An Equity Analysis of Bicycle Infrastructure Around Light Rail Stations in Seattle, WA

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Abstract

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Urban Design and Planning

This thesis explores whether there is any relationship between an area's equity variables – the proportion of a Census Block Group population that is a racial minority, below the federal poverty line, under the age of 18, and 65 and older – and the density of bicycle infrastructure in these neighborhoods, especially in the areas surrounding light rail stations. The lack of bicycle facilities is often a barrier to someone to begin using a bicycle for transportation purposes. Riding a bicycle to access high capacity transit can reduce commute times, make a commute more enjoyable, and incorporate healthy activity into one's every day routine. The 2-mile radius around light rail stations is considered the bikeshed, or the distance within which most people are able and willing to ride a bicycle. Two sets of analysis were conducted: the first using all bicycle facilities in Seattle and the second using only "low-stress" bicycle facilities, and comparing them with equity variables. Low-stress is defined as Class 1 (off street trails), Class 2 (protected bicycle lanes), and Class 4 facilities (low-speed, low-volume streets). Class 3 (shared lane bicycle facilities) make up about half of the city's bicycle infrastructure, but are the least safe of the four types. The results of both sets of analysis show that there are many service gaps in Southeast Seattle's Rainier Valley, where many diverse and historically disadvantaged people live, and

where the Link light rail currently operates. There are also service gaps in more homogeneous areas. Statistically, bicycle infrastructure is allocated equally across the City of Seattle. In order to pursue a future of equity for all Seattleites, we must follow a Rawlsian approach to distributive justice and first improve the communities that need the most help. There are opportunities for bicycle infrastructure network improvements around light rail stations both in areas with high concentrations of historically marginalized populations as well as those without. Resources should be focused on the communities where historically marginalized populations live in order to improve equity outcomes in the City of Seattle and King County.

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This research is dedicated to those who have lost their lives because of inadequate or nonexistent bicycle infrastructure. May it contribute to the prevention of further hardship.

Table of Contents

Acknowledgments 4
Table of Contents 5
List of Figures 7
List of Tables 8
List of Abbreviations 9
Chapter 1: Introduction 10
  Seattle Context: Race, Income, and Commute Mode 12
  Comparison to National Trends 14
  Seattle Race and Income Statistics 15
  Cycle-Transit 26
Chapter 2: Literature Review 29
  Synergy of Cycle-Transit (CT) 32
  Cycle-Transit User Profile 34
  Biking and Marginalized Communities 36
  Attitudes Toward Commute Mode 37
Bikeshed 38
  Definition 38
Bicycle infrastructure 41
  If You Build it, Will They Come? 42
  The Role of Seattle Bicycle Master Plan in Siting Bicycle Infrastructure 47
  Seattle Bicycle Advisory Board 48
Equity 49
  Introduction 49
  King County, 'The Determinants of Equity' 49
Chapter 3: Methodology 53
  GIS Methodology 53
Chapter 4: Findings 60
  Introduction of the Data 60
  Equity Analysis of All Bicycle Infrastructure 73
    Bicycle Infrastructure Density and Race and Poverty 90

Equity Analysis of Low-Stress Bicycle Infrastructure 93
Comparisons & Differences of Two Analyses 107
Chapter 5: Conclusion 109
References 113

List of Figures

Figure 1. Equality versus equity. 11
Figure 2. Map of Seattle's neighborhoods. 16
Figure 3. Map of Seattle's non-Hispanic White population. 21
Figure 4. Map of Seattle's Black/African American population. 22
Figure 5. Map of Seattle's Asian population. 23
Figure 6. Map of Seattle's Hispanic/Latino population. 24
Figure 7. Graph of average one-way commute miles by commute mode for downtown Seattle employees. 41
Figure 8. Mean travel time to work and mode share in Boulder, CO. 44
Figure 9. Seattle's Center City 45
Figure 10. Mode split among Center City employees in 2014. 46
Figure 11. Change in commute modes between 2012 and 2014. 47
Figure 12. Example of Class 1 bicycle facility, a multi-use trail. 55
Figure 13. Example of Class 2 bicycle facility, a two-way protected bicycle lane. 55
Figure 14. Alternative example of Class 2 bicycle facility, a one-way buffered bicycle lane. 55
Figure 15. Alternative example of Class 2 bicycle facility, conventional bicycle lane. 56
Figure 16 Example of Class 3 bicycle facility, 'sharrow'. 56
Figure 17. Example of Class 4 bicycle facility, in Seattle called "Neighborhood Greenway". 56
Figure 18. Gap analysis procedure for bicycle infrastructure density by CBG and minority concentration. 58
Figure 19. Map of Seattle's Census Block Groups and Link light rail line. 61
Figure 20. Map of Link light rail line with current and planned stations. 63
Figure 21. Map of all bicycle facilities in Seattle, Link light rail corridor, current and future light rail stations. 65
Figure 22. Map of bicycle infrastructure distribution by CBG in Seattle. 66
Figure 23. Map of Seattle's bicycle infrastructure density by CBG and bicycle infrastructure network. 68
Figure 24. Map of bicycle infrastructure density in bikesheds around light rail stations. 70
Figure 25. Map of private vehicles per person by Census Block Groups. 72
Figure 26. Bicycle infrastructure service gaps in CBGs and higher concentration of people of color. 74
Figure 27. Map of poverty concentration in Seattle. 76
Figure 28. Bicycle infrastructure service gaps and high poverty CBGs. 78
Figure 29. Map of bicycle infrastructure service gaps in CBG's and a disproportionate concentration of youth. 80
Figure 30. Map of bicycle infrastructure service gaps in CBGs with a disproportionate concentration of senior citizens. 82
Figure 31 Map of geometric mean and service gaps. 84
Figure 32. Map of geometric mean values in bikesheds around light rail stations. 86
Figure 33. Map of Link light rail station area service gaps. 88
Figure 34. Plot of geometric mean and bicycle infrastructure density among the 480 CBGs in Seattle. 89
Figure 35. Map of service gap CBGs and the geometric mean of high racial minority and high poverty in light rail station bikesheds. 91

Figure 36. Scatter plot of the relationship between all classes of bicycle infrastructure and the geometric mean of race and poverty. 92
Figure 37. Map of low-stress bicycle facilities in Seattle. 94
Figure 38. Map of low stress bicycle infrastructure, defined as Class 1, 2, and 4 bicycle facilities. 96
Figure 39. Map of high minority and low-stress bicycle facility service gaps. 98
Figure 40. Map of CBGs which have high poverty and low-stress bicycle infrastructure service gaps. 100
Figure 41. Low-stress bicycle infrastructure service gaps and high concentration of youth population. 102
Figure 42. Low-stress bicycle infrastructure service gaps for high concentration of senior population. 104
Figure 43. Map of geometric mean and low-stress bicycle infrastructure service gaps. 106
Figure 44. Scatter plot showing the relationship between geometric mean and low-stress bicycle infrastructure. 107

List of Tables

Table 1. Summary of statistics on bicycle infrastructure in CBGs with above average non-White population. 75
Table 2. Summary of high poverty CBGs and bicycle infrastructure density compared to the rest of the city. 79

List of Abbreviations

ACS: American Community Survey. Annual survey conducted by the U.S. Census Bureau.

BMP: Bicycle Master Plan

CBG: Census Block Group. CBGs from the 2010 Census were used for this thesis.

CT: Cycle-transit

CTR: Commute Trip Reduction

CTU: Cycle-transit user

DSTT: Downtown Seattle Transit Tunnel

LR: Light Rail

SAC: Stakeholder Advisory Committee

SBAB: Seattle Bicycle Advisory Board

SDOT: Seattle Department of Transportation

SOV: Single-Occupant Vehicle

TDM: Travel Demand Management

VMT: Vehicle Miles Traveled

WSDOT: Washington State Department of Transportation

Chapter 1: Introduction

One of the roles of urban planners is to act as intermediaries between government and the public, working to fairly allocate limited public resources to help improve the communities in which we work. However, there are several different ways to define “fairness” or “equity”. In this thesis, I shall use John Rawls’ theory of justice as fairness. Rawls’ theory is based on the idea that all citizens are fundamentally created equal, and so should receive equal treatment and equal allocation of goods and harms. (Wenar, 2017) However, we know that we live in a world in which people are born into arbitrary groups including socioeconomic classes, certain talents, races or genders. These factors often result in inequalities among people, but because they are arbitrary groups to which one’s belonging cannot be influenced, these increased benefits are unearned. Rawls goes on to develop a thesis of distributive justice, which states that benefits should be allocated to the groups with the greatest disadvantage in society. The goal of this is to create a more equitable society of people who all benefit from cooperatively produced goods, in this case, publicly funded transportation infrastructure. (Wenar, 2017) Figure 1 shows an illustration of the difference between equity and equality. Under a system of equal provision, or equality, those who start out with an advantage are only elevated, while those who start out disadvantaged are helped somewhat, but not brought up to a functional level. In the equitable scenario, those who start out with the most advantage might not be helped at all, while those who start out in a disadvantaged position receive the most assistance, and are elevated to a position of equal status with their peers.

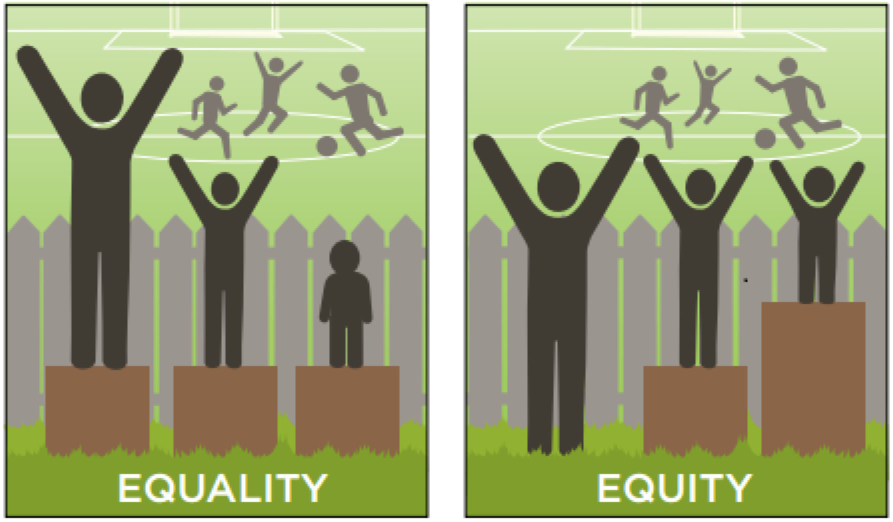


Figure 1. Equality versus equity.
Source: King County http://kingcounty.gov/elected/executive/constantine/priorities/building-equity.aspx

The purpose of this thesis is to conduct an equity analysis on Seattle's bicycle infrastructure network and identify geographic areas around light rail stations where the bicycle network can be built out to improve access to high capacity transit in Seattle for low-income, minority, youth, and senior citizen populations. The research question is: In which areas could Seattle's bicycle infrastructure network be more equitable, especially surrounding light rail transit stations? How does Seattle's Bicycle Master Plan align with King County's Equity and Social Justice Master Plan?

Seattle City Council passed Resolution 31164 "affirming the City's race and social justice work and directing City Departments to use available tools to assist in the elimination of racial and social disparities across key indicators of success, including health, education, criminal justice, the environment, employment and the economy; and to promote equity within the City workplace and in the delivery of City services." (City of Seattle, 2009) This language is echoed in the city's comprehensive plan, entitled *Seattle 2035*, which includes an objective to, "Close racial and social disparities with capital and program investments." (City of Seattle, 2009) Capital and program investments include bicycle facilities which provide access to transit.

Access to transit and the ease of biking, or bikeability, in a person's neighborhood are important for equity. They reduce carbon emissions and improve low-income and minority populations' access to jobs, education, and services by alternative transportation modes.

Seattle Context: Race, Income, and Commute Mode

There is a great deal of racial and income disparity between White people and non-Whites. Whites tend to commute by automobile more and their incomes tend to be higher. According to the 2015 ACS, 31.5% of Black or African American people over the age of 16 in Seattle used public transportation to get to work (7.4% walked, 1.5% 'other'). This compares to only 19.3% of Whites who used public transportation to get to work (10.4% walked, 6.3% 'other'). 22.8% of Asians in Seattle relied on public transportation to get to work; 15% walk, and 4% 'other'. (US Census ACS, 2015) Among Hispanic and Latino people, 25.5% used public transportation to get to work, 3.2% walked, and 2.7% reported 'other'. Minorities and low income people are more likely to be dependent upon transit.

In the city of Seattle, the overall median earnings per capita over the past 12 months was $51,028. Those who drive alone to work earn a median of $54,984; those who use transit earn the least of any mode, a median of $41,882; those who walk earn slightly more, a median of $42,450, and those who responded 'other' earned the most of any mode at $62,458. (US Census ACS, 2015). Accounting for commuters who ride bicycles is very difficult because the US Census and ACS group taxicab, motorcycle, bicycle and other into one group.

Minority and low income populations are often disproportionately subject to air pollution and other externalities resulting from transportation. (Sinha, 2015) Therefore improving zero-emissions transportation options in neighborhoods with a higher concentration of vulnerable populations is particularly important to reduce these negative externalities and improve environmental justice outcomes.

Improving access to transit through bicycle infrastructure provision is also important because transportation makes up the majority of the Seattle metropolitan area's greenhouse gas (GHG) emissions. In 2014 road transportation made up 64% of Seattle's greenhouse gas emissions; 45% from passenger vehicles and 19% from freight transport. (Erickson and Tempest, 2014) The intention of promoting the use of alternative transportation modes is to reduce vehicle miles traveled by automobiles and thus greenhouse gas emissions from fossil-fuel burning vehicles. Aside from the consumption of fossil fuels and the concern about greenhouse gas-induced climate change, Seattle's population is rapidly increasing and congestion is becoming more of a problem to residents throughout the city and county. GHG emissions in the city have increased 9% since 1990, mostly due to the rising population. Vehicle emissions per capita have declined due in part to increased fuel efficiency and fewer miles driven. (Erickson and Tempest, 2014) The Puget Sound region is investing in high capacity light rail, expanding bus route service, and investing millions of dollars on restructuring mobility throughout downtown and around the entire city. (City of Seattle, 2015; King County 2016b; Sound Transit, 2014) It is important that passengers of all incomes and races are able to access these transit routes and get to where they need to go.

Access to transit, and thus access to jobs, is strongly correlated with unemployment. (Kaufman et al., 2015; Chetty and Hendren, 2016) If incremental changes in access to transit can improve unemployment rates, reduce poverty levels, and improve the quality of life and economic opportunity for marginalized communities, then planners should do all they can to facilitate convenient, safe, and inexpensive access to transit and jobs.

Comparison to National Trends

In 2001, about 88% of American residents over the age of 15 were reported as drivers. The average number of personal vehicles, 1.9, outnumbers the average number of drivers per household, which is only 1.8. Most American households have a private vehicle; only about 8% of households nationwide do not own a personal vehicle. The distribution of vehicles across households is not uniform or equitable: those with annual household incomes of less than $25,000 are almost nine times as likely not to own a vehicle as households with incomes above $25,000. Relatedly, people who own their homes are six times more likely to also own a car than people living in rented homes. Condo and apartment dwellers are almost five times as likely to be non-vehicle households as their counterparts in single family or non-apartment residences. Household size influences vehicle ownership rates also: 19% of single-person households do not own vehicles compared to only 4% of multi-person households. (Bureau of Transportation Statistics, 2001)

According to the 2015 American Community Survey, there were an estimated 316,515,021 people living in the U.S and 133,351,840 total housing units in the country. (US Census ACS, 2015) 73.6% of people are White; 12.6% of people are Black or African American;

5.1% are Asian; 0.8% of people are American Indian and Alaska Native; 3.0% of people are two or more races. 17.1% of the population identifies as Hispanic or Latino (of any race).

The 2015 ACS results show that 15.5% of the American population fell below the federal poverty level at some time in the preceding 12 months. 10.8% of Whites (alone, not Hispanic or Latino) experienced poverty in the previous year. Comparatively, 27.0% of Blacks fell below the poverty line, as did 12.6% of Asians; 28.3% of American Indian or Alaska Natives; 21.0% of Native Hawaiian and other Pacific Islanders alone; 26.5% of people of some other race; and 19.9% of multiracial people. 24.3% of people of Hispanic or Latino origin of any race fell below the poverty line in the preceding 12 months. (US Census ACS, 2015)

21.7% of people under 18 years of age experienced poverty compared to only 14.5% of adults between the ages of 18 and 64 years; only 9.4% of adults older than 65 experienced poverty. (US Census ACS, 2015)

Seattle Race and Income Statistics

The following map shows the neighborhoods of Seattle. Broad terms are used where applicable and are labeled in all capital letters. Where there is no broader term, the localized neighborhood title is used for the label. The neighborhood boundaries do not line up exactly with the Census Block Groups, so neighborhood titles are used to discuss approximate areas where trends develop in the findings.

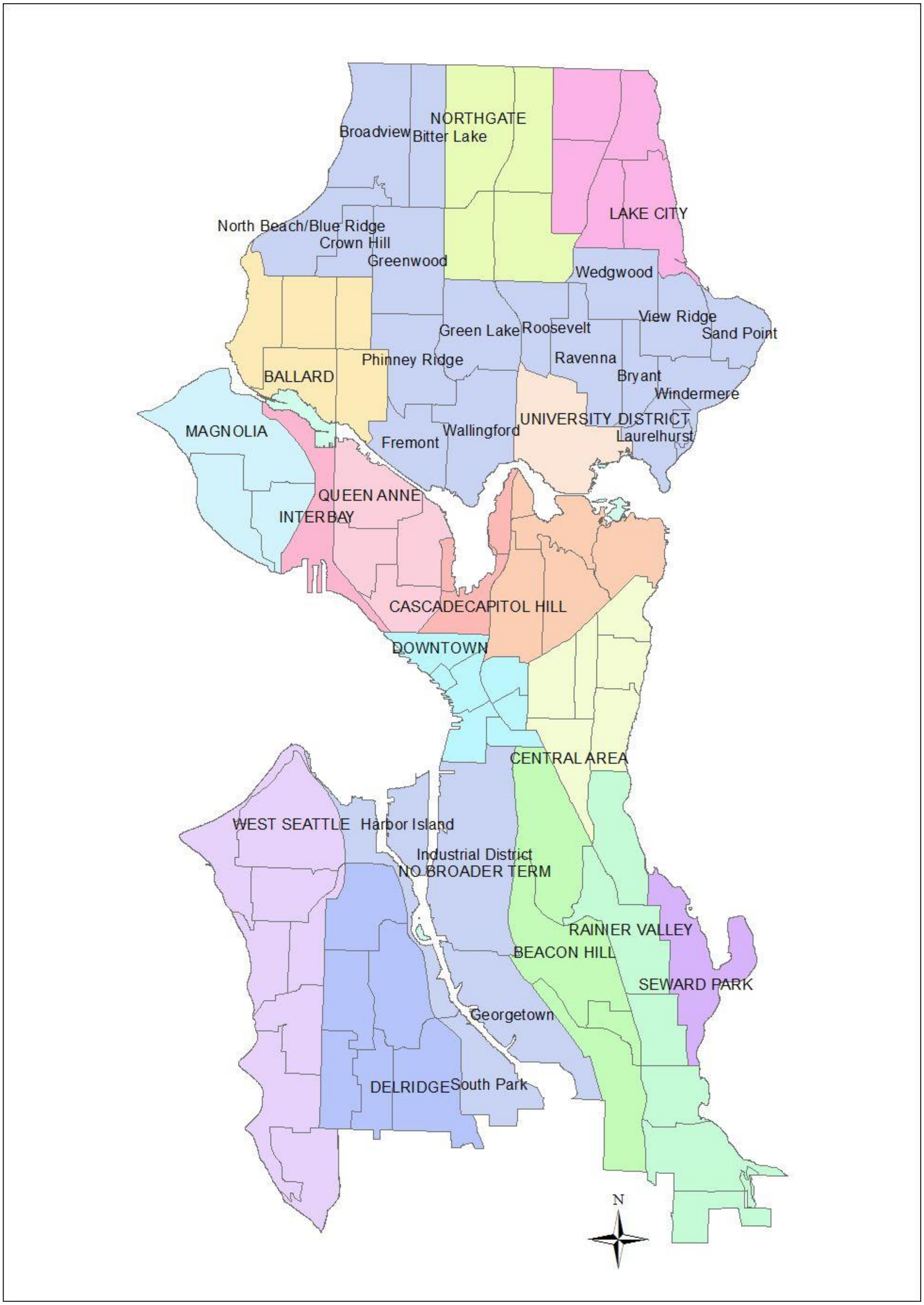


Figure 2. Map of Seattle's neighborhoods.
Source: Author.

Comparing the national statistics above to Seattle statistics provides context for this thesis. According to the 2015 ACS 5-year estimate, Seattle's total population is 653,017. Of that total, 454,000 people are White alone, making up 69.5% of the city's population; 47,202 individuals are Black or African American alone, making up 7.2% of the city's population; 92,776 individuals are Asian alone, making up 14.2% of the city's population; 39,922 individuals are two or more races, making up 6.1% of the city's population. There were 42,490 Hispanic or Latino respondents of any race which makes up 6.5% of the city's population. 6.1% of Seattleites are multiracial. For the purposes of this research, people who identified as multiracial are counted in the non-White, or racial minority, segment of the population. The largest margin of error in racial demographics is among Whites, where the percent of the population is determined to be 69.5% +/- 0.5%.

Of the 45,750 Black or African American individuals, 15,380, or 33.6%, fell below the poverty line at some point in the preceding year. Contrastingly, of the 420,047 non-Hispanic White individuals in Seattle, only 37,800 or 9.0% fell into poverty in the previous year. The poverty occurrence among other racial groups was between these two extremes except for the American Indian and Alaska Native alone group; among a total population of 4,258 individuals 1,440 or 33.8% experienced poverty in the past year. Among the estimated 89,510 Asians in Seattle, 19.6%, or 17,530 individuals fell below the poverty line in the previous year.

The above statistics show the disparity among different racial groups, especially the disproportionate level of poverty between Blacks and Whites. This is one of the reasons this thesis emphasizes the importance of infrastructure investment in neighborhoods with a high concentration of people of color. Moreover, there are spatial segregation patterns in Seattle, which are most pronounced for Black and African American populations. Other racial groups, Whites, Asians, and Hispanics are more dispersed around the city. Massey and Denton discuss the history of redlining and systemic racial segregation in American cities in their book, *American Apartheid.* (Massey and Denton, 1993) The spatial segregation visible today stems from discriminatory real estate practices used in the 1950's and 60's, including deterrents to homeownership among Blacks, steering to particular neighborhoods, exclusionary zoning, racially restrictive covenants, racist lending practices by banks for mortgages and home improvement loans, and regulations which prohibited homeowners' insurance. These practices directly targeted Blacks, but also negatively impacted Asians and Jews. (Massey and Denton, 1993) Up until the 1970's in Seattle, Blacks were limited to neighborhoods south of downtown, as well as Capitol Hill and the Central District. These patterns are still somewhat visible today, but waves of gentrification have recently displaced many longtime residents of color in the latter two neighborhoods. Georgetown, Othello, and Rainier Beach are areas of the city where historic redlining has shaped the racial composition of the current residents. (Central Seattle Community Council Federation, 1975) This thesis does not attempt to study bicycle infrastructure in the neighborhoods of American Indian and Alaska Native people, the other high-poverty racial group, because the clustering tendency of this group does not concentrate in a particular area of the city, and the population of this group is considerably smaller than Black and African Americans.

Please refer to the Figures 3 through 6 for a geographic representation of concentrations of racial groups around the city. All map data is displayed using natural breaks. The first map shows where White people live; being the majority race in the city, Whites make up over 73% of the population in many areas. The waterfront Census Block Groups in the city are almost all in the highest quartile of White residents. The exception exists in Southeast Seattle, near Seward Park.

The second map shows concentrations of Black or African American residents. There is a close inverse relationship between the first and second maps; where the proportion of Whites is low, the proportion of Blacks is high. Consistent with the above discussion on redlining and segregation patterns in Seattle, the highest proportion of Blacks is in the Rainier Valley. In Southeast Seattle, there is a cluster of CBGs with the highest quartile proportion of Blacks in the city, which is 30-52% of the total population. The four southernmost light rail stations in the city are in CBGs with at least 25% percentile Black population. In Queen Anne, Magnolia, Ballard, West Seattle, Northeast Seattle, and Wallingford there are very few Black people; less than 6% of the population is Black in these areas, indicating severe segregation. There is a smaller cluster of Blacks around the Delridge neighborhood, on the west side of the Duwamish River. The Duwamish River is highly polluted from decades of industrial activity on its banks, and a Superfund cleanup effort is currently underway. (Environmental Protection Agency, 2017) The clustering of people of color near pollution and industrial uses is a trend found in environmental justice research. (Mohai and Saha, 2006)

The settlement patterns of Asians also forms a distinct pattern. The highest concentration can be found around Chinatown-International District and Beacon Hill. There are also many continuous CBGs in Northgate, Delridge, Queen Anne, Capitol Hill, the University District, and South Lake Union neighborhoods with proportions of Asians in the 50^{th} percentile.

The highest concentrations of Latino and Hispanic people of any race are around Beacon Hill, South Park, and Delridge where 21-48% of the population are part of this group. There are CBGs where 11-24% of the population is Latino or Hispanic (the 50th-percentile), these are on the banks of the Duwamish River from SODO to the City's southern border. There are many more CBGs sprinkled throughout the City with higher proportions (25th-percentile and above) of this group, but there does not appear to be a strong trend. This map serves only for reference. Seattle's Latino and Hispanic population is not explicitly studied using spatial analysis; Latino and Hispanic people are grouped instead based on the race or races with which they have identified themselves in the most recent ACS.

Despite the stark disparities between White people and Black people discussed thus far, this thesis studies infrastructure differences between the concentrations of White and all non-White people in each Census Block Groups.

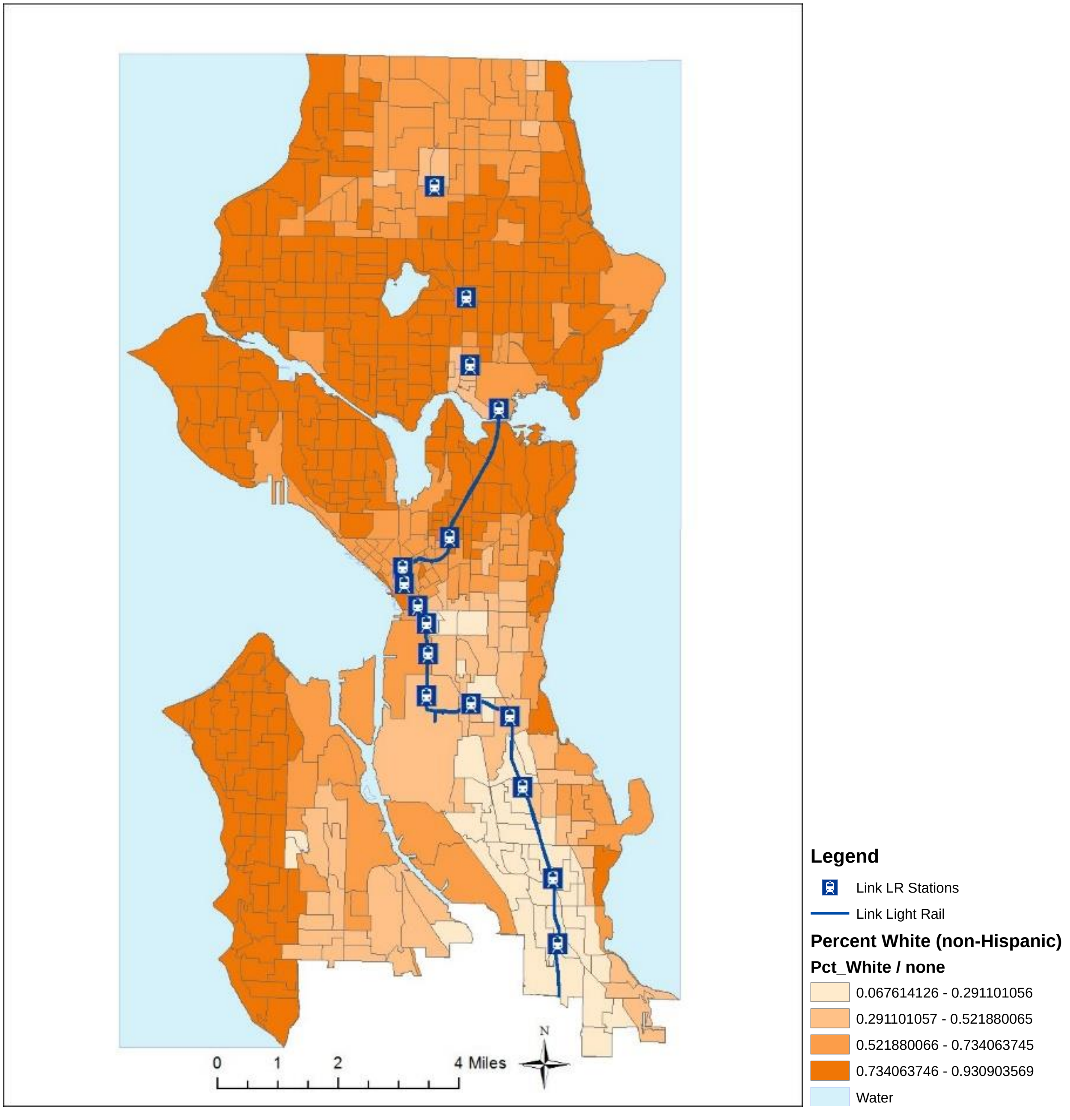


Figure 3. Map of Seattle's non-Hispanic White population.
Source: Author.

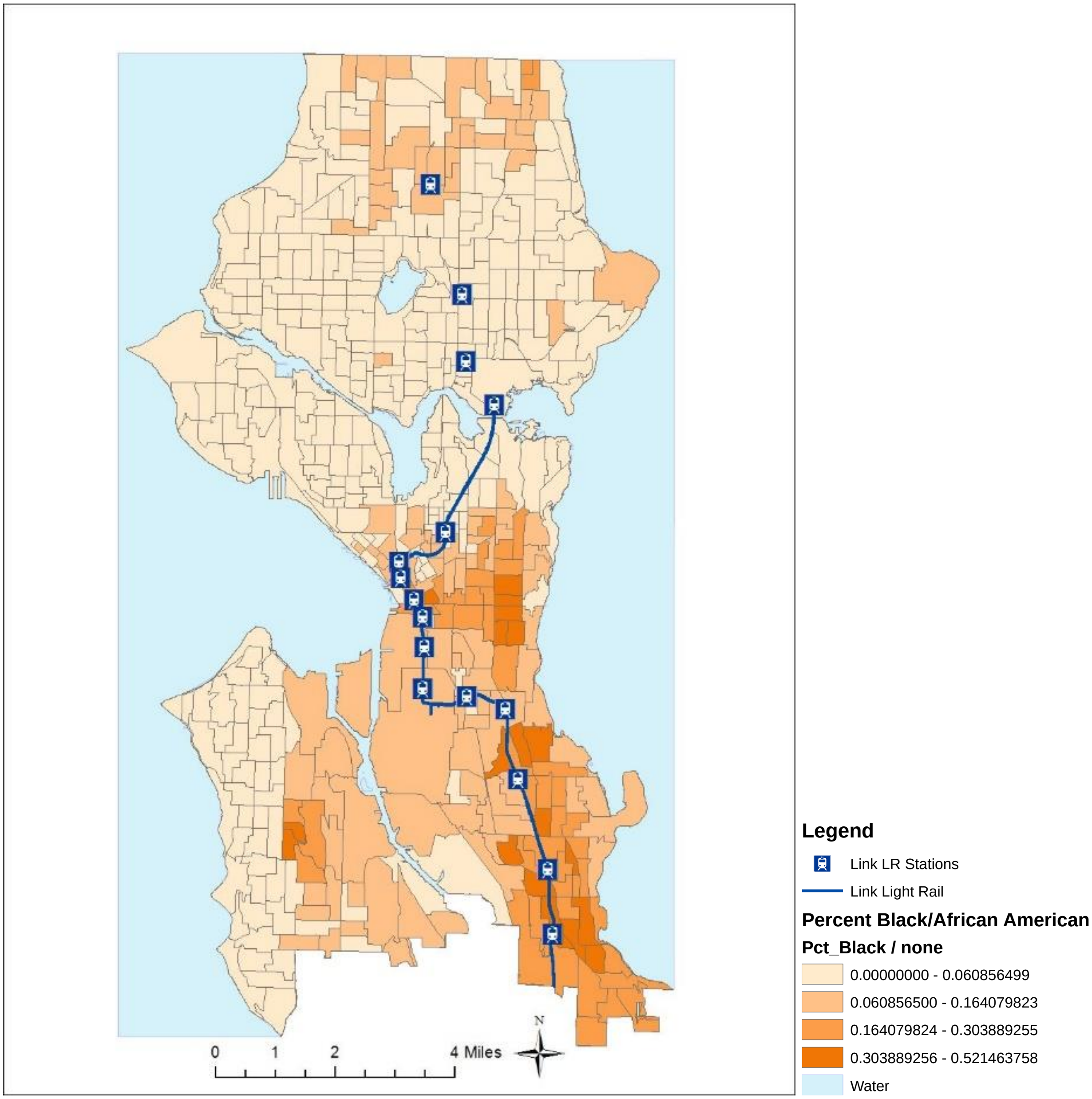


Figure 4. Map of Seattle's Black/African American population.
Source: Author.

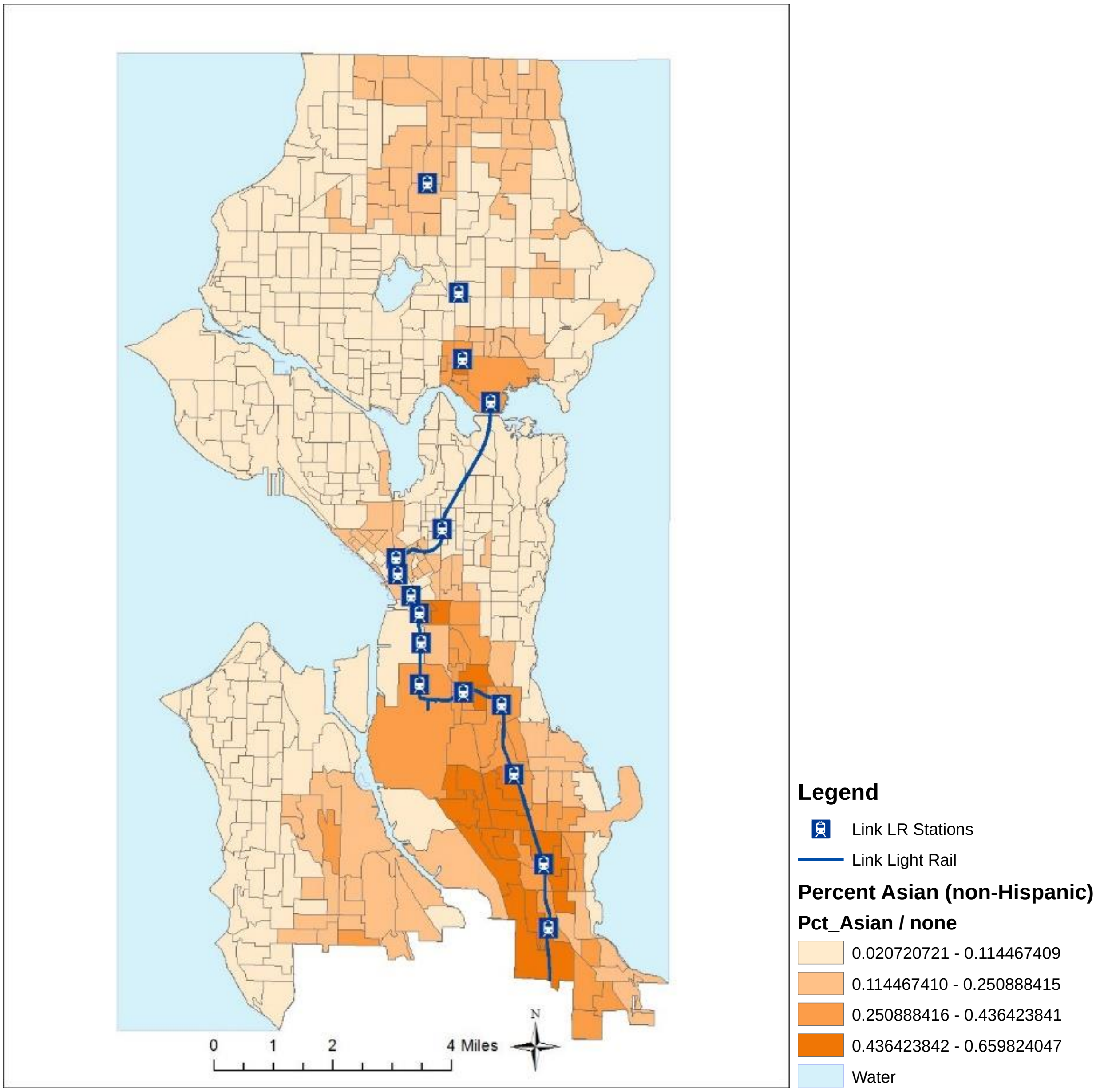


Figure 5. Map of Seattle's Asian population.
Source: Author.

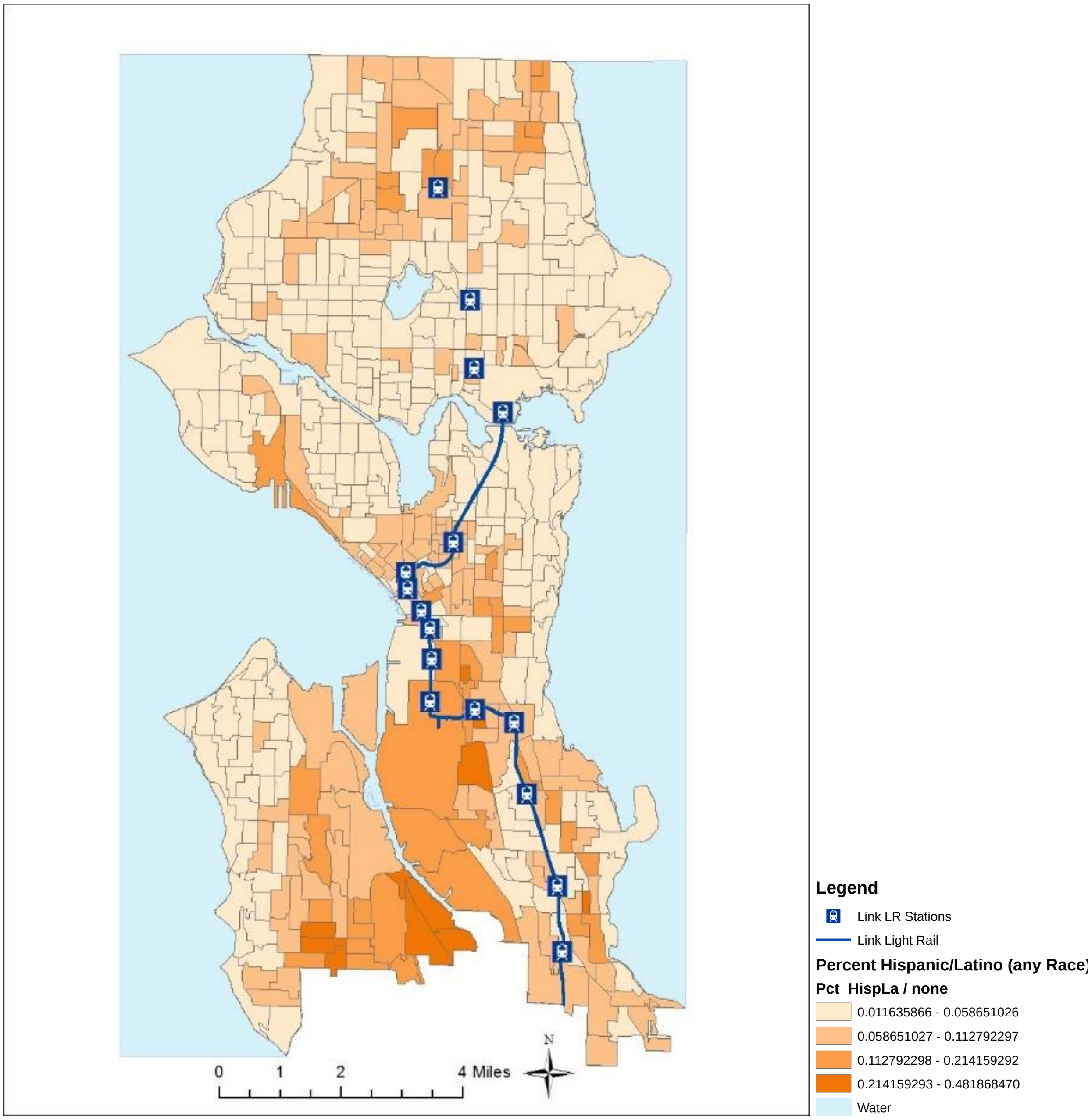


Figure 6. Map of Seattle's Hispanic/Latino population.
Source: Author.

More than one in four residents of Seattle are either youth or senior citizens. 100,548 individuals are under the age of 18, making up 15.4% of the city's population. 75,797 people are over 65 years of age, making up 11.6% of the city's population. (US Census ACS, 2015)

The ACS definition of poverty status is that a respondent "has fallen below the poverty line in the past twelve months". Poverty status was determined for 99,112 individuals under the age of 18. The ACS is unable to determine poverty status for people living in institutionalized settings such as college or university dormitories or military barracks. Poverty thresholds are determined annually based on the Consumer Price Index. Thresholds take into account the number of people in a household. The poverty line is a nationwide figure, it is not geographically sensitive to localized cost of living. (Bishaw and Glassman, 2016) According to the US Census, the poverty level for a single person in 2015 was $12,082. (US Census, 2015) The survey results showed that 13,985 youth did fall below the poverty line, making up 14.1% of the city's youth population. Poverty status was determined for 73,561 people over 65 years of age. 9,652 Seattle seniors fell below the poverty line, making up 13.1% of the city's senior citizen population. (US Census, 2015) The map below shows a spatial representation of poverty concentration in Seattle, displayed in thirds (low, medium, high). There are poor households across the city, and there are several areas where the census block groups with high poverty (over 24% of households having experienced poverty in the previous year) cluster. In the University District, where there are many full-time students attending the University of Washington, a cluster of high-poverty census block groups has formed. A similar phenomenon can be interpolated near Seattle Pacific University in North Interbay/Queen Anne. The First Hill/Central District neighborhoods east of Downtown show 20 contiguous CBGs with a high poverty incidence. There are seven contiguous CBGs with high poverty rates spreading east-west in the Delridge area. Northgate and Lake City are also clusters of high poverty concentrations. And in the Rainier Valley, there are 22 CBGs with high poverty, including the areas around the Beacon Hill, Columbia City, and Othello light rail stations. When comparing to the racial distribution maps above, these poverty clusters in Southeast Seattle largely coincide with CBGs that have high concentrations of Black and Asian people. Please refer to Figure 27 for a map of the spatial distribution of poverty in Seattle.

Cycle-Transit

There is a good deal of literature on the potential for bicycles and transit to be combined for a more optimal integrated transportation mode: cycle-transit. Cycle-transit has largely been unrealized in the United States for many reasons, not least of them being the country's underwhelming bicycle and transit uptake separately. According to the 2009 National Household Transportation Survey, only 1% of Americans ride a bicycle to get to work and only 4.6% ride transit (including city and suburban bus, subway, light rail, commuter rail, school bus, charter bus, airplane, and Amtrak) to get to work (Wang et. al, 2013). Seattle's numbers are considerably higher than the national averages, with 4% of the population riding a bicycle for commute purposes, and 21% utilizing transit. (US Census ACS, 2015) Unfortunately the ACS table which differentiates the commute mode category 'other' into bicycle as a distinct mode does not correspond to race or income data of respondents, so it's difficult to know with any certainty how many people of each race or poverty level are using a bicycle to commute.

Following the opening of Sound Transit's U-Link in March 2016, transit ridership in the region has drastically shifted to light rail. Unfortunately, it is not clear from what mode these riders shifted; the opening of U-Link coincided with a major bus route restructuring so some bus riders may have altered their commutes to use light rail instead. U-Link added stations in Capitol Hill and at the University of Washington's Husky football stadium. In September 2016, the Angle Lake station opened south of Sea-Tac airport, extending the light rail line farther to the south. The Capitol Hill station connects the city's densest residential neighborhood with the University of Washington, the state's third-largest employer. (Puget Sound Regional Council, 2013; Economic Development Council of Seattle & King County, 2015) The January year-over-year change in the number of passenger boardings on Link light rail from 2016 to 2017 was 93.8%, from 908,411 to 1,760,914. Weekday ridership increased 89.0% from January 2016 to January 2017 and. Saturday boardings increased 134.7% in the same period. (Sound Transit, 2017c) The entire Link light rail system's weekday ridership increased 89% in the January year-over-year, from 34,956 to 66,060 average weekday riders. Existing stations also saw a bump in ridership after U-Link opened, up to 86% at Pioneer Square and 89% at University Street station. (Sound Transit, 2017b)

Studies have shown that active transportation users enjoy their commutes the most of any mode, and even wish their commutes were longer. (Páez and Whalen, 2010) Transit riders, on the other hand, enjoy their commutes the least, and wish they were shorter. Unfortunately, the city in which this survey took place only has bus service, and not light rail. (City of Hamilton, 2017) It is thus difficult to compare the attitudes of light rail riders to those of active commuters. The combination of these two modes may reduce the unpleasant part of one's trip (the bus or train ride) and increase or include the more enjoyable part (the bicycle ride). In addition, bicycling is beneficial to public health; Americans have many health problems that could be mitigated or prevented entirely through regular exercise, as achievable by a shift to bicycle commuting. (Donaire-Gonzalez et al., 2015)

The second chapter of this thesis will elaborate on the aforementioned topics and summarize the existing literature on the subject matter. Chapter three will include the methodology; chapter four will include the analyses, results and discussion thereof. Chapter four is divided into four sections, the first introducing the datasets used in the equity analyses. The second section includes an analysis of all bicycle facilities (Class 1-4) in the city and uses the equity variables and geometric mean to identify any service gaps. The third section will narrow bicycle facilities to include only Class 1, 2, and 4, to investigate low-stress bicycle facilities, then use all equity variables and geometric mean to identify any service gaps. The final section will be a summary comparing the two sets of analysis. Chapter five will conclude the thesis, providing recommendations to prioritize the implementation of Seattle Bicycle Master Plan projects as viewed through an equity lens and an access-to-transit lens.

Unfortunately there has been little research conducted on the equitable allocation of bicycle infrastructure around light rail stations, and relatively little work done on the prevalence of bicycle and transit use together (much on the potential, but little on the reality). This thesis will attempt to bridge these gaps using case studies, local policies, Census and American Community Survey data, and narratives from comparable cities around the US and Canada.

Chapter 2: Literature Review

This chapter will first discuss the issues of racial tension and cultural awareness in the planning and policymaking process, then the concept and benefits of cycle-transit (CT) as a transportation mode; moving on to the characteristics of a typical person who uses cycle-transit, the topic of bicycling and marginalized communities, as well as users' attitudes toward their respective commute modes; followed by definitions for and a discussion of 'bikeshed' and bicycle infrastructure, and finally a discussion on how such infrastructure is sited in Seattle. The chapter concludes with information on mode share in the city and King County's approach to making the area more equitable.

In the ongoing effort toward a more sustainable society, planners and policymakers have for a long time skirted the issues of race and class in their processes. If these fields are to truly achieve the outcome of "sustainability", including social sustainability, then race and class discussions must become a regular part of the process until institutional racism is eliminated. As Amy Lubitow argues, the depoliticization of sustainability projects like bike lanes leads to the inability of environmental justice to gain traction in the discussion about the design of such projects. (Lubitow and Miller, 2013) However, planning is an inherently political activity. Whenever a finite amount of resources is allocated, there are winners and losers. Power structures become salient and louder voices often receive responses. Due to the nature of the typical public engagement process, diverse voices and opinions are frequently left out of the process. One example is taken from Portland, Oregon in 2011, and is used as a case study in Amy Lubitow's article "Contesting Sustainability: Bikes, Race, and Politics in Portlandia". The Portland Bureau of Transportation (PBOT) proposed a project for a new bike lane in a rapidly gentrifying area of the city, Northeast Portland. The historically black neighborhood had been requesting pedestrian improvements for many years, and was very upset when PBOT announced its bicycle infrastructure project on North Williams Ave in 2010, reportedly in response to newcomers' requests. At the first stakeholder advisory committee (SAC) meeting in 2011, there were disproportionately few people of color in attendance to represent the neighborhood, and tensions boiled over about the culturally sterile narrative provided by PBOT. This project started out as a seemingly simple bike lane project, but community members of color spoke out against the project and its design, suggesting that the type of sustainability it promotes is actually a form of injustice and is exclusionary of minority populations. This project evolved through thorough public participation, moving from an apolitical sustainability project intended to increase safety and access, to a hotly contested and racially insensitive tool of gentrification, ultimately to a community-supported and culturally sensitive design which met the needs of longtime residents of color and their newer bicyclist neighbors. The success in this case study lies in the community's willingness to engage with planners to mold the project into something which supported the historic and cultural narratives of the community and would meet the apolitical intentions (sustainability, safety, access) of the project. It shows that contestation is an opportunity for dialogue, and dialogue can vastly improve the outcome of a project. It also makes an example of culturally sensitive planning, and the need to listen to all stakeholders, not just the usual voices. Melody Hoffman's 2016 book, *Bike Lanes are White Lanes*, reiterates similar stories from across the country; requests from communities of color have long been ignored by planning departments but upon the gentrification of a neighborhood by upwardly mobile, young, oftentimes White people, the municipality responds by building bicycle lanes and other roadway improvements. Communities of color in Milwaukee, Portland, and Minneapolis shared such stories. (Hoffman, 2016)

Sanders and Cooper surveyed drivers, pedestrians, bicyclists, and transit users in the San Francisco Bay Area about roadway design. The results revealed that users of all modes would like the same roadway design improvements. All respondent groups had the same top five priorities: bicycle lanes, improved pedestrian crossings, slowing traffic and improving driver behavior, increasing street lighting, and increasing traffic signals and stop signs. (Sanders and Cooper, 2013) While this report may seemingly contribute to the depoliticization of roadway design, sustainability projects, and bicycle infrastructure, Liz Cornish of Baltimore's nonprofit Bikemore discusses in an interview with Citylab how to frame a discussion about bicycle infrastructure projects in a diverse community. Cornish begins by addressing the strong correlation between commute time and one's ability to get out of poverty. She goes on to say that when engaging with the community it is more effective to start with asking what the community's needs are; oftentimes they will respond with concerns about safety, desires to lower vehicle speeds, for mixed use retail within walking distance, and safe places for kids to bike and play. Eventually the conversation shifts to bike lanes as a means by which some or all of these desires may be achieved. Contrary to the Portland example used above, Cornish's examples from Baltimore highlight the disparity between bicycle infrastructure and minority and low-income populations. Bike infrastructure in that city is disproportionately built in whiter, more affluent neighborhoods, yet is desired by all. (Dudley, 2016)

Synergy of Cycle-Transit (CT)

The integration of bicycling and transit ridership (referred to as cycle-transit or CT) is a flexible, convenient, healthy, and low- or zero-carbon emitting mode of transportation. (Bachand-Marleau et al., 2011) Cycle-transit users (CTU's) are able to spend less time waiting for buses and more time riding their bicycle, and, as will be commented on later on, bicycle riders tend to enjoy their commute more than people using other modes. (Páez and Whalen, 2010) Cycle-transit integration is also beneficial for transit agencies as it increases the service area at the beginning and end of the bus or rail route, without any investment on behalf of the agency itself. It is still unclear if CTU's will directly reduce rates of single occupancy vehicle use, because CTU's are often drawn from transit use only, rather than from SOV's. (Mees, 2010) Researchers in Montreal led by Julie Bachand-Marleau administered a survey to learn more about potential CTU's, including their current mode or modes of transportation, needs, and priorities. Information gathered included demographic, travel behavior, and spatial questions to discover the nuances of factors which affect adoption of CT. Those most likely to become CTU's come from a group who are already using more than one mode of transit to reach their destination. (Bachand-Marleau et al., 2011)

There are four means by which CT can be implemented or improved: 1) allowing bicycles on transit vehicles, 2) increasing the number and quality of bicycle parking spaces at transit stops, 3) siting transit stations close to bicycle facilities (and vice versa), and 4) placing bicycle sharing stations near transit stations and other destinations. (Bachand-Marleau et al., 2011) To briefly summarize the survey results compiled by Bachand-Marleau, bikes-on-transit remains the highest demand of the respondent group, but the responses show that bicycle parking at stations would be used more regularly.

This thesis primarily explores the capacity of Seattle area transit, particularly Link light rail, to improve CT through the third strategy: by siting and improving connectivity of bicycle lanes, trails, and paths near stations. Previous Masters of Urban Planning student theses have researched transit agencies' policies regarding the first strategy, taking bicycles on transit vehicles (Koster, 2014) and the second strategy, bicycle parking at the University of Washington Husky Stadium Link light rail station (Scanlan, 2015). Seattle's bike share system, Pronto!, was terminated in March 2017, so researching ways to improve CT through bike share is not currently possible.

As is predictable, bicycling rates decrease during winter months (based on a survey of commuters in Montreal), and transit ridership subsequently increases. (Bachand-Marleau et al., 2011) This arguably means that bicycling and transit ridership are comparable substitutes for mobility options. Another MUP graduate wrote a thesis on the usage of Pronto! bicycle share with regard to weather patterns. She found that inclement weather has a significant effect on ridership, with poor weather conditions strongly correlated to low ridership numbers. (Ding, 2016)

Bachand-Marleau acknowledges two primary limitations of her study: that her method invokes the risk of sample bias and that it highlights the difficulty of analyzing a marginal transportation practice. The threat of sample bias is addressed by using multiple survey dissemination tools. The latter limitation is a shortcoming that can only be overcome as CT becomes more widespread.

Cycle-Transit User Profile

In a survey of Montreal commuters by Bachand-Marleau et al., many respondents expressed interest in the concept of CTU as a transportation mode. Of the respondents interested in CT trips, 40% said they would utilize it for regular trips (to work or school) and 60% said they would utilize it for irregular trips (shopping, socializing). High quality (safe from theft and covered from the elements) bicycle parking facilities would be most useful to regular commuters. The ability to bring bikes on transit vehicles would be most helpful for occasional CTU's. The ability to bring bikes on transit vehicles was prioritized by 45% of respondents. Parking at stations was identified by 34% of respondents as their priority. 13% of respondents stated that bicycle infrastructure network connectivity to transit was a top priority. These are the top three priorities derived from survey results; the fact that they are so disparate suggests that CT can be improved through multiple improvements. Unfortunately such a survey has not been conducted in the Seattle area.

Using data from the National Household Transportation Survey, Wang et al. notes that CTU's are more statistically significant in high-density communities (residential density above 10,000 people per square mile). (Wang et al., 2013) This may be conflated with more transit routes in high-density areas, rather than more bicycle trips to and from transit. In a study of CTU statistics in 2001 and 2009, Wang found that the gender imbalance increased by a statistically significant margin. In 2001, about 58% of CTU's were male. By 2009, nearly 90% of CTU's were male. Similarly, the average age of a CTU shifted significantly in this period from 41 years of age in 2001 to 36 years of age in 2009. In this study, the researchers found that the majority of CTU's were White. Only 40% of transit riders were White, but the majority of cycle-transit users were White. There was some growth in CTU utilization by Hispanic populations between the 2001 and 2009 datasets (0% share of CTU's to about 10% respectively); for all other racial groups, the share CTU utilization held steady or decreased slightly over the eight year period.

There was a significant increase in CT integration among the lowest income level studied, defined as households earning less than $25,000 per year. According to an article written by the Kinder Institute for Urban Research and published on Governing.com, 49% of people who cycle to work earn less than $25,000 per year (using 2014 ACS 1-year estimates). In 2001 this group making less than $25,000 made up less than 10% of CTU's and by 2009, they composed nearly 30% of those integrating bicycling and transit. (Wang et al., 2013) Similarly, there was a change in CTU's by education level. CT usage increased among the least educated population: in 2001 about 0.2% of those with less than a high school education were CTU's and by 2009 about 1.45% of this population was taking advantage of this combined mode. Several other factors were determined to be significant in Wang's study: housing tenure type, unit type, and community housing tenure composition showed change between 2001 and 2009. Renters' use of CTU grew substantially. Thus, communities with high populations of renters showed increases in CTU in 2009. Vehicle ownership was not shown to be an important determinant in CTU.

Biking and Marginalized Communities

Charles Brown, a professor at Rutgers University, recently conducted a survey to discover the barriers to bicycling for residents in Black and Hispanic communities in New Jersey. Fear of traffic collision was the number one barrier to bicycling, as it is in most surveys about barriers to bicycling. The second most prevalent response was fear of robbery or assault. This concern reflects the crime statistics: the majority of Blacks and Hispanics surveyed reside in the six “Major Urban” centers and the “Urban 15” municipalities in New Jersey (as classified by the New Jersey State Police). Between 2005 and 2014, these six major urban centers accounted for 39% of all violent crime in the state. (Brown, 2016) Brown goes on to state that traffic engineers should use crime data in addition to collision data when making design decisions. Crash statistics only make up part of the total “safety” element of mobility; it’s perceptually more difficult to rob or assault someone on a bicycle compared to someone on foot. He concludes by saying that decisions about active transportation infrastructure must be made with consideration of the social context and reality of the community in which they are proposed to be built. Working with James Sinclair, Brown has also conducted focus groups to explore racial profiling by police as a potential barrier to bicycling for people of color. (Cox and Brown, 2017) In this context again Brown suggests that “transportation planners and bicycle advocates must work to empower historically marginalized voices” and hold a public outreach program which is accessible to all members of the community. (Cox, 2017)

According to Ewing et al., the prevalence of non-motorized transportation is correlated with better health outcomes. Non-motorized transportation is defined as walking or bicycling for utility rather than as an activity in and of itself. Whether there are destinations within walking and bicycling distance is largely dependent upon land use and urban form. (Ewing et al., 2003)

In his article on bike-and-ride implementation at San Francisco's Bay Area Regional Transit (BART) stations, Robert Cervero makes the claim that "investing in bike-and-ride facilities promotes social justice since many transit users have no or limited car access". (Cervero et al., 2013)

Attitudes Toward Commute Mode

A study of university students in Hamilton, Ontario showed that people who ride transit would prefer their commutes to take less time, and those who utilize active transportation in their commute would prefer their commute time to be longer. Bicycle commuters would like their trips to last an additional 6.7 minutes each way. (Páez and Whalen, 2010) Transit users' responses are in part informed by the respondents' attitudes toward their commutes and whether they enjoy their commute, value the time as productive, or enjoy the social aspect of commuting. Respondents who do not enjoy traveling with others would like their transit trips to be 7 minutes shorter; those who do enjoy traveling with others would still like their trips to be shorter, but by only 4.1 minutes. (Páez and Whalen, 2010) Unfortunately, the survey does not take into account the quality of bicycle routes or facilities available, nor does it survey light rail riders. The city of Hamilton only had bus transit at the time of this survey. (City of Hamilton, 2017) This study calls into question the inherent utility and disutility associated with traveling; normally travel is considered a disutility, a means to an end destination. Transportation time and costs are an unavoidable reality. But if people actually enjoy their commute, and want to prolong it, then the travel in itself possesses some utility or enjoyment. This also shakes up transportation planners' goal: if people enjoy their time spent travelling, should the aim still be to reduce travel time and distances as much as possible?

Taking these findings and applying them to cycle-transit as a commute mode, it is plausible that the combination of bicycling and transit may achieve both desires derived from the results of this study: A commuter could reduce their time spent on transit and also increase the amount of time spent commuting by bicycle. CTU's can choose to travel with others, or solo, at least for the bicycling portion of the trip. For example, a commuter that usually needs to take two buses could avoid their first bus by bicycling to the bus stop of the second bus. Implementing cycle-transit increases cycling time from zero to some measurable amount of time, and reduces time spent waiting for and riding transit by eliminating the first bus segment of this hypothetical trip.

Bikeshed

Definition

A bikeshed is a geographic area around a node which is accessible by bicycle to the average bicyclist. For the analysis of this paper, a bikeshed is calculated around light rail stations to determine the effective range which encompasses homes and businesses whose occupants are able to comfortably access light rail by riding a bicycle. Bachand-Marleau states that the majority of survey respondents were willing to bike to a station if the distance to the station was 2.4 km (1.5 miles), or less.

Bikesheds are typically analyzed considering distance and time required to bicycle that distance. A fine-grained street network can be helpful and hurtful to a bicyclist: it may increase the number of possible routes thereby allowing a bicyclist to avoid dangerous traffic or other undesirable factors, but it may also present more instances which require a complete stop, thus requiring more energy to begin moving the two wheeled vehicle again.

Hiroyuki Iseki has developed and tested methods to incorporate variables which contribute to travel impedance. His GIS methodology includes street network connectivity (start-stop opportunities) and topography to calculate energy expenditure required by a bicyclist to calculate a bikeshed in a perhaps more accurate manner. 2.7 km in the Netherlands may feel like a much shorter distance than 2.7 km in hilly Seattle. A study in the UK determined the elasticity of bicycling related to topography to be -0.894. (Parkin, 2007) In other words, as topography increases by 10%, bicycling decreases by 8.94%.

Krizek and Stonebraker write that a cyclist's "sweet spot", meaning the distance one is willing to ride, varies based on the destination. For accessing transit, 2 miles is an appropriate bikeshed. If a person is able to reach their destination, then 3 miles is an appropriate bikeshed. (Krizek and Stonebraker, 2010) For the purpose of this thesis, I will consider 2 miles the appropriate bikeshed because the study focuses on accessing transit. Krizek and Stonebraker write that the speed of transit which is accessed by bicycle may influence how far a commuter is willing to ride a bicycle: if a longer bicycle ride to a faster train or bus results in a shorter overall commute time, then it is a better option for some commuters. It is also noted that distances less than 5 miles can oftentimes be traversed faster by bicycle than by transit. (Krizek and Stonebraker, 2010) Flamm et al. summarizes other studies when writing that the majority of cycle transit users in America ride their bicycle at least a mile to access transit (Hagelin, 2005); and that in San Francisco and Philadelphia metro regions, CTUs' median bicycle trip is between 2.0 and 3.3 miles. (Flamm, et al., 2014; Flamm and Rivasplata 2014)

Commute Seattle's 2014 Center City employee survey shows that the average one-way distance bicycle commuters traveled to get to work in Seattle was 6.5 miles. This shows that bikesheds may be variable from place to place, or that Center City Seattle bicycle commuters may have unusual tendencies and are willing to ride longer distances to get to work. The survey question which determined commute mode did not allow for a response of CT, it said: "if you used more than one type [sic: mode] fill in the type used for the LONGEST DISTANCE." (Commute Seattle, 2014) It is possible that some of the 100 people who responded that they commuted by bicycle also rode transit, and possible that some of the 163 people who responded that they commuted by transit also rode a bicycle as part of their commute. See Figure 7 below.

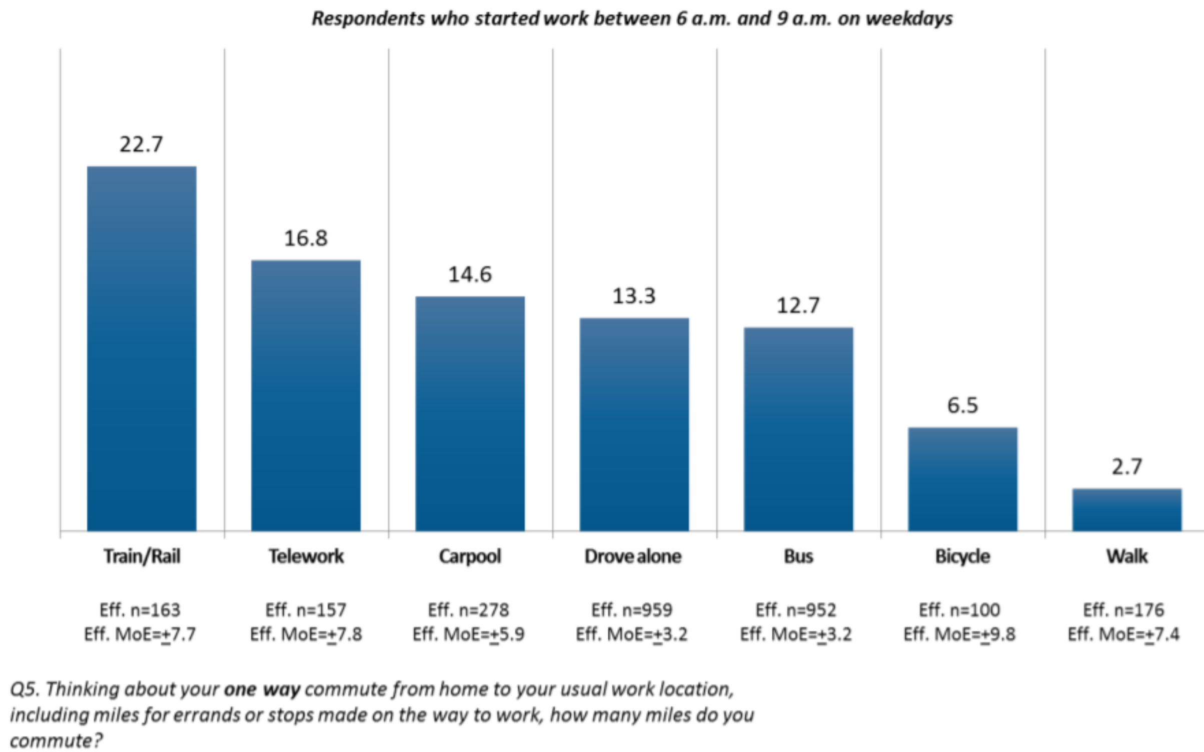


Figure 7. Graph of average one-way commute miles by commute mode for downtown Seattle employees.
Source: Commute Seattle 2014.

Bicycle infrastructure

In general, the literature suggests that the presence of bicycle infrastructure is correlated to more bicyclists, especially novice bicyclists. Krizek and Stonebraker studied a bus corridor to test a hypothesis that several sociodemographic factors influence CT uptake. The factors studied were median household income, percent of the population aged 20-39, density (dwelling units per acre), percent transit commuters (people commuting three times or more per week), percent bicycle commuters (commuting three times or more per week), and bicycle facilities (kilometers of bicycle routes). Only household income was negatively correlated with

CTU. Bicycle facilities and percent of commuters bicycling are the most strongly correlated to the expected success of CT around a transit station, and these two variables are seemingly related given the data thus far. (Krizek and Stonebraker 2010)

Taylor and Mahmassani conducted a stated preference survey of cyclists and non-cyclists in Texas to determine which variables influence a person's willingness to utilize CT in their commute. One significant obstacle was the relative inability of commuters to be able to carry what they need for work on a bicycle. Only 44% of respondents said they would be able to carry their necessary items on a bicycle, while 80% said that would be possible on a bus. (Taylor and Mahmassani 1996) 88% of respondents stated they would be comfortable riding a bicycle in light car traffic, only 53% remarked the same thing when traffic was elevated to "medium", and 19% would still be comfortable in heavy traffic. Among the non-cyclists surveyed in Taylor's study, the presence of bicycle lanes had four times the effect on encouraging bike-and-ride variation of CT among inexperienced riders relative to cyclists with more experience. This discovery leads to the conclusion that good infrastructure is truly a barrier to entry for potential CTU's. If infrastructure investments are made to improve the safety of bicycling around stations, then those who currently do not ride a bicycle will feel more comfortable doing so.

If You Build it, Will They Come?

A case study of Boulder, Colorado has shown a correlation between investment in sustainable urban mobility infrastructure and mode shares that use this infrastructure. The results of this analysis suggest that for every $10 million in municipal budget allocation to pedestrian, bicycle, and transit infrastructure enhancement is related to a 1% increase in combined non-automobile mode-share. (Henao et al. 2015) Investments encompass both operations and maintenance costs, as well as enhancements to improve or expand a network. These investments are in line with the city's Transportation Master Plan goal of reducing the SOV rate to 25%. This goal was drafted in response to the public's desire, so it shouldn't be too surprising that residents follow the crest of this investment wave and change their behaviors in small increments following investment in alternative modes.

There are several factors that may be related to the outcomes observed in Boulder that are also shared by Seattle. First, Boulder established a geographic growth boundary to contain its urban sprawl, as Seattle is similarly bound by the Washington State Growth Management Act. Secondly, Boulder has an organized populace which advocates for environmental and progressive changes in the community, similar to Seattle's history of activism and environmental stewardship. A third characteristic of Boulder is that there is a large university and relatively flat geography. Davis, California; Madison, Wisconsin; Cambridge, Massachusetts, and Eugene, Oregon are frequently grouped as comparable cities with Boulder for these shared characteristics, as well as their above-national-average alternative transportation modal share. I think that Seattle could also be placed in this group with a handicap considered for its difficult topography. Boulder's non-automobile mode share at the time of this article was 32%, compared to the national average of 8.5%, according to the 2009 American Community Survey. In the 2015 ACS survey, it had increased to 33% non-automobile, largely accounted for by walking (12%) and biking (10%). The proportion of the population who worked at home is considerably higher than the national average: 14% in Boulder compared to 5% nationwide. See Figure 8 below.

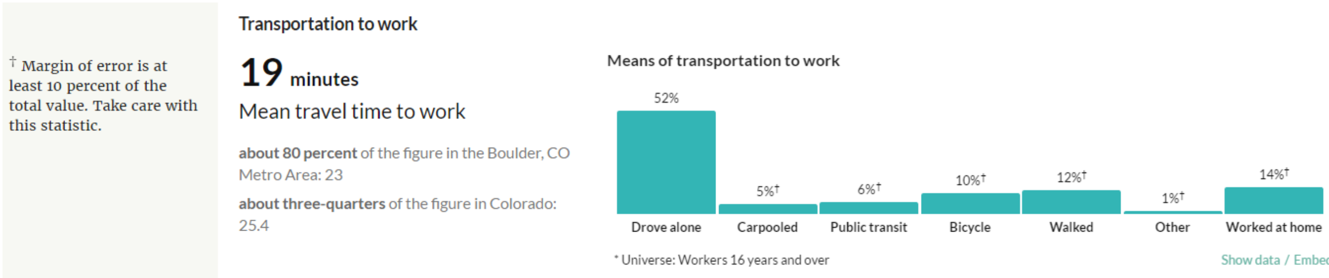


Figure 8. Mean travel time to work and mode share in Boulder, CO.
Source: Census Reporter

The fourth similarity is that both cities are governed by policies which encourage the use of non-SOV modes. Washington State passed its Commute Trip Reduction (CTR) law in 1991 with the goals of reducing air pollution, reducing congestion, and reducing fuel consumption. This policy placed the onus for reducing single occupancy vehicles on employers in counties in the Urban Growth Area. If SOV goals are not met, the Washington State Department of Transportation (WSDOT) may withhold funding for the jurisdiction's transportation projects. (*Washington State Legislature* 1996) In 2006, the Washington state legislature updated the CTR with a policy titled "the CTR Efficiency Act". The purpose of this ordinance was to revise the original goals so that by 2011 all cities and counties would reduce their SOV mode share to major work sites by 10%. The law also states that reducing commute trip vehicle miles traveled (VMT) is a priority. (King County 2017) The City of Seattle revised the Seattle Municipal Code (SMC) to include language which reflects the revised state CTR law. This revision was made in 2008 by Mayor Nickels. It states that workplaces with over 100 employees must make a good faith effort to meet their SOV and VMT reduction goals. Employee commute surveys must be conducted every two years and the results submitted to the city. Noncompliance may result in a $250 fine for each day of noncompliance. (City of Seattle Ordinance No. 122825)

Henao's article concludes that more research is also necessary to discern the benefits of a well-rounded transportation network to improve a community's resiliency in the face of volatile prices of goods that threaten the accessibility and affordability of automobile use. This is another way to look at non-SOV through an equity lens.

In Commute Seattle's most recent survey of downtown employees, it was found that Seattle's downtown core has a 70% non-SOV rate. The 2014 commute survey does not count all of Seattle, only the Center City. See the map below for surveyed employment centers.

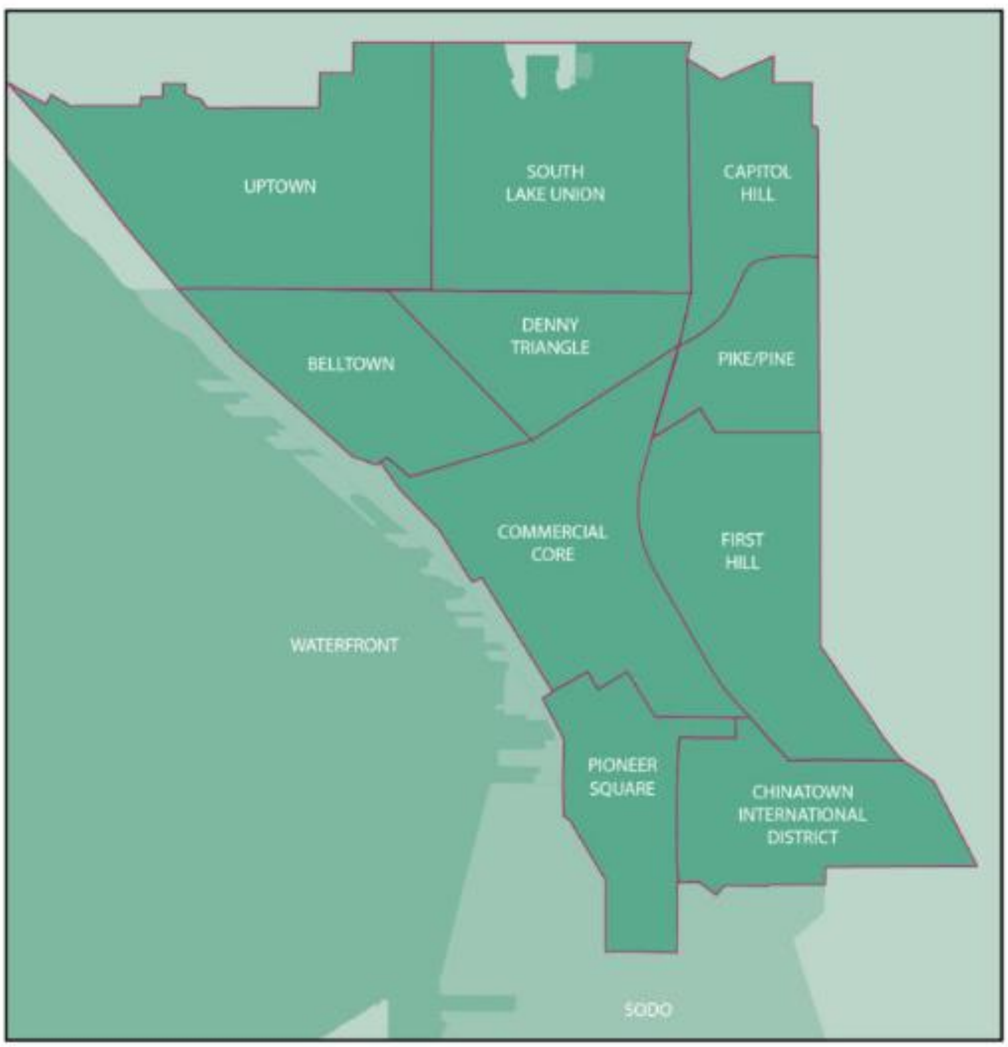


Figure 9. Seattle's Center City
Source: Commute Seattle 2017,

More research would be necessary to determine whether infrastructure investments such as Boulder's course of action or commute trip reduction policies, such as those in place to increase non-SOV use in Boulder and Washington State, is more effective and economical. See the figure below for the results of Commute Seattle's 2014 Center City commuter survey. 38% of employees entering the Center City, as defined in Figure 9, above, get to work by bus. As of 2015 King County Metro's bus service network covers 2,134 square miles and an estimated 2.05 million people, about 1.1 million of whom are estimated to be employed. Annually, King County Metro's fixed route buses achieve a ridership level of 121.8 million passengers. (County 2016a)

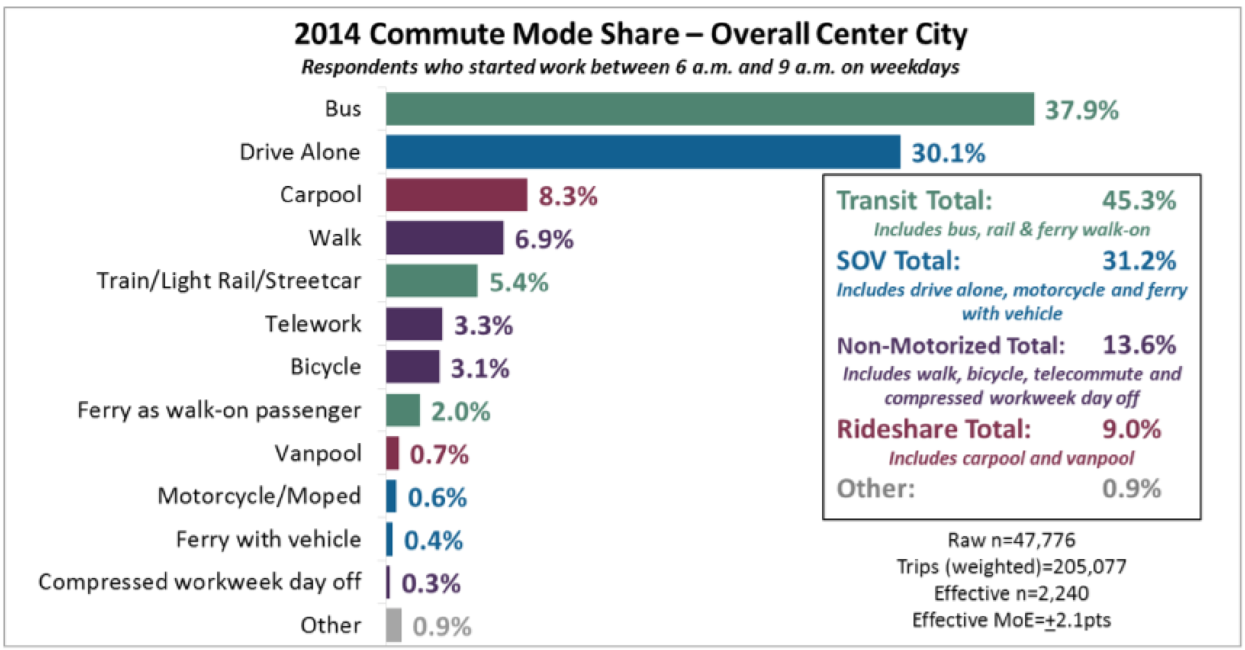


Figure 10. Mode split among Center City employees in 2014.
Source: Commute Seattle, 2014. Figure 3-1.

The SOV mode share has decreased 3% since the previous Center City employee survey. Commute Seattle's research has shown that non-motorized modes have increased about 1% and transit's share has increased 2.2% between 2012 and 2014. See Figure 11 below. It's also important to note that in this period, the population of employees working in downtown

Seattle has increased. Between 2010 and 2016, downtown Seattle added 45,000 new jobs. Of these, 95% commuted by transit. (Downtown Seattle Association, 2017)

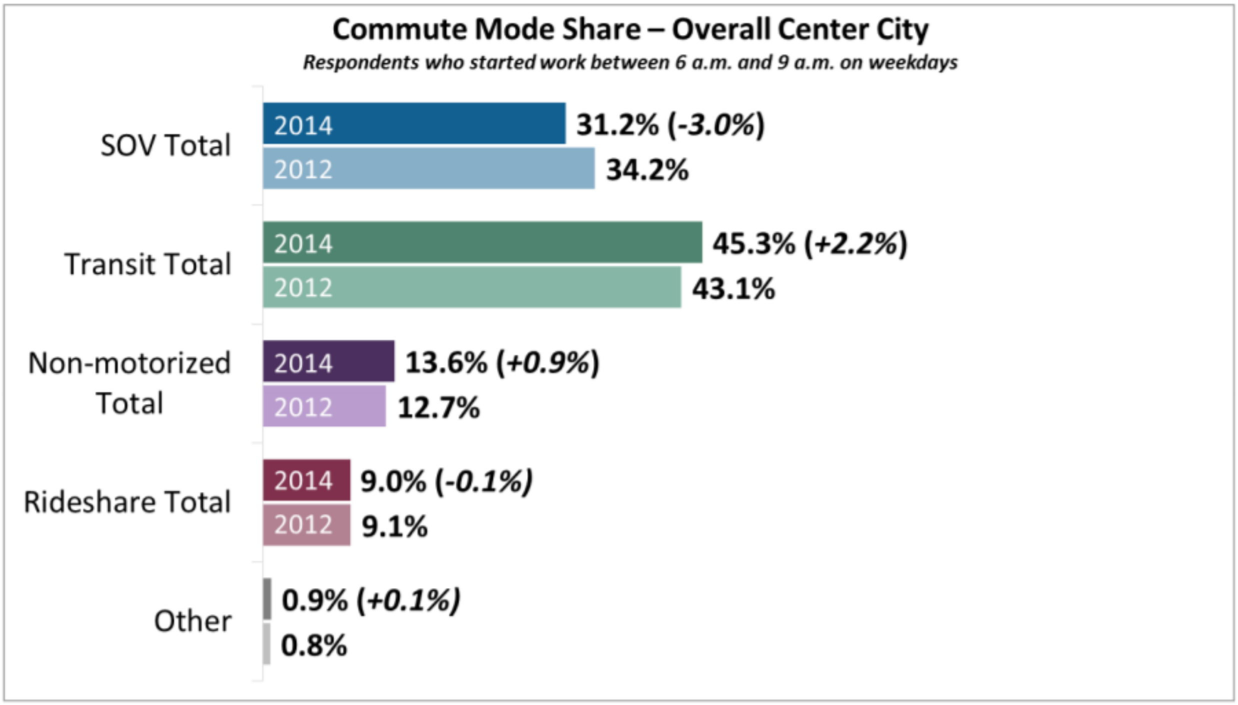


Figure 11. Change in commute modes between 2012 and 2014.
Source: Commute Seattle, 2014, Figure 3-2

The Role of Seattle Bicycle Master Plan in Siting Bicycle Infrastructure

The Seattle Bicycle Master Plan is the guiding document for the city's construction of bicycle infrastructure. It emphasizes the desire to make Seattle a city where people of all ages and abilities feel comfortable riding a bike for daily purposes. The document calls out equity as an important factor for consideration in infrastructure allocation; however, the statistic used as a measurement of equity is "access to a vehicle". The policy states that 16% of Seattle households do not have access to a motor vehicle for their use. Thus, providing bicycle infrastructure is important to improve access for this group of people without automobiles. However, the way equity is measured in the implementation is based on areas of the city without infrastructure. Success is contingent upon 'zero areas of the city lacking bicycle facilities by 2030'. The baseline measurement is the 2012 Initial Conditions Report. (City of Seattle, 2013) It is unclear how much bicycle infrastructure is required for a neighborhood to be considered "having" or "not having" bicycle infrastructure. The type of bicycle infrastructure desired in every area is also not stated. Further, the loose term 'area' is not defined in the document.

Seattle Bicycle Advisory Board

The Seattle Bicycle Advisory Board (SBAB) is responsible for stewarding the Bicycle Master Plan and providing ongoing citizen input on implementation activities. As the City starts to implement a project from the BMP, they look to the standing SBAB for guidance and public input. The SBAB assists with monitoring the BMP's progress and advising city departments and City Council on bicycle-related issues in the city. (City of Seattle, 2016) SBAB members are leaders in the community from all neighborhoods; they are often vocal advocates for bicycle interests in their respective neighborhoods and for their respective groups. They work together to implement projects which connect the city by bicycle and make the bicycle infrastructure network safer for all ages and abilities and more comprehensive to aid in bicyclists' route selection. There are several SBAB members who are people of color, and it appears that the Board as a whole has worked to advocate for infrastructure in geographic areas with high percentages of minorities and youth. The SBAB is currently divided up into North, Central, and South Seattle. (Personal interview with Kelsey Mesher of Cascade Bicycle Club, March 17, 2017) This division serves as a proxy for equity because the city is racially segregated roughly based on these three areas. See racial distribution maps above, Figures 3-6.

Equity

Introduction

There are three primary ways to define equity with regard to transportation, so first I will summarize the different types, as written by Todd Littman of the Victoria Transport Policy Institute, and then discuss why I will use “vertical equity with respect to income and social class” for my equity analysis. Equity, also referred to as “justice” and “fairness”, is the distribution of positive and negative impacts resulting from a policy or project, and whether those impacts are appropriate. (Litman) The first type of equity is horizontal equity, or egalitarianism. This means that all individuals are treated equally, pay the same amount, and receive equal impacts (positive and negative) regardless of their status in life. One example of horizontal equity is a flat rate toll, which is regressive because when compared to one’s income, the toll is a larger proportion of a poor person’s income than a wealthy person’s. The second is vertical with-respect-to income and social class, or Rawlsian justice. This factors in economic and social disadvantage and seeks to ameliorate the costs and harms of transportation to these groups. An example of this type of equity is a reduced transit fare for low-income, senior, and youth riders. The third variation on equity is vertical with regard to mobility need and ability. This would apply to users with various needs who require special accommodation to get around, and usually advocates for universal designs which can accommodate all ages and abilities. An example of this third type of equity is the provision of paratransit to people with physical or mental disabilities which prevent them from independently using another mode.

King County, ‘The Determinants of Equity’

Policymakers in King County have been discussing the importance of equity in the recent decades. In 2008, King County Executive Ron Sims launched the Equity and Social Justice (ESJ) Initiative. This was in response to several studies, including the 2006 Dellums Commission Report and the Place

Matters report, which identified policy topics which negatively affect men of color, and health outcomes that are related to social conditions. In 2010, King County Ordinance 16948 was passed which codified the language "fair and just" and included it in the County's strategic plans; it also established the 14 determinants of equity to be discussed further below. "Determinants of equity" are the social, environmental, and economic factors which determine equity outcomes, or the level of equity in King County. Specifically, they are: early childhood development; education; jobs and job training; health and human services; food systems; parks and natural resources; built and natural environment; transportation; community economic development; neighborhoods; housing; community and public safety; and law and justice. Under these 14 determinants, there are a total of 67 indicators which are used to measure the status (and progress over time) of the particular determinant. Measurable equity indicators under the transportation determinant of equity include the following:

- Metro Transit Rider Satisfaction with Safety
- Metro Transit Passenger Crowding & Schedule Reliability
- Reliance on Metro Transit
- Proximity to Metro Transit
- Metro Transit On-Time Performance
- Walk Score
- Bike Score
- Transit Score
- Metro Transit Reduced Fare Utilization
- Metro Transit Low-Income Fare Utilization
- Transportation Cost-Burden

In 2014, researchers began to work on the Determinants of Equity Baseline Project, which, as the name implies, intended to measure the determinants of equity prior to policy changes in order to measure the effects of subsequent changes.

The purpose of the report is summarized as follows: "Developing a community-scale equity baseline and dashboard in collaborations with other civic, public, and private organization involved in ESJ efforts is vital to regional success and will create an ability to track community conditions over time. This is important because it can help strengthen decisions in resource allocation, provides information about which ESJ efforts are having the intended effect, and guide course corrections so efforts can achieve positive change... The complexity of this undertaking requires thoughtful consideration from leadership and key stakeholders on how to orchestrate activities to create a methodically sound and community supported tool." (Beatty and Foster 2015)

Due to time constraints, the researchers were only able to establish a baseline measurement for *Proximity to Metro Transit* and *Transportation Cost-Burden* in King County with regard to transportation. It is noted on the scorecard of indicators that median household income is strongly linked to many other indicators, including transportation. Because the county is responsible for providing public transit services, much of the transportation research has focused on King County Metro bus service. The 2016 system evaluation report includes the County's revised service guidelines which emphasize providing transit service to improve social equity and maximize geographic value. (County 2016a)

The countywide goal for transportation provision as stated in Ordinance 16948 is for 'Transportation that provides everyone with *safe, efficient, affordable, convenient and reliable* mobility options including public transit, walking, carpooling and biking.' (Beatty and Foster 2015) The report also notes that these parameters are difficult to define, and often overlap one another. For example, 'convenient' transportation is also 'efficient' and 'reliable', making these parameters indistinct and nebulous. The County does not define an appropriate distance for bicycle access to transit. They use 0.25 mile for walking and 2.0 miles for driving to a park-and-ride. (Beatty and Foster 2015)

This thesis should be a useful starting point for King County in measuring the equitable distribution of bicycle infrastructure to all people in the county, especially those who belong to historically underserved groups. The scope of this thesis is limited to Seattle, but Seattle is the largest city in the county and the county seat.

To summarize, this chapter has covered the benefits of cycle-transit which include reduced commute times, greater flexibility in timing, more enjoyable commute experiences, and better public health outcomes from regular exercise. Cycle-transit users are typically White, highly educated men with high incomes, however there has been a recent uptick in the proportion of Hispanic/Latino people using CT. It also covered the barriers to bicycling, the foremost of which is lack of safe bicycle infrastructure. Among surveyed men of color in New Jersey, personal safety and racial profiling by police are also reasons bicycling is not used more for transportation. The depoliticization of bicycle infrastructure projects was discussed in light of the Portland, Oregon project written about by Amy Lubitow. Communities of color must be sincerely engaged from the beginning of a project's planning and outreach to address any issues which may stem from racial and cultural history, priorities, and concerns. This chapter also defines a bikeshed as the area around a destination within which people are willing to ride a bicycle to access that destination. When the destination is a transit stop, the bikeshed is commonly defined as 2 miles. The chapter also discusses the mode share in Seattle's center city, which in 2014 was 38% bus, 30% single occupant vehicles, 8% carpool, 7% walking, 5% train/light rail/street car, 3% telework, and 3% bicycle. The chapter finishes with an overview of King County's Determinants of Equity, the county's multipronged plan to improve the equitable provision of services, programs, and projects by the organization.

Chapter 3: Methodology

GIS Methodology

Dr. Jennifer Dill and Brendon Haggerty of Portland State University conducted an equity analysis of the Portland, Oregon Bicycle Master Plan in 2009. They provided the final report to the Portland Bureau of Transportation (PBOT) in order for the agency to prioritize the implementation of its Draft Bicycle Master Plan projects to make the most impact in neighborhoods of historically underserved populations. (Dill and Haggerty 2009) The analysis identified areas where historically disadvantaged populations live, work, learn, play, and shop for groceries and where service gaps in the city's bicycle network overlap with these populations' residences. Historically underserved populations in their analysis included racial/ethnic minorities, households below the poverty line, youth under the age of 18, seniors aged 65 and over, and those with limited English proficiency. The intended outcome is to make the mode of traveling by bicycle more attractive to people who are not already bicycle riders. This study was conducted because of a planning objective that arose in the process of writing Portland's Bicycle Master Plan which stated that "an equity gap analysis shall be performed which includes demographic/income indicators overlaid with existing bike facility gap analysis to inform priority settings where people live, learn, work, and play." (Dill and Haggerty 2009) Dill's study also addressed access to transit by bicycle, noting that many neighborhoods of Portland are outside of a bikeshed to many workplaces, schools, and parks.

The methodology of this thesis was inspired by Dill and Haggerty's methodology. I used 2015 ACS data at the Census Block Group (CBG) level to identify areas of Seattle where the concentrations of minorities (non-White) people, households below the poverty line, youth under the age of 18, and seniors aged 65 and older are higher than the citywide average. This above citywide average concentration measurement was used for all factors besides poverty. Poverty was divided into three equal groups of high, medium, and low concentrations of people in poverty. It is important to note that this measures in the proportion of people in poverty in a CBG, not how poor the people are. The CBG shapefile is from King County, and the CBG shapes are the same as those used in the 2010 Census.

The density of bicycle infrastructure was calculated using a City of Seattle GIS layer for bicycle lanes and the previously mentioned CBG shapefile from King County. The City's GIS layer has bicycle facilities typified from Class 1 to 4, with 1 being off-street trails, 2 being protected- and conventional bicycle lanes, 3 being low to medium-speed traffic lanes designated as bicycle routes, also called "sharrows" or minor separation striped bicycle lanes, and 4 being low-speed and low-volume streets. See Figures 12 through 17 for examples of bicycle facilities. Class 3 facilities make up about half of the city's bicycle network, yet are the least safe of the four options. There are safety benefits which correspond to bicycles and vehicles being physically separated in the right of way which occurs in Class 1 and Class 2 facilities. (Harris et al., 2011) Class 4 facilities are low-speed, low-volume, usually residential streets with additional traffic calming elements such as speech humps, low speed limits, traffic diversion and sharrows. The Seattle Department of Transportation calls these Class 4 facilities "Neighborhood Greenways". According to the University of British Columbia Cycling in Cities Research Program, this type also has safety benefits. The research group states that the safer types of bicycle facilities are also those most preferred routes by cyclists. The most dangerous routes are those which feature streetcar tracks, steep downhills, construction areas, shared car/bike lanes, and traffic circles, all situations which can be found in Seattle.

The methodology is repeated two times: the first equity analysis includes all bicycle infrastructure and all equity variables. The second equity analysis intends to see if there is any disparity in the provision of "low-stress" bicycle facilities, which includes Class 1, Class 2, and Class 4 facilities, and all equity variables.

Figure 12. Example of Class 1 bicycle facility, a multi-use trail.
Source: Dennis Johnson, seattlemet.com

Figure 13. Example of Class 2 bicycle facility, a two-way protected bicycle lane.
Source: seattle.gov

Figure 14. Alternative example of Class 2 bicycle facility, a one-way buffered bicycle lane.
Source: mynorthwest.com (AP Photo/File)

Figure 15. Alternative example of Class 2 bicycle facility, conventional bicycle lane.
Source: pedbikeimages.org

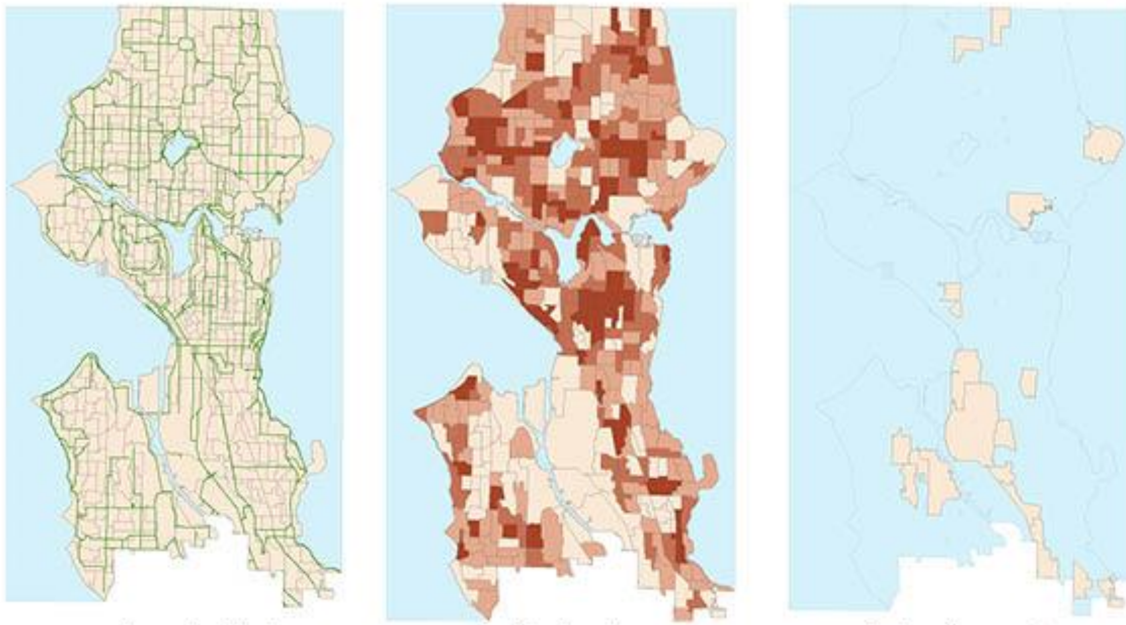
Figure 16 Example of Class 3 bicycle facility, 'sharrow'.
Source: blog.sdot.gov

Figure 17. Example of Class 4 bicycle facility, in Seattle called "Neighborhood Greenway".
Source: sdot.gov

Bicycle infrastructure density was calculated by taking bicycle lane miles divided by the square miles of each block group.

Bicycle Infrastructure Density = *Bicycle Lane Miles in CBG / Square Miles of CBG*

This way, the area of the census block group is controlled for and bike lane densities can be compared from one CBG to another. The density of bike lanes has been broken into quartiles. The series of maps in Chapter 4 show the spectrum of bicycle infrastructure density with CBGs of each map's respective equity indicator highlighted when it overlaps with the lowest quartile of bicycle infrastructure. Please see the conceptual model for this methodology below in Figure 18.



Step 1: Draw layers for bike lanes and Census Block groups. Calculate bike lane density for each CBG.

Step 2: Display bike lane density per CBG using quartiles.

Step 3: Calculate the citywide average minority population. Display only the CBG's with higher than average minority populations.

Step 4: Find the CBG's with high minority population AND low bike lane density, or service gaps.

Step 5: Create a new layer of minority CBG's and service gaps.

Step 6: Redraw the bicycle lane density by CBG with minority CBG's high-lighted.

Figure 18. Gap analysis procedure for bicycle infrastructure density by CBG and minority concentration.
Source: Author.

In order to compare the percentages for the four different equity variables, a geometric mean was used which takes the product of the previously calculated percentages, then finds the n^{th} root of the product. Geometric mean serves as a proxy for diversity, with higher values having higher percentages of people of color, people in poverty, youth and/or seniors in the CBG.

Geometric Mean =

$$\sqrt[4]{(Percent\ minority * Percent\ poverty * Percent\ youth * Percent\ senior)}$$

Following this calculation and mapping this data by quartile, I highlighted the CBGs in the highest quartile of geometric mean which also have the lowest quartile of bicycle infrastructure density.

Bikesheds were calculated by using a 2-mile buffer based on Krizek and Stonebraker's article which concluded that a 2-mile bikeshed is appropriate for someone accessing transit. Buffered areas were then overlaid with the geometric mean map to find Census Block Groups which have a high geometric mean and are within 2 miles from a light rail station. The GIS function used was a clip with settings that only required some portion of a CBG to fall within the 2-mile radius of a station. Only the portion of the CBG falling within the bikeshed is highlighted. See Figure 33. The CBG is the smallest area for which such data is available, so it is not currently possible to use more fine-grained information.

The second equity analysis is also a series of maps which are the results of spatial analysis after removing Class 3 bicycle facilities, or in-lane minor separation bicycle lanes. According to research led by Harris at the UBC Cycling in Cities Research Program, this type of bicycle infrastructure is the least safe. (Harris et al. 2011) See Figure 16 above for an example of a Class 3 bicycle facility. About half of Seattle's bicycle infrastructure, measured in lane miles, is this type of facility. This second analysis intends to explore the relationship between the percentages of people of racial minorities, who've experienced poverty, youth, and seniors, and the existence of safer "low-stress" bicycle infrastructure in Seattle.

Chapter 4: Findings

The first section of this chapter will introduce the data sets used. The second section will present the findings from the equity analysis conducted on the entire bicycle network in Seattle. This includes Class 1 (off-street trails), Class 2 (protected bicycle lanes), Class 3 (in-lane minor separation bicycle facilities), and Class 4 (Neighborhood Greenways) bicycle facilities. The density of all of these facilities is calculated, then overlaid with the percentage of the population of each CBG which is non-White, below the poverty line, youth, and senior, respectively. CBGs with a high proportion of the respective equity indicator *and* the lowest quartile of bicycle facilities is highlighted. Then the geometric mean is conducted, along with bikesheds around light rail stations. The third section will present the findings from the second equity analysis for low-stress bicycle facilities, which uses only Class 1, Class 2, and Class 4 bicycle facilities. The bicycle infrastructure density of these facilities is then overlaid with the same four equity variables, and the geometric mean calculated from them. Bikesheds around light rail stations are also displayed on the maps. The final section is a discussion on the comparisons and differences between the two analyses.

Introduction of the Data

The following map shows the boundaries of the 480 Census Block Groups in the City of Seattle. Census Block Groups are not the same size in terms of geographic area, but they do have approximately the same number of residents, generally between 600 and 3,000 people. (US Census, 2015) The map also shows the existing Link light rail line operated by Sound Transit. The existing stations are in blue, and the future stations are in green. The future stations are expected to open in 2021. (Sound Transit, 2017a) Census Block Groups were most recently redrawn during the 2010 Census; those shapes are used for this analysis.

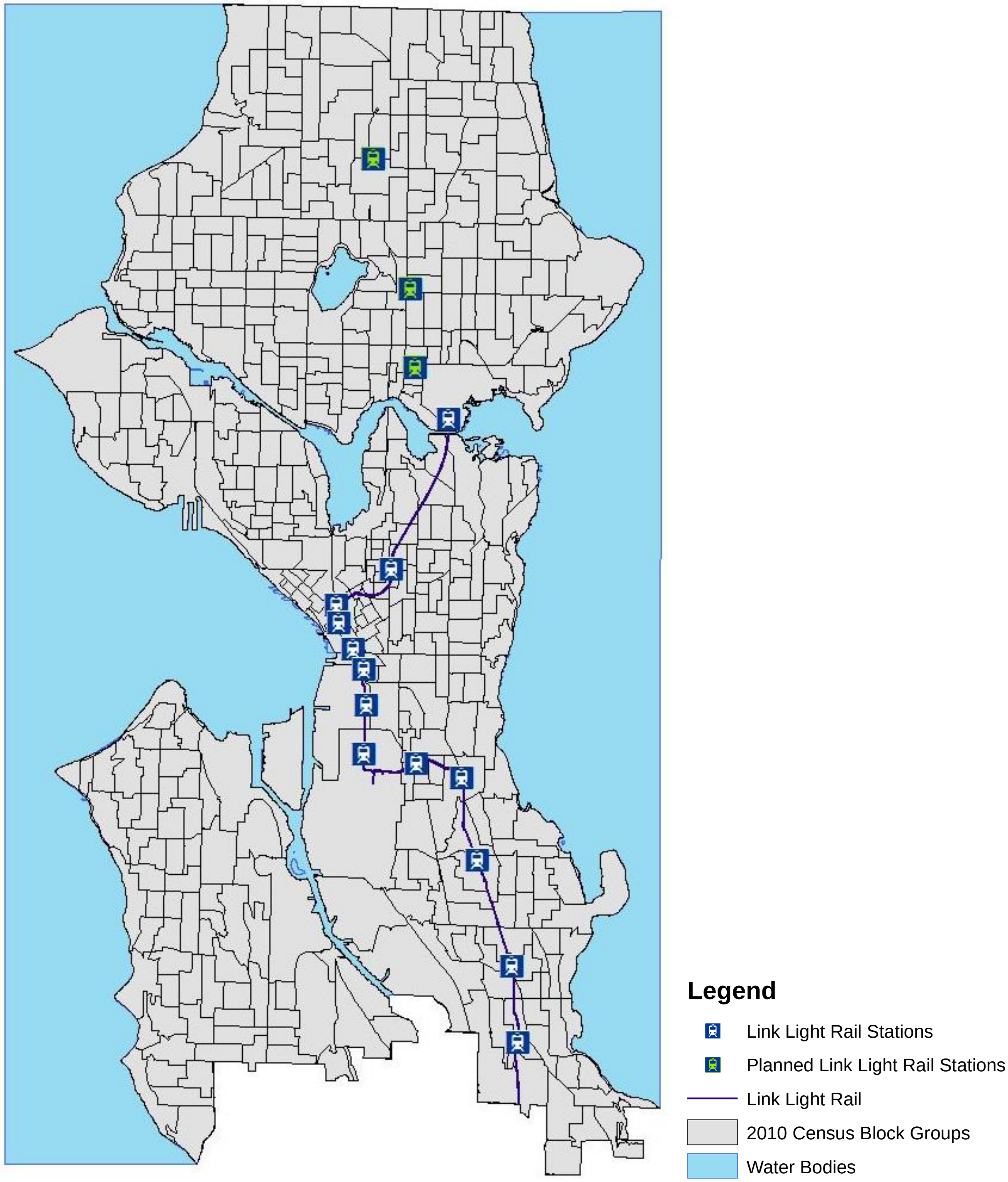


Figure 19. Map of Seattle's Census Block Groups and Link light rail line.
Source: Author.

The following map shows the names of light rail stations in the Link light rail system. The three northernmost stations are under construction and are expected to open in 2021. (Sound Transit 2017a) The blue line indicates the route of the current light rail line. It breaks from the International District station to the Westlake station where it goes through the Downtown Seattle Transit Tunnel (DSTT). The service continues underground all the way to the University of Washington station, but not in the DSTT.

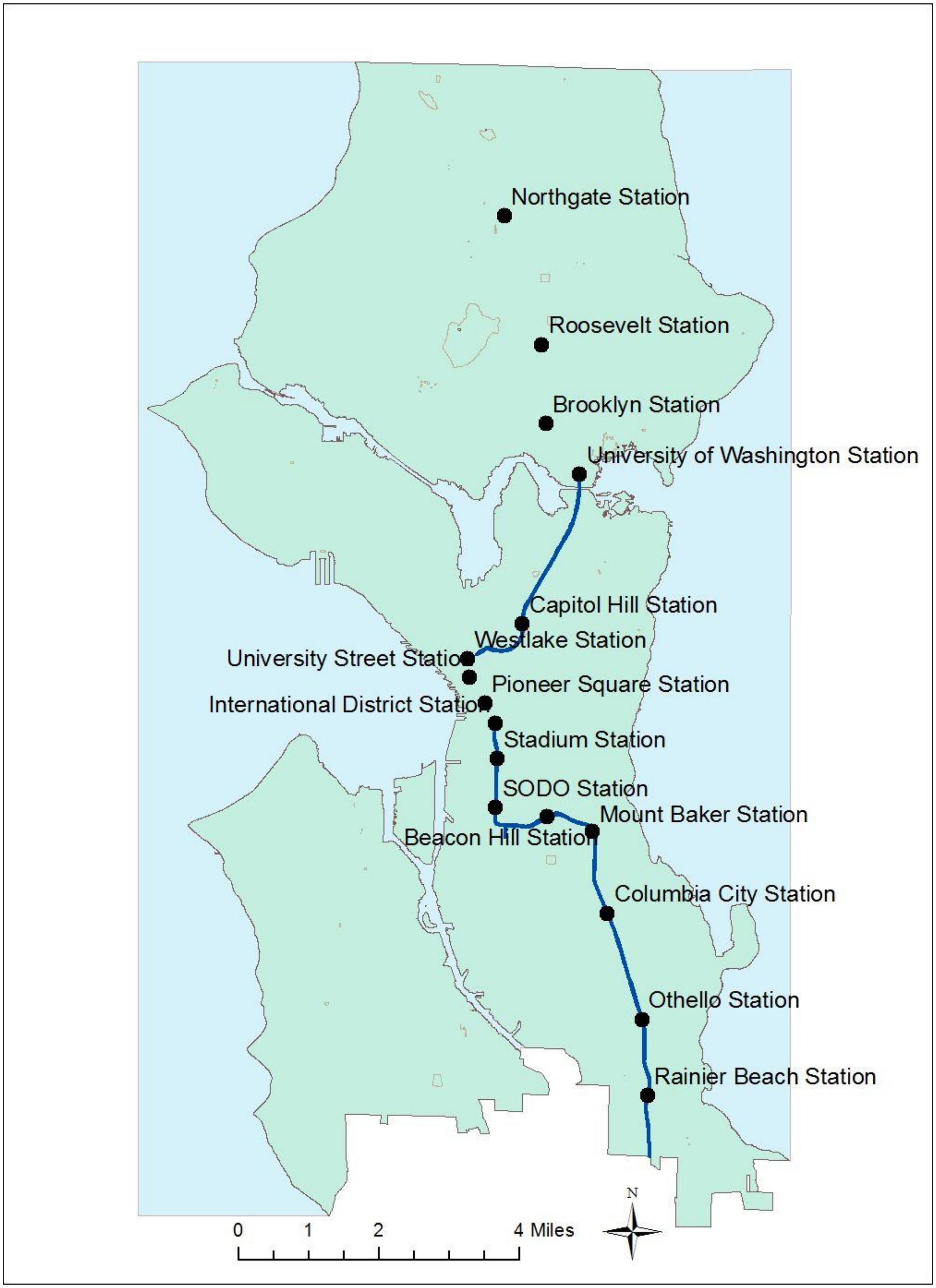


Figure 20. Map of Link light rail line with current and planned stations.
Source: Author.

The following map shows the Link light rail line, all current and future stations, and all bicycle facilities in Seattle. All bicycle facilities from Class 1 to Class 4 are included on this map. There are approximately 343 miles of total bicycle facilities across the city.

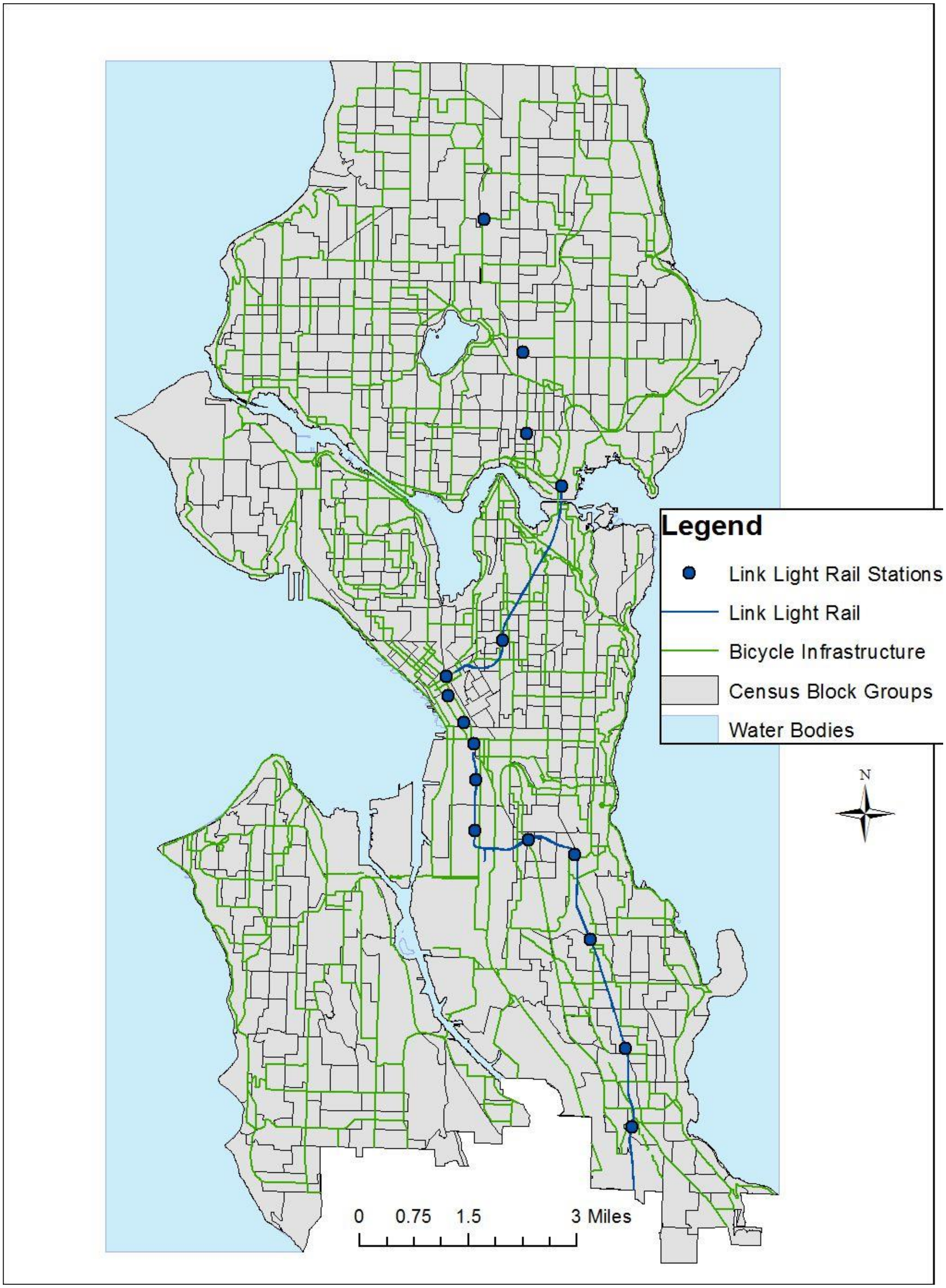


Figure 21. Map of all bicycle facilities in Seattle, Link light rail corridor, current and future light rail stations.
Source: Author.

The following map highlights the 39 CBGs in Seattle which do not have any bicycle infrastructure within them or bordering them.

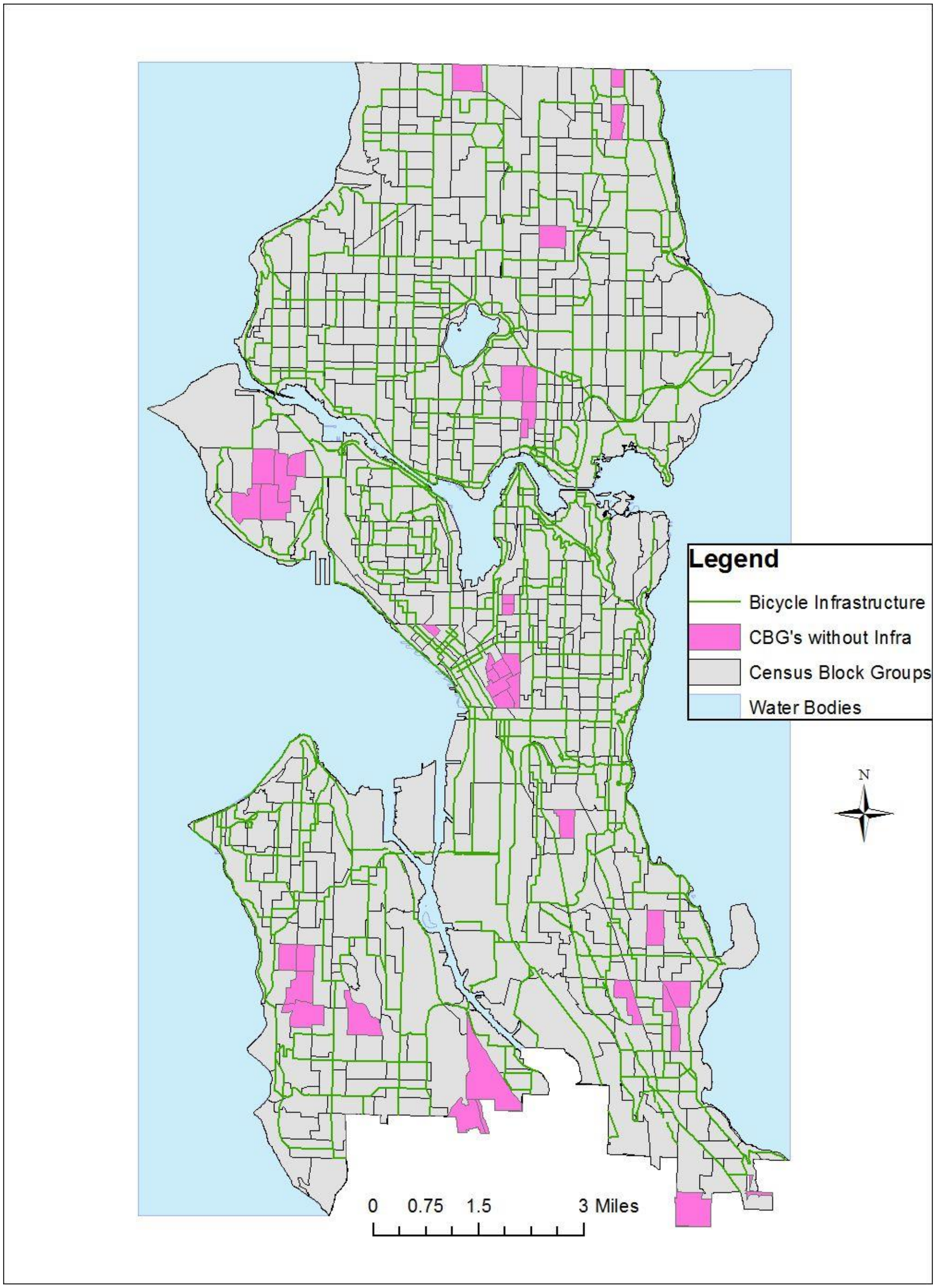


Figure 22. Map of bicycle infrastructure distribution by CBG in Seattle.
Highlighted CBGs do not have any bicycle infrastructure. Source: Author.

The following map, Figure 23, shows the relative density of bicycle infrastructure by block group, displayed using quartiles. Using City of Seattle GIS data, existing bicycle facility miles in each block group were divided by the area (in square miles) of the respective block group to calculate the density of bicycle facilities. The results ranged from 0 to 33.8 miles/square mile. The average was 6.53 miles/square mile. There are 119 block groups in the city categorized as service gaps, where there is little or no bicycle infrastructure (less than 3.57 bike lane miles per square mile). This equates to the lowest quartile of bicycle infrastructure density. CBGs without any bicycle infrastructure are included in the lowest quartile. The census block group with the highest density of bicycle facilities is a two block area in the Downtown neighborhood of Belltown, between Elliott Ave, 1st Ave, Broad St, and Clay St.

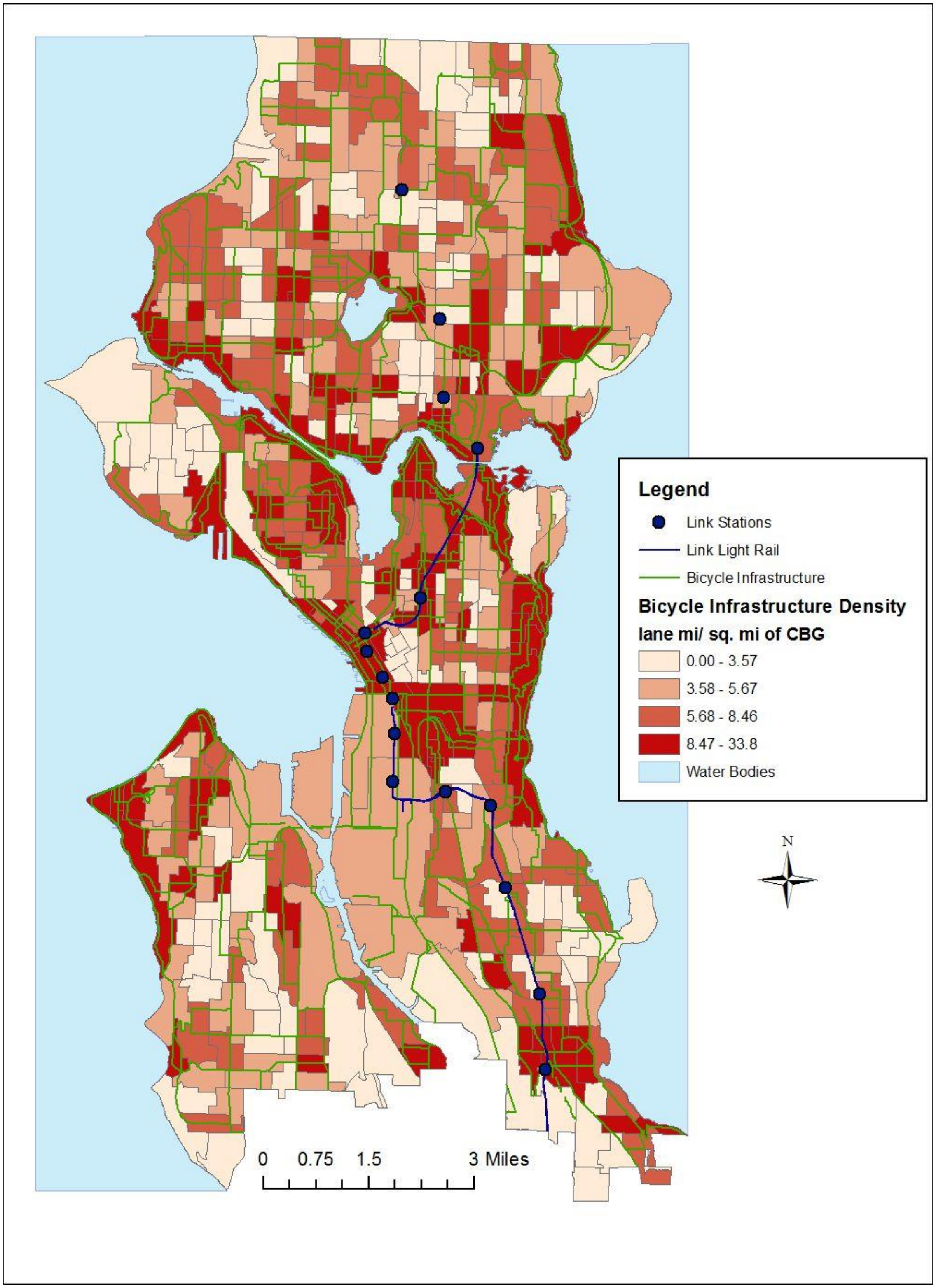


Figure 193. Map of Seattle's bicycle infrastructure density by CBG and bicycle infrastructure network.
Source: Author.

The following map shows a comparison of bicycle infrastructure density in 2-mile bikesheds comparing station to station. While of course there are other considerations to factor in when calculating a bikeshed, this is a rough estimation of a person's comfortable range for riding a bicycle to access transit, based on the literature review in chapter 3. The analysis would be more detailed if it accounted for topography or street network density. The light rail stations in the center of the city have the most dense bicycle infrastructure in their bikesheds while the more outlying stations have lower bicycle infrastructure density. The distribution is highly normalized from city center to outlying areas, which likely matches population density and street network patterns.

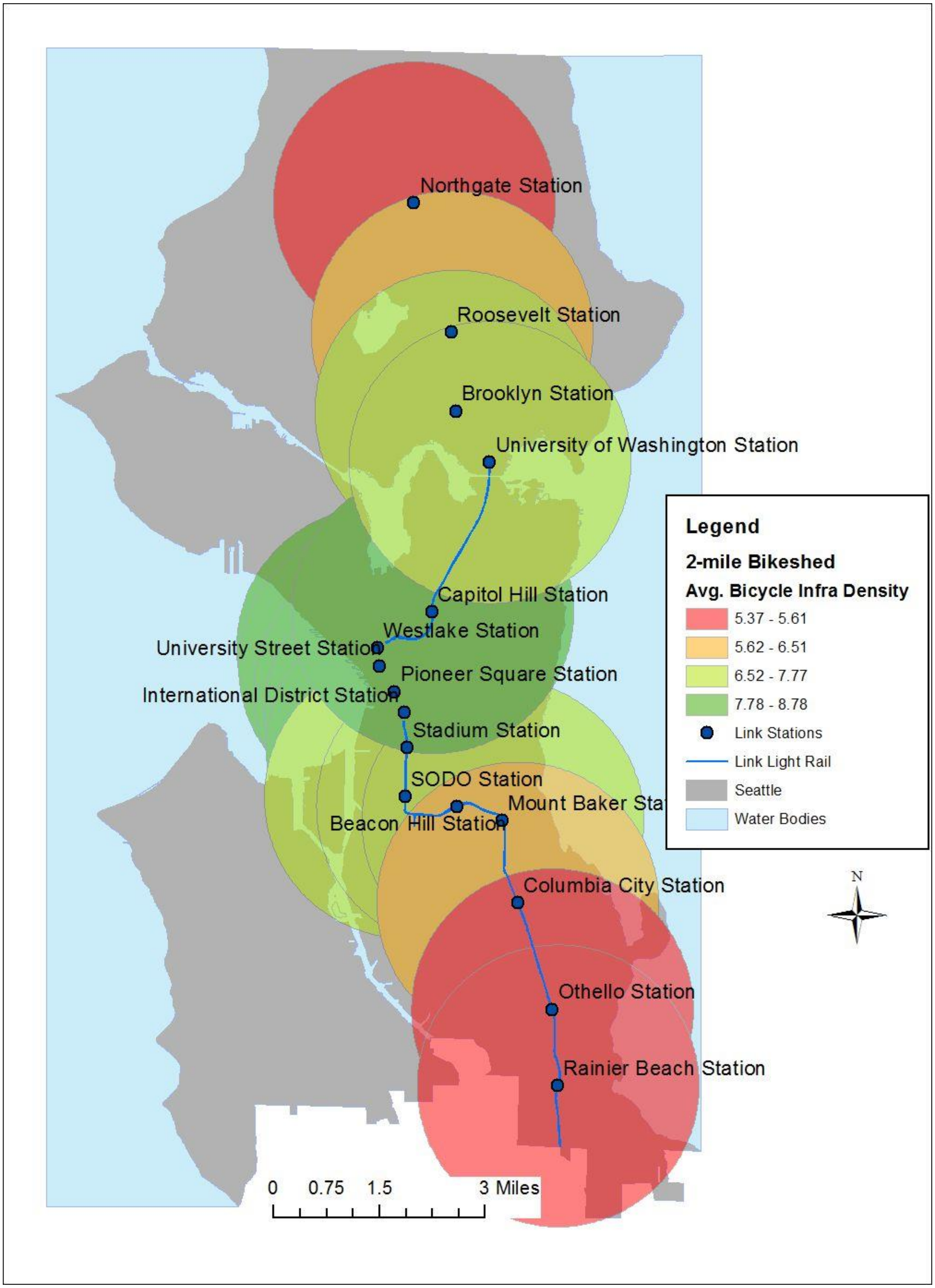


Figure 24. Map of bicycle infrastructure density in bikesheds around light rail stations.
Source: Author.

The following map shows the number of private vehicles per person in each census block group. Citywide, 16.4% of people do not own a vehicle for personal use, a statistic that is cited in the Seattle Bicycle Master Plan. Lack of a private vehicle may be a conscious decision or it may be due to lack of resources to purchase and maintain a vehicle, or the inability to drive. The map shows the proportion of vehicle ownerships by CBGs; total number of private vehicles divided by total estimated population of the CBG. It does not take into account whether the population of the CBG is of driving age, over 16 years of age. It does not take into account the number of people per household, which may be related to whether a vehicle is shared between two or more adults of driving age. There are several CBGs in the Rainier Valley, the University District, downtown, Capitol Hill, and the Central District where the density of vehicles per person is in the lowest quartile, with 0-0.5 vehicles per person. Mobility substitutes to the private automobile such as walking and transit may be more commonly used in these areas with higher intensity and diversity of land uses. Vehicle ownership is not explicitly studied in this thesis, but the map is provided for reference.

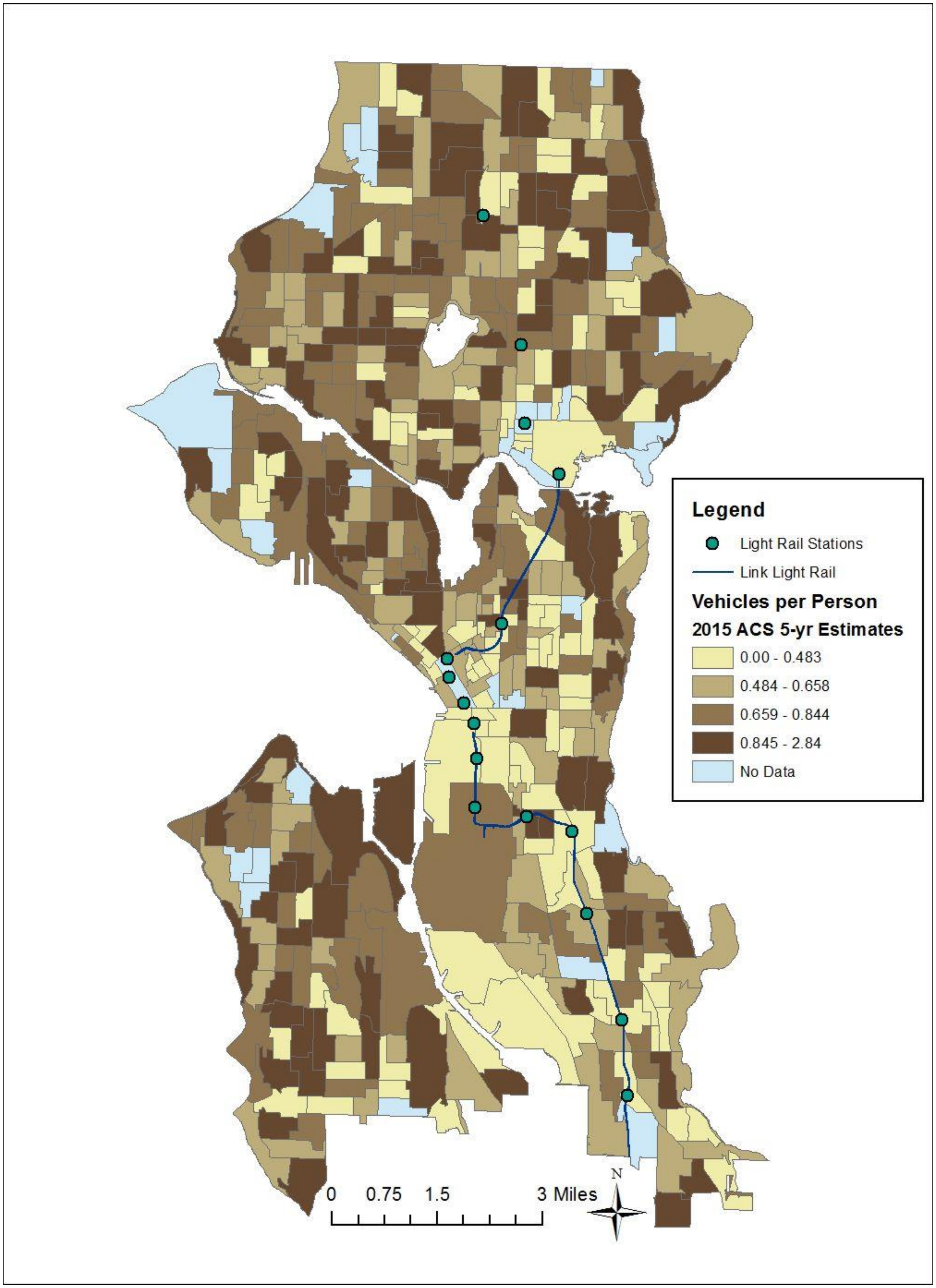


Figure 25. Map of private vehicles per person by Census Block Groups.
Source: Author.

Equity Analysis of All Bicycle Infrastructure

This section will review the findings of the equity analysis conducted on all bicycle infrastructure in the city and all four equity variables.

The first equity variable studied was race. In this thesis, I am defining racial minority as any race besides White alone. Latino and/or Hispanic people are grouped based on the racial group with which they identified in the 2015 ACS. The citywide average of non-White residents is 29%, therefore any census block group with more than 29% non-White residents is considered an area with a high concentration of people of racial minorities. (US Census ACS, 2015) The map highlights the *service gaps*: the CBGs with a higher than citywide average concentration of people of racial minorities *and* the lowest quartile of bicycle infrastructure density. The CBGs with service gaps are revealed in pink on the map. (See Figure 26 below). Table 1 summarizes the citywide bicycle infrastructure and compares the density, average distance, and number of service gaps to the CBGs which have a high minority population. There is slightly more bicycle infrastructure as measured in lane miles and density in CBGs with above average minority populations than the citywide average.

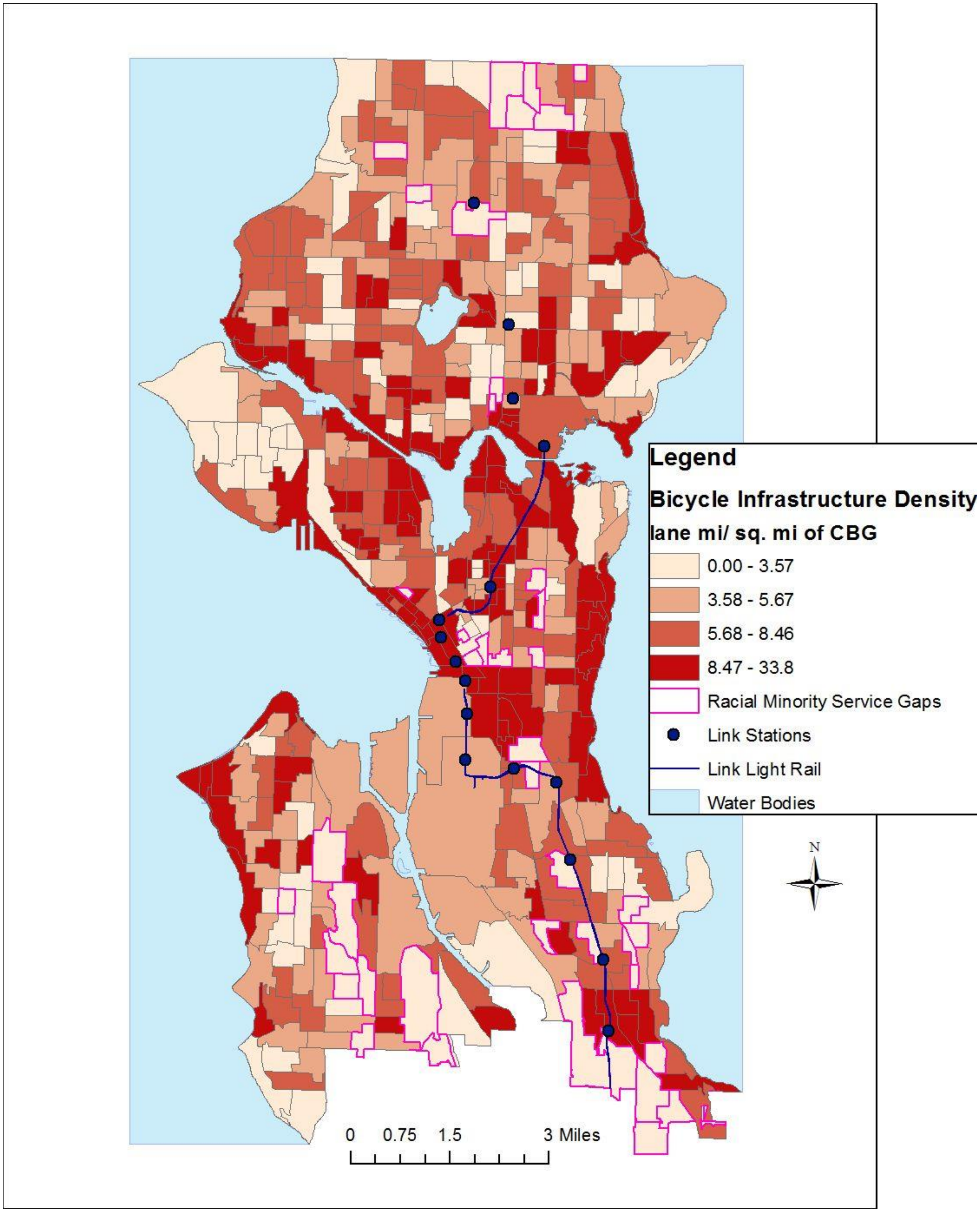


Figure 26. Bicycle infrastructure service gaps in CBGs and higher concentration of people of color.
Source: Author.

Table 1. Statistics on bicycle infrastructure in CBGs with above average minority population.

Summary – Racial Minority				
	Number of Block Groups	Average Bike Infra Miles	Average Density of Bike Infra Miles	Number of Service Gaps
Total	480	1.12	6.53	119
Above Average Minority	174	1.18	6.78	43

The following map shows the concentration of poverty in Seattle. The low, medium, and high groups are made up of about the same number of CBGs. Poverty is determined if a person responded to the 2015 American Community Survey stating that their income was lower than the federal poverty line in the previous 12 months. The low, medium, and high groups show the concentration of people in poverty in a CBG, not how poor the people are. Clusters of high poverty CBGs, where 23-78% of the population has dropped below the poverty line in the past year, appear in downtown, Capitol Hill, the Central Area, the University District, Northgate, Beacon Hill, Rainier Valley, and Seward Park.

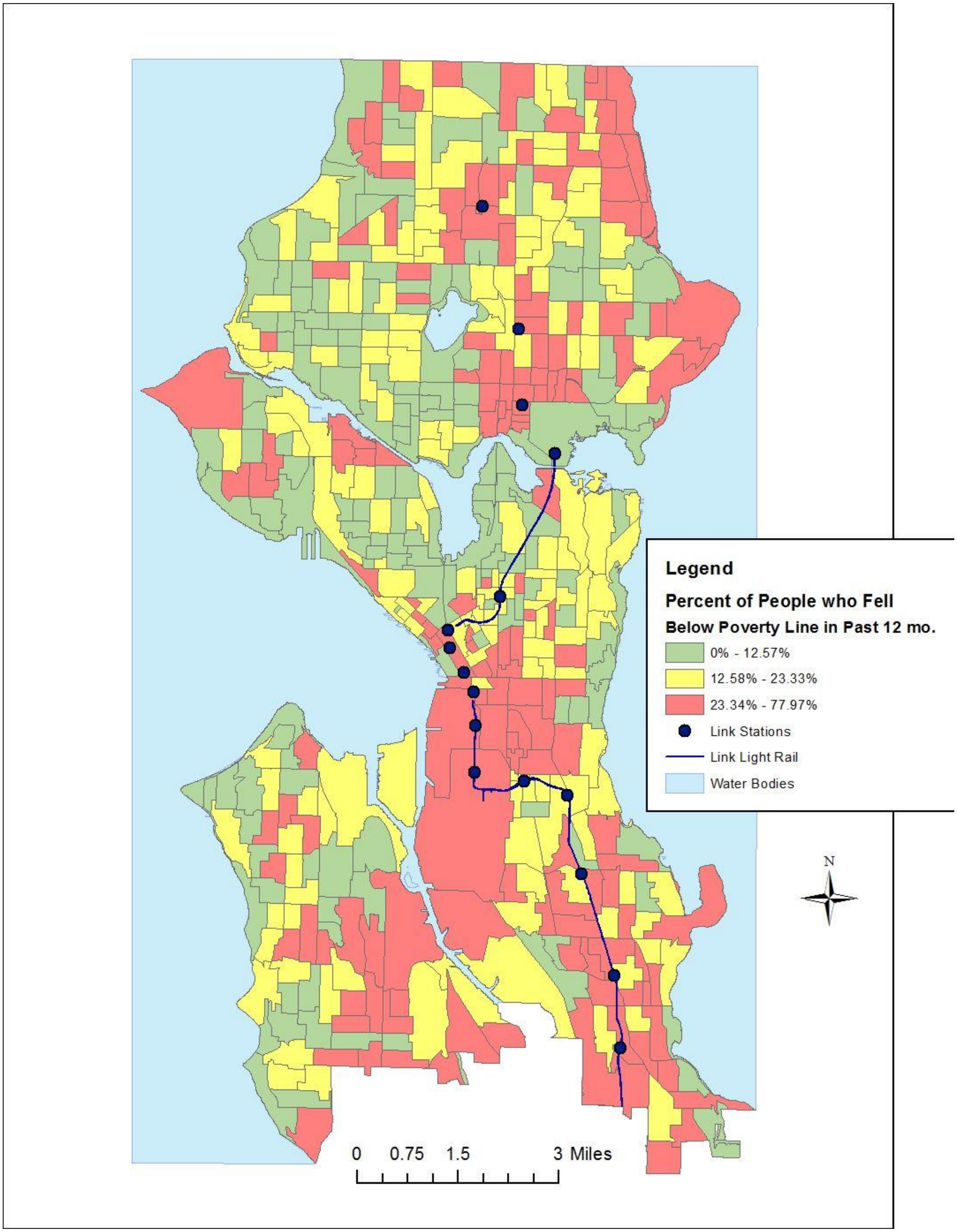


Figure 207. Map of poverty concentration in Seattle.
Source: Author.

The following map shows the same bicycle infrastructure density information as Figures 23 and 26. CBGs with high poverty concentration service gaps and are highlighted. The data used quantifies the percentage of people experiencing poverty, not the degree of poverty (how poor they are). The data were divided into three quantiles: low poverty (0-12.57% of households having fallen below the poverty line in the previous 12 months), medium poverty (12.58%-23.33%), and high poverty (23.34%-78.0%). There appear to be fewer highlighted CBGs than the map identifying service gaps among racial minorities. That is because the selection criteria for this map is more stringent: only one third of CBGs are selected based on high poverty concentration whereas approximately half of all CBGs were selected based on being above average minority concentration.

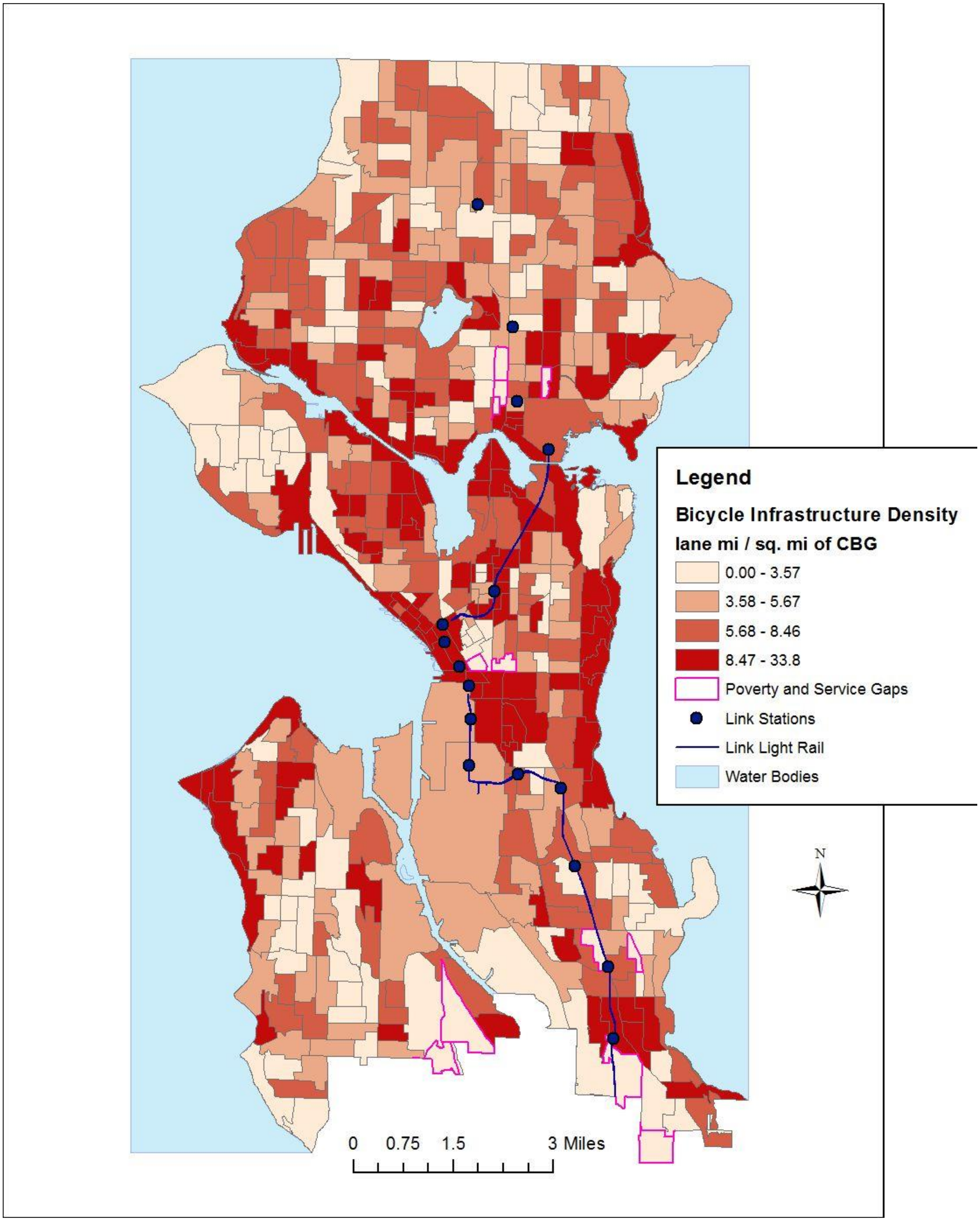


Figure 28. Bicycle infrastructure service gaps and high poverty CBGs.
Source: Author.

Table 2. Summary of high poverty CBGs and bicycle infrastructure density compared to the rest of the city.

Summary - Poverty				
	Number of Block Groups	Average Bike Facility Miles	Average Density of Bike Facility Miles	Number of Service Gaps
Total	480	0.07	0.58	228
Low Prevalence: 0-18.5%	159	1.18	7.29	25
Medium Prevalence: 18.6-41.8%	143	1.03	6.22	40
High Prevalence: 41.8%-78.0%	160	1.12	6.14	12

15.4% of people in Seattle are under the age of 18. The following map shows the census block groups with a higher than citywide average percent of youth per CBG overlaid with bicycle infrastructure service gaps. Service gaps where young people live are scattered around the city, but there are some areas where they concentrate. These areas include Rainier Valley, Seward Park, Magnolia, Ballard, West Seattle, and Delridge.

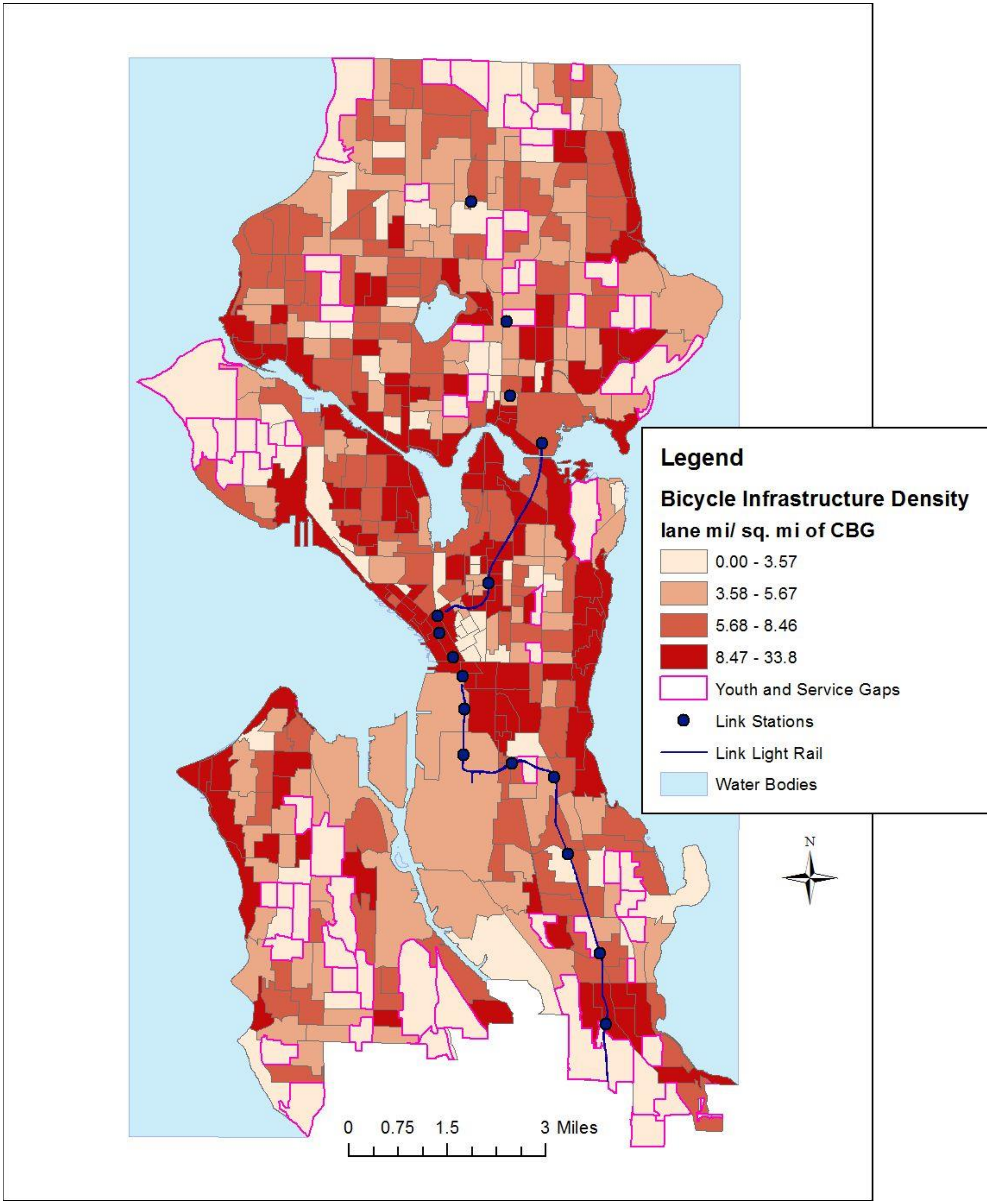


Figure 29. Map of bicycle infrastructure service gaps in CBGs and a disproportionate concentration of youth.
Source: Author.

11.6% of people in Seattle are aged 65 or older. The following map highlights the block groups with a higher than average proportion of seniors and bicycle infrastructure service gaps. These service gaps are spread around the city, with clustering in Rainier Valley, Seward Park, Magnolia, Downtown, and Northgate.

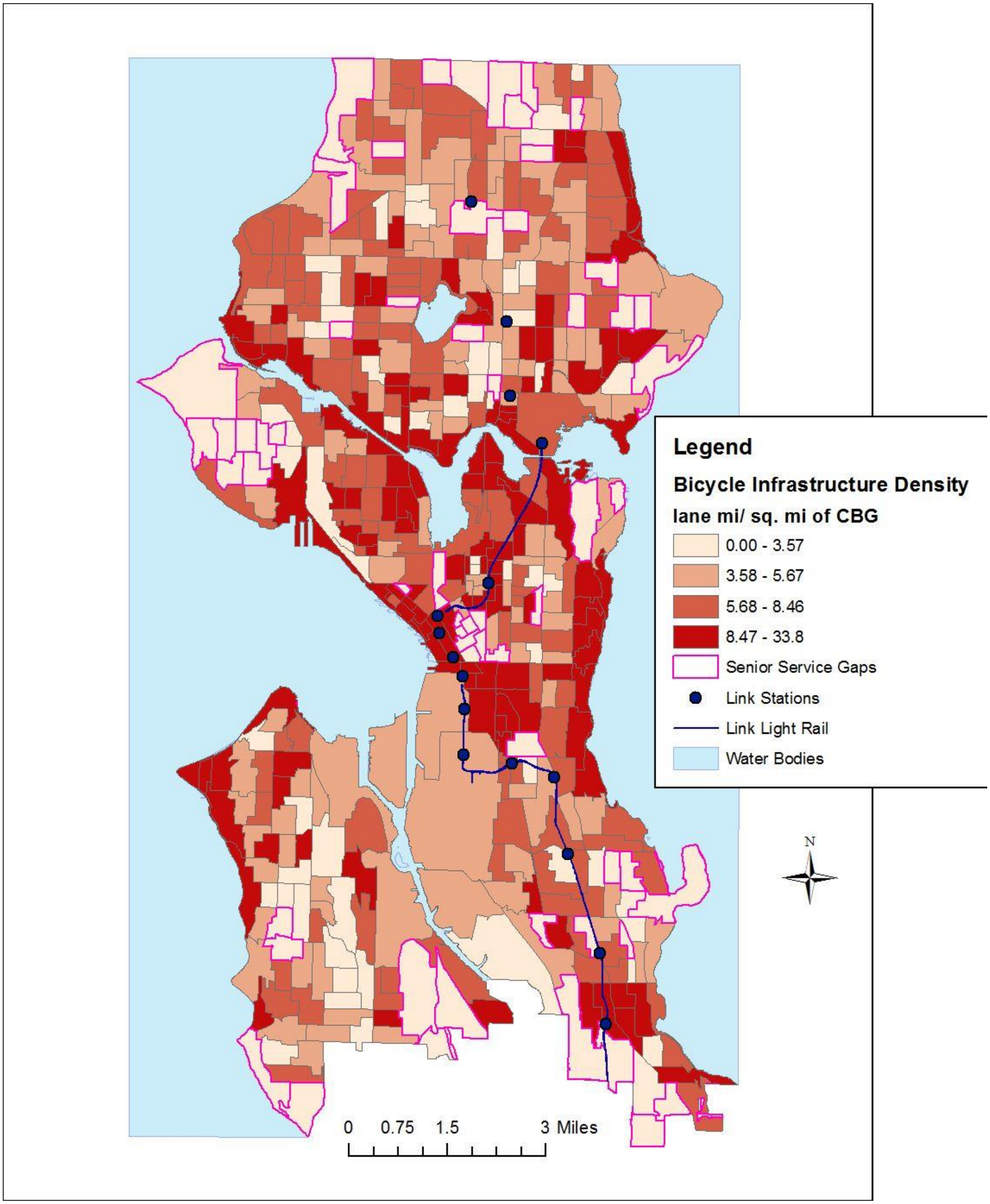


Figure 30. Map of bicycle infrastructure service gaps in CBG's with a disproportionate concentration of senior citizens.
Source: Author.

The geometric mean, shown in Figure 31 below, was calculated by combining the percentages of the population in each CBG which is a racial minority, below the poverty line, youth, and senior. A high geometric mean indicates a high degree of diversity measured by these equity variables.

Again, the equation for geometric mean is as follows:

$$\sqrt[4]{(Percent\ minority * Percent\ poverty * Percent\ youth * Percent\ senior)}$$

A geometric mean is useful when comparing averages for variables which are unrelated. It produces an average which weighs each of the variables. It is helpful in this research because it allows a visual representation of the previous four maps showing equity variables. The CBGs in darker shades on the geometric mean map, below, correspond to CBGs with greater diversity. As with the previous series of maps, the pink highlighted CBGs are those with the highest quartile of geometric mean and the lowest quartile of bicycle infrastructure density. There are 37 service gaps, or CBGs which fall into both categories of having low bicycle infrastructure density and high diversity.

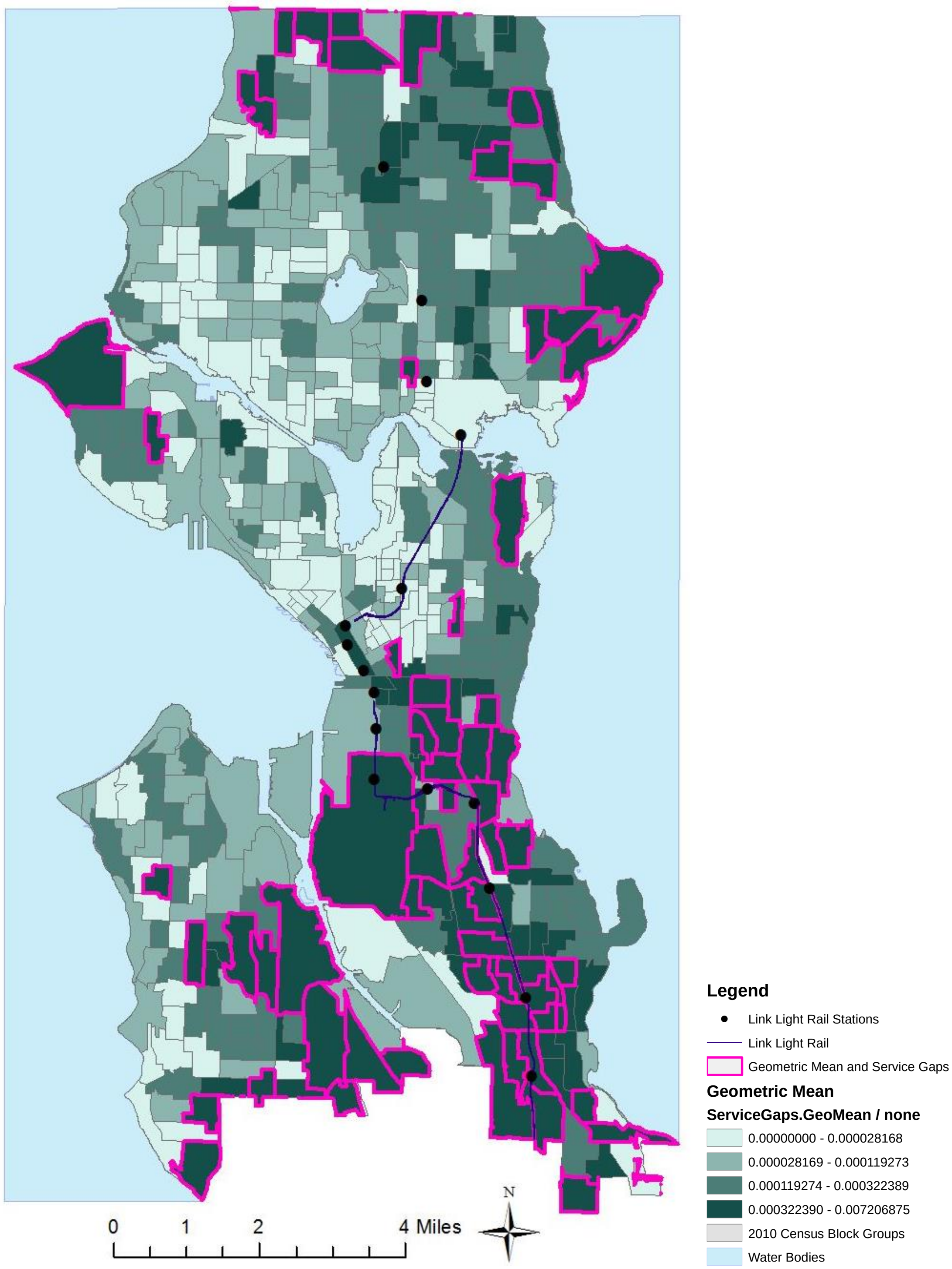


Figure 31. Map of geometric mean and service gaps.
Source: Author.

The following map shows 2-mile bikesheds around light rail stations and the average geometric mean of the CBGs in that bikeshed. Geometric mean is a rough estimate for diversity, with high values indicating a higher proportion of one or more equity variable studied – race, income, youth, or seniors. The highest geometric mean values are found in the bikesheds around the Rainier Beach, Othello, and Columbia City light rail stations. The lowest geometric means are found around the University Street, Westlake, Capitol Hill, University of Washington, Brooklyn, and Roosevelt stations. These are more demographically homogenous areas.

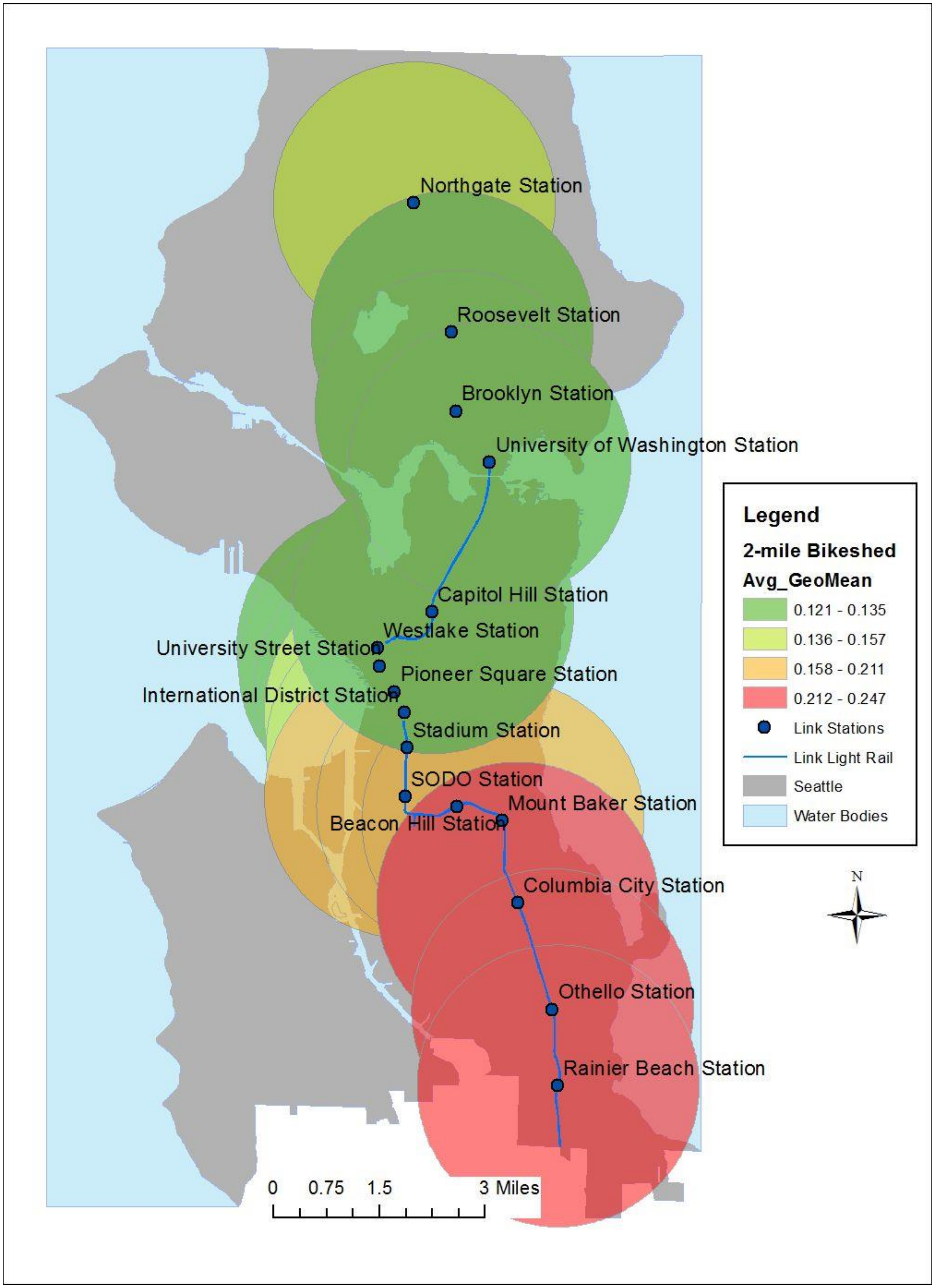


Figure 32. Map of geometric mean values in bikesheds around light rail stations.
Source: Author.

The following map shows a bikeshed of 2 miles around each light rail station. Bicycle infrastructure density is the same base map as the previous series of equity variable maps. The semi-transparent circles are the Euclidean 2-mile bikesheds. The green highlighted CBGs are those with the lowest quartile of bicycle infrastructure density, the highest quartile of geometric mean values, and which overlap with a station area bikeshed. Several areas of the city such as West Seattle are precluded from the service gaps shown on this map because they are not near enough to any light rail station. The largest continuous swath of land which fulfills all three criteria is in the Duwamish River industrial area, where the CBGs are very large, a disproportionate amount of diverse people live, and there is sparse bicycle infrastructure. Among more populated diverse bikesheds, the Beacon Hill, Rainier Valley, Seward Park, and Downtown areas are lacking a dense network of bicycle infrastructure.

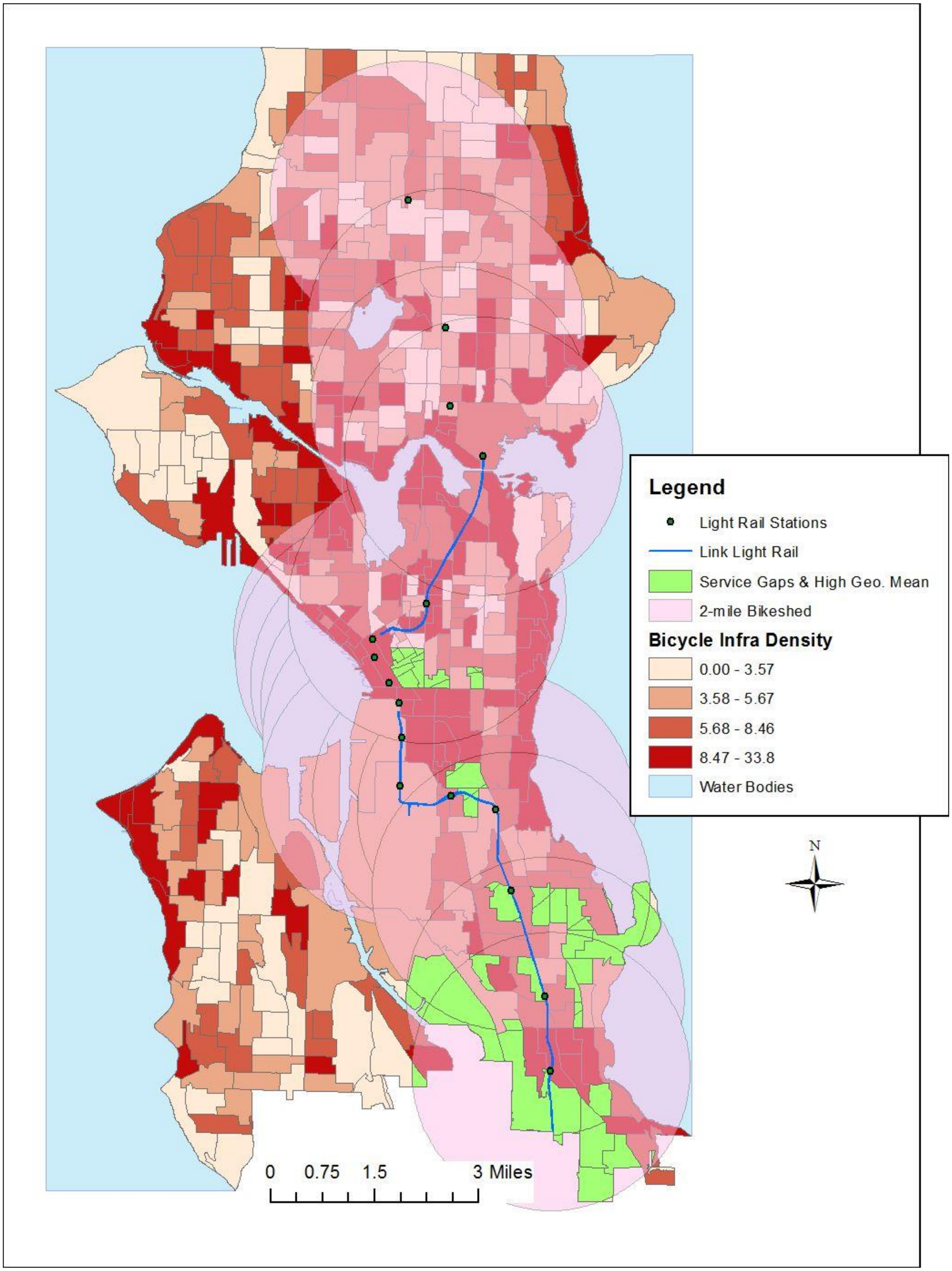


Figure 33. Map of Link light rail station area service gaps.

Light rail station areas (drawn as 2-mile bikesheds around stations), bicycle infrastructure density; highlighted in green are CBGs in the bottom quartile for bicycle infrastructure and which fall at least in part within a bikeshed. Source: Author.

The null hypothesis is that the presence of diversity (geometric mean of equity variables) in a CBG and bicycle infrastructure in a CBG are not related at all. The geometric mean was used as the independent variable and bicycle infrastructure density was used as the dependent variable when conducting a correlation analysis. The data from Seattle's 480 census block groups resulted in an r^2 value of 0.0103. In other words, 1.03% of the variation in the presence of bicycle infrastructure may be attributable to the geometric mean in a CBG. Using the geometric mean as the independent variable prevents multicollinearity by combining these equity variables (minority, poverty, youth, senior) prior to running the statistical test. Multicollinearity would be possible if all equity variables were used as independent variables compared to bicycle infrastructure density as the dependent variable. The p-value is 0.027 (less than 0.05), so the correlation's r-squared value is reliable. A more diverse census block group is slightly less likely to have an equally dense bicycle infrastructure network as a less diverse census block group.

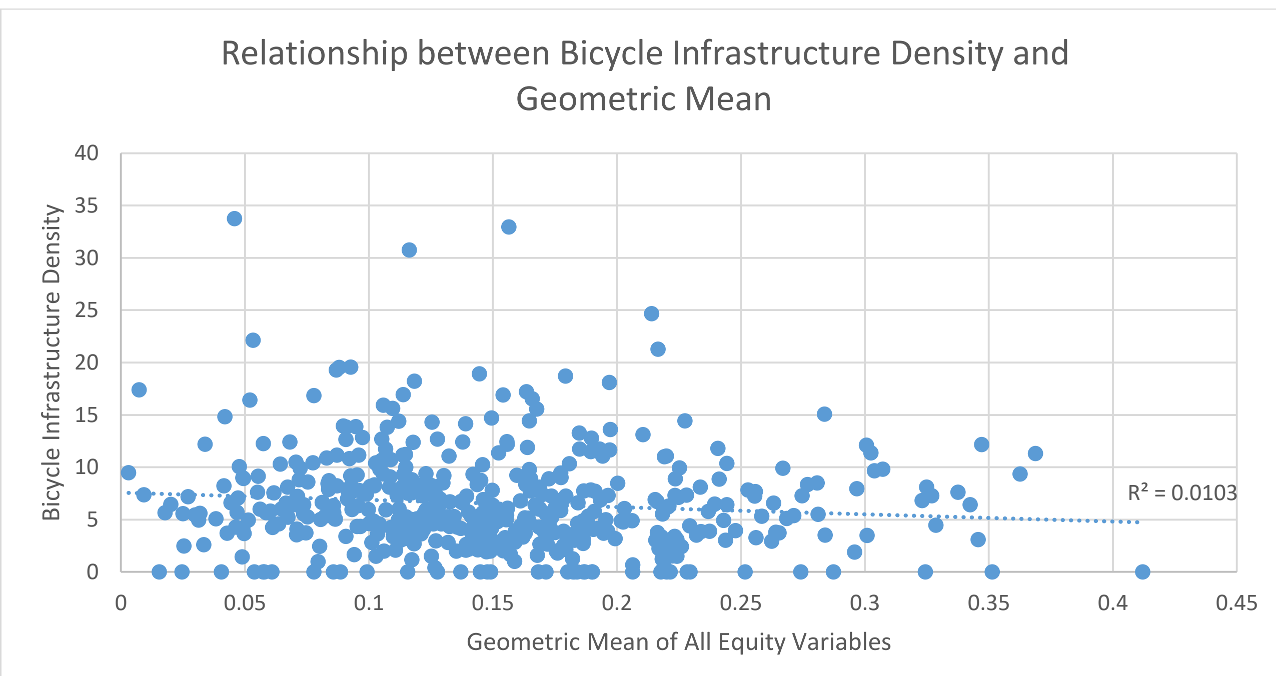


Figure 214. Plot of geometric mean and bicycle infrastructure density among the 480 CBGs in Seattle.
Source: Author.

Bicycle Infrastructure Density and Race and Poverty

Because youth and seniors likely don't rely on cycle-transit for commuting as much as working-aged adults, the two age related equity variables are excluded from the following geospatial analysis. The following map shows the geometric mean of the percent of the CBG population in poverty and the percent minority, overlaid with bikesheds around light rail stations. The equation for calculating this geometric mean is as follows:

$$\textbf{Geometric Mean2} = \sqrt{(\boldsymbol{Percent\ in\ Poverty} * \boldsymbol{Percent\ Minority})}$$

The pink highlighted CBGs are those which have the highest quartile of geometric mean and the lowest quartile of bicycle infrastructure density, using the same density map as the previous maps. There are several clusters with high geometric mean and bicycle infrastructure service gaps: Rainier Valley, Beacon Hill, Downtown, the Central District, the University District, and Northgate. Nearly all of the service gaps are located within the light rail stations' bikesheds.

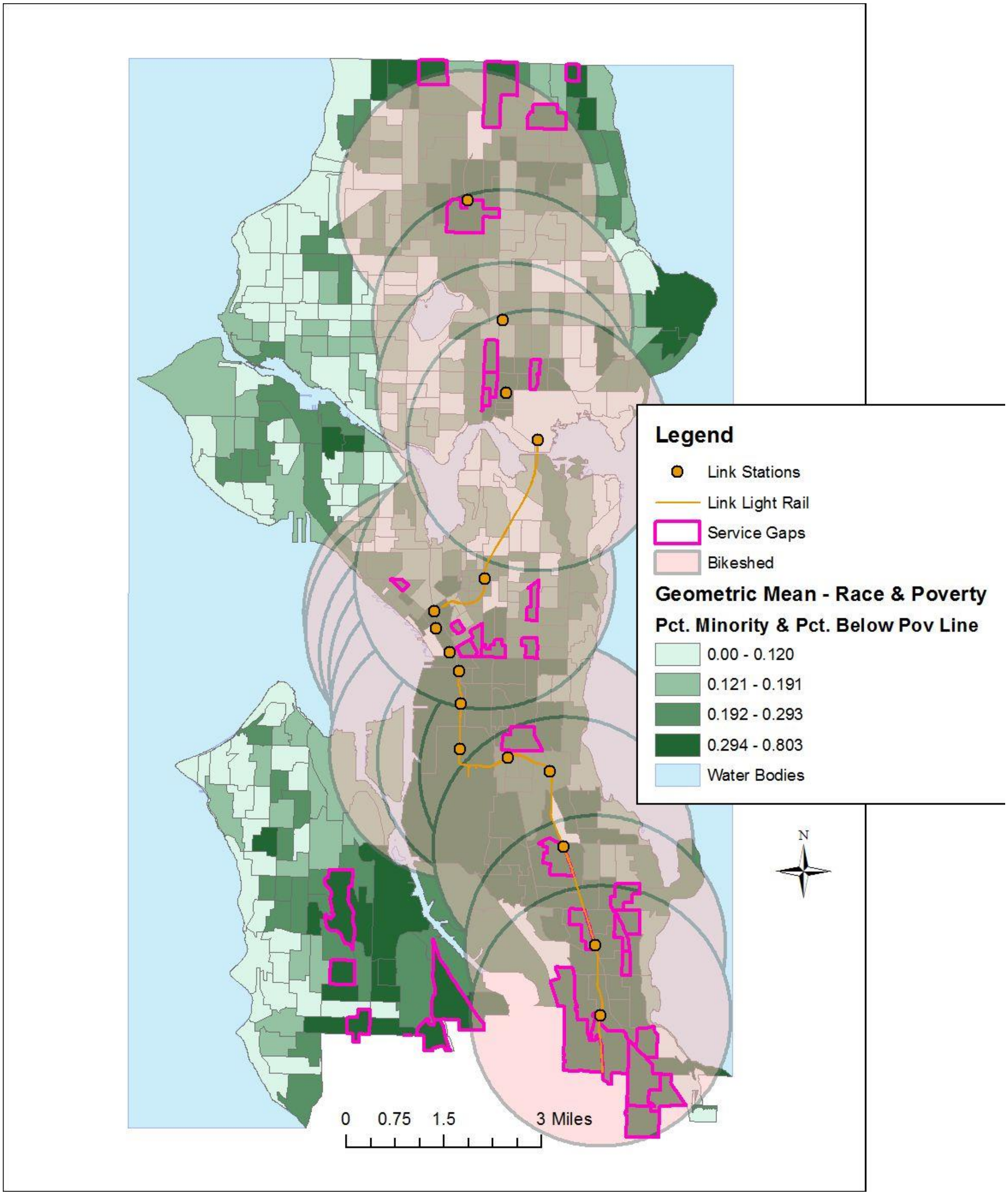


Figure 35. Map of service gap CBGs and the geometric mean of high racial minority and high poverty in light rail station bikesheds.

Source: Author.

As the Sanders article points out, there are ancillary benefits to bicycle infrastructure from which even non-users will benefit. For example, sidewalk users benefit from bicycle lanes because then bicycles will use their dedicated space, making user behavior more predictable and making the pedestrian realm safer for all. To more thoroughly address the research question, we must look more closely at race, poverty, and bicycle infrastructure to determine whether there is any correlation between these variables. The r^2 value quantifying the relationship between the geometric mean of these two equity variables and bicycle infrastructure density is 0.0006. This means that about 0.6% of the difference between bicycle infrastructure densities among CBGs may be related to the geometric mean of that CBG. The p-value is less than 0.05, indicating that the r^2 value is reliable.

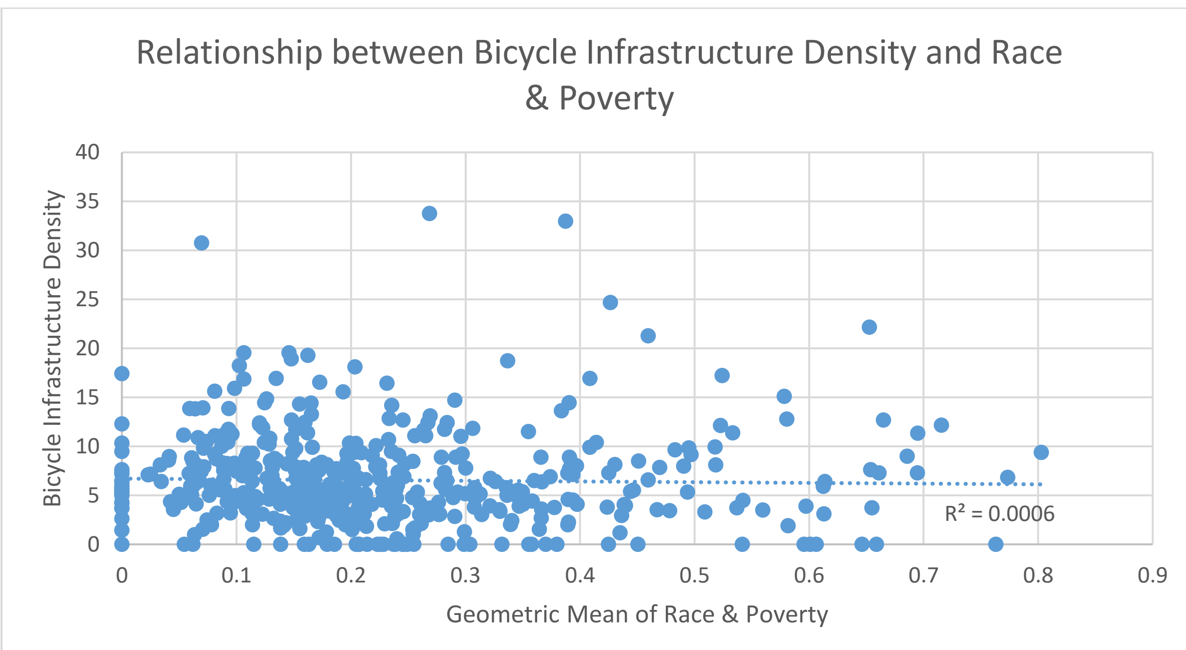


Figure 36. Scatter plot of the relationship between all classes of bicycle infrastructure and the geometric mean of race and poverty.
Source: Author.

Equity Analysis of Low-Stress Bicycle Infrastructure

Now the analysis will move on to the geospatial analysis of low-stress bicycle infrastructure and the concentration of diversity. The same equity variables will be studied, but rather than include all classes of bicycle infrastructure, this analysis only includes Class 1, Class 2, and Class 4, leaving out the most dangerous type. About half of Seattle's bicycle infrastructure is made up of Class 3 facilities, so removing this type of infrastructure significantly decreases the density of bicycle facilities citywide. Please refer to Figure 37 for a color coded map showing the three different classes used for this analysis, adding up to 168 lane miles.

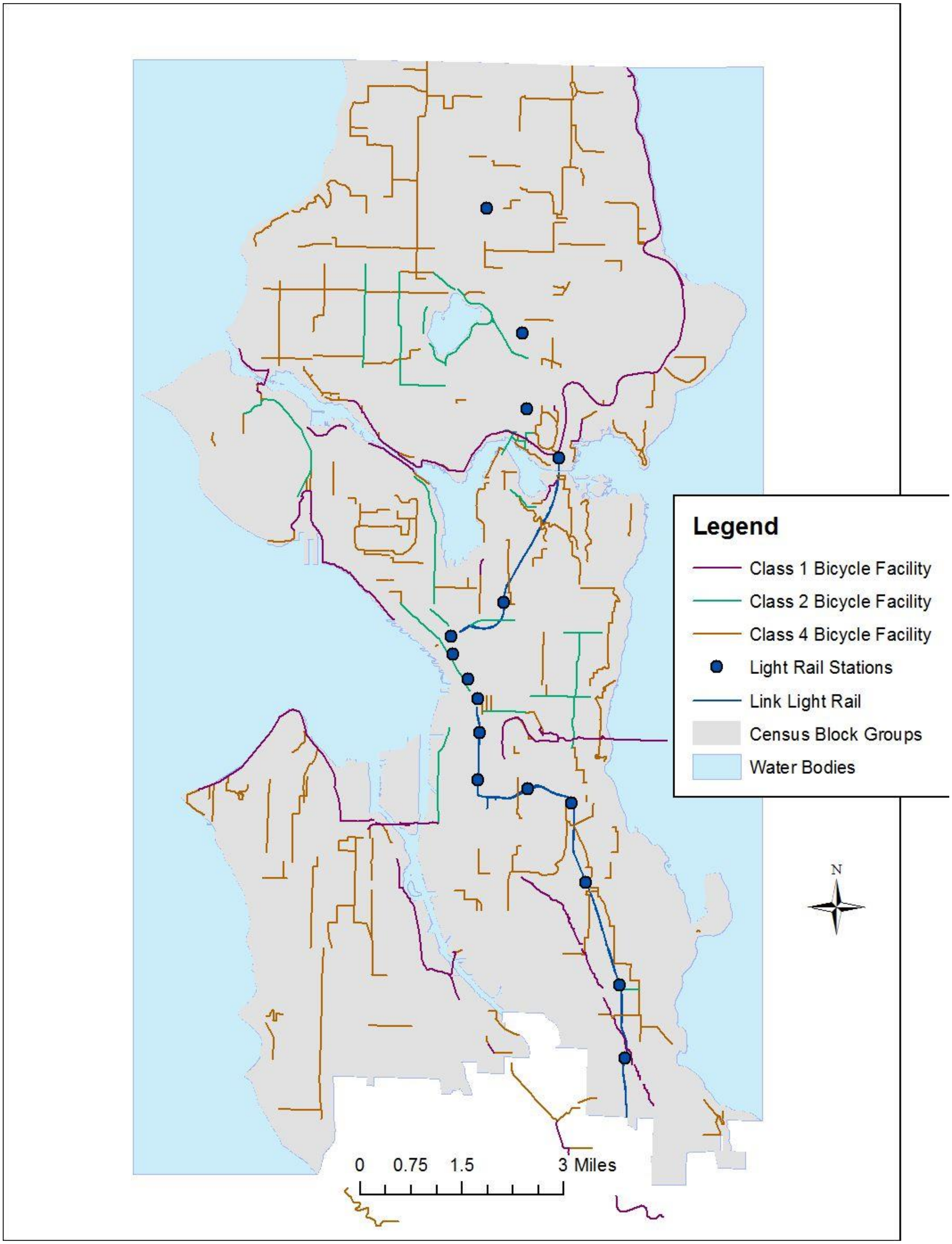


Figure 37. Map of low-stress bicycle facilities in Seattle.
Source: Author.

Using the low-stress bicycle infrastructure routes displayed in Figure 37, the following map displays the CBGs which do not have any low-stress bicycle infrastructure. The following map shows the Class 1, Class 2, and Class 4 facilities that will be used for this series of analysis, with the CBGs lacking bicycle infrastructure highlighted. 145 of the city's CBGs have no Class 1, 2, or 4 bicycle facilities. This makes up an entire quarter of the city's CBGs. Service gaps are henceforth defined using the lowest quartile, which is equivalent to entirely lacking low-stress bicycle facilities.

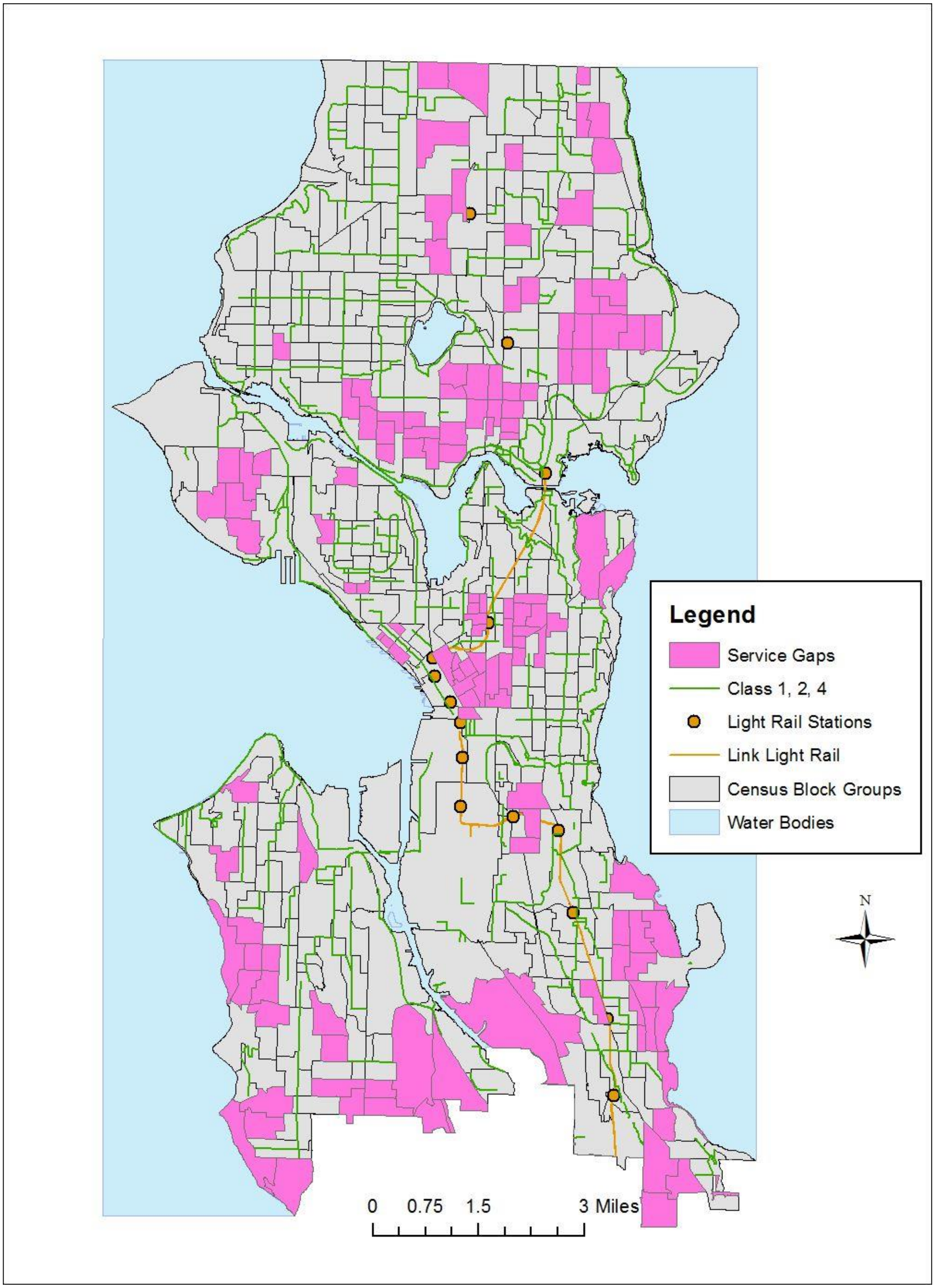


Figure 228. Map of low stress bicycle infrastructure, defined as Class 1, 2, and 4 bicycle facilities. Highlighted CBGs are those which do not have any low-stress bicycle facilities. Source: Author.

The following map highlights CBGs which have higher than the citywide average concentration of people of color and which lack low-stress bicycle facility service gaps. Clusters appear in the University District, Downtown, Capitol Hill, the Central Area, Beacon Hill, and Rainier Valley.

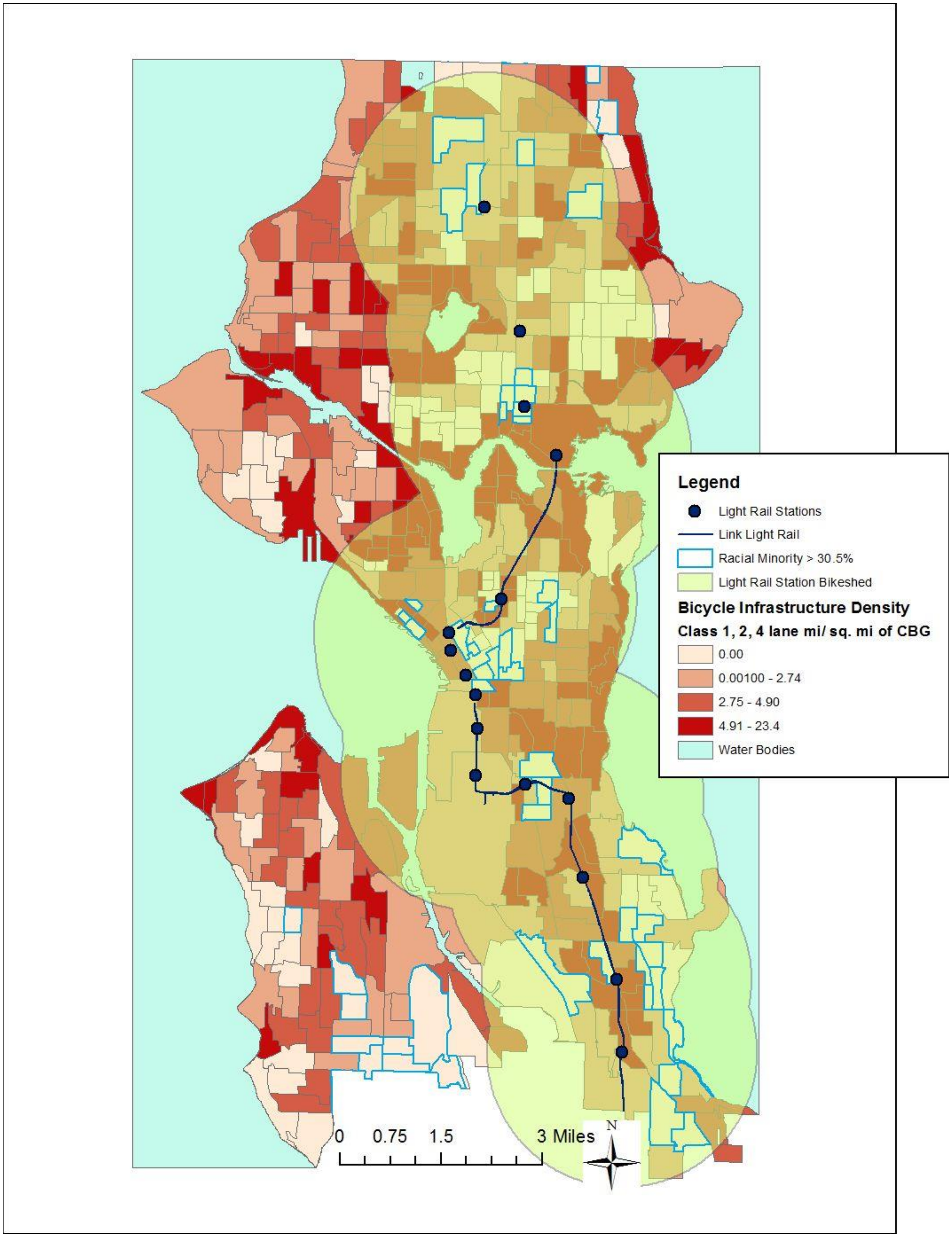


Figure 39. Map of high minority and low-stress bicycle facility service gaps.
Source: Author.

The following map shows the CBGs which have high poverty and low-stress bicycle infrastructure service gaps. There are clusters of CBGs which fall into both categories around Northgate, the University District, Downtown, and Rainier Valley.

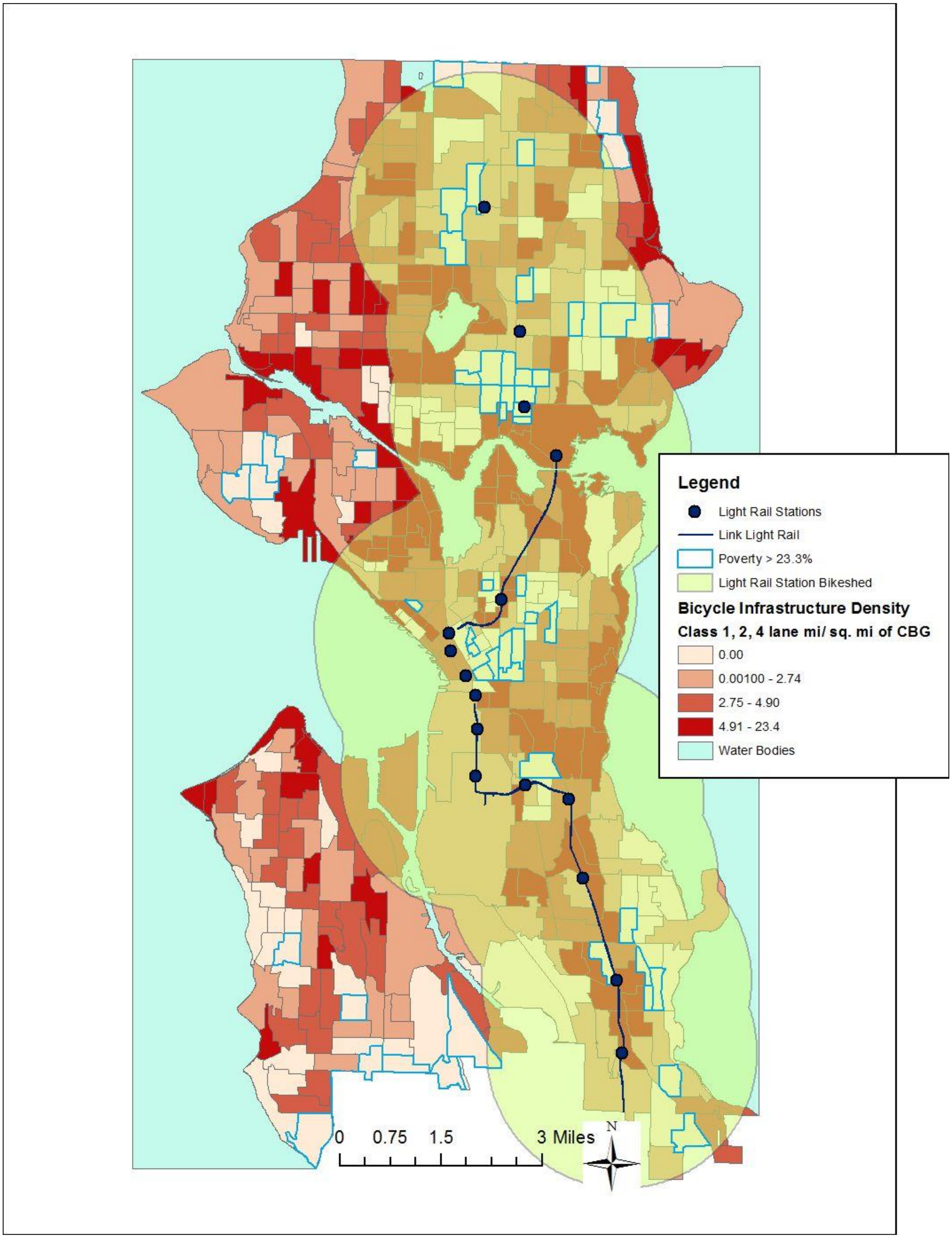


Figure 40. Map of CBGs which have high poverty and low-stress bicycle infrastructure service gaps.
Source: Author.

The following map shows CBGs with high concentrations of youth and which lack low-stress bicycle infrastructure. Clusters of CBGs can be found in the Rainier Valley, Seward Park, Wallingford, Ravenna, and Bryant neighborhoods.

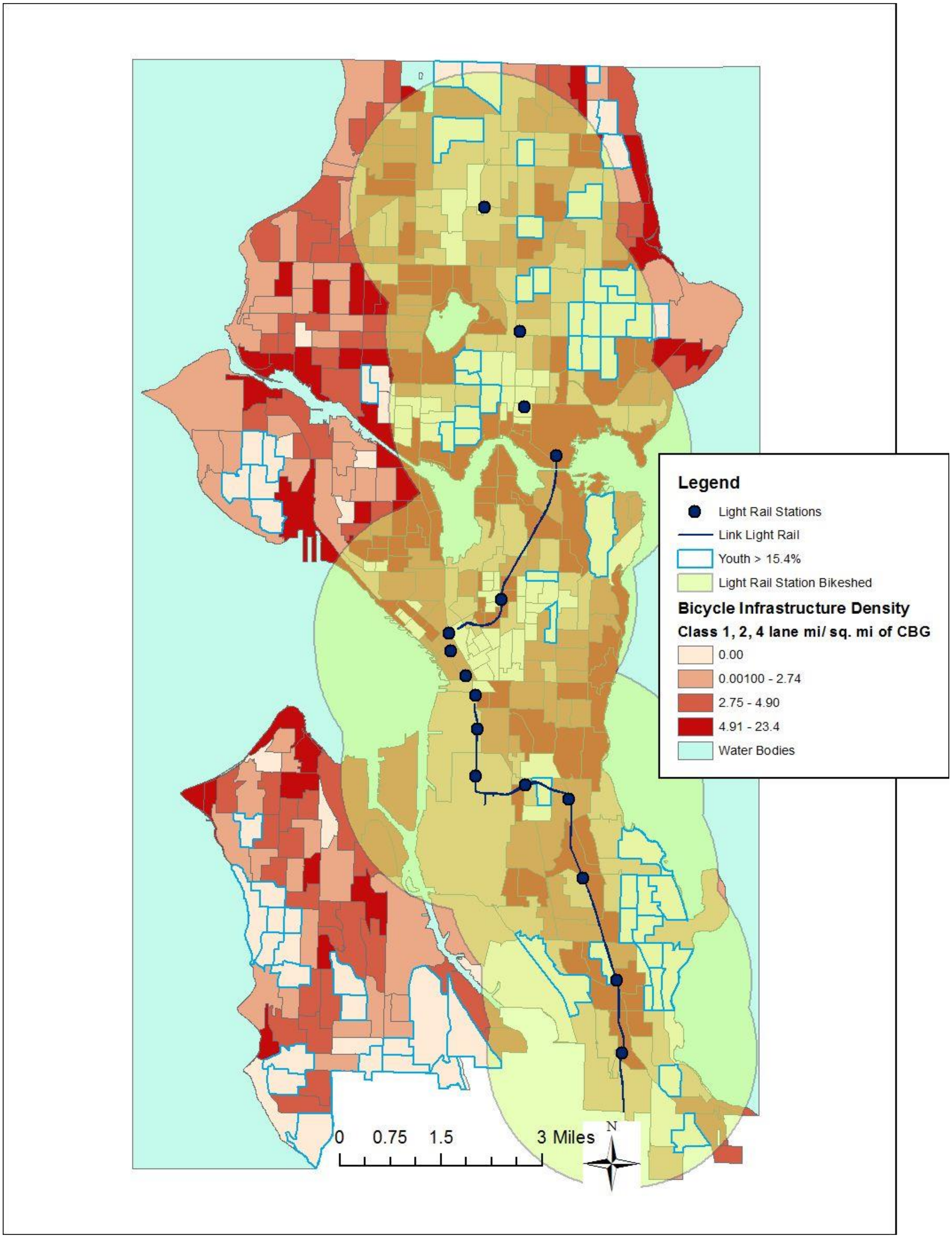


Figure 41. Low-stress bicycle infrastructure service gaps and high concentration of youth population.
Source: Author.

The following map shows the CBGs which have higher than citywide average concentrations of senior citizens and which lack low-stress bicycle infrastructure. Areas where these CBGs appear to cluster are Seward Park, Downtown, Ravenna, Bryant, and Northgate.

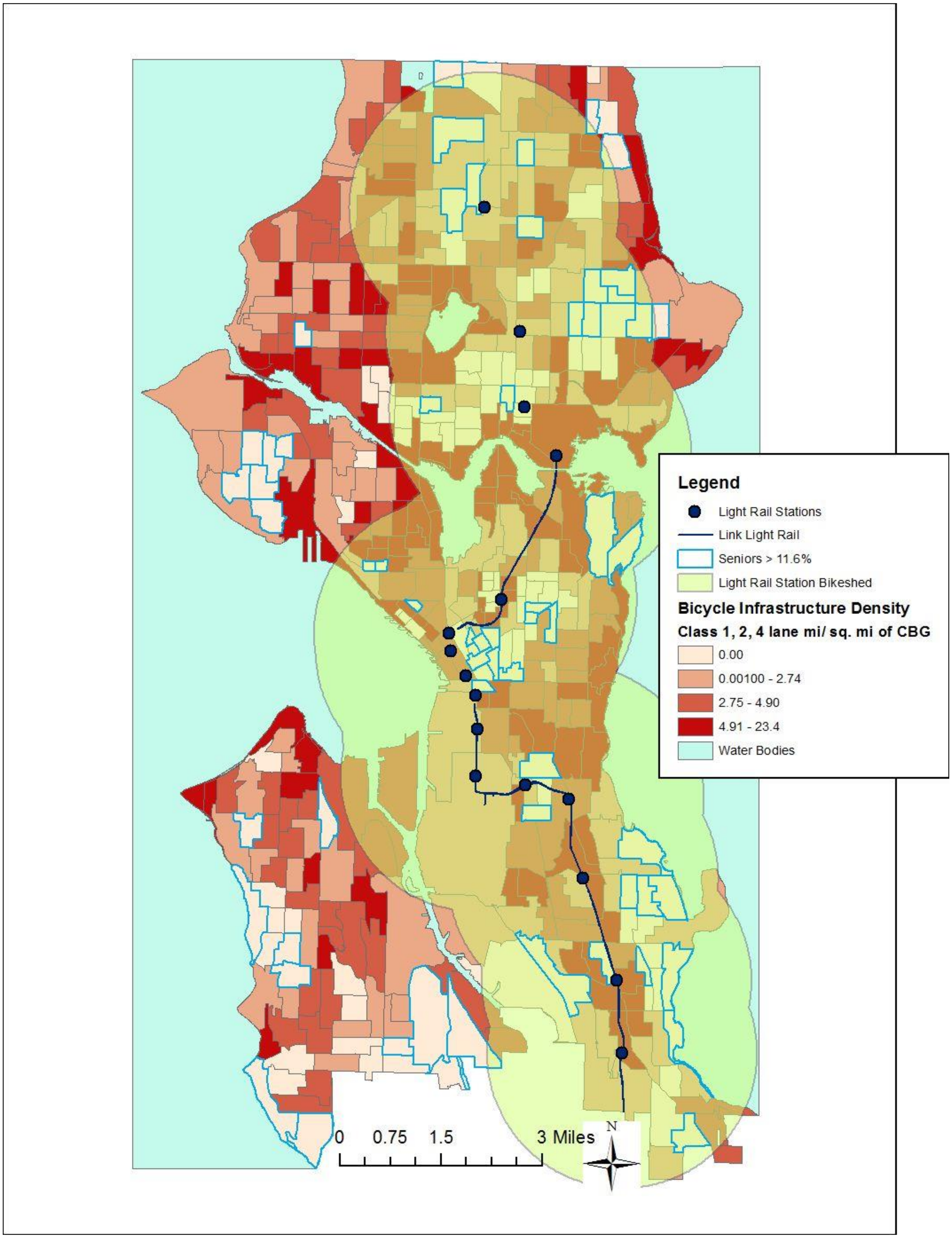


Figure 42. Low-stress bicycle infrastructure service gaps for high concentration of senior population.
Source: Author.

The following map highlights the CBGs with the highest quartile of geometric mean for all four equity variables and fall in the lowest quartile of low-stress bicycle infrastructure density. There are only four CBGs which fall within the bikeshed of light rail stations and have high diversity and a low density of safe bicycle infrastructure. These CBGs are in Rainier Valley and Beacon Hill. There are fewer CBGs which fulfill all three of these metrics (highest quartile geometric mean, lowest quartile low-stress bicycle facilities density, station area bikeshed) because the lowest quartile in this analysis is equal to zero low-stress bicycle facilities. Thankfully, there are very few CBGs within station area bikesheds which do not have any low-stress bicycle facilities.

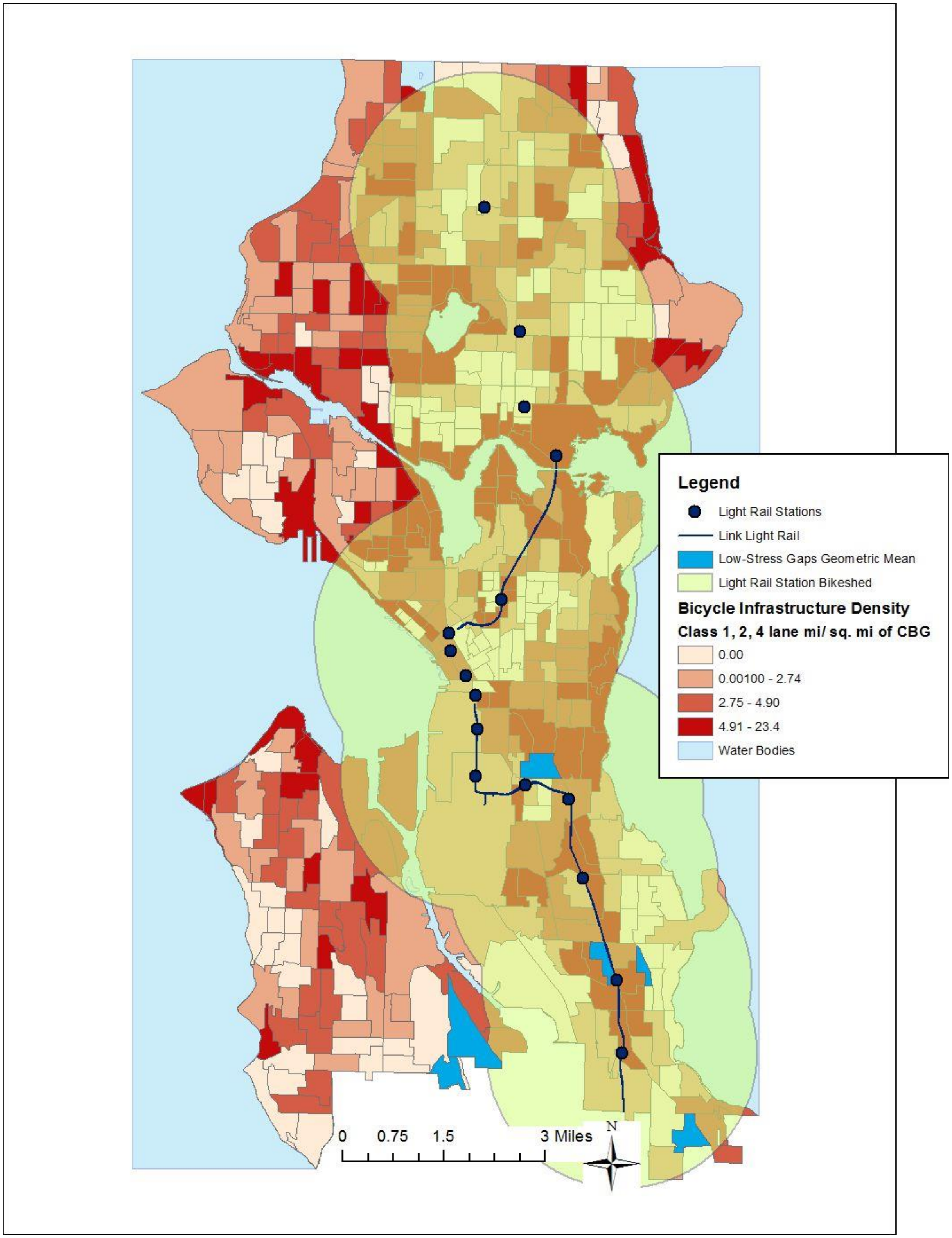


Figure 43. Map of geometric mean and low-stress bicycle infrastructure service gaps.
Source: Author.

This dataset also results in a very small r^2 value of 0.003 or 0.3% of variation may be attributable to the differences in geometric mean. The p-value is smaller than 0.05 indicating that the r^2 value is statistically reliable. There is essentially no difference in the provision of safe bicycle infrastructure on the basis of equity variables (race, poverty, youth, older population).

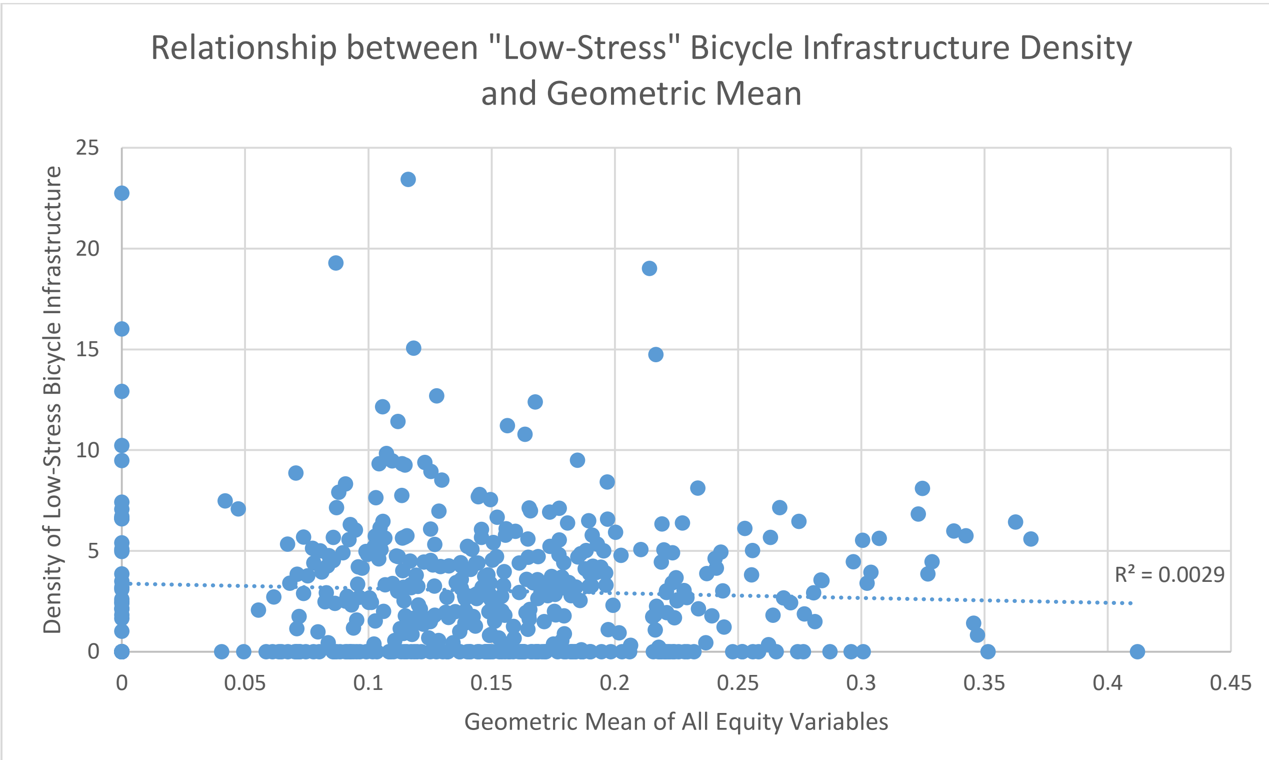


Figure 44. Scatter plot showing the relationship between geometric mean and low-stress bicycle infrastructure.
Source: Author.

Comparisons & Differences of Two Analyses

The results of both equity analyses show that the provision of bicycle infrastructure in Seattle is very equal. Going back to the Rawlsian definition of equity, more public goods should be allocated to the communities with the greatest need. Therefore, the CBGs with the highest geometric means should receive more bicycle facilities. The average density of all bicycle infrastructure per CBG is 6.54

miles/square mile compared to 2.75 miles of low-stress bicycle facilities per square mile of CBG. There are some CBGs with no infrastructure and some with very high densities. There are 39 CBGs which do not have any bicycle infrastructure; there are 145 which do not have any low-stress bicycle infrastructure. Yet there are fewer CBGs identified as service gaps lacking low-stress facilities; 7 compared to 37 service gaps looking at all types of bicycle infrastructure. This is because of the stringency of the “lowest quartile” of low-stress facilities. Only CBGs with absolutely no low-stress facilities made the cut for the lowest quartile. This means that the CBGs surrounding light rail have higher quality bicycle infrastructure, but the presence of diversity does not seem to impact the siting of bicycle infrastructure.

Chapter 5: Conclusion

This thesis set out to determine whether bicycle infrastructure is equitably allocated in the city of Seattle, especially around light rail stations. If inequities exist, the goal was to quantify them in order to make data-driven changes to the way the City sites bicycle infrastructure. The results indicate that bicycle infrastructure is equally allocated throughout the city. There is essentially no difference in the density of bicycle infrastructure between the Census Block Groups that have a lot of diversity and those that have little. However, Rawlsian equity indicates that diverse areas should be receiving more benefits than less diverse areas. 'Diversity' in the context of this research, is used to encompass people of color, people who have experienced poverty in the past year, youth under 18 years of age, and senior citizens 65 and older. These four equity variables were quantified using 2015 5-year ACS data. Census Block Groups that have a higher than citywide average of people of color, poverty, youth, or seniors are considered to have high diversity. The methodology used was a GIS geospatial analysis to find CBGs with low densities of bicycle infrastructure and high concentrations of these equity variables. CBGs where both variables coexist are highlighted in the series of maps in Chapter 4, Findings. A geometric mean calculation was used to combine the percentages of all four equity variables in order to approximately measure diversity. CBGs with high diversity values and low densities of bicycle infrastructure are also highlighted in the maps in previous chapter. Two analyses were done: the first using all bicycle infrastructure in the city, and the second using only low-stress bicycle infrastructure.

The methodology and findings of this thesis contribute to how to prioritize the implementation of bicycle infrastructure in order to help disadvantaged populations in the city. The City of Seattle, its bicycle advocacy groups, transportation planners, policymakers, and landowners where light rail stations have been constructed should use this information to prioritize the implementation of bicycle infrastructure in order to help disadvantaged populations. The advantage of this methodology is that it is duplicable by city, county, or other entities, in essentially any locale with accurate GIS records. Bicycle infrastructure data should be checked for currency prior to any further analysis, as well as census block shapes and ACS survey data.

There are many service gaps in Southeast Seattle's Rainier Valley, where many diverse and historically disadvantaged people live, and where the Link light rail currently operates. In order to pursue a future of equity for all Seattleites, we must follow a Rawlsian approach to distributive justice and first improve the communities that need the most help. Large service gaps also exist in Delridge and the Central District, areas not very close to light rail stations, but very diverse. There are many noted benefits to bicycle infrastructure and improved access to transit, as discussed in the literature review in chapter 3. These include lower commute times, expanded access to jobs and the upward mobility that comes with employment; better public health metrics, and a more enjoyable commute. In order to enhance CT accessibility in the areas with higher concentrations of disadvantaged populations, a culturally sensitive presentation and a process which can incorporate feedback through iteration can be implemented. Planning for bicycle lanes in diverse neighborhoods will not have the negative connotation that Melody Hoffman writes about in *Bike Lanes are White Lanes*. Improved bicycle connectivity to light rail will result in improved accessibility to employment, education, services, and entertainment, for a better quality of life.

In order to maximize bicycle access to light rail stations in communities of color, poor communities, and areas of the city where there are a lot of young and older people, the areas around light rail stations with high geometric means should be prioritized for bicycle infrastructure projects. As Lubitow writes, the community must be involved in a meaningful and sensitive way so as to limit negativity surrounding the project and the general "depoliticization" of sustainability projects. As Cornish and Sanders write, bicycle infrastructure projects can address concerns raised by all roadway users, but as Hoffman writes, such projects can be viewed as agents of gentrification and negative change for communities of color. In particular, bicycle infrastructure projects which are proposed in the Seattle BMP should be prioritized if they fall within the green highlighted areas in Figure 33 'Map of Link light rail station area service gaps'; these are areas within bikesheds which have a high degree of diversity (as measured by geometric mean) and have a low density of bicycle infrastructure. Ideally, the City should not build any more Class 3 facilities and all infrastructure going forward will be high quality and high safety. Figure 43 'Map of geometric mean and low-stress bicycle infrastructure service gaps' shows the CBGs where there are no low-stress bicycle facilities and which have high geometric mean values; this would be another map to use for prioritization of projects. Figure 35 'Map of low-stress bicycle facilities in Seattle' would be the most appropriate map to use to decide where to allocate bicycle infrastructure specifically to communities of color and areas where impoverished people live. This map shows only the equity variables of racial minority and poverty, excluding the age-related equity variables.

The r-squared value relating the geometric mean of the four equity variables studied - race, poverty, youth, and seniors – and all types of bicycle infrastructure density was 0.0103. The r-squared value of the geometric mean of race and poverty along with bicycle infrastructure was 0.006. Finally, the r-squared value of the geometric mean of all four equity variables (race, poverty, youth, and senior) and low-stress bicycle infrastructure (Class 1, Class 2, and Class 4) was 0.0029. The city should continue to build bicycle infrastructure in low income, racially diverse neighborhoods where lots of youth and senior citizens live in order for the distribution to become truly *equitable* – so that these historically marginalized groups receive the benefits of expanded access to transit and to generally improve their mobility in the city. Rawlsian equity is defined as providing public goods and services to the people who are most disadvantaged in society. This concept of distributive justice intends to equalize outcomes.

King County may also use this information to work to implement their strategic equity goals of transportation equity and access for all. The County does not currently have a role in City bicycle planning, but perhaps if City of Seattle projects can be carried out in a way that reflect County priorities, all levels of government will vocally support a project.

Further work can be done to expand the scope of this research in several ways: bikesheds around light rail stations can be made more accurate using topographical features. Biking two miles on a flat surface feels like a much different amount of work than biking two miles up and down hills, of which Seattle has many. Access to Bus Rapid Transit (BRT) could help expand the bikesheds around high capacity transit to include more areas of the city which are not currently close to Link light rail. As the region’s light rail system is built out in the coming years, land uses and property values around stations may change. Housing costs especially influence where people will live. Further analysis several years into the future would help to deepen the understanding about equitable bicycle infrastructure allocation in Seattle.

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