Walkability Study for School Accessibility:
Case Study of the San Juan, Puerto Rico Elementary Schools

by

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DEDICATION

I dedicate this document to my grandmother Berta Camacho, my friends Suzika Pagán, Shannon Prescott and Heather Kelley for their constant support, patience and understanding. Also I want to recognize my committee chair Dr. Robert Vos, who has helped me through this project in understanding the concepts and theories behind the research and for his support in completing this project.

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LIST OF ABBREVIATIONS

CRIM	*El Centro de Recaudación de Ingresos Municipales*
CDC	Center for Disease Control
DE	*Departamento de Educación*
DTOP	*Departamento de Transportación y Obras Públicas*
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
GIST	Geographic Information Science and Technology
MAUP	Modifiable Areal Unit Problem
PRTE	Reorganization and Transformation School program
SSI	Spatial Sciences Institute
US	United States
USC	University of Southern California

ABSTRACT

Geographic Information Systems (GIS) mapping applications have proven to be an integral part in school site planning. However, most school site planning does not take walkability into account. This study describes a method to measure how walking access to schools was affected by the closure of elementary schools in the San Juan County. Recent studies in students walking to school in the US have found that there has been a major decrease overall (National Household Travel Society 2013). Using population density and dasymetric mapping, the number of students in each parcel in the San Juan School County was estimated. A walkability service area was derived from a network dataset using the functional classification of roadways from the Federal Highway Administration (FHWA). Accessibility was calculated ¼ miles away from the school using the service areas before and after school closure. It was determined that after school closure pedestrian accessibility and total distance walked to school did not change significantly. Network analysis represents a direct approach that assesses accessibility and physical barriers of the urban environment. Combining the walkability service area and the population per parcel, student accessibility was calculated. The use of this methodology will allow a better assessment for the school site planning and can be used to develop initiatives that will promote walking to and from school.

CHAPTER 1: INTRODUCTION

Geographic information systems (GIS) are designed to capture, manipulate, analyze, manage, store and display geographical data, and they are an important tool for planning and development of spatial events (Longley, et al. 2011). As time goes by and technology evolves, GIS mapping technology can be implemented in many aspects of our society. Carey (2011) explains that GIS mapping is an important process for projecting student enrollments for school locations, which is an integral part for school site planning. Carey (2011) further explains that with GIS mapping technology, planners and researchers have the ability to incorporate factors that affect school planning such as race, school enrollment, proximity of schools to demographic groups, growth and decline of neighborhoods. All of these factors can be considered for overall impacts on school districts and siting of school locations (Carey 2011) (K. D. Carey 2011). Carey also points out the importance of mapping in school planning, and how walking as a mode of transportation to schools is an effective and economic practice that should be implemented. The US Environmental Protection Agency (EPA) has addressed the importance of the site location of a school, accessibility, and walking to and from are school, and how they greatly affect the communities around the school (EPA 2013). Walking to and from school is usually referred to as walkability, and it should play an important role in school site location.

Although there are numerous definitions for walkability, it is defined here as a measure of how accessible an area is to walking (Bliesner, Bouton and Schults 2010). Walkability is the combination of the physical activity of walking and the physical elements that support it, like the presence of sidewalks, which make up the environment that can be walked on. Walkability should be considered an important measure of how active and suitable a city is, because it represents how the populations of certain areas move to and from one place to another. The intention of this study is to conduct a walkability assessment to see the population affected following the elementary school closure in the San Juan, Puerto Rico County. It is the intention of this study that walkability could be then added to the criteria considered in making decisions about which schools to keep and which school to close. Currently, the decision to close the school was made without taking walkability into account, seeing that 65 percent of the student population walks to and from school (Departament de Educacion de Puerto Rico 2014).

Using population density, roadways, and parcel data along with network analysis in GIS, a walkability analysis can be created, displaying which schools are easily walked to and how school closures will affect them. To develop a base for this study, the ArcGIS Network Analyst extension was researched to better understand the use of a road network in a spatial analysis. Accessibility was defined using the roadways classifications. This classification was based on the functional classification of roads from the Federal Highway Administration (FHWA). This organization classifies roadway groups in streets and highways according to the service they provide.

Once the accessible routes were identified, ArcMap software can be used to calculate walking distance between the schools and residential parcels using the network analyst tool and then Census data was used to calculate population per household. This information was used to determine how the closing of schools affected the population of the school in the San Juan County.

1.1 Defining Accessibility

Accessibility to schools is determined by the capability of a person to reach a destination. This can be usually answered using a car or as conceived in this study simply walking. How accessibility is defined for schools influences greatly the population of students affected by the schools closure. Not all places have the same accessibility. Thus, the way this study measures accessibility is important for construction of the service area that represent the walkability area to schools. There are two main concepts that accessibility relies on: location and distance. Location is the relative space in relation to the transport infrastructure. The second concept of accessibility is distance, which is the physical separation between locations (Rodrigue 2013). This can only exist when there is a separation between locations. In the case of this study, there is a separation between the schools and the parcels where students reside.

For this study the approach that followed involved the definitions of the roadways as presented by the FHWA, which are applicable to roadways in Puerto Rico. Even though roadways are mainly associated with vehicle transportation, they serve as the main structure for walking. Not all roadways are meant to be walkable but using the FHWA classification of roadways it is possible to identify which roadways are walkable and which one are not. This approach also does not take into account temporary physical barriers that prevent people from walking like road construction. While accessible deals more with the network created by the roadways, walkability deals with the service area around the schools. Accessible roadways are accessible by walking.

1.2 Service Area to Walkability

Service areas in GIS are determined from a network of roads and it determines the distance around a location that a person travels on a network. How service areas are defined for a study greatly influences the population affected by the closure of the schools. Some methods to calculate service area involve the use of buffers around the locations to travel (Yin and Zhan 2014). The problem with the use of buffers is that this method does not take into account roadways, buildings, topography or any obstruction around the schools. In truth, buffer analysis poorly represents accessibility to any location.

A main concern with buffers is that parcels that fall inside the buffer area may not be able to access the schools because buffer areas do not represent the true distance along the road network from the parcels to the schools. Whereas, service area analyses does represent a better spatial analysis for accessibility to and from schools. Service areas describe a polygon around the facility selected based on a network dataset created from the roads. In addition to roads, this network can contain stop signs, street signs, and other things that affect walkability can be added to the network dataset to increase the service area analyses accuracy. Also, service area analysis can be set up in a way that they will not overlap with other facilities. This can be done in case some of the schools are too close together as a way of estimating what neighborhoods should send students to particular schools.

1.3 Measuring Population

One of the reasons to create a service area is to assess the student population that has access to schools. The source for population data comes from the United States (US) Census and was further edited by the *Sistemas de Datos Geograficos* (Portal Datos Geograficos Gubernamentales 2003). By using the smallest scale of measurement for the census block it is possible to calculate the parcel around the service areas of the schools. This assessment would not be possible using buffer analysis because in a buffer analysis some parcels are not directly ¼ miles always from the schools. Alongside the census information and the parcel data type, it is possible to calculate the student population in each parcel.

Dasymetric mapping is method of thematic mapping that utilizes areal symbols to spatially classify data (Mennis 2003). When dealing with census and parcel data it is possible to calculate the actual population in each parcel based on a shared attribute. This proved to be an accurate assessment of the student affected by the closure of the elementary school in the San Juan County.

1.4 Case Study Area

Puerto Rico is located in the Caribbean Sea to the east of the Dominican Republic and north of South America. The island extends 115 miles from east to west and 41.66 miles from north to south making it the smallest island in the Greater Antilles. As an unincorporated territory of the US, Puerto Rico is officially known as the Commonwealth of Puerto Rico and it comprises 78 counties with San Juan being the main capital. An initial report from *El Departamento de Educación* (Puerto Rico Department of Education, DE) indicates that 73 schools (Figure 1) were closed between 2013 and 2015 (Departament de Educacion de Puerto Rico 2014). Not only San Juan County is the most populated county on the island, but it is also the county most affected by the school closure (Instituto de Estadísticas de Puerto Rico 2014).

Figure 1 San Juan County Schools

1.5 Motivation

School construction projects such as renovations and new buildings are occurring continually in Puerto Rico. Decisions about construction greatly affect and influence communities. It is not only communities, but the schools inside of them that face changes in their environmental atmospheres and economies. These changes are usually overlooked by the government and sometimes their effects go unnoticed until the damage is already done. An Environmental Protection Agency (EPA) study finds that school proximity matters, meaning that students with shorter times to walk to or from school are more likely to walk (EPA 2013). Also, the study determined that it is the built environment that influences the options of traveling to school because students traveling through higher quality and more accessible roads are more likely to walk. As a result of travel behavior difference, school locations have an impact on air emissions. If more accessibly located schools can be reached by walking, then this can help with the reduction of air pollution (EPA 2013). These results suggest that smart growth planning, accomplished in part through GIS mapping can act as a tool to improve students walking behavior.

Others studies have found a significant decrease in the numbers of children in the US walking and biking to school. From 2000 to 2010, the National Household Travel Survey (NHTS) reported that 15% of students between 5 and 15 years old walked to and from school, and 1% biked (National Household Travel Society 2013). An older study from the Federal Highway Association (FHWA) found that for the years 1969 to 1990, 48% of students walked or biked to school (FHWA 1972). This is an alarming decrease that should not be taken lightly. In a survey by the Center for Disease Control (CDC), it was found that this decline in walking to and from school was mostly due to accessibility and distances traveled by the students to walk to school (Dellinger and Staunton 1999).

Several organizations in the US have started to pay attention to the decrease in students walking to school and are trying to make a difference by implementing new programs to increase the quality of walking and accessibility to school. Institutions like the "Safest Routes to School Programs" within the State of California, works to increase the number of children who walk or bike to school by funding projects and programs that remove the barriers that currently prevent them from doing so (Dellinger and Staunton 1999). Collected data that the organization considers walking barriers included lack of infrastructure and unsafe infrastructure, such as construction sites and cul-de-sac roadways. This data is then routed to other organizations and agencies like the National Center for Safe Routes to School and the federal government. These organizations use these data to get rid of these barriers. Even the US Department of Health and Human Services, and the CDC have started a Kids-Walk-to-School campaign, citing the rising rates of childhood obesity, diabetes, and asthma as reasons to encourage walking to school (Centers for Disease Control and Prevention 2011).

1.6 Problem Statement

In November of 2014, the DE in a project called "*Plan de Transformación y Reorganización de Escuelas*" (Reorganization and Transformation School program, PRTE), decided to close 73 schools, and announced future plans to close 580 more by 2020 (Departament de Educacion de Puerto Rico 2014). After a study performed by The Boston Consulting Group (BCG), a consulting firm on business strategy, they discovered that the enrollment in public schools went down by 41% from 1980 to 2013 (Departament de Educacion de Puerto Rico 2014).

The BCG study and DE action did not take into account how school closures could affect the communities around the closed schools and those students that walked daily to and from school. The DE criteria for choosing which school to close included: physical condition of the school, academic performance, utilization, closeness to a similar school, and student enrollment (Departament de Educacion de Puerto Rico 2014). Proximity to a similar school may function as a sort of proxy criteria for maintaining walkability, but this deserves measurement and testing.

The use of GIS technology for smart school site planning, accessibility and walkability can be used to better understand this issue and even find a solution. This research attempts to add to the literature and propose a methodology to measure accessibility and the impacts of the 73 schools closing to the communities' surroundings in the San Juan County, Puerto Rico school district.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

For many years people did not rely on vehicle transportation to get to school. Walking to and from school was part of our daily lives. As years go by and people became dependent on automobiles for transportation this culture began to change around the world. It is our choice to walk as a mode of transportation and this is a simple fact that defines any walkability study. There are many elements involving walkability: population, land use, tree canopies, number of intersections, accessibility, and steepness of terrain and so on. Many studies only focus their efforts on defining walkability based on the elements found in their specific urban environment (Chen 2012; Parson 2015; Yin 2014).

Urban sprawl often creates obstructions that hinder our journey from one place to another (Speck 2013). Instead of deciding to walk, people start finding that it is a burden to get anywhere. Walkability does not have to be a burden, but it can instead be a measure of a healthy urban environment. There is no perfect combination of elements that truly defines walkability and in some cases it goes beyond the urban environment into the needs of current society. Populated and urban places usually are in need of walkable pathways. It is in populated places where roadways are usually cramped with cars and traffic where the environment becomes unbearable (Kunstler 1994). Populated places also have many types of locations that are closer together. This means that it should be easy to walk from one place to another. Less populated and rural places do not have the same need for walkable pathways. Locations are far apart and roads are not very walkable. The San Juan County is an urban and populated place with many roadways and walkable pathways. At the time of this study, no type of walkability study in Puerto Rico has been published to the best of the author’s knowledge. This fact makes this study new and unique.

The purpose of this chapter is to explore the literature and compare the different methods used to measure walkability. How have previous studies assessed and measured accessibility? Approaches to accessibility vary depending on the area and focus of the study. This was taken into account for this research. Defining accessibility in this study takes taken a different approach from some of the studies discussed in this section. The literature review also discusses some methods used to measure walkability. Most previous studies on walkability reviewed used a buffer analysis approach with Census data organized by Census geographical units. However, this approach does not work well in urban or suburban environments where roads have no direct access to the locations and there are urban and environmental barriers. Also, as an alternative to relying solely on Census geographical units, dasymetric mapping is discussed in this section. The following discussion establishes the basis for this research and sheds more light on the optimal elements to include in walkability metrics.

This chapter is organized into four subsections: accessibility, walkability, and dasymetric mapping of student population. A thorough understanding of these concepts influences the makeup of this study. The foundation of this study relies on bringing these concepts together to interpret and assess a spatial event. At the end of this chapter, a summary is provided that outlines how the main findings build the method proposed for this study.

2.1 Pedestrian Access to Facilities

Parson's (2015) research describes the use of cadastral-based applications and buffer mapping techniques to measure access to parks for residents. Cadastral-based applications utilize dasymetric mapping to estimate the number of people that live in each parcel. This way it is possible to measure how many people have access to parks. Using road network data and cadastral data, along with Network Analyst extension in ArcMap, Parson's (2015) produced a walking distance assessment between parcels and parks in Wake County, North Carolina. By comparing the traditional buffer method with the cadastral-based method, he showed that the cadastral-based method was more accurate than the buffer method. The buffer method covers areas around parks without regards to accessibility, unlike the cadastral method that allowed him to see which parks are more accessible using urban barriers and walkability. Parson's spatial analysis is built in a model to be used as a decision support.

Parson's (2015) research demonstrated that the buffer methods do not always work and that is a very unreliable method to analyze walkability. Buffers do not assess physical barriers in urban environments and thus do not show true accessibility to areas. To measure the accessibility to parks, Parsons (2015) utilized service areas analysis to derive a walkability path to and from the parcel. This service area was derived from a network dataset created from the roads. Once the service areas were derived, Parsons calculated the population on those service areas.

Unlike Parsons (2015) who focused on parks, in this study the service areas represent an area were the population has access to schools. The service area that he used was derived from a network data dataset created from the roadways. For his study Parson's (2015) did not utilize any criteria on the roads. His network data set was based mainly on local roads and did not take into account other walkable pathways. For this thesis, a similar approach was taken but the criteria for the creation of the network data set was adapted to the context of the Puerto Rico road network and school accessibility problem.

2.2 Walkability and Pedestrian Access to School

Typically, walkability has been measured by the use of buffer areas or service areas around the target location. But to truly derive walkability areas, roadways have to be taken into account.

Chen (2012) has discussed how GIS can be used to contribute to bus network design by applying the concept of walkability to bus route planning. She examined two bus routes in Orange County California that were under different urban development patterns to determine if there is a difference in the walkability score. The major two factors that influenced these urban development patterns is the difference in street connectivity. These two urban set ups were normal grid street and cul-de-sac streets. Normal Grid streets are traditional urban roads, connected along arterials, highways and local streets, and cul-de-sac neighbors are usually dead end roads that are meant to control flow of traffic. Using population density, street connectivity, steepness and tree canopies she examined these different bus routes extracting a walkability score for each. She concluded that normal grid streets are highly walkable compared to cul-de-sac streets.

Chen's (2012) thesis has the right idea of using population density and street connectivity for her walkability index, and steepness and tree canopy are a great measurement of walkability and could be important to measure the walkability in Puerto Rico. Factors that drastically affect walkability usually deals with urban and environmental barriers. Even though she did not conduct a full network analysis, street connectivity proved to be a major element in measuring walkability. Chen (2012) also considered non-street paths like short cuts through parks. Without street connectivity walkability is not possible. People that walk to and from place to places will be deterred from walking if the pathways are intricate to walk. Normal grid street and cul-de-sac street definitions can be viewed as elements of accessibility, normal grid street being more accessible than cul-de-sac streets. This element plays a major role in walkability.

Yin's (2014) research in walkability based in Wuhan, China utilized buffer analysis approach. In his study, Yin (2014) integrates the factors of transportation, population and land use to determine if the educational facilities in the Wuhan Province were in accessible places. Yin (2014) highlights the need for a “green” mind set for Wuhan Province. In his view, for many years urban development has been more oriented toward motor vehicle popularity without regard for an active life style or a pollution free environment. The streets in the province have become a harsh place to walk, and space for walking is slowly being swallowed up by non-accessible areas used for motor vehicles. Pedestrians are being pushed back into less walkable pathways by the rapid extension of urban sprawl. Places that normally used to be safe to walk have become more vehicle friendly rather than pedestrian friendly.

From Wuhan City plans, Yin (2014) identified 2,294 educational facilities in the area. He identified population density as the major factor in the measurement of walkability. He assumed that if there is a high population density in an area, that area will have a larger and stronger demand for walking, unlike areas with low-density population.

To evaluate walkability of the area, Yin (2014) added population density, road density, and intersection density together in a raster format. He later compared the walkability index with the land use to evaluate which areas were more or less walkable. He found that urban areas were more walkable than rural areas. Yin’s (2014) research has some major deficiencies. He made too many assumptions without regards of the built environment in Wuhan City. His buffers analyses did not take into account that population does not have direct access to many types of locations. Urban environment in this city are labyrinths of pathways that cannot be assessed by a buffer area. Also his study relies too much on buffer analyses that did not cover urban barriers. There needs to be a better understanding of the physical factors or elements in an urban environment that affect walkability.

Leslie et al.'s (2006) research dealt with elements that were present and affected the urban environment. His research was based on the idea that there were objective measures for urban planning and transportation that help to better understand the relationship between factors that define physical environment and physical behaviors of an urban environment. Coming from this, she assumes that walking is the primary drive for environmental policies and public health. To Leslie et al. (2006) there were elements built into the environment that may or may not promoted walkability. GIS has the capability of using spatial data to create measure of walkability. In this way, Leslie et al. (2006) believes that GIS can be used to create polices that will encourage walking.

To Leslie et al. (2006) the choice of walking is greatly influenced by the built environmental factors in a city. These elements are those that encourage walking, like shade, steepness, and accessibility. One of the focuses of Leslie et al.'s (2006) research is based on the role of land use in walkability. This comes from the idea that land use is a major influence for walking. Where there is a high population and mixtures of land use, walking becomes more practical (Butterworth and Edwards 2006). The more mixed the urban environment is, the shorter are the distances in a city. Leslie (2006) also discussed the relationship between distance and walking, scoring neighborhood paths. The longer the distance is in the urban environment the less likely it is that someone will walk. Street connectivity also affects walkability. Where there is better connectivity, the walking tends to be easier because fewer barriers are encountered.

Leslie et al.'s (2006) research described how four elements relevant for walking can be used to create a walkability index. This index can be used to measure walkability to and from schools, work and other destinations. These four elements were dwelling density, street connectivity, land use mix, and net retail area. These elements were taken from raster and network data.

According to Leslie et al. (2006) the concept of dwelling density deals, with the ratio of number of dwelling units (parcel) to the land area in total. The level of street connectivity emphasizes the use of street centerlines and number of connections. In addition, the ratio of the number of intersections to the land area was calculated. Higher connectivity means greater choices of potential routes and easier access to major roads and collectors. Land use mix (accessibility and diversity) was also calculated by using the land use and zoning data. Using the entropy score, which calculates the degree to which different land uses are scattered within an area, provides a score with respect to the land use and land zone. The result of the score ranges from 0 representing homogeneity (all lands uses are a single type) to 1, which represents heterogeneity (developed areas are evenly distributes among all land use categories). This is based on the idea that the more varied the land use is, the more conducive it is to walk to various destinations.

Leslie (2006) standardized these four elements into four scores that can be summed in order to obtain an overall walkability index. Derived from this, highly walkable areas were flat with well-interconnected grid like streets, with higher population density and a mixture of dwelling styles and high land use type. The low walkable areas were larger sized blocks with fewer intersections and greater distance between them, low residential density, and homogenous land use with little retail.

Based on what was learned from the studies described above, street connectivity plays an important role into measure the network of the roadways for walkability. Roadways feed the pedestrian from location to location and they support walkability.

2.3 Dasymetric Mapping

Holt (2011) researched the way spatial analysis was done when ancillary data, such as parcel information is used. He saw that data collected and used by agencies usually is constrained by the level of aggregation. This data when used for spatial analysis usually was problematic, and it was difficult for the user to represent the spatial phenomenon without some sort of error. Not only that, but this data also is also affected by the Modifiable Areal Unit Problem (MAUP). This refers to the variation in scales and spatial aggregation of units that may results in a change in statistical analysis results for areal data. When this type of data incompatibility is presented, it is best to use a technique of areal interpolation. The purpose of Holt's research was to describe one technique of areal interpolation that can minimize MAUP, dasymetric mapping.

MAUP is defined as the occasion in which modifying the boundaries and scale of aggregate data significantly affects the results of spatial data. This is a problem of great concern when performing spatial analysis, especially when using census block or census tract data. It is often not clear if results of census data display the reality of the region, a problem often seen in Choropleth maps of population. Menni's (2003) proposed surface model for representation of population data as it allows the data aggregation to be represented in any desired areal unit. If census data are reorganized this way and estimated to the areas where people likely reside, the data will be less vulnerable to MAUP during analysis.

Surface representation also allows for a graphic unit to be uniform across a region, offering a more accurate cartographic representation. Menni's (2003) main focus was to describe a methodology for generating a surface-based representation of demographic data using the dasymetric mapping technique.

As previously mentioned, dasymetric mapping is a type of areal interpolation, it uses ancillary data, such as parcel data, to aid in the areal interpolation process. In dasymetric mapping the boundaries of cartographic representation are not random and they reflect the spatial distribution of the phenomena being mapped. Menni's (2003) used remote sensing ancillary data to redistribute population to a raster grid. The example used by Menni's (2003) covered five counties in Pennsylvania, where there was a significant difference in the size of rural and urban areas. Dasymetric mapping can be used to generate a surface model that is a more accurate representation of the population in rural and urban blocks.

Walkability studies usually rely on many factors, but as mentioned above not all of them produce reliable results. Dasymetric mapping was also an integral of this study. Like Menni's (2003) and Parsons (2015), dasymetric mapping is the considered most accurate procedure for calculating parcel per population decreasing errors from that cause MAUP. This way the distributions of the population per parcel can be close to the spatial phenomena.

2.4 Summary

To better understand the relationship between parcels and accessibility, of the schools under consideration in this study, there must be an analysis that measures accessibility to schools. The techniques utilized in this thesis employed some of the concepts explained in this chapter, and goes further by utilizing roadways classification to derive accessibility.

It is the main objective of this study to research the extent of accessibility to schools that avoids the problems inherent a buffer analysis and takes into account environmental and urban barriers. For the size of San Juan County datasets, GIS tools were appropriate for this type of analysis. As explained in the next Chapter 3 Methodology, the technique proposed in this study, takes into account the size of the area studied and number of school sites to be represented.

CHAPTER 3: METHODOLOGY

GIS techniques to assess the effect of school closures on pedestrian accessibility are discussed in this chapter. The data needed to carry out the analysis and present the method to combine parcel and census data to dasymetrically map student population on the closed school inside the San Juan County. Measuring the relationship between physical location of schools and parcels was accomplished by utilizing some of the basic tools in ArcMap. The first subsection of this chapter discusses the overall framework of the study, presents variables needed, and defines formulas used to calculate the desire output. Some of these workflows will be presented as they were constructed in Arc GIS ModelBuilder to accelerate the processing of some of the data and the overall analysis of the studied area.

The analysis used in this methodology tests how closing of elementary schools in San Juan County, Puerto Rico affected pedestrian accessibility for student population. Network analysis procedures were used to quantify specified walking distances, defined as service areas, between schools and residential parcels. The number of children within contrasting service areas was compared before and after school closures. Furthermore, an origin/destination (OD) analysis was performed to measure average distance walked to school for each child in the district in order to assess which are the most accessible schools in the San Juan school district. It is common for parcel data to have residential property information within its attributes. This was an important and unique part of methodology developed for this study, as described below.

Walkability areas around schools were calculated using service area analysis tool from ArcMap. To create the service area, a network dataset was built using accessible roads. Then populations per parcel and service area were combined to determine the affected student population before and after school closure. Finally, to assess the OD distance between schools and parcels the OD Matrix Cost tool was used. This tool determines the shortest distance along the network from the origin to the destination feature.

This executed methodology generated a walkability, and cadastral approach to the closure of the schools in San Juan County. To develop this analysis, the following steps were completed: 1) extracted single and multifamily parcels; 2) assigned student population per parcel using census block data; 3) identified pedestrian accessible roadways to create a network dataset; 4) select parcel inside walkability area to assess school closure; 5) completed origin destination analysis to assess mean distance to school; and 6) generated map visualization for review and assessment. Figure 2 provides a detailed outline of this workflow.

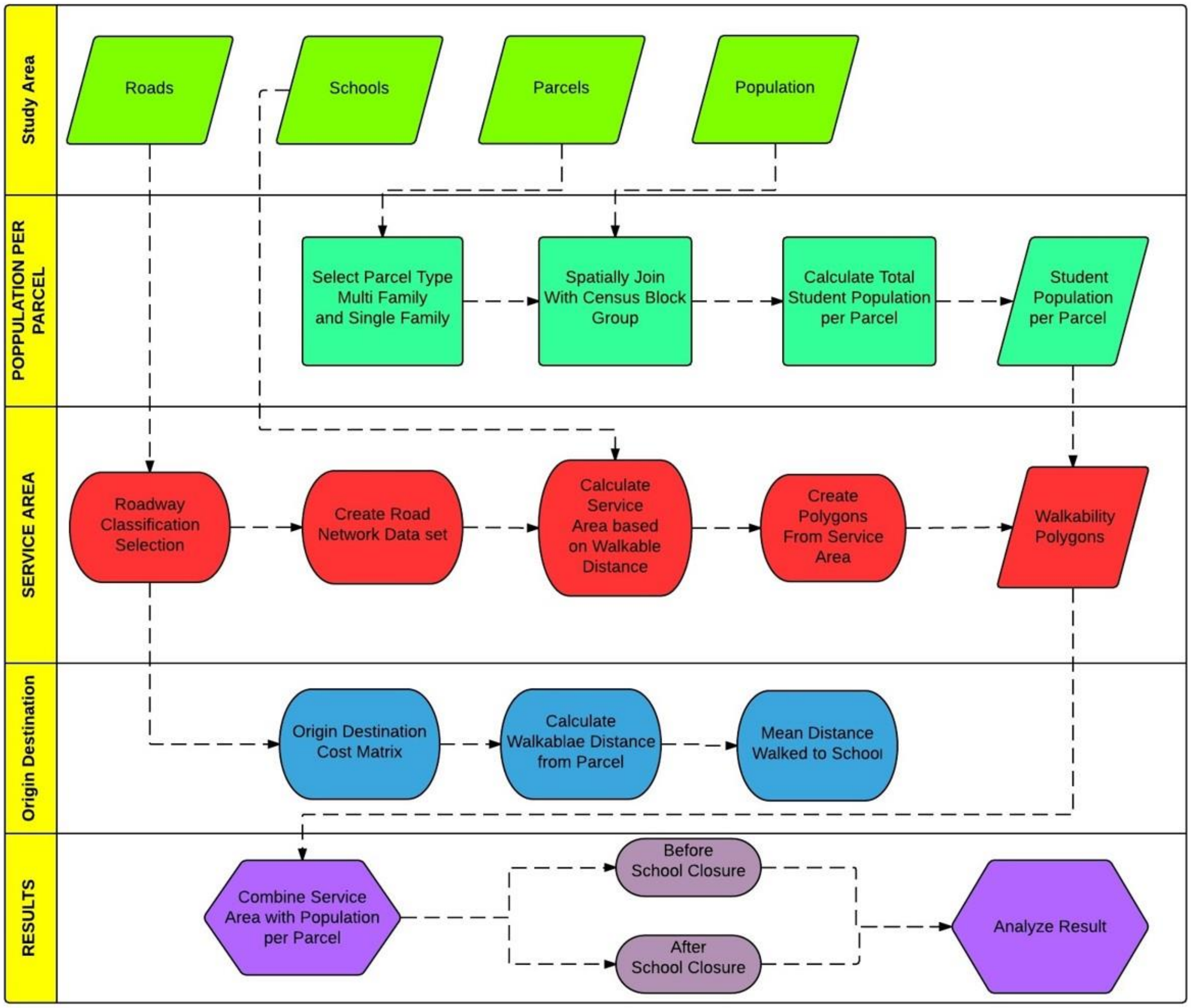

Figure 2 Overview diagram of study workflow

3.1. Data Selection and Output Products

The input data utilized in this study is summarized in Table 1. The output of this study is dependent on the quality of the information used to calculate student population per parcel and to create the service area that represents walkability to and from schools (Table 1). Various maps were generated to calculate student population per parcel and walkability in schools combining all outputs of data. The datasets used in this study were drawn from Puerto Rico's *Sistemas de Datos Geográficos* (Puerto Rico Geographic Data Systems). These data included parcels, US census blocks, roads, and schools.

The population census blocks contain information on the demographics in Puerto Rico (Table 1). This data was used to calculate population per parcel. School data was also obtained from Puerto Rico's *Sistemas de Datos Geográfícos*. This data set contained all schools in point geometry for Puerto Rico. Information on each school contained the classification of the schools as stated by DE (Elementary, Middle, and High school). This data was used as the facility center for the service area that derive walkability polygons.

Parcel data was obtained from *El Centro de Recaudación de Ingresos Municipales* (CRIM 2015). This organization is in charge of tax and land information in Puerto Rico. This parcel data contains single and multifamily parcels in Puerto Rico. This data was used with the census block groups to dasymetrically map the study area. Thus dasymetric mapping was used in areal interpolation including ancillary data such as parcels and census block data, which aided in the calculation of student population per parcel.

Parcel data is an integral part of this analysis (Table 1). Thanks to dasymetric mapping it is possible to add student population to each residential parcel in San Juan School district. For this study dasymetric mapping was designed to calculated population below the age of 18 years. The steps necessary for completing this analysis are outlined in the following sections. By assigning student population to each parcel, it was possible to identify the areas where student populations were most affected by school closure.

The roadways dataset, tiger roads, was obtained from the *Sistemas de Datos Geográficos* (Puerto Rico Geographic Data Systems) and was the primary input for the networks analysis that generated the service area (Table 1). Roadways were classified in order to identify accessible roadways for pedestrians based on FHWA classification. Inside the attributes of the tiger roads dataset, the road type classification was identified as stated by the FHWA.

ArcMap provided most of the necessary tools to organize key data layers for this study for the analysis. The primary tools used in this study included “select by location,” “select by attributes,” “spatial join,” and “summarize statistic.” The select by location tool allowed parcels inside the walkability area to be selected. The select by attributes permitted selection of features based on their attributes. For this study, this tool was used to select single and multifamily residential parcels. The spatial join tool joins brings together attributes of different feature, based on their spatial relationship. This was used to merge census block data population to the parcel dataset and polygons. Finally, the summarize statistic tool was used to gather student population from attributes of the spatial join. The output of this processing provided the basis for a better understanding of the effects of closing schools (Table 1).

Table 1 Source Data Output

Feature Class	**Source**	**Output Data**
Parcelas (2014)	Puerto Rico CRIM (CRIM 2015)	Household Units
CensusBlockGroup (CensusBlockGroup 2013)	Puerto Rico Sistemas de Datos Geográfícos (Portal Datos Geograficos Gubernamentales, 2003)	Population
DOTACIONES_EDUCACION_ESCUELAS_PUBLICAS (Schools 2014)	Puerto Rico Sistemas de Datos Geográficos (Portal Datos Geograficos Gubernamentales, 2003)	Schools
Tiger Roadways Tiger_rds_2006se	Puerto Rico Sistemas de Datos Geográficos (Portal Datos Geograficos Gubernamentales, 2003)	Accessible Roadways

3.2 Population per Parcel

To assess student populations per parcel, a dasymetric mapping technique was implemented using census block and parcel datasets. This analysis depended on parcel dataset attributes, parcel classification and census block population attribute, population under 18 years. The following subsections provide an overview of how these calculations were derived.

3.2.1 Population per Parcel Calculation

Total population per parcel was calculated by combining cadastral parcel data with US census data at the block level. Thesis method proposed by Maantayet al. (2007) as Cadastral-Based Expert Dasymetric Systems (CEDS) and also used by Holt (2004) included areal interpolation, to determine population in urban areas utilizing cell classification from raster data. Utilizing land use data and raster image, population per cell was calculated. Parsons (2015) further developed his analysis for measuring population density using parcel data for pedestrian access to parks. Based on their research, total population per parcel can be calculated according to the equations below.

$$Hu1 = P1 \times 1$$

$$Hu2 = P2 \times R$$

$$Hut = Hu1 + Hu2$$

In these equations *P1*= The number of single family parcels in a block unit, *P2*= The number of multi Family parcels in a block unit, $Hu1$= Household Units Single Family, $Hu2$ = Household Units Multi Family, *R* = estimated mean number of households on multi-family parcel, and *Hut* = Total household units. For this study, *R* was estimated as 2 households per multi-family parcel. Once total household units were calculated for each parcel, another set of formulas was used to distribute the census block population of those person aged 18 and younger across parcels in a given census block.

$$Hup = Bp/Hut$$

$$Pp1 = 1 \times Hup$$

$$Pp2 = R \times Hup$$

In these equations, *Hup* = People per Household, *Pp*1= Population per Parcel Single Family, *Pp*2= Population per Parcel Multi-Family, and *Bp* = Total Population 18 and Younger per census block.

Single or Multi Family parcels included in this analysis were defined using the parcel classification contained in the attributes of this dataset. The data classifies single-family parcels as an individual freestanding, unattached dwelling unit, normally built on a lot larger than the structure itself. Multifamily includes many categories, from side to side townhomes to high-rise buildings (Meyer 2004). Once the classification for parcels was determined, the desired parcels were isolated and joined with the census block data (Figure 3).

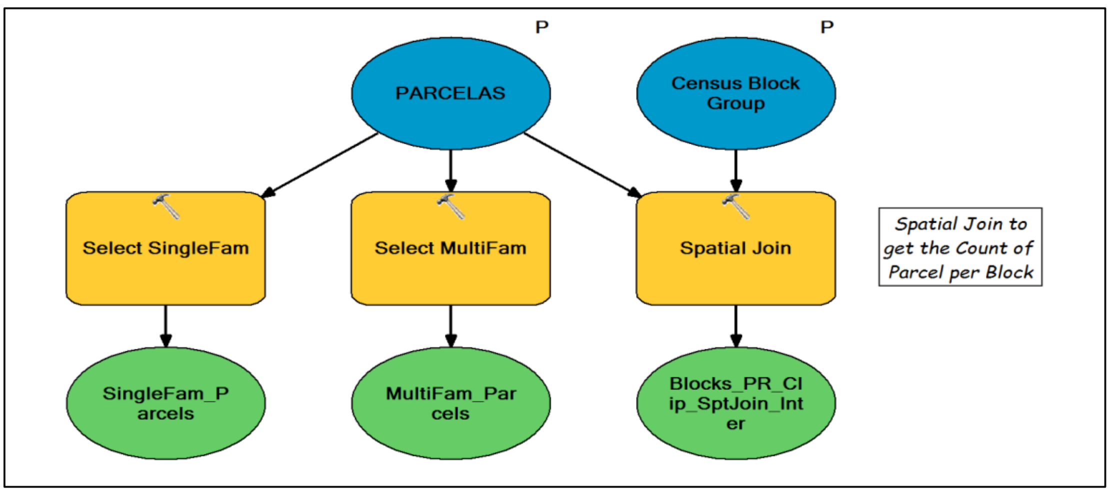

Figure 3 ModelBuilder Showing Selection of Parcel and Spatial Join

3.2.2 Dasymetric Mapping

Dasymetric mapping is a technique to map data that are not equally distributed in order to minimize the distribution mistakes presented in MAUP. With the use of ancillary data, parcel data in this case, population per parcel was calculated. Utilizing two datasets, parcels and census block group, student population per parcel was estimated using the spatial join tool in ArcMap

(Figure 4). Using this resulting attribute information, field named Pp1_Pp2, a closer look at eh map can be seen in Figure 5. The darker shades symbolize the higher student population per parcel while the lighter shades symbolize the lowest student population per parcel.

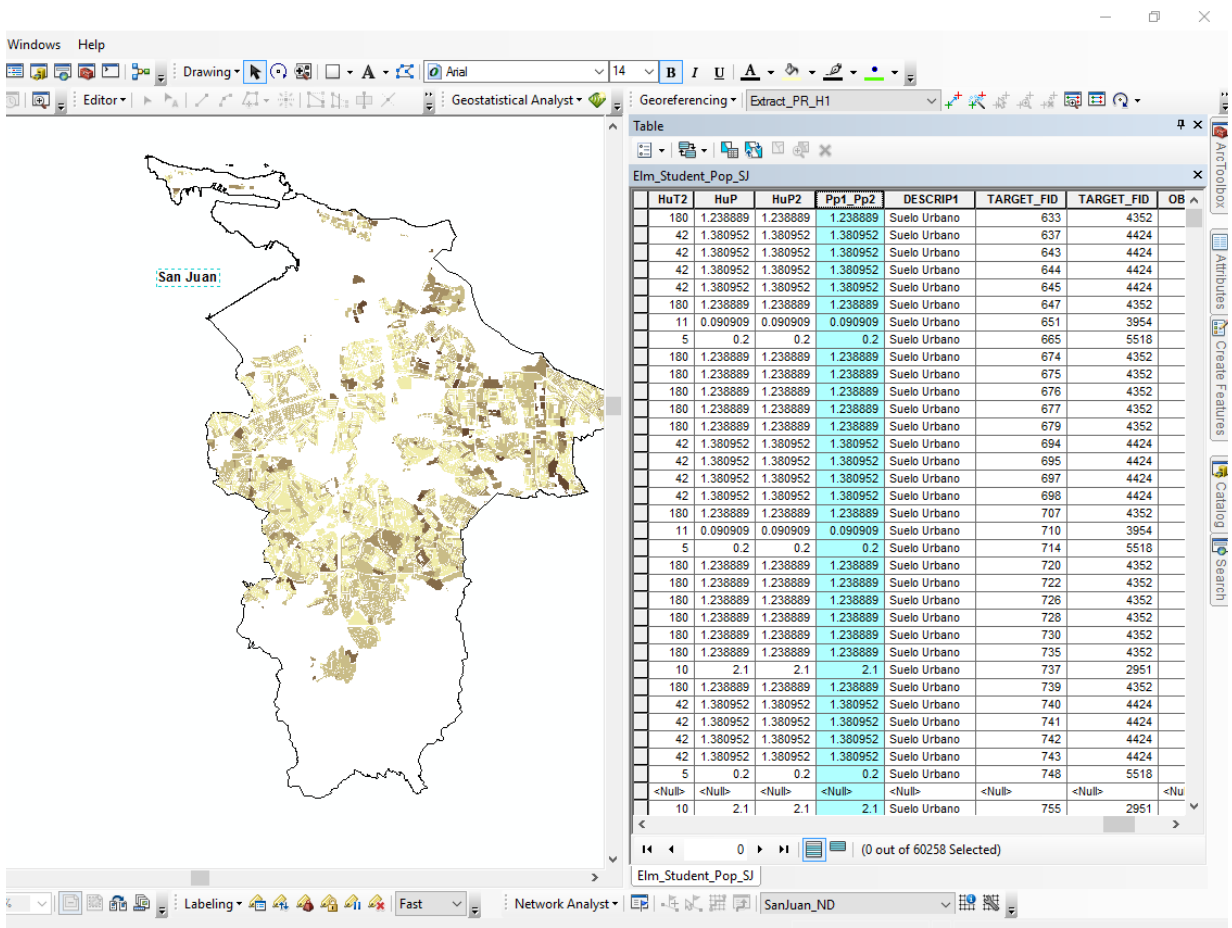

Figure 4 Student Population per Parcel Calculated

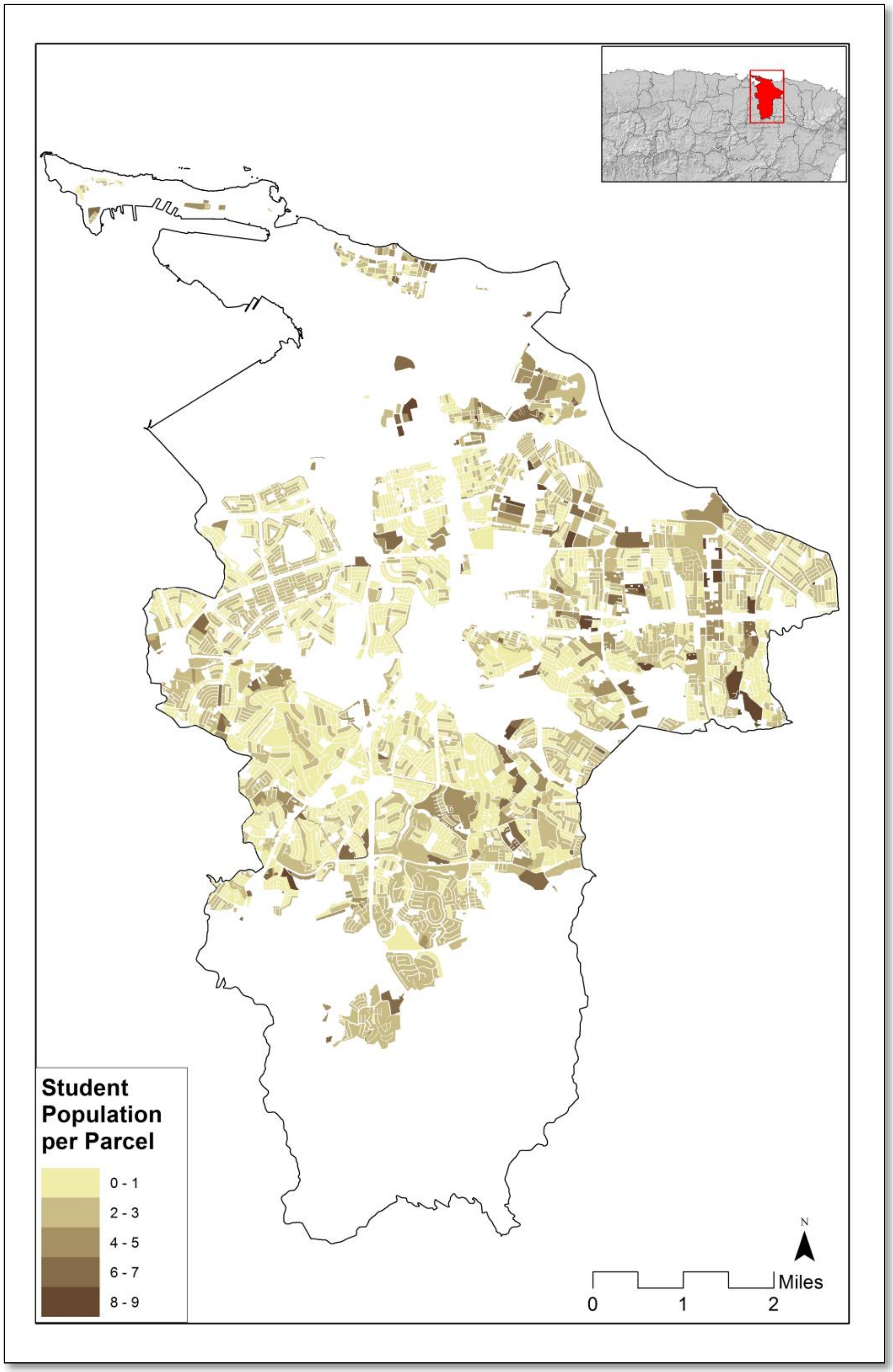

Figure 5 Student Population per Parcel Distribution

3.4 Walkability

The network analyst extension in ArcGIS functionality can be used to assess the quickest route from one point to the other, and also service areas for facilities. For example, what stores are within a certain distance when travelling by road from consumers' homes? The use of network analyst is beneficial to determine the least-cost network path between several origins and destinations. The network path, derived from the road network layer consists of a system of interconnected elements, such as lines and points, which represent the possible routes from one location to another. For this report, a network dataset was created from accessible roads identified within the Tiger roadways dataset. This data was the basis for generating the service areas that establish walkability around the schools.

3.4.1 Accessible Roadways

Accessible roadways are defined as those that allow pedestrians to walk to and from locations. All roadways have a classification that distinguishes them based on their characteristics. These classifications are based on the meticulous criteria followed by any planning transportation department (FHWA 1972). Because Puerto Rico is part of the US, the Puerto Rico Department of Transportation utilizes US roadway classification standards (*Departamento de Transportación y Obras Públicas*, 2015).

For this research, accessible roads were selected from Puerto Rico roadways dataset following the FHWA functional classification. The FHWA is the organization responsible for the construction, maintenance, and preservation of the Nation's highways, bridges, and tunnels (U.S. Department of Transportation 2013). This organization is responsible for describing the functional criteria for road classification. This functional classification is based on a variety of data points that indicate whether the roads are major network connectors or minor local roads.

These network connectors in road classification are influenced by mobility and access. Access deals with means of entry, and exit on a road, while mobility deals with the congestion from vehicles. Because most of the travel happens on a network of roadways, the functional classification defines particular roadways segments within a hierarchy according to the characteristic provided by the roadway. This classification was originally used for vehicles, but it can also be used for pedestrian access. As it explained further below, some of the classification for the roadways describes walkable pedestrian conditions.

The roadway hierarchy comes in three major categories (Figure 4): 1) Arterials are roads that provide a low level of accessibility, 2) Collectors are roads that balance between mobility and access, and 3) Locals are roads that provide a high level of accessibility. Based on this, the functional classes are further divided as follow: 1) Interstate, 2) Other Freeways and Expressways, 3) Other Principal Arterial, 4) Minor Arterial, 5) Major and Minor Collectors, and 6) Local Roads.

Interstates are the highest in the classification of arterials and are designed for large mobility and longer distance travel. Other freeways and expressways look very similar to interstates but are limited by physical barriers, access and exit points, and on- and off-ramps. Other principal arterials serve as major centers for metropolitan areas. They have a high degree of mobility but they also provide access to urban areas and driveways in specific parcels. Minor arterials service moderate length trips and serve geographic areas smaller than its arterials counterparts. Arterial roadways do not have sidewalk and walking on these roadways is not encouraged and often illegal.

To create the network dataset that will support walkability, only roads accessible to pedestrians were selected from the FHWA classification. These roadways were collectors and local streets, which play a critical role in the network. Collectors are roadways that gather traffic from local roads and funnel it to arterial roadways and are usually accessible for pedestrians. Both urban and rural areas have collector roadways. Local roads are the largest proportion of linear miles of all the roadways. They have short lengths, public transportation does not run on them, and these roadways are often designed to discourage through traffic. Collectors and local roadways usually have sidewalks and their speed limit is not high, thus are very accessible and easy to walk along. Because of the accessibility of collectors and local roadways they comprised the main input for the network data set used to create the service area for walkability (Figure 6).

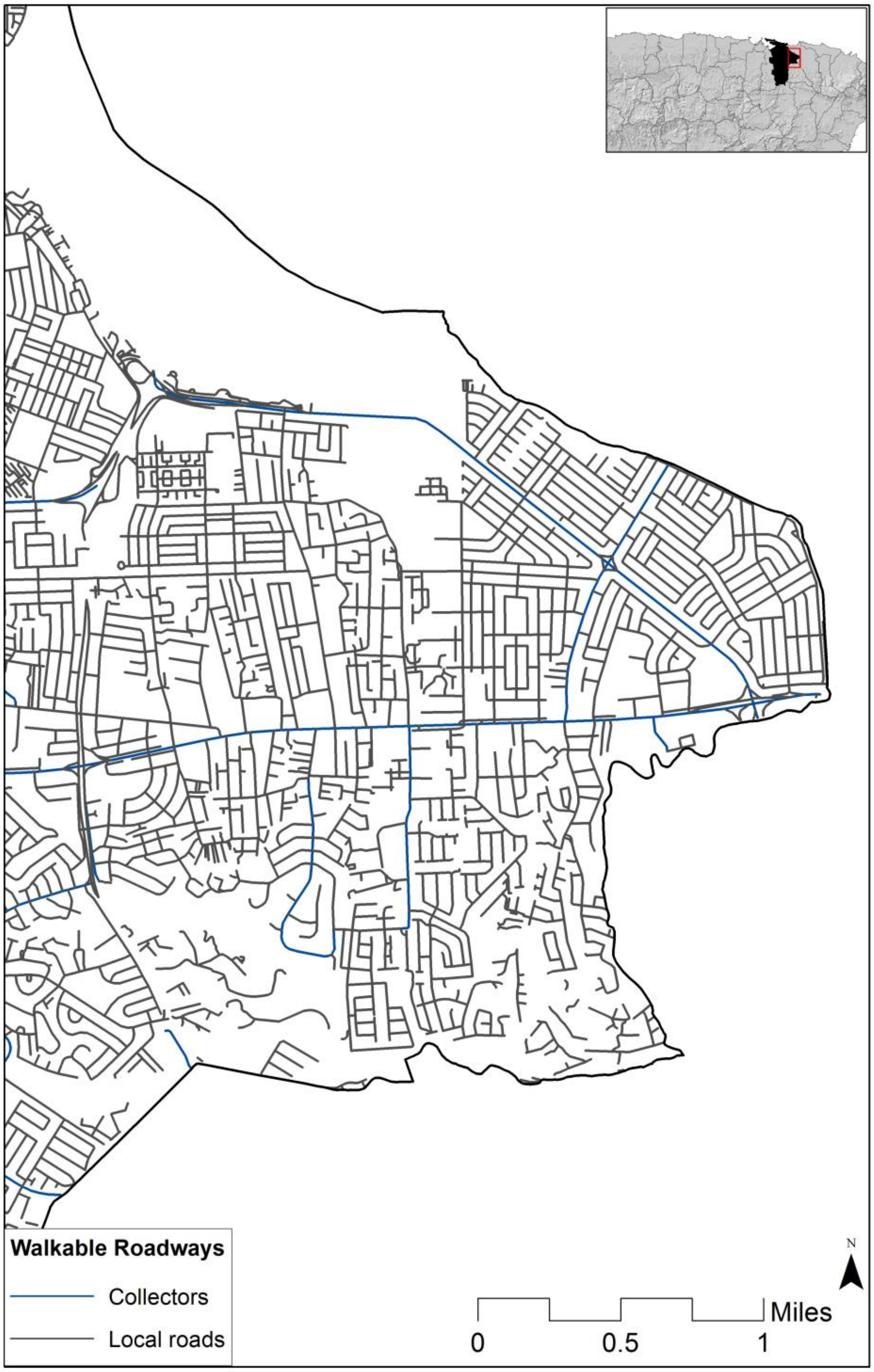

Figure 6 Walkable Roadways in San Juan County

3.4.2 Service Area Methodology

Once the accessible roads were selected from the road dataset, a network dataset feature was created. Using the network feature dataset created from the accessible roadways, a service area was created using the network analyst tool in ArcMap (Figure 7). Service areas help evaluate accessibility to and from a facility. The initial service area was created away from the school within a distance of 0.25, 0.5, 1, and 2 miles from closing schools and recipient schools. This is considered the average distance children usually walk to school (Horeck et al. 2012).

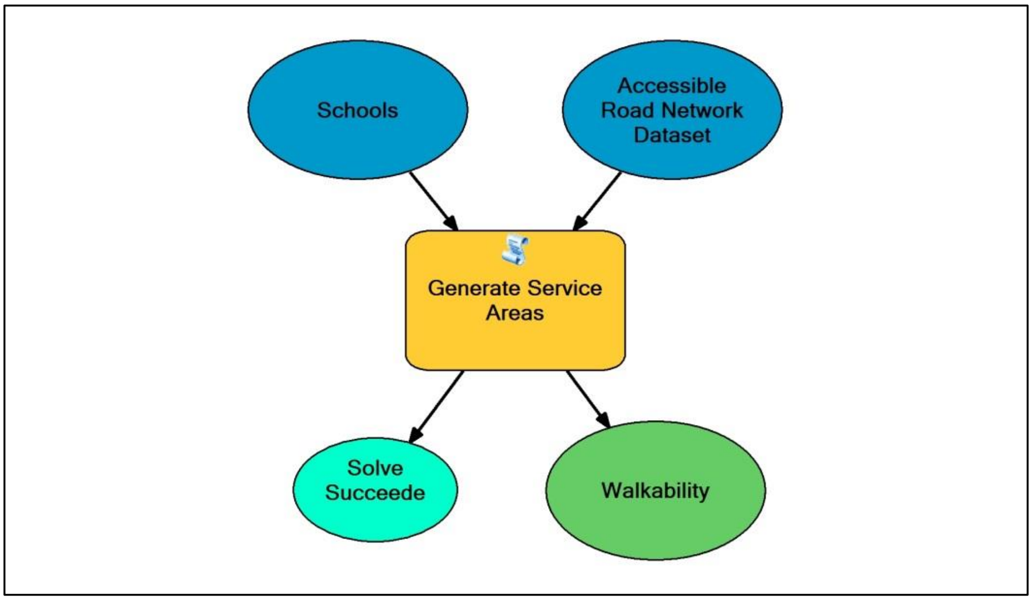

Figure 7 ModelBuilder Showing Selection of Parcel and Spatial Join

3.4.3 Walkability Output

The output of this study is a service area in the form of a polygon that shows the walkable areas surrounding schools in San Juan County. This analysis was conducted on each school closed (73), both before and after school closure (Figure 8 and 9). In combination with population per parcel, the service area polygon was used to determine pedestrian accessible areas and population affected by the closing of schools.

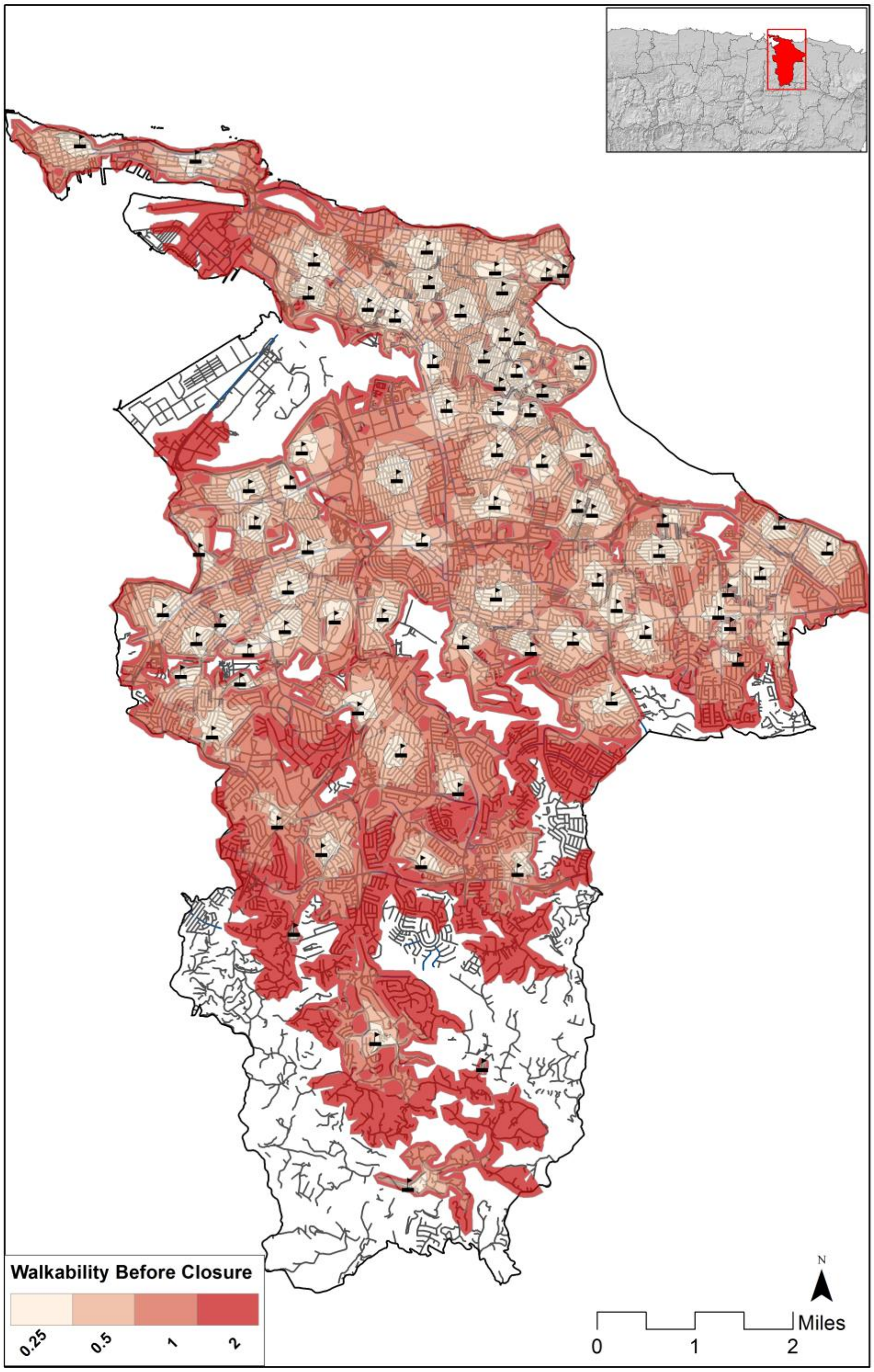

Figure 8 Walkability Area before School Closure

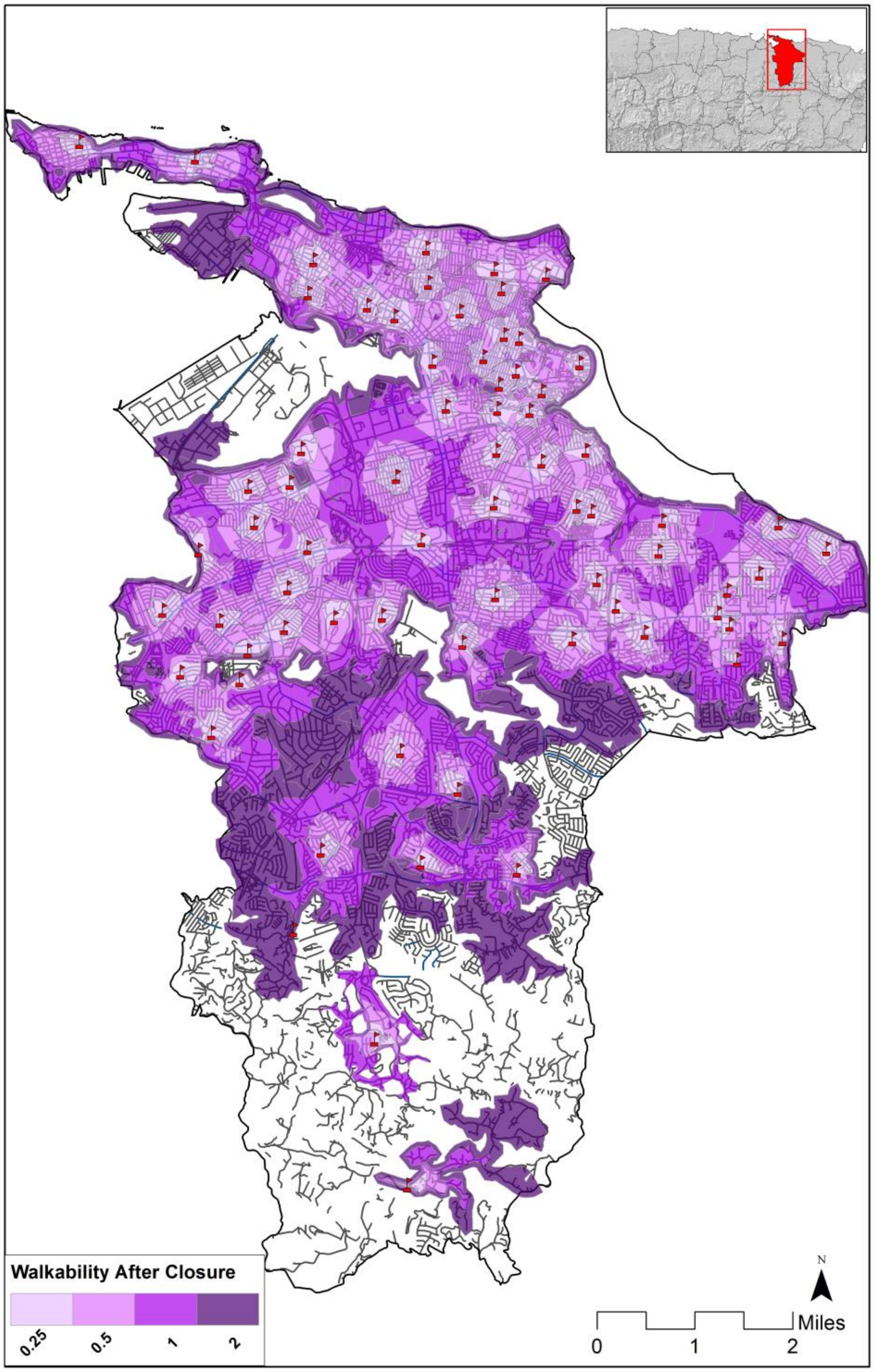

Figure 9 Walkability Areas after Closure

3.5 Student Population Affected

After the student population per parcel was derived and walkability area was calculated for each school. The student population affected by school closure was determined. Using “Select by Location” tool in ArcMap the parcels inside each section of the walkability area 0.25, 0.5, 1, and 2 miles were select and exported. Once completed using the “Summarize by Statistic” option, the total student population affected was calculated in each section from the attributes in the dataset. This method was repeated for each school in the San Juan County (Figure 10).

Figure 10 Parcels Affected Inside Service Area

3.6 Origin Destination Cost Matrix Analysis

The OD cost matrix analysis is a network analysis tool within ArcMap that calculates the least cost distance for a road feature. The tool is used to compute a table that contains the total shortest distance traveled from each origin to each destination.

The primary input for the walkability analysis was the network dataset containing the accessible roads. Once the network dataset was processed the output is a series of line features from origin to destination (Figure 11). The lines connect the origins to the destination but do not represent the actual paths that were calculated, which give the shortest distance along the accessible road network to the destination. This data is stored in the attributes of the dataset. For example, Figure 11 shows the destination to facility lines produced by the OD tool.

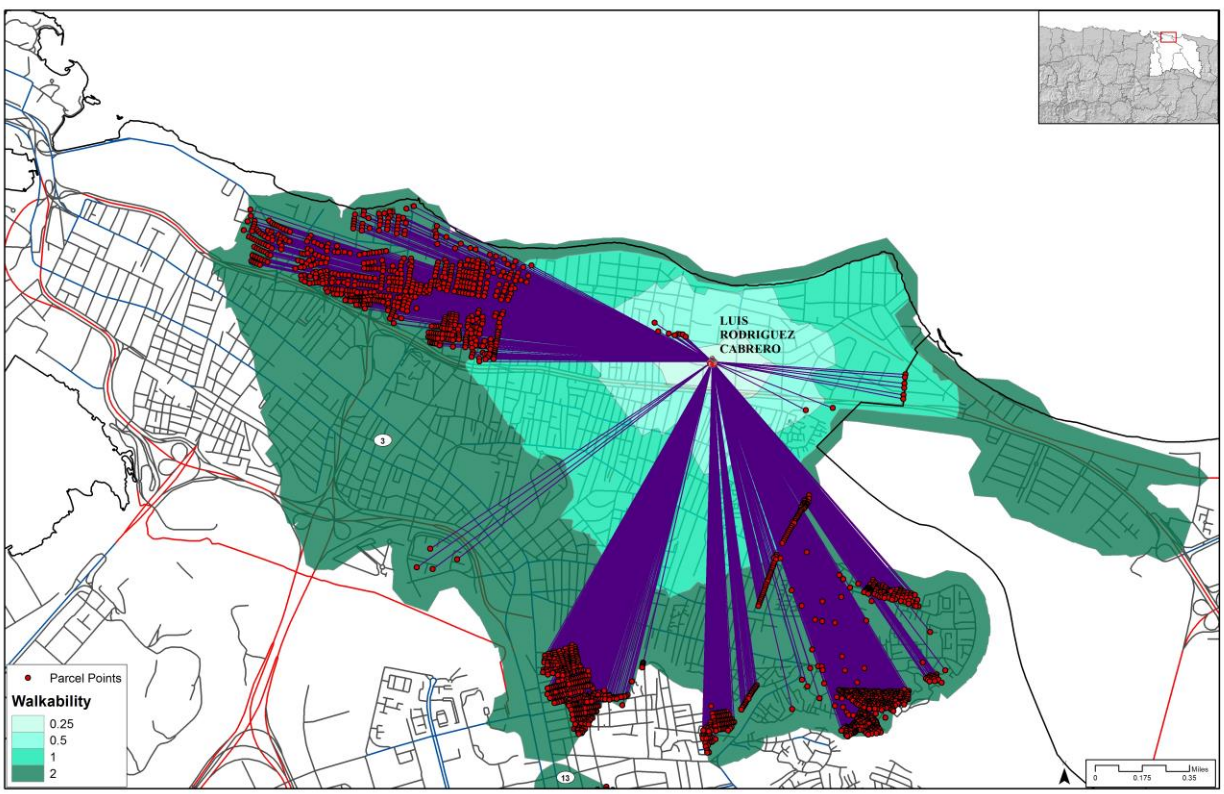

Figure 11 OD Cost Matrix Analysis of a School Facility

The purpose of the OD analysis is to measure the mean distance walked to school before and after school closure. All paths to schools in the county, in miles (Td), were added and divided by the total student population for the respective school walkability area (Pw) to represent the average journey (Aj) a student travels to school.

$$Aj = Td/Pw$$

Using the calculated average journey values, histograms were created for each school before and after school closure in order to assess the change in average distance walked. The primary purpose of the histograms is to create visualizations of the data for results that can meaningfully inform decision-makers in the school district about the consequences of the decisions to close given schools on walkability. Further, the visualizations demonstrate the community impact of the disappearance of "neighborhood schools." The results of the analyses described in this chapter are presented in detail in the following Chapter 4 Results.

CHAPTER 4: RESULTS

The main goal of this study was to develop techniques to assess how the student populations in San Juan County were affected by the closure of the elementary schools. The techniques developed in Chapter 3 are required because a road network provides the spatial relationship between parcels and elementary school locations. It is the job of the network analysis tools in ArcMap to utilize this spatial relationship to derive a potential solution in the form of tables or features that can be evaluated.

This chapter reviews the lessons learned using the Network Analyst extension in ArcMap to create the service areas, in performing the Origin Destination Cost Matrix (OD) analysis. Various sections in this chapter cover the comparison of the student population accessibility derived from the walkability assessment of the schools, a narration of the schools that lost more access and gained more access, and the mean percentage access within ¼ miles. A discussion about landscape elements that might change the accessibility, and reports on a measure of the changes in the average distance walked before and after school closures is also provided.

4.1 Network Analysis Issues and Solutions

To create the origin destination analysis, a network dataset was created from the accessible roadways. When the tool ran for the first time a failure to return locations appeared. The error was due to the Origin Destination (OD) cost matrix solver running out of memory to process a 10k by 10k matrix. To avoid this, the tools had to be run on each school individually.

For the service area analyses there was an output of 73 school walkability polygons before school closure and 71 after school closure. Each polygon was made from four different distances boundaries ¼, ½, 1, and 2 miles. In order to select the parcels with access to the school in each location, the select by location tool was used to query the distances layer for each school.

For this study, although ¼ mile accessibility was emphasized, the other distances were also calculated.

4.2 School Accessibility Results

Walkability analysis made from the accessible roads served as the first layer of the analysis to identify accessibility of the student population. By using the select by location tool in ArcMap it was possibly to observe all parcels inside each walkability areas. As previously mentioned, this information collection method was performed before and after school closure. Before school closure, 8,738 students had pedestrian accessibility at ¼ miles. After the school closure, the students who could walk to the school at ¼ miles went down to 8,504 (Figure 12).

Using the numbers obtained from the output and indicated above, the decrease in accessibility for student population was approximately 3%. This means that 3% of the total student population of San Juan County that live within ¼ miles of a school that was closed lost accessibility and are outside the normal range of walkability.

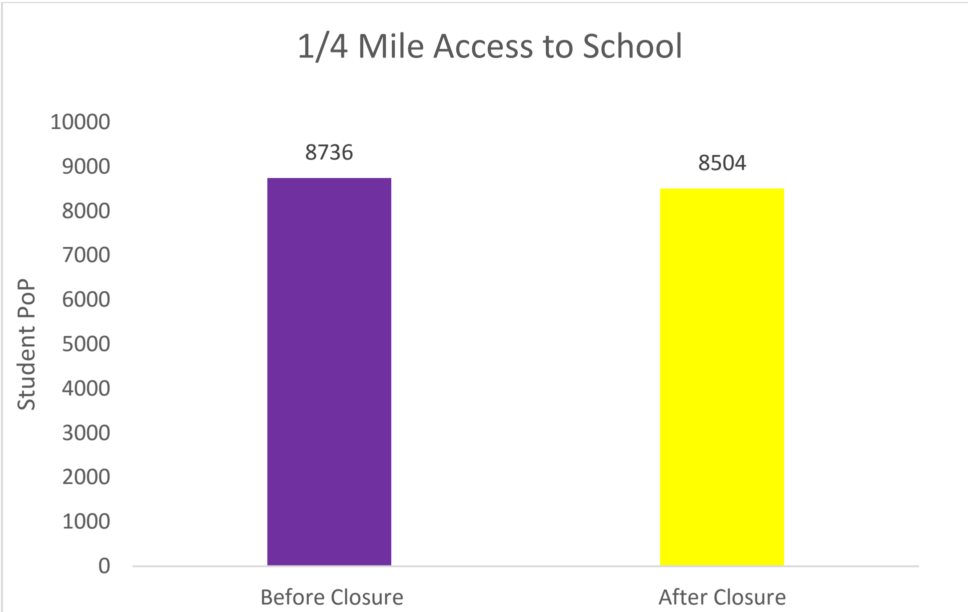

Figure 12 Graph of 1/4 Mile Access Results

By visually checking Figure 13 and Figure 14, one can observe that students living in parcels affected by schools closures had to move in order to be able to walk to the next closest school that had not been closed their walkable service area. In the maps below some schools have no service areas nearby, because they have no single or multifamily parcels around them. Even though these schools do not have a student population within a 2 mile service areas, these schools were not picked to be closed by the local government. As illustrated in Figure 15, school closing did not have major changes on accessibility with the exception of those five schools.

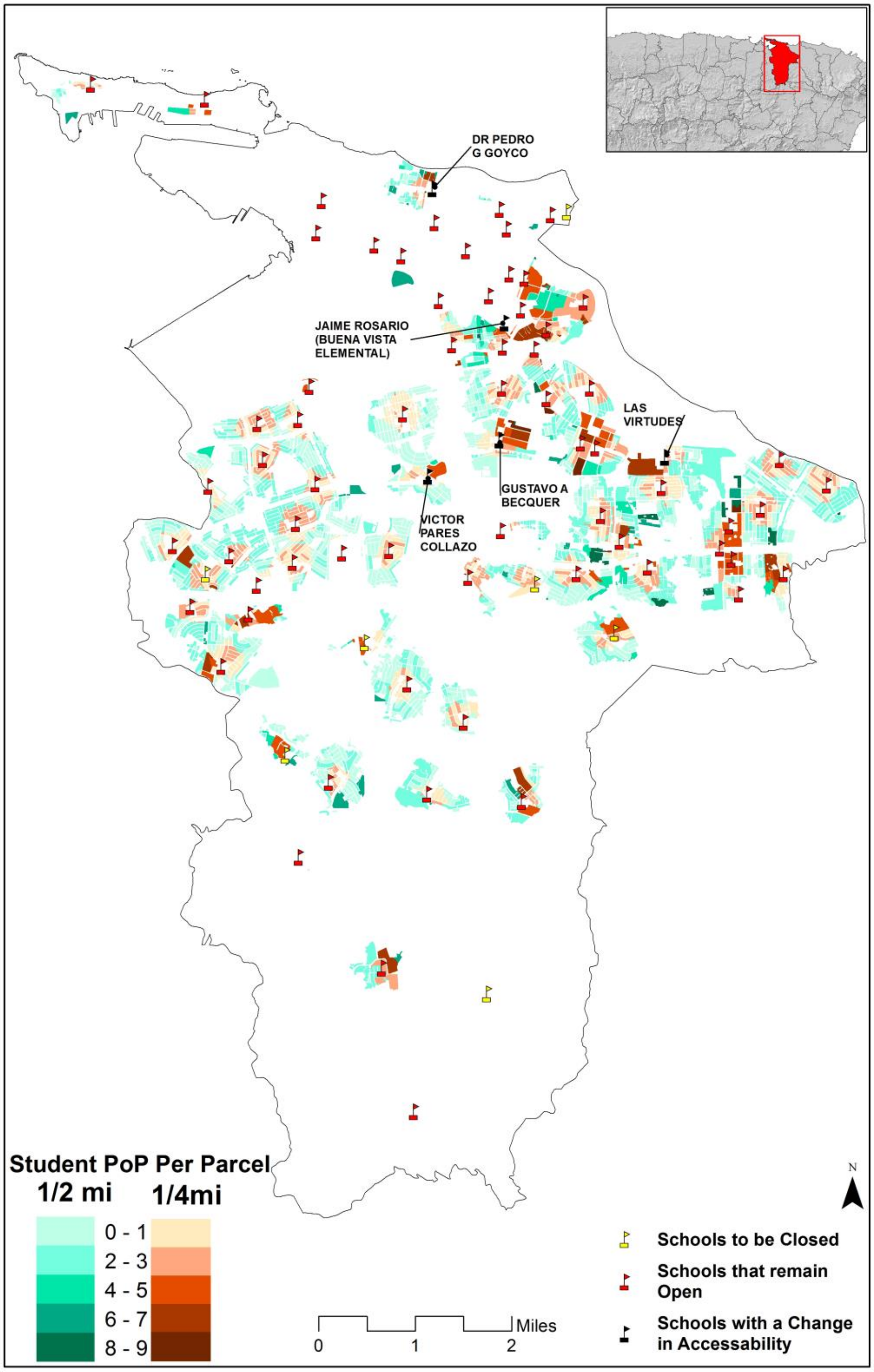

Figure 13 Student Population Accessibility before Closure

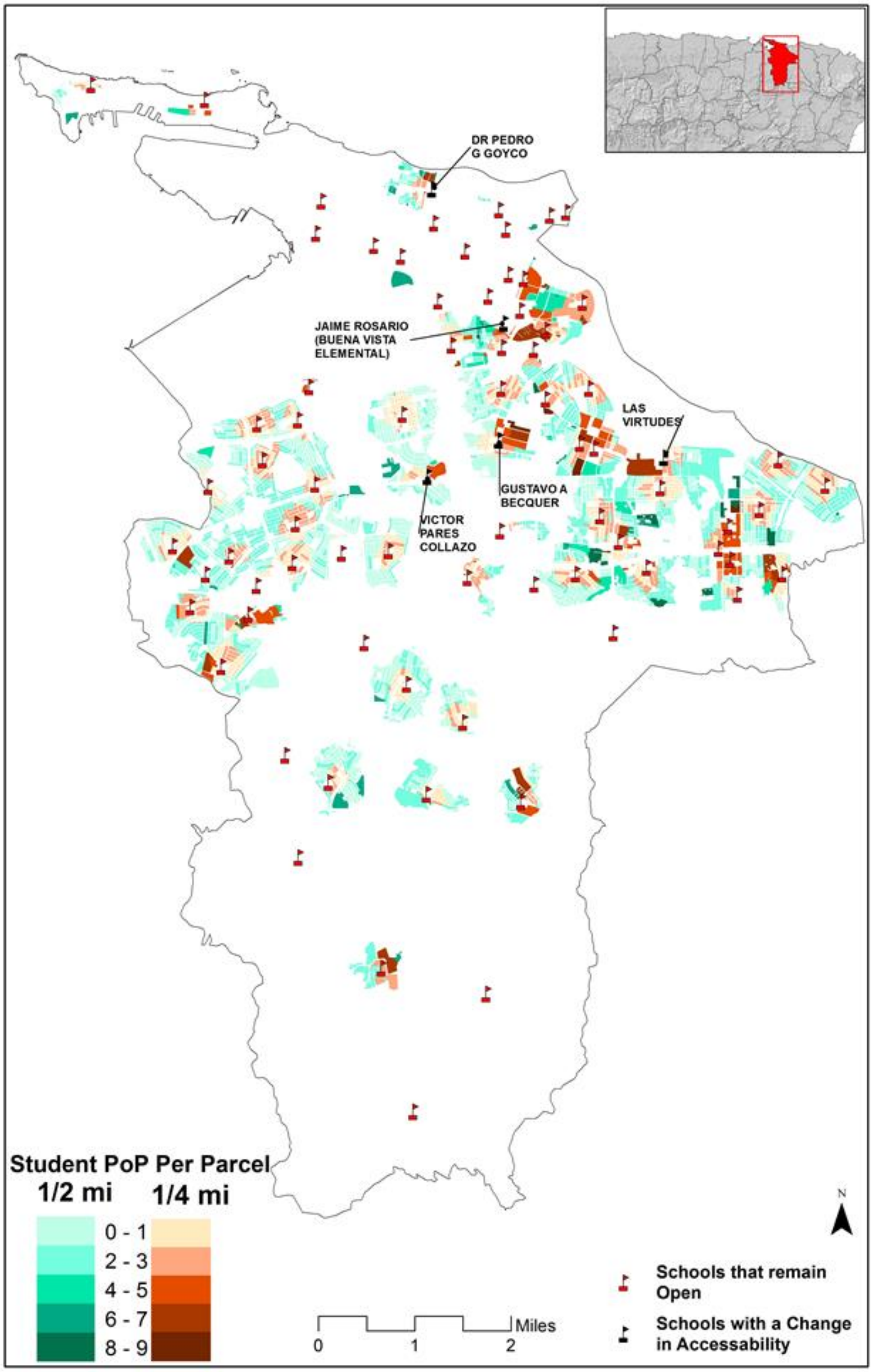

Figure 14 Student Population Accessibility after Closure

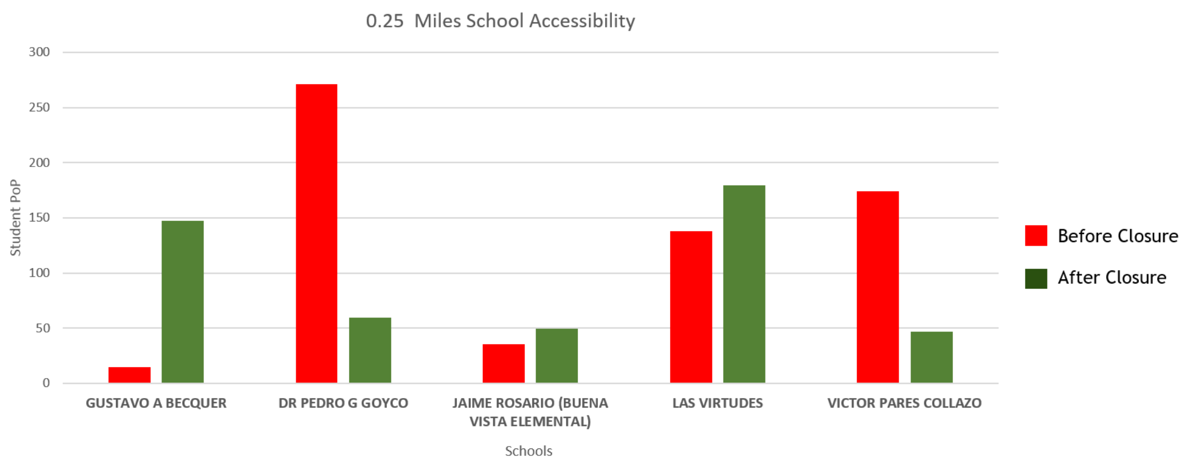

Figure 15 Schools in San Juan Most Affected School by Closure

From the original 73 schools analyzed, only 5 demonstrated major changes in accessibility after the elementary school closure (Figure 15). A major change is defined as more than the average of the student population for each school. Interestingly three of them, Gustavo A. Becker, Jaime Rosario and Las Virtudes showed an increase of their accessibility at ¼ miles this is because students of the schools that were closed will attend to these schools. While the other two schools, Dr. Pedro G. Goyco, and Victor Pares Collazo demonstrated a marked decrease in their student accessibility at ¼ mile. For these schools, the idea of neighborhood schools is in some sense lost.

Of these five schools most affected by the closures Dr. Pedreo G. Goyci lost the most accessibility. Before the school was closed, 250 students had access to the school at ¼ mile, while after the school closed only 50 students had ¼ miles access to school.

The results of this study indicate that the school closures did not have a major effect on the County overall regarding accessibility at a ¼ mile access. Figure 16 and 17 illustrate the student population accessibility before and after school closure.

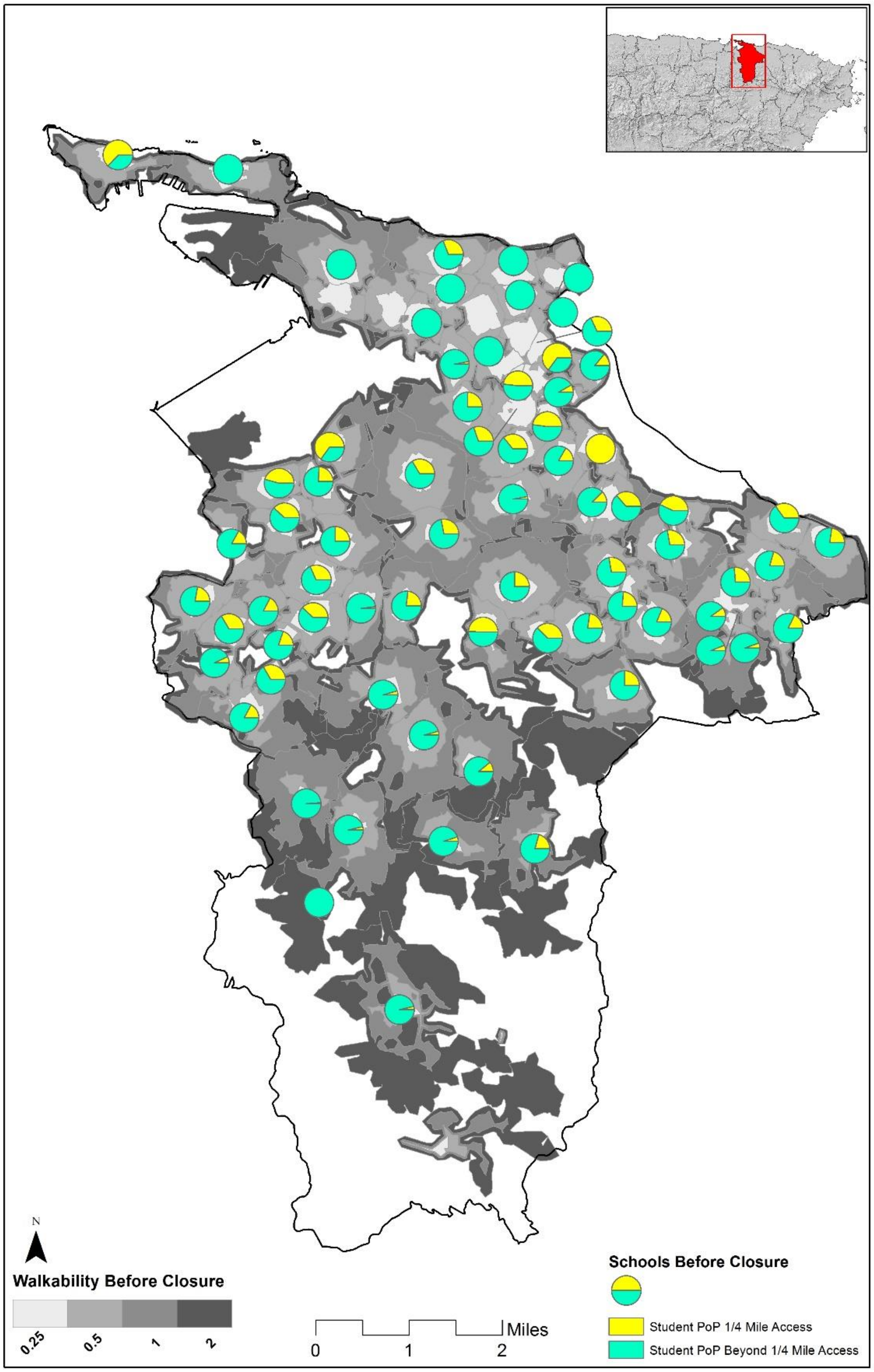

Figure 16 Student Population at a 1/4 Mile Access before School Closure

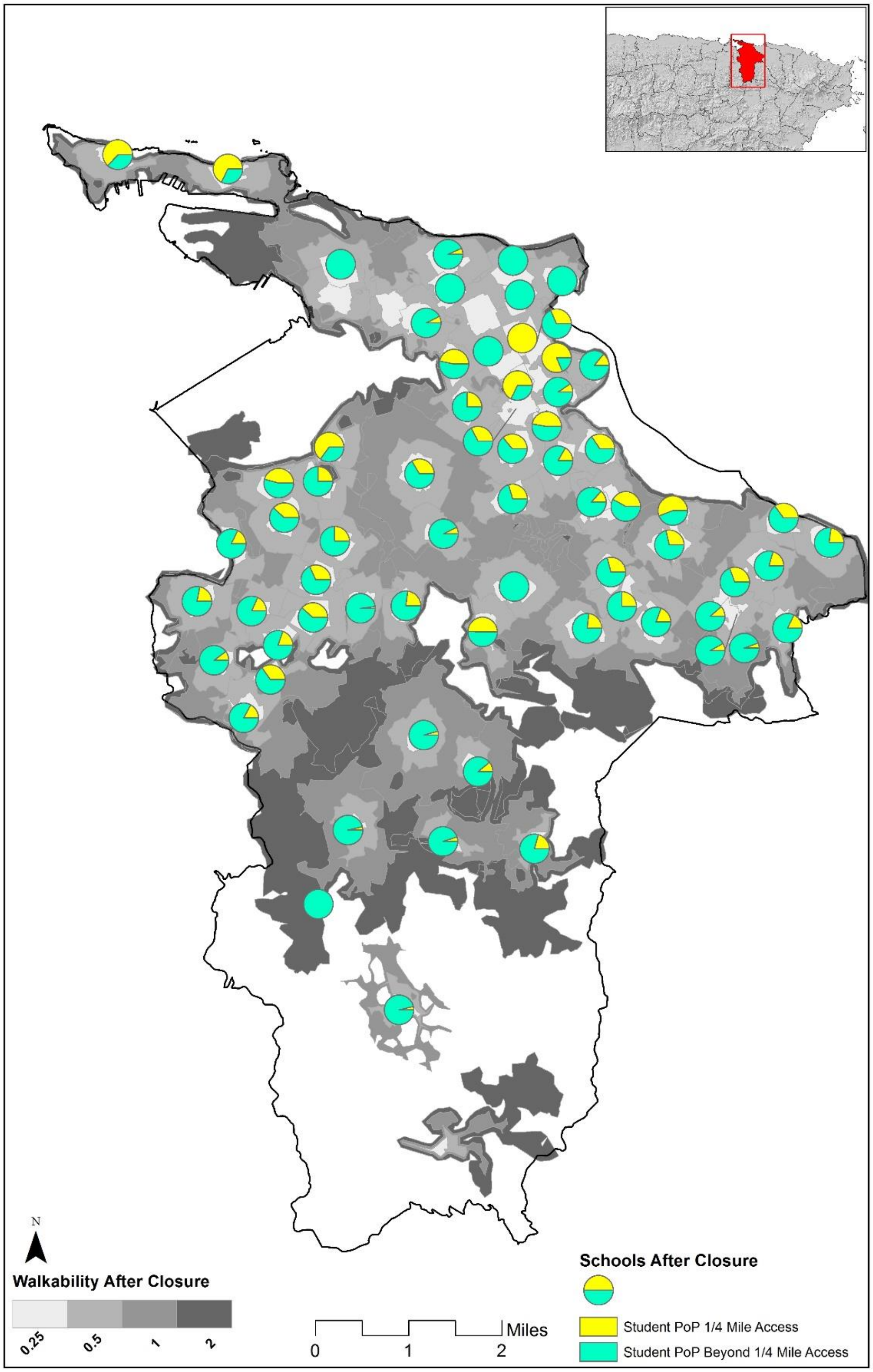

Figure 17 Student Population at a 1/4 Mile Access after School Closure

4.3 Environmental and Urban Obstacles

Environmental or urban obstacles affect walkability of an area directly. For Leslie et al. (2006) these obstacles define the landscape of the urban growth, shaping the way cities develop, thus affecting the way people move from place to place. Inspecting an aerial image of San Juan County identifies one major obstacle that may affect accessibility; it is La Laguna San José (Figure 18). This is a natural lagoon that connects to San Juan Bay, with an area of 3.85 square meters (Recursos de Agua de Puerto Rico 2012).

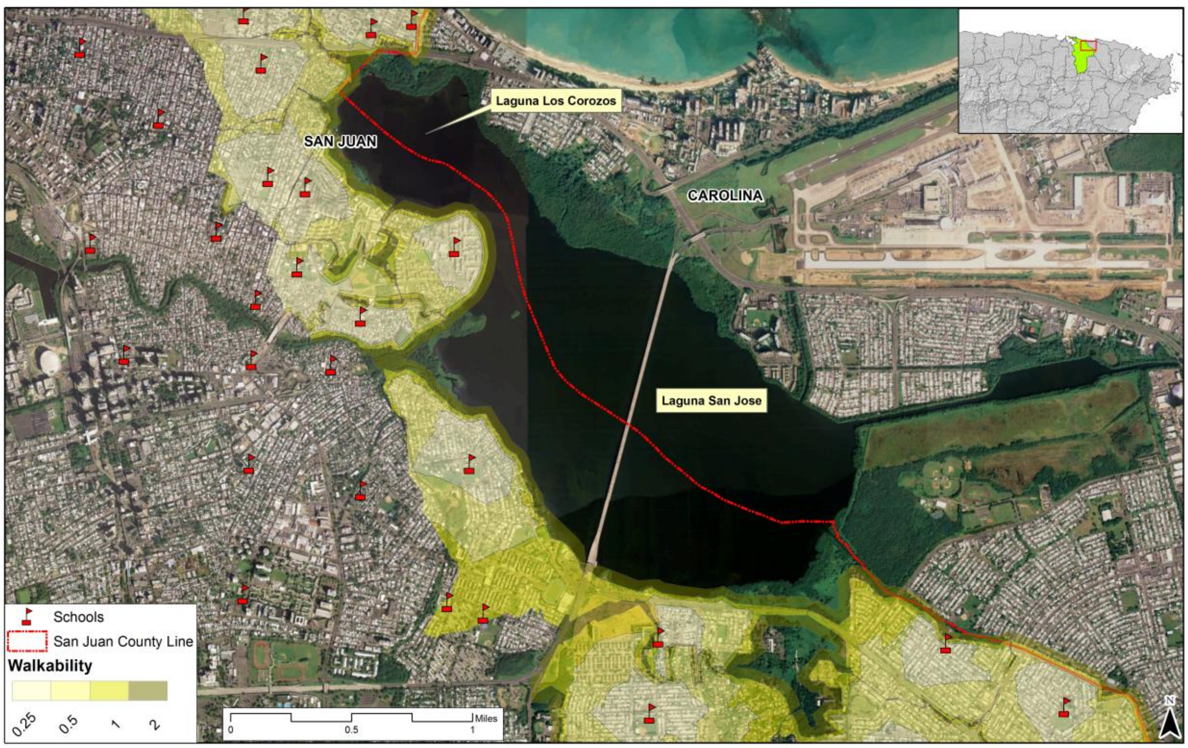

Figure 18 Laguna San José and Laguna Los Corozos

To travel from one side of the *laguna* to the other there is only one bridge, *el Teodoro Moscoso.* This bridge has 6 lanes, no walkable sidewalks and a toll of $3.25 each direction. There is no way to walk across, as the bridge was not constructed for pedestrian use. As shown in the Figure 18 above some of the school closed to the edge of the lakes have their service areas interrupted, meaning that accessibility across the *laguna* to on those schools is prevented.

4.3. Changes in Average Distance

The results of this study indicate that overall walking distance to schools in San Juan County did not change significantly due to the school closures. The OD Cost Matrix Analyst tool was used to calculate the shortest distance from an origin, the parcel where student or students live, to an origin location, and the schools they attend. The output of this analysis was a feature line that provided the total distance walked to school before and after school closure (Figure 19). Before the school closures the total distance walked to the 73 schools was 25,005 miles, and after closure the total increase to 28,039 miles. This is an increase of 3,033 miles. Using this information the increase was calculated for the mean distance walked to school.

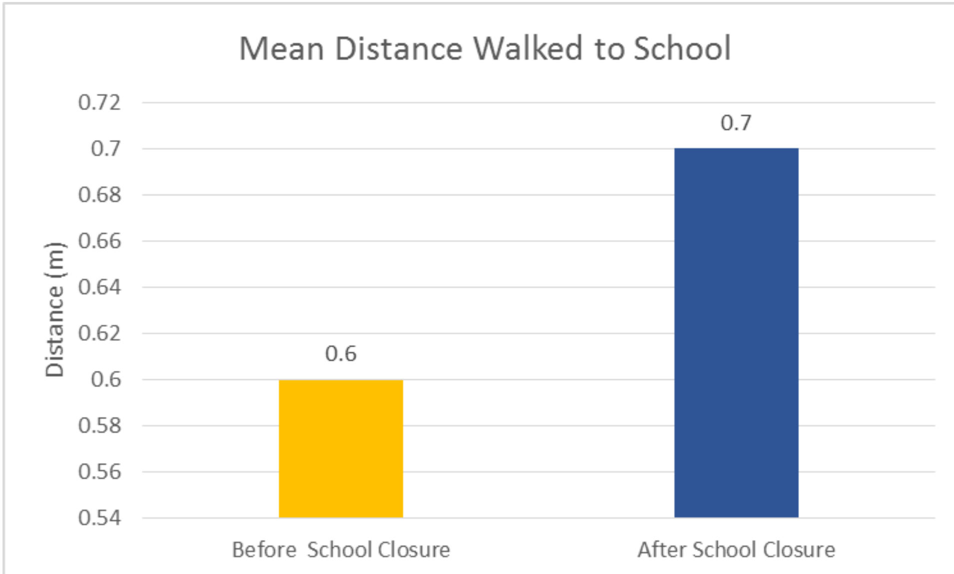

Figure 19 Mean Distance Walked Before and after School Closure

This information was calculated by using the following formula:

$$Md = \frac{TdxPp}{Tp}$$

Md equals mean distance walked, *Td* is total distance walked for that school, *Pp* is the student population of a parcel, and *Tp* is the total population of the service area for those schools. Using a spatial join between the feature dataset from the output of the OD analysis and the parcel, a new feature class was derived that displayed the distance walked before and after school closure as shown in.

In Figures 20 and 21, one can observe at the parcel level an estimate of areas of the city where students have particularly long or short walks to school. Also, by comparing the maps it is possible to see that no particular area of the city suffered more of the burden of the school closures on pedestrian accessibility. The relative walking distance to school of most areas of the county to school remained the same. As displayed in these figures, there is a relative high total distance walked to schools in the southern part of San Juan County. This is due to the fact that the south side of the county us less urbanized than the north of the county with fewer accessible roads to walk along to school.

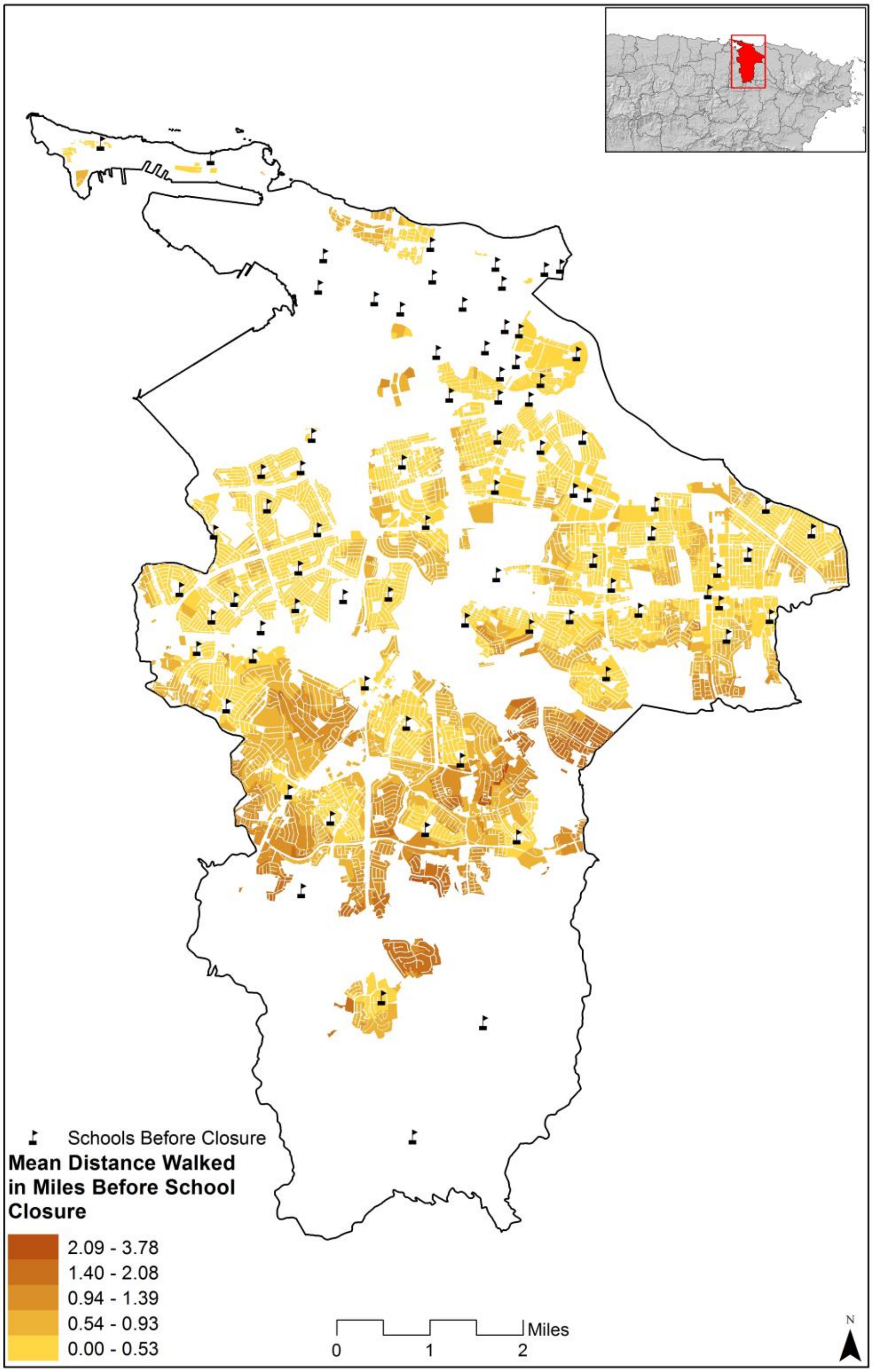

Figure 20 Mean Distance Walked Before School Closure

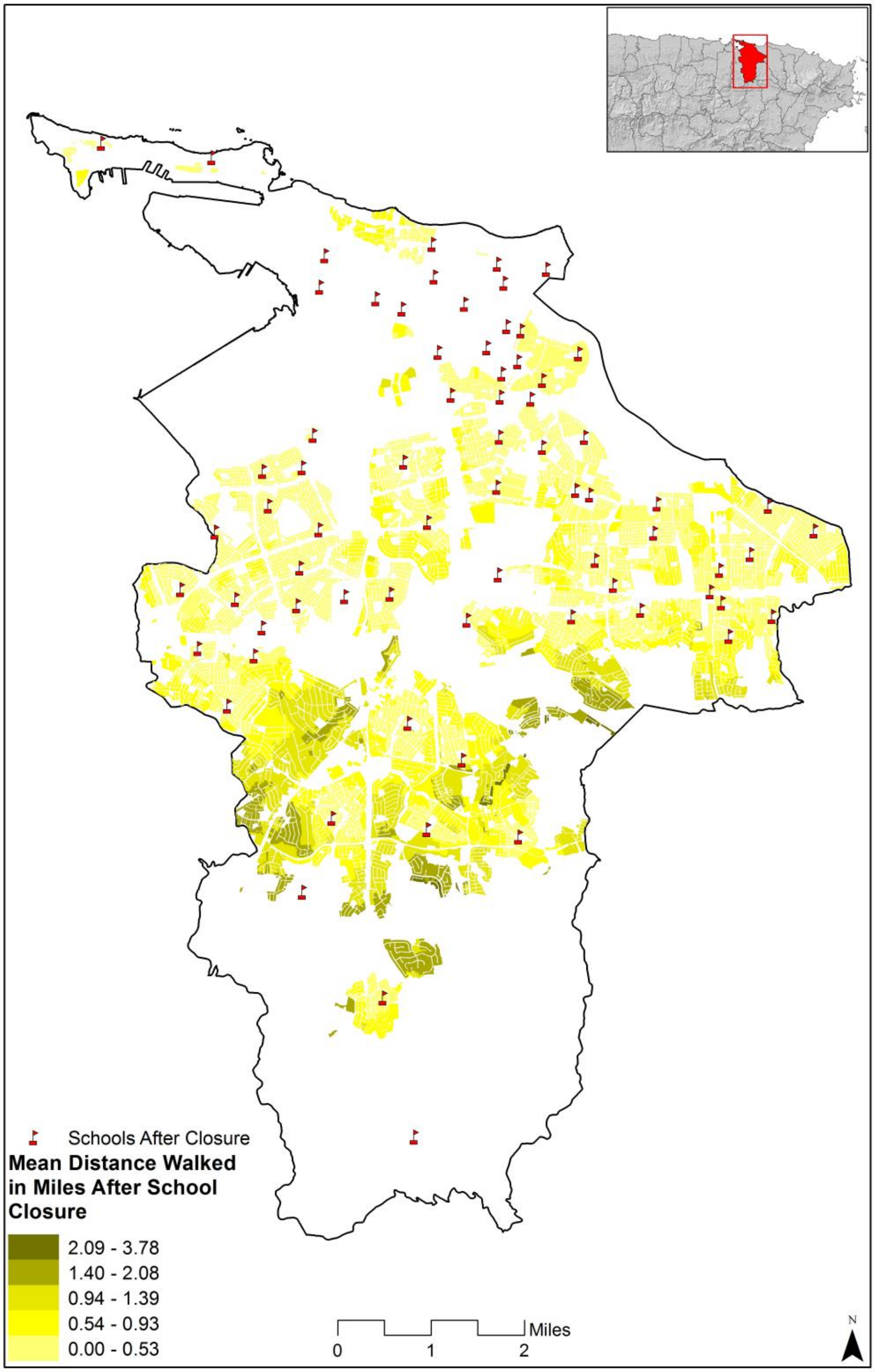

Figure 21 Mean Distance Walked After School Closure

There were some individual schools that were affected by the school closure. One of them was *San Agustín* elementary school. Figure 22 displays the histogram of the total distance walked to schools before closure. The form of the histogram is symmetrical, meaning that the mode, mean, and median for the distance walked to school is identical. In Figure 23, the histograms is skewed. The distribution of the total distance walked to school reduces after school closures. In this case, students actually cluster closer to the school after the closure of adjacent schools.

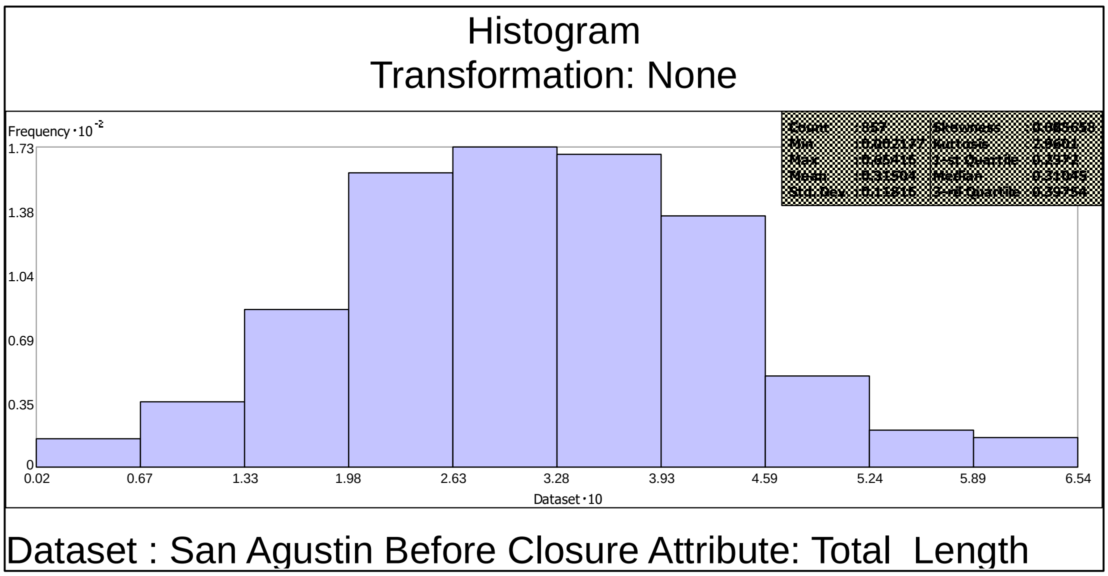

Figure 22 Histogram of Total Distance Walked Before School Closure

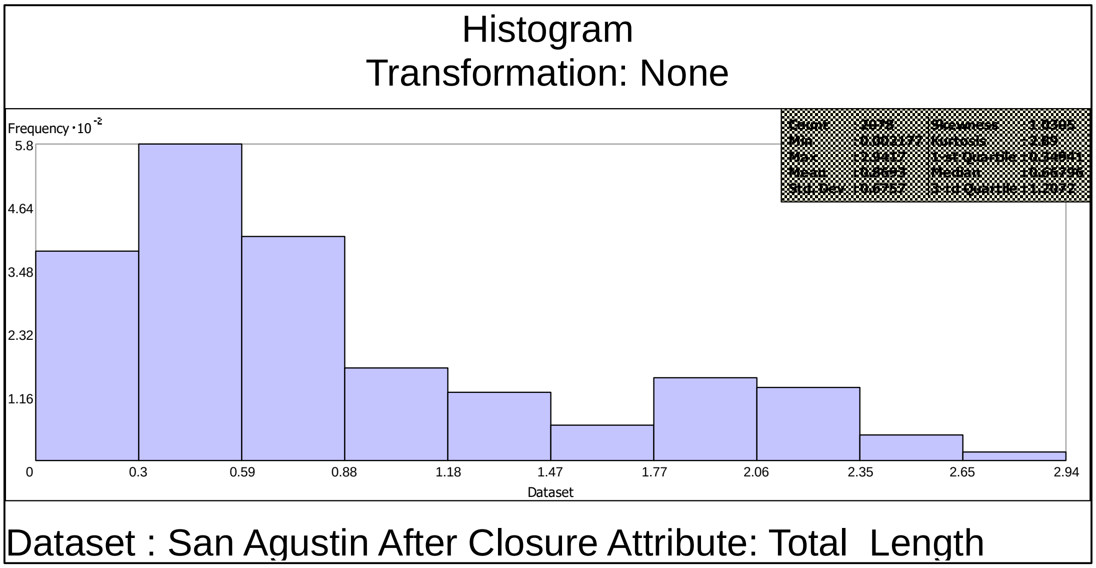

Figure 23 Histogram of Total Distance Walked After School Closure

4.4 Scenario Analysis

The initial criteria designs by the Puerto Rico Department of Education (DE) for choosing which schools to close did not include proximity to other schools. The proximity that two schools have to each other could potentially change school accessibility at ¼ mile and the total distance walked to school in San Juan County if a different set of schools were closed. To explore this point, two schools that were close together were chosen for further analysis. These schools were not included in the original wave of school closures. For this validation analysis, the original schools that were closed were hypothetically modeled to remain open and the schools that remained open were hypothetically modeled as closed (see Figure 24). This maintains the same number of school closures overall. The originally closed schools were *Luis Pereira Leal* and *Manuel Cepero*, as seen on the map in Figure 25. It is important to note however that theses schools were not as close together as *Manuel A. Perez* and *Bolivar Pagan* both of which were analyzed as open.

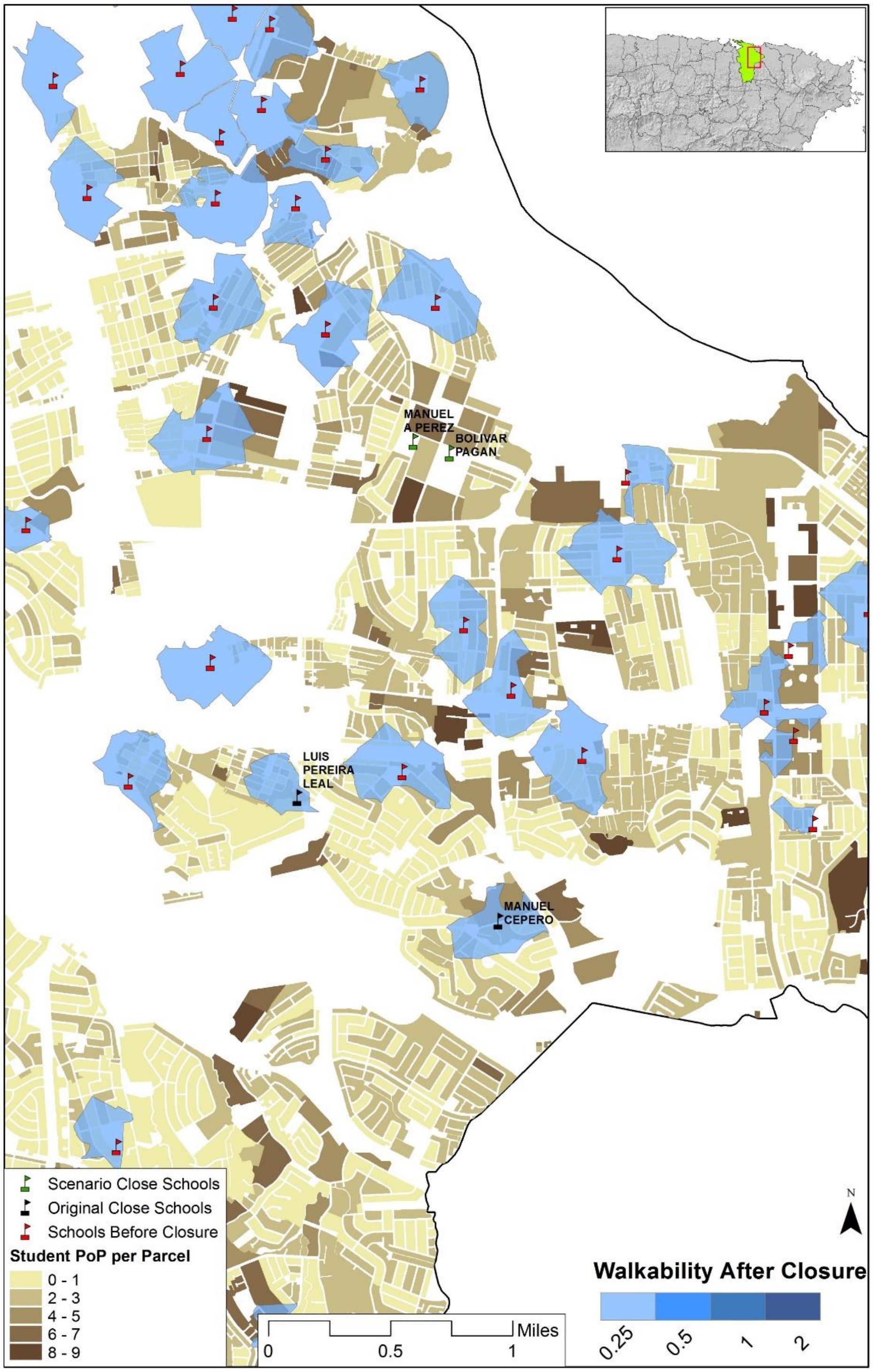

Figure 24 Case Scenario of School Closure at ¼ mile access

The same analysis performed in the original study was performed on this scenario. For the ¼ miles accessibility the total student population affected was of 8,736 before school closure and 8,707 after school closure (Figure 25). The percentage of decrease for this scenario was less 0.3%. This indicates that closing schools that are in close proximity to one another does no change the ¼ mile accessibility for the students.

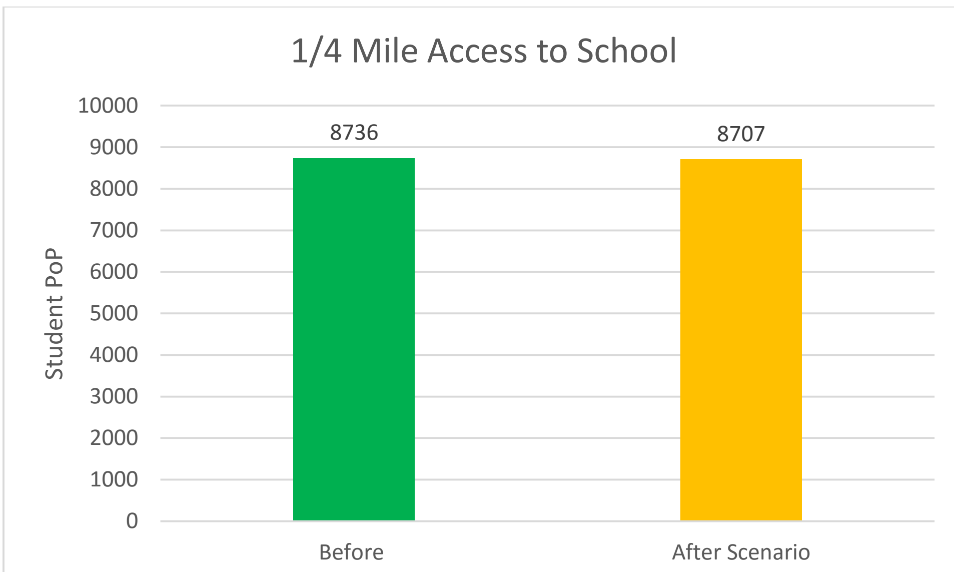

Figure 25 Bar Graph 1/4 Mile Access to school before and after school closure scenario

The OD analysis was again performed in this new scenario before and after school closure. In this scenario, the total distance walked to schools after school was the same as the total distance walked after school closure (Figure 26). Unlike the original criteria, closing those schools that were together did not result in a signficant increase or decrease on the total distance walked to school before and after school closure.

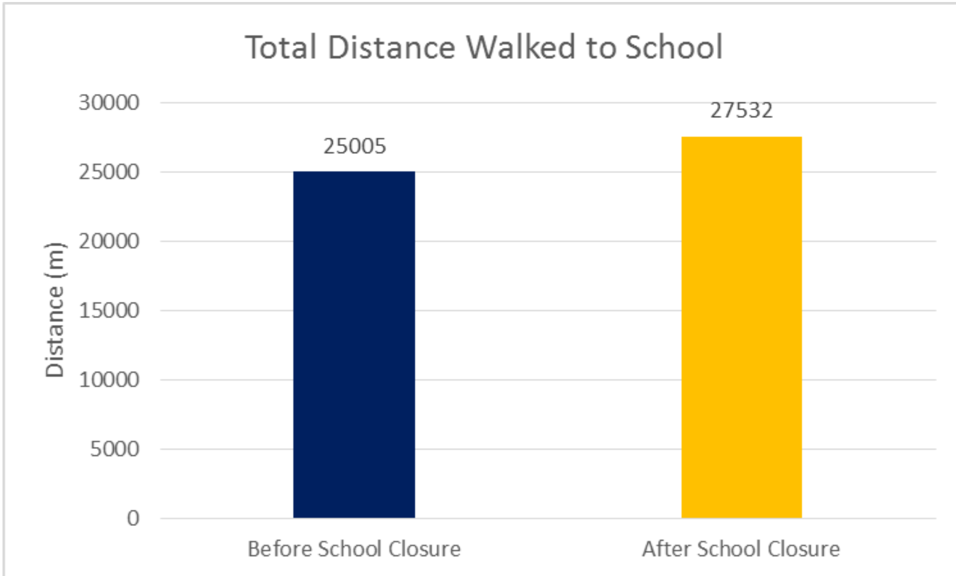

Figure 26 Bar Graph Total Distance Walked to School Scenario

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This study set out to develop a technique using the Network Analyst extension on ArcGIS, to assess the effects of elementary school closures in San Juan School county, after the Department of Education (DE) decided to close schools that fit their new criteria for closure in the "*Plan de Transformación y Reorganización de Escuelas*" (Reorganization and Transformation School Program, PRTE). The assessment performed in this study was completed using the Network Analyst extension and Origin Destination (OD) Cost Matrix tools in ArcGIS Software. Network Analyst was used to discern the accessibility of students to schools by creating a service area around the location based on a network dataset, and the OD analysis tool was used to estimate the shortest distance each student walked to school. This analysis was made before and after school closure for a dataset of 73 schools, and the output was presented in the form of datasets, tables and maps. The study shows the usefulness of Network Analysis and Origin Destination (OD) Cost Matrix in the assessment of school site planning. This study also identified the potential development of an automatic tool that could be used for school planners to model school sites locations using the ModelBuilder extension in ArcGIS.

5.1 Benefits of Using Network Analyst and OD Cost Matrix

Most studies that use Network Analyst and OD analysis usually deal with park access as in Parsons (2015) and Javed et al. (2013), but there is little information about the use of these tools for school site planning. As of today, the general benefits of GIS for school site planning are heavily explored (Cropper 2003), but no current studies utilize the methods presented in this study to research schools accessibility, using network and population datasets.

It is also the first time a GIS study of this type has been performed for Puerto Rico.

In the past two years, the Puerto Rico DE used the following criteria to decide the school closure: physical condition of the school, academic performance, utilization, and student enrollment (Departament de Educacion de Puerto Rico 2014). And from all of these criteria, only enrollment has an implicitly spatial component. Enrollment deals with the student population that has access to school depending on how attendance boundaries or school assignment zones are drawn. While enrollment was taken into account, the DE did not take into account walkability in terms of how many students lost or gained pedestrian accessibility before and after school closure. The methods utilized on this research focus on the spatial aspect that affected student accessibility to schools. The information and results involved in this study contained parcel, road, and population datasets and after analyzing the data, the study yielded information about the affected areas after student closure.

5.1.1 Accessibility Measures

Accessibility is usually defined as the ease with which a location or service can be reached (Nicholls 2001). This can be a measure of the spatial health of a city and can define the quality of access in a spatial setting. Studies involving accessibility usually have a geometric approach (Nicholls 2001). This geometric approach involves taking advantage of the spatial environment using buildings, roadways, sidewalks and other elements to measure accessibility of locations. This study utilized this geometric approach to assess accessibility using the roadways as the primary input to create a network dataset. The roadways were classified using the FHWA functional classification. This approach successfully facilitated the identification of those areas that were more accessible for students to walk to and from school. Combined with the service area analysis the areas affected by the school closure were successfully determined. No other studies in Puerto Rico have taken the FHWA road classification into account for accessibility purposes nor to create the service areas used in this study Thus, it was the purpose of this study to present that option for future research.

5.1.2 Service Area Analysis

The Network Analyst extension uses the roadway data and creates a network dataset that compromised of lines and nodes. This was the principal input that allowed Network Analyst tool to create service areas around the schools. Services areas were displayed as ring shapes articulated by connecting the outermost points along the road network at given network distances. These areas represented the pedestrian accessibility around the schools. In the future, service areas can become more precise by adding more feature layers. For examples, adding features like stop signs and streetlights to the network could help to depict safer versus less safe intersections for pedestrian crossing. If these were added as decision points in the network analysis, it might be possible to increase the accuracy of the service area estimates.

Overall, the service area analysis in this study proved to be a valuable tool in the assessment of school site planning, by identifying students that have access within walking distance of the schools. Without this type of spatial distribution measurement, accessibility to school cannot be judged with spatial precision. It is important to distinguish this from a buffer method of analysis. A buffer method analysis do not represent the actual accessibility when used in this type of assessment, thus are not considered a good way to measure student accessibility to schools (Javed and Ahmad 2013). This is due to the fact that buffers lack an available network. Buffer areas are a measurement of a direct route from the center of the buffer to the outside, while service areas used the road network.

5.1.3 OD Analysis

The OD analysis is often used in transportation planning analysis (Yang 2002), and its benefits are well documented when dealing with accessibility (Parsons 2015), but none of these studies have dealt with school site planning. The OD analysis tool on this study was able to accurately measure total distance walked to school. As demonstrated in Chapter 4, the output of this analysis was a table that contained the distance walked to school from each parcel in which the student reside to the closest school in their location. With this information the average distance walked to school was calculated and compare before and after school closure. This analysis played an important part in measuring what was the change after school closure in the distance walked to school. In this analysis it was assumed that students would always take the shortest path when traveling to and from school, and it accurately represented the spatial distance from origin to destination. In this study it was demonstrated that the OD analysis is an effective assessment tool to measure distances walked to and from school from any given location.

5.2 Limitations of the Project

Due to the availability and quality of the data there were some limitations in this study. GIS data in Puerto Rico is very scarce, and those organizations that host most of the data do not share it that easily. Roadways and population data can be found on the Puerto Rico *Sistemas de Datos Geografícos* (Portal Datos Geograficos Gubernamentales, 2003) web site, but the road data set had to be fixed before running the analysis using topology rules. These are rules that can be added to spatial features with a spatial relationship to check for errors in their geometry (ESRI 2013). Population data available through the above website was in an unusual shape. The original data was taken from the Census Bureau and merged with statistical analysis of the population in Puerto Rico. For these reason there were only two attributes with the information of the population. These two attributes were the population over 18 years old and the population under 18 years old. For this study the populations under 18 years old was used as the student population.

In this study, the parcel data was the only original data well formatted. This data belonged to *El Centro de Recaudación de Ingresos Municipales* (CRIM 2015). Even though this data was in good shape, there were some attribute definitions that were difficult in translation. Some of the terms used for Parcel Type classification were not the common word used in English. After contacting the San Juan city planners, these attributes were clarified. Even though the data had limitations, after some minor editing it was in a good state for the research.

If the original school dataset had included information on school assignment zones, this would have improved this research significantly. School assignment zones delimit sectors that go with a specific school and are used to assigned student to their schools based on the student proximity to the school like other counties in Puerto Rico, San Juan County is supposed to be divided into spatially smaller districts. These districts are then divided into sectors with the general expectation that students attend the school closest to where they reside. Upon further research and conversation with personal from the DE, it was noted that there are no official school assignment zone maps. The current protocol of the DE is that the student will attend the closest school from their house unless the enrollment of that school is at maximum. Based on this general rule, this study approximated the school assignment zone boundaries by using the closest fitting service area to each school. Therefore, the results of this analysis present a best-case scenario. If the precise changes in school assignment zones could have been mapped, the actual effects of school closures on student walking distances to each school might actually be worse than estimated here.

To calculate the student per parcel populations some assumptions were made. Two parcel types were selected from the parcel type dataset, namely single family, and multifamily parcels. To distribute the number of children per parcel, an assumption was made that there was double the number of student population per parcel in multifamily compare to single family. This assumption was made following the dasymetric mapping techniques used by Mennis (2003), Holt (2004) and Parson (2015). It is possible that in some areas of San Juan County the relative density of children in multi-family versus single-family parcels is higher or lower than this, but unfortunately there was no data available on which to confirm this assumption.

5.3 Future Research

In June 2015, the governor of Puerto Rico, Honorable Alejandro García Padilla announced that the island would not be able to pay back the public debt they owned of 72 billion dollars (El Caribe 2015). This crisis affected all branches of the government, and of course the DE. It was announced later by the DE that they will close 100 more school this year and that the plan is to close 600 more school by the end of 2016 (El Caribe 2015). So far, the same criteria used before will be used to close the schools next year and this will affect hundreds of students. This study could potentially serve as a tool for the DE to decide which schools are more suitable to close based on accessibility and distance walked to school. With additions to the network dataset like sidewalks, tree canopy and crime data, this analysis could help to preserve the walkability to school for the children of Puerto Rico.

Another area for future research would be to develop the analysis carried out in ArcGIS ModelBuilder. These models developed in this study are automated workflows that string a sequence of processes to produce an output. With some work, the methodology presented in the current investigation can be automated such as by combining the models into an ArcGIS Add-In or Extension which could be easily shared with other Esri software users. By automating this process it would be possible for less advanced GIS users to quickly run the analyses conducted as part of this thesis research. In this way, perhaps users would be able to perform analysis on school districts. This could be of great benefit for schools planners and school districts.

5.4 Final Conclusion

Even though data quality and availability limited this research, the analysis performed is considered successful. Being able to accurately assess schools accessibility and distance walked to school is a valuable factor in school site planning (Carey 2011). The processes used in this research could be potentially automated and integrated into a criterion that the DE could use for future decision-making.

With better data quality this research could prove to be of significant use for school site planning. As the first of this type of research in Puerto Rico, these results could increase awareness of the potential benefits GIS for improved decision making for the growing investment of data would signify better ways of measuring accessibility. It was the intention of this study to add to the literature regarding school site planning through the use of development of a methodology for measuring walkability. The approach used in this study can promote awareness of the importance of spatial analysis.

References

Bliesner, Jim, Steve Bouton, and Barry Schults. 2015. *Walk San Diego*. Accessed February 13, 2015. http://walksandiego.org/download_file/view/108/96/.

Butterworth, Iain, and Edwards, Melissah. 2006. "Measuring the Walkability of Local Communities Using Geographic Information Systems Data." *The 7th International Conference on Walking and Livable Communities.* Melbourne Australia: School of Health and Social Development 7: 1-14.

Carey, Kelley D,. 2011. *School District Master Planning.* New York: Rowman & Littlefield Publishers, Inc.

Centers for Disease Control and Prevention. 2011. "Morbidity and Mortality Weekly Report." *School Health Guidelines to Promote Healthy Eating and Physical Activity*. Accessed June 5, 2015 http://www.cdc.gov/mmwr/preview/mmwrhtml/rr6005a1.htm.

CRIM. 2015. "Parcelario de Puerto Rico" Centro de Recaudación de Ingresos Municipales. Accessed March 25, 2015. https://www.crimpr.net/crimdnn.

Cropper, Matt. 2003. "GIS In School Facility Planning." *School Planning & Management* 2: 56-60.

Dellinger, A.M., y C.E. Staunton. 1999. "Barriers to Children Walking and Bicycling to School." *Morbidity and Mortality Weekly* 51: 701-704.

Departament de Educacion de Puerto Rico. 2014. *Plan de Transformación y Reorganización de Escuelas*.Accessed February 5, 2015. http://www.de.gobierno.pr/51-noticias/2251-plan-de-transformacion-y-reorganizacion-de-escuelas.

El Caribe. 2015. *Puerto Rico Cierra más de 150 escuelas por crisis económica*. Accessed June 15, 2015. http://www.elcaribe.com.do/2015/05/14/puerto-rico-cierra-decenas-escuelas-debido-crisis-economica.

EPA. 2013. "Travel and Environmental Implications of School Siting." *Environmental Protection Agency*. Accessed March 10,2015. http://www.epa.gov/smartgrowth/pdf/school_travel.pdf. Accessed:.

ESRI. 2013. *ArcGIS Resources*. Accessed June 15, 2015. http://resources.arcgis.com/en/help/main/10.1/index.html#//0017000000nq000000.

FHWA. 2001 "Transportation Characteristics of School Children." *Federal Highway Administration*. Accessed March 25, 2015. http://www.fhwa.dot.gov/ohim/1969/q.pdf.

Instituto de Estadísticas de Puerto Rico. 2014. "Publicaciones.". Accessed January, 15 2015. http://www.estadisticas.gobierno.pr/iepr/LinkClick.aspx?fileticket=m8j9w8ftbhE%3D&tabid=165.

Javed, M.A., y S.R. Ahmad. 2013. "Assessment of Neighborhood Parks Using GIS Techniques in Sheikhupura City." *Pakistan Journal of Science* 2: 296-302.

Kunstler, James H. 1994. *The Geography of Nowhere: The Rise and Decline of America's Man-Made Landscape.* New York: Touchstone.

Longley, Paul A., Michael, F. Goodchild, David J. Maguire, and David W. Rhind. 2011. *Geographic Informationn Systems & Science.* New Jersey: John Wiley & Sons, Inc.

Mennis, Jeremy. 2003. "Generating surface models of population using dasymetric mapping." *The Professional Geographer* 5:31-42.

Meyer, Nancy. 2004. *GIS and Land Records The ArcGIS Parcel Data Model.* California: ESRI Press.

National Household Travel Society. 2013. *NHTS Version 1.0 CD (Preliminary CD).* Washington, DC: Bureau of Transportation Statistics.

Nicholls, Sarah. 2001. "Measuring the Accessibility and Equity of Public Parks: A Case Study Using GIS." *Managing Leisure* 6: 201-219.

Parsons, Jonathan Edward. 2015. "Mapping Uniformity of Park Access Using Cadastral Data Within Network Analyst in Wake County, NC." MS thesis, University of Southern California.

Portal Datos Geograficos Gubernamentales. 2003. *Sistemas de Información Geografíca.* Accessed April 25, 2015. http://www2.pr.gov/agencias/gis/Pages/default.aspx.

Recursos de Agua de Puerto Rico. 2012. "Recursos de Agua de Puerto Rico." *Lagunas del Estuario de San Juan.* Accessed August 1, 2015. http://www.recursosaguapuertorico.com/Lagunas-San-Juan.html.

Rodrigue, Jean Paul. 2013. "The Geography of Transport Systems." *Methods in Transport Geography*. Accessed July 20, 2015. https://people.hofstra.edu/geotrans/eng/methods/ch2m1en.html.

Speck, Jeff. 2013 *Walkable City*. New York: North Point Press.

U.S. Department of Transportation. 2013. "Federal Highway Administration." *Highway Functional Classification Concepts, Criteria and Procedures.* Accessed March 5, 2015. http://www.fhwa.dot.gov/planning/processes/statewide/related/highway_functional_classifications/fcauab.pdf.

Yang, Zhongzhen. 2002. "GIS-Based Analysis of Railway's Origin/Destination Path-Selecting Behavior." *Computer-Aided Civil and Infrastructure Engineering* 3: 221-226.

Yin, Jie, and Qingming: Qian, Yi Zhan. 2014. "The GIS-based Research of Measurement and Planning on Walkability of Educational Public Services Facilities - a case study in Wuhan." *Advanced Materials Research* 926: 4037-4040.