variable in the difference in area definition was the use of road network to derive the coverage. This created smaller areas due to the types of road networks present within the study area

Nicholls (2001) carried out his study in Bryan Texas. Testing these differences further, a comparison was made between the population sampled from the buffer model and from the traditional coverage model. The difference was calculated at over 8,547 people, a significant difference when considering the accessibility of the people to the population.  When comparing just small neighborhood parks, the difference between service techniques was much smaller, less than 7% (Nicholls 2001).

In both conditions, it is important to consider issues with sampling the population. The census tracts were selected based on the location within the coverage of the service area.  This created the potential for errors regarding arbitrary census boundaries.  This opens the analysis up to the Modifiable Areal Unit Problem (MAUP), as portions of the census block units that are within the coverage may or may not be inhabited, yet still be selected and thus included in the population calculation (Holt and Hodler 2004).  This can lead to miscalculations in the percent in coverage of the population for those people within the service area in both accords.  To correct this, parcel data or physical household locations needs to be utilized to better identify how many people are within the service area.

A secondary issue of this network-based analysis involved the classifications of the road system within the network analysis.  The hierarchy of the roads as stored within the Wake County streets dataset allows classifying thoroughfares that are not conducive of pedestrian circulation, and as residential collector class streets, which are pedestrian, oriented.  The road network was not physically assessed to determine which roads were or were not passable for pedestrian traffic, as this would require significant resources beyond the scope of this study.  This study uses the road generalization to test practical application, a more detailed road network dataset would be needed to account for assessing the nuances of road design that influence pedestrian circulation in the future analysis (Nicholls 2001).

From the Nicholls study, there is a noticeable gap in application of network analysis in determining park equality. The logic revealed in the work done by Nicholls (2001) shows that it is a viable method to consider when detail is necessary for evaluating a park's physical accessibility when compared to the straight line buffer approach (Liu et al. 2014). It also shows that there is further work needed in terms of understanding the relationship of physical and assumed barriers within a community in regards to access and how these may influence the measurement technique.

The most direct influences on access are physical barriers, such as large transportation thoroughfares, railways, and natural features such as rivers and topographic barriers (Lynch 1960). The physical barriers are often easier to define and account for during an analysis. Soft boundaries, such as political or social boundaries, are often more difficult (Lynch 1960; Nicholls 2001; Cary 2012). Network analysis can incorporate a variety of barrier features to reflect on costs or increased weights in order to access a specific park (Esri 2014).

This study accounts for the physical barriers through the classification of the roads; by limiting the road types to neighborhood collectors and residential streets, unsafe pedestrian routes associated with highways and thoroughfares should be excluded. It is also assumed that the road network already facilitates the necessary crossings over water bodies and topographic barriers. How the soft barriers may influence the likely population will need to be explored further. These concerns will be discussed within chapter 5.

The drawback in both the Nicholls (2001) study and a similar network approach tested by Hass (2009) is how the population is measured within the service area district. In both accounts, it is coverage based sampling of the population data. The strength of a route based analysis is the ability to select those addresses, or properties, along a given route that are able to access a given park facility at the distance specified. This is important to consider as an improvement to the Nicholls (2001) and Hass (2009) network analysis techniques.

### *2.1.3 Walkability and the Influence of Routes*

Walkability as a concept is important for determining physical accessibility. The likelihood of a person to utilize a park is dependent on the convenience of accessing that park in terms of cost, or resources necessary, in comparison to the opportunities that it offers (Talen and Anselin 1998). An accepted planning metric is to utilize a walking distance between 0-¼ miles with the total round trip being less than ½ mile for those with small children (Nicholls 2001). The ¼ mile is tied to the National Recreation and Parks Association standards for the distribution of neighborhood parks to be within ¼ mile or less of residents being served and not blocked by arterial roads or other physical barriers. The accepted standards for park area per person is established in research conducted by the American Planning Association and the NRPA, and assesses park coverage on a acreage per person unit (Moeller 2014)

In economic terms, this means the benefit of experience offered by the park must exceed the cost, whether time, energy, or actual capital necessary to reach it. This concept of cost is further complicated by the nature of human activity. In an urban environment, the likelihood of a person to utilize a park is based on its location along the main transportation routes that that person may use on a regular basis. An illustrative example to consider would be how a person travels along an imaginary Main Street to reach a grocery store from the primary residence. A park that is located along Main Street between the house and store is more likely to be utilized than a park that is located beyond the store on the same path. A park located off to the side of the main travel path along a side road would be even less likely to be utilized as the costs to access increases. This is where coverage based analysis breaks down in assessing the potential user-base of a park. While this study is not focused on economic modeling of the transportation network, the importance of understanding the road hierarchy regarding travel paths and how this hierarchy can influence the user group is important whether specific marginal costs and benefits are estimated.

### 2.2. Population Distribution and Dasymetric Mapping

The physical location of residential properties to the park can be overlooked through the generalization of the population data when conducting gap analysis. Current practice has focused on the use of census data aggregated at the level of the census tract or the census block group as the primary means to calculate the people served by a particular park (Tarrant 1999). While this method produces practical estimates, the increasing quality and detail of GIS data warrants the exploration of improving this process to reflect the ground conditions more accurately.

Census Data is inherently a generalization of where people are located within a given community. Even at the smallest scale, or most detailed unit, the census block group, there is a large amount of generalization in regards to actual household locations within the areal unit.

While the differing units of scale can improve the detail of the areal aggregation, the units themselves are still generalizations of the ground plane. This means that locations of houses, apartments, and other residential structures are not specifically known. When doing a distance-based analysis to determine accessibility, population sampled based on area and not on household locations creates concern, specifically in situations that focus on the use of coverage methods.

Such detail may not be necessary at larger regional scale assessments, where a container-based analysis is being utilized to do rough order magnitude assessments. However, there is need for a higher level of detail when considering park sites. The use of a parcel-centric analysis approach is one way to provide such detail. The work by Nicholls starts to set the stage for developing a service area mapping method that mitigates the hard cut-off but continues to use the census data units rather than applying the same level of detail to refining the population mapping through dasymetric mapping (Nicholls 2001).

A means to resolve this is by mapping the population to the ground condition through re-association, or dasymetric mapping. Dasymetric mapping is a process in which an analyst can reassign demographic attributes typically from Census data from one areal unit to others based on determinations from alternative map layers. In the case of population, with appropriate cadastral data layers, it is possible to reassign the population based on the total residential tracts within specific census unit using either lot area or housing units as means to determine the ratios.

Maantay et al. (2007) proposed a technique for modeling population density against the urban environment using the parcel data to provide density that is more realistic and location based maps. The system, referred to as the Cadastral-based Expert Dasymetric System (CEDS), projects the census population information onto the target parcels, aggregating the population based on the size of the parcel divided against the total area of all of the parcels within a given census unit. Within the CERD, where the parcel intersects multiple census areas, a calculation is conducted to add the population proportional to the coverage. This approach works within existing GIS data as opposed to the raster based approach proposed by Langford (2007), in which the underlying subject area is rendered at a value per pixel rate, with which the total is then calculated by means of sampling the pixels within a given selection area.

In this study, a similar concept is proposed to Maantay (200, but instead of doing a strict areal conversion, it will be possible to assign population based on the household units per parcel. Wake County GIS maintains an active database for all of the property within Wake County with attributes that depict residential uses, structure types, and total number of household units on a given parcel (WakeGIS 2014).

### 2.3 Measurements of Park Availability

The measurement of park availability is divergent in the literature. Depending on the source, availability is either measured by the number of parks available within a given service area (container method) or the amount of parkland available per person is measured in regards to the geographic area covered (coverage method). This creates a challenge when determining the most appropriate metric to utilize.

There are benefits and drawbacks to each approach. The initial response may be to provide a tool that calculates both as that will ensure flexibility for the analyst in terms of final output.

Within the planning community the guidelines for park planning is to provide a minimum of 10 acres of open space per 1000 residents square feet per person as noted by the National Parks and Recreation Association (Nicholls 2001). This measurement is assumed to provide the diversity necessary to encourage active play and recreation when influencing a healthy lifestyle (Lindsey et al. 2001). This standard is also compounded by the need to provide a diversity of facilities within a given system (Moeller 2014). However when there is only one park available within a given distance, this may have a negative influence on diversity (Sister et al. 2007). Appropriate methods for determining the area per person available require developing a means to isolate those people within the park service area accurately.

In contrast to the area-per-person metric, some metrics on the number of parks available to a given community (Moeller 2014). By counting the number of parks within a given community, an analyst has a means to evaluate the potential diversity of the park system within that community. This is an important consideration as in a community. With one single large park, there are benefits to the larger space. However, there is only one facility, whereas, by including neighborhood parks of varying size and character, communities may offer users a more diverse experience.

Both aspects of park measurement must be considered when assessing a park system. From a planning perspective, having numerous small parks in a specific area will show a high level of accessibility if utilizing a count based criteria. However, using a count based criteria in conjunction with an area per person based counting would allow for a park system to be evaluated more effectively since the system is being evaluated for both the potential diversity of location as well as overall quantity of space available.

How these two data points are stored within the final database can help lead to further analysis when elements such as park facility types and quality of these facilities integrated into an overall database.

Social access is a measurement of the diversity of people served by a specific park. This type of access would include measuring factors such as age, ethnicity, and economics. This study is focused on physical access and how parcels access parks; exploring the distance and uniformity of this relationship. Determining the mode of travel guides the direction of the analysis in regards to search area distance from a park. This form of areal analysis defines the service area of a park**.** The mode of travel, whether by bike, car, or walking, can also influence which residents are able to access the park (Tarrant 1999; Heckert 2013). How accessibility is measured will have great influence over the planning of the park system.

### 2.4 Limitations of Existing Park Accessibility Models

Within GIS, the creation of digital representations of spatial phenomena can create generalized and even arbitrary representations of real world conditions. The coverage-based analysis method in itself is an arbitrary means of analysis often based on political or social boundaries. These boundaries based on geographic features, roads, assumed break lines between changing values, or any combination of other factors. Both the coverage and container methods are susceptible to the Modifiable Unit Area Problem (MAUP) as they create a generalized if not arbitrary approach to determining the access to the park.

Physical access routes will not always correspond to container analysis and coverage based service area measurements. Accessibility studies often assume that all sides of the facility are open and clear, with access available from all of sides. This accessibility assumption is not always true due to physical constraints on the ground that prevent ready access to the park facility along sidewalks and public rights of way (Moroko 2009). In an extreme example, research testing the accessibility of users to a specific store found that while the buffer map distance measured 4,500 feet, the actual travel distance approaches three and a half miles (Nicholls 2001; Clift 1994). The other challenge of the buffer approach is that it creates a sharp cutoff instead of a decaying parameter.

The concept of a decaying parameter is important as some park users may be just a fraction beyond ¼ mile, but within the GIS analysis, but this user would be cutout from the population assessment. It may be more appropriate to use a multi distance buffer as an approach to evaluate park accessibility across the region (Hass 2009). A multi-distance buffer analysis could allow for a ranked assessment of users that is more reflective of the real world user base for a park. With Geographic Information System software, network analysis can be used in place of buffering as a more accurate means to measure physical access to a specific park. Road and greenway data serves as route data to measure the actual ground path from residential areas into the park. Using point of origins, destination points, and routings, allows ArcGIS Network Analyst to calculate accurate travel distances between parks and residential areas for use are origin-to-destination analysis (Esri 2014).

It is also possible to assess the overall distribution of parkland per person as a method to determine if there are adequate resources to facilitate access (Boone 2009; Sister Et. al 2009). This may serve as a first step in analyzing the equitable distribution of parkland per person within a given geographic region. Historically this has been used to evaluate current park and open space inventory and to project future needs on a broad scale. Having a concise means for measuring access from the parcel to the parks would allow for quick assessment of availability.

A second challenge to the traditional method of physical assessment is the need to evaluate the different types of space within the system and to compare these to the overall distribution. To blanket an area with facilities based on purely a geometric basis will lead to inequality, as the facilities may not correlate with the target users (Nicholls 2001). People need to have access to a variety of public spaces to adequately serve their social and cultural needs (Burgess et al. 1988).

### 2.5 Summary

In order to understand the parcel-to-park relationships, analysts must be able to accurately measure whether populations in given residential areas can access a specific park. Proposed measurement techniques need to be scalable allowing for regional analysis. How these measurement techniques function in terms of calculating the social and physical aspects may greatly influence the perceived results of an accessibility analysis (Hass 2009).

This study is concerned with how the influence of the physical access can limit the ability of populations to access a given park. While this physical access has a direct relationship when conducting a detailed park-by-park analysis, GIS-based analysis tools can allow this physical analysis to be conducted across a regional scale, as demonstrated below. This would allow for evaluating the overall success of the parks and open space element of a plan in serving residents across a large area.

# CHAPTER 3: METHODS AND DATA

This study proposes a method to measure the uniformity of park access by quantifying parkland available within a given distance to a residential parcel.  This cadastral method will depart from the container and coverage based methods by completing this measurement for all of the residential parcels within a given community or region.  It would allow analysts to review the uniformity of park access based on the physical relationship, mitigating the challenges of using more generalized approaches as noted in the literature review.

Measuring this relationship between parcel and park will be accomplished by utilizing network analysis procedures to quantify the distance between the physical access points of the parks and the physical locations of residential properties.  Residential property information is often stored within the cadastral data maintained by municipalities as a means to track tax information and map infrastructure requirements. Developing a workflow that is repeatable and scalable with commonly available data will be key for this technique to be utilized by parks planners and municipal leaders.

The techniques and data used to complete the cadastral-based approach will be discussed in this chapter.  The discussion is organized into the following sections: 1) Method framework and variable definitions, 2) Network Analyst overview 3) Workflow development and obstacles, and 4) Methods for presenting results.  The first subsection will discuss the overall framework, describe the key variables needed, and introduce the formulas necessary to calculating the desired outputs.  The workflow development and data overview sub-section will present the sequence of work necessary to demonstrate the measurement technique including the use of model builder and the manipulation of the input data necessary to incorporate it into the workflow. The final sub-section will describe how the workflow outputs were compiled into the final analysis maps and measurements.

While the use of Esri model builder will be necessary to assist in developing automated sequences for executing complex and repetitive workflows, the focus of this study is on testing the practicality of the proposed measurement technique, rather than developing an application per se. How the various model steps operate with the data will be described in terms of inputs, parameters, desired outputs, and linked to summary formulas. Long term, the development of a comprehensive tool that automates the entire workflow would expand the potential for deployment of the technique across varied scales such as statewide or citywide analysis; the merits of this are discussed in the conclusions chapter.

### 3.1 Method Framework and Variables

The proposed measurement method generates a cadastral-based assessment of the uniformity of access for parks within Wake County, NC. Successfully developing and executing the workflow required completing following stages: 1) Extract the residential areas from the parcel data; 2) Map the locations of park access point; 3) Assign population to the parcels using census data; 4) Quantify the amount of parkland available to each parcel per person; and 5) Output the information for review and assessment. Figure 4 illustrates the proposed workflow, identifying the two main processing tasks in parallel columns. The left column illustrates the work needed to process the park data. The right column illustrates the processes for the parcel preparation.

The ArcGIS tool Network Analyst was used as the primary tool in evaluating the final

park access. Using Network Analyst requires several steps to be completed that will be discussed in the following section. Network Analyst was selected because of its ability to work with the existing data within ArcGIS, a common industry tool for conducting spatial analysis such as park accessibility.

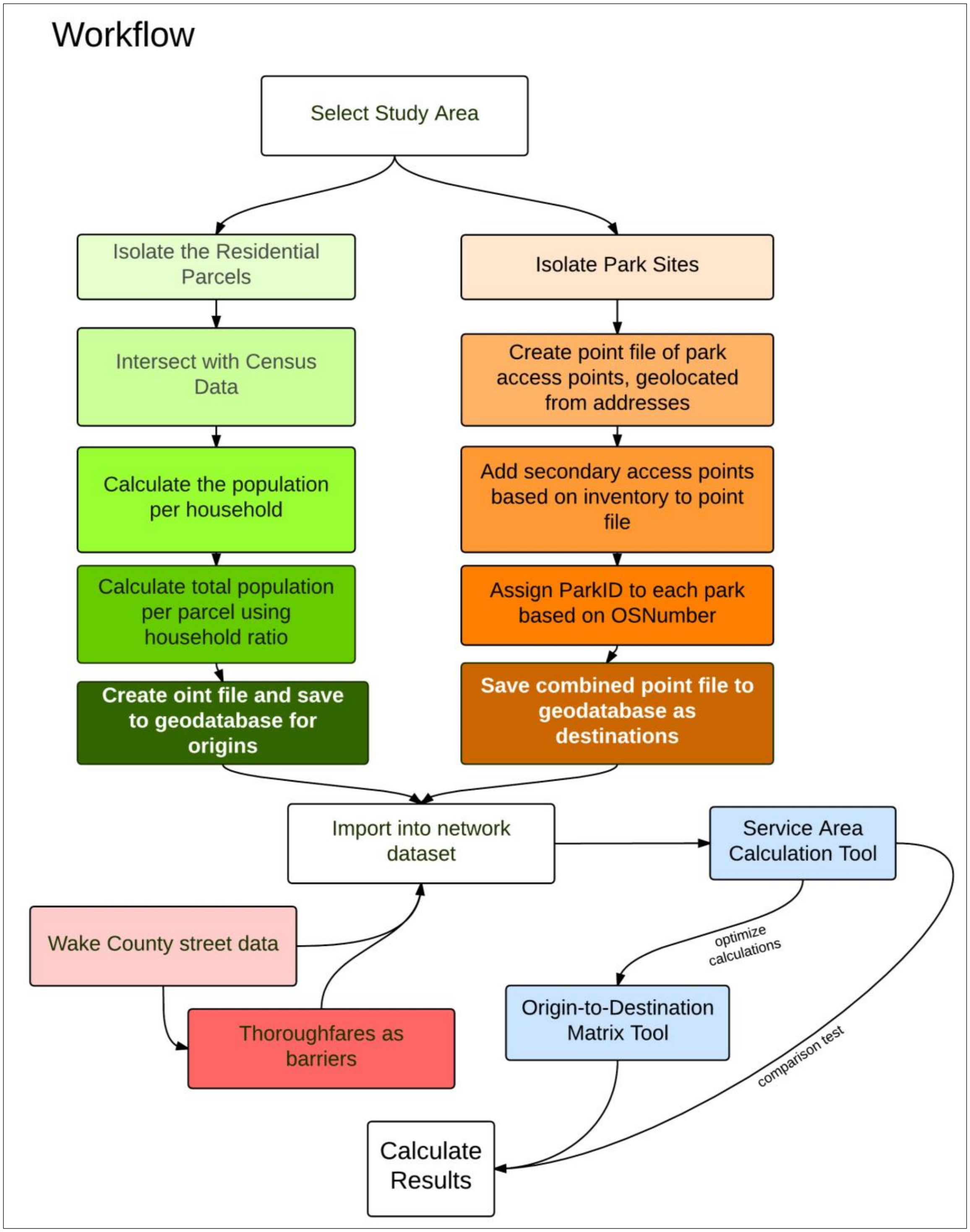



**Figure 4 Workflow Diagram Illustrating the Cadastral Based Uniformity Assessment**

### *3.1.1 Output Products*

The desired outputs of the workflow included both feature data sets and data tables. The tables were key outputs that provided the summary information necessary to generate the final accessibility maps based on the compilation of population data, parkland area, and quantity of parks at a parcel-by-parcel level based on the ¼ mile walking distance. The cadastral-based apportioning of parkland by parcel allows planners to evaluate park system accessibility based on the area of parkland available per parcel within the specified search distance. For this analysis, three primary maps were selected for rendering: population density, quantity of parks per person and acreage of parks per person.

Generating these maps required the output data table to be combined with the parcel feature information through a join process. Joins are a technique within ArcGIS that unite the data from one table to another based on common attributes. While the three primary maps were generated from the processed data, a fourth map was also rendered that utilized the raw data accumulated from the Network Analyst solution of the origin-to-destination matrix table (ODMT). To construct the ODMT the parcel data needed to be combined into a summary table that calculated the distances to the parks based on the original Parcel Identification Numbers (PIN). This summary table tabulated each park within ¼ mile based on the PIN, allowing for a review of the closest park and total number of parks to each individual parcel. Summarizing this output table based on the PIN then created a final output table that totaled the number of parks per parcel and a total sum of acreage of park per parcel. The latter of these values serving as the final variable to conduct a calculation of acreage available per person based on the parcel populations.

### *3.1.2 Data Sources*

Utilizing parcel data within the workflow is important in identifying the locations, walking paths, and distances for residents to reach parks in comparison to the generalized areal units of census blocks and tracts. While the parcel data in itself may be limited in the level of detail, the modeling approach accommodates a method for relating the census data to the parcel data to allow for joining additional data points such as demographics, income information, and population statistics depending on the type of follow-up analysis desired. The steps necessary for completing the dasymetric mapping of the population to residential areas will require a specific subroutine within the model. The following sections discuss this. Assigning the population per parcel will allow for assessment of parkland at a per person level if the model is successful.

A key aspect of this study involves departing from a Euclidean geometry based approach and focusing on the use of physical access paths. Euclidean geometry, as discussed in chapter two, forms the basis of containers generated from fixed distance buffers used to represent the service area of a park based on the study distance selected. The fallacy with such an approach when working within the built environment is consideration of how travel routes follow the built road network instead of following a simple point-to-point straight line calculation that may overlook issues such as geographic boundaries and physical influences such as hydrology and topography. To measure physical access to parks, it is important to employ network analysis techniques utilizing physical walking paths that reflect the ground condition in terms of how people will access the park.  For this study, the road network will serve as a surrogate for the pedestrian network to test the model routine.

The core functionality of ArcGIS accommodates the workflow needed to assign population based on parcel location.  The primary tools utilized within ArcGIS are "select-by-attribute," "select-by-location," "join," and "summarize."  The select-by-attribute tool selects the features, or objects, based on specific values.  For this study, the target values identify residential parcels with one or more housing units.  The select-by-location tool allows for selection of features that are within a specified straight-line distance buffer from the source object.  The select by location tool also selects target features that intersect a source feature.  The summarize tool generates output tables that totals, averages, and calculates the standard deviation of the individual features, grouping them by common features.  This study uses parcel identification numbers and unique object identifiers to facilitate the generation of the summary tables.  Beyond theses built-in capabilities of the base ArcGIS implementation, a network analysis tool is needed in order to study the travel distances between the facilities and residential properties, ArcGIS Network Analyst is used to measure route information.  The necessary data for completing this analysis is sourced from Wake County GIS.  Table 1 provides an illustrative link between the source data acquired from Wake County GIS Department and USDA and the target variables.

**Table 1 Source Data and Output Matrix**

| Feature Class | Source | Variable-fulfilled |
|---|---|---|
| WakeProperty | Wake County GIS (WakeA 2014) | Household Units |
| CensusBlockGroupData | Wake County GIS (WakeB 2014) | Total Population |
| WakePublicOpenspace | Wake County GIS (WakeC 2014) | Parks |
| WakeStreets | Wake County GIS (WakeD 2014) | Travel Routes |
| WakeMjrRoads | Wake County GIS (WakeE 2014) | Route Barriers |
| Aerial Photo | USDA 2012 | Visual locating of access points. |

## 3.2 Key Variables and Formulas

The development of the cadastral-based access measurement depends on calculating three key variables. These variables are total population per parcel, total parkland per parcel, and total parkland per person. The following subsections provide an overview of how these variables are calculated. These formulas serve as a foundation for the functions within model builder.

### *3.2.1 Total Population per Parcel*

Total population per parcel was defined by combining the US Census Data Census Block Group Data set, CensusBlockGroupData, and the cadastral data maintained by Wake County GIS Department. The first step prior to calculating the population information was linking the census data to the parcels using a spatial join. A spatial join allows for all of cadastral data intersecting the census unit to be assigned that unit's unique identification number. This allowed for grouping of the parcels within the cadastral layer and totaling the household units within the individual census units. The final output is a table of household units per each census unit and the number of parcels within that census unit.

Calculating total population per parcel requires three variables to be resolved: total population per block, total household units per parcel, and total population per parcel. Equation 1 shows a view of how the final calculation is resolved to create a total population per parcel. Understanding this relationship between the total populations of the block to the covered parcels allows for an accurate aggregation of population data to the parcels based on the household units. This approach builds upon on the dasymetric processes proposed by both Holt (2004) and Maantay (2007), but moves from areal aggregation to household units. This study also crosschecked the individual block totals in aggregation to verify that the final total matched the 2010 Census estimate for the overall population of Wake County.

**Equation 1 Population per Household**

$Ph = \frac{\mathrm{Cp}}{\mathrm{Th}}$ with variables as follows:

Ph= Population per household

Cp = total population per census unit

Th = total households per census block

To derive the population per household rate, the data needed to be combined allowing for all of the households within the census unit to be totaled together. Figure 5 shows the model developed to calculate the households per block. Once totaled, the number of households was divided into the total population of the census unit to derive the ratio for People per Household for all of the parcels within that census unit. This allows the calculation to scale to the level of detail available regarding population data. Once completed, the population per household ratio can be applied back to each parcel, as shown in Equation 2 to calculate the total population per parcel.

**Equation 2  Calculation for Total Population per Parcel**

$Pp\ = Ht * Ph$ Population variables as follows:

Ht= total household units per parcel

Pp = Population per parcel

Ph = population per household

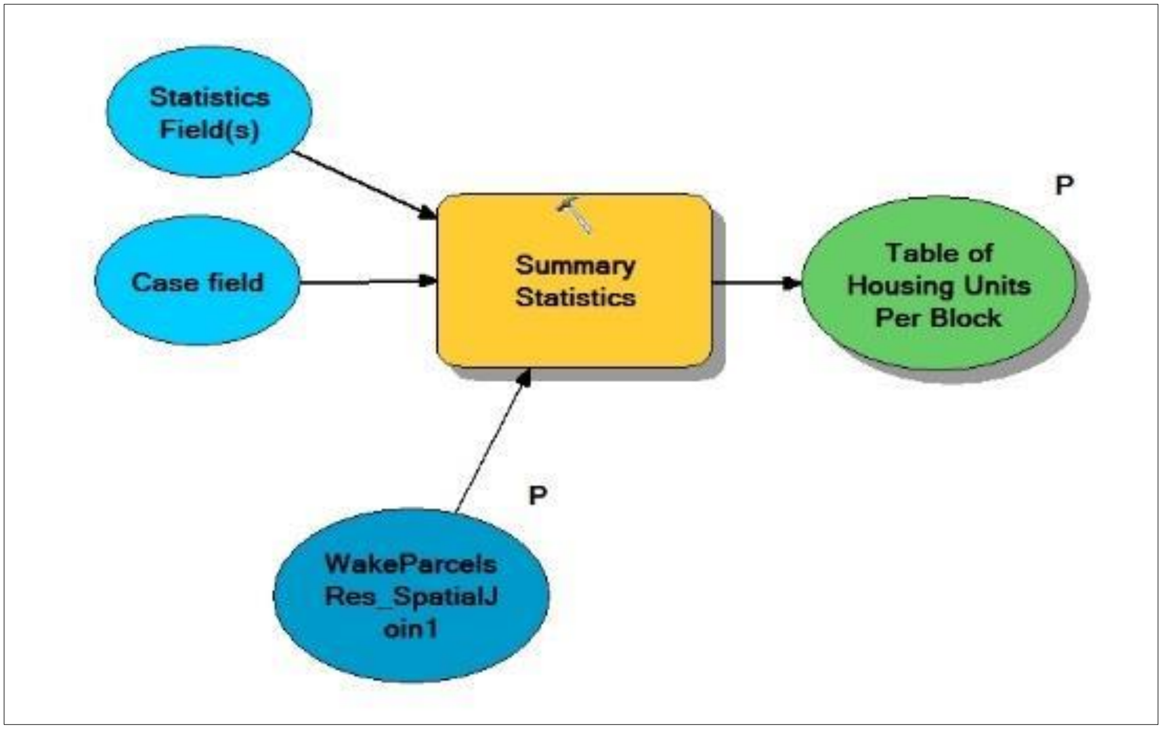



**Figure 5 Model Showing Household Unit by Census Unit**

### *3.2.2 Total Parkland per Parcel*

Total parkland per parcel is defined by the total parkland area, in acres, within the search distance of the specific parcel. Parkland area is contained within the Wake County Parks inventory file and is based off deed acreage. Parkland per parcel is calculated by totaling the acreage of all of the parks within the search area. Using Network Analyst, this was a two-stage process to generate the table. The first step was to running the ODMT to extract a solution table that had the OriginID, DestinationID, and Length as attributes for all parks within ¼ mile of each parcel. The OriginID represented the parcel, and the DestinationID represented park access points.

**Equation 3 Total Parkland Per Parcel**

$$Tpl = P(n) + P(n+1) \ldots with\ variables:$$

P(n) = park within search distance of Parcel(i) and is repeated for all parks found within the search distance for each parcel.

Tpl=Total parkland

### *3.2.2 Total Parkland per Person*

Total parkland per person will compare the total population per parcel to the total parkland per parcel providing the analyst with a ratio of the available parkland per person for each parcel. This will allow a final gap analysis to be generated. While this step can also be handled utilizing symbology settings within choropleth mapping, it is also important to extract as an output table for further calculations and for those park planners not able to work within GIS.

**Equation 4 Parkland per Person**

$$PLp = \frac{Tpl}{Pt} \mathit{with\ variables\ as\ follows}:$$

PLp= Total Parkland per person

Tpl = Total parkland per parcel

Pt= Population per parcel

### 3.3 Application of Network Analysis

There are several options available for conducting network analysis research. Esri offers the Network Analyst Extension within ArcGIS. This extension provides planners a means to evaluate multiple questions based on route data and facility information, such as the quickest route to a location, which locations are within a specific distance of an origin, and what service areas are available to a specific business (Esri 2014). While originally developed to conduct retail market analysis for both the logistics and facilities development aspects, the same criteria can be applied to evaluate park accessibility.

Network Analyst offers two key tools that were utilized in this study: the "Origin-Destination Matrix Tool" and the "Service Area Calculation Tool." The Service Area Calculation Tool generates a polygon based on the specified distance that is measured from an origin point outward along the available routes at a specified travel distance. This measurement can be conducted with or without vertical elevation data, allowing it to function at varying levels based on the quality of the existing data. The resulting polygon is created by connecting temporary vertices that are generated at the intersection of the search distance on the available route. The detail, or level of refinement to the output polygon is controlled within the tool parameters and is useful in modifying how the output shape reflects the surface condition (Esri 2014). For this study, the refinement was set to 150 feet, allowing for a polygon output that accounted for the varying widths of right of way and variability in lot sizes. Running this tool for the entire county created a series of polygons that were used as a preliminary test to serve as a benchmark evaluating the outputs from the Origin-to-Destination Matrix Tool. The service area tool was utilized as part of the coverage-based analysis utilized in the study conducted by Nicholls (2001).

In contrast to the service area tool, the Origin-to-Destination Matrix Tool (ODMT) generates a set of output lines and a data table that measures the route distance between a set of origin points and a set of destination points. This tool is primarily used in logistics planning when determining the influence of how destination locations can be manipulated to determine where new facilities would best serve the business. This study utilized the ODMT to map the distance from residential parcels to the parks based on the location of the park access points. The ODMT offered the ability to link specific parcels to specific parks.

This approach offered the opportunity to conduct an exhaustive system-wide analysis of the resources available to each parcel depending on a specified search distance. This also allowed the study to deviate from the container approach, as it would allow for a more detailed analysis of real world access from parcel to park as well as the potential to assess open space at a parcel or even person level.

Network Analyst requires three basic components to run the different routing solutions. These components are facility locations or origins, travel routes, and destinations. These different feature classes were loaded into a geodatabase. More details on the development of the geodatabase, including the isolation of park and residential parcel shape files, are provided in Section 3.4 below.

Once within the database, the files were associated within a network relationship. The network relationship then allowed the components to be loaded within a Network Analyst layer for processing (Esri 2014). Prior to loading the data, the facility and destination locations were converted to point information. The route data needed to be converted into a network using the integrated data import wizard found within the Network Analyst Extension (Esri 2014).

Facility locations for both parks and parcels were stored as point information within the network feature class. Developing appropriate methods for both the parcel point location and the park information to define these access point locations will influence the outcomes of both the Service Area modeling and the ODMT. Details on how park access points were determined are provided in section 3.4.3 below. For example, single family homes are located within the center of the parcels based on development guidelines as established in the Wake County Unified Development Ordinance. Multi-family and Condo developments follow a similar methodology in order to accommodate required public service and parking space.

### *3.3.1 Details of Network Analyst*

The route information needs to be compatible with the requirements of ArcGIS Network Analyst. These requirements are focused on how the data is input into the feature set. Consider how a road network may be digitized into the data set. The road has a start and stop point. These two points will coincide with intersections. Within network analysis, these intersections are nodes. It is imperative that the segments for roads are continuous between nodes, without breaks in the lines. It is also important to ensure that there are no redundant or incorrectly drawn line segments within the route data (Esri 2014). These elements influence completion of the ArcGIS Network Analyst tools. The route input wizard will assist the user in checking the data for potential conflicts in the data for review and validation.

During the execution of the ODMT, there were inconsistencies in completing the solutions. There were two conditions observed that affected the completion: the number of possible solutions and inconsistencies in the route data. Repairing the route data to function within the analysis required using the rebuild option within Network Analyst. This rebuild was accomplished by making a complete copy of the route data and removing duplicate and unnecessary vertices and route lines. Crosschecking of this data was then done by reviewing the provided output file that captured the removed vertices and lines against the original data set.

### 3.4 Data Selection

Data used within this study included US Census Bureau Census Block Data, Wake County parcel data (WakeA 2014), Wake County parks data, Wake County streets data (WakeB 2014), Wake County major road data (WakeC 2014), and aerial photography from the US Department of Agriculture Natural Resource Conservation Geospatial Gateway (USDA 2012).

US Census Bureau Census Block Group data was utilized because of its fine level of detail and correlation with parcel data, allowing locating neighborhood scaled phenomena regarding population density and social makeup (Tarrant et al. 1999). The average block size contains information for between 250 and 500 housing units.

### *3.4.1 Parcel Points*

The Parcel data was first culled to locate the residential information. This was accomplished during the execution of a model that selected all of the residential property based on the use codes for the parcel. This is shown in which shows the process for selecting the residential data, completing a spatial join to assign the census data to the parcels, and generate an output feature class that has parcel number and census id number. Once this tool was executed, the centroids for each parcel were generated to create a point file representation of the parcels for loading within the network data set to use in the ODMT as origin information.

The cadastral information, stored as feature class WakeCountyProperty contains all of the attributes maintained by the Wake County Tax Administrator's Office in addition to the desired criteria for identifying parcel size, housing units, PIN, and current use. Using the ArcGIS tool select-by-attribute, all of the residential parcels can be selected from the overall parcel database based on the use codes. Once these parcels are selected, they were exported into a new feature dataset within the file geodatabase and the stored attributes to those necessary for park system analysis. The desired attributes include PIN, Owner Name, Owner Address, Calc_Area, Value, APA_USE, APA_Type, and TotalUnits. To separate the selected residential parcels from the overall parcel data set, a new feature class was made from the selection and named "ResidentialParcels" within the study geodatabase. While this step may not be fully necessary on more sophisticated computer hardware, this isolation was conducted to improve the processing speed of the workflow by reducing the overall dataset size for use with the existing computer hardware.

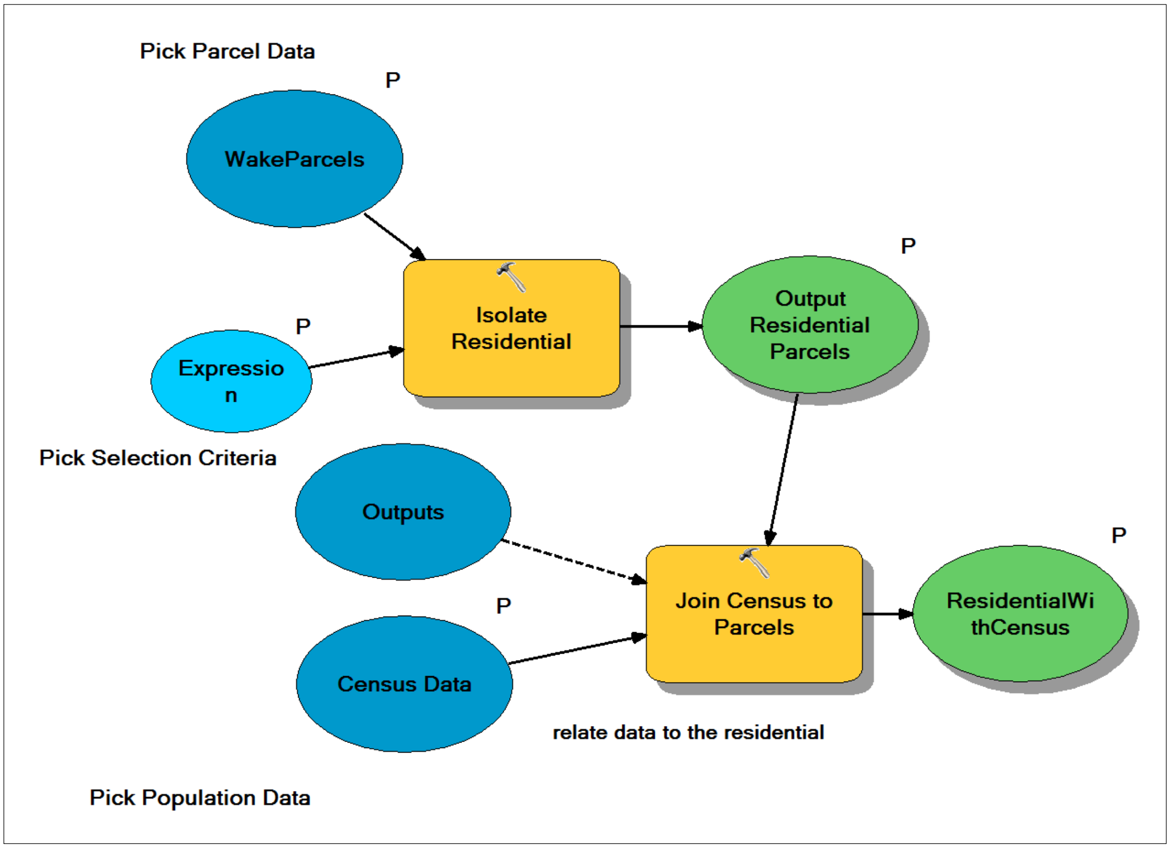
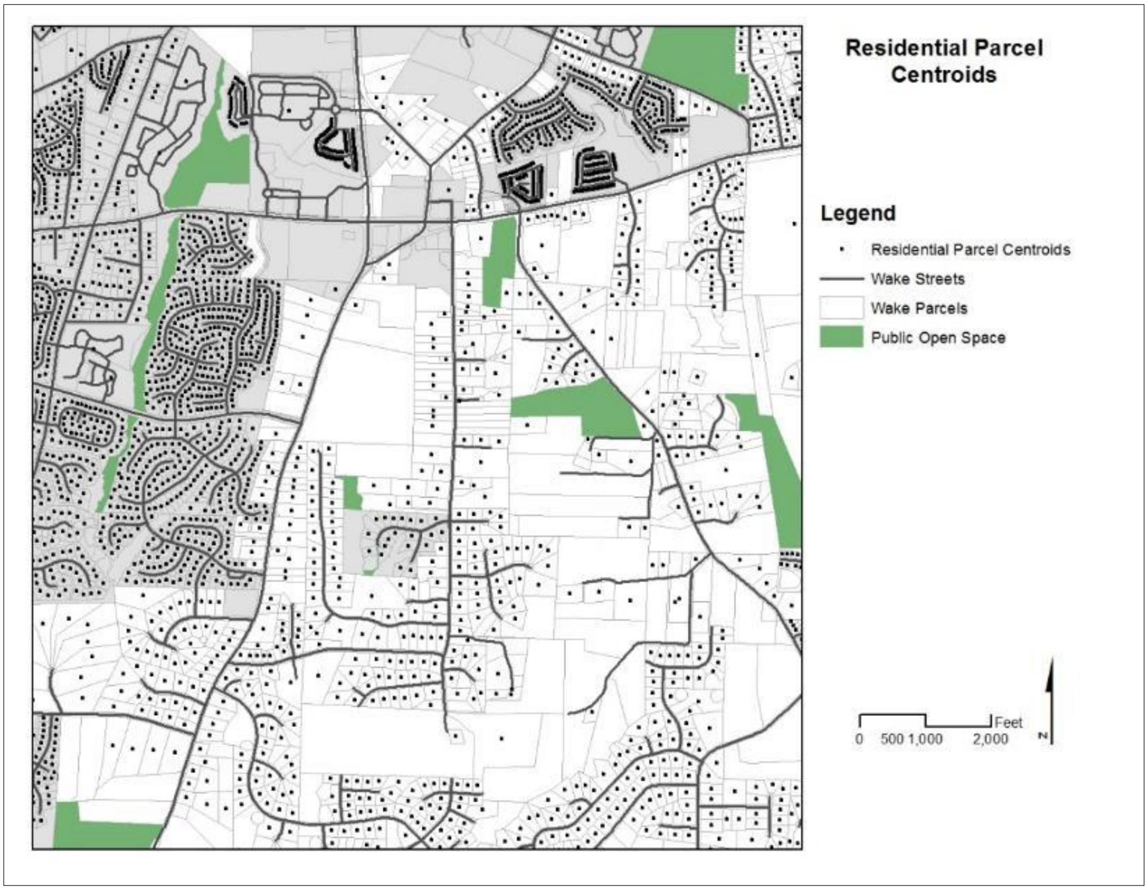



**Figure 6  Model for Isolating Residential Parcels and Joining Census Data**

The composition of the Wake County development pattern is predominantly suburban single-family homes. Figure 7 shows a view of Wake County focused on the area south of Raleigh, NC demonstrating the output of the Points-from-Feature tool within ArcGIS. These points were used as origins in the ODMT. While it would be even more accurate to locate each origin point at the road frontage, the use of centroids approximates where the location of the residential structure is within the parcel. The smaller the lot, the less influence there is in using the centroid approach.

**Figure 7 Residential Development Pattern of Wake County, NC**



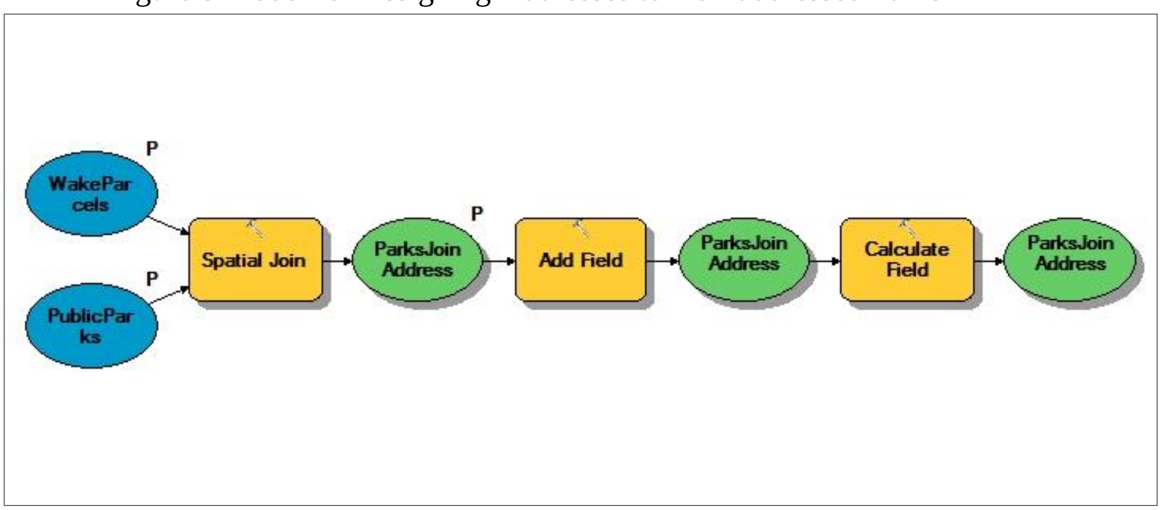

### *3.4.2 Park Data Preparation*

The Wake County GIS department maintains a countywide parks and open space database and 268 of these features are distinct parks. The parks were isolated from the other types of open space based on the "park type" attribute contained within the dataset. Parks were focused on because of their clear assignment, future work will need to review the classifications of the other types of open space within the data set to add those features to the park inventory that serve as recreation facilities. Using the resulting selection set, facility location points were created for the park features to serve as destinations within the network analysis.

Creating the park points was a major decision path in the analysis as not all parks have street addressing, preventing a simple automated approach for assigning park access points. This study tested several different methods for automatically creating access point locations including the use of geocoding to assign points based on the known street addresses and hand locating the unassigned parks, using intersections surrounding the parks to generate access points based on proximity of the roads, and assigning points where roads physically intersected the parks.

City parks will have access potentially on all four sides while suburban parks may have access only on one side based on both hard and soft edges. While this will be more visually apparent when running a service area solution through the polygon output, the origin-to-distance calculation may not reveal incorrect routings. Using the centroid of the park is not desirable, as it will negate the effectiveness of this study outlining the issues of physical access through a network-based analysis. Figure shows the workflow exported from model builder to assign address based access points to a park Access layer.

Figure 8 Model for Assigning Addresses to Non-addressed Parks




### *3.4.3 Resolving Park Access Points*

A systematic approach for determining park facility pedestrian access points proved challenging for this study. Within Wake County, there are several park types typical of a modern open space system. Like other large counties, Wake County has tight clusters of urban areas surrounded by large swaths of suburban development. The variation of the parks includes size, type, and class. Size and context were the two main aspects that challenged development of a systematic approach.

Size was a major hurdle for using the centroid as a potential destination point. Using the centroid of the property to place a location point in the middle of a park larger than 2-3 acres, such as Fred G. Bond Park in Cary, a 3,000-acre park shown in Figure 9 below can lead to false measurement when generating routing from this location point outward into the community. A park this size has an entry drive that exceeded ¼ mile just to enter to the park. While this was an extreme example, it required additional considerations in how the points where located. Beyond the area of cover, the configuration of the park also had to be considered when establishing access points. Several linear parks were found within the county; these parks are long and narrow with diverse access points.

The contextual location of the park was also of concern when locating the access points. Wake County has a variety of development patterns ranging from rural residential to a dense urban form. In the urbanized areas within Raleigh, NC, the parks tended to have roads surrounding the perimeter of the park, often with three to four sides offering multiple access point opportunities. In contrast, parks that were located out within the county proper were typically located within a cluster of residential properties with limited access points typical of the cul-de-sac development suburban style. Neither configuration offered a simple formula to generate appropriate access points.

Figure 9 shows Fred G. Bond Park located in Cary, NC. This park is a large metro park within the Town of Cary. The access points for this park are located along the north edges of the park, while the surrounding residential areas are located to the south, east, and west. Residential parcels that block access to the park from the south, east, and west sides line the perimeter of the park.


**Figure 9 Map of Access Points at Bond Park**

### *3.4.4 Systematic Approach to Locating Access Points*

To assign the access points of a large park like Bond Park shown in Figure 9 , the access points need to be directly located at the physical entry points in order to capture the potential users of the park. Erroneous points needed to be prevented by avoiding false point creation around the remaining perimeter of the park polygon. With the residential parcels directly adjacent to the park, access along the south, east and west sides would not be possible without traipsing through private backyards. To account for this "soft edge" required checking the outputs to verify no false points were created. An approach like this was required for all suburban, cul-de-sac style parks. The main entrance point was established and soft edges were eliminated as viable access.

While large parks posed, one challenge when mapping the physical access, so do linear parks, a type of park that is common in Wake County, NC. An example of this is shown in Figure 10, demonstrating the pair of linear parks, Forest Park and Wells Park, within Raleigh, NC. These parks are linear and help demonstrate a second issue when trying to develop an automated approach to assigning the access points using park centroid. If this study assigned the park access as the centroid for forest park, there would be over 300 linear feet from the center to the tip of the park. In a condition like this, 300 feet represents over a third of the walking distance of a ¼ mile distance.

To combat the problem, access points were defined at the main intersections surrounding the park, this allowed for a more accurate interpretation of the access locations when running the solutions through Network Analyst. If this park were located in a suburban area, limiting access to one or two sides, the number of access points would be reduced to reflect only those points that the public can access, not edges bordered by private property.


**Figure 10 Defining Access for Linear Parks**

Three steps were utilized to assign park access points while accounting for the difference in the park sizes and configurations.  The first step was to identify the frontage roads for each park; this was accomplished using the "select by location" tool within ArcMap to capture all of the streets within 100 feet of the park edges.  The frontage roads were also exported to a new feature class for reference.  The "intersect" tool was then utilized to capture the places where the frontage roads cross the park parcel, the "output_to_point" option was utilized to generate node points at all of the intersections. Through exploration, it was possible to expand the search radius of the intersect tool to capture the road nodes closest to the property corners at edge.

Once the execution of the intersect tool was complete, a second series of points was added to the newly created access point feature class by using the  geocoded street addresses acquired through the parcel information.  The address information proved to be inconsistent in terms of completeness and required a spatial join with the underlying parcel data to provide a complete address list.  The address points were added to supplement the initial points as they provided locations associated with the street address of the parcel, in some cases the midpoint of the street frontage of the large parks, and in most instances the primary entry points.  This step was also necessary, as in several instances a quality control review of the points was completed, the geocoded point became the only viable access point in several instances.  The access points were stored with attributes for ParkID to capture the Park ObjectID from the WakeCountyOpenSpace feature class.  This allowed the data to be joined back to the overall database to acquire acreage information and park name information.  Both stages of point generation developed a large dataset depicting over 1,508 potential access points for the 308 park sites.

Visual inspection of the resulting output was conducted to determine the effectiveness of the assignment technique. While it appeared effective, several parks were found to have incorrectly assigned access points. An example of this occurred at ParkID 92, where the intersection tool captured points at the corners of the park that were not accessible by car or pedestrian. To accommodate for this, parks were inspected using the aerial imagery to evaluate the location of the automated points in comparison to the physical entry points. A new feature class was created titled "Access." Within this feature class, the physical access points were added for the parks based on three rules: vehicular entry points, sidewalk access along the perimeters, and greenway access. Greenways are pedestrian trails that are located off-road. These trails are not currently digitized in the same manner of the road networks, lacking the vertices and directional information found in the base road data. In addition, the base greenway data also lacks information regarding the entry points to the greenways and locations where the greenways can access the parks. Locations that were identified during the access point analysis that appeared to have greenway access were stored within the data set as they could be incorporated into future work assessing the influence the greenways could have in the gap analysis and improving access to parks. The greenway features and the greenway access points were not included in the ODMT, removing them from the results.

### *3.4.5 Preparing the Census Data*

The US Census Block Group Data represents the smallest scale data available for analyzing population data. This level of detail is desirable when conducting a physical access analysis as it should most closely coincide with the residential areas on the ground. In order to use the data within the model, several brief processes were completed. These included calculations for total population per block, assignment of the geoID to the underlying parcels, and the calculation of people per parcel. The census block data were assigned to the parcels using a spatial join. The join functioned as a means to transfer the geoID number of each census block group to each parcel within that census block. The scale of the block group prevented conflicts where parcels were located in two or more census blocks. This unique geoID served as the link between the source population data and the final output features allowing for a consistent link back to the source data.

Figure 11 shows the model developed to calculate the total population of the study area to use as a means for cross checking the outputs of the population assignments to the parcels. Executing the model returns a total population of 900,993 people using all of the Census Block Data within Wake County. This model provides a means to accept future data formats that may have multiple instances of the same Block ID. It also simplified the output table to object ID, GEOID, and Sum_total_population representing the total population of each block. The Frequency attribute column provides a review of the features determining if any blocks occur twice.

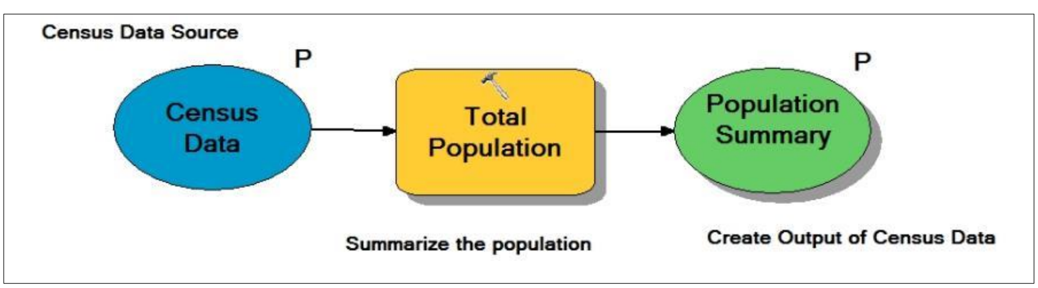



**Figure 11 Totaling Population by Census Unit**

### 3.5 Dasymetric Mapping of Population Data

Building on Equations 1 and 2, a series of models were created automating the output population per parcel calculations. The population data were sourced from the US Census Data. Within the model, the desired outcome is to have the total population per census block distributed to the total residential parcels within the specific census block. This distributes the population to the actual residential locations providing for more spatially accurate analysis when computing a Network Analyst based origin-to-destination. This was handled by assigning the census blocks to the residential parcels through a spatial join. The spatial join integrated the geoID of the Census Block within the parcels, allowing a unique identifier to tie the block to the contained parcels.

Statistics from the join that needed to complete the final preparation calculations included the join count, total population per block, and the total parcels per block. Using the "summary statistic" tool allowed for these items to be calculated and added within a revised attribute table for the residential parcel data.

The majority of housing within Wake County, NC is single-family homes. However, there are also concentrations of multifamily homes located in clusters throughout the county. As part of the data management, the Wake County GIS Department, in conjunction with the Wake County Tax Office, monitors the number of housing units on a parcel level. This is a key metric for the Tax Collector to assign tax values and assess fees to landowners within the county. Using this information, it is possible to account for the differences in housing type when applying population calculations. Within the parcel data, the use of the housing units as the means for calculating the population reduces the risk of the MAUP as opposed to using parcel area.

This is because the population is calculated by using the direct ratio of people per unit as calculated per census unit to the known total of household units. This mitigates the risk as the application of average people per household of that specific block to the actual housing units of the parcel, as stored within the Wake County cadastral information, allows this study to account for both single family and multifamily housing as opposed to those studies that aggregate population based on land area derived density calculations.

### *3.5.1 Final Output Table*

The final output table from the population mapping contained the core information for population per parcel, geoID for the census blocks, and the total number of households per blocks, and the PIN. These attributes are what were used at the completion of the ODMT to create a final summary table. Figure 12 shows an illustration of the table of the residential parcels with the assigned population per parcel calculated.

ResidentialWithPopulationAnd1

| OBJECTID * | PIN_NUM * | TOTUNITS | GEOID10 | PopPerParcel | SUM_TOTUNITS | PopPerHU |
|---|---|---|---|---|---|---|
| 1 | 1709679765 | 1 | 371830538061 | 2.638921 | 853 | 2.638921 |
| 2 | 0773130471 | 1 | 371830535051 | 2.568965 | 522 | 2.568965 |
| 3 | 1714545231 | 2 | 371830519002 | 5.576876 | 813 | 2.788438 |
| 4 | 0784414065 | 1 | 371830524072 | 1.842215 | 957 | 1.842215 |
| 5 | 1706539629 | 1 | 371830526021 | 2.38471 | 811 | 2.38471 |
| 6 | 0783865473 | 1 | 371830524043 | 2.506536 | 306 | 2.506536 |
| 7 | 0755375183 | 1 | 371830536091 | 1.97878 | 377 | 1.97878 |
| 8 | 0639875203 | 1 | 371830532072 | 2.186944 | 2022 | 2.186944 |
| 9 | 1715899609 | 242 | 371830527041 | 743.2655 | 855 | 3.071345 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

**Figure 12 Illustration of Summary Data for Residential Parcels with Population Calculated**

## 3.6 The Origin to Destination Matrix Tool Solution

Once the data preparation was completed in the subsections above, it was loaded into the ODMT working layer. Origins were loaded from the residential parcel data, destinations were loaded from the Access layer created for the parks, and the Routes were added from the revised route information. Barriers to the routes were added from the WakeMajorRds dataset.

This created a total network dataset that had 276,860 residential parcel origins, 672 distinct destination points for the 268 unique park features, and over 8,668 barrier features for the routes. The parameters selected for the ODTM were left bi-directional as pedestrians can use the sidewalks in any direction as opposed to limitations in vehicular circulation. The search distance for identifying nodes that could be used in the ODMT solution were limited to a 2 mile search pattern, or 10,560 linear feet. This larger search area was utilized in order to make sure that the ¼ mile distances were not lost due to cutoffs in the network solution.

To crosscheck the output of the ODTM an equation was developed to verify that the solution outputs were within the predicted outcomes where the total should equal one mapped route for each possible destination from each origin.

**Equation 5 ODMT Output Check**

$$ODTM\ Solutions = Origin * Destination$$

With variables:
Origin = Total origin points input into the ODMT
Destination = Total park access points input into the ODMT, excluding greenway access points

This total was based on the number of destinations found within the ¼ mile search distance, calculated using the service area generated polygons. This allowed for an estimate to be completed of 17,965 origins within ¼ mile of a park. As the service area tool also was grounded in the same route data, it returns a similar number of destinations when the service area polygon is used to select the residential parcels it overlays.

Once the ODMT completes a solution, there are three outputs stored within a ODMT layer within the map document. These output classes are a copy of the origins, a copy of the destinations, and the lines generated to represent the origin to destination paths. These lines, depicted as straight lines between the points, are used to visually illustrate which points have been connected to the origin.  To complete the final output table, a series of joins are required, associating the target data information to the now generated distances.

Step 1 was to join the park Access data back to the destination data. This join, or uniting of data tables, is accomplished using the ParkID from the Access file and the Name attribute of the destination features. Once this was completed, the destinations are now mapped to park name and park acreages.

Step 2 joined the revised destination table to the lines table using the DestinationID stored within the lines feature class to the ObjectID within the Destination class. This created a table that now contained the DestinationID, ParkID, Park Acreage, and Lengths.

Step 3 was to join this revised line table to the Origin features using the OriginID within the Lines feature and the ObjectID within the Origin features. Once complete, this final table was exported to a database file table (DBF) and added the map. This DBF contained a breakdown of attributes for Length (between origin and park access point), ParkID, ParkArea, and ParcelID. This table was then summarized to create a refined summary table that had the total park acreage and count of parks within ¼ mile to each origin. This final table was saved as ParksPerParcel.dbf and added to the map.

By joining this final table to the original cadastral data, the final result was an updated parcel feature class that contained all of the parkland assigned to all of the parcels as found within the ¼ mile search distance. This allowed for the generation of the final review maps for Parks per Parcel, Acres of Park per Person, and a Population Density Map based on the cadastral information. The lines file, once joined to a second copy of the cadastral data was used to generate a gap analysis map that showed the closest park within 2 miles for all of the residential parcels within Wake County, NC.

### 3.7 Test Hardware and Software Setup

The testing for the workflow was accomplished on a Lenovo Thinkpad W530 portable workstation. This system was equipped with a Samsung ev840 mSATA system drive and a 500 GB Samsung ev840 SATA data drive. The workstation was powered by a single Intel Core i7-340QM processor running at 2.7 GHz. The processor was supported by 24 GB of RAM to aid in completing the computations. The system was running Windows 7 Professional 64bit with Service Pack 1 installed. The graphics card installed was an NVIDIA Quadro K1000M mobile graphics processor. This laptop was purchased in 2013.

The initial phase of this study was started within ArcGIS 10.2.2 Advanced Desktop running ArcMap with the Network Analyst extension and ArcCatalogue. To improve performance and success rates, ArcGIS 10.2.2 was updated to ArcGIS 10.3 Advanced Desktop prior to executing the final testing of the workflow and production of the output maps. Computations were completed using the Background Geoprocessing tool for 64-bit systems, also available from Esri as part of the ArcGIS install platform. All map production and table generation was accomplished within ArcGIS Map and Catalogue. PyScripter 2.7 was used to check the script outputs from model builder to aid in finishing the calculation portion of the workflow.

While more advanced computing resources were available at the time of this study, it was important to test this workflow on a computer that most likely would equal what the typical park planning staff may have at hand. The laptop, classified as a workstation, utilizes a standard mobile processor that is common on many desktop computers and consumer grade laptops.

Microsoft Excel and Microsoft Word 2014 were utilized to generate the report tables once the primary formatting was completed within ArcGIS. Adobe Photoshop CC was utilized to combine the individual maps into the exhibits presented within this report, with no modifications or manipulation of the color ramps stored within the choropleth maps.

# CHAPTER 4: RESULTS

The goal of this study is to develop a measurement technique that will best determine park accessibility based on the real world ground conditions for both populations and for travel distance. This measurement technique focuses on population location linked to access points for the parks utilizing access points that have been mapped based on physical connectivity on the road network. The connectivity of the road system within the data is directly related to the ability of the ArcGIS tool Network Analyst to execute potential solutions. The proposed method depends on the Network Analyst extension to complete its solution in order to generate the required tables and features necessary for evaluating the accessibility of the park system.

This chapter reviews lessons learned in applying Arc GIS Network Analyst to develop the cadastral-based accessibility measurement technique. The study results also include comparisons in levels and locations of park access for the Wake County, NC study area between the origin-to-destination matrix table (ODMT), a buffer based coverage analysis, and the Service Area Calculation tool (SAC) provide a means to quantify the improvements from using Network Analyst in measuring access.

## 4.1 Lessons Learned in Applying Network Analyst

As mentioned in Chapter 3, attempting to calculate network distances for all parks and parcels in Wake County, NC using the ODMT tool quickly exhausted the computational resources as the number of possible origin-to-destination (OD) pairs, according to a calculation similar to Equation 5 in Chapter 3, were in the millions. ArcGIS did return results, but a check of the resulting tables, showed them to be incomplete. It is likely that ArcGIS simply stopped processing when memory capacity was reached, but it is important to note that no error messages were returned.

To better steward the computational resources, it was necessary to first complete the service area assessment across the county using the Network Analyst Service Area Calculation (SAC). This tool as noted in the methods generates points based on the distance along available routes from a given destination and then connects the closest vertices together to create the polygon. Settings within the SAC allow for the control and refinement of how this polygon is created. As noted in the methods, the detail level was kept high and the search distance was limited to 100 ft.

Completing the SAC was able to be accomplished on the test hardware and software. The overall process for the Service Area Calculation did not require any deviation from the stated methods. At the completion of the solution, 284 park sites were represented within the SAC by the 636 access points located through geo-referencing of the street addresses and locating through aerial photography for each park. The SAC tool was run using the three distances of 1320, 2640, and 5280 feet, with feet being the calculated length provided in the Network Analyst outputs. The distance cutoffs represent ¼, ½, and 1 mile distances. While the focus of the analysis is on the ¼ mile walking distance, it was of interest to this study to gauge the performance of the SA tool and explore how its functionality could be further integrated into the gap analysis workflow.

Using the three distances, one can compute the number of service area polygons according to Equation 6.

**Equation 6 Total Paths Possible ODMT**

$$TotalServiceAreas = nDestinations * nDistance$$

Destinations= Number of Sources
nDistance = the number of distance cutoffs input into the variables

Calculating values similar to Equation 5 and Equation 6, although simple, also proved necessary as a means to conduct quality assessment checks on the OD matrix outputs. As the number of facilities being assessed increase, so does the complexity of the computations as well as the size of the map file in terms of file storage. Issues in file size are further discussed in Chapter 5 below.

For Wake County, the use of 3 distance cutoff values and 636 access point's results in a total of 1,908 polygons. These polygons are then able to be used to conduct a coverage based selection of the residential parcels within 1 mile of the park access points based on the road network. In comparison to calculating links for all parcels and parks in the county, this use of the SAC greatly reduces the number of potential line calculations and allows for the ODMT routine to complete when generated in conjunction with the barriers.

**4.2 Determining the Parcels Served**

The parcels served is the first stage in completing the gap analysis. Through the development of the methodology, the SAC was utilized as a means to conduct comparisons between the buffer based coverage analysis and the ODMT outputs. The generation of the SAC also served as a visual check to assess which sites were potentially within the specified distance of the park facility by creating the polygons at the specified search distances of ¼ mile, ½ mile, and 1 mile. The limitation of the SAC is that it is a singularly oriented process in which the service area is defined outward from the park access points.

The SAC also allows for the assignment of distances to the lines traveling from the access point for the specified distance. These travel lines are an overlay of the roads following the search distance criteria and provide for a visual check of the road network, confirming its functionality prior to being used within the ODMT. Adding these lines to the network analysis layer provides the analyst the ability to display the routes from the parks outward using a color ramp. Using the roads after verifying connectivity within the SAC also improved the success rate of the ODMT calculations as breaks within the road network were quickly identified. A second advantage for generating the service area is the SAC tool updates the spatial information within the network for all of the park points allowing for computational efficiency and a corresponding reduction in the processing time within the ODMT. Figure 13 shows the output of the Service Area tool for all of Wake County, NC. The processing time for the overall county was less than 5 minutes and proved to be replicable using all of the access points for the parks.

One of the key criteria established in the methodology is a park's ability to be walkable. With walkability estimated to be manageable at ¼ mile, this will be the primary metric for evaluating the service coverage of the park. Using the service area as a visual assessment, it is readily apparent that there appear to be large gaps in the coverage between the areas of park coverage.

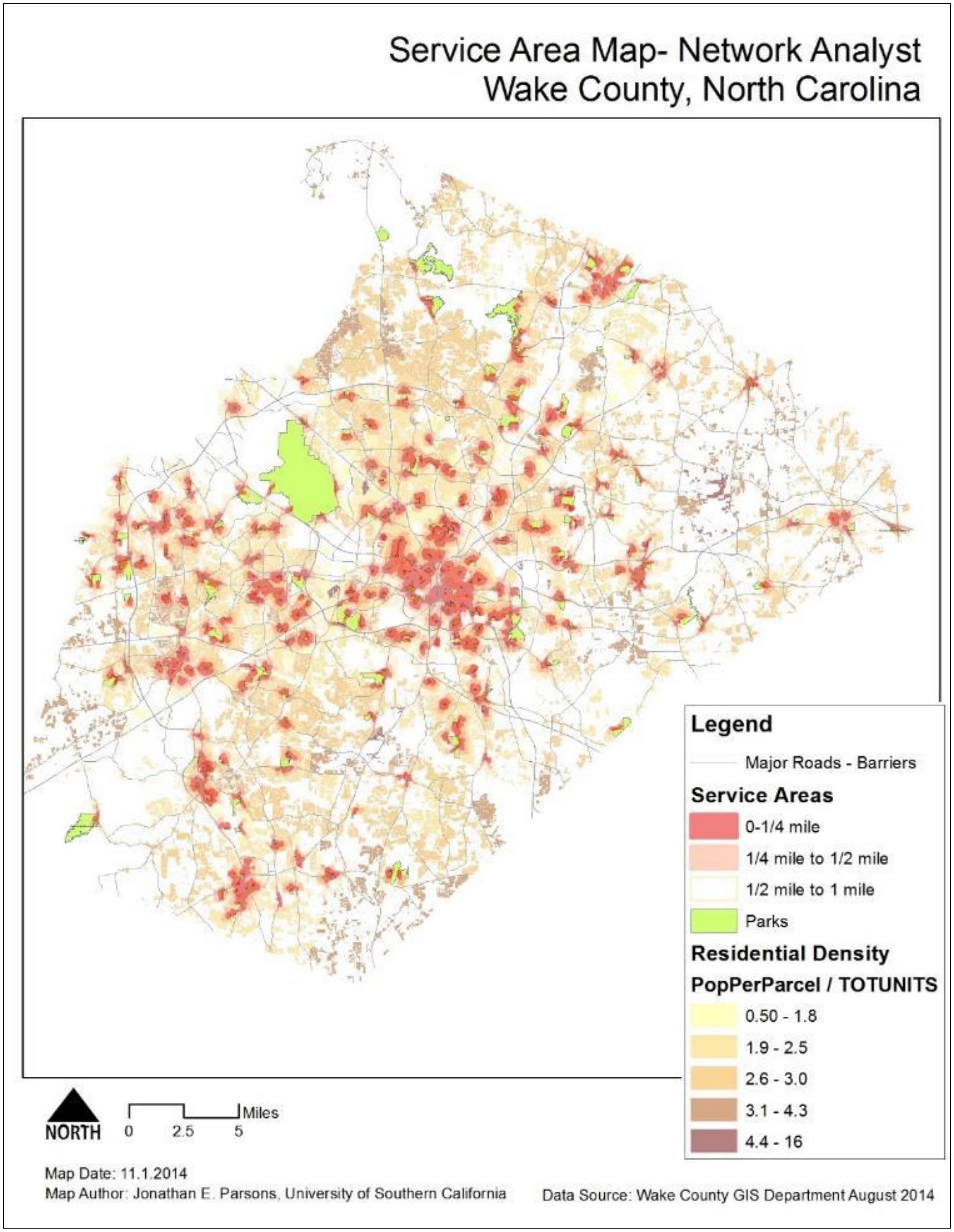
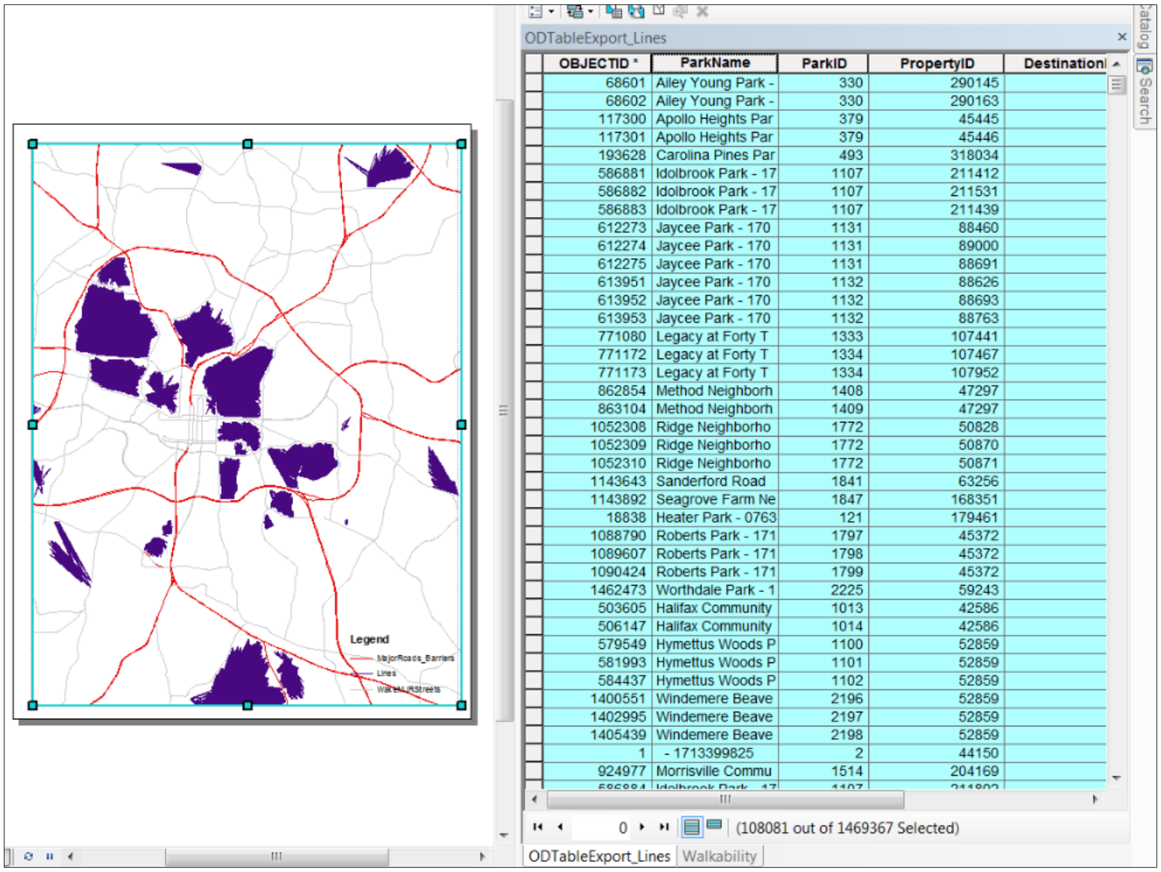



**Figure 13 Service Area Map Based on Service Area Calculation**

### 4.3 Output from the OD Matrix Tool

Completing the ArcGIS Origin Destination Matrix Table (ODMT) for a countywide analysis requires working within the limitations of the computer memory available and file size limitations imposed by ArcGIS. This study found that a maximum search distance of 2 miles processed before the ODMT stopped returning complete solutions. Using this limit in conjunction with the barriers allowed the ODMT to execute successfully. A secondary improvement on the ODMT was using the origins and routes utilized in the ArcGIS Service Area Calculation Tool as they were previously located and improved the computing speed in resolving the ODMT outputs using the origins and routes mapped in the SAC.

The ODMT returned a solution that measured connection lines for all of the parcels within 2 mile access of each park. Using the select by attribute feature, those origins located within ¼ mile of the park were able to be isolated to just over 31,000 origin-to-destination outputs. Once summarized, 17,795 unique parcels had park access within ¼ mile. The results were limited to those points that were located along a continuous route to the park. Routes that were blocked by the barrier led to exclusion of those origins to the destination park. Figure 14 provides an illustration showing the ODMT output running within ArcGIS, with the mapped lines representing the solved OD pairs and the redlines showing the barriers. The table on the right of the map shows the typical output of the lines once joined with the Origins attributes linking ParkIDs back to the line data for analysis.




| OBJECTID * | ParkName | ParkID | PropertyID | Destination |
|---|---|---|---|---|
| 68601 | Ailey Young Park - | 330 | 290145 | |
| 68602 | Ailey Young Park - | 330 | 290163 | |
| 117300 | Apollo Heights Par | 379 | 45445 | |
| 117301 | Apollo Heights Par | 379 | 45446 | |
| 193628 | Carolina Pines Par | 493 | 318034 | |
| 586881 | Idolbrook Park - 17 | 1107 | 211412 | |
| 586882 | Idolbrook Park - 17 | 1107 | 211531 | |
| 586883 | Idolbrook Park - 17 | 1107 | 211439 | |
| 612273 | Jaycee Park - 170 | 1131 | 88460 | |
| 612274 | Jaycee Park - 170 | 1131 | 89000 | |
| 612275 | Jaycee Park - 170 | 1131 | 88691 | |
| 613951 | Jaycee Park - 170 | 1132 | 88626 | |
| 613952 | Jaycee Park - 170 | 1132 | 88693 | |
| 613953 | Jaycee Park - 170 | 1132 | 88763 | |
| 771080 | Legacy at Forty T | 1333 | 107441 | |
| 771172 | Legacy at Forty T | 1334 | 107467 | |
| 771173 | Legacy at Forty T | 1334 | 107952 | |
| 862854 | Method Neighborh | 1408 | 47297 | |
| 863104 | Method Neighborh | 1409 | 47297 | |
| 1052308 | Ridge Neighborho | 1772 | 50828 | |
| 1052309 | Ridge Neighborho | 1772 | 50870 | |
| 1052310 | Ridge Neighborho | 1772 | 50871 | |
| 1143643 | Sanderford Road | 1841 | 63256 | |
| 1143892 | Seagrove Farm Ne | 1847 | 168351 | |
| 18838 | Heater Park - 0763 | 121 | 179461 | |
| 1088790 | Roberts Park - 171 | 1797 | 45372 | |
| 1089607 | Roberts Park - 171 | 1798 | 45372 | |
| 1090424 | Roberts Park - 171 | 1799 | 45372 | |
| 1462473 | Worthdale Park - 1 | 2225 | 59243 | |
| 503605 | Halifax Community | 1013 | 42586 | |
| 506147 | Halifax Community | 1014 | 42586 | |
| 579549 | Hymettus Woods P | 1100 | 52859 | |
| 581993 | Hymettus Woods P | 1101 | 52859 | |
| 584437 | Hymettus Woods P | 1102 | 52859 | |
| 1400551 | Windemere Beave | 2196 | 52859 | |
| 1402995 | Windemere Beave | 2197 | 52859 | |
| 1405439 | Windemere Beave | 2198 | 52859 | |
| 1 | - 1713399825 | 2 | 44150 | |
| 924977 | Morrisville Commu | 1514 | 204169 | |

**Figure 14  Raw Output from ODMT within ArcGIS**

The raw table allowed for several quick assessments of the park system. The first and most simple was to summarize the data based on the ParkID. This allows for a chart and graph to be generated to depict the number of parcels served by a specific park, average distance between the park and the parcels, and the number of parks that serve a particular parcel. An example of the output is shown in Figure 15.

Table

ODTableExport_Lines

| OBJECTID * | ParkName | ParkID | PropertyID | DestinationRank | Total_Length |
|---|---|---|---|---|---|
| 68601 | Ailey Young Park - | 330 | 290145 | 1 | 0 |
| 68602 | Ailey Young Park - | 330 | 290163 | 2 | 0 |
| 117300 | Apollo Heights Par | 379 | 45445 | 1 | 0 |
| 117301 | Apollo Heights Par | 379 | 45446 | 2 | 0 |
| 193628 | Carolina Pines Par | 493 | 318034 | 1 | 0 |
| 586881 | Idolbrook Park - 17 | 1107 | 211412 | 1 | 0 |
| 586882 | Idolbrook Park - 17 | 1107 | 211531 | 2 | 0 |
| 586883 | Idolbrook Park - 17 | 1107 | 211439 | 3 | 0 |
| 612273 | Jaycee Park - 170 | 1131 | 88460 | 1 | 0 |
| 612274 | Jaycee Park - 170 | 1131 | 89000 | 2 | 0 |
| 612275 | Jaycee Park - 170 | 1131 | 88691 | 3 | 0 |
| 613951 | Jaycee Park - 170 | 1132 | 88626 | 1 | 0 |
| 613952 | Jaycee Park - 170 | 1132 | 88693 | 2 | 0 |
| 613953 | Jaycee Park - 170 | 1132 | 88763 | 3 | 0 |
| 771080 | Legacy at Forty T | 1333 | 107441 | 1 | 0 |
| 771172 | Legacy at Forty T | 1334 | 107467 | 1 | 0 |
| 771173 | Legacy at Forty T | 1334 | 107952 | 2 | 0 |
| 862854 | Method Neighborh | 1408 | 47297 | 1 | 0 |
| 863104 | Method Neighborh | 1409 | 47297 | 1 | 0 |
| 1052308 | Ridge Neighborho | 1772 | 50828 | 1 | 0 |
| 1052309 | Ridge Neighborho | 1772 | 50870 | 2 | 0 |
| 1052310 | Ridge Neighborho | 1772 | 50871 | 3 | 0 |
| 1143643 | Sanderford Road | 1841 | 63256 | 1 | 0 |
| 1143892 | Seagrove Farm Ne | 1847 | 168351 | 1 | 0 |
| 18838 | Heater Park - 0763 | 121 | 179461 | 1 | 0.008465 |
| 1088790 | Roberts Park - 171 | 1797 | 45372 | 1 | 0.467968 |
| 1089607 | Roberts Park - 171 | 1798 | 45372 | 1 | 0.467968 |
| 1090424 | Roberts Park - 171 | 1799 | 45372 | 1 | 0.467968 |
| 1462473 | Worthdale Park - 1 | 2225 | 59243 | 1 | 0.499737 |

**Figure 15 Output Table from the OCDM Calculation**

The ODMT chart is joinable to the original parcel data. A comparison of the number of parks by parcel and the amount of open space by person was accomplished through the joining of the data based on the common attribute of the originID and the objectID.

In Figure 16 Population Density per Parcel, hard edges defined by transportation corridors, and soft edges created by areas of non-residential development break up, or segment, the residential areas into isolated clusters. It is also of note how areas of the highest population concentrations are located at main thorough intersections around the edges of the urban core. Generalized density mapping approaches overlook this type of density distribution when using larger areal units.

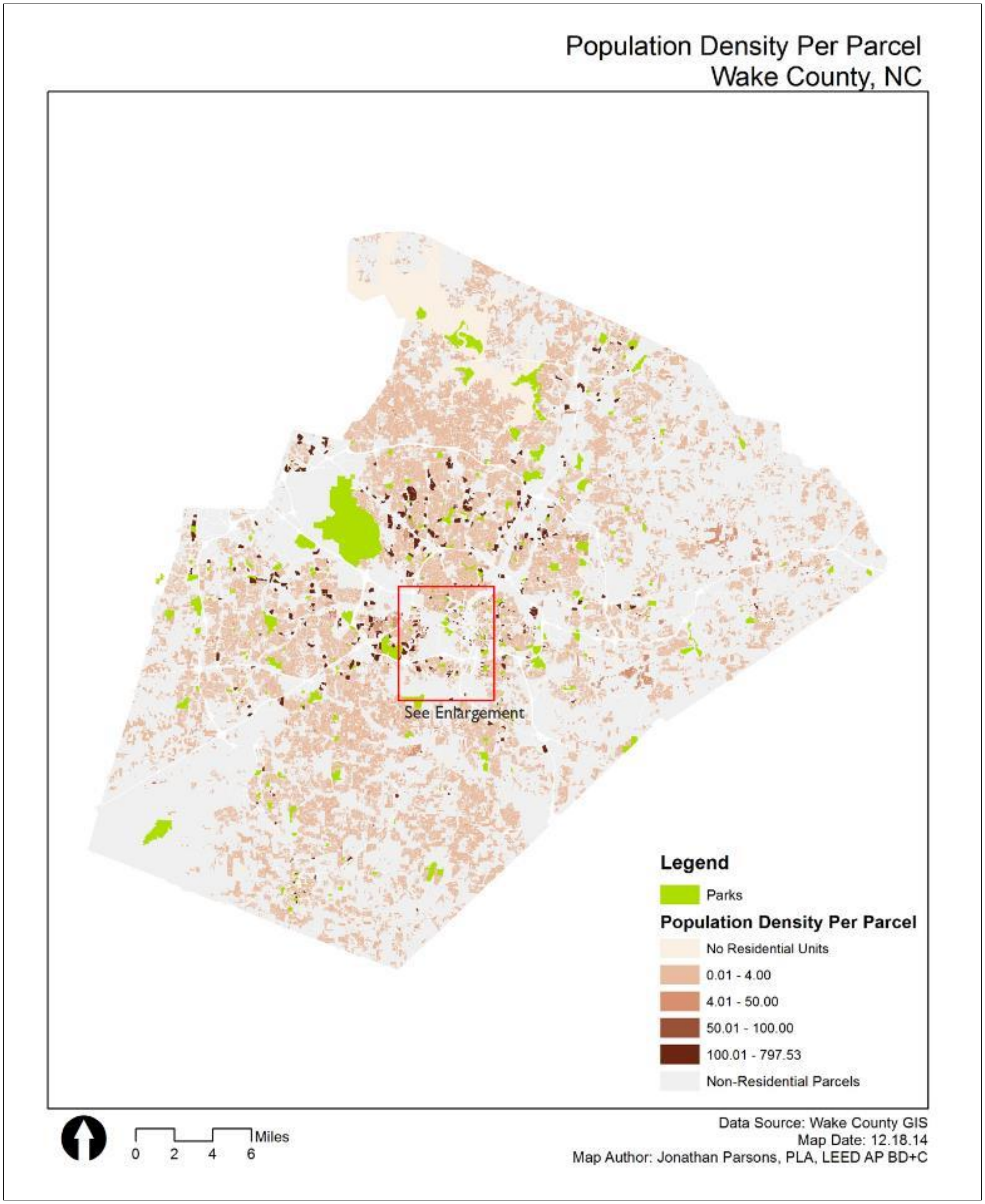



**Figure 16 Population Density per Parcel, Overall County**

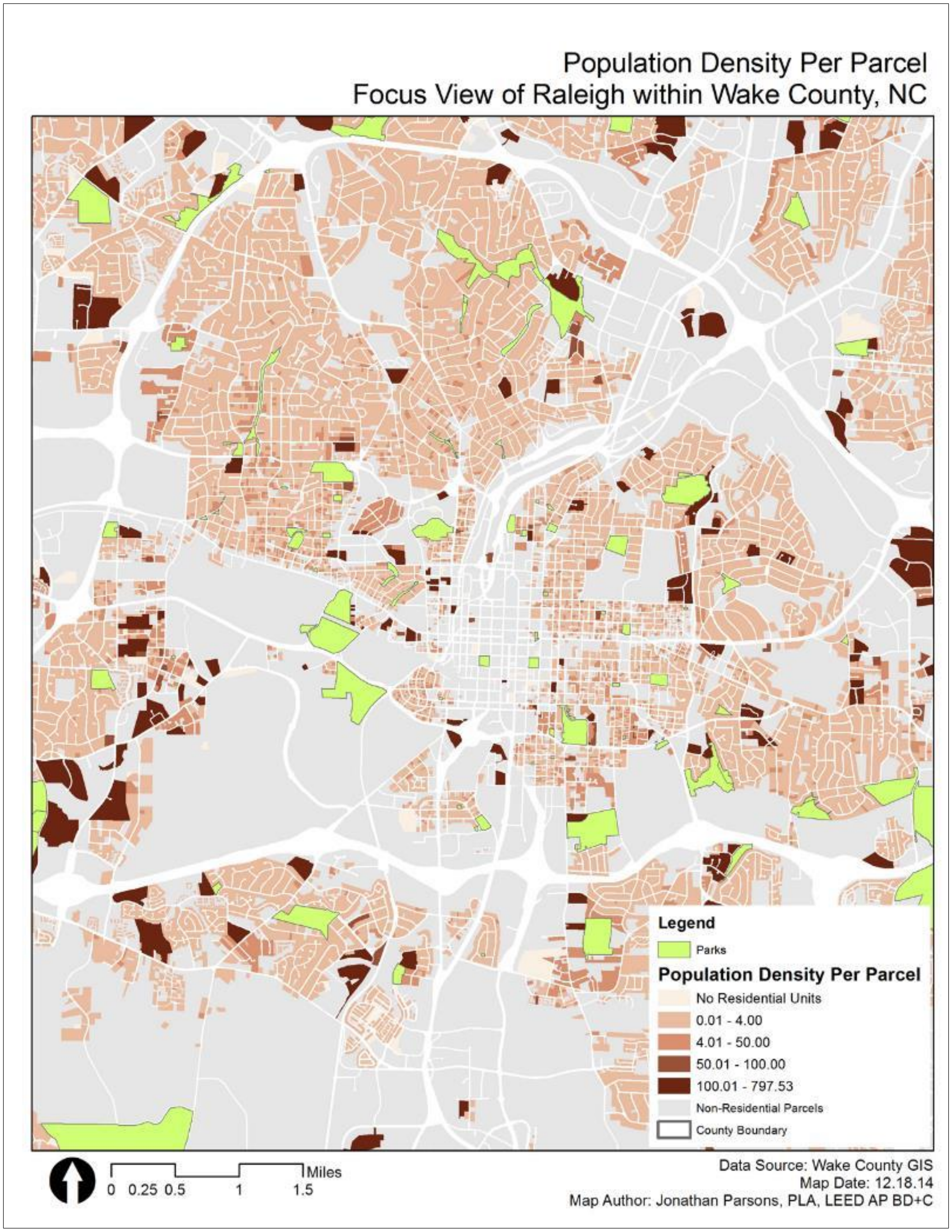



**Figure 17 Population Density per Parcel, Focus View**

Figure 18 and Figure 19 illustrates the number of parks by parcel within 1/4 mile showing that there are areas in the urban core have more parks available to them in comparison to the suburban parts of the county. Refer to Figure 18 to Figure 16 to compare the difference in number of parks per parcel to residential density. Assessing the difference in values between the residential clusters and the clusters of parcels with the greatest quantity of parks will reveal issues with uniformity of access. The network barriers significantly influence this output. Adding proposed access improvements to the network dataset, such as bridges over the major roads, updates the ODMT solution; this allows for evaluating one or more modifications to the park system to determine the potential benefits through additional parcel connectivity. Similarly, adding parks to the areas of lower coverage would improve the overall availability of park facilities. The ODMT allows for on the fly testing of such scenarios by allowing for new destinations or network paths to be added and updating of the output table.

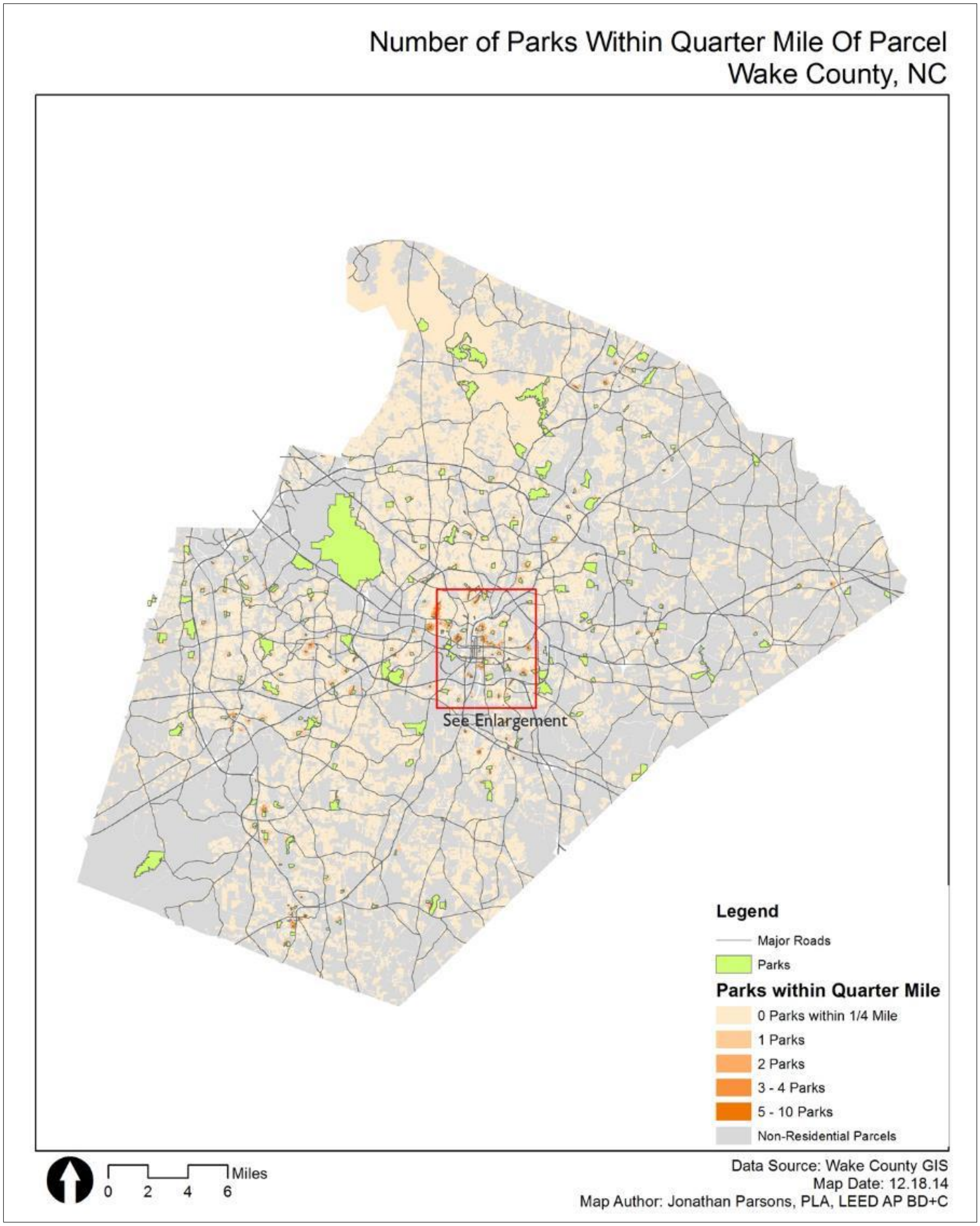



**Figure 18 Parks per Parcel, Countywide**

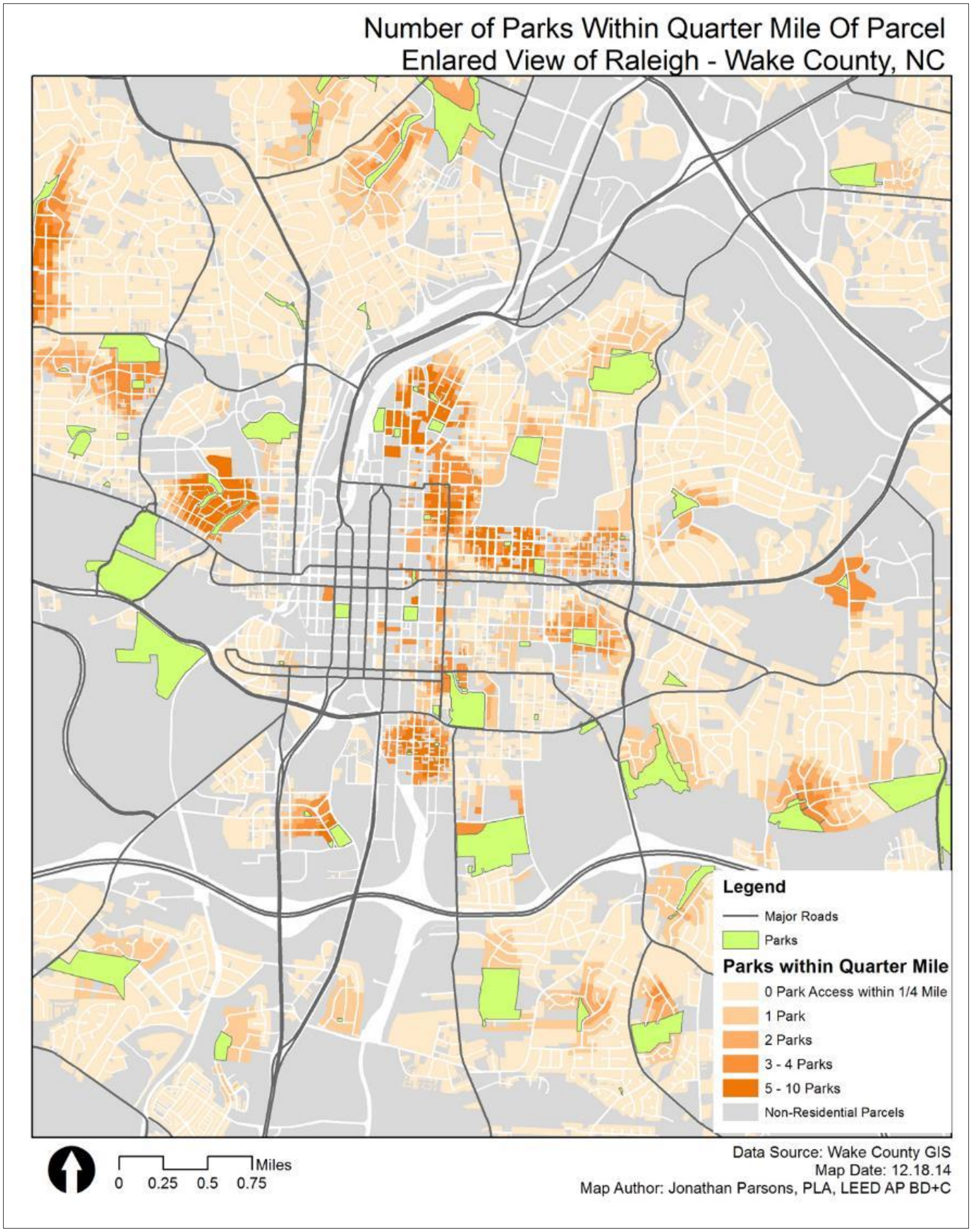



**Figure 19 Park Count within ¼-mile, Enlarged View**

Using the ODMT output information, a third map was created depicting the area parkland available per available per person for each parcel. This map shows the variation in the amount of parkland that occurs across the county. This allows for a clear depiction of where there are shortages in total area available to each parcel, an accepted standard in planning park spaces. Figure 20 and Figure 21 depict the acreage of parkland available per person as derived from the cadastral data and the ODMT outputs.  Figure 20 is a view of the output at a countywide scale, Figure 21 is a view an enlarged view focused on the parcels near Raleigh, NC.

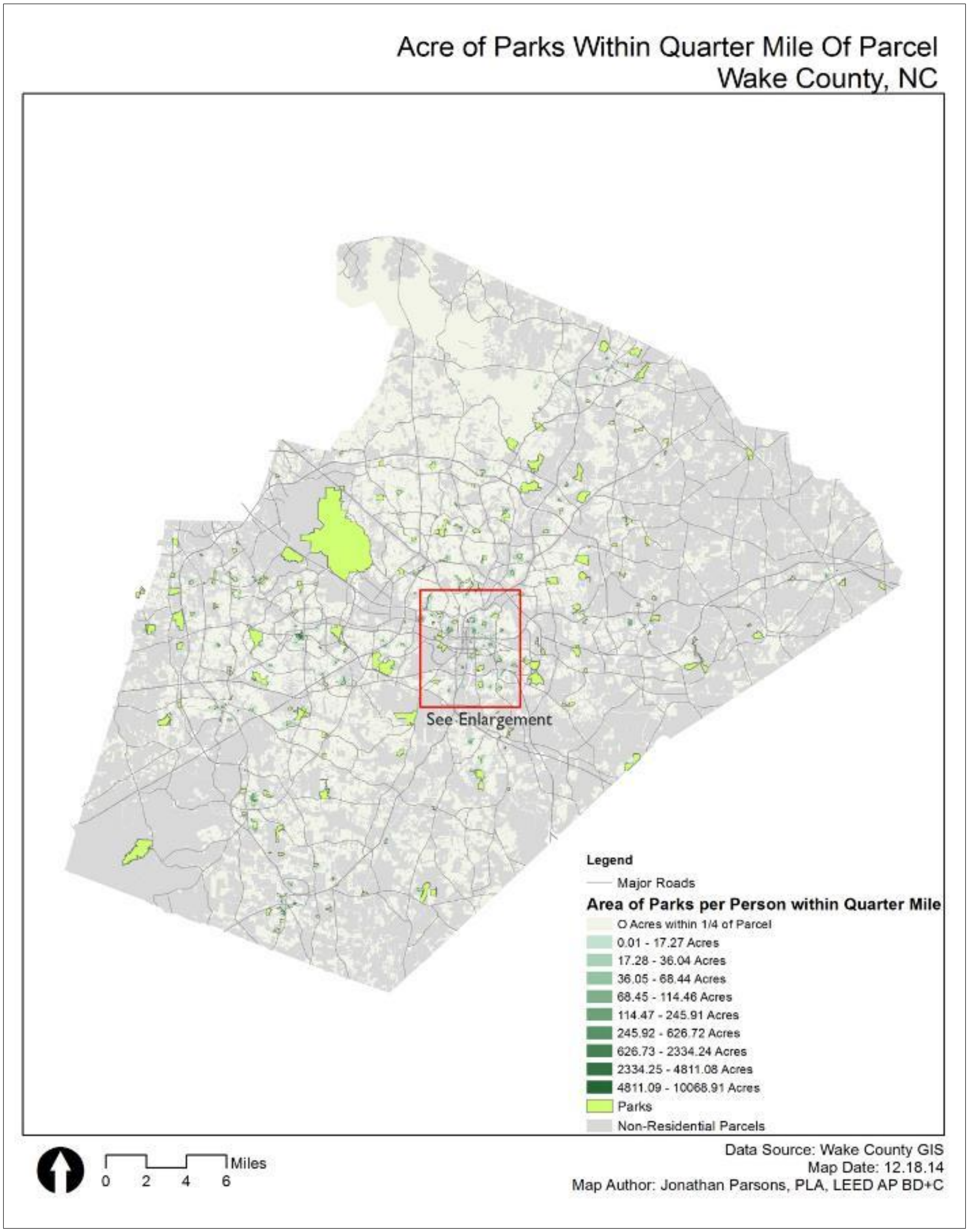



**Figure 20 Acre of Parks within ¼ mile of Parcel, Countywide**

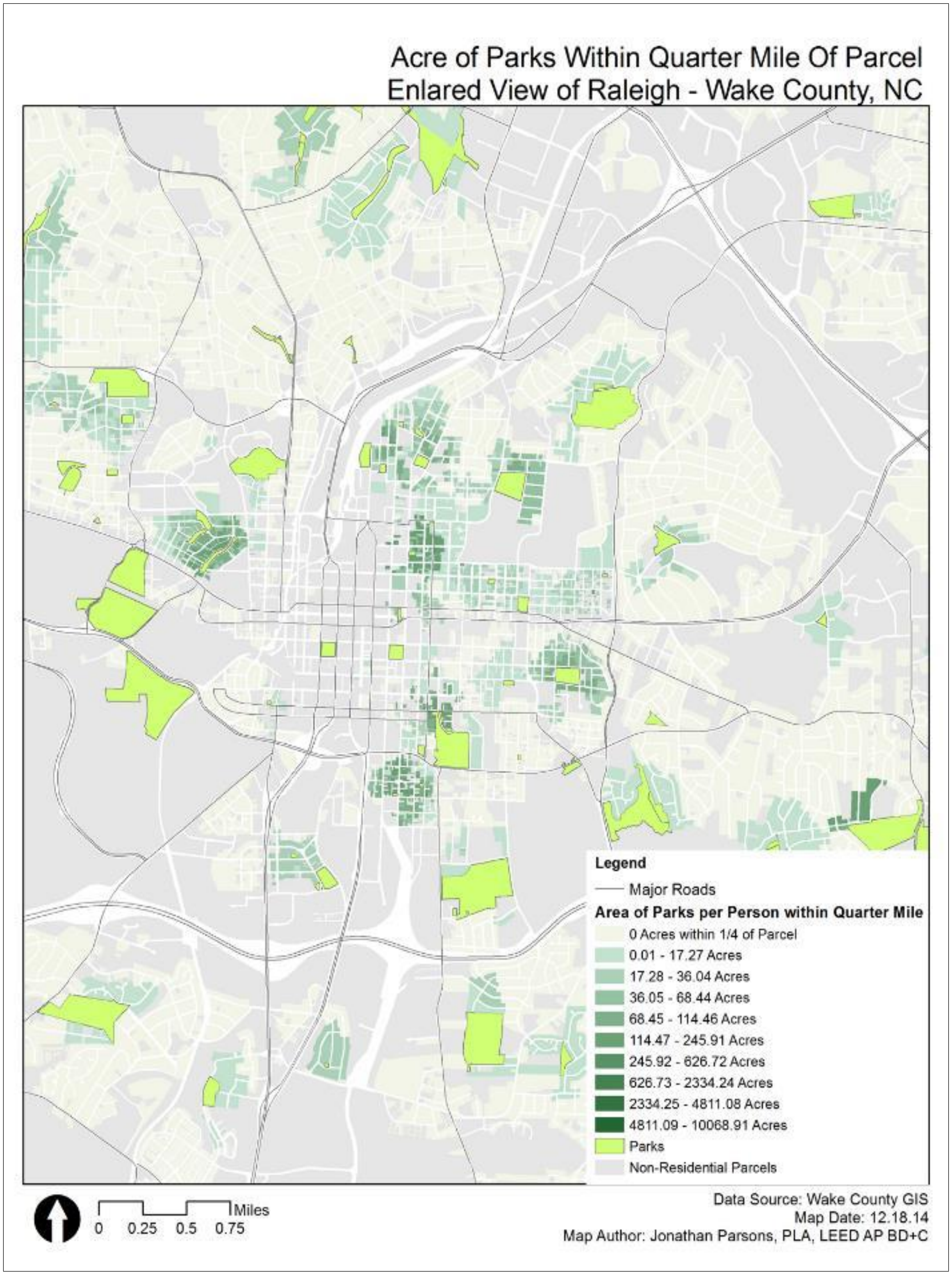



**Figure 21 Acre of Parks within ¼ mile of Parcel, Enlarged View**

### 4.4 Comparison of Accessibility Measurements

Using the ODMT to generate a countywide solution processed 687,651 solutions for the original 276,860 origins and potential pool of 636 access points; using a 2 mile search distance. The access points, as noted in the SAC calculation represent 284 park sites. The max possible results of a completed ODMT solution would reach 78,628,240 Origin-to-Destination pairs when using Equation 1. However, running the OD solution using the barriers (i.e. the major roads) this number drastically reduces. To estimate the potential output, the SAC polygon intersected 14,095 of the 27,680 parcels when using the break distance of 1,320 ft. or 1/4 mile. The SAC number represents the intersection of one parcel to one park service area, for a one-to-one relationship. While the SAC is useful in assessing service gaps, the ODMT tool will return a one-to-many relationship between each parcel to all parks (access points) within the specified search distance. In instances of multiple access points for a single park, the ODMT selects the closest access to the parcel (Esri 2014). In contrast to the SAC estimate, the ODMT returns a value of 31,963 parcels to park relationships. The discrepancy in these two values shows that multiple parcels have two or more parks associated within the search distance. This is the strength of the ODMT tool in providing highly detailed results with limited post processing on the data. A secondary benefit of the ODMT is the ability to identify the closest park for each parcel based on the calculated OD pair lengths.

The ArcGIS Summarize tool isolated the unique instances of the parcels, totaling the amount of park acreage per parcel instance, and counting the number of instances of parks that were within the target search distance. The summarized parcel count is 17,795 parcels located within ¼ mile of a park access point. The summarize tool also returned the first of the vectors being tested, gauging how many parcels have access to more than one park. Based on this study's results the park access for parcels is highly skewed: 6,473 parcels that have access to more than one park. In contrast, this study shows that 259,065 residential parcels are not within 1/4 mile of a public park based on the available routes.

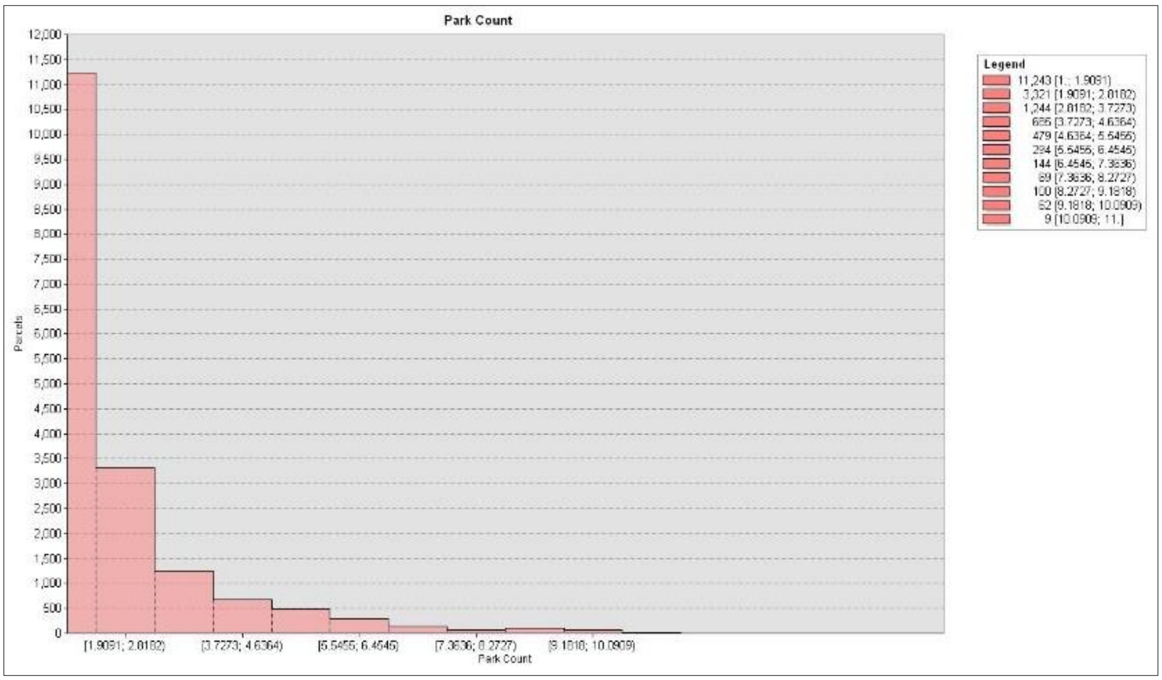



**Figure 22 Summary Statistics for Number of Parks per Parcel for Wake County, NC**

The overall output of the ODMT provides a high level of detail in terms of understanding the relationship of parks to parcels. The following set of tables illustrates the comparison between the ODMT output and previous methods. In Table 2 Review of Residential Parcels within Wake County, NC, there are 276,860 residential parcels, or roughly, 82.23% of the county has residential features.

**Table 2 Review of Residential Parcels within Wake County, NC**

| Description | Parcel Count | Percent of Total |
|---|---|---|
| Total Wake Parcels | 336,667 | 100% |
| Residential Parcels | 276,860 | 82.23% |

Table 3 provides a summary table showing the difference in residential parcels identified within ¼ mile of a park. The Service Area Solution uses the ¼ mile search distance to generate a ¼ mile service area from each of the access points for each park. As explained in the methods section, the SAC uses road network information to locate vertices ¼ mile from the access point based on travel path. Parks with multiple access points generate multiple service areas, these were converted into single service area polygons for each park using the ArcGIS Join tool. Once complete, all of the parcels within the service area polygons were selected and totaled in the table below.

The ODMT total was collected from the output data. The interesting point of note is that there is less than 0.3% difference between the SAC output and the ODMT output. The notable difference is in comparing a traditional ¼ mile buffer based coverage analysis that shows over 26.27% of the residential parcels are within ¼ mile of a park. This is much higher than the cadastral-based approaches, either the SAC or ODMT models, which show between 6-7% of the residential parcels having access. This difference in levels of accuracy quickly illustrates the value in using a cadastral-based approach to measuring park access.

**Table 3 Comparison of Selection Methods**

| Vector | Method | Count | Percent of Total |
|---|---|---|---|
| Residential Parcels | | 276,860 | |
| Residential within ¼ mile of Park | Coverage (SA Polygon Hybrid) | 18,627 | 6.72% |
| Residential within ¼ mile of Park | ODMT | 17,795 | 6.42% |
| Residential within ¼ mile of Park | Coverage – Radial Buffer, Park Edge | 72,735 | 26.27% |

A histogram generated from the ODMT provides a graphical representation of the distribution of the acreage of parks available per person. Figure 23 shows the mapping of the parcels that are located within ¼ mile park, ranked by the amount of park acreage available. This type of analysis shows that there are areas within the park system that have more parkland available to concentrated areas of residential development compared to the overall distribution.

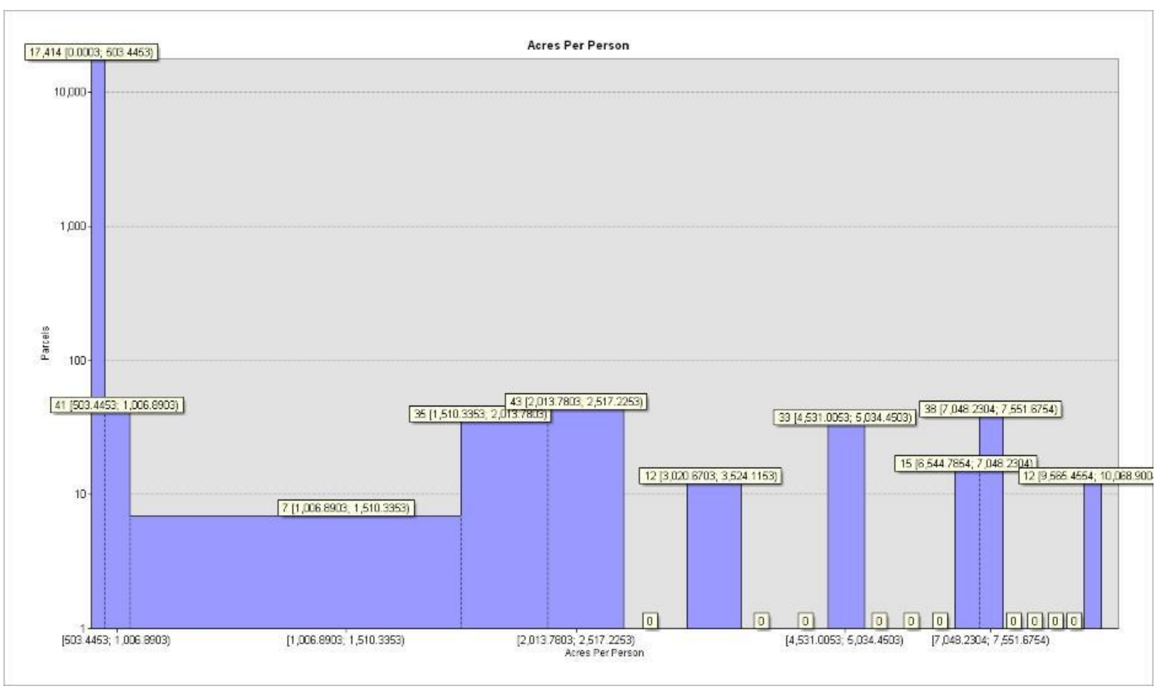


**Figure 23 Histogram Graph of Park Acres per Parcel**

A final map generated from the line data feature of the ODMT may prove to be the most compelling reason to utilize the ODMT instead of the SAC based analysis. The ODMT measures the distance between each origin to each destination, only stopping when it hits the specified search distance or quantity of returns desired. By storing the distance between each parcel to each park within a data table, completing a closest facility analysis to evaluate the trends in travel distance across the park system is possible.

Using the travel distance information stored in the ODMT data table facilitates a uniformity of park access assessment showing the minimum, maximum, and average travel distance. Figure 24 is a histogram graph displaying the trend of travel distance using the closest park per each parcel found within a 2 mile maximum search distance.

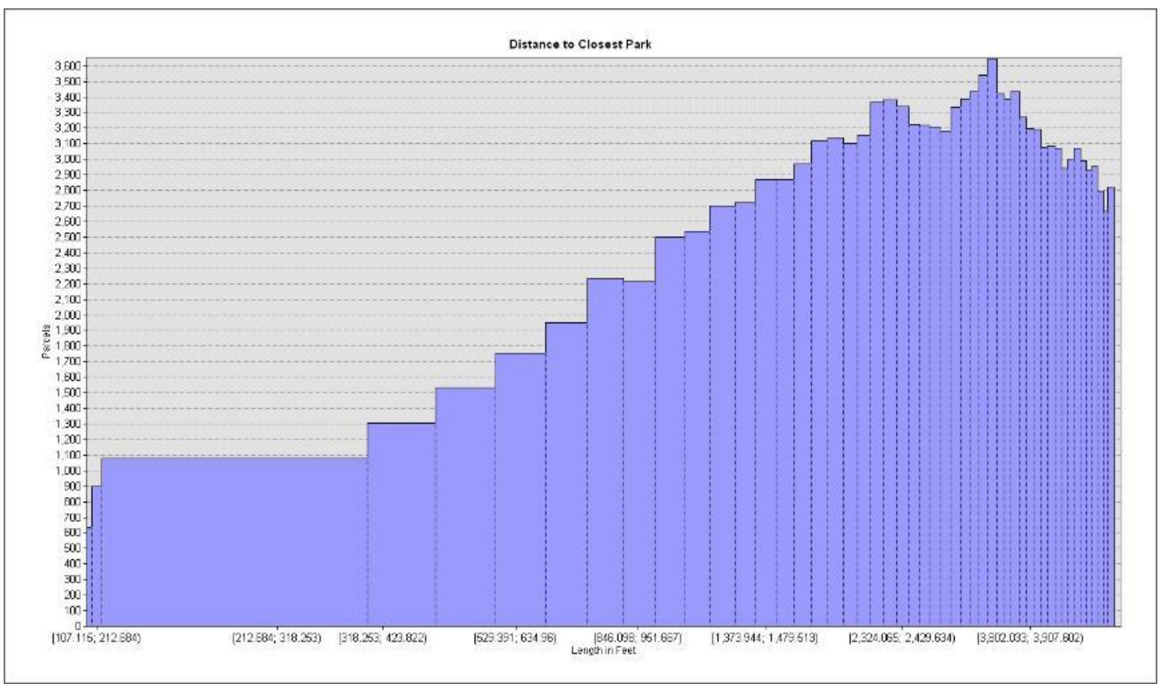



**Figure 24 Histogram Showing the Variation in Distance to Parks**

Figure 25 and Figure 26 use the ODMT to generate choropleth maps identifying where there are parcels that are quite close to a 1/4 mile cut off, but do not quite reach pedestrian access by the 1/4 mile rubric. Figure 25 is a countywide view of the distance between parcel and closest park using the full ODMT search of 2 miles. Figure 26 shows an enlarged view of the parcels near Raleigh, NC. These maps would allow planners to search for physical gaps in the access using the direct output from the ODMT tool. This is an important distinction from the SAC because it will allow for quick assessments in terms of how new park sites and additional access paths (e.g. public rights of way, overpasses, or nature trails) can improve the overall functionality of the system. To do a similar analysis using the SAC, additional work would be necessary to regenerate and identify where the gaps area.

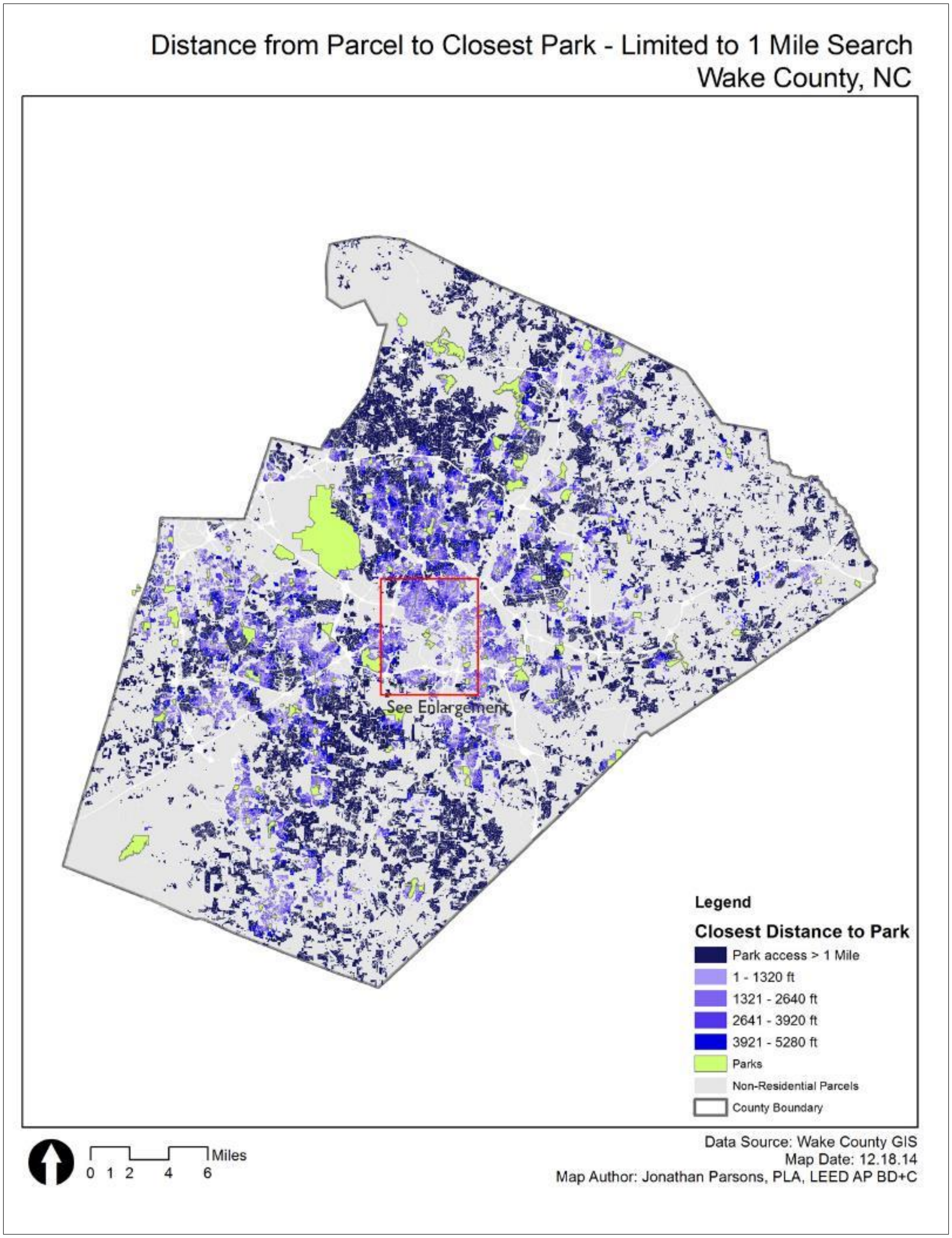



**Figure 25 Maps Showing Park Access Based on Nearest Distance to Parcel**

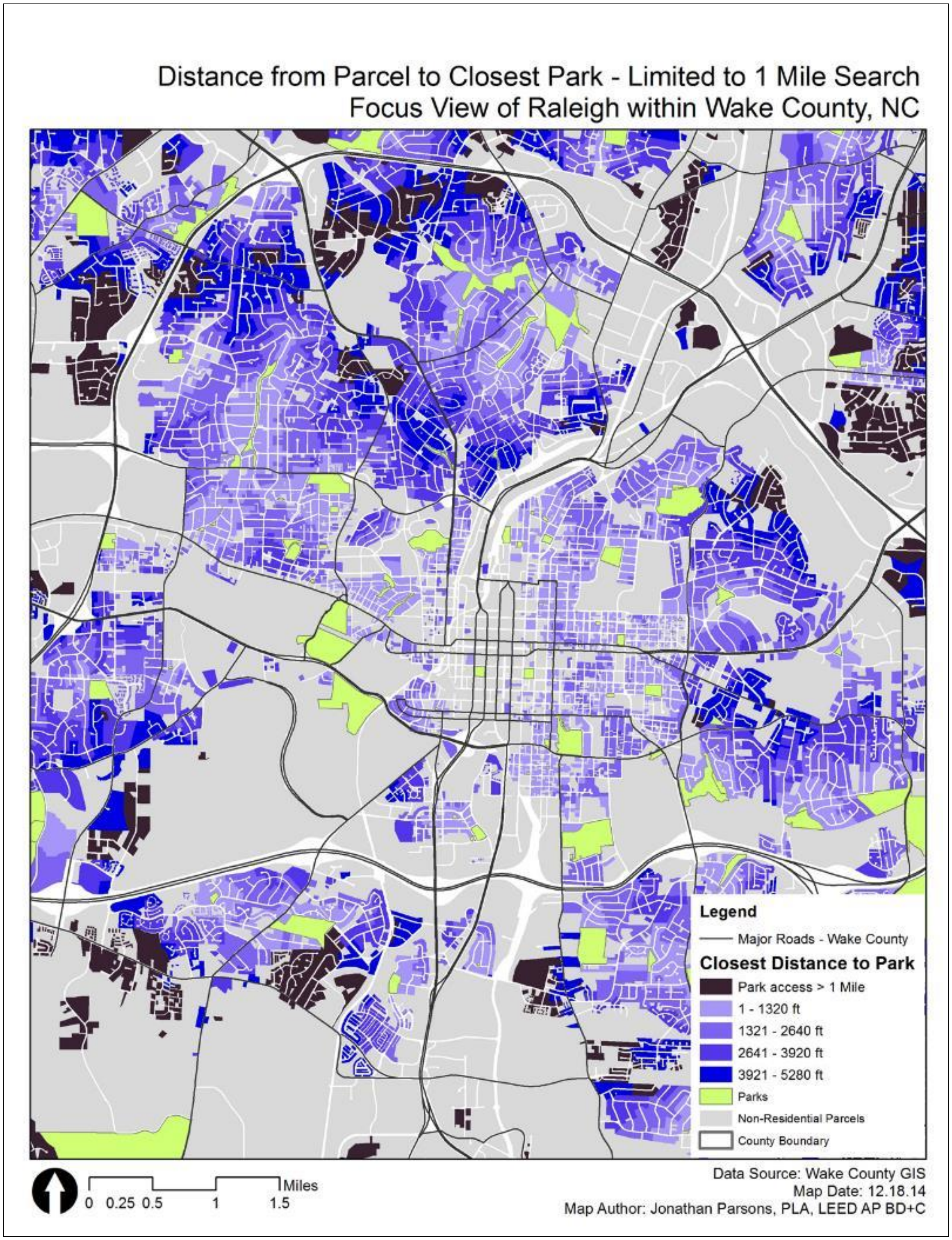



**Figure 26 Maps Showing Park Access Based on Nearest Distance to Parcel**

# CHAPTER 5: DISCUSSION AND CONCLUSIONS

This study set out to develop a technique for measuring and assessing the physical accessibility of an existing park system in order to map the accessibility of parks on a parcel by parcel, in this case Wake County, North Carolina. To resolve the three questions asked in the initial onset, the study completed a series of trials in order to arrive at the best combination of variables to generate the most useful output. This study has revealed the potential benefits for using this measurement technique to evaluate park accessibility. Developing this process has also helped identify potential issues in automating this process and areas meriting future research.

## 5.1 Benefits of the Cadastral Based Measurement Technique

While there are numerous aspects to siting a park, the ability of target populations to access a site is a key metric for evaluating the potential benefit. The cadastral-based method proposed here uses a series of processes to combine population data, household data, park access points, and streets into a final output that totals the number of parks and quantity of park space available within the specified walking distance. The search distance is adjustable depending on the mode of travel allowing for a comprehensive assessment of the distribution of parks and a quick assessment of the park coverage to identify the gaps in the system.

Within this study, the ArcGIS Origin-to-Destination Matrix Tool (ODMT) proves capable of measuring the number of parks available to each parcel based on the route data within the study area. Adjusting the variables within the ODMT allows the analyst to tailor the output to focus on search distances based on study criteria. The initial output of the ODMT is a matrix table and a line feature class that maps each parcel to each park. The use of choropleth mapping and histogram charts based on the distance field of the travel lines assigned to the parcels provides a quick visual illustrating where the gaps in coverage exist. More importantly, once generated, the ODMT solution is stored within ArcGIS as part of a geodatabase, or container file that holds all of the information necessary to rerun the evaluation.  This allows quick adjustments to access points or origin locations, followed with an updated ODMT solution utilizing less computing resources.

The ability to rerun the ODMT using updated data and new origins or destinations quickly is a second benefit as it allows the tool to be interactive beyond the initial analyst.  Park planners can modify access point locations, add new locations, and update the underlying parcel information as new residential areas develop; quickly evaluating how these changes influences the overall uniformity of access.

The advantage of this output is the user can combine the different components through a shared attribute, such as the originID, to evaluate the entire data set or specific parcels. Exploring the data output also shows an advantage over other service area coverage approaches as the origins can be sorted and summarized by instance, or conversely the travel distance can be used to further refine selection sets within the study to evaluate trends.  One example is searching for the number of parks that serve more than one parcel within 1/8 of a mile; using standard query expressions within ArcGIS or even through the database server will allow analysts explore the nuances in access and site locations.

### 5.2 Disadvantages of the Cadastral-based Technique

Conducting Origin-to-Distance Matrix Tool (ODMT) solutions creates an output table that exponentially increases in relationship to the number of origins to destinations.  There are definite limitations in ArcGIS Network Analyst due to computer memory, computer processor, and data storage and file size limitations.  Several tests were conducted countywide utilizing all of the residential parcels evaluating the performance thresholds.  For reference using an ODMT for all of the over 286,000 residential parcels and 308 parks (with 626 access points) can create upwards of 88 million separate lines when using a simple 1 parcel (origin) to 1 park access point (destination) calculation. The output data tables for the calculations using just a 1/4 milesearch distance exceed over 600,000 different returned solutions, expanding this to a regional approach would exponentially increase the output. Running the ODMT for all of Wake County pushed the limits of the ArcGIS file size, with the output map files exceeding 1.2 gigabytes; this appeared to be the limit of ArcGIS.

### 5.3 Origin to Destination Matrix Tool Compared to the Service Area Calculation

One product of this study is the comparison of the ODMT tool to the Service Area Calculation (SAC), both of which are within ArcGIS Network Analyst. The output of the SAC selected a similar number of parcels using the ¼ search distance. In addition to reaching a similar number of served parcels, the SAC was able to generate the output areas using the same destination and route sets as the ODMT. While there is a tangible benefit for increased processing speed using an SAC in place of the ODMT when regarding multiple assessments, there are several key issues to consider.

The Service Area Calculation tool generates a polygon that is useful within a coverage type approach. The strongest advantage of the SAC polygon is its foundation based on travel distance along the road networks, reducing the generalization found within traditional buffers. Beyond this advantage, incorporating the SAC within coverage-based evaluations, the analyst must define the search criteria, this variable will modify the output numbers of the selection set. Setting this variable too high or low will the benefit of the detailed routes is potentially lost. This risk, while using a more realistic service area as opposed to buffers, may be acceptable within certain studies depending on the allowance for tolerances.

The output from this type of coverage analysis also results in a one-to-one selection between park and parcel. Modifying this output to allow for tallying total parks available to each parcel and calculating the acreage requires a large amount of interaction. The ODMT selects all features within the specified travel distance along the navigable routes, creating a one-to-many output that reduces the amount of manipulation needed on behalf of the analyst to derive the same output from the SAC coverage based analysis. The ODMT output assigns the calculated length, parkID, and occurrence information to each parcel, something the SAC also cannot do without additional manipulation by the analyst.

While computationally more taxing, the ODMT proves to require less interaction to generate the most comprehensive set of output data. A key component in any assessment is choosing a tool that requires minimal input and generates the most useful data for the target analysis. Reducing the number of steps within a process will potentially reduce the opportunities for incorporating sources of error; equally important is minimizing the number of variables that a user can modify in order to return consistent results.

**5.4 Future Research**

The overall process of using the combination of dasymetric mapping and ArcGIS Network Analyst as part of a parks planning workflow reveals several areas that warrant additional research. These additional areas of research would evaluate data acquisition, data standards, workflow streamlining, and improving the functionality of the process through automation. Automation through development of a plug and play style geospatial application could make the cadastral-based measurement approach accessible to city planning departments with varying levels of GIS expertise.

The quality and completeness of the input data can greatly influence how the model functions. The standards that govern measuring, naming, and acquisition scale directly influences the quality of the data collected. This study is possible in part due to the level of detail maintained by Wake County GIS department for cadastral information, road networks, and the inventory of public and private open space.

For example, within the cadastral data for Wake County, NC, there is an up-to-date attribute field for tracking the number of housing units within a given parcel. This attribute allowed for the reassignment of population at a very large scale across the county. This cadastral data also maintains attributes that track the year built, site function/use, land value, and acreage. All of these attributes can lead to a more comprehensive analysis on park accessibility such as limitations in moving closer to a recreation area due to land costs or lack of available housing units.

Population census data is currently on a 10-year renewal cycle within the United States. Conducting park service analysis needs accurate population projections to predict how the density of a given area may change, create pressures on existing parks and guide future park site selections. The use of an ODMT to assign park distances across the study area creates an output feature class that may integrate within a predictive population model to assess redeveloping areas to identify areas with potential future park shortages. Such a model would be plausible if population modeling uses a constant like housing units found within the cadastral information. The dasymetric model documented here provides a means for apportioning future census data to the cadastral data. With the potential for census blocks to change in area as populations increase, this linkage would require some careful thought.

The complexity of integrating the population data and parcel data in the base form of this work into a completely automated process is also worth additional research. One of the initial intents of this study was to develop an automated tool, as least as implemented through model builder. During the model development process, an automated process for generating the final population tables and the park access points was not completed. The processes for the dasymetric mapping component is automated through the use of tools developed within ArcGIS Model Builder including calculating the census block population numbers, assigning census block ids to parcels, totaling of household units per census unit, and total population for each parcel.

#### *5.4.1 Adding Social Variables*

This workflow has been tested using existing data for population, household units, and park locations based on a physical road network. These vectors are quantifiable and mapped within existing data. Advancing this workflow to incorporate the social variables associated with demographics, public opinion, and current user statistics would allow for further analysis of how the differing social groups within the study area have access to the parks. Considering this interaction, there are two directions to evaluate, looking at the parcel level to create a clear definition of how the different groups can access the park independently, and at the larger scale using neighborhood and social boundaries within the ODMT calculation to understand the influence of perceived soft edges in regards to park distribution.

This latter concern could reveal an even larger level of fragmentation within an open space system as neighborhood demographics can serve as a source of perceptions including safety as well as social acceptance when crossing these soft edges to utilize a park in a different neighborhood. Mapping safety by adding in point instances of crime tied to the same census block group data, providing a more tangible set of data points to create a calculable result. Incorporating social perceptions would require a more comprehensive approach that may include gathering direct survey data from residents regarding parks they use across the county, identifying the parks not visited due to social factors separate from measurable travel distance. These surveys, sampled from each of the different racial and income groups, would provide insights in mapping potential social barrier lines when incorporating perceived cultural and emotional barriers as realized barriers within the ODMT.

#### *5.4.2 Automation and Portability*

Fully automating the process is a second focus of future research. At the start of this study, several stages of the data management and dasymetric process were automated through model builder. Due to limits in knowledge of scripting and advanced data management, further study and exploration would allow for a complete model to be developed that can function regardless of geographic location. This revised automated model would allow analysts to input their source data for parcels, population, park access points, and barriers and execute multiple solutions with minimal input within the workflow.

Beyond automating the main workflow, developing an automated approach for determining access points for subject parks would be of tremendous value in improving the practicality of this approach across multiple regions. For Wake County, while the geocoded addresses provided a basic level of access points, the field conditions showed that many parks have multiple access points that required further mapping. Omitting these access points from the ODMT calculation would create false gaps in the coverage area. Manually inputting these points for over 300 park sites requires a commitment of time in both the field and through remote analysis comparing different data layers and aerial photography in order to make accurate demarcations.

The quality of the geodatabase for the road network is also of concern as the scale of the study area increases. Having a cleanly digitized road network with concise locations for intersections, sidewalk information, locations of pedestrian crossings and speed limit attributes would allow for higher accuracy and improve the ability for the ODMT to complete successfully. In the initial work-through, the calculations for the ODMT within Wake County had inconsistent completion rates. Improving the completion rates required several changes. In ArcGIS Network Analyst for example it was necessary to use repair and re-build tools to strip out redundant vertices and overlapping lines. However, this tool can lead to oversimplification, requiring the analysis to review the output network to verify its completeness.

The use of roads as barriers is also a crude method when considering the proximity of parcels to the road and how the ODMT handles parcels that are on the same side of the road along a barrier as the park. This will require additional research to evaluate methods for automating the identification, digitization, and categorization of sidewalks along existing travel routes. Once identified, these sidewalk routes could be incorporated into the network dataset to create a more complete route network for use in the ODMT calculations.

### *5.4.3 Workflow Accessibility Evaluation*

Integrating ArcGIS Network Analyst into this study limits the initial user group capable of executing this workflow. Limitations include skill set, cost of hardware and software (acquisition and maintenance), and the availability of the required base data. Distribution of an automated tool will mitigate the skills gap for those communities and organizations that that have access to the appropriate software licenses.

Mitigating the software and hardware costs requires further evaluation.  Computer power and equipment costs will continue to improve, however the cost of operating and maintaining the hardware continues to increase.  There are options that are developing within the geographic information systems industry that may prove viable as alternatives (Lwin et al. 2012).  These opportunities include the advancement of online-based GIS services such as ArcGIS Online. The Trust for Public Lands maintains a system branded ParkScore that may also support the proposed workflow.

The availability of Open Source alternatives to ArcGIS and ArcGIS Network Analyst is increasing, candidates that include Grass and QGIS both support network analysis type workflows, but require learning the software.  Developing an automated script that works within these platforms would allow communities that have an existing GIS infrastructure to utilize their data to conduct this type of workflow, while avoiding having to purchase ArcGIS and Network Analyst.

Improving base data is a more complex challenge when considering the need for detail regarding routing information and parcel data.  In North Carolina, parcel data is comprehensive at the county level, in order to support the tax collection infrastructure.  In other states, this may not be the case.  The use of crowd-sourced data such as that from the OpenStreets project may improve the route analysis as users can add information regarding sidewalks, overpasses, and other components to the data set that will greatly improve the quality of the output.

### *5.4.4 Scaling Workflow*

Testing this methodology on a large county within North Carolina that is representative of the level of complexity expected within the state in terms of parcel count and total parks serves as a means to evaluate the potential limitations in equipment and software.  Wake County, with its mixture of urban and suburban development areas also serves as a viable test case for experimenting with the road network and necessary level of detail for resolving detailed origin-to-destination measurements. This study used the walk distance variable as a means to cull the potential number of Origin to Destination pairs within a single county. Despite the observed limitations in computer processing and file size, this workflow may be scalable through one of two methods that will need to be evaluated further in order to address larger more developed counties, such as Los Angeles, and how to account for multi-county scenarios common in regional assessments.

Successfully implementing the automation of the proposed approach will be a primary step in refining this approach to work at the larger scale. In order to handle larger counties, the automated script (or model) requires modification to evaluate a fixed area within the overall study area. Once the first area is complete, the focus area would shift to analyze the next set of origins, processing the larger county in a grid. This technique compartmentalizes the county into smaller segments that are manageable within the limitations of the hardware and software. Once the ODMT solutions complete for each of the focus area, a script needs to collect the output tables into a large unified table via a database management program capable of handling file sizes larger than ArcGIS, such as Microsoft Access or within the SQL server. Within the database program, one can summarize the ODMT data and merge the output to the parcel database. This allows analysts to complete the uniformity analysis for the larger county.

A similar approach will solve the multiple county scenarios. The consistent link is the use of the automation script to facilitate the larger volume of source data. The challenges that face this scenario include consolidating the park information, the parcel data, and acquiring a unified route database. The route database is of significant concern, as the roads need to connect in order to solve for parcels using parks in adjacent counties. If the input counties are of a higher complexity than Wake County, using the focus area approach described above will aid in improving the completion rates.

### 5.5 Future Applications

The motivation for this study stems from the role that planners have in park and recreation planning from site selection, funding allocation, and maintenance and operation. Having a method such as the one proposed can greatly reduce the generalization that is often present in current park system analysis. Wake County is a suburban community with very fragmented urban areas. This study shows how the difference between the ODMT and a buffer based coverage approach has a high degree of separation. However, in the past, funding and site selection studies utilize buffer-based coverages to determine the priority areas.

As shown in the comparison of the ODMT to the buffer coverage, the issues of access paths, appropriately located entry points, distribution of services and land area, and user demand are not readily discernible in the buffer; this creates a highly generalized view of the park system. Using the ArcGIS Network Analyst to conduct this cadastral-based workflow creates an output that incorporates these elements and creates a grounded analysis revealing significant gaps in the areas of the county depending on community.

Funding, such as that from the Parks and Recreation Trust Fund (PARTF), awards on a need-based calculation that evaluates the number of people served as well as income and demographics. A challenge facing this program is ensuring that not only are the intended populations being served by the facility, but also verifying that the funds are being equally distributed across all of the communities. PARTF looks at two variables in their ranking matrix, location of residents and location of neighboring commercial services. Dense urban areas will score higher when using a coverage-based approach compared to more suburban developments. The census data for the urban areas is highly fragmented into a large number of objects; observable when looking at Cary, NC compared to Raleigh, NC. Utilizing the cadastral approach will eliminate the potential bias of the coverage approach. The cadastral approach also aids planners in quickly mapping the residents within the 1/4 mileservice area for targeted surveys.

In a reverse of this workflow, the cadastral approach will also allow for the conducting of user surveys at each facility location. Collecting the user information over a 30-day or 45-day period will facilitate executing an ODMT solution that maps the address of the users to the park location, creating an actual user group based service area for each facility within the system. This would show the average travel distances and frequency of visits per park, that when linked back to the overall workflow, would allow further ranking of the parks based on the user count and distances traveled. This would be of benefit when evaluating the effectiveness of a facility in terms of total users and real service area. This will also allow making decisions about the value of a specific park within the system, highlighting either the need for improvements to that facility or the potential for selling the facility in exchange for a more beneficial site.

## 5.6 Final Conclusions

While automating the proposed workflow is not complete, the successful completion of the test process utilizing a manual approach to the calculations shows that there can be benefit to focusing on the parcel-to-parcel approach of measurement. Knowing which pathways are traversable for a resident accessing a specific park parks and being able to measure these travel distances accurately through the ODMT is a valuable component in reviewing the long-range needs of a park system. This type of process can potentially be reverse integrated into a site selection tool to allow planners to see how well a particular site will suit the community residents.

The limitations of the computer hardware and file size will continue to improve and as computational resources, increase further automations to the proposed workflow will be possible. The continual evolution of computer hardware in conjunction with GIS data storage and acquisition aids significantly in evaluating and planning for the future needs of a community in an equitable and equally accessible manner. However, the costs may be outweighed by the advantages of a ground based measurement technique compared to those of generalized areal units, like containers and buffers, and may prove cost effective in identifying more appropriate land acquisitions and even identifying and prioritizing surplus properties that could be used for park development.

The overall benefits of the cadastral-based technique fill the voids found in literature by introducing a means that combines the strengths of network analysis methodologies to proven dasymetric techniques for apportioning the population data to the mapped dwelling locations. This type of approach will help bring better validity in future uniformity of access assessments and serve as a solid foundation for equality assessments.

## REFERENCES

Boone, Christopher G., Geoffrey Buckley, J. Morgan Grove, and Chona Sister. 2009. "Parks and people: An Environmental Justice Inquiry in Baltimore, Maryland." *Annals of the Association of American Geographers* 99: 767-87. Accessed August 14, 2014. http://www.researchgate.net/publication/238043978_Parks_and_People_ An_Environmental_Justice_Inquiry_in_Baltimore_Maryland.

Carleyolsen, Sanya, Tanya Meyer, Joseph Rude, Ian Scott. 2005. "Measuring the Economic Impact and Value of Parks, Trails, and Open Space in Jefferson County: Accounting for Current and Future Scenario." Paper presented at the Urban and Regional Planning Workshop Fall 2005, University of Wisconsin-Madison, Madison, Wisconsin, December 15, 2005.

Chandio, Imtiaz Ahmed, Abd Nasir B. Matori, and Dano Umar Lawal. 2011. "GIS-Based Accessibility Analysis Using Suitable Land for Public Parks in Larkana City Pakistan." *Research Journal of Applied Sciences, Engineering and Technology* 3: 553-57. Accessed August 1, 2014. http://www.researchgate.net/publication/233883820_GIS-based_Accessibility_Analysis_Using_Suitable_Landfor_Public_Parksin_Larkana_City_Pakistan.

City of Raleigh (Raleigh). 2014. "Raleigh Demographics." City of Raleigh Business and Development Department, September 23. Accessed September 29, 2014. http://www.raleighnc.gov/government/content/PlanDev/Articles/LongRange/RaleighDemographics.html

Dalton, Alice M., Andrew Jones, David Ogilvie, Mark Petticrew, Martin White, and Steven Cummins. 2013. "Using Spatial Equity Analysis in the Process Evaluation of Environmental Interventions to Tackle Obesity: the Healthy Towns Programme in England." *International Journal for Equity in Health* 12: 43-53. Accessed July 2, 2014. http://www.equityhealthj.com/content/12/1/43.

Duncan, Dustin T., Ichiro Kawachi, Kellee White, and David R. Williams. 2012. "The Geography of Recreational Open Space: Influence of Neighborhood Racial Composition and Neighborhood Poverty." *Journal of Urban Health: Bulletin of the New York Academy of Medicine* 90: 618-631.

Esri. 2014. “Network Analyst Tutorial.” ArcGIS Resource Center, July 1, 2012. Accessed July 1, 2014. http://help.arcgis.com/en/arcgisdesktop/10.0/pdf/network-analyst-tutorial.pdf

Hass, Kara. 2009. “Measuring Accessibility of Regional Parks: A Comparison of Three GIS Techniques.” Master’s thesis, San Jose State University. Accessed August 14, 2014. http://scholarworks.sjsu.edu/cgi/viewcontent.cgi?article=4637&context=etd_theses.

Heckert, Megan. 2013. “Access and Equity in Greenspace Provision: A Comparison of Methods to Assess the Impacts of Greening Vacant Land.” *Transactions in GIS.* 17: 808-27. Accessed September 5, 2014. http://onlinelibrary.wiley.com.libproxy.usc.edu/doi/10.1111/tgis.12000/abstract

Higgs, Gary, Richard Fry, and Mitchel Langford. 2012. “Investigating the Implications of Using Alternative GIS-based Techniques to Measure Accessibility to Green Space.” *Environment and Planning B: Planning and Design* 39: 326-43. Accessed September 5, 2015. http://www.envplan.com.libproxy.usc.edu/epb/fulltext/ b39/b37130.pdf

James B. Holt, C.P. Lo, and Thomas W. Hodler. 2004. “Dasymetric Estimation of Population Density and Areal Interpolation of Census Data.” *Cartography and Geographic Information Science* 31: 103-121. Accessed September 5, 2014. http://www.researchgate.net/publication/250016044_Dasymetric_Estimation_of_Population_Density_and_Areal_Interpolation_of_Census_Data.

Joseph, Laura D. 2011. "Park Accessibility in Atlanta." Master’s thesis, Georgia State University. Accessed July 27, 2014. http://scholarworks.gsu.edu/geosciences_theses /32Langford.

Langford, Mitchel. 2007. “Rapid Facilitation of Dasymetric-based Population Interpolation by Means of Raster Pixel Maps.” *Computers, Environment and Urban Systems* 31: 19-32. Accessed September 5, 2015. http://www.sciencedirect.com/science/article/pii/S0198971506000330

Lindsey, G., Maltie Maraj, and Son Cheong Kuan. 2001. “Access, Equity, and Urban Greenways: An Exploratory Investigation.” *The Professional Geographer* 53: 332-46. Accessed September 6, 2014. http://onlinelibrary.wiley.com/doi/10.1111/0033-0124.00288/pdf

Liu, Lin, and Xia Li. 2014. “GIS and Built Environment.” *Geojournal* 79: 127-8. Accessed August 1, 2014. http://link.springer.com/article/10.1007/s10708-013-9507-9.

Loukaitou-Sideris, Anastasia and Orit Stieglitz. 2002. "Children in Los Angeles Parks: A Study of Equity, Quality and Children's Satisfaction with Neighborhood Parks." *The Town Planning Review* 73: 467-488. Accessed August 14, 2013. http://www.jstor.org/stable/40112531

Lynch, Kevin. 1960. *The Image of the City*. Cambridge, MA: MIT Press.

Lwin, Ko, and Yuji Murayama. 2012. “GIS Network Model in Geospatial Analysis.” In *Progress in Geospatial Analysis,* edited by Yuji Murayama, 183-194. Tokyo: Springer Japan. Accessed August 5, 2014. http://link.springer.com/chapter/10.1007%2F978-4-431-54000-7_12

Maantay, Juliana Astrud, Andrew R. Maroko, and Christopher Herrmann. 2007. “Mapping Population Distribution in the Urban Environment: The Cadastral-Based Expert Dasymetric System (CEDS).” *Cartography and Geographic Information Science* 34: 77-102. Accessed September 5, 2014. http://www.lehman.edu/deannss/geography/publications/Dasymetric_CaGIS_Maantay.pdf

Makse, Hernán A., Shlomo Havlin, and H. Eugene Stanley. 1995. “Modelling Urban Growth Patterns.” *Nature* 377: 608-12. Accessed July 20, 2014. http://www.nature.com/nature/journal/v377/n6550/pdf/377608a0.pdf

Maroko, Andrew R., Juliana A. Maantay, Nancy L. Sohler, Kristen L. Grady, and Peter S. Arno. 2009. “The Complexities of Measuring Access to Parks and Physical Activity Sites in New York City: A Quantitative and Qualitative Approach.” *International Journal of Health Geographics* 8: 34-57. Accessed July 5, 2014. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2708147/pdf/1476-072X-8-34.pdf

Marusic, Barbara Golicnik. 2011. “Analysis of Patterns of Spatial Occupancy in Urban Open Space Using Behaviour Maps and GIS.” *URBAN DESIGN International* 16: 36-50. Accessed August 7, 2015. http://www.palgrave-journals.com/udi/journal/v16/n1/full/udi201020a.html

Mertes, James D. and James R. Hall. 1996. *Park, Recreation, Open Space and Greenway Guidelines.* Arlington, VA: National Recreation and Park Association.

Moeller, John. 2014. "Standards for Outdoor Recreational Areas." American Planning Association. Accessed September 5, 2014. http://www.planning.org/pas/at60/report194.htm.

Nicholls, Sarah. 2001. "Measuring the Accessibility and Equity of Public Parks: A Case Study Using GIS." *Managing Leisure* 6: 201-19. Accessed August 10, 2014. http://staff.washington.edu/kwolf/Archive/Classes/ESRM304_SocSci/304%20Soc%20Sci%20Lab%20Articles/Nicholls_2001.pdf

Office of State Budget and Management (OSBM). 2014. "2013 Certified County Population Estimates." Office of State Budget and Management, September 19. Accessed September 25, 2014. http://www.osbm.state.nc.us/ncosbm/facts_and_figures/socioeconomic_data/population_estimates/demog/countygrowth_cert_2013.html.

Sister, Chona, Jennifer Wolch, and John Wilson. 2010. "Got Green? Addressing Environmental Justice in Park Provision." *GeoJournal* 75: 229-248. Accessed September 5, 2014. http://link.springer.com/article/10.1007%2Fs10708-009-9303-8.

Talen, Emily, and Luc Anselin. 1998. "Assessing Spatial Equity: An Evaluation of Measures of Accessibility to Public Play-grounds." *Environment and Planning A*, 30: 595-613.

Tarrant, Michael, and H. Ken Cordell. 1999. "Environmental Justice and the Spatial Distribution of Outdoor Recreation Sites: An Application of Geographic Information Systems." Journal of Leisure Research 31:18-34. Accessed August 8, 2013. http://search.proquest.com.libproxy.usc.edu/docview/201178702/fulltextPDF/1CEF0A8C1A56424CPQ/1?accountid=14749.

Town of Cary (Cary). 2012. “Chapter 4: Inventory & Level of Service Analysis.” *Parks and Open Space Master Plan*. Cary, NC: Town of Cary, November 13. Accessed July 30, 2014. http://www.townofcary.org/Departments/fdts/facilities/Current_Projects /prcrmasterplan.htm.

Wake County GIS Department (WakeA). 2014. *Wake_Property_2014_06*. Wake County, NC: Wake County GIS Department, June 30. Accessed July 1, 2014. http://www.wakegov.com/gis/Pages/default.aspx.

Wake County GIS Department (WakeB). 2014. *Wake_Census_2010*. Wake County, NC: Wake County GIS Department, June 30. Accessed July 1, 2014. http://www.wakegov.com/gis/Pages/default.aspx.

Wake County GIS Department (WakeC). 2014. *Wake_PublicOpenSpace_2014_06.* Wake County, NC: Wake County GIS Department, June 30. Accessed July 1, 2014. http://www.wakegov.com/gis/Pages/default.aspx.

Wake County GIS Department (WakeD). 2014. *Wake_Streets_2014_06.* Wake County, NC: Wake County GIS Department, September 5. http://www.wakegov.com/gis/Pages/default.aspx. Accessed July 1, 2014.

Wake County GIS Department (WakeE). 2014. *WakeMajorRds.* Wake County, NC: Wake County GIS Department, September 5. Accessed July 1, 2014. http://www.wakegov.com/gis/Pages/default.aspx.

Wake County Planning Department (Wake). 2014. *Unified Development Ordinance of Wake County*. Wake County, NC: Wake County Planning Department, October 6. Accessed November 1, 2014. http://www.wakegov.com/planning/zoning/Documents /adoptedordinance.pdf

Wolch, Jennifer, John P. Wilson, and Jed Fehrenbach. 2005. "Parks and Park Funding in Los Angeles: An Equity-mapping Analysis." *Urban Geography* 26:4-35. Accessed August 5, 2014. http://www.tandfonline.com/doi/pdf/10.2747/0272-3638.26.1.4#.VMVDMrt0wiQ.