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A Comparison Of Food Accessibility From 2002 To 2012 In St. Paul, Minnesota

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A COMPARISON OF FOOD ACCESSIBILITY FROM 2002 TO 2012 IN ST. PAUL, MINNESOTA

by

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This thesis, submitted by Brett Sergenian in partial fulfillment of the requirements for the degree of Master of Arts from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Brett Sergenian

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ABSTRACT

This study compared the changes in the healthy food accessibility landscape of St. Paul from 2002 to 2012. Food deserts are areas of limited or no accessibility to healthy food options. Local food landscapes in the U.S. and Canada have changed significantly over the past 50 years as many supermarkets have relocated out of the inner cities and into the suburbs. As a result, many inner city neighborhoods no longer have adequate access to healthy food. Despite supermarkets relocating out of the inner city, small and mid-sized grocers could stock healthy food options. The research questions answered are: Where are the underserved areas in St. Paul at the Census Block Group (CBG) level? How has the food desert landscape changed from 2002 to 2012? Which socioeconomic groups have the highest and lowest access to grocery stores and supermarkets? Grocery stores included all types of grocery stores and supermarkets were defined as grocery stores with more than 50 employees. Each food outlet location from 2002 and 2012 was geocoded and distances were calculated from each population-weighted CBG centroid to the nearest food outlet using the Network Analyst extension in ArcGIS 10.1. To be classified as a potential food desert, CBGs have to be more than 1,000 meters from the nearest food establishment by walking distance and more than 3,000 meters or 5,000 meters from the nearest grocery store by public transit. In addition to these criteria, potential food deserts must have a socioeconomic deprivation index above the fifth quintile of all CBGs in St. Paul. The results showed that there were few food deserts in St. Paul in 2002 and

2012 with the inclusion of public transit at the 3,000-meter threshold for grocery stores and at the 5,000-meter threshold for supermarkets. In 2012, the general trend showed more underserved CBGs by both walking and public transit to grocery stores and supermarkets than in 2002. Socioeconomic deprivation was linked to higher grocery store access but lower supermarket access for both 2002 and 2012. Future research and ground truth data is needed to verify if some of the smaller grocers stock healthy food or if there are other sources of healthy food that are accessible to the underserved CBGs identified in this analysis.

CHAPTER I

INTRODUCTION

Food deserts have become a widely known issue in many North American cities. Food deserts are areas that have limited accessibility to healthy food, usually by physical distance (USDA 2013). Most food desert studies attempt to find the underserved areas, analyze the demographics of underserved populations, and find cost-effective solutions (Sparks, Bania, and Leete 2008; Regan and Rice 2012). The majority of food desert studies use supermarkets as the primary supplier of healthy food although smaller grocers, farmers' markets, and mobile markets are often sufficient alternatives (Short et al. 2007; Larsen and Gilliland 2009; Widener, Metcalf, and Bar-Yam 2012). To reduce the impacts of food deserts, some municipalities have opted for alternative plans to provide affordable healthy food options for food desert residents. Recently, local municipalities have subsidized urban gardens and re-evaluated zoning regulations to encourage urban gardening opportunities (Ramsey County Food and Nutrition Commission 2012).

Over the past half-century, chain grocery stores and supercenters have overtaken small locally owned grocery stores (Larsen and Gilliland 2008). Starting in the 1950s, grocery stores relocated to the suburbs to follow the wealthy and middle-class customer who moved out of the inner city. Larger chain stores often locate in the suburbs because land is less expensive and closer to major roadways (Larsen and Gilliland 2008). The result is that low-income inner-city residents have reduced accessibility to grocery stores and fewer healthy food options. Healthy food is often defined as fruits and vegetables, these items are more likely to be found in supermarkets, grocery stores, supercenters, and farmer's markets (Widener, Metcalf, and Bar-Yam 2012). Convenience stores, which usually also serve as gas stations stock either a limited choice of fruits and vegetables or simply do not sell them (Morland et al. 2002).

With limited access to healthy food options, the public health of the underserved population is of concern. For example, obesity rates have risen steadily over the past 50 years. The rate for adults in the U.S. is at 35.7% (Chi et al. 2013). In 1986, there were no states that exceeded a 15% obesity rate, and in 1996, 30 states had obesity rates above 15% (Chi et al. 2013). In 2010, the lowest obesity rate of any state in the U.S. was Colorado at 20.5% (Ogden et al. 2010). Minnesota's rate was at 25.7% in 2012, an increase of 0.9% from 2010 (Ogden et al. 2010; CDC 2012). Recent studies have shown obesity rates are higher in many areas of the southern U.S., specifically the Deep South (Chi et al. 2013). Most researchers attribute obesity to individualistic choices, but studies since the 1990s are examining the impacts of the built environment on obesity and other health concerns (Chi et al. 2013).

These studies have shown that residents of food deserts face higher rates of obesity, diabetes, cancer, and heart disease (Bader et al. 2010; Fuller, Cummins, and Matthews 2013). Numerous studies identify a link between obesity and limited access to supermarkets.

The term "food desert" implies that there is an absence of healthy food options, The criteria and methodology for identifying food deserts is not uniform (Bitler and Haider 2009). The U.S. Department of Agriculture (USDA) defines food deserts specifically as census tracts with more than 20% of the population below the poverty line and 33% of the population residing a half-mile or more from the nearest supermarket (USDA 2009). Other studies have questioned the USDA's methodology and definition because of its simplicity and coarse scale (Goldsberry 2010; Shannon and Harvey 2013). The USDA uses census tracts as their unit of analysis and currently uses multiple thresholds to define food deserts in urban and rural census tracts (USDA 2013). The USDA only includes supermarkets in the Food Desert Locator and the Food Desert Research Atlas. A supermarket is a grocery store that exceeds $2 million in annual sales (USDA 2013). Other studies use square footage and the number of employees to define supermarkets (Lee and Lim 2008; Larson and Moseley 2012). These definitions are often subject to the data available on each food outlet (Bitler and Haider 2010). Many studies exclude small grocers because it is difficult to distinguish small grocers from convenience stores. Supermarkets are easier to verify and there is likely more local knowledge of their existence. In large metropolitan areas, specifically the Minneapolis-St. Paul Metropolitan Statistical Area, many smaller and mid-sized grocers stock food that is culturally acceptable to specific ethnic groups.

The Minneapolis-St. Paul Metropolitan Statistical Area, commonly referred to as the "Twin Cities" fits the urban food desert profile because of the large suburban population and lack of healthy food options. Downtown and inner-city St. Paul, Minnesota has relatively few supermarkets compared suburban areas of the Twin Cities. This trend was first documented by Chung and Myers (1999). Minneapolis has been extensively studied but there is little research focusing on St. Paul (Morland et al. 2002; Hendrickson, Smith, and Eikenberry 2006; Larson and Moseley 2011; Shannon 2013).

Parts of North Minneapolis have been identified as current or past food deserts. Many residents of the Twin Cities use public transit to commute to work and other destinations if they lack access to a vehicle. Walking is more time-consuming than driving or public transit for grocery store shopping, especially if heavy groceries are transported for long distances (Shaw 2006; Hallett and McDermott 2010). In winter months, walking is often more difficult.

The Twin Cities has an extensive bus public transit system called Metro Transit. Metro Transit has bus routes serving most of the Twin Cities. Public transit is a common mode of transportation for traveling to the workplace, but it can also be very useful for grocery shopping trips (Larsen and Gilliland 2008).

The purpose of this study is to identify underserved areas in St. Paul, and to examine changes over the past decade. My primary objective is to identify and compare the food desert landscape in 2002 to 2012 in St. Paul in terms of socioeconomic deprivation and access to grocery stores and supermarkets. In this analysis grocery stores constitute all types of grocery stores including small grocers to supermarkets.

Another objective is to determine if the inclusion small food establishments and public transit provide a more complete analysis of the local food environment. If smaller grocers are discarded because some do not sell healthy food, then my study will underestimate the sources of healthy food. Walking to and from the nearest supermarket is not always a viable option for consumers, leaving public transit as an alternative to access supermarkets or grocery stores from longer distances (Larsen and Gilliland 2008).

I seek to quantify accessibility at the Census Block Group (CBG) level by measuring the physical distance between each population-weighted centroid to the nearest grocery store and the nearest supermarket in both 2002 and 2012. I calculated distances along a road network for the walking distances and along a transit route network for public transit access. I used statistical methods such as the Gi* statistic and bivariate Local Moran's I tests to better understand and visualize the results.

My research questions are: (1) Where are the underserved areas in St. Paul by walking distance and public transit in 2012? (2) Has the food desert landscape changed from 2002 to 2012? (3) Does public transit significantly increase accessibility for low-income residents in St. Paul in 2002 and 2012? (4) Are there differences between socioeconomically deprived and non-socioeconomically deprived CBGs in terms of healthy food access? (5) How has supermarket accessibility changed over the past decade and do low-income CBGs have higher access to all grocery stores than supermarkets? Previous studies have found that more socioeconomically deprived populations typically have better access to corner stores and fast-food restaurants than supermarkets (Morland et al. 2002; Block and Kouba 2005; Sharkey et al. 2009) (6) Do public transit routes and bus stops coincide with grocery store and supermarket locations? And (7) how can statistical analysis, explain and visualize food accessibility in St. Paul for 2002 and 2012?

CHAPTER II

LITERATURE REVIEW

Researchers from various disciplines have studied the food desert problem. Research on this topic falls into three categories: quantitative, qualitative, and environmental equity studies. Quantitative studies on food deserts use GIS network analysis or other GIS methods, such as proximity analysis to determine the extent of food deserts. Other food desert research has examined the impacts of secondary business data source accuracy on the identification of underserved areas (Lake et al. 2010; Ma et al. 2013). Numerous food desert studies have used spatial statistics to examine global and local patterns within a given study area (Lee and Lim 2008; Stein 2010).

Most food desert research is done in urban areas because of the higher densities of lower-income residents than rural environments (Widener, Metcalf, and Bar-Yam 2011). Almost all studies are done in urban areas in the U.S., Canada, United Kingdom, and Australia (Donkin et al. 1999; Larsen and Gilliland 2008). Notable exceptions include a study done in Tokyo (Murakami et al. 2009) and another in Bratislava, Slovakia (Krizan, Tolmaci, and Lauko 2008). Many North American cities are more car-oriented than European cities such as Bratislava or East Asian cities such as Tokyo, but public transit is still a mode of transportation for those without vehicle access. The Twin Cities is typical of a car-oriented urban area, but the region has public transit by both bus and light rail.

There is an extensive public transit system in the Twin Cities MSA by bus and by light rail (MetroGIS 2013). As of 2012, the light rail system only operated in Minneapolis and the surrounding suburbs, which is why it is not included in my analysis. These transportation systems provide inexpensive transit to travel across the Twin Cities for low-income residents. Data availability and time constraints have reduced the number of publications that include public transit (Larsen and Gilliland 2008). Larsen and Gilliland (2008) and Bader et al. (2010) published food desert studies including both walking distances and public transit. Krizan, Tolmaci, and Lauko (2008) also included public transit in their food accessibility analysis of Bratislava.

Accessibility to affordable healthy food options is important for the health and well-being of food desert residents. Inner cities and rural communities have seen a decline in local grocery stores because small and mid-sized grocers cannot compete with urban grocery stores as a result of economies of scale (Larsen and Gilliland 2008). Economies of scale occur when chain supermarkets have the ability to purchase items in bulk at cheaper prices, and smaller grocers cannot afford to make large purchases at once, or simply do not have the space for bulk purchases (Larsen and Gilliand 2008)

Convenience stores and fast food primarily offer calorie-dense foods or non-perishable items (Morland et al. 2002). These types of food establishments are more likely to occur in low-income neighborhoods in inner cities (Chung and Myers 1999; Morland et al. 2002; Sharkey and Horel 2009; Stein 2011). In inner city neighborhoods, zoning restrictions and real estate have deterred potential supermarkets and mid-sized grocers from locating their businesses there (Stein 2011). Some downtown areas and surrounding areas often lack ample parking spaces (Block and Kouba 2005; Fuller, Cummins, and Matthews 2013). Numerous studies have measured accessibility to fast food restaurants and supermarkets to test their hypothesis that fast food restaurants are more likely to be in low-income areas (Pearce et al. 2007; Stein 2011). This study is not concerned with fast-food restaurants; the methodology used in these studies is applicable to measuring socioeconomic deprivation and distance to the nearest grocery store or supermarket.

2.1 Quantitative Studies

Larsen and Gilliland (2008) challenged the idea that food deserts were not a problem for Canadian cities, based on previous studies. Two previous studies of Montreal, Quebec, and Edmonton, Alberta, showed no evidence of low food access (Smoyer-Tomic, Spence, and Amrhein 2006; Apparicio, Cloutier, and Shearmur 2008). Larsen and Gilliland (2008) analyzed food accessibility by walking distance and public transit in London, Ontario. Their study analyzed the temporal changes in food environments from 1961 to 2005. The walking distance threshold was 1,000 meters and public transit was a ten-minute bus ride or 3 km. The results showed that parts of East London were underserved in 2005 despite public transit being included (Larsen and Gilliland 2008). Public transit data for 1961 were likely unavailable and at the time there may have not been a need for public transit for London.

Larsen and Gilliland (2009) researched the impact of farmers' markets on healthy food access after identifying East London as a food desert from their 2008 study. In 2008, prices of food (both healthy and unhealthy) increased at supermarkets but decreased at local shops and farmers' markets for East London from 2005. Larsen and

Gilliland (2009) concluded that East London was no longer a food desert after the introduction of the farmers' market in 2006. Most farmers' markets in a humid-continental climate operate seasonally, although the farmers' market in East London is open year-round as of 2014 (London Farmers' Markets 2014).

Lu et al. (2012) performed a temporal analysis of the food desert landscape in Baltimore, using a 500-meter threshold. Unlike Larsen and Gilliland (2008), they found that food deserts decreased in Baltimore from 2000 to 2010. Other food desert studies that use similar methodologies show different results. The reason may have been a result of population loss from 2000 to 2010. Lu et al. (2012) did not analyze public transit, but it was mentioned as a limitation. Depending on the study area, different thresholds are used. Bader et al. (2010) used an 800-meter walking distance threshold and the public transit threshold was 1,600 meters and a census tract centroid within 400 meters of a bus or subway stop. New York City is a unique study area because approximately 50% of the population does not own a vehicle (Bader et al. 2010).

The results showed nearly all of New York City had public transit access although African-American and Latino majority census tracts had better access to public transit by bus than by subways (Bader et al. 2010). These studies influenced the methodology that is used in my study, specifically from the 1,000-meter and 3,000-meter thresholds used in Larsen and Gilliland (2008).

Smoyer-Tomic, Spence, and Amrhein (2006) found that lower income populations in Edmonton, Alberta had higher access to healthy food options and their results were countered by other studies. This study observed a clustering of supermarkets in central Edmonton and to the areas north and south of the Athabasca River near downtown Edmonton. Suburban populations in Edmonton with the highest income had the lowest access to supermarkets (Smoyer-Tomic, Spence, and Amrhein 2006). They concluded that the food environment was relatively "ideal" for Edmonton and for most Canadian, United Kingdom, and Australian cities based off of other studies, unlike most U.S. studies. Apparicio, Cloutier, and Shearmur (2008) also concluded that healthy food access was not a problem for Montreal, Quebec.

Other studies have measured public transit accessibility for other purposes than obtaining food. Mavoa et al. (2012) compared accessibility to destinations by land use in Auckland, New Zealand, by public transit and walking. A public transit walking accessibility index (PTWAI) was developed to categorize each area based on the amount of time it took to reach each destination. A meshblock is the equivalent of a census block in the U.S. The results showed most of Auckland had a high accessibility to transit stops although the frequency of transit stops was highly variable (Mavoa et al. 2012). One of the limitations with this analysis is that the 78-meters-per-minute rate was uniform for Auckland without considering hills and crosswalks. Using uniform speeds is more simplistic than using multiple speeds for each crossing or steep slope.

Eckert and Shetty (2011) used GIS network analyst to locate underserved CBGs of Toledo, Ohio. Their results showed that a few CBGs had above average poverty rates also traveled the farthest distance to the nearest grocery store. Eckert and Shetty (2011) used individual addresses, which is highly unusual for an urban food desert study. Many rural studies use individual addresses because census tracts and block groups are significantly larger in rural areas (McEntee and Agyeman 2009; Sadler, Arku, and Gilliland 2011). Most urban food desert studies use CBG centroids, census tract centroids, and other population weighted centroids used as a point of origin (Zenk et al. 2005).

Sharkey et al. (2009) sought to determine if there is a correlation between neighborhood deprivation to proximity to grocery stores and fast food restaurants in the Lower Rio Grande Valley in Texas. In this study, the authors also included vehicle availability and access to dollar stores, convenience stores, and large department stores. Fast food restaurants, dollar stores, and convenience stores are often associated with low-income neighborhoods (Pearce et al. 2007; Sharkey et al. 2009; Stein 2011). The results showed that populations in the most socioeconomically deprived CBGs traveled greater distances to the nearest supermarket and shorter distances to the nearest convenience store and fast food outlets. CBGs with lower vehicle availability had greater accessibility to supermarkets and grocery stores (Sharkey and Horel 2009).

Other studies have avoided the use of absolute measures such as Leslie, Frankenfield, and Makara (2011). Their study analyzed the retail food environment by conducting a co-location analysis of food establishments in Washington D.C. (Leslie, Frankenfield, and Makara 2011). Results showed that food environments were highly varied and fast-food restaurants were more likely to be in poor food environments, similar to other studies, specifically Stein (2011), Pearce et al. (2007) that examined access to fast-food outlets.

Lee and Lim (2009) used the G-statistic to map local hot spots of calculated by a discrepancy index of healthy food access in Buffalo, a typical rust-belt city that has been in decline when manufacturing jobs diminished. The discrepancy index is useful for not being an absolute measure of distance, but uses a statistical approach to calculate expected demand for healthy food and observed healthy food access. Lee and Lim (2009) also used ReferenceUSA to calculate store attractiveness based on estimated square footage, number of employees, and sales volume. Larson and Moseley (2012) calculated spatial accessibility by using a Gaussian measure. The Gaussian measure weights attractiveness of a store (square footage) and multiplied the value by a distance-decay function. North Minneapolis was identified as a food desert with only one supermarket in the area and Frogtown was classified as moderately food insecure. For this analysis, Frogtown has a high accessibility to smaller grocers, many of which are Asian and East African markets.

Stein (2011) measured accessibility to both healthy food and unhealthy food by calculating a bivariate local indicator of spatial association (LISA) to identify food deserts and food swamps. The bivariate LISA measures the statistical significance of CBGs of a certain variable (e.g. percentage of a CBG with access to a food outlet) to socioeconomic deprivation. Socioeconomic deprivation (SED) was determined by calculating a SED index based on Cutter's (1997) social vulnerability index. Most of the CBGs with high SED index values were not food deserts when considering all supermarkets, but were food deserts when only considering the healthiest supermarkets.

Food swamps were the CBGs with high SED index values and high accessibility to fast-food restaurants, or high-high LISA associations (Stein 2011). Food deserts were identified by high-low bivariate LISA associations, for the supermarket analysis. Few other studies examined food deserts and food swamps in one study (Sharkey et al. 2009; Stein 2011). The results of Stein (2011) were consistent with the results of other studies linking low-income or socioeconomically deprived areas with high accessibility to fast-food outlets and low access to healthy food options (Sharkey et al. 2009; Leslie, Frankenfield, and Makara 2011).

Raja, Ma and Yadav (2008) found that no food deserts existed when restaurants were included but their study found racial disparities for accessing healthy food in Buffalo. African-Americans had to travel greater distances to the nearest supermarket than white populations (Raja, Ma, and Yadav 2008). Other studies have come to similar conclusion to Raja, Ma, and Yadav (2008) and found lower quality produced in predominantly minority or low-income areas (Zenk et al. 2005). In addition to the lack of supermarkets in low-income areas, numerous studies have found that low-income and minority neighborhoods have better access to fast-food restaurants and convenience stores (Block, Scribner, and Desalvo 2004; Pearce et al. 2007). Block, Scribner, and Desalvo (2004) identified that fast food restaurants were more concentrated in low-income and African-American neighborhoods.

Regan and Rice (2012) found that including small grocery stores, ethnic food stores, and convenience stores in South Dallas nearly eliminated most of the USDA defined food deserts. However, a few census blocks were still considered "food deserts" despite the inclusion of convenience stores (Regan and Rice 2012). If public transit were included, perhaps this study would yield different results

Goldsberry et al. (2010) quantified the separation costs of traveling to a grocery store. Their study looked analyzed several measures accessibility to different produce in the Lansing, Michigan, Metropolitan Area. These methods were the container method, the weighted method, and cumulative distance (Goldsberry et al. 2010). As a result, their study found that the food accessibility was highly variable when different methodologies were employed. A similar study done by Kwan (2012) stated that using different measurements of accessibility and different unit sizes can significantly alter the results of a food desert study.

Sadler, Arku, and Gilliland (2011) looked at the impacts of the "edge effect" to determine the extent of food deserts in Middlesex County, Ontario, just outside of London. Many food desert studies only consider grocery stores within a city, county, state, or other political boundary (Sadler, Arku, and Gilliland 2011). Their results showed that residents of eastern Middlesex County traveled shorter distances when the political boundaries of Middlesex County were removed. Other studies have addressed the edge effect as a limitation (McEntee and Agyeman (2009). For St. Paul, there are numerous suburbs that border the city and neglecting the food establishments in eastern Minneapolis or other suburbs could significantly alter distance measurements. In other studies, a buffer is applied around the study area to account for grocery stores and supermarkets outside of a study area (Ma et al. 2013).

Hallett and McDermott (2010) used a cost raster analysis to quantify the costs of traveling to the nearest grocery store from each raster cell. A cost raster analysis was used to determine the time costs and monetary costs of obtaining food in Lawrence, Kansas (Hallett and McDermott 2010). The results showed that food deserts were not a problem in Lawrence, except for residents without vehicle access (Hallett and McDermott 2010). The results fit with Shaw (2006) analysis that food deserts can occur for one segment of the population but not for others. In rural communities, vehicle ownership is vital for obtaining groceries because there is no public transit or alternative transportation method.

McEntee and Agyeman (2009) addressed the problem of limiting food desert studies to urban areas. Their study showed that several rural census tracts in Vermont were 10 miles from the nearest grocery store (McEntee and Agyeman 2009). Hubley (2011) researched food accessibility in rural Maine and found that convenience stores in more densely populated areas stocked lower quality and higher priced food than in rural areas of Somerset County, Maine. Another study analyzed the price of healthy food in rural areas of Mississippi (Blanchard and Lyson 2003).

Nicholls (2001) compared the results of using Euclidean and network distances for park accessibility in Bryan, Texas. The results did not prove that the network or Euclidean methods had a statistically significant difference for distance, but Nicholls (2001) argued that network distances were more realistic than Euclidean distance because people travel by road or sidewalk networks. Euclidean distance does not account for private property, sidewalk availability, and land cover features when calculating. Sparks, Bania, and Leete (2010) came to a similar conclusion about the different measurements of distance. Their study also found that there was little difference between using Euclidean distance and network distance (Nicholls 2001). The vast majority of food access studies use network distance, especially studies published in the last decade (Smoyer-Tomic, Spence, and Amrhein 2006; Apparicio, Cloutier, and Shearmur 2007; Larsen and Gilliland 2008). Several geostatistical studies still use Euclidean distance for simplicity purposes (Lee and Lim 2009; Ma et al. 2013).

Widener et al. (2012) questioned the method of using residences as the point of origin for food desert studies. Instead of using residences, Widener et al. (2012) used traffic analysis zones (TAZs) to measure distances traveled to the nearest grocery store during daily commuting (Widener et al. 2012). The results showed several census blocks designated as food deserts had increased accessibility from their workplace than their residence (Widener et al. 2012). More block groups had higher accessibility to healthy food when residence is used as the origin. Future studies could measure food access from childcare centers, schools, or recreational locations to identify other potential origins of a grocery shopping trip. Potentially, research on food accessibility from the workplace in other cities could yield different results.

Farmers markets' are often excluded as a source of healthy food for food desert studies because they are not open on a regular basis. Widener, Metcalf, and Bar-Yam (2013) used an agent based model to measure the number of households with fruits and vegetables in Buffalo. Their model included supermarkets, convenience stores, and farmers' markets as sources of healthy food. This study used weekly, bi-weekly, and monthly shopping for the frequency and probabilities were assigned for whether an agent (shopper) would purchase fruits and vegetables. As expected, the number of households that had fruits and vegetables in stock was higher during the summer months than the winter months. Depending on the frequency of shopping trips to a grocery store, an individual or household will have a continuous or infrequent supply of fresh produce (Widener, Metcalf, and Bar-Yam). Seasonal temporal variations of food accessibility are more problematic for cities in the northern U.S. and Canada. Chen and Lee (2013) mapped food accessibility variation throughout an average weekday and identified that food access was lower during late evening and early morning hours.

Previous studies have used multiple accessibility measurements and different definitions of what constitutes "healthy" food (McEntee and Agyeman 2009). Most studies consider fresh produce healthy food, although frozen vegetables and fruit are considerably healthier options than frozen fried meat. Hendrickson, Smith and Eikenberry (2006) analyzed the quality of produce. These types of studies collect data from store surveys. The primary shortcoming of this methodology is excluding the price of healthy food options. Block and Kouba (2005) included price in their store survey of two Chicago suburbs and found that stores in low-income neighborhoods charged more for their food than in wealthier suburbs.

Different food desert studies have used different distances or ratios to define accessibility to healthy food. The USDA used a 1-mile Euclidean buffer in 2008 and in 2012 both 1-mile and a 0.5-mile (USDA 2013). Lu et al. (2012) used 500 meters as the walking distance threshold, and Larsen and Gilliland (2008) used 1,000 meters as the walking distance threshold. The only consensus on measuring accessibility is the preference to use network distance rather than Euclidean distance and Manhattan block distance (Zenk et al. 2005; Lu et al. 2012). Determining what distances are accessible is even more problematic for public transit because of the lack of food desert literature on that topic (Larsen and Gilliland 2008; Widener, Metcalf, and Bar-Yam 2013). Previous food desert literature and the USDA use multiple buffers to avoid solely relying on one threshold for classifying food deserts (Sharkey et al. 2009, USDA 2013). Sharkey et al. (2009) used network buffers of 1 and 3-miles around each CBG centroid to determine accessibility by walking or driving at different thresholds. La Rosa (2013) used buffers of 300 and 600 meters for accessibility to green spaces. McEntee and Agyeman (2009) and the USDA used a 10-mile threshold for their rural food desert study. These methods resulted in different types of food deserts, as seen in Table 4. Past research has shown varying degrees of food access.

2.2 Qualitative Studies

Previous qualitative studies of food deserts have acquired survey data of low-income populations. Few studies have included interviews in their study, but Shaw (2006) and Walker et al. (2011) did for their analyses. The authors were able to collect data from residents and gained insight into unexpected barriers. Taxis did not serve a low-income neighborhood in Pittsburgh, which took the researchers by surprise (Walker et al. 2011). Businesses are often reluctant to locate or deliver goods and services in low-income areas with high crime because it is unprofitable (Bitler and Haider 2009). This process is known as redlining. Shaw (2006) challenged the definition of food deserts and the results showed different types of food deserts exist. The elderly populations in Leeds, England, were more likely to reside in a food desert if they did not have access to a vehicle and if they had limited physical mobility (Shaw 2006).

Another question that Shaw (2006) raised was whether food deserts can exist for different types of people in the same location. For minority ethnic groups, accessing culturally acceptable food could be a problem. Donkin et al. (2000) surveyed food outlets in a socioeconomically deprived neighborhood of London, United Kingdom, and found that areas of high population density had high accessibility to healthy food, less than 500 meters by the study's definition. The researchers identified both healthy and culturally acceptable foods among whites, Gujarati Hindus, North African residents, and Black Caribbean residents. They concluded that low-income populations in the study area may be unable to afford healthy food. These studies identified potential barriers that are often unaccounted for in other studies that use absolute measurements, specifically affordability and cultural barriers.

Wrigley et al. (2004) analyzed the impacts of a government-subsidized supermarket on a previously underserved low-income neighborhood in Leeds, United Kingdom. A big question for any food desert study is will previously underserved populations purchase and consume more fruits and vegetables with increased accessibility? After a new supermarket was opened in the Seacroft neighborhood of Leeds, several problems still persisted. Low-income residents still perceived fresh fruits and vegetables as "too expensive" resulting in the non-purchasing of produce at the new supermarket or a continuation of shopping at a limited-service discount store (Wrigley et al. 2004). The reasons for the observed shopping patterns (either purchasing healthy food or not) were quite complex (Wrigley et al. 2004). Others saw the new supermarket as "too upscale" and other participants had negative perceptions of healthy food (Wrigley et al. 2004).

Few other studies have examined the impacts of a new supermarket or other initiative to alleviate food deserts (Bitler and Haider 2009). Weatherspoon et al. (2012) analyzed the purchasing patterns of fruits and vegetables by low-income residents in Detroit. Results showed that low-income residents would purchase and consume more fresh fruits and vegetables if prices were lower and if their incomes were higher (Weatherspoon et al. 2012). To be competitive to supermarkets in the Detroit Metropolitan area, the city would have to heavily subsidize mobile produce markets (Weatherspoon et al. 2012).

Many food desert studies map the absolute distances from the point of origin to the nearest grocery store. Shannon and Harvey (2013) used aerial interpolation by mapping the Supplemental Nutrition Assistance Program (SNAP) density and SNAP inflow and outflow data at the zip-code level. Their results showed North Minneapolis and other areas located a short distance from Downtown Minneapolis and St. Paul had a higher density of SNAP recipients. Shannon (2013) built off of the Shannon and Harvey (2013) study by using a survey of low-income residents to understand their shopping patterns. Results showed that low-income residents of two Minneapolis neighborhoods were more mobile than previous researchers had thought (Shannon 2013). Carpooling, and individual preferences are difficult to detect in most studies and typically require extensive surveys (Shannon 2013).

Short, Guthman, and Raskin (2007) surveyed several smaller grocery stores in two low-income neighborhoods in the San Francisco area. They asked "Do smaller and mid-sized grocery stores sell healthy food at an affordable price"? Short, Guthman, and Raskin (2007) also examined the quality of produce within the surveyed stores. Their results showed smaller and mid-sized grocers supplied produce at a lower price than the supermarket that Short, Guthman, and Raskin (2007) surveyed. Other studies and the USDA discard smaller and mid-sized grocers because they are difficult to verify and not all stock produce, but Short, Guthman, and Raskin provided evidence that some small and mid-sized grocers supply affordable and high-quality healthy food. Chung and Myers (1999) conducted a price analysis of chain grocers and smaller grocers in the Twin Cities to determine if residents in poorer zip codes paid more for their food. They identified that residents of poorer zip codes did not pay significantly higher prices for their food but that 89% of supermarkets in Hennepin and Ramsey Counties were outside of lower-income zip codes and smaller, non-chain grocers were within lower-income zip codes. Despite the non-statistically significant results, many of the inner city grocers either charged more for their fresh produce than supermarkets or did not stock fresh produce at all (Chung and Myers 1999). These two studies showed that prices at smaller grocers are not necessarily more expensive than supermarkets.

Previous studies have sought to link healthy food access and consumption with obesity (Fuller, Cummins, and Matthews 2013). They sought to answer whether there was any association between the mode of transportation, socioeconomic status, and the Body Mass Index (BMI) of low-income residents in Philadelphia (Fuller, Cummins, and Matthews 2013). Their results indicated that there was no statistical association between fruit and vegetable consumption and BMI, but those who used public transit to access their primary grocery store had statistically significant lower BMIs.

2.3 Analyzing Secondary Business Data Sources

Filomena, Scanlin, and Morland (2013) analyzed the stability of the food retail environment in Brooklyn, New York, from 2007 to 2011. Their research investigated grocery store closures, ownership changes, and new stores. Food outlets are highly dynamic, although my study is focusing on permanent closures and new stores or locations because these events have impacts on healthy food access. Approximately 17.2 % of food retail outlets that were open in 2007 closed by 2011 although this rate is higher for my study because of the decade time-span. Filomena, Scanlin, and Morland (2013) showed that the food retail environment was more dynamic in low-income neighborhoods than wealthy neighborhoods.

Rossen, Pollack, and Curriero (2012) examined the validity of using Google Street View and ground truthing to verify food outlet locations in Baltimore. Most food desert studies obtain food outlet locations from secondary sources such as ReferenceUSA, Hoovers Inc., or local health Departments (Rossen, Pollack, and Curriero 2012; Widener, Metcalf, and Bar-Yam 2013). Remote sensing technologies such as Google Street View, Google Earth, and NAIP imagery are cost-effective and time-efficient methods to validate food outlet locations (Taylor 2012). The results showed that ground truthing had an 84.6 % accuracy rate and Google Street View only had a 68.6% accuracy rate (Rossen, Pollack, and Curriero 2012). Other studies analyzing the quality of secondary data sources on a food desert analysis showed similar results; with most of them finding that secondary sources had approximately an 80% agreement rate with ground truthed stores (Lake et al. 2010; Fleishacker et al. 2013; Ma et al. 2013). Interestingly, one study found that government sources had the most variable agreement rates from as a low as 34% to 88% (Fleishacker et al. 2013). For this analysis of St. Paul, Google Earth, Google Street View, and NAIP imagery were used to verify grocery store locations. Recently, Google Street View has allowed users to virtually see inside buildings, allowing researchers to analyze the merchandise that grocery stores sell.

The results of these studies shows the potential impact that secondary sources could have on overestimating or underestimating food accessibility based on the accuracy rates of secondary sources (Ma et al. 2013). Secondary sources have little impact when examining a broad area, with the study in central South Carolina serving as an example, but field verification should be conducted for food desert studies of cities or smaller areas Ma et al. (2013). Further research needs to be done to identify the impacts of using secondary sources to identify mid-sized and smaller grocers as their closure rates are higher.

2.4 Studies on Environmental Equity and Built Environments

Built environments have also been studied using GIS, though not as extensively as food accessibility. Kipke et al. (2006) research the impacts of green space and the proximity of fast food establishments near schools in East Los Angeles. Their study focused on youth populations, and the results showed that fast food was more accessible than grocery stores and green spaces from schools (Kipke et al. 2006). Wolch, Wilson, and Fehrenbach (2002) researched the park equity landscape in Los Angeles and found that funding for remodeling and building new parks was more frequent in middle-class neighborhoods than low-income neighborhoods. Another study used a Normalized Difference Vegetation Index (NDVI) other classification techniques to identify potential urban garden sites in Philadelphia (Peleg and DeLiberty 2011). McClintock (2012) conducted a soil analysis of potential urban garden sites in Oakland and found higher lead concentrations in western Oakland, an industrial and lower-income neighborhood of Oakland.

Many cities have implemented or subsidized urban agricultural programs to increase the accessibility of fruits and vegetables to low-income residents. The Massachusetts Avenue Project (MAP) in Buffalo has developed a mobile produce market system and the Fargo-Moorhead Council of Governments (Metro COG) is currently addressing zoning and urban agriculture (Widener, Metcalf, and Bar-Yam 2012; Fargo-Moorhead COG 2013). The Ramsey County Food and Nutrition Commission evaluated current zoning regulations to locate future urban gardens (Ramsey County Food and Nutrition Commission 2012).

Few studies have addressed potential solutions to the "food desert" problem because locating a grocery store in a low-income neighborhood makes it difficult to generate a profit (Walker et al. 2011; Widener 2011). Bitler and Haider (2009) explained that economies of agglomeration and completion often result with firms locating outside of low-income neighborhoods. The land values for grocery stores are lower but the customer base does not have the purchasing power and potential customers are deterred by negative perceptions of a low-income neighborhood. With the demand decreasing, grocery stores limit the selection of food products because of economies of scale. Bitler and Haider (2009) mentioned zoning as a potential barrier to locating a grocery store in low-income areas. Supermarkets and supercenters have fewer options for business location decisions because of square-footage limits and limited zoning options for a B-4 zoning code, which indicates high commercial density. Inner cities and downtown areas where low-income populations often reside do not have sufficient space to house supermarkets.

My study adds new research to the existing food desert literature by specifically focusing on temporal patterns, walking and public transit accessibility, and the inclusion of smaller food outlets. Past temporal studies, specifically Larsen and Gilliland (2008) and Lu et al. (2012) did not include public transit at all or only for the most recent year of analysis. To the best of my knowledge, no previous study has included public transit in a temporal food desert analysis for each year of analysis. The results will indicate if the food desert landscape has changed significantly and if the public transit system is effective for accessing healthy food. My study incorporates spatial statistics, specifically the bivariate LISA and the Gi* statistic, to visualize the relationships between socioeconomic deprivation and accessibility to grocery stores and supermarkets.

CHAPTER III

DATA AND METHODS

This chapter discusses the where the data came from for this study and the methods for analyzing food accessibility in St. Paul. The secondary data sources are ReferenceUSA, the 2001-2002 Minnesota State Business Directory, MetroGIS, U.S. Census Bureau, and the National Historic GIS Database (NHGIS). Nearly all of the data came from secondary data sources, with the exception of several grocery store locations that were observed during site visits but not included in ReferenceUSA. ReferenceUSA and the 2001-2002 Minnesota State Business Directory provided the grocery store locations, MetroGIS provided most of the shapefiles, and the NHGIS provided most of the demographic data for this analysis. All of the distances were calculated by generating a closest facility layer within the Network Analyst extension of ArcGIS. The spatial statistics calculations were done in GeoDa.

3.1 Study Area

The Twin Cities are in eastern Minnesota along the Mississippi River near the Wisconsin border (Fig. 1). The Twin Cities Metropolitan area includes Ramsey, Hennepin, Washington, Anoka, Dakota, Carver, Scott, Sherburne, and St. Croix counties. For this study, grocery store locations were collected from St. Paul, Minneapolis, and the suburbs directly bordering St. Paul or within ten miles of the St. Paul city limits. The climate of the Twin Cities is humid continental with cold winters and a relatively short summer season. Average monthly temperatures at the Minneapolis-St. Paul Airport range from 73.8 degrees Fahrenheit in July to 15.6 degrees Fahrenheit in January (Minnesota State Climatology Office 2010). Short summers result in shorter growing seasons, limiting the availability of locally grown fruit and vegetables to the spring and summer months. During the winter, residents may choose to walk shorter distances. It is likely that the average travel time by walking distance is increased with sub-optimal sidewalk conditions, specifically ice and snow. In addition to traveling shorter distances, many Twin Cities residents may avoid engaging in physical activities during the winter months.

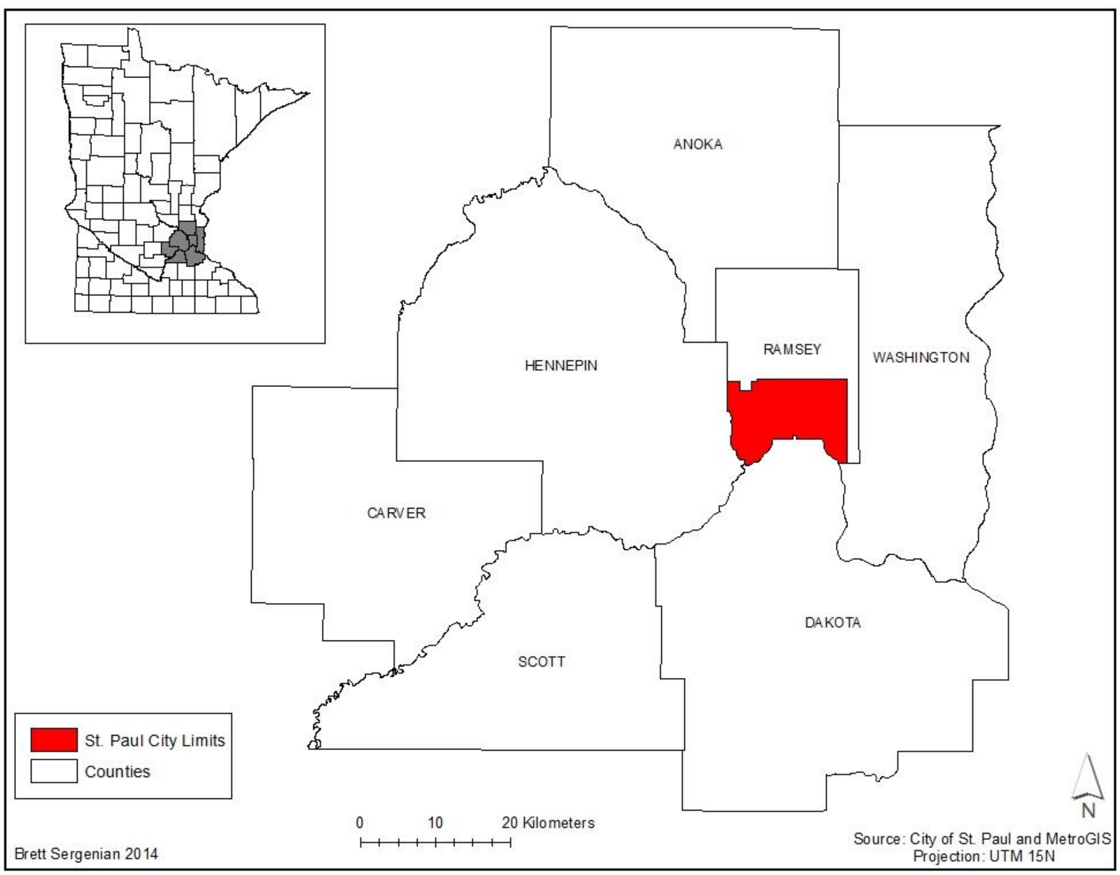


Figure 1. St. Paul and the Twin Cities Metropolitan Area

St. Paul is smaller than Minneapolis with a population of 287,000 in 2000 and 285,000 in 2010 (U.S. Census Bureau 2013). The Twin Cities Metropolitan Area has a population of 2.9 million as of 2010 and had a population of 2.7 million in 2000 (U.S. Census Bureau 2013). Ramsey County has a population of 520,000 and minorities comprise 40% of St. Paul's population (U.S. Census Bureau 2013). African-Americans constitute 15% of the population, Asians 18%, and Latinos nearly 10% (U.S. Census Bureau 2013). The median household income is $46,305, which is lower than the Minnesota median household income of $59,126. St. Paul is home to the largest Hmong population in the U.S. with a 29,662 in 2010, up from 26,509 in 2000 (U.S. Census Bureau 2010). In the Twin Cities MSA, the 2010 Hmong population is 64,422 (U.S. Census Bureau 2010). Recent demographic trends have shown an increasing suburban Hmong population. The large Hmong population is reflected by the numerous ethnic Hmong and Southeast Asian grocers in St. Paul (Larson and Moseley 2011). Many of the Southeast Asian grocers are small (e.g. Tiger Supermarket) but several mid-sized grocers, specifically Double Dragon Foods and Sun Foods supply a large variety of ethnic Asian and other international foods. In addition to the large Hmong community, there is a sizeable East Asian population within the Twin Cities (U.S. Census Bureau 2013). There are several East Asian grocery stores in the study area including Chinese grocers Shuang Hur, Shanghai Market, and a few Korean grocers on Snelling Avenue (ReferenceUSA 2013).

Other significant minority populations are present including 41,883 African-Americans or 14.5%, and 28,514 Latinos, approximately 10% of the city's population (U.S. Census Bureau 2013). The Twin Cities also has a large Somali and East African immigrant population, which is reflected by halal markets and other African ethnic food stores (Ferris 2010).

The City of St. Paul is the study area for all of the demographic data and as the origin for all of the accessibility measurements. My study only analyzed healthy food access for populations within the St. Paul city limits. For populations on the edges of St. Paul, some of them are closer to grocery stores in the surrounding suburbs or Minneapolis.

In 2002, there were 258 CBGs and in 2002 and 2012 there were 250 CBGs. One CBG, CBG 980 group 1, was omitted from this analysis because the CBG had a population of zero (NHGIS 2013). This particular CBG was located within the Mississippi River, Pigs Eye Lake, and any land was likely within the flood plain. On all of the maps, this CBG is displayed in grey as it was not included in the analysis. My study only analyzed healthy food access for populations within the St. Paul city limits. For populations on the edges of St. Paul, some of them are closer to grocery stores in the surrounding suburbs or Minneapolis. Most of the CBGs in the Westside neighborhood were closer to the Dick's IGA supermarket in West St. Paul than a supermarket within the city limits.

Outside of St. Paul, grocery stores were included because grocery shopping is not confined to city limits. Grocery stores in Minneapolis, Woodbury, White Bear Lake, Maplewood, Roseville, West St. Paul and other parts of Ramsey, Hennepin, Washington, Dakota, and Anoka counties were included in this study to account for edge effects. Some of the St. Paul CBGs are closer to grocery stores outside of the St. Paul city limits or Ramsey County. All of the grocery stores in the cities mentioned above were included. In Figure 2, the cities in white show the extent of the food outlet locations that were originally collected. The unlabeled cities were part of White Bear Lake as it was divided into different sections. Several suburbs, particularly Minneapolis, Roseville, West St. Paul, Maplewood, and Woodbury all had at least one nearest grocery store or supermarket in each St. Paul CBG. The farthest extent of the nearest grocery store/supermarket was in the New Brighton/St. Anthony city limits for a CBG in the northwestern corner of St. Paul. The nearest grocery store is determined by calculating a closest facility layer between each CBG centroid and the nearest grocery store or supermarket.

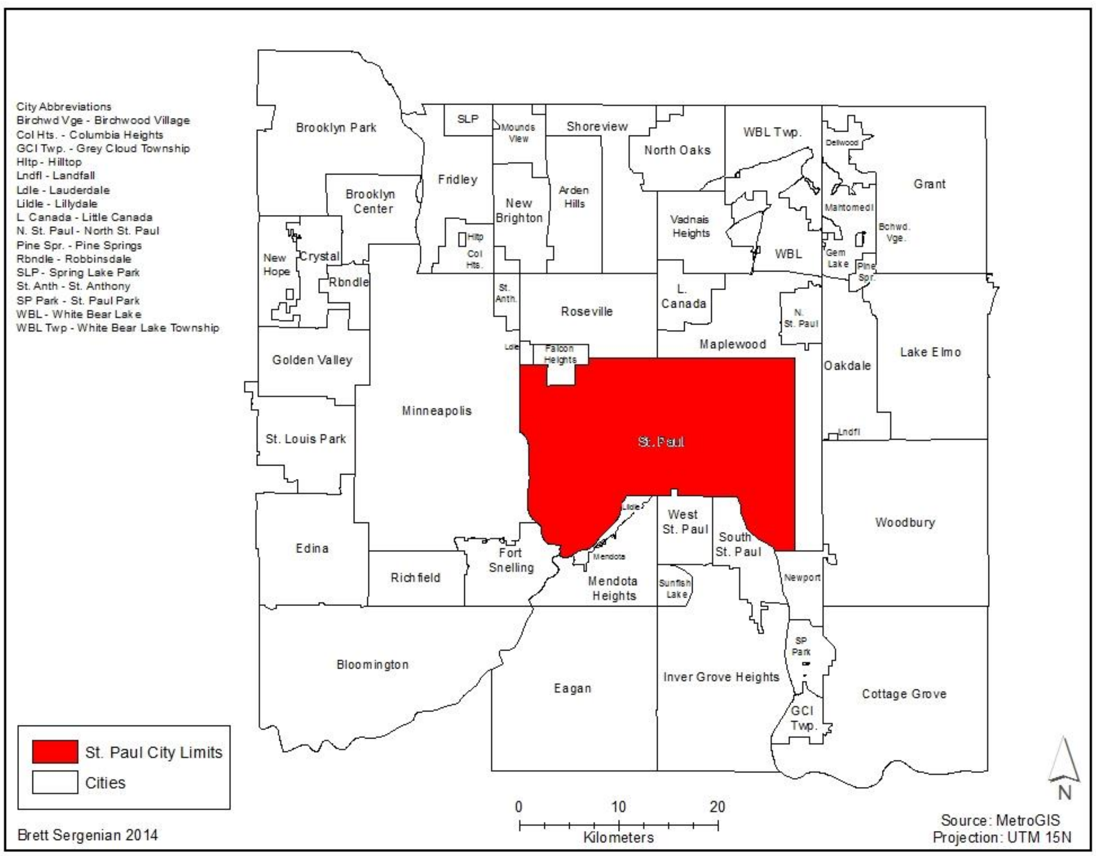


Figure 2. Cities with grocery store locations in the study area

The eastern half of St. Paul is generally considered the lower-income or more "blue collar" side of St. Paul (Ferris 2010; Ramsey County Food and Nutrition 2012). Neighborhoods in eastern St. Paul include the Dayton's Bluff neighborhood in east-central St. Paul, the Payne-Phalen neighborhood in northeastern St. Paul, and the Battle Creek neighborhood in southeastern St. Paul (Ferris 2010; City of St. Paul 2012) (Fig. 3). North and central Frogtown has also been identified as a low-income and ethnically diverse neighborhood situated just west of downtown St. Paul bounded by University Avenue to the south and the Burlington-Northern rail line to the north (Larson and Moseley 2011). Most of the studies and reports focusing on St. Paul have identified the Dayton's Bluff, Payne-Phalen, Frogtown, and Battle Creek neighborhoods as potential food deserts or displaying food security problems (Ferris 2010; Larson and Moseley 2011).

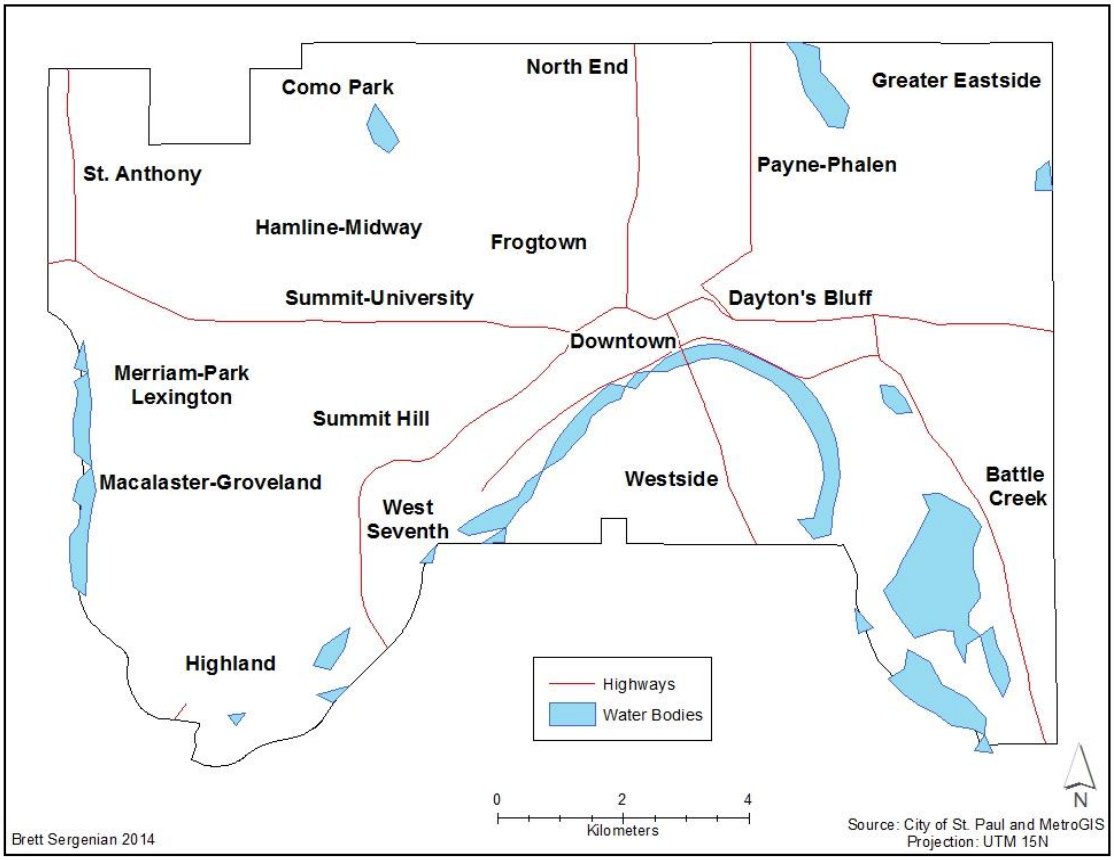


Figure 3. St. Paul neighborhood

The primary interstates in St. Paul are Interstate 94 and Interstate 35E. Interstate 94 runs east-west through central St. Paul and Interstate 35E runs north-south in central St. Paul from West St. Paul to the Roseville and Maplewood border. For non-highways, Larpenteur Road is serves as the northern border of St. Paul along the border of Roseville, and has one supermarket. McKnight Road is along the southeast border of St. Paul, along the Maplewood border. University Avenue is located just west of downtown St. Paul and north of Interstate 94, and is home to many supermarkets, mid-sized grocers, and ethnic grocers. Payne Avenue and Rice Street have numerous small grocers and Snelling Avenue has several small grocers. Several mid-sized grocers are located on St. Clair Avenue, Selby Avenue, and Randolph Avenue (Fig. 4).

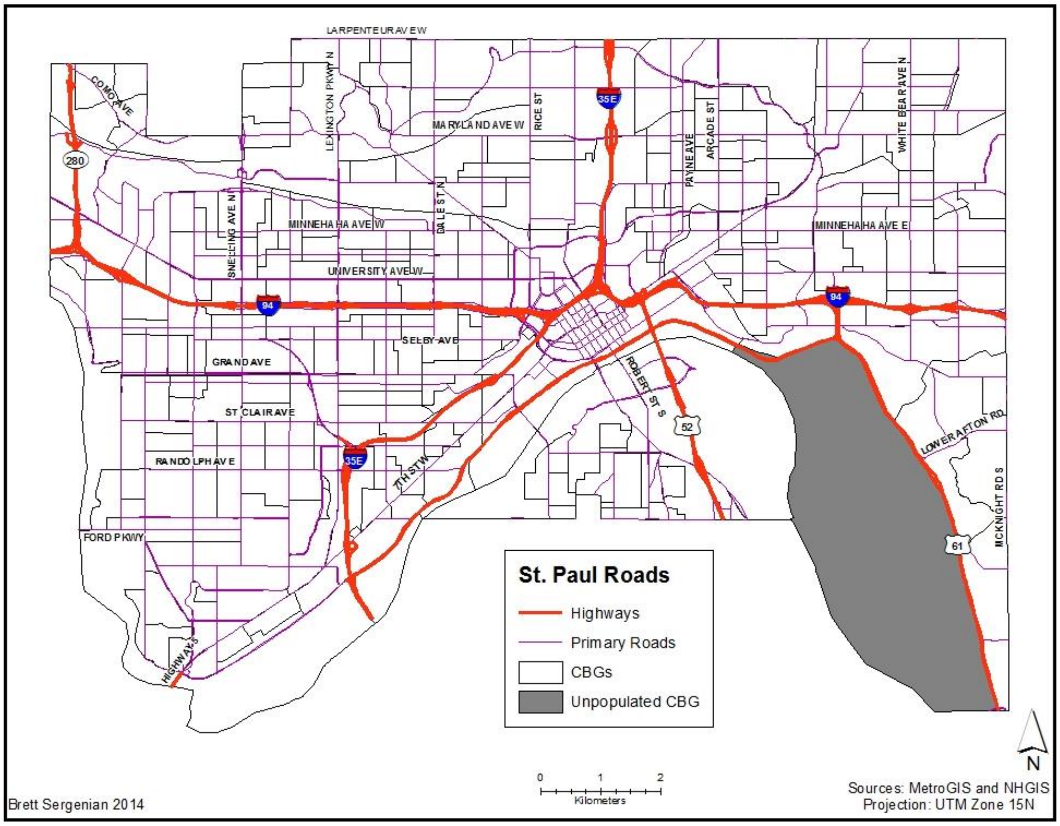


Figure 4. Primary Roads in St. Paul

3.2 Data

I gathered grocery store locations and data for the year 2012 from ReferenceUSA, an online business database that is organized by the North American Industrial Code System (NAICS) at ReferenceUSA.com. The majority of the grocery stores fell under the NAICS code 445110 (Supermarkets/Grocery Stores, excluding convenience stores) (Table 1). Since smaller ethnic grocers were included for this study, NAICS codes 445210 and 445299 representing meat markets, small food stores, and specialty food stores were accepted as small grocers. Club warehouses, e.g. (Sam's Club) fell under the NAICS code 452910 and Supercenters e.g. (Wal-Mart Supercenter) were under the department stores NAICS code 531102.

Table 1. 2012 NAICS Codes

NAICS Code	Grocery Store Type
445110	Supermarkets/Grocery Stores (excluding convenience stores)
445210	Meat Markets/Food stores
445299	All other specialty stores
452910	Club Warehouses/Supercenters
452111	Department Stores (excluding discount stores)
445230	Fruit and Vegetable Markets

Only 2012 locations were collected from the ReferenceUSA database because past data were not available. The 2001-2002 Minnesota State Business Directory provided the locations for the 2002 food outlets. Unlike ReferenceUSA, the Minnesota State Business directory did not provide NAICS codes and sales volume data. The Minnesota State Business Directory was primarily a collection of phonebooks throughout Minnesota, but did provide a range for the number of employees. ReferenceUSA included opening year information for businesses but did not include the grocery stores that existed in 2002 but no longer existed in 2012. Ideally the same data source should be used for both 2002 and 2012, but this was not possible since ReferenceUSA data are routinely updated. Other potential sources of healthy food exist in St. Paul, specifically food pantries, farmers' markets, community supported agriculture (CSAs) and urban gardens.

Farmers' markets are highly dynamic and there is no listing of 2002 markets publicly available. Several organizations and public entities were contacted to obtain past farmers' market locations, but none of the inquiries yielded a response. Since I was unable to obtain a list of the 2002 farmers' markets, they were excluded from this study.

TIGER line shapefiles and some demographic data were obtained from the U.S. Census Bureau website (www.uscensus.gov). I used the 2010 road network as the 2012 roads for the Twin Cities and the 2000 roads shapefile for the 2002 road network, because the road shapefiles for 2012 and 2002 were unavailable. Each of the road datasets were downloaded by county, including Ramsey, Dakota, Washington, Hennepin, and Anoka counties.

MetroGIS is a GIS data resource website that includes data on the seven county Twin Cities Metropolitan Area. MetroGIS also provided a current Metro Transit bus route shapefile and a shapefile of bus stops. Both of these shapefiles are available on the MetroGIS website (www.metrogis.org). Bus route data are routinely updated on a weekly basis by MetroGIS staff (MetroGIS 2013). I collected these shapefiles in early 2013. MetroGIS provided me with a December 2002 Metro Transit routes shapefile and a Microsoft Excel (Microsoft Corporation, Redmond, Washington) table of 2002 bus stops by email (MetroGIS 2013).

The boundaries of CBGs, census blocks, census tracts, and counties were obtained from NHGIS. The St. Paul city limits, suburban city limits, water bodies, parks, and counties were included as separately data layers (shapefiles) from MetroGIS. Census tracts and CBGs provide demographic data for a socioeconomic deprivation comparison. Census tracts are larger than CBGs, and the average population is 4,000, CBGs have an average population 1,500 (U.S. Census Bureau 2013). The size of both census tracts and CBGs varies based on population density. Census blocks are smaller than CBGs but they fail to provide enough data for a demographic analysis, thus they cannot be used a valid point of origin. This leaves the CBGs as the smallest unit possible to collect enough socioeconomic data to calculate an SED index.

Physical land characteristics such water boundaries and parks are useful for land cover purposes and parks can provide footpaths to stores. Originally, I attempted to incorporate bike and pedestrian trails into the walking network dataset. However, the 2002 data for bike and pedestrian trails were unavailable, resulting in the omission of bike and pedestrian trails in this analysis.

A NAIP image was downloaded as a .tiff file from the USDA website (www.usda.gov). High spatial resolution NAIP imagery with 1-meter spatial resolution is a cost-effective method to analyze land cover, and to correct geocoding errors. Unlike most other high-spatial resolution imagery, NAIP images are free. Individual stores are often visible on NAIP imagery, although ground truth data are helpful to verify a store's location and entrance. If a geocoding error occurred, it was helpful to use NAIP imagery and Google Earth to interpret the location of an unknown grocery store (Rossen, Pollack, and Curriero 2012). Several stores were not geocoded in ArcGIS. In order to include them in this analysis, I collected their UTM coordinates from Google Earth.

I imported these locations into ArcGIS 10.1 as XY coordinates and then exported into a shapefile. The shapefiles were projected into a Universe Transverse Mercator Zone 15 North (UTM 15N) projection using the Batch Projection command.

3.3 Methods

The business data downloaded from ReferenceUSA contain a field that indicates whether a business is verified. Many of the small grocery stores and ethnic food stores were unverified. Unverified locations were still included, although I examined each of those locations closely. Surprisingly, several mid-sized grocery stores and supermarkets that existed were unverified, specifically Lund's Ford Parkway and Shuang Hur Supermarket in St. Paul. This study conducted website visits, phone calls, and some site visits to verify if a store was still in its present location. For phone calls, I asked people who answered whether they were at the store name listed in ReferenceUSA and verified their address. If a food outlet location had a disconnected phone line, the location was discarded from analysis. In addition to verifying if a supermarket or grocery store was in its listed location, I examined each location for 2012 to determine if the food outlet was a grocery store or another business.

Initially, my intent was to discard convenience stores and only include grocery stores that sold produce. This was problematic as ReferenceUSA and the 2001-2002 Minnesota State Business Directory listed some convenience stores as grocery stores. Both convenience stores and grocery stores are commonly listed under the NAICS code 445110, despite the code stating that convenience stores are excluded (Morland et al. 2002). The inability to distinguish convenience stores from small grocers resulted in the inclusion of convenience stores as small grocers under code 445110. Discarding all convenience stores from 2002 was not feasible given the large number of small grocers that closed before 2012. After several site visits, some of the food outlets listed as grocery stores turned out to be convenience stores but these locations were still retained if the convenience store did not serve as a gas station.

I cross-listed food outlets with the convenience store and gas station list in the 2001-2002 Minnesota Business Directory. I discarded any food outlet that appeared as both a convenience store and a gas station. This method reduced the probability of including a gas station as a small grocer although non-gas station convenience stores were classified as small grocers.

There is no cost and time-effective method to include only stores that sell healthy food. St. Paul has numerous small ethnic grocers that sell healthy food and only including supermarkets and mid-sized grocers would underestimate healthy food options. To compensate for this problem, closest facility layers, OD cost matrices, and service area layers were calculated for all stores, mid-sized grocers and supermarkets, and for supermarkets only.

If a grocery store was listed as closed in ReferenceUSA, but closed after 2012, it was still included in the analysis. A few grocery stores closed during 2012 (e. g. Eisenberg's Produce Market) and these locations were discarded from the 2012 dataset since they were not open for the entire year.

Produce markets under 445230 are also included since their primary merchandise is healthy food; but there are relatively few of them in the study area. Some grocery store locations were assigned under other NAICS codes such as 445310 or 722511 indicating that these locations were florists and full-service restaurants. I included locations if their secondary NAICS code was 445110 or if their store name was a recognizable chain. Supermarket chains are likely to include florists and potentially house a full-service restaurant resulting in an error. Examples of these locations included Byerly's on Suburban Avenue and Kowalski's on Grand Avenue in St. Paul. I discarded food outlet locations if they did not have a recognizable name and if they were classified as a full-service restaurant (Stein 2011). Other ReferenceUSA data such as SIC codes, square footage, data on stores in the same chain, and annual sales volume were used to classify grocery stores for 2012.

In addition to convenience stores, food production companies, industrial food warehouses, and home businesses are commonly listed as grocery stores from ReferenceUSA. Some of the addresses provided were the locations of the owner or the company headquarters. Other grocery store addresses had incorrect city locations, with grocery stores in West St. Paul, Shoreview, and Andover listed as in St. Paul. Incorrect addresses were changed in Microsoft Excel or were changed during the geocoding process.

After I downloaded the data from the sources mentioned above, I categorized food establishments into supercenters, grocery stores, mid-sized grocers, small grocers, club warehouses, and fruit/vegetable markets (Table 2, Fig. 4, and Fig. 5). For example, Wal-Mart and Target Supercenters are classified under supercenters, and the listing will indicate if a food is a supercenter by the business name. There was only one supercenter in St. Paul in 2012, a Target supercenter on University Avenue. I discarded Wal-Mart, Kmart, Target, and other department stores from the dataset that are not supercenters because they primarily sell food similar to what is sold at an average convenience store (Morland et al. 2002). Most large chain grocers, such as Rainbow Foods, Cub Foods, and Byerly's, and Dick's IGA were classified as supermarkets. Dick's IGA is just south of the St. Paul city limits in West St. Paul, which can be seen in Figure 5 and Figure 6. If a grocery store had more than 50 employees it was considered a supermarket (Larson and Moseley 2012).

Table 2. Types of Grocery stores in the Study Area, 2002 and 2012

Store Type	2002	2012
Small Grocers	68	67
Mid-sized Grocers	13	16
Supermarkets	11	12
Supercenters	0	1
Club Warehouses	0	0
Produce Markets	3	1
Total	95	97

The employee range was one of the few common denominators between ReferenceUSA and the 2001-2002 Minnesota Business Directory. Food outlets were classified as mid-sized grocers if the number of employees ranged from 10 to 50. Examples of mid-sized grocers include ALDI's, Double Dragon Foods, Ha Tien Grocery Store, and Mississippi Market (ReferenceUSA 2013). Grocery stores with fewer than ten employees were listed as small grocers. Most of the non-chain grocery stores and ethnic grocers fell into this category.

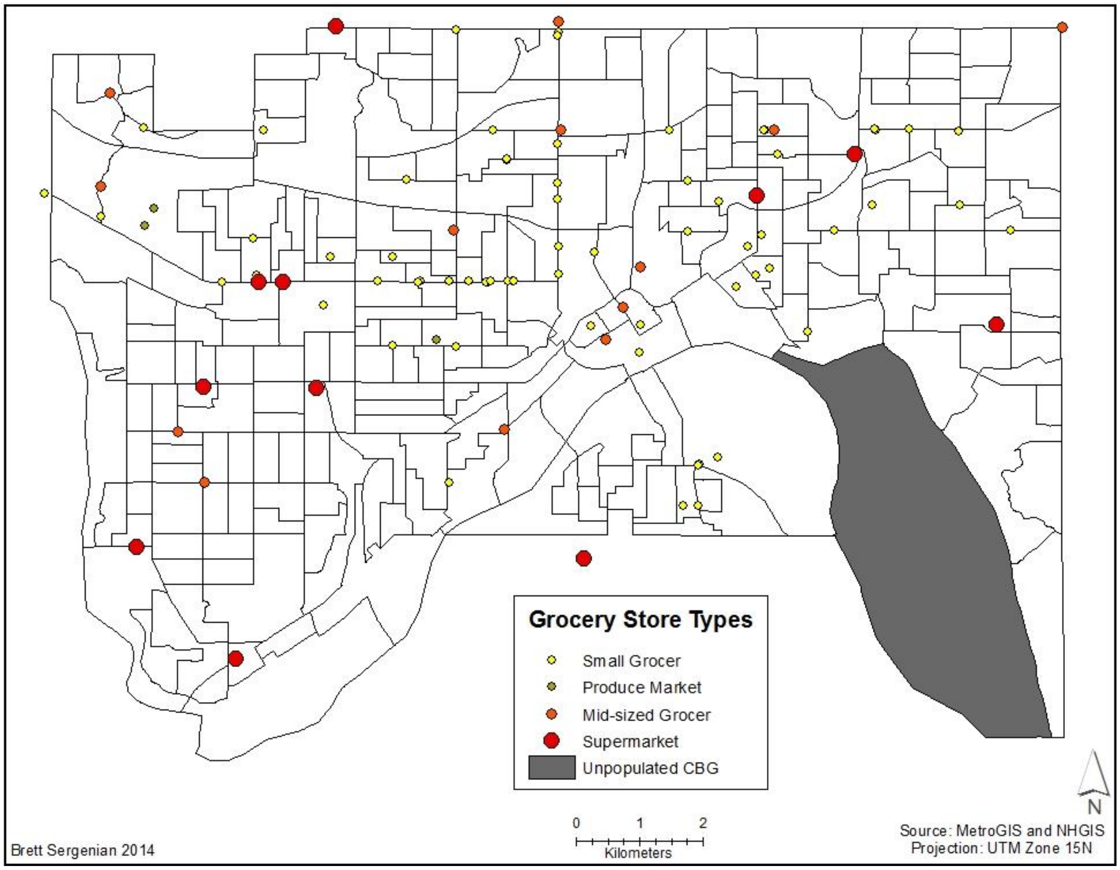


Figure 5. Grocery stores in St. Paul, 2002, by type

A grocery store includes small grocers, produce markets, mid-sized grocers, supermarkets, and supercenters. Supermarkets are defined as grocery stores with more than 50 employees. For this analysis, access to grocery stores includes supermarkets to avoid omitting a nearest grocery store.

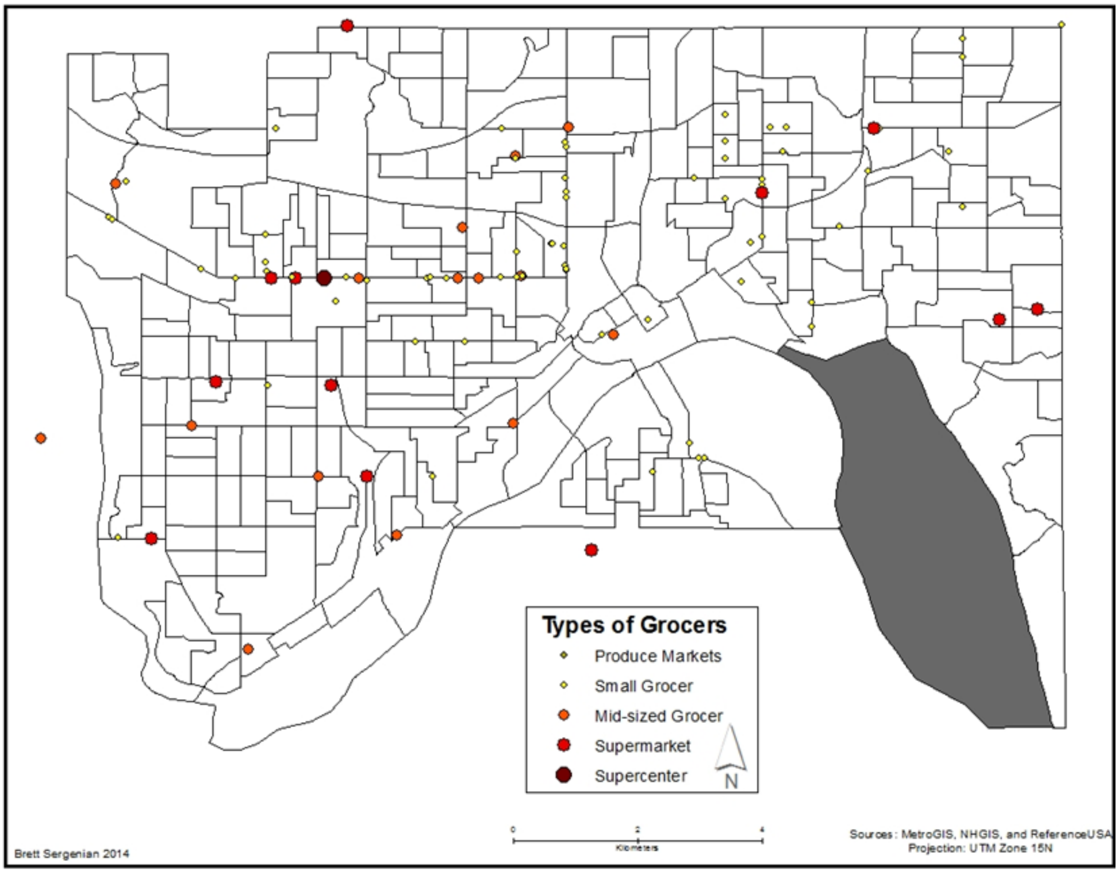


Figure 6. Grocery stores in St. Paul, 2012, by type

The food outlet locations were geocoded using the ArcGIS 10.1 U.S. Street Address locator. Geocoding at least 85% of the addresses correctly is the accepted threshold for accuracy and geocoding score standards state that locations should have no scores below 80 (Chang 2012). All of the geocoded locations had scores above 85. After the geocoding results for 2002 and 2012 were loaded into ArcGIS, I projected each layer into UTM Zone 15 North. After geocoding the grocery store locations in ArcGIS 10.1, I added X, Y data from Google Earth to obtain UTM coordinates. This method was useful for georeferencing several locations that I could not geocode in the first place. Most of these locations were on the fringes of the study area (e.g. Eagan and Fridley), despite being within the road network.

I used network distance to calculate both walking distance and for public transit. Network distance uses roads to measure distance and is more realistic than Euclidean distance that measures straight-line distance (Goldsberry et al. 2010).

Larsen and Gilliland (2008) used 1,000-meter thresholds for walking and a seven-minute bus ride or a 3-kilometer bus ride as a threshold for public transit. Other studies have used a 500-meter threshold for walking distance or 1.6 kilometers (1 mile) (Eckert and Shetty 2011; Lu et al. 2012). The optimal method for setting a threshold is to survey St. Paul residents asking how far are they willing to walk to the grocery store and to take a bus to a grocery or supermarket. I used a 1,000-meter threshold for walking distance because it is one of the most commonly used thresholds in food access literature (Smoyer-Tomic, Spence, and Amrhein 2006; Larsen and Gilliland 2008). The 3-kilometer threshold for public transit was selected from Larsen and Gilliland (2008) and the 5-kilometer threshold was a secondary measure of accessibility (Table 3).

Table 3. Food desert thresholds for walking and public transit

Food Accessibility Thresholds
a. Walking to the nearest grocery store or supermarket – 1,000 meters
b. Public transit to the nearest grocery store – 3,000 and 5,000 meters
c. Public transit to the nearest supermarket – 3,000 and 5,000 meters

Since Shannon (2013) found that low-income residents were more mobile than previously thought in the Twin Cities, the 5-kilometer threshold was selected. For grocery store access by public transit, distances less than 3,000 meters is considered good access and anything over 3,000 meters is considered poor access. Since there are far fewer supermarkets, 3,000 meters is considered good access and 5,000 meters is considered adequate public transit access, with above 5,000 meters indicating poor access. My study identifies CBGs that may not have access to healthy food by walking but have access by public transit (Table 4) (Shaw 2006; Hallett and McDermott 2010).

The U.S. Census Bureau provided a list of latitude and longitude coordinates for population weighted centroid for each CBG in the U.S. A population weighted centroid accounts for the population distribution throughout each CBG by weighting the population for each census block to generate the mean center of population. The coordinates for each population weighted CBG centroid were already recorded in Microsoft Excel and then I added them to ArcGIS 10.1 as XY data. After bringing in each population weighted CBG centroid, I used the convert coordinate notation tool to convert the latitude/longitude coordinates into UTM coordinates. Geographic CBG centroid locations are inaccurate proxies for residences because numerous centroids were in parks, outside of residential areas, or within water bodies. CBGs provide a coarse resolution for this analysis, but they are the finest resolution units available with sufficient socioeconomic data.

Table 4. Types of Food Deserts by walking and public transit

a. More than 1,000 meters by walking distance to the nearest grocery store and under 3,000 meters by public transit distance to the nearest grocery store
b. More than 1,000 meters by walking distance to the nearest grocery store and under 5,000 meters by public transit distance to the nearest grocery store
c. More than 1,000 meters by walking distance to the nearest grocery store and over 5,000 meters by public transit distance to the nearest grocery store
d. More than 1,000 meters by walking distance to the nearest supermarket and under 3,000 meters by public transit to the nearest supermarket
e. More than 1,000 meters by walking distance to the nearest supermarket and under 5,000 meters by public transit to the nearest supermarket
f. More than 1,000 meters by walking distance to a supermarket and over 5,000 meters by public transit to the nearest supermarket

Other studies have used randomly generated locations to obtain more precise measurements of healthy food access (Widener, Metcalf, and Bar-Yam 2013). One shortcoming of using population centroids is that they may be situated in between two housing developments or residential areas on each end of a CBG (Maantay, Maroko, and Hermann 2007). This compensates for the dispersed population but also provides inaccurate distance measurements. Other studies use areal interpolation to omit uninhabited areas such as parks and industrial areas (Maantay, Maroko, and Hermann 2007; Shannon 2013). Another commonly used method is calculating the percentage of each CBG area that is covered by a service area (Sharkey et al. 2009; Stein 2011). One of the downsides of this method is if a service area is covering a water body, park, or a non-residential area, then it does not accurately represent where potential customers live.

For the 2002 analysis, I built a network dataset from the 2000 roads shapefile in ArcGIS. A total of four network datasets were created in ArcGIS to measure both walking and public transit accessibility in 2002 and 2012. These network datasets were: (1) Walking network dataset created from the 2000 TIGER line shapefile to calculate walking distances in 2002. (2) The walking network dataset created from the 2010 TIGER line shapefile to represent the 2012 walking distances. (3) The public transit network dataset created from the December 2002 bus routes to measure public transit distance in 2002. (4) The public transit network dataset created from the March 2013 bus routes to represent public transit distances in 2012.

Then I calculated a closest facility layer to measure walking distances from each CBG centroid to the nearest grocery store and supermarket. I repeated the same process for the 2012 analysis. Since there are no sidewalks along interstates, I deleted all of the interstates, entry ramps, and exit ramps from the 2000 and 2010 road shapefiles (Stein 2011). All of the distances were measured exclusively along road networks, excluding distances from each CBG centroid to the nearest road and from grocery store entrances to the nearest road. If my study was calculating distances from each parcel centroid, then the distance from the centroid to the nearest road would be applicable.

For all of the choropleth maps of food access in St. Paul, the natural breaks method was used to visualize the differences between distances traveled to the nearest grocery store and supermarkets (Chang 2012). The objective of the natural breaks method is to highlight the differences between classes, which makes it easier to identify

CBGs whose population travels longer distances to the nearest grocery store or supermarket.

For walking, CBG centroids are the origin and the grocery store is the endpoint. For public transit, the origin is the CBG centroid and the distance is calculated from the between the CBG centroid to the nearest bus stop along the walking network dataset. The bus route is the second distance calculation, and is calculated along the public transit network dataset. The final step calculated the distance walking from the bus stop nearest to the grocery store or supermarket to the grocery store or supermarket. All three distances were summed to obtain the total public transit distances to the nearest grocery store or supermarket in 2002 and 2012. These three steps are highlighted in Table 5. Using the distances from each CBG centroid to the nearest bus stop was more realistic than the distance to the nearest bus route.

Bus stops are considered the facilities and the CBG centroids are input as the incidents. Incidents are on the opposite end of a route from facilities and often serve as origins. The walking network dataset is used because it is the primary mode of transportation to and from bus stops. A walking network dataset is comprised of all roads in the Twin Cities with the exception of interstates, to include all walkable streets. For the second closest facility layer, the bus stops nearest to each grocery store are input as the facilities and the bus stop nearest to each CBG centroid constitute the incident layer.

Table 5. Measuring public transit distance

a. Walking distance between each CBG centroid and the nearest bus stop
b. Distance between the nearest bus stop to each CBG centroid and the nearest bus stop to each grocery store or supermarket (distance traveled by bus)
c. Walking distance between each grocery store and the nearest bus stop
d. The sum of these distance measurements constitutes public transit access

Using the nearest bus stop to each CBG centroid does not necessarily represent the shortest route to the nearest grocery store. Several CBG centroids were originally routed to the nearest bus stop resulting in several bus routes being significantly longer than if the second or third closest bus stop was used.

My study calculated closest facility layers instead of an Origin-Destinations (OD) cost matrix for data quality purposes. A closest facility layer draws lines along each route and an OD cost matrix uses straight lines to display network distances. An OD cost matrix is used for studies that are primarily interested in the attribute tables, not the locations of the routes themselves (Chang 2012). For public transit, I selected closest facility over an OD cost matrix to verify that each CBG centroid and grocery store is routed to the nearest bus stop. TIGER line shapefiles may contain topological errors, which result in errors for the distance calculations. A closest facility layer shows the highlighted route along a road network, making it easier to identify errors if a route appears longer than it should be because of a gap in the network dataset.

If the closest facility layer looked abnormal or provided a larger distance value than expected, then I conducted a data quality check. When the network was built using the 2000 and 2010 TIGER line shapefiles, there were several errors including undershoots causing some of the walking and public transit distances to be overestimated. These errors were corrected by manually editing the roads in the network dataset. I used a 2012 NAIP image and Google Maps as reference maps to verify road locations.

Invalid bus stop locations included bus stops that are not located along the bus route. If an OD cost-matrix is used to analyze route distances, it would be more difficult to detect route errors. For both 2002 and 2012, there were numerous bus stop locations that were not on any bus routes. If a bus stop was not located along a bus route, then it was deemed an inactive bus stop and deleted. Inactive bus stops may have not been deleted by MetroGIS because of human error or a lag in updating.

According to MetroGIS, the acceptable walking distance to the nearest bus stop is 0.4 km (0.25) miles for the Twin Cities (Walking access to bus stops, communications via email, Podany 2013). Larsen and Gilliland (2008) applied a 500-meter buffer to the 2005 bus routes in London. Other studies have used distances of 400 meters or 500 meters as the threshold for walking to a bus stop (Larsen and Gilliland 2008; Biba et al. 2010). For this study, I selected a conservative distance of 500 meters (approximately 0.31 miles).

Public transit distances were calculated by adding a new field called "road_length" in the attribute table of the public transit network dataset. To obtain distances for each segment in meters, the calculate geometry function was used during an editing session. The road_length field is used as an evaluator within Network Analyst to determine distances in meters instead of shape_length or shape, the default option. The same process is repeated to calculate the distances in meters for the bus routes.

To address the edge effect, I included grocery stores from surrounding cities. State, city, county, and other political boundaries are not considered by a shopper when deciding where to shop for groceries (Sadler, Gilliland, and Arku 2011). St. Paul borders Minneapolis, Maplewood, and Roseville, MN, and all of these cities have major grocery stores. Rainbow Foods on Larpenteur Avenue in Roseville, is right on the border between Roseville and St. Paul. If grocery stores outside St. Paul or Ramsey County were not included, grocery stores accessible to the study area would be excluded (Sadler, Gilliland, and Arku 2011). The vast majority of the CBG centroids that were routed to all grocery stores were primarily within the St. Paul city limits, with several exceptions, including Roseville, Maplewood, Woodbury, Minneapolis, and West St. Paul.

After I ran the network analysis to calculate distances to the nearest grocery store or supermarket by public transit and walking, I identified the CBGs that are potential food deserts based on the walking and public transit thresholds. There will be several categories of food deserts, which are identified in Table 4. To identify a potential food desert, a CBG must be in the fifth quintile of SED for all of these criteria. Some of the CBG centroids will fall within the public transit threshold of 3 or 5 kilometers, but not within the 1,000-meter threshold. The criteria for public transit to the nearest grocery store (all grocers) are that a CBG centroid needs to be within 3,000 meters of a grocery store by public transit distance and in the fifth quintile.

Physical features such as land cover can be potential barriers for walking. Rivers, steep topography, busy highways, and dense vegetation cover can impede or prevent efficient accessibility to a grocery store (Shaw 2006). Steep topography can be particularly problematic for the elderly, who may have limited mobility. Walking 1-km on relatively flat terrain and walking 1-km along steep topography have the same absolute distance, but not the same relative distance and time. Previous studies have not used slope and climate as impedances on Network Analyst or a cost raster analysis. Traveling uphill on the way back from a grocery store could considerably take more time. The steepest areas in St. Paul are in the CBGs along the Mississippi River bluffs (Fig. 7). For public transit, steep slopes are not an issue, except in inclement weather (Mavoa et al. 2012. I calculated a SED index to compare the status of different CBGs in St. Paul. Previous studies have included a number of variables for a neighborhood deprivation index or a social vulnerability index (Cutter, Boruff, and Shirley 2003; Pearce et al. 2007)

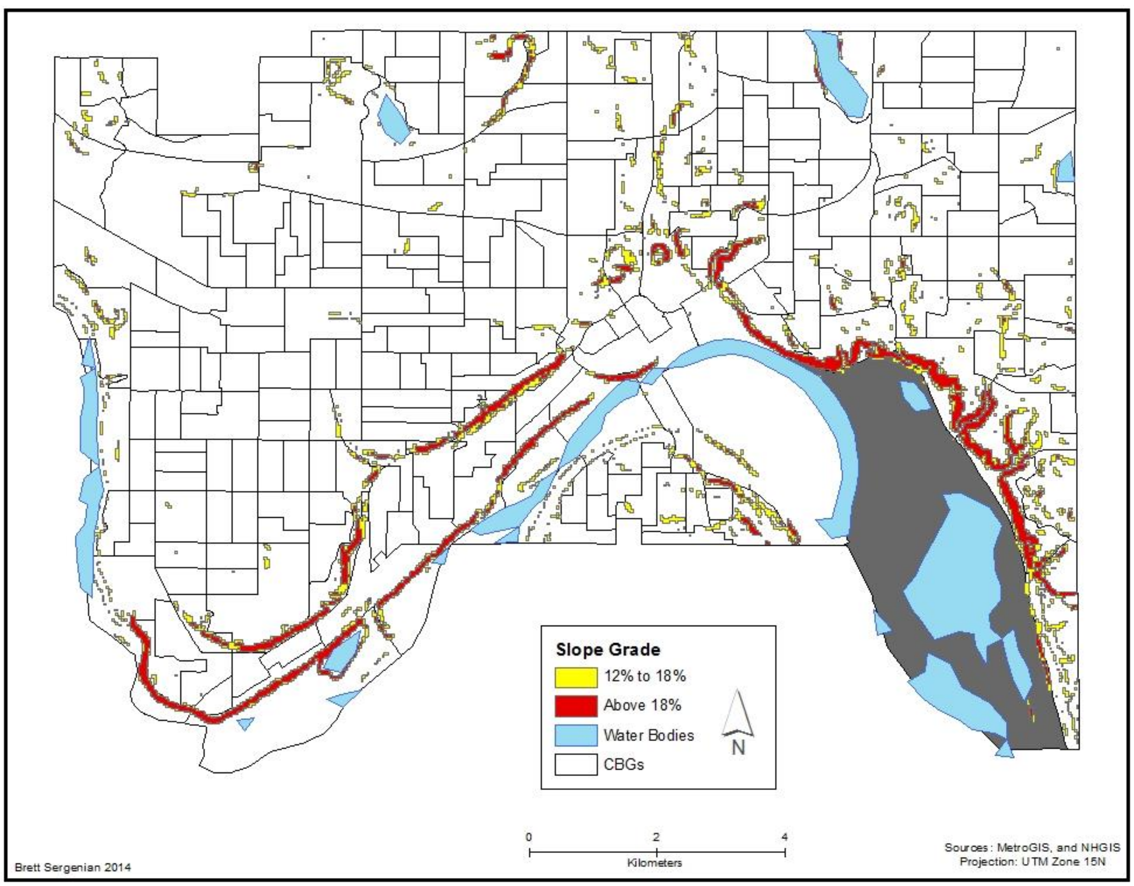


Figure 7. Steep slope areas in St. Paul

The factors included in the SED index here for this study were median household income, median home value, the number of people below the poverty line, education attainment, minority population, public assistance, lone parenthood, and population without a vehicle (Cutter, Mitchell, and Scott 1998; Apparicio, Cloutier, and Shearmur 2007). Several of these variables were included in the social vulnerability index and are used by the USDA (Cutter, Mitchell, and Scott 1998; USDA 2013). The calculations and formulas are the same as the Cutter, Mitchell, and Scott (1998) methods for calculating a social vulnerability index by county.

The SED index was calculated by dividing the population of each variable within each block group, (X) (e.g. number of people with an educational attainment less than a high school diploma) by the entire city population without a high school diploma above the age of 25 or Y (Cutter, Mitchell and Scott 1998). To obtain Y, all of the x values from each CBG are summed. Then the population without a high school diploma in each CBG is divided by the city population (or sum of all the CBGs) to obtain Z (Cutter, Mitchell, and Scott 1998). Then the maximum Z (Zmax) is determined by using the descriptive statistics tool in Microsoft Excel. Each Z-value is divided by Zmax to obtain the SED score (Cutter, Mitchell, and Scott 1998). This value results in a ratio and the greater the ratio, the higher the neighborhood deprivation (Cutter, Mitchell, and Scott 1998). The most socioeconomically deprived CBG for each variable (e.g. public assistance) will have a score of one, while the least socioeconomically deprived CBG will have a value of zero or near zero, depending on the variable (Cutter, Mitchell, and Scott 1998). After calculating the individual SED scores for each variable, the nine indices for each variable are summed to obtain the total SED value.

Median household income and median home values are calculated differently from the other variables because these variables cannot be quantified at the CBG level as an absolute number (Cutter, Mitchell, and Scott 1998). First, the median home value of each block group is subtracted from the median home value of St. Paul to obtain X (Cutter, Mitchell, and Scott 1998; Stein 2011).

X = Median home value (St. Paul) – Median home value (each CBG)

CBGs with lower median values have positive values and any CBG with median home values above the median home value of St. Paul has negative values. Then the absolute value of the maximum difference is added to X to eliminate the remaining negative values, which results in (Y).

Y = |X furthest from 0| to X

The Y value from each CBG is divided by maximum Y (Ymax) to determine the SED index value (Cutter, Mitchell, and Scott 1998; Stein 2011). The Ymax is the most deprived CBG value for either the lowest median home value or median income value (Cutter, Mitchell, and Scott 1998). Similar to the population variables, the SED index values for median household income and median home values range from zero to one (Cutter, Mitchell, and Scott 1998; Stein 2011).

Other food desert studies have used variations of the social vulnerability index as a proxy for neighborhood deprivation. Stein (2011) used a SED index with the proportion of single parent households in each CBG compared to all families in the CBG, proportion of those unemployed, proportion of recent immigrants, median household income, and the proportion of the population over 20 with less than a ninth grade education. In my study proportion of immigrants is replaced with proportion of minorities; and the educational attainment was less than a high school diploma. An example is dividing the median household income of a CBG by the median household income for the city.

Median household income, number of people below the poverty line, lone parenthood, minority population, and educational attainment were included in Cutter, Mitchell, and Scott (1998). The USDA included vehicle ownership and group quarters for the Food Desert Locator and Food Environment Research Atlas, but did not calculate a SED index. The USDA noted that population in group quarters may not access food from grocery stores, particularly colleges, prisons, and military bases (USDA 2013). Public assistance was included in other studies, specifically in Pearce et al. (2007).

To classify the SED score for each CBG, the CBGs were divided into quintiles, a commonly used classification technique used by other studies (Apparicio, Cloutier, and Shearmur 2007; Pearce et al. 2007; Stein 2010). Pearce et al. (2007) divided meshblocks into deciles for their analysis of fast-food access in New Zealand. Deciles are similar to quintiles, but divided into ten classes instead of five. Messer et al. (2012) used a similar methodology to Pearce et al. (2007).

For statistical analysis, a paired t-test was conducted to compare the differences between the following four variables: Walking distance to the nearest grocery store in 2002 and 2012, public transit distance to the nearest grocery store in 2002 and 2012, walking distance to the nearest supermarket in 2002 to 2012, and public transit distance to the nearest supermarket in 2002 and 2012. Some CBG boundaries and identification numbers have changed between 2000 and 2010, leaving approximately 40 CBGs unpaired. These CBGs were excluded from the independent t-test analysis. The number of CBGs in St. Paul in 2000 was 258 and the total number of CBGs in 2010 was 250. As mentioned earlier, one CBG had no population which left 257 and 249 CBGs to be analyzed in 2002 and 2012, respectively.

A localized statistical test such as the Gi* statistic is useful for identifying hotspots and cold spots of a specific attribute while including the target feature. The Gi* statistic tests if the CBGs are next to other CBGs with similar values. For walking distance to the nearest grocery store, a cold spot shows clustering of low-distances next to other CBGs with low-distances, displaying areas of relatively good access to the nearest grocery store (Mitchell 2005). Hotspots are CBGs that have statistically significant z-scores displaying long distances traveled to the nearest grocery store or supermarket next to other CBGs where populations travel long distances. The Gi* statistic, developed by Getis and Ord (1992) is calculated by

$$\mathrm{GI} * (d) = \sum W_{ij}(\mathrm{d})\, X_j / \sum_j X_j.$$

where W is the weight, d is the distance between neighboring block groups, X is the value for the distance traveled to the nearest grocery store or supermarket, and i and j are two neighboring block groups.

The expected value for the Gi* equation is calculated by

$$E(Gi^*) = \frac{\sum W_{ij}\ (d)}{n-1}$$

and the z-score for the Gi* is calculated by the following equation:

$$Z(Gi^*) = Gi * -E(Gi^*)/\sqrt{Var(Gi^*)}$$

where Z(Gi*) is the z-score, E(Gi*) is the expected Gi* statistic, and this value is divided by the standard variance to obtain the z-score. For the 95% confidence interval, the z-score value below -1.96 indicates a cold spot and above 1.96 a hotspot (Getis and Ord 1992).

To calculate the Gi-statistic (local Getis-Ord), used a first order queen contiguity matrix, which includes all diagonal and corner bordering CBGs. Any CBG that shares a border with the target CBG is assigned a weight of one and non-bordering CBGs are assigned a weight of zero (Anselin 1995). Unlike the rook contiguity method, the first order queen contiguity matrix includes adjacent features along the corners of the target CBG (Anselin 2003). For analyzing CBGs, a CBG bordering the corner of the targeted CBG may have significant influence on the targeted CBG, particularly if a major road is running diagonally through two CBGs. I calculated the Gi* statistic for both the 2002 and the 2012 data. The primary limitation of the Gi* statistic is that it only displays the CBGs with low accessibility to grocery stores and supermarkets, so it cannot distinguish between highly deprived and less-deprived CBGs (Getis and Ord 1992). A separate analysis is needed to identify hotspots and cold spots for socioeconomic deprivation since the Gi* only uses on variable. The Gi* statistic is useful to visualize distances traveled to the nearest grocery store or supermarket within neighborhoods of St. Paul. To identify which of the hotspots displayed on the Gi* maps are potentially food deserts, a bivariate Local Moran's I is calculated to visualize the relationships of socioeconomic deprivation and accessibility to grocery stores and supermarkets (Anselin 1996).

The results of the bivariate Anselin's Local Moran's I or bivariate Local Indicators of Spatial Association (LISA) test if walking distances to all grocers showed any clustering of high-high relationships, low-low relationships, high-low, or low-high relationships among CBGs in St. Paul (Anselin 1995). Another advantage of the bivariate LISA is that is provides an unbiased result when analyzing SED index values and distance to the nearest supermarket (Anselin 2003). The bivariate LISA visualizes the results of the bivariate Local Moran's I statistic to identify neighborhoods of positive and negative associations (Anselin 1995). Positive associations are indicated by the low-low and high-high classifications (e.g. high SED values associated with long distances traveled to the nearest supermarket). Both of these values would be indicated by positive values, with values closer to one indicating a stronger positive correlation. Negative associations are indicated by low-high or high-low LISA classes. Values closer to negative one indicate For the LISA test to be statistically significant, the high clusters must have a z-score above 1.96 and low clusters below -1.96 (Anselin 1996; Mitchell 2005). The bivariate LISA statistic is calculated by the following equation (Anselin 1995):

$$Z_{xi} \sum_{j=1\ j\neq i}^{N} W_{ij} Z_{yj}$$

where x is the SED index value and y is the distance to the nearest grocery store or supermarket by public transit, Z_{xi} is the standardized scores of x and y (Anselin 1995; Stein 2011). W_{ij} is the spatial weights matrix that provided spatial structure to the CBGs (Stein 2011). Variables i and j represent two different block groups. For the neighboring CBGs that are adjacent to the target CBG, a weight of one is assigned, for all other CBGs, a weight of zero is assigned (Anselin 1995). Previous studies typically use the shortest distance at which every CBG has a neighbor. For the bivariate LISA analysis, I also used a first order queen contiguity matrix, the same technique was used for the Gi* statistic.

For randomization, I selected the 999 permutations option to further test the significance of the bivariate LISA (Anselin 2003). These permutations generate pseudo-values throughout the study area and are compared to the observed values. The equation to test the statistical significance is

$$(M+1)/(R+1)$$

where M is the number of times a permuted value is equal than or greater to the observed I value if positive or less than or equal to the observed value if the observed I is negative. The permutations provide a pseudo dataset of randomly generated I values, and these pseudo I values are compared to the observed I value to determine the statistical association (Anselin 2003). If the surrounding CBGs are less deprived than the target CBG, the target CBG was classified as high-high and the surrounding CBGs as low-high if their significance exceeded the 0.05 p-value-threshold. R represents the number of permutations, which in this case totaled 999.

These permutations provide additional validation of the statistical significance of the bivariate LISA statistical relationships (Anselin 1995). Each block group fell into five types of LISA classes: not significant, low-low, low-high, high-low, and high-high (Anselin 2003; Stein 2011) (Table 6). My study used a 95% confidence interval and a p-value of less than 0.05 denotes statistical significance.

Table 6. Bivariate LISA Relationships

No Significance (NS)	The values of the SED index were not associated with accessibility to the nearest grocery store or supermarket
Low-Low (LL)	CBGs that have low SED values that have good access to a grocery store or supermarket
Low-High (LH)	CBGs that have low SED values and have poor access to a grocery store or supermarket
High-Low (HL)	CBGs that have high SED values and have good access to grocery stores or supermarkets
High-High (HH)	CBGs that have high SED values and have poor access to grocery stores or supermarkets (food deserts)

Once the bivariate LISA classes are determined for accessibility to grocery stores and supermarkets in 2002 and 2012, the HH associations were weighted and summed. For walking distance, each CBG with a HH association was assigned a weight of one. These weights were applied for both walking distance to the nearest grocery store and to the nearest supermarket. For public transit, HH associations were assigned a weight of two since the mean distance is longer, particularly for supermarkets. For the CBGs that have populations travel long distances by walking and public transit to the nearest grocery store, accessing healthy food can be particularly difficult, which is why the HH associations for public transit distance are weighted at two. When the bivariate LISA sums were mapped, it provided a composite overview of underserved CBGs by both walking and public transit distance to the nearest grocery store or supermarket. CBGs with the highest bivariate LISA sums would be the areas that planners should focus on to ameliorate the impacts of food deserts.

CHAPTER IV

RESULTS

The results showed that the changes in distances traveled to the nearest grocery store and supermarket did not change significantly among the comparable CBGs. Mean distances to the nearest grocery store by walking and public transit increased slightly in 2012, while distances to supermarkets by walking stayed nearly the same. When comparing accessibility to all grocery stores, the two most deprived quintiles had the best access in 2002. In 2012, the most deprived quintiles traveled farther to the nearest grocery store and supermarket in 2012. For supermarket access, the least deprived CBGs and lower two quintiles traveled the shortest distances by walking and public transit to the nearest supermarket. Nearly all CBGs were within 3,000 meters of any grocery store for 2002 and 2012 by public transit, and all but two CBGs were within 5,000 meters of a supermarket by public transit for 2002 and 2012. Approximately 60% of the grocery stores that existed in 2002 had closed or relocated by 2012, but the number of grocery stores still increased slightly from 95 to 97.

4.1 SED Index Results

None of the variables in the SED index were weighted, and few other studies had applied weights to their analyses (Apparicio, Cloutier, and Shearmur 2007; Pearce et al. 2007; Stein 2011). The lowest potential minimum value of the SED index is zero and the maximum deprivation is nine. As expected, none of the CBGs had values of zero or nine.

The minimum SED index value for 2002 was 0.44 in tract 362 group 5 in southwestern St. Paul. The maximum SED value was CBG 305 group 1 at 7.61 in north-central St. Paul in 2002 (refer to Appendix B to reference individual CBGs). For 2012, the lowest SED score was 0.25 in CBG 375 group 1 in southwestern St. Paul and the highest SED score was 7.19 in CBG 306 group 1 group in north-central St. Paul, immediately to east of I-35 E.

Quintile one represents the CBGs with the lowest scores and the least deprived CBGs. The 2002 quintile range and the 2012 quintile range varied slightly, with the greatest range occurring in 2002 (Table 7). Quintile range for the quintiles one and five are lower in 2012 than 2002 but quintiles three and four are higher in 2012. Quintile two remained the same at 1.96 for both years.

Table 7. SED quintiles for 2002 and 2012

SED Quintiles	2002	2012
1	1.53	1.46
2	1.96	1.96
3	2.39	2.46
4	3.06	3.34
5	7.61	7.19

The spatial distribution of the SED values across St. Paul showed some clustering of low SED values in southwestern St. Paul, but CBGs in quintile five were dispersed in 2012. Quintiles four and five combined were clustered in CBGs north of downtown St. Paul, with some a few CBGS along the Mississippi River in southwest St. Paul in the fifth quintile in 2002 and the fourth quintile in 2012. Overall, the SED index values does not appear to change dramatically from 2002 to 2012 as most of the SED index values that changed quintiles, shifted by only one quintile. Examples of shifts in quintiles are an

SED index value dropping resulting in CBG changing from the fifth quintile to the fourth quintile. North-central St. Paul shifted to the fourth and fifth SED quintiles and several CBGS in northeastern St. Paul saw a similar pattern. Neighborhoods with high socioeconomic deprivation included Frogtown, the north end, Payne-Phalen, parts of the Westside, and parts of the Battle Creek neighborhood, particularly in 2012. Low SED values are concentrated near the Summit Hill neighborhood, Macalaster-Groveland, parts of the Highland neighborhood, and the Como Park area (Figs.8 and 9).

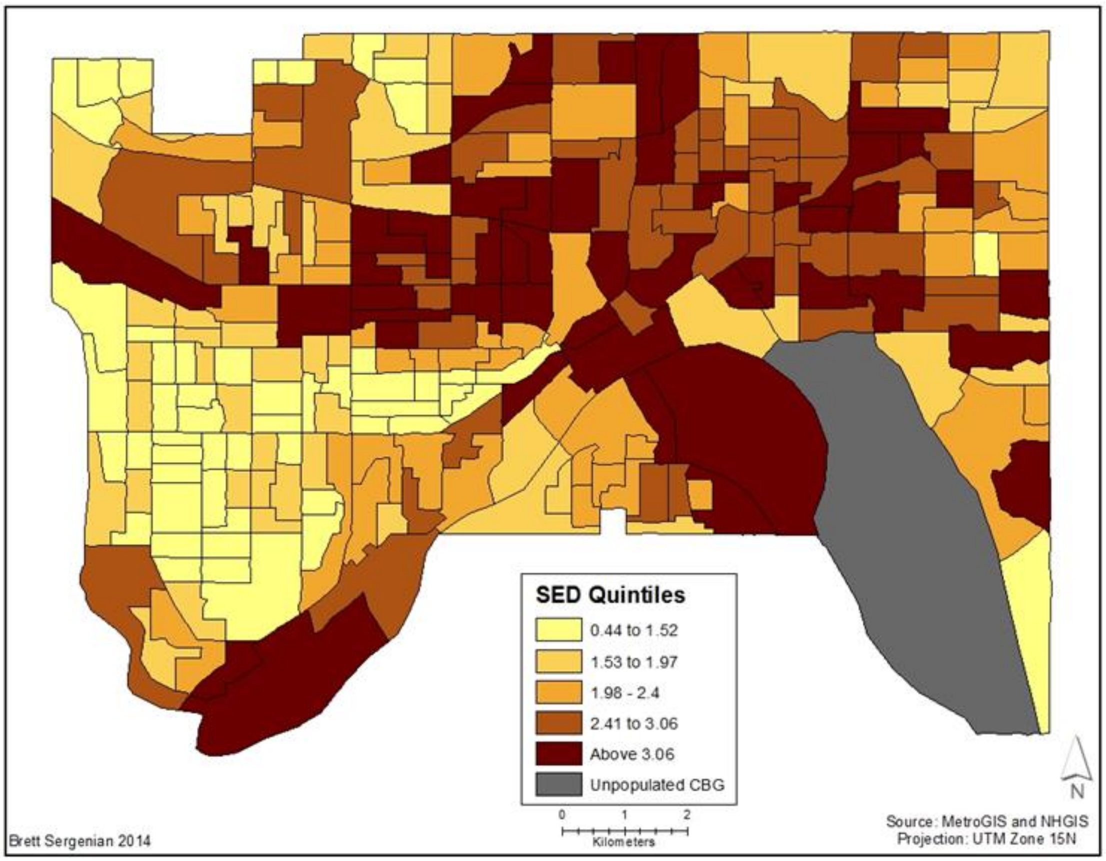


Figure 8. SED Index, 2002

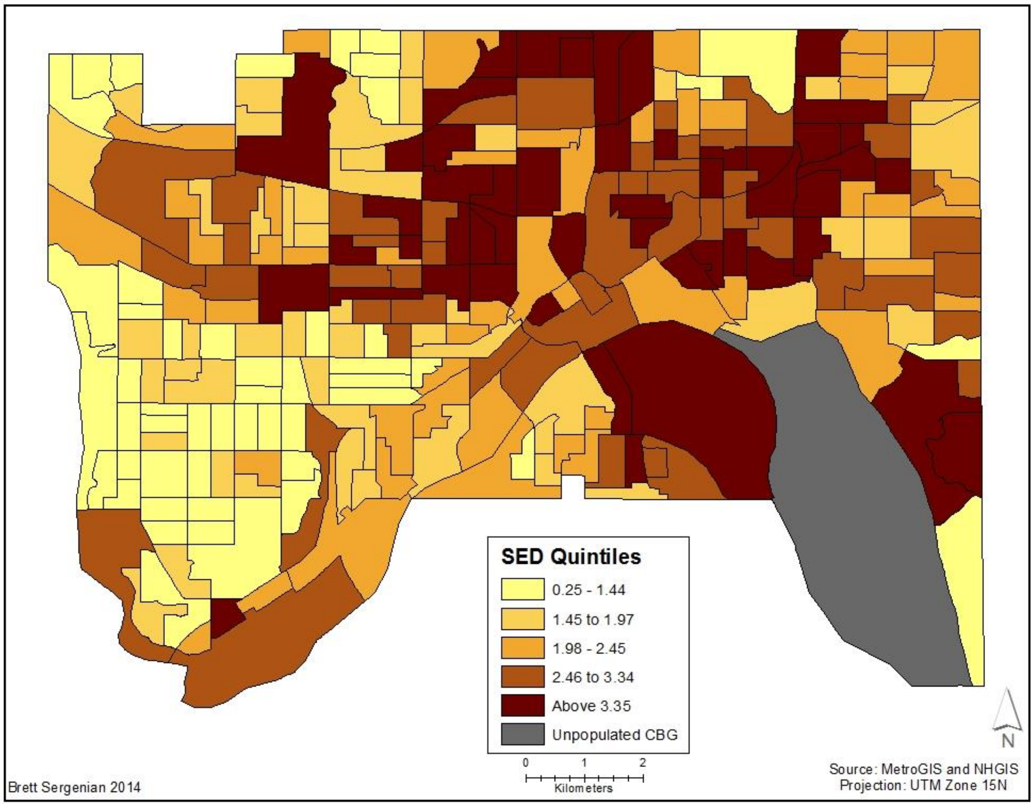


Figure 9. SED Index, 2012

4.2 Accessibility to grocery stores and supermarkets by walking distance

The mean walking distance to the nearest grocery store in 2002 was 826 meters and the mean distance for 2012 was 880 meters. The number of grocery stores in St. Paul and the surrounding suburbs did not change significantly despite the high turnover rate among small grocery stores. It is likely that most of the grocery stores that closed were replaced by other grocery stores either in the same or a nearby location. Within the St. Paul area, there were 95 grocery stores in 2002 and a total of 423 grocery stores when including all of the grocery stores in the surrounding cities. One of the grocery store chains, Tom Thumb Food Markets, closed all of their stores in the Twin Cities by 2012 (ReferenceUSA 2013). Most of the Supervalue supermarkets and all of the Jubilee Foods grocery stores had closed by 2012. One explanation for the mean increase in distance, is that the CBGs near Rice Street had several small grocers in the area that closed by 2012 and most of the small grocers in the St. Anthony neighborhood that were open in 2002, had closed by 2012.

Walking distance to the nearest supermarket in each quintile for 2002 and 2012 were compared in Figures 10 and 11. One key limitation of comparing quintiles is that not all CBGs were in the same quintile for both years. The two most socioeconomically deprived quintiles had higher access to all grocers by walking distance in 2002 than the least socioeconomically deprived CBGs (Fig.10).

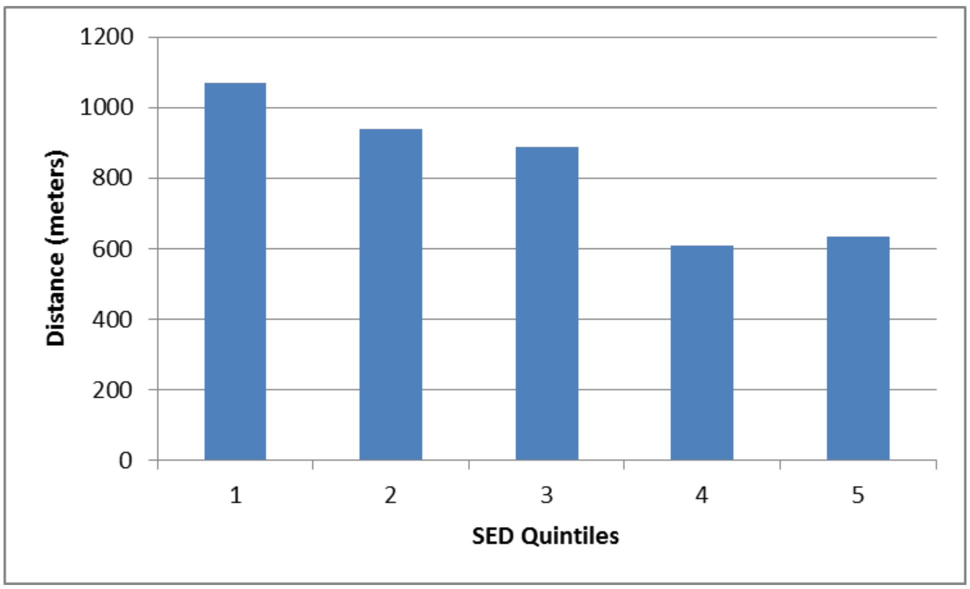


Figure 10. Mean walking distance to grocery stores by SED quintiles, 2002

Quintile four, with moderately high deprivation, had the best access, with a mean walking distance of 626 meters in 2002 and the best access to all grocers in 2012 with a mean of 617 meters. The fifth quintile had the second best access to all grocers in 2002 at 634 meters and dropped to the third highest access in 2012 at 825 meters (Fig. 11). Conversely, the least-deprived CBGs, quintiles one and two, had the lowest accessibility by walking distance to all grocers with a mean distance of 1,093 meters in 2002 (Table 8) and 1,195 meters in 2012 (Table 9). Quintile three, moderately deprived CBGS, had the third best access of all quintiles in 2002 and had the second-best access in 2012, surpassing quintile five. In 2012, the most deprived quintile, quintile five traveled a mean distance of 209 more meters to the nearest grocery store by walking distance than the fourth quintile.

Many of the smaller grocers along Rice Street and University Avenue are ethnic grocers and there are several convenience stores. Most of the CBGs surrounding University Avenue and Rice Street are in the fourth or fifth quintiles.

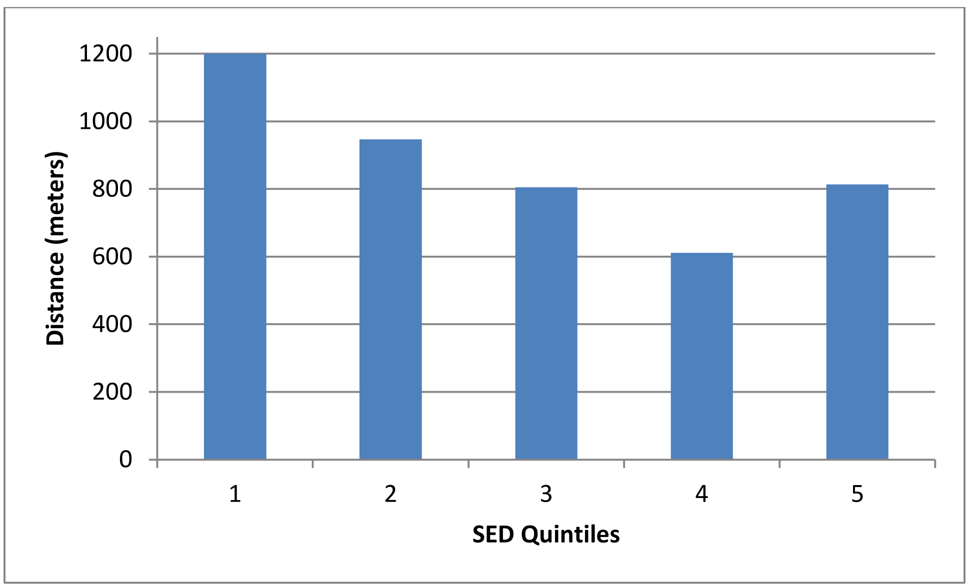


Figure 11. Mean walking distance to grocery stores by SED quintiles, 2012

The overall pattern showed that the least deprived CBGs had the lowest access to all grocers for both 2002 and 2012.

Table 8. Mean distances traveled to the nearest grocery store or supermarket by SED quintiles, 2002

SED Quintiles	Walk All Grocers	Walk Supermarkets	Public Transit All Grocers	Public Transit Supermarkets
1	1,068.53	1,686.68	1,547.46	2,293.23
2	938.64	1,739.07	1,324.34	2,440.19
3	889.76	2,329.60	1,189.97	3,175.90
4	609.43	2,083.72	819.70	2,855.50
5	633.66	2,434.52	831.11	3,040.53

Table 9. Mean distances traveled to the nearest grocery store or supermarket by SED quintiles, 2012

SED Quintiles	Walk All Grocers	Walk Supermarkets	Public Transit All Grocers	Public Transit Supermarkets
1	1,194.81	1,716.02	1,530.80	2,214.80
2	981.71	1,893.61	1,298.91	2,567.68
3	761.66	2,242.48	1,180.31	2,928.36
4	616.62	1,874.88	803.61	2,457.30
5	825.19	2,575.36	1,081.37	3,279.87

. Figure 12 shows that southeastern St. Paul had the least access by walking distance to grocery stores overall. Of the 52 CBGs in quintile five in 2002, eight of them had their population weighted centroid greater than 1,000 meters from the nearest grocery store. For 2012, there were 17 CBG centroids that were more than 1,000 meters from the nearest grocery store that had an SED score in the fifth quintile. In 2012, there were more than twice as many underserved CBGs by walking distance to the nearest grocery store.

Figure 12 shows clustering of high accessibility to grocery stores for most of downtown and central St. Paul in 2002. All of the map distances were measured in meters. The only CBG centroids with populations traveling more than 2,300 meters to the nearest grocery store were in the St. Anthony neighborhood and southeastern St. Paul.

In 2012, a similar pattern occurred, although parts of downtown and northern St. Paul showed decreased accessibility. Southwestern St. Paul had increased accessibility because of the additional grocery stores and supermarkets that opened after 2002.

Many of the grocery stores that existed in 2002 had closed or relocated by 2012. In St. Paul, 58 of the 97 grocery stores had been closed, mostly small grocers. Four other stores relocated within the St. Paul area. St. Paul did not see a decline in the total number of grocery stores as 97 grocery stores were within St. Paul or 500 meters of the city limits in 2012.

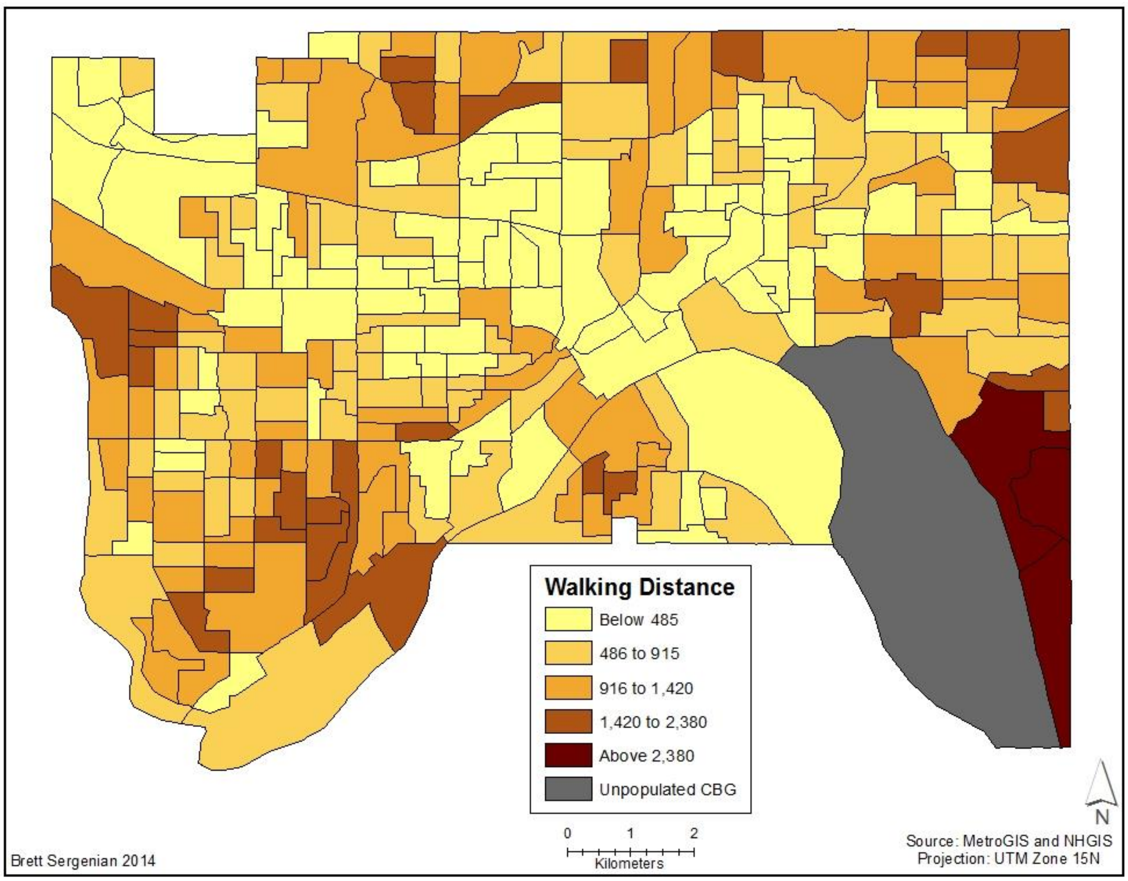


Figure 12. Walking distance to the nearest grocery store in 2002

This result was surprising since other cities had seen a decline in the number of smaller grocers in favor of supercenters and supermarkets (Larsen and Gilliland 2008). However, some of the smaller grocers could have been convenience Populations in CBGs that were routed to three small grocers on Rice Street in 2002 in north-central St. Paul traveled farther by walking distance to the nearest grocery store in 2012 (Fig. 13). For three of the CBGs routed to the small grocer Rice Oriental Groceries in 2002, two of them had their distances increase by approximately 1,000 meters in 2012. The closure of Tom Thumb Food Market on Larpenteur Avenue also increased the distances for a few CBGs in north central St. Paul. These stores were all small grocers so they may have not stocked produce in 2002.

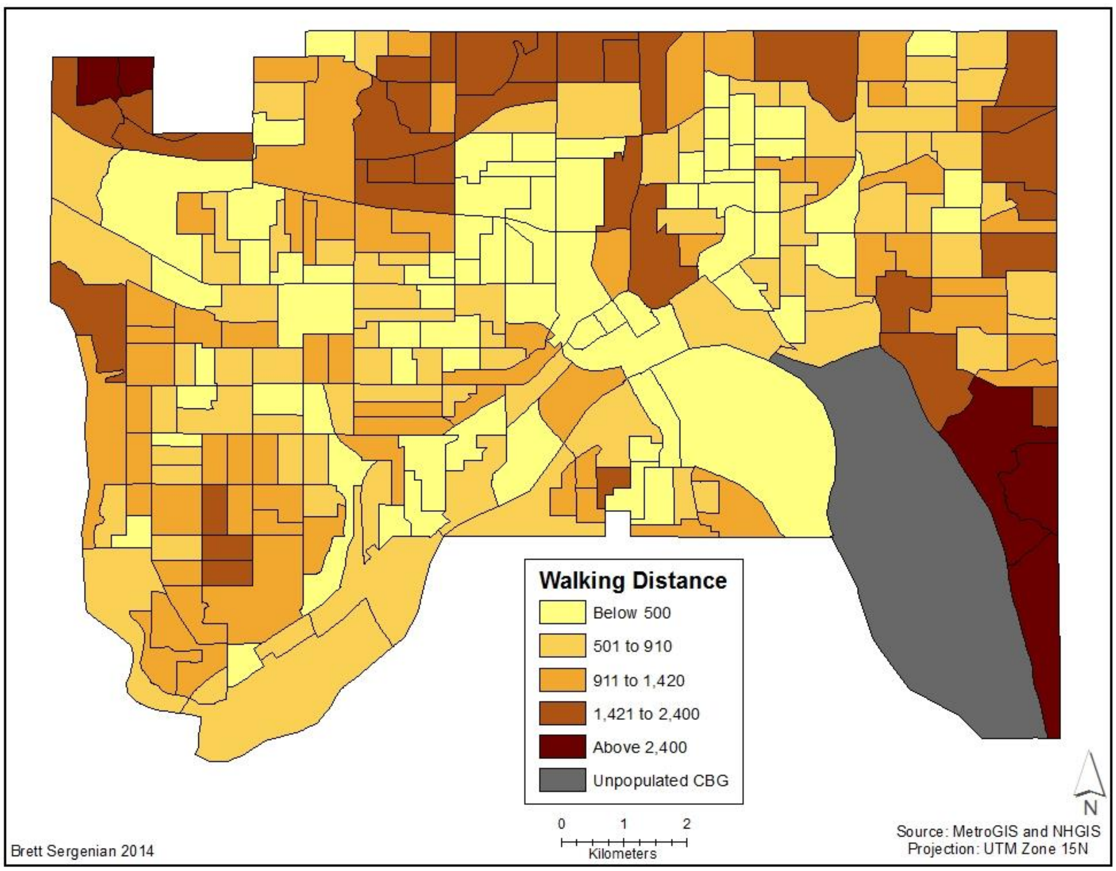


Figure 13. Walking distance to the nearest grocery store, 2012

The results for supermarket access by walking distance showed the opposite trend from the walking accessibility to grocery stores. The mean walking distance to the nearest supermarket in 2002 was 2,055 meters compared to 2,060 for 2012. Despite two additional supermarkets, there was very little change in walking distance to the nearest supermarket. CBGs in the first quintile had the shortest distance to supermarkets with a mean of 1,687 meters in 2002 and 1,716 meters in 2012. The higher mean distances were expected because there were far fewer supermarkets in St. Paul than small grocers. In 2002, there were nine supermarkets within St. Paul, and two supermarkets were within 500 meters of the city limits. Rainbow Foods on Larpenteur Avenue in Roseville and Dick's IGA in West St. Paul were present in both 2002 and 2012. In 2002, there was a noticeable cluster of CBGs located more than 3,500 meters from the nearest supermarket (Fig. 14). In 2012, there were 13 supermarkets within the St. Paul area, an increase of two supermarkets from 2002. In 2012, the CBG centroids greater than 3,850 meters were more dispersed, but still concentrated in downtown St. Paul and just north of downtown (Fig. 15). The fifth quintile had the lowest supermarket accessibility for both 2002 at 2,435 meters and 2012 at 2,575 meters. For both 2002 and 2012, there was a noticeable cluster of supermarkets in southwestern St. Paul from University Avenue to Ford Parkway. The majority of the least deprived CBGs were in southwestern St. Paul, partially explaining why the first quintile had the best access to supermarkets by walking distance. Seven of the eleven supermarkets in 2002 were located in the western half of St. Paul and all but one of the CBGs in the first quintile were also in western St. Paul. For eastern St. Paul, there were only three supermarkets, and one supermarket in south central St. Paul. Several of these supermarkets are luxury grocers or specialize in organic and natural foods in 2002 (e.g. Trader Joes and Whole Foods). It is likely that the majority of the customer bases for these grocery stores reside in the less deprived neighborhoods of western St. Paul.

Figures 14 and 15 were very similar to each other, with little noticeable change. Most of the CBGs in quintile one remained the same, with most of them in western St. Paul. Many of the CBGS in downtown St. Paul had increased accessibility to supermarkets when Kowalski's opened a supermarket on Grand Avenue. In east-central St. Paul, the opening of Cub Foods on Old Hudson Road also increased access for some CBGs in the Battle Creek neighborhood.

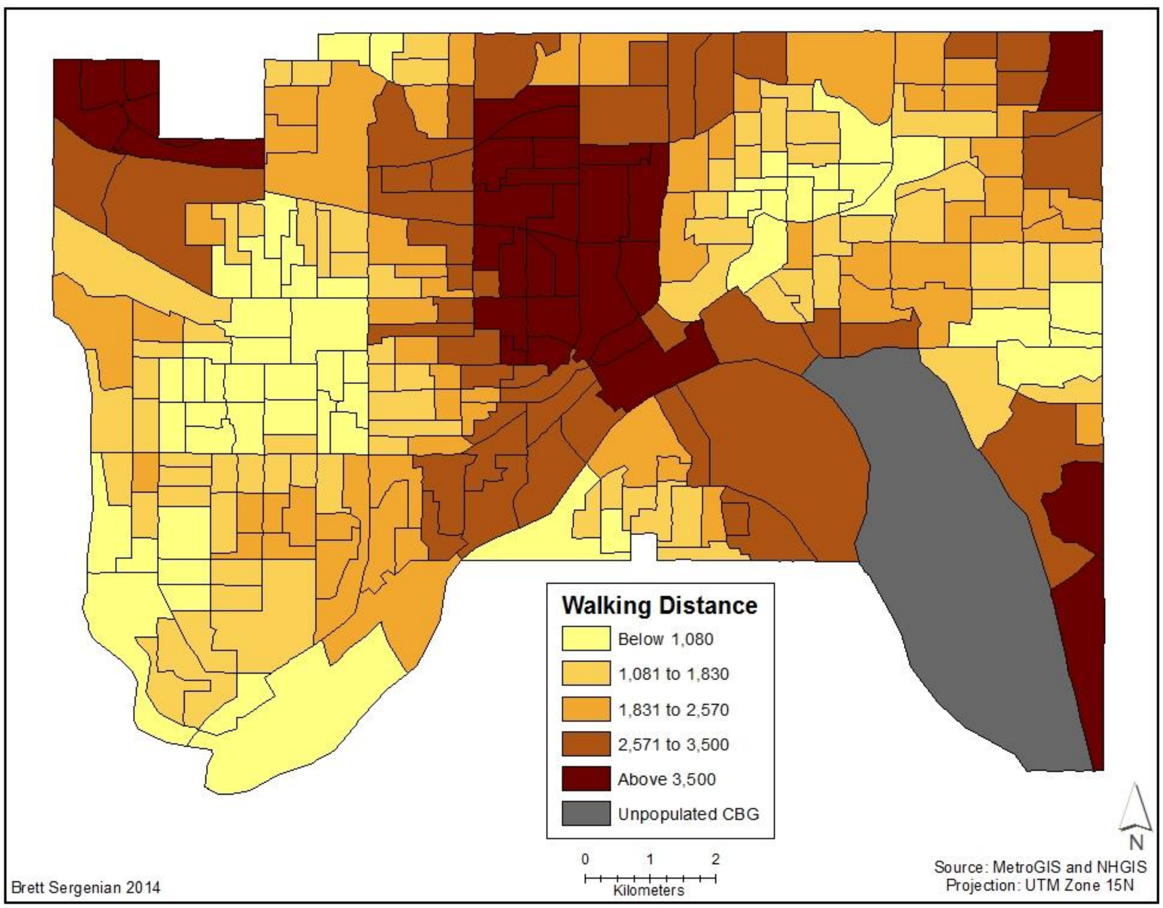


Figure 14.Walking distance to the nearest supermarket, 2002

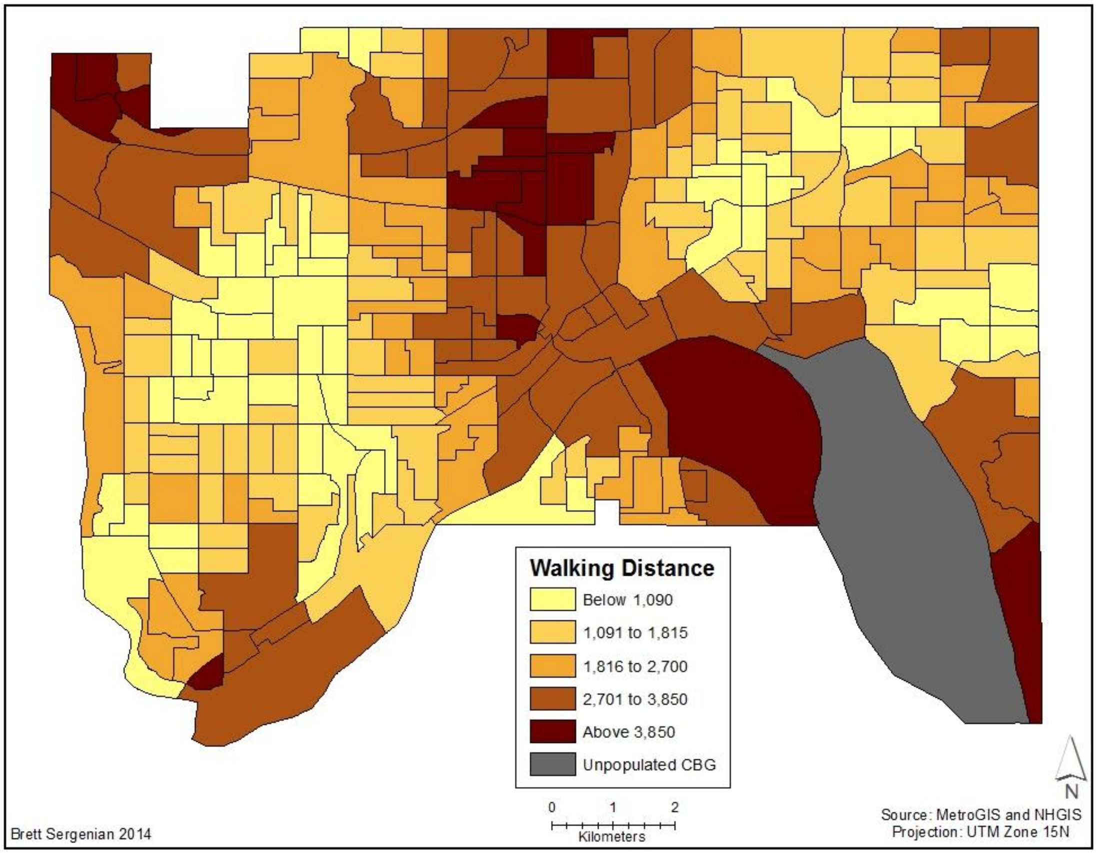


Figure 15. Walking distance to the nearest supermarket, 2012

Lund's, Whole Foods, and Kowalski's supermarkets are considered luxury grocers, so their locations close to their primary customer base is expected (MPR 2013). Since luxury grocers are more expensive than regular chain supermarkets, their locations within less-deprived neighborhoods is not surprising as wealthier populations are more likely to shop at these stores.

Much of the downtown area is more than 1,000 meters from the nearest supermarket, as is Frogtown and north-central St. Paul. Lund's is opening a new supermarket in downtown St. Paul, in Penfield place, which could significantly increase supermarket access for downtown St. Paul CBGs. Since the Lund's grocery store is opening in 2014, it was not included in this analysis.

Table 10 shows the number of underserved CBGs by all four categories for 2002 and 2012. Underserved CBGs are block groups that are located more than 1,000 meters away from the nearest grocery store or supermarket by walking distances or outside of the 3,000-meter and 5,000-meter threshold by public transit to the nearest grocery store or supermarket. As expected, the number of underserved CBGs when including all grocery stores is far fewer than only including supermarkets. When public transit was included, the number of underserved CBGs dropped dramatically for access to grocery stores.

Table 10. A comparison of underserved CBGs by walking and public transit

Year	2002	2012
Underserved CBGs by walking distance to the nearest grocery store	8	17
Underserved CBGs by walking distance and public transit to the nearest grocery store	1	2
Underserved CBGs by walking distance to the nearest supermarket	42	44
Underserved CBGs by walking and public transit to the nearest supermarket at 3,000 m	30	35
Underserved CBGs by walking and public transit to the nearest supermarket at 5,000 m	2	2

4.3 Public Transit Accessibility to grocery stores and supermarkets

Public transit accessibility to the nearest grocery store and to the nearest supermarket was calculated for each CBG centroid by using distances between each bus stop. One common problem with this method was that it was more efficient to walk to the nearest grocery store than to access the nearest grocery by bus for populations in some CBGs. These situations occurred when the CBG centroid was routed to the nearest bus stop that also served as the nearest bus stop to a grocery store or supermarket. Since there was no distance to measure between bus stops, the bus route distance was zero. In 2002, 37 of the CBG centroids were routed to a bus stop that also served as the closest bus stop to a grocery store. For supermarkets, this number was vastly reduced because there were far fewer supermarkets, only 11 and 13 for 2002 and 2002 compared to 95 and 97 grocery stores.

For the 2002 food outlets, approximately 88% of the grocery stores were within 100 meters of the bus routes and there was little change in 2012, with 89% of all stores within 100 meters of a bus route. The bus routes from 2002 and 2012 saw slight changes, but were mostly similar, with the exception of some downtown St. Paul and suburban routes.

The mean distance from each CBG centroid to the nearest bus stop was 233 meters in 2002. Table 11 lists the mean distance traveled to the nearest bus stop for each quintile in 2002 and 2012. In 2012, the general pattern of the more deprived quintiles having the best access to bust stops was similar to 2002, although quintile three had the shortest mean distance. Quintile five still had the second best access at 226 meters in 2012. Table 12 shows the mean distance traveled to the nearest bus stop for St. Paul in 2002 and 2012. The overall pattern showed that the most deprived CBGs have the most accessibility to bus stops and the least deprived CBGs had the least access.

The vast majority of CBG centroids were within 500 meters of a bus stop. For the CBGs more than 500 meters from a bus stop, they were still included in the analysis but were considered to have low bus stop access. This CBG centroid was also the furthest from any grocery store or supermarket in St. Paul. However, CBG 374.03 group 4 was in the first quintile for both 2002 and 2012. Figure 16 shows the 12 CBGs that have inadequate access to bus stops and Figure 17 shows 18 CBGs have inadequate access in 2012. The probability that a resident will walk more than 500 meters to a bus stop is low, indicating that populations near the CBG centroid are unlikely to use bus services (Biba et al. 2009). Twelve CBGs in 2002 were more than 500 meters from a bus stop and CBG 374.03 group 4 was more than 700 meters from the nearest bus stop. Only two of the twelve CBGs with their centroids more than 500 meters from nearest bus stop were in the fifth quintile, with one in north-central St. Paul, and the other in the Payne-Phalen Neighborhood.

Table 11. Mean distance for all quintiles traveled to the nearest bus stop by SED quintile

Quintile	2002	2012
1	265.86	288.6
2	228.53	275.79
3	235.15	216.32
4	233.03	255.79
5	199.24	225.99

Table 12. Mean distance from each CBG centroid the nearest bus stop in St. Paul

Year	Distance
2002	231.12
2012	252.81

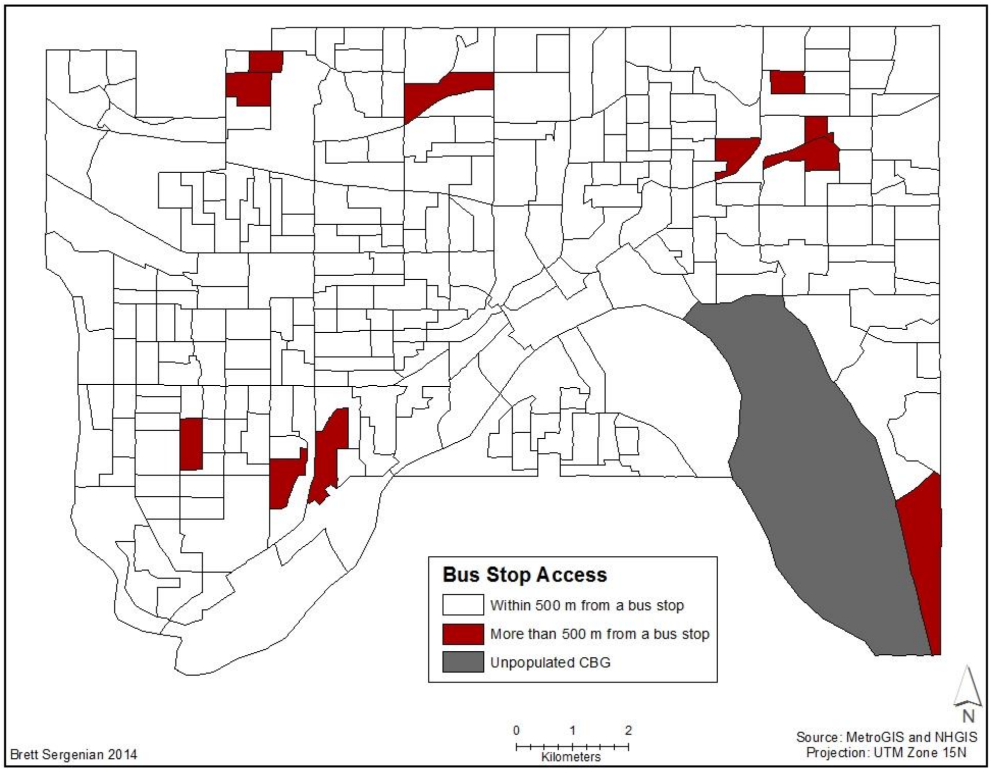


Figure 16. CBGs with inadequate-access to bus stops, 2002

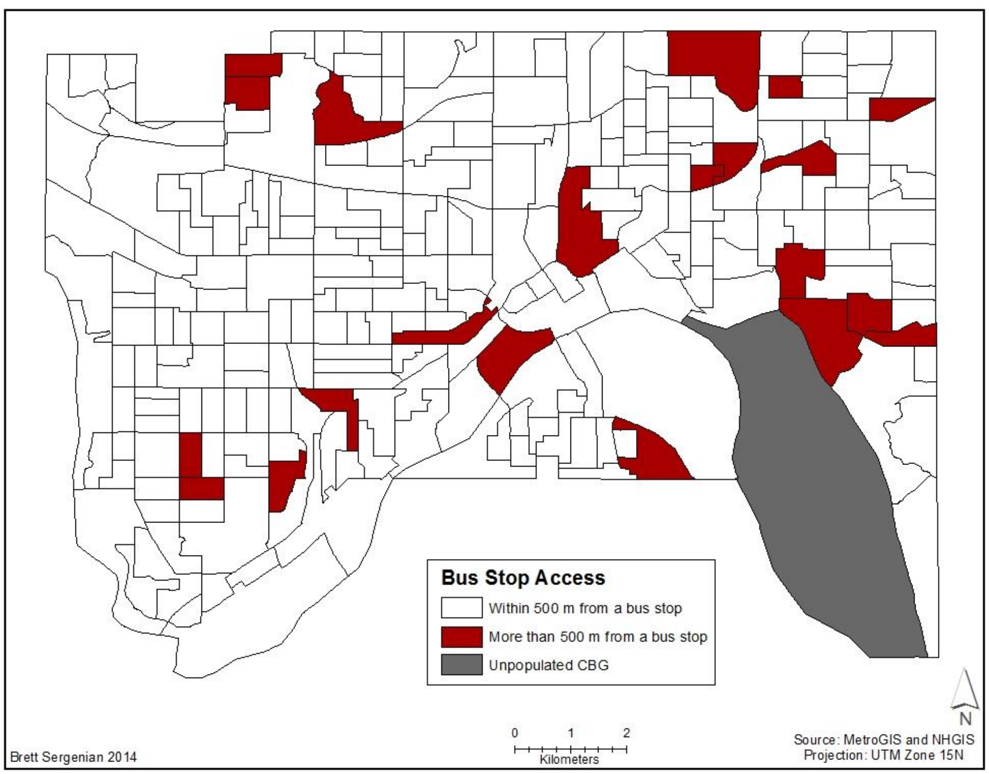


Figure 17. CBGs with inadequate-access to bus stops, 2012

Overall, bus stop access in 2012 decreased slightly with a mean distance of 252.8 meters from each CBG centroid to the nearest bus stop as seen in Table 10. In 2012, populations in 21 CBGs traveled more than 500 meters to the nearest bus stop, six more CBGs than in 2002. Numerous bus stop locations have changed since 2002 but the routes largely remained the same, except for parts of downtown St. Paul. In 2012, a couple of block groups in downtown St. Paul had insufficient bus stop access from the CBG centroid. Other residences within these block groups may have sufficient bus stop access, depending on their proximity to the CBG centroid. Only two of the 21 CBGs with insufficient bus stop access were in the fifth quintile, both of which were in the Payne-Phalen Neighborhood in northeastern St. Paul.

For all grocers that were included in the closest facility layers, the mean distance from grocery stores to the nearest bus stop was 95.5 meters in 2002. In 2012, the mean distance from grocers to the nearest bus stop dropped to 68.3 meters. These results indicate that more 2012 bus stops were established within closer proximity to grocery stores or grocery stores had relocated closer to bus stops and public transit routes.

The results for public transit accessibility to the nearest grocery store for both 2002 and 2012 reflected the results of the walking access with the exception the distances were slightly longer because of the addition of walking distances to bus stops. In 2002, the mean distance from each CBG centroid to the nearest grocery store was 1,139 meters. Quintiles four and five had the best access to grocers by public transit (Fig. 18). In 2012, the general trend remained the same, with the exceptions of quintile three and five having longer distances traveled to the nearest grocery store (Fig. 19).

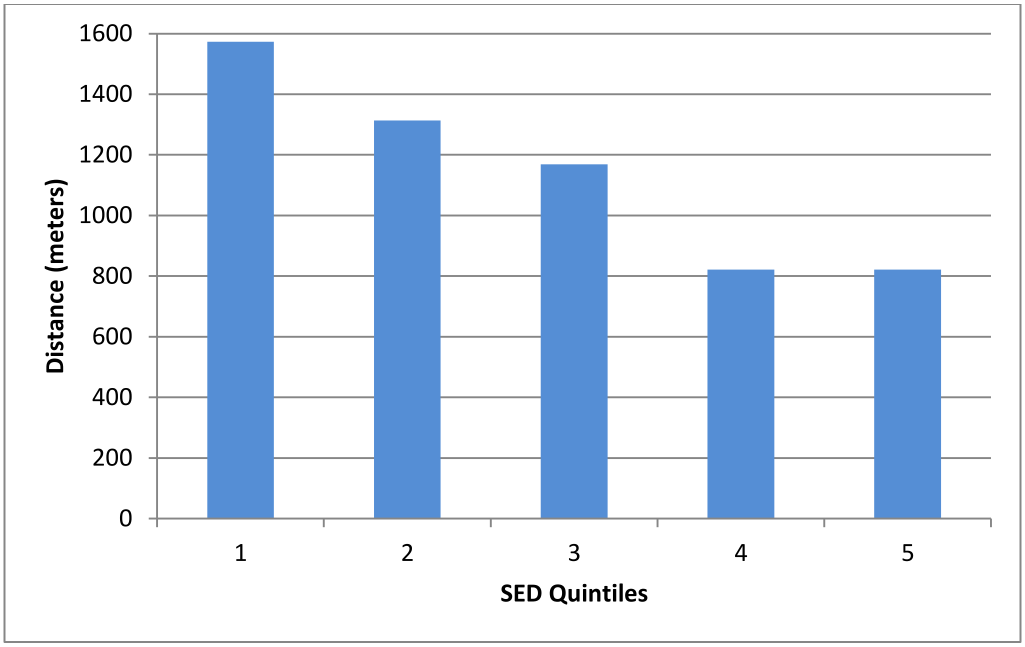


Figure 18. Mean public transit distance to the nearest grocery store by SED quintiles, 2002

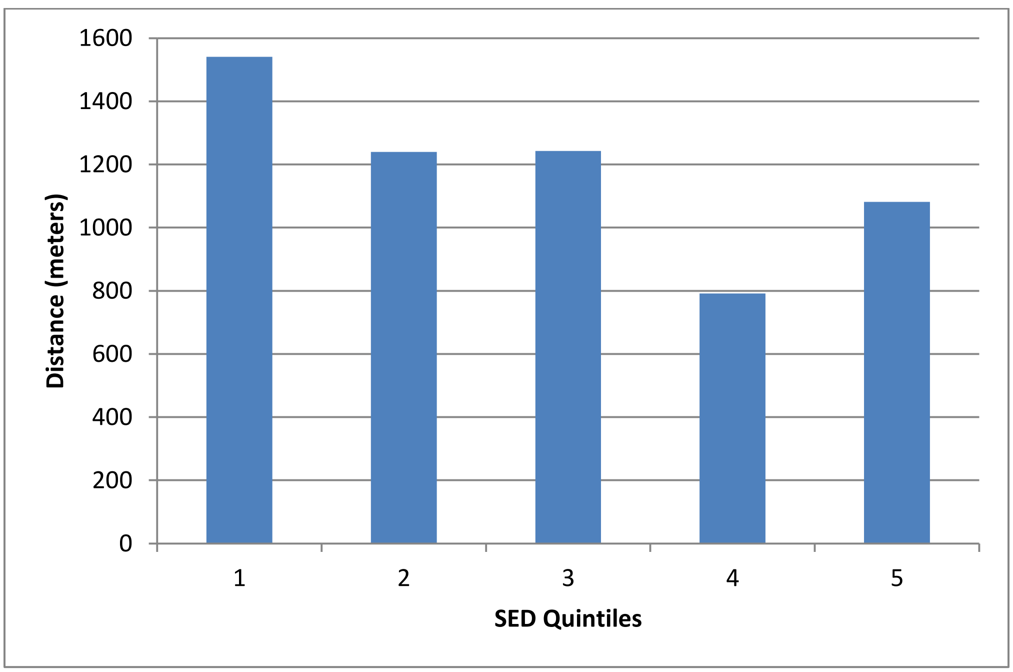


Figure 19. Mean public transit distance to the nearest grocery store by SED quintiles, 2012

Downtown and central St. Paul had the highest accessibility to all grocery stores by public transit in 2002. The southeastern corner of St. Paul and southwestern St. Paul had the least access to all grocers, similar to the walking distances for these areas. Both the public transit and walking distances in 2002 were highly correlated to each other, with a correlation coefficient of 0.843 with a p-value statistically significant at a 95% confidence interval.

Did public transit significantly increase access to all grocery stores at the 3,000-meter threshold for 2002 and 2012? A select by attribute function determined that eight CBGs were potential food deserts by walking distance (in fifth quintile and over 1,000 meters from the nearest grocery store) and one CBG was a potential food desert by both walking distance and public transit at 3,000 meters. CBG 374.03 group 3 was 3,712 meters from the nearest grocery store in 2002 by walking distance and from the nearest grocery store by public transit. For CBG 374.03 group 3 and CBG 374.03 group 5 on the western border on CBG 374.03 group 5, the nearest grocery store were both supermarkets, Byerly's in 2002 and Cub Foods on Old Hudson Road in 2012 (For the CBG locations, refer to Appendix B).

In 2002, 38 CBGs were routed to a bus stop that also served as a bus stop to the nearest grocery store. For the 2012 analysis, 29 CBGs were routed to a bus stop that also served as a bus stop to the nearest grocery store. People residing near the population-weighted centroid are much more likely to walk to the nearest grocery store or supermarket than to use public transit, particularly if the nearest bus stop is only a 100 or 200 meters from the nearest grocery store. These routes were still included in the distance calculations and these CBGs were considered to have good public transit access. Without including these CBGs, the mean public transit distance was 1,268 meters in 2002 and 1,293 meters in 2012.

The overall pattern of public transit distance to the nearest grocery store in 2002 showed relatively high accessibility for downtown St. Paul and in the CBGs around University Avenue just to the west of downtown St. Paul (Fig. 20). Populations in some CBGs in southwestern St. Paul also had lower access to grocery stores by public transit. Both southeastern St. Paul and southwestern St. Paul had relatively few grocery stores, but more so for southeastern St. Paul, resulting in poor access by both walking and public transit distance for both 2002 and 2012.

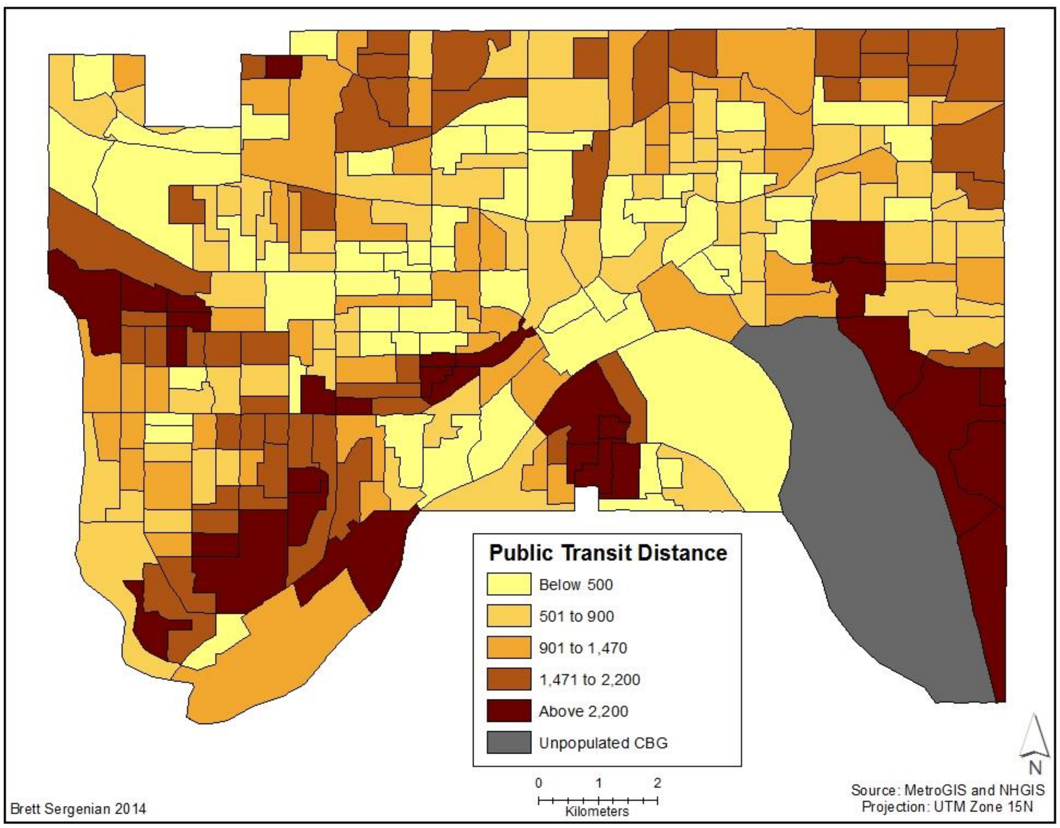


Figure 20. Public transit distance to the nearest grocery store, 2002

In 2012, the patterns showed similar patterns with the southeastern and southwestern portions of the city having the least access to all grocers by public transit. Some of the CBGs in north-central St. Paul had decreased public transit access (Fig. 21) Public transit significantly increased accessibility to all grocers at the 3,000-meter threshold as seven of the eight CBGs that had low access by walking had access to healthy food by public transit (Fig. 22).

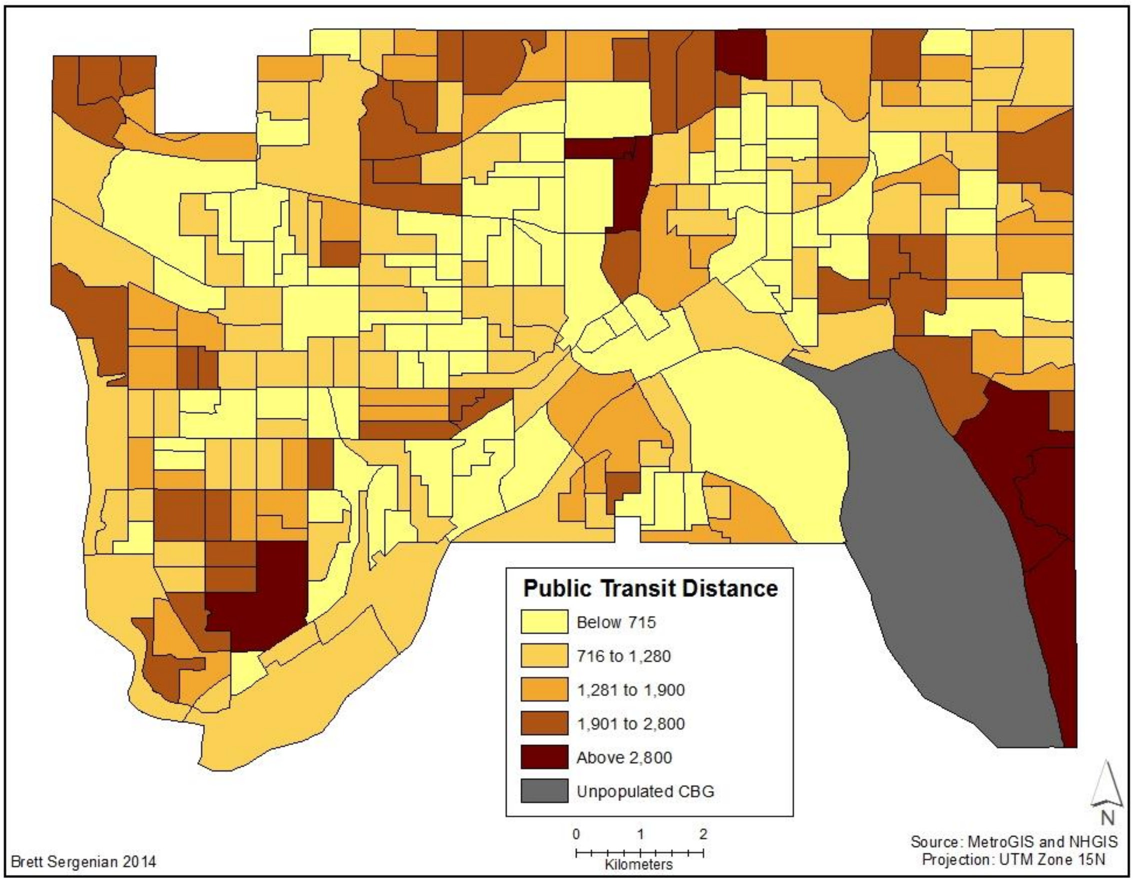


Figure 21. Public transit distance to the nearest grocery store, 2012

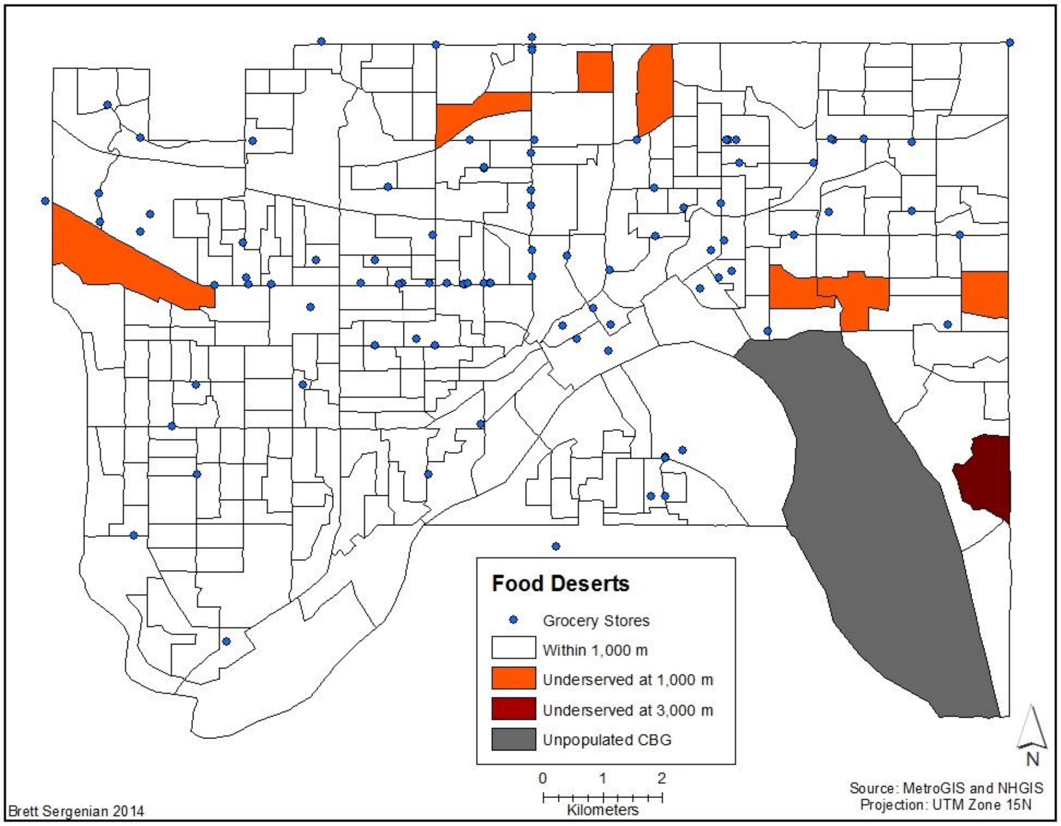


Figure 22. Food deserts by both walking and public transit to all grocers, 2002

CBG 374.03 group 3, in southeastern St. Paul, which is listed in Appendix B, was within the 5,000 meter threshold, resulting in no underserved CBGs at the 5,000 meters. In 2012, the mean distance grocery stores by public transit increased to 1,179 meters, a slight increase from 2002. In addition to the 39-meter increase in public transit distance, one more CBG was outside of the 3,000-meter threshold for 2012 for all grocers. These CBGs were tract 374.03 block groups 3 and 5, both in the Battle Creek neighborhood of southeastern St. Paul. CBG 374.03 group 5 had an increase from 2.09 to 3.49 for the SED index value, placing the block group in the fifth quintile. The distance traveled to the nearest grocery store was the same as 2002. Despite the low population density of CBG 374.03 group 5, it still has population of 1,805, putting the CBG near the mean population of all CBGs.   There were 17 CBGs that had SED values in the fifth quintile with their population weighted centroids located more than 1,000 meters from the nearest grocery store, thus underserved by walking distance. Sixteen of the CBGs that were underserved by walking distance were within 3,000 meters of the nearest grocery store (Fig. 23). This leaves only one additional underserved CBG at the 3,000-meter threshold than in 2002.

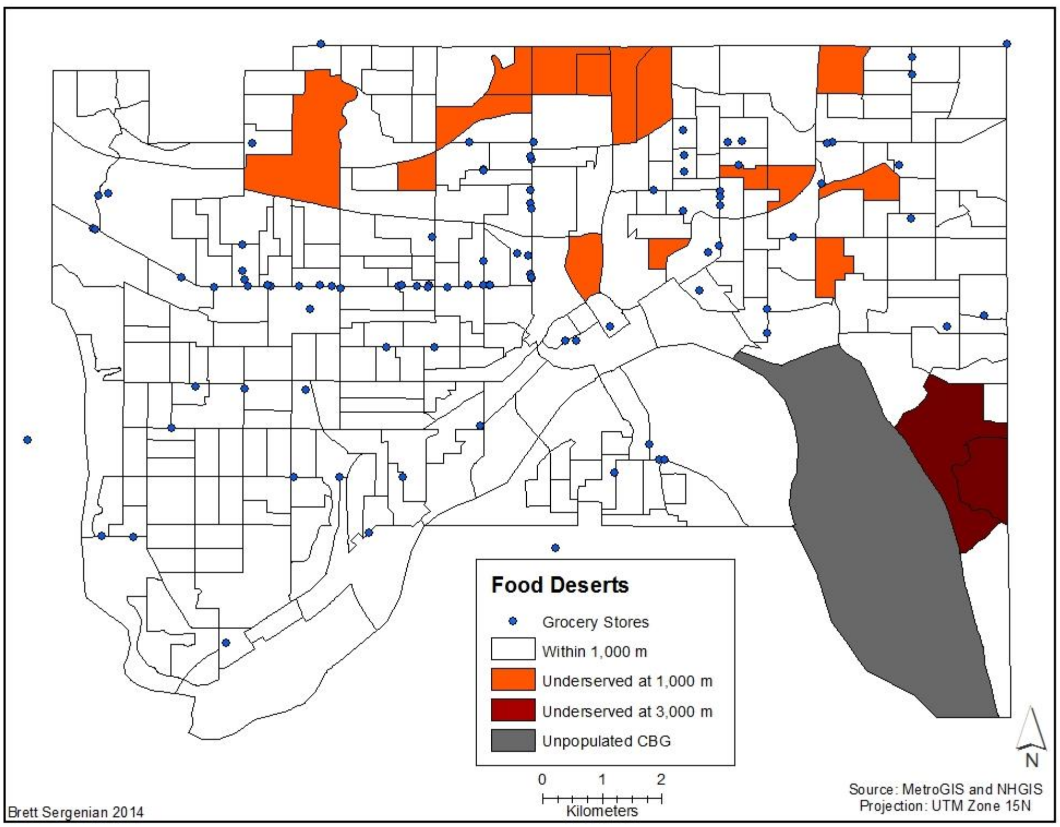


Figure 23. Food deserts by walking and public transit to all grocers, 2012

The distances for walking to the nearest supermarket were greater than 2,000 meters for both 2002 and 2012, reducing the probability of walking to the nearest supermarket. For populations without a vehicle, they would likely walk to the nearest small grocer or a convenience or use public transit. Public transit is more viable option to travel to the majority of supermarkets for residents without vehicle access than walking. Unlike the other three distance measurements which all had increased distanced in 2012 compared to 2002, the mean distance by public transit to the nearest supermarket in 2002 was 2,751 meters and decreased by 62 meters to 2,689 meters in 2012. In 2002, quintile one had the best access to supermarkets by public transit at 2,293 meters and quintile three had the least access at 3,176 meters (Fig. 24). Compared to walking distance to the nearest supermarket in 2002, the results were similar with the exception that quintile five had better access to supermarkets by public transit than quintile three. Quintile five had the second-least access to supermarkets by public transit as quintile five with a mean distance of 3,040 meters. Similar to the walking distances to the nearest supermarket, quintile four had higher access to supermarkets by public transit than quintile five.

In 2012, quintile one still had the best access to supermarkets by public transit compared to the rest of the quintiles. Quintile four had the second highest accessibility to supermarkets at 2,457 meters and quintile three decreased to 2,928 meters in 2012. Quintile five traveled a mean distance of more than 200 more meters in 2012 than in 2002. In 2012, quintile five had the least access to supermarkets by mean public transit distance (Fig. 25).

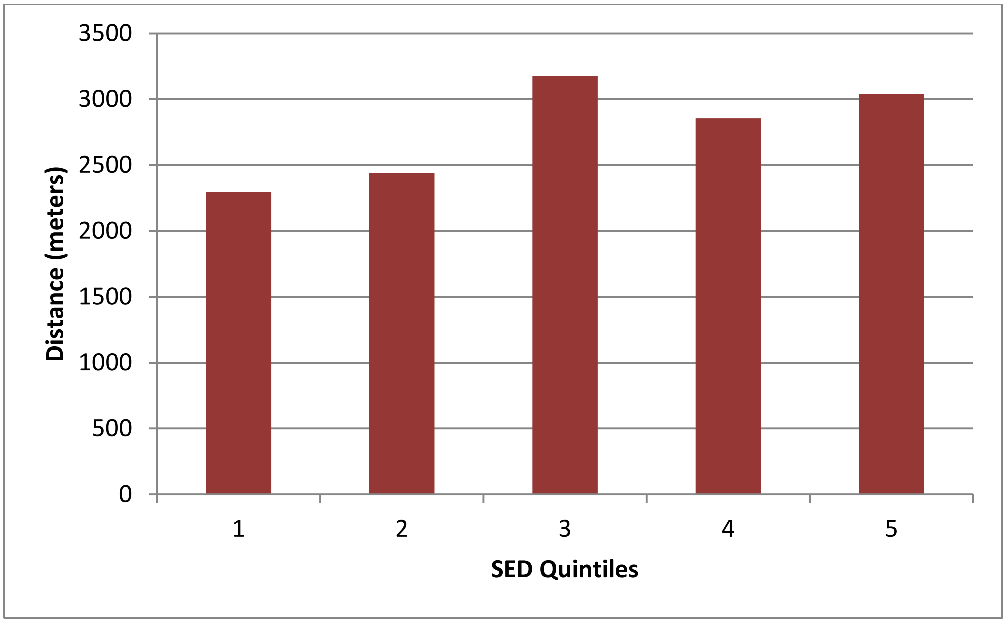


Figure 24. Distance to the nearest supermarket by public transit, 2002

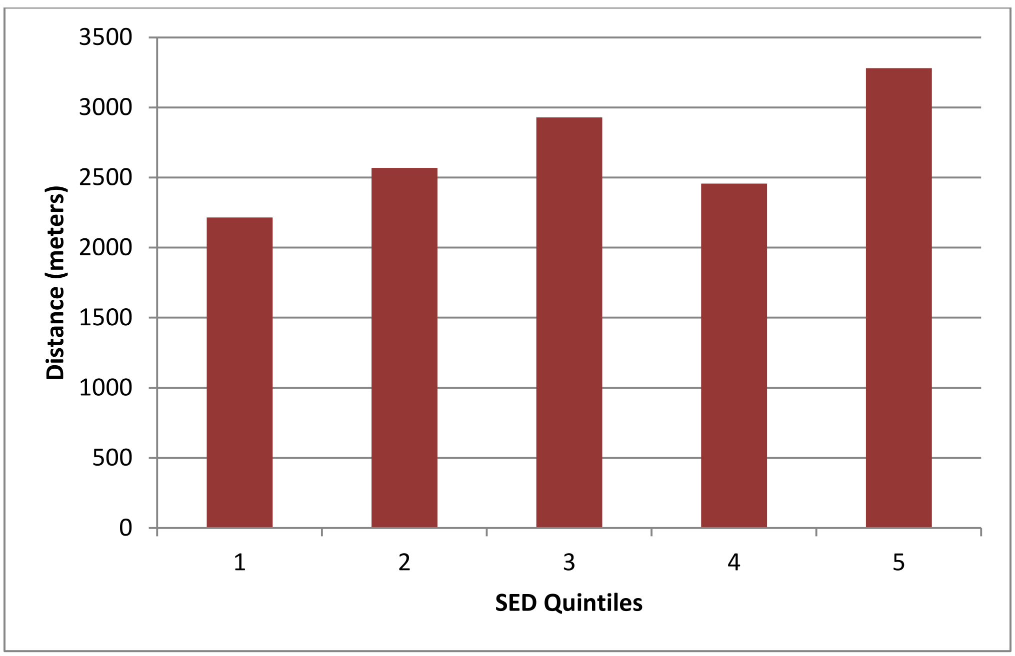


Figure 25. Distance to the nearest supermarket by public transit, 2012

In 2002, 28 of the 52 CBGs in quintile five were located more than 3,000 meters to the nearest supermarket by public transit. For the 5,000-meter threshold, two CBGs met the criteria for a potential food desert (Fig. 26). Those CBGs were tracts 309 group 3 and 313 group two located north of downtown St. Paul. Public transit did not increase supermarket access as much as it did for grocery store access in 2002 at the 3,000-meter threshold, with only 15 of 43 CBGs that were not within the 1,000-meter walking threshold were within a 3,000-meter bus ride of a supermarket.

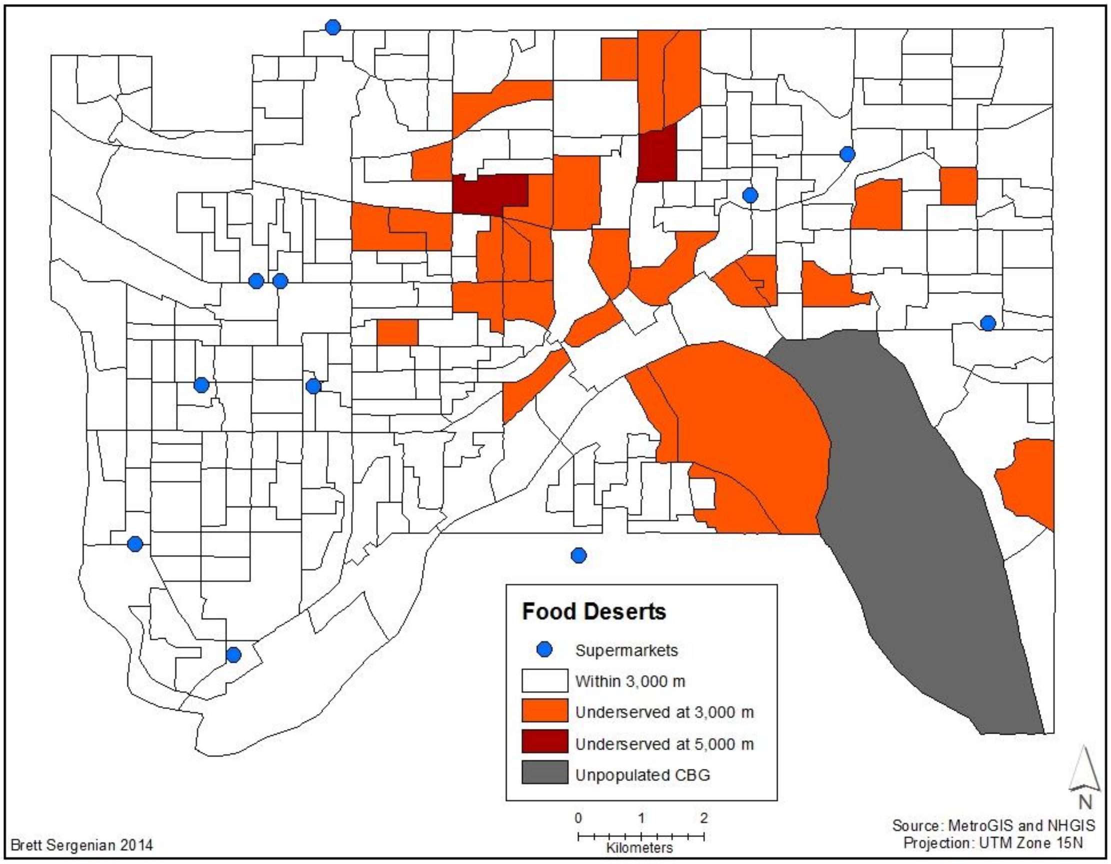


Figure 26. Underserved CBGs by public transit distance to supermarkets, 2002

Public transit significantly increased supermarket access at the 5,000-meter threshold as 41 CBGs that were underserved by walking distance were within a 5,000-meter bus ride to the nearest supermarket. None of the CBG centroids were more than 6,000 meters from a supermarket in either year. In 2012, there were two CBGs that were outside of the 5,000-meter public transit threshold for supermarkets (Fig. 27).

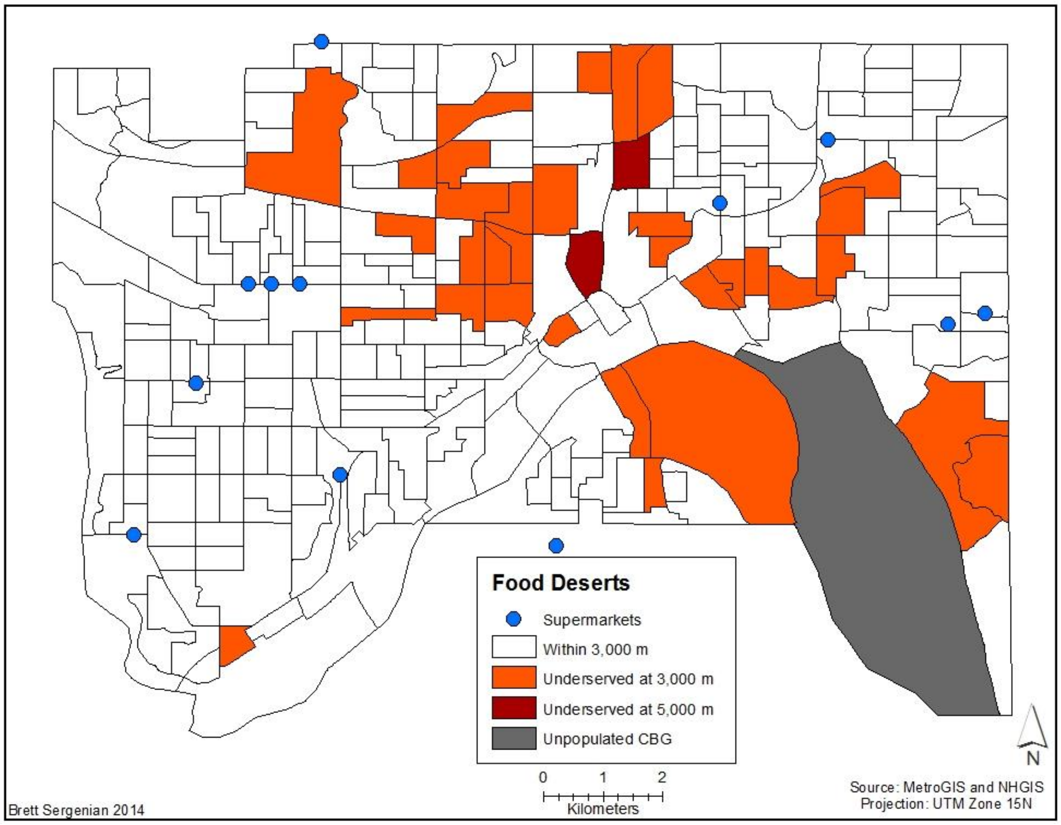


Figure 27. Underserved CBGs by public transit distance to supermarkets, 2012

Most of the CBG centroids in St. Paul are underserved by walking distance to the nearest supermarket, with 211 of the 256 CBGs traveling more than 1,000 meters to the nearest supermarket. With only 11 supermarkets in St. Paul in 2002 and 13 in 2012, these results were expected. At the 3,000-meter threshold, 105 CBGs that were underserved by walking distance traveled less than 3,000 meters to the nearest grocery store. At the 5,000-meter threshold, 12 CBG centroids were more than 5,000 meters from the nearest supermarket. Of these 12 CBGs with populations traveling more than 5,000 meters to the nearest supermarket, two CBGs were in quintiles one, two, three, and five each. Quintile four had four CBGs located more than 5,000 meters to the nearest supermarket. Most of these CBGs were located in the downtown area with two outliers in the southeastern and northwestern corners of St. Paul (Fig. 28).

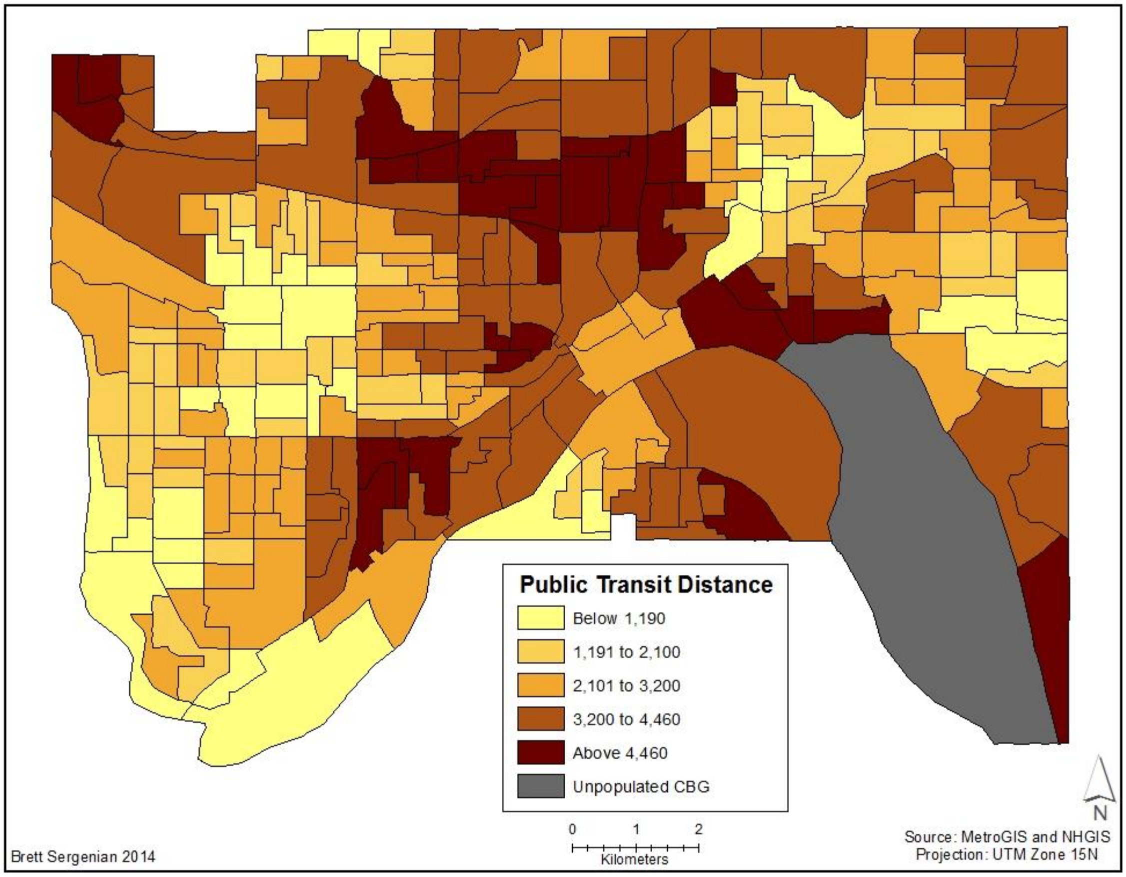


Figure 28. Public transit distance to the nearest supermarket in 2002

In 2012, the mean distance to the nearest supermarket dropped by 62.7 meters. For the CBGs in quintile five, 43 of them had populations traveling more than 1,000 meters to the nearest supermarket, the same number of CBGs as in 2002. Eight CBGs that traveled more than 1,000 meters by walking distance to the nearest supermarket, were within a 3-km bus ride of a supermarket. When the 5,000 meter threshold was applied, only two CBGs exceeded this threshold, the same as 2002. One of them was tract 309 group 3, which also exceeded the 5,000 meter threshold in 2002, and the other was tract 428 group 2. For both 2002 and 2012, public transit did not significantly increase supermarket access at the 3,000-meter threshold, but significantly increased supermarket access at the 5,000-meter threshold for the most socioeconomically deprived

CBGs. Figure 29 shows a similar pattern to Figure 28, with central St. Paul having the least access to supermarkets by public transit.

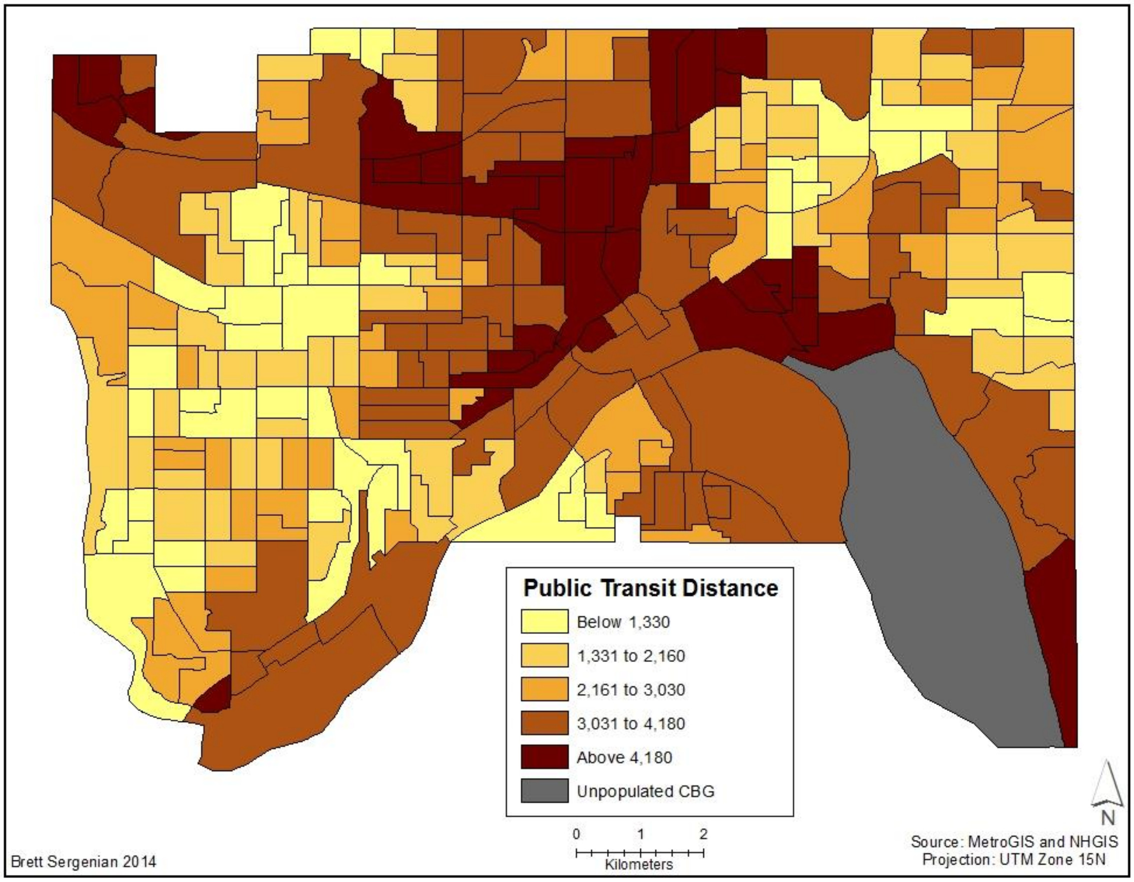


Figure 29. Public transit distance to the nearest supermarket in 2012

Similar to 2002, 207 CBGs had populations traveling farther than 1,000 meters to the nearest supermarket, in 2012 or 83.1%, up 0.7% from 2002. This shows that the vast majority of CBGs are outside of the 1,000-meter threshold of a supermarket in St. Paul. These results fit the mean distances of 2054.7 meters and 2059.7 meters for 2002 and 2012, respectively.

At the 3,000-meter threshold, 103 CBGs or 41.37% of the CBGs exceeded the threshold, down 0.5% from 2002. Eleven CBGs exceeded the 5,000-meter threshold, or 4.4%, down 0.3% from 2002. With the exception of two CBGs in the northwestern corner of St. Paul and one CBG in the southeastern corner, the rest of the CBG populations traveling greater than 5,000 meters to the nearest supermarket were in downtown St. Paul or just north of downtown. Quintile one had three CBGs exceeding the 5,000 meter threshold, quintile 2 had one, quintile 3 had four, quintile four had two, and quintile five had two.

4.4 Spatial Statistics

To compare SED values from 2002 to 2012, I calculated a paired t-test on the 216 matching CBGs, resulting in a t-statistic of -0.43, between the critical t-value of 1.96 and -1.96. A t-statistic of less than -1.96 or 1.96 would indicate that the change between accessibility from 2002 to 2012 was significant. If the value fell in between -1.96 and 1.96, the null hypothesis was not rejected. This indicated that the SED index has not changed significantly between the 216 CBGs that were paired. A positive t-statistic shows an increase in accessibility from 2002 to 2012 and a negative t-statistic shows a decrease in accessibility. The Pearson correlation coefficient was 0.828, indicating the values were highly correlated. If my study analyzed data that were more than a decade apart, the correlation results would likely be lower.

I calculated an independent t-test for accessibility to grocery stores by walking, access to grocery stores by public transit, access to supermarkets by walking, and access to supermarkets by public transit. The t-test for SED change, seen in Appendix A, tests the significance of SED values in 2002 and 2012 between the 216 CBGs. The t-statistic of -0.429 shows that there was little change and the p-value of 0.668 indicates that the t-statistic is not statistically significant at a 95% confidence interval. Appendices B through F shows that none of the walking or public transit distances increased significantly for the entire city of St. Paul. These results must be interpreted with caution because only 216 CBGs could be compared because of boundary or number changes after the 2010 census.

I calculated a Gi* Statistic for walking and public transit distances to the nearest grocery store and supermarket for both 2002 and 2012. Cold spots are CBGs with z-scores from -1.65 to -2.58 (two-tailed) indicate clustering of low distances next to other areas of low distances. The cold spots represent clusters of CBGs with relatively good accessibility to grocery stores or supermarkets. Hotspots represent CBGs whose populations travel longer distances to the nearest grocery store or supermarket next to other CBGs with long distances. For walking and public transit distances in 2002 and 2012, the cold spots occurred in downtown St. Paul, Frogtown, and in northwestern St. Paul (Fig. 30).

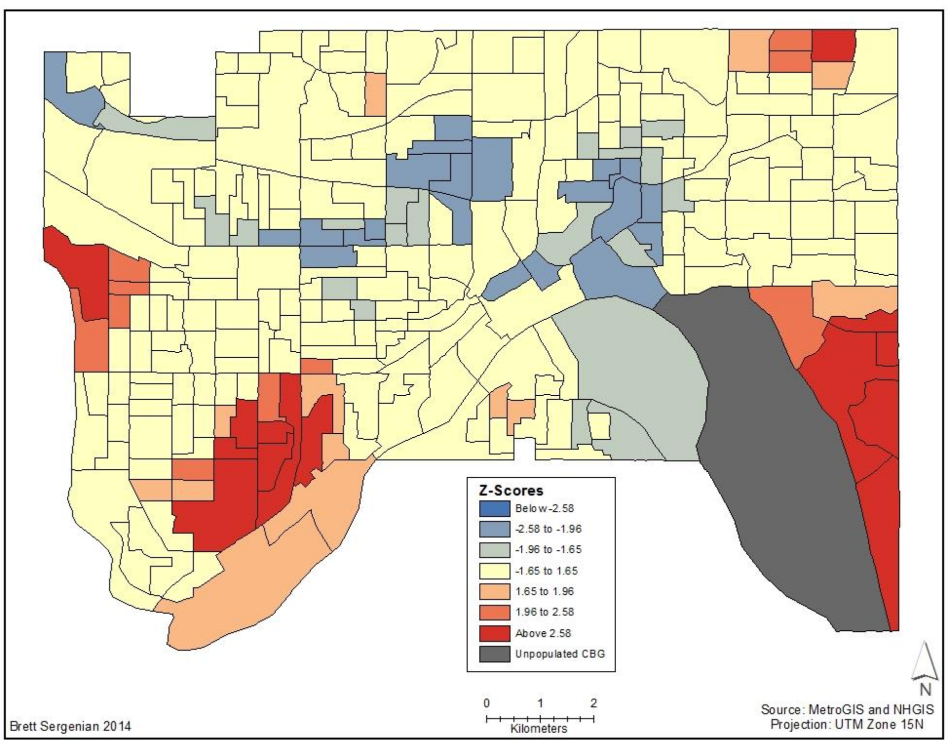


Figure 30. Gi* Statistic of walking distance to the nearest grocery store, 2002

Southeastern St. Paul was the noticeable hotspot, which can be seen in other figures. This indicates that there is significant clustering in both 2002 and 2012 of longer distances traveled to the nearest grocery store by residents of these CBGs for 2002 and 2012. One of the reasons why parts of southeastern St. Paul lack grocery stores is because much of the area is part of Battle Creek Regional Park or within the Mississippi River Floodplain. Unlike the situation in southeastern St. Paul, the closure of small grocery stores in the St. Anthony neighborhood and in north central St. Paul, two of the previous cold spots in Figure 30 became hotspots in Figure 31 in 2012. Despite the closure of several small grocers in parts of northwestern St. Paul, specifically grocery stores such as Front Avenue Superette and Abu Nader's Grocery and Deli in the St. Anthony Neighborhood resulted in these CBGs being classified as hotspots.

In Figure 32, the most socioeconomically deprived CBGs became hotspots with z-scores above 1.65 level for CBGs 305 group 1 and 306 group 1 along the northern edge of St. Paul next to Interstate 35 near the Maplewood City limits. These two CBGs were not only two of the most socioeconomically deprived CBGs within the St. Paul city limits, but also among the most populous block groups within the city.

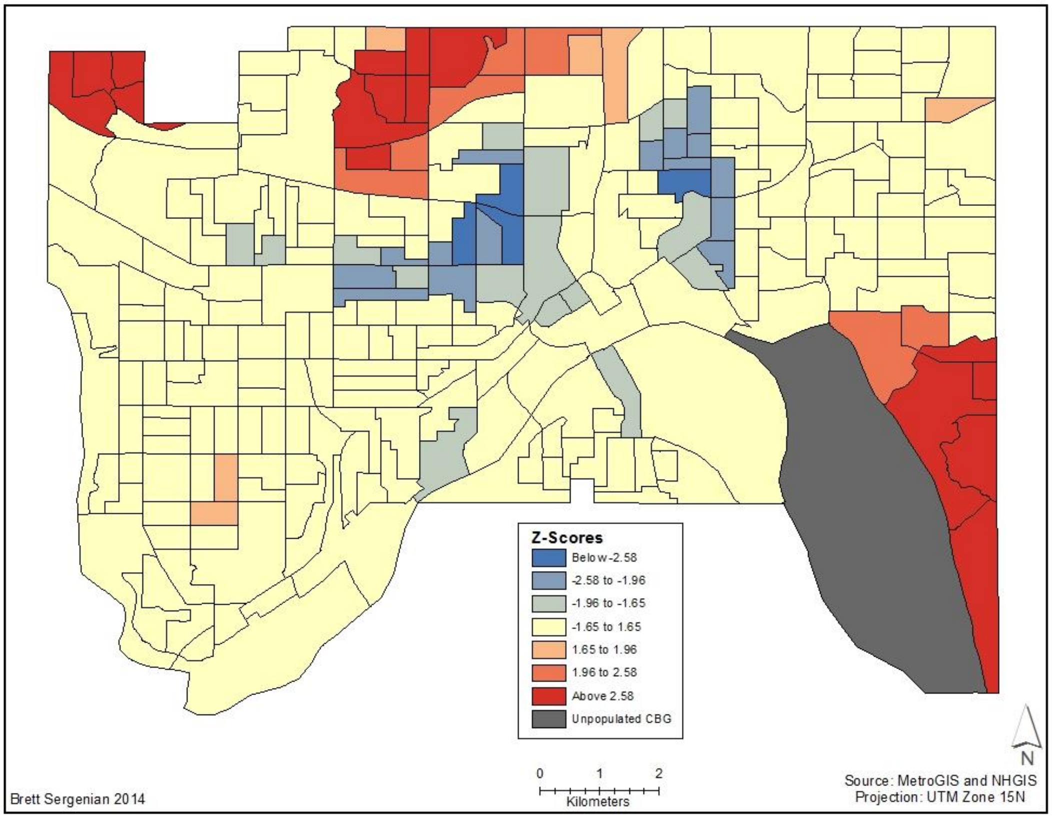


Figure 31. Gi* Statistic of walking distance to the nearest grocery store, 2012

The closure of the smaller grocers in north-central and northwestern St. Paul was less noticeable in Figures 32 and 33. From Figure 37, the Summit Hill Neighborhood in southwestern St. Paul had several additional grocers open in the area, including in Kowalski's, Trader Joes, and Mississippi Market, which eliminated the hotspot from 2002.

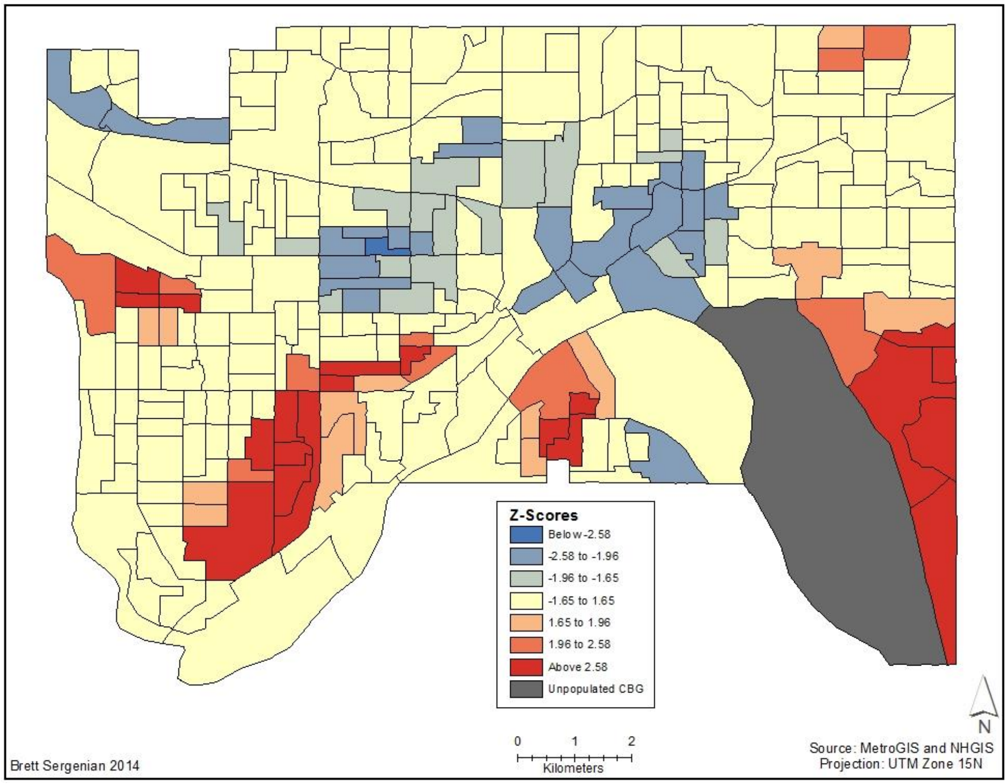


Figure 32. Gi* Statistic of public transit distance to the nearest grocery store, 2002

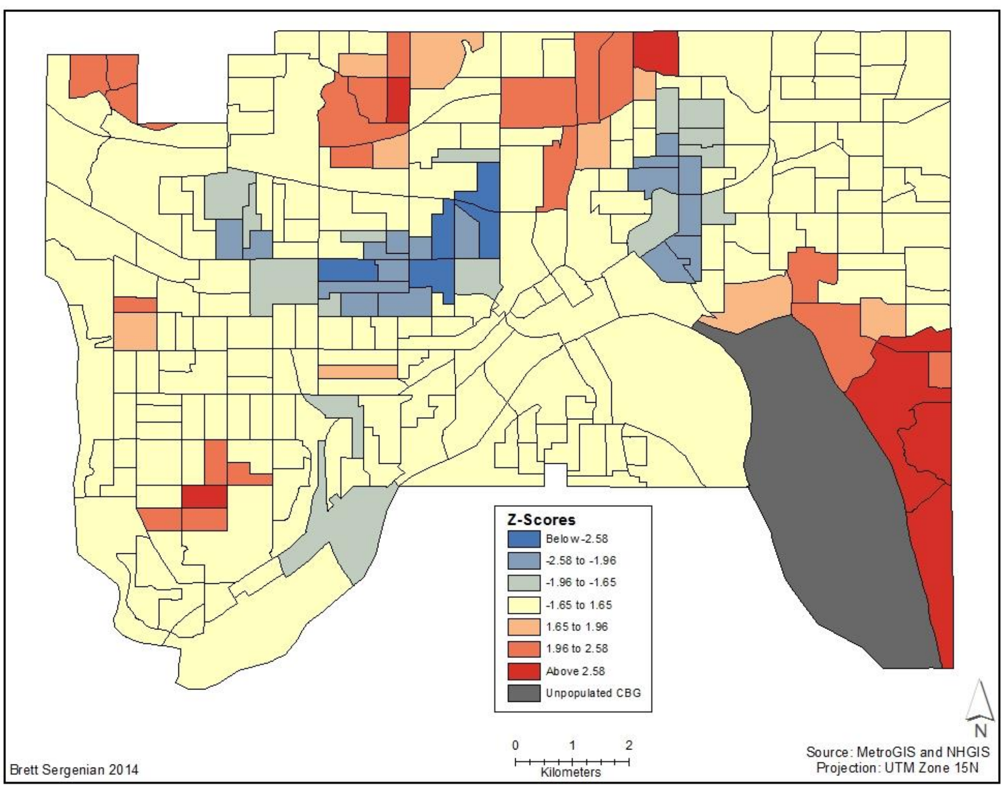


Figure 33. Gi* Statistic of public transit distance to the nearest grocery store, 2012

All of the Gi* statistic maps for supermarket accessibility by walking clearly showed where and hotspots throughout central St. Paul, similar to the walking distance maps (Fig. 34 and Fig. 35). These results were expected as supermarket access showed concentrations of higher distances traveled in central St. Paul and several CBGs in southeastern and northwestern St. Paul.

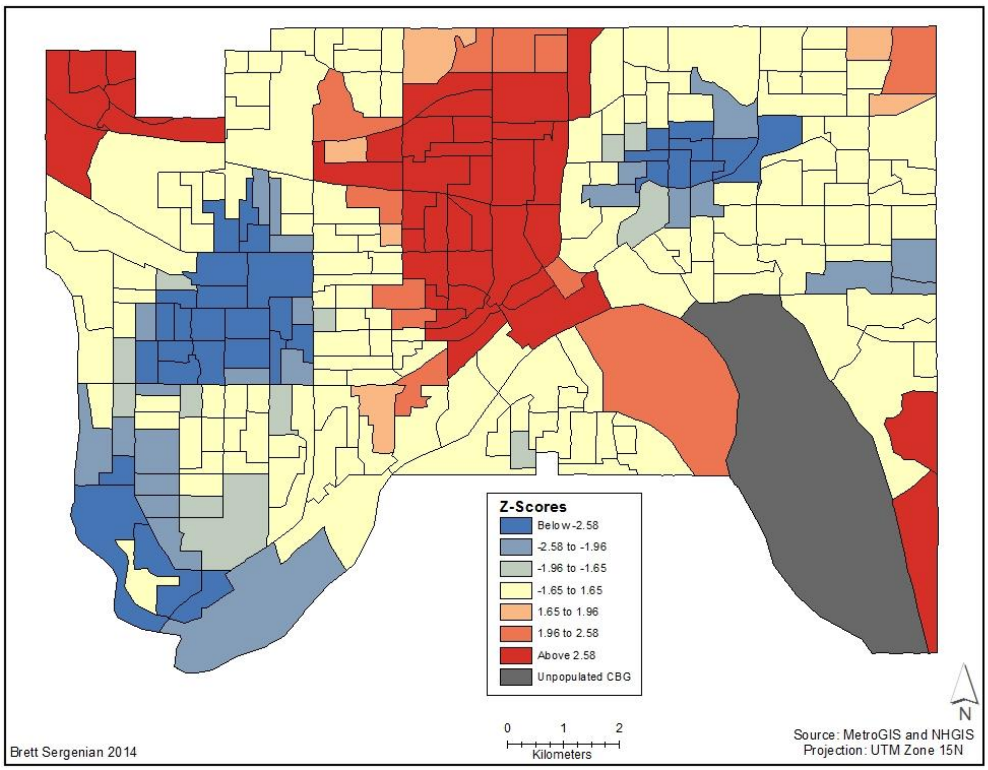


Figure 34. Gi* Statistic of walking distance to the nearest supermarket, 2002

The clustering of negative z-scores essentially shows where the supermarkets are located within St. Paul. In 2002, the noticeable cold spots cluster around Rainbow Foods and Jerry's Newmarket in northeastern St. Paul, along University Avenue and in southwestern St. Paul. The supermarkets did not change as much as the smaller grocers, which is reflected by the figures showing the Gi* statistic for public transit to the nearest supermarket.

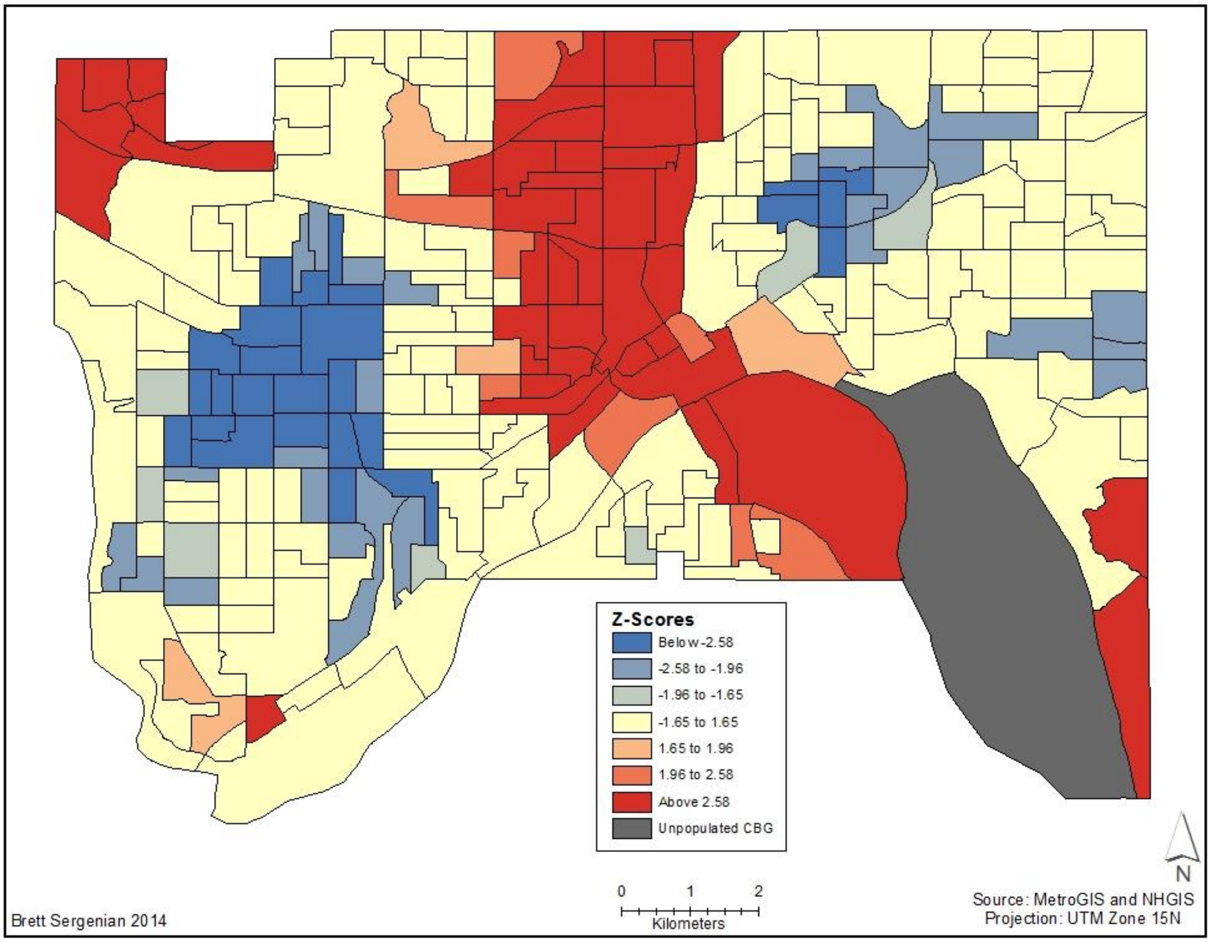


Figure 35. Gi* Statistic of walking distance to the nearest supermarket, 2012

These results were also reflected by the public transit distances to the nearest supermarket in 2002 and 2012, as seen in Figures 36 and 37. Compared to the walking distance to the nearest supermarket or Figure 34, there is little change between public transit accessibility and walking accessibility to supermarkets in 2002.

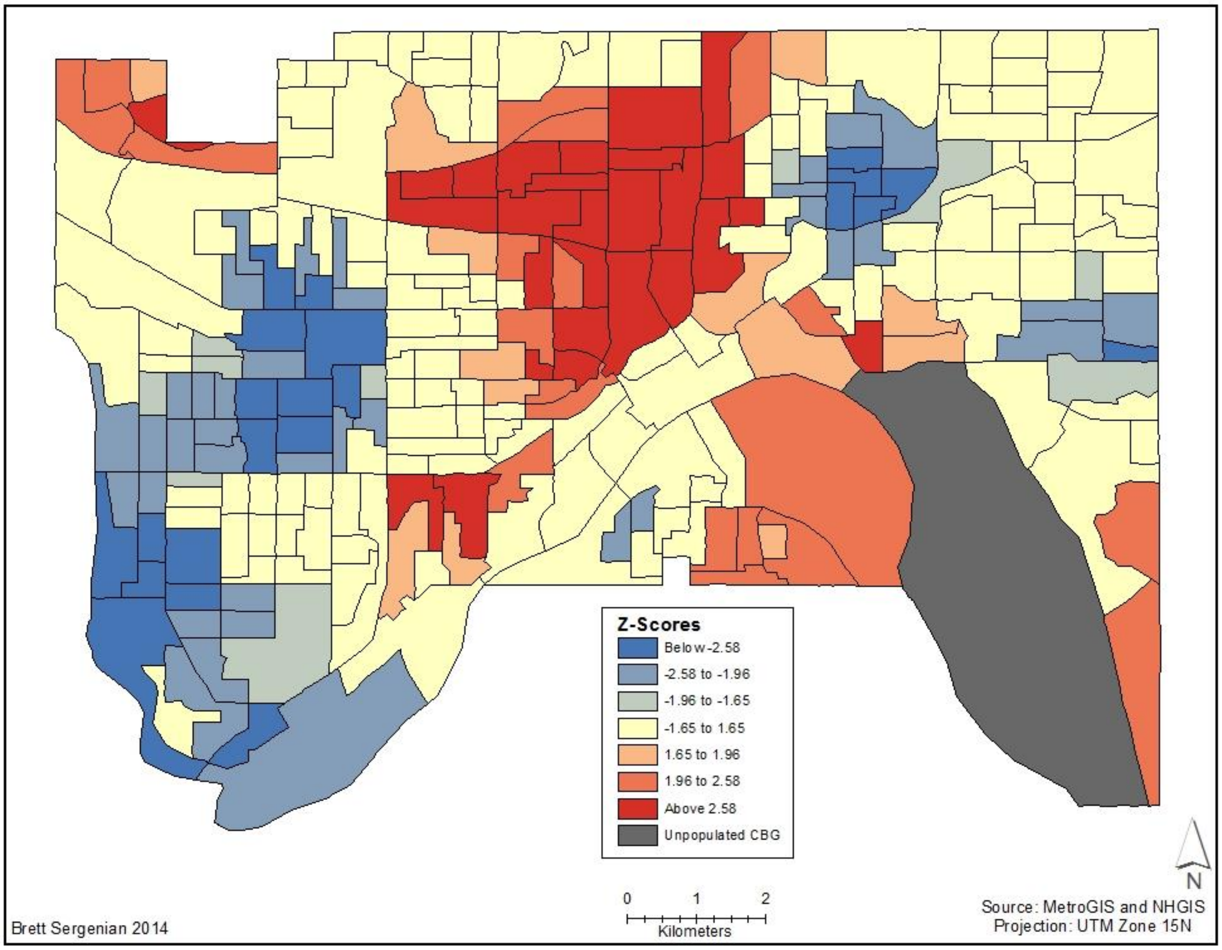


Figure 36. Gi* Statistic of public transit distance to the nearest supermarket, 2002

For public transit access in 2012, most of the z-scores for CBGs in the St. Anthony neighborhood and far southeastern St. Paul were between 1.65 and 2.58 while most of downtown St. Paul was above 2.58. For both walking and public transit distance, downtown St. Paul has poor access to supermarkets. The Westside Neighborhood had z-scores between 1.65 and 1.96, as the northeastern end of the neighborhood was a hotspot compared to the surrounding areas as populations within these CBGs traveled longer distances to Dick's IGA in West St. Paul. When comparing figures 37 and 35, CBG 361 group 1 has is not as strong of a hotspot for public transit compared to walking distance.

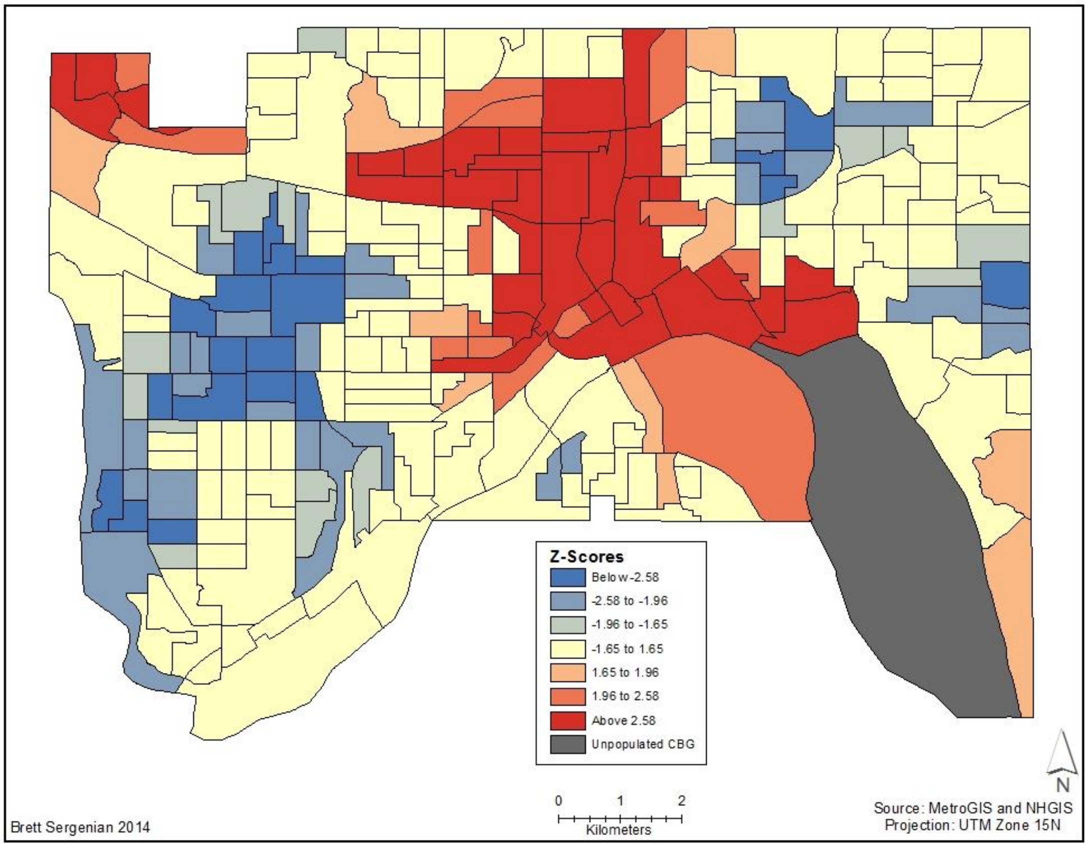


Figure 37. Gi* Statistic of public transit access to supermarkets, 2012

Results of the bivariate LISA statistical analysis of the walking distances in 2002, to all grocers showed most of the downtown and CBGs immediately to the east and west of downtown St. Paul as high-low indicating CBGs with high SED index values travel shorter distances to the nearest grocery store. Low-low LISA classes are CBGs that have low SED values and good access to grocery stores. Low-high LISA classes constitute CBGS with low SED values and poor access to grocery stores. The CBGs with a high-high relationship are food deserts. Most of the downtown CBGs and throughout central St. Paul displayed a high-low relationship, indicating they have high socioeconomic deprivation and good access to grocery stores. These results fit the Local Moran's I of -0.11 for 2002. In 2002, the food deserts identified by the bivariate LISA for walking distance were two CBGs in the Battle Creek neighborhood of southeast St. Paul (Fig. 38).

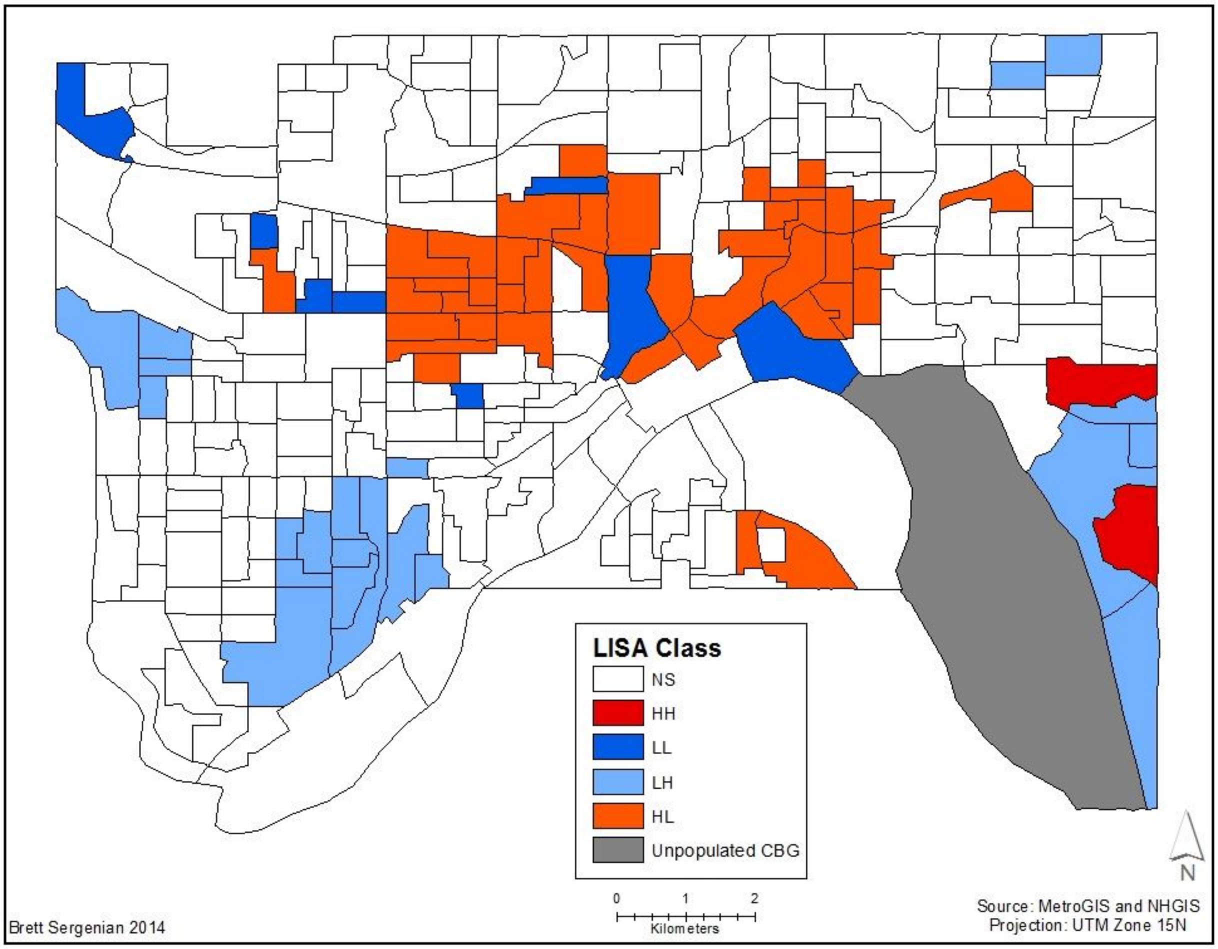


Figure 38. Bivariate LISA of walking distance to the nearest grocery store, 2002

In 2012, two additional CBGs in the Battle Creek neighborhood were food deserts shown in Figure 39. Figure 39 also shows the addition of four CBGs as food deserts in north-central St. Paul in 2012.

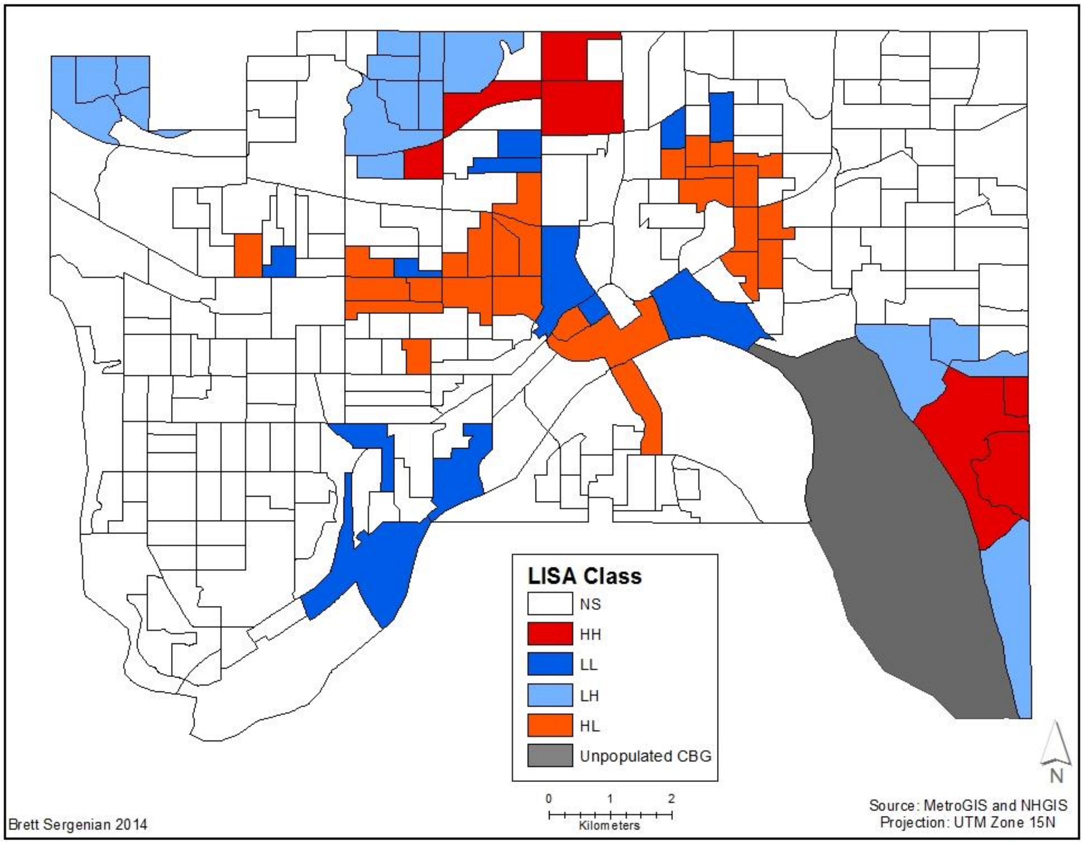


Figure 39. Bivariate LISA of walking distance to the nearest grocery store, 2012

Figure 40 showed only two CBGs displaying a high-high relationship for public transit to the nearest grocery store, CBG 374.03 group 3 and 374.02 group 5. The two neighboring CBGs in 2002 displayed a statistically significant low-high relationship. In 2012, all of the CBGs neighboring CBG 374.03 group 3, with the exception of CBG 374.03 group 4, all displayed a high-high relationship indicating that these CBGs had an increase in socioeconomic deprivation from 2002 to 2012.

Another noticeable change between Figure 40 and Figure 41 was the addition of five CBGs in north-central St. Paul displaying a high-high relationship. Unlike the CBGs in tract 374.03, the shift to a high-high relationship cannot be solely attributed to an increase in socioeconomic deprivation. Some of the CBGs had increased socioeconomic deprivation; specifically 306.01 groups 1 and 2, near Interstate 35, other CBGs had decreased SED index values.

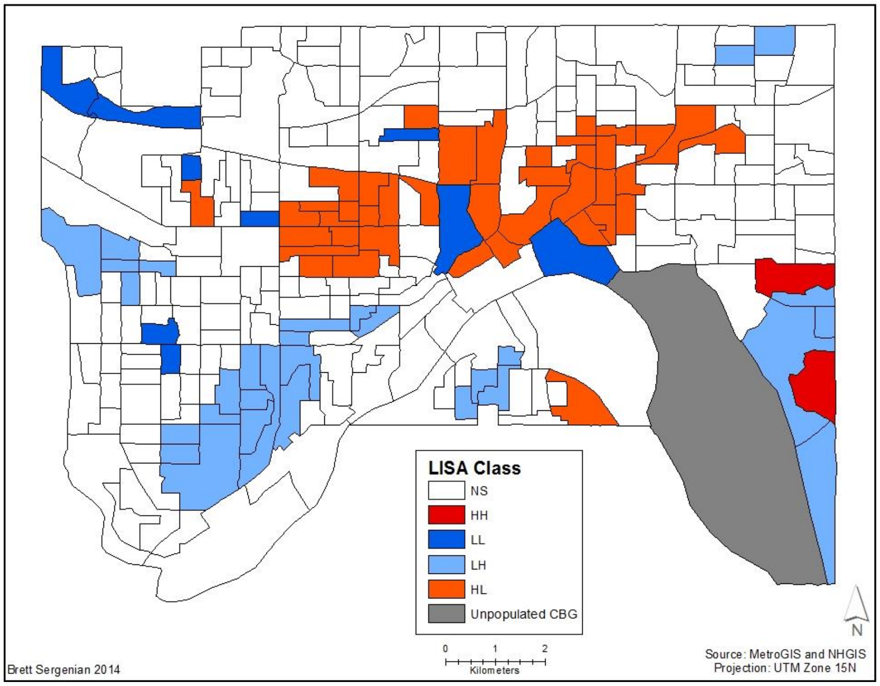


Figure 40. Bivariate LISA of public transit distance to the nearest grocery store, 2002

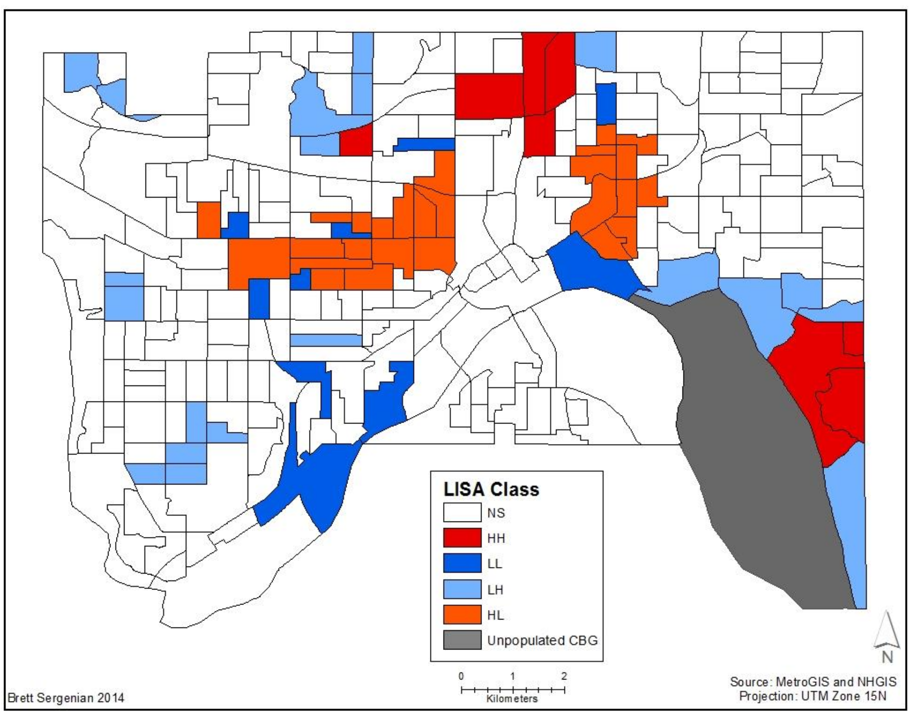


Figure 41. Bivariate LISA for public transit to the nearest grocery store, 2012

The bivariate LISA results for walking to the nearest supermarket in 2002 showed most of the clustering of high-high relationships were concentrated in central and northern St. Paul (Fig. 42). The low-low and high-low associations essentially show where the supermarkets are located, particularly the supermarkets along University Avenue, Lund's Ford Parkway, Jubilee Foods in far southwestern St. Paul, and Rainbow Foods on Arcade Street.

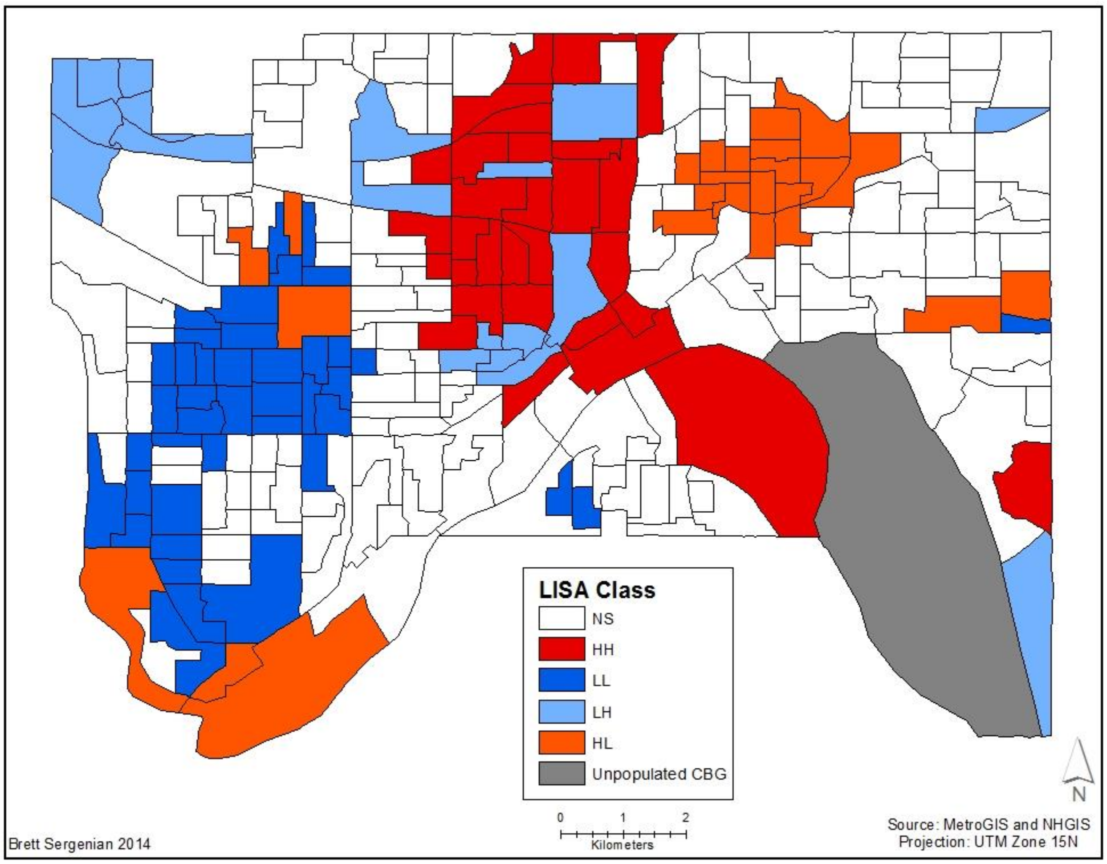


Figure 42. Bivariate LISA map of walking to the nearest supermarket, 2002

The results of the bivariate LISA statistics for public transit to the nearest supermarket were similar to the maps displaying walking distance to the nearest supermarket. For the 2012 analysis, there was little change among the CBGs from 2002 (Fig. 43). One difference was CBG 374.03 group 3 was not significant in 2012 for public transit distance, while it had a high-high relationship for public transit distance to the nearest supermarket in 2002 and walking distance to the nearest supermarket in 2002 and 2012. In the Westside neighborhood, a couple more CBGs were categorized as high-high, likely because of an increase in deprivation because the only nearby supermarket, Dick's IGA was in the same location for both years.

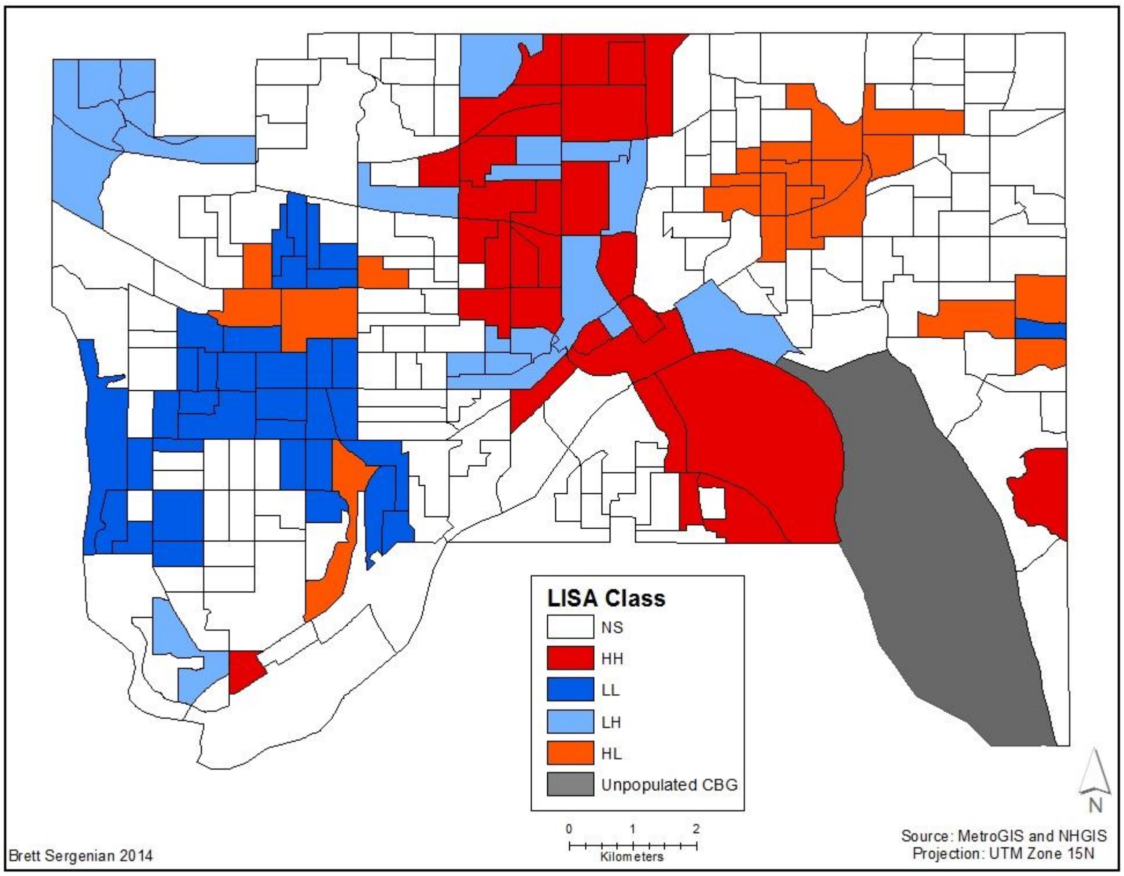


Figure 43. Bivariate LISA of walking distance to the nearest supermarket, 2012

Similar to Figure 42, Figure 44 showed three CBGs south of the Mississippi along Robert Street that were food deserts according to the bivariate LISA. These CBGs have good access to smaller grocery stores but have poor access to supermarkets by walking and public transit distance. From Figures 44 and 45, there are several CBGs in central St.

Paul that have low-high relationships, meaning that these CBGs have low deprivation but are next to CBGs with high deprivation.

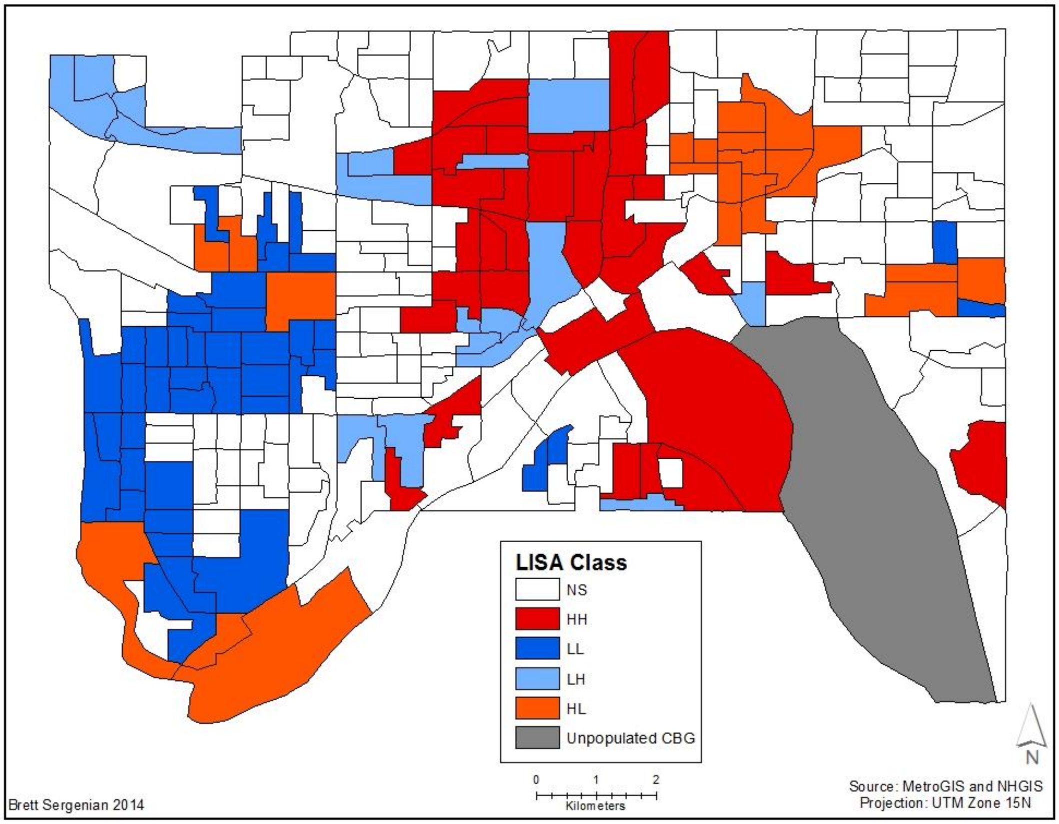


Figure 44. Bivariate LISA of public transit distance to the nearest supermarket, 2002

The results of the bivariate LISA analysis concur with the food desert criteria using distance thresholds with an inverse relationship between the distance to the nearest grocery store and socioeconomic deprivation. From the bivariate LISA analysis, the percentage of CBGs that were classified as high-high increased for all four categories except for supermarket access by public transit. The number of food deserts dropped from 31 to 30 or 0.2% from 2002 to 2012 when using the bivariate LISA analysis. For walking to supermarkets, the number of food deserts stayed the same but the percentage of food deserts increased by 0.45% since 2010 had eight less CBGs than 2000. When comparing access to grocery stores, the number of CBGs increased by seven CBGs for both walking and public transit.

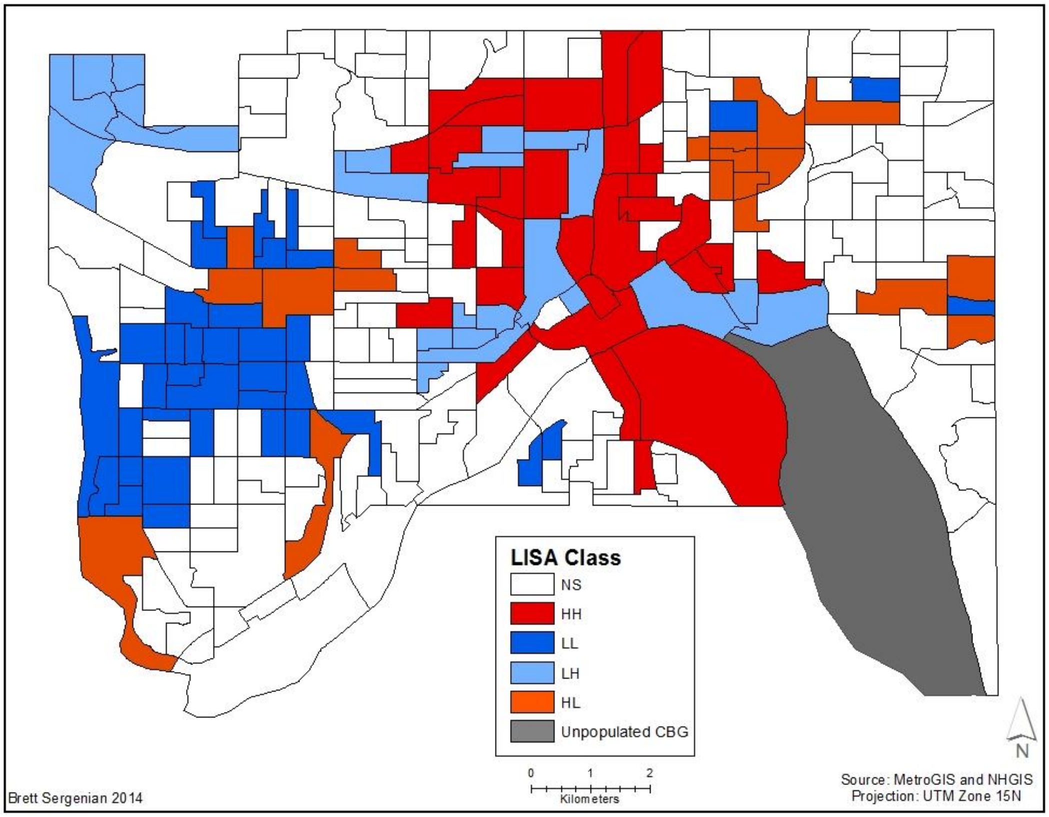


Figure 45. Bivariate LISA of public transit distance to the nearest supermarket, 2012

One exception was the additional food deserts identified by the bivariate LISA for grocery stores by walking and public transit distance. Compared to the food deserts identified by the quintile analysis, there was a more dramatic increase in food deserts from 2002 to 2012 from the bivariate LISA analysis. In Tables 13 and 14, the number of CBGs cannot be compared directly because the number of CBGs decreased from 258 to 250 from 2000 to 2010.

Table 13. 2002 Bivariate LISA Statistical Relationships

LISA Class	Walking Grocery Stores	Public Transit Grocery Stores	Walking Supermarkets	Public Transit Supermarkets
NS	183	181	145	151
HH	**2**	**1**	**29**	**31**
LL	9	8	41	38
LH	21	29	17	18
HL	42	38	25	19

Table 14. 2012 Bivariate LISA Statistical Relationships

LISA Class	Walking Grocery Stores	Public Transit Grocery Stores	Walking Supermarkets	Public Transit Supermarkets
NS	187	185	142	140
HH	**7**	**8**	**29**	**30**
LL	12	10	35	37
LH	16	20	21	23
HL	27	26	22	19

The results of the bivariate LISA analysis were summed to provide a more complete analysis of where the underserved areas exist in St. Paul for both 2002 and in 2012. In 2002, most of the food deserts when considering both supermarkets and grocery stores are still within central St. Paul, partially because of the poor access by public transit to the nearest supermarket. In southeastern St. Paul, two CBGs stood out as potential food deserts, because of limited access to the nearest grocery store by public transit and walking distances. In tract 374.02 group 1, to the north of CBG 374.03 group 3, the primary reason why it was classified as a potential food desert was a result of its centroid being on the eastern side of the CBG while the Byerly's is just outside of the western side of the CBG boundary. All of these patterns were displayed in Figure 46.

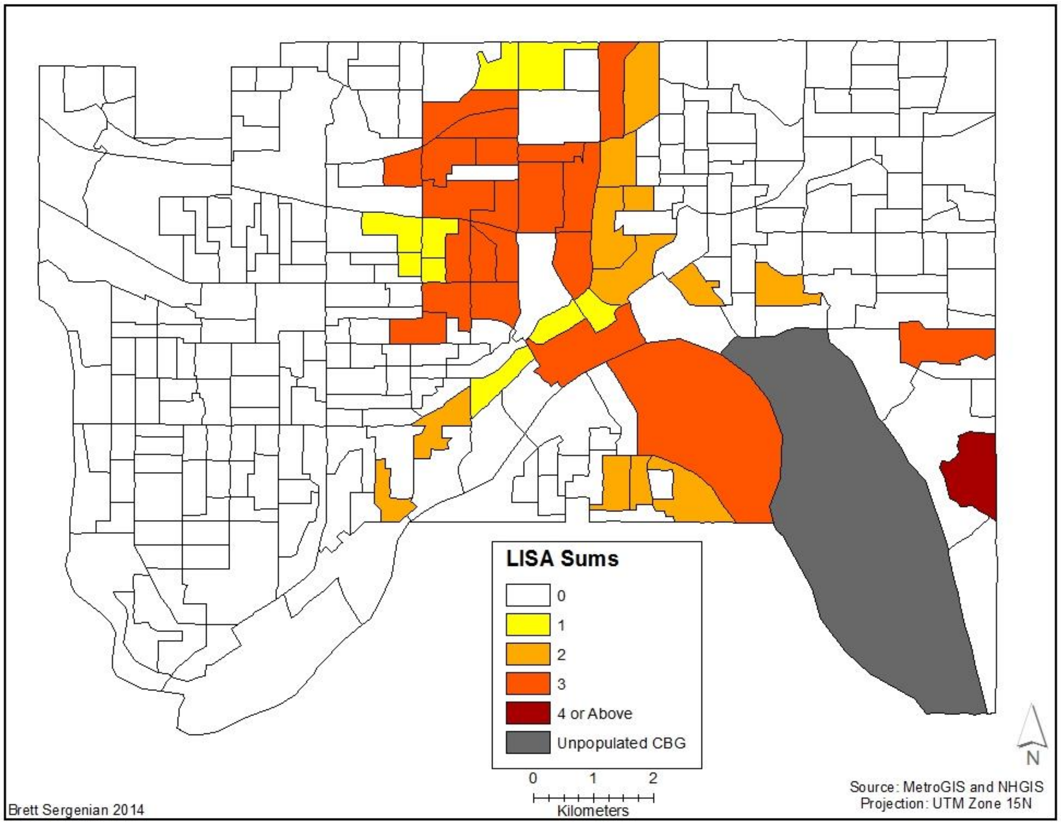


Figure 46. Weighted total of bivariate LISA high-high associations, 2002

In 2012, the patterns remained similar, with the exception that the CBGs in north-central St. Paul had several nearby grocery stores closures. This resulted in several additional CBGs in north-central St. Paul to have increased walking and public transit distances to the nearest grocery store. In southeastern St. Paul, the addition of Cub Foods on Old Hudson essentially eliminated the food desert in CBG 374.02 group 1, and dropped CBG 374.03 group 1 to a score of 4. Surrounding CBGs in the Battle Creek Neighborhood had increased SED index values compared to 2002, causing two CBGs to be considered potential food deserts (Fig. 47).

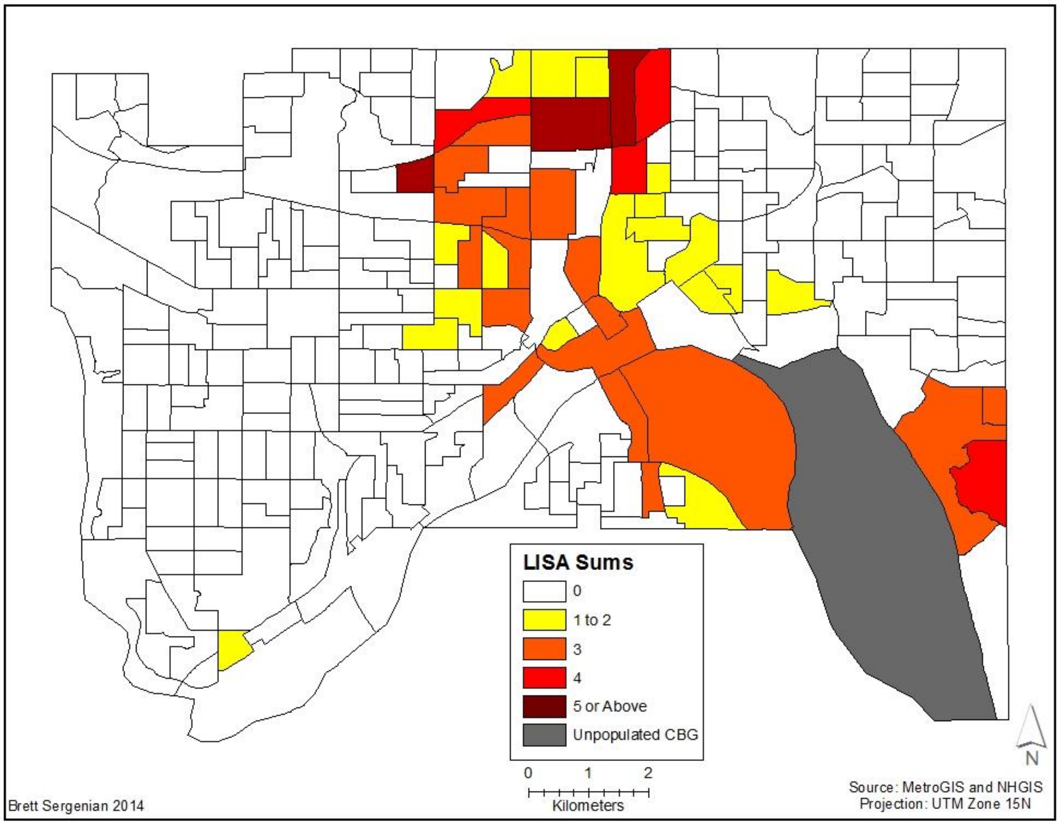


Figure 47. Weighted total of bivariate LISA high-high associations, 2012

For 2002, the area of focus for planners to ameliorate the impacts of food insecurity would be the CBGs in central St. Paul and the two CBGs in southeastern St. Paul with scores of four and six. In 2012, the most food insecure areas according to the summed bivariate LISA values are in north-central St. Paul. In 2012, there were seven CBGs that had a weighted score of four or higher compared to only one in 2002. These results show an increase of six potential food deserts with LISA sums above four, but further analysis is needed to determine if populations residing in these CBGs have limited access to healthy food options. The most socioeconomically deprived CBG in 2012, had a total weight of 5 in 2012, placing it behind two other CBGs in north-central St. Paul. Planners could potentially place mobile markets that accept electronic benefit transfer

(EBT) or SNAP dollars in those areas, if further research indicates that these populations lack access to fresh produce. Some of these CBGs that have sums of four or greater may have access to other sources of healthy food that were not included in this study.

CHAPTER V

DISCUSSION AND CONCLUSIONS

When measuring healthy food access by using all grocers as a supplier of healthy food, the results did not change dramatically by walking distance or by public transit from 2002 to 2010. The mean walking distances for 2002 and 2012 were 826 meters and 880 meters respectively. Accessibility to grocery stores and supermarkets by walking and public transit did not change significantly, according to the results of the paired t-test, despite the change in CBG boundaries. Other temporal food desert literature has identified both an increase in the number of food deserts and a decrease in the number of food deserts (Larsen and Gilliland 2008; Lu et al. 2012). The results of this study show a slight increase of food deserts, consistent with the Larsen and Gilliland (2008) study.

The two key trends that were identified in both 2002 and 2012 were that the most deprived CBGs had the best access to all grocers while the least deprived CBGs had the best access to supermarkets. These results are similar to what other studies have found, specifically Chung and Myers (1999), Morland et al. (2002), Powell et al. (2006), Larsen and Gilliland (2008), Sharkey et al.(2009), and Larson and Moseley (2011). Generally, most studies expect to find that socioeconomically deprived neighborhoods to have lower access to supermarkets, with several exceptions (Donkin et al. 2000; Smoyer-Tomic, Spence, and Amrhein. 2006; Apparicio, Cloutier, and Shearmur 2007). Since most supermarkets sell food at lower prices than smaller and mid-sized grocers, it was expected that the residents of CBGs in the fifth quintile were more likely to have significantly limited food options and potentially pay more healthy food, although past studies have been inconclusive (Chung and Myers 1999; Short, Guthman, and Raskin 2007).

The results for the two most deprived quintiles displayed starkly different trends for supermarket accessibility. For two most socioeconomically deprived quintiles, the results showed the fourth quintile and fifth quintile showing opposite trends. These results show a complex situation as the most deprived CBGs had least accessibility for three of the four distance measurements to the nearest supermarket for 2002 and 2004. The fourth quintile had the third best access by walking and public transit to supermarkets in 2002 and in 2012 it had the second best access to supermarkets by walking and public transit.

Public transit or walking may be the only viable option to access the nearest supermarket for those who reside in the most socioeconomically deprived neighborhoods, especially populations without vehicle access. For the populations that would likely use public transit the most; they have to travel the furthest of any quintile to reach the nearest supermarket. However, the fifth quintile had the best access to bus stops in 2002 and the second best access in 2012.

Of the 11 supermarkets that were open in 2002, two of them had closed prior to 2012. One of the supermarkets, Jerry's Newmarket in northeastern St. Paul was essentially replaced by Cub Foods a few blocks away. The closure Jubilee Foods in southwestern St. Paul was not replaced by any other supermarket in the area, significantly increasing the walking and public transit distances to the nearest supermarket for CBGs along West 7th street in southwestern St. Paul. The increase in walking distances for the first quintile could partially be attributed to the closure of Jubilee Foods. Two CBGs close to Jubilee Foods were in the fifth quintile in 2002.

For both 2002 and 2012 access to supermarkets, downtown and north-central St. Paul have the least access. Most of the food deserts by public transit to the nearest supermarket at 3,000 meters were in downtown St. Paul, Frogtown, and the North End for both 2002 and 2012. The only two CBGs that are food deserts at 5,000 meters were situated to the north of downtown St. Paul. The Gi* maps of supermarket access by walking and public transit clearly show CBGs in central St. Paul travel farther to the nearest supermarket than western or eastern St. Paul. These results are consistent with Larsen and Gilliland (2008) analysis of supermarkets relocating to the city fringes and suburbs to follow their customer base and for more inexpensive land. The only food deserts by walking and public transit were two block groups in southeastern St. Paul. By walking distance, most of the food deserts were concentrated in northern St. Paul. Most of the food deserts by walking and by public transit access to supermarkets at the 3,000 and 5,000-meter thresholds were in central and downtown St. Paul. The number of food deserts increased for the following categories: Walking to the nearest grocery store, walking and public transit to the nearest grocery store, and walking to the nearest supermarket.

From the mean distances for walking to the nearest supermarket for both 2002 and 2012, walking is not a viable option for most block groups. Other than the 47 CBGs within 1,000 meters in 2002, the rest of the city would likely drive, carpool, or use public transit to travel to a supermarket. For 2002, 42 CBGs were within 1,000 meters, and the majority of these were in the first quintile. The longer walking distances were expected as there were only 11 and 13 supermarkets within St. Paul for 2002 and 2012, respectively. For those who walk to the nearest supermarket, there is a limited amount of groceries that can be carried back to their residence (Hallett and McDermott 2010).

For some of the CBGs, public transit is a viable option to travel to the nearest grocery store. Several of the CBGs, it would be more efficient to access a grocery store by walking. This is because the nearest grocery store was not along a bus route or if the route to the nearest bus stop was also the bus stop closest to the nearest grocery store. If the bus route distance was less than 500 meters, it is probably more efficient to walk to the nearest grocery store than to use public transit. In 2012, there were 48 CBGs with their total public transit distance below 500 meters and 59 in 2002.

From 2002 to 2012, the overall public transit access to supermarkets improved slightly as the mean distance to the nearest supermarket in 2002, 2,751 meters, dropped to 2,688 meters in 2012. One explanation for the decrease in public transit distance to the nearest supermarket is the walking distance from the nearest bus stop to Jerry's Newmarket was 449 meters. In 2012, Cub Foods on Clarence Street had a bus stop nearly on-site, or approximately 15 meters by Euclidean distance to the geocoded location. However, the mean decrease in public transit distance did not reduce the number of underserved CBGs in 2012, primarily because the two additional supermarkets were not in north-central St. Paul.

The number of food deserts by public transit to the nearest supermarket at 5,000 meters was the same for both 2002 and 2012. For distance, a paired t-test showed the changes between 2002 and 2012 were not statistically significant for any of the distance measurements. Public transit significantly increased accessibility to grocery stores at the 3,000-meter threshold, with only one CBG considered a food desert by both walking and public transit distance in 2002. For supermarket access, public transit significantly reduced accessibility for all but two CBGs in 2002 and 2012 at the 5,000-meter threshold. In 2002, 88% of the grocery stores were within 100 meters of a bus route, and in 2012, 89% of all grocery stores were within 100 meters of a bus route.

The statistical analysis visualized which CBGs had high access to grocery stores, and which CBGs had high access to supermarkets. The Gi* statistic clearly visualized the CBGs that have to travel further to the nearest grocery store by identifying cold spots and hotspots. Maps of the bivariate LISA identified food deserts compared the relationship between socioeconomic deprivation and accessibility to grocery stores and supermarkets. A bivariate LISA showed an inverse relationship between distance to the nearest grocery store and socioeconomic deprivation. The bivariate LISA showed a positive relationship between distance to the nearest supermarket by walking and public transit. When all of the HH associations were summed for 2002 and 2012, parts of southeastern St. Paul and north-central St. Paul were identified as potential food deserts. In 2002, the highest sums were in southeastern St. Paul, but in 2012, north-central St. Paul had the highest sums.

The identified "food deserts" in this study are subjective to the criteria used to identify food deserts (Bitler and Haider 2009). Numerous studies only include full-service supermarkets as proxies for healthy food, which results in more food deserts than if all grocery stores are included (Larsen and Gilliland 2008; Regan and Rice 2012).

One big question from this study still remains unanswered. Do these results show that the most socioeconomically deprived CBGs have the least access to healthy food? None of the supermarkets included the mid-sized ethnic grocers and many of the smaller grocers could sell fresh produce. Without surveying all of the smaller grocers, it impossible to determine if they sell fresh produce. Several mid-sized grocers stocked fresh produce, specifically Dragon Star Oriental Foods, Double Dragon Foods, Sun Foods, and Shuang Hur. None of these mid-sized grocers met the criteria in ReferenceUSA to be classified as supermarkets, but Double Dragon Foods, Sun Foods, and Shuang Hur were either missing or their employee range was underestimated by ReferenceUSA.

If more grocery stores is not the solution to alleviate the effects of food deserts, than what are other alternatives? From the Ramsey County Food and Nutrition Commission survey, approximately one third of the low-income residents surveyed frequently purchased food at local farmers' markets (Ramsey County Food and Nutrition Commission 2013). The survey conducted by the Ramsey County Food and Nutrition Commission only included a sample size of 478 people.

It is unrealistic to expect that everyone in St. Paul should have access to a supermarket or grocery store within 1,000 meters (Larsen and Gilliland 2008). For some areas, this is simply not possible because there are no commercial zones or the lack of commercial zones in a particular CBG. Within St. Paul, the number of grocery stores has remained steady at 97 grocery stores for both 2002 and 2012, and this number is not likely to change significantly. Minneapolis had 22 fewer grocery stores in 2012 than in 2002 (2001-2002 Minnesota State Business Directory 2002; ReferenceUSA 2013).

Recent studies have implied that the number of grocery stores, especially smaller grocers is declining as they cannot compete with supermarkets (Larsen and Gilliland 2008). With higher real estate prices and more prohibitive zoning codes within inner cities, supermarkets will likely continue to locate in suburban areas of the Twin Cities (Larsen and Gilliland 2008).

This analysis had some key limitations because of the temporal analysis and because of time and cost restraints. Despite these limitations, this study provided results using GIS and geostatistical methods to identify key patterns of food accessibility in St. Paul between 2002 and 2012.

The fifth quintile of CBGs had decreased access for walking and public transit to all grocery stores and for public transit and walking distance to supermarkets. The mean distance to the nearest bus stop also increased for the fifth quintile suggesting that accessibility to healthy food options have been declining over the past decade. However, an independent t-test did not show that walking and public transit access to grocery stores significantly from 2002 to 2012. Perhaps if this analysis examined food accessibility over a longer period time, the change may have been statistically significant.

5.1 Limitations

CBG centroids are the origin instead of individual residences because of time constraints. Using a census block centroid would yield results at a finer scale, but there is not enough data for an analysis. CBG data cannot be scaled down to the census block level because of the MAUP (Sharkey et al. 2009). Population-weighted centroids were the best data available to represent proxies for residences at the block group level (Larsen and Gilliland 2008; Stein 2011). Another limitation is that some population weighted centroids are placed outside of residential areas but in between two residential areas Maantay, Maroko, and Hermann (2007). This occurred for several CBGs in St. Paul. For larger or elongated CBGs, the population-weighted centroid, some residences may be significantly closer or farther from a grocery store or supermarket than the population-weighted centroid.

This study analyzed data at the block group level, a commonly used census unit for many food desert studies (Sharkey et al. 2009; Eckert and Shetty 2011; Stein 2011). Census blocks or measuring distance from residential parcels would provide more accurate distance measurements and the data can be scaled up to the block group level. Conducting an analysis at the parcel or block level was not possible because of time and cost restraints. Areal interpolation of residential areas would provide more accurate measurements of distance from each CBG (Shannon 2013).

Ideally, a price or market basket analysis is conducted to provide data on food prices (Bader et al. 2010). The nearly 60% turnover rate of businesses from 2002 that did not exist in 2012 also complicates a price analysis. Only one known study, to the best of my knowledge has included a price analysis in a temporal food desert study. Larsen and Gilliland (2009) compared food prices before and after the farmers' market opened in East London. Produce selections often vary within chain supermarkets and smaller grocers are likely to have higher prices for their produce (Goldsberry et al. 2010). Supermarkets such as Whole Foods, Kowalski's Byerly's, and Lund's are considered luxury grocers, so the average price of item is likely to be more expensive than other chain stores in the Twin Cities (MPR 2013).

For simplicity and data availability purposes, I did not include the travel times and directions of bus routes for this analysis. The 2002 bus route shapefile did not provide any data on the average time it took to traverse a segment and the 2012 bus route shapefile only provided the hours of operation throughout weekends and weekdays. Ideally time would be included for this analysis to account for traffic volumes and speed limits.

The nearest grocery store or supermarket is not necessarily the preferred option for St. Paul residents (Goldsberry 2010). Numerous CBGs were routed to small ethnic grocers that may not be culturally acceptable to certain segments of the population. A resident may prefer to shop at an ethnic Southeast Asian grocery store rather than a chain grocer for additional choices on produce or seafood. Others may prefer chains stores to an ethnic grocery store. In many instances, shoppers prefer to purchase certain items at one grocery store and other items at another grocery store, even stores within the same chain (Goldsberry et al. 2010; Shannon 2013). Other shoppers may prefer Cub Foods to Rainbow Foods or vice versa (Hallett and McDermott 2010).

Studies such as Goldsberry et al. (2010) and Larsen and Gilliland (2008) used site visits to ensure the quality of their data. Site visits not only verify that a food establishment is in its present location, but it can also identify if fresh fruit and vegetables are sold. This study has conducted several site visits to grocery stores in St. Paul, Roseville, Maplewood, and other suburbs.

Secondary business data sources such as ReferenceUSA, business directories, InfoUSA, public health sources all have errors within in their databases. These errors occur by including closed food outlets or leaving out existing food outlets (Rossen, Pollack, and Curriero 2012; Ma et al. 2013). Other food outlets are misclassified by their NAICS codes or by their employee size (Morland et al. 2002; Ma et al. 2013). There are grocery stores that were likely to be missed and closed stores that may have been included. Potential supermarkets may have been missed if the NAICS codes were incorrect or if the number of employees were incorrect (Rossen, Pollack, and Curriero 2012). As mentioned earlier, Sun Foods and Double Dragon Foods were listed in ReferenceUSA as having one to four employees, but site visits proved that there were more employees. Dragon Star Foods had 45 employees, which puts it close to supermarket status, and given the errors in secondary business data sources, Dragon Star could have more than 50 employees. Other mid-sized grocers may be in a similar situation.

One problem with using the 2001-2002 Minnesota Business Directory is that it is impossible to verify if some of the stores were grocery stores and not food production companies, restaurants, or company headquarters, specifically the stores that have closed. The best methodology to alleviate this limitation is through local knowledge of the food landscape, which this study is lacking. Most food desert studies conduct their analyses in local locations (Block and Kouba 2005; Zenk et al. 2005; Widener 2013).

Without conducting site visits for all of the grocery stores, my study is unable to identify whether socioeconomically deprived populations have less access to healthy food. By physical distance the least deprived CBGs traveled the shortest distance to supermarkets and the most deprived CBGs traveled the farthest distance. This pattern was reversed for access to all types of grocery stores. Supermarkets normally stock produce, but smaller grocery stores may not stock non-perishable items (Morland et al.

2002). Mid-sized grocery stores are likely to stock produce, although produce could be more expensive at mid-sized grocery stores than supermarkets.

5.2 Future Research

Urban planners and potentially store location analysts can use this data to identify locations for an additional grocery store or supermarket or a mobile market. Limited commercial zoned areas in several CBGs, particularly CBG 374.03 group 3, will have to rely on alternative healthy food sources such as mobile markets and urban gardens. A mobile market system was developed during the summer of 2013 for low-income areas of St. Paul (Ramsey County Food and Nutrition Commission 2013).

My study did not include mid-sized grocers within the same category as supermarkets. If mid-sized grocers such as Double Dragon Foods on Maryland Avenue, Dragon Star Foods on Dale Street, and Kortes Supermarket on Randolph Avenue were included for the supermarket analysis, the results of my study would be quite different. A mid-sized grocery store and supermarket analysis could potentially be a more accurate indicator of healthy food access than just including supermarkets.

This research helps to fill the gap of food desert literature that includes both public transit and walking distances for food accessibility. Although similar research has already been done before by Larsen and Gilliland (2008), they did not include public transit for their 1961 analysis, likely a result of data accessibility. The inclusion of public transit reduced the number of food deserts significantly at 3,000 meters for all grocery stores and 5,000 meters for supermarkets. Other than Larsen and Gilliland (2008), no other known studies came to a similar conclusion. Most studies focus on quantifying food accessibility in its current state, or a snapshot in time (Morland et al. 2002; Block and Kouba 2004; Larsen and Gilliland 2008).

Future research could investigate food accessibility in St. Paul from a longer time span than a decade in St. Paul if the necessary data is available. Many of the same limitations in this study would exist in other temporal food desert studies. Other studies could examine the impacts of initiatives to alleviate food deserts in St. Paul, specifically the mobile markets that the Ramsey County Food and Nutrition Commission implemented in 2013. The food deserts identified in this study are listed as "potential food deserts" because there are sources of healthy food that were likely missed by this analysis.

Future studies could analyze the impact of farmers markets, urban gardens, restaurants, and other potential sources of healthy food on food accessibility in St. Paul. Farmers' markets and urban gardens are limited to only a few months of the year, but recent surveys of Twin Cities' residents show they are used by a third of the population (Ferris 2010; Ramsey County Food and Nutrition Commission 2013).

Another aspect of food accessibility that has yet to be examined is the impact of climate on how far people are willing to walk to obtain groceries. A survey of low-income residents asking how far they are willing to walk during the summer and the winter could yield interesting results. In northern U.S. cities and Canada, cold weather could serve as an impedance, and in the southern U.S., warm summers could limit the opportunities to bring perishable items back to their residence. These studies could use a cost raster analysis similar to Hallett and McDermott (2010) or add additional travel time to a Network Analyst model. The agent-based modelling techniques used by Widener, Metcalf, and Bar-Yam (2013) could be used to simulate different traveling speeds and costs of obtaining healthy food in winter.

APPENDICES

APPENDIX A
Descriptive Statistics

A. Paired t-test for SED Index values

Mean	2.372	2.391
Variance	0.949	1.314
Observations	216	216
Pearson Correlation	0.828	
Hypothesized Mean Difference	0	
df	216	
t Stat	-0.429	
P(T<=t) one-tail	0.334	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.668	
t Critical two-tail	1.97	

B. Paired t-test for walking distance to the nearest grocery store

Mean	841.862	890.099
Variance	381726.7	379838.059
Observations	216	216
Pearson Correlation	0.624	
Hypothesized Mean Difference	0	
df	215	
t Stat	-1.325	
P(T<=t) one-tail	0.0933	
t Critical one-tail	1.651972	
P(T<=t) two-tail	0.186526	
t Critical two-tail	1.97	

C. Paired t-test of public transit distance to the nearest grocery store

Mean	1,158.393	1,200.312
Variance	666149.7	608706.6
Observations	216	216
Pearson Correlation	0.584	
Hypothesized Mean Difference	0	
df	215	
t Stat	-0.846	
P(T<=t) one-tail	0.199	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.399	
t Critical two-tail	1.97	

D. Paired t-test for walking distances to the nearest supermarket

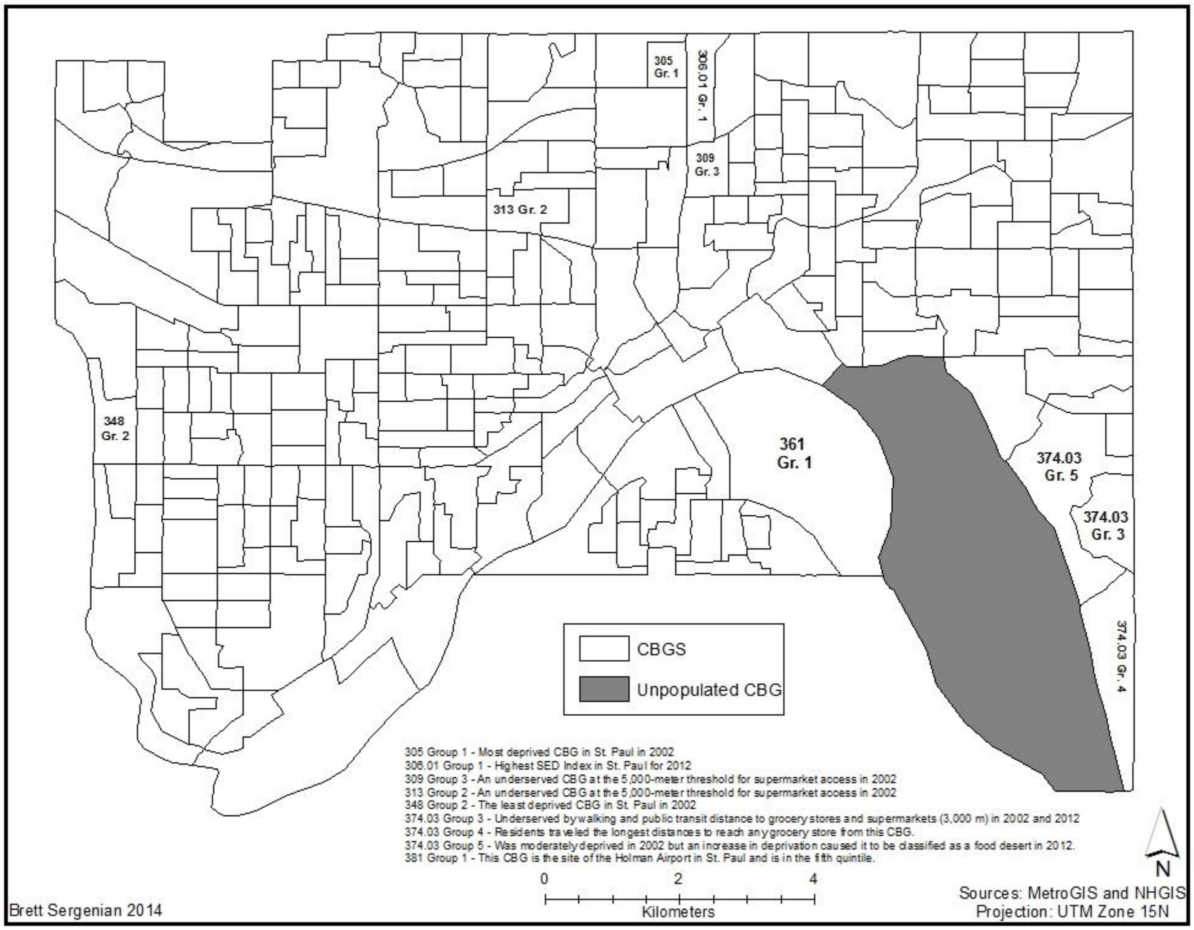
Mean	2,103.736	2,053.809
Variance	1142531	1268145
Observations	216	216
Pearson Correlation	0.831	
Hypothesized Mean Difference	0	
df	215	
t Stat	1.15	
P(T<=t) one-tail	0.126	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.251	
t Critical two-tail	1.97	

F. Paired t-test for public transit distance to the nearest supermarket

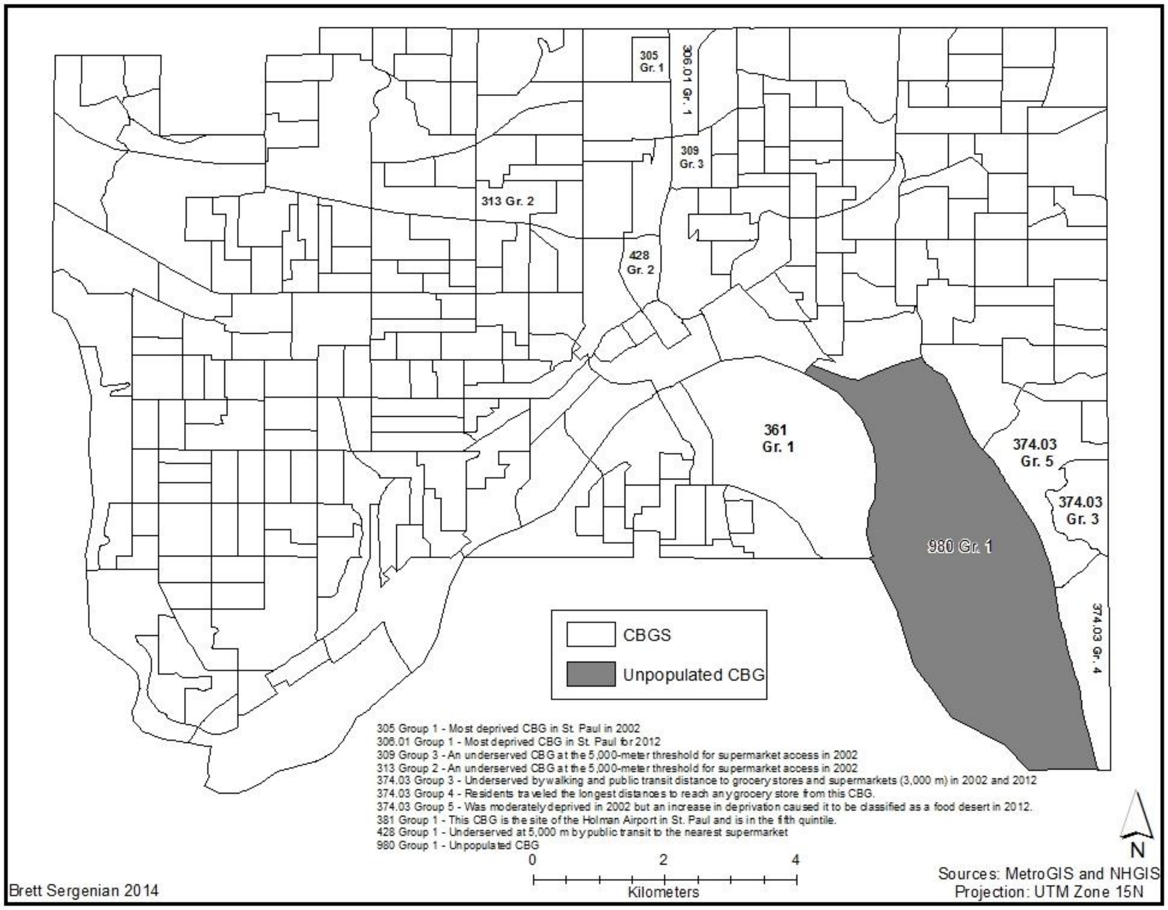
Mean	2,823.266	2,677.802
Variance	1950191	1734124
Observations	216	216
Pearson Correlation	0.62405	
Hypothesized Mean Difference	0	
df	215	
t Stat	1.84	
P(T<=t) one-tail	0.036	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.071	
t Critical two-tail	1.97	

APPENDIX B

CBG Reference Maps



Appendix A. Reference map of St. Paul CBGs in 2002



Appendix B. Reference map of St. Paul CBGs in 2002

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