Utilizing the Probability Gravity Model to Evaluate Supermarket Expansion in Southern Palm Beach County, Florida

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Introduction

Shopping, it is said, is the second most important leisure activity in North America next to watching television (Goss, 18). Shopping centers, and in particular supermarkets, lead a predominant role in the lives of the daily consumer. The evolution of the large retail grocery store center, which is essentially a modern adaptation of the historical marketplace, can be traced back to the early 20th century with the opening of the first Safeway and Piggly Wiggly stores. These first supermarkets were centered on the automobile, built according to a unified plan rather than as a random group of stores and owned and operated by a single entity who leased space to tenants. With the continued reliance of the motor vehicle as a primary means of transportation throughout the later half of the 20th century, the construction of supermarkets dramatically increased as the nation transformed itself into a suburban, consumer based society. Supermarkets, on average, range from approximately 40,000 to 60,000 square feet in size, depending on the location and type of amenities offered in the store. While current construction of the traditional supermarket has declined from its peak in the 1970's and 80's it is by no means dead as evidenced in the continued development of grocery store sites throughout the nation and in particular those areas where persistent suburban expansion exists.

One particular area in the United States where construction of the supermarket continues in earnest is south Florida. At current count there are 99 supermarkets within Palm Beach County, Florida. This is due to the fact that development of residential suburbs continues to grow at a rapid pace throughout all of south Florida and tend to be marketed, as can be shown by the location of recently opened stores, to those in the middle to upper middle class or to those who have just retired. Both these segments of the population have a rather

large amount of disposable income and therefore, according to the contemporary retail business marketing, are well served by large retail centers.

The process of determining potential sites for supermarkets in Palm Beach County, or anywhere else across the nation, has not changed a great deal in the past 50 years. In fact most if not all real estate market analysts continue to utilize many of the same ideas created by the pioneers of business geography: Homer Hoyt, William Applebaum and W.J. Reilly. Hoyt, in particular, focused on the development of retail centers across the United States at a time when shopping centers were just beginning to take hold and pioneered the idea that retail site selection required the following (Thrall, 1997,1):

1) Estimation of demand
2) Identification of the retail outlet's trade area or market hinterlands
3) Determination of the appropriate size of the retail market
4) Estimation of the optimal location to obtain maximum revenue
5) Consideration of specialized and perhaps unique local market conditions
6) Consideration that demographic patterns may change in time

Reilly's influence on retail market analysis was the application of Newtonian physics to measure market areas. In particular, Reilly adapted Newton's law of gravity to calculate the market area surrounding a shopping center (Thrall, 1997, 2). This adaptation was based off work by revolutionary 19th century social scientists who were the first to adapt Newtonian measurements of gravity to analyze local human phenomena. The development of the "gravity model" from these studies has been utilized in numerous fields to explain issues such as migration and transportation modeling.

The use of models, particularly in supermarket site location analysis, has dramatically increased with the use of Geographical Information System (GIS) software. One of the greatest advantages of GIS is the ability not only to measure space accurately in an absolute (x.y) but also in a relative (distance from x,y) manner (Thrall, 1997, 2). Therefore, many time consuming mathematical models, such as the gravity model, can be much easily derived for a particular area than by past traditional methods. This in turn has allowed for a greater utilization of the gravity model by retail market analysts or others not skilled in solving difficult mathematics equations.

The purpose of this paper is to analyze the estimation of demand for supermarket sites within a particular study area in southern Palm Beach County, Florida through the identification and modeling of trade areas based on each grocery store's overall square footage. These trade areas will then be analyzed with residential property values in order to determine specific spending patterns for each supermarket. This study has been undertaken in order to obtain a better understanding of the various market forces involved in retail site analysis as well as to provide a preliminary assessment of potential future supermarket sites within southern Palm Beach County based on existing capacity.

Methodology

Supermarket Sites

The first step in locating potential supermarket sites is to acquire the location of existing grocery stores not only for the study area (Figure 2) but for Palm Beach County (Figure 1) in it's entirety. This was accomplished by first determining what supermarket chains are located in Palm Beach County. A qualitative "drive by" analysis was performed at various locations of the county and it was determined that there are three primary supermarket chains in the area: Publix, Winn Dixie and Albertsons.

Once this information was obtained, the exact address of every supermarket chain could be located through each company's web site. In all, 99 supermarket locations were found between these three grocery store chains for Palm Beach County. The addresses for each supermarket were inserted into a database along with the particular name of the supermarket (ex. Shoppes of Madison Green Publix), store type (ex. Publix, Winn Dixie, Albertsons) and overall square footage if available. This last figure was needed to assist in the creation of the gravity surface for each location.

Once all the information was inserted into a database, the data was geocoded using the geocoding engine in ArcMap with an accurate road coverage of Palm Beach County provided by the Palm Beach County Department of Engineering. When first performed, this yielded a match ratio of 85%. The remaining unmatched supermarket locations were then interactively matched using a variety of criteria for a final match percentage of 100%. See Figure 1 for a location map of all supermarkets in Palm Beach County sorted by type.

Parcel Coverage

A digital parcel coverage was obtained for Palm Beach County through the assistance of the Palm Beach County Property Appraisers Office. This data coverage depicted all property parcels regardless of type within the confines of the county. Unfortunately, the only attribute information attached to the coverage was parcel type (residential, commercial, industrial, etc.). Information needed to perform the gravity model analysis (assessed value and/or market value) could not be obtained from the Property Appraisers office.

In order to reduce the size of the parcel coverage as well as to constrain the dataset for the specific purpose of analyzing residential lands, all residential land located within the study area was queried out from the main dataset. The final output was then utilized in the final analysis of grocery store spending.

The Gravity Model

The gravity model is a mathematical model which was created to represent a wide range of flow patterns in human geography. A variety of subjects such as migration routes, telephone traffic, passenger movements, commodity flow, etc. have been analyzed using this particular model (Johnston, 320). This model is based on Newton's hypothesis that interaction between two objects is directly proportional to the mass of the objects and inversely proportional to the distance between the two objects. Therefore, as distance increases – all other things being equal – the interaction between the two objects decreases. Conversely, as mass increases, so does the interaction between the two objects (Thrall, 1997, 3).

As previously mentioned, Newton's original equation was derived to measure gravitational forces. This formula can be interpreted as (Johnston, 320):

$$Gij = gMiMj/dij^2$$

G = Gravitational force between two masses
Mi, Mj = Masses
G = Gravitational constant
D = Distance between two masses
i,j = locations or bodies

Reilly, as well as other market analysts, were able to modify Newton's formula to account for the measurement of interaction between places where interaction increases as a multiple of the masses involved and decreased as distance separates the places: (Thrall, 1997, 4):

$$Tij = PiPj/dij$$

Tij = Measure of the total interaction between places i and j
Pi, Pj = Populations
d = Distance separating the places
i,j = places

From this formula, interactions between populations decrease from distance at a rate of dij^-1 and therefore must decline at a rate equal to the square of the distance.

This basic formula, while still valid, was subject to modification in order to more accurately measure interaction between two phenomena. The formula Tij = PiPj/dij is typically only utilized today to measure the *friction of distance* – the resistance to or the willingness of customers to travel, as a square of the distance between two places. Not all phenomena, especially in retail activities, have the same friction of distance. Therefore, the original formula can be modified to include friction of distance as dij^- β (Thrall, 1997, 4).

In addition, populations typically are not equal when forecasting interaction. Populations with higher incomes and greater education would likely have more interaction with other places than would places with populations of lower incomes and less education. Therefore, weights were placed at the population of place i by the amount of exponent α and at

the population of place j by the amount of exponent μ. The larger the amount of the exponents, the greater the attraction or propulsion of the population to interact.

A final modification to the original equation was needed so that calculations generated from this formula could be interpreted with a known scale or unit of measurement. A constant of proportionality, or k, was added to the formula to accomplish this. This revised formula is among the most applied geographic models in business geography (Thrall, 1997, 4):

$$Tij - kPi^{\alpha} Pj^{\mu} / dij^{\beta}$$

Research/Analysis

All relevant data to the project (point supermarket data, road coverage, study area boundary) was added in ESRI's ArcMap GIS software. As a first step in the creation of gravity surfaces for each grocery store located within the study area, straight line surfaces were created for each of the points using the Spatial Analyst extension available in ArcMap (Figure 4). This surface is essentially a raster buffer of the selected grocery store point based on parameters such as cell size and surface area extent. For this project, a cell size of 100 was utilized to produce a smooth surface and the extent of the surface was set to cover the entire county. Straight line surfaces were created for each of the supermarket points within the study area.

Once the straight line surfaces were created, analysis could begin on creating gravity surfaces for each point. This was accomplished by first using the Raster Calculator function in Spatial Analyst to calculate the specific gravity for each supermarket point based off the straight line surfaces and the square footage of each supermarket. Unfortunately, the square footage figures for each supermarket could not be obtained. Therefore, an average square footage figure of 50,000, which is the average size of supermarket structures in the United States, was employ for this analysis. The formula utilized for this calculation (Sq. Ft. of Supermarket A / Sqr (Straight Line Surface of A) produced a specific density or gravity surrounding that specific point. The surface created from this calculation did not produce anything that could visually analyzed, however, it is required in order to create a accurate gravity surface.

At the completion of creating the specific gravity surfaces of each point, a surface was created utilizing all the specific gravity surfaces with the formula (specific gravity surface of supermarket A + specific gravity surface of supermarket B + specific gravity surface of

supermarket C, etc.) until all the specific gravity surfaces were added together. This composite surface, again, while not visually discernable, was then incorporated into the final step in the creation of gravity surfaces.

To create the final gravity surfaces for each point the previously created specific gravity surfaces for each point were divided into the composite surface using the Raster Calculator. The formula for this procedure was (Specific Gravity Surface / Total Gravity Surface Composite). The purpose of this formula was to compare the specific gravity surface of each supermarket in the study area against the specific gravities of all other supermarkets within the area. The surface created from this analysis (Figure 5) gives an accurate spatial depiction of the gravitation influence each supermarket has in comparison to others within the same market. As Figure 6 shown in detail, the calculation produces a smooth gradient, depicting areas where the gravitational attraction is high in lighter shades to those where the gravitational attraction is lower in darker shades. Figure 7 depicts all gravity model surfaces created for each supermarket point within the study area.

Once the gravity surfaces were created, analysis could then begin on the amount of spending generated by residences surrounding each supermarket within the study area. This was accomplished by incorporating the residential property parcel coverage. Unfortunately, the market values for each parcel could not be obtained from the Palm Beach County Property Appraisers Office. Therefore, an average market value cost of $280,000 was given for each property within the study area. Because most of the housing in this area has been recently constructed and caters to the upper middle class and retirement communities, it is believed that the average value is an accurate depiction of the area. However, it is known that not all housing has equal value due to location, amenities, etc. causing temporal variations of differing sale

and market prices. Therefore, this model is not a true depiction of spending values within the study area.

The mean average of distance based on the gravity surface to each specific supermarket within the study area was calculated (Figure 8) for the parcel coverage. This mean average was derived from the gravity surfaces for each point and therefore correlates exactly with the surface. The formula (Market Value * Mean Value) /3 *.1 was then utilized to creating a spending surface using the residential parcel coverage. The Market Value ($280,000) and Mean distance value to the nearest supermarket for each property was calculated and divided by 3 (3 being an average real estate determination of the amount of annual gross income of a residential property owner, better depicted as Market Value / 3 = Gross Annual Income). The .1 in the formula represents the average annual household spending towards groceries. Literature on this figure ranges from .7 (8%) to .13 (13%) of annual household income .10 (10%) was used as an average of these figures.

The final surface created (Figure 10) depicts the average amount spent per residence. Because an average figure was utilized to determine market value, the surface does not accurately represent spending. What is does represent accurately is the fact that more is spent by household closer to a local supermarket than to those farther away. By analyzing the spending surface, it was determined that each supermarket received approximately $23,678,111 of revenue based on the surface calculation. However, this figure is much higher than the $12,000,000 on average of revenue generated by supermarkets nationwide. This discrepancy again can be attributed to the fact that the actual market values for each property were not utilized.

Figure 11 depicts the overall modeling diagram for this project.

Conclusion

Based on the results of this project, use of the gravity model in analyzing the estimation of demand for supermarket sites can be accomplished easily and accurately so long as precise data exists for both the supermarket and residential properties. As evidenced in this project, missing data, especially when determining surface spending, can be greatly altered based on the data (or lack of data) received from a government agency or vendor.

However, there are a number of issues with using the gravity model in forecasting sales or attendance besides the aforementioned availability of data. A major concern with using the gravity model is that the model assumes a uniform surface, devoid of any major impediments such as canals, limited access highways and physical landforms such as lakes, mountains and rivers. These barriers, depending on size and location, can seriously alter the amount of traffic going to a particular supermarket. In some instances, customers might travel farther in order to avoid issues such as traffic congestion or delays based on the time to cross a mountain or to locate a bridge to cross. This is the reason why ring studies have, for the most part, been replaced by drive time analysis in order to best determine where a customer will shop.

Another issues with the gravity model is that is does not take into consideration personal choice preference. In south Florida, there is a definite bias in many communities towards shopping at a Publix supermarket rather than at a Winn Dixie or Albertsons. This is based by many consumers on the belief that the Publix supermarkets are cleaner, more friendly and offer a wider variety of goods. There seems to also be a correlation between race and supermarket patronage. Publix supermarkets, in general, are located in areas considered middle to upper middle class in status. Because these income classes tend to be predominately white in south Florida, there is a definitely a higher propensity of white customers at a Publix

supermarket than compared to their counterparts. Winn Dixie and Albertson supermarkets, conversely, tend to be located in lower to lower middle class neighborhoods and these areas tend to be dominated by minority families. While this certainly should not be a limiting factor in determining store patronage, many consumers unfortunately feel more comfortable in supermarkets with like racial characteristics, even if it requires a longer drive from their residence.

Nonetheless, gravity model surfaces are a good first predictor in determining consumer bias based solely on location to a supermarket and should continue to be used in retail assessment. When utilized with other models, such as spatial interaction or diffusion analysis, an accurate determination of customer patronage can be provided. While the utilization of gravity models in retail site analysis does not provide all the answers, it does give the business geographer a better understanding of the forces at work within a specific study area.

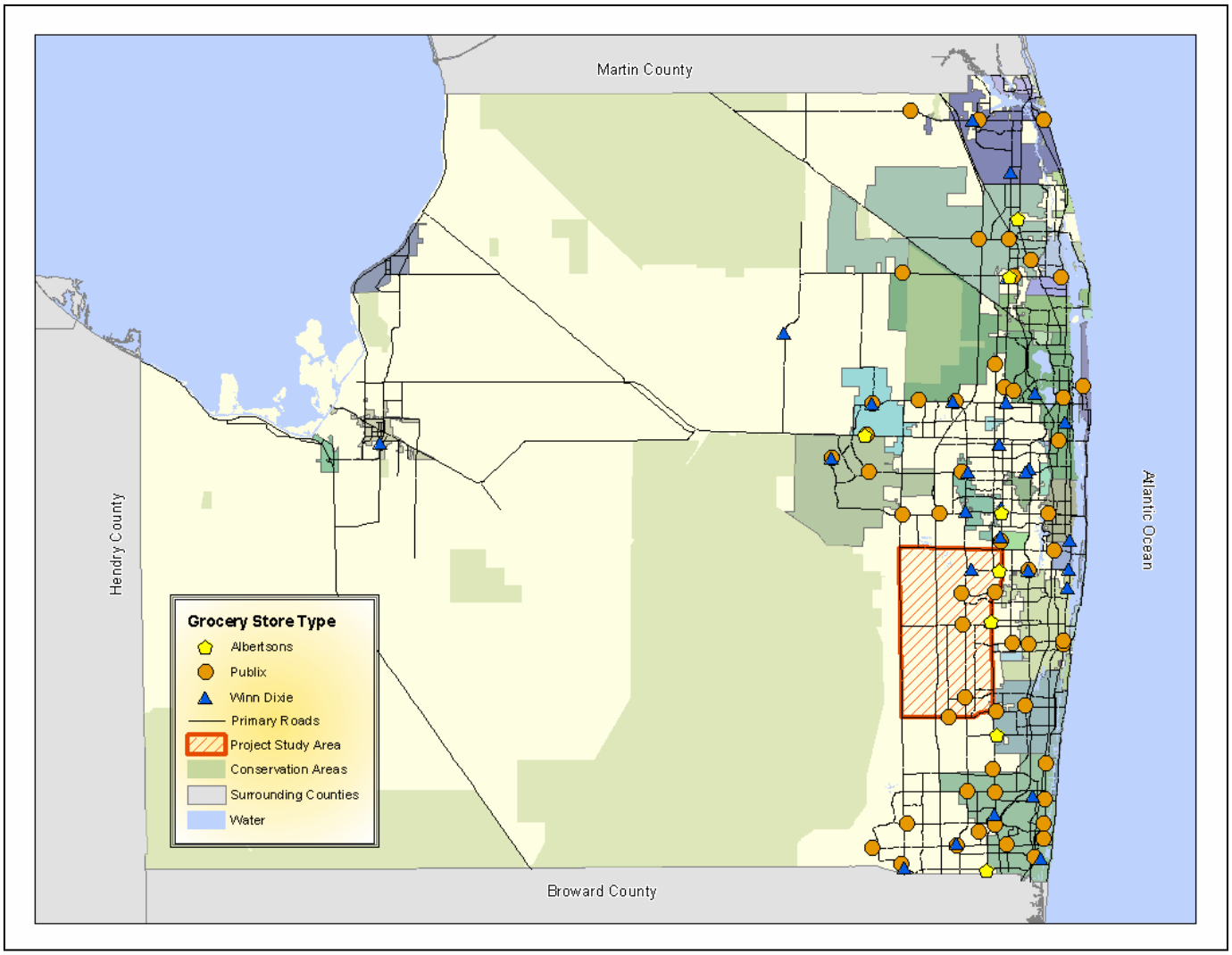

Figure 1: Location map of Palm Beach County, Florida with geocoded supermarkets broken down by type.

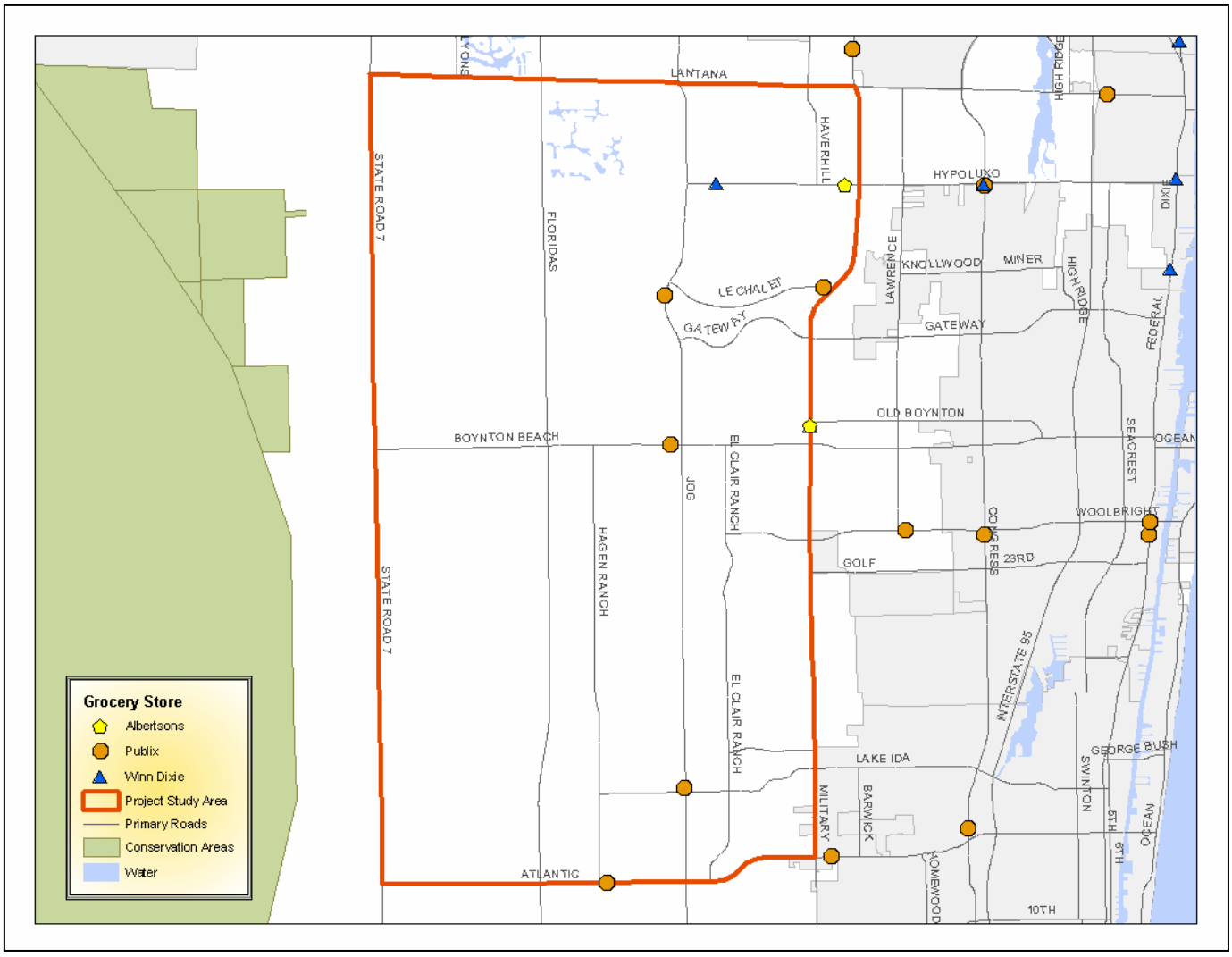

Figure 2: Location map of study area in southern Palm Beach County, Florida with geocoded supermarkets broken down by type.

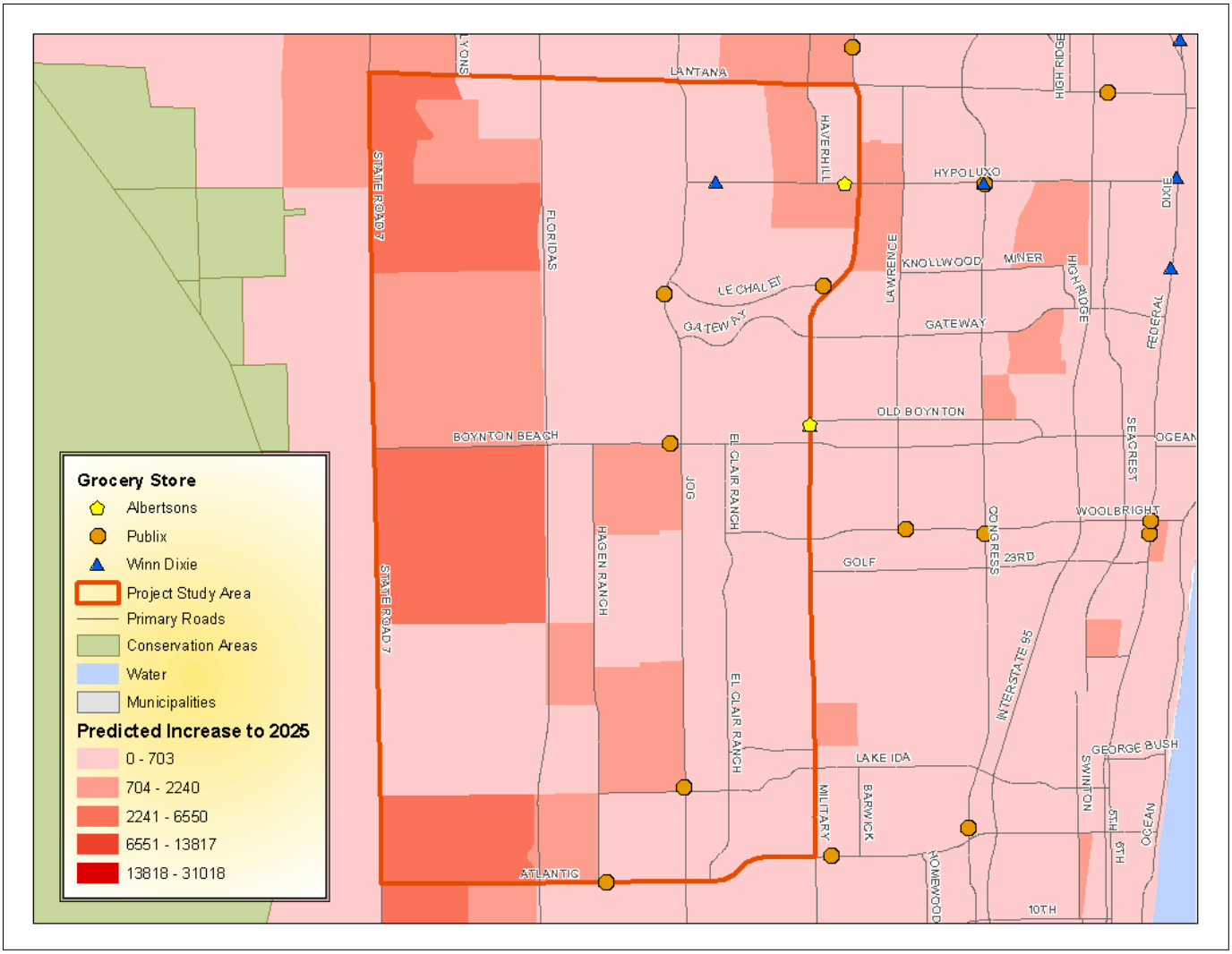

Figure 3: Population increase by Traffic Analysis Zone (TAZ) from 2003 to 2025 within study area in southern Palm Beach County.

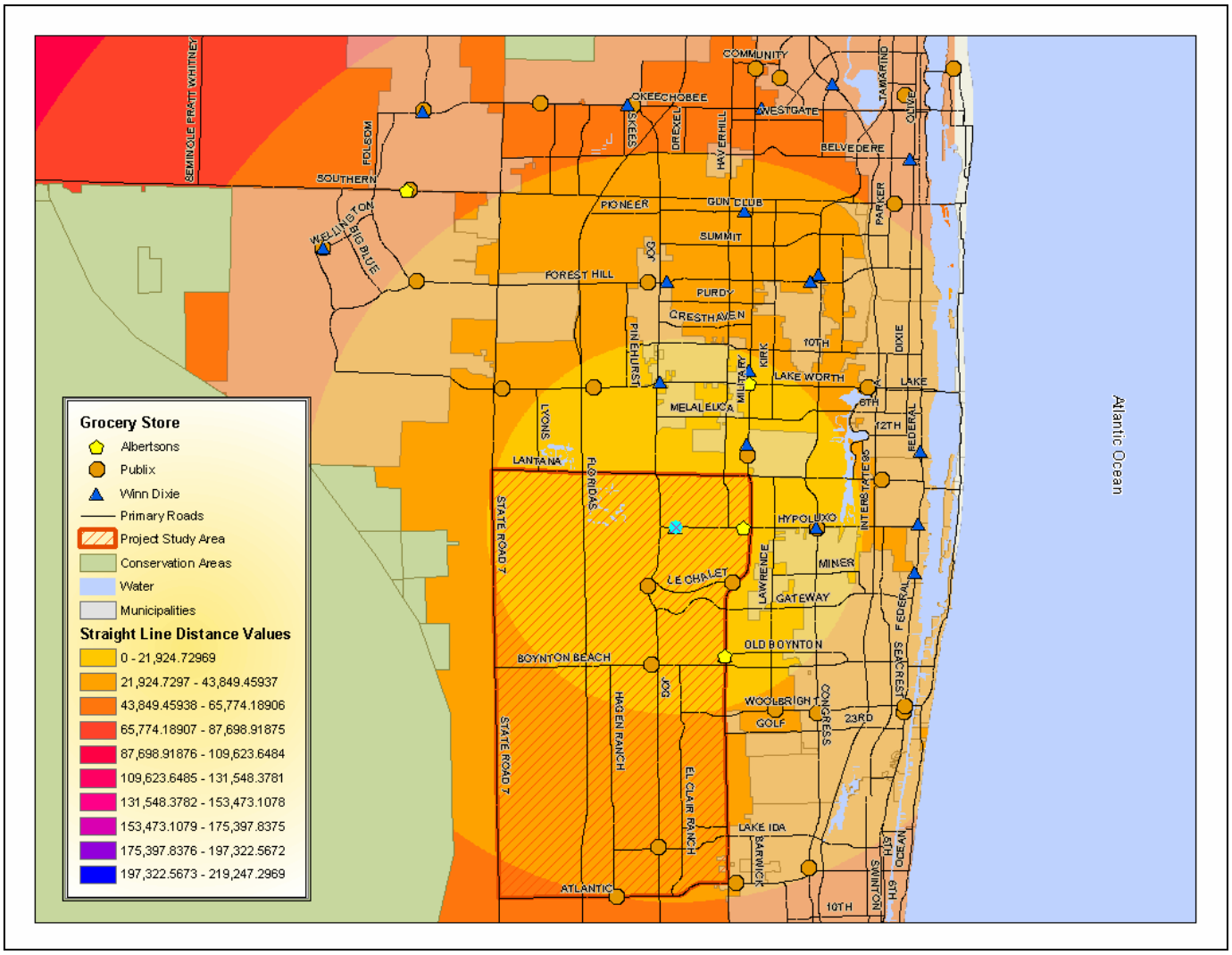

Figure 4: Straight line distance surface of Winn Dixie grocery store located within study area.

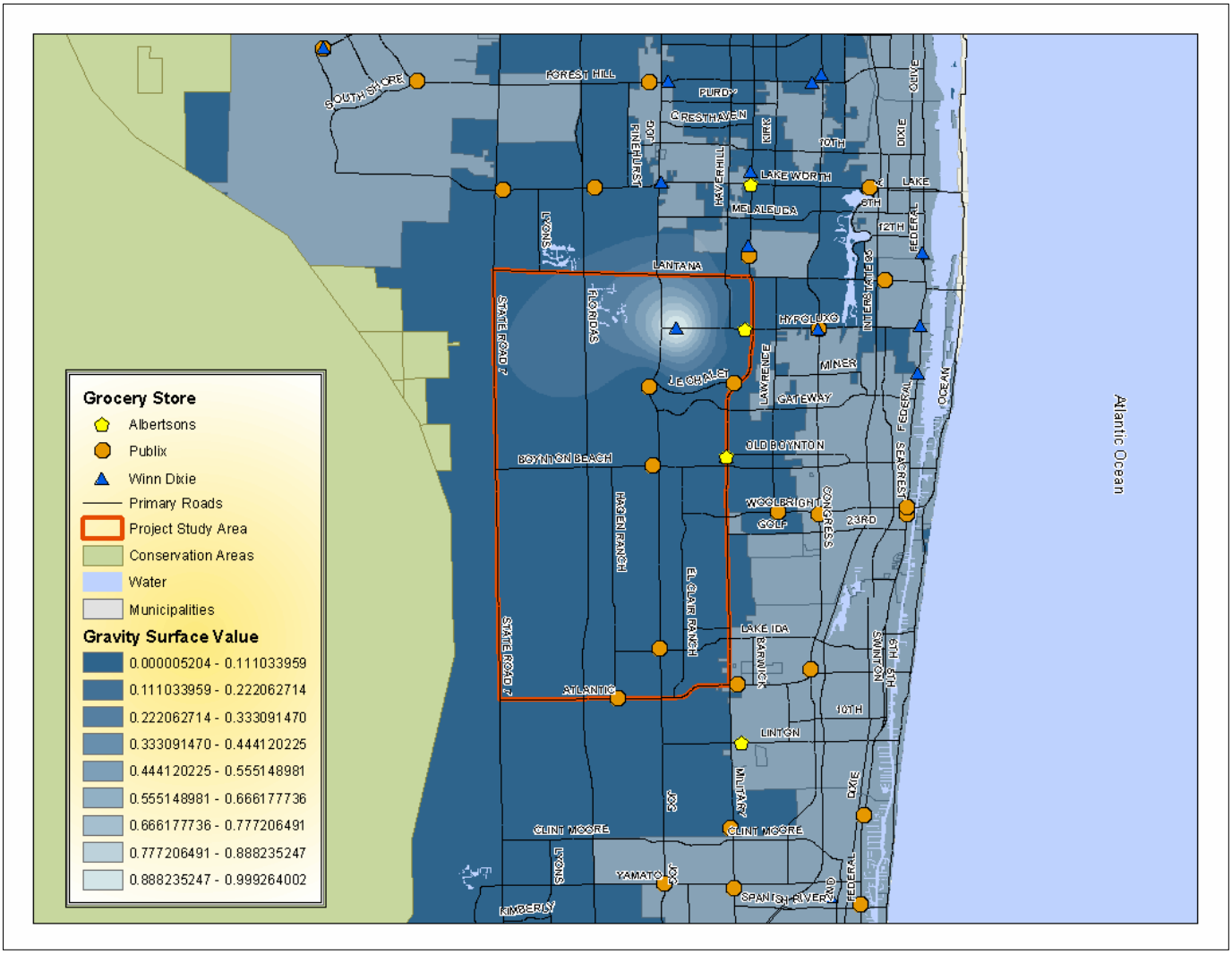

Figure 5: Gravity model surface of Winn Dixie grocery store located within study area.

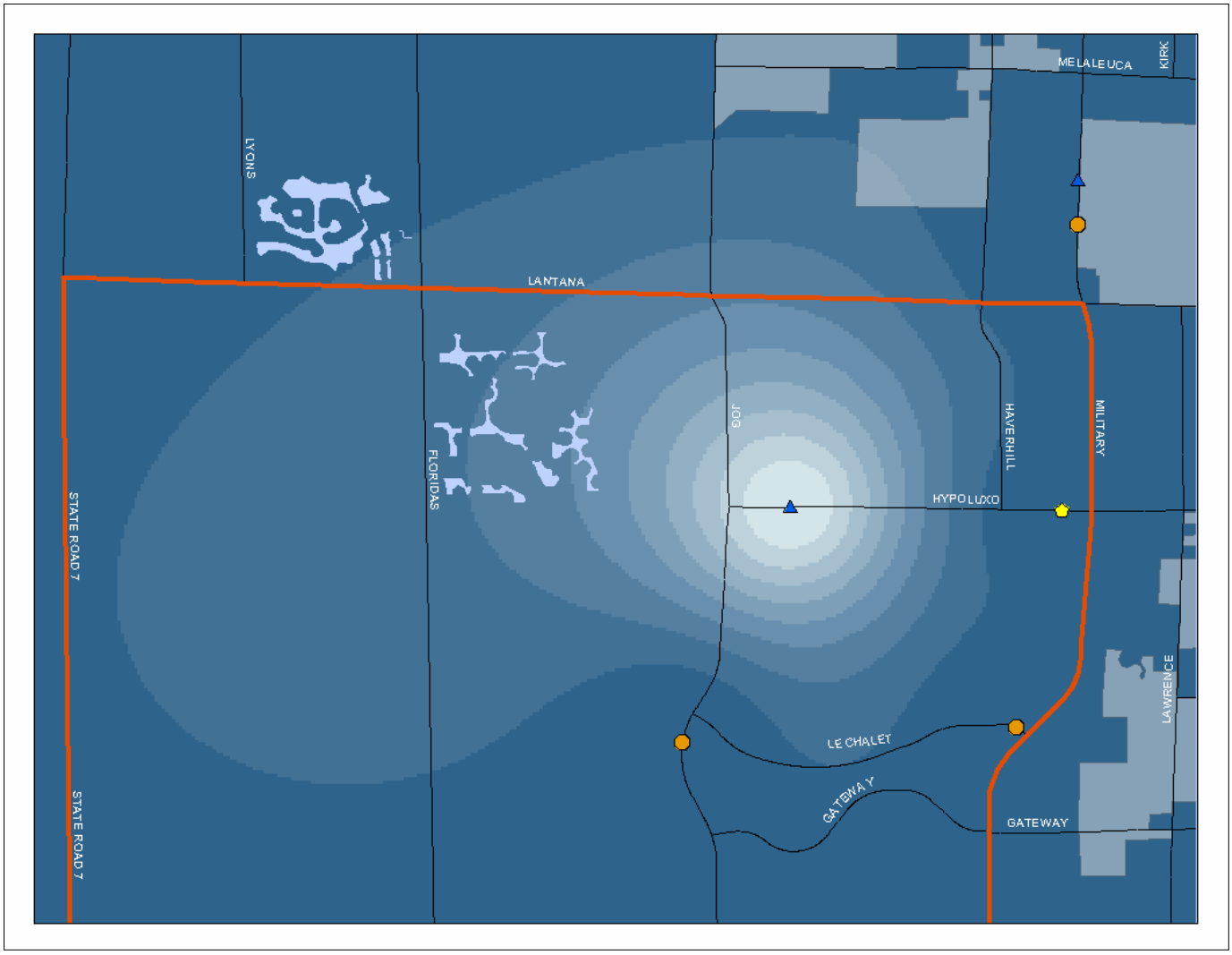

Figure 6: Detailed gravity model surface of Winn Dixie grocery store located within study area.

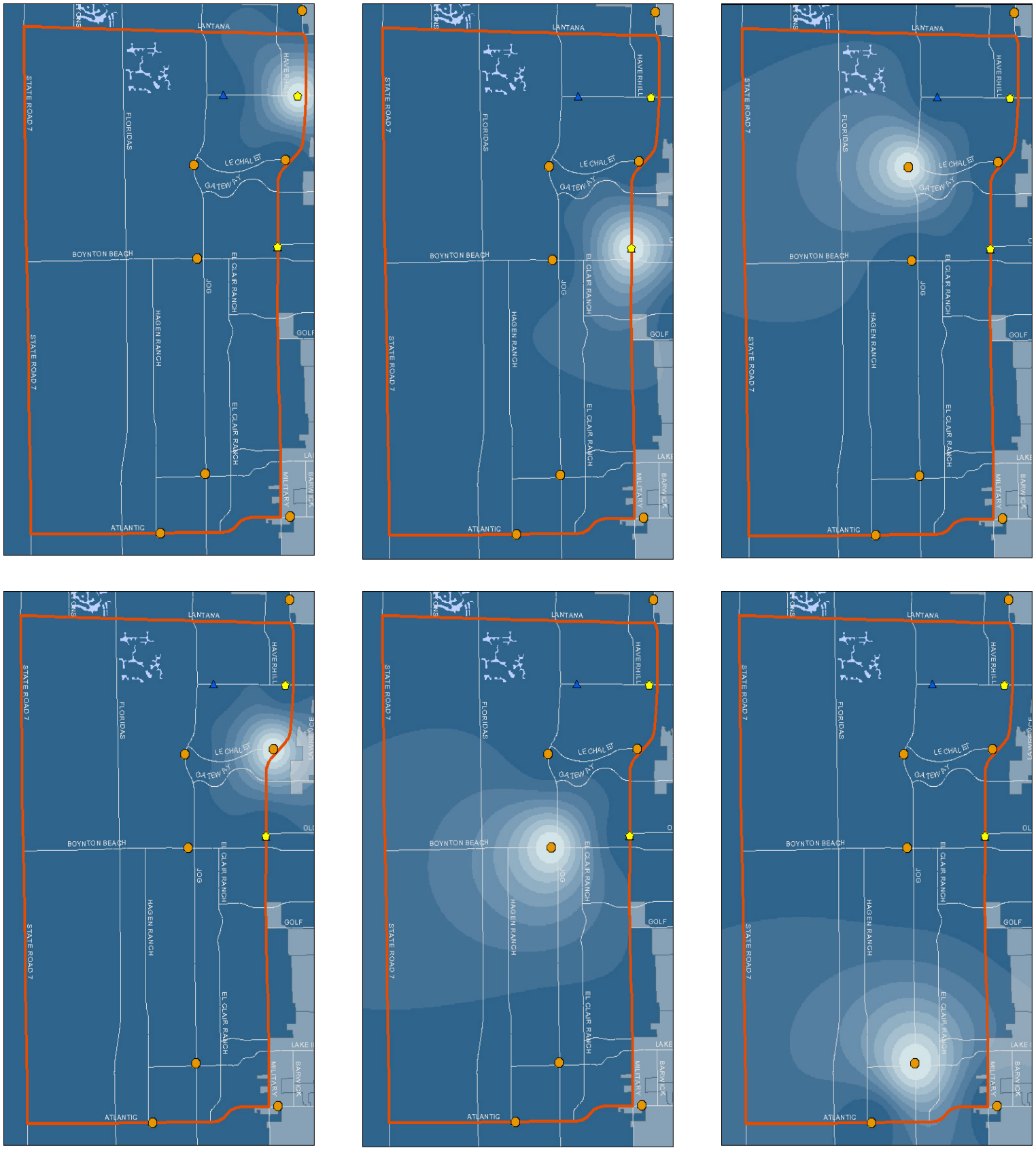

Figure 7: Gravity model surface of supermarkets located within study area.

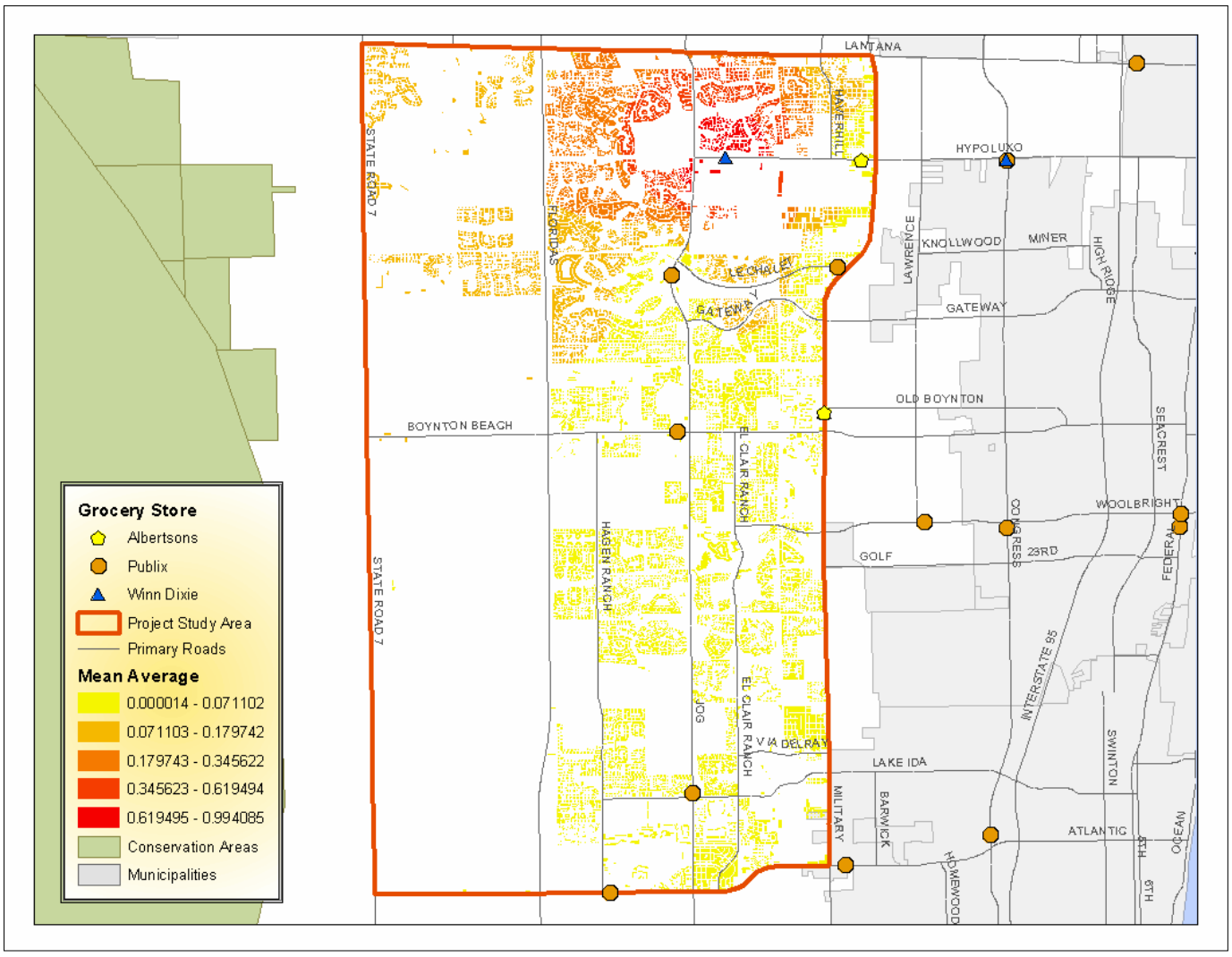

Figure 8: Mean average of residences based on distance to Winn Dixie supermarket.

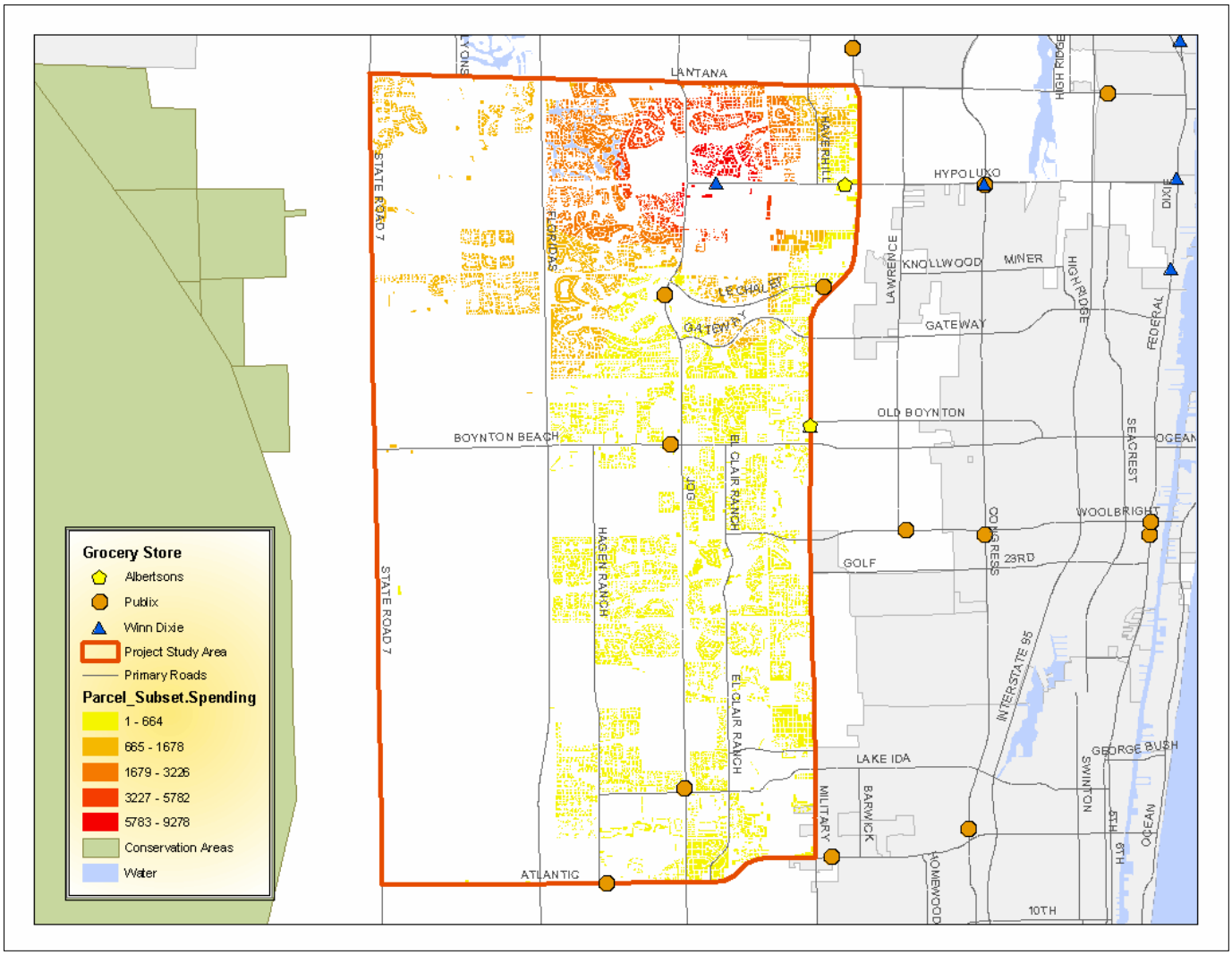

Figure 9: Consumer spending based on market value of residential parcels. Parcel coverage combined with gravity model surface of Winn Dixie grocery store located within study area to produce this analysis.

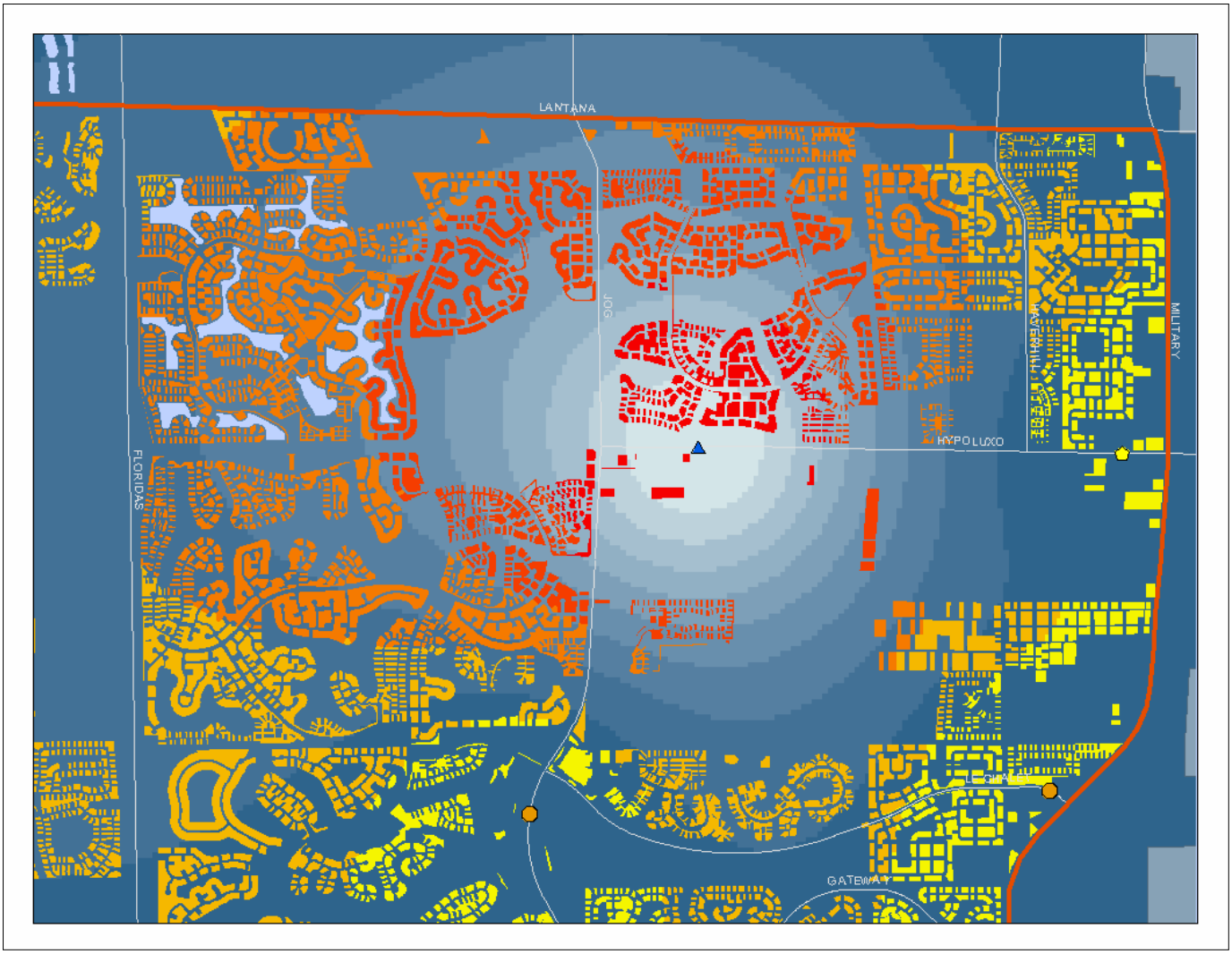

Figure 10: Detailed view of consumer spending based on market value of residential parcels.. Parcel coverage combined with gravity model surface of Winn Dixie grocery store located within study area to produce this analysis.

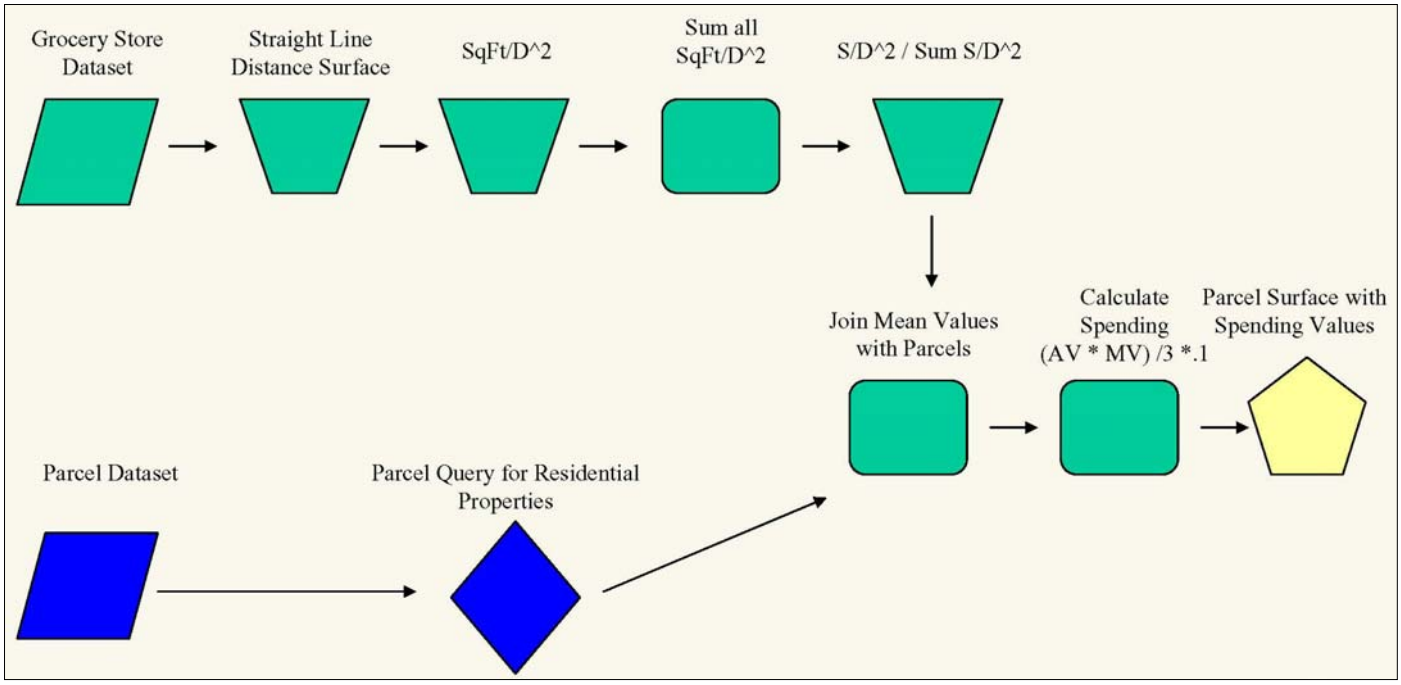

Figure 11: Overall modeling diagram of project.

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