Worcester, MA Bike Share Feasibility Study

Corinne Jachelski
Clark University, cjachelski@clarku.edu

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By: Corinne Jachelski

Advisor: Prof. Samuel Ratick; Second Reader: Kathryn Madden

Masters Candidate, Environmental Science and Policy

International Development, Community, Environment Department

Clark University

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Academic History

Corinne Jachelski graduated magna cum laude from Clark University in 2015 with a Bachelor's in Global Environmental Science and minors in Geography and Political Science. Corinne earned membership to the Gamma Theta Upsilon International Geographic Honor Society. Her focus within her major was on conservation and sustainability. She continued at Clark University to pursue an accelerated M.S. in Environmental Science and Policy with a focus on sustainability and the built environment.

Acknowledgements

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Preface

Clark University's Masters in Environmental Science and Policy requires a comprehensive final research component. This project was chosen by the student due to interest in intersection of the built environment, sustainability, and health. It is the hope that the research and practical aspects of this project will be of use to the City of Worcester in thinking about planning a bike share in the future, though cannot replace the expertise of a contracted planning firm. Additionally, it is anticipated that students will have interest in continued research on this topic, addressing some of the limitations and shortcomings outlined in this paper.

Executive Summary

The Worcester, MA Bike Share Feasibility Study was conducted to determine whether the City of Worcester is suitable for a city wide bike share. This study includes a general history of bike shares; their benefits based on major categories of social, environmental, economic, and transit; and overview of demographic composition of Worcester. Several cities of similar population size to Worcester that have implemented bike share systems are reviewed as context for system size. Other completed bike share feasibility studies informed the methods employed in this study, as well as provided more information broadly and specifically about all of the elements of a bike share system.

The majority of this study focuses on a GIS analysis that aims to determine areas of highest demand or suitability. Three models were developed with slightly varying attributes, with variables chosen according to both theory-based and experience-based bike share systems. The three models are Baseline Model, High Income Model, and Underserved Communities Model. Historically, many bike share systems have not been successful in attracting low income users, due to physical, cultural, and economic barriers, though underserved communities are least likely to own a personal vehicle and rely more on alternative means of transport. This study focuses especially on methods of engagement of underserved communities, as the results of the GIS models and the demographic landscape of Worcester lends itself to this focus.

Based on these models and recommendations from extensive reports on bike shares, a system size and cost is estimated. For a program with 13 stations and 101 bikes, the first year costs of equipment, installation, and maintenance would be between $841,000 and $940,000. Bike shares can be funded and operated according to various models, which are also outlined. A public-private partnership is recommended. Finally, local policies are examined, including discussion of the necessity for bicycling infrastructure expansion and means of public outreach and education.

The results of the Underserved Communities Model indicate that conditions exist for a pilot launch of a bike Share in the downtown area of Worcester, some of the surrounding neighborhoods, and along the length of Shrewsbury Street.

Overall recommendations of this study are expansion and investment in bicycle lanes, contributing to both traffic calming and increased bike ridership; conducting a community survey to validate station location and estimate demand; and formalizing dedication to creating a bicycling city by creating a Bicycle Master Plan and hiring a full time bicycle and pedestrian City staff member.

Purpose of the Plan

The purpose of this Worcester Bike Share Feasibility Study is to determine whether the City of Worcester is suitable for implementing and operating a bike share program. Worcester city officials have expressed interest in a bike share program to serve the nine colleges and universities located within the city, and to attract and retain an educated workforce. Other goals of the study include increasing Worcester Regional Transit Authority (WRTA) ridership through increased connectivity and bridging gaps in transportation opportunities; and providing affordable, reliable transport options to low income communities. Worcester is known for its rich industrial history and continues to be a hub of rail activity, contributing to economic opportunities but posing physical barriers. As the second largest city in New England, Worcester is in a position to take advantage of existing tourism and leverage recreation infrastructure through a bike share program.

Feasibility studies are generally concerned with defining a system service area and extrapolating demand to determine the financial solvency of a proposal (Daddio 2012, 6). The scope of the service area in this study is the entire city of Worcester, Massachusetts (Figure 1). This feasibility study defines key parameters for planning, includes a GIS analysis to determine the spatial suitability of a bike share, develops an initial financial analysis, and determines next steps. Table 1 fully outlines Purpose and Methods.

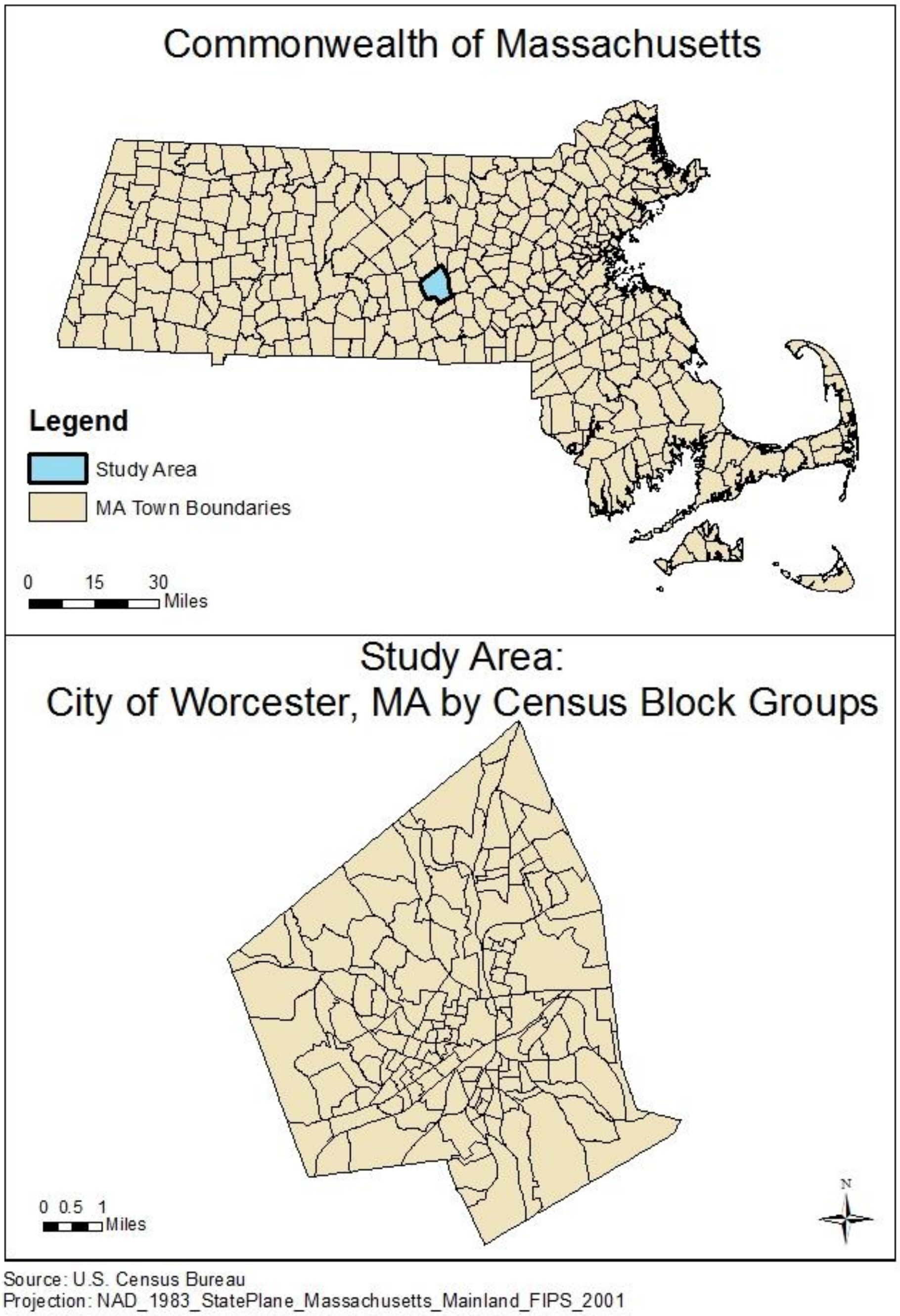

Figure 1. Study Area

Table 1. Purpose and Methods

Purpose	Method
Find comparable size cities or municipalities that have implemented bike share systems	Research bike share systems in places with similar population size, giving consideration to land size as well
Find ideal/suitable bike share locations based on potential users	Research previous feasibility studies, determine user profiles and community indicators, create map identifying spatial distribution of users and ideal locations
Incorporate connection of bike share to existing public transport system	Incorporate WRTA bus stops and bus routes into GIS analysis
Determine ideal locations for placement of bike share kiosks	Create a composite/weighted suitability map according to spatial distribution of community indicators and potential users
Examine local policy structure and initiatives that support or inhibit bike infrastructure	Research state-wide MassDoT policies (Complete Streets) and city-level planning initiatives/incentives
Provide an overview of funding models and opportunities	Compare funding models, identify stakeholders, and recommend strategies for operation and maintenance issues
Identify overall barriers to a bike share in the local context to make informed recommendations on feasibility	Summarize findings from research, GIS analysis, and both theory-based and experience-based determinants of bike share success

Strategy
Table 2 below is based on best practices outlined in the Bike-Share Planning Guide written by the Institute for Transportation and Development Policy, a leading international organization in the promotion of environmentally sustainable and equitable transportation policies and projects worldwide. (Cohen et al. 2013, 33)

Table 2. Study-specific strategies

Overall Strategy	Study-specific Strategy Defined
Define the proposed coverage area	City of Worcester
Create a demand profile	Review existing demand and conditions for cycling, taking into account the population of the coverage area, the number of commuters, current modal split, existing transit, bicycle and pedestrian networks, and existing major attractions that will draw people to the area. (See Table 5 for all attributes used in demand profile)
Size the system by defining station density, bike density, and bikes per station.	Review active number of bikes and stations servicing bike share systems in places with similar population size, giving consideration to land size and population density.

History of Bike Shares

There have been three generations of bike-sharing systems over the past 45 years, with the fourth generation emerging with more recent technological advances. The first generation of bike-sharing programs began in Amsterdam in 1965. Ordinary bikes were painted white and provided for public use. This quickly proved unsuccessful, as bikes were stolen or vandalized (Brushaber et al 2013, 12). In the early 1990s, Denmark launched second generation bike shares in a few of their cities, launching the first large-scale 2nd generation bike-sharing program in Copenhagen in 1995. The Copenhagen bikes were specially designed for “intense utilitarian use with solid rubber tires and wheels with advertising plates,” and could be picked up and returned at specific locations throughout the central city with a coin deposit. These bikes still were subject to theft, as the user was anonymous and there was no accountability (DeMaio 2009, 42).

This gave rise to a third generation of bike-sharing with improved customer tracking via electronic card-reading kiosks, smartcards and fobs, mobile applications that show the availability of bikes and available docks in real time, and on-board computers. Paris brought international attention to bike shares as a mode of transit in 2007 when it launched its program Vélib', with about 7,000 bikes, which has expanded to more than 23,600 bikes in the city and suburbs since. Outside Europe, bike-sharing began to take hold in 2008, with new programs in Brazil, Chile, China, New Zealand, South Korea, Taiwan, and the U.S (DeMaio 2009, 43). Bike sharing systems have increased rapidly since the mid-2000s, growing from 13 in 2004 to 855 a decade later. Of these systems, 54 are in the United States (Walter Kille 2015). This growth in bike shares is expected to continue as the emergence of a more cost effective fourth generation is expected soon. These fourth generation systems will be characterized by improved transit integration, solar power, and increased versatility of modular stations.

Benefits of Bike Shares

Bike shares have a multitude of benefits broadly including social, economic, transit, and environmental benefits. With appropriate and comprehensive planning, bikes can be used for riding the last mile to work, increasing physical activity, accessing employment opportunities, increasing business in the downtown, improving connectivity, reducing congestion, and reducing carbon impacts (Brushaber et al. 2013, 13).

Social

Bike sharing programs offer significant opportunity for improvements in personal health and quality of life. Not only is our personal vehicle centered transportation economy expensive and inadequate for the needs of large groups of citizens, it is contributing to the dual health crises of air pollution and obesity. Though difficult to quantify, the savings in health care costs that go back to the community is considerable. Thomas Gotschi, Director of Research at the Rails-to-Trails Conservancy, finds that obesity and lack of physical activity costs upward of $100 billion yearly and causes more preventable diseases than smoking (2013). "Increasingly it is becoming clear that the American health-care crisis is largely an urban-design crisis, with [active modes of transport] at the heart of the cure," writes Jeff Speck, a leading international advocate for smart growth and sustainable design (2013, 38).

In the mid-1970s, only about 1 in 10 (10%) of Americans was obese. By 2007, that rate had risen to 1 in 3 (33%), with a second third of the population "clearly overweight." The childhood obesity rate has almost tripled since 1980 and the rate for adolescents has more than quadrupled. According to the U.S. Centers for Disease Control (CDC), fully one-third of American children born after 2000 will become diabetics. This is due "partly to diet, but partly to planning: the methodical eradication from our communities of 'the useful walk' has helped create the least active younger generations in American history" (Speck 2012, 38-40). Capital Bikeshare in Washington, D.C., along with researchers at George Washington University, conducted a user survey in Fall 2012, primarily focused on the system's health benefits. Of over 3,100 responses, 31.5% reported reduced stress, and about 30% indicated they lost weight due to using Capital Bikeshare (Shaheen et al. 2014, 16). This study is especially important, as lower income communities are typically more prone to chronic obesity, leading the CDC to launch an initiative titled "Communities Putting Prevention to Work." As part of this initiative, NiceRide, the bike share program in Minneapolis, MN, placed 8 kiosks in underserved areas of the city. The expansion led to a tremendous increase in ridership over the course of only a few months (Brushaber 2013, 13).

An important consideration of any bike share system is social justice, as bike shares have primarily been designed to cater to users of higher income levels. According to the Transportation Research Record, the average North American bicycle commuter is a 39-year-old male professional with a household income in excess of $45,000 who rides 10.6 months per year (People for Bikes 2015). In a study of Washington D.C.'s Capital Bike Share, users were likely to have lower average incomes than regular cyclists, but higher than the city's general population (Walter Kille 2015). The U.S. Bicycling Participation Benchmarking Study Report by People for Bikes found that those with incomes less than $20,000 rode most frequently—17% indicated that they had ridden more than 100 days in the past 12 months, while only 10% of all higher income brackets could say the same (2015). However, non-whites who didn't ride are least likely to have ever ridden a bike, but more likely to intend to ride in the future than are their white counterparts (People for Bikes 2015). Susan Dannenberg, policy fellow at Bicycle Coalition of Greater Philadelphia, notes that many cities have addressed equity issues "from a purely economic standpoint," while education and cultural barriers have seldom been addressed (Bergman 2013). The importance of education in attracting cyclists in an urban environment is discussed in the Public Outreach and Education section on page 53.

Bicycling is highest among whites and Hispanics, with Hispanics being the most likely group to have ridden a bicycle within the last year (U.S. Bicycling Participation 2015). For whites and the majority of cyclists, bicycles are mostly used for recreation, while for Hispanics, bicycles are typically used to reach the workplace (Pucher and Renne 2003). Figure 2 outlines reasons for bicycling by percentage from the 2012 National Survey of Pedestrian and Bicyclist Attitudes and Behaviors (Pedestrian and Bicycle Information Center).

Reasons for Bicycling	Percent
Recreation	33
Exercise or health	28
Personal errands	17
Visit a friend or relative	8
Commuting to/from work	7
Commuting to/from school	4

Figure 2. Reasons for Bicycling - 2012 National Survey of Pedestrian and Bicyclist Attitudes and Behaviors (Pedestrian and Bicycle Information Center)

Another major barrier to attracting a diversity of riders, especially riders of color, is the fear of being personally targeted. On average, 41 percent of people who want to bike more worry about their personal safety when riding a bicycle because of fear of being targeted by a criminal or by law enforcement, but there is a lot of variation among races—shown in Figure #3 (Andersen 2015).

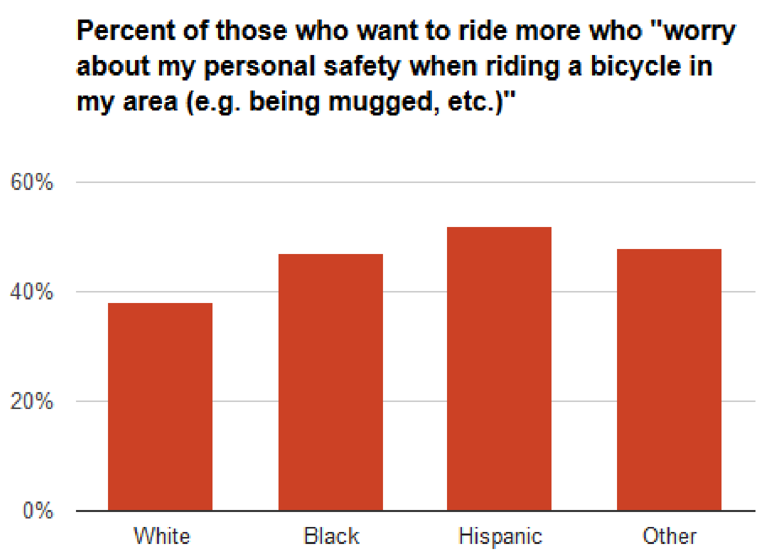

Figure 3. Percent of those who want to ride more but "worry about my personal safety when riding a bicycle in my area"

A key finding in a survey conducted by People for Bikes found that bicycle ownership is a significant barrier to riding, especially among poorer households (Andersen 2015). Forty-eight percent of adults in the U.S. don't have access to an operational bicycle at home (People for Bikes 2015). By extrapolation, this would indicate that a bike share could solve this ownership and access problem, if designed with the intention of attracting riders from underserved communities. Some bike share systems have had a difficult time attracting lower income users, who often already utilize public transport, likely due to barriers around cost, accessing a membership without a credit card, and physical accessibility of stations.

A survey conducted among several bike share operators regarding strategies to address equity found that out of 20 responses from the U.S. and Canada, 35% had existing stations sited based on equity reasons, 35% subsidized membership, 25% had annual membership payment plans, 25% assisted low-income members to obtain bank accounts and credit/debit cards, and 25% did not hold a security deposit on low-income users' credit/debit cards (Shaheen et al. 2014, 20). Denver B-cycle works with local housing authorities to make memberships available to residents of public housing (Bergman 2013). Methods of attracting users across the income spectrum should be considered in the planning stages, including financial assistance via subsidized memberships, community specific marketing.

Economic

As driving distances have grown along with fuel and other vehicle costs, the impact on household budgets has expanded so that, on average, transportation costs consume more than 1 in five dollars spent—20% of income. With transportation as one of the largest expense for households, second only to housing, creating more inclusive transportation options is crucial, especially as the income inequality gap widens. In addition, nearly 85% of money spent on cars and gas leaves the local economy (Speck 2012, 29-30).

Bike sharing spurs economic development by increasing access and exposure to local business and employment opportunities. A 2011 survey of Washington D.C.'s Capital Bikeshare members conducted by LDA Consultants reported that "almost half of survey respondents made a trip in the past month that they would not have without the bike share program." Additionally, Minneapolis NiceRide users spend an average of $7-$14 during each bike share trip (Brushaber 2013, 13-14).

The Victoria Transportation Policy Institute estimates that for every mile that someone in the U.S. travels in an automobile, on a bike, or on foot, the costs of public infrastructure are 29.3 cents, .9 cents, and .2 cents, respectively (VTPI 2015, 25). As more car trips are replaced with bike trips, this can amount to huge transportation budget savings.

Transit

As stated above, biking infrastructure is far less costly to maintain compared to other modes. The estimated replacement cost of Portland, Oregon's entire 300+ mile bikeway network—acknowledged as the best in North America—is approximately $60 million in 2008 dollars, which is roughly the cost of one mile of four-lane urban freeway (Geller 2011). In addition, compared to the car, a bicycle's spatial demands are minimal. Ten bikes can park in the space of a single car and the typical bike lane handles five to ten times the traffic volume of a car lane twice its width (Speck 2012, 191).

In many cities, bike shares serve as the "final mile" of the commute. With proper planning, bike sharing can promote greater transit use by filling gaps in the transportation system between existing points of public transportation and desired destinations (Midgley 2009, 23).The Journal of Transportation Research states that bike shares increase the visibility of cycling and the mode share of cycling (Brushaber et al. 2013, 15). With increased visibility of cycling, safety increases and creates a feedback loop of attracting more cyclists and decreasing auto congestion.

Environmental

If every American biked an hour per day instead of driving, the United States would cut its gasoline consumption by 38% and greenhouse gas emissions by 12%-- meeting the Kyoto Accords instantly (Speck 2012, 191). Each mile someone rides on a bike-share bike instead of driving a car means about 1 pound of carbon dioxide is kept out of the atmosphere, according to Susan Shaheen, co-director of the Transportation Sustainability Research Center at the University of California-Berkeley (Magill 2014). In Boston, Hubway data show a carbon offset of 285 tons since public bikesharing began there in July 2011 (Shaheen et al. 2014, 13). This figure can vary greatly depending on the size of the system. One of the key findings in a report by the European Cyclists Federation was that emissions from cycling are more than 10 times lower than those stemming from the passenger car, "even taking into account the additional dietary intake of a cyclist compared with that of a motorized transport user." Bicycle-share programs also have the potential to reduce further emissions, as trips taken are a substitute for motorized transport for 50-75% of the users

(Maus 2011). Figure 4# shows the amount of CO_2 emissions per passenger mile for various modes of transportation.

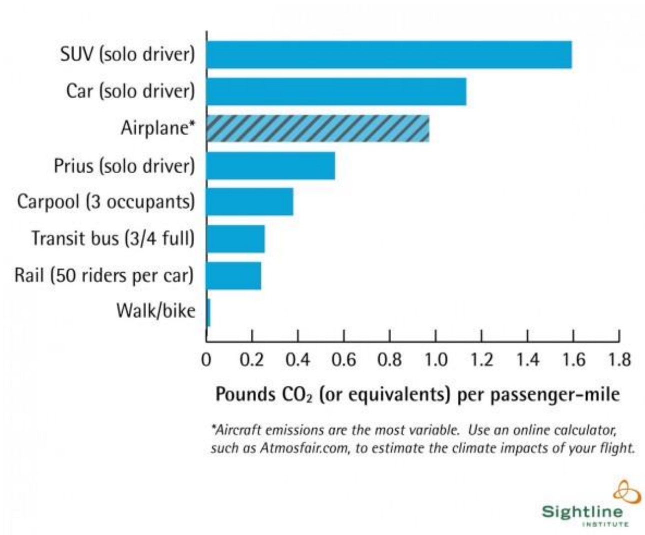

Figure 4. CO_2 emissions per passenger mile from various modes of transportation

In the United States, on-road vehicles are responsible for nearly 26% of volatile organic compounds (VOCs) and 35% of nitrogen oxide ($NO_{x)}$ emissions, which combine to form ozone and particulate matter (PM). In 2011, more than 200 counties home to 88 million total residents failed to meet U.S. EPA standards for $PM_{2.5}$, partially due to pollution from short vehicle trips. A large fraction of emissions—25% of VOC and 19% of $PM_{2.5}$—are emitted in the first few minutes of automobile operation before pollution control devices begin operating, according to the Federal Highway Administration, making bicycles a great option for replacing these short trips and improving air quality (Grabow et al. 2012, 68). The U.S. EPA estimates that 63,000- 88,000 premature deaths per year can be attributed to $PM_{2.5}$—a concern of particular importance in terms of environmental justice issues.

A study that modeled eliminating short car trips, defined as less than 8 km round trip, in urban areas of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin would reduce residential vehicle use by 20%-- based on a comprehensive census-tract level travel and mobile emission inventory. The study region comprised a population of 31.3 million and it was estimated that eliminating short car trips and completing half of them by bicycle would result in mortality declines of approximately 1295 deaths per year. Of these deaths, 608 were due to improved air quality and 687 attributed to increased physical activity. With the combined impacts of improved air quality and physical fitness, estimates on savings in net health benefits would exceed $8.7 billion/year—equivalent to 2.5% of the total cost of health care for the five Midwestern states based on 2004 figures (Grabow et al. 2012; 69, 73). While the scale of this study estimates impacts in terms of large, regional benefits, the potential is staggering.

Overview of System Elements

Bike share systems employ a number of different methods of service and operation. Largely these differences are in technology. Many newer bike share programs choose to include a computer in their bicycles to track stolen bicycles and collect other useful metrics such as when and where the bikes are being used, by whom, and mileage. This data allows for better understanding of the system to optimize service and capitalize on potential revenue (Brushaber et al. 2013, 27).

Each station is characterized by electronic locking mechanisms and a kiosk with pricing and membership information, maps for tourists, and credit card payment ability. While credit card payment is important to ensure that the user is held accountable, this excludes a significant number of people from underserved, low-income communities. This is discussed further in the Customer Fees and Payment section. The bikes themselves are three-speed in nearly all systems, which gives some variety to cycle with ease across changing grades and cost efficient in terms of maintenance (Brushaber et al. 2013, 28). Many systems also have included baskets on the front of the bikes for convenience, as cycling while wearing a backpack or bag on one side can be impede riders' balance.

Smart phones have contributed to the success of many bike shares, as users are typically able to download an app that allows them to see real-time data on where there is an available dock or how many bikes are available for check out at any station. These apps can be created by the operator if a large-scale operator is managing the system. However, creation of the app can be seen as an opportunity for community engagement, leveraging the strength of computer science programs at Worcester Polytechnic Institute and other local colleges and universities.

Customer Fees and Payment Structures

Bike share systems vary in the membership levels they offer, as well as pricing structure and length of trip allowed. Most individual trips are limited to 30 minutes or 1 hour to ensure bike availability and rebalance. Nearly every bike share system offers a 24 hour pass with unlimited trips of a specified duration. The most popular or standard membership types include monthly and annual. Some systems offer student and senior discounts for memberships. Typically these memberships are purchased online through the city's designated bike share website and will receive a key with a microchip in the mail. If a customer only wants to purchase a 24- hour pass, this can be done at any station with a credit card. If accountability can be ensured, integration with Charlie Card is recommended for maximize ease of use. Table 3 offers an overview of user fees for comparable communities.

Table 3. User Fees for Comparable Communities

	24 hour pass	1 month pass	1 year pass	1 year Student	First 30 minutes	30-60 minutes	Each add'l 30 minutes	Max cost per day
Des Moines B-Cycle	$6	$30	$50	$40	Free	Free	$2.50	$65
Bike Chattanooga	$8	n/a	$50	n/a	Free	Free	$5.00	$100
Boulder B-Cycle	$8	$11	$70	$40	Free	$3	$3	varies on membership type
Fort Collins Bike Library	$10	n/a	n/a	n/a	n/a	n/a	n/a	$10

	Hourly	90 days	UB Students, Faculty, Staff
Buffalo	$3	$65	$15 annual (1 hour free daily)

Low-Income Engagement

If bikes are only able to be checked out with a credit card to ensure accountability, this effectively excludes low-income people who don't have bank accounts. About 17 million people across the U.S., or about 1 in 12 households, are "unbanked," according to a recent report from the FDIC, a disproportionate number of which are black and Hispanic. More than 21 percent of African American households and 20 percent of Hispanic households are "unbanked," compared to 4 percent of white households and just over 2 percent of Asian households (Schmitt 2012).

Marketing and outreach is key to selling the subsidized memberships. Boston Hubway representatives spent considerable time visiting social service agencies in low-income neighborhoods to raise awareness about their subsidized memberships. Additionally, the program extended its window for usage charges for subsidized members. Usually after 30 minutes a member is charged additional usage fees. Subsidized members can ride for an hour without being charged. Nicole Freedman, Executive Director of Boston Bikes, notes this is because many of Boston's low-income neighborhoods are located at the edge of Hubway's system, where density is not as great, often meaning longer trips (Bergman 2013). Washington, D.C. has made significant effort in attempting to reach unbanked residents with a program called Bank on DC, which allows low-income people to set up no-fee, no-minimum bank accounts. As an incentive, those who take part in the program are eligible for a $25 discount on an annual Capital Bikeshare membership. However, local bicyclist associations have noted that this method of engagement is a process, and one that is "out of the ordinary" for most low-income people. As Philadelphia has been planning its bike share, its founder Russell Meddin has suggested the idea of tying bike-share payments to cell phones, which many low-income people do have — allowing them to purchase memberships when they pay their phone bill (Schmitt 2013).

Comparison of Operating Models

Four primary models for operating and financing bikes shares are typically used: non-profit ownership, private ownership, government ownership, or a public-private partnership.

The non-profit model has been popular, as it allows the city set-up the non-profit that will be in charge of the bike share operations or assign this operation to an existing non-profit organization. The non-profit is responsible for "funding, gathering, equipment, establishing guidelines, and finding suitable locations" (Brushaber 2013, 28). The drawback of this model is lack of experience that may lower the potential success of the bike share, and the already over-extended nature of non-profits. However, if a new non-profit is established and staffed with experienced professionals, this model presents an opportunity for job creation and obtaining grant money. The Better Bike Share Partnership provides grants of $25,000 – $75,000 for collaborations of non-profit community-based organizations, cities, and bike share operators to support the development and implementation of strategies to increase bike share use in underserved communities (Corbin 2015).

Privately owned and operated systems are another option. In the model, a contracted company is responsible for the entire bike share program. The drawbacks of this model are that the city has no control over the system dynamics or the company may go out of business due to lack of funds, leaving the city without a bike share (Brushaber et al 2013, 28). Government ownership is funded by tax payers and typically run through a Department of Transportation. Attracting sponsors is more difficult with this model, as well as difficult to sustain.

Public-private partnerships operate via a contract between a non-profit and the city. The non-profit will be responsible for hiring a private business to plan the bike share system. This model has a number of benefits including flexibility in funding sources, maintaining city control, operating expertise, and assistance with marketing and advertising of the system (Brushaber et al 2013, 29). Of these models, a public-private partnership would likely be the most successful with least risk of failure.

Worcester Background and Demographics

Worcester, Massachusetts is located in Central Massachusetts and is the second biggest city in New England behind Boston with a population of 182,544 as of 2013. A population of more than 6 million people lives within a 50 mile radius of Worcester. Since 2000, the population of Worcester has increased by 5.7%. The median resident age is 32.7 years old, compared to 39.4 years in the state of Massachusetts. Median household income in 2013 was estimated at $45,011—an increase from $35,623 in 2000 in inflation adjusted dollars. The population in Worcester grew 4.9% between 2000 and 2010 (Worcester Regional Research Bureau 2013).

Worcester's racial composition is 57.5% white alone, 22.2% Hispanic, 12.2% Black, and 6.2% Asian. Hispanics only account for 10% of the population across Massachusetts (Pew Research Center, 2010 U.S. Census). In Worcester, 20% of residents speak Spanish, with 47.8% reporting they speak English less than very well (City-data.com). This presents a unique challenge in engaging underserved communities in terms of a bike share, as information at station kiosks would need to be considered in Spanish as well.

There are 5,100 businesses in the City of Worcester. In addition, there are 13 colleges and universities located within the city's limits, bringing more than 35,000 higher education students to Worcester. Worcester's colleges and universities comprise the second largest employer in the city. Developments in biotechnology and high tech industries, the health industry, manufacturing, and downtown development make up Worcester's areas of greatest recent growth. The presence of so many higher education opportunities in Worcester means that the community's workforce is highly skilled and well-trained

(Worcester: Economy 2009). Among the largest cities in New England, Worcester has the 2nd highest percentage of adults with a Bachelor's degree (18.10% of population 25 years and older), 30% of the population have a bachelor's degree or higher, and 84% of that population has a greater than high school education (City of Worcester 2013, Worcester Chamber of Commerce).

The average climate of Worcester poses a limitation on a bike share system. Worcester experiences year-round temperatures that are on average lower than the U.S. average (Figure 5). Worcester also tends to experience intense winters, with daily January averages around 25˚F. In addition, Worcester typically receives more precipitation year-round than the U.S. average, shown in Figure 6, posing a challenge in snowy winters. Many smaller bike shares do not operate from the end of November through the beginning of April, however, larger systems in similar climates like Toronto and New York City are able to keep their bike shares running year round.

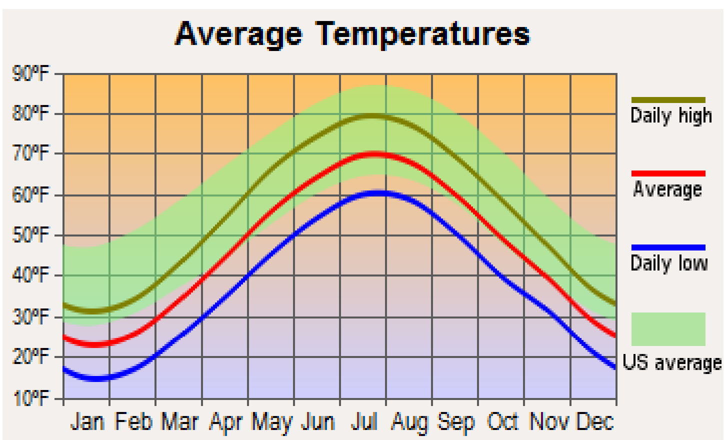

Figure 5. Average monthly temperature in Worcester, MA

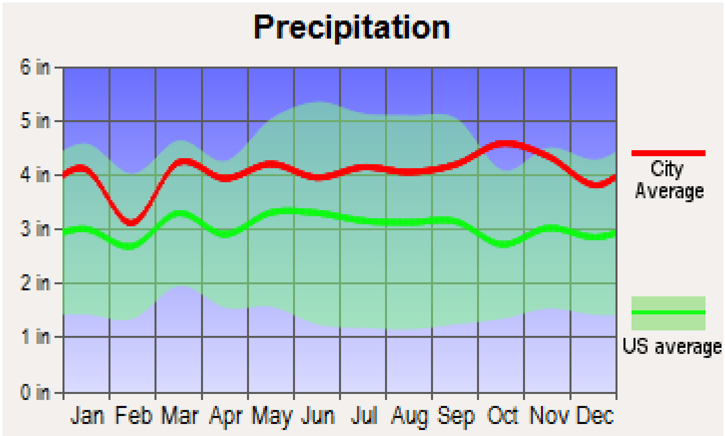

Figure 6. Average monthly precipitation in Worcester, MA

Methods

Based on a literature review of many bike share feasibility studies and other studies regarding factors that maximize ridership, variables outlined in Table 3 were chosen to be included in suitability models for this study. General categories of pertinent variables are sociodemographic, built environment, and transportation infrastructure.

Suitability analysis in GIS refers to a process that is used to determine how appropriate a given geographic area is for a given use. In this case, suitability is being evaluated for bike share locations through a number of attributes defined in Tables 4 and 5. This process is also sometimes referred to as multi-criteria analysis. Each variable that goes into the analysis has certain intrinsic or user-defined characteristics that fall along a range of unsuitable or suitable for the given use. The results are a map that highlights and classifies areas of high and low suitability. From the maps produced in this study, one can see areas within Worcester that are most suited for a bike share, based on the attributes included in the models. This study does not take the next step to determine specific locations for bike share stations, but a general area that is most appropriate for placing bike share stations.

Three models were conceptualized from both theory-based models and experience-based models found in the literature review: Baseline Model, High Income Model, Underserved Communities Model. The varying attributes used in each model are detailed in Table 4. The Baseline Model is used as the control model with attributes selected based on methods from previous bike share feasibility studies and research indicating that population density, age of population, and trip generators (retail and employment locations) are basic prerequisites for a bike share station. The High Income Model and Underserved Communities Model are to provide more nuanced insight into other factors that influence bike share station success. As mentioned previously, bike share systems tend to be designed for higher income populations, with underserved communities being left out of the planning process. In this study, the intention is to include underserved communities from the very beginning to ensure that bike share locations are inclusive, as these are critical communities in the local context.

The High Income Model and Underserved Communities Model were compared to each other spatially and quantitatively in terms of their continuity of suitable areas and overall area of extent. While the models are separate from one another, it is the intention that the bike share system will be planned to include both high income and underserved populations. These models are treated as distinct, however, in order to see whether spatial segregations of race and class exist, as well as their intersections and distributions in physical space.

Table 4. Attributes included in each model

Baseline Model:	**High Income Model:**	**Underserved Communities Model:**
· Population Density · Retail and Employment · Proportion of Population Ages 16 to 49	· Population Density · Proportion of Population- White Alone · Median Household Income · Alternate Commuters (Biking, Walking, Public Transit) · WRTA Bus Stop Density · WRTA Bus Route Density · Retail and Employment · Proportion of Population Ages 16 to 49	· Population Density · Proportion of Population Other Than White Alone * · Percent Low Income * · Alternate Commuters (Biking, Walking, Public Transit) · WRTA Bus Stop Density · WRTA Bus Route Density · Retail and Employment · Proportion of Population Ages 16 to 49 · Proportion Owning Zero Vehicles * (asterisks* indicate attributes that vary from High Income Model)

Identifying Crucial Attributes

As mentioned, general categories of pertinent variables are sociodemographic, built environment, and transportation infrastructure.

Sociodemographic:

Some of the demographics regarding cyclists in the United States and who uses bike shares have been previously discussed in the Social Benefits section. Previous bike share feasibility studies found race, income and high-income jobs, alternative commuters, and total jobs to be statistically significant user attributes (Brushaber et al. 2013, 37). From syntheses of existing studies, general statements can be made about the profile of people who use bike shares.

The following characteristics outline potential user demand for a bike share program:

- College students
    - Young (20-39 years), well educated, environmentally conscious are the early adopters (Daddio 2012)
- People with higher incomes
    - As discussed in the Social Benefits section, bike shares have struggled to attract lower-income people and people of color. Methods of engagement for lower income communities are discussed on page 24
- Alternative commuters
    - Those who are already biking, walking, or using public transport
- Tourists
- Local population (Population density)
    - Maximum potential of users is based on population density within an accessible range of stations, and other community indicators

Monthly bike share rentals are also related to other trip generation factors including (lack of) vehicle ownership; cultural sites; and proximity to jobs, colleges, and parks (Wang et al. 2012, 5).

Built Environment:

A comprehensive report from the Mineta Transportation Institute details station location metrics crucial to bike share membership, ridership, and revenue in Figure 7. Approximately 50% of bike share operators who responded indicated that stations near tourist locations contributed to greatest membership and greatest revenue (Shaheen et al

2014, 44). A study in the Transportation Research Record found that 8 of the 10 top most used stations in Minnesota's NiceRide system are located among high concentrations of retail destinations, such as clusters of shops and restaurants and retail hubs (Wang et al. 2012, 4). A top contributor to both membership and ridership is high-density mixed use locations.

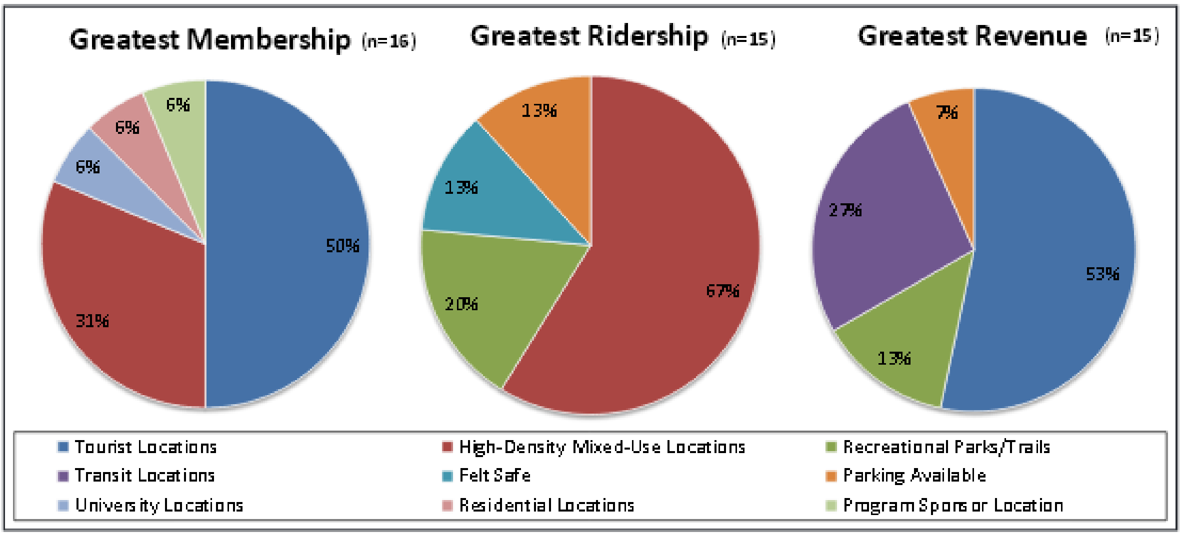

Figure 7. Operators were asked to provide data on which bike sharing station locations: 1) produce the greatest membership, 2) yield the greatest ridership, and 3) generate the most revenue.

Transportation Infrastructure:

Bike share stations co-located with transit stations are another major generator of revenue (Figure 7). The Capital Bikeshare Member Survey Report found that 54% of members started or ended a bike-sharing trip at a transit station (Shaheen et al. 2014, 16). Other studies found a significant correlation between the presence of bicycle lanes and Capital Bikeshare usage, and also highlighted the importance of population density and mixed-use attractions in encouraging ridership (Buck and Buehler 2011, 2).

This information and research on crucial attributes provides the basis for which variables are included in the models. The goal of these methods is to determine where bike share stations should be placed in order to meet the criteria of critical mass, targeting racial and economic diversity of users, and connecting to existing transit systems. All attributes and sources of data included or considered in the models are outlined in Table 5.

Table 5. Sources of data and attributes included in models

Source	Aggregation Level	Type	Attributes Used
Sociodemographic Variables			
American Community Survey 5-year estimates 2010-2014	Block Group	Polygon feature	- Proportion of population that is White Alone - Population Density - Alternate Commuters (Biking, Walking, Public Transport) - Proportion of Owners and Renters Owning 0 Vehicles
U.S. Census 2010	Block Group	Polygon feature	- Percent Low Income - Median Household Income - Proportion of Population (Male and Female) Ages 16 to 49
Built Environment Variables			
Worcester Regional Chamber of Commerce	Study area- density of points located within 400 square meters of one another	Points	Chamber of Commerce Member locations (retail and proxy for employment)
MassGIS	Study area	Points	Colleges and Universities
MassGIS	Study area	Polygons	Open Space
Transportation Variables			
Massachusetts Department of Transportation	Study area	Points	Bike Inventory
Massachusetts	Study area	Polygons	- Top 200 Crash

Department of Transportation			Clusters 2011 - 2013 - Bicycle Crash Clusters 2004 – 2013 - Pedestrian Crash Clusters 2004 - 2013
Worcester Regional Transit Authority	Study area	Lines	WRTA bus routes
Worcester Regional Transit Authority	Study area	Points	WRTA bus stops

GIS Methods

Based on the research outlined in previous sections, variables were identified and compiled into a GIS database using data from the American Community Survey, U.S. Census, Worcester Chamber of Commerce, MassGIS, Massachusetts Department of Transportation, and WRTA (Table 3). All methods were implemented using ArcMap 10.3. American Community Survey and U.S. Census data was downloaded at Block Group level, which serves as the level of analysis for the sociodemographic variables.

The Worcester Chamber of Commerce Member points serve as the variable for retail and tourist locations, as well as a proxy for places of employment, as employment density data could not be located in a GIS-processable form. All of the sociodemographic variables were rasterized using the Feature to Raster tool in ArcMap. The point layers were converted to rasters using the Point Density tool with a radius of 200 square meters (400 square meter totalarea). The output values indicate the number of points (bus stops or retail/employment locations) per square meters within a 400 meter range of each cell. The Line Density tool was used with the same parameters. The value of 400 square meters was chosen, as the literature and previous studies deemed this an appropriate walkable distance within a radius of a bike share station.

All rasters were then converted to a consistent 0 to 1 scale using the Fuzzy Membership Tool. This transformation indicates the strength of membership in a set based on a specific algorithm. In this case, the membership value indicates increasing suitability. A linear relationship was used for all variables, as linear functions are for ordered data and allows for simple transformation of both positive and negative slopes. Once all rasters were transformed to the same 0 to 1 scale, the attributes then could be made into a composite suitability map using the Weighted Sum tool with all variables given a weight of 1.

The Weighted Sum Rasters for each model were brought into the TerrSet software to utilize the IDRISI GIS Analysis modules. The models were filtered using the Reclass tool so that only cells with suitabilities of 0.5 and above (on a 0 to 1 scale) were shown on the map, providing visual information about the extent and continuity of the most suitable areas of the models. The Area module was used to calculate the number of square miles and square meters covered by each model for quantitative comparison. While crash data from MassDOT was not included in the models, this data was overlayed with the Underserved Communities Model for spatial comparison.

Limitations of Methods

Additional variables that were considered in the study but not included were bicycle inventory data, open spaces, and locations of colleges and universities. The bicycle inventory data is crucial to this study, however, the data provided by MassDOT had not been updated in several years. The Worcester Department of Parks and Public Works does not keep detailed records on these infrastructure updates, many of which have happened recently. When the Line Density tool was run on the bicycle inventory data, only a very small area was covered. Therefore, this data was left out, as its influence on the model would be minimal. Data on distance from parks was left out due to its likelihood to skew the model, as Worcester is fortunate to have open space as an asset. When 400 meter buffers were placed around each existing green space location, nearly the entire city was covered (page 76). Colleges and universities were left out of these models as well, for including them based on student body population size could skew the model. The data for colleges and universities was in the form of individual point locations, and would not have greatly influenced the models or been accurate in terms of the area that these institutions cover. In addition, many of these institutions are private and arrangements could be made during the planning process for interested institutions to fund their own bike share station(s) that could be integrated with the full system.

American Community Survey (ACS) data was used for many of the attributes, as this data is not collected in the U.S. Census. ACS data is based on estimates, not actual counts. The 5-year estimates were used, which has the largest sample size and most reliable data compared to other aggregations of ACS data (1-year and 3-year). A limitation of this data selection is that 5-year estimates are least current, but the U.S. Census Bureau recommends this data set when precision is more important than currency.

All attributes in each model were given the same weight, which may not reflect accurate conditions. Crash data was not included in the models, but was overlayed after production of the suitability maps. The crash data itself has limitations, as pedestrian and cycling crashes tend to be underreported. Missing information from many of these incidents includes contributing factors, demographics, and other factors that would be useful in analyzing patterns to improve safety conditions (Litman 2015, 15).

Perhaps the limitation of greatest significance is the use of Worcester Regional Chamber of Commerce Member points as a proxy for employment, using this data as the variable for both retail and employment. Data for employment density could not be located in a format that was functional for GIS mapping. If future studies are continued on the subject of the feasibility of a bike share in Worcester, it is recommended that employment density is included as a variable.

Lastly, topography data was not included in this model, as it could not be located in a functional format. While Worcester is known for being characterized by hills, topography has been found to play a minimal role when comparing biking and nonbiking places, evidenced by San Francisco having three times the ridership of relatively flat Denver (Speck 2012, 191). However, slopes at a grade of 4% or higher are considered a major barrier for bicyclists (Brushaber et al. 2013, 59). This is a variable that should be considered in the planning stages if hills are in between major destinations and stations, which could affect usage and operations due to lack of bike return to the uphill station.

Results and Analysis

Individual maps of all attributes included in the models are included in the Map Appendix.

Baseline Model

The Primary Indicator Model consists of variables for age, population density, and attractors. The Worcester Regional Chamber of Commerce Member points are used for attractors, serving as a retail locations and a proxy for employment. There are 3917 points in the Chamber Member data set for Worcester. Figure 8 shows the density of these points, defined by total number of points within a 400 meter range. This variable is used in the other models as well. The suitability map for this model is displayed in Figure 9. This model is not suitable for a city-wide bike share system, as can be seen by the overall dearth and lack of continuity in the areas of highest suitability on the map in Figure 9. Continuity is important in these models, as all stations should be located within suitable areas and placed at uniform distances away from each other across the system. In addition, overall, there are very few areas of high suitability. If a bike share were to be feasible in Worcester, it is not recommended that the system be planned simply based on age, population density, and attractors. However, as discussed in the limitations of methods, proper data for employment and employment density could not be located. With this data, it is likely that the model would show more areas of suitability.

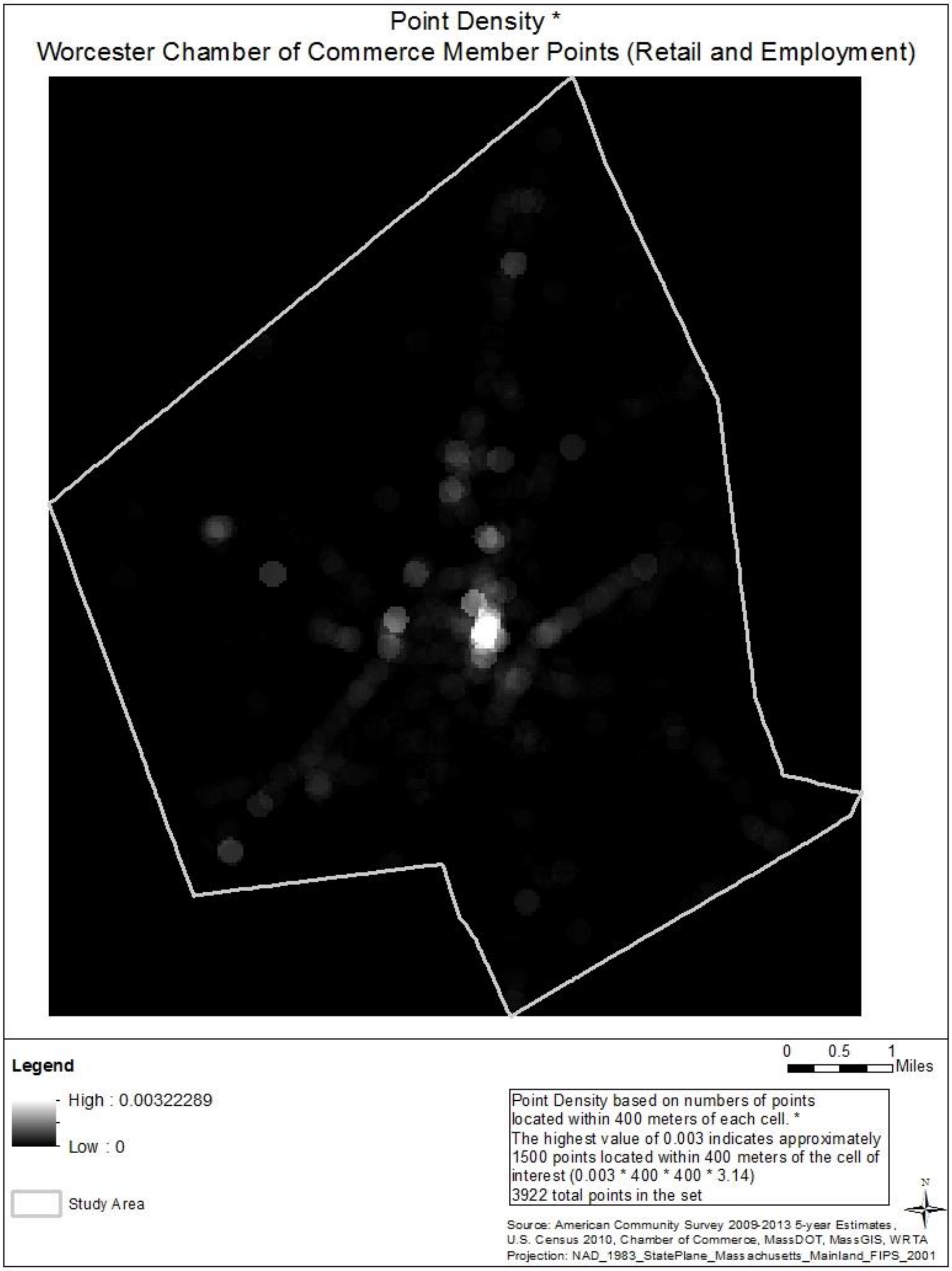

Figure 8. Worcester Chamber of Commerce Member Points Density

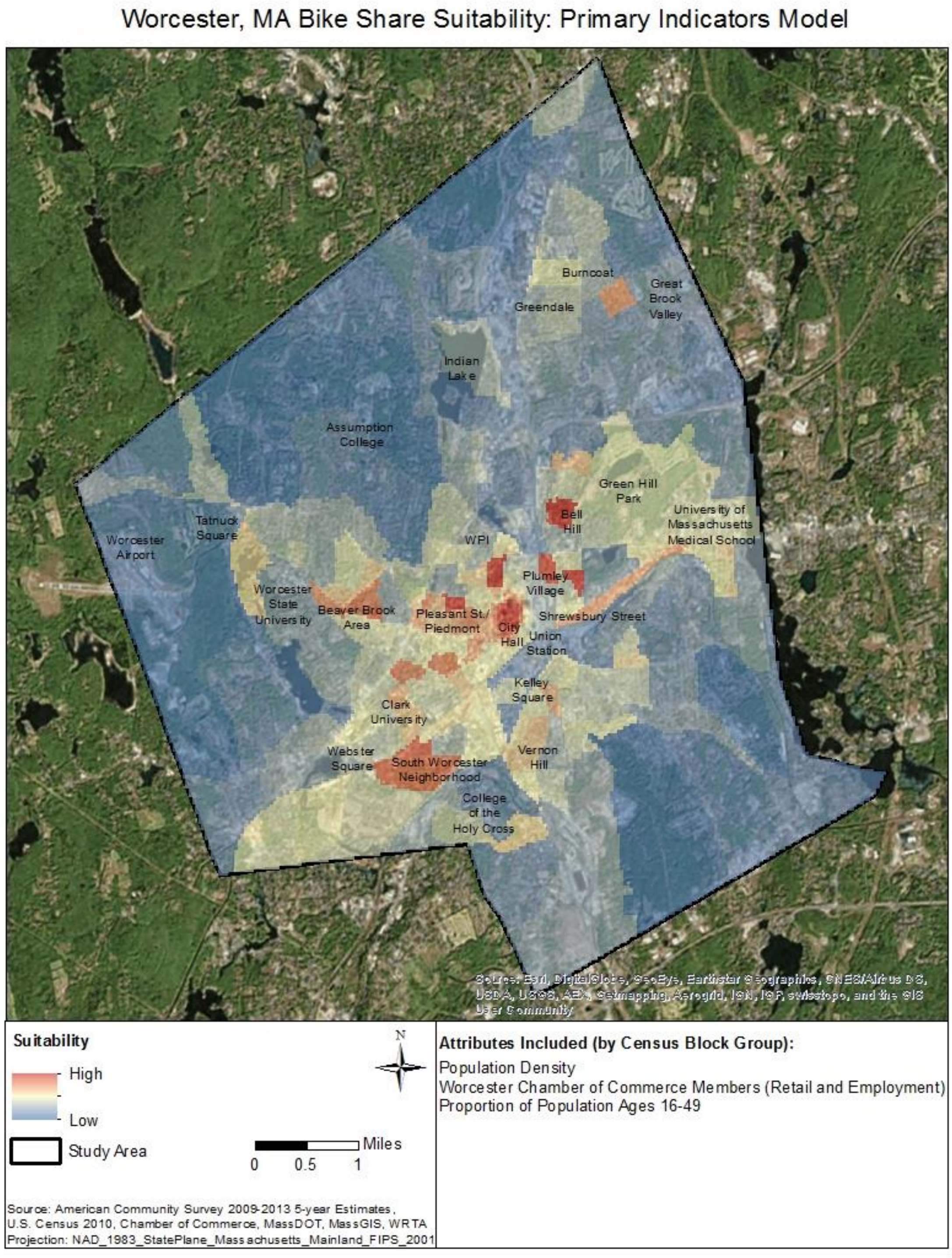

Figure 9. Suitability Map of Baseline Model

High Income Model

The High Income Model, shown in Figure 10, has more continuity among areas of high suitability and has more areas of high suitability compared to the Baseline Model. However, there are still gaps in connectivity and the most suitable areas (defined as suitability of > 0.5) of the system only cover 0.82 square miles (Table 6). The gaps in connectivity of highly suitable areas are evident in Figure 12, with only areas of suitability with values of 0.5 or higher displayed. While the High Income Model is more feasible than the Baseline model, the range of this system would be very small. This model could potentially serve as an area for a pilot program in the immediate downtown of Worcester, but if there aren't other station locations for where people want to go beyond downtown, the bike share will not be successful.

Table 6. Total area of suitabilities > 0.5 for High Income Model

Category	Square Miles	Square Meters
Suitability 0.5 – 0.75 (light gray)	0.7622	1,974,053
Suitability 0.75- 1 (dark gray)	0.0628	162,598
Total	0.825	2,136,651

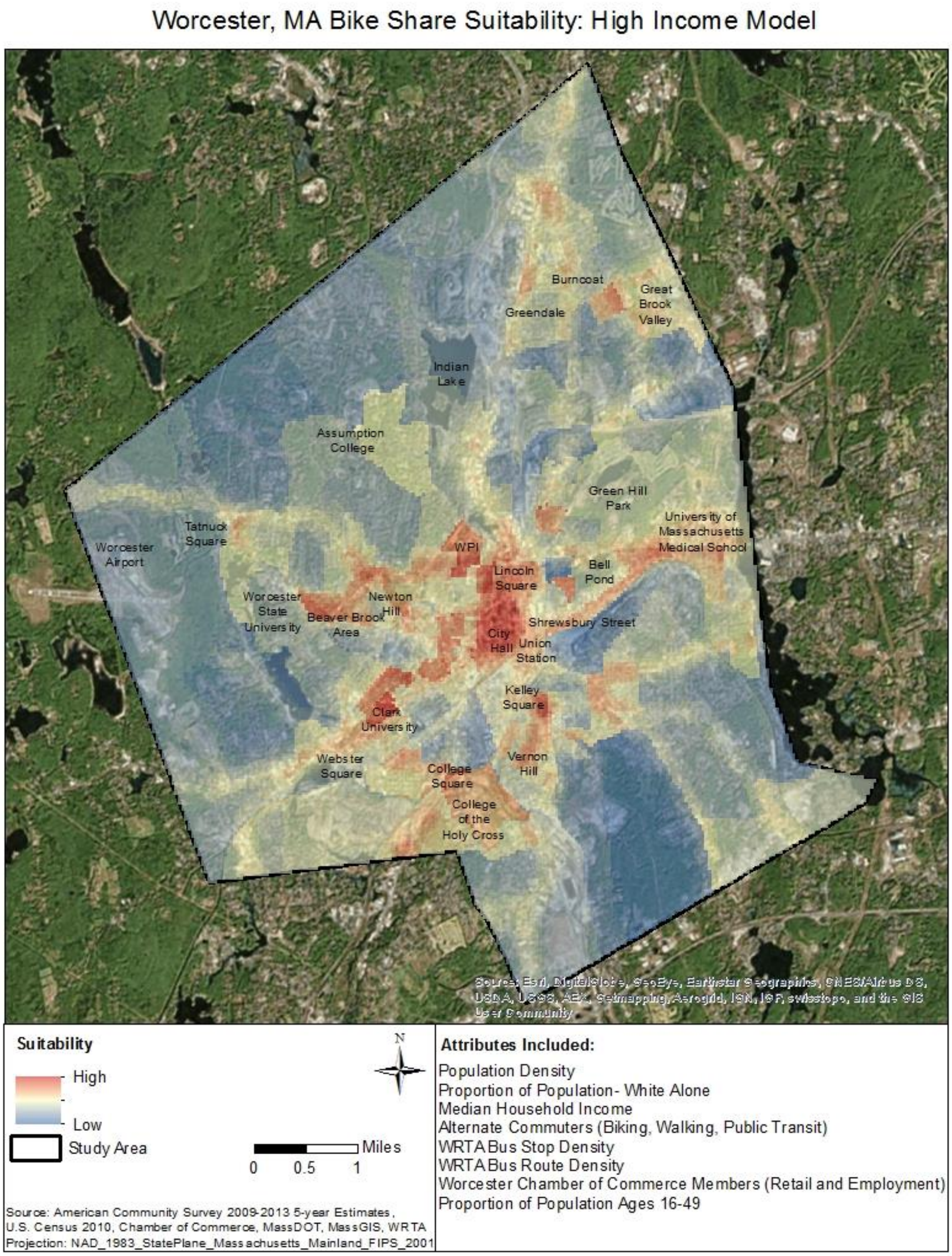

Figure 10. Suitability Map for High Income Model

Underserved Communities Model

The Underserved Communities Model shows a fairly continuous area that is highly suitable, across the downtown area to the end of Shrewsbury Street. The most suitable areas of this model cover 2.5 square miles (Table 7), making it a feasible option for a Phase 1 bike share system that could provide enough extent to be useful and versatile. Of all three models, the Underserved Communities model provides the most continuity, both spatially and quantitatively in terms of total area covered (Figure 12).

Table 7. Total area of suitabilites >0.5 for Underserved Communities Model

Category	Square Miles	Square Meters
Suitability 0.5 – 0.75 (light gray)	2.365	6,124,408
Suitability 0.75- 1 (dark gray)	0.120	309,954
Total	2.485	6,434,362

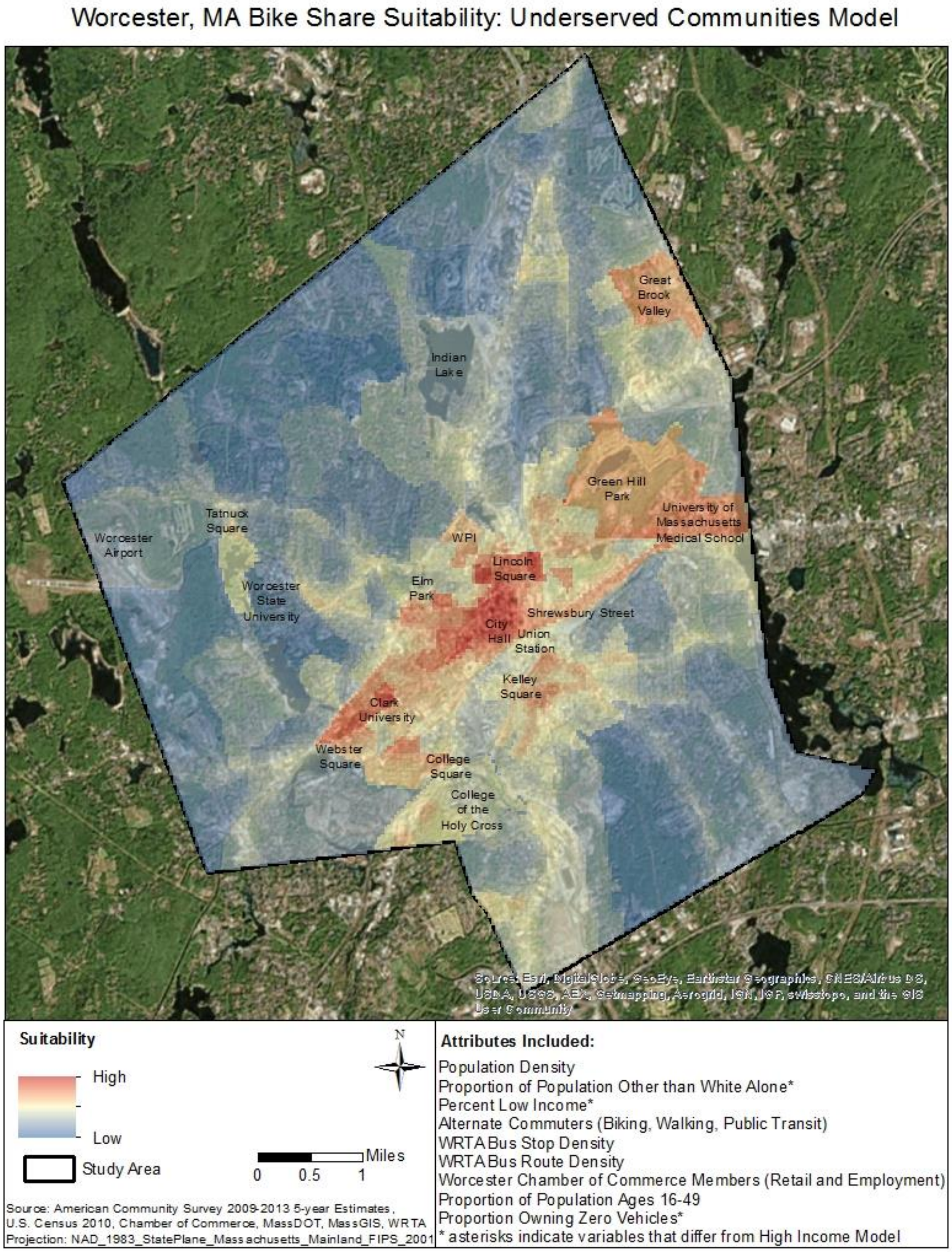

Figure 11. Suitability Map for Underserved Communities Model

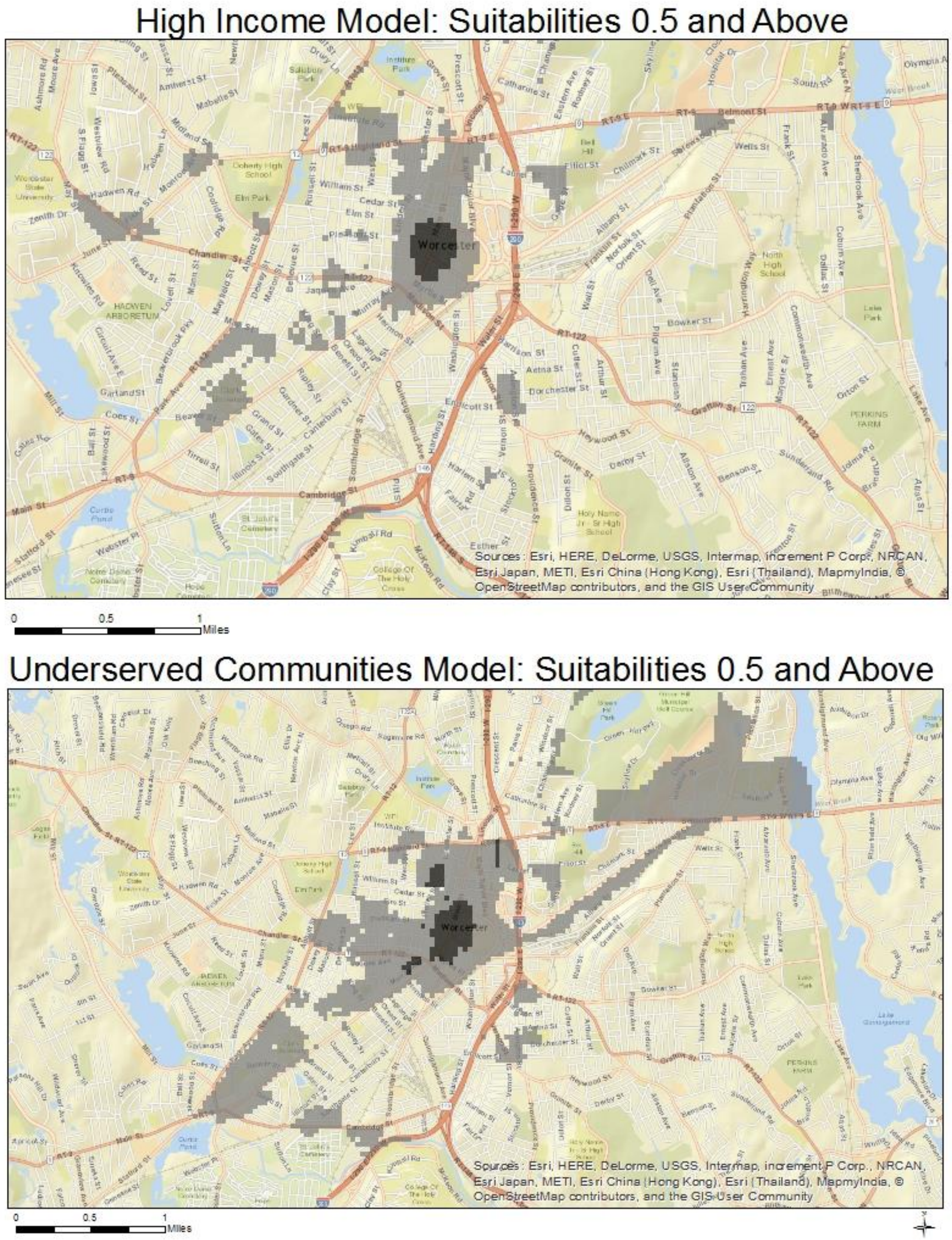

Figure 12. Suitabilities 0.5 and Above for High Income Model and Underserved Communities Model

Findings

Combining the extent of both the High Income and Undeserved Communities model would give comprehensive coverage, as measured by the extent of continuous areas of suitability in the map (Figure 13). Together, these models would cover 2.69 square miles of highly suitable area. However, a major limitation shown in Figure 14 is that the top crash clusters occur in the most suitable areas. The City would need to undertake a major strategic plan for slowing traffic and implementing other road safety measures around downtown. Intersections that function well for cyclists are critical in creating a safe cycling network, and poorly designed intersections represent significant gaps (Buffalo Bicycle Master Plan, 20). In addition, methods such as financial assistance and others discussed in the Low-Income Engagement section would need to be utilized to best attract users from across the income spectrum for this bike share system to be effectively utilized.

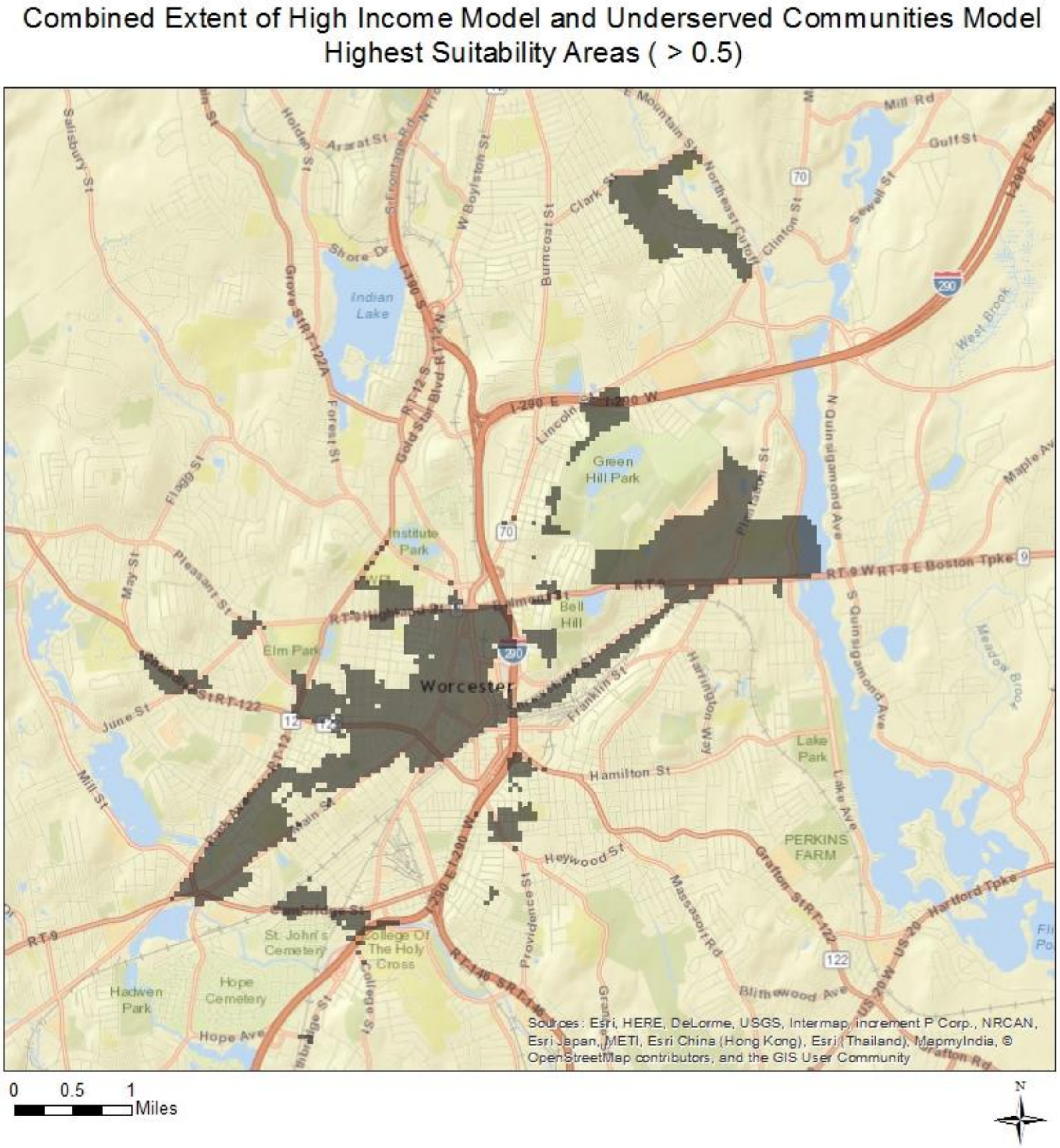

Figure 13. Combined Extent of High Income Model and Underserved Communities Model (Suitabilities > 0.5)

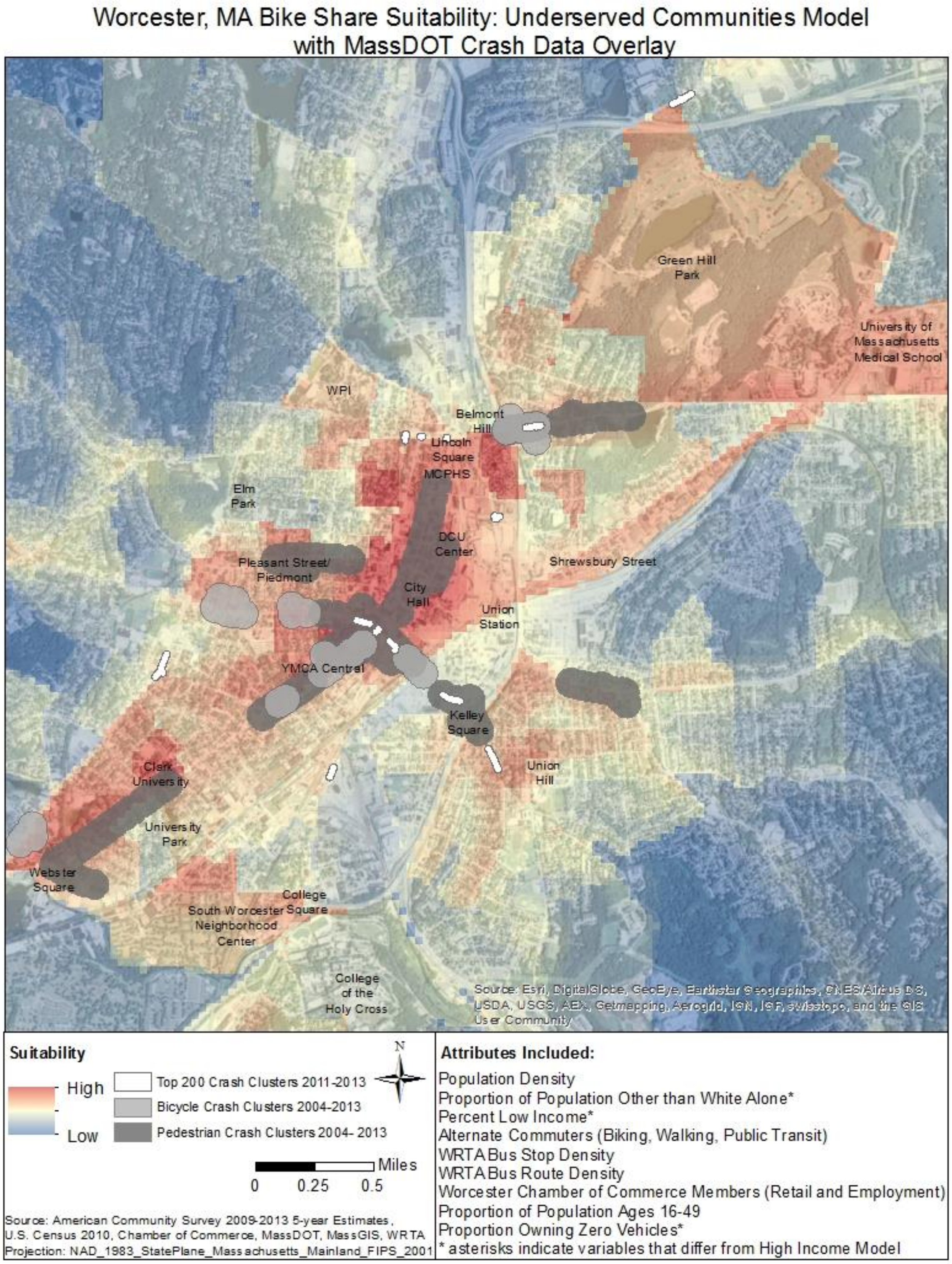

Figure 14. Underserved Communities Model with Crash Data Overlay

System Size

Station density recommended by North American City Transportation Officials (NACTO) is 1,000 feet apart or 5 minutes walking, as research shows that users typically are not willing to walk any farther to use a bike. This translates to a recommendation of 28 stations per square mile; however, even bike shares in the largest cities such as New York City only have a station density of 23 stations per square mile. In neighborhoods with fewer destinations or less population density, station size (number of bikes) should be reduced, but station spacing should remain the same (NACTO 2015; 2, 5).

Density of stations is one of the most crucial elements of success for a bike share system, so certainly more stations are better. NACTO notes that:

> Bike share usage is predominantly driven by convenience. Thus, having more options of places to go will increase ridership overall. Placing bike share stations uniformly close together over a large area is one of the best ways to ensure that a city's bike share system will be a real transportation option for a wide demographic of users. Conversely, a low-density system, with only a few stations within a walkable distance, will see lower ridership (2015, 2)

Determining ideal station location is a two-step process of creating a first draft of all station locations and then finalizing the positions through site visits and stakeholder engagement (Cohen et al. 2013, 58). The suitability maps are a guide for narrowing down sites contained only within the most suitable areas. Stakeholder and community engagement in the form of surveys or other online services can help determine what user demand might be at each potential station, informing how many bikes are appropriate for the station.

Several cities that already operate bike share systems and have similar population sizes to Worcester were identified. Information regarding number of stations and total number of bikes was gathered as a reference for estimating an appropriate system size in Worcester. Table 8 outlines these existing systems. Unfortunately, data regarding square mileage of system coverage was not found.

Table 8. Overview of similar sized cities and bike share system size

City	Population (2013)	Sq. mileage of city	Population density (people per sq. mile)	Number of stations	Number of bikes
Boulder	**103,166**	**25.7**	**4014.24**	**39**	**275**
Chattanooga	**173,366**	**143.2**	**1210.65**	**33**	**300**
Buffalo	**258,959**	**52.5**	**4932.55**	**20**	**86**
Des Moines	**207,510**	**82.6**	**2512.23**	**10**	**66**
Fort Collins	**152,061**	**55.83**	**2723.64**	**4**	**228**
Average	**179,012**	**71.996**	**3078.66**	**22**	**191**
Worcester	**182,544**	**38.6**	**4729.12**		

Based on these figures and a combined extent of 2.69 miles from the High Income and Underserved Communities models, calculated using the Area tool in Idrisi, at least 13 stations are recommended, for a density of 5 stations per square mile (13 divided by 2.69). This number was arrived at by using the recommended figure of 5 minutes walking between stations. If 1000 feet and 5 minutes are proportionally equated, this means that a mile would be covered in 26.4 minutes (1000 ft/ 5280 ft per mile = 5 minutes/ 26.4 minutes per mile). Using minutes to estimate station density, approximately 5 stations per square mile are recommended (26.4/5 = ~5), as a walk can occur in any direction and assumes uniform distribution. This is not a scientific estimate, but the value does fit within the range of appropriate number of stations compared to existing bike shares of comparable sized communities. In addition, *at least* 13 stations are recommended for a successful Phase 1 system. Certainly, more stations would be better, but this seems to be an appropriate value for at least piloting a bike share with the option to expand service.

System Cost

Table 9 below from the Federal Highway Administration outline estimates from the literature for stations of various size. In terms of station sizing, it is important that note that "stations need about 15 docks to be efficient from an operations standpoint and data shows that about a 2:1 ratio of docks to bikes is needed" in order to ensure bikes are able to be returned to high traffic stations at peak times (Brushaber 2013, 34, 76). For a program with 13 stations and 101 bikes from variably sized stations (Tables 10 and 11), the first year costs of equipment, installation, and maintenance would be between $841,000 and $940,000.

Table 9. Average Operating and Capital Costs

Cost estimates (per station)			
Bikes	Docks	Equipment and installation	Maintenance per year
6	11	$35,000-40,000	$12,000-15,000
8	15	$45,000-48,000	$18,000-21,000
11	19	$53,000-58,000	$24,000-28,000

Table 10. Estimated System Size and Initial Capital Costs

	Station size (bikes per station)	Number of stations	Number of bikes by station size	First Year Capital Costs - Low Estimate (Cost per station * number of stations)	First Year Capital Costs - High Estimate (Cost per station * number of stations)
	6	3	18	$105,000	$120,000
	8	5	40	$225,000	$240,000
	11	5	55	$265,000	$290,000
Total:		13	101	$595,000	$650,000

Table 11. Estimated Annual Maintenance Costs

	Station size (bikes per station)	Number of stations	Number of bikes by station size	Maintenance - Low Estimate (Cost per station * number of stations)	Maintenance - High Estimate (Cost per station * number of stations)
	6	3	18	$36,000	$ 45,000
	8	5	40	$90,000	$ 105,000
	11	5	55	$120,000	$140,000
Total:		13	101	$246,000	$290,000

Cost considerations would also need to include winter storage facilities for the bicycles. The methods of this study and research do not support cost estimates for storage, nor does it support cost estimates for sample revenue calculation based on estimated demand. As such, this study cannot provide accurate operating costs. In addition, operating costs are highly variable, as each system has different approaches to administration and marketing.

Funding

Sources of funding for bike shares can come from a variety of sources including city, state, federal, grants, or donations/sponsorships. The Better Bike Share Partnership was mentioned in the previous section. National grants that are relevant for bike share funding include EPA funding and the federal Congestion Mitigation and Air Quality (CMAQ) program, which spends $70 million each year on bicycle and pedestrian improvement projects. Universities and local foundations can also be substantial sources of funding. Local businesses are also “proven aids for smaller-scale bike shares” (Brushaber et al. 2013, 32).

Potential Private Sponsors for City and MassDOT to Partner with:

o Bank of America
o Blue Cross Blue Shield
o Charter
o DCU Center
o Dick’s Sporting Goods
o Fallon Health
o The Hanover Insurance Group
o Harvard Pilgrim Health Care
o Polar Beverages
o St. Vincent’s Hospital
o TUFTS Health Plan
o UMass Medical School
o United Healthcare
o Worcester Art Museum
o Worcester Bravehearts
o Worcester Polytechnic Institute
o Greendale YMCA
(Breen 2013)

Local Policies, Goals, and Opportunities

Jeff Speck finds that the biggest factors in establishing a biking city are primarily physical. There needs to be urbanism, in the form of density and mixed-use development, and streets that are designed to welcome bikes through safe design and extensive cycling infrastructure (Speck 2012, 192). Cities across Massachusetts and the U.S. have begun to integrate a “complete streets” approach into their transportation planning and funding decisions. These policies require agencies to balance the needs of all users– including pedestrians, bicyclists, motorists, transit riders, older people, children and those with disabilities – in the planning, design and construction of all transportation projects (Smart Growth America 2016). As of November 2014, Worcester’s Department of Public Works was working on a draft policy. With these policies formalized, requiring newly paved streets to have striped bike lanes, Worcester will gain access to funding for critical infrastructure that would support a bike share.

In addition, the City of Worcester and the Central Massachusetts Regional Planning Commission (CMRPC) announced the launch of the Bicycle Parking Program for the Central Massachusetts region at the beginning of February 2016. The Massachusetts Department of Transportation (MassDOT) and the Federal Highway Administration (FHWA) will provide $100,000 of Transportation Alternatives Program funding through the City of Worcester. This funding provides full reimbursement of the cost of purchasing bicycle racks, minus the shipping and installation costs. Racks can be installed on public property such as libraries, town halls, schools, parks, etc. Though these racks would not directly benefit a bike share, the presence of bike racks at various public properties across the city will ideally increase the visibility of bikers and the demand for bike lanes and other bicycle infrastructure.

Statewide, the Commonwealth’s Global Warming Solutions Act (GWSA) of 2008 requires statewide reductions in greenhouse gas (GHG) emissions of 25 percent below 1990 levels by the year 2020, and 80 percent below 1990 levels by 2050. As part of the GWSA, the Executive Office of Energy and Environmental Affairs developed the Massachusetts Clean Energy and Climate Plan (CECP), which outlines programs to attain the 25 percent reduction by 2020 – including a 7.6 percent reduction that would be attributed to the transportation sector. By providing public infrastructure that increases accessibility to bicycles through a bike share program, Worcester can help move the state towards their goals while decreasing air pollution and creating more future security.

However, Worcester's city-level policies regarding future goals and comprehensive strategic planning are severely lacking. Many bike share feasibility studies have referenced long-term city Master Plans and Bicycle Master Plans. Neither of these exists for Worcester in a specific and extensive form, well-communicated with the public, which is a major limitation in the City's ability to plan overall. As climate change rapidly becomes an issue of increasing pressure and fossil fuels are phased out, there will be major paradigm shifts in everything from the way energy is distributed to the ways in which humans and goods are able to move around. Cities that are able to anticipate these necessary resilience measures that contribute to thriving communities are the cities that will succeed.

Bicycling Infrastructure

Bicycle infrastructure data was not included as a variable in the models due to lack of density, but it is important to acknowledge this is a limitation of the current system in Worcester. A survey conducted by People for Bikes found that one third of people who want to bike more are dissatisfied with existing bike infrastructure (Andersen 2013). Capital Bikeshare data reveals a significant and positive relationship between bike lane supply near Capital Bikeshare stations and the number of trips originating from those stations (Buck and Buehler 2011, 10).

Significant findings in the 2015 U.S. Bicycling Participation Benchmarking Study Report are:

- Concern about motor vehicle traffic is a key barrier to riding that infrastructure improvements can address
- More than half of Americans (ages 18 and older) would like to bicycle more often and perceive bicycling as a convenient mode of transportation
- Infrastructure improvements will have the biggest impact on underserved populations, such as young adults, females, and non-whites (13)

While a bike-share can be implemented even if there is little existing cycling infrastructure, pairing the construction of new bicycle lanes with the opening of a bike-share system can contribute to public acceptance and improve safety for users of the new system. Additionally, the city can conduct a safety campaign to teach motorists and cyclists how to share the street with each other (Cohen et al. 2013, 62)

Public Outreach and Education

Of equal importance to infrastructure and much less costly, but given far less consideration are cultural and educational aspects of attracting bikers in an urban area. If cycling is to become successful as a mode of transportation, it is crucial that motorist training and licensing procedures incorporate the need for motorists to share the road with cyclists and how to avoid endangering them (Pucher and Buehler 2009, 57). For example, in Amsterdam—a city with one of the highest cycling rates in the world— drivers learn to reach for the door handle with their opposite hand, so that they cannot exit the car without checking for bikes (Speck 2012, 193).

As mentioned in the Social Benefits section, non-whites who didn't ride are least likely to have ever ridden bike, but more likely to intend to ride in the future than are their white counterparts (People for Bikes 2015). If a bike share system is to be successful in attracted underserved communities, the engagement has to go beyond just subsidized memberships. Community resources need to be made widely available via a city-wide safety campaign.

Worcester has a number of existing biking resources dedicated to education in the community. Worcester Earn a Bike is an organization that has been working the bridge the income and accessibility divide in cycling. It states that its mission is to "teach fun, affordable bike repair to neighborhood youth and community members by providing instruction, tools, and repairable bikes and parts. We encourage bike riding as an empowering, economical, and healthy alternative to car culture." A local advocacy group, WalkBike Worcester, was founded in 2011 and works to bring the "complete streets" approach into multiple city plans, policies, and practices; and increase public support for bicycling.

Cities in the U.S. such as Portland, Oregon that are recognized as successful biking cities have extensive education information and programming through the Portland Bureau of Transportation (PBOT). The Bureau's website provides a Portland Biking Guide with a comprehensive overview of laws, gear, and safety. There are several tools linked to assist with planning your trip via bicycle, and a form for reporting and requesting bike route maintenance. A Bike Lunch and Learn session takes place monthly at their City Hall, in addition to a full brochure of classes and guided bike rides (PBOT 2016).

In terms of actual planning for the system, a community survey regarding attitudes towards a bike share program and suggestions for desired locations would provide indispensable knowledge. In 2012, Bike Nation launched a website where the public can suggest a station location and either "like" or "dislike" suggested locations (Bike Nation, 2013).

Such public involvement has become commonplace, and several other programs have solicited public input on station locations both at public meetings and via online “suggest-a-station” platforms (Shaheen et al. 2014, 19). These public engagement measures can help validate station location and estimate potential demand.

Recommendations

The following is a list of recommendations for Worcester based on the literature reviewed for this study and the findings of this study:

- Draft and finalize a Bicycle Master Plan with community input that includes comprehensive short-term and long-term goals for bicycle ridership and infrastructure, as well as system of metrics to evaluate success of programs and infrastructure improvements.

- Compose and widely communicate a City of Worcester Comprehensive Plan with 20 year projections for major areas such as economy, community, education/schools, infrastructure, environment, planning and zoning, financial capacity and control (Buffalo Bicycle Master Plan, 5).

- Create a dedicated position for Bicycle and Pedestrian Coordinator in the Planning Department or Department of Public Works and Parks.

- Form a Bicycle and Pedestrian Advisory Board- 12 members, meets one or more times a month to assist with Bicycle Master Plan implementation and monitoring (Buffalo Bicycle Master Plan, 14; Portland Bureau of Transportation).

- Finalize Complete Streets policies for Worcester.

- Draft and issue a city-wide ordinance requiring that bike parking is provided at all new building developments (Buffalo Bicycle Master Plan, 14).

- Establish goal to have 100% of WRTA buses with front-mounted bicycle racks.

- Develop an education campaign for cyclists and motorists about sharing the road safety, leveraging bike advocacy groups in Worcester.

- Create Level of Stress maps and classifications for entire road network in Worcester.

- Identify streets in Worcester that are already wide enough to simply add a striped bike lane, contributing to both traffic calming and increased bike ridership.
    - Contact WalkBike Worcester for this information and assign as a task to the Department of Public Works and Parks.

Conclusion

A bike share in Worcester is feasible based on these models, though the system would not end up being truly city-wide initially. The areas of highest suitability in the High Income and Underserved Communities models correspond to locations in the city with dense retail options, popular attractions, densest transit linkages, and areas where people are already walking. Safe bicycle infrastructure is lacking in Worcester, evidenced by the lack of density from MassDOT's Bike Inventory data and by the crash clusters overlapping with the most suitable areas of the model. Work around infrastructure and traffic slowing measures downtown should be implemented prior to launching a bike share, accompanied by a biker and driver education campaign

Overall recommendations of this study are expansion and investment in bicycle lanes, contributing to both traffic calming and increased bike ridership; conducting a community survey to validate station location and estimate demand, with special measures to reach underserved communities and tracking of demographics in the survey; and formalizing dedication to creating a bicycling city by creating a Bicycle Master Plan and hiring a full time bicycle and pedestrian City staff member.

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Map Appendix

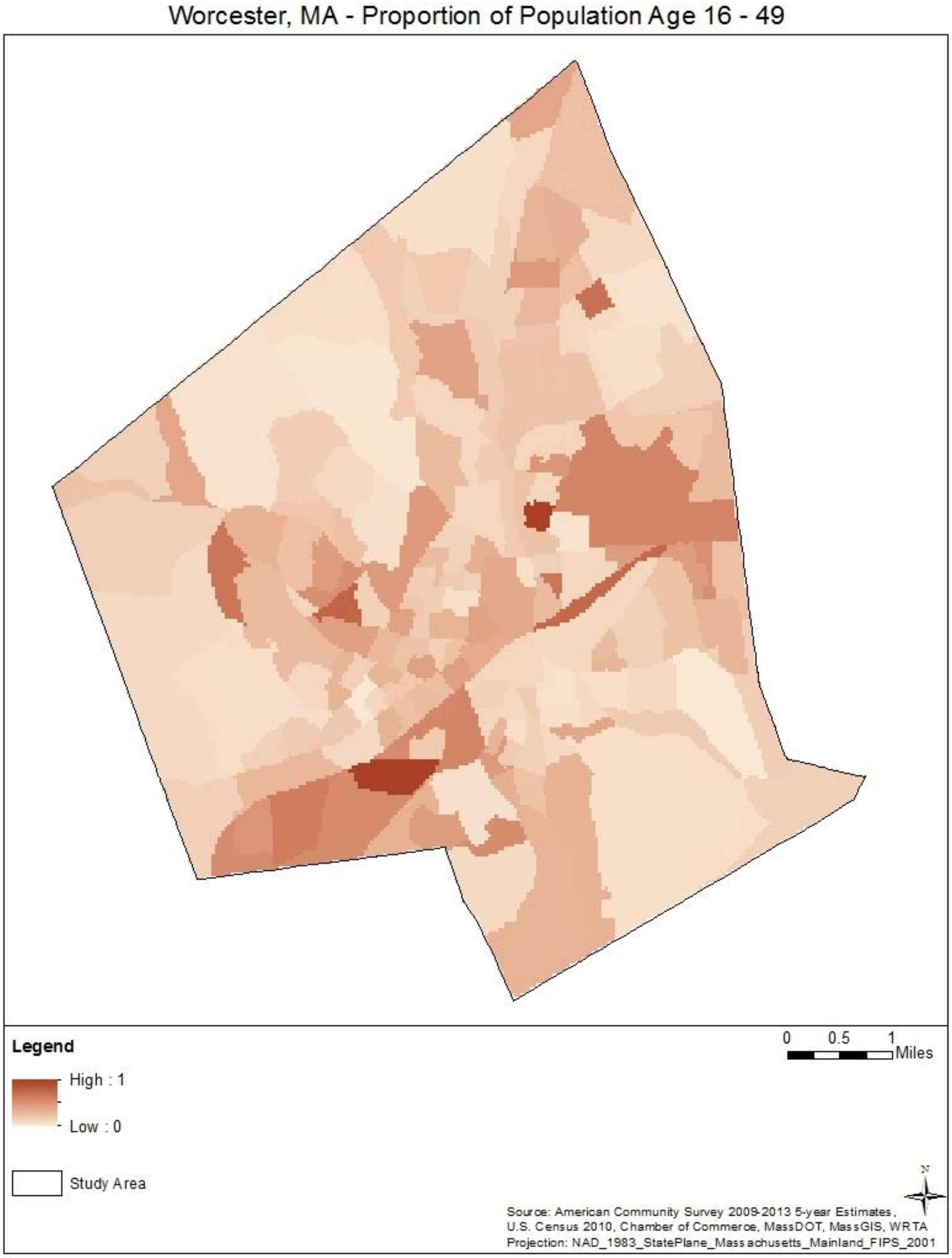

Figure 15. Proportion of Population Ages 16-49

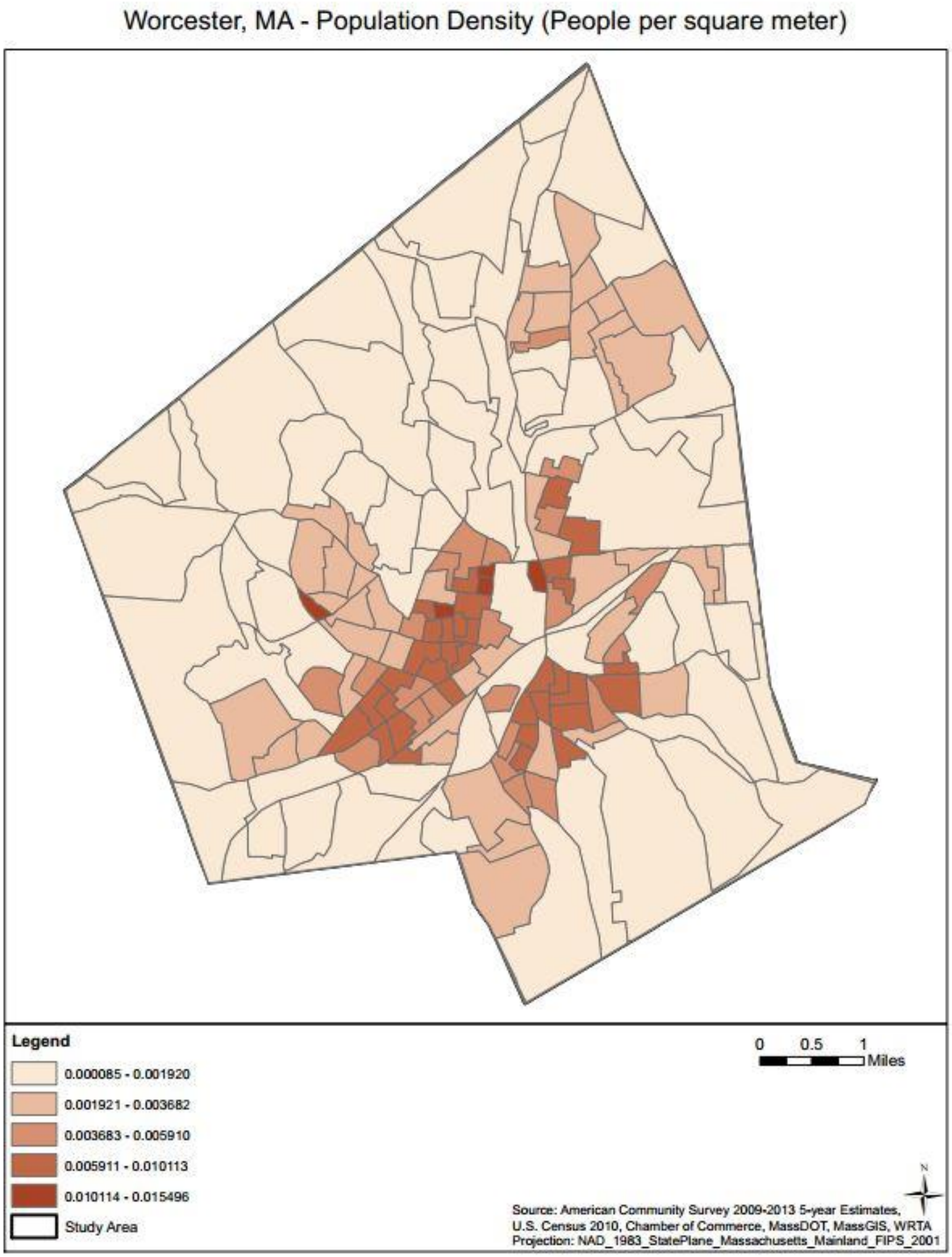

Figure 16. Population Density

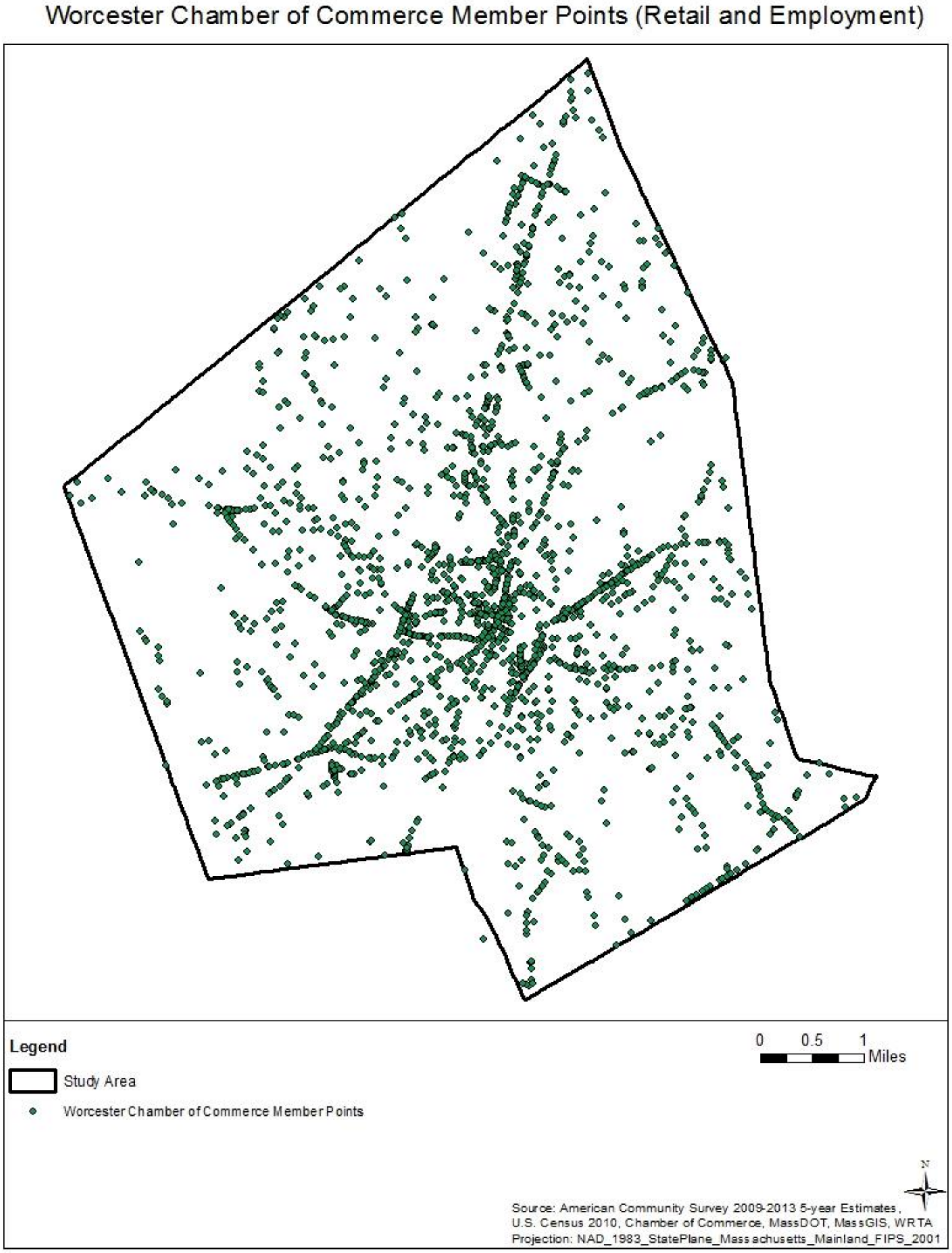

Figure 17. Retail and Employment Points (Chamber of Commerce)

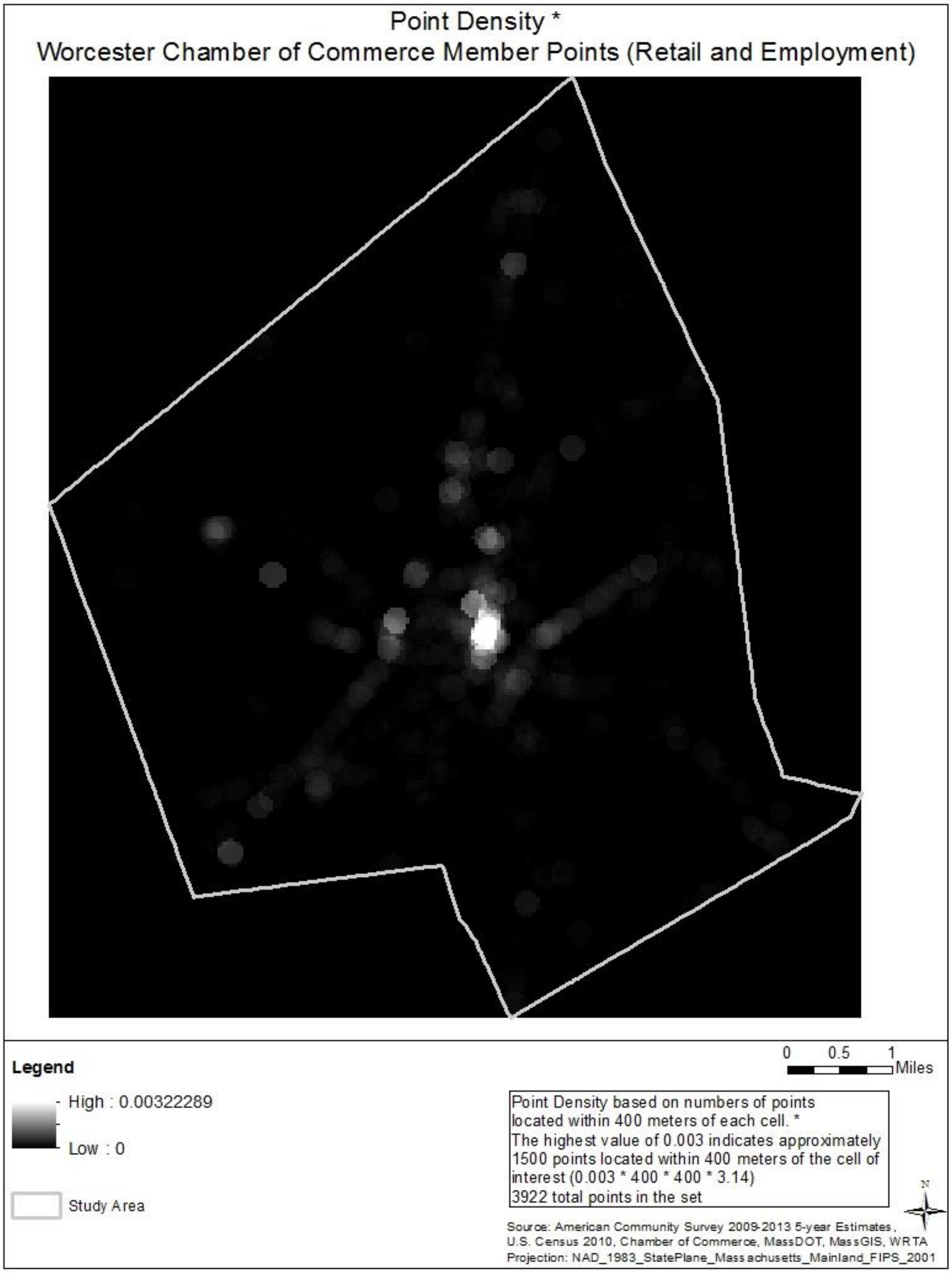

Figure 18. Retail and Employment Point Density

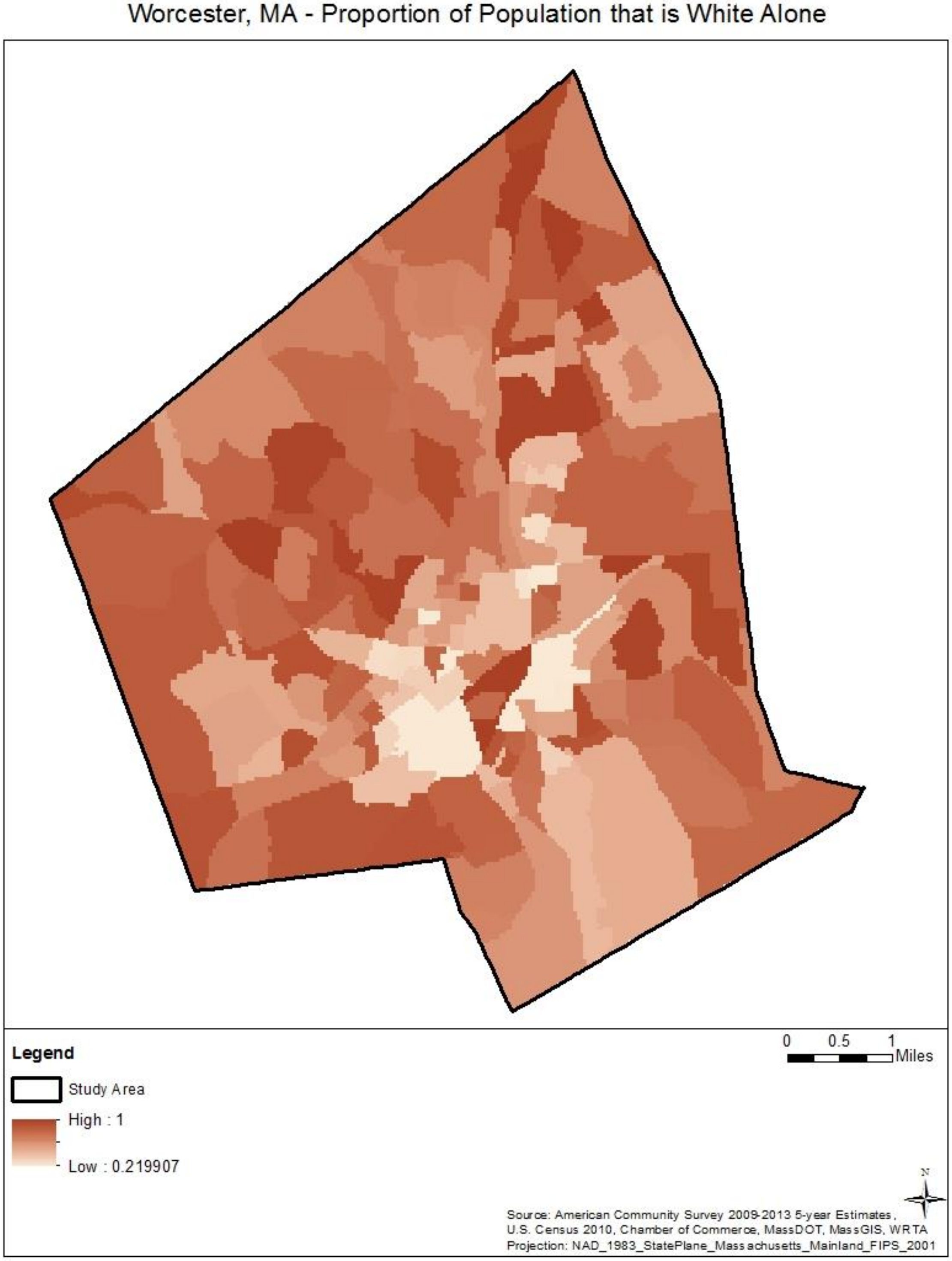

Figure 19. Proportion of Population - White Alone

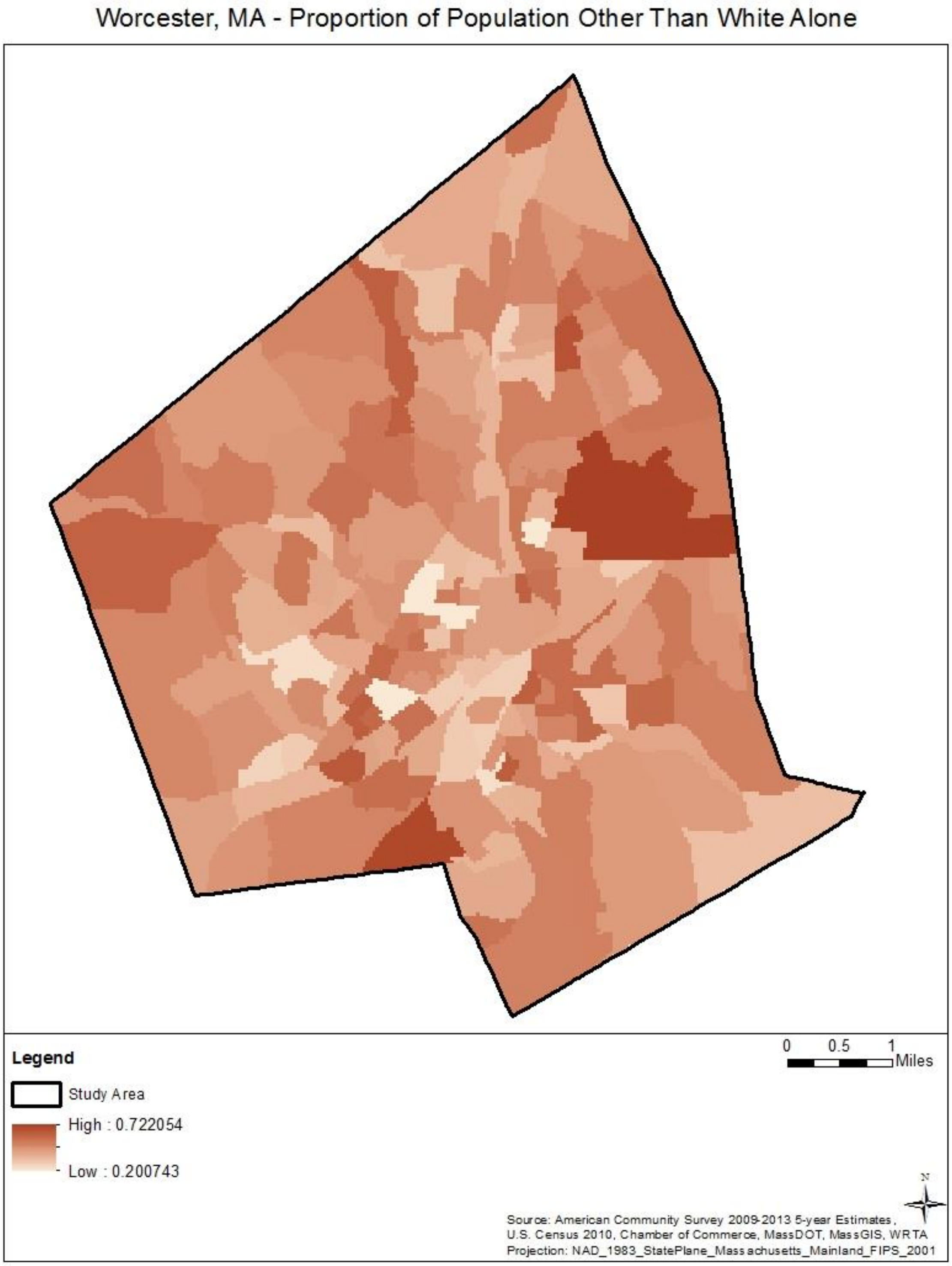

Figure 20. Proportion of Population - Other Than White Alone

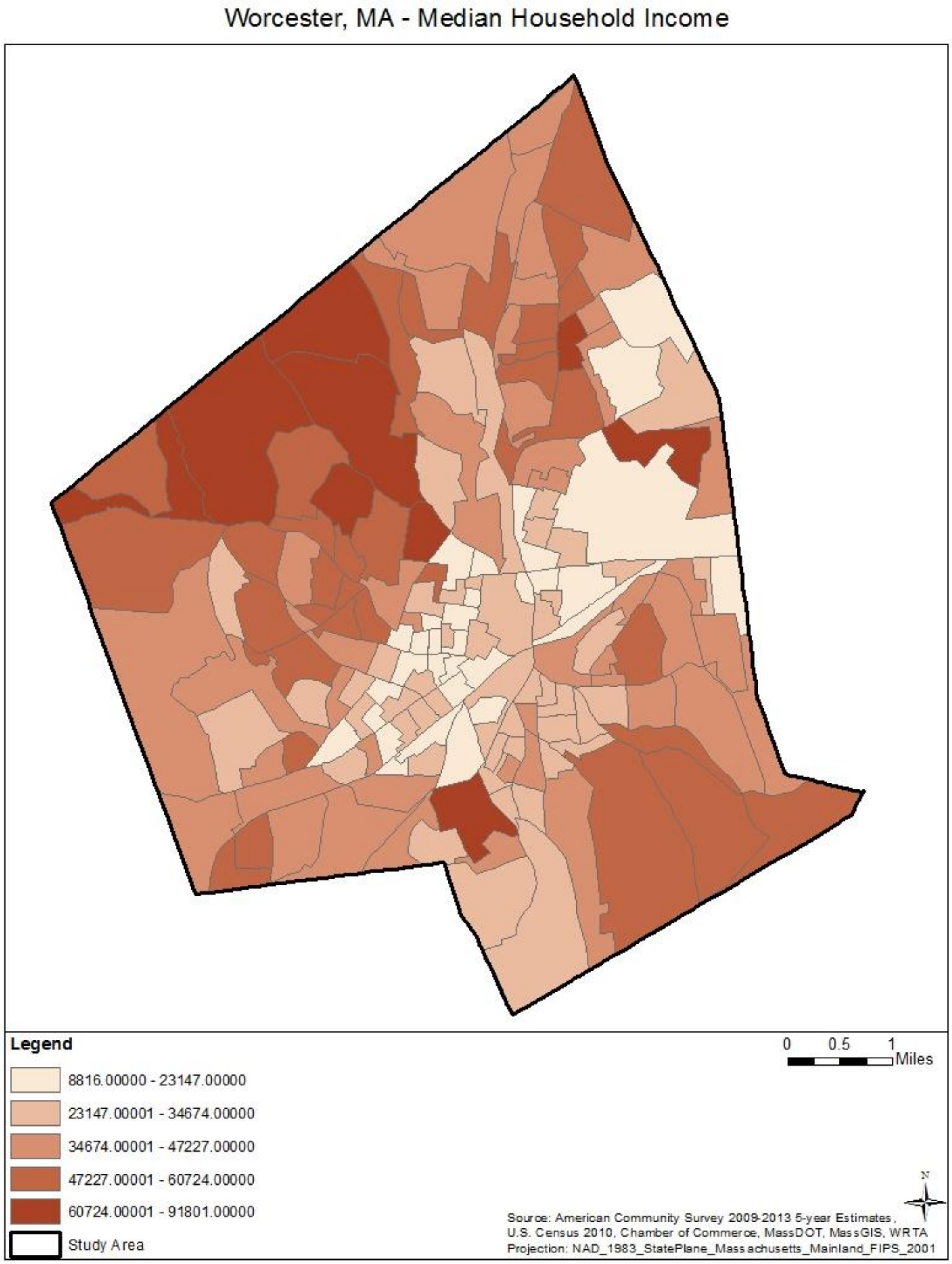

Figure 21. Median Household Income

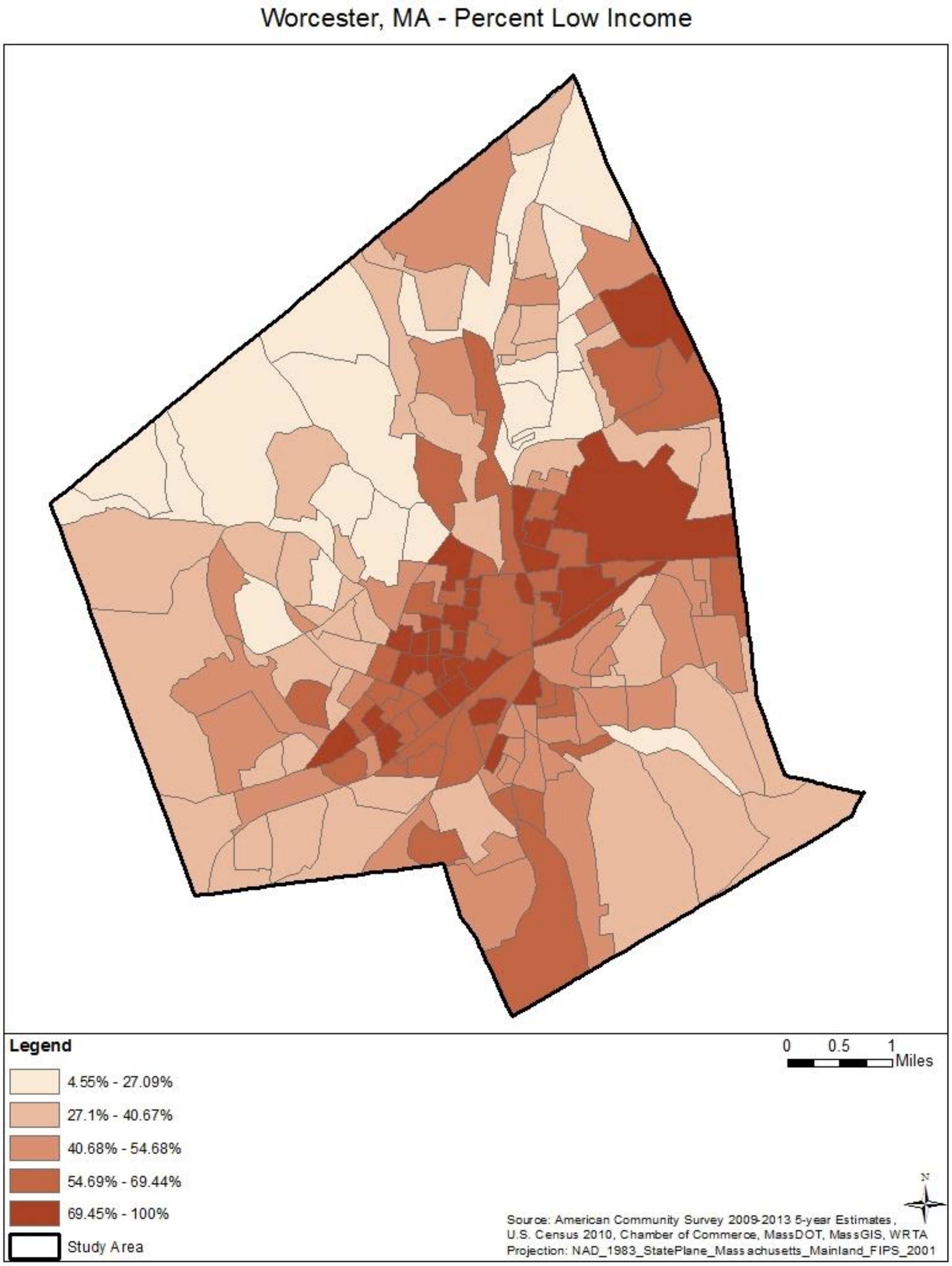

Figure 22. Percent Low Income

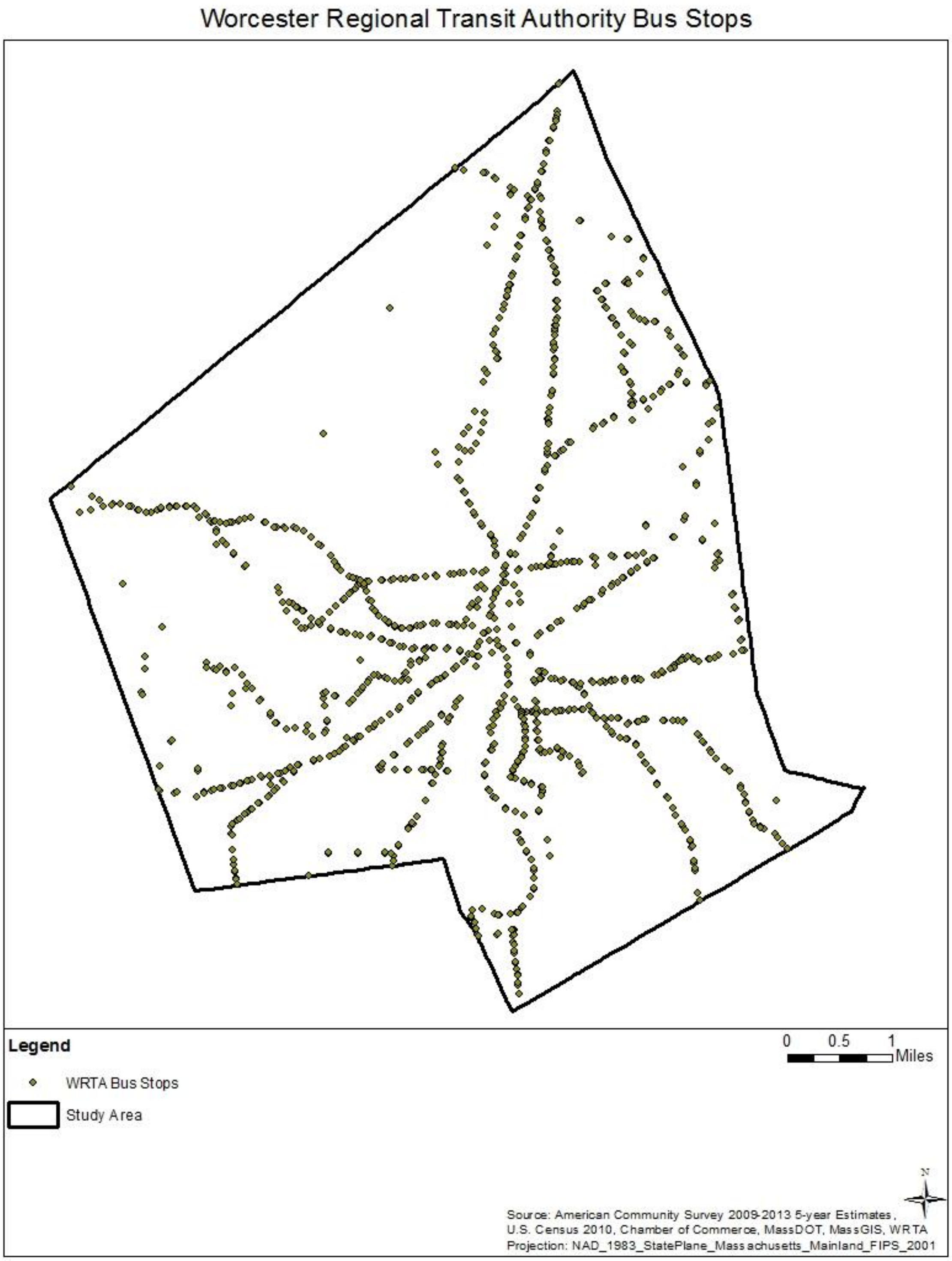

Figure 23. WRTA Bus Stop Points

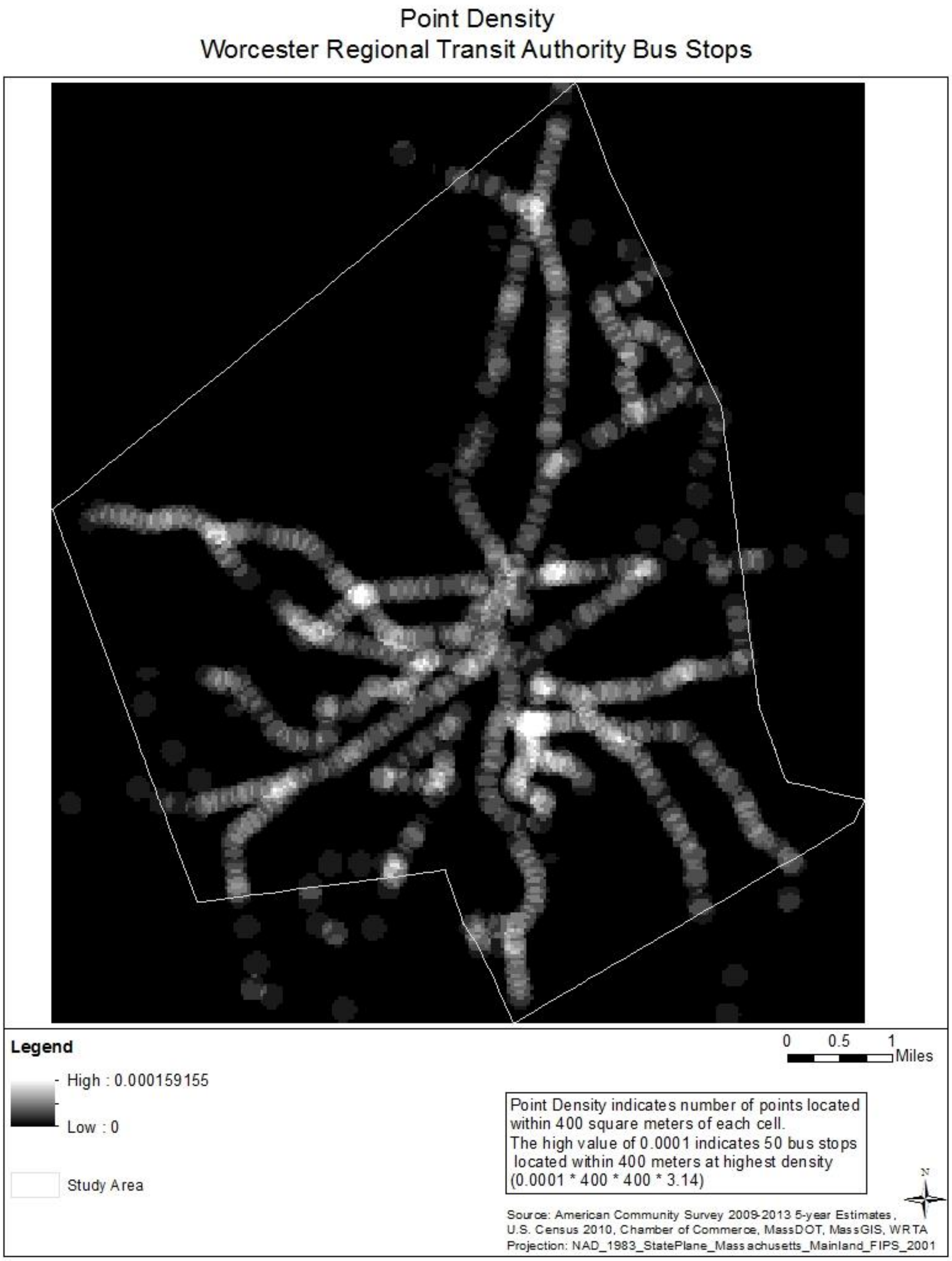

Figure 24. WRTA Bus Stop Point Density

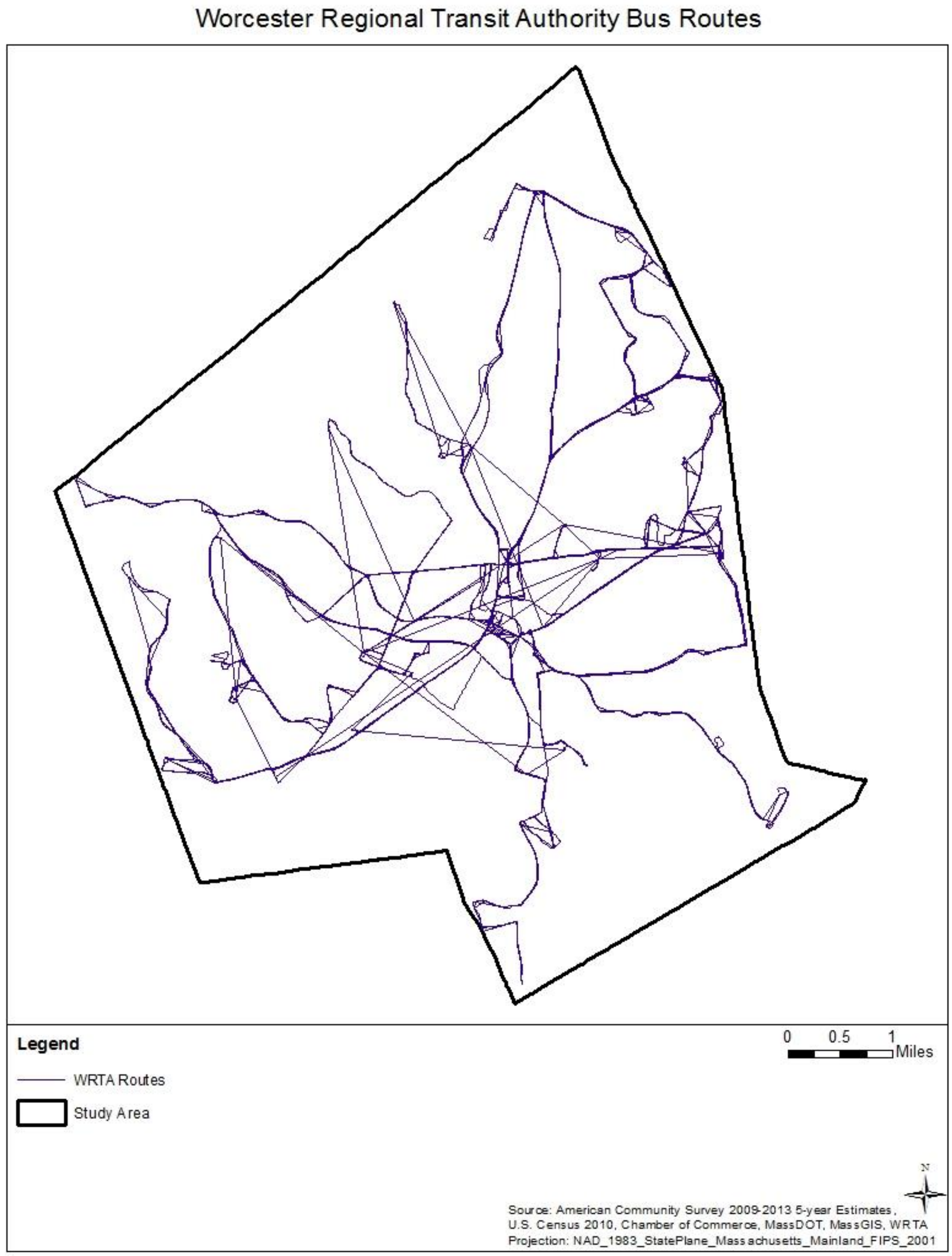

Figure 25. WRTA Bus Routes

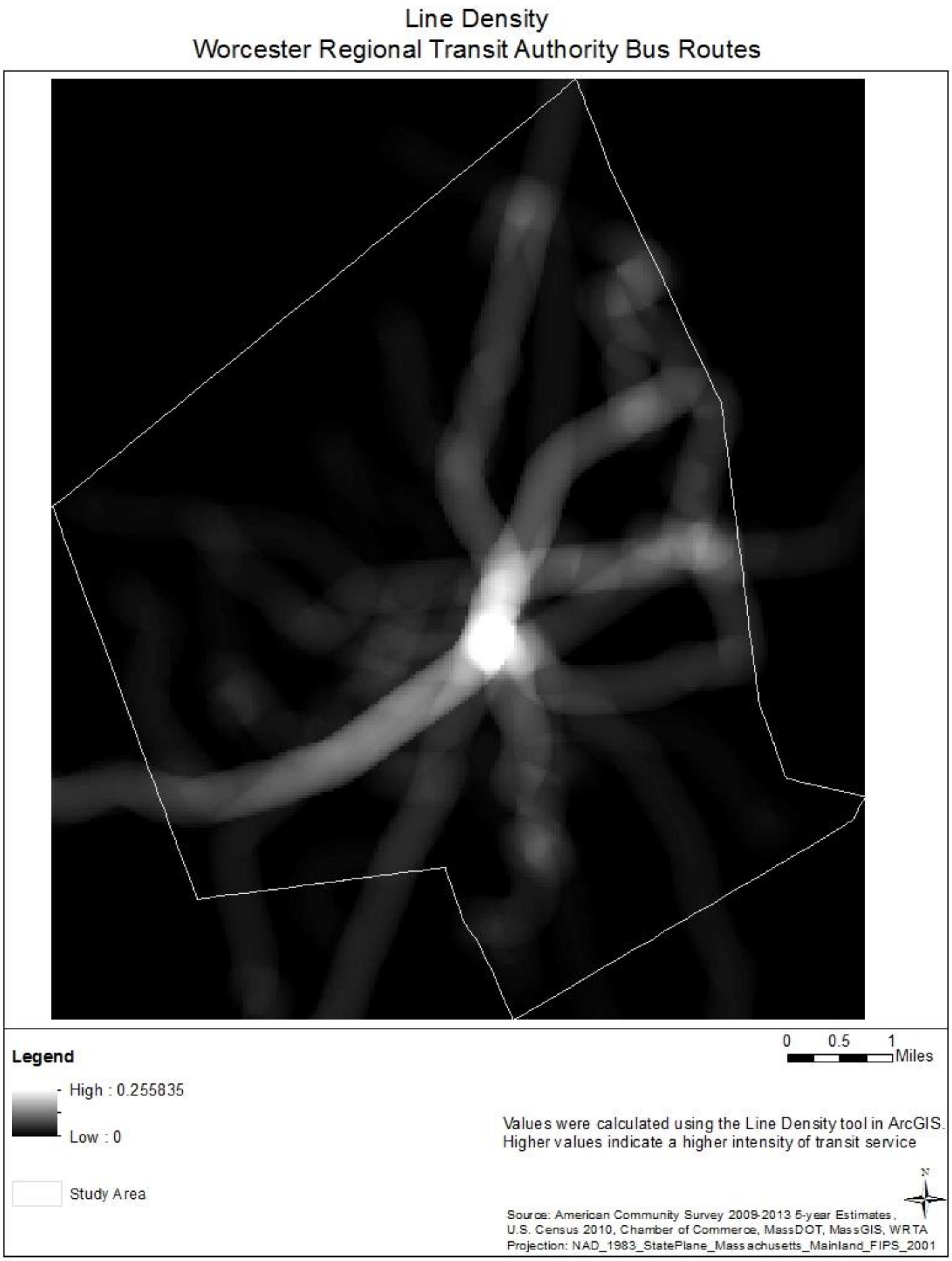

Figure 26. WRTA Bus Route - Line Density

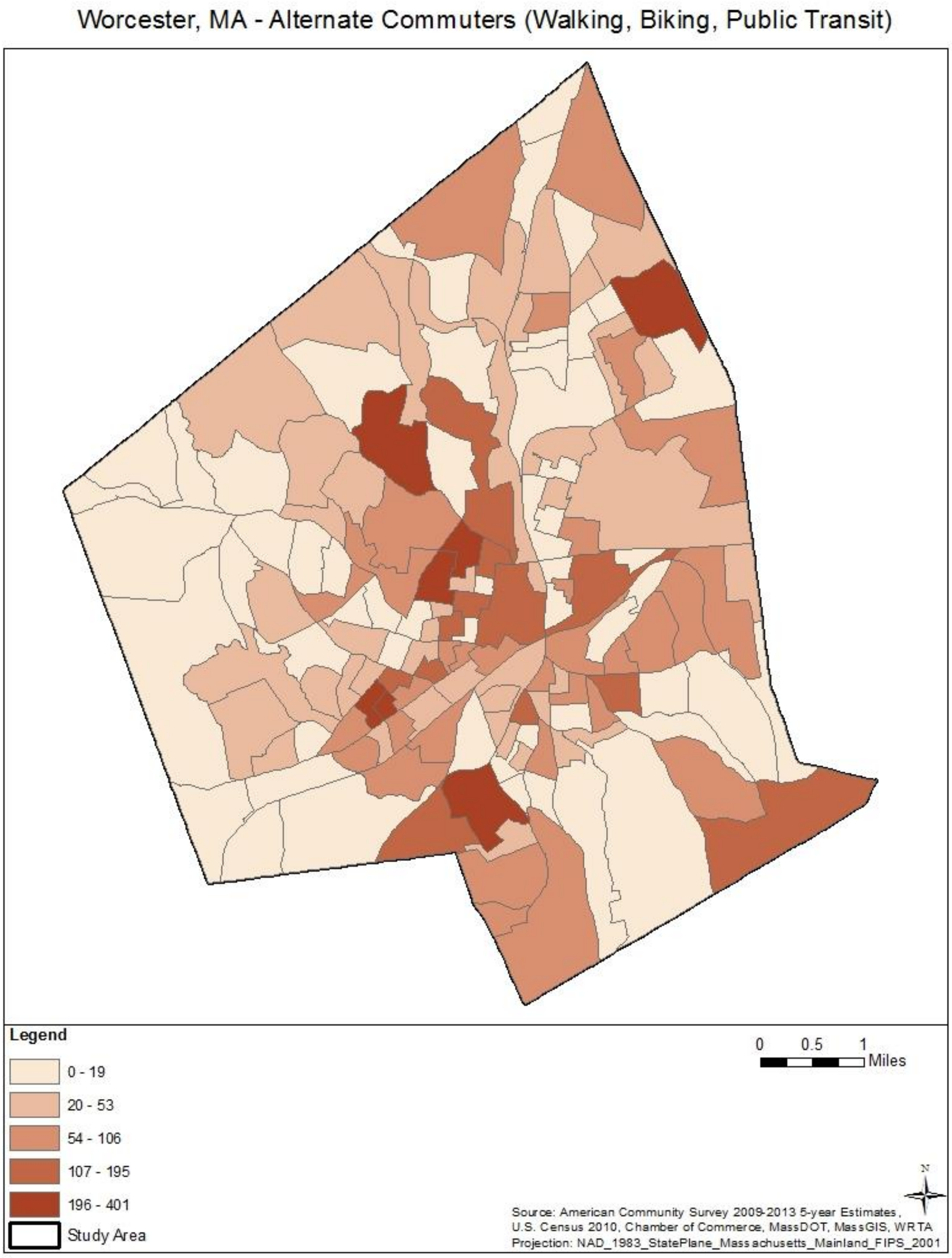

Figure 27. Alternative Commuters (Walking, Biking, Public Transit)

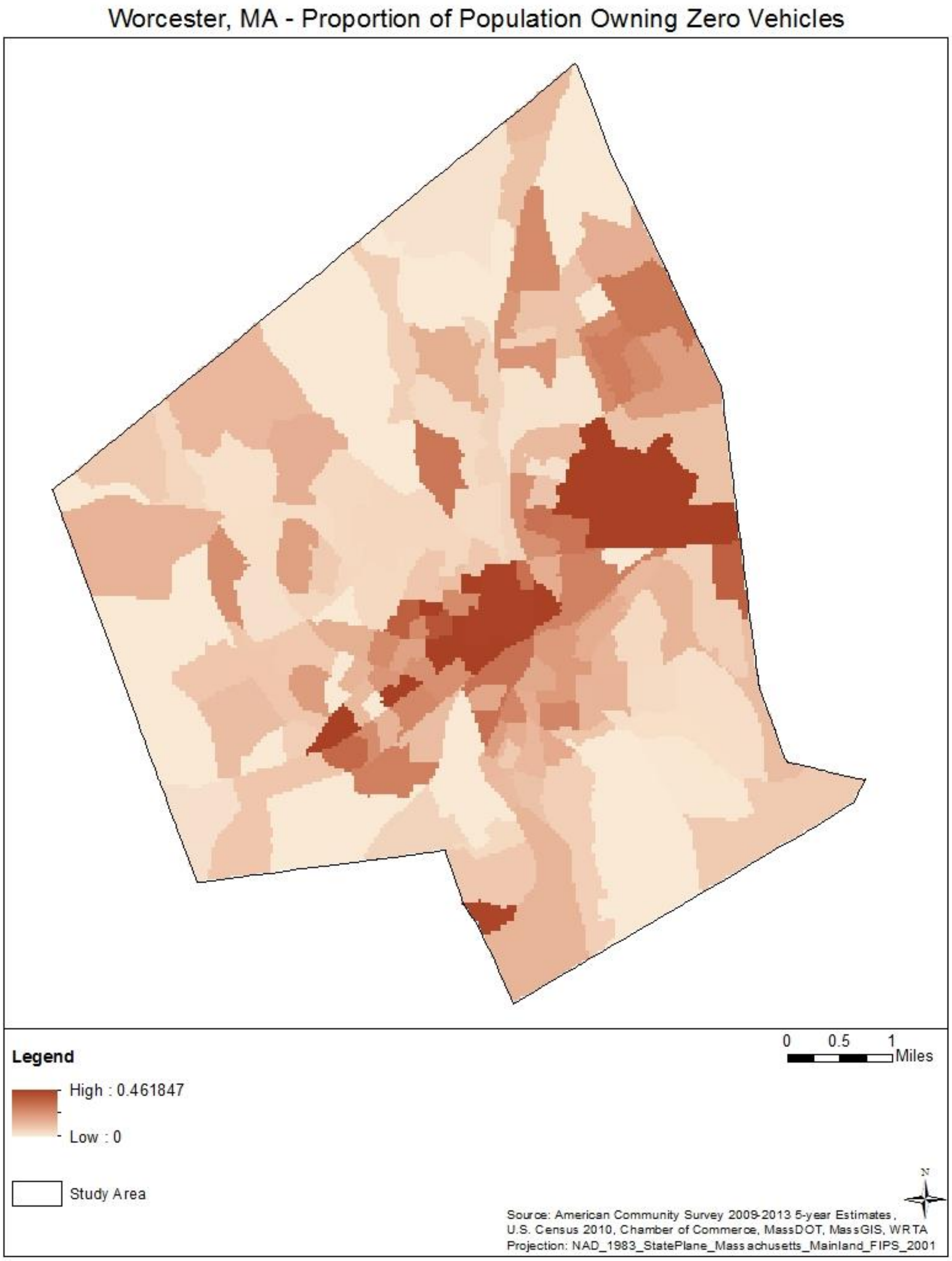

Figure 28. Proportion of Population Owning 0 Vehicles

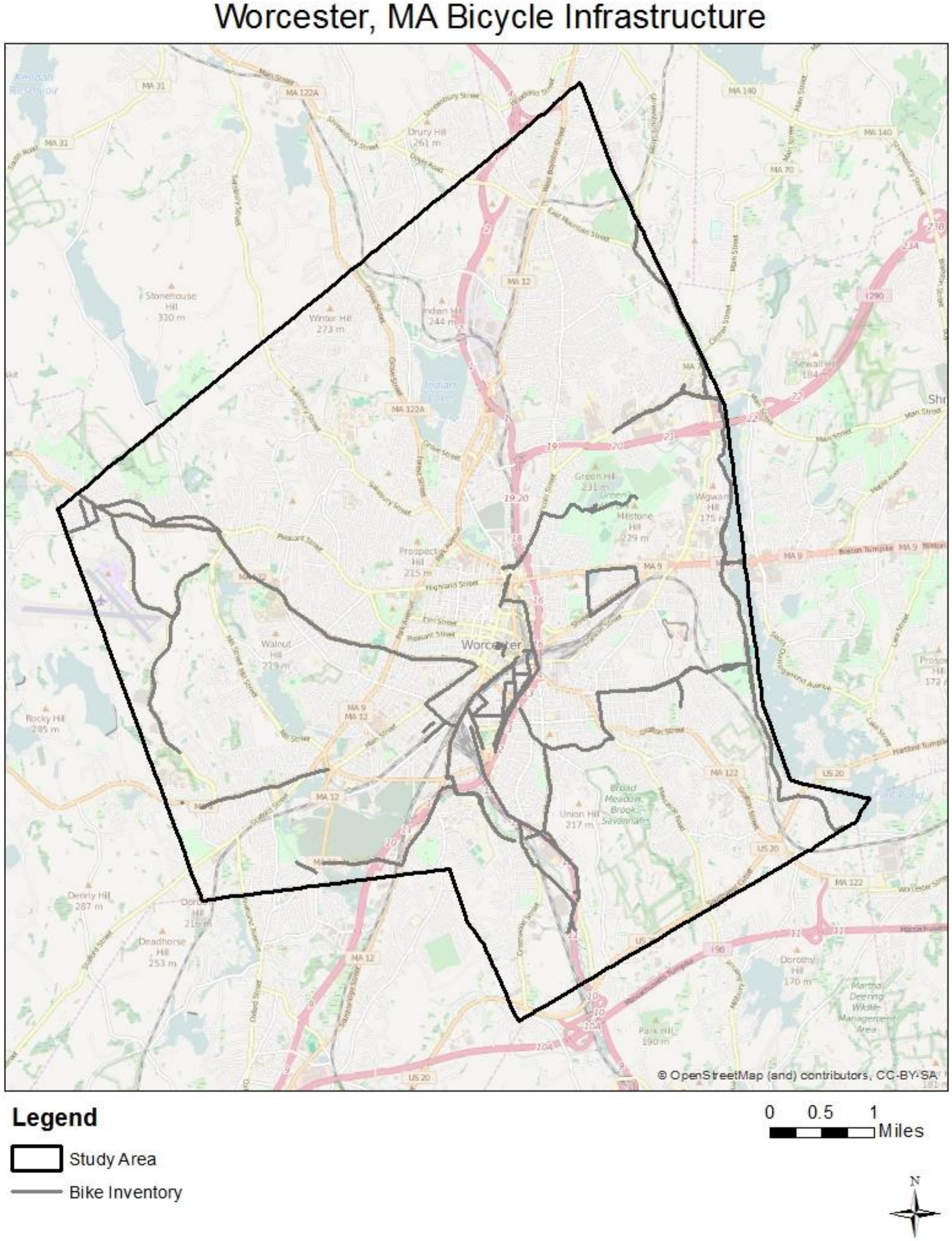

Figure 29. Worcester Bicycle Lanes

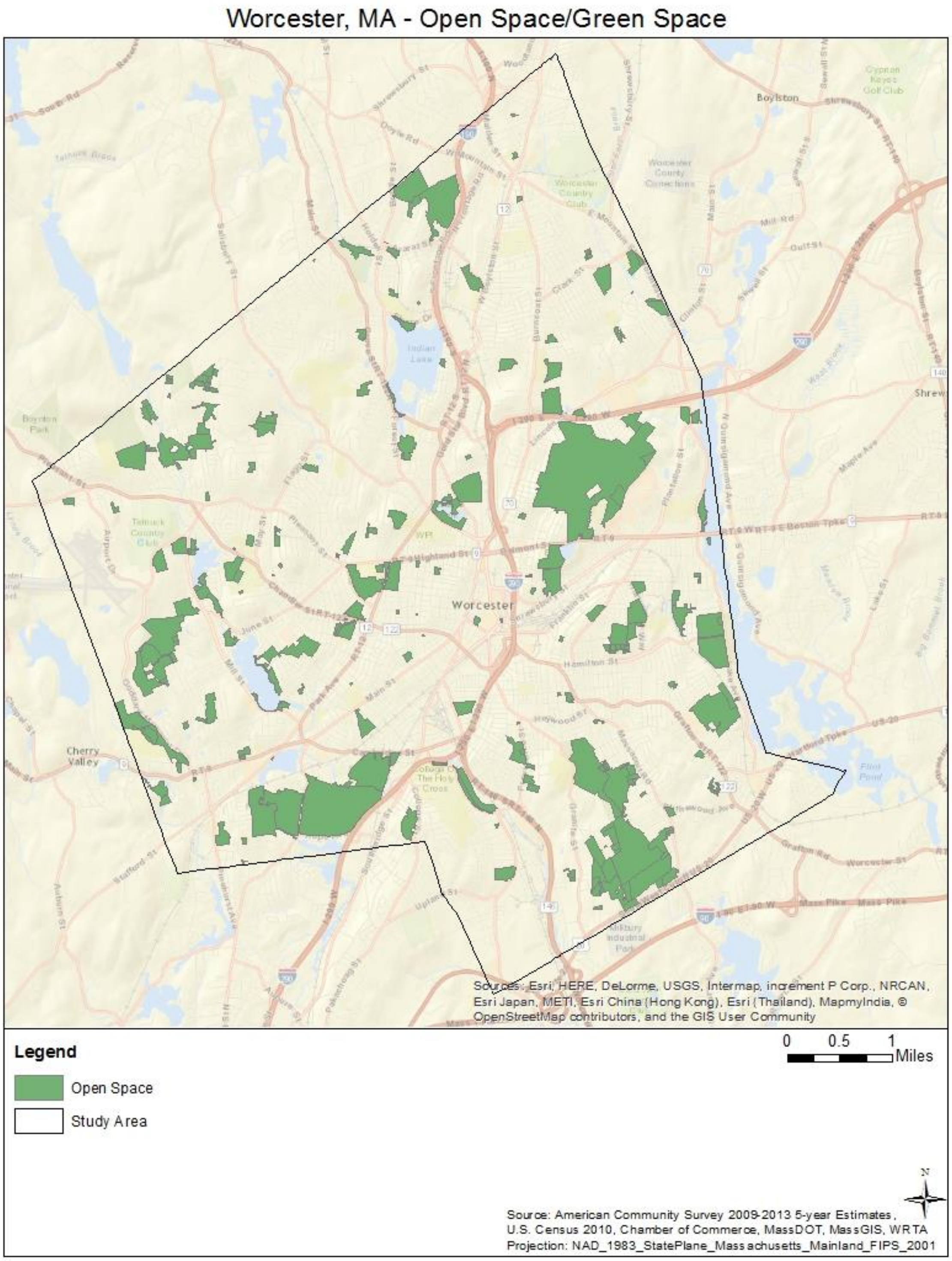

Figure 30. Worcester Green/Open Spaces

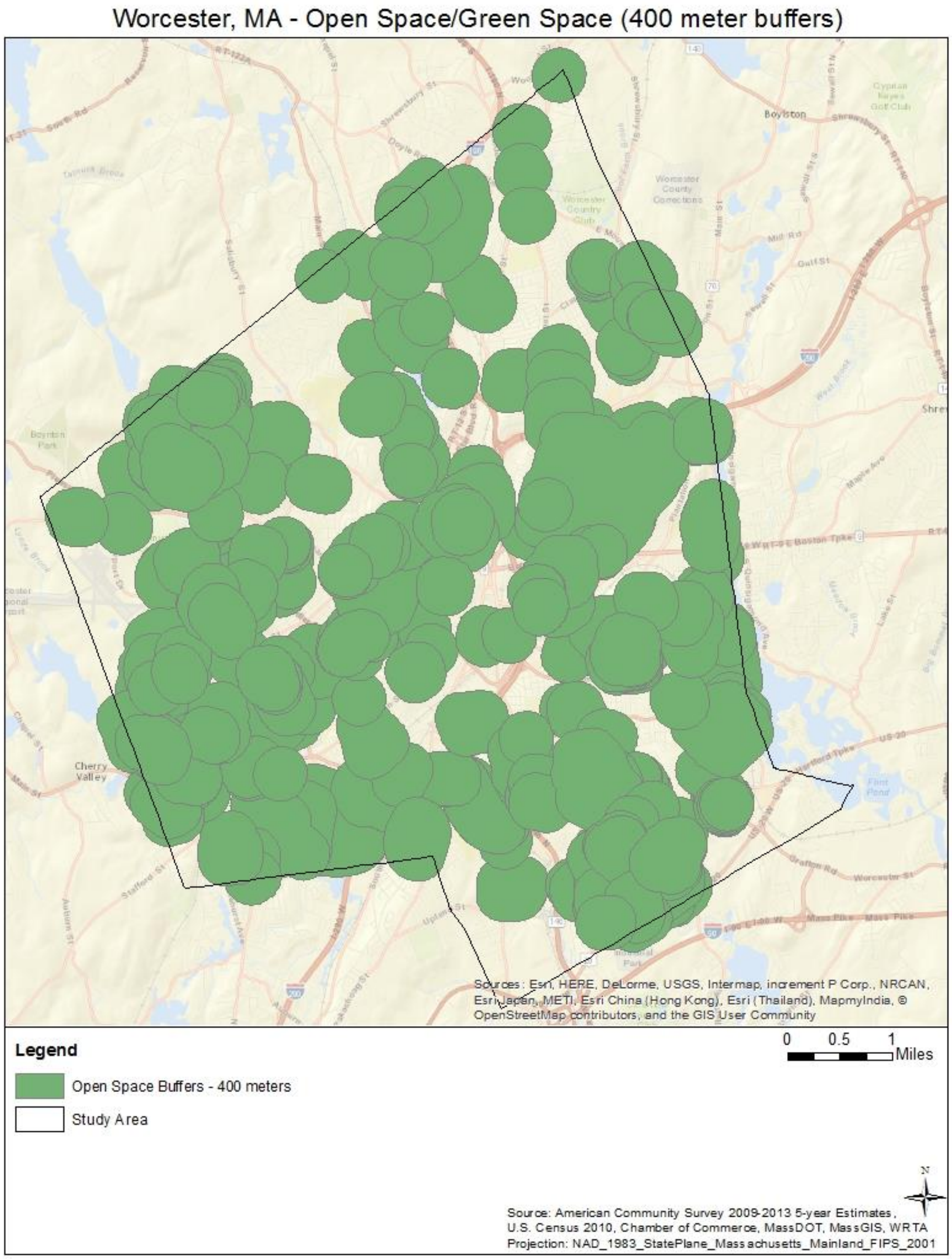

Figure 31. Worcester Green/Open Spaces with 400 meter buffers

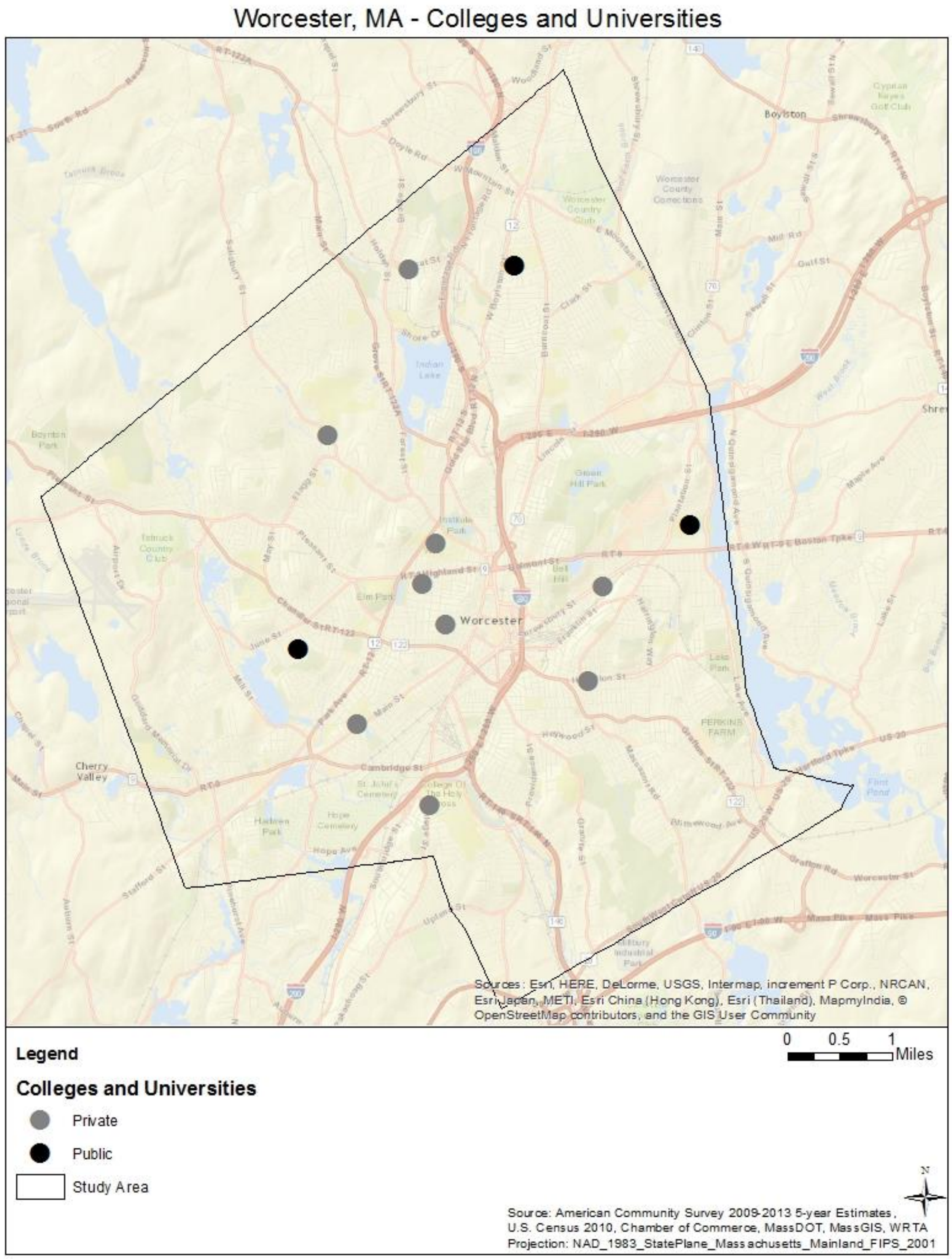

Figure 32. Colleges and Universities in Worcester

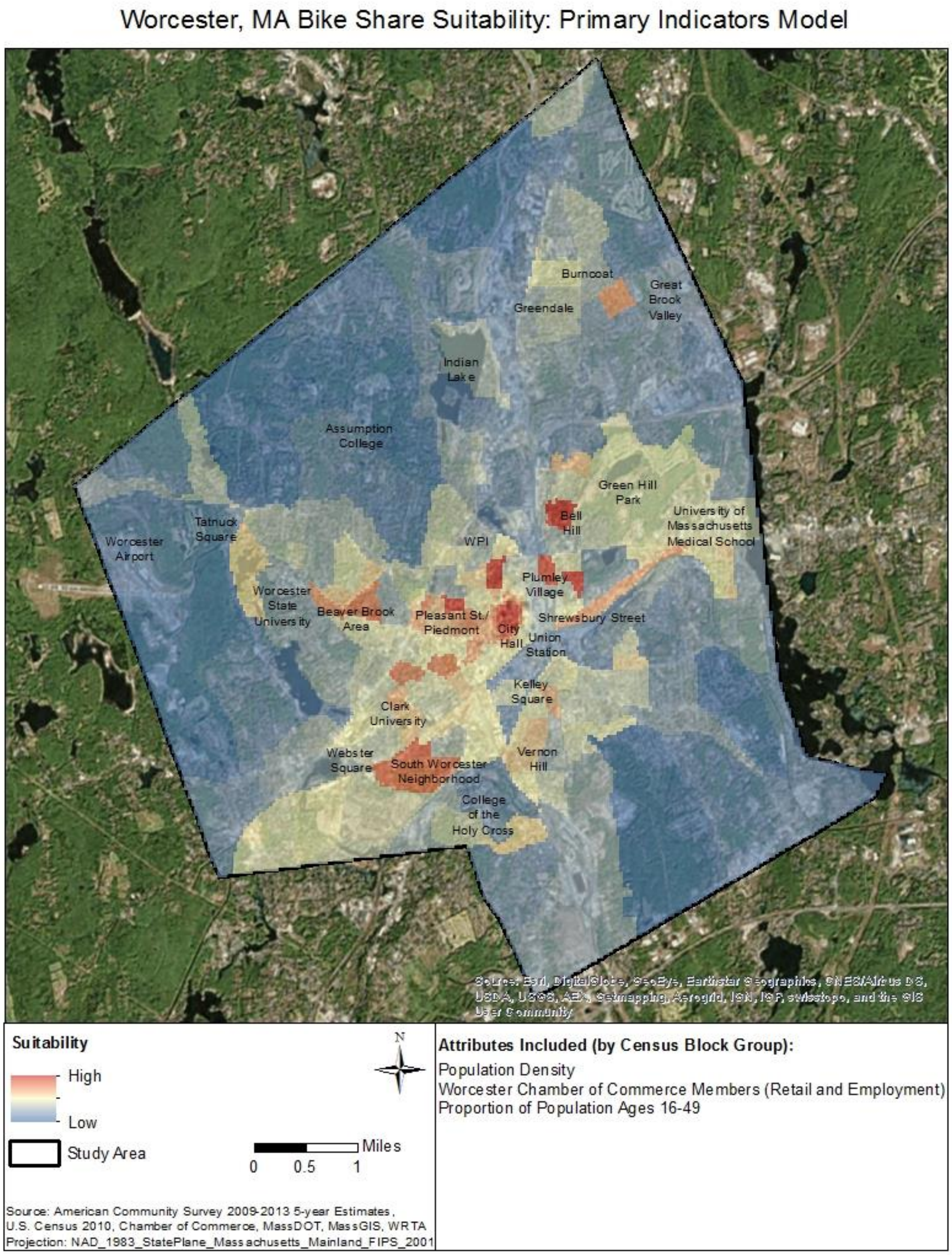

Figure 33. Basline Model Suitability Map

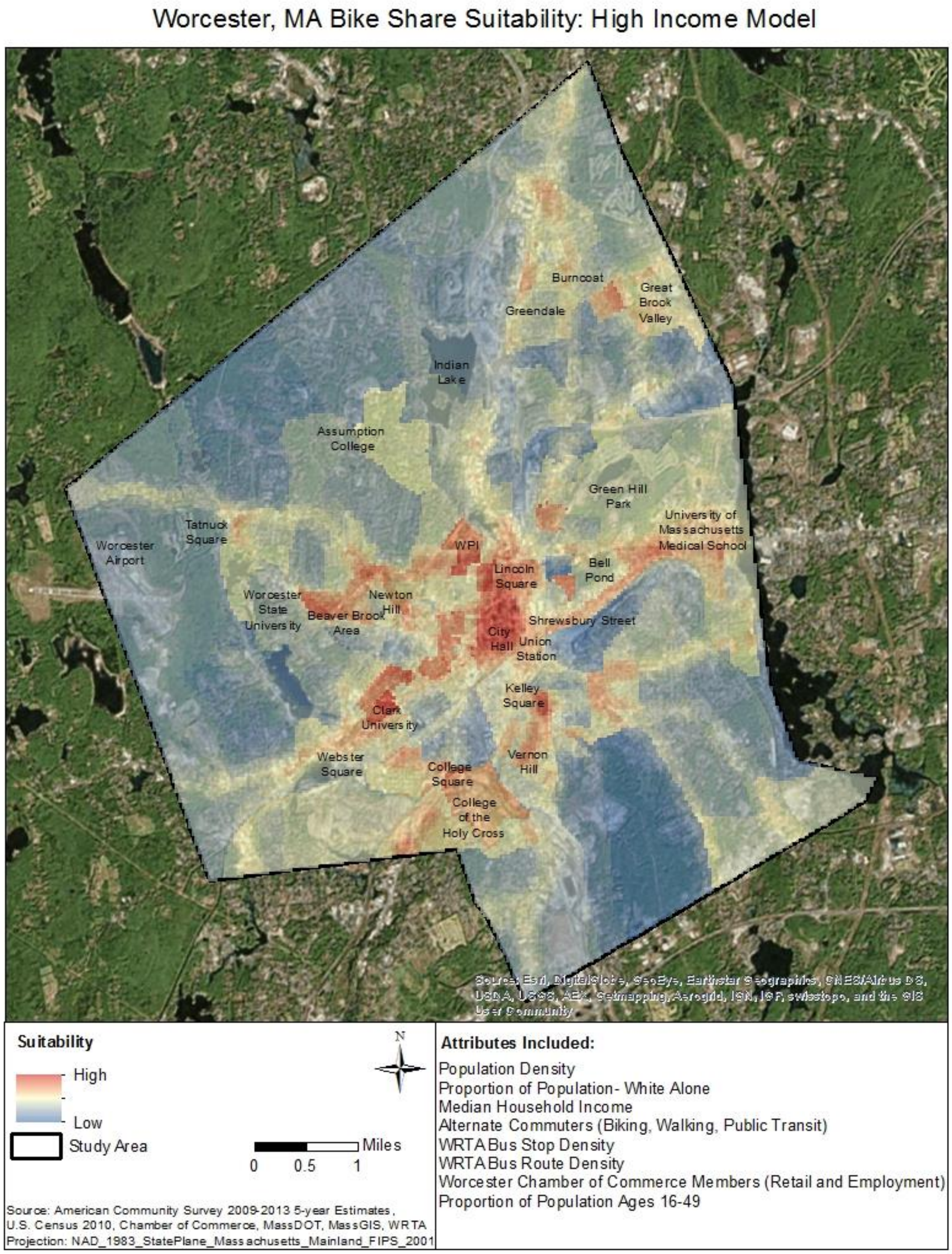

Figure 34. High Income Model Suitability Map

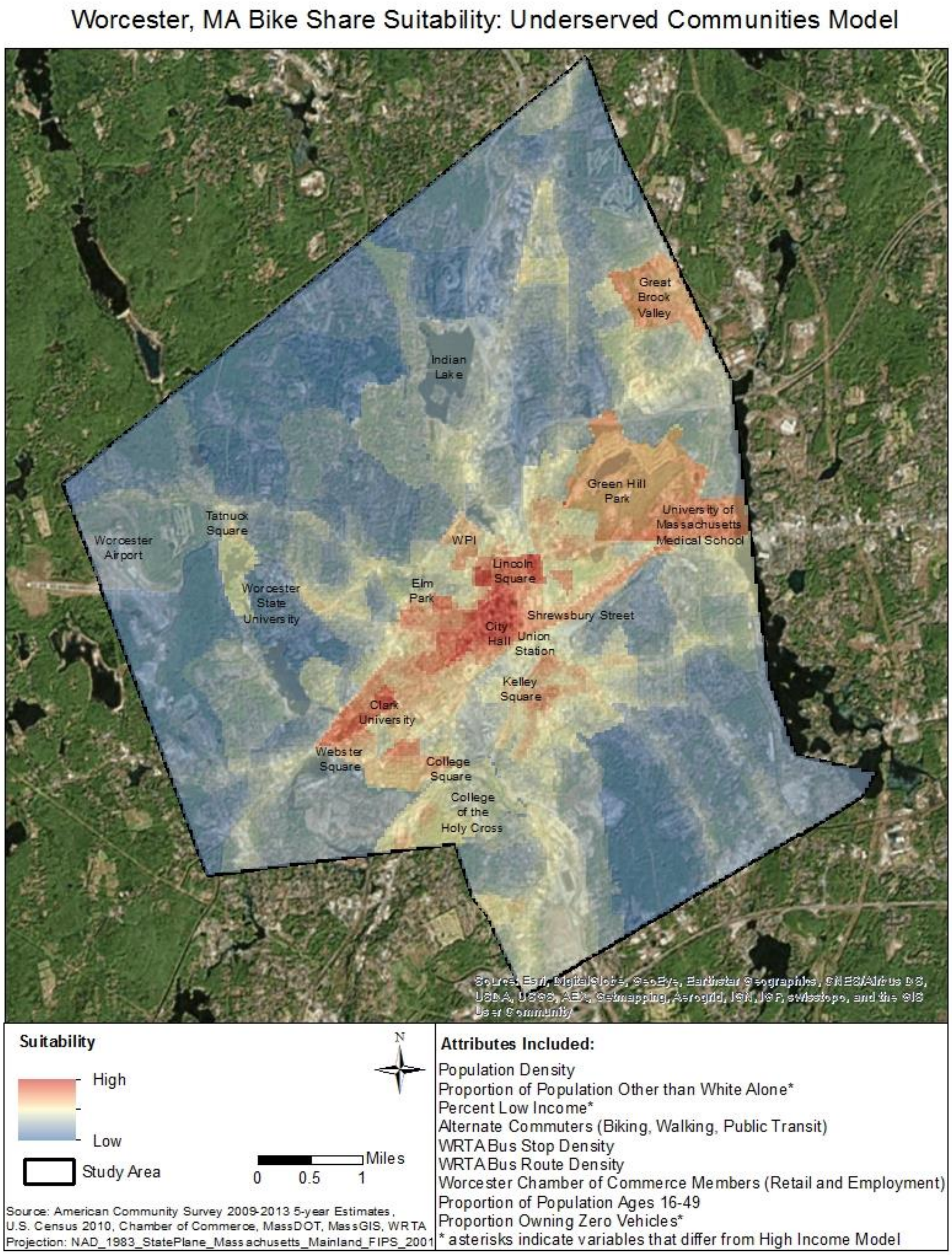

Figure 35. Underserved Communities Model Suitability Map

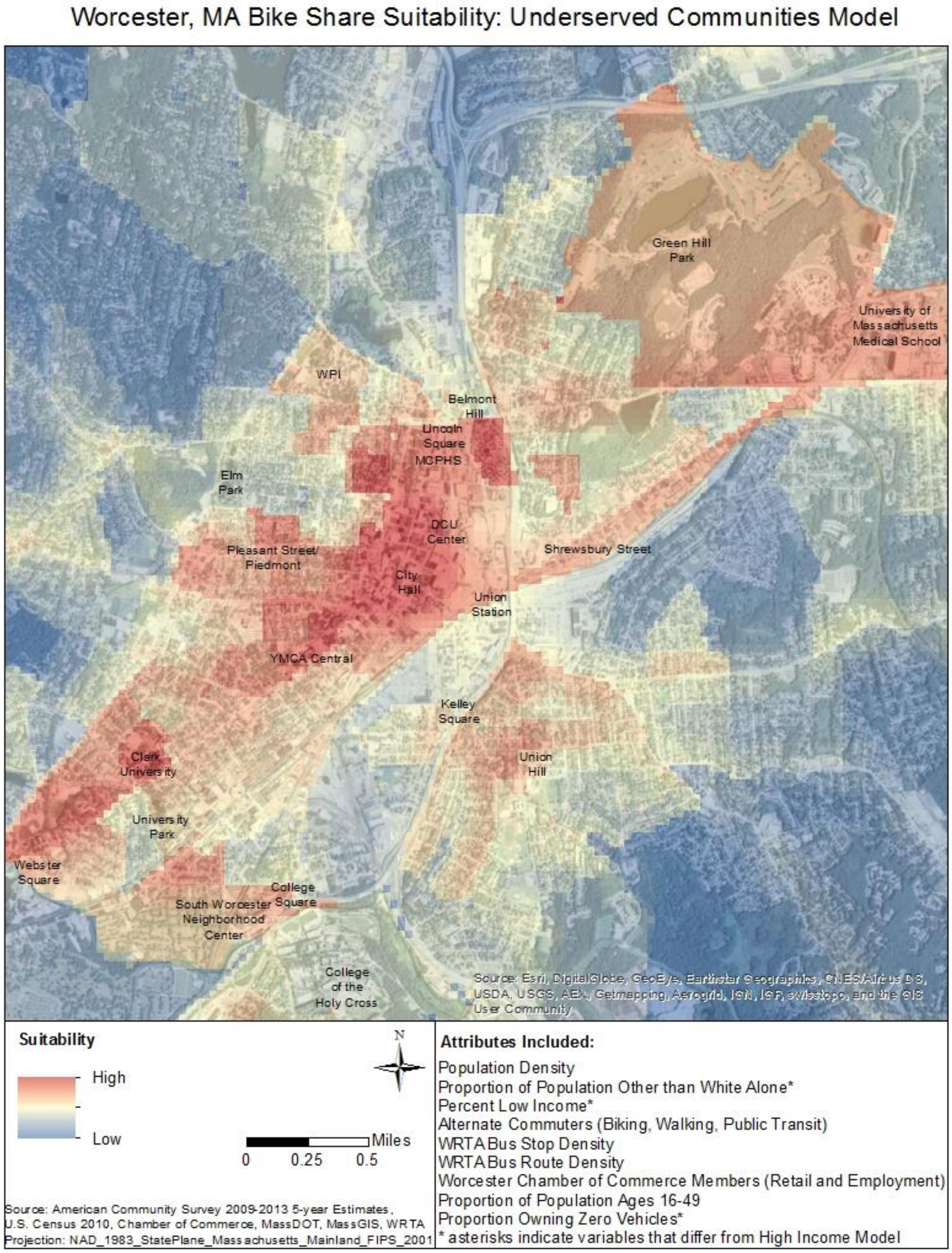

Figure 36. Underserved Communities Model Suitability Map (Up Close)

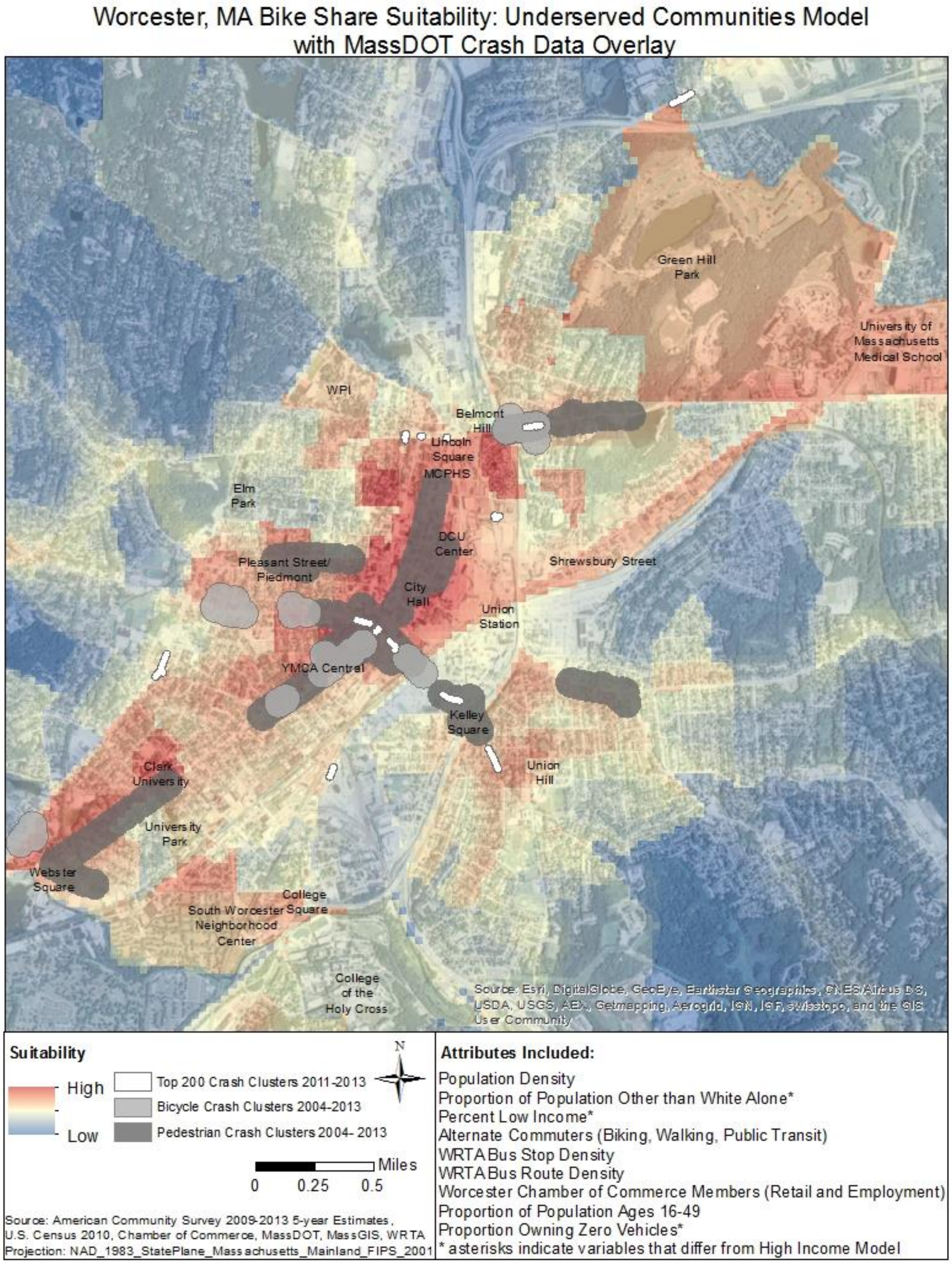

Figure 37. Underserved Communities Model with MassDOT Crash Data Overlay

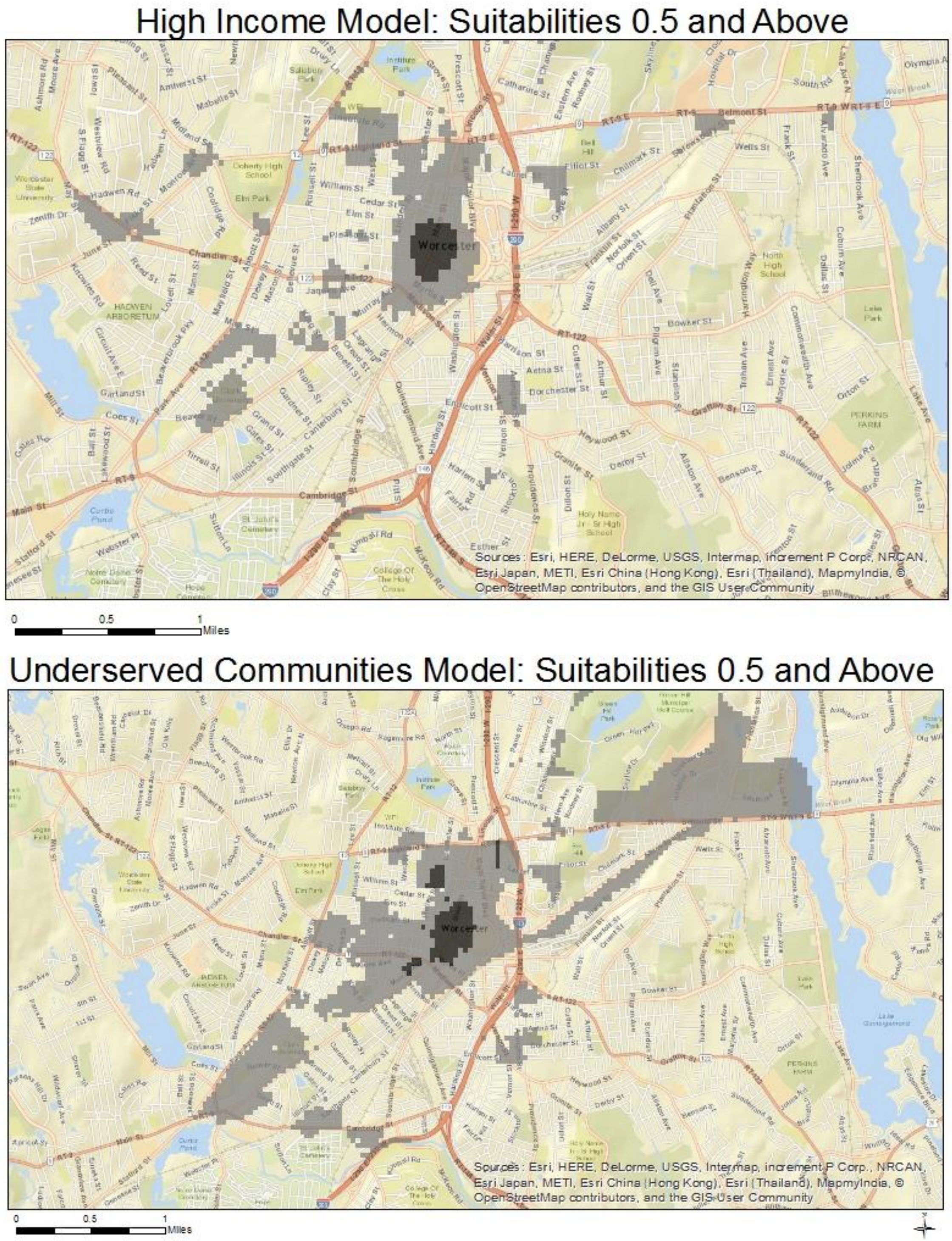

Figure 38. Suitabilities 0.5 and Above

Combined Extent of High Income Model and Underserved Communities Model
Highest Suitability Areas (> 0.5)

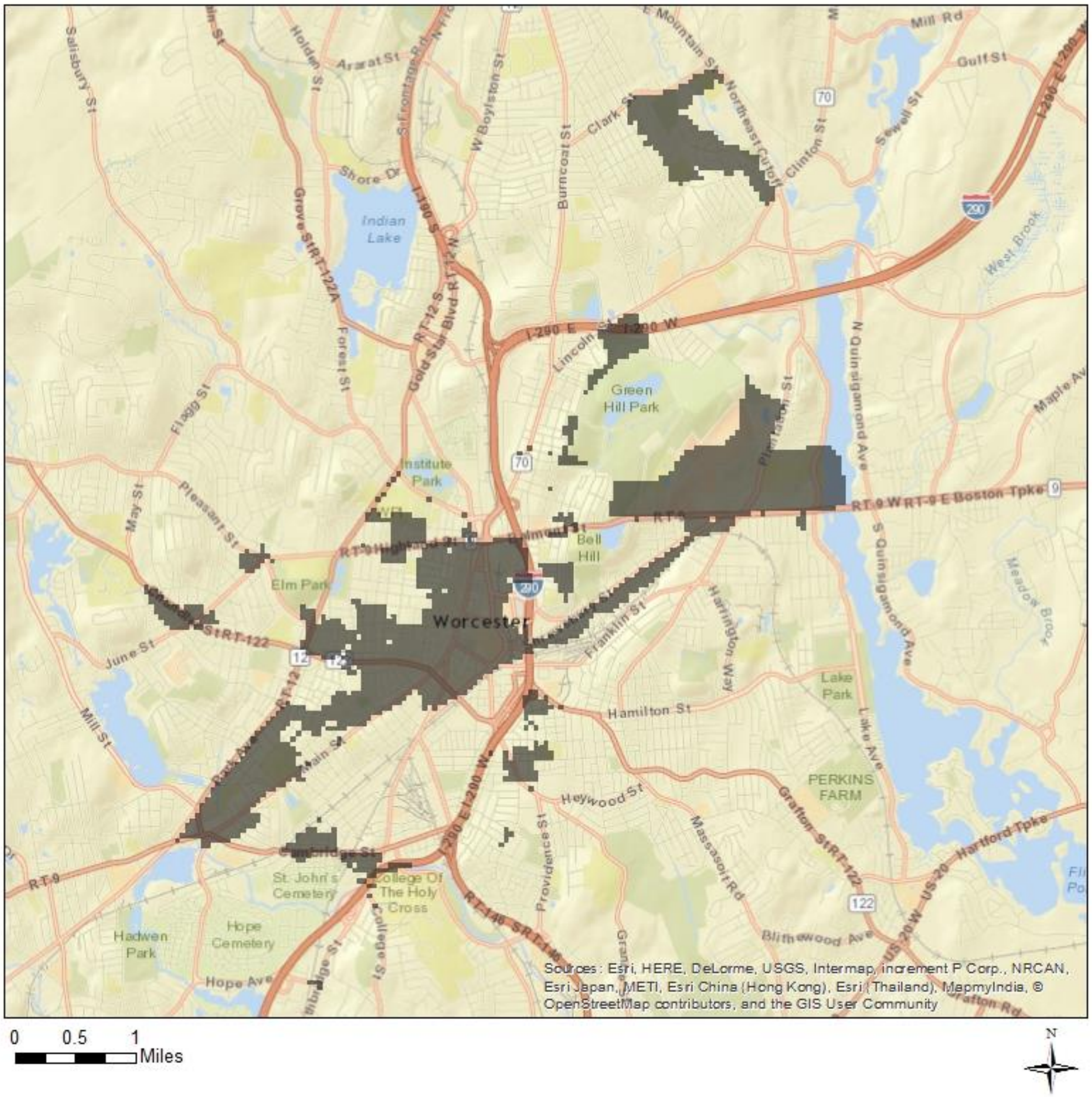

Figure 39. Combined Extent of High Income and Underserved Communities Models-Suitabilties > 0.5