# SUITABILITY STUDY FOR A BICYCLE SHARING PROGRAM IN SACRAMENTO, CALIFORNIA

by

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## Executive Summary

This report presents the findings of a study of local conditions in Sacramento and how they might support a bicycle sharing program in the near future. While past studies have had to rely on observations from European systems, this project makes use of recently-released data from the "Nice Ride" program in Minneapolis, Minnesota. Through the evaluation of actual experiences from this program, the factors that influence bike-share ridership in a U.S. city can be more fully understood and used to accomplish the following objectives:

http://www.ktis.fm/2010/10/hop-a-bike-and-pass-it-on-in-minneapolis/

- Identify the most suitable locations for a bicycle sharing program in Sacramento
- Recommend a program service area based on these findings
- Estimate the number of bike-share rentals that can be expected within this service area

Through these tasks, this study offers a thorough understanding of how a bicycle sharing program might look and operate within the Sacramento context. The results of this analysis, as summarized in the sections that follow, will allow local planners and officials to make well-informed decisions as they consider investing in a bicycle sharing program to enhance the sustainability and quality of life of their city.

### ***What are the Factors that Influence Bike-Share Ridership?***

To answer this question, this study analyzes the bicycle sharing program in Minneapolis using August 2010 rental data. Each of the program's 65 stations are mapped and evaluated based on surrounding destinations and a variety of demographic, socioeconomic, and transportation factors thought to be important in explaining ridership. The relative influences of these characteristics on bike-share rentals are then evaluated to identify the conditions that make an area "suitable" for bike-share use and to develop a model for predicting rentals in Sacramento.

This analysis suggests that the following seven characteristics are important in determining how suitable an area is for bike-share use:

- **Job density**
- **Non-auto commute levels**
- **Median income**
- **Proximity to parks**
- **Density of high-income jobs**
- **Minority population**
- **Proximity to rail stops**

In addition to these suitability factors, the results indicate that the following factors are important in explaining ridership patterns:

- **Retail density** has a positive effect on bike-share rentals
- Rentals tend to be lower in areas where a large proportion of households have **low access to vehicles**
- Rentals tend to be higher at stations that offer a greater **number of bike-share spaces**

Based on the seven key factors identified for Minneapolis, bike-share suitability scores are calculated and mapped across the Sacramento study area. These scores are shown in Figure A to the right, with red areas corresponding to highly suitable locations and green areas showing less suitable locations. Based on these results, two potential service areas are drawn to connect the most suitable areas in Sacramento for a bicycle sharing program. The primary service area, which is outlined in white in Figure A, is located in downtown Sacramento with significant extensions to the south and east to reach highly suitable areas. The secondary service area, outlined in black in Figure A, is smaller and connects relatively suitable areas to the north of the American River.

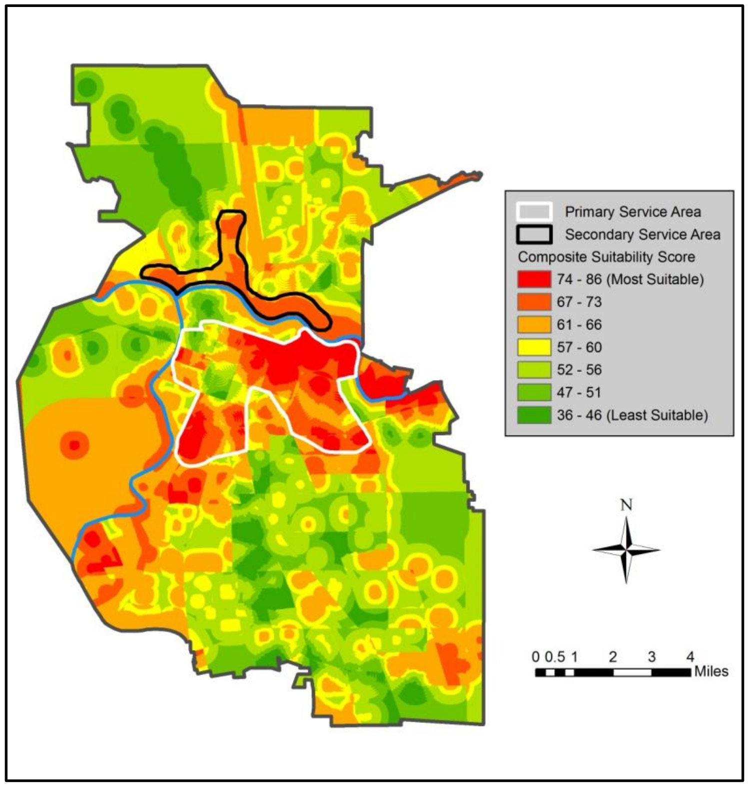


**Figure A: Potential Service Areas in Sacramento**

## *How Many Rentals can be Expected for the Proposed Program in Sacramento?*

Based on the model developed to explain bike-share rentals in Minneapolis, this study predicts monthly rentals within the primary and secondary service areas proposed for Sacramento. This analysis involves placing a series of hypothetical stations throughout the proposed service areas; measuring demographic, socioeconomic, transportation, and destination characteristics around each station; and applying the results of the Minneapolis model to these characteristics.

Through this approach and based on two different station placement schemes, this study projects the following ranges of monthly rentals for the proposed Sacramento program:

- Primary Service Area Only: **between 23,722 and 25,124 rentals per month**
- Primary and Secondary Areas Combined: **between 26,864 and 28,266 rentals per month**

The spatial distributions of rentals by station in the two service areas are shown in Figures B and C on the following page. It is important to note three factors that could affect these estimates. First, because the projections are based on an empirical analysis that is subject to error, a much wider range of potential values—higher or lower than these estimates—may be experienced. Second, as the Minneapolis rentals used for this analysis were recorded during the month of August, these values should be considered to be estimates for the months that are most conducive to cycling in Sacramento. Finally, these estimates may be somewhat low due to the arbitrary process of placing “stations” in this study.

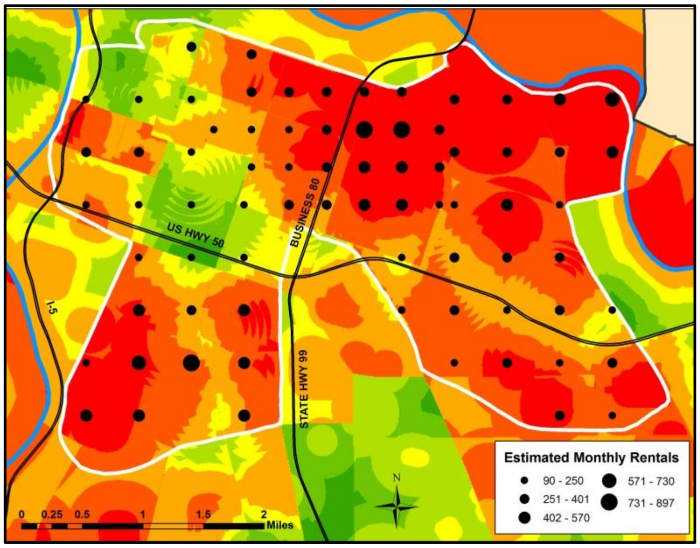


**Figure B: Estimated Rentals, Primary Service Area**

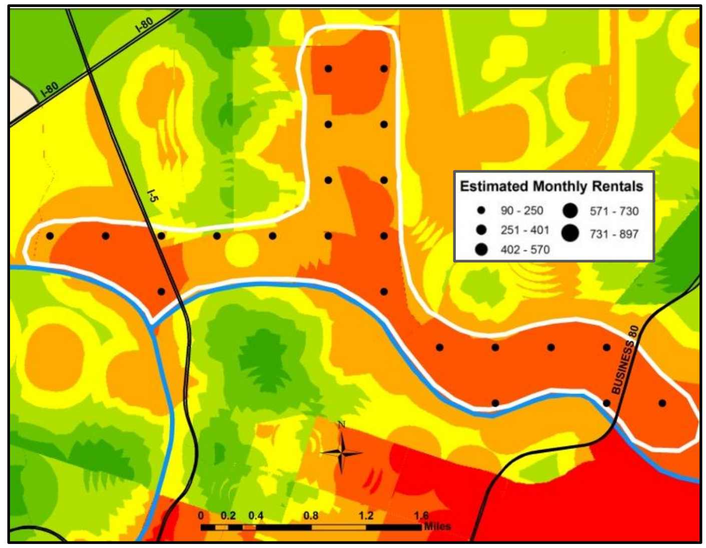


**Figure C: Estimated Rentals, Secondary Service Area**

The predictions suggest that rentals would be relatively low in the downtown area and high in outlying areas. Potential explanations for these results are as follows:

- **Employment density is much higher in Minneapolis than in Sacramento.** A negative relationship between job density and bike-share rentals is found in Minneapolis, which could result from competition with other modes and the presence of large employment campuses. Because job density is lower in Sacramento, the influence of modal competition and large campuses—with the exception of the State Capitol—may not be as significant.
- **Transit service is much more extensive in Minneapolis than in Sacramento.** While bus and rail are significant competitors to bike-share in Minneapolis, this competition may not be as great in downtown Sacramento, where transit service is much less frequent.
- **Minneapolis and Sacramento have different spatial dynamics.** While income is high in downtown Minneapolis relative to outlying areas, income is relatively low in downtown Sacramento. This could explain the positive relationship between income and bike-share rentals in Minneapolis, as well as the low rentals projected for downtown Sacramento.

## *What do the Results Mean for Sacramento?*

These estimates will allow planners to evaluate program costs in light of potential ridership (and thus revenue). In addition, the following recommendations are made about program structure and station placement in both cities:

- Planners should **maximize connections between bicycle sharing and other travel modes**.
- Operators should consider **programming efforts and fare structures** that attract lower-income and minority users.
- Planners should maximize ridership by placing stations in areas that are **highly visible**; that offer a **diverse mix of retail and employment**; and that contain **extensive cycling facilities**.

Through the recommendations made in this study, planners in Sacramento can implement a successful bicycle sharing program that promotes cycling in the interest of environmental sustainability, reduced congestion, and enhanced public health.

## Introduction

As planners in Sacramento strive to create a more sustainable and bicycle-friendly city, they have a variety of policy options at their disposal. Local officials are currently considering the adoption of a bicycle sharing program, which would provide users with short-term bicycle access and allow them to rent and return bicycles at different stations placed strategically throughout the city. By encouraging increased levels of cycling, this approach has the potential to relieve traffic congestion, improve air quality, and enhance public health.

Following widespread popularity and success on the international scene, bicycle sharing programs have recently emerged in a number of cities across the United States. Despite their popularity, these programs may require large financial investments for bicycles, stations, technology, maintenance, and bicycle redistribution. Moreover, the literature is currently limited in its treatment of the cost effectiveness of these programs, making it unclear whether alternative approaches may more effectively promote cycling at lower relative costs. For these reasons, it is important for planners to carefully and objectively evaluate the potential for bicycle sharing efforts in their communities.

This study analyzes the potential for a bicycle sharing program in Sacramento by evaluating local conditions and determining how they might support a bicycle sharing program in the near future. While past studies have had to rely on observations from European systems, this project makes use of recently-released data from the "Nice Ride" program in Minneapolis, Minnesota. Through the evaluation of actual experiences from this program, the factors that influence bike-share ridership in a U.S. city can be more fully understood and used to accomplish the following objectives:

- Identify the most suitable locations for a bicycle sharing program in Sacramento
- Recommend a program service area based on these findings
- Estimate the number of bike-share rentals that can be expected within this service area

Through these tasks, this study offers a thorough understanding of how a bicycle sharing program might look and operate within the Sacramento context. Importantly, the results of this analysis will allow local planners and officials to make well-informed decisions as they consider investing in a bicycle sharing program to enhance the sustainability and quality of life of their city.

## Approach

This study employs a combination of regression and spatial analysis to fulfill four major objectives:

- Identify key factors that determine how "suitable" an area is for bike-share use
- Develop a regression model that most effectively explains bike-share rentals in Minneapolis
- Delineate a set of proposed service areas for a program in Sacramento
- Estimate potential bike-share rentals in Sacramento within these proposed service areas

These objectives are achieved through a variety of analytical techniques, as indicated in Figure 1 and described in the sections that follow.

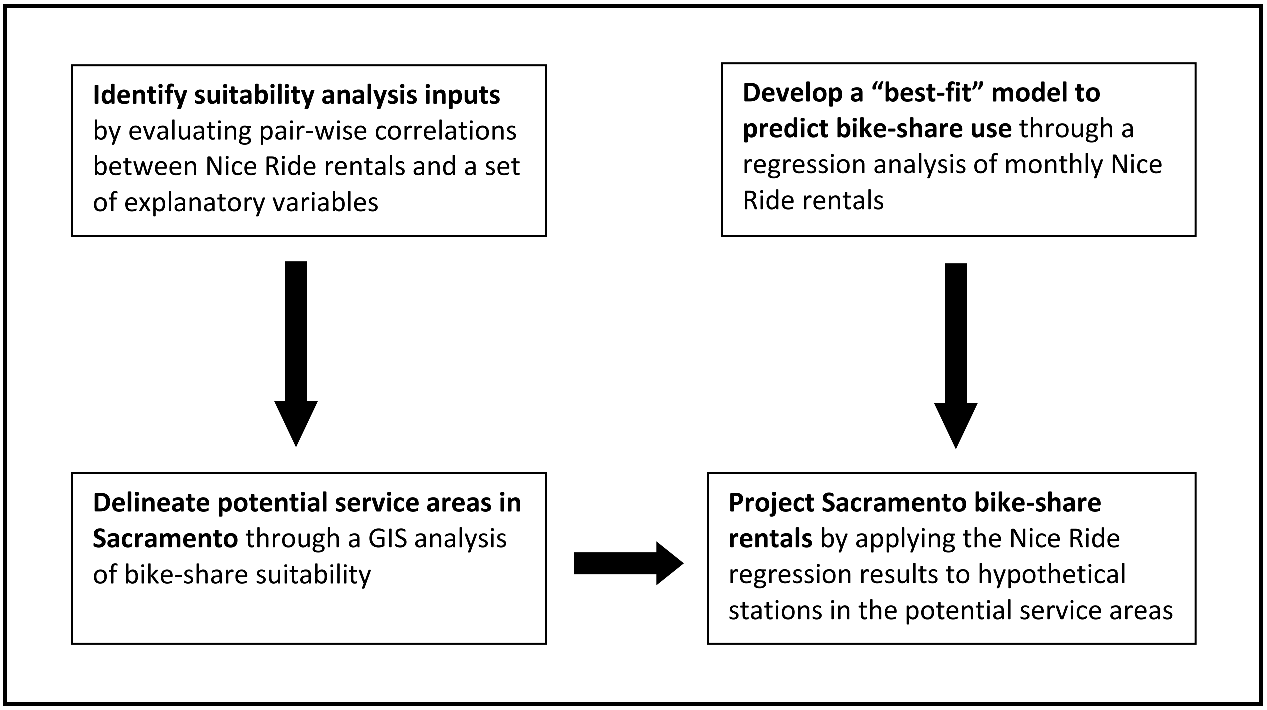


**Figure 1: Flow Chart Describing Project Methodology**

The identification of suitability inputs and the development of a model to predict bike-share rentals are based on an empirical investigation of Nice Ride rental data. For these two steps of the project, Nice Ride stations and a series of additional GIS layers are mapped to facilitate an analysis using stations as observations (n=65) and August 2010 rentals as the dependent variable. A variety of independent variables are included to account for factors believed to be important in explaining rental levels. The majority of these variables are measured within a 400-meter buffer of each station to reflect a typical walking distance of approximately one-quarter mile. This general data framework supports the identification of suitability inputs and the development of a predictive model through the specific approaches outlined below.

Identification of Suitability Analysis Inputs

To identify key suitability inputs, a preliminary regression containing all independent variables is estimated. The standardized coefficients of this model are then analyzed to determine which variables exert the strongest influence on the dependent variable. Two explanatory variables are found to have a particularly strong influence in the preliminary model, and these variables are therefore used as controls in a series of adjusted pair-wise correlations examined for each remaining input. Five additional variables are found to have a significant relationship with monthly rentals even after controlling for the two influential factors. Through this process, a total of seven explanatory variables are identified as appropriate inputs for the bike-share suitability analysis to be conducted for Sacramento.

Development of a Regression Model to Predict Bike-Share Rentals

Next, the preliminary regression is refined to develop an effective predictive model of bike-share rentals based on the Nice Ride experience. Given this purpose, measures of fit rather than variable significance

are emphasized in model selection. A variety of model inputs are tested, resulting in the development of a preferred model that can be used to predict monthly rentals for the proposed Sacramento program.

Following the development of a preferred predictive model, the nature and sources of error in this model are more fully considered. The values of the independent variables for each Nice Ride station are entered into the model to generate a *predicted* rental value for each station, which is then compared to *actual* August 2010 rental values. Based on this analysis, stations for which rentals are significantly under- or over-estimated are evaluated through a conversation with the Nice Ride Operations Director to understand the potential limitations of the model. Additionally, this analysis is used to develop recommendations for bike-share station placement in both Minneapolis and Sacramento.

Delineation of Bike-Share Service Areas in Sacramento

To define potential service areas, a Geographic Information Systems (GIS) analysis is performed to calculate bike-share suitability throughout the City of Sacramento and several surrounding areas. Conceptually, this technique divides the city of Sacramento into a grid of 10-meter-by-10-meter cells and measures the bike-share suitability of each cell based on the seven key inputs identified through the analysis of Nice Ride data. To perform the suitability analysis, GIS shapefiles are collected for each input and "rasterized" (transformed) into a 10-meter grid across the study area. Data for each layer are grouped into ten numerical bins and then reclassified into a ten-point scale, with 10 representing the value most suitable for bicycle sharing. Suitability scores for each cell are calculated based on the sum of these reclassified inputs and then mapped according to a graduated color scheme across the study area.

This graphic representation forms the basis for the delineation of potential program service areas in Sacramento. More specifically, primary and secondary service areas are drawn to connect cells with the highest suitability values as implied from the Minneapolis experience. This objective, analytical, and experience-based approach results in a graphical display of the most suitable areas in Sacramento for a bicycle sharing program, as well as a delineation of the most appropriate service areas for the proposed system.

Projection of Monthly Bike-Share Rentals in Proposed Sacramento Service Areas

To estimate potential bike-share ridership within the proposed service areas, the results of the Minneapolis regression are applied to the Sacramento context. This approach involves placing a series of hypothetical bike-share stations throughout the Sacramento service areas and measuring the values of the preferred regression model variables for each hypothetical station. These values are then multiplied by their respective model coefficients and summed to project monthly rentals for each station and for the proposed program as a whole. To create low and high demand scenarios, two station placement schemes are evaluated: one in which stations are evenly spread throughout the service areas, and a second in which stations are clustered in areas determined through the suitability analysis to be particularly conducive to bike-share ridership. For consistency, the number of stations in each scenario is the same. Additionally, given the empirical nature of this approach and the potential for error, the confidence intervals of the estimates are evaluated to more fully understand potential rental levels.

Finally, following the completion of these primary analyses, the spatial differences between Minneapolis and Sacramento are examined. This exercise facilitates the development of both caveats and recommendations for the proposed bicycle sharing program in Sacramento.

## Data and Study Area

A dataset containing the locations of Nice Ride stations and the number of August 2010 rentals at each station has been obtained. To facilitate regression and spatial analysis, data for a variety of explanatory variables have been obtained for Minneapolis and imported into GIS shapefiles. These variables account for factors that affect bike-share rentals at the trip origin and destination levels and for factors that describe the transportation network around stations. To ensure the usefulness of the analysis for Sacramento, emphasis has been placed on collecting information that is also available for Sacramento.

Dependent (Outcome) Variable: Monthly Nice Ride Rentals

For the identification of suitability inputs and the development of a predictive model of bike-share rentals, the number of August 2010 rentals per Nice Ride station is considered as the dependent variable. This variable is continuous, with rental values ranging from a minimum of 29 to a maximum of 1,107. The mean rental value for the system is 356. However, the frequency distribution of monthly rentals, as displayed in Figure 2, suggests that this variable is not normally distributed: many stations record relatively low rentals, while few experience very high rentals. In light of this distribution, the dependent variable has been transformed to the natural log of monthly rentals.

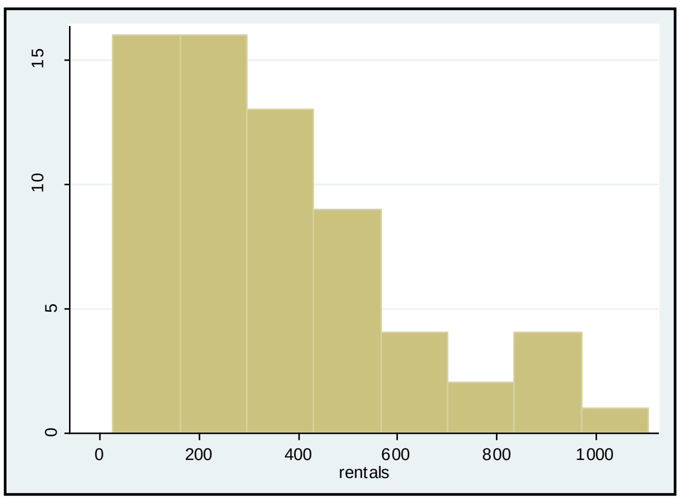


**Figure 2: Frequency Distribution of August 2010 Nice Ride Rentals**

Independent (Explanatory) Variables

As previously noted, the independent variables in this study account for trip generation, trip attraction, and transportation network factors. With the exception of variables measuring proximity to parks and rail stations, all independent variables are measured within a 400-meter (radius) buffer of each station to reflect a typical walking distance of approximately one-quarter mile. Importantly, bicycle facilities are measured as a density variable, rather than the proximity measure used in previous studies, in order to reflect the connectivity that is so important for safe, efficient, and accessible bicycle travel.

All independent variables have been collected for both cities, as they are first used in the empirical analysis of Nice Ride rentals and then evaluated within the Sacramento context. Definitions and sources for all variables are presented in Table 1. Summary statistics for the data in both cities can be found in Appendix A of this report.

**Table 1: Definitions and Sources of Project Variables**

| Variable | Definition (with units, as applicable) | Anticipated Effect | Source | Original Data Aggregation Level | Date | Phase(s) in which Data are Used*** |
|---|---|---|---|---|---|---|
| **Dependent** | | | | | | |
| *Rentals* | Number of rentals during August 2010, by station | N/A | Nice Ride | Station | 2010 | I, II |
| *ln(Rentals)* | Natural log of the number of rentals during August 2010, by station | N/A | Nice Ride | Station | 2010 | I, II |
| **Independent** | | | | | | |
| Trip Generation Factors | | | | | | |
| *Population* | Total population (in 100s of persons) | Positive | American Community Survey* | Census Tract | 2005-09 | I, II, IV |
| *Age 18-49* | Population between the ages of 18 and 49 (in 100s of persons) | Positive | American Community Survey* | Census Tract | 2005-09 | I, II |
| *Non-White Population* | Proportion of population that is of a race other than "white alone" | Unknown | American Community Survey* | Census Tract | 2005-09 | I, II, III, IV |
| *Low-Vehicle Household Prevalence* | Proportion of households that have one or zero vehicles available | Unknown | American Community Survey* | Census Tract | 2005-09 | I, II, IV |
| *Income* | Median household income (in 1000s of dollars) | Unknown | American Community Survey* | Census Tract | 2005-09 | I, II, III, IV |
| *Alternative Commuters* | Proportion of workers who commuted by bicycle, walking, or public transportation before 2010 (in 100s of workers) | Positive | American Community Survey* | Census Tract | 2005-09 | I, II, III, IV |
| *High-Income Jobs* | Number of workers (all job categories) who earn more than $3,330 per month (in 100s of workers) | Positive | Local Employment Dynamics* | Census Tract | 2008 | I, II, III, IV |
| Trip Attraction Factors | | | | | | |
| *Jobs* | Jobs within "appropriate"** NAICS sectors (in 100s of jobs) | Positive | Local Employment Dynamics* | Census Tract | 2008 | I, II, III, IV |
| *Retail Jobs* | Retail jobs (in 10s of jobs) | Positive | Local Employment Dynamics* | Census Tract | 2008 | I, II, IV |
| *Work Destinations* | Workers (by place of employment) who both live and work in the study area (in 100s of workers) | Positive | Local Employment Dynamics* | Census Tract | 2008 | I, II |
| *Home Destinations* | Workers (by place of residence) who both live and work in the study area (in 100s of workers) | Positive | Local Employment Dynamics* | Census Tract | 2008 | I, II |
| *Attractors* | Number of "attractors" (shopping centers, cultural/historic/civic sites, sports complexes, entertainment centers, museums, etc.) | Positive | Geographic Names Information System (GNIS), Reference USA | Study Area | 2010-11 | I, II, IV |
| *College* | 1 if a college is located within 400 meters of a station, 0 otherwise | Positive | Minn. Metro Council, SACOG | Study Area | 2010 | I, II, IV |
| *Distance to Park* | Distance to nearest park/recreation site (in 10s of meters) | Negative | Minn. Metro Council, SACOG | Study Area | 2010 | I, II, III, IV |
| Transportation Network Factors | | | | | | |
| *Transit Intensity* | Bus/rail vehicles serving the area per hour during the AM peak (in 10s of vehicles) | Positive | Minn. Metro Council, SACOG | Study Area | 2010 | I, II, IV |
| *Bus Stops* | Number of bus stops (in 10s of stops) | Positive | Minn. Metro Council, SACOG | Study Area | 2010 | I, II, IV |
| *Distance to Rail* | Distance to nearest light/commuter rail stop (in 100s of meters) | Negative | Minn. Metro Council, SACOG | Study Area | 2009-10 | I, II, III, IV |
| *Bikeways* | Length of existing bike lanes and paths (in 100s of meters) | Positive | Minn. Metro Council, SACOG | Study Area | 2007-10 | I, II, IV |
| *Bike-Share Spaces* | Number of spaces/docks offered at a station | Positive | Nice Ride | Station | 2010 | II |

* U.S. Census Bureau Source

** "Appropriate" jobs are those within NAICS sectors (2-digit codes) deemed to be appropriate for bike-share use, as destinations for both employees and patrons (see Appendix B for list)

*** Phases defined as follows: I = Identification of Suitability Analysis Inputs; II = Development of a Regression Model to Predict Monthly Bike-Share Rentals; III = Delineation of Bike-Share Service Areas in Sacramento; IV = Projection of Monthly Bike-Share Rentals in Proposed Sacramento Service Areas

Study Area

The study area for the analysis in Sacramento has been defined based on data availability and input from local officials. As displayed in Figure 3, the study area includes the Sacramento city limits, a portion of West Sacramento, and areas just outside of the Sacramento city limits (north-central and southeast) for which information is available.

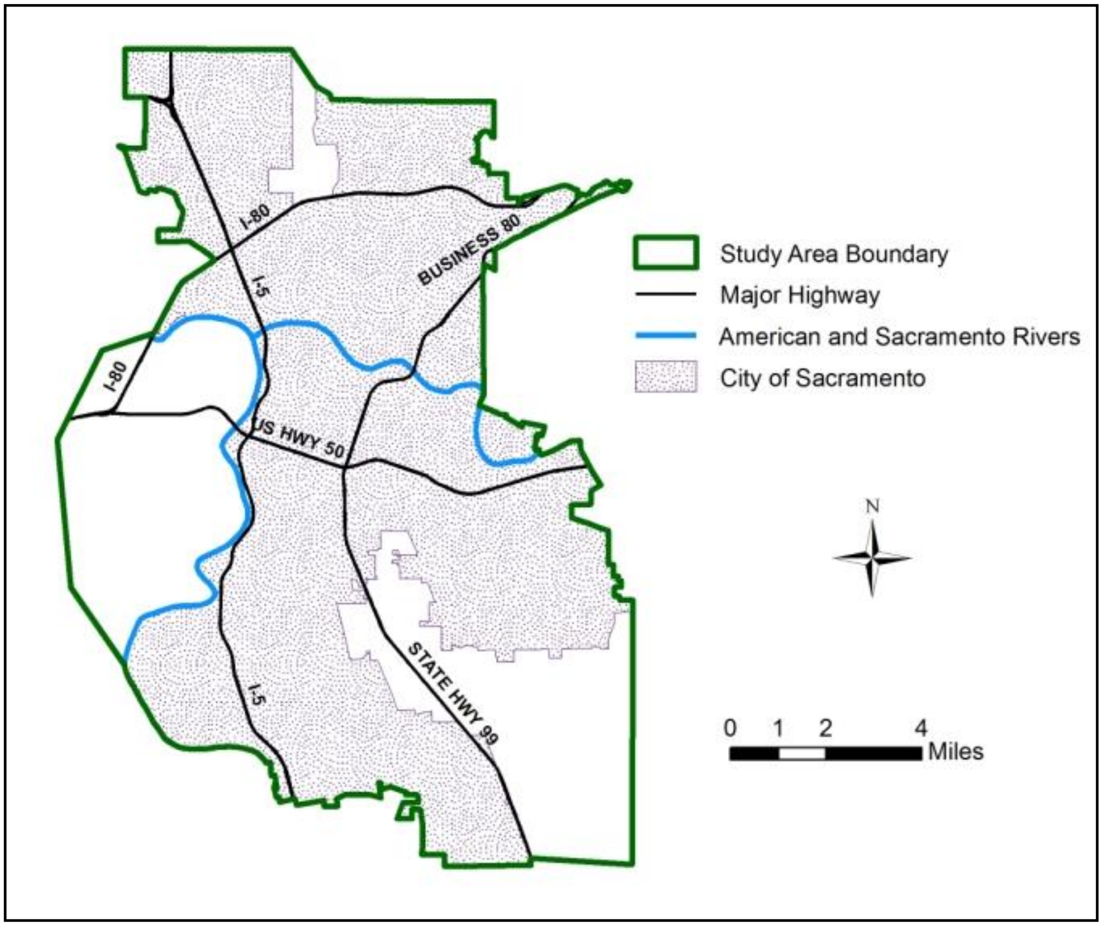


**Figure 3: Project Study Area**

## Identification of Suitability Analysis Inputs

This study uses GIS analysis to recommend suitable areas within Sacramento for a bicycle sharing program. To determine the factors that should be included in this suitability analysis, rental patterns for the Nice Ride program are evaluated and key determinants of bike-share rentals are identified. The identification of suitability inputs is based on a preliminary analysis of August 2010 rentals across Nice Ride stations (n=65). The natural log of monthly rentals is used as the dependent variable, and a variety of theoretically important independent variables are included (see Table 1).

Due to high collinearity among the variables examined (see Appendix C), it is appropriate to select suitability inputs based on the pair-wise correlations between each independent variable and monthly rentals rather than on the results of a full regression model. However, the standardized coefficients for a

preliminary regression model (see Appendix C) incorporating all independent variables listed in Table 1 indicate that *Jobs* and *High-Income Jobs* are highly influential variables in the regression of bike-share rentals. In light of these results, these two variables are appropriate inputs for the suitability analysis. Moreover, these variables are used as controls in the adjusted pair-wise correlations analyzed to identify additional inputs. This approach, as presented in Table 2, determines whether each variable is significant after controlling for the two influential factors.

**Table 2: Adjusted Pair-Wise Correlations between Each Variable and Monthly Nice Ride Rentals (n=65)**

| Results in Separate Regression *ln(Rentals) = Jobs + High-Income Jobs* + [X] | | | |
|---|---|---|---|
| **Variable** | **Coefficient** | **Standard Error** | **p-value** |
| *Population* | -0.006 | 0.014 | 0.66 |
| *Non-White Population* | -3.128 | 0.422 | 0.00*** |
| *Low-Vehicle Household Prevalence* | 1.064 | 0.685 | 0.13 |
| *Income* | 0.029 | 0.005 | 0.00*** |
| *Alternative Commuters* | 8.327 | 2.420 | 0.00*** |
| *Retail Jobs* | 0.006 | 0.005 | 0.32 |
| *Work Destination* | 0.100 | 0.128 | 0.44 |
| *Home Destination* | 0.046 | 0.033 | 0.17 |
| *Attractors* | 0.044 | 0.045 | 0.33 |
| *College* | -0.166 | 0.262 | 0.53 |
| *Distance to Park* | -0.009 | 0.005 | 0.10* |
| *Distance to Rail* | 0.019 | 0.011 | 0.10* |
| *Transit Vehicles* | 0.020 | 0.019 | 0.31 |
| *Bus Stops* | 0.020 | 0.014 | 0.15 |
| *Bikeways* | 0.008 | 0.007 | 0.26 |

*,**, and *** indicate statistical significance at the 10, 5, and 1 percent levels, respectively.

Five variables are found to have a significant relationship with monthly bike-share rentals even after controlling for the effects of *Jobs* and *High-Income Jobs*. Interestingly, the unexpected positive sign of the *Distance to Rail* coefficient suggests that greater distances from rail stations are associated with higher bike-share rental levels. This finding, while not aligning with initially anticipated theory, suggests that rail and bike-share may represent competing rather than complementary travel modes in the Minneapolis context. Similarly, the negative association found between *Jobs* and *ln(Rentals)* could be interpreted as evidence that when all other factors are held equal, bike-share use is not as prevalent in employment centers that may be highly walkable and well-served by alternative, competing modes.

Importantly, this analysis has suggested a total of seven significant inputs, as well as their respective directions, to be included in the Sacramento suitability analysis.

## Development of a Regression Model to Predict Bike-Share Rentals

While the preliminary regression model exhibits relatively high measures of fit (see Appendix C), further adjustments are necessary to improve the model as a tool for predicting bike-share rentals. From this starting point, several independent variables were tested and were either retained or removed based on their effects on model fit and estimation error. Although squared configurations of *Income* and *Population* were tested to evaluate whether these variables share a non-linear relationship with bike-share rentals, they were found to be insignificant. Similarly, *Age 18-49* and an interaction term between

*Transit Intensity* and *Bus Stops* were tested but were not found to contribute to the model as a predictive tool. Finally, although *Home Destinations* and *Work Destinations* were tested to account for in-commuting within the program service area, they were found to be insignificant. This iterative process has resulted in a preferred model for predicting bike-share rentals, as displayed in Table 3.

**Table 3: Results of Preferred Regression of Monthly Nice Ride Rentals (n=65)**

| Variable | Coefficient | Standard Error | p-value |
|---|---|---|---|
| *Population* | -0.001 | 0.014 | 0.94 |
| *Non-White Population* | -2.522 | 0.770 | 0.00*** |
| *Low-Vehicle Household Prevalence* | -1.909 | 0.832 | 0.03** |
| *Income* | 0.015 | 0.006 | 0.01** |
| *Alternative Commuters* | 5.405 | 3.146 | 0.09* |
| *High-Income Jobs* | 0.068 | 0.033 | 0.04** |
| *Jobs* | -0.059 | 0.028 | 0.04** |
| *Retail Jobs* | 0.010 | 0.006 | 0.09* |
| *Attractors* | 0.051 | 0.034 | 0.14 |
| *College* | 0.102 | 0.201 | 0.61 |
| *Distance to Park* | -0.013 | 0.004 | 0.00*** |
| *Transit Intensity* | -0.008 | 0.015 | 0.58 |
| *Bus Stops* | 0.014 | 0.011 | 0.20 |
| *Distance to Rail* | -0.014 | 0.013 | 0.27 |
| *Bikeways* | -0.000 | 0.005 | 0.99 |
| *Bike-Share Spaces* | 0.028 | 0.014 | 0.05* |
| *Constant* | 5.672 | 0.971 | 0.00 |
| $R^2$ | 0.7362 | | |
| Adjusted-$R^2$ | **0.6483** | | |
| F (Prob > F) | 8.37 (0.0000) | | |

*,**, and *** indicate statistical significance at the 10, 5, and 1 percent levels, respectively.

It is important to recognize two caveats of this regression model. First, the variables in the model exhibit very high collinearity (see Appendix C). This may explain the insignificance of some theoretically important variables and may also be obscuring the true relationships between the variables in the model. Second, the model contains a large number of independent variables (X=16) relative to observations (n=65), which reduces the power of the model. However, given the available data, the model presented in Table 3 is found to be the best tool for projecting bike-share rentals in Sacramento.

The preferred model contains a total of nine independent variables that are statistically significant. Given the natural log format of the dependent variable, the coefficients of these significant variables can be interpreted as follows: **A one-unit increase in [*independent variable*] is associated with a [*coefficient x 100*] percent increase/decrease in monthly rentals.** It is important to note that the coefficients should not be interpreted as *causal*, but rather as measures of the *association* or *correlation* between the dependent and independent variables. Additionally, these interpretations must be qualified as the effects of an input with all other variables held equal. Based on the coefficients derived in the model, the effects of the significant independent variables can be interpreted as follows:

- *Non-White Population*: A 100 percent increase in the proportion of the population within 400 meters of a station that is of a race other than "white alone" is associated with a *252 percent decrease* in monthly rentals.
- *Low-Vehicle Household Prevalence*: A 100 percent increase in the proportion of households within 400 meters of a station that have one or zero vehicles available is associated with a *191 percent decrease* in monthly rentals.

- *Income*: A $1,000 increase in median household income within 400 meters of a station is associated with a *1.5 percent increase* in monthly rentals.
- *Alternative Commuters*: A 100 percent increase in the proportion of workers within 400 meters of a station that commute by alternative modes (bicycle, walking, public transportation) is associated with a *541 percent increase* in monthly rentals.
- *High-Income Jobs*: For every additional 100 workers within 400 meters of a station earning more than $3,333 per month, monthly rentals can be expected to *increase by 6.8 percent*.
- *Jobs*: For every additional 100 "bike-share appropriate" jobs within 400 meters of a station, monthly rentals can be expected to *decrease by 5.9 percent*.
- *Retail Jobs*: For every additional 10 retail jobs within 400 meters of a station, monthly rentals can be expected to *increase by 0.99 percent*.
- *Distance to Park*: A 10-meter increase in the distance between a station and the nearest park is associated with a *1.3 percent decrease* in monthly rentals.
- *Bike-Share Spaces*: For every additional bike-share space/dock offered at a station, monthly rentals can be expected to *increase by 2.8 percent*.

Interestingly, the preferred model offers insight into several socioeconomic variables identified in Table 1 to have ambiguous theoretical relationships with bike-share ridership. Based on the Nice Ride experience, rentals can be expected to be higher in areas with higher median incomes, greater densities of high-earnings jobs, lower minority presence, and lower proportions of households with one or zero vehicles available. However, it is important to recognize that these findings were recorded during an early stage of the program, when a full cultural shift may not have occurred among all sub-groups of the population; and that the provision of services based on these findings could have significant political and equity implications. Moreover, these findings may indicate that certain groups may be more effectively attracted to the bike-share mode through programming efforts and alternative fare structures. Thus, the results of the preferred regression model with respect to socioeconomic variables must be interpreted with caution.

With the exception of *Jobs*, the directions of the remaining significant variables in the preferred model are as expected. As previously stated, this unexpected finding could result from competition from other modes in dense, walkable, and transit-friendly employment centers.

To understand the limitations of the preferred model and to derive lessons for station placement in both cities, an evaluation is conducted of stations for which monthly rentals are significantly under- or over-predicted by the model. Based on a conversation with the Nice Ride Operations Director, these stations are analyzed to identify factors that may account for their departure from the estimated model. The results of this conversation are presented in Appendix D and summarized below.

- **Timing, visibility, and construction activities matter.** Among the stations evaluated, three stations that recorded actual rentals *lower* than those predicted by the model were established after the program officially began. As a result of this late placement, these stations may not have been on preliminary system maps and may not have generated sufficient awareness by August 2010 to reach predicted rental levels. Similarly, two stations with lower-than-predicted rentals were not initially placed in locations that made them highly visible to potential users. Finally, nearby construction activities had opposing effects for two Nice Ride stations: one station with lower-than-anticipated rentals was negatively affected by construction in the immediate vicinity, while one station with higher-than-predicted rentals benefited from more distant construction activities that diverted users who would have otherwise used alternative stations.

- **For the treatment of retail destinations, the *type* of establishments matters.** As measured for this study, *Retail Jobs* does not appear to have adequately captured the mix of retail that is vital to bike-share use. Two of the stations for which rentals are significantly underestimated are unique in their retail composition, offering a diverse array of establishments and, in the case of the Midtown Global Exchange, providing a unique experience for patrons and passersby alike. While total retail figures for these stations are below the mean for the sample—perhaps due to the presence of smaller businesses—the type and mix of retail in these areas may have played a role in the higher-than-estimated rental values. Based on these results, areas offering unique and mixed retail establishments, including small businesses, should be considered as particularly suitable locations for bike-share stations in both Sacramento and Minneapolis.
- **When considering employment density, the *size* and *type* of establishments matter.** Large employers often function as self-contained entities that leave users with little need to travel to outside destinations. Large facilities may also create physical barriers that discourage travel between surrounding uses. Furthermore, similar to the treatment of retail establishments, the *mix* of employment appears to matter: rentals are overestimated at the Minneapolis Convention Center station, which is surrounded by large and homogenous sources of employment. These observations could help to explain the negative regression coefficient obtained for *Jobs*, as very large employers with contained campuses may have skewed the measurement of this variable. These findings suggest that bike-share planners in Minneapolis and Sacramento should consider the implications of large, centralized, and homogenous employment centers in the placement of stations. This may have particularly strong implications for Sacramento, given the presence of the State Capitol.
- **For the treatment of colleges and universities, the *size* and *type* of campus matters.** Actual August 2010 rentals exceeded those predicted by the model for the University of Minneapolis station, while rentals were lower than predicted for the Augsburg College station. This divergence could be explained by the relative sizes of these two institutions: the need to travel by Nice Ride on a small, more self-contained campus like Augsburg College may be significantly lower than that on the University of Minneapolis campus, where distances between related destinations may be quite large. Additionally, major universities are more likely than smaller colleges to draw visitors from the general community, an observation that may have played an important role in this analysis given that rentals were recorded during a summer month. In light of these findings, planners in both cities should expect greater ridership at large universities than at small colleges.
- **The preferred regression model may not offer an adequate treatment of *transportation network factors* such as proximity to rail and density of cycling amenities.** The underestimation of rentals for the Franklin Avenue LRT station could have been driven by the station's prime location at a light rail stop and along a popular cycling trail. Similarly, the other two underestimated stations in this evaluation are surrounded by considerable cycling amenities and facilities. Although *Distance to Rail* and *Bikeways* are found to be insignificant in the preferred model, the error analysis suggests that bike-share planners in both cities should consider these transportation network variables to be important factors in station placement.
- **The *network effects* between bike-share stations are important.** The comments of the Nice Ride Operations Director suggest that although some stations recorded lower-than-anticipated rentals due to their proximity to other popular stations, interaction with other stations and integration into the larger system was crucial to the recorded success of others. These findings indicate that when creating an initial system map and planning for future placements, bike-share planners should strive to anticipate the complex ways in which stations will interact with one another.

Thus, the analysis of stations with high error has revealed a variety of factors that should be considered as bike-share planners in Sacramento and Minneapolis interpret the results of the preferred model and place new stations throughout their respective programs.

## Delineation of Bike-Share Service Areas in Sacramento

This phase of the study delineates a series of potential bike-share service areas in Sacramento using GIS analysis and based on the seven significant inputs identified for Minneapolis. As outlined in the overview of project methodology, these inputs are “rasterized” (transformed) into a 10-meter grid across the study area, reclassified into a ten-point scale (with 10 representing the values most suitable for bike-share use), and summed to calculate a bike-share suitability score for each cell. These scores are then mapped to evaluate suitability across the study area and to define potential program service areas.

Methods of rasterization and reclassification differ based on the type of input, as explained in Table 4. Map layouts displaying each of the rasterized inputs are included in Appendix E of this report.

**Table 4: Rasterization Methods for Suitability Analysis Inputs**

| Layer | Field Rasterized | Rasterization Method | Initial Grouping | Reclassification Direction |
|---|---|---|---|---|
| *Non-White Population* | Proportion of population that is of a race other than “white alone” | Value of Tract attributed to all cells whose centers fall within the Tract | Natural Breaks | Negative |
| *Income* | Median household income | Value of Tract attributed to all cells whose centers fall within the Tract | Natural Breaks | Positive |
| *Alternative Commuters* | Proportion of workers who commute by bicycle, walking, or public transportation | Value of Tract attributed to all cells whose centers fall within the Tract | Natural Breaks | Positive |
| *High-Income Jobs* | Workers per acre (by place of employment) earning more than $3,333/month | Value of Tract attributed to all cells whose centers fall within the Tract | Natural Breaks | Positive |
| *Jobs* | Total “appropriate” jobs per acre | Value of Tract attributed to all cells whose centers fall within the Tract | Natural Breaks | Negative |
| *Distance to Park* | n/a | Distance between all cells and the nearest park calculated | Manual* | Negative |
| *Distance to Rail* | n/a | Distance between all cells and the nearest rail stop calculated | Manual* | Positive |

* Manual: 10 bins with breaks at 100, 200, 300, 400, 500, 600, 700, 800, and 900 meters. This classification has been chosen due to the presence of cells with very high values that fall outside of typical walking distances.

Due to the prior lack of rental data for a U.S. program, previous studies have relied primarily on theory to construct suitability models. For purposes of comparison, an initial suitability scenario has been constructed with inputs corresponding to factors believed in *theory* to be important determinants of bike-share ridership. The inputs and results of this analysis are presented in Appendix E of this report.

The primary, empirical suitability model for this analysis incorporates the seven inputs determined to have significant adjusted pair-wise correlations with monthly rentals. While the input directions for *Jobs* and *Distance to Rail* differ from those anticipated in theory, the pair-wise correlation findings are prioritized over theory in suitability construction due to their origin in actual Nice Ride experiences. As all inputs are based on variable significance, equal weights are assigned throughout the model. The components of this model are summarized in Table 5 and the graphic results are presented in Figure 4.

**Table 5: Inputs, Direction, and Weights for Empirical Suitability Model**

| Layer | Direction Used for Analysis | Weight |
|---|---|---|
| *Income* | Positive | 1 |
| *Non-White Population* | Negative | 1 |
| *Alternative Commuters* | Positive | 1 |
| *High-Income Jobs* | Positive | 1 |
| *Jobs* | Negative | 1 |
| *Distance to Park* | Negative | 1 |
| *Distance to Rail* | Positive | 1 |

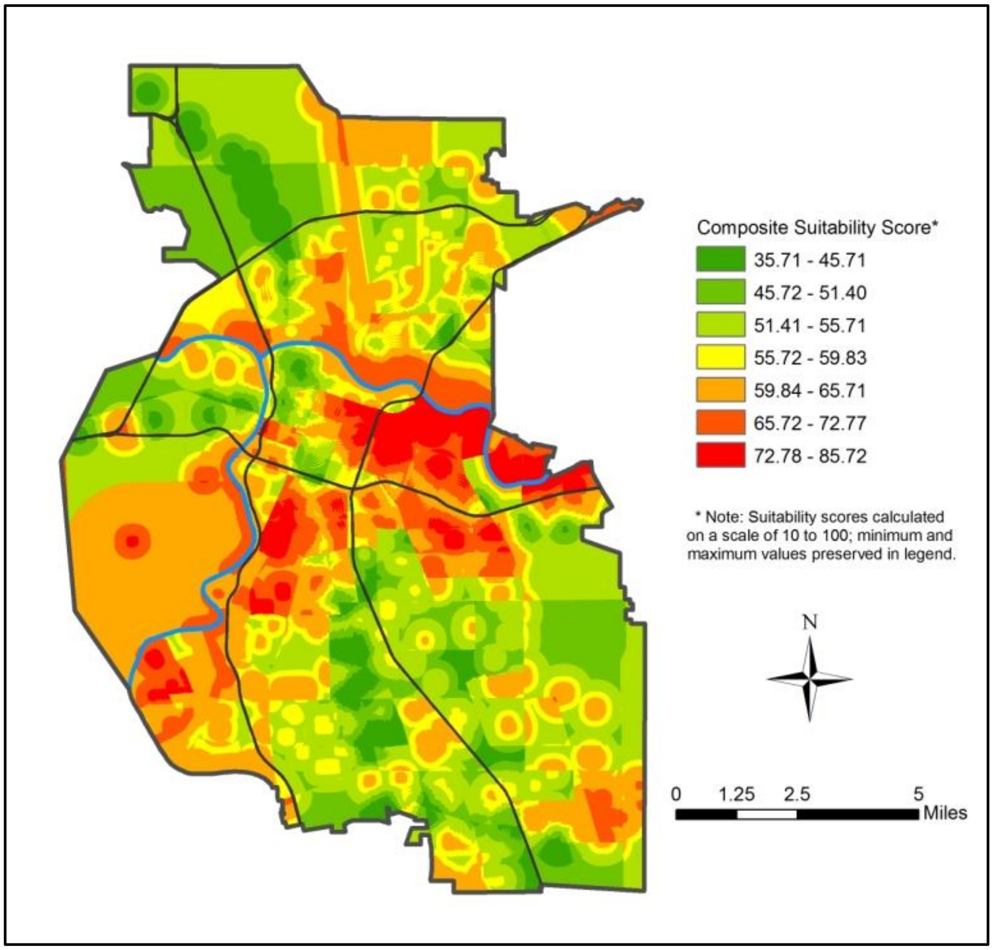


**Figure 4: Results of Empirical Suitability Analysis**

The results of the empirical suitability analysis differ considerably from those of the theory-based model displayed in Appendix E. While theory dictates that bike-share suitability will generally be highest in the central city and lower in outlying areas, Figure 4 suggests that the application of Minneapolis data to the Sacramento context results in a different spatial distribution of suitability. Bike-share suitability is found to be relatively low in downtown Sacramento, while areas to the south and east of this district are found to be quite high when suitability is calculated based on Nice Ride rental experiences.

These spatial differences result from the different inputs used to explain suitability in these two models. While the empirical model contains only those factors identified as significant inputs through the Nice Ride analysis, the theory-based model incorporates the following additional inputs:

- Population density
- Retail density
- Density of attractors
- Transit intensity
- Bus stop density
- Density of bikeways

Furthermore, the theory-based model excludes *Income* and *Non-White Population*, which do not share clear theoretical relationships with cycling; assigns a positive direction to *Jobs* based on traditionally accepted theory; and considers *Distance to Rail* as a negative input. These differences explain the potential divergence between *theory* and *experience*, as determined through Minneapolis data.

It is important to note a potential limitation of the process used to map suitability scores in both models. Scores have been mapped using Natural Breaks (Jenks) classification, which groups scores in a way that minimizes variation *within* categories and maximizes variation *between* categories. Thus, the selected method clusters similar cells and may impose relatively artificial breaks in the values. While this method has been chosen over quantile classification to avoid the assumption that a pre-determined proportion of the study area will be highly suitable, it should nevertheless be recognized as a caveat.

<u>Delineation of Primary and Secondary Service Areas</u>

Several objectives have been pursued to define potential service areas based on the suitability results:

- Connect the areas in Sacramento exhibiting the highest levels of suitability
- Define at least two service areas in order to provide alternative configurations
- Create a program of a manageable spatial extent, approximately in line with the size of the Nice Ride program (which is approximately 11 square miles)
- Incorporate the downtown area, despite the relatively low suitability scores generated through the regression-based model
- Overlay the boundary with the results of the theory-based model and with layers describing median income and racial composition to ensure that otherwise suitable areas with lower incomes and higher minority presence are not excluded
- Overlay the boundary with aerial images to ensure that the delineated service area is rational

Two distinct service areas have been created through this process, as presented in Figure 5. These service areas generally connect the most suitable cells in the study area. While it was anticipated at the outset of the project that adjustments would be needed based on the presence of rivers, contiguous and highly suitable groups of cells are generally not found to cross these natural boundaries.

The primary service area defined for Sacramento is approximately 12 square miles in area, making it slightly larger than the Nice Ride program. This boundary encompasses the downtown area and provides considerable extensions to the south and east in order to incorporate several outlying concentrations of highly suitable cells. Notably, some suitable areas—particularly to the south of the primary service boundary—have been excluded in order to create a continuous service area of a manageable extent.

A secondary service area has also been defined to the north of the American River and its confluence with the Sacramento River, adding approximately 3 square miles to the program. This area primarily encompasses Discovery Park and the American River Parkway, two linear recreation areas along the American River. The secondary service boundary also incorporates areas to the north and west of these recreation resources, and the eastern limit of the area has been defined based on aerial imagery to reach the Cal Expo Center. Importantly, if the secondary service area is to be fully incorporated into the program rather than remaining a mere satellite of the primary boundary, efforts should be pursued to increase the safety and convenience of crossing the Sacramento and American Rivers by bicycle.

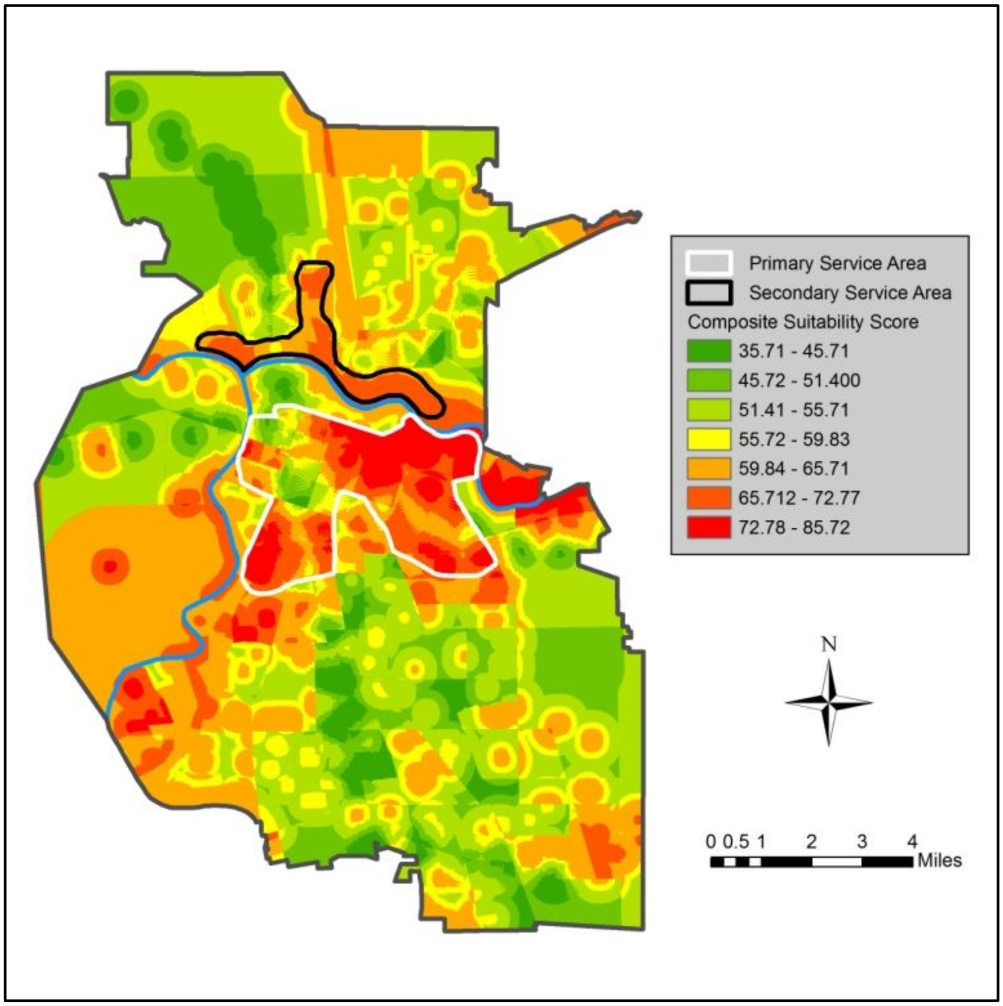


**Figure 5: Delineation of Primary and Secondary Service Areas in Sacramento**

## Projection of Monthly Bike-Share Rentals in Proposed Sacramento Service Areas

The final phase of this study estimates the number of rentals that can be expected for the proposed Sacramento program, based on the results of the Nice Ride regression. In order to apply the results of the preferred regression to the Sacramento context, it is necessary to place hypothetical bike-share stations within the primary and secondary Sacramento service areas. To ensure a practical distribution of stations, the objective of station placement in this exercise is to create an average spacing similar to that of the Nice Ride program, which offers a total of 65 stations within an approximately 11-square-mile service area. Thus, alternative spacing scenarios are tested to achieve a total of 75 stations within the 12-square-mile primary service area in Sacramento. Under this general constraint, two alternative station placement schemes are created in order to project low and high rental scenarios.

*Scenario 1 – Even Coverage, 650-Meter Spacing (Low)*: The first scenario achieves the desired station-to-area ratio by placing stations evenly throughout the service areas at 650-meter intervals. This results in the placement of 75 stations within the primary service area and 19 in the secondary service area. As this spacing does not "over-sample" particularly suitable areas, it is anticipated that Scenario 1 will generate a low rental estimate.

*Scenario 2 – Different Spacing for Higher and Lower Suitability Areas (High):* To achieve the desired ratio under a more realistic station configuration, Scenario 2 creates a denser placement of stations (at 500-meter intervals) in a central concentration of highly suitable cells, a less dense placement (at 800-meter intervals) outside of this area, and the original 650-meter spacing in the secondary area. The number of stations in each service area is the same as in Scenario 1. As this spacing "over-samples" highly suitable areas, it is expected that Scenario 2 will create a high rental estimate.

Rental Projections in Sacramento

A 400-meter (radius) buffer is placed around each Sacramento station to measure the values of the variables included in the preferred Minneapolis regression model. To account for the *Bike-Share Spaces* variable in this model, 21 spaces are assigned to stations falling within the central concentration of highly suitable cells, while 16 spaces are assumed for stations outside of this area. These figures are based on the average number of spaces for central and outlying stations in Minneapolis.

The values for each variable are multiplied by their respective preferred-model coefficients and summed to calculate rentals per station. As these figures are calculated based on a regression model that is subject to error, a confidence interval is constructed around each estimate. This interval indicates the range of values within which estimates can be expected with 68.2 percent confidence to fall. The results of this analysis are presented in Table 6, with the ranges implied by the confidence intervals indicated in parentheses below each estimate.

**Table 6: Projected Rentals under Alternative Station Placement Scenarios**

<table>
<tr><th></th><th></th><th>Primary Service Area</th><th>Secondary Service Area</th><th>Combined Service Area, Total Rentals Only</th></tr>
<tr><td rowspan="4">Scenario 1</td><td>Total Rentals per Month<br>(68.2% Confidence Interval)</td><td>23,722<br>(12,636 – 45,125)</td><td>3,142<br>(1,751 – 5,648)</td><td rowspan="4">26,864<br>(14,387 – 50,773)</td></tr>
<tr><td>Average Per Station<br>(68.2% Confidence Interval)</td><td>316<br>(168 – 602)</td><td>143<br>(80 – 257)</td></tr>
<tr><td>Minimum Station Value<br>(68.2% Confidence Interval)</td><td>70<br>(35 – 140)</td><td>90<br>(44 – 181)</td></tr>
<tr><td>Maximum Station Value<br>(68.2% Confidence Interval)</td><td>869<br>(492 – 1,537)</td><td>211<br>(120 – 371)</td></tr>
<tr><td rowspan="4">Scenario 2</td><td>Total Rentals per Month<br>(68.2% Confidence Interval)</td><td>25,124<br>(13,436 – 47,585)</td><td>3,142<br>(1,751 – 5,648)</td><td rowspan="4">28,266<br>(15,187 – 53,233)</td></tr>
<tr><td>Average Per Station<br>(68.2% Confidence Interval)</td><td>335<br>(179 – 634)</td><td>143<br>(80 – 257)</td></tr>
<tr><td>Minimum Station Value<br>(68.2% Confidence Interval)</td><td>95<br>(45 – 176)</td><td>90<br>(44 – 181)</td></tr>
<tr><td>Maximum Station Value<br>(68.2% Confidence Interval)</td><td>897<br>(498 – 1,888)</td><td>211<br>(120 – 371)</td></tr>
</table>

Depending on station placement, the Sacramento program can be expected to have between 23,722 and 25,124 monthly rentals within the primary service area, with individual station values ranging from 70 to 897 rentals per month and averaging between 316 and 335 rentals per month. If the secondary service area to the north of the American River is incorporated into the system, total monthly values can be expected to reach between 26,864 and 28,266 rentals for the program as a whole. These figures are approximately on par with those observed for the Nice Ride program, which reported a system-wide

total of 23,112 rentals during August 2010 (average of 356 rentals per station, ranging from 29 to 1,107). As the rentals for Minneapolis were recorded during the month of August, the figures in Table 6 should be considered as estimates for the months most conducive to cycling in Sacramento.

When empirical error is taken into account, the estimates range widely: it can be stated with 68.2 percent confidence that values will be between 14,387 and 53,233 monthly rentals for the program as a whole. While it is possible that Sacramento rental values will converge on the estimates around which the confidence intervals are constructed, this range of values demonstrates the importance of noting and accounting for potential deviations from empirically estimated values.

Additionally, it should be noted that the Sacramento estimates are likely to be low due to the process of placing stations for this analysis. Although the delineation of service areas has been driven by the results of the suitability analysis, the placement of stations *within* these areas results from a high-level process rather than consideration of micro-level characteristics. In reality, Sacramento planners will benefit from local knowledge when determining the exact intersections and amenities at which stations should be located within highly suitable areas, thus achieving maximum ridership potential.

The spatial distribution of stations and estimates for Scenarios 1 and 2 (not accounting for confidence intervals) are displayed in Figures 6 through 8.

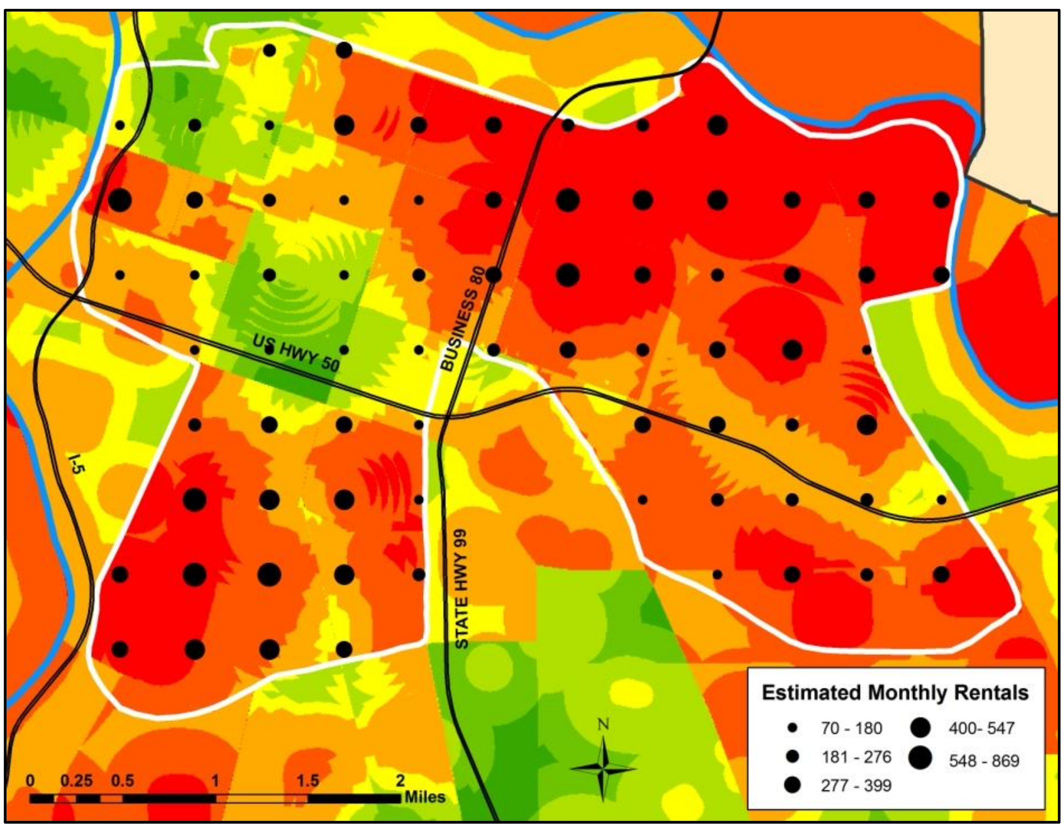


**Figure 6: Estimated Rentals by Station in the Primary Service Area, Scenario 1 (Low)**

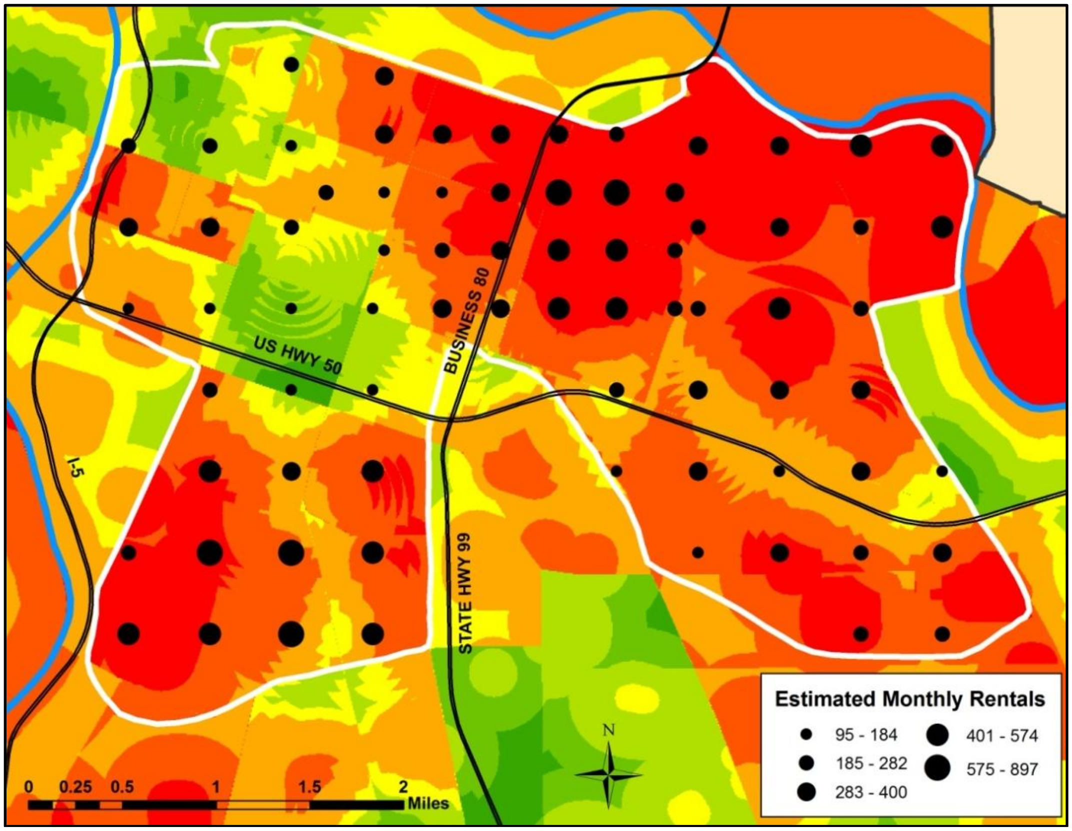


**Figure 7: Estimated Rentals by Station in the Primary Service Area, Scenario 2 (High)**

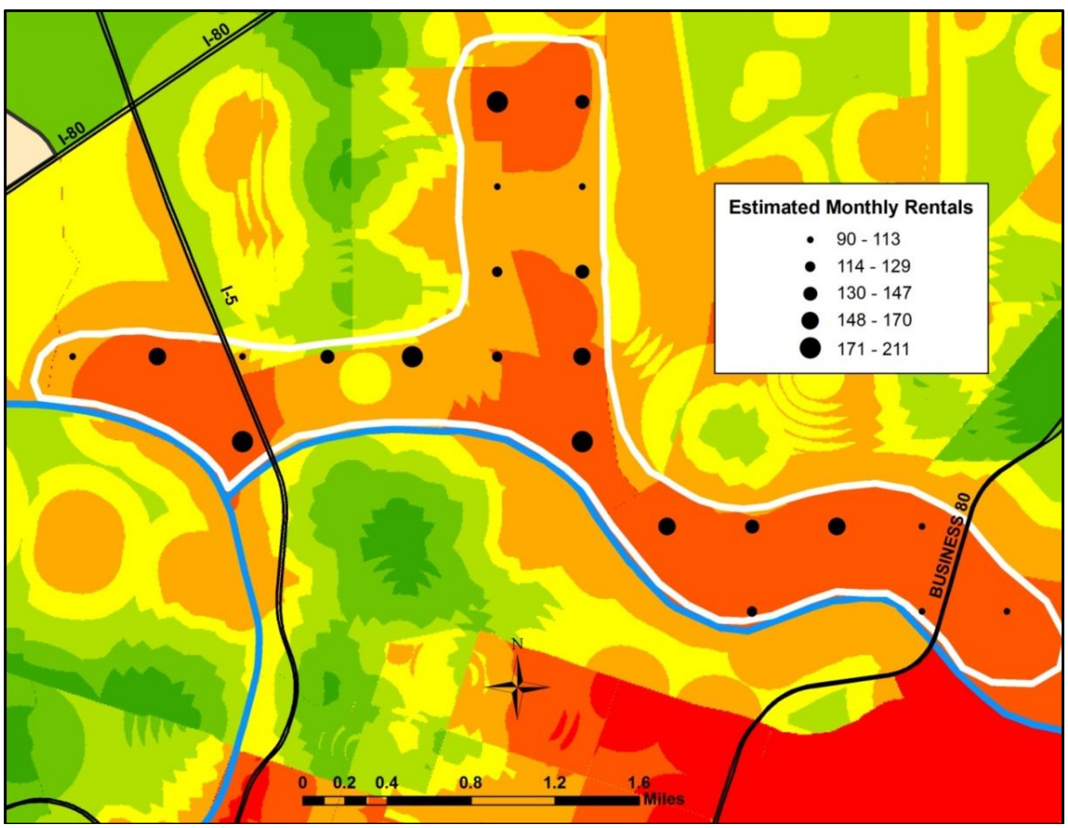


**Figure 8: Estimated Rentals by Station in the Secondary Service Area, Both Scenarios**

## Discussion

Although suitability and rental calculations in Sacramento are based on observed experiences in Minneapolis, the results are somewhat unexpected. As demonstrated in Figure 4, the distribution of suitability as calculated through the regression-based model does not adhere to the theory that bike-share rentals will be highest in the central business district and lower in outlying areas. Not surprisingly, as the delineation of service areas is based on this analysis and as the projection of rentals is based on the Minneapolis regression, Figures 6 and 7 show a similar pattern of lower estimated rentals within the central city and higher rentals in areas to the south and east.

These results must be interpreted with caution given their origin in data estimated for another city. When extrapolating results in this manner, the differences between locations must be carefully considered in order to ensure meaningful and appropriate interpretation. More specifically, the application of Minneapolis findings to the Sacramento context may be affected by two major sources of bias: out-of-range predictions and underlying differences between the two cities.

First, the model developed for Minneapolis is based on a set of observations with specific ranges for each variable. As the applicability of the model may be called into question when observations fall outside of these ranges, it is important to examine the descriptive statistics of the final model variables for both Minneapolis and Sacramento. As indicated in Appendix A of this report, eleven independent variables in Sacramento have values that fall outside of the range of values observed in Minneapolis. Because the preferred regression model has not been calibrated using these values, the application of the model to the Sacramento context is subject to bias that could play a role in the unexpected results.

Second, the results must be considered in light of the underlying differences between Minneapolis and Sacramento. Such differences, which can be identified through an evaluation of descriptive statistics and spatial patterns, could bias the suitability and rental calculations made for Sacramento.

As indicated by the descriptive statistics of the data (see Appendix A), ten variables in the preferred regression model have notably different mean values in Sacramento and Minneapolis. The density of population, employment (total and retail), high-income jobs, and attractors is considerably lower in Sacramento, as are the values for three key transportation factors. Particularly dramatic among the latter variables is the lower degree of transit intensity in Sacramento. Alternatively, both median income and the proportion of households with low vehicle availability are substantially higher in Sacramento. In addition to introducing potential bias, these comparisons have two interesting implications for the results of the suitability analysis and rental projections, as outlined below:

- Although it is insignificant, the coefficient for *Transit Intensity* in the preferred regression model suggests that there is a negative association between transit service and bike-share rentals in Minneapolis. This relationship could indicate that transit and bike-share are primarily competing rather than complementary modes in this city, which is very well-served by the transit network. In Sacramento, however, transit service is comparatively low: the average hypothetical station area in Scenario 2 is served by only 9 transit vehicles during the morning peak hour, compared to a mean of 142 vehicles in Minneapolis. Given this relatively low level of bus and rail service in Sacramento, it is possible that the bike-share mode would not face significant competition from transit but would instead serve as an attractive alternative or complementary mode. Thus, both suitability and rentals may be higher in downtown Sacramento than predicted through this Minneapolis-based analysis.

- Similarly, a negative coefficient is obtained for *Jobs* in the Minneapolis regression. While this result is unexpected, two potential explanations have previously been suggested. First, as noted in the interpretation of preferred model coefficients, areas with very high job density may be highly walkable and well-served by alternative, competing modes. Second, as discussed in the evaluation of under- and over-estimated rentals, large employers often function as self-contained units and impose physical barriers to surrounding uses. Given that job density is considerably lower in Sacramento, these conditions may not hold and both suitability and rentals may be higher in the downtown area than predicted based on the Nice Ride experience.

Finally, in order to more fully understand the relatively low estimated suitability and rentals in downtown Sacramento, the spatial distributions of significant variables from the preferred regression model are observed in both Sacramento and Minneapolis. This analysis suggests that the low rentals projected for the downtown area may result in part from underlying differences in urban structure and dynamics between the two cities.

These findings are most clearly demonstrated through the distribution of median income and low vehicle availability in the two cities, as presented in Appendix F of this report. These two figures show markedly different distributions of median income in Minneapolis and Sacramento. Median income is relatively high in downtown Minneapolis compared to outlying areas, an observation that could explain the positive coefficient for *Income* in the preferred regression model. Alternatively, the Sacramento study area demonstrates the opposite pattern, with notably lower median incomes downtown than in peripheral areas. Given the positive effect applied to median income in the suitability analysis and rental projections, this spatial distribution provides a potential explanation for the low values estimated for downtown Sacramento. Similarly, the distribution of tracts with low vehicle availability is more even in Minneapolis than in Sacramento, where this socioeconomic condition is concentrated primarily in the downtown area. As the association between *ln(Rentals)* and *Low-Vehicle Household Prevalence* is found to be negative in the preferred regression model, this difference in spatial distribution between the two cities could have influenced the low suitability and rentals projected for downtown Sacramento.

These observations suggest a variety of potential explanations for the somewhat unexpected results obtained for Sacramento. Given these observations, the results of this analysis must be carefully considered in light of the underlying differences between Minneapolis and Sacramento for several key regression variables.

## Conclusions and Recommendations

Through a variety of techniques, this study has accomplished its four primary objectives while providing additional insights into the nuances of bike-share suitability and station placement. Most importantly, the study has identified the key determinants of suitability and ridership in Minneapolis and has used these results to first recommend program service areas in Sacramento, then project potential monthly rentals within these areas. Based on these analyses, the following major conclusions are reached:

- **As implied by the Nice Ride experience, bike-share suitability is highly influenced by an area's income, racial composition, job density, high-earnings job density, commute patterns, and proximity to rail stations and parks.** These factors should be given particular weight by Sacramento planners as they determine the location and extent of the proposed bicycle sharing program.

- **In light of these findings, Sacramento planners should consider implementing the recommended service areas defined in Figure 5.** Based on funding availability, it may be useful to pursue a phased implementation approach. Under this scenario, the primary service area should be implemented first due to its higher predicted station-level ridership estimates and thus its potential to initiate a successful and high-profile program. After this initial phase, which will provide additional insight into the factors that affect ridership in Sacramento, the secondary service area to the north of the American River should be incorporated. Importantly, to increase ridership potential and to ensure that the program remains cohesive, improvements should be sought to enhance the safety and convenience of crossing the American and Sacramento Rivers by bicycle.

- **Based on the regression analysis of rental patterns in Minneapolis, the full Sacramento program can be expected to record between 26,864 and 28,266 bike-share rentals per month.** Rentals may in fact be higher in Sacramento due to several underlying differences from Minneapolis, and rentals will likely be higher if stations are placed more densely in areas determined through this study to be particularly suitable for bike-share use. While these empirical results are subject to error that makes the potential range of rentals much larger, the estimates provide a relatively realistic expectation of rentals in Sacramento. Importantly, these projections can be used to more fully evaluate the feasibility of the program in light of the required investment.

- **Planners in Sacramento should recognize the importance of demographic and socioeconomic factors in influencing bike-share ridership.** While past studies have emphasized "traditional" factors such as transportation infrastructure and population density, this study suggests that characteristics such as median income, racial composition, and household vehicle availability are key determinants of bike-share rentals. These characteristics must be carefully considered for equity reasons, and they should be used only to *expand* service rather than to contract it. Indeed, a variety of locations in the Sacramento study area are not found to be suitable based on theory alone, but are incorporated into the program when demographic and socioeconomic variables are considered. Additionally, the influences of race and income imply that program operators in both cities should seek a fare structure and programming efforts that more effectively attract lower-income and minority users.

- **Planners in both cities should recognize and attempt to anticipate the ways in which other modes will interact with the bicycle sharing program.** Based on the Minneapolis experience, the bike-share mode may face significant competition from pedestrian travel and public transit. While the underlying differences between the two cities suggest that this competition may not be as great within the Sacramento context, planners should nevertheless seek to maximize synergies with alternative modes to make them complementary to bike-share use.

- **Finally, planners in both cities can maximize ridership by placing stations in areas that are highly visible; that offer a diverse mix of retail and employment destinations; and that contain a high degree of cycling amenities and facilities.** Additionally, bike-share ridership at large employment sites, such as hospitals and government centers, may be increased by offering incentives for employer-based programs that encourage alternative commuting among workers.

Through the recommendations derived from this study, planners in Sacramento can implement a successful bicycle sharing system that is based on the actual experiences of a U.S. program. By creating an integrated network of stations in locations that are determined through this analysis to be particularly suitable for bicycle sharing initiatives, Sacramento planners can more effectively promote cycling in their city in the interest of environmental sustainability, reduced congestion, and enhanced public health.

# Appendix A: Descriptive Statistics for Variables in Minneapolis and Sacramento

### Table A1: Descriptive Statistics for Regression Variables in Minneapolis

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Population | 65 | 20.59827 | 7.98822 | 6.659612 | 41.32414 |
| Non-Wt. Pop. | 65 | .3400124 | .1692962 | .096563 | .907906 |
| Low Veh. Av. | 65 | .3805934 | .1488029 | .118667 | .6821254 |
| Income | 65 | 38.32512 | 17.59174 | 15.16951 | 110.5009 |
| Alt. Commut. | 65 | .2201296 | .052406 | .0456408 | .3014066 |
| Jobs | 65 | 69.372 | 87.82725 | 1.368414 | 278.7519 |
| Retail Jobs | 65 | 26.28851 | 36.1063 | .0695151 | 146.0403 |
| College | 65 | .3230769 | .4712912 | 0 | 1 |
| Dist. to Park | 65 | 25.78234 | 17.76119 | 0 | 72.75823 |
| Attractors | 65 | 2.430769 | 2.968424 | 0 | 15 |
| Dist. to Rail | 65 | 13.18595 | 9.791412 | .6866294 | 41.12153 |
| Trans. Intens | 65 | 14.17697 | 14.24111 | .35 | 47.25011 |
| Bus Stops | 65 | 21.01538 | 16.14533 | 3 | 65 |
| Bikeways | 65 | 31.31858 | 13.97271 | 6.54647 | 64.00099 |
| High Inc. Job | 65 | 48.80566 | 69.808 | .3497039 | 220.4943 |
| Rentals | 65 | 355.5692 | 243.3107 | 29 | 1107 |
| ln(Rentals) | 65 | 5.615551 | .785394 | 3.367296 | 7.009409 |
| Work Dest | 65 | 7.858866 | 9.50189 | 0 | 30.53996 |
| Home Dest | 65 | 2.893975 | 2.831805 | 0 | 12.20029 |
| Spaces | 65 | 18.41538 | 4.827953 | 11 | 33 |

### Table A2: Descriptive Statistics for Regression Variables in Sacramento (Preferred Model Only)

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Population | 75 | 11.50178 | 3.940976 | 5.692417 | 21.06034 |
| Non-Wt Pop | 75 | .243519 | .1135563 | .110153 | .613495 |
| Low-Veh Hshd | 75 | .5799862 | .1597938 | .301349 | .947678 |
| Income | 75 | 58.4861 | 21.46814 | 16.22386 | 99.37473 |
| Alt Commute | 75 | .1870708 | .1007618 | .014984 | .611225 |
| Jobs | 75 | 13.76935 | 25.35996 | .5116545 | 192.3235 |
| Retail Jobs | 75 | 5.835423 | 9.366357 | .0665785 | 61.31137 |
| College | 75 | .1466667 | .3561556 | 0 | 1 |
| Dist to Park | 75 | 31.84438 | 23.69488 | 0 | 92 |
| Attractors | 75 | .84 | 1.708801 | 0 | 10 |
| Dist to Rail | 75 | 9.768823 | 6.744222 | .4207749 | 29.35901 |
| Trans Intens | 75 | .9370222 | 1.491266 | 0 | 10.27667 |
| Bus Stops | 75 | 10.29333 | 11.93991 | 0 | 71 |
| Bikeways | 75 | 19.54127 | 10.41517 | 0 | 46.66822 |
| High-Inc Jobs | 75 | 7.514285 | 16.57914 | .12995 | 129.0581 |
| Spaces | 75 | 17.6 | 2.348087 | 16 | 21 |

# Appendix B: List of 2-Digit NAICS Sectors for "Appropriate" Jobs

**Table B1: List of 2-Digit NAICS Sectors for "Appropriate" Jobs**

| NAICS Sector | Description |
|---|---|
| 44-45 | Retail Trade |
| 51 | Information |
| 52 | Finance and Insurance |
| 53 | Real Estate and Rental and Leasing |
| 54 | Professional, Scientific, and Technical Services |
| 55 | Management of Companies and Enterprises |
| 56 | Administrative and Support and Waste Management and Remediation Services |
| 61 | Educational Services |
| 62 | Health Care and Social Assistance |
| 71 | Arts, Entertainment, and Recreation |
| 72 | Accommodation and Food Services |
| 81 | Other Services (except Public Administration) |
| 92 | Public Administration |

# Appendix C: Supplemental Regression Analysis Materials

**Table C1: Variance Inflation Factors (VIFs) Demonstrating Collinearity among Variables (Minneapolis)**

| Variable | VIF | 1/VIF |
|---|---|---|
| Jobs | 2841.50 | 0.000352 |
| High-Inc Jobs | 2473.43 | 0.000404 |
| Work Dest | 678.95 | 0.001473 |
| Population | 104.45 | 0.009574 |
| Age 18-49 | 68.25 | 0.014652 |
| Pop Squared | 51.68 | 0.019350 |
| Trans Interac | 46.51 | 0.021502 |
| Income | 42.24 | 0.023673 |
| Retail Jobs | 29.80 | 0.033557 |
| Inc Squared | 27.61 | 0.036221 |
| Trans Intens | 26.97 | 0.037084 |
| Low-Veh Hshd | 23.44 | 0.042668 |
| Bus Stops | 22.31 | 0.044830 |
| Alt Commmute | 14.94 | 0.066925 |
| Home Dest | 13.67 | 0.073136 |
| Dist to Rail | 6.83 | 0.146427 |
| Non-Wt Pop | 6.02 | 0.166227 |
| Attractors | 3.59 | 0.278649 |
| College | 3.41 | 0.293058 |
| Dist to Park | 1.60 | 0.624927 |
| Bikeways | 1.60 | 0.626665 |
| Spaces | 1.45 | 0.690254 |
| Mean VIF | 295.01 | |

**Table C2: Preliminary Regression Model with Standardized Coefficients ("Beta" Values)**

| Source | SS | df | MS |
|---|---|---|---|
| Model | 29.7964561 | 22 | 1.35438437 |
| Residual | 9.68153926 | 42 | .23051284 |
| Total | 39.4779954 | 64 | .616843678 |

| | |
|---|---|
| Number of obs | = 65 |
| F( 22, 42) | = 5.88 |
| Prob > F | = 0.0000 |
| R-squared | = 0.7548 |
| Adj R-squared | = 0.6263 |
| Root MSE | = .48012 |

| lnrentals | Coef. | Std. Err. | t | P>\|t\| | Beta |
|---|---|---|---|---|---|
| Population | .084142 | .076784 | 1.10 | 0.279 | .8558059 |
| Pop Squared | -.0013035 | .0011267 | -1.16 | 0.254 | -.6355414 |
| Age 18-49 | -.0277531 | .0822024 | -0.34 | 0.737 | -.2131347 |
| Non-Wt Pop | -2.788927 | .8694809 | -3.21 | 0.003 | -.6011695 |
| Low-Veh Hshd | -2.239056 | 1.952513 | -1.15 | 0.258 | -.4242179 |
| Income | .0014512 | .0221731 | 0.07 | 0.948 | .0325044 |
| Inc Squared | .0001496 | .0001777 | 0.84 | 0.405 | .3380137 |
| Alt Commute | 7.030714 | 4.426708 | 1.59 | 0.120 | .4691297 |
| Jobs | -.0751787 | .0364252 | -2.06 | 0.045 | -8.406911 |
| Retail Jobs | .0177851 | .0090737 | 1.96 | 0.057 | .8176212 |
| College | .1802165 | .2352295 | 0.77 | 0.448 | .1081425 |
| Dist to Park | -.0110419 | .0042744 | -2.58 | 0.013 | -.2497058 |
| Attractors | .0392113 | .0383004 | 1.02 | 0.312 | .1482004 |
| Dist to Rail | -.0192726 | .0160178 | -1.20 | 0.236 | -.2402694 |
| Trans Intens | -.0113102 | .0218837 | -0.52 | 0.608 | -.2050814 |
| Bus Stops | .0071321 | .017556 | 0.41 | 0.687 | .146614 |
| Trans Interac | .000256 | .0004932 | 0.52 | 0.606 | .2704778 |
| Bikeways | .00207 | .0054257 | 0.38 | 0.705 | .0368262 |
| High-Inc Jobs | .0977593 | .0427565 | 2.29 | 0.027 | 8.68912 |
| Work Dest | -.0999 | .1645764 | -0.61 | 0.547 | -1.208615 |
| Home Dest | .0076691 | .0783663 | 0.10 | 0.923 | .0276516 |
| Spaces | .0293469 | .014962 | 1.96 | 0.056 | .1804004 |
| constant | 5.24738 | 1.290436 | 4.07 | 0.000 | . |

## Appendix D: Profiles of Stations with High Estimation Error

| Midtown Exchange (Underestimate) | | |
|---|---|---|
| *Actual Rentals: 313* | *Predicted Rentals: 139* | *Difference: 125%* |

- Uses surrounding the station site include high-density housing, a busy retail area, a large healthcare campus (healthcare facilities and healthcare-related corporate offices), and the Sheraton Midtown Hotel.
- The primary retail area (Midtown Global Exchange) contains a variety of small businesses (food service, clothing and retail stores) in a condensed, vibrant, and bazaar-like setting.
- Despite this unique retail destination, the number of retail jobs within 400 meters of this station is notably lower than that for the entire sample.
- The station is surrounded by many cycling amenities and is located near an off-road bikeway.
- Another station is located nearby at a hospital, and individuals traveling between these healthcare campuses enjoy convenient access to both stations.
- While large healthcare campuses typically contain sufficient amenities that employees do not need to leave the site after arriving, employees at this particular facility are more likely to leave the site due to the presence of the Midtown Global Exchange.

| 4th Street & 13th Avenue SE (Underestimate) | | |
|---|---|---|
| *Actual Rentals: 545* | *Predicted Rentals: 308* | *Difference: 77%* |

- The station is located on the northwestern corner of the University of Minnesota campus, which is a primary access point that provides easy access to the entire campus.
- Given this location, the station is surrounded by higher-density student housing.
- The station is located one block west of one of the two major retail districts near the University of Minneapolis campus. This district contains a wide variety of retail uses.
- Similar to the Midtown Exchange station, the number of retail jobs within 400 meters of this station is considerably lower than the sample mean despite the unique retail destination it offers.
- There are marked bike lanes along the street traveling both east and west from the station, allowing users to ride on dedicated, on-street facilities.

| Franklin Avenue LRT (Underestimate) | | |
|---|---|---|
| *Actual Rentals: 188* | *Predicted Rentals: 92* | *Difference: 104%* |

- Interestingly, this station is not located near many destinations; the closest surrounding uses include a motorcycle shop and three bars.
- Although there is high-density housing to the north of the station, access from these areas is extremely difficult due to interstate freeways. Similarly, the light rail tracks nearly block all access from the west. Nice Ride officials are seeking to relocate this station for greater access.
- The station is located along the Hiawatha Bike Trail, a transportation and recreation source for cyclists.
- The Nice Ride Operations Director was quite surprised that the station recorded *higher*-than-predicted rentals, given the access issues and surrounding environment.

| Minneapolis Convention Center (Overestimate) | | |
|---|---|---|
| *Actual Rentals: 119* | *Predicted Rentals: 361* | *Difference: 67%* |

- This station is located between several hotels and the Minneapolis Convention Center. However, the Convention Center is accessible from almost all surrounding hotels through a second-story skyway system.
- Other than the Convention Center, there is not a very high density of employment or population surrounding the station. Density is also limited by the presence of freeways.
- The street on which this station is located is not the primary route into downtown; other surrounding streets carry a higher volume of pedestrian and cycling traffic to downtown destinations.
- Two additional Nice Ride stations are located within 1.5 blocks. Notably, these nearby stations are quite prominent and record some of the highest rentals in the system.
- The mix of businesses and destinations in the surrounding area is limited. The area is somewhat dominated by the Convention Center and contains a limited mix of commercial and retail establishments.

| Augsburg (Overestimate) | | |
|---|---|---|
| *Actual Rentals: 57* | *Predicted Rentals: 139* | *Difference: 59%* |

- This station is located directly on the campus of Augsburg College, a liberal arts institution with enrollment of approximately 4,000 students.
- The street on which the station is located offers brand-new marked bike lanes in both directions.
- The station is located across the street from a large hospital/medical facility.
- Several additional Nice Ride stations are located near the Augsburg station, making it a well-connected rather than outlying part of the network.
- Nice Ride officials are surprised by the low rental figures but have thus far been unable to determine whether the station is actually used by many Augsburg students. Additionally, they note that given the small size of the campus, students and other users (faculty, staff, visitors) may not see a need to use Nice Ride for daily travel.

| 7th Street & 4th Avenue S (Overestimate) | | |
|---|---|---|
| *Actual Rentals: 236* | *Predicted Rentals: 523* | *Difference: 55%* |

- The station is located near the Hennepin County Government Center, a major employer and potential citizen destination. Several areas of high-density housing are also located nearby.
- Although late placement may have played a role in the overestimate, Nice Ride officials believe that the presence of the Government Center may have contributed to this result. As previously described, large employment centers such as healthcare and government facilities tend to function as entities unto themselves; individuals traveling to these campuses for work or other reasons do not typically need to leave to find everyday uses such as convenience stores, banks, and restaurants. Additionally, the size of these campuses may also exert a barrier effect that decreases perceived or actual accessibility to surrounding uses.

# Appendix E: Supplemental Suitability Analysis Materials

**Table E1: Inputs, Directions, and Weights for Theory-Based Suitability Model**

| Layer | Direction Used for Analysis | Weight |
|---|---|---|
| *Population Density* | Positive | 1 |
| *Alternative Commuters* | Positive | 1 |
| *Job Density* | Positive | 1 |
| *Retail Density* | Positive | 1 |
| *Attractors* | Positive | 1 |
| *Distance to Park* | Negative | 1 |
| *Transit Intensity* | Positive | 1 |
| *Bus Stop Density* | Positive | 1 |
| *Distance to Rail* | Negative | 1 |
| *Bikeways Density* | Positive | 1 |

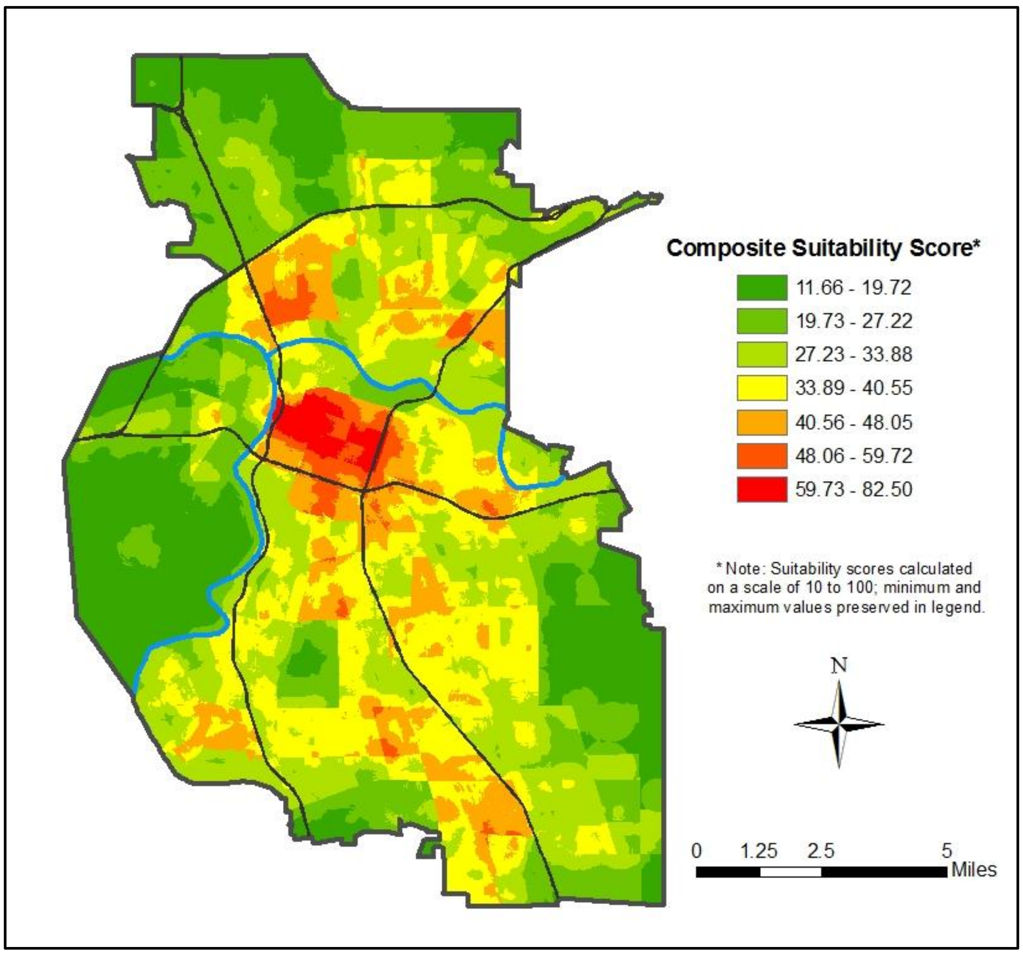


**Figure E1: Mapped Results of Theory-Based Suitability Model**

**Map Layouts of Rasterized Suitability Analysis Inputs**

[Full page layouts of inputs used in either theory-based or empirical model on the pages that follow]

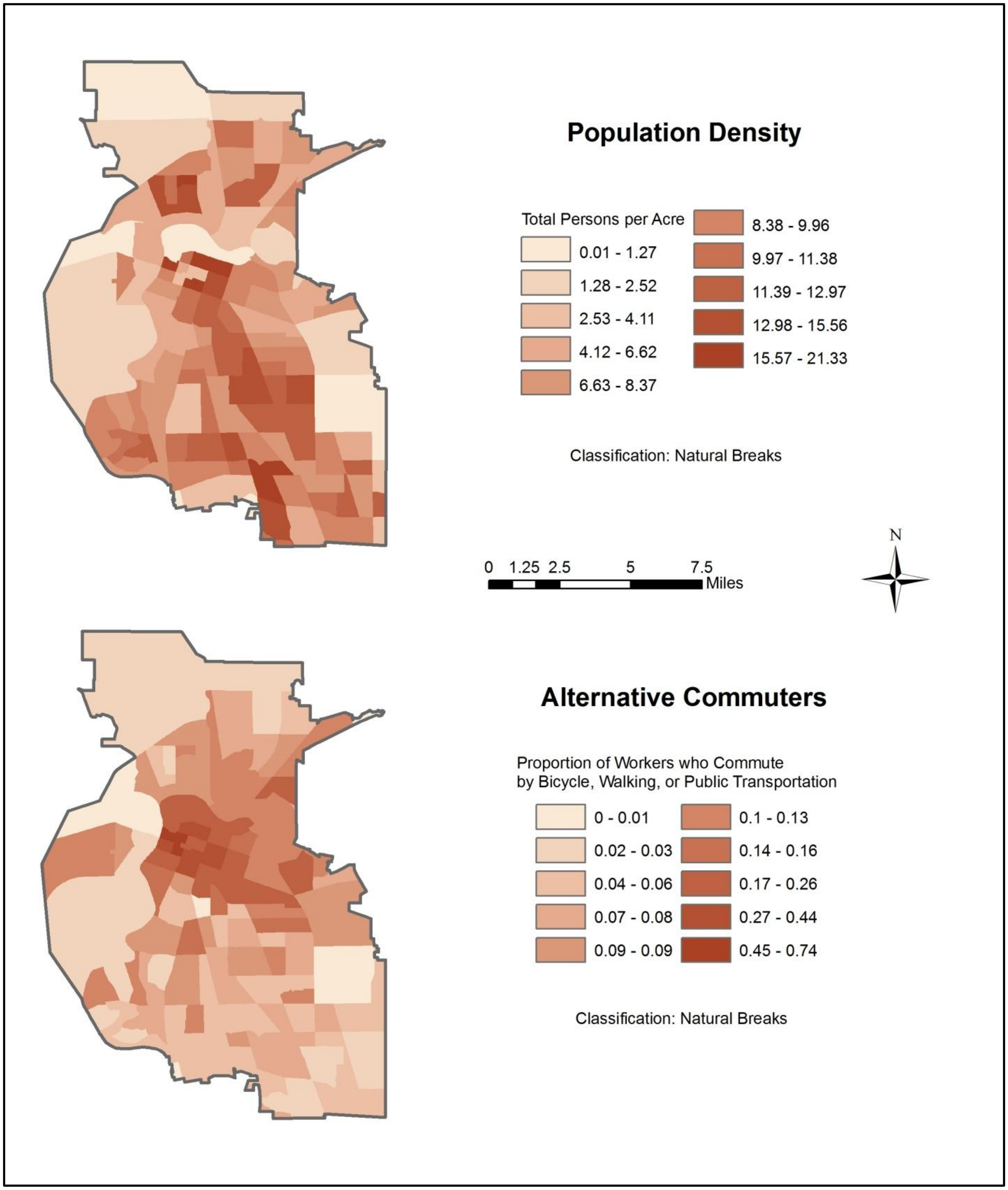


**Figure E2: Rasterized Suitability Analysis Inputs, Trip Generation Factors – Population Density and Alternative Commuters**


**Figure E3: Rasterized Suitability Analysis Inputs, Trip Generation Factors – Median Income and Non-White Population**

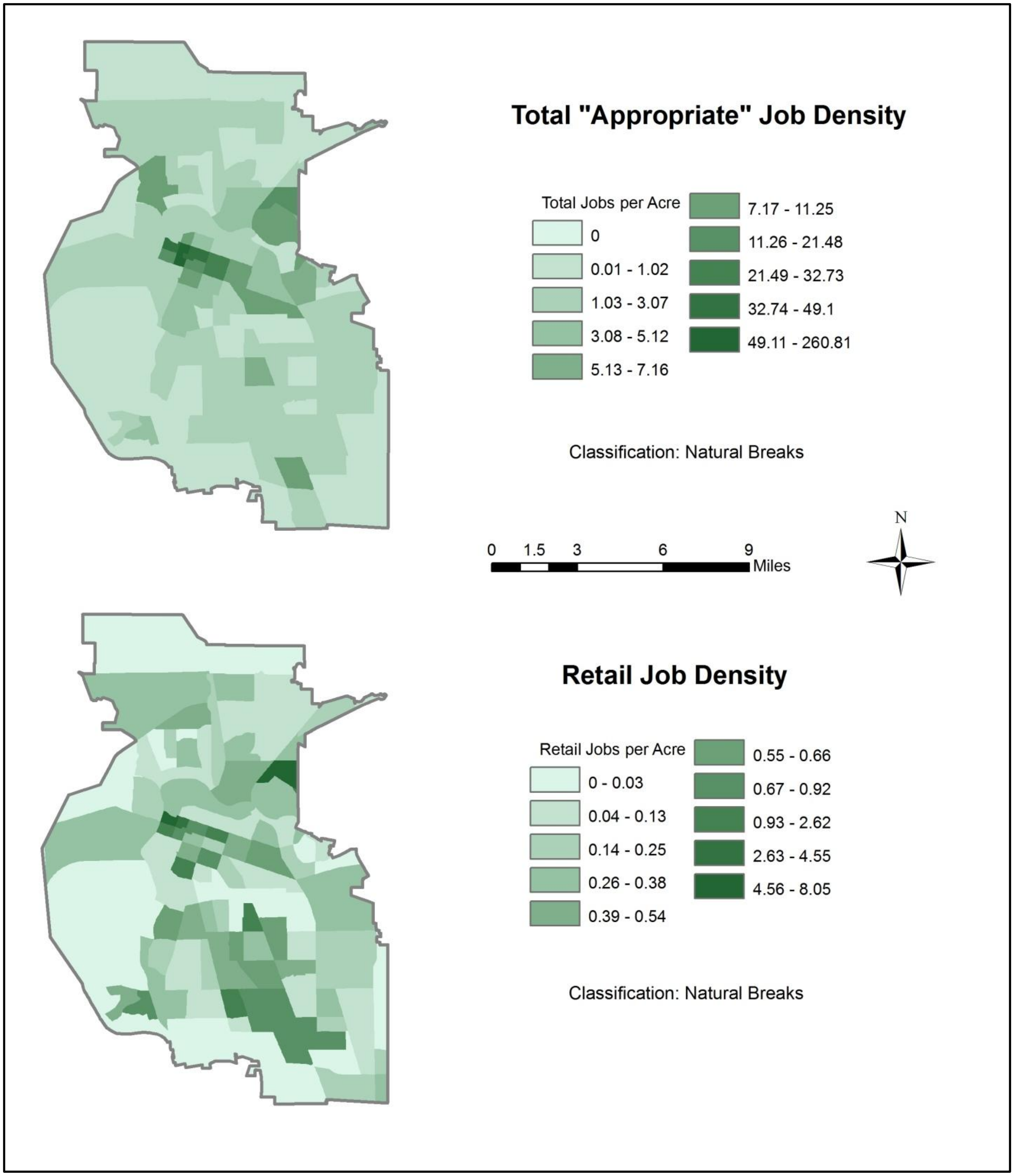


**Figure E4: Rasterized Suitability Analysis Inputs, Trip Attraction Factors – Jobs and Retail Jobs**

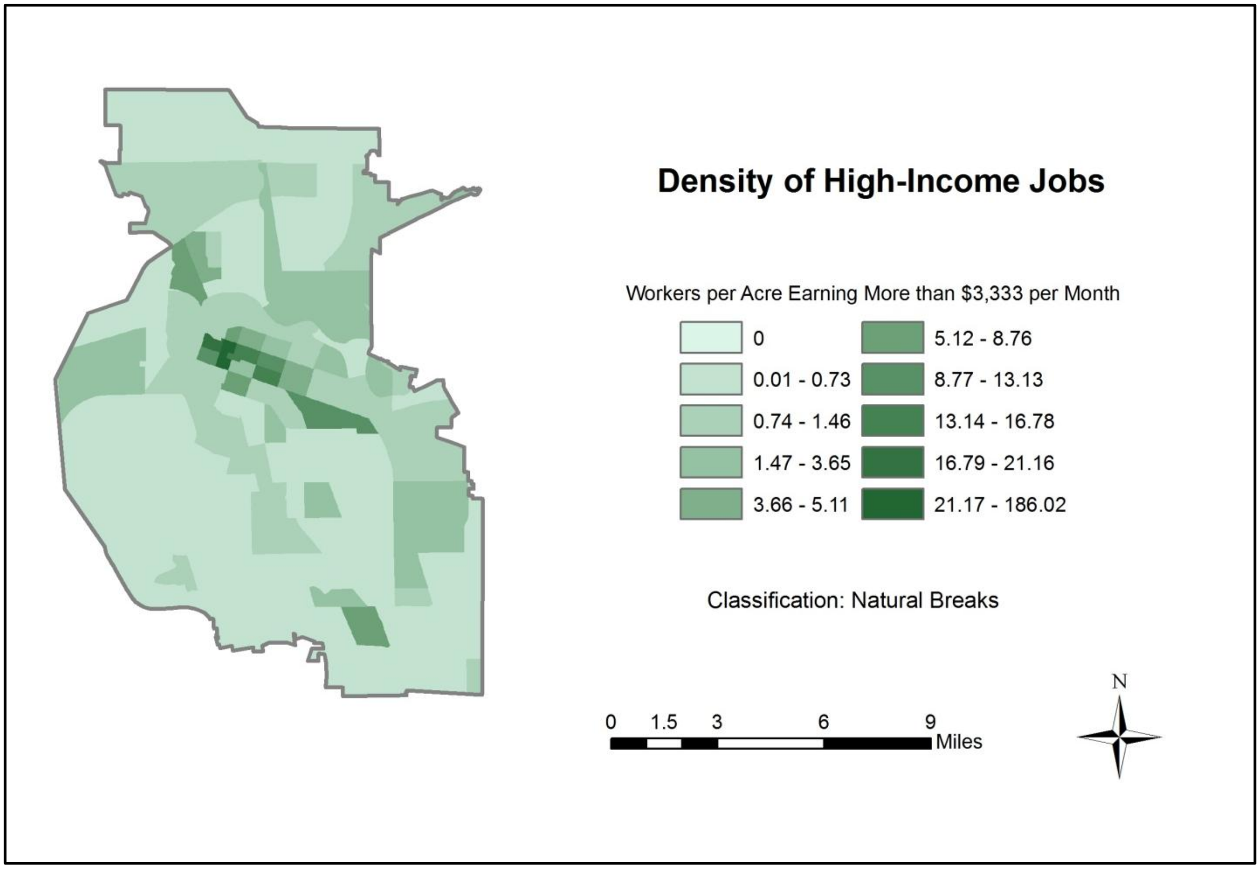


**Figure E5: Rasterized Suitability Analysis Inputs, Trip Attraction Factors – High-Income Jobs**

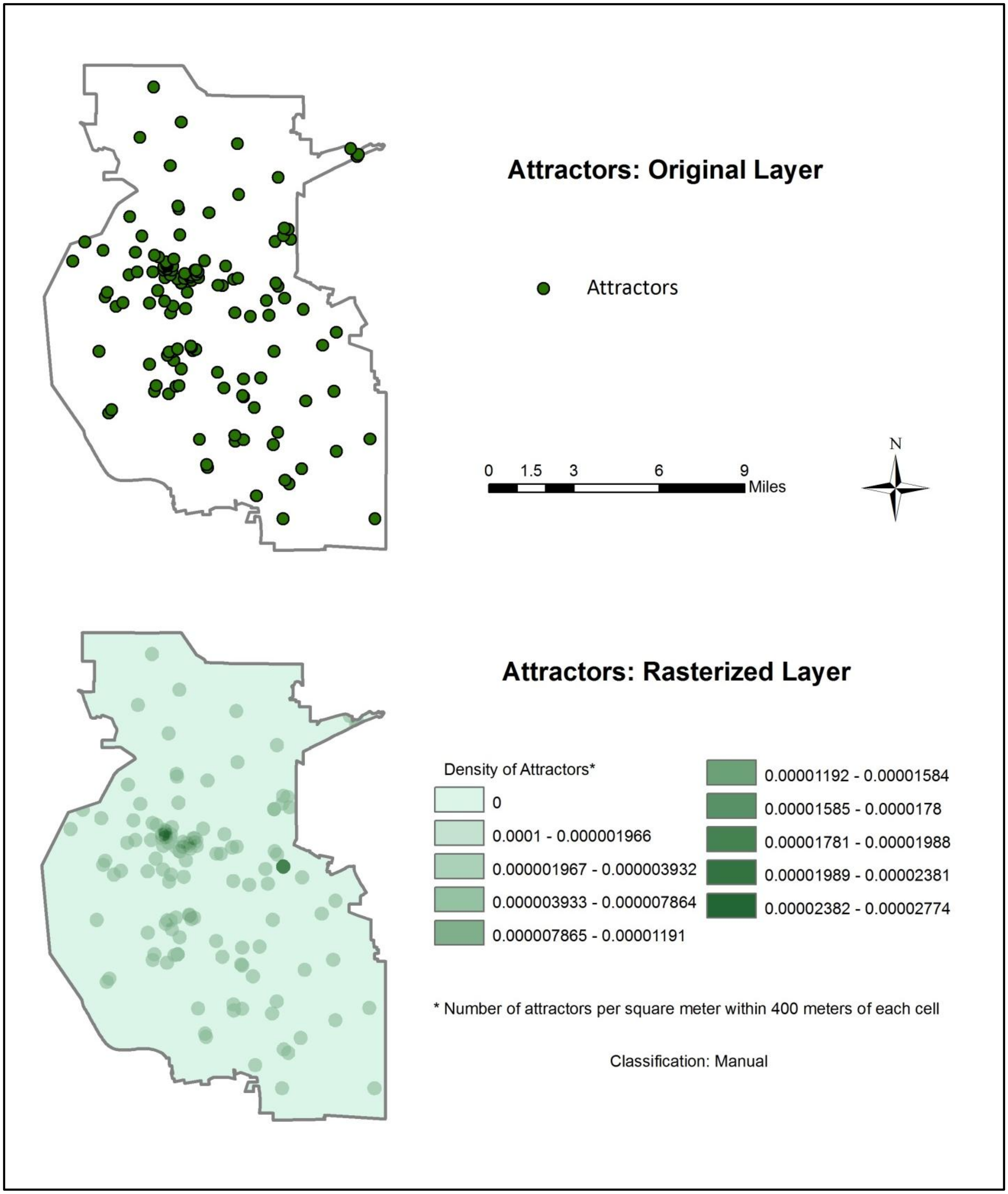


**Figure E6: Rasterized Suitability Analysis Inputs, Trip Attraction Factors – Attractors**

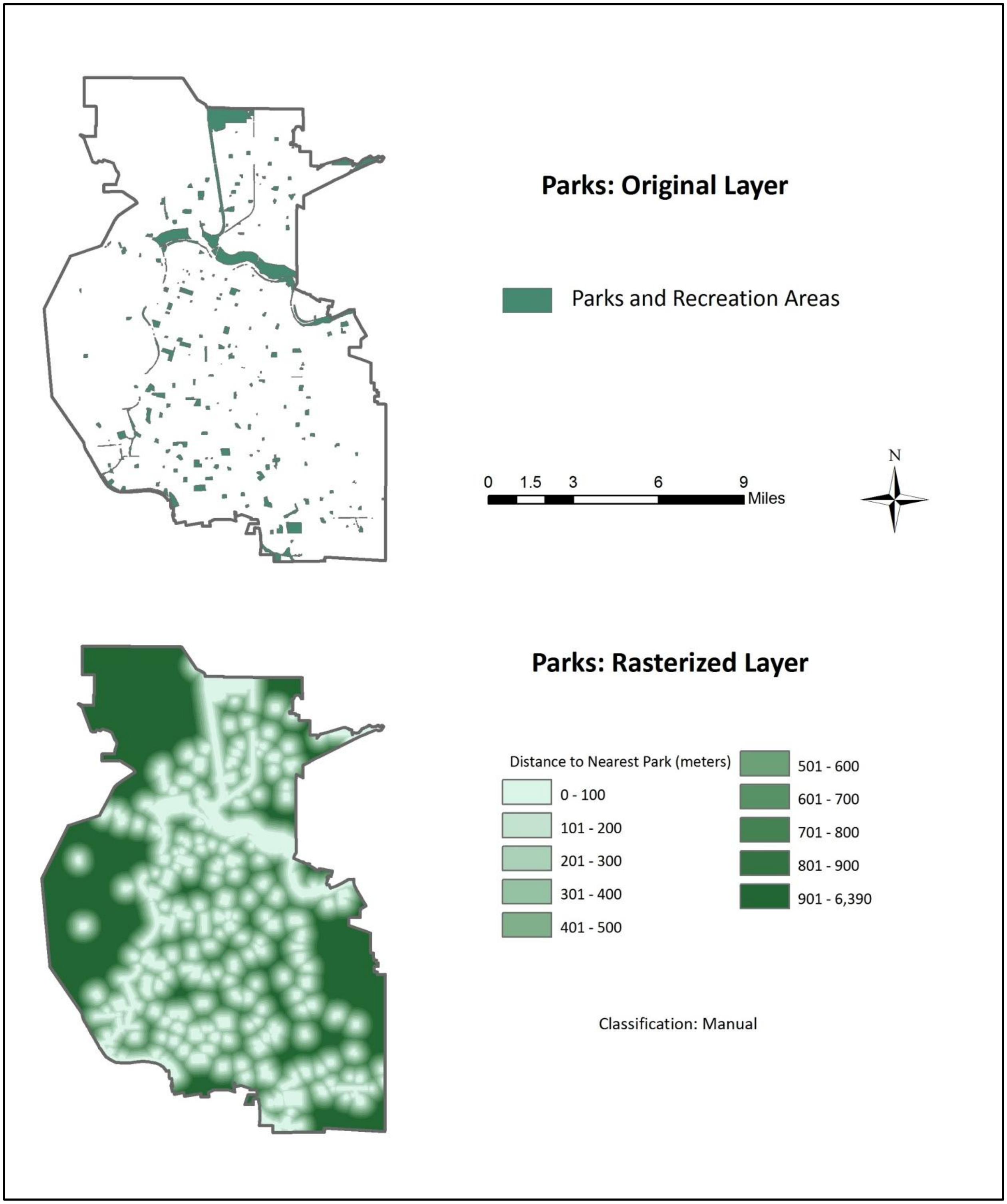


**Figure E7: Rasterized Suitability Analysis Inputs, Trip Attraction Factors – Distance to Parks**

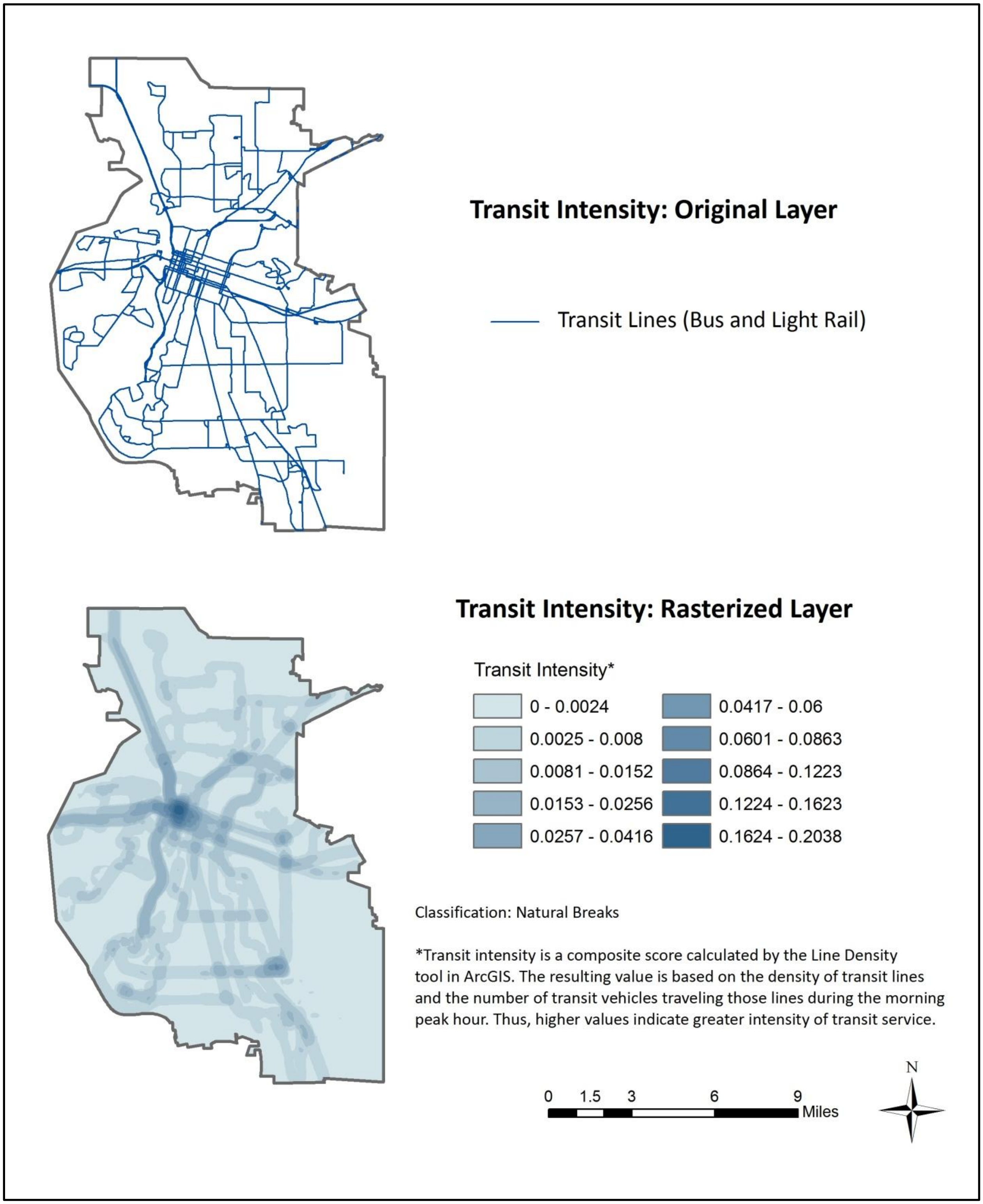


**Figure E8: Rasterized Suitability Analysis Inputs, Transportation Network Factors – Transit Intensity**

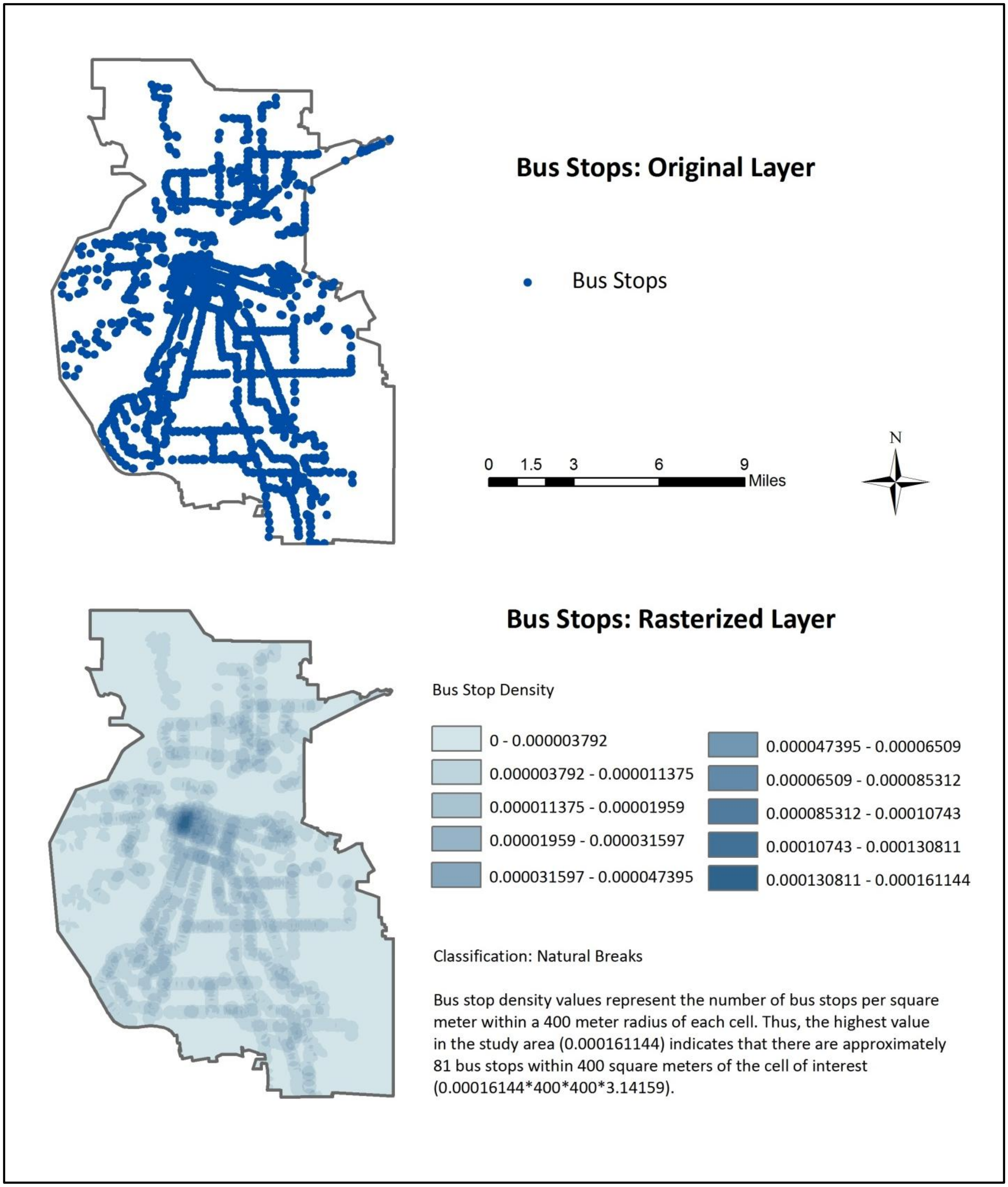


**Figure E9: Rasterized Suitability Analysis Inputs, Transportation Network Factors – Bus Stops**

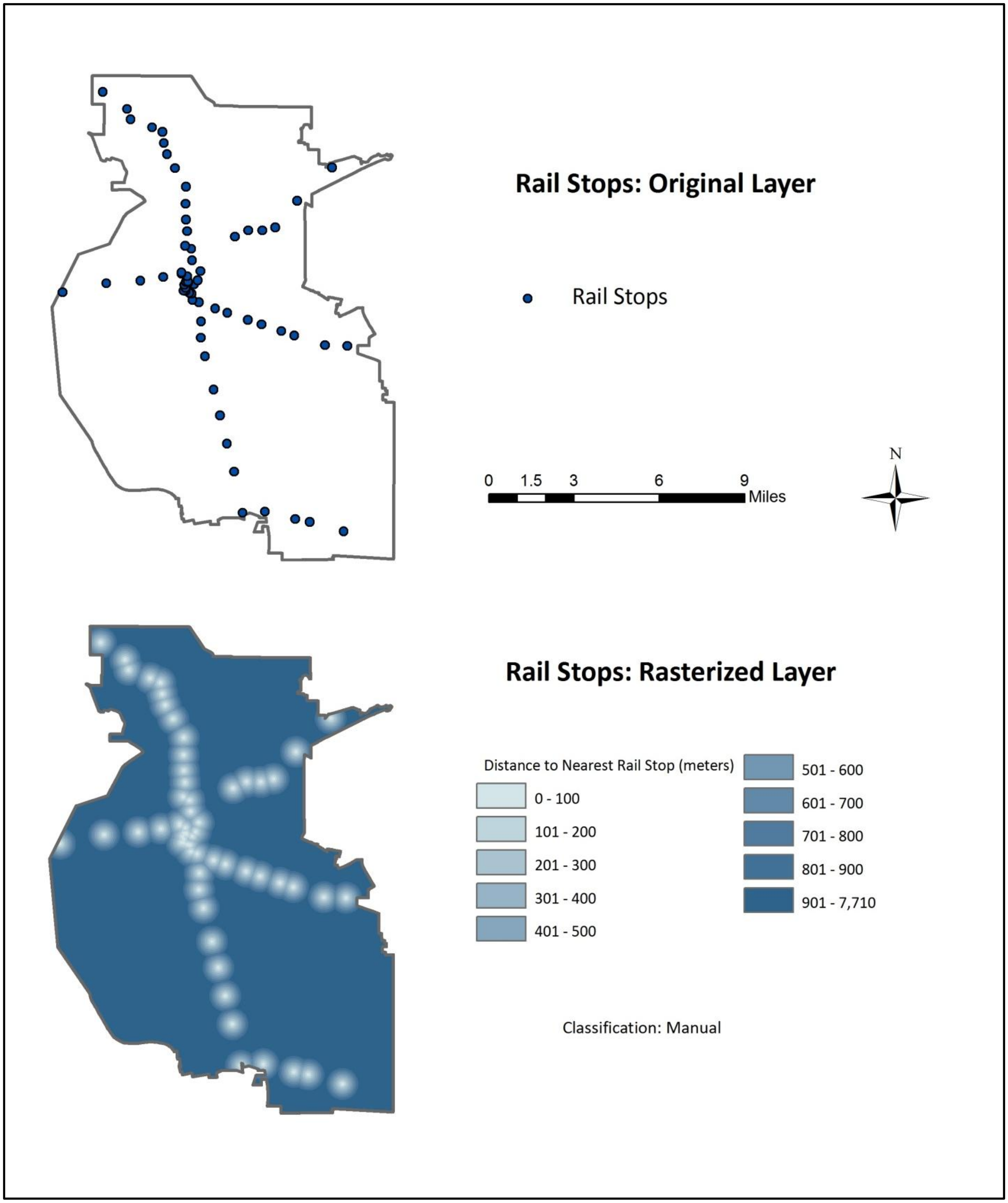


**Figure E10: Rasterized Suitability Analysis Inputs, Transportation Network Factors – Distance to Rail**

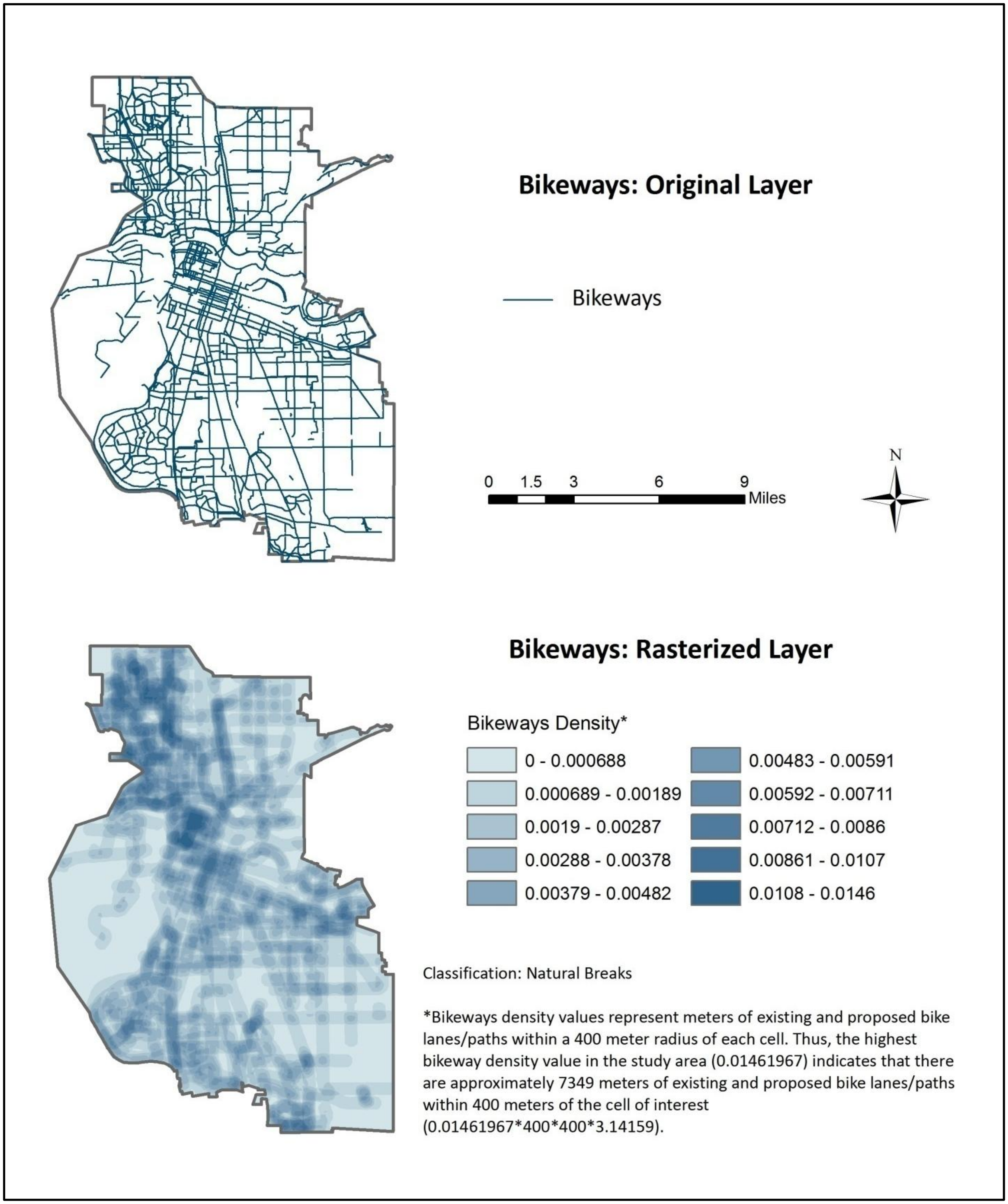


**Figure E11: Rasterized Suitability Analysis Inputs, Transportation Network Factors – Bikeways**

# Appendix F: Analysis of Spatial Differences between Minneapolis and Sacramento


**Figure F1: Spatial Distribution of Median Income in Minneapolis and Sacramento, by Census Tract**

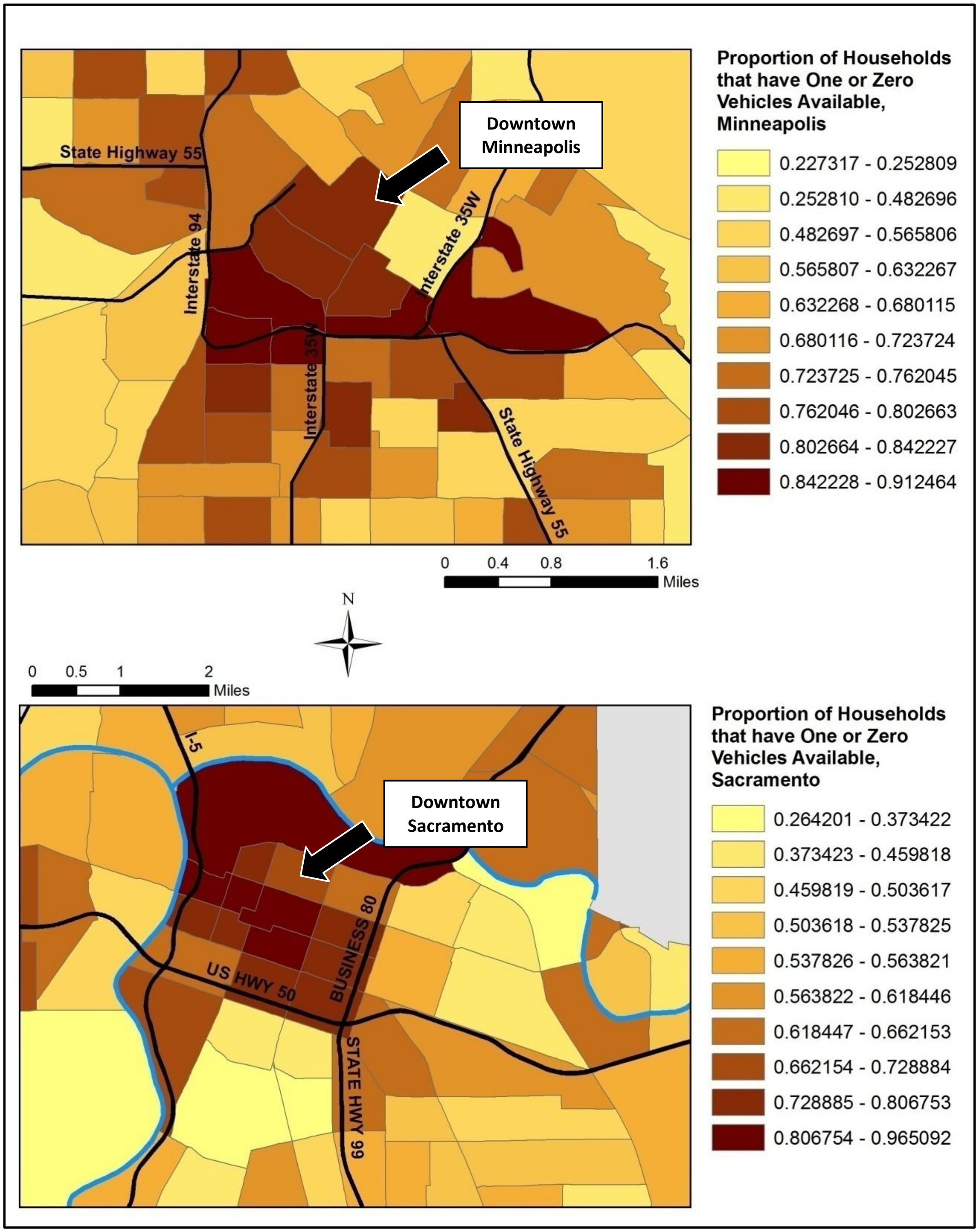


**Figure F2: Spatial Distribution of Low-Vehicle Household Prevalence in Minneapolis and Sacramento, by Census Tract**